AMAT

Release v2.1.8

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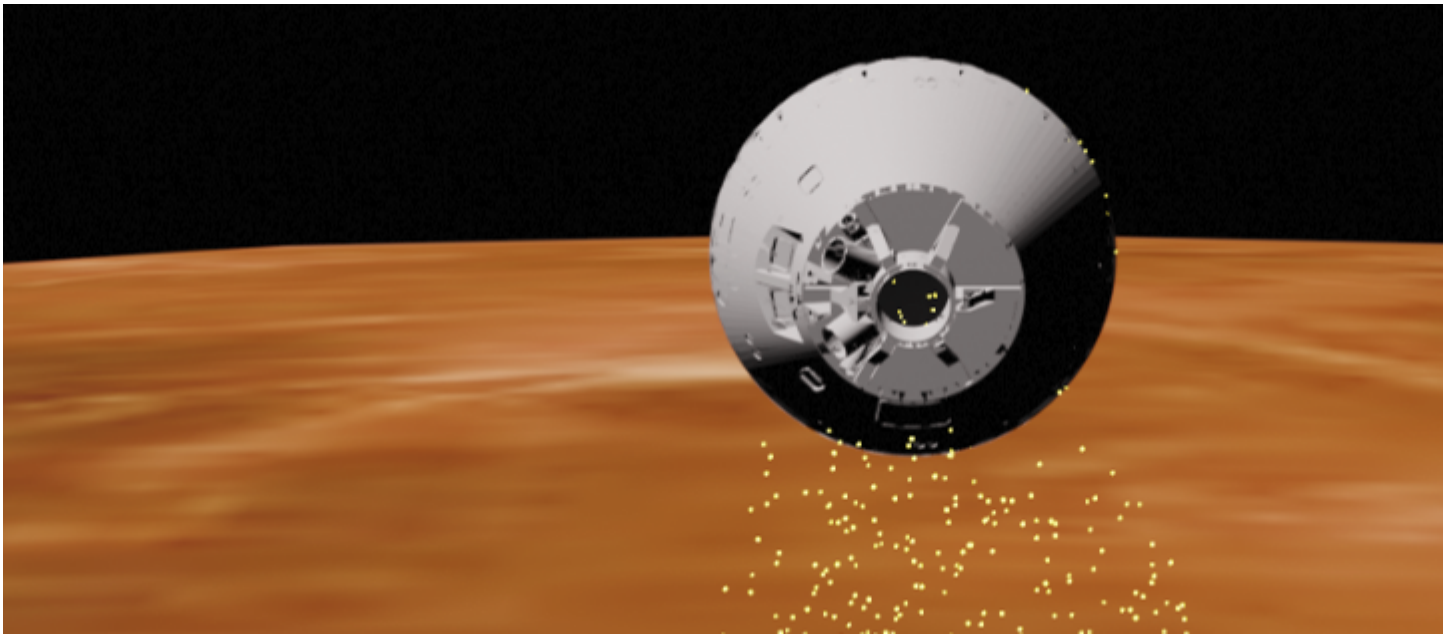
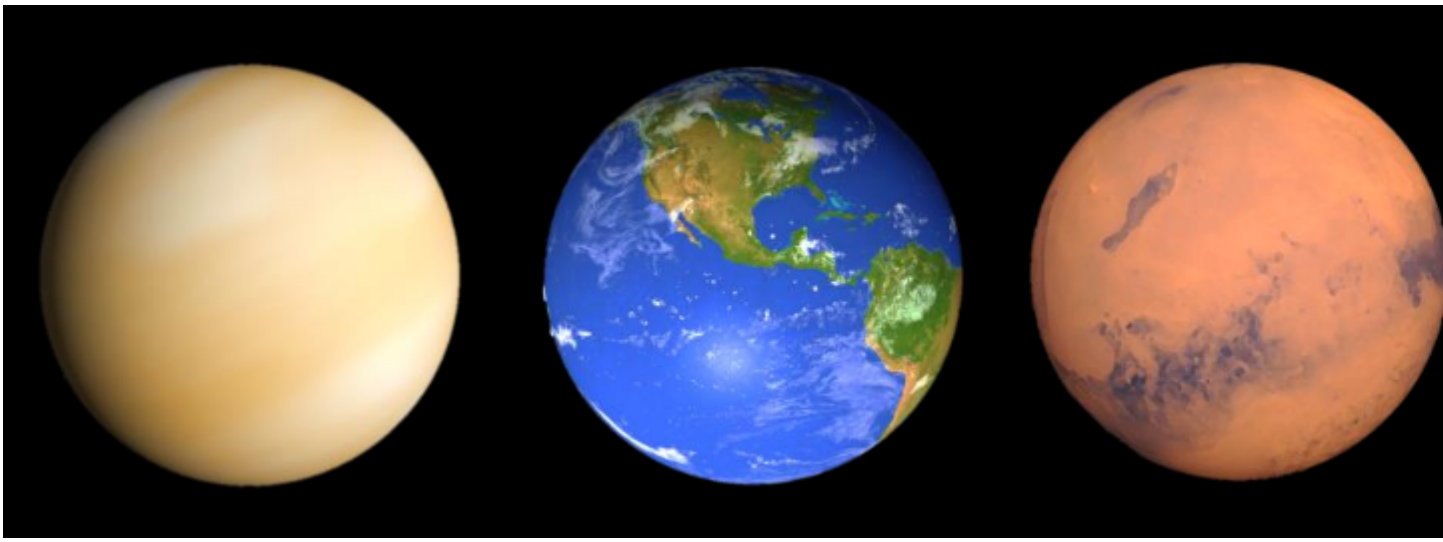
Contents:



AMAT is designed to provide rapid mission analysis capability for aerocapture mission concepts to the planetary science community.

See Jupyter notebooks to get started or refer to examples in the GitHub repository.

AMAT allows the user to peform low-fidelity broad sweep parametric studies; as well as high fidelity Monte Carlo simulations to quantify aerocapture performance. AMAT comes with a suite of interplanetary trajectories, planetary atmosphere models, aeroheating correlations, and guidance algorithms for rapid conceptual mission design. AMAT provides aerocapture and Entry, Descent, Landing (EDL) mission analysis capability for Venus, Earth, Mars, Jupiter, Saturn, Titan, Uranus, and Neptune.



For sub-routine documentation, see modindex

CHAPTER 1

About AMAT

1.1 Overview

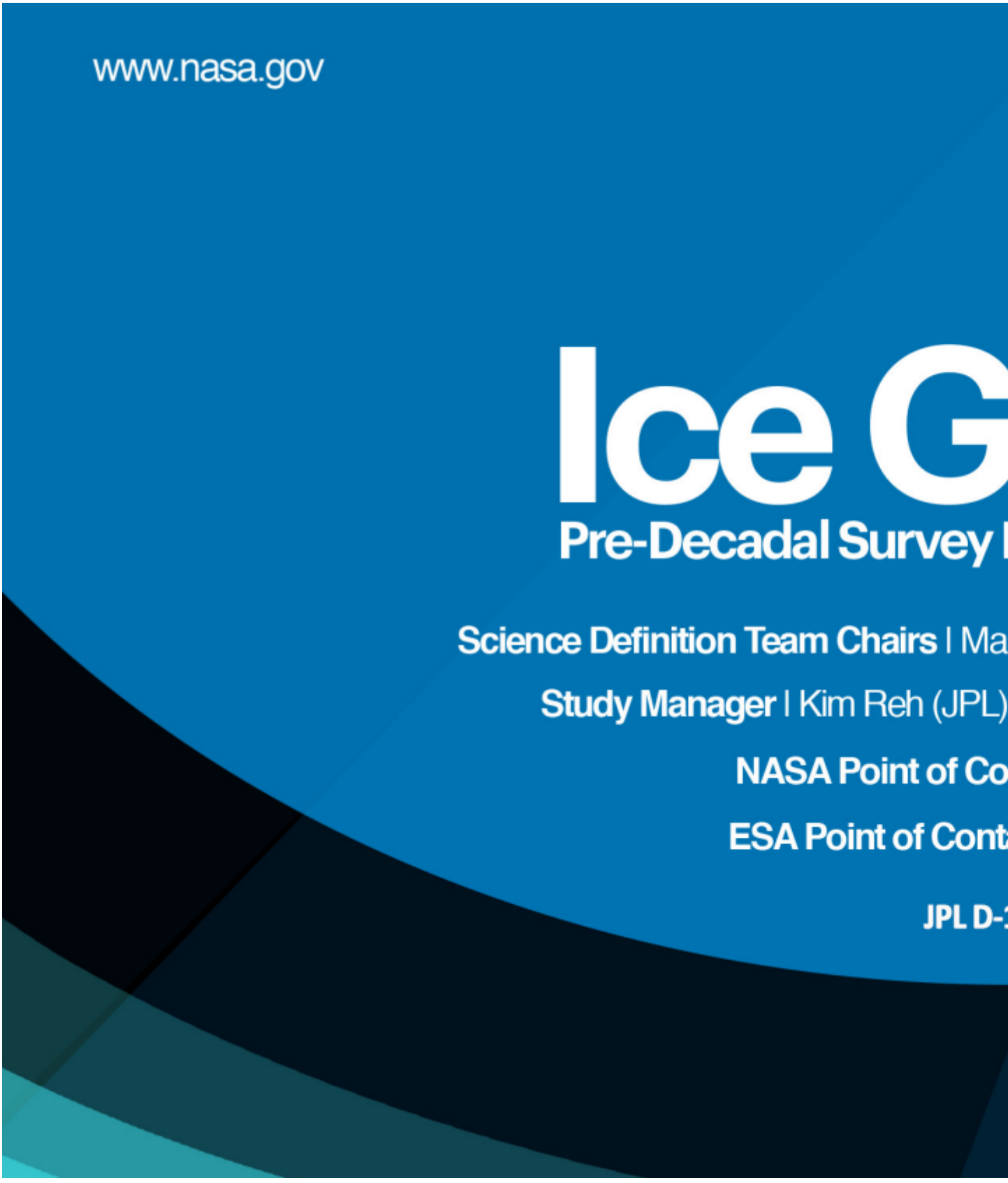
AMAT is an open source collection of Python subroutines for rapid conceptual design of aerocapture and atmospheric Entry, Descent, and Landing (EDL) missions in a Jupyter environment.

AMAT comes with a suite of tools to allow end-to-end conceptual design of aerocapture missions: launch vehicle performance calculator, database of interplanetary trajectories, atmosphere models, vehicle control techniques, and aeroheating models. AMAT supports analysis for all atmosphere-bearing Solar System destinations for both lift and drag modulation control techniques.

AMAT has been extensively used in various aerocapture mission studies at the Advanced Astrodynamics Concepts (AAC) research group at Purdue University in collaboration with the NASA Jet Propulsion Laboratory (JPL).

1.2 History

The lack of a rapid mission design tool for aerocapture mission concepts was identified by the NASA Ice Giants Pre Decadal (IGPD) Study led by JPL in 2016. This meant there was no quick way of performing architectural level assessments without resorting to resource intensive, subsystem-level design exercises such as the NASA Aerocapture Systems Analysis Team studies in 2004.



A team of researchers at Purdue University (Saikia et al.) led the aerocapture assessment studies in support of IGPD.

Graduate researchers have since then further developed and extended the methods and tools for other atmosphere-bearing Solar System destinations. The focus was on developing an integrated systems engineering framework to allow mission designers to quickly evaluate the feasibility and performance of aerocapture mission concepts. Ye Lu and Athul P. Girija from the AAC research group conceptualized the **aerocapture feasibility charts**, now a commonly used graphical method for aerocapture mission design. An earlier version of the feasibility charts was presented by Saikia et al. in the IGPD study report.

Athul P. Girija formulated a systems framework for rapid conceptual design of aerocapture missions for his doctoral thesis. Much of the AMAT source code was originally written in support of his Ph.D. dissertation work. AMAT was first publicly released in November 2019, and has since then been maintained by the author at Purdue University. In the spirit of open code for open science, AMAT is free and open-source to foster universal access to the knowledge, and allow reproducibility of results by other researchers. Sugestions for improvement and potential contributions are greatly welcome.

1.3 Related software

There are industrial software tools which offer mission analysis capabilities for aerocapture missions. These offer much higher fidelity, but are also substantially more complex to set up and run. Such fidelity is most often not required at the level conceptual studies. These tools are not in the public domain, and is generally available only to U.S. government affiliated labs, and U.S. persons at academic or industrial institutions.

- POST2: According to NASA Langley Research Center, "The Program to Optimize Simulated Trajectories II (POST2) is a generalized point mass, discrete parameter targeting and optimization program. POST2 provides the capability to target and optimize point mass trajectories for multiple powered or un-powered vehicles near an arbitrary rotating, oblate planet. POST2 has been used successfully to solve a wide variety of atmospheric ascent and entry problems, as well as exo-atmospheric orbital transfer problems."
- DSENDS: According to NASA Jet Propulsion Laboratory, "DSENDS is a high-fidelity spacecraft simulator for Entry, Descent and Landing (EDL) on planetary and small-bodies. DSENDS (Dynamics Simulator for Entry, Descent and Surface landing) is an EDL-specific extension of a JPL multi-mission simulation toolkit Darts/Dshell which is capable of modeling spacecraft dynamics, devices, and subsystems, and is in use by interplanetary and science-craft missions such as Cassini, Galileo, SIM, and Starlight. DSENDS is currently in use by the JPL Mars Science Laboratory project to provide a high-fidelity testbed for the test of precision landing and hazard avoidance functions for future Mars missions. "

1.4 Future ideas

Some things I would like to implement in the future:

- Pairing AMAT with Blender and NASA 3D models of planets and spacecraft to produce high resolution renders of aerocapture vehicle trajectories.
- Improved guidance schemes for lift and drag modulation aerocapture such as direct force control.
- Improved support for EDL mission concepts in the areas of precision landing, parachute dynamics, terminal descent and landing phases.

1.5 Note from the original author

I am Athul P Girija, an aerospace engineer with a passion for robotic exploration of our Solar System. At the time of writing, I am a Ph.D. candidate in the Advanced Astrodynamics Concepts (AAC) research group led by Prof. Sarag

Saikia and Prof. James Longuski at Purdue University. My interests lie in the general areas of planetary science, mission design and concept formulation, open-source software, and scientific programming.

Google Scholar

CHAPTER 2

Installation

Note: AMAT is designed to work with Python 3.0 or greater. You must have a Python 3 installation in your system.

There are three ways to install AMAT.

2.1 Option 1 : Install from pip (recommended)

Note: Python Package Index limits the amount of additional data that can be packaged in the distribution, hence all data cannot be included in the built version. You will need to clone the GitHub repository to get the required data files, examples, and start using AMAT.

For Linux machines:

- `$ pip install AMAT`
- `$ git clone https://github.com/athulpg007/AMAT.git`

If you are unable to clone the repository, you can download the repository as a .zip file from GitHub and extract it. Once AMAT is installed, run an example Jupyter notebook to check everything works correctly.

- `$ cd AMAT/examples`
- `$ jupyter-notebook`

This will display the full list of example Jupyter notebooks included with AMAT. Open and run the `example-01-hello-world` notebook to get started with AMAT.

For Windows machines:

- `$ pip install AMAT`

(You must have Anaconda installed. Use the pip command from the Anaconda Prompt terminal). Open a Windows Powershell terminal and clone the GitHub repository. You must have Git installed.

- `$ git clone https://github.com/athulpg007/AMAT.git`

Run an example Jupyter notebook. From the Anaconda Prompt terminal:

- `$ cd AMAT/examples`
- `$ jupyter-notebook`

This will display the full list of example Jupyter notebooks included with AMAT. Open and run the `example-01-hello-world` notebook to get started with AMAT.

2.2 Option 2 : Install from source

This will clone the repository from GitHub and install AMAT from the source code.

For Linux machines:

- `$ pip install numpy scipy matplotlib pandas jupyterlab`

Clone the GitHub repository and install AMAT.

- `$ git clone https://github.com/athulpg007/AMAT.git`
- `$ cd AMAT`
- `$ python setup.py install`
- `$ cd examples`
- `$ jupyter-notebook`

For Windows machines (from the Anaconda Prompt terminal):

- `$ pip install numpy scipy matplotlib pandas jupyterlab`

Open a Windows Powershell terminal, clone the GitHub repository and install AMAT.

- `$ git clone https://github.com/athulpg007/AMAT.git`
- `$ cd AMAT`
- `$ python setup.py install`
- `$ cd examples`
- `$ jupyter-notebook`

To uninstall AMAT:

1. If you installed AMAT using pip:

- `$ pip uninstall AMAT`

2. If you installed AMAT from source, from the main AMAT directory:

- `$ python setup.py develop -u`

This will remove the AMAT installation from Python. You may simply delete the root folder where AMAT was installed to completely remove the files.

2.3 Option 3 : Install in a virutalenv

If you plan to modifty the source code or add features, the recommended option is to install it in a virtual environment.

1. Change directory to where you want the virtual environment to be created.

- `$ cd home/path`

2. Create a virutal environment and activate it.

On Linux machines:

- `$ python3 -m venv env1`
- `$ source env1/bin/activate`

On Windows machines (from Anaconda Prompt):

- `$ conda create --name env1`
- `$ conda activate env1`
- `$ conda install pip`

4. Follow the steps outlined in Option #2 (build from source) to clone the repository and install AMAT. If you make changes to the source code, remove the existing installation, update the setup file with a new version number, and re-install:

- `$ python setup.py develop -u`
- `$ python setup.py install`

If you want to create a new distrubution package:

- `$ python3 setup.py sdist bdist_wheel`

To re-make docs if you made changes to the source code (you must have Sphinx installed):

- `$ cd ~root/docs`
- `$ sphinx-apidoc -f -o source/ ../`
- `$ make html`

If you added a new AMAT module, appropriate changes must be made to docs/source/AMAT.rst.

2.4 AMAT Usage

- `from AMAT.planet import Planet`
- `from AMAT.vehicle import Vehicle`
- `from AMAT.launcher import Launcher`

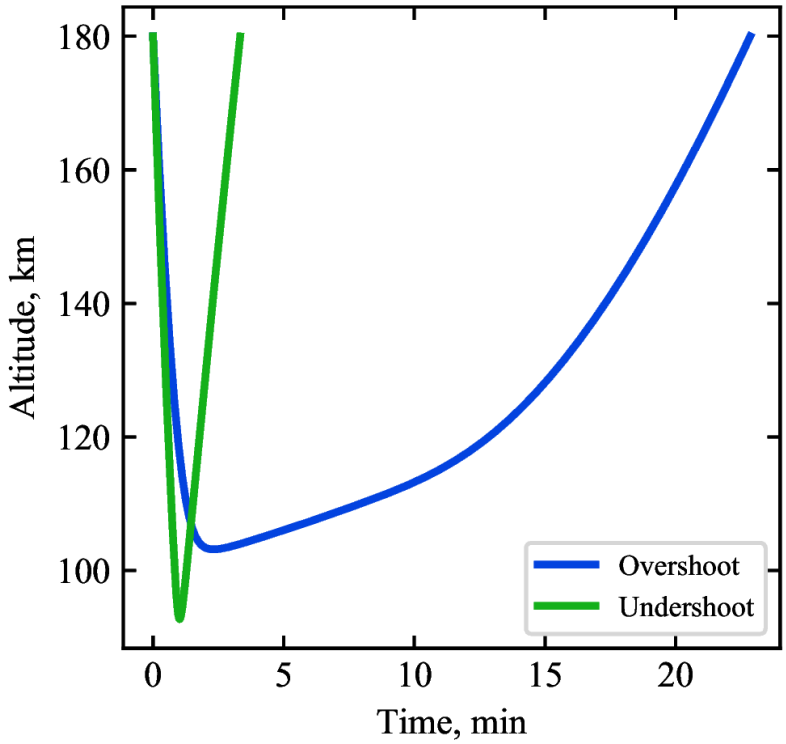
CHAPTER 3

Capabilities

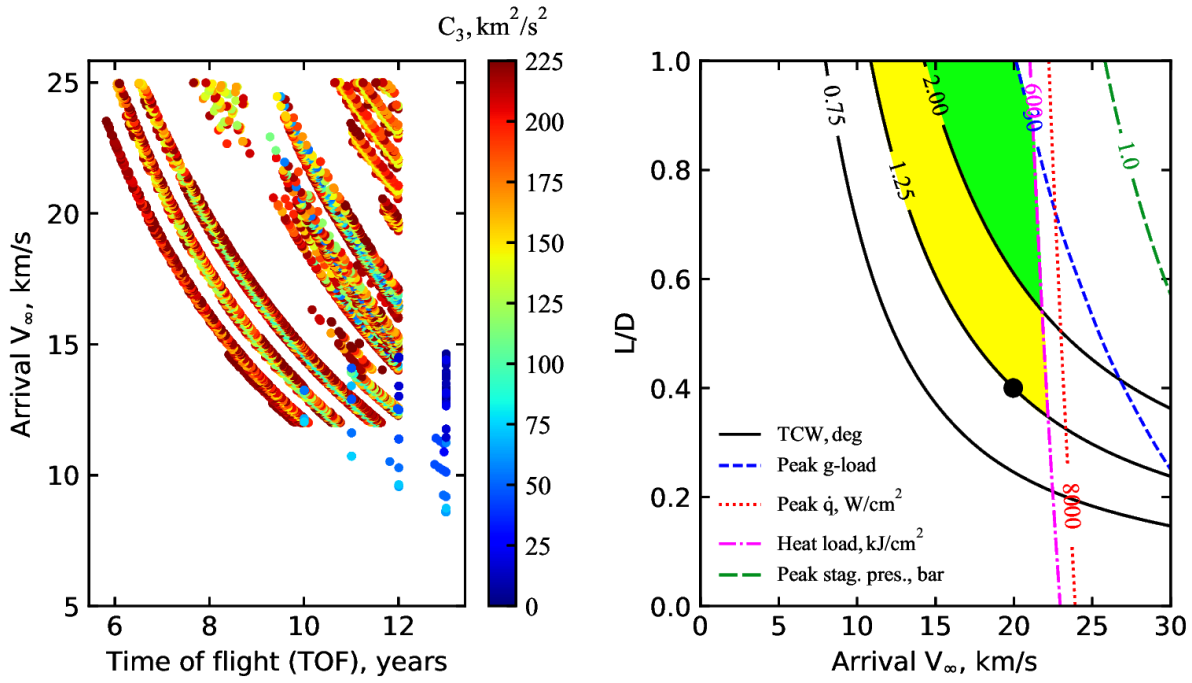
AMAT allows the user to perform low-fidelity broad sweep parametric studies; as well as high fidelity Monte Carlo simulations to quantify aerocapture performance. AMAT supports analysis for all atmosphere-bearing destinations in the Solar System: Venus, Earth, Mars, Jupiter, Saturn, Titan, Uranus, and Neptune.

3.1 Sample results

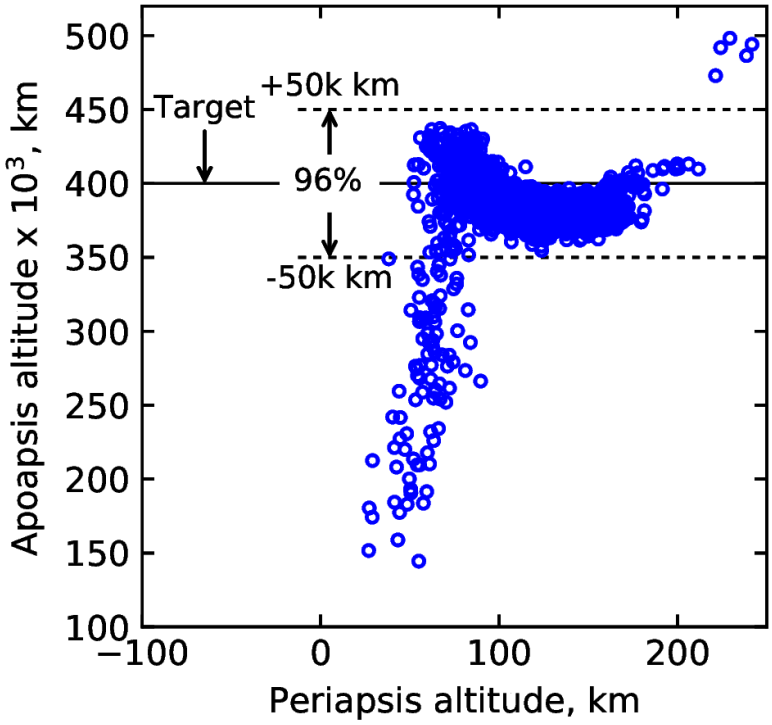
3.1.1 Venus Aerocapture Trajectory



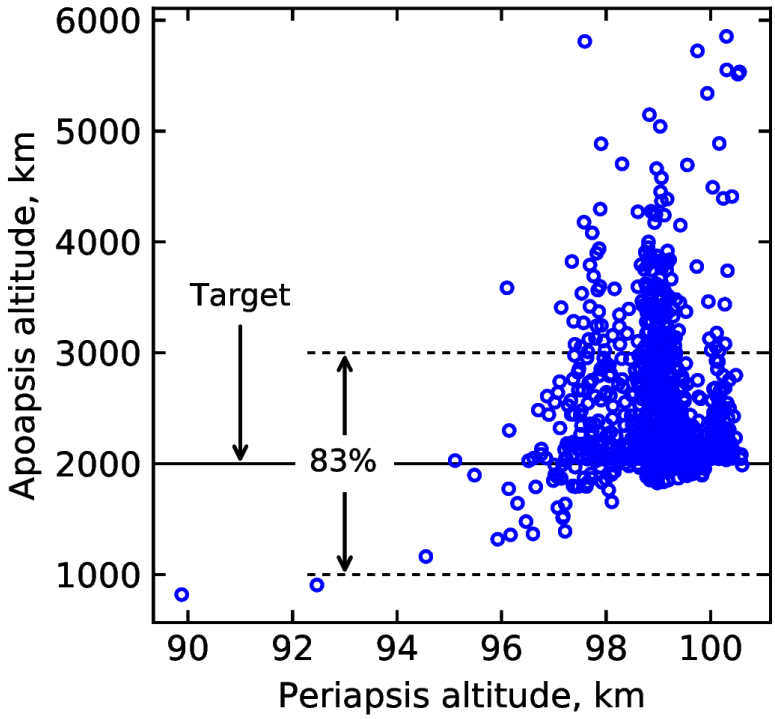
3.1.2 Neptune Aerocapture Feasibility Chart



3.1.3 Monte Carlo simulations - Neptune aerocapture



3.1.4 Monte Carlo simulations - SmallSat aerocapture at Venus



3.2 What kind of problems can AMAT solve?

AMAT can be used to quickly assess the feasibility of an aerocapture mission concept using aerocapture feasibiility charts, and perform trade studies involving vehicle type, control authority, thermal protection system materials, and useful delivered mass to orbit. AMAT can also be used to set up and run high-fidelity Monte Carlo simulations of aerocapture trajectories considering delivery errors, atmospheric uncertainties, and aerodynamic uncertainties to evaluate system performance under uncertainty.

CHAPTER 4

Example Jupyter Notebooks

4.1 Example - 01 - Hello World!

In this 'hello world' program, you will learn to use AMAT to create a planet object.

First let us import the Planet class from AMAT

[1]:
```
from AMAT.planet import Planet
```

Now let us create a planet object which represents Venus.

[2]:
```
planet = Planet("VENUS")
```

Let us look at the an attribute of the created object. For example let us, print the radius of the planet. A full list of attributes and functions can be obtained using help(planet).

[3]:
```
print(planet.RP)
```

```
6051800.0
```

Congratulations! You have now created a planet object using AMAT. In the next example, we will add an atmosphere model to this planet object.

4.2 Example - 02 - Atmosphere

In this example, you will learn to use add an atmosphere model to planets.

Let us re-use the code from example-01 to create a planet object for Venus.

[1]:
```
from AMAT.planet import Planet
planet = Planet("VENUS")
```

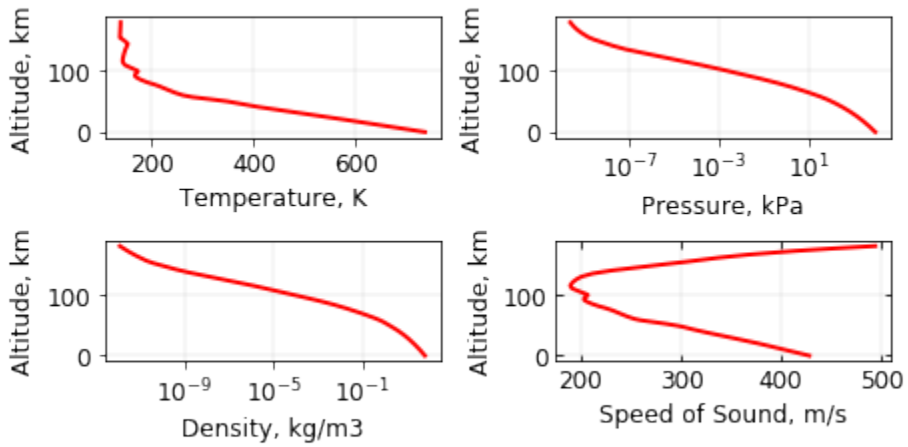
We are now ready to add an atmosphere model to the planet object.

AMAT stores atmospheric data in the form of look up tables located in ~root/atmdata. Typically, data is stored in the following format.

#Z(m)	Temp(K)	Pres (Nm2)	rho(kgm3)	a (m/s)
0	735.30	9.209E+06	6.479E+01	428.03
1000	727.70	8.645E+06	6.156E+01	425.46
2000	720.20	8.109E+06	5.845E+01	422.88
3000	712.40	7.601E+06	5.547E+01	420.27
4000	704.60	7.120E+06	5.262E+01	417.63
5000	696.80	6.666E+06	4.987E+01	415.09

[2]:
```
# the atmosphere model provided in atmdata/Venus/venus-gram-avg.dat.
# The columns for height, Temp, pressure, density are 0, 1, 2, 3
planet.loadAtmosphereModel('../atmdata/Venus/venus-gram-avg.dat', 0 , 1 ,2, 3)
```

[3]:
```
# Let us now use the checkAtmProfiles function to inspect the atmospheric profiles.
planet.checkAtmProfiles()
```



[4]:
```
# Compute the scale height at the Venusian surface for illustration.
# planet.density_int is the interpolation function created by planet object
# when atmosphere model is loaded.
planet.scaleHeight(0, planet.density_int)
```

[4]:
```
16127.792366356383
```

Congratulations! Your planet now has an atmosphere model. In the next example, we will compute aerocapture trajectories for a vehicle flying in the Venusian atmosphere.

4.3 Example - 03 - Venus Aerocapture: Part 1

In this example, you will learn to create a vehicle object in AMAT and simulate its aerocapture trajectory in the Venusian atmosphere.

For reference, we will re-create a few results from the paper "Craig and Lyne, Parametric Study of Aerocapture for Missions to Venus, Journal of Spacecraft and Rockets, Vol. 42, No. 6., 2005. DOI:10.2514/1.2589

Let us re-use the code from example-01, 02 to create a planet object for Venus and add an atmosphere model. In addition to Planet, import the Vehicle class from AMAT for this example.

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle

# Create a planet object
planet=Planet("VENUS")

# Load an nominal atmospheric profile with height, temp, pressure, density data
planet.loadAtmosphereModel('../atmdata/Venus/venus-gram-avg.dat', 0 , 1 ,2, 3)
```

[2]:
```
# Create a vehicle object flying in the target planet atmosphere.
# with params m = 300 kg, beta = 78.0, L/D = 0.35, A = 3.1416, AoA = 0, RN = 1.54

# These values are taken from the reference article mentioned above.
vehicle=Vehicle('Apollo', 300.0, 78.0, 0.35, 3.1416, 0.0, 1.54, planet)
```

Set initial conditions for the vehicle at atmospheric entry interface.

[3]:
```
# h0 = 180 km, LON = 0 deg, LAT = 0 deg
# v0 = 12 km/s, HDG = 0 deg, FPA = 0 deg
# DOWNRANGE0 = 0 deg, HEATLOAD0 = 0.

# See help(vehicle) for more details.
vehicle.setInitialState(180.0,0.0,0.0,12.0,0.0,-4.5,0.0,0.0)

# Set solver tolerance = 1E-6 (recommended value)
# Setting this too low can result in long execution times.
vehicle.setSolverParams(1E-6)
```

[4]:
```
# Compute the overshoot and undershoot limit EFPA

# Set max. propogation time = 2400.0 secs.
# Set max. time step = 0.1 sec.
# Set low value for guess = -80.0 deg
# Set high value for guess = -4.0 deg
# Set EFPA tolerance = 1E-10 (recommended)
# Set target apoapsis = 407 km

# This calculation migt take a couple of minutes. Hang on!
overShootLimit, exitflag_os  = vehicle.findOverShootLimit (2400.0,0.1,-80.0,-4.0,1E-
↪10,407.0)
underShootLimit,exitflag_us  = vehicle.findUnderShootLimit(2400.0,0.1,-80.0,-4.0,1E-
↪10,407.0)
```

[5]:
```
# exitflag_os and exitflag_us will be set to 1 if a solution was found. Otherwise, it␣
↪will be 0.
print(exitflag_os)
print(exitflag_us)
```

```
1.0
1.0
```

[6]:
```
# print the overshoot and undershoot limits we just computed.
print("Overshoot  limit : "+str('{:.4f}'.format(overShootLimit))+ " deg")
print("Undershoot limit : "+str('{:.4f}'.format(underShootLimit))+ " deg")
```

```
Overshoot  limit : -7.0519 deg
Undershoot limit : -9.4396 deg
```

These are the limiting flight path angles for our vehicle at Venus. Let us now calculate these trajectories, and their associated deceleration and heating profiles.

[7]:
```
import matplotlib.pyplot as plt
from matplotlib import rcParams

# Reset initial conditions and propogate overshoot trajectory
vehicle.setInitialState(180.0,0.0,0.0,12.0,0.0,overShootLimit,0.0,0.0)
vehicle.propogateEntry (2400.0,0.1,180.0)

# Extract and save variables to plot
t_min_os         = vehicle.t_minc
h_km_os          = vehicle.h_kmc
acc_net_g_os     = vehicle.acc_net_g
q_stag_con_os    = vehicle.q_stag_con
q_stag_rad_os    = vehicle.q_stag_rad

# Reset initial conditions and propogate undershoot trajectory
vehicle.setInitialState(180.0,0.0,0.0,12.0,0.0,underShootLimit,0.0,0.0)
vehicle.propogateEntry (2400.0,0.1,0.0)

# Extract and save variable to plot
t_min_us         = vehicle.t_minc
h_km_us          = vehicle.h_kmc
acc_net_g_us     = vehicle.acc_net_g
q_stag_con_us    = vehicle.q_stag_con
q_stag_rad_us    = vehicle.q_stag_rad

'''
Create fig #1 - altitude history of aerocapture maneuver
'''

fig = plt.figure()
fig.set_size_inches([3.25,3.25])
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)
plt.plot(t_min_os , h_km_os, linestyle='solid' , color='xkcd:blue',linewidth=2.0, ␣
↪label='Overshoot')
plt.plot(t_min_us , h_km_us, linestyle='solid' , color='xkcd:green',linewidth=2.0, ␣
↪label='Undershoot')

plt.xlabel('Time, min',fontsize=10)
plt.ylabel("Altitude, km",fontsize=10)

ax = plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
plt.tick_params(direction='in')
plt.tick_params(axis='x',labelsize=10)
plt.tick_params(axis='y',labelsize=10)

plt.legend(loc='lower right', fontsize=8)
```

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```
plt.savefig('../plots/craig-lyne-altitude.png',bbox_inches='tight')
plt.savefig('../plots/craig-lyne-altitude.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/craig-lyne-altitude.eps', dpi=300,bbox_inches='tight')

plt.show()

fig = plt.figure()
fig.set_size_inches([3.25,3.25])
plt.rc('font',family='Times New Roman')
plt.plot(t_min_os , acc_net_g_os, linestyle='solid' , color='xkcd:blue',linewidth=1.0,
↪  label='Overshoot')
plt.plot(t_min_us , acc_net_g_us, linestyle='solid' , color='xkcd:green',linewidth=1.
↪0,  label='Undershoot')

plt.xlabel('Time, min',fontsize=10)
plt.ylabel("Deceleration, Earth g",fontsize=10)

ax = plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
plt.tick_params(direction='in')
plt.tick_params(axis='x',labelsize=10)
plt.tick_params(axis='y',labelsize=10)

plt.legend(loc='upper right', fontsize=8)


plt.savefig('../plots/craig-lyne-deceleration.png',bbox_inches='tight')
plt.savefig('../plots/craig-lyne-deceleration.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/craig-lyne-deceleration.eps', dpi=300,bbox_inches='tight')

plt.show()

fig = plt.figure()
fig.set_size_inches([3.25,3.25])
plt.rc('font',family='Times New Roman')
plt.plot(t_min_os , q_stag_con_os, linestyle='solid' , color='xkcd:blue',linewidth=1.
↪0,  label='Overshoot convective')
plt.plot(t_min_os , q_stag_rad_os, linestyle='solid' , color='xkcd:red',linewidth=1.0,
↪  label='Overshoot radiative')
plt.plot(t_min_us , q_stag_con_us, linestyle='solid' , color='xkcd:magenta',
↪linewidth=1.0,  label='Undershoot convective')
plt.plot(t_min_us , q_stag_rad_us, linestyle='solid' , color='xkcd:green',linewidth=1.
↪0,  label='Undershoot radiative')

plt.xlabel('Time, min',fontsize=10)
plt.ylabel("Stagnation-point heat rate, "+r'$W/cm^2$',fontsize=10)

ax = plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
plt.tick_params(direction='in')
plt.tick_params(axis='x',labelsize=10)
```

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```
plt.tick_params(axis='y',labelsize=10)

plt.legend(loc='upper right', fontsize=8)


plt.savefig('../plots/craig-lyne-heating.png',bbox_inches='tight')
plt.savefig('../plots/craig-lyne-heating.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/craig-lyne-heating.eps', dpi=300,bbox_inches='tight')

plt.show()
```

```
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
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↪will be rendered opaque.
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↪will be rendered opaque.
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↪will be rendered opaque.
```

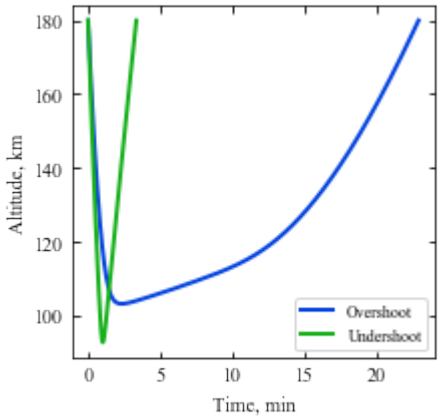


```
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↪will be rendered opaque.
```

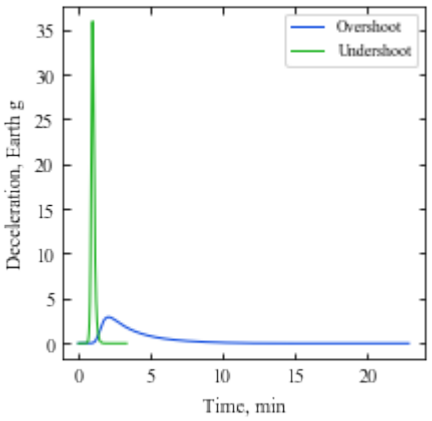


```
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
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↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
```
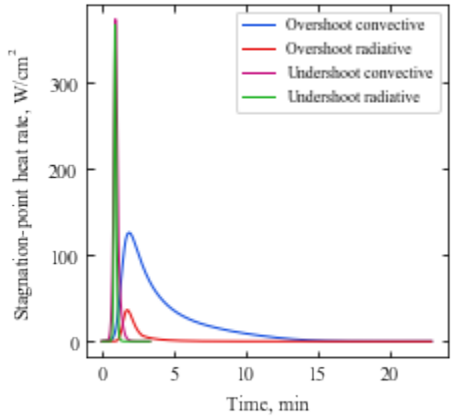



The plots are now saved in plots/craig-lyne-* and should match with the results from the paper.

Congratulations! You have simulated an aerocapture vehicle flying in the Venusian atmosphere. In the next tutorial, we will compute the corridor widths for drag modulation aerocapture at Venus.

4.4 Example - 04 - Venus Aerocapture: Part 2

In this example, you will learn to create a drag modulation vehicle object and compute the theoretical corridor width available for drag modulation aerocapture at Venus.

For reference, we will re-create a figure from the paper "Putnam and Braun, Drag-Modulation Flight-Control System Options for Planetary Aerocapture, Journal of Spacecraft and Rockets, Vol. 51, No. 1, 2014. DOI: 10.2514/1.A32589

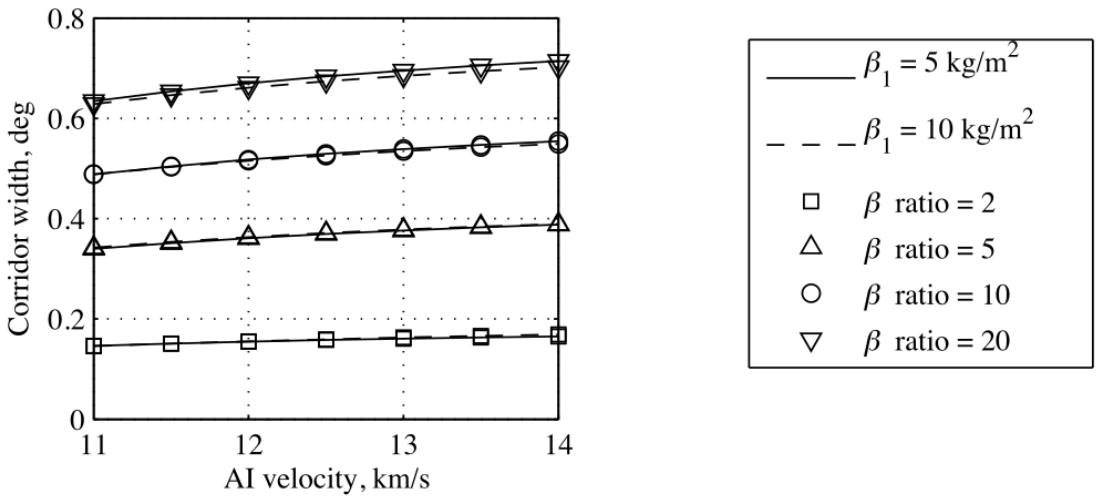
Import AMAT and required libraries

[2]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle

import numpy as np
import matplotlib.pyplot as plt
from matplotlib import rcParams
import os
```

[3]:
```
# Create a planet object
planet=Planet("VENUS")

# Load an nominal atmospheric profile with height, temp, pressure, density data
planet.loadAtmosphereModel('../atmdata/Venus/venus-gram-avg.dat', 0 , 1 ,2, 3)

# The reference paper uses 150 km as entry interface altitude (vs 180 km as pre-
↪defined in AMAT).
# Hence reset planet.h_skip to 150 km
planet.h_skip = 150000.0
# Create a vehicle object flying in the target planet atmosphere
vehicle=Vehicle('DMVehicle', 1500.0, 50.0, 0.0, 3.1416, 0.0, 0.10, planet)

# Set vehicle conditions at entry interface
# Note that the EFPA initial value is arbitrary. It will be computed and reset later.
vehicle.setInitialState(150.0,0.0,0.0,11.0,0.0,-4.5,0.0,0.0)
vehicle.setSolverParams(1E-6)
```

[4]:
```
from IPython.display import Image
Image(filename='../plots/putnam-2014-reference.png')
```

[4]:



This is the figure that we want to reproduce using AMAT. Let us start setting up the simulation parameters.

[7]:
```
# Define the AI velocity and ballistic ratio range
VAI_array = np.linspace(11,14,7)
BR_array  = np.array([2.0,5.0,10.0,20.0])

# NOTE: You will get a FileExistsError if you run this as such. Re-name the directory␣
↪to something else.
```

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```
# Create a directory in ../data/ to store the data
os.makedirs('../data/putnamBraun2013')

# Store the speed range and ballistic coefficient range
np.savetxt('../data/putnamBraun2013/VAI_array.txt',VAI_array)
np.savetxt('../data/putnamBraun2013/BR_array.txt' , BR_array)

# Create two empty matrices to store the TCW values
TCW_array1 = np.zeros((len(VAI_array),len(BR_array)))
TCW_array2 = np.zeros((len(VAI_array),len(BR_array)))

# Define the two values for beta_1 used in the paper.
beta11 = 5.0
beta12 = 10.0
```

[8]:
```
# Compute the corridor width values to create the figure.
# NOTE: This calculation will take several minutes.
print('Running beta1=5.0')

for i in range(0,len(VAI_array)):
    for j in range(0,len(BR_array)):
        vehicle.setInitialState(150.0,0.0,0.0,VAI_array[i],0.0,-4.5,0.0,0.0)
        vehicle.setDragModulationVehicleParams(beta11,BR_array[j])
        TCW_array1[i,j] = vehicle.computeTCWD(2400.0, 0.1,-80.0,-4.0,1E-10,400.0)
        print('VAI: '+str(VAI_array[i])+' km/s, BETA RATIO: '+str(BR_array[j])+' TCW:
↪'+str(TCW_array1[i,j])+' deg.')

np.savetxt('../data/putnamBraun2013/TCW_array1.txt', TCW_array1)

print('Running beta1=10.0')
for i in range(0,len(VAI_array)):
    for j in range(0,len(BR_array)):
        vehicle.setInitialState(150.0,0.0,0.0,VAI_array[i],0.0,-4.5,0.0,0.0)
        vehicle.setDragModulationVehicleParams(beta12,BR_array[j])
        TCW_array2[i,j] = vehicle.computeTCWD(2400.0, 0.1,-80.0,-4.0,1E-10,400.0)
        print('VAI: '+str(VAI_array[i])+' km/s, BETA RATIO: '+str(BR_array[j])+' TCW:
↪'+str(TCW_array2[i,j])+' deg.')

np.savetxt('../data/putnamBraun2013/TCW_array2.txt', TCW_array2)
print('Done!')
```

```
Running beta1=5.0
VAI: 11.0 km/s, BETA RATIO: 20.0 TCW: 0.6330942395761667 deg.
VAI: 14.0 km/s, BETA RATIO: 20.0 TCW: 0.7133574859435612 deg.
Running beta1=10.0
VAI: 11.0 km/s, BETA RATIO: 20.0 TCW: 0.6273882169480203 deg.
VAI: 14.0 km/s, BETA RATIO: 20.0 TCW: 0.7018732332253421 deg.
Done!
```

Load the data and make the plot.

[9]:
```
VAI_array  = np.loadtxt('../data/putnamBraun2013/VAI_array.txt')
BR_array   = np.loadtxt('../data/putnamBraun2013/BR_array.txt')
TCW_array1 = np.loadtxt('../data/putnamBraun2013/TCW_array1.txt')
```

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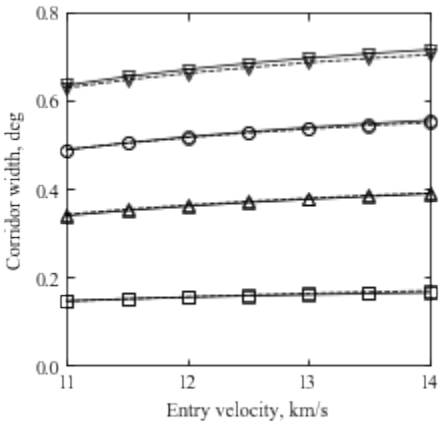
```
TCW_array2 = np.loadtxt('../data/putnamBraun2013/TCW_array2.txt')

fig = plt.figure()
fig.set_size_inches([3.25,3.25])
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.plot(VAI_array, TCW_array1[:,0], linestyle='-', linewidth=0.75, marker='s',ms=6,␣
↪markerfacecolor="None", markeredgecolor='black', markeredgewidth=0.75, color='black
↪', clip_on=False)
plt.plot(VAI_array, TCW_array1[:,1], linestyle='-', linewidth=0.75, marker='^',ms=6,␣
↪markerfacecolor="None", markeredgecolor='black', markeredgewidth=0.75, color='black
↪', clip_on=False)
plt.plot(VAI_array, TCW_array1[:,2], linestyle='-', linewidth=0.75, marker='o',ms=6,␣
↪markerfacecolor="None", markeredgecolor='black', markeredgewidth=0.75, color='black
↪', clip_on=False)
plt.plot(VAI_array, TCW_array1[:,3], linestyle='-', linewidth=0.75, marker='v',ms=6,␣
↪markerfacecolor="None", markeredgecolor='black', markeredgewidth=0.75, color='black
↪', clip_on=False)

plt.plot(VAI_array, TCW_array2[:,0], linestyle='--', linewidth=0.75, marker='s',ms=6,␣
↪markerfacecolor="None", markeredgecolor='black', markeredgewidth=0.75, color='black
↪', clip_on=False)
plt.plot(VAI_array, TCW_array2[:,1], linestyle='--', linewidth=0.75, marker='^',ms=6,␣
↪markerfacecolor="None", markeredgecolor='black', markeredgewidth=0.75, color='black
↪', clip_on=False)
plt.plot(VAI_array, TCW_array2[:,2], linestyle='--', linewidth=0.75, marker='o',ms=6,␣
↪markerfacecolor="None", markeredgecolor='black', markeredgewidth=0.75, color='black
↪', clip_on=False)
plt.plot(VAI_array, TCW_array2[:,3], linestyle='--', linewidth=0.75, marker='v',ms=6,␣
↪markerfacecolor="None", markeredgecolor='black', markeredgewidth=0.75, color='black
↪', clip_on=False)

plt.xlabel('Entry velocity, km/s', fontsize=10)
plt.ylabel('Corridor width, deg',fontsize=10)
plt.yticks(np.arange(0, 0.9, step=0.2))
plt.xticks(np.arange(11.0, 14.5, step=1.0))

plt.xlim([11.0,14.0])
plt.ylim([0.0,  0.8])

ax = plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
plt.tick_params(direction='in')
plt.tick_params(axis='x',labelsize=10)
plt.tick_params(axis='y',labelsize=10)


plt.savefig('../plots/putnam-braun-2013.png',bbox_inches='tight')
plt.savefig('../plots/putnam-braun-2013.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/putnam-braun-2013.eps', dpi=300,bbox_inches='tight')

plt.show()
```



The plots are now saved in plots/putnam-braun-* and should match with the results from the paper.

Congratulations! You have now computed the corridor widths for a drag modulation aerocapture vehicle at Venus. In the next example, we will create an aerocapture feasibility chart for Titan.

[ ]:

4.5 Example - 05 - Titan Aerocapture: Part 1

In this example, you will learn to create an aerocapture feasibility chart for Titan.

For reference, we will re-create a figure from the paper "Lu and Saikia, Feasibility Assessment of Aerocapture for Future Titan Orbiter Missions, Journal of Spacecraft and Rockets, Vol. 55, No. 5, 2018". DOI: 10.2514/1.A34121

[3]:
```
from IPython.display import Image
Image(filename='../plots/lu-saikia-reference-a.png', width=400)
```

[3]:

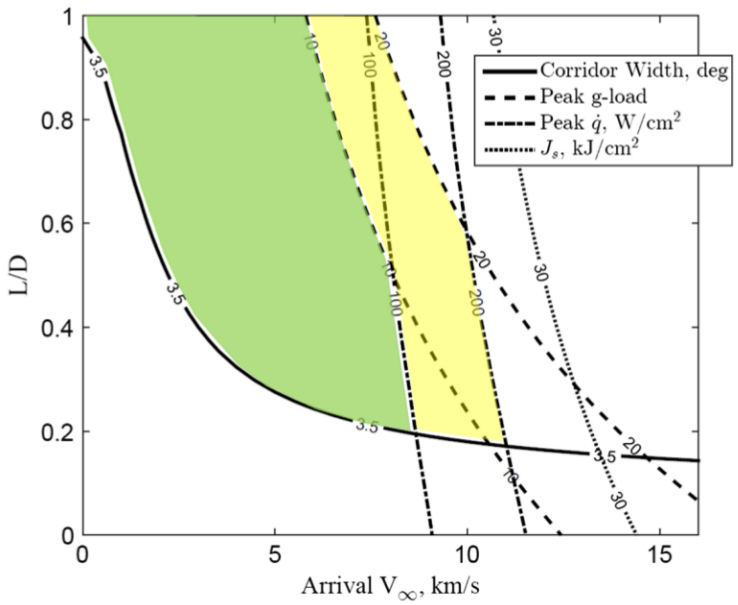


Fig. 16 Aerocapture applicable regions for β of 90 kg/m^2.

We will use AMAT to recreate this figure.

[4]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle

import numpy as np
from scipy import interpolate
import pandas as pd

import matplotlib.pyplot as plt
from matplotlib import rcParams
from matplotlib.patches import Polygon
import os
```

[6]:
```
# Create a planet object for Titan
planet=Planet("TITAN")

# Load an nominal atmospheric profile with height, temp, pressure, density data
planet.loadAtmosphereModel('../atmdata/Titan/titan-gram-avg.dat', 0 , 1 , 2, 3)

# Define the range for arrival Vinf and vehicle L/D
vinf_kms_array = np.linspace( 0.0,   16.0,  17)
LD_array       = np.linspace( 0.0,    1.0 , 11)

#vinf_kms_array = np.linspace( 0.0,   16.0,  2)
#LD_array       = np.linspace( 0.0,    1.0 , 2)
```

[7]:
```
# Create a directory to store the data.
# NOTE: You will get an error if the file already exists,
# Rename the folder to something else.

os.makedirs('../data/luSaikia2018a')
```

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```
# Use a runID to prefix the files for easy access for post-processing.
runID = 'BC90RAP1700'

num_total      = len(vinf_kms_array)*len(LD_array)
count = 1

# Compute the inertial entry speed from the hyperbolic excess speed.
v0_kms_array    = np.zeros(len(vinf_kms_array))
v0_kms_array[:] = np.sqrt(1.0*(vinf_kms_array[:]*1E3)**2.0 + \
                          2*np.ones(len(vinf_kms_array))*\
                          planet.GM/(planet.RP+1000.0*1.0E3))/1.0E3

# Initialize matrices to store data.
overShootLimit_array  = np.zeros((len(v0_kms_array),len(LD_array)))
underShootLimit_array = np.zeros((len(v0_kms_array),len(LD_array)))
exitflag_os_array     = np.zeros((len(v0_kms_array),len(LD_array)))
exitflag_us_array     = np.zeros((len(v0_kms_array),len(LD_array)))
TCW_array             = np.zeros((len(v0_kms_array),len(LD_array)))
```

[8]:
```
# Compute the corridor width over the defined Vinf and L/D matrix.
# Note this will take maybe about an hour.
# If you simply want to create the plot, you can load the existing data
# in the ../data/luSaikia2018a folder as done below this cell.

for i in range(0,len(v0_kms_array)):
    for j in range(0,len(LD_array)):
        vehicle=Vehicle('Kraken', 1000.0, 90.0, LD_array[j], 3.1416, 0.0, 1.00,␣
↪planet)
        vehicle.setInitialState(1000.0,0.0,0.0,v0_kms_array[i],0.0,-4.5,0.0,0.0)
        vehicle.setSolverParams(1E-5)
        overShootLimit_array[i,j],  exitflag_os_array[i,j] = \
        vehicle.findOverShootLimit (6000.0, 1.0 , -88.0, -2.0, 1E-10, 1700.0)
        underShootLimit_array[i,j], exitflag_us_array[i,j] =  \
        vehicle.findUnderShootLimit(6000.0, 1.0 , -88.0, -2.0, 1E-10, 1700.0)

        TCW_array[i,j] = overShootLimit_array[i,j] - underShootLimit_array[i,j]

        print("Run #"+str(count)+" of "+ str(num_total)+\
              ": Arrival V_infty: "+str(vinf_kms_array[i])+\
              " km/s"+", L/D:"+str(LD_array[j]) +\
              " OSL: "+str(overShootLimit_array[i,j])+\
              " USL: "+str(underShootLimit_array[i,j])+\
              ", TCW: "+str(TCW_array[i,j])+\
              " EFOS: "+str(exitflag_os_array[i,j])+\
              " EFUS: "+str(exitflag_us_array[i,j]))

        count = count +1

np.savetxt('../data/luSaikia2018a/'+runID+'vinf_kms_array.txt',vinf_kms_array)
np.savetxt('../data/luSaikia2018a/'+runID+'v0_kms_array.txt',v0_kms_array)
np.savetxt('../data/luSaikia2018a/'+runID+'LD_array.txt',LD_array)
np.savetxt('../data/luSaikia2018a/'+runID+'overShootLimit_array.txt',overShootLimit_
↪array)
np.savetxt('../data/luSaikia2018a/'+runID+'exitflag_os_array.txt',exitflag_os_array)
```

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```
np.savetxt('../data/luSaikia2018a/'+runID+'undershootLimit_array.txt',underShootLimit_
↪array)
np.savetxt('../data/luSaikia2018a/'+runID+'exitflag_us_array.txt',exitflag_us_array)
np.savetxt('../data/luSaikia2018a/'+runID+'TCW_array.txt',TCW_array)
```

```
Run #1 of 4: Arrival V_infty: 0.0 km/s, L/D:0.0 OSL: -24.635471317420524 USL: -24.
↪635471317420524, TCW: 0.0 EFOS: 1.0 EFUS: 1.0
Run #2 of 4: Arrival V_infty: 0.0 km/s, L/D:1.0 OSL: -23.422944245403414 USL: -27.
↪0515137471466, TCW: 3.6285695017431863 EFOS: 1.0 EFUS: 1.0
Run #3 of 4: Arrival V_infty: 16.0 km/s, L/D:0.0 OSL: -37.36673820708165 USL: -37.
↪36673820708165, TCW: 0.0 EFOS: 1.0 EFUS: 1.0
Run #4 of 4: Arrival V_infty: 16.0 km/s, L/D:1.0 OSL: -33.47214682791673 USL: -73.
↪89901192915568, TCW: 40.426865101238945 EFOS: 1.0 EFUS: 1.0
```

Compute the deceleration and heating loads.

[9]:
```
acc_net_g_max_array       = np.zeros((len(v0_kms_array),len(LD_array)))
stag_pres_atm_max_array   = np.zeros((len(v0_kms_array),len(LD_array)))
q_stag_total_max_array    = np.zeros((len(v0_kms_array),len(LD_array)))
heatload_max_array        = np.zeros((len(v0_kms_array),len(LD_array)))

for i in range(0,len(v0_kms_array)):
    for j in range(0,len(LD_array)):
        vehicle=Vehicle('Kraken', 1000.0, 90.0, LD_array[j], 3.1416, 0.0, 1.00,␣
↪planet)
        vehicle.setInitialState(1000.0,0.0,0.0,v0_kms_array[i],0.0,overShootLimit_
↪array[i,j],0.0,0.0)
        vehicle.setSolverParams(1E-5)

        vehicle.propogateEntry(6000.0, 1.0, 180.0)

        # Extract and save variables to plot
        t_min_os         = vehicle.t_minc
        h_km_os          = vehicle.h_kmc
        acc_net_g_os     = vehicle.acc_net_g
        q_stag_con_os    = vehicle.q_stag_con
        q_stag_rad_os    = vehicle.q_stag_rad
        rc_os            = vehicle.rc
        vc_os            = vehicle.vc
        stag_pres_atm_os = vehicle.computeStagPres(rc_os,vc_os)/(1.01325E5)
        heatload_os      = vehicle.heatload

        vehicle=Vehicle('Kraken', 1000.0, 90.0, LD_array[j], 3.1416, 0.0, 1.00,␣
↪planet)
        vehicle.setInitialState(1000.0,0.0,0.0,v0_kms_array[i],0.0,underShootLimit_
↪array[i,j],0.0,0.0)
        vehicle.setSolverParams(1E-5)

        vehicle.propogateEntry(6000.0, 1.0, 0.0)

        # Extract and save variable to plot
        t_min_us         = vehicle.t_minc
        h_km_us          = vehicle.h_kmc
        acc_net_g_us     = vehicle.acc_net_g
        q_stag_con_us    = vehicle.q_stag_con
        q_stag_rad_us    = vehicle.q_stag_rad
        rc_us            = vehicle.rc
```

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```
        vc_us            = vehicle.vc
        stag_pres_atm_us = vehicle.computeStagPres(rc_us,vc_us)/(1.01325E5)
        heatload_us      = vehicle.heatload

        q_stag_total_os  = q_stag_con_os + q_stag_rad_os
        q_stag_total_us  = q_stag_con_us + q_stag_rad_us

        acc_net_g_max_array[i,j]      = max(max(acc_net_g_os),max(acc_net_g_us))
        stag_pres_atm_max_array[i,j]  = max(max(stag_pres_atm_os),max(stag_pres_atm_
↪os))
        q_stag_total_max_array[i,j]   = max(max(q_stag_total_os),max(q_stag_total_us))
        heatload_max_array[i,j]       = max(max(heatload_os),max(heatload_us))

        print("V_infty: "+str(vinf_kms_array[i])+" km/s"+", L/D: "+str(LD_array[j])+"␣
↪G_MAX: "+str(acc_net_g_max_array[i,j])+" QDOT_MAX: "+str(q_stag_total_max_array[i,
↪j])+" J_MAX: "+str(heatload_max_array[i,j])+" STAG. PRES: "+str(stag_pres_atm_max_
↪array[i,j]))

np.savetxt('../data/luSaikia2018a/'+runID+'acc_net_g_max_array.txt',acc_net_g_max_
↪array)
np.savetxt('../data/luSaikia2018a/'+runID+'stag_pres_atm_max_array.txt',stag_pres_atm_
↪max_array)
np.savetxt('../data/luSaikia2018a/'+runID+'q_stag_total_max_array.txt',q_stag_total_
↪max_array)
np.savetxt('../data/luSaikia2018a/'+runID+'heatload_max_array.txt',heatload_max_array)
```

```
V_infty: 0.0 km/s, L/D: 0.0 G_MAX: 0.0810485245607735 QDOT_MAX: 1.0607636054752763 J_
↪MAX: 1020.003796275038 STAG. PRES: 0.0007204224444467468
V_infty: 0.0 km/s, L/D: 1.0 G_MAX: 0.20202892551813917 QDOT_MAX: 1.3893301148573975 J_
↪MAX: 1252.170615904772 STAG. PRES: 0.0004253391968484517
V_infty: 16.0 km/s, L/D: 0.0 G_MAX: 17.704051243426182 QDOT_MAX: 536.4530046363565 J_
↪MAX: 35907.65472341787 STAG. PRES: 0.15433527803169042
V_infty: 16.0 km/s, L/D: 1.0 G_MAX: 125.7389398961218 QDOT_MAX: 1065.8317771270392 J_
↪MAX: 63948.52565398295 STAG. PRES: 0.044601211536270044
```

We are now ready to create the plot!

[17]:
```
x = np.loadtxt('../data/luSaikia2018a/'+runID+'vinf_kms_array.txt')
y = np.loadtxt('../data/luSaikia2018a/'+runID+'LD_array.txt')

Z1 = np.loadtxt('../data/luSaikia2018a/'+runID+'TCW_array.txt')
G1 = np.loadtxt('../data/luSaikia2018a/'+runID+'acc_net_g_max_array.txt')
Q1 = np.loadtxt('../data/luSaikia2018a/'+runID+'q_stag_total_max_array.txt')
H1 = np.loadtxt('../data/luSaikia2018a/'+runID+'heatload_max_array.txt')

f1 = interpolate.interp2d(x, y, np.transpose(Z1), kind='cubic')
g1 = interpolate.interp2d(x, y, np.transpose(G1), kind='cubic')
q1 = interpolate.interp2d(x, y, np.transpose(Q1), kind='cubic')
h1 = interpolate.interp2d(x, y, np.transpose(H1), kind='cubic')

x_new =  np.linspace( 0.0,   16,  170)
y_new =  np.linspace( 0.0,   1.0 ,110)
z_new =  np.zeros((len(x_new),len(y_new)))

z1_new =  np.zeros((len(x_new),len(y_new)))
```

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```
g1_new =  np.zeros((len(x_new),len(y_new)))
q1_new =  np.zeros((len(x_new),len(y_new)))
h1_new =  np.zeros((len(x_new),len(y_new)))

for i in range(0,len(x_new)):
    for j in range(0,len(y_new)):

        z1_new[i,j] = f1(x_new[i],y_new[j])
        g1_new[i,j] = g1(x_new[i],y_new[j])
        q1_new[i,j] = q1(x_new[i],y_new[j])
        h1_new[i,j] = h1(x_new[i],y_new[j])

Z1 = z1_new
G1 = g1_new
Q1 = q1_new
H1 = h1_new/1000.0

X, Y = np.meshgrid(x_new, y_new)

Zlevels = np.array([2.5,3.5])
Glevels = np.array([10.0, 20.0])
Qlevels = np.array([100.0, 200.0])
Hlevels = np.array([30.0])


fig = plt.figure()
fig.set_size_inches([3.25,3.25])
plt.ion()
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

ZCS1 = plt.contour(X, Y, np.transpose(Z1), levels=Zlevels, colors='black')
plt.clabel(ZCS1, inline=1, fontsize=10, colors='black',fmt='%.1f',inline_spacing=1)
ZCS1.collections[0].set_linewidths(1.50)
ZCS1.collections[1].set_linewidths(1.50)
ZCS1.collections[0].set_label(r'$TCW, deg.$')

GCS1 = plt.contour(X, Y, np.transpose(G1), levels=Glevels, colors='blue',linestyles=
↪'dashed')
plt.clabel(GCS1, inline=1, fontsize=10, colors='blue',fmt='%d',inline_spacing=0)
GCS1.collections[0].set_linewidths(1.50)
GCS1.collections[1].set_linewidths(1.50)
GCS1.collections[0].set_label(r'$g$'+r'-load')

QCS1 = plt.contour(X, Y, np.transpose(Q1), levels=Qlevels, colors='red',linestyles=
↪'dotted',zorder=11)
plt.clabel(QCS1, inline=1, fontsize=10, colors='red',fmt='%d',inline_spacing=0)
QCS1.collections[0].set_linewidths(1.50)
QCS1.collections[1].set_linewidths(1.50)
QCS1.collections[0].set_label(r'$\dot{q}$'+', '+r'$W/cm^2$')


HCS1 = plt.contour(X, Y, np.transpose(H1), levels=Hlevels, colors='xkcd:brown',
↪linestyles='dashdot')
plt.clabel(HCS1, inline=1, fontsize=10, colors='xkcd:brown',fmt='%d',inline_spacing=0)
HCS1.collections[0].set_linewidths(1.75)
```

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```
HCS1.collections[0].set_label(r'$Q$'+', '+r'$kJ/cm^2$')

plt.xlabel("Arrival "+r'$V_\infty$'+r', km/s' ,fontsize=10)
plt.ylabel("L/D",fontsize=10)
plt.xticks(fontsize=10)
plt.yticks(fontsize=10)
ax = plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
plt.legend(loc='upper right', fontsize=8)


dat0 = ZCS1.allsegs[1][0]
x1,y1=dat0[:,0],dat0[:,1]
F1 = interpolate.interp1d(x1, y1, kind='linear',fill_value='extrapolate', bounds_
↪error=False)

dat1 = GCS1.allsegs[0][0]
x2,y2=dat1[:,0],dat1[:,1]
F2 = interpolate.interp1d(x2, y2, kind='linear',fill_value='extrapolate', bounds_
↪error=False)

dat2 = QCS1.allsegs[0][0]
x3,y3= dat2[:,0],dat2[:,1]
F3 = interpolate.interp1d(x3, y3, kind='linear',fill_value='extrapolate', bounds_
↪error=False)


x4 = np.linspace(0,30,301)
y4 = F1(x4)
y5 = F2(x4)
y6 = F3(x4)

y7 = np.minimum(y5,y6)

plt.fill_between(x4, y4, y7, where=y4<=y7,color='xkcd:neon green')
plt.xlim([0.0,16.0])
plt.ylim([0.0,1.0])

plt.savefig('../plots/LuSaikia2018a-fig16.png',bbox_inches='tight')
plt.savefig('../plots/LuSaikia2018a-fig16.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/LuSaikia2018a-fig16.eps', dpi=300,bbox_inches='tight')
```

```
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
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↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
```
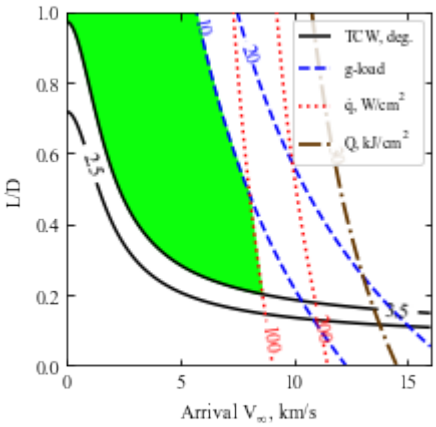
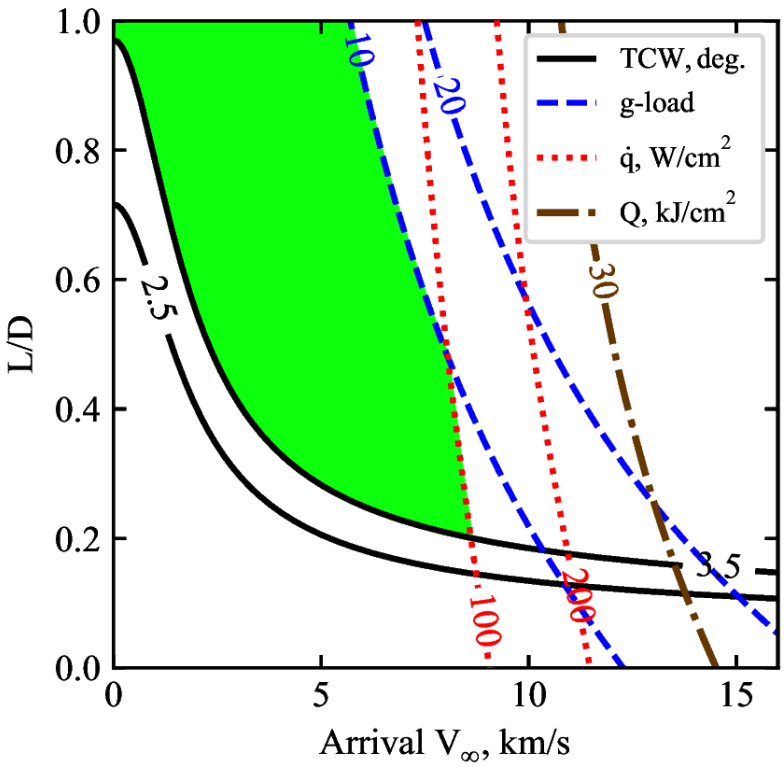



[18]:
```
from IPython.display import Image
Image(filename='../plots/LuSaikia2018a-fig16-higher-res.png', width=400)
```

[18]:


The plots are now saved in plots/LuSaikia2018a and should match with the results from the paper.

Congratulations! You have created an aerocapture feasibility chart for Titan. In the next example, you will recreate the same chart for a different vehicle ballistic coefficient.

4.6 Example - 06 - Titan Aerocapture: Part 2

In this example, you will learn to create an aerocapture feasibility chart for Titan.

For reference, we will re-create another figure from the paper "Lu and Saikia, Feasibility Assessment of Aerocapture for Future Titan Orbiter Missions, Journal of Spacecraft and Rockets, Vol. 55, No. 5, 2018". DOI: 10.2514/1.A34121

[2]:
```
from IPython.display import Image
Image(filename='../plots/lu-saikia-reference-b.png', width=600)
```

[2]:

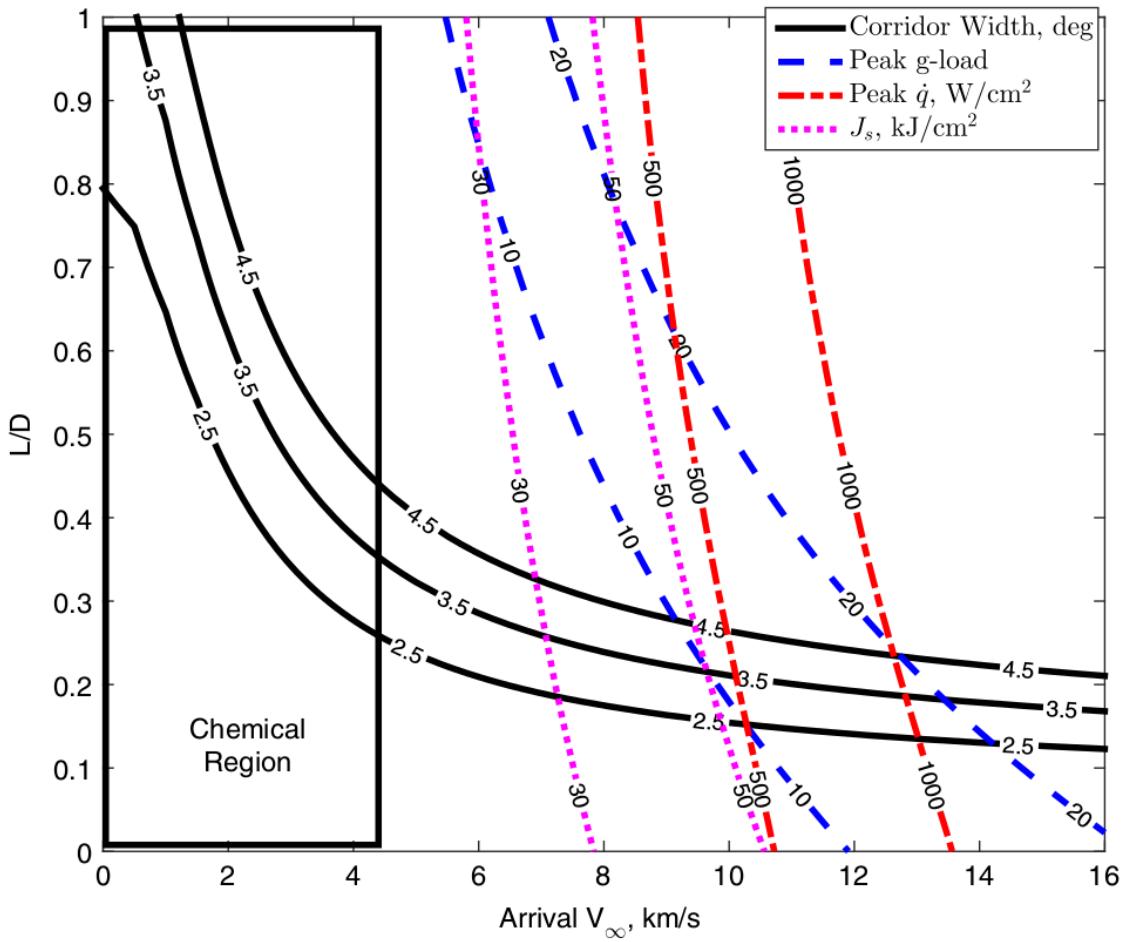


Fig. 18 Constraints summarized in a single plot for $\beta = 800$ kg/m^2.

We will use AMAT to recreate this figure.

[4]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle

import numpy as np
from scipy import interpolate
import pandas as pd

import matplotlib.pyplot as plt
from matplotlib import rcParams
from matplotlib.patches import Polygon
import os
```

[5]:
```
# Create a planet object for Titan
```

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```
planet=Planet("TITAN")

# Load an nominal atmospheric profile with height, temp, pressure, density data
planet.loadAtmosphereModel('../atmdata/Titan/titan-gram-avg.dat', 0 , 1 , 2, 3)

# Define the range for arrival Vinf and vehicle L/D
#vinf_kms_array = np.linspace( 0.0,   16.0,  17)
#LD_array       = np.linspace( 0.0,    1.0 , 11)

vinf_kms_array = np.linspace( 0.0,   16.0,  2)
LD_array       = np.linspace( 0.0,    1.0 , 2)
```

[8]:
```
# Create a directory to store the data.
# NOTE: You will get an error if the file already exists,
# Rename the folder to something else.

os.makedirs('../data/luSaikia2018b')

# Use a runID to prefix the files for easy access for post-processing.
runID = 'BC800RAP1700'

num_total      = len(vinf_kms_array)*len(LD_array)
count = 1

# Compute the inertial entry speed from the hyperbolic excess speed.
v0_kms_array    = np.zeros(len(vinf_kms_array))
v0_kms_array[:] = np.sqrt(1.0*(vinf_kms_array[:]*1E3)**2.0 + \
                          2*np.ones(len(vinf_kms_array))*\
                          planet.GM/(planet.RP+1000.0*1.0E3))/1.0E3

# Initialize matrices to store data.
overShootLimit_array  = np.zeros((len(v0_kms_array),len(LD_array)))
underShootLimit_array = np.zeros((len(v0_kms_array),len(LD_array)))
exitflag_os_array     = np.zeros((len(v0_kms_array),len(LD_array)))
exitflag_us_array     = np.zeros((len(v0_kms_array),len(LD_array)))
TCW_array             = np.zeros((len(v0_kms_array),len(LD_array)))
```

[9]:
```
# Compute the corridor width over the defined Vinf and L/D matrix.
# Note this will take maybe about an hour.
# If you simply want to create the plot, you can load the existing data
# in the ../data/luSaikia2018b folder as done below this cell.

for i in range(0,len(v0_kms_array)):
    for j in range(0,len(LD_array)):
        vehicle=Vehicle('Kraken', 1000.0, 800.0, LD_array[j], 3.1416, 0.0, 1.00,␣
↪planet)
        vehicle.setInitialState(1000.0,0.0,0.0,v0_kms_array[i],0.0,-4.5,0.0,0.0)
        vehicle.setSolverParams(1E-5)
        overShootLimit_array[i,j],  exitflag_os_array[i,j] = \
        vehicle.findOverShootLimit (6000.0, 1.0 , -88.0, -2.0, 1E-10, 1700.0)
        underShootLimit_array[i,j], exitflag_us_array[i,j] =  \
        vehicle.findUnderShootLimit(6000.0, 1.0 , -88.0, -2.0, 1E-10, 1700.0)

        TCW_array[i,j] = overShootLimit_array[i,j] - underShootLimit_array[i,j]

        print("Run #"+str(count)+" of "+ str(num_total)+\
```

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```
                ": Arrival V_infty: "+str(vinf_kms_array[i])+\
                " km/s"+", L/D:"+str(LD_array[j]) +\
                " OSL: "+str(overShootLimit_array[i,j])+\
                " USL: "+str(underShootLimit_array[i,j])+\
                ", TCW: "+str(TCW_array[i,j])+\
                " EFOS: "+str(exitflag_os_array[i,j])+\
                " EFUS: "+str(exitflag_us_array[i,j]))

        count = count +1

np.savetxt('../data/luSaikia2018b/'+runID+'vinf_kms_array.txt',vinf_kms_array)
np.savetxt('../data/luSaikia2018b/'+runID+'v0_kms_array.txt',v0_kms_array)
np.savetxt('../data/luSaikia2018b/'+runID+'LD_array.txt',LD_array)
np.savetxt('../data/luSaikia2018b/'+runID+'overShootLimit_array.txt',overShootLimit_
↪array)
np.savetxt('../data/luSaikia2018b/'+runID+'exitflag_os_array.txt',exitflag_os_array)
np.savetxt('../data/luSaikia2018b/'+runID+'undershootLimit_array.txt',underShootLimit_
↪array)
np.savetxt('../data/luSaikia2018b/'+runID+'exitflag_us_array.txt',exitflag_us_array)
np.savetxt('../data/luSaikia2018b/'+runID+'TCW_array.txt',TCW_array)
```

```
Run #1 of 4: Arrival V_infty: 0.0 km/s, L/D:0.0 OSL: -26.956788590394353 USL: -26.
↪956788590394353, TCW: 0.0 EFOS: 1.0 EFUS: 1.0
Run #2 of 4: Arrival V_infty: 0.0 km/s, L/D:1.0 OSL: -25.871938262091135 USL: -29.
↪038724038098735, TCW: 3.1667857760076004 EFOS: 1.0 EFUS: 1.0
Run #3 of 4: Arrival V_infty: 16.0 km/s, L/D:0.0 OSL: -39.84376757530299 USL: -39.
↪84376757530299, TCW: 0.0 EFOS: 1.0 EFUS: 1.0
Run #4 of 4: Arrival V_infty: 16.0 km/s, L/D:1.0 OSL: -36.570328679677914 USL: -73.
↪23443301925363, TCW: 36.664104339575715 EFOS: 1.0 EFUS: 1.0
```

Compute the deceleration and heating loads.

[11]:
```
acc_net_g_max_array       = np.zeros((len(v0_kms_array),len(LD_array)))
stag_pres_atm_max_array   = np.zeros((len(v0_kms_array),len(LD_array)))
q_stag_total_max_array    = np.zeros((len(v0_kms_array),len(LD_array)))
heatload_max_array        = np.zeros((len(v0_kms_array),len(LD_array)))

for i in range(0,len(v0_kms_array)):
    for j in range(0,len(LD_array)):
        vehicle=Vehicle('Kraken', 1000.0, 800.0, LD_array[j], 3.1416, 0.0, 1.00,␣
↪planet)
        vehicle.setInitialState(1000.0,0.0,0.0,v0_kms_array[i],0.0,overShootLimit_
↪array[i,j],0.0,0.0)
        vehicle.setSolverParams(1E-5)

        vehicle.propogateEntry(6000.0, 1.0, 180.0)

        # Extract and save variables to plot
        t_min_os         = vehicle.t_minc
        h_km_os          = vehicle.h_kmc
        acc_net_g_os     = vehicle.acc_net_g
        q_stag_con_os    = vehicle.q_stag_con
        q_stag_rad_os    = vehicle.q_stag_rad
        rc_os            = vehicle.rc
        vc_os            = vehicle.vc
        stag_pres_atm_os = vehicle.computeStagPres(rc_os,vc_os)/(1.01325E5)
        heatload_os      = vehicle.heatload
```

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```
        vehicle=Vehicle('Kraken', 1000.0, 800.0, LD_array[j], 3.1416, 0.0, 1.00,␣
↪planet)
        vehicle.setInitialState(1000.0,0.0,0.0,v0_kms_array[i],0.0,underShootLimit_
↪array[i,j],0.0,0.0)
        vehicle.setSolverParams(1E-5)

        vehicle.propogateEntry(6000.0, 1.0, 0.0)

        # Extract and save variable to plot
        t_min_us         = vehicle.t_minc
        h_km_us          = vehicle.h_kmc
        acc_net_g_us     = vehicle.acc_net_g
        q_stag_con_us    = vehicle.q_stag_con
        q_stag_rad_us    = vehicle.q_stag_rad
        rc_us            = vehicle.rc
        vc_us            = vehicle.vc
        stag_pres_atm_us = vehicle.computeStagPres(rc_us,vc_us)/(1.01325E5)
        heatload_us      = vehicle.heatload

        q_stag_total_os  = q_stag_con_os + q_stag_rad_os
        q_stag_total_us  = q_stag_con_us + q_stag_rad_us

        acc_net_g_max_array[i,j]      = max(max(acc_net_g_os),max(acc_net_g_us))
        stag_pres_atm_max_array[i,j]  = max(max(stag_pres_atm_os),max(stag_pres_atm_
↪os))
        q_stag_total_max_array[i,j]   = max(max(q_stag_total_os),max(q_stag_total_us))
        heatload_max_array[i,j]       = max(max(heatload_os),max(heatload_us))

        print("V_infty: "+str(vinf_kms_array[i])+" km/s"+", L/D: "+str(LD_array[j])+"␣
↪G_MAX: "+str(acc_net_g_max_array[i,j])+" QDOT_MAX: "+str(q_stag_total_max_array[i,
↪j])+" J_MAX: "+str(heatload_max_array[i,j])+" STAG. PRES: "+str(stag_pres_atm_max_
↪array[i,j]))

np.savetxt('../data/luSaikia2018b/'+runID+'acc_net_g_max_array.txt',acc_net_g_max_
↪array)
np.savetxt('../data/luSaikia2018b/'+runID+'stag_pres_atm_max_array.txt',stag_pres_atm_
↪max_array)
np.savetxt('../data/luSaikia2018b/'+runID+'q_stag_total_max_array.txt',q_stag_total_
↪max_array)
np.savetxt('../data/luSaikia2018b/'+runID+'heatload_max_array.txt',heatload_max_array)
```

```
V_infty: 0.0 km/s, L/D: 0.0 G_MAX: 0.08593800433366519 QDOT_MAX: 3.3840702698532916 J_
↪MAX: 3105.3432488210888 STAG. PRES: 0.006791519497339366
V_infty: 0.0 km/s, L/D: 1.0 G_MAX: 0.2138845693807405 QDOT_MAX: 4.4347653958262985 J_
↪MAX: 3779.309589359269 STAG. PRES: 0.004034330122158686
V_infty: 16.0 km/s, L/D: 0.0 G_MAX: 19.241162906177003 QDOT_MAX: 1655.1562320104672 J_
↪MAX: 104695.16040529005 STAG. PRES: 1.490930766802923
V_infty: 16.0 km/s, L/D: 1.0 G_MAX: 152.35197757039305 QDOT_MAX: 3435.125582934429 J_
↪MAX: 187897.62494657672 STAG. PRES: 0.4145223323207587
```

We are now ready to create the plot!

[14]:
```
x = np.loadtxt('../data/luSaikia2018b/'+runID+'vinf_kms_array.txt')
y = np.loadtxt('../data/luSaikia2018b/'+runID+'LD_array.txt')
```

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```
Z1 = np.loadtxt('../data/luSaikia2018b/'+runID+'TCW_array.txt')
G1 = np.loadtxt('../data/luSaikia2018b/'+runID+'acc_net_g_max_array.txt')
Q1 = np.loadtxt('../data/luSaikia2018b/'+runID+'q_stag_total_max_array.txt')
H1 = np.loadtxt('../data/luSaikia2018b/'+runID+'heatload_max_array.txt')

f1 = interpolate.interp2d(x, y, np.transpose(Z1), kind='cubic')
g1 = interpolate.interp2d(x, y, np.transpose(G1), kind='cubic')
q1 = interpolate.interp2d(x, y, np.transpose(Q1), kind='cubic')
h1 = interpolate.interp2d(x, y, np.transpose(H1), kind='cubic')

x_new =  np.linspace( 0.0,   16,  170)
y_new =  np.linspace( 0.0,   1.0 ,110)
z_new =  np.zeros((len(x_new),len(y_new)))

z1_new =  np.zeros((len(x_new),len(y_new)))
g1_new =  np.zeros((len(x_new),len(y_new)))
q1_new =  np.zeros((len(x_new),len(y_new)))
h1_new =  np.zeros((len(x_new),len(y_new)))

for i in range(0,len(x_new)):
    for j in range(0,len(y_new)):

            z1_new[i,j] = f1(x_new[i],y_new[j])
            g1_new[i,j] = g1(x_new[i],y_new[j])
            q1_new[i,j] = q1(x_new[i],y_new[j])
            h1_new[i,j] = h1(x_new[i],y_new[j])

Z1 = z1_new
G1 = g1_new
Q1 = q1_new
H1 = h1_new/1000.0

X, Y = np.meshgrid(x_new, y_new)

Zlevels = np.array([2.5,3.5,4.5])
Glevels = np.array([10.0, 20.0])
Qlevels = np.array([500.0, 1000.0])
Hlevels = np.array([30.0, 50.0])


fig = plt.figure()
fig.set_size_inches([6.5, 6.5])
plt.ion()
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

ZCS1 = plt.contour(X, Y, np.transpose(Z1), levels=Zlevels, colors='black')
plt.clabel(ZCS1, inline=1, fontsize=14, colors='black',fmt='%.1f',inline_spacing=1)
ZCS1.collections[0].set_linewidths(1.50)
ZCS1.collections[1].set_linewidths(1.50)
ZCS1.collections[2].set_linewidths(1.50)
ZCS1.collections[0].set_label(r'$TCW, deg$')

GCS1 = plt.contour(X, Y, np.transpose(G1), levels=Glevels, colors='blue',linestyles=
↪'dashed')
```

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```
plt.clabel(GCS1, inline=1, fontsize=14, colors='blue',fmt='%d',inline_spacing=0)
GCS1.collections[0].set_linewidths(1.50)
GCS1.collections[1].set_linewidths(1.50)
GCS1.collections[0].set_label(r'$g$'+r'-load')

QCS1 = plt.contour(X, Y, np.transpose(Q1), levels=Qlevels, colors='red',linestyles=
↪'dotted',zorder=11)
plt.clabel(QCS1, inline=1, fontsize=14, colors='red',fmt='%d',inline_spacing=0)
QCS1.collections[0].set_linewidths(1.50)
QCS1.collections[1].set_linewidths(1.50)
QCS1.collections[0].set_label(r'$\dot{q}$'+', '+r'$W/cm^2$')


HCS1 = plt.contour(X, Y, np.transpose(H1), levels=Hlevels, colors='xkcd:brown',
↪linestyles='dashdot')
plt.clabel(HCS1, inline=1, fontsize=14, colors='xkcd:brown',fmt='%d',inline_spacing=0)
HCS1.collections[0].set_linewidths(1.75)
HCS1.collections[1].set_linewidths(1.75)
HCS1.collections[0].set_label(r'$Q$'+', '+r'$kJ/cm^2$')

plt.xlabel("Arrival "+r'$V_\infty$'+r', km/s' ,fontsize=16)
plt.ylabel("L/D",fontsize=16)
plt.xticks(fontsize=16)
plt.yticks(fontsize=16)
ax = plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
plt.legend(loc='upper right', fontsize=16)


dat0 = ZCS1.allsegs[2][0]
x1,y1=dat0[:,0],dat0[:,1]
F1 = interpolate.interp1d(x1, y1, kind='linear',fill_value='extrapolate', bounds_
↪error=False)

dat1 = GCS1.allsegs[0][0]
x2,y2=dat1[:,0],dat1[:,1]
F2 = interpolate.interp1d(x2, y2, kind='linear',fill_value='extrapolate', bounds_
↪error=False)

dat2 = HCS1.allsegs[0][0]
x3,y3= dat2[:,0],dat2[:,1]
F3 = interpolate.interp1d(x3, y3, kind='linear',fill_value='extrapolate', bounds_
↪error=False)


x4 = np.linspace(0,30,301)
y4 = F1(x4)
y5 = F2(x4)
y6 = F3(x4)

y7 = np.minimum(y5,y6)

plt.fill_between(x4, y4, y7, where=y4<=y7,color='xkcd:neon green')
plt.xlim([0.0,16.0])
plt.ylim([0.0,1.0])
```

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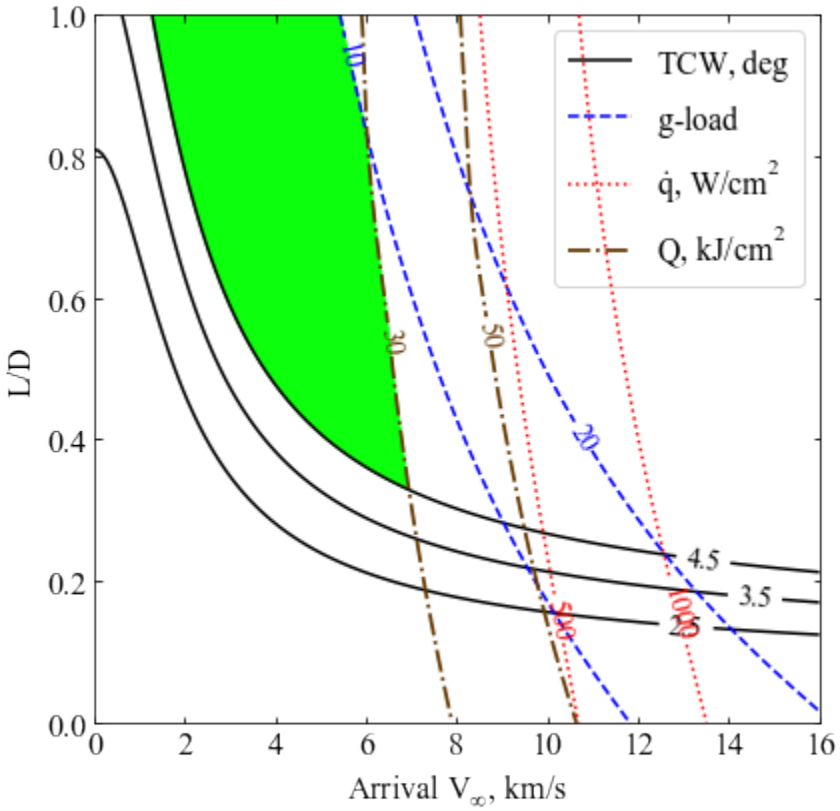
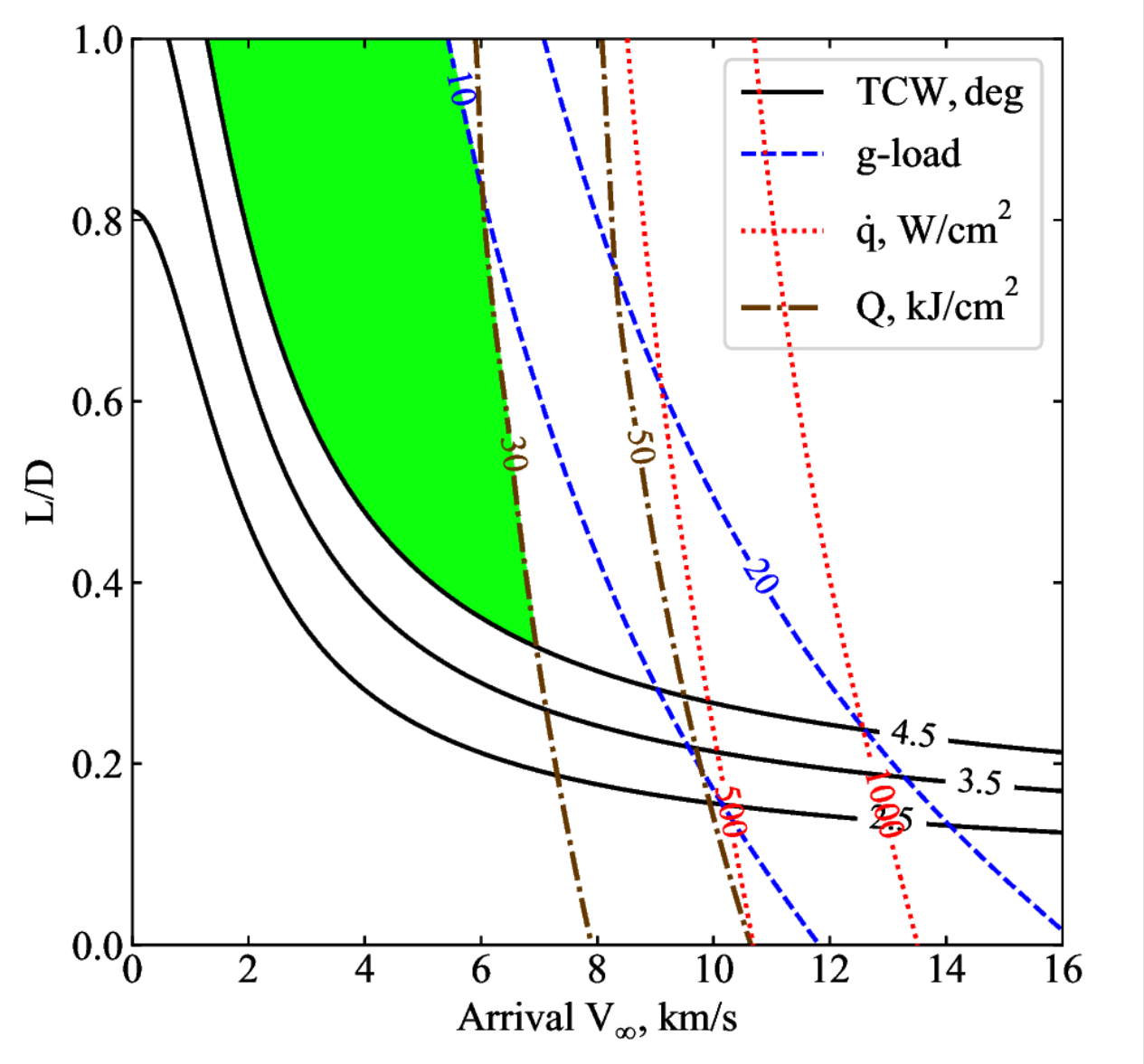
```
plt.savefig('../plots/LuSaikia2018b-fig18.png',bbox_inches='tight')
plt.savefig('../plots/LuSaikia2018b-fig18.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/LuSaikia2018b-fig18.eps', dpi=300,bbox_inches='tight')

plt.show()
```

```
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
```



[16]:
```
from IPython.display import Image
Image(filename='../plots/luSaikia2018b-higher-res.png', width=600)
```

[16]:



The plots are now saved in plots/LuSaikia2018b and should match with the results from the paper.

Congratulations! You have created another aerocapture feasibility chart for Titan. In the next example, you will recreate the similar feasibility charts for Venus.

4.7 Example - 07 - Venus Aerocapture: Part 3

In this example, you will learn to create an aerocapture feasibility chart for Venus.

For reference, we will re-create a figure from the paper "Girija, Lu, and Saikia, Feasibility and Mass-Benefit Analysis of Aerocapture for Missions to Venus, Journal of Spacecraft and Rockets, Vol. 57, No. 1" DOI: 10.2514/1.A34529

[1]:
```
from IPython.display import Image
Image(filename='../plots/girijaYe2020a-reference.png', width=600)
```

[1]:

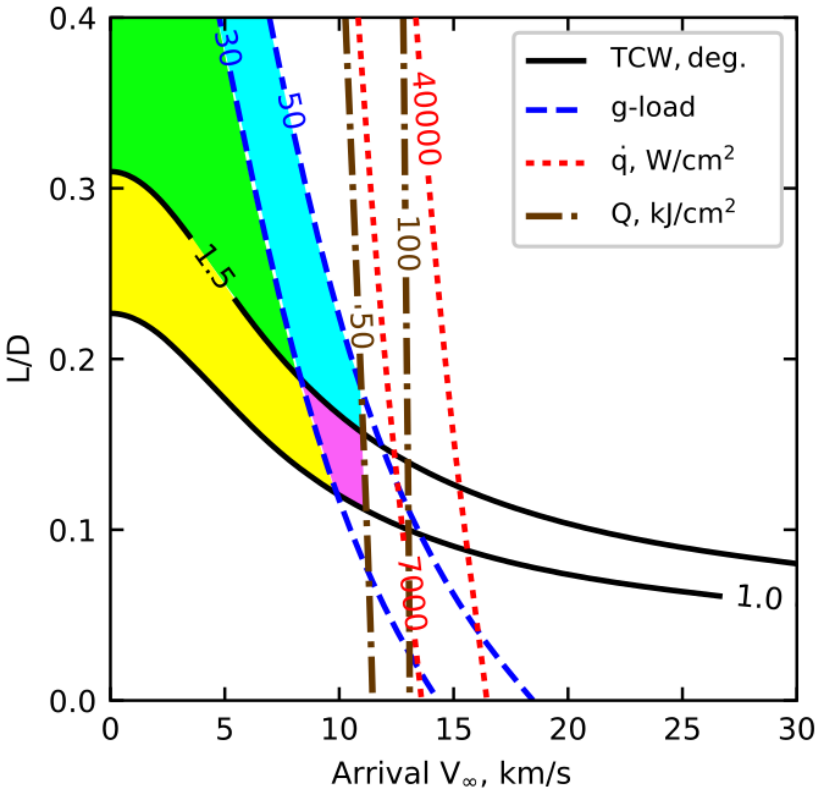


Fig. 12 Feasible design space for lift modulation aerocapture with $\beta = 50$ kg/m^2.

[3]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle

import numpy as np
from scipy import interpolate

import matplotlib.pyplot as plt
from matplotlib import rcParams
from matplotlib.patches import Polygon
import os
```

[4]:
```
# Create a planet object
planet=Planet("VENUS")
planet.h_skip = 150000.0

# Load an nominal atmospheric profile with height, temp, pressure, density data
planet.loadAtmosphereModel('../atmdata/Venus/venus-gram-avg.dat', 0 , 1 ,2, 3 )

vinf_kms_array = np.linspace( 0.0,   30.0,  11)
LD_array       = np.linspace( 0.0,    0.4 , 11)
```

[5]:
```
os.makedirs('../data/girijaYe2019a')
runID = 'BC50RAP400EI150-'

num_total      = len(vinf_kms_array)*len(LD_array)
count = 1

v0_kms_array    = np.zeros(len(vinf_kms_array))
v0_kms_array[:] = np.sqrt(1.0*(vinf_kms_array[:]*1E3)**2.0 +\
                          2*np.ones(len(vinf_kms_array))*\
                          planet.GM/(planet.RP+150.0*1.0E3))/1.0E3

overShootLimit_array  = np.zeros((len(v0_kms_array),len(LD_array)))
underShootLimit_array = np.zeros((len(v0_kms_array),len(LD_array)))
exitflag_os_array     = np.zeros((len(v0_kms_array),len(LD_array)))
exitflag_us_array     = np.zeros((len(v0_kms_array),len(LD_array)))
TCW_array             = np.zeros((len(v0_kms_array),len(LD_array)))
```

[6]:
```
# NOTE: This will take about an hour.

for i in range(0,len(v0_kms_array)):
    for j in range(0,len(LD_array)):
        vehicle=Vehicle('Apollo', 1000.0, 50.0, LD_array[j], 3.1416, 0.0, 1.00,␣
↪planet)
        vehicle.setInitialState(150.0,0.0,0.0,v0_kms_array[i],0.0,-4.5,0.0,0.0)
        vehicle.setSolverParams(1E-6)
        overShootLimit_array[i,j],  exitflag_os_array[i,j]  = vehicle.
↪findOverShootLimit (2400.0, 0.1, -80.0, -4.0, 1E-10, 400.0)
        underShootLimit_array[i,j], exitflag_us_array[i,j] =  vehicle.
↪findUnderShootLimit(2400.0, 0.1, -80.0, -4.0, 1E-10, 400.0)

        TCW_array[i,j] = overShootLimit_array[i,j] - underShootLimit_array[i,j]

        print("Run #"+str(count)+" of "+ str(num_total)+": Arrival V_infty:
↪"+str(vinf_kms_array[i])+" km/s"+", L/D:"+str(LD_array[j]) + " OSL:
↪"+str(overShootLimit_array[i,j])+" USL: "+str(underShootLimit_array[i,j])+", TCW:
↪"+str(TCW_array[i,j])+" EFOS: "+str(exitflag_os_array[i,j])+ " EFUS: "+str(exitflag_
↪us_array[i,j]))
        count = count +1

np.savetxt('../data/girijaYe2019a/'+runID+'vinf_kms_array.txt',vinf_kms_array)
np.savetxt('../data/girijaYe2019a/'+runID+'v0_kms_array.txt',v0_kms_array)
np.savetxt('../data/girijaYe2019a/'+runID+'LD_array.txt',LD_array)
np.savetxt('../data/girijaYe2019a/'+runID+'overShootLimit_array.txt',overShootLimit_
↪array)
np.savetxt('../data/girijaYe2019a/'+runID+'exitflag_os_array.txt',exitflag_os_array)
np.savetxt('../data/girijaYe2019a/'+runID+'undershootLimit_array.txt',underShootLimit_
↪array)
np.savetxt('../data/girijaYe2019a/'+runID+'exitflag_us_array.txt',exitflag_us_array)
np.savetxt('../data/girijaYe2019a/'+runID+'TCW_array.txt',TCW_array)
```

```
Run #1 of 4: Arrival V_infty: 0.0 km/s, L/D:0.0 OSL: -5.0166317711664306 USL: -5.
↪0166317711664306, TCW: 0.0 EFOS: 1.0 EFUS: 1.0
Run #2 of 4: Arrival V_infty: 0.0 km/s, L/D:0.4 OSL: -4.650539502421452 USL: -6.
↪815560043607547, TCW: 2.165020541186095 EFOS: 1.0 EFUS: 1.0
Run #3 of 4: Arrival V_infty: 30.0 km/s, L/D:0.0 OSL: -7.44011820455853 USL: -7.
↪44011820455853, TCW: 0.0 EFOS: 1.0 EFUS: 1.0
```

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```
Run #4 of 4: Arrival V_infty: 30.0 km/s, L/D:0.4 OSL: -6.604976565784455 USL: -22.
↪98797720550283, TCW: 16.383000639718375 EFOS: 1.0 EFUS: 1.0
```

[7]:
```
acc_net_g_max_array       = np.zeros((len(v0_kms_array),len(LD_array)))
stag_pres_atm_max_array   = np.zeros((len(v0_kms_array),len(LD_array)))
q_stag_total_max_array    = np.zeros((len(v0_kms_array),len(LD_array)))
heatload_max_array        = np.zeros((len(v0_kms_array),len(LD_array)))


for i in range(0,len(v0_kms_array)):
    for j in range(0,len(LD_array)):
        vehicle=Vehicle('Apollo', 1000.0, 50.0, LD_array[j], 3.1416, 0.0, 1.00,␣
↪planet)
        vehicle.setInitialState(150.0,0.0,0.0,v0_kms_array[i],0.0,overShootLimit_
↪array[i,j],0.0,0.0)
        vehicle.setSolverParams(1E-6)
        vehicle.propogateEntry (2400.0, 0.1, 180.0)

        # Extract and save variables to plot
        t_min_os         = vehicle.t_minc
        h_km_os          = vehicle.h_kmc
        acc_net_g_os     = vehicle.acc_net_g
        q_stag_con_os    = vehicle.q_stag_con
        q_stag_rad_os    = vehicle.q_stag_rad
        rc_os            = vehicle.rc
        vc_os            = vehicle.vc
        stag_pres_atm_os = vehicle.computeStagPres(rc_os,vc_os)/(1.01325E5)
        heatload_os      = vehicle.heatload

        vehicle=Vehicle('Apollo', 1000.0, 50.0, LD_array[j], 3.1416, 0.0, 1.00,␣
↪planet)
        vehicle.setInitialState(150.0,0.0,0.0,v0_kms_array[i],0.0,underShootLimit_
↪array[i,j],0.0,0.0)
        vehicle.setSolverParams(1E-6)
        vehicle.propogateEntry (2400.0, 0.1, 0.0)

        # Extract and save variable to plot
        t_min_us         = vehicle.t_minc
        h_km_us          = vehicle.h_kmc
        acc_net_g_us     = vehicle.acc_net_g
        q_stag_con_us    = vehicle.q_stag_con
        q_stag_rad_us    = vehicle.q_stag_rad
        rc_us            = vehicle.rc
        vc_us            = vehicle.vc
        stag_pres_atm_us = vehicle.computeStagPres(rc_us,vc_us)/(1.01325E5)
        heatload_us      = vehicle.heatload

        q_stag_total_os  = q_stag_con_os + q_stag_rad_os
        q_stag_total_us  = q_stag_con_us + q_stag_rad_us

        acc_net_g_max_array[i,j]      = max(max(acc_net_g_os),max(acc_net_g_us))
        stag_pres_atm_max_array[i,j]   = max(max(stag_pres_atm_os),max(stag_pres_atm_
↪os))
        q_stag_total_max_array[i,j]   = max(max(q_stag_total_os),max(q_stag_total_us))
        heatload_max_array[i,j]       = max(max(heatload_os),max(heatload_us))
```

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```
        print("V_infty: "+str(vinf_kms_array[i])+" km/s"+", L/D: "+str(LD_array[j])+"␣
↪G_MAX: "+str(acc_net_g_max_array[i,j])+" QDOT_MAX: "+str(q_stag_total_max_array[i,
↪j])+" J_MAX: "+str(heatload_max_array[i,j])+" STAG. PRES: "+str(stag_pres_atm_max_
↪array[i,j]))


np.savetxt('../data/girijaYe2019a/'+runID+'acc_net_g_max_array.txt',acc_net_g_max_
↪array)
np.savetxt('../data/girijaYe2019a/'+runID+'stag_pres_atm_max_array.txt',stag_pres_atm_
↪max_array)
np.savetxt('../data/girijaYe2019a/'+runID+'q_stag_total_max_array.txt',q_stag_total_
↪max_array)
np.savetxt('../data/girijaYe2019a/'+runID+'heatload_max_array.txt',heatload_max_array)
```

```
V_infty: 0.0 km/s, L/D: 0.0 G_MAX: 3.953230700877381 QDOT_MAX: 108.34036601208729 J_
↪MAX: 10463.898911024176 STAG. PRES: 0.019145177375447076
V_infty: 0.0 km/s, L/D: 0.4 G_MAX: 15.806088566064293 QDOT_MAX: 209.94886974217718 J_
↪MAX: 18096.44195688157 STAG. PRES: 0.006702446102743174
V_infty: 30.0 km/s, L/D: 0.0 G_MAX: 139.56205504004248 QDOT_MAX: 34169148.177942365 J_
↪MAX: 236829784.25897062 STAG. PRES: 0.6754469940813033
V_infty: 30.0 km/s, L/D: 0.4 G_MAX: 1480.2009655208392 QDOT_MAX: 396622642.1911957 J_
↪MAX: 353048193.59636647 STAG. PRES: 0.1343203200123287
```

[8]:
```
x = np.loadtxt('../data/girijaYe2019a/'+runID+'vinf_kms_array.txt')
y = np.loadtxt('../data/girijaYe2019a/'+runID+'LD_array.txt')

Z1 = np.loadtxt('../data/girijaYe2019a/'+runID+'TCW_array.txt')
G1 = np.loadtxt('../data/girijaYe2019a/'+runID+'acc_net_g_max_array.txt')
Q1 = np.loadtxt('../data/girijaYe2019a/'+runID+'q_stag_total_max_array.txt')
H1 = np.loadtxt('../data/girijaYe2019a/'+runID+'heatload_max_array.txt')
S1 = np.loadtxt('../data/girijaYe2019a/'+runID+'stag_pres_atm_max_array.txt')


f1 = interpolate.interp2d(x, y, np.transpose(Z1), kind='cubic')
g1 = interpolate.interp2d(x, y, np.transpose(G1), kind='cubic')
q1 = interpolate.interp2d(x, y, np.transpose(Q1), kind='cubic')
h1 = interpolate.interp2d(x, y, np.transpose(H1), kind='cubic')
s1 = interpolate.interp2d(x, y, np.transpose(S1), kind='cubic')


x_new =  np.linspace( 0.0,   30,  110)
y_new =  np.linspace( 0.0,   0.4 ,110)
z_new =  np.zeros((len(x_new),len(y_new)))

z1_new =  np.zeros((len(x_new),len(y_new)))
g1_new =  np.zeros((len(x_new),len(y_new)))
q1_new =  np.zeros((len(x_new),len(y_new)))
h1_new =  np.zeros((len(x_new),len(y_new)))
s1_new =  np.zeros((len(x_new),len(y_new)))

for i in range(0,len(x_new)):
    for j in range(0,len(y_new)):

            z1_new[i,j] = f1(x_new[i],y_new[j])
            g1_new[i,j] = g1(x_new[i],y_new[j])
            q1_new[i,j] = q1(x_new[i],y_new[j])
```

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```
            h1_new[i,j] = h1(x_new[i],y_new[j])
            s1_new[i,j] = s1(x_new[i],y_new[j])


Z1 = z1_new
G1 = g1_new
Q1 = q1_new
S1 = s1_new
H1 = h1_new/1000.0

X, Y = np.meshgrid(x_new, y_new)


Zlevels = np.array([1.0,1.5])
Glevels = np.array([30.0, 50.0])
Qlevels = np.array([7000.0, 40000.0])
Hlevels = np.array([50.0, 100.0])
Slevels = np.array([0.8])


fig = plt.figure()
fig.set_size_inches([3.25,3.25])
plt.ion()
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

ZCS1 = plt.contour(X, Y, np.transpose(Z1), levels=Zlevels, colors='black')
plt.clabel(ZCS1, inline=1, fontsize=10, colors='black',fmt='%.1f',inline_spacing=1)
ZCS1.collections[0].set_linewidths(1.50)
ZCS1.collections[1].set_linewidths(1.50)
ZCS1.collections[0].set_label(r'$TCW, deg.$')

GCS1 = plt.contour(X, Y, np.transpose(G1), levels=Glevels, colors='blue',linestyles=
↪'dashed')
plt.clabel(GCS1, inline=1, fontsize=10, colors='blue',fmt='%d',inline_spacing=0)
GCS1.collections[0].set_linewidths(1.50)
GCS1.collections[1].set_linewidths(1.50)
GCS1.collections[0].set_label(r'$g$'+r'-load')

QCS1 = plt.contour(X, Y, np.transpose(Q1), levels=Qlevels, colors='red',linestyles=
↪'dotted',zorder=11)
plt.clabel(QCS1, inline=1, fontsize=10, colors='red',fmt='%d',inline_spacing=0)
QCS1.collections[0].set_linewidths(1.50)
QCS1.collections[1].set_linewidths(1.50)
QCS1.collections[0].set_label(r'$\dot{q}$'+', '+r'$W/cm^2$')


HCS1 = plt.contour(X, Y, np.transpose(H1), levels=Hlevels, colors='xkcd:brown',
↪linestyles='dashdot')
plt.clabel(HCS1, inline=1, fontsize=10, colors='xkcd:brown',fmt='%d',inline_spacing=0)
HCS1.collections[0].set_linewidths(1.75)
HCS1.collections[1].set_linewidths(1.75)
HCS1.collections[0].set_label(r'$Q$'+', '+r'$kJ/cm^2$')


#SCS1 = plt.contour(X, Y, transpose(S1), levels=Slevels, colors='cyan')
```

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```
#plt.clabel(SCS1, inline=1, fontsize=10, colors='xkcd:neon green',fmt='%.1f',inline_
↪spacing=1)
#SCS1.collections[0].set_linewidths(1.75)
#SCS1.collections[0].set_label(r'$Peak$'+r' '+r'$stag. pressure,atm$')

plt.xlabel("Arrival "+r'$V_\infty$'+r', km/s' ,fontsize=10)
plt.ylabel("L/D",fontsize=10)
plt.xticks(fontsize=10)
plt.yticks(np.array([ 0.0, 0.1, 0.2, 0.3, 0.4]),fontsize=10)
ax = plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
plt.legend(loc='upper right', fontsize=8)


dat0 = ZCS1.allsegs[1][0]
x1,y1=dat0[:,0],dat0[:,1]
F1 = interpolate.interp1d(x1, y1, kind='linear',fill_value='extrapolate', bounds_
↪error=False)

dat1 = GCS1.allsegs[0][0]
x2,y2=dat1[:,0],dat1[:,1]
F2 = interpolate.interp1d(x2, y2, kind='linear',fill_value='extrapolate', bounds_
↪error=False)

dat2 = HCS1.allsegs[0][0]
x3,y3= dat2[:,0],dat2[:,1]
F3 = interpolate.interp1d(x3, y3, kind='linear',fill_value='extrapolate', bounds_
↪error=False)

dat0a = ZCS1.allsegs[0][0]
x1a,y1a=dat0a[:,0],dat0a[:,1]
F1a = interpolate.interp1d(x1a, y1a, kind='linear',fill_value='extrapolate', bounds_
↪error=False)


x4 = np.linspace(0,30,301)
y4 = F1(x4)
y4a =F1a(x4)
y5 = F2(x4)
y6 = F3(x4)

y7 = np.minimum(y5,y6)
y8 = np.minimum(y4,y5)

plt.fill_between(x4, y4, y7, where=y4<=y7,color='xkcd:neon green')

plt.fill_between(x4, y4a, y8, where=y4a<=y8,color='xkcd:bright yellow')

plt.xlim([0.0,30.0])
plt.ylim([0.0,0.4])

plt.savefig('../plots/girijaYe2019a-fig12.png',bbox_inches='tight')
plt.savefig('../plots/girijaYe2019a-fig12.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/girijaYe2019a-fig12.eps', dpi=300,bbox_inches='tight')
```

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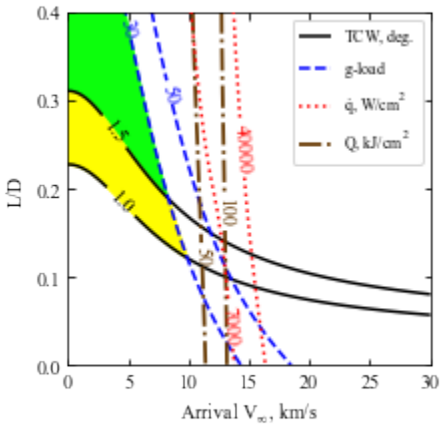
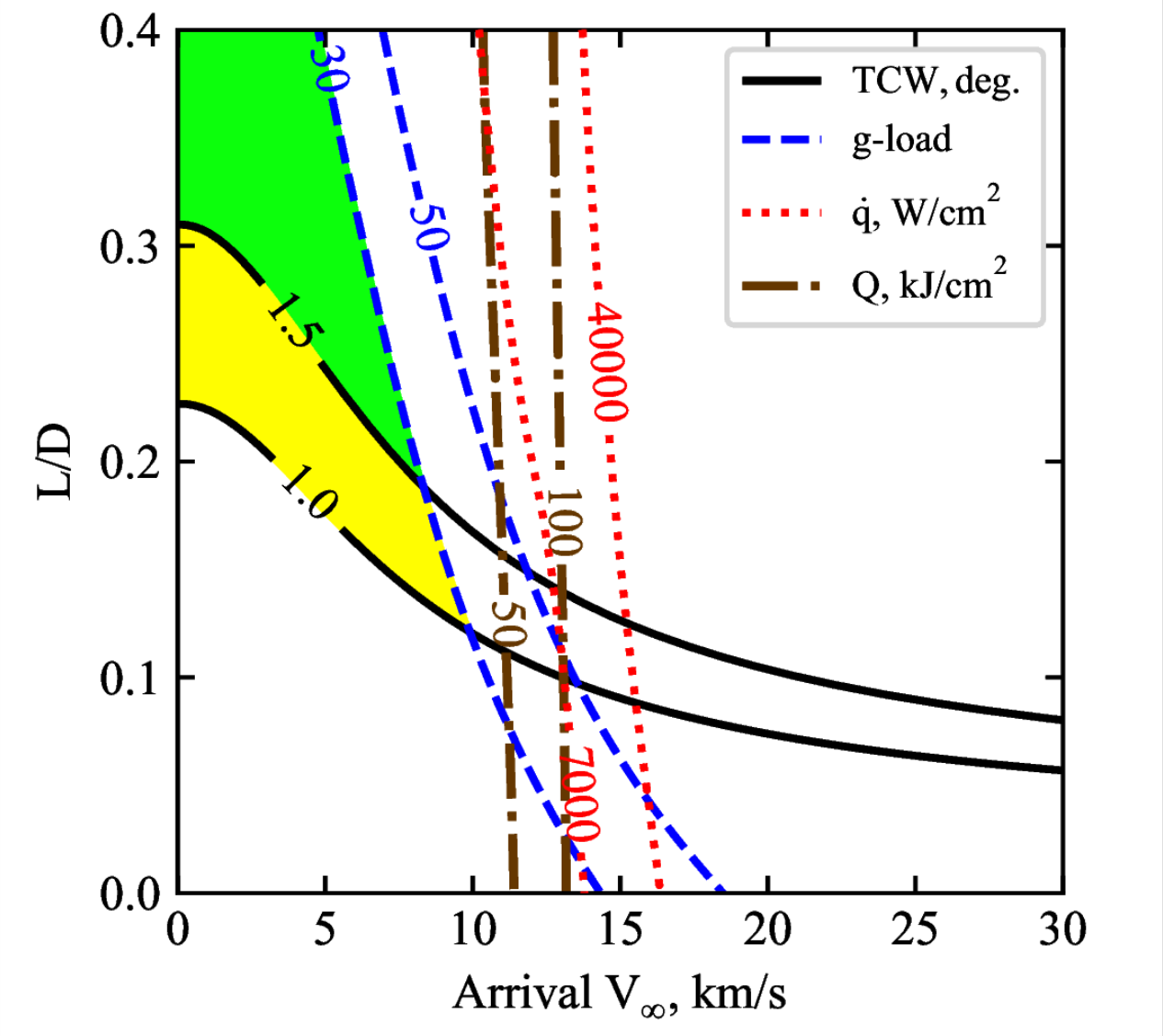
```
plt.show()
```

```
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
```



[11]:
```
from IPython.display import Image
Image(filename='../plots/girijaYe2020a-higher-res.png', width=600)
```

[11]:



The plots are now saved in plots/girijaYe2019a and should match with the results from the paper.

Congratulations! You are now becoming an expert at creating aerocapture feasibility charts using AMAT. In the next example, we will create a similar feasibility chart for drag modulation aerocapture at Venus.

4.8 Example - 08 - Venus Aerocapture: Part 4

In this example, you will learn to create a drag modulation aerocapture feasibility chart for Venus.

For reference, we will re-create another figure from the paper "Girija, Lu, and Saikia, Feasibility and Mass-Benefit Analysis of Aerocapture for Missions to Venus, Journal of Spacecraft and Rockets, Vol. 57, No. 1" DOI: 10.2514/1.A34529

[1]:
```
from IPython.display import Image
Image(filename='../plots/girijaYe2020c-reference.png', width=600)
```

[1]:

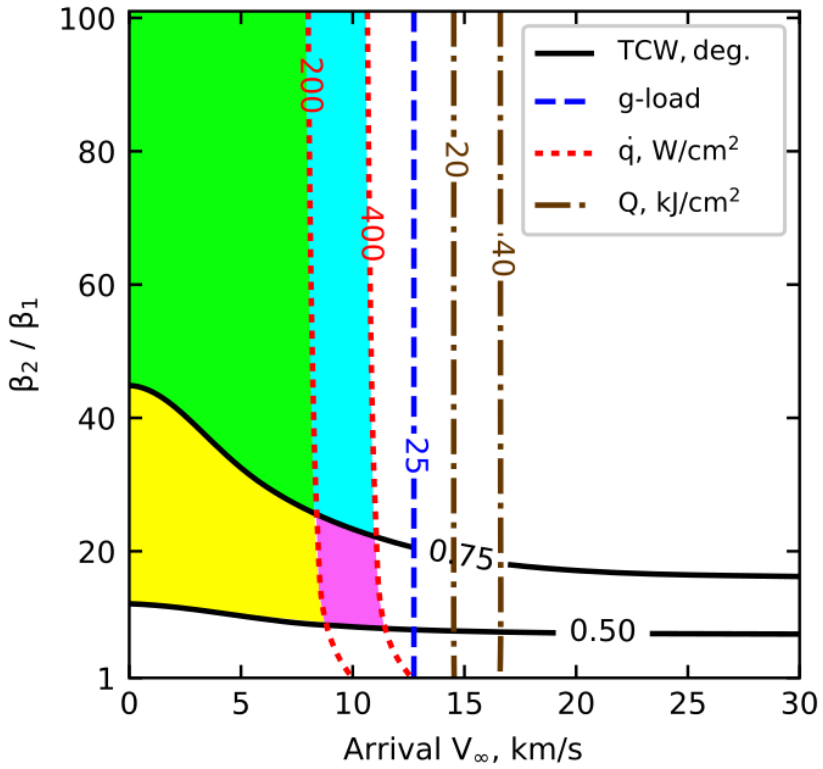


Fig. 16 Feasible design space for drag modulation aerocapture with $\beta_1 = 5$ kg/m^2.

[2]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle

import numpy as np
from scipy import interpolate

import matplotlib.pyplot as plt
from matplotlib import rcParams
from matplotlib.patches import Polygon
import os
```

[3]:
```
# Create a planet object
planet=Planet("VENUS")
planet.h_skip = 150000.0

# Load an nominal atmospheric profile with height, temp, pressure, density data
planet.loadAtmosphereModel('../atmdata/Venus/venus-gram-avg.dat', 0 , 1 ,2, 3)

vinf_kms_array  = np.linspace( 0.0,   30.0,   11)
betaRatio_array = np.linspace( 1.0,   101.0 , 11)

#vinf_kms_array  = np.linspace( 0.0,   30.0,   2)
#betaRatio_array = np.linspace( 1.0,   101.0 , 2)
```

[4]:
```
beta1 = 5.0

os.makedirs('../data/girijaYe2019c')
runID = 'DMBC5RAP400EI150'
```

[5]:
```
v0_kms_array    = np.zeros(len(vinf_kms_array))
v0_kms_array[:] = np.sqrt(1.0*(vinf_kms_array[:]*1E3)**2.0 + 2*np.ones(len(vinf_kms_
↪array))*planet.GM/(planet.RP+150.0*1.0E3))/1.0E3

overShootLimit_array  = np.zeros((len(v0_kms_array),len(betaRatio_array)))
underShootLimit_array = np.zeros((len(v0_kms_array),len(betaRatio_array)))
exitflag_os_array     = np.zeros((len(v0_kms_array),len(betaRatio_array)))
exitflag_us_array     = np.zeros((len(v0_kms_array),len(betaRatio_array)))
TCW_array             = np.zeros((len(v0_kms_array),len(betaRatio_array)))
```

[6]:
```
for i in range(0,len(v0_kms_array)):
    for j in range(0,len(betaRatio_array)):
        vehicle=Vehicle('DMVehicle', 1500.0, beta1, 0.0, 3.1416, 0.0, 0.10, planet)
        vehicle.setInitialState(150.0,0.0,0.0,v0_kms_array[i],0.0,-4.5,0.0,0.0)
        vehicle.setSolverParams(1E-6)
        vehicle.setDragModulationVehicleParams(beta1,betaRatio_array[j])

        underShootLimit_array[i,j], exitflag_us_array[i,j] = vehicle.
↪findUnderShootLimitD(2400.0, 0.1, -80.0,-4.0,1E-10,400.0)
        overShootLimit_array[i,j] , exitflag_os_array[i,j] = vehicle.
↪findOverShootLimitD (2400.0, 0.1, -80.0,-4.0,1E-10,400.0)

        TCW_array[i,j]    = overShootLimit_array[i,j] - underShootLimit_array[i,j]

        print('VINF: '+str(vinf_kms_array[i])+' km/s, BETA RATIO: '+str(betaRatio_
↪array[j])+' TCW: '+str(TCW_array[i,j])+' deg.')

np.savetxt('../data/girijaYe2019c/'+runID+'vinf_kms_array.txt',vinf_kms_array)
np.savetxt('../data/girijaYe2019c/'+runID+'v0_kms_array.txt',v0_kms_array)
np.savetxt('../data/girijaYe2019c/'+runID+'betaRatio_array.txt',betaRatio_array)
np.savetxt('../data/girijaYe2019c/'+runID+'overShootLimit_array.txt',overShootLimit_
↪array)
np.savetxt('../data/girijaYe2019c/'+runID+'exitflag_os_array.txt',exitflag_os_array)
np.savetxt('../data/girijaYe2019c/'+runID+'underShootLimit_array.txt',underShootLimit_
↪array)
np.savetxt('../data/girijaYe2019c/'+runID+'exitflag_us_array.txt',exitflag_us_array)
np.savetxt('../data/girijaYe2019c/'+runID+'TCW_array.txt',TCW_array)
```

```
VINF: 0.0 km/s, BETA RATIO: 1.0 TCW: 0.0 deg.
VINF: 0.0 km/s, BETA RATIO: 101.0 TCW: 0.8981981236029242 deg.
VINF: 30.0 km/s, BETA RATIO: 1.0 TCW: 0.0 deg.
VINF: 30.0 km/s, BETA RATIO: 101.0 TCW: 1.192248803385155 deg.
```

[8]:
```
acc_net_g_max_array       = np.zeros((len(v0_kms_array),len(betaRatio_array)))
stag_pres_atm_max_array   = np.zeros((len(v0_kms_array),len(betaRatio_array)))
q_stag_total_max_array    = np.zeros((len(v0_kms_array),len(betaRatio_array)))
heatload_max_array        = np.zeros((len(v0_kms_array),len(betaRatio_array)))


for i in range(0,len(v0_kms_array)):
```

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```
    for j in range(0,len(betaRatio_array)):
        vehicle=Vehicle('DMVehicle', 1500.0, beta1, 0.0, 3.1416, 0.0, 0.10, planet)
        vehicle.setInitialState(150.0,0.0,0.0,v0_kms_array[i],0.0,overShootLimit_
↪array[i,j],0.0,0.0)
        vehicle.setSolverParams(1E-6)

        vehicle.propogateEntry (2400.0, 0.1, 0.0)

        # Extract and save variables to plot
        t_min_os         = vehicle.t_minc
        h_km_os          = vehicle.h_kmc
        acc_net_g_os     = vehicle.acc_net_g
        q_stag_con_os    = vehicle.q_stag_con
        q_stag_rad_os    = vehicle.q_stag_rad
        rc_os            = vehicle.rc
        vc_os            = vehicle.vc
        stag_pres_atm_os = vehicle.computeStagPres(rc_os,vc_os)/(1.01325E5)
        heatload_os      = vehicle.heatload


        vehicle=Vehicle('DMVehicle', 1500.0, beta1*betaRatio_array[j], 0.0, 3.1416, 0.
↪0, 0.10, planet)
        vehicle.setInitialState(150.0,0.0,0.0,v0_kms_array[i],0.0,underShootLimit_
↪array[i,j],0.0,0.0)
        vehicle.setSolverParams( 1E-6)

        vehicle.propogateEntry (2400.0, 0.1, 0.0)

        # Extract and save variable to plot
        t_min_us         = vehicle.t_minc
        h_km_us          = vehicle.h_kmc
        acc_net_g_us     = vehicle.acc_net_g
        q_stag_con_us    = vehicle.q_stag_con
        q_stag_rad_us    = vehicle.q_stag_rad
        rc_us            = vehicle.rc
        vc_us            = vehicle.vc
        stag_pres_atm_us = vehicle.computeStagPres(rc_us,vc_us)/(1.01325E5)
        heatload_us      = vehicle.heatload

        q_stag_total_os  = q_stag_con_os + q_stag_rad_os
        q_stag_total_us  = q_stag_con_us + q_stag_rad_us

        acc_net_g_max_array[i,j]      = max(max(acc_net_g_os),max(acc_net_g_us))
        stag_pres_atm_max_array[i,j]  = max(max(stag_pres_atm_os),max(stag_pres_atm_
↪os))
        q_stag_total_max_array[i,j]   = max(max(q_stag_total_os),max(q_stag_total_us))
        heatload_max_array[i,j]       = max(max(heatload_os),max(heatload_us))

        print("V_infty: "+str(vinf_kms_array[i])+" km/s"+", BR: "+str(betaRatio_
↪array[j])+" G_MAX: "+str(acc_net_g_max_array[i,j])+" QDOT_MAX: "+str(q_stag_total_
↪max_array[i,j])+" J_MAX: "+str(heatload_max_array[i,j])+" STAG. PRES: "+str(stag_
↪pres_atm_max_array[i,j]))

np.savetxt('../data/girijaYe2019c/'+runID+'acc_net_g_max_array.txt',acc_net_g_max_
↪array)
np.savetxt('../data/girijaYe2019c/'+runID+'stag_pres_atm_max_array.txt',stag_pres_atm_
↪max_array)
```

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```
np.savetxt('../data/girijaYe2019c/'+runID+'q_stag_total_max_array.txt',q_stag_total_
↪max_array)
np.savetxt('../data/girijaYe2019c/'+runID+'heatload_max_array.txt',heatload_max_array)
```

```
V_infty: 0.0 km/s, BR: 1.0 G_MAX: 4.2619678756684065 QDOT_MAX: 107.04783114721339 J_
↪MAX: 9963.95886102549 STAG. PRES: 0.00206384918146089
V_infty: 0.0 km/s, BR: 101.0 G_MAX: 4.2619678756684065 QDOT_MAX: 1069.8045659113661 J_
↪MAX: 105153.41622997135 STAG. PRES: 0.00206384918146089
V_infty: 30.0 km/s, BR: 1.0 G_MAX: 143.43437041606074 QDOT_MAX: 763604.549664235 J_
↪MAX: 4964898.795992032 STAG. PRES: 0.06941820444237855
V_infty: 30.0 km/s, BR: 101.0 G_MAX: 143.43437041606074 QDOT_MAX: 182872814.4356986 J_
↪MAX: 1231040818.2242763 STAG. PRES: 0.06941820444237855
```

[9]:
```
x = np.loadtxt('../data/girijaYe2019c/'+runID+'vinf_kms_array.txt')
y = np.loadtxt('../data/girijaYe2019c/'+runID+'betaRatio_array.txt')

Z1 = np.loadtxt('../data/girijaYe2019c/'+runID+'TCW_array.txt')
G1 = np.loadtxt('../data/girijaYe2019c/'+runID+'acc_net_g_max_array.txt')
Q1 = np.loadtxt('../data/girijaYe2019c/'+runID+'q_stag_total_max_array.txt')
H1 = np.loadtxt('../data/girijaYe2019c/'+runID+'heatload_max_array.txt')
S1 = np.loadtxt('../data/girijaYe2019c/'+runID+'stag_pres_atm_max_array.txt')


f1 = interpolate.interp2d(x, y, np.transpose(Z1), kind='cubic')
g1 = interpolate.interp2d(x, y, np.transpose(G1), kind='cubic')
q1 = interpolate.interp2d(x, y, np.transpose(Q1), kind='cubic')
h1 = interpolate.interp2d(x, y, np.transpose(H1), kind='cubic')
s1 = interpolate.interp2d(x, y, np.transpose(S1), kind='cubic')


x_new =  np.linspace( 0.0,   30,  110)
y_new =  np.linspace( 0.0,   101 ,110)

z1_new =  np.zeros((len(x_new),len(y_new)))
g1_new =  np.zeros((len(x_new),len(y_new)))
q1_new =  np.zeros((len(x_new),len(y_new)))
h1_new =  np.zeros((len(x_new),len(y_new)))
s1_new =  np.zeros((len(x_new),len(y_new)))

for i in range(0,len(x_new)):
    for j in range(0,len(y_new)):

        z1_new[i,j] = f1(x_new[i],y_new[j])
        g1_new[i,j] = g1(x_new[i],y_new[j])
        q1_new[i,j] = q1(x_new[i],y_new[j])
        h1_new[i,j] = h1(x_new[i],y_new[j])
        s1_new[i,j] = s1(x_new[i],y_new[j])


Z1 = z1_new
G1 = g1_new
Q1 = q1_new
S1 = s1_new
H1 = h1_new/1000.0

X, Y = np.meshgrid(x_new, y_new)
```

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```
Zlevels = np.array([0.5,0.75])
Glevels = np.array([25.0])
Qlevels = np.array([200.0, 400.0])
Hlevels = np.array([20.0,40.0])

fig = plt.figure()
fig.set_size_inches([3.25,3.25])
plt.ion()
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

ZCS1 = plt.contour(X, Y, np.transpose(Z1), levels=Zlevels, colors='black')
plt.clabel(ZCS1, inline=1, fontsize=10, colors='black',fmt='%.2f',inline_spacing=1)
ZCS1.collections[0].set_linewidths(1.50)
ZCS1.collections[1].set_linewidths(1.50)
ZCS1.collections[0].set_label(r'$TCW, deg.$')

GCS1 = plt.contour(X, Y, np.transpose(G1), levels=Glevels, colors='blue',linestyles=
↪'dashed')
Glabels=plt.clabel(GCS1, inline=1, fontsize=10, colors='blue',fmt='%d',inline_
↪spacing=0)
GCS1.collections[0].set_linewidths(1.50)

GCS1.collections[0].set_label(r'$g$'+r'-load')

QCS1 = plt.contour(X, Y, np.transpose(Q1), levels=Qlevels, colors='red',linestyles=
↪'dotted',zorder=11)
plt.clabel(QCS1, inline=1, fontsize=10, colors='red',fmt='%d',inline_spacing=0)
QCS1.collections[0].set_linewidths(1.50)
QCS1.collections[1].set_linewidths(1.50)
QCS1.collections[0].set_label(r'$\dot{q}$'+', '+r'$W/cm^2$')


HCS1 = plt.contour(X, Y, np.transpose(H1), levels=Hlevels, colors='xkcd:brown',
↪linestyles='dashdot')
Hlabels=plt.clabel(HCS1, inline=1, fontsize=10, colors='xkcd:brown',fmt='%d',inline_
↪spacing=0)
HCS1.collections[0].set_linewidths(1.75)
HCS1.collections[1].set_linewidths(1.75)
HCS1.collections[0].set_label(r'$Q$'+', '+r'$kJ/cm^2$')

for l in Hlabels:
    l.set_rotation(-90)
for l in Glabels:
    l.set_rotation(-90)


#SCS1 = plt.contour(X, Y, transpose(S1), levels=Slevels, colors='cyan')
#plt.clabel(SCS1, inline=1, fontsize=10, colors='xkcd:neon green',fmt='%.1f',inline_
↪spacing=1)
#SCS1.collections[0].set_linewidths(1.75)
#SCS1.collections[0].set_label(r'$Peak$'+r' '+r'$stag. pressure,atm$')

plt.xlabel("Arrival "+r'$V_\infty$'+r', km/s' ,fontsize=10)
plt.ylabel(r'$\beta_2$'+' / '+r'$ \beta_1 $' ,fontsize=10)
```

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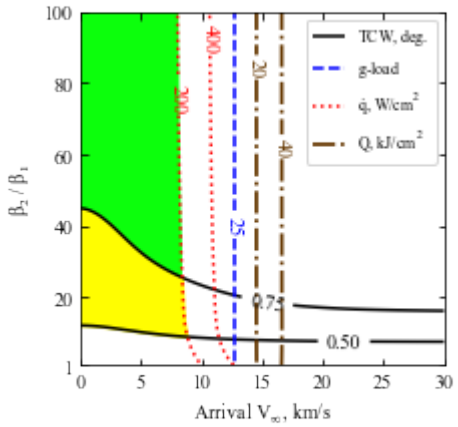
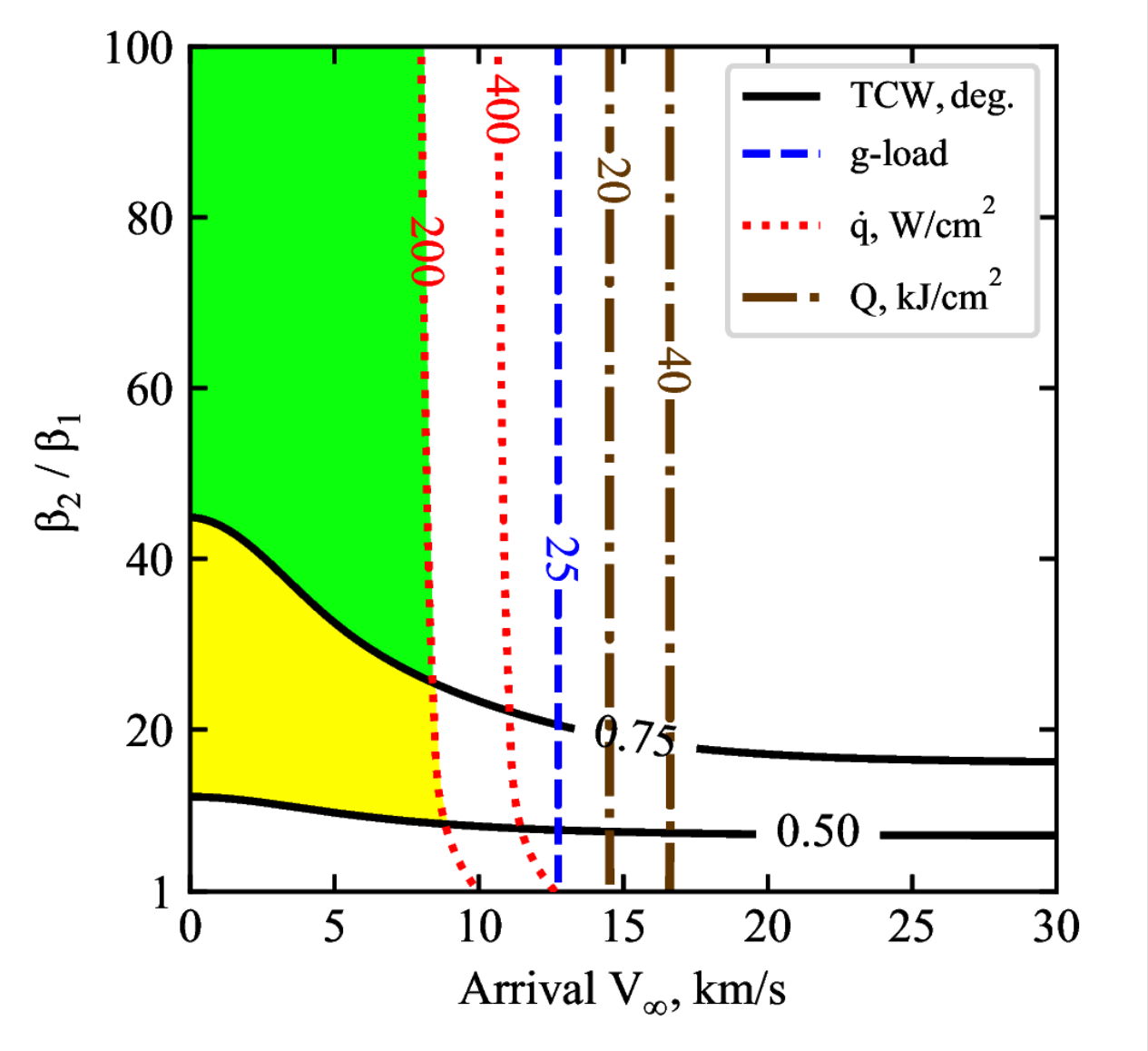
```
plt.xticks(fontsize=10)
plt.yticks(np.array([ 1, 20, 40, 60, 80, 100]),fontsize=10)
ax = plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
plt.legend(loc='upper right', fontsize=8)


dat0 = ZCS1.allsegs[1][0]
x1,y1=dat0[:,0],dat0[:,1]
F1 = interpolate.interp1d(x1, y1, kind='linear',fill_value='extrapolate', bounds_
↪error=False)

dat1 = QCS1.allsegs[0][0]
x2,y2=dat1[:,0],dat1[:,1]
F2 = interpolate.interp1d(x2, y2, kind='linear',fill_value='extrapolate', bounds_
↪error=False)

dat0a = ZCS1.allsegs[0][0]
x1a,y1a=dat0a[:,0],dat0a[:,1]
F1a = interpolate.interp1d(x1a, y1a, kind='linear',fill_value='extrapolate', bounds_
↪error=False)


x3 = np.linspace(0,30,301)
y3 = F1(x3)
y4 = F2(x3)
y4a =F1a(x3)

y8 = np.minimum(y3,y4)


plt.fill_between(x3, y3, y4, where=y3<=y4, color='xkcd:neon green')
plt.fill_between(x3, y4a, y8, where=y4a<=y8, color='xkcd:bright yellow')

plt.xlim([0.0,30.0])
plt.ylim([1.0,100])


plt.savefig('../plots/girijaYe2019c-fig16.png',bbox_inches='tight')
plt.savefig('../plots/girijaYe2019c-fig16.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/girijaYe2019c-fig16.eps', dpi=300,bbox_inches='tight')

plt.show()
```

```
/home/athul/anaconda3/lib/python3.7/site-packages/scipy/interpolate/interpolate.py:
↪609: RuntimeWarning: divide by zero encountered in true_divide
  slope = (y_hi - y_lo) / (x_hi - x_lo)[:, None]
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
```



[10]:
```
from IPython.display import Image
Image(filename='../plots/girijaYe2020c-higher-res.png', width=600)
```

[10]:



The plots are now saved in plots/girijaYe2019c.

Congratulations! You could now create the results for referenced journal article in less than a day. It took nearly a year for the authors to put everything together to create these results!

4.9 Example - 09 - Uranus Aerocapture

In this example, we will create combined interplanetary and aerocapture feasibility charts for Uranus.

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle

import numpy as np
from scipy import interpolate
import pandas as pd
```

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```
import matplotlib.pyplot as plt
from matplotlib import rcParams
from matplotlib.patches import Polygon
import os
```

[3]:
```
# Create a planet object
planet=Planet("URANUS")

# Load an nominal atmospheric profile with height, temp, pressure, density data
planet.loadAtmosphereModel('../atmdata/Uranus/uranus-ames.dat', 0 , 1 , 2, 3)

vinf_kms_array = np.linspace( 0.0,   30.0,  11)
LD_array       = np.linspace( 0.0,    1.0 , 11)

#vinf_kms_array = np.linspace( 0.0,   30.0,  2)
#LD_array       = np.linspace( 0.0,    1.0 , 2)
```

[4]:
```
os.makedirs('../data/girijaSaikia2019a')
runID = '20DAYBC200FINEGRID1'


num_total      = len(vinf_kms_array)*len(LD_array)
count = 1

v0_kms_array    = np.zeros(len(vinf_kms_array))
v0_kms_array[:] = np.sqrt(1.0*(vinf_kms_array[:]*1E3)**2.0 +\
                          2*np.ones(len(vinf_kms_array))*\
                          planet.GM/(planet.RP+1500.0*1.0E3))/1.0E3

overShootLimit_array  = np.zeros((len(v0_kms_array),len(LD_array)))
underShootLimit_array = np.zeros((len(v0_kms_array),len(LD_array)))
exitflag_os_array     = np.zeros((len(v0_kms_array),len(LD_array)))
exitflag_us_array     = np.zeros((len(v0_kms_array),len(LD_array)))
TCW_array             = np.zeros((len(v0_kms_array),len(LD_array)))
```

[5]:
```
for i in range(0,len(v0_kms_array)):
    for j in range(0,len(LD_array)):
        vehicle=Vehicle('Oberon', 1000.0, 200.0, LD_array[j], 3.1416, 0.0, 1.00,␣
↪planet)
        vehicle.setInitialState(1500.0,0.0,0.0,v0_kms_array[i],0.0,-4.5,0.0,0.0)
        vehicle.setSolverParams(1E-6)
        overShootLimit_array[i,j],  exitflag_os_array[i,j]  = vehicle.
↪findOverShootLimit (2400.0, 0.1, -80.0, -4.0, 1E-10, 1491329.10)
        underShootLimit_array[i,j], exitflag_us_array[i,j] =  vehicle.
↪findUnderShootLimit(2400.0, 0.1, -80.0, -4.0, 1E-10, 1491329.10)

        TCW_array[i,j] = overShootLimit_array[i,j] - underShootLimit_array[i,j]

        print("Run #"+str(count)+" of "+ str(num_total)+": Arrival V_infty:
↪"+str(vinf_kms_array[i])+" km/s"+", L/D:"+str(LD_array[j]) + " OSL:
↪"+str(overShootLimit_array[i,j])+" USL: "+str(underShootLimit_array[i,j])+", TCW:
↪"+str(TCW_array[i,j])+" EFOS: "+str(exitflag_os_array[i,j])+ " EFUS: "+str(exitflag_
↪us_array[i,j]))
        count = count +1
```

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```
np.savetxt('../data/girijaSaikia2019a/'+runID+'vinf_kms_array.txt',vinf_kms_array)
np.savetxt('../data/girijaSaikia2019a/'+runID+'v0_kms_array.txt',v0_kms_array)
np.savetxt('../data/girijaSaikia2019a/'+runID+'LD_array.txt',LD_array)
np.savetxt('../data/girijaSaikia2019a/'+runID+'overShootLimit_array.txt',
↪overShootLimit_array)
np.savetxt('../data/girijaSaikia2019a/'+runID+'exitflag_os_array.txt',exitflag_os_
↪array)
np.savetxt('../data/girijaSaikia2019a/'+runID+'undershootLimit_array.txt',
↪underShootLimit_array)
np.savetxt('../data/girijaSaikia2019a/'+runID+'exitflag_us_array.txt',exitflag_us_
↪array)
np.savetxt('../data/girijaSaikia2019a/'+runID+'TCW_array.txt',TCW_array)
```

```
Run #1 of 4: Arrival V_infty: 0.0 km/s, L/D:0.0 OSL: -8.036447100388614 USL: -8.
↪036447100388614, TCW: 0.0 EFOS: 1.0 EFUS: 1.0
Run #2 of 4: Arrival V_infty: 0.0 km/s, L/D:1.0 OSL: -7.976950472933822 USL: -8.
↪093977107666433, TCW: 0.11702663473261055 EFOS: 1.0 EFUS: 1.0
Run #3 of 4: Arrival V_infty: 30.0 km/s, L/D:0.0 OSL: -14.479022156530846 USL: -14.
↪479022156530846, TCW: 0.0 EFOS: 1.0 EFUS: 1.0
Run #4 of 4: Arrival V_infty: 30.0 km/s, L/D:1.0 OSL: -13.721204087287333 USL: -21.
↪917360380572063, TCW: 8.19615629328473 EFOS: 1.0 EFUS: 1.0
```

[6]:
```
acc_net_g_max_array       = np.zeros((len(v0_kms_array),len(LD_array)))
stag_pres_atm_max_array   = np.zeros((len(v0_kms_array),len(LD_array)))
q_stag_total_max_array    = np.zeros((len(v0_kms_array),len(LD_array)))
heatload_max_array        = np.zeros((len(v0_kms_array),len(LD_array)))

for i in range(0,len(v0_kms_array)):
    for j in range(0,len(LD_array)):
        vehicle=Vehicle('Oberon', 1000.0, 200.0, LD_array[j], 3.1416, 0.0, 1.00,␣
↪planet)
        vehicle.setInitialState(1500.0,0.0,0.0,v0_kms_array[i],0.0,overShootLimit_
↪array[i,j],0.0,0.0)
        vehicle.setSolverParams(1E-6)

        vehicle.propogateEntry(2400.0, 0.1, 180.0)

        # Extract and save variables to plot
        t_min_os         = vehicle.t_minc
        h_km_os          = vehicle.h_kmc
        acc_net_g_os     = vehicle.acc_net_g
        q_stag_con_os    = vehicle.q_stag_con
        q_stag_rad_os    = vehicle.q_stag_rad
        rc_os            = vehicle.rc
        vc_os            = vehicle.vc
        stag_pres_atm_os = vehicle.computeStagPres(rc_os,vc_os)/(1.01325E5)
        heatload_os      = vehicle.heatload

        vehicle=Vehicle('Oberon', 1000.0, 200.0, LD_array[j], 3.1416, 0.0, 1.00,␣
↪planet)
        vehicle.setInitialState(1500.0,0.0,0.0,v0_kms_array[i],0.0,underShootLimit_
↪array[i,j],0.0,0.0)
        vehicle.setSolverParams(1E-6)

        vehicle.propogateEntry(2400.0, 0.1, 0.0)
```

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```
        # Extract and save variable to plot
        t_min_us         = vehicle.t_minc
        h_km_us          = vehicle.h_kmc
        acc_net_g_us     = vehicle.acc_net_g
        q_stag_con_us    = vehicle.q_stag_con
        q_stag_rad_us    = vehicle.q_stag_rad
        rc_us            = vehicle.rc
        vc_us            = vehicle.vc
        stag_pres_atm_us = vehicle.computeStagPres(rc_us,vc_us)/(1.01325E5)
        heatload_us      = vehicle.heatload

        q_stag_total_os  = q_stag_con_os + q_stag_rad_os
        q_stag_total_us  = q_stag_con_us + q_stag_rad_us

        acc_net_g_max_array[i,j]      = max(max(acc_net_g_os),max(acc_net_g_us))
        stag_pres_atm_max_array[i,j]  = max(max(stag_pres_atm_os),max(stag_pres_atm_
↪os))
        q_stag_total_max_array[i,j]   = max(max(q_stag_total_os),max(q_stag_total_us))
        heatload_max_array[i,j]       = max(max(heatload_os),max(heatload_us))

        print("V_infty: "+str(vinf_kms_array[i])+" km/s"+", L/D: "+str(LD_array[j])+"␣
↪G_MAX: "+str(acc_net_g_max_array[i,j])+" QDOT_MAX: "+str(q_stag_total_max_array[i,
↪j])+" J_MAX: "+str(heatload_max_array[i,j])+" STAG. PRES: "+str(stag_pres_atm_max_
↪array[i,j]))

np.savetxt('../data/girijaSaikia2019a/'+runID+'acc_net_g_max_array.txt',acc_net_g_max_
↪array)
np.savetxt('../data/girijaSaikia2019a/'+runID+'stag_pres_atm_max_array.txt',stag_pres_
↪atm_max_array)
np.savetxt('../data/girijaSaikia2019a/'+runID+'q_stag_total_max_array.txt',q_stag_
↪total_max_array)
np.savetxt('../data/girijaSaikia2019a/'+runID+'heatload_max_array.txt',heatload_max_
↪array)
```

```
V_infty: 0.0 km/s, L/D: 0.0 G_MAX: 0.05394060815860674 QDOT_MAX: 74.06491463780053 J_
↪MAX: 41374.247055160056 STAG. PRES: 0.0010473053416354748
V_infty: 0.0 km/s, L/D: 1.0 G_MAX: 0.08366575834728353 QDOT_MAX: 77.03205462674941 J_
↪MAX: 42091.96352516038 STAG. PRES: 0.0010461973471433495
V_infty: 30.0 km/s, L/D: 0.0 G_MAX: 12.243125885881222 QDOT_MAX: 28618.290301651356 J_
↪MAX: 2374794.7913468257 STAG. PRES: 0.23721295548140664
V_infty: 30.0 km/s, L/D: 1.0 G_MAX: 127.05514958454569 QDOT_MAX: 51744.90580336135 J_
↪MAX: 3659758.2791496087 STAG. PRES: 0.0539571845570865
```

[7]:
```
N1 = pd.read_excel('../interplanetary-data/Uranus/U1.xlsx', sheet_name='Sheet1')
N2 = pd.read_excel('../interplanetary-data/Uranus/U2.xlsx', sheet_name='Sheet1')
N3 = pd.read_excel('../interplanetary-data/Uranus/U3.xlsx', sheet_name='Sheet1')
N4 = pd.read_excel('../interplanetary-data/Uranus/U4.xlsx', sheet_name='Sheet1')
N5 = pd.read_excel('../interplanetary-data/Uranus/Uranus.xlsx', sheet_name='Uranus')

TOF1 = N1['Atof'].values
TOF2 = N2['Atof'].values
TOF3 = N3['Atof'].values
TOF4 = N4['Atof'].values
TOF5 = N5['TOF'].values*365.0

VINF1 = N1['Avinf'].values
```

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```
VINF2 = N2['Avinf'].values
VINF3 = N3['Avinf'].values
VINF4 = N4['Avinf'].values
VINF5 = N5['ArrVinf_mag'].values

LC31 = N1['LC3'].values
LC32 = N2['LC3'].values
LC33 = N3['LC3'].values
LC34 = N4['LC3'].values
LC35 = N5['C3'].values

TOF   = np.concatenate((TOF1, TOF2, TOF3, TOF4),axis=0)
TOF_y = TOF / 365.0

VINF_kms = np.concatenate((VINF1, VINF2, VINF3, VINF4),axis=0)

LC3 = np.concatenate((LC31,LC32,LC33, LC34),axis=0)



#plt.axhline(y=13.5,linewidth=1, linestyle='dotted' ,color='black',zorder=0)
#plt.axvline(x=13.0,linewidth=1, linestyle='dotted' ,color='black',zorder=0)

fig, axes = plt.subplots(1, 2, figsize = (6.5, 3.5))
fig.tight_layout()
plt.subplots_adjust(wspace=0.30)
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

a0 = axes[0].scatter(TOF5 / 365.0, VINF5, c=LC35, cmap='jet',vmin=0, vmax=LC35.max(),␣
↪zorder=10,s=5.0)
a1 = axes[0].scatter(TOF_y, VINF_kms , c=LC3, cmap='jet',vmin=0, vmax=LC35.max(),␣
↪zorder=11, s=5.0)
cbar = fig.colorbar(a0, ax=axes[0])
cbar.ax.tick_params(labelsize=10)
cbar.set_label(r'$C_3, km^2/s^2$', labelpad=-27, y=1.10, rotation=0, fontsize=10)
cbar.ax.tick_params(axis='y', direction='in')

axes[0].tick_params(direction='in')
axes[0].yaxis.set_ticks_position('both')
axes[0].xaxis.set_ticks_position('both')

axes[0].set_xlabel("Time of flight (TOF), years" ,fontsize=10)
axes[0].set_ylabel("Arrival "+r'$V_{\infty}$'+', km/s',fontsize=10)

axes[0].set_yticks(np.arange(5, 26, step=5))
axes[0].set_xticks(np.arange(6, 13, step=2))

axes[0].tick_params(axis='x',labelsize=10)
axes[0].tick_params(axis='y',labelsize=10)


x = np.loadtxt('../data/girijaSaikia2019a/'+runID+'vinf_kms_array.txt')
y = np.loadtxt('../data/girijaSaikia2019a/'+runID+'LD_array.txt')

Z1 = np.loadtxt('../data/girijaSaikia2019a/'+runID+'TCW_array.txt')
```

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```
G1 = np.loadtxt('../data/girijaSaikia2019a/'+runID+'acc_net_g_max_array.txt')
Q1 = np.loadtxt('../data/girijaSaikia2019a/'+runID+'q_stag_total_max_array.txt')
H1 = np.loadtxt('../data/girijaSaikia2019a/'+runID+'heatload_max_array.txt')
S1 = np.loadtxt('../data/girijaSaikia2019a/'+runID+'stag_pres_atm_max_array.txt')


f1 = interpolate.interp2d(x, y, np.transpose(Z1), kind='cubic')
g1 = interpolate.interp2d(x, y, np.transpose(G1), kind='cubic')
q1 = interpolate.interp2d(x, y, np.transpose(Q1), kind='cubic')
h1 = interpolate.interp2d(x, y, np.transpose(H1), kind='cubic')
s1 = interpolate.interp2d(x, y, np.transpose(S1), kind='cubic')


x_new =  np.linspace( 0.0,   30,  110)
y_new =  np.linspace( 0.0,   1.0 ,110)
z_new =  np.zeros((len(x_new),len(y_new)))

z1_new =  np.zeros((len(x_new),len(y_new)))
g1_new =  np.zeros((len(x_new),len(y_new)))
q1_new =  np.zeros((len(x_new),len(y_new)))
h1_new =  np.zeros((len(x_new),len(y_new)))
s1_new =  np.zeros((len(x_new),len(y_new)))

for i in range(0,len(x_new)):
    for j in range(0,len(y_new)):

        z1_new[i,j] = f1(x_new[i],y_new[j])
        g1_new[i,j] = g1(x_new[i],y_new[j])
        q1_new[i,j] = q1(x_new[i],y_new[j])
        h1_new[i,j] = h1(x_new[i],y_new[j])
        s1_new[i,j] = s1(x_new[i],y_new[j])


Z1 = z1_new
G1 = g1_new
Q1 = q1_new
S1 = s1_new
H1 = h1_new/1000.0

X, Y = np.meshgrid(x_new, y_new)

Zlevels = np.array([0.5,1.0,1.5,2.0])
Glevels = np.array([30.0])
Qlevels = np.array([8000.0])
Hlevels = np.array([700.0])
Slevels = np.array([1.0])


ZCS1 = axes[1].contour(X, Y, np.transpose(Z1), levels=Zlevels, colors='black')

plt.clabel(ZCS1, inline=1, fontsize=10, colors='black',fmt='%.1f',inline_spacing=1)
ZCS1.collections[0].set_linewidths(1.0)
ZCS1.collections[1].set_linewidths(1.0)
ZCS1.collections[2].set_linewidths(1.0)
ZCS1.collections[3].set_linewidths(1.0)
ZCS1.collections[0].set_label(r'$TCW, deg$')
```

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```
GCS1 = axes[1].contour(X, Y, np.transpose(G1), levels=Glevels, colors='blue',␣
↪linestyles='dashed')

plt.clabel(GCS1, inline=1, fontsize=10, colors='blue',fmt='%d')
GCS1.collections[0].set_linewidths(1.0)
GCS1.collections[0].set_label(r'$Peak$'+ r' '+r'$g$'+r'-load')



QCS1 = axes[1].contour(X, Y, np.transpose(Q1), levels=Qlevels, colors='red',
↪linestyles='dotted')

plt.clabel(QCS1, inline=1, fontsize=10, colors='red',fmt='%d')
QCS1.collections[0].set_linewidths(1.0)
QCS1.collections[0].set_label(r'$Peak$'+r' '+r'$\dot{q}$'+', '+r'$W/cm^2$')


HCS1 = axes[1].contour(X, Y, np.transpose(H1), levels=Hlevels, colors='magenta',␣
↪linestyles='dashdot')
plt.xlim([0.0,30.0])
plt.clabel(HCS1, inline=1, fontsize=10, colors='magenta',fmt='%d',inline_spacing=1)
HCS1.collections[0].set_linewidths(1.0)
HCS1.collections[0].set_label(r'$Heat$'+' '+r'$ load, kJ/cm^2$')



SCS1 = axes[1].contour(X, Y, np.transpose(S1), levels=Slevels, colors='xkcd:emerald␣
↪green', linestyles='dashed')
plt.xlim([0.0,30.0])
plt.clabel(SCS1, inline=1, fontsize=10, colors='xkcd:emerald green',fmt='%.1f',inline_
↪spacing=1)
SCS1.collections[0].set_linewidths(1.0)
SCS1.collections[0].set_label(r'$Peak$'+r' '+'stag. pres., bar')

for c in SCS1.collections:
    c.set_dashes([(0.5, (7.0, 2.0))])

axes[1].tick_params(direction='in')
axes[1].yaxis.set_ticks_position('both')
axes[1].xaxis.set_ticks_position('both')

#axes[1].set(xlabel="Exam score-1", ylabel="Exam score-2")

axes[1].set_xlabel("Arrival "+r'$V_{\infty}$'+r', km/s' ,fontsize=10)
axes[1].set_ylabel("L/D",fontsize=10)

axes[1].tick_params(axis='x',labelsize=10)
axes[1].tick_params(axis='y',labelsize=10)


legend1 = axes[1].legend(loc='lower left', fontsize=8, frameon=False)


dat0 = ZCS1.allsegs[3][0]
x1,y1=dat0[:,0],dat0[:,1]
F1 = interpolate.interp1d(x1, y1, kind='linear',fill_value='extrapolate', bounds_
↪error=False)
```

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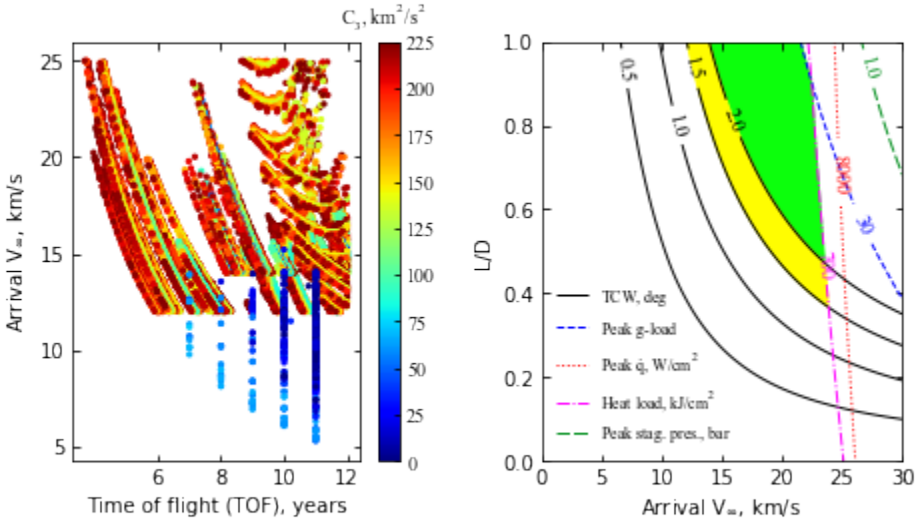
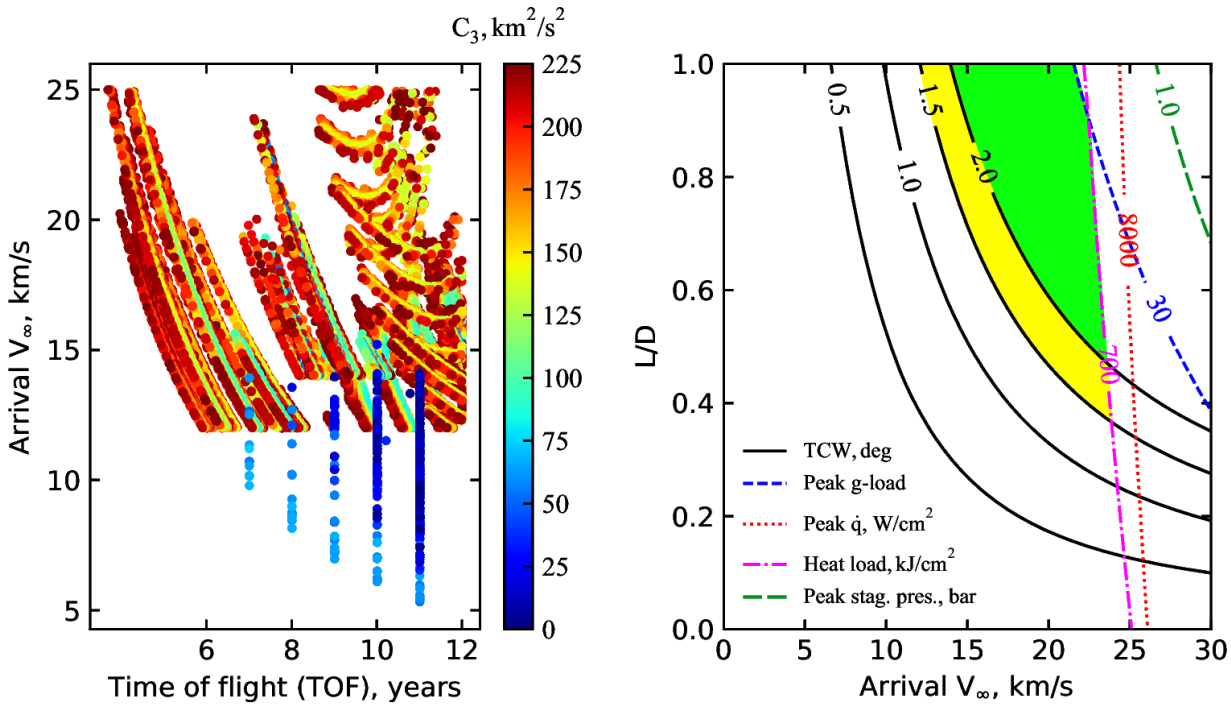
```
dat1 = GCS1.allsegs[0][0]
x2,y2=dat1[:,0],dat1[:,1]
F2 = interpolate.interp1d(x2, y2, kind='linear',fill_value='extrapolate', bounds_
↪error=False)

dat2 = HCS1.allsegs[0][0]
x3,y3= dat2[:,0],dat2[:,1]
F3 = interpolate.interp1d(x3, y3, kind='linear',fill_value='extrapolate', bounds_
↪error=False)


x4 = np.linspace(0,30,301)
y4 = F1(x4)
y5 = F2(x4)
y6 = F3(x4)

y7 = np.minimum(y5,y6)

plt.fill_between(x4, y4, y7, where=y4<=y7,color='xkcd:neon green')

dat0 = ZCS1.allsegs[2][0]
x1,y1=dat0[:,0],dat0[:,1]
F1 = interpolate.interp1d(x1, y1, kind='linear',fill_value='extrapolate', bounds_
↪error=False)

dat1 = ZCS1.allsegs[3][0]
x2,y2=dat1[:,0],dat1[:,1]
F2 = interpolate.interp1d(x2, y2, kind='linear',fill_value='extrapolate', bounds_
↪error=False)

dat2 = HCS1.allsegs[0][0]
x3,y3= dat2[:,0],dat2[:,1]
F3 = interpolate.interp1d(x3, y3, kind='linear',fill_value='extrapolate', bounds_
↪error=False)


x4 = np.linspace(0,30,301)
y4 = F1(x4)
y5 = F2(x4)
y6 = F3(x4)

y7 = np.minimum(y5,y6)

plt.fill_between(x4, y4, y7, where=y4<=y7,color='xkcd:bright yellow')
plt.xlim([0.0,30.0])
plt.ylim([0.0,1.0])

plt.savefig('../plots/girijaSaikia2019a.png',bbox_inches='tight')
plt.savefig('../plots/girijaSaikia2019a.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/girijaSaikia2019a.eps', dpi=300,bbox_inches='tight')

plt.show()
```



[9]:
```
from IPython.display import Image
Image(filename='../plots/girijaSaikia2019a-high-res.png', width=800)
```

[9]:



4.10 Example - 10 - Neptune Aerocapture - Part 1

In this example, we will create combined interplanetary and aerocapture feasibility charts for Neptune.

We re-create the feasibility chart from the paper "Girija, Saikia, Longuski et al. Feasibility and Performance Analysis of Neptune Aerocapture Using Heritage Blunt-Body Aeroshells, Journal of Spacecraft and Rockets, June, 2020, In press. DOI: 10.2514/1.A34719

[3]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle

import numpy as np
from scipy import interpolate
import pandas as pd

import matplotlib.pyplot as plt
from matplotlib import rcParams
from matplotlib.patches import Polygon
import os
```

[4]:
```
# Create a planet object
planet=Planet("NEPTUNE")

# Load an nominal atmospheric profile with height, temp, pressure, density data
planet.loadAtmosphereModel('../atmdata/Neptune/neptune-gram-avg.dat', 0 , 7 ,6, 5 , \
                           heightInKmFlag=True)

vinf_kms_array = np.linspace( 0.0,   30.0,  11)
LD_array       = np.linspace( 0.0,    1.0 , 11)

#vinf_kms_array = np.linspace( 0.0,   30.0,  2)
#LD_array       = np.linspace( 0.0,    1.0 , 2)
```

[5]:
```
os.makedirs('../data/girijaSaikia2019b')
runID = '20DAY'

num_total      = len(vinf_kms_array)*len(LD_array)
count = 1

v0_kms_array    = np.zeros(len(vinf_kms_array))
v0_kms_array[:] = np.sqrt(1.0*(vinf_kms_array[:]*1E3)**2.0 + \
                          2*np.ones(len(vinf_kms_array))*\
                          planet.GM/(planet.RP+1000.0*1.0E3))/1.0E3

overShootLimit_array  = np.zeros((len(v0_kms_array),len(LD_array)))
underShootLimit_array = np.zeros((len(v0_kms_array),len(LD_array)))
exitflag_os_array     = np.zeros((len(v0_kms_array),len(LD_array)))
exitflag_us_array     = np.zeros((len(v0_kms_array),len(LD_array)))
TCW_array             = np.zeros((len(v0_kms_array),len(LD_array)))
```

[6]:
```
for i in range(0,len(v0_kms_array)):
    for j in range(0,len(LD_array)):
        vehicle=Vehicle('Trident', 1000.0, 200.0, LD_array[j], 3.1416, 0.0, 1.00,␣
↪planet)
        vehicle.setInitialState(1000.0,0.0,0.0,v0_kms_array[i],0.0,-4.5,0.0,0.0)
        vehicle.setSolverParams(1E-6)
        overShootLimit_array[i,j],  exitflag_os_array[i,j]  = vehicle.
↪findOverShootLimit (2400.0, 0.1, -80.0, -4.0, 1E-10, 1553575.10)
        underShootLimit_array[i,j], exitflag_us_array[i,j] =  vehicle.
↪findUnderShootLimit(2400.0, 0.1, -80.0, -4.0, 1E-10, 1553575.10)

        TCW_array[i,j] = overShootLimit_array[i,j] - underShootLimit_array[i,j]

        print("Run #"+str(count)+" of "+ str(num_total)+": Arrival V_infty:
↪"+str(vinf_kms_array[i])+" km/s"+", L/D:"+str(LD_array[j]) + " OSL:
↪"+str(overShootLimit_array[i,j])+" USL: "+str(underShootLimit_array[i,j])+", TCW:
↪"+str(TCW_array[i,j])+" EFOS: "+str(exitflag_os_array[i,j])+ " EFUS: "+str(exitflag_
↪us_array[i,j]))
```

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```
        count = count +1

np.savetxt('../data/girijaSaikia2019b/'+runID+'vinf_kms_array.txt',vinf_kms_array)
np.savetxt('../data/girijaSaikia2019b/'+runID+'v0_kms_array.txt',v0_kms_array)
np.savetxt('../data/girijaSaikia2019b/'+runID+'LD_array.txt',LD_array)
np.savetxt('../data/girijaSaikia2019b/'+runID+'overShootLimit_array.txt',
↪overShootLimit_array)
np.savetxt('../data/girijaSaikia2019b/'+runID+'exitflag_os_array.txt',exitflag_os_
↪array)
np.savetxt('../data/girijaSaikia2019b/'+runID+'undershootLimit_array.txt',
↪underShootLimit_array)
np.savetxt('../data/girijaSaikia2019b/'+runID+'exitflag_us_array.txt',exitflag_us_
↪array)
np.savetxt('../data/girijaSaikia2019b/'+runID+'TCW_array.txt',TCW_array)
```

```
Run #1 of 4: Arrival V_infty: 0.0 km/s, L/D:0.0 OSL: -10.88548090497352 USL: -10.
↪88548090497352, TCW: 0.0 EFOS: 1.0 EFUS: 1.0
Run #2 of 4: Arrival V_infty: 0.0 km/s, L/D:1.0 OSL: -10.83489821571493 USL: -10.
↪93779864834869, TCW: 0.10290043263375992 EFOS: 1.0 EFUS: 1.0
Run #3 of 4: Arrival V_infty: 30.0 km/s, L/D:0.0 OSL: -14.18370732049516 USL: -14.
↪18370732049516, TCW: 0.0 EFOS: 1.0 EFUS: 1.0
Run #4 of 4: Arrival V_infty: 30.0 km/s, L/D:1.0 OSL: -13.15751718847605 USL: -20.
↪524218087299232, TCW: 7.366700898823183 EFOS: 1.0 EFUS: 1.0
```

[7]:
```
acc_net_g_max_array       = np.zeros((len(v0_kms_array),len(LD_array)))
stag_pres_atm_max_array   = np.zeros((len(v0_kms_array),len(LD_array)))
q_stag_total_max_array    = np.zeros((len(v0_kms_array),len(LD_array)))
heatload_max_array        = np.zeros((len(v0_kms_array),len(LD_array)))

for i in range(0,len(v0_kms_array)):
    for j in range(0,len(LD_array)):
        vehicle=Vehicle('Trident', 1000.0, 200.0, LD_array[j], 3.1416, 0.0, 1.00,␣
↪planet)
        vehicle.setInitialState(1000.0,0.0,0.0,v0_kms_array[i],0.0,overShootLimit_
↪array[i,j],0.0,0.0)
        vehicle.setSolverParams(1E-6)

        vehicle.propogateEntry(2400.0, 0.1, 180.0)

        # Extract and save variables to plot
        t_min_os         = vehicle.t_minc
        h_km_os          = vehicle.h_kmc
        acc_net_g_os     = vehicle.acc_net_g
        q_stag_con_os    = vehicle.q_stag_con
        q_stag_rad_os    = vehicle.q_stag_rad
        rc_os            = vehicle.rc
        vc_os            = vehicle.vc
        stag_pres_atm_os = vehicle.computeStagPres(rc_os,vc_os)/(1.01325E5)
        heatload_os      = vehicle.heatload

        vehicle=Vehicle('Trident', 1000.0, 200.0, LD_array[j], 3.1416, 0.0, 1.00,␣
↪planet)
        vehicle.setInitialState(1000.0,0.0,0.0,v0_kms_array[i],0.0,underShootLimit_
↪array[i,j],0.0,0.0)
        vehicle.setSolverParams(1E-6)

        vehicle.propogateEntry(2400.0, 0.1, 0.0)
```

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```
        # Extract and save variable to plot
        t_min_us         = vehicle.t_minc
        h_km_us          = vehicle.h_kmc
        acc_net_g_us     = vehicle.acc_net_g
        q_stag_con_us    = vehicle.q_stag_con
        q_stag_rad_us    = vehicle.q_stag_rad
        rc_us            = vehicle.rc
        vc_us            = vehicle.vc
        stag_pres_atm_us = vehicle.computeStagPres(rc_us,vc_us)/(1.01325E5)
        heatload_us      = vehicle.heatload

        q_stag_total_os  = q_stag_con_os + q_stag_rad_os
        q_stag_total_us  = q_stag_con_us + q_stag_rad_us

        acc_net_g_max_array[i,j]      = max(max(acc_net_g_os),max(acc_net_g_us))
        stag_pres_atm_max_array[i,j]  = max(max(stag_pres_atm_os),max(stag_pres_atm_
↪os))
        q_stag_total_max_array[i,j]   = max(max(q_stag_total_os),max(q_stag_total_us))
        heatload_max_array[i,j]       = max(max(heatload_os),max(heatload_us))

        print("V_infty: "+str(vinf_kms_array[i])+" km/s"+", L/D: "+str(LD_array[j])+"␣
↪G_MAX: "+str(acc_net_g_max_array[i,j])+" QDOT_MAX: "+str(q_stag_total_max_array[i,
↪j])+" J_MAX: "+str(heatload_max_array[i,j])+" STAG. PRES: "+str(stag_pres_atm_max_
↪array[i,j]))


np.savetxt('../data/girijaSaikia2019b/'+runID+'acc_net_g_max_array.txt',acc_net_g_max_
↪array)
np.savetxt('../data/girijaSaikia2019b/'+runID+'stag_pres_atm_max_array.txt',stag_pres_
↪atm_max_array)
np.savetxt('../data/girijaSaikia2019b/'+runID+'q_stag_total_max_array.txt',q_stag_
↪total_max_array)
np.savetxt('../data/girijaSaikia2019b/'+runID+'heatload_max_array.txt',heatload_max_
↪array)
```

```
V_infty: 0.0 km/s, L/D: 0.0 G_MAX: 0.1330431053594133 QDOT_MAX: 140.91155406501474 J_
↪MAX: 29874.621801169895 STAG. PRES: 0.002580414807141991
V_infty: 0.0 km/s, L/D: 1.0 G_MAX: 0.19458771430807223 QDOT_MAX: 143.0988625244372 J_
↪MAX: 30285.689932384335 STAG. PRES: 0.0024914483287594756
V_infty: 30.0 km/s, L/D: 0.0 G_MAX: 17.53516238321169 QDOT_MAX: 50974.88161005046 J_
↪MAX: 3359148.4906504373 STAG. PRES: 0.3397375503761374
V_infty: 30.0 km/s, L/D: 1.0 G_MAX: 120.73071641252108 QDOT_MAX: 93546.94104353685 J_
↪MAX: 5072351.332692758 STAG. PRES: 0.08214636492111621
```

[8]:
```
N1 = pd.read_excel('../interplanetary-data/Neptune/N1.xlsx', sheet_name='Sheet1')
N2 = pd.read_excel('../interplanetary-data/Neptune/N2.xlsx', sheet_name='Sheet1')
N3 = pd.read_excel('../interplanetary-data/Neptune/N3.xlsx', sheet_name='Sheet1')
N4 = pd.read_excel('../interplanetary-data/Neptune/N4.xlsx', sheet_name='Sheet1')
N5 = pd.read_excel('../interplanetary-data/Neptune/Neptune.xlsx', sheet_name='Neptune
↪')

TOF1 = N1['Atof'].values
TOF2 = N2['Atof'].values
TOF3 = N3['Atof'].values
TOF4 = N4['Atof'].values
TOF5 = N5['TOF'].values*365.0
```

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```
VINF1 = N1['Avinf'].values
VINF2 = N2['Avinf'].values
VINF3 = N3['Avinf'].values
VINF4 = N4['Avinf'].values
VINF5 = N5['ArrVinf_mag'].values

LC31 = N1['LC3'].values
LC32 = N2['LC3'].values
LC33 = N3['LC3'].values
LC34 = N4['LC3'].values
LC35 = N5['C3'].values

TOF   = np.concatenate((TOF1, TOF2, TOF3, TOF4),axis=0)
TOF_y = TOF / 365.0

VINF_kms = np.concatenate((VINF1, VINF2, VINF3, VINF4),axis=0)

LC3 = np.concatenate((LC31,LC32,LC33, LC34),axis=0)



#plt.axhline(y=13.5,linewidth=1, linestyle='dotted' ,color='black',zorder=0)
#plt.axvline(x=13.0,linewidth=1, linestyle='dotted' ,color='black',zorder=0)

fig, axes = plt.subplots(1, 2, figsize = (6.5, 3.5))
fig.tight_layout()
plt.subplots_adjust(wspace=0.30)
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

a0 = axes[0].scatter(TOF5 / 365.0, VINF5, c=LC35, cmap='jet',vmin=0, vmax=LC35.max(),␣
↪zorder=10,s=5.0)
a1 = axes[0].scatter(TOF_y, VINF_kms , c=LC3, cmap='jet',vmin=0, vmax=LC35.max(),␣
↪zorder=11, s=5.0)
cbar = fig.colorbar(a0, ax=axes[0])
cbar.ax.tick_params(labelsize=10)
cbar.set_label(r'$C_3, km^2/s^2$', labelpad=-27, y=1.10, rotation=0, fontsize=10)
cbar.ax.tick_params(axis='y', direction='in')

axes[0].tick_params(direction='in')
axes[0].yaxis.set_ticks_position('both')
axes[0].xaxis.set_ticks_position('both')

axes[0].set_xlabel("Time of flight (TOF), years" ,fontsize=10)
axes[0].set_ylabel("Arrival "+r'$V_{\infty}$'+', km/s',fontsize=10)

axes[0].set_yticks(np.arange(5, 26, step=5))
axes[0].set_xticks(np.arange(6, 13, step=2))

axes[0].tick_params(axis='x',labelsize=10)
axes[0].tick_params(axis='y',labelsize=10)


x = np.loadtxt('../data/girijaSaikia2019b/'+runID+'vinf_kms_array.txt')
y = np.loadtxt('../data/girijaSaikia2019b/'+runID+'LD_array.txt')
```

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```
Z1 = np.loadtxt('../data/girijaSaikia2019b/'+runID+'TCW_array.txt')
G1 = np.loadtxt('../data/girijaSaikia2019b/'+runID+'acc_net_g_max_array.txt')
Q1 = np.loadtxt('../data/girijaSaikia2019b/'+runID+'q_stag_total_max_array.txt')
H1 = np.loadtxt('../data/girijaSaikia2019b/'+runID+'heatload_max_array.txt')
S1 = np.loadtxt('../data/girijaSaikia2019b/'+runID+'stag_pres_atm_max_array.txt')


f1 = interpolate.interp2d(x, y, np.transpose(Z1), kind='cubic')
g1 = interpolate.interp2d(x, y, np.transpose(G1), kind='cubic')
q1 = interpolate.interp2d(x, y, np.transpose(Q1), kind='cubic')
h1 = interpolate.interp2d(x, y, np.transpose(H1), kind='cubic')
s1 = interpolate.interp2d(x, y, np.transpose(S1), kind='cubic')


x_new =  np.linspace( 0.0,   30,  110)
y_new =  np.linspace( 0.0,   1.0 ,110)
z_new =  np.zeros((len(x_new),len(y_new)))

z1_new =  np.zeros((len(x_new),len(y_new)))
g1_new =  np.zeros((len(x_new),len(y_new)))
q1_new =  np.zeros((len(x_new),len(y_new)))
h1_new =  np.zeros((len(x_new),len(y_new)))
s1_new =  np.zeros((len(x_new),len(y_new)))

for i in range(0,len(x_new)):
    for j in range(0,len(y_new)):

        z1_new[i,j] = f1(x_new[i],y_new[j])
        g1_new[i,j] = g1(x_new[i],y_new[j])
        q1_new[i,j] = q1(x_new[i],y_new[j])
        h1_new[i,j] = h1(x_new[i],y_new[j])
        s1_new[i,j] = s1(x_new[i],y_new[j])


Z1 = z1_new
G1 = g1_new
Q1 = q1_new
S1 = s1_new
H1 = h1_new/1000.0

X, Y = np.meshgrid(x_new, y_new)

Zlevels = np.array([0.75,1.25,2.0])
Glevels = np.array([30.0])
Qlevels = np.array([8000.0])
Hlevels = np.array([600.0])
Slevels = np.array([1.0])



ZCS1 = axes[1].contour(X, Y, np.transpose(Z1), levels=Zlevels, colors='black')

plt.clabel(ZCS1, inline=1, fontsize=9, colors='black',fmt='%.2f',inline_spacing=1)
ZCS1.collections[0].set_linewidths(1.0)
ZCS1.collections[1].set_linewidths(1.0)
ZCS1.collections[2].set_linewidths(1.0)
```

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```
ZCS1.collections[0].set_label(r'$TCW, deg$')


GCS1 = axes[1].contour(X, Y, np.transpose(G1), levels=Glevels, colors='blue',␣
↪linestyles='dashed')

plt.clabel(GCS1, inline=1, fontsize=9, colors='blue',fmt='%d')
GCS1.collections[0].set_linewidths(1.0)
GCS1.collections[0].set_label(r'$Peak$'+ r' '+r'$g$'+r'-load')



QCS1 = axes[1].contour(X, Y, np.transpose(Q1), levels=Qlevels, colors='red',
↪linestyles='dotted')

plt.clabel(QCS1, inline=1, fontsize=9, colors='red',fmt='%d')
QCS1.collections[0].set_linewidths(1.0)
QCS1.collections[0].set_label(r'$Peak$'+r' '+r'$\dot{q}$'+', '+r'$W/cm^2$')


HCS1 = axes[1].contour(X, Y, np.transpose(H1), levels=Hlevels, colors='magenta',␣
↪linestyles='dashdot')
plt.xlim([0.0,30.0])
plt.clabel(HCS1, inline=1, fontsize=9, colors='magenta',fmt='%d',inline_spacing=1)
HCS1.collections[0].set_linewidths(1.0)
HCS1.collections[0].set_label(r'$Heat$'+' '+r'$ load, kJ/cm^2$')



SCS1 = axes[1].contour(X, Y, np.transpose(S1), levels=Slevels, colors='xkcd:emerald␣
↪green', linestyles='dashed')
plt.xlim([0.0,30.0])
plt.clabel(SCS1, inline=1, fontsize=9, colors='xkcd:emerald green',fmt='%.1f',inline_
↪spacing=1)
SCS1.collections[0].set_linewidths(1.0)
SCS1.collections[0].set_label(r'$Peak$'+r' '+'stag. pres., bar')

for c in SCS1.collections:
            c.set_dashes([(0.5, (7.0, 2.0))])

axes[1].tick_params(direction='in')
axes[1].yaxis.set_ticks_position('both')
axes[1].xaxis.set_ticks_position('both')

#axes[1].set(xlabel="Exam score-1", ylabel="Exam score-2")

axes[1].set_xlabel("Arrival "+r'$V_{\infty}$'+r', km/s' ,fontsize=10)
axes[1].set_ylabel("L/D",fontsize=10)

axes[1].tick_params(axis='x',labelsize=10)
axes[1].tick_params(axis='y',labelsize=10)


legend1 = axes[1].legend(loc='lower left', fontsize=8, frameon=False)

plt.scatter(19.96, 0.40, s=40, c='k', marker='o', zorder=25)
```

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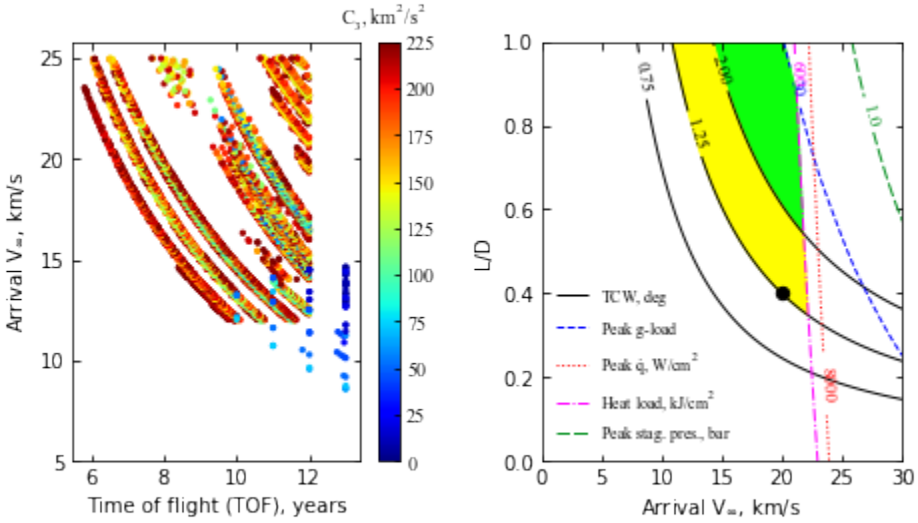
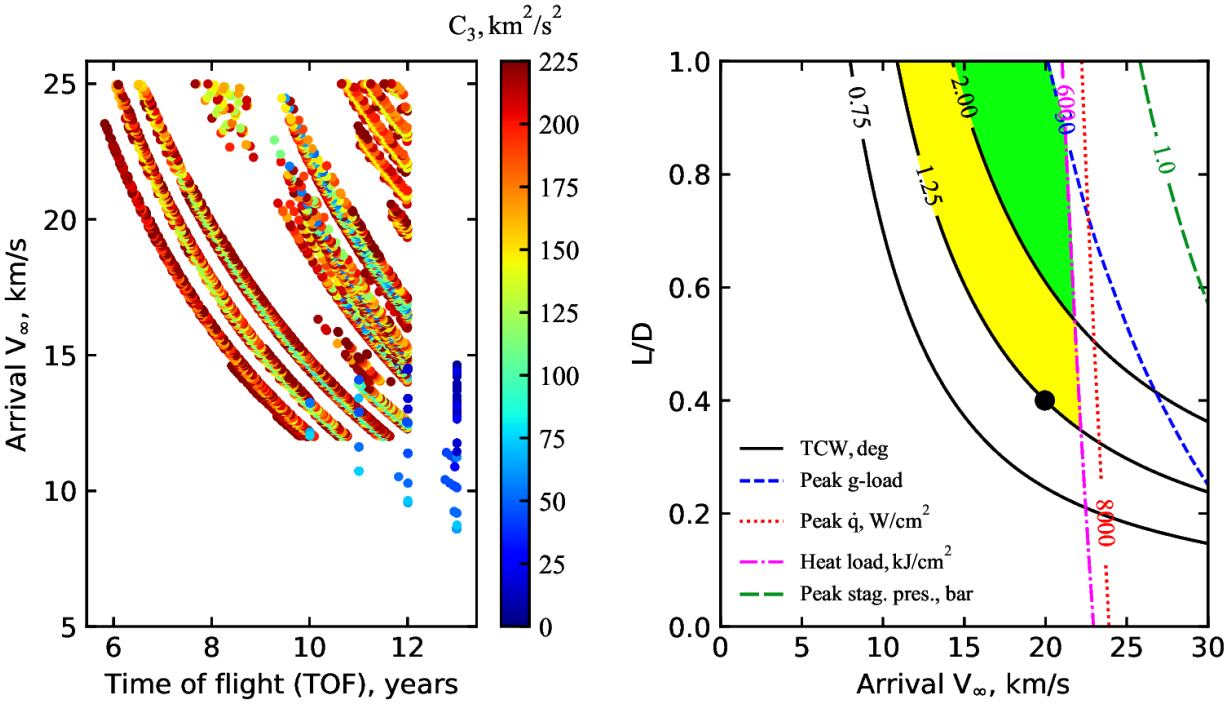
```
dat0 = ZCS1.allsegs[2][0]
x1,y1=dat0[:,0],dat0[:,1]
F1 = interpolate.interp1d(x1, y1, kind='linear',fill_value='extrapolate', bounds_
↪error=False)

dat1 = GCS1.allsegs[0][0]
x2,y2=dat1[:,0],dat1[:,1]
F2 = interpolate.interp1d(x2, y2, kind='linear',fill_value='extrapolate', bounds_
↪error=False)

dat2 = HCS1.allsegs[0][0]
x3,y3= dat2[:,0],dat2[:,1]
F3 = interpolate.interp1d(x3, y3, kind='linear',fill_value='extrapolate', bounds_
↪error=False)


x4 = np.linspace(0,30,301)
y4 = F1(x4)
y5 = F2(x4)
y6 = F3(x4)

y7 = np.minimum(y5,y6)

plt.fill_between(x4, y4, y7, where=y4<=y7,color='xkcd:neon green')

dat0 = ZCS1.allsegs[1][0]
x1,y1=dat0[:,0],dat0[:,1]
F1 = interpolate.interp1d(x1, y1, kind='linear',fill_value='extrapolate', bounds_
↪error=False)

dat1 = ZCS1.allsegs[2][0]
x2,y2=dat1[:,0],dat1[:,1]
F2 = interpolate.interp1d(x2, y2, kind='linear',fill_value='extrapolate', bounds_
↪error=False)

dat2 = HCS1.allsegs[0][0]
x3,y3= dat2[:,0],dat2[:,1]
F3 = interpolate.interp1d(x3, y3, kind='linear',fill_value='extrapolate', bounds_
↪error=False)


x4 = np.linspace(0,30,301)
y4 = F1(x4)
y5 = F2(x4)
y6 = F3(x4)

y7 = np.minimum(y5,y6)

plt.fill_between(x4, y4, y7, where=y4<=y7,color='xkcd:bright yellow')
plt.xlim([0.0,30.0])
plt.ylim([0.0,1.0])

plt.savefig('../plots/girijaSaikia2019b.png',bbox_inches='tight')
plt.savefig('../plots/girijaSaikia2019b.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/girijaSaikia2019b.eps', dpi=300,bbox_inches='tight')

plt.show()
```



[9]:
```
from IPython.display import Image
Image(filename='../plots/girijaSaikia2019b-high-res.png', width=800)
```

[9]:



The plots are now saved in plots/girijaSaikia2019b

Congratulations! You have created the aerocapture feasibility chart for Neptune. The black dot indicates a baseline reference design selected for Monte Carlo analysis in the next example.

4.11 Example - 11 - Neptune Aerocapture - Part 2a: Monte Carlo Simulations

In this example, we will use AMAT to perform Monte Carlo simulations to assess aerocapture vehicle performance.

We reproduce the example Monte Carlo results from "Girija, Saikia, Longuski et al. Feasibility and Performance Analysis of Neptune Aerocapture Using Heritage Blunt-Body Aeroshells, Journal of Spacecraft and Rockets, June, 2020, In press. DOI: 10.2514/1.A34719. Refer Section VIII A: Results for **prograde** entry with maximum range of FMINMAX.

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle

import numpy as np
from scipy import interpolate
import pandas as pd

import matplotlib.pyplot as plt
from matplotlib import rcParams
from matplotlib.patches import Polygon
```

[2]:
```
# Create a planet object
planet=Planet("NEPTUNE")

# Load an nominal atmospheric profile with height, temp, pressure, density data
planet.loadAtmosphereModel('../atmdata/Neptune/neptune-gram-avg.dat', 0 , 7 , 6 , 5 ,␣
↪\
                           heightInKmFlag=True)

# Create a vehicle object
vehicle=Vehicle('Trident', 1000.0, 200.0, 0.40, 3.1416, 0.0, 1.00, planet)

# Set vehicle conditions at entry interface
# The EFPA selection process is described in Sec. VII in the reference article.
vehicle.setInitialState(1000.0, 0.0, 0.0, 28.00, 0.0,-13.85, 0.0, 0.0)
vehicle.setSolverParams(1E-6)
```

[3]:
```
# Set the guidance parameters described in the paper.
# See the function description for parameter details.

# Set max roll rate constraint to 30 deg/s
vehicle.setMaxRollRate(30.0)

# Set Ghdot = 75
# Set Gq = 3.0
# Set v_switch_kms = 18.9
# Set low_Alt_km = 120
# Set numPoints_lowAlt = 101
# Set hdot_threshold = -500 m/s
vehicle.setEquilibriumGlideParams(75.0, 3.0, 18.9, 120.0, 101, -500.0)

# Set target orbit parameters
# periapsis = 4000.0 km
# apoapsis = 400,000 km
# apoapsis tolerance = 10 km
vehicle.setTargetOrbitParams(4000.0, 400.0E3, 10.0E3)
```

[4]:
```
# Set path to atmfiles with randomly perturbed atmosphere files.

atmfiles = ['../atmdata/Neptune/FMINMAX-10L.txt',
            '../atmdata/Neptune/FMINMAX-08L.txt',
            '../atmdata/Neptune/FMINMAX-06L.txt',
            '../atmdata/Neptune/FMINMAX-04L.txt',
            '../atmdata/Neptune/FMINMAX-02L.txt',
            '../atmdata/Neptune/FMINMAX+00L.txt',
            '../atmdata/Neptune/FMINMAX+02L.txt',
            '../atmdata/Neptune/FMINMAX+04L.txt',
            '../atmdata/Neptune/FMINMAX+06L.txt',
            '../atmdata/Neptune/FMINMAX+08L.txt',
            '../atmdata/Neptune/FMINMAX+10L.txt']
```

[5]:
```
# Set up Monte Carlo simulation parameters

# See function description for details.

# NPOS = 1086
# NMONTE = 200

vehicle.setupMonteCarloSimulation(1086, 200, atmfiles, 0, 1, 2, 3, 4, True, \
                                  -13.85, 0.11, 0.40, 0.013, 0.5, 0.1, 2400.0)
```

[6]:
```
# Run the Monte Carlo simulation.

# N = 10 shown here, run for a few thousand to be realistic. This will take several␣
↪hours.

vehicle.runMonteCarlo(10, '../data/girijaSaikia2020a/MCB1')
```

```
BATCH :../data/girijaSaikia2020a/MCBX, RUN #: 1, PROF: ../atmdata/Neptune/FMINMAX-04L.
↪txt, SAMPLE #: 22, EFPA: -13.97, SIGMA: -1.04, LD: 0.41, APO : 379646.10
BATCH :../data/girijaSaikia2020a/MCBX, RUN #: 2, PROF: ../atmdata/Neptune/FMINMAX+10L.
↪txt, SAMPLE #: 194, EFPA: -13.86, SIGMA: 1.66, LD: 0.39, APO : 397722.98
BATCH :../data/girijaSaikia2020a/MCBX, RUN #: 3, PROF: ../atmdata/Neptune/FMINMAX+04L.
↪txt, SAMPLE #: 188, EFPA: -13.89, SIGMA: -0.71, LD: 0.39, APO : 367641.10
BATCH :../data/girijaSaikia2020a/MCBX, RUN #: 4, PROF: ../atmdata/Neptune/FMINMAX+10L.
↪txt, SAMPLE #: 125, EFPA: -13.79, SIGMA: -1.81, LD: 0.41, APO : 360589.69
BATCH :../data/girijaSaikia2020a/MCBX, RUN #: 5, PROF: ../atmdata/Neptune/FMINMAX-02L.
↪txt, SAMPLE #: 172, EFPA: -13.83, SIGMA: 1.24, LD: 0.40, APO : 383384.65
BATCH :../data/girijaSaikia2020a/MCBX, RUN #: 6, PROF: ../atmdata/Neptune/FMINMAX+02L.
↪txt, SAMPLE #: 29, EFPA: -13.77, SIGMA: -0.44, LD: 0.39, APO : 372647.16
BATCH :../data/girijaSaikia2020a/MCBX, RUN #: 7, PROF: ../atmdata/Neptune/FMINMAX-04L.
↪txt, SAMPLE #: 63, EFPA: -13.71, SIGMA: 0.76, LD: 0.39, APO : 376441.97
BATCH :../data/girijaSaikia2020a/MCBX, RUN #: 8, PROF: ../atmdata/Neptune/FMINMAX+00L.
↪txt, SAMPLE #: 162, EFPA: -13.67, SIGMA: -2.19, LD: 0.41, APO : 380977.85
BATCH :../data/girijaSaikia2020a/MCBX, RUN #: 9, PROF: ../atmdata/Neptune/FMINMAX+06L.
↪txt, SAMPLE #: 60, EFPA: -13.73, SIGMA: 0.86, LD: 0.40, APO : 382393.74
BATCH :../data/girijaSaikia2020a/MCBX, RUN #: 10, PROF: ../atmdata/Neptune/
↪FMINMAX+00L.txt, SAMPLE #: 161, EFPA: -13.77, SIGMA: 0.79, LD: 0.40, APO : 368610.27
```

[7]:
```
# Post process Monte Carlo simulation data.


peri  = np.loadtxt('../data/girijaSaikia2020a/MCB1/terminal_periapsis_arr.txt')
apoa  = np.loadtxt('../data/girijaSaikia2020a/MCB1/terminal_apoapsis_arr.txt')
```

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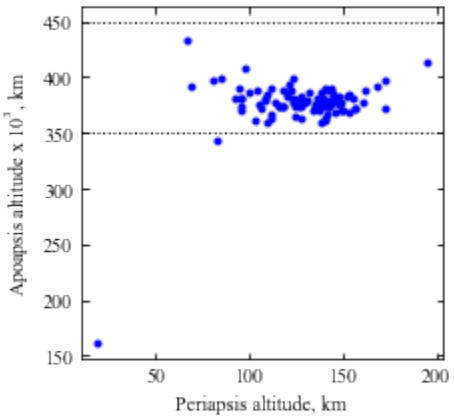
```
peri_dv  = np.loadtxt('../data/girijaSaikia2020a/MCB1/periapsis_raise_DV_arr.txt')

del_index1 = np.where(apoa < 0)
del_index2 = np.where(apoa>800.0E3)

del_index = np.concatenate((del_index1, del_index2), axis=1)

print('Simulation statistics')
print('-----------------------------------------------')
print("No. of cases escaped :"+str(len(del_index1[0])))
print("No. of cases with apo. alt > 800.0E3 km :"+str(len(del_index2[0])))
```

```
Simulation statistics
-----------------------------------------------
No. of cases escaped :3
No. of cases with apo. alt > 800.0E3 km :0
```

[8]:
```
# Remove escaped cases before plotting
peri_new = np.delete(peri, del_index)
apoa_new = np.delete(apoa, del_index)
peri_dv_new  = np.delete(peri_dv, del_index)
```

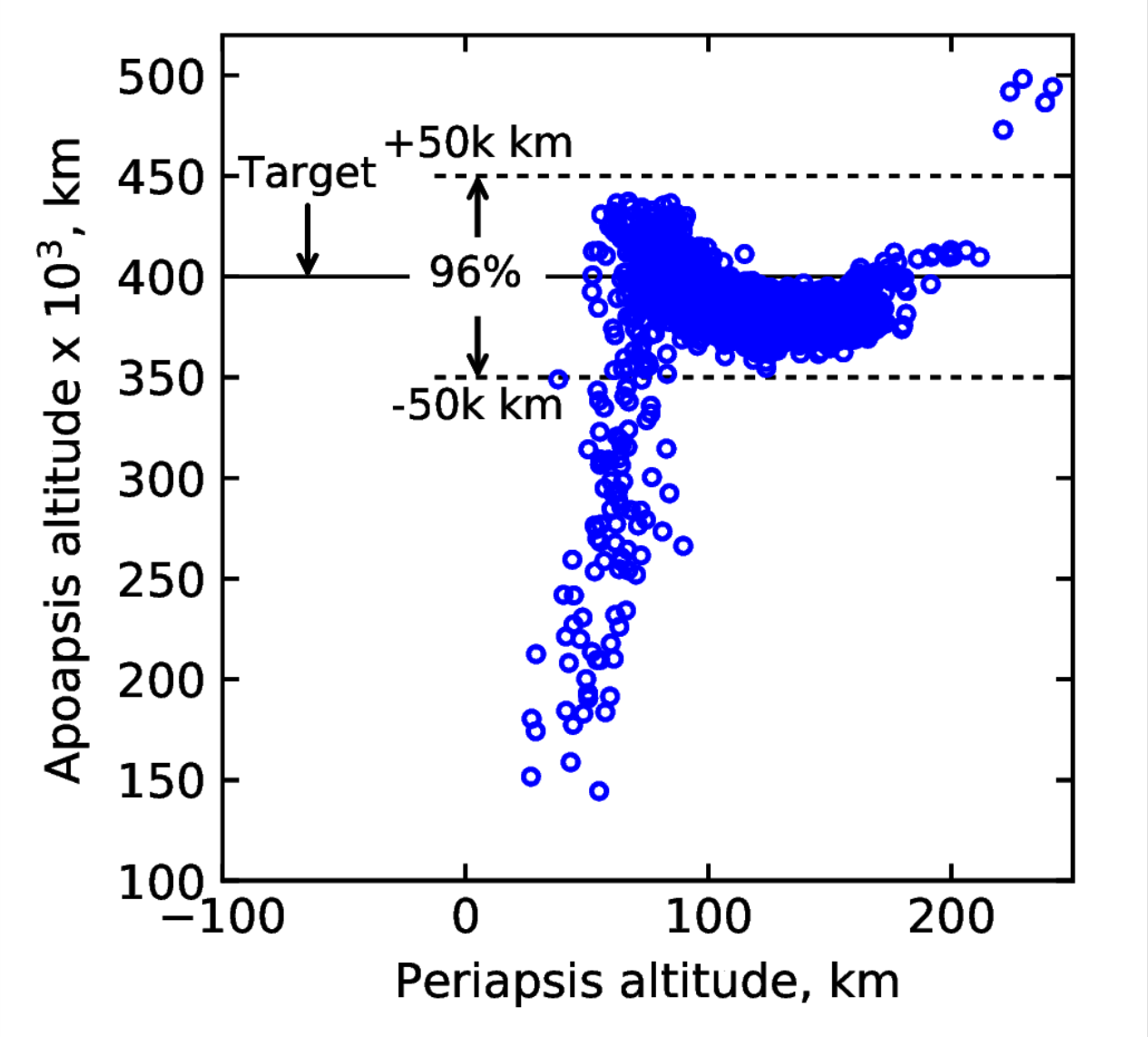
[9]:
```
# Create apoapsis dispersion plot.

fig = plt.figure()
fig.set_size_inches([3.25,3.25])
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.plot(peri_new, apoa_new/1000.0, 'bo', markersize=3)

plt.xlabel('Periapsis altitude, km',fontsize=10)
plt.ylabel('Apoapsis altitude x '+r'$10^3$'+', km', fontsize=10)

plt.axhline(y=350.0, linewidth=1, color='k', linestyle='dotted')
plt.axhline(y=450.0, linewidth=1, color='k', linestyle='dotted')

ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=10)
ax.tick_params(axis='y',labelsize=10)

plt.savefig('../plots/girijaSaikia2020a-fig-15-N100.png',bbox_inches='tight')
plt.savefig('../plots/girijaSaikia2020a-fig-15-N100.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/girijaSaikia2020a-fig-15-N100.eps', dpi=300,bbox_inches='tight')
```



This plot only has 100 trajectories. Below is a similar plot with 5000 trajectories

[15]:
```
from IPython.display import Image
Image(filename='../plots/prograde-higher-res.png', width=600)
```

[15]:



[13]:

```
# Create histogram of periapse raise manuever DV

fig = plt.figure()
fig.set_size_inches([3.25,3.25])
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.hist(peri_dv_new, bins=100, color='xkcd:periwinkle')
plt.xlabel('Periapse raise '+r'$\Delta V$'+', m/s', fontsize=10)
plt.ylabel('Number of cases', fontsize=10)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=10)
ax.tick_params(axis='y',labelsize=10)
```

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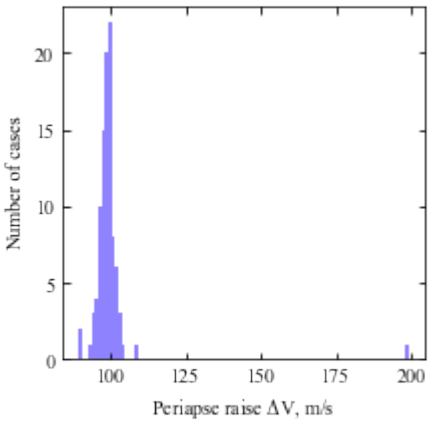
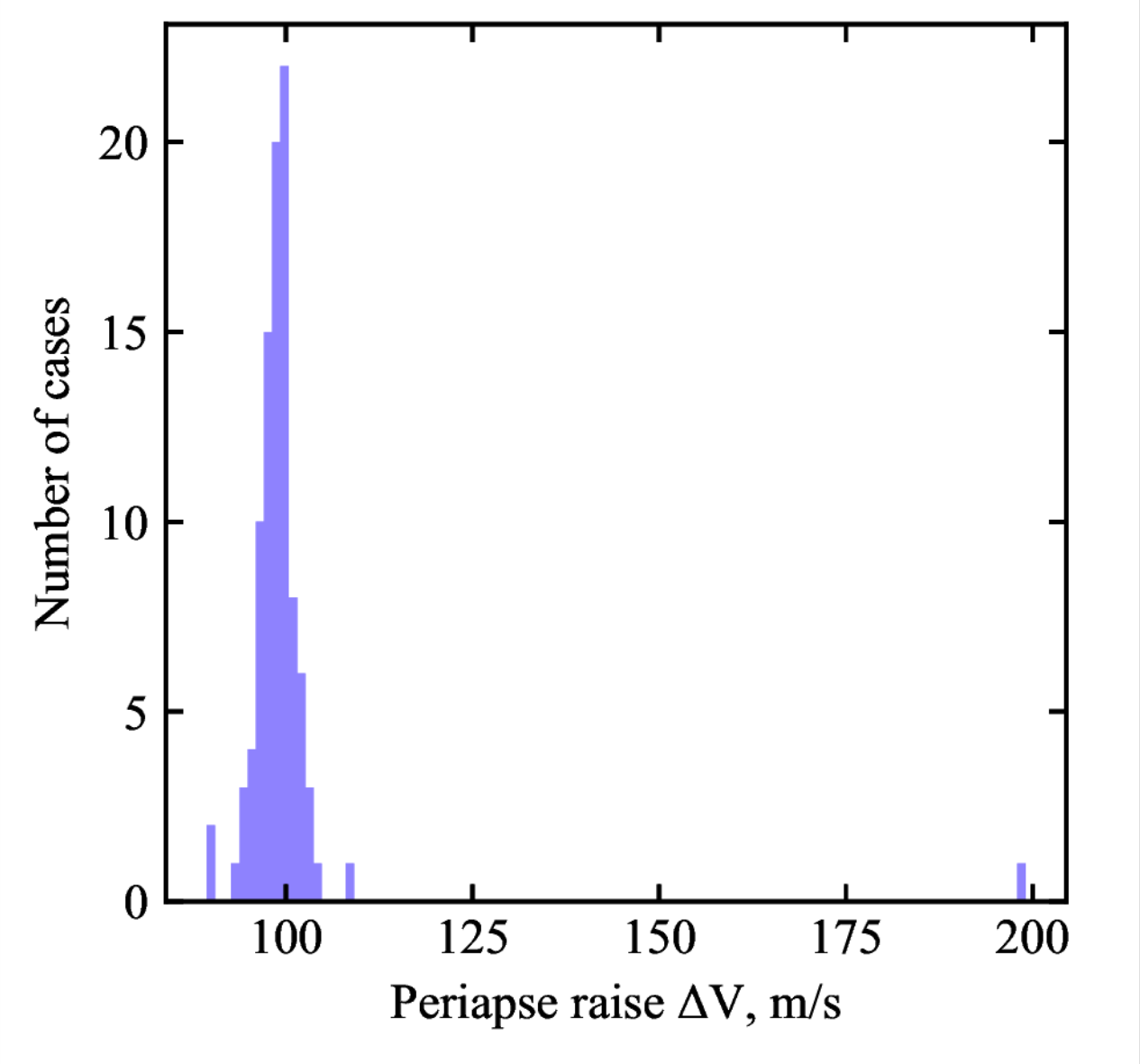
```
plt.savefig('../plots/girijaSaikia2020a-prm-histogram.png',bbox_inches='tight')
plt.savefig('../plots/girijaSaikia2020a-prm-histogram.pdf', dpi=300,bbox_inches='tight
↪')
plt.savefig('../plots/girijaSaikia2020a-prm-histogram.eps', dpi=300,bbox_inches='tight
↪')

plt.show()
```



[14]:
```
from IPython.display import Image
Image(filename='../plots/girijaSaikia2020a-PRM-higher-res.png', width=600)
```

[14]:



4.12 Example - 12 - Neptune Aerocapture - Part 2b: Monte Carlo Simulations

In this example, we will demonstrate the another published result for aerocapture at Neptune.

We reproduce the example Monte Carlo results from "Girija, Saikia, Longuski et al. Feasibility and Performance Analysis of Neptune Aerocapture Using Heritage Blunt-Body Aeroshells, Journal of Spacecraft and Rockets, June, 2020, In press. DOI: 10.2514/1.A34719. Refer Section VIII A: Results for **retrograde** entry with maximum range of FMINMAX.

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

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```
import numpy as np
from scipy import interpolate
import pandas as pd

import matplotlib.pyplot as plt
from matplotlib import rcParams
from matplotlib.patches import Polygon
```

[2]:
```
# Create a planet object
planet=Planet("NEPTUNE")

# Load an nominal atmospheric profile with height, temp, pressure, density data
planet.loadAtmosphereModel('../atmdata/Neptune/neptune-gram-avg.dat', 0 , 7 , 6 , 5 ,␣
↪\
                           heightInKmFlag=True)

# Create a vehicle object
vehicle=Vehicle('Trident', 1000.0, 200.0, 0.40, 3.1416, 0.0, 1.00, planet)

# Set vehicle conditions at entry interface
# Note these conditions are for retrograde equatorial entry
# The EFPA selection process is described in Sec. VII in the reference article.
vehicle.setInitialState(1000.0, 0.0, 0.0, 33.00, 180.0,-11.43, 0.0, 0.0)
vehicle.setSolverParams(1E-6)
```

[3]:
```
vehicle.setMaxRollRate(30.0)
vehicle.setEquilibriumGlideParams(75.0, 3.0, 18.9, 120.0, 101, -500.0)
vehicle.setTargetOrbitParams(4000.0, 400.0E3, 10.0E3)
```

[4]:
```
atmfiles = ['../atmdata/Neptune/FMINMAX-10L.txt',
            '../atmdata/Neptune/FMINMAX-08L.txt',
            '../atmdata/Neptune/FMINMAX-06L.txt',
            '../atmdata/Neptune/FMINMAX-04L.txt',
            '../atmdata/Neptune/FMINMAX-02L.txt',
            '../atmdata/Neptune/FMINMAX+00L.txt',
            '../atmdata/Neptune/FMINMAX+02L.txt',
            '../atmdata/Neptune/FMINMAX+04L.txt',
            '../atmdata/Neptune/FMINMAX+06L.txt',
            '../atmdata/Neptune/FMINMAX+08L.txt',
            '../atmdata/Neptune/FMINMAX+10L.txt']
```

[5]:
```
vehicle.setupMonteCarloSimulation(1086, 200, atmfiles, 0, 1, 2, 3, 4, True, \
                                  -11.43, 0.11, 0.40, 0.013, 0.5, 0.1, 2400.0)
```

[6]:
```
# N = 10 shown here, run for a few thousand to be realistic. This will take several␣
↪hours.

vehicle.runMonteCarlo(100, '../data/girijaSaikia2020b/MCB1')
```

```
BATCH :../data/girijaSaikia2020b/MCBX, RUN #: 1, PROF: ../atmdata/Neptune/FMINMAX+06L.
↪txt, SAMPLE #: 42, EFPA: -11.53, SIGMA: 1.86, LD: 0.41, APO : 210233.74
BATCH :../data/girijaSaikia2020b/MCBX, RUN #: 2, PROF: ../atmdata/Neptune/FMINMAX+00L.
↪txt, SAMPLE #: 82, EFPA: -11.47, SIGMA: 0.65, LD: 0.42, APO : 404021.05
BATCH :../data/girijaSaikia2020b/MCBX, RUN #: 3, PROF: ../atmdata/Neptune/FMINMAX-08L.
↪txt, SAMPLE #: 197, EFPA: -11.39, SIGMA: -0.66, LD: 0.39, APO : 389028.95
```

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```
BATCH :../data/girijaSaikia2020b/MCBX, RUN #: 4, PROF: ../atmdata/Neptune/FMINMAX+06L.
↪txt, SAMPLE #: 172, EFPA: -11.34, SIGMA: 0.10, LD: 0.40, APO : 374039.92
BATCH :../data/girijaSaikia2020b/MCBX, RUN #: 5, PROF: ../atmdata/Neptune/FMINMAX+08L.
↪txt, SAMPLE #: 160, EFPA: -11.48, SIGMA: -0.25, LD: 0.41, APO : 294339.22
BATCH :../data/girijaSaikia2020b/MCBX, RUN #: 6, PROF: ../atmdata/Neptune/FMINMAX+04L.
↪txt, SAMPLE #: 196, EFPA: -11.46, SIGMA: 0.90, LD: 0.40, APO : 404630.18
BATCH :../data/girijaSaikia2020b/MCBX, RUN #: 7, PROF: ../atmdata/Neptune/FMINMAX-10L.
↪txt, SAMPLE #: 167, EFPA: -11.44, SIGMA: 1.80, LD: 0.38, APO : 386631.37
BATCH :../data/girijaSaikia2020b/MCBX, RUN #: 8, PROF: ../atmdata/Neptune/FMINMAX+08L.
↪txt, SAMPLE #: 78, EFPA: -11.53, SIGMA: -0.14, LD: 0.42, APO : 209689.06
BATCH :../data/girijaSaikia2020b/MCBX, RUN #: 9, PROF: ../atmdata/Neptune/FMINMAX+08L.
↪txt, SAMPLE #: 135, EFPA: -11.46, SIGMA: 0.30, LD: 0.40, APO : 245398.87
BATCH :../data/girijaSaikia2020b/MCBX, RUN #: 10, PROF: ../atmdata/Neptune/
↪FMINMAX+10L.txt, SAMPLE #: 45, EFPA: -11.34, SIGMA: 0.40, LD: 0.40, APO : 410500.72
```

[7]:
```
peri  = np.loadtxt('../data/girijaSaikia2020b/MCB1/terminal_periapsis_arr.txt')
apoa  = np.loadtxt('../data/girijaSaikia2020b/MCB1/terminal_apoapsis_arr.txt')

peri_dv  = np.loadtxt('../data/girijaSaikia2020b/MCB1/periapsis_raise_DV_arr.txt')

del_index1 = np.where(apoa < 0)
del_index2 = np.where(apoa>800.0E3)

del_index = np.concatenate((del_index1, del_index2), axis=1)

print('Simulation statistics')
print('----------------------------------------------')
print("No. of cases escaped :"+str(len(del_index1[0])))
print("No. of cases with apo. alt > 800.0E3 km :"+str(len(del_index2[0])))
```

```
Simulation statistics
----------------------------------------------
No. of cases escaped :0
No. of cases with apo. alt > 800.0E3 km :0
```

[8]:
```
peri_new = np.delete(peri, del_index)
apoa_new = np.delete(apoa, del_index)
peri_dv_new  = np.delete(peri_dv, del_index)
```

[9]:
```
fig = plt.figure()
fig.set_size_inches([3.25,3.25])
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.plot(peri_new, apoa_new/1000.0, 'bo', markersize=3)

plt.xlabel('Periapsis altitude, km',fontsize=10)
plt.ylabel('Apoapsis altitude x '+r'$10^3$'+', km', fontsize=10)

plt.axhline(y=350.0, linewidth=1, color='k', linestyle='dotted')
plt.axhline(y=450.0, linewidth=1, color='k', linestyle='dotted')
```

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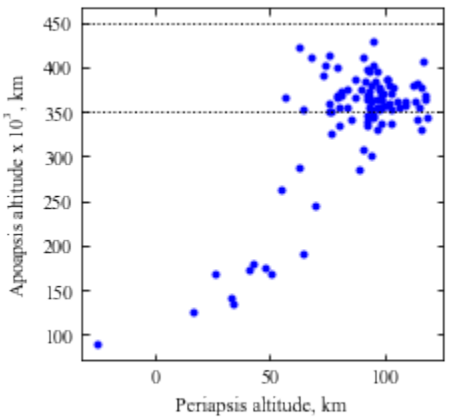
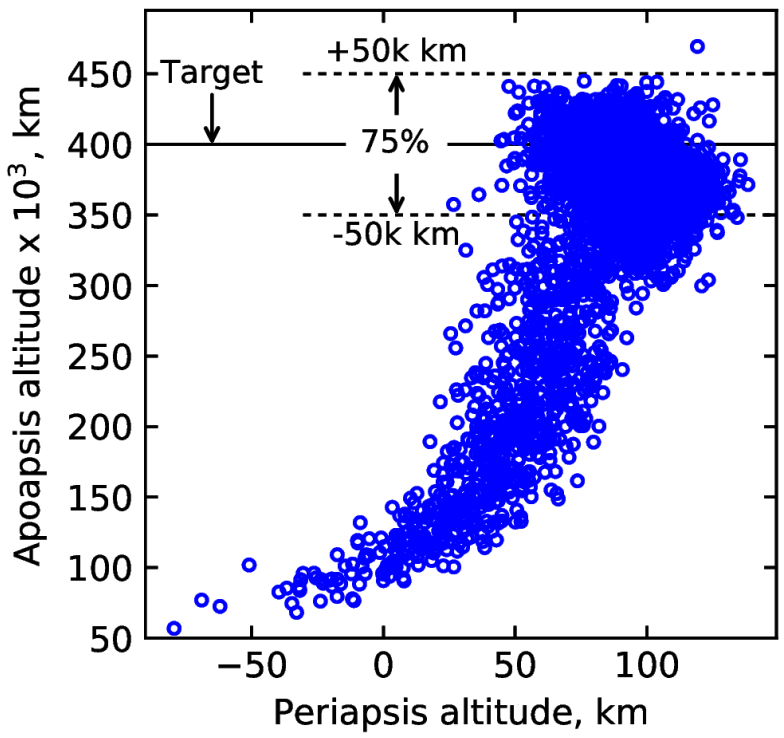
```
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=10)
ax.tick_params(axis='y',labelsize=10)

plt.savefig('../plots/girijaSaikia2020b-fig-13-N100.png',bbox_inches='tight')
plt.savefig('../plots/girijaSaikia2020b-fig-13-N100.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/girijaSaikia2020b-fig-13-N100.eps', dpi=300,bbox_inches='tight')
```



This plot only has 100 trajectories. Below is a similar plot with 5000 trajectories

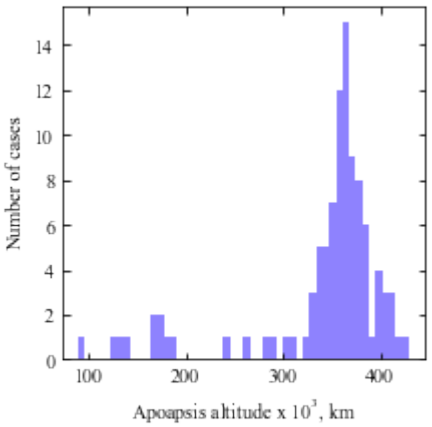
[11]:
```
from IPython.display import Image
Image(filename='../plots/retrograde-higher-res.png', width=400)
```

[11]:



[12]:

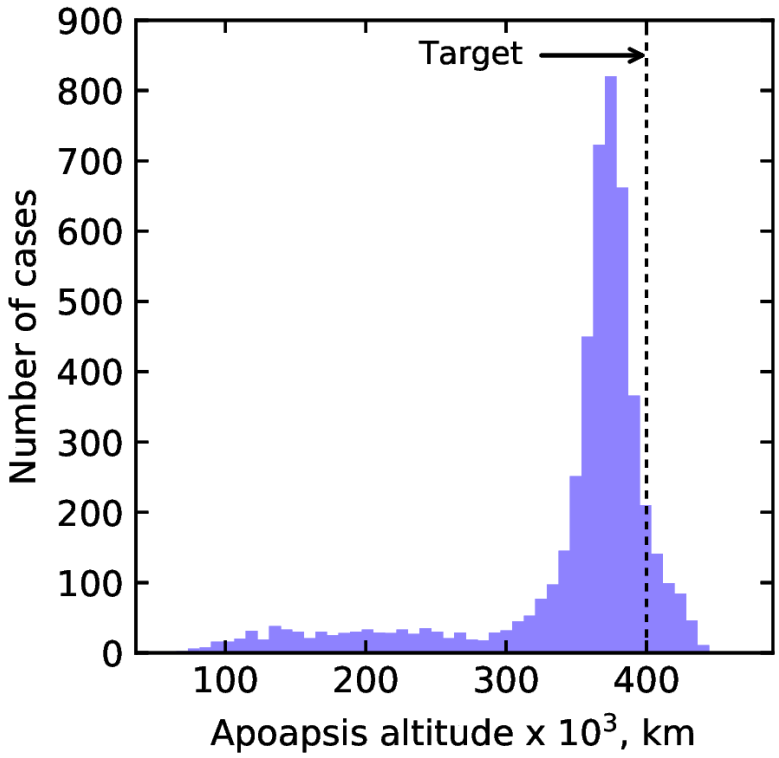
```
fig = plt.figure()
fig.set_size_inches([3.25,3.25])
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.hist(apoa_new/1000.0, bins=50, color='xkcd:periwinkle')
plt.xlabel('Apoapsis altitude x '+r'$10^3$'+', km', fontsize=10)
plt.ylabel('Number of cases', fontsize=10)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=10)
ax.tick_params(axis='y',labelsize=10)

plt.savefig('../plots/girijaSaikia2020b-apo-histogram-N100.png',bbox_inches='tight')
plt.savefig('../plots/girijaSaikia2020b-apo-histogram-N100.pdf', dpi=300,bbox_inches=
↪'tight')
plt.savefig('../plots/girijaSaikia2020b-apo-histogram-N100.eps', dpi=300,bbox_inches=
↪'tight')

plt.show()
```



With more runs, the apoapsis histograms is as shown below.

[16]:
```
from IPython.display import Image
Image(filename='../plots/retrograde-apo-hist-higher-res.png', width=400)
```

[16]:



Congratulations! You have now perfomed and post-processed the results from a Monte Carlo simulation for aerocapture at Neptune.

4.13 Example - 13 - Venus Aerocapture - Part 5a: Monte Carlo Simulations

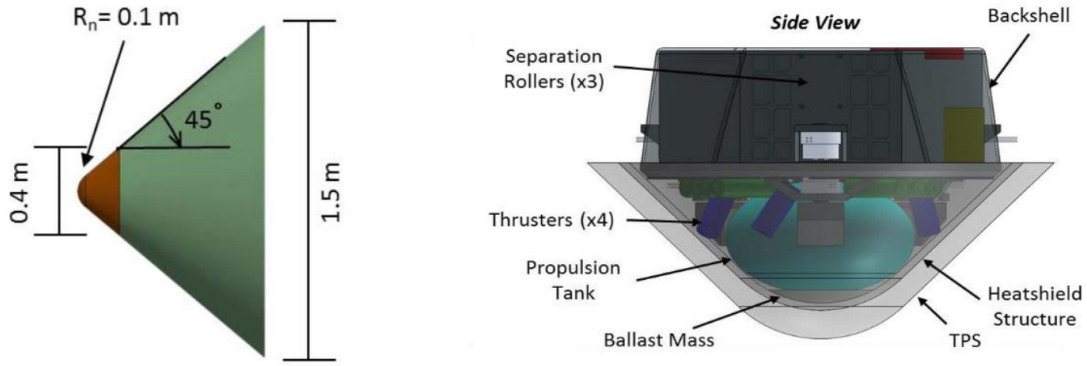
In this example, we will demonstrate the application of aerocapture for SmallSat missions to Venus.

We analyze the design proposed by "Austin et al. SmallSat Aerocapture to Enable a New Paradigm of Planetary Missions, IEEE Aerospace Conference, 2019, Big Sky, MT. DOI: 10.1109/AERO.2019.8742220

Shown below is the aerocapture vehicle design for Venus SmallSat proposed by Austin et al. The design consists of a drag skirt (shown in green), which is jettisoned. The vehicle parameters are $m = 68.1$ kg, $\beta_1 = 38.1$ kg/m2, $\beta_2/\beta_1 = 7.5$. The objective is to insert the small satellite (shown in brown) into a 2,000 km x 200 km orbit around Venus. We will use AMAT to perform Monte Carlo analysis to assess aerocapture performance.

[3]:
```
from IPython.display import Image
Image(filename='../plots/drag-modulation-vehicle.png', width=800)
```

[3]:



[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
from scipy import interpolate
import pandas as pd

import matplotlib.pyplot as plt
from matplotlib import rcParams
from matplotlib.patches import Polygon
```

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("VENUS")
planet.loadAtmosphereModel('../atmdata/Venus/venus-gram-avg.dat', 0 , 1 ,2, 3)
planet.h_skip = 150000.0

# Set up the drag modulation vehicle.
vehicle=Vehicle('DMVehicle', 68.2, 38.1, 0.0, 3.1416, 0.0, 0.10, planet)
vehicle.setInitialState(150.0,0.0,0.0,11.0,0.0,-5.50,0.0,0.0)
vehicle.setSolverParams(1E-6)
vehicle.setDragModulationVehicleParams(38.1,7.5)

# Set up the drag modulation entry phase guidance parameters.
vehicle.setDragEntryPhaseParams(6.0, 80.0, 101, -300.0)

# Set the target orbit parameters.
vehicle.setTargetOrbitParams(200.0, 2000.0, 50.0)

# Define the path to atmospheric files to be used for the Monte Carlo simulations.
atmfiles = ['../atmdata/Venus/LAT80S.txt',
            '../atmdata/Venus/LAT60S.txt',
            '../atmdata/Venus/LAT40S.txt',
```

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```
            '../atmdata/Venus/LAT20S.txt',
            '../atmdata/Venus/LAT10S.txt',
            '../atmdata/Venus/LAT80N.txt',
            '../atmdata/Venus/LAT60N.txt',
            '../atmdata/Venus/LAT40N.txt',
            '../atmdata/Venus/LAT20N.txt',
            '../atmdata/Venus/LAT10N.txt',
]

# Set up the Monte Carlo simulation for drag modulation.
# NPOS = 151, NMONTE = 200
# Target EFPA = -5.40 deg
# EFPA 1-sigma error = +/- 0.033 deg
# Nominal beta_1 = 38.1 kg/m2
# beta_1 1-sigma = 0.0
# guidance time step for entry = 0.1s (Freq. = 10 Hz)
# guidance time step after jettison = 1.0 s
# max. solver time step = 0.1 s
# max. time used by solver = 1200 s

vehicle.setupMonteCarloSimulationD(151, 200, atmfiles,0, 1, 2, 3, 4, True,
                                   -5.40,  0.033, 38.1, 0.0,
                                    0.1, 1.0, 0.1, 1200.0)
```

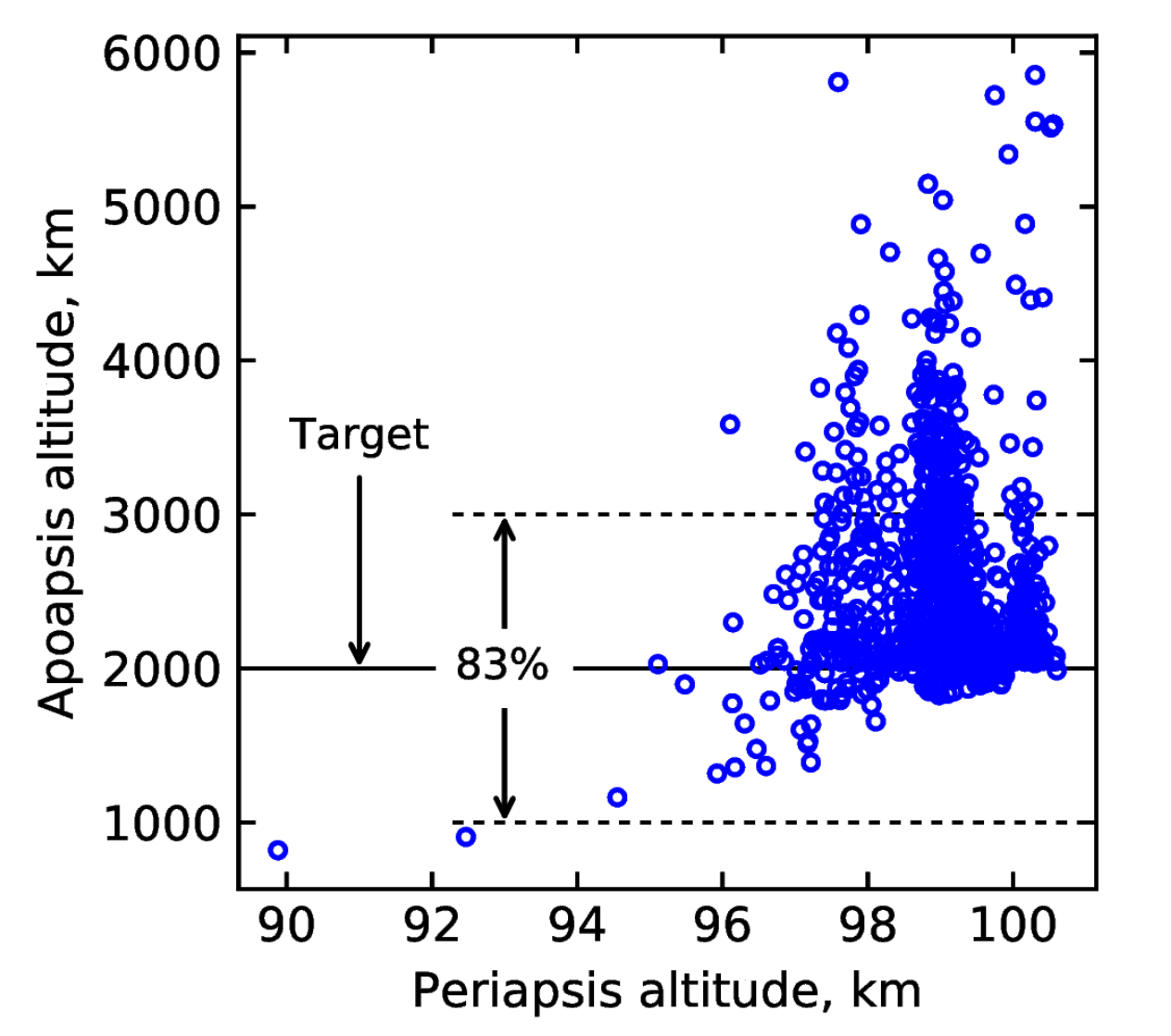
[4]:
```
# N = 10 shown here, run for a few thousand to be realistic. This will take several␣
↪hours.

vehicle.runMonteCarloD(10, '../data/austin2019/MCB1')
```

```
BATCH :../data/austin2019/MCX1, RUN #: 1, PROF: ../atmdata/Venus/LAT10N.txt, SAMPLE #:
↪ 51, EFPA: -5.43, SIGMA: -1.67, APO : 2881.64
BATCH :../data/austin2019/MCX1, RUN #: 2, PROF: ../atmdata/Venus/LAT40S.txt, SAMPLE #:
↪ 77, EFPA: -5.41, SIGMA: 0.10, APO : 2290.41
BATCH :../data/austin2019/MCX1, RUN #: 3, PROF: ../atmdata/Venus/LAT80N.txt, SAMPLE #:
↪ 108, EFPA: -5.43, SIGMA: 2.31, APO : 4615.14
BATCH :../data/austin2019/MCX1, RUN #: 4, PROF: ../atmdata/Venus/LAT60S.txt, SAMPLE #:
↪ 195, EFPA: -5.41, SIGMA: 1.61, APO : 2753.68
BATCH :../data/austin2019/MCX1, RUN #: 5, PROF: ../atmdata/Venus/LAT40S.txt, SAMPLE #:
↪ 194, EFPA: -5.40, SIGMA: 0.26, APO : 2283.65
BATCH :../data/austin2019/MCX1, RUN #: 6, PROF: ../atmdata/Venus/LAT80N.txt, SAMPLE #:
↪ 61, EFPA: -5.37, SIGMA: -1.13, APO : 2059.74
BATCH :../data/austin2019/MCX1, RUN #: 7, PROF: ../atmdata/Venus/LAT20N.txt, SAMPLE #:
↪ 126, EFPA: -5.38, SIGMA: -0.53, APO : 2918.58
BATCH :../data/austin2019/MCX1, RUN #: 8, PROF: ../atmdata/Venus/LAT80N.txt, SAMPLE #:
↪ 188, EFPA: -5.42, SIGMA: 2.00, APO : 2318.39
BATCH :../data/austin2019/MCX1, RUN #: 9, PROF: ../atmdata/Venus/LAT40N.txt, SAMPLE #:
↪ 8, EFPA: -5.40, SIGMA: 1.06, APO : 2264.39
BATCH :../data/austin2019/MCX1, RUN #: 10, PROF: ../atmdata/Venus/LAT80N.txt, SAMPLE
↪#: 183, EFPA: -5.42, SIGMA: 0.05, APO : 2667.25
```

Shown below is the apoapsis dispersion for 1000 runs.

[5]:
```
from IPython.display import Image
Image(filename='../plots/austin-drag-modulation-N1000.png', width=600)
```

[5]:

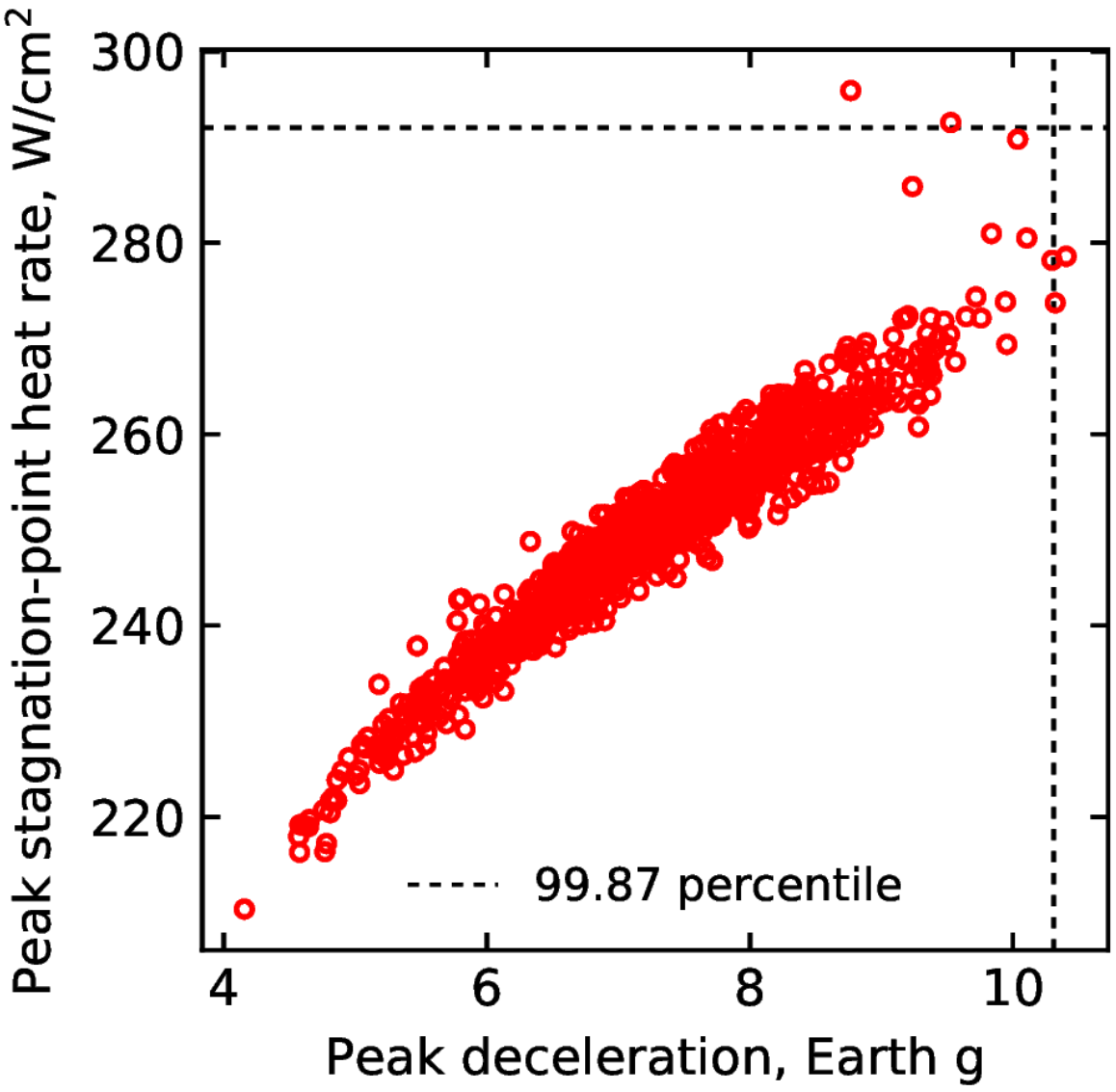


No cases resulted in escape or crashing into the planet. 3 of 1000 cases resulted in apoapsis exceeding 6000 km.

Shown below is the heating rate and g-load dispersion.

[6]:
```
from IPython.display import Image
Image(filename='../plots/austin-drag-modulation-heat.png', width=600)
```

[6]:



4.14 Example - 14 - Fire-II - Earth

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Fire II technology demonstrator for the Apollo heating re-entry environment. See: https://en.wikipedia.org/wiki/Project_FIRE

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("EARTH")
planet.loadAtmosphereModel('../atmdata/Earth/earth-gram-avg.dat', 0 , 1 ,2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('Fire-II', 86.5, 180.0, 0.0, 0.354, 0.0, 0.805, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(120.0,0.0,0.0,11.35,0.0,-14.70,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (2400.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
```

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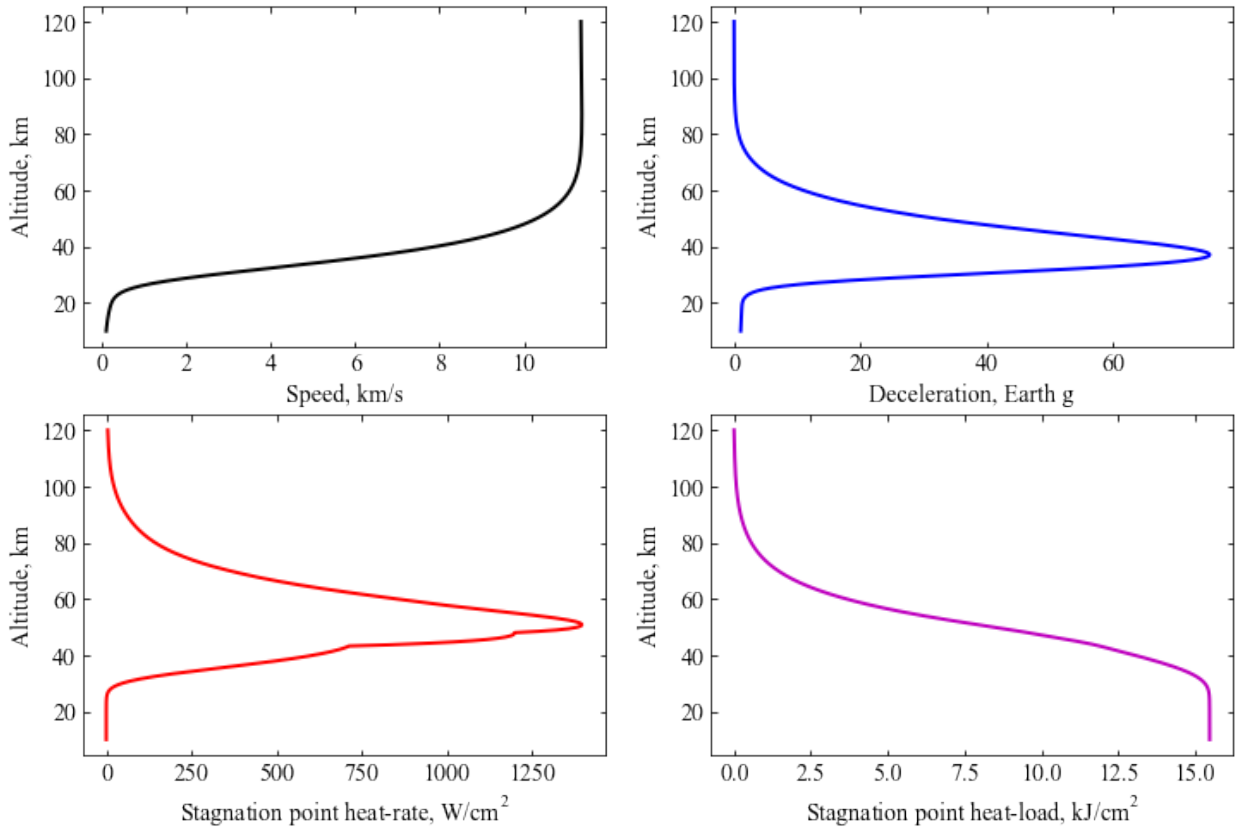
```
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/fire-II-earth.png',bbox_inches='tight')
plt.savefig('../plots/fire-II-earth.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/fire-II-earth.eps', dpi=300,bbox_inches='tight')

plt.show()
```



[ ]:

4.15 Example - 15 - Apollo-AS-201 - Earth

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Apollo AS-201 suborbital flight test. https://en.wikipedia.org/wiki/AS-201

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("EARTH")
planet.loadAtmosphereModel('../atmdata/Earth/earth-gram-avg.dat', 0 , 1 ,2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('Apollo-AS-201', 5400.0, 400.0, 0.3, 12.0, 0.0, 3.0, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(120.0,0.0,0.0,7.67,0.0,-9.03,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (2400.0,0.1,60.0)
# bank angle = 60 deg arbitrary, actual profile will give more realistic results
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
```

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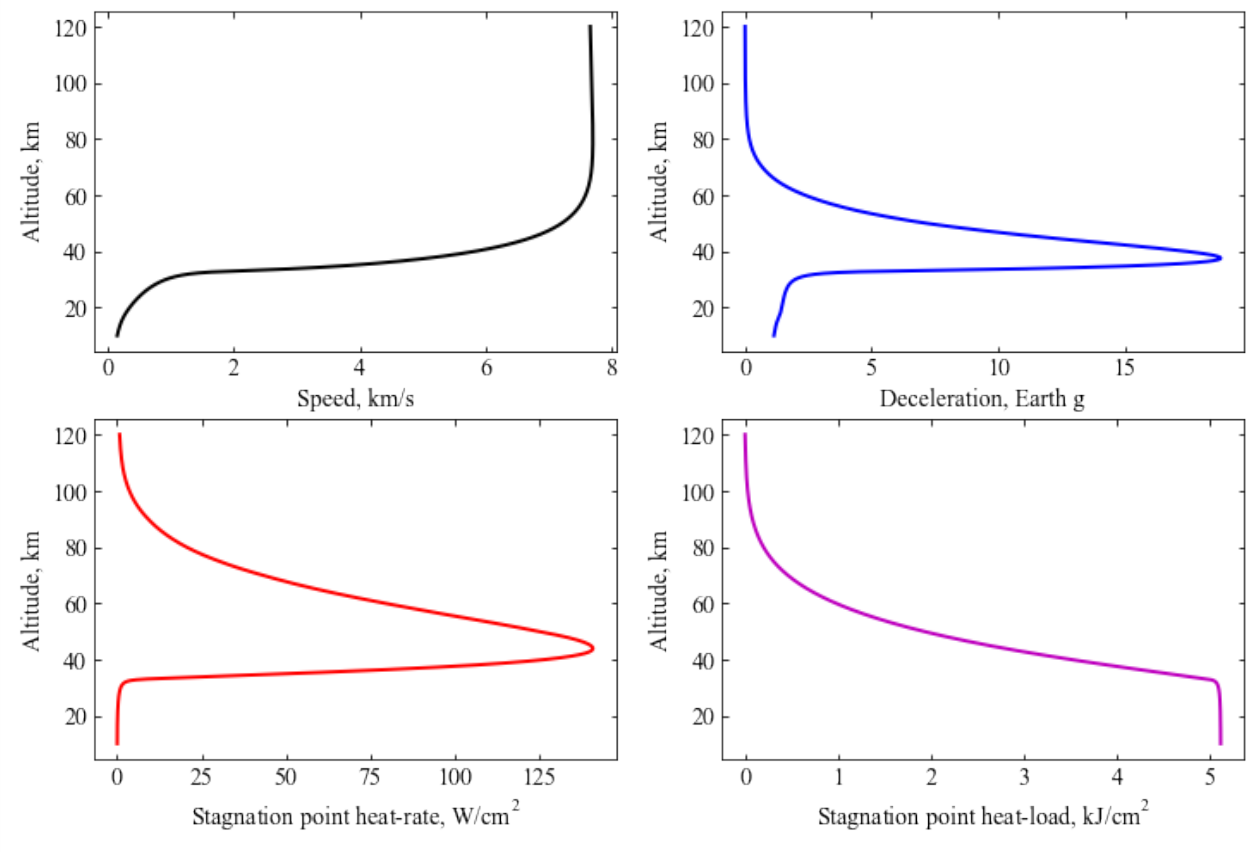
```
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/apollo-as-201-earth.png',bbox_inches='tight')
plt.savefig('../plots/apollo-as-201-earth.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/apollo-as-201-earth.eps', dpi=300,bbox_inches='tight')

plt.show()
```



[ ]:

4.16 Example - 16 - Apollo-AS-202 - Earth

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Apollo AS-202 suborbital flight test. https://en.wikipedia.org/wiki/AS-202

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("EARTH")
planet.loadAtmosphereModel('../atmdata/Earth/earth-gram-avg.dat', 0 , 1 ,2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('Apollo-AS-202', 5400.0, 400.0, 0.3, 12.0, 0.0, 3.0, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(120.0,0.0,0.0,8.29,0.0,-3.53,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (2400.0,0.1,70.0)
# bank angle = 70 deg arbitrary, actual profile will give more realistic results
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
```

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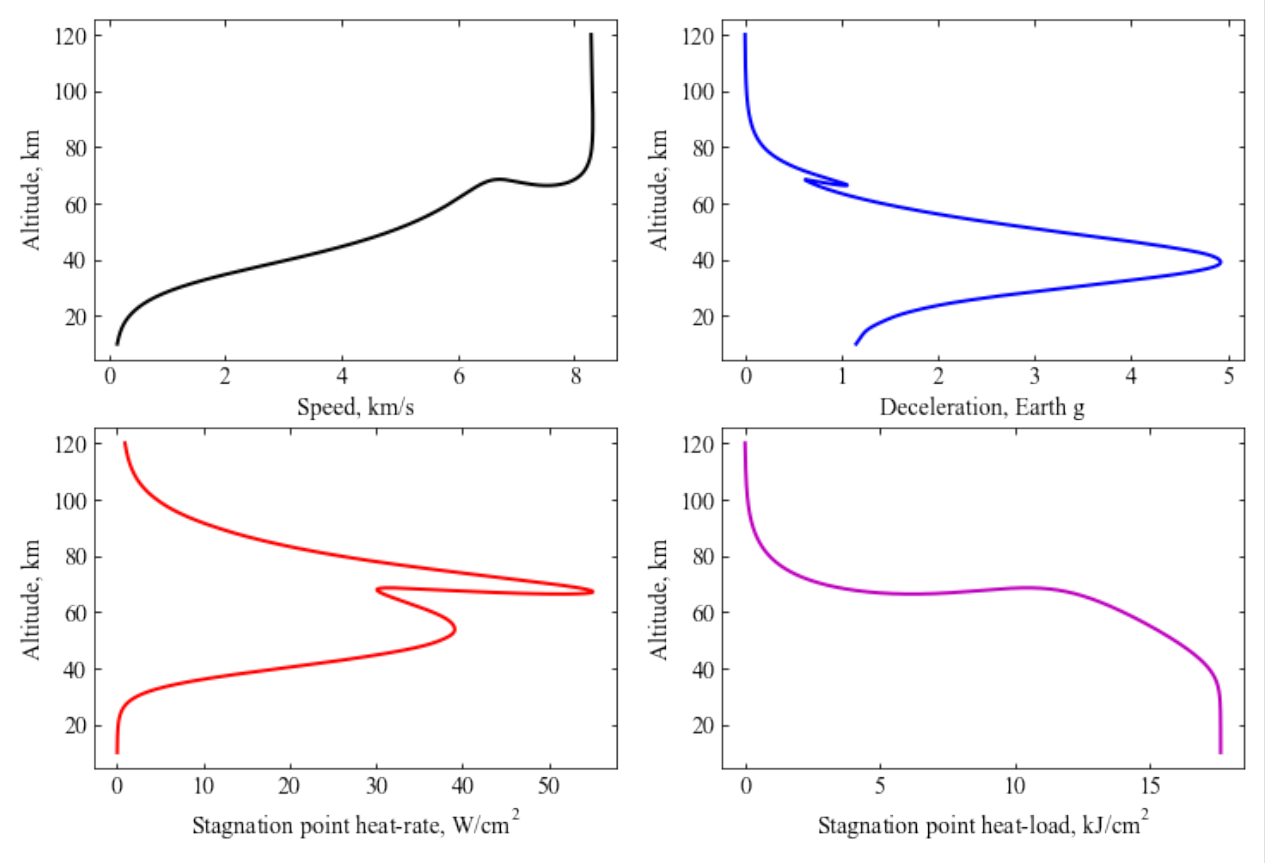
```
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/apollo-as-202-earth.png',bbox_inches='tight')
plt.savefig('../plots/apollo-as-202-earth.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/apollo-as-202-earth.eps', dpi=300,bbox_inches='tight')

plt.show()
```



[ ]:

4.17 Example - 17 - Apollo-4 - Earth

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Apollo-4 flight test. https://en.wikipedia.org/wiki/Apollo_4

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("EARTH")
planet.loadAtmosphereModel('../atmdata/Earth/earth-gram-avg.dat', 0 , 1 ,2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('Apollo-4', 5400.0, 400.0, 0.3, 12.0, 0.0, 3.0, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(120.0,0.0,0.0,10.73,0.0,-7.13,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (2400.0,0.1,70.0)
# bank angle = 70 deg arbitrary, actual profile will give more realistic results
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
```

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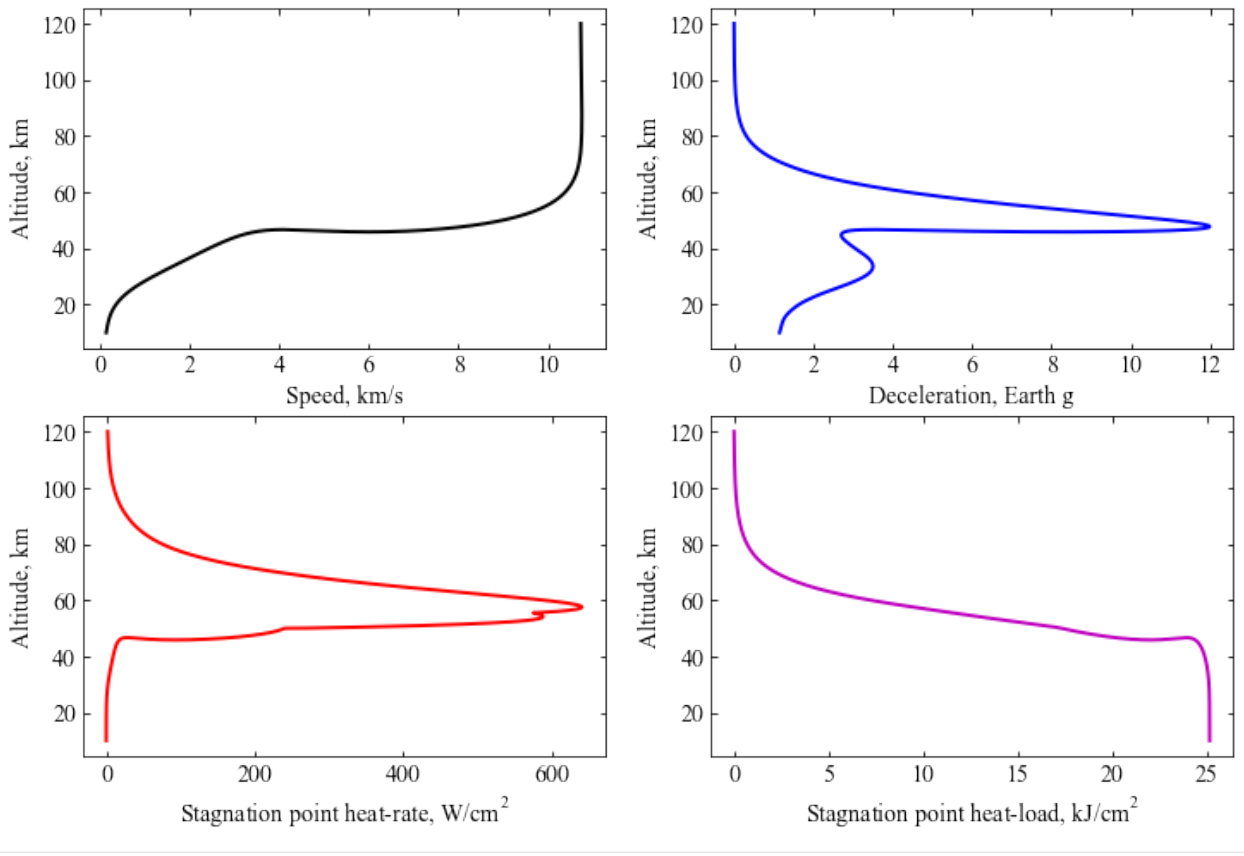
```
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/apollo-4-earth.png',bbox_inches='tight')
plt.savefig('../plots/apollo-4-earth.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/apollo-4-earth.eps', dpi=300,bbox_inches='tight')

plt.show()
```



4.18 Example - 18 - Apollo-6 - Earth

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Apollo-6 flight test. https://en.wikipedia.org/wiki/Apollo_6

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("EARTH")
planet.loadAtmosphereModel('../atmdata/Earth/earth-gram-avg.dat', 0 , 1 ,2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('Apollo-6', 5400.0, 400.0, 0.3, 12.0, 0.0, 3.0, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(120.0,0.0,0.0,9.60,0.0,-5.90,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (2400.0,0.1,60.0)
# bank angle = 70 deg arbitrary, actual profile will give more realistic results
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)
```

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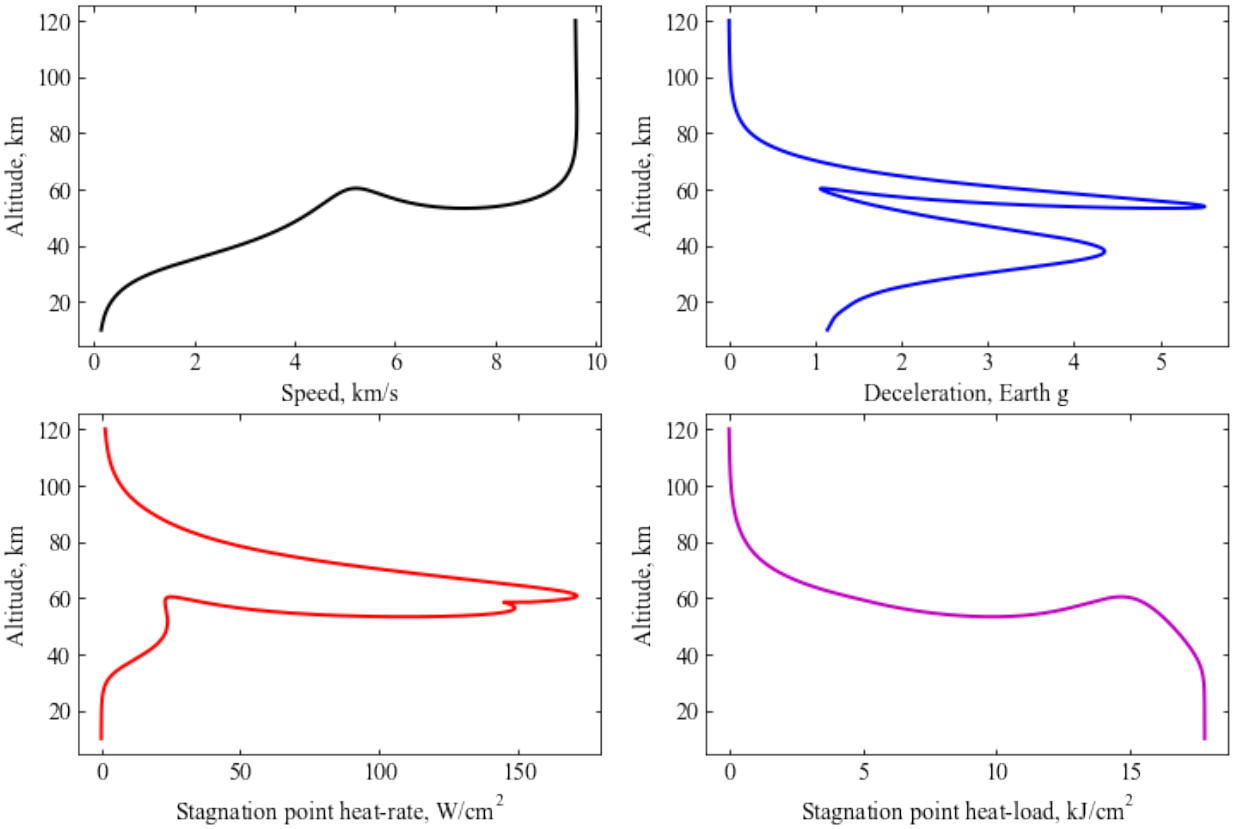
```
plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/apollo-6-earth.png',bbox_inches='tight')
plt.savefig('../plots/apollo-6-earth.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/apollo-6-earth.eps', dpi=300,bbox_inches='tight')

plt.show()
```



4.19 Example - 19 - PAET - Earth

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the PAET flight test. https://ntrs.nasa.gov/search.jsp?R=19720045287

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("EARTH")
planet.loadAtmosphereModel('../atmdata/Earth/earth-gram-avg.dat', 0 , 1 ,2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('PAET', 62.1, 69, 0.0, 0.66, 0.0, 0.46, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(90.0,0.0,0.0,6.56,0.0,-40.8,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (2400.0,0.1,0.0)
# bank angle = 70 deg arbitrary, actual profile will give more realistic results
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
```

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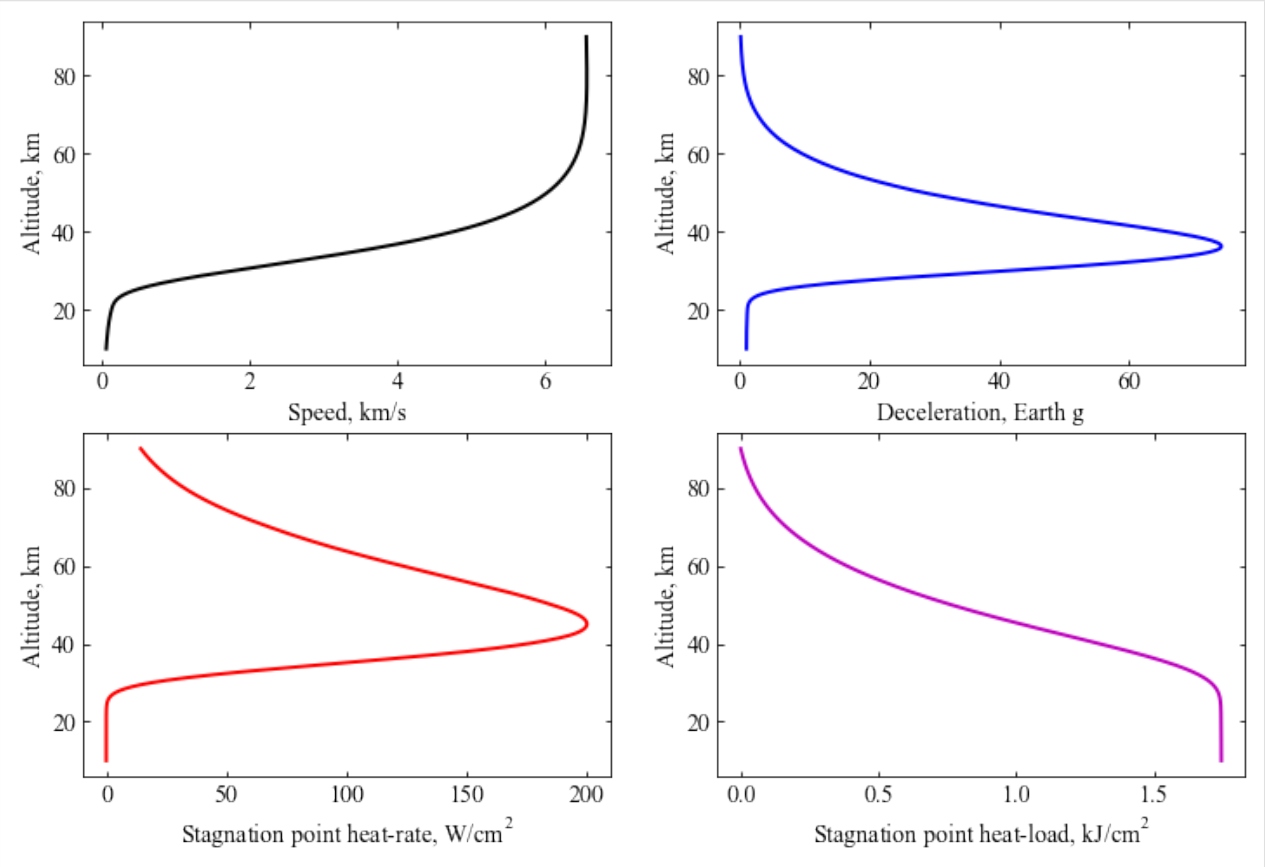
```
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/paet-earth.png',bbox_inches='tight')
plt.savefig('../plots/paet-earth.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/paet-earth.eps', dpi=300,bbox_inches='tight')

plt.show()
```



4.20 Example - 20 - Viking-1 - Mars

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Viking-1 Lander. https://en.wikipedia.org/wiki/Viking_1

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("MARS")
planet.loadAtmosphereModel('../atmdata/Mars/mars-gram-avg.dat', 0 , 1 ,2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('Viking-1', 980, 63.0, 0.18, 9.65, 0.0, 0.88, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(120.0,0.0,0.0,4.42,0.0,-16.99,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (2400.0,0.1,20.0)
# bank angle = 20 deg arbitrary, actual profile will give more realistic results
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
```

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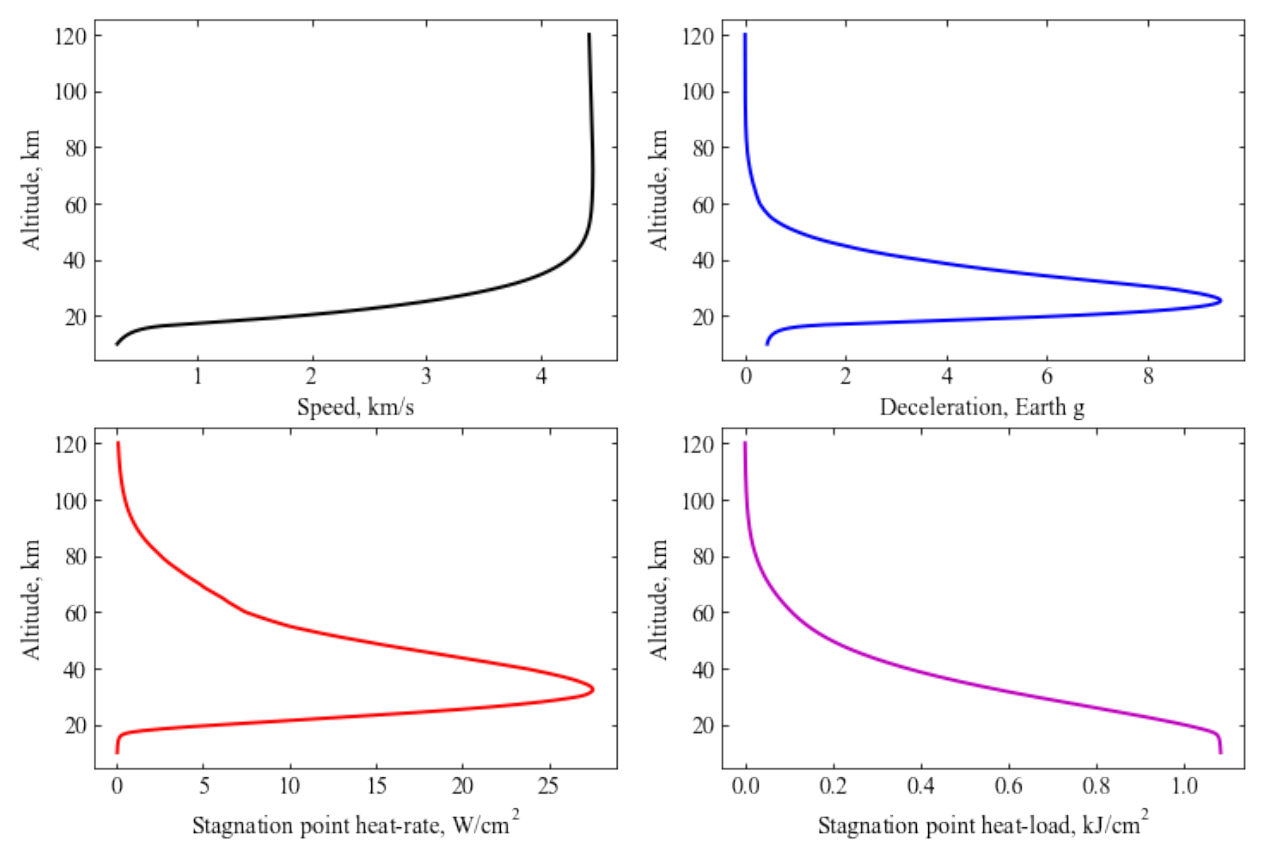
```
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/viking-1-mars.png',bbox_inches='tight')
plt.savefig('../plots/viking-1-mars.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/viking-1-mars.eps', dpi=300,bbox_inches='tight')

plt.show()
```



[ ]:

4.21 Example - 21 - Viking-2 - Mars

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Viking-2 Lander. https://en.wikipedia.org/wiki/Viking_2

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("MARS")
planet.loadAtmosphereModel('../atmdata/Mars/mars-gram-avg.dat', 0 , 1 ,2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('Viking-2', 982, 63.6, 0.18, 9.65, 0.0, 0.88, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(120.0,0.0,0.0,4.48,0.0,-17.08,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (2400.0,0.1,20.0)
# bank angle = 20 deg arbitrary, actual profile will give more realistic results
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
```

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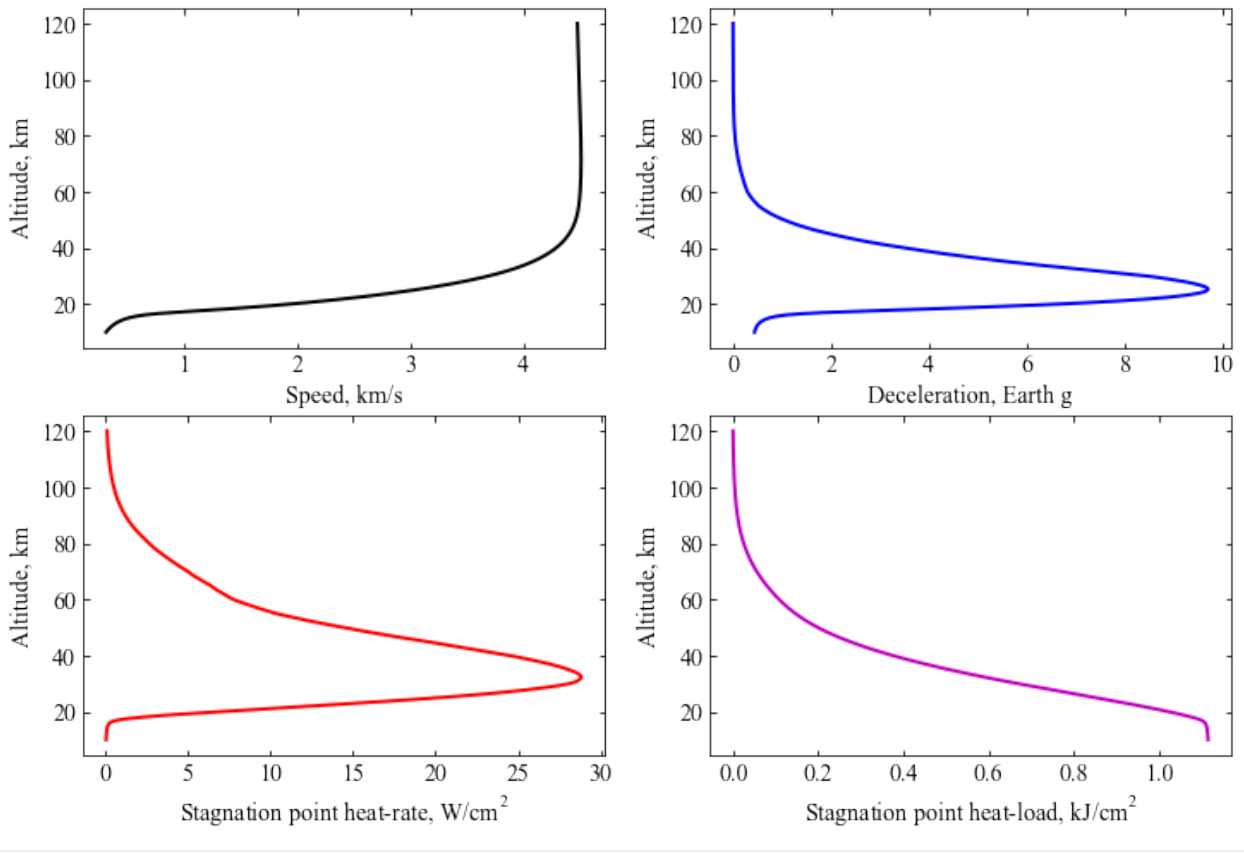
```
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/viking-2-mars.png',bbox_inches='tight')
plt.savefig('../plots/viking-2-mars.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/viking-2-mars.eps', dpi=300,bbox_inches='tight')

plt.show()
```



[ ]:

4.22 Example - 22 - PV Small North - Venus

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Pioneer Venus Small North probe. https://en.wikipedia.org/wiki/Pioneer_Venus_Multiprobe

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("VENUS")
planet.loadAtmosphereModel('../atmdata/Venus/venus-gram-avg.dat', 0 , 1 , 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('PV-Small-North', 91, 190, 0.00, 0.46, 0.0, 0.19, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(180.0,0.0,0.0,11.54,0.0,-68.7,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (2400.0,0.1,0.0)
# bank angle = 20 deg arbitrary, actual profile will give more realistic results
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
```

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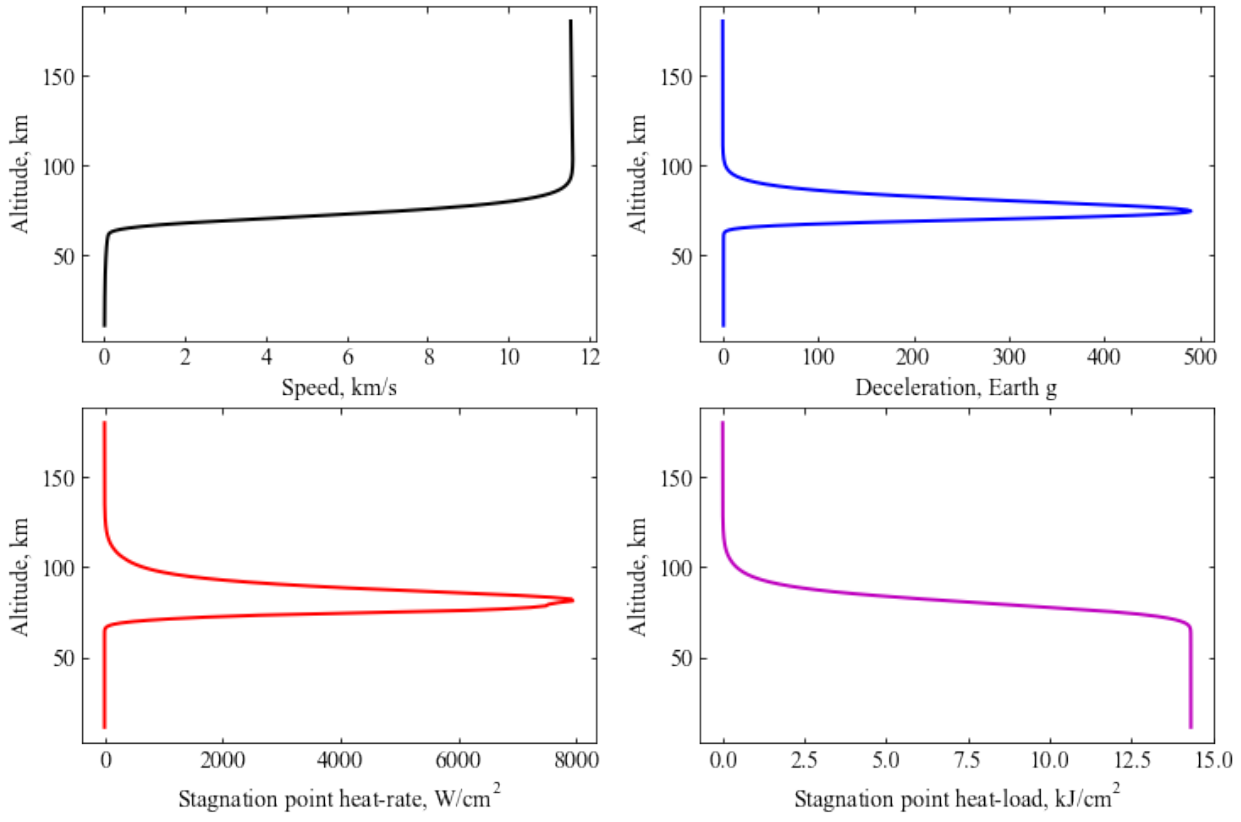
```
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/pv-small-north-venus.png',bbox_inches='tight')
plt.savefig('../plots/pv-small-north-venus.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/pv-small-north-venus.eps', dpi=300,bbox_inches='tight')

plt.show()
```



4.23 Example - 23 - PV Small Night - Venus

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Pioneer Venus Small Night probe. https://en.wikipedia.org/wiki/Pioneer_Venus_Multiprobe

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("VENUS")
planet.loadAtmosphereModel('../atmdata/Venus/venus-gram-avg.dat', 0 , 1 , 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('PV-Small-Night', 91, 190, 0.00, 0.46, 0.0, 0.19, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(180.0,0.0,0.0,11.54,0.0,-41.5,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (2400.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
```

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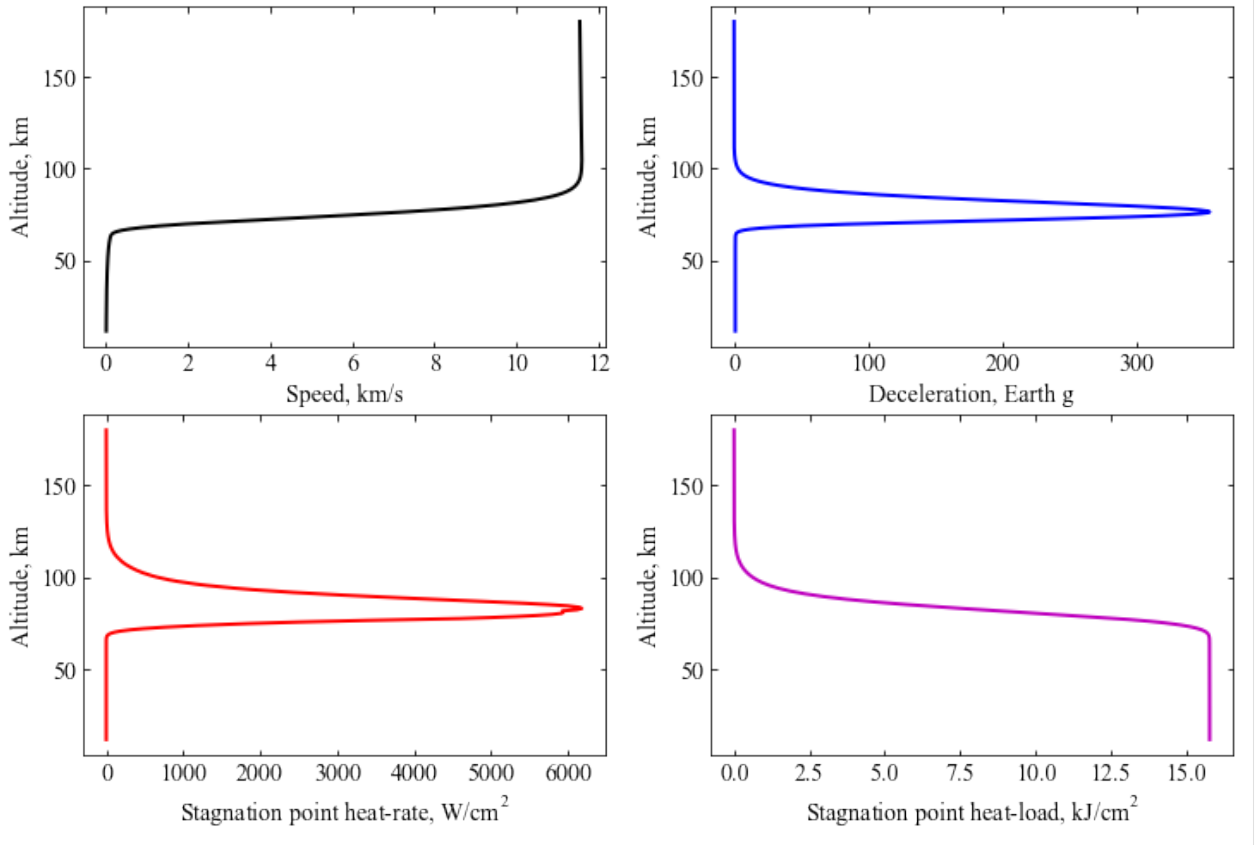
```
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/pv-small-night-venus.png',bbox_inches='tight')
plt.savefig('../plots/pv-small-night-venus.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/pv-small-night-venus.eps', dpi=300,bbox_inches='tight')

plt.show()
```



[ ]:

4.24 Example - 24 - PV Small Day - Venus

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Pioneer Venus Small Day probe. https://en.wikipedia.org/wiki/Pioneer_Venus_Multiprobe

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("VENUS")
planet.loadAtmosphereModel('../atmdata/Venus/venus-gram-avg.dat', 0 , 1 , 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('PV-Small-Day', 91, 190, 0.00, 0.46, 0.0, 0.19, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(180.0,0.0,0.0,11.54,0.0,-25.4,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (2400.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
```

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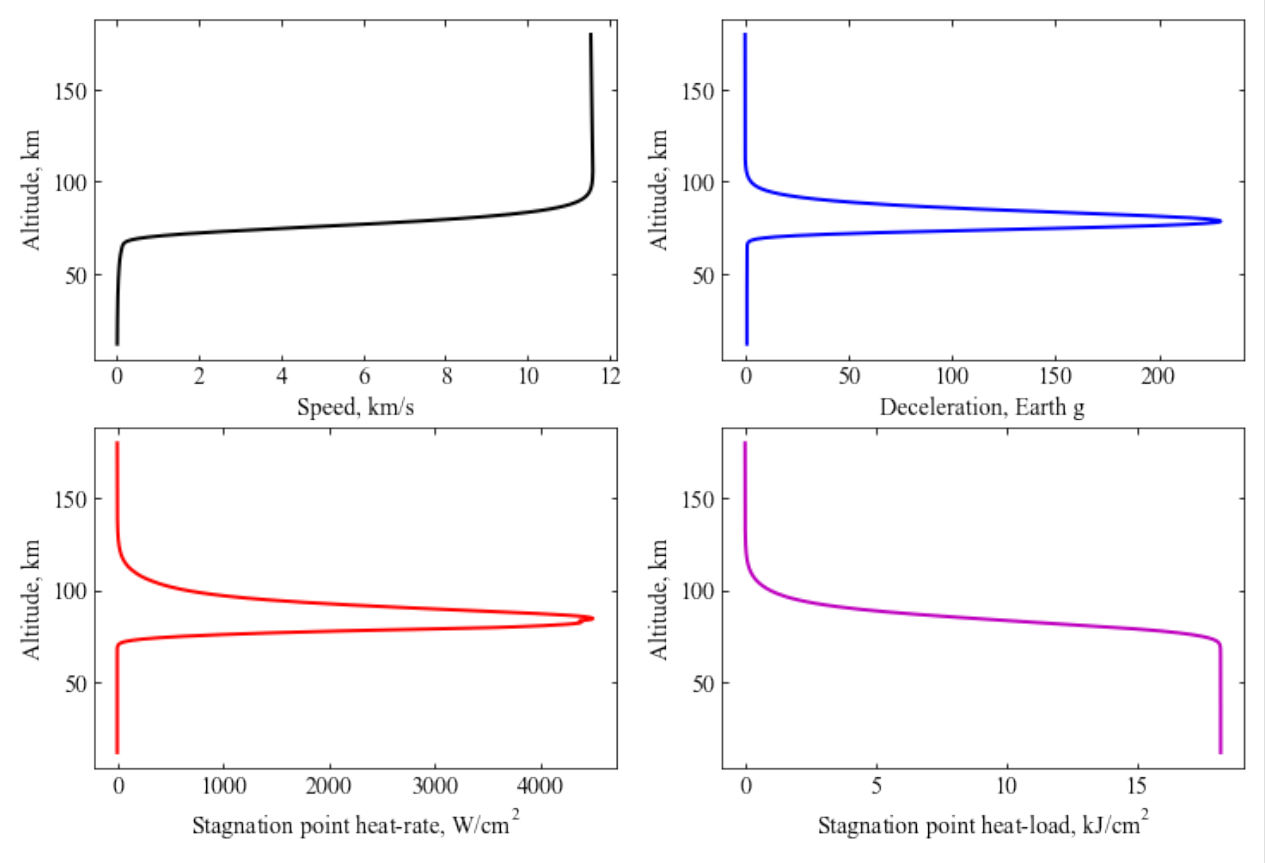
```
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/pv-small-day-venus.png',bbox_inches='tight')
plt.savefig('../plots/pv-small-day-venus.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/pv-small-day-venus.eps', dpi=300,bbox_inches='tight')

plt.show()
```



[ ]:

4.25 Example - 25 - PV Large - Venus

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Pioneer Venus Large probe. https://en.wikipedia.org/wiki/Pioneer_Venus_Multiprobe

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("VENUS")
planet.loadAtmosphereModel('../atmdata/Venus/venus-gram-avg.dat', 0 , 1 , 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('PV-Large', 316 , 188, 0.00, 1.59, 0.0, 0.36, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(180.0,0.0,0.0,11.54,0.0,-32.4,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (2400.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
```

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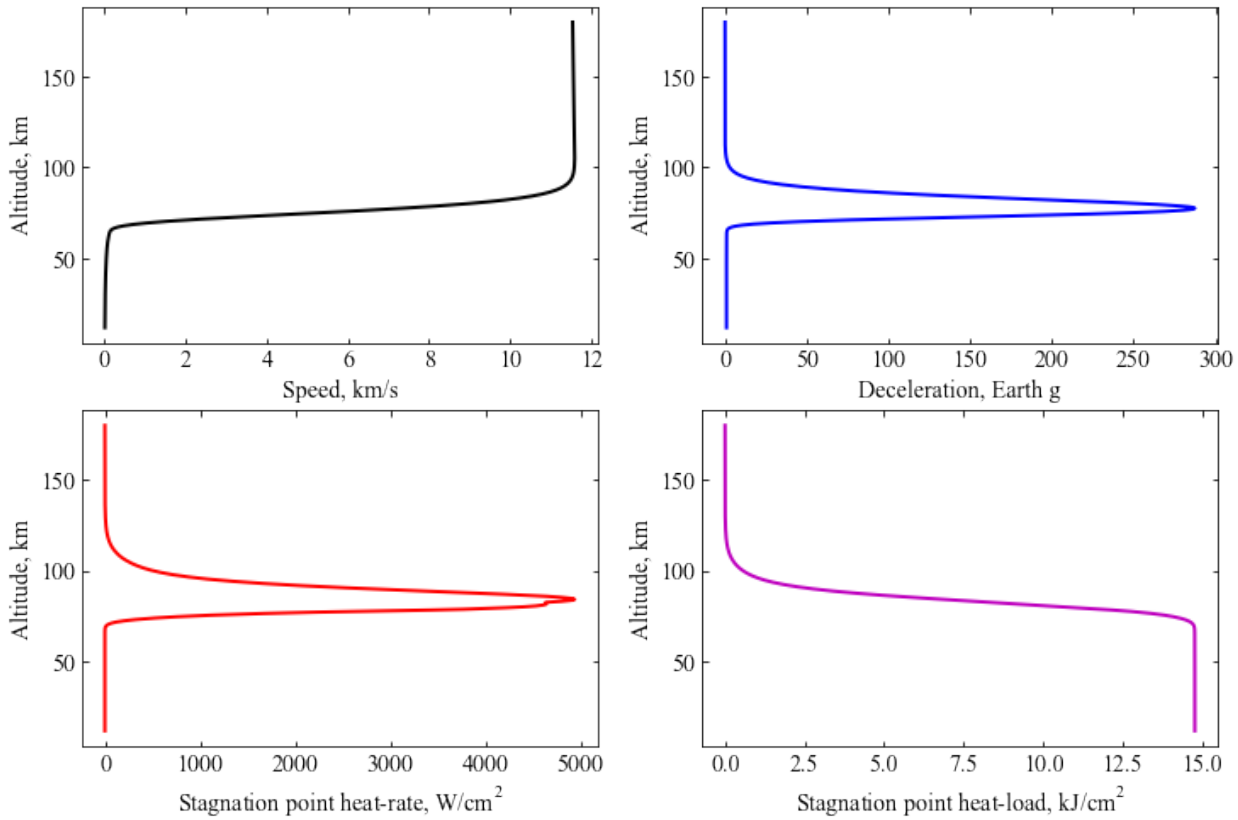
```
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/pv-large-venus.png',bbox_inches='tight')
plt.savefig('../plots/pv-large-venus.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/pv-large-venus.eps', dpi=300,bbox_inches='tight')

plt.show()
```



4.26 Example - 26 - Galileo - Jupiter

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Galileo entry probe. https://en.wikipedia.org/wiki/Galileo_Probe

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("JUPITER")
planet.h_trap = -130.0E3
planet.loadAtmosphereModel('../atmdata/Jupiter/jupiter-galileo-asi.dat', 0 , 1 , 2, 3,
↪ heightInKmFlag=True)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('Galileo', 335.0 , 256.0, 0.00, 1.26, 0.0, 0.22, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(450.0,0.0,0.0,47.37,0.0,-8.5,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (9400.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
```

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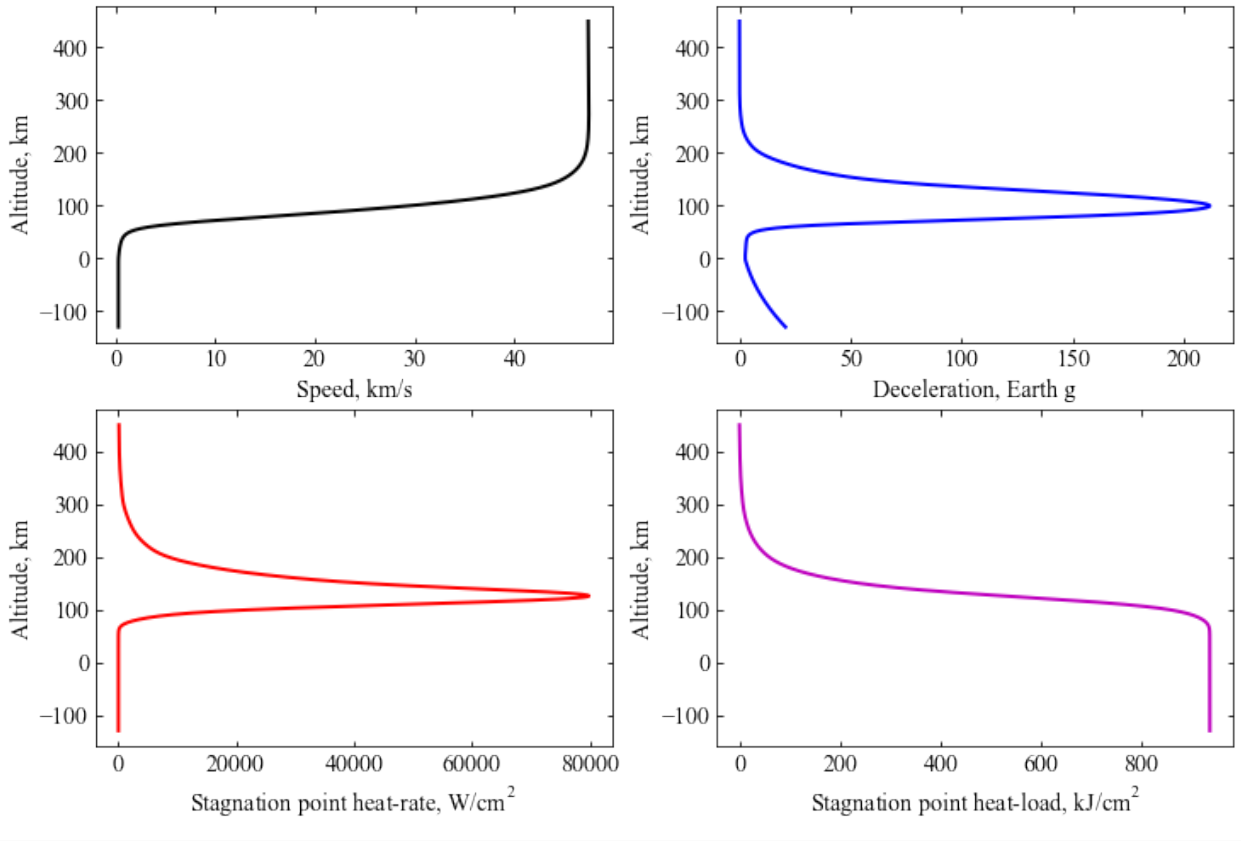
```
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/galileo-jupiter.png',bbox_inches='tight')
plt.savefig('../plots/galileo-jupiter.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/galileo-jupiter.eps', dpi=300,bbox_inches='tight')

plt.show()
```



Results are off because presumably because of poor validity of heating correlations under extreme entry conditions at Jupiter.

4.27 Example - 27 - OREX - Earth

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the OREX entry probe. http://adsabs.harvard.edu/full/1995ESASP.367..271I

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("EARTH")
planet.loadAtmosphereModel('../atmdata/Earth/earth-gram-avg.dat', 0 , 1 , 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('OREX', 761 , 56, 0.00, 9.08, 0.0, 1.35, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(120.0,0.0,0.0,7.43,0.0,-3.17,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (2400.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
```

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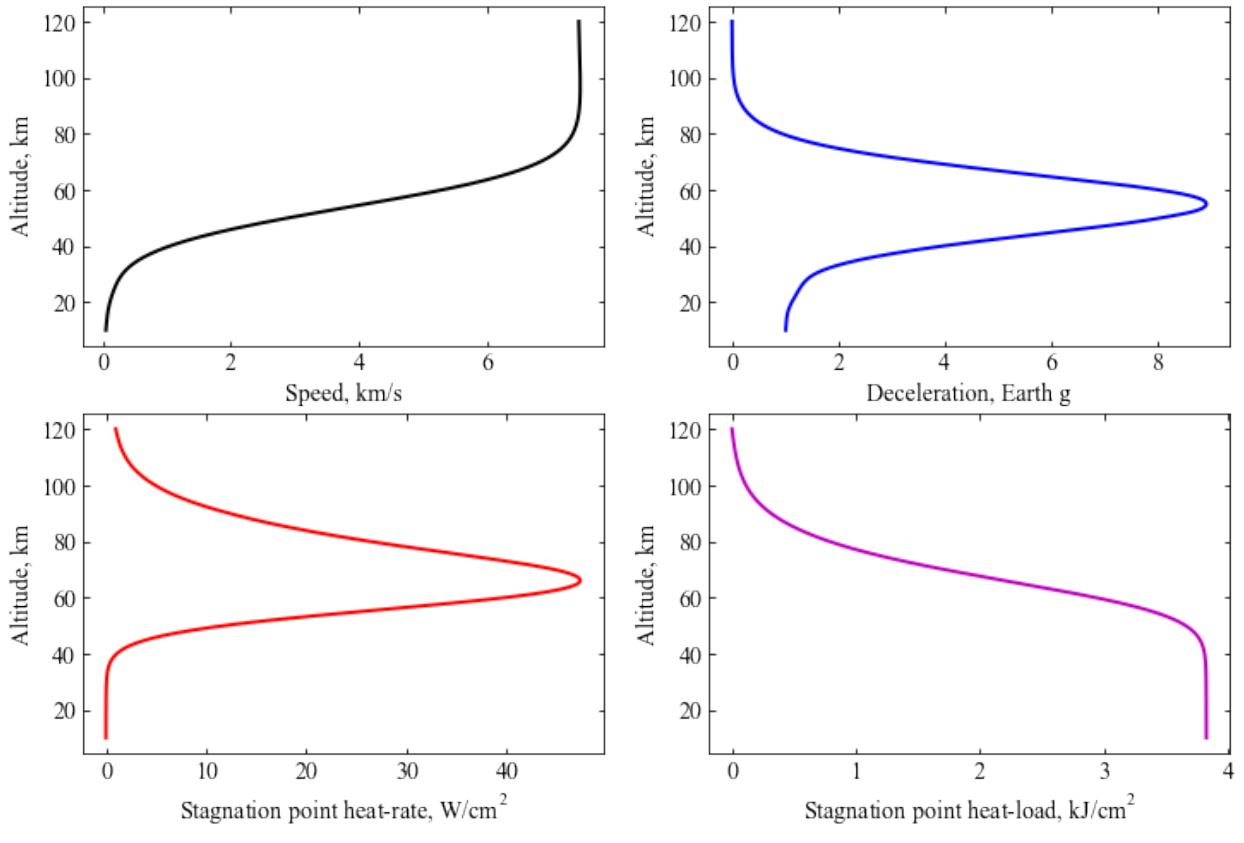
```
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/orex-earth.png',bbox_inches='tight')
plt.savefig('../plots/orex-earth.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/orex-earth.eps', dpi=300,bbox_inches='tight')

plt.show()
```



4.28 Example - 28 - Pathfinder - Mars

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Pathfinder mission. https://en.wikipedia.org/wiki/Mars_Pathfinder

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("MARS")
planet.loadAtmosphereModel('../atmdata/Mars/mars-gram-avg.dat', 0 , 1 , 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('Pathfinder', 586 , 62.0, 0.00, 5.52, 0.0, 0.66, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(120.0,0.0,0.0,7.48,0.0,-14.06,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (2400.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
```

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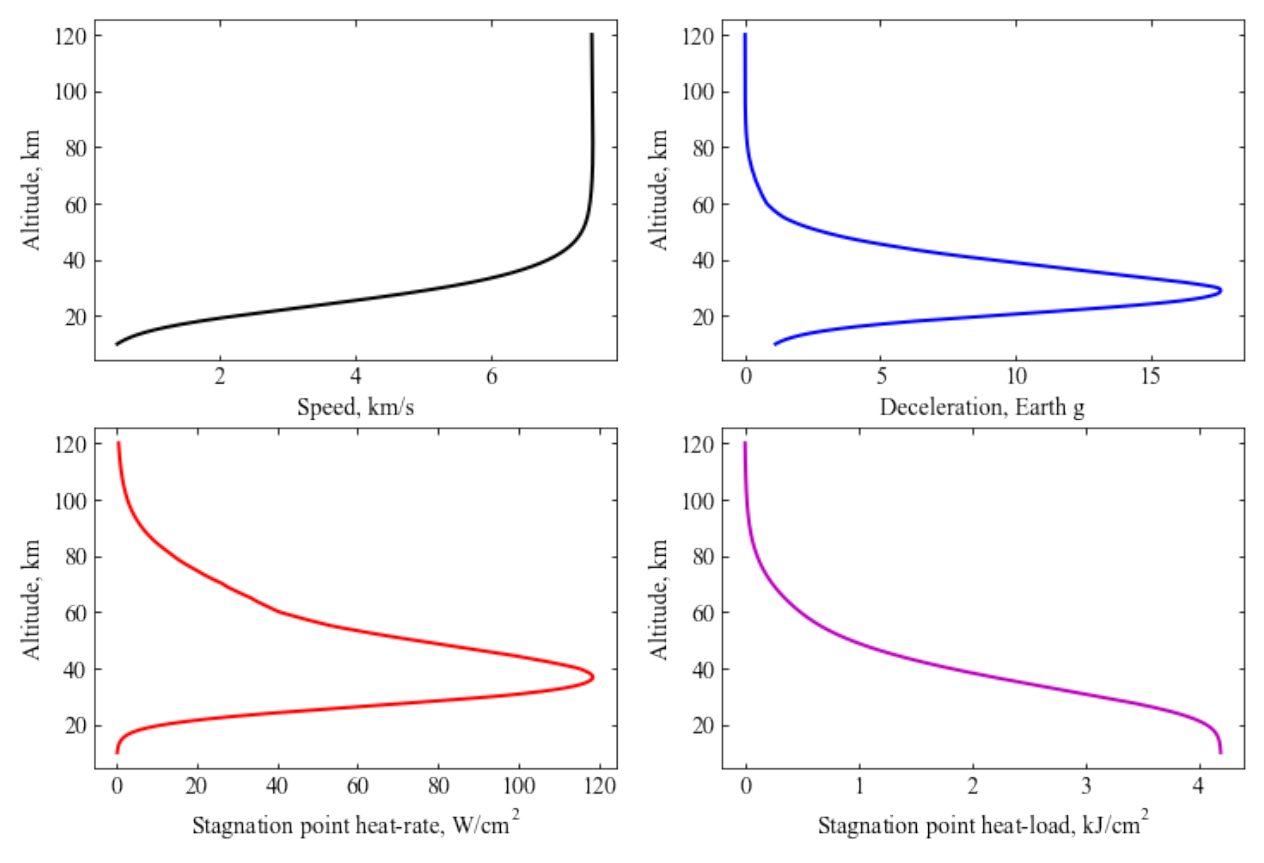
```
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/pathfinder-mars.png',bbox_inches='tight')
plt.savefig('../plots/pathfinder-mars.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/pathfinder-mars.eps', dpi=300,bbox_inches='tight')

plt.show()
```



4.29 Example - 29 - Mirka - Earth

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Mirka entry probe. http://adsabs.harvard.edu/full/2006ESASP.631E..26B

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("EARTH")
planet.loadAtmosphereModel('../atmdata/Earth/earth-gram-avg.dat', 0 , 1 , 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('Mirka', 154.0 , 214.9, 0.00, 0.785, 0.0, 0.5, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(120.0,0.0,0.0,7.60,0.0,-2.51,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (2400.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/mirka-earth.png',bbox_inches='tight')
```

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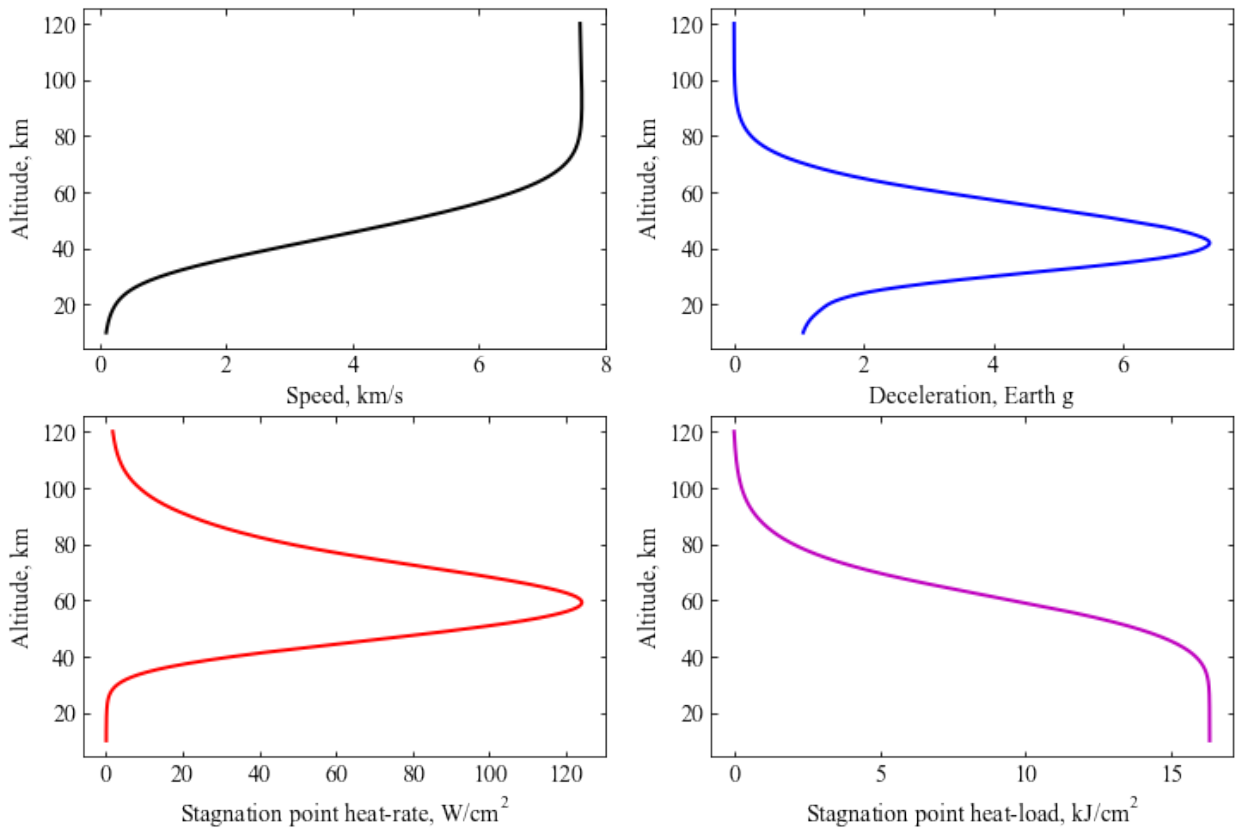
```
plt.savefig('../plots/mirka-earth.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/mirka-earth.eps', dpi=300,bbox_inches='tight')

plt.show()
```



4.30 Example - 30 - Huygens - Titan

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Huygens probe. https://en.wikipedia.org/wiki/Huygens_(spacecraft)

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("TITAN")
planet.h_skip = 1270.0E3
planet.loadAtmosphereModel('../atmdata/Titan/titan-gram-avg.dat', 0 , 1 , 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('Huygens', 318.0 , 35.0, 0.00, 5.73, 0.0, 1.25, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(1270.0,0.0,0.0,6.0,0.0,-65.4,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (120*60.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
```

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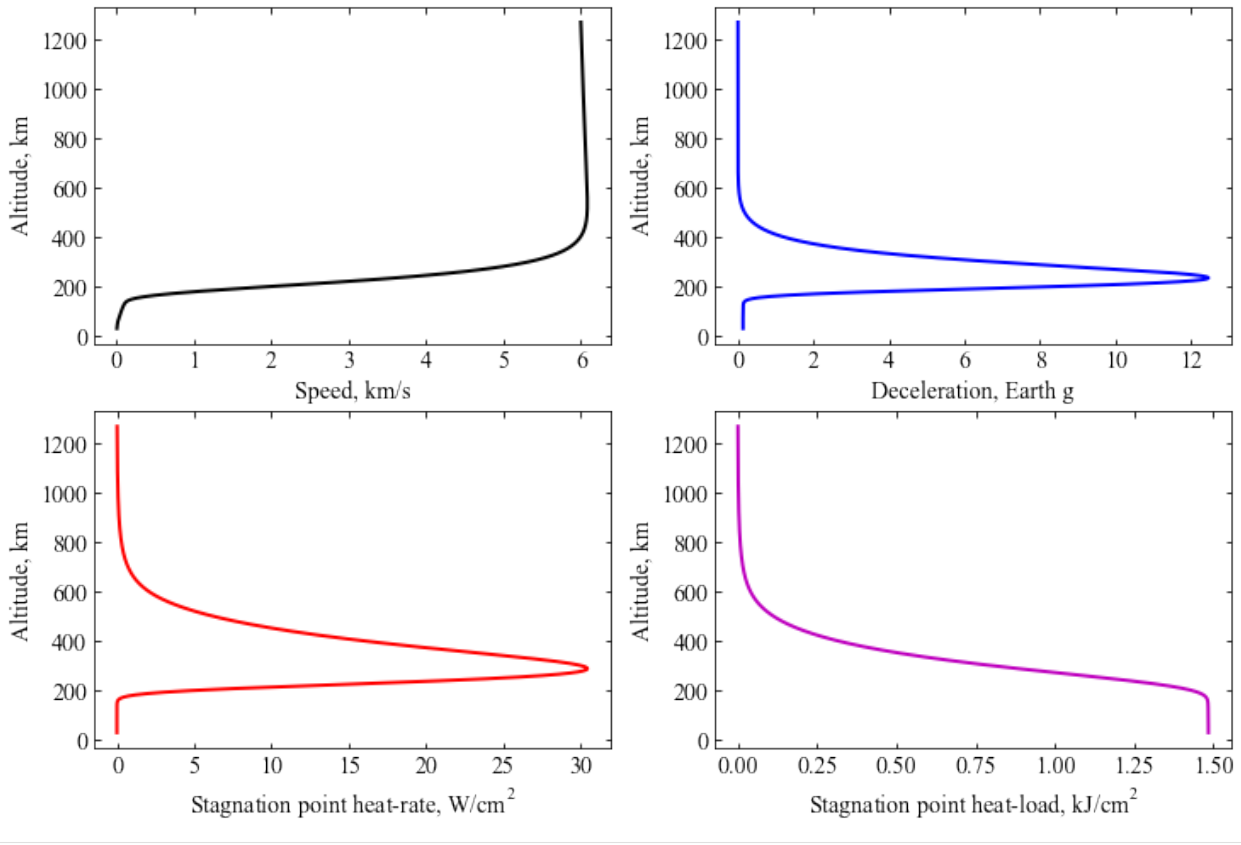
```
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/huygens-titan.png',bbox_inches='tight')
plt.savefig('../plots/huygens-titan.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/huygens-titan.eps', dpi=300,bbox_inches='tight')

plt.show()
```



Radiative heating is neglected in these calculations.

4.31 Example - 31 - Atm. Reentry Demonstrator - Earth

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the ESA Atmospheric Reentry Demonstrator. https://en.wikipedia.org/wiki/Atmospheric_Reentry_Demonstrator

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("EARTH")
planet.h_skip = 120.0E3
planet.loadAtmosphereModel('../atmdata/Earth/earth-gram-avg.dat', 0 , 1 , 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('ARD', 2715.0 , 403.0, 0.00, 6.15, 0.0, 3.36, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(120.0,0.0,0.0,7.54,0.0,-2.6,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (30*60.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
```

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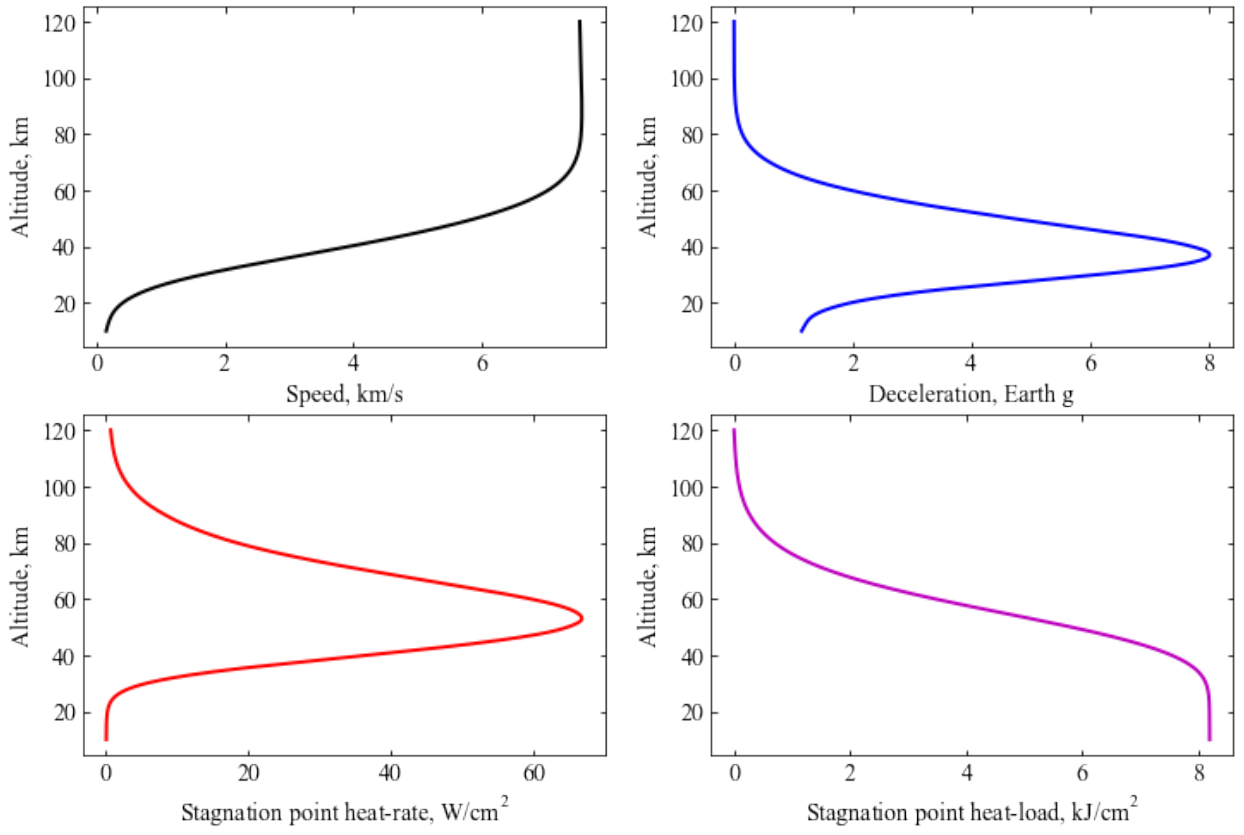
```
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/ard-earth.png',bbox_inches='tight')
plt.savefig('../plots/ard-earth.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/ard-earth.eps', dpi=300,bbox_inches='tight')

plt.show()
```



4.32 Example - 32 - Deep Space 2 - Mars

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Deep Space 2 aeroshells. https://en.wikipedia.org/wiki/Deep_Space_2

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("MARS")
planet.h_skip = 128.0E3
planet.loadAtmosphereModel('../atmdata/Mars/mars-gram-avg.dat', 0 , 1 , 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('DS2', 3.67, 36.2, 0.00, 0.096, 0.0, 0.0875, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(128.0,0.0,0.0,6.90,0.0,-13.25,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (30*60.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
```

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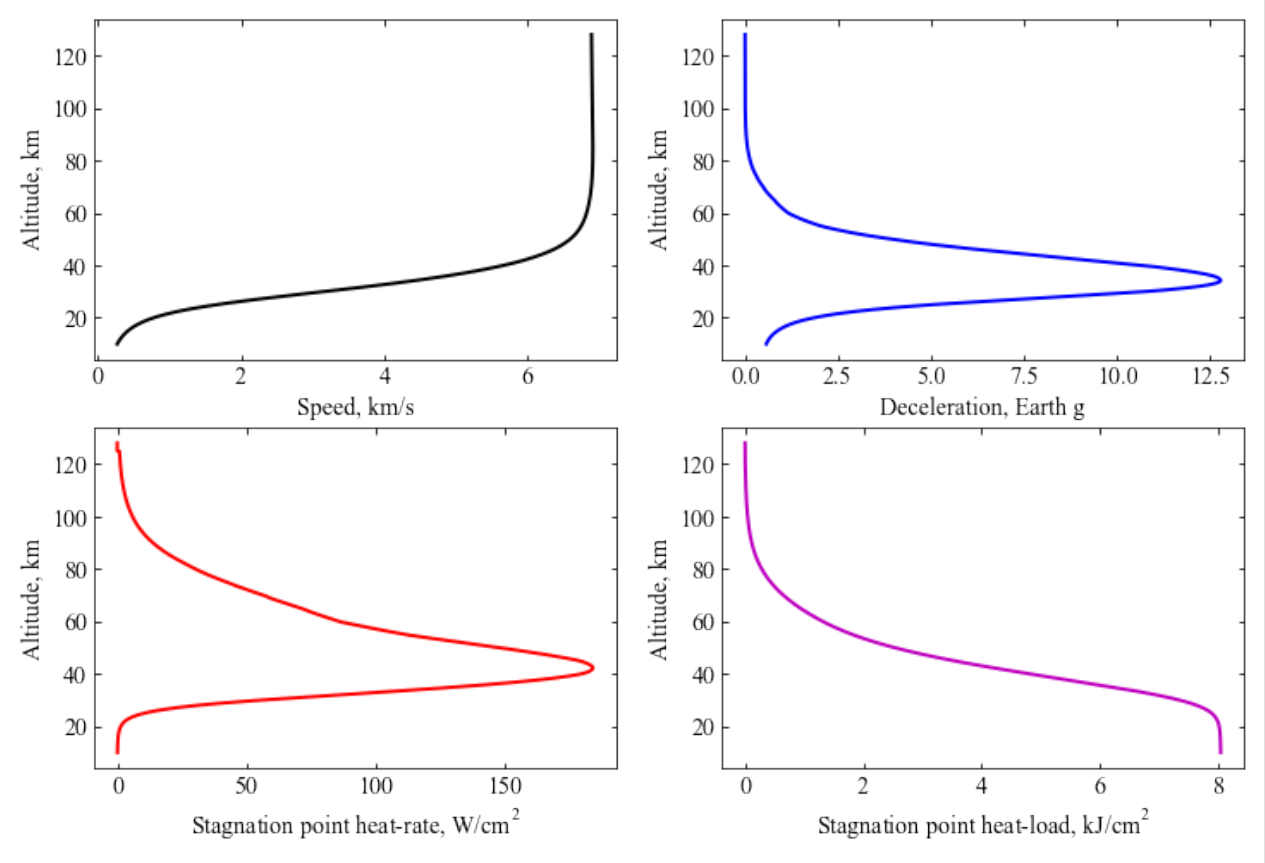
```
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/deep-space-2-mars.png',bbox_inches='tight')
plt.savefig('../plots/deep-space-2-mars.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/deep-space-2-mars.eps', dpi=300,bbox_inches='tight')

plt.show()
```



[ ]:

4.33 Example - 33 - Stardust - Earth

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Stardust sample return aeroshell. https://en.wikipedia.org/wiki/Stardust_(spacecraft)

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("EARTH")
planet.h_skip = 125.0E3
planet.loadAtmosphereModel('../atmdata/Earth/earth-gram-avg.dat', 0 , 1 , 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('Stardust', 45.8, 60.0, 0.00, 0.52, 0.0, 0.23, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(125.0,0.0,0.0,12.6,0.0,-8.2,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (30*60.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
```

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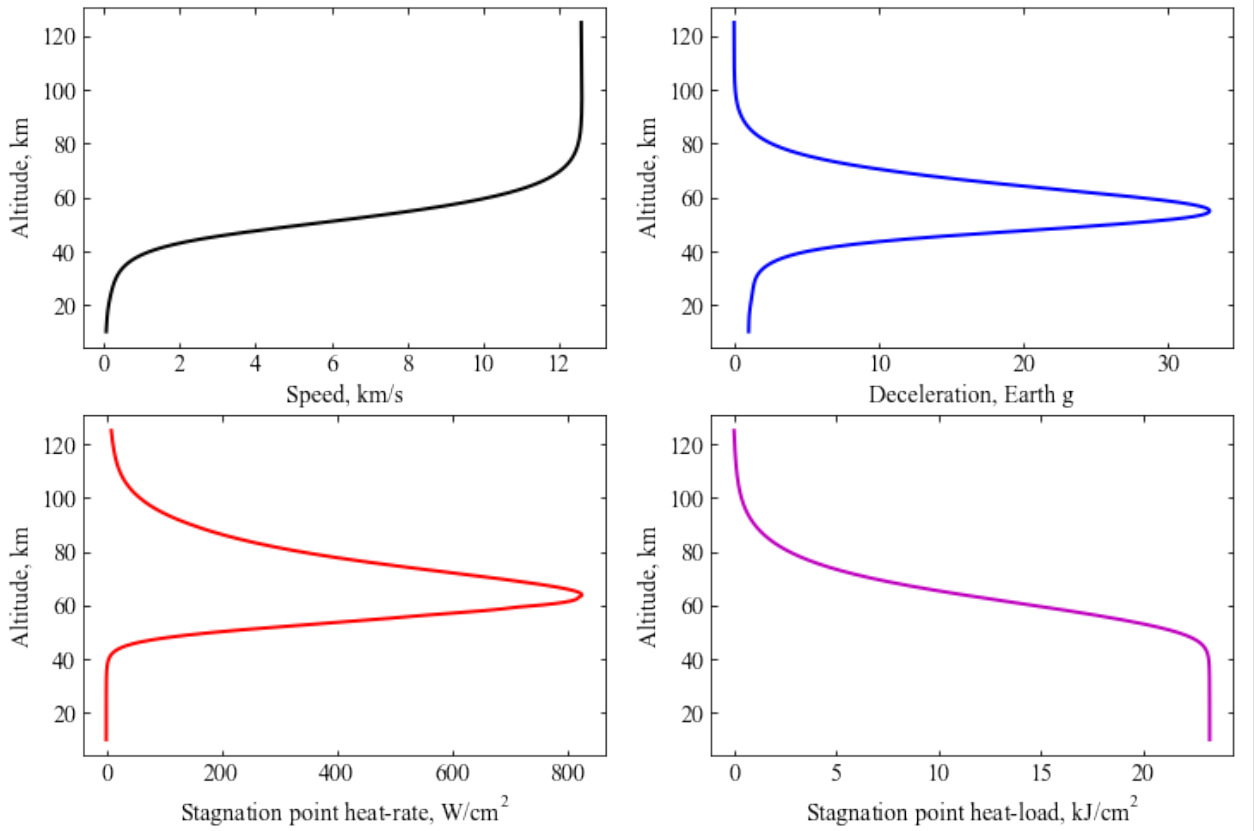
```
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/stardust-earth.png',bbox_inches='tight')
plt.savefig('../plots/stardust-earth.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/stardust-earth.eps', dpi=300,bbox_inches='tight')

plt.show()
```



4.34 Example - 34 - Genesis - Earth

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Genesis sample return aeroshell. https://en.wikipedia.org/wiki/Genesis_(spacecraft)

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("EARTH")
planet.h_skip = 125.0E3
planet.loadAtmosphereModel('../atmdata/Earth/earth-gram-avg.dat', 0 , 1 , 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('Genesis', 210, 80, 0.00, 1.78, 0.0, 0.43, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(125.0,0.0,0.0,10.8,0.0,-8.0,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (30*60.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
```

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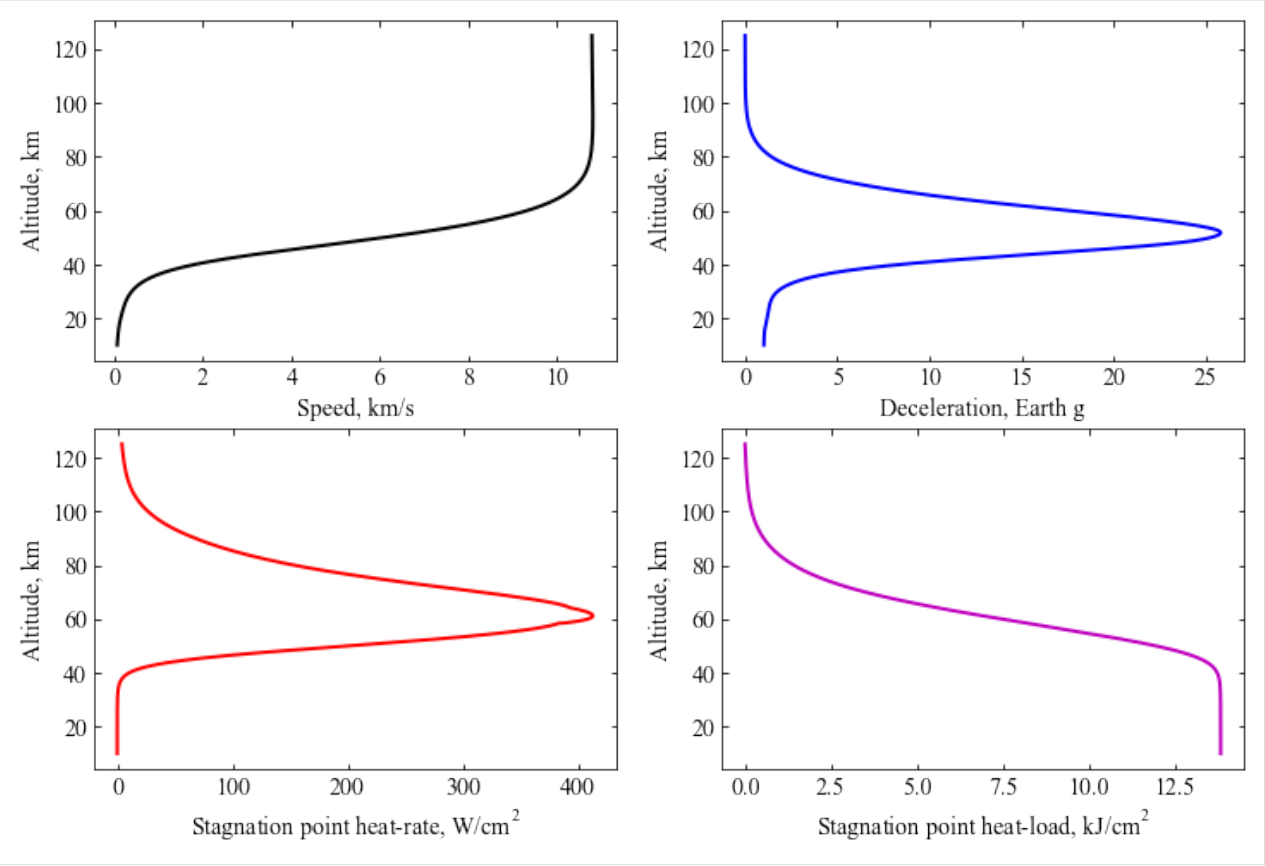
```
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/genesis-earth.png',bbox_inches='tight')
plt.savefig('../plots/genesis-earth.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/genesis-earth.eps', dpi=300,bbox_inches='tight')

plt.show()
```



4.35 Example - 35 - Hayabusa - Earth

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Hayabusa sample return aeroshell. https://en.wikipedia.org/wiki/

Hayabusa

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("EARTH")
planet.h_skip = 120.0E3
planet.loadAtmosphereModel('../atmdata/Earth/earth-gram-avg.dat', 0 , 1 , 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('Hayabusa', 16.27, 114.0, 0.00, 0.128, 0.0, 0.202, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(120.0,0.0,0.0,11.3,0.0,-13.8,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (30*60.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
```

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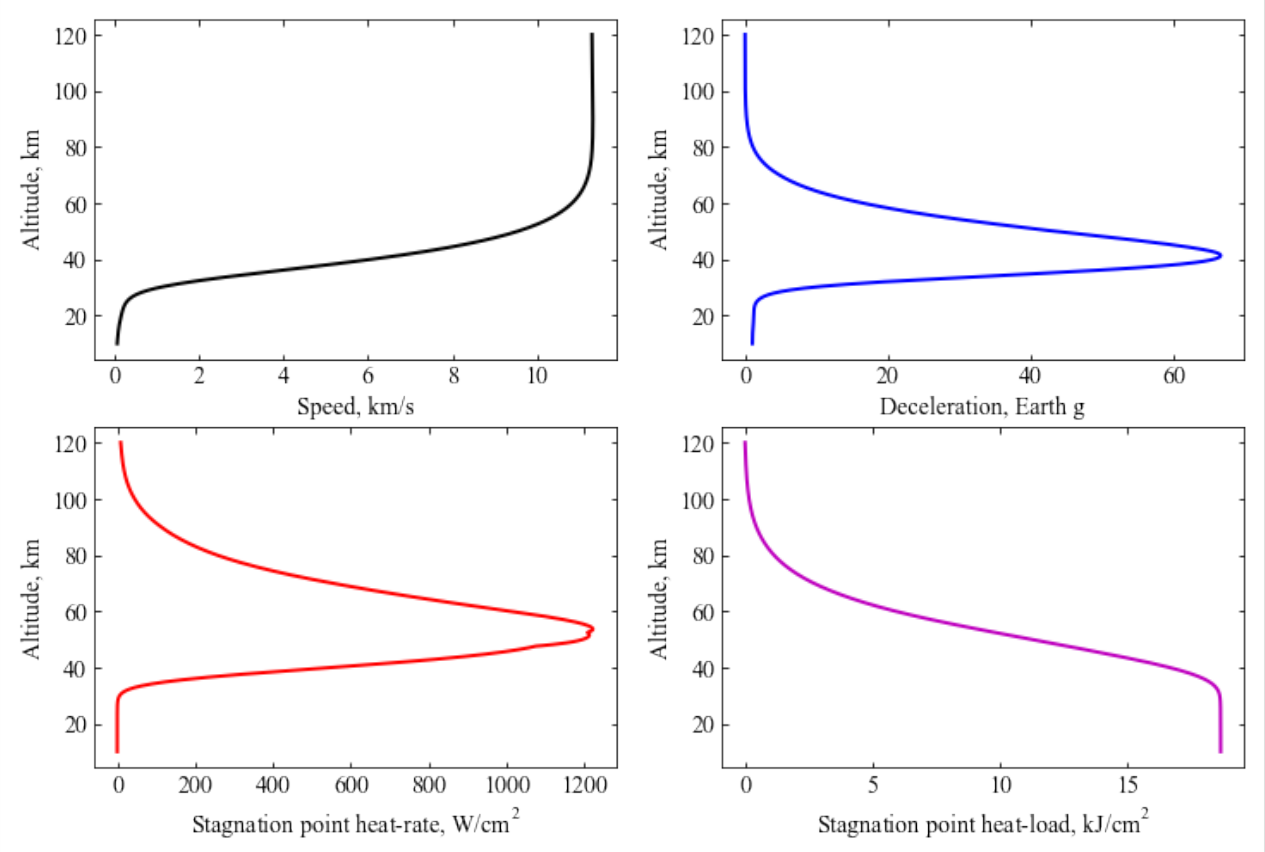
```
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/hayabusa-earth.png',bbox_inches='tight')
plt.savefig('../plots/hayabusa-earth.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/hayabusa-earth.eps', dpi=300,bbox_inches='tight')

plt.show()
```



4.36 Example - 36 - Beagle-2 - Mars

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Beagle 2 aeroshell https://en.wikipedia.org/wiki/Beagle_2

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("MARS")
planet.h_skip = 120.0E3
planet.loadAtmosphereModel('../atmdata/Mars/mars-gram-avg.dat', 0 , 1 , 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('Beagle-2', 68.46, 70.0, 0.00, 0.67, 0.0, 0.417, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(120.0,0.0,0.0,5.40,0.0,-15.8,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (30*60.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
```

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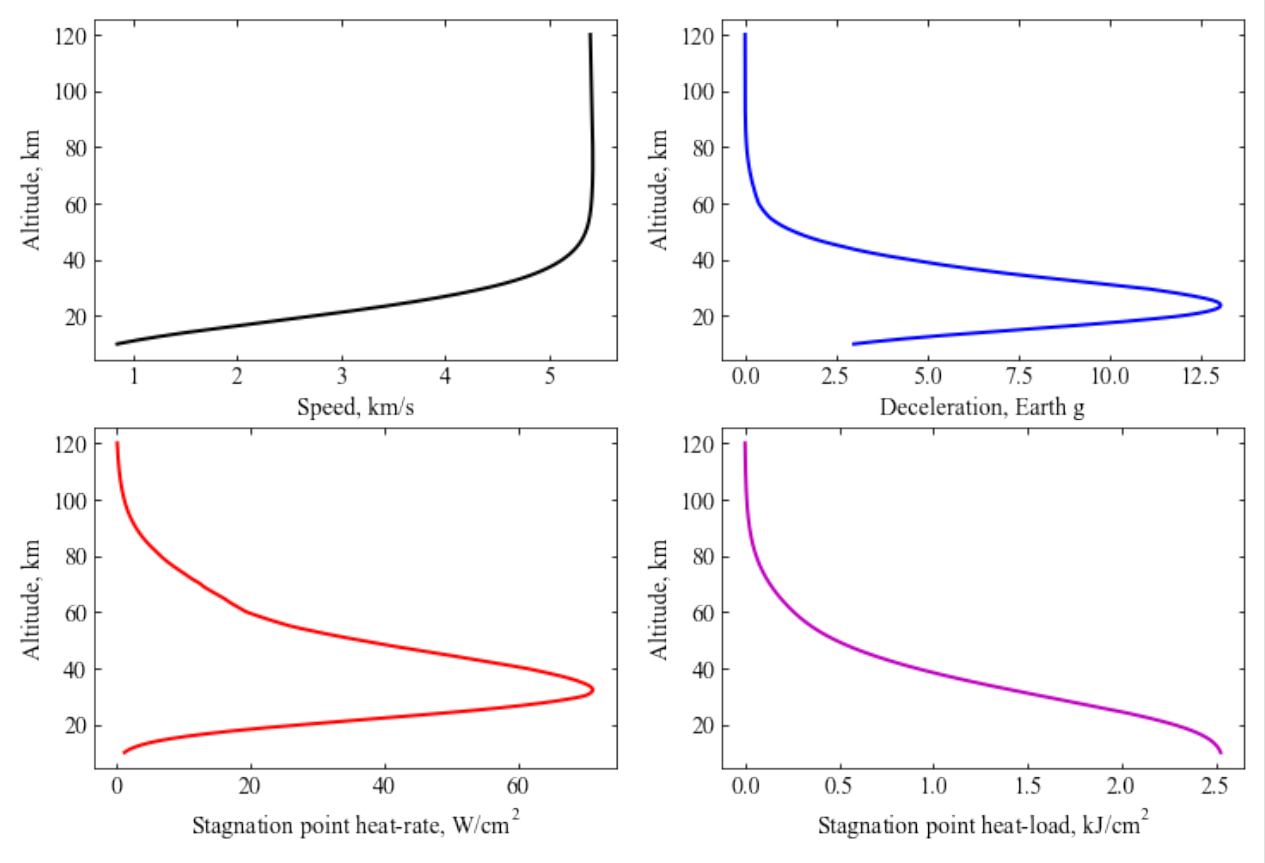
```
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/beagle-2-mars.png',bbox_inches='tight')
plt.savefig('../plots/beagle-2-mars.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/beagle-2-mars.eps', dpi=300,bbox_inches='tight')

plt.show()
```



4.37 Example - 37 - Opportunity - Mars

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Opportunity aeroshell (MER-B) https://en.wikipedia.org/wiki/Opportunity_(rover)

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("MARS")
planet.h_skip = 125.0E3
planet.loadAtmosphereModel('../atmdata/Mars/mars-gram-avg.dat', 0 , 1 , 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('Opportunity', 836, 88.0, 0.00, 5.52, 0.0, 0.66, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(125.0,0.0,0.0,5.55,0.0,-11.5,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (30*60.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
```

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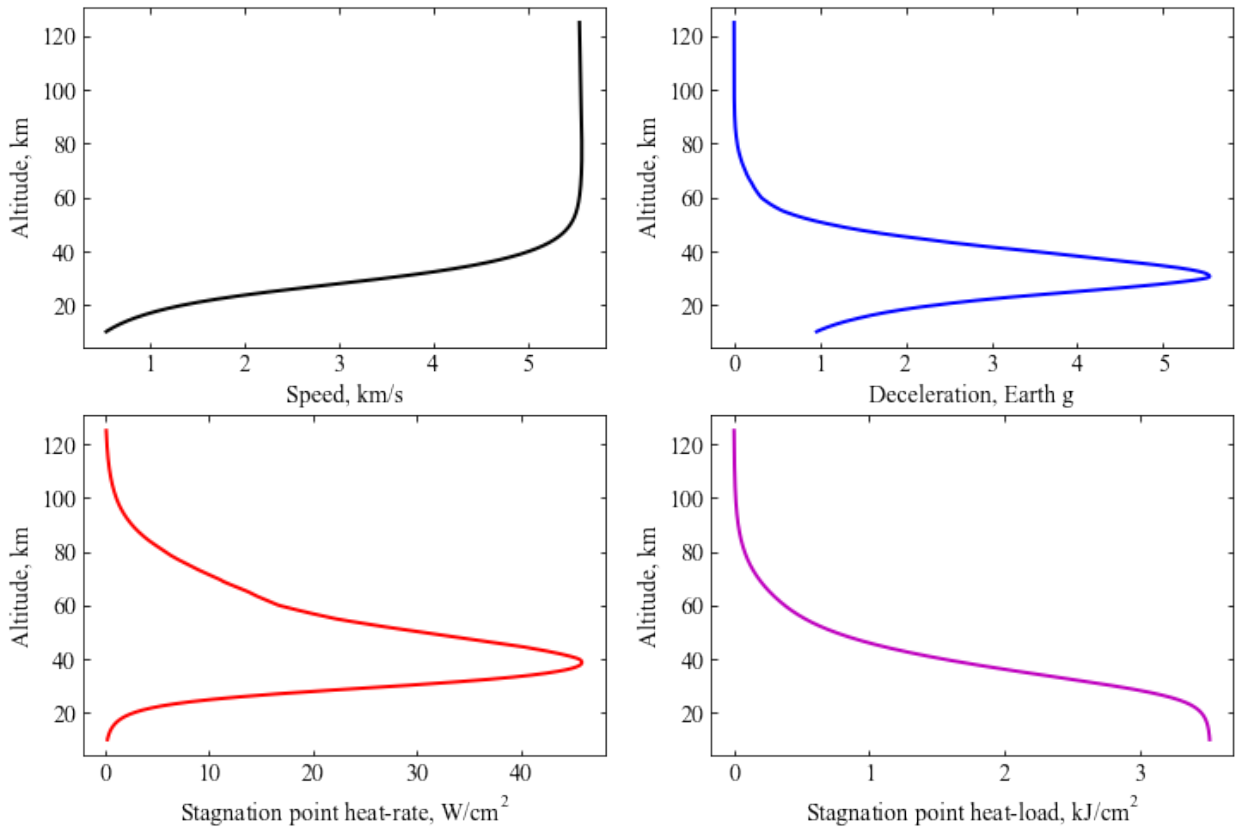
```
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/opportunity-mars.png',bbox_inches='tight')
plt.savefig('../plots/opportunity-mars.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/opportunity-mars.eps', dpi=300,bbox_inches='tight')

plt.show()
```



4.38 Example - 38 - Curiosity - Mars

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Curiosity aeroshell (MSL) https://en.wikipedia.org/wiki/Curiosity_(rover)

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("MARS")
planet.h_skip = 126.0E3
```

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```
planet.h_trap = 2.0E3
planet.loadAtmosphereModel('../atmdata/Mars/mars-gram-avg.dat', 0 , 1 , 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('Curiosity', 3257.0, 146.0, 0.00, np.pi*4.5**2.0, 0.0, 1.125, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(125.0,0.0,0.0,6.08,0.0,-15.48,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (30*60.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
```

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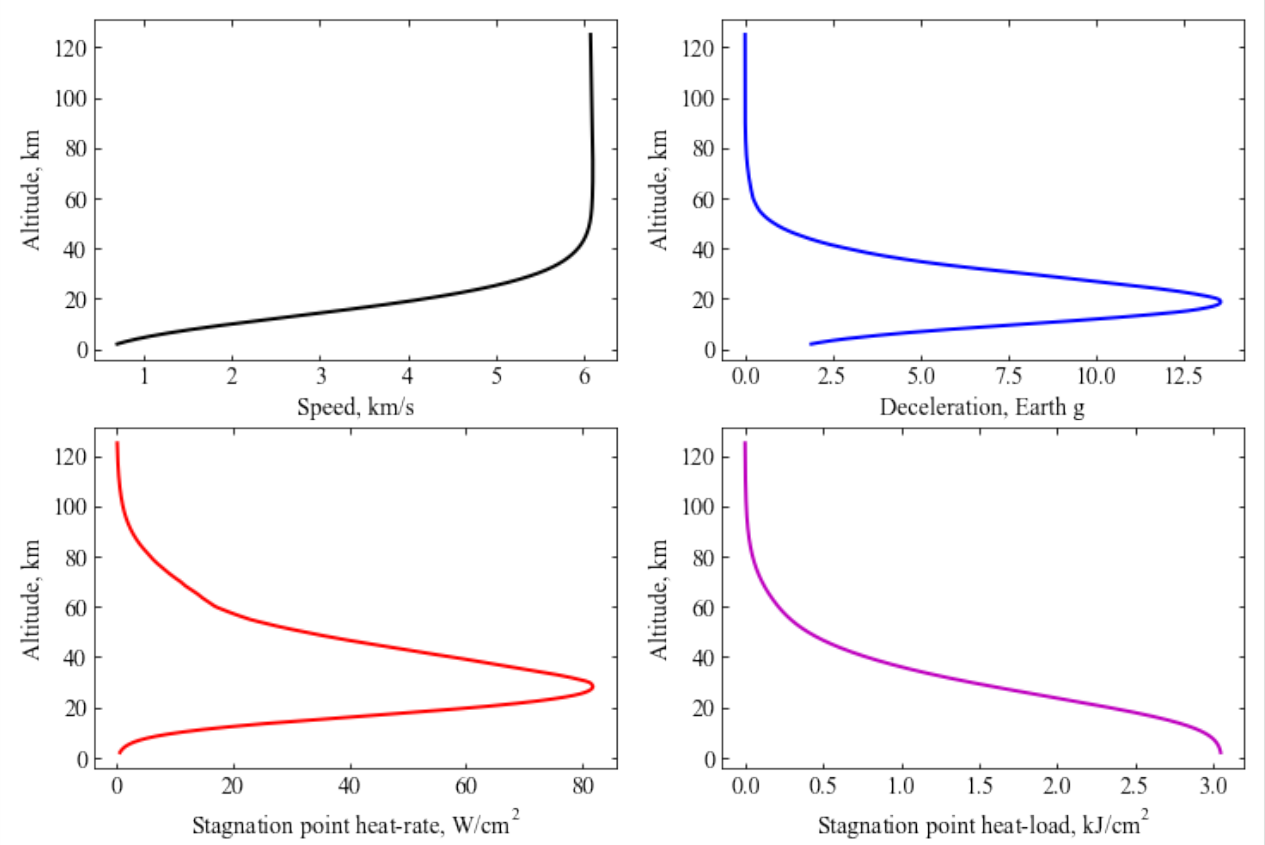
```
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/curiosity-mars.png',bbox_inches='tight')
plt.savefig('../plots/curiosity-mars.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/curiosity-mars.eps', dpi=300,bbox_inches='tight')

plt.show()
```



4.39 Example - 39 - Oceanus - Saturn (Concept)

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Saturn entry probe which was part of the Oceanus mission study https://doi.org/10.1016/j.asr.2017.02.012

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("SATURN")
planet.h_skip = 1200.0E3
planet.h_trap = -100.0E3
planet.loadAtmosphereModel('../atmdata/Saturn/saturn-nominal.dat', 0 , 1 , 2, 3,␣
↪heightInKmFlag=True)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('Oceanus-Saturn-Probe', 140.0, 127.0, 0.0, np.pi*1.0**2.0*0.25, 0.0,␣
↪0.18, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(1200.0,0.0,0.0,28.46,0.0,-11.40,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (100*60.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)
```

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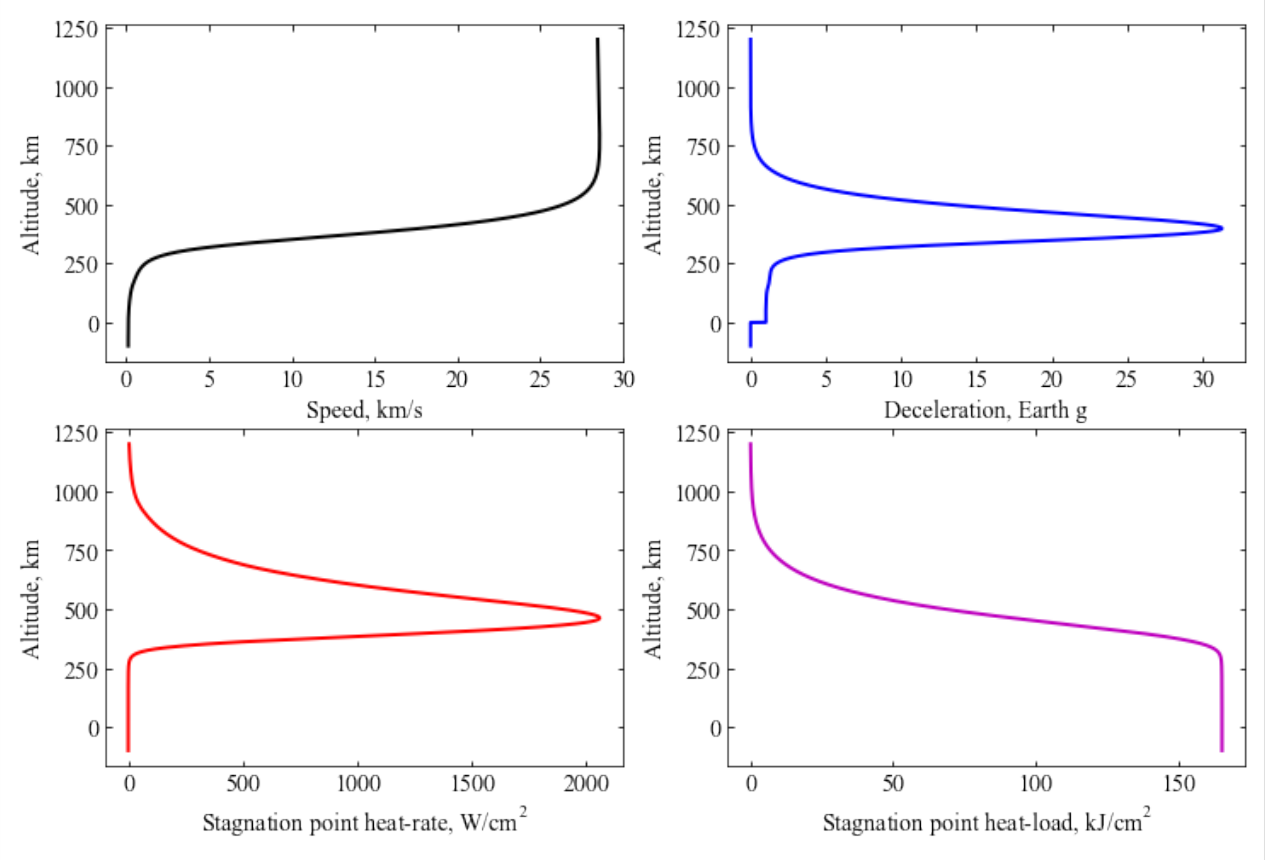
```
plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/oceanus-saturn-probe.png',bbox_inches='tight')
plt.savefig('../plots/oceanus-saturn-probe.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/oceanus-saturn-probe.eps', dpi=300,bbox_inches='tight')

plt.show()
```



The max. heat rate is smaller than reported in the paper by about a factor of 3. The difference is attributed to different heating correlations used.

4.40 Example - 40 - Oceanus - Uranus (Concept)

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Uranus entry probe which was part of the Oceanus mission study https://doi.org/10.1016/j.asr.2017.02.012

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("URANUS")
planet.h_skip = 1000.0E3
planet.h_trap = -100.0E3
planet.loadAtmosphereModel('../atmdata/Uranus/uranus-ames.dat', 0 , 1 , 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('Oceanus-Uranus-Probe', 120.0, 170.0, 0.0, np.pi*0.8**2.0*0.25, 0.0,␣
↪0.28, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(1000.0,0.0,0.0,21.47,0.0,-31.5,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (100*60.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
```

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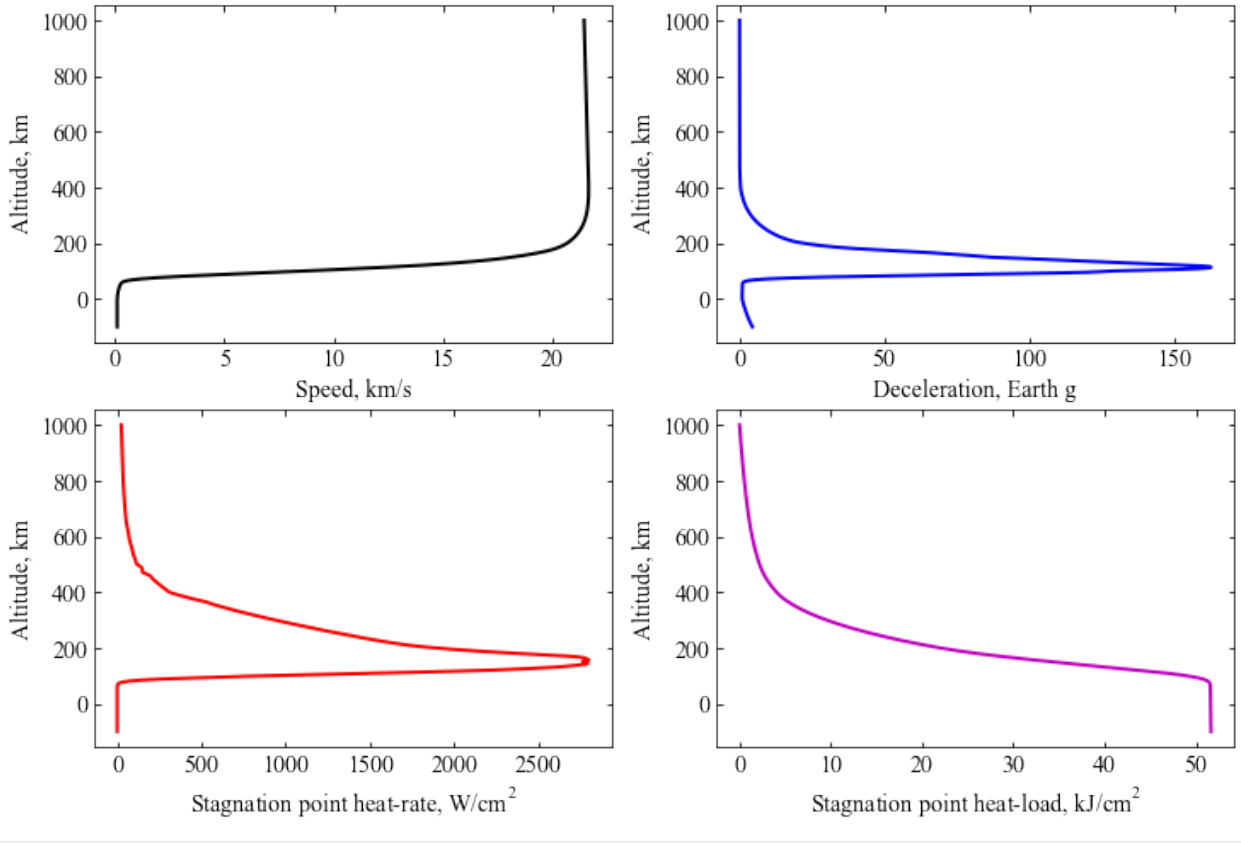
```
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/oceanus-uranus-probe.png',bbox_inches='tight')
plt.savefig('../plots/oceanus-uranus-probe.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/oceanus-uranus-probe.eps', dpi=300,bbox_inches='tight')

plt.show()
```



4.41 Example - 41 - Hera - Saturn (Concept)

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Saturn entry probe which was part of the Hera mission concept study. http://dx.doi.org/10.1016/j.pss.2015.06.020

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("SATURN")
planet.h_skip = 1000.0E3
planet.h_trap = -100.0E3
planet.loadAtmosphereModel('../atmdata/Saturn/saturn-nominal.dat', 0 , 1 , 2, 3,␣
↪heightInKmFlag=True)
```

[4]:
```
# Set up the vehicle
vehicle1=Vehicle('Hera-Saturn-Probe-steep', 220, 269, 0.0, np.pi*1.0**2.0*0.25, 0.0,␣
↪0.18, planet)
vehicle2=Vehicle('Hera-Saturn-Probe-shallow', 220, 269, 0.0, np.pi*1.0**2.0*0.25, 0.0,
↪ 0.18, planet)
```

[5]:
```
# Set up entry parameters
vehicle1.setInitialState(1000.0,0.0,0.0,26.3,0.0,-22.0,0.0,0.0)
vehicle2.setInitialState(1000.0,0.0,0.0,26.3,0.0,-9.0,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle1.setSolverParams(1E-6)
vehicle2.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle1.propogateEntry (100*60.0,0.1,0.0)
vehicle2.propogateEntry (100*60.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle1.v_kmsc, vehicle1.h_kmc, 'k-', linewidth=2.0, label='Steep')
plt.plot(vehicle2.v_kmsc, vehicle2.h_kmc, 'k--', linewidth=2.0, label='Shallow')
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
plt.legend(loc='upper left', fontsize=12, frameon=False)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle1.acc_net_g, vehicle1.h_kmc, 'b-', linewidth=2.0, label='Steep')
plt.plot(vehicle2.acc_net_g, vehicle2.h_kmc, 'b--', linewidth=2.0, label='Shallow')
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
plt.legend(loc='upper right', fontsize=12, frameon=False)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
```

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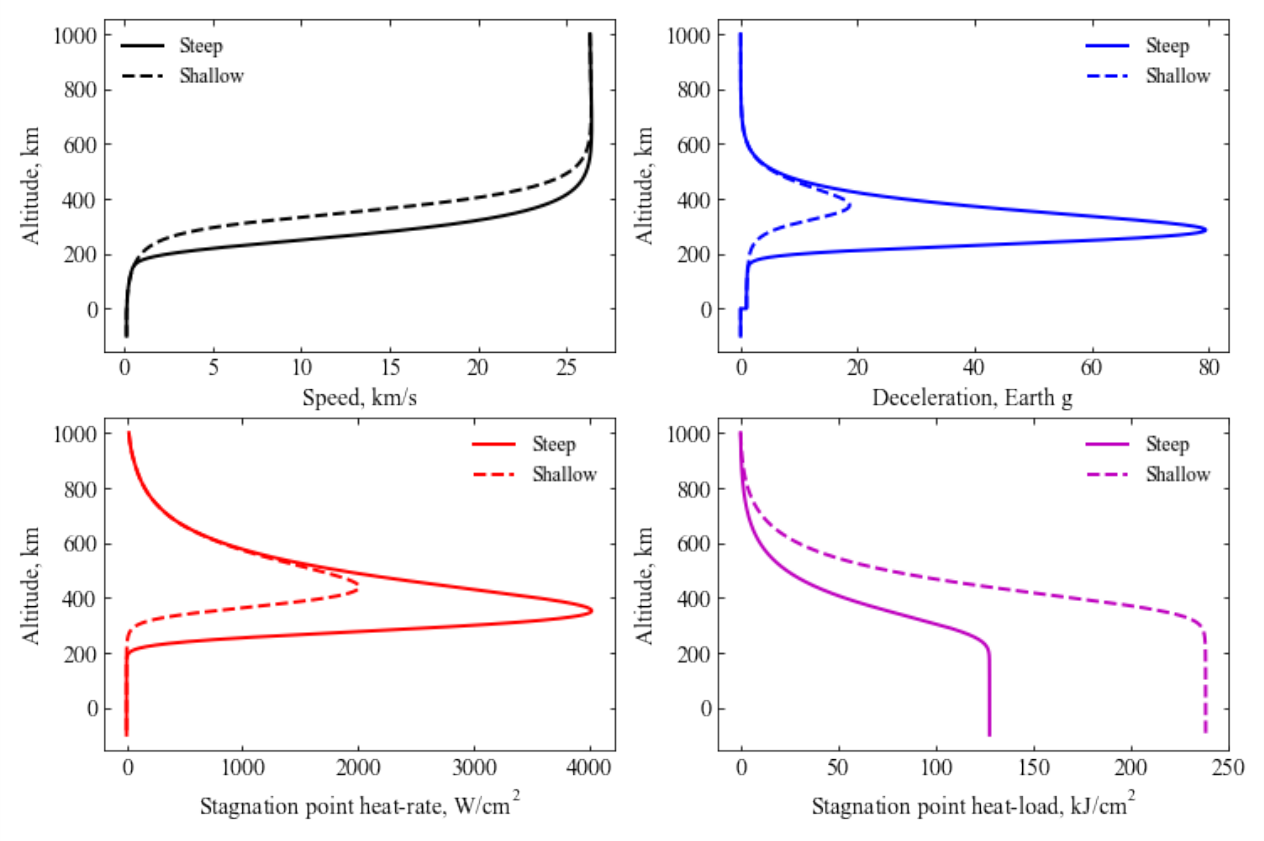
```
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle1.q_stag_total, vehicle1.h_kmc,'r-', linewidth=2.0, label='Steep')
plt.plot(vehicle2.q_stag_total, vehicle2.h_kmc,'r--', linewidth=2.0, label='Shallow')
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
plt.legend(loc='upper right', fontsize=12, frameon=False)
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle1.heatload/1.0E3, vehicle1.h_kmc, 'm-', linewidth=2.0, label='Steep')
plt.plot(vehicle2.heatload/1.0E3, vehicle2.h_kmc, 'm--', linewidth=2.0, label='Shallow
↪')
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
plt.legend(loc='upper right', fontsize=12, frameon=False)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/hera-saturn-probe.png',bbox_inches='tight')
plt.savefig('../plots/hera-saturn-probe.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/hera-saturn-probe.eps', dpi=300,bbox_inches='tight')

plt.show()
```



4.42 Example - 42 - Dragonfly - Titan (Planned)

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Dragonfly probe at Titan. https://en.wikipedia.org/wiki/Dragonfly_(spacecraft)

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("TITAN")
planet.h_skip = 1270.0E3
planet.h_trap =    0.0E3
planet.loadAtmosphereModel('../atmdata/Titan/titan-gram-avg.dat', 0 , 1 , 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle1=Vehicle('Dragonfly', 1000.0, 140.0, 0.0, np.pi*3.7**2.0*0.25, 0.0, 0.43,␣
↪planet)
```

[5]:
```
# Set up entry parameters
vehicle1.setInitialState(1270.0,0.0,0.0,7.3,0.0,-49.7,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle1.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle1.propogateEntry (120*60.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle1.v_kmsc, vehicle1.h_kmc, 'k-', linewidth=2.0)

plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle1.acc_net_g, vehicle1.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle1.q_stag_total, vehicle1.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle1.heatload/1.0E3, vehicle1.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
```

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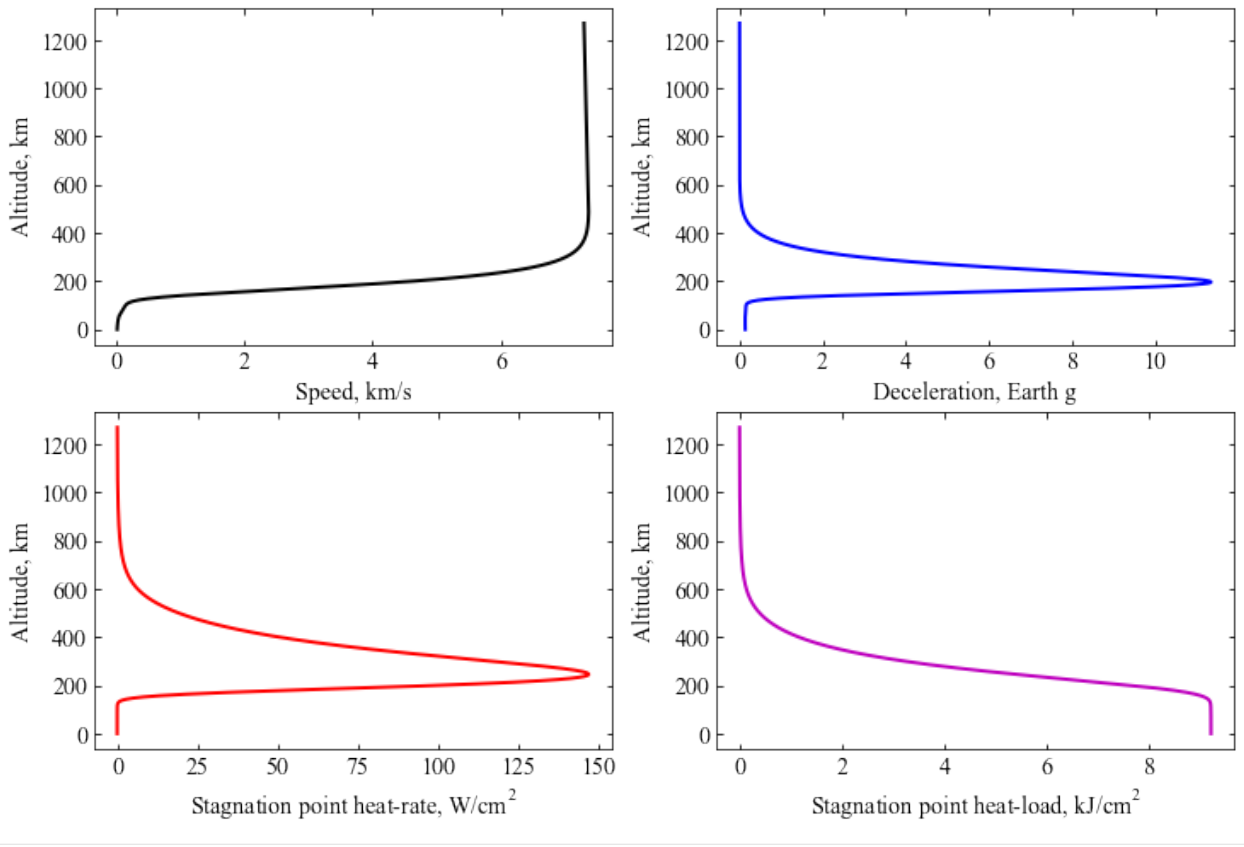
```
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/dragnofly-titan.png',bbox_inches='tight')
plt.savefig('../plots/dragnofly-titan.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/dragnofly-titan.eps', dpi=300,bbox_inches='tight')

plt.show()
```



Vehicle geometry and ballistic coefficient data is not publicly available in the literature. Hence, results are only approximate.

4.43 Example - 43 - Ice Giant Pre-Decadal - Uranus Probe (Concept)

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Uranus entry probe described in Sec. A.5.3 of the Ice Giants Pre-Decadal Mission Study. https://www.lpi.usra.edu/icegiants/mission_study/Full-Report.pdf

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("URANUS")
planet.h_skip = 1015.0E3
planet.h_trap = -100.0E3
planet.loadAtmosphereModel('../atmdata/Uranus/uranus-ames.dat', 0 , 1 , 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle1=Vehicle('igpd-uranus', 325.0, 205.0, 0.0, np.pi*1.2**2.0*0.25, 0.0, 0.20,␣
↪planet)
```

[5]:
```
# Set up entry parameters
vehicle1.setInitialState(1015.0,0.0,0.0,23.10,0.0,-30.0,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle1.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle1.propogateEntry (120*60.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle1.v_kmsc, vehicle1.h_kmc, 'k-', linewidth=2.0)

plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle1.acc_net_g, vehicle1.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle1.q_stag_total, vehicle1.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
```

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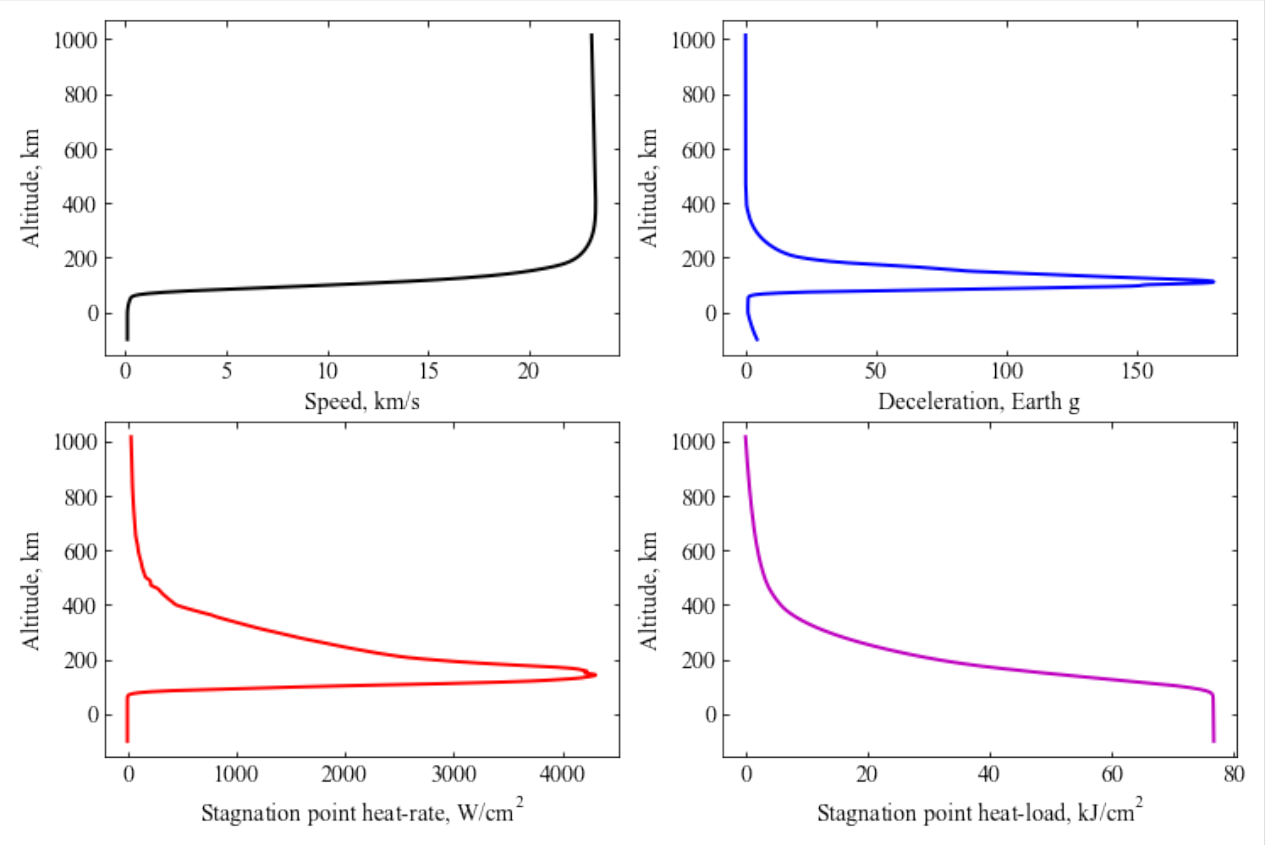
```
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle1.heatload/1.0E3, vehicle1.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/igpd-uranus.png',bbox_inches='tight')
plt.savefig('../plots/igpd-uranus.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/igpd-uranus.eps', dpi=300,bbox_inches='tight')

plt.show()
```



Discrepancies are attributed to initial state being not properly converted to planet-relative frame, and different heating relations used in the studies.

4.44 Example - 44 - Ice Giant Pre-Decadal - Neptune Probe (Concept)

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Neptune entry probe described in Sec. A.5.3 of the Ice Giants Pre-Decadal Mission Study. https://www.lpi.usra.edu/icegiants/mission_study/Full-Report.pdf

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("NEPTUNE")
planet.h_skip = 1000.0E3
planet.h_trap = -100.0E3
planet.loadAtmosphereModel('../atmdata/Neptune/neptune-gram-avg.dat', 0 , 7 ,6, 5 ,␣
↪heightInKmFlag=True)
```

[4]:
```
# Set up the vehicle
vehicle1=Vehicle('igpd-neptune', 325.0, 205.0, 0.0, np.pi*1.2**2.0*0.25, 0.0, 0.20,␣
↪planet)
```

[5]:
```
# Set up entry parameters
vehicle1.setInitialState(1000.0,0.0,0.0,25.73,0.0,-20.0,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle1.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle1.propogateEntry (120.0*60.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle1.v_kmsc, vehicle1.h_kmc, 'k-', linewidth=2.0)

plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle1.acc_net_g, vehicle1.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
```

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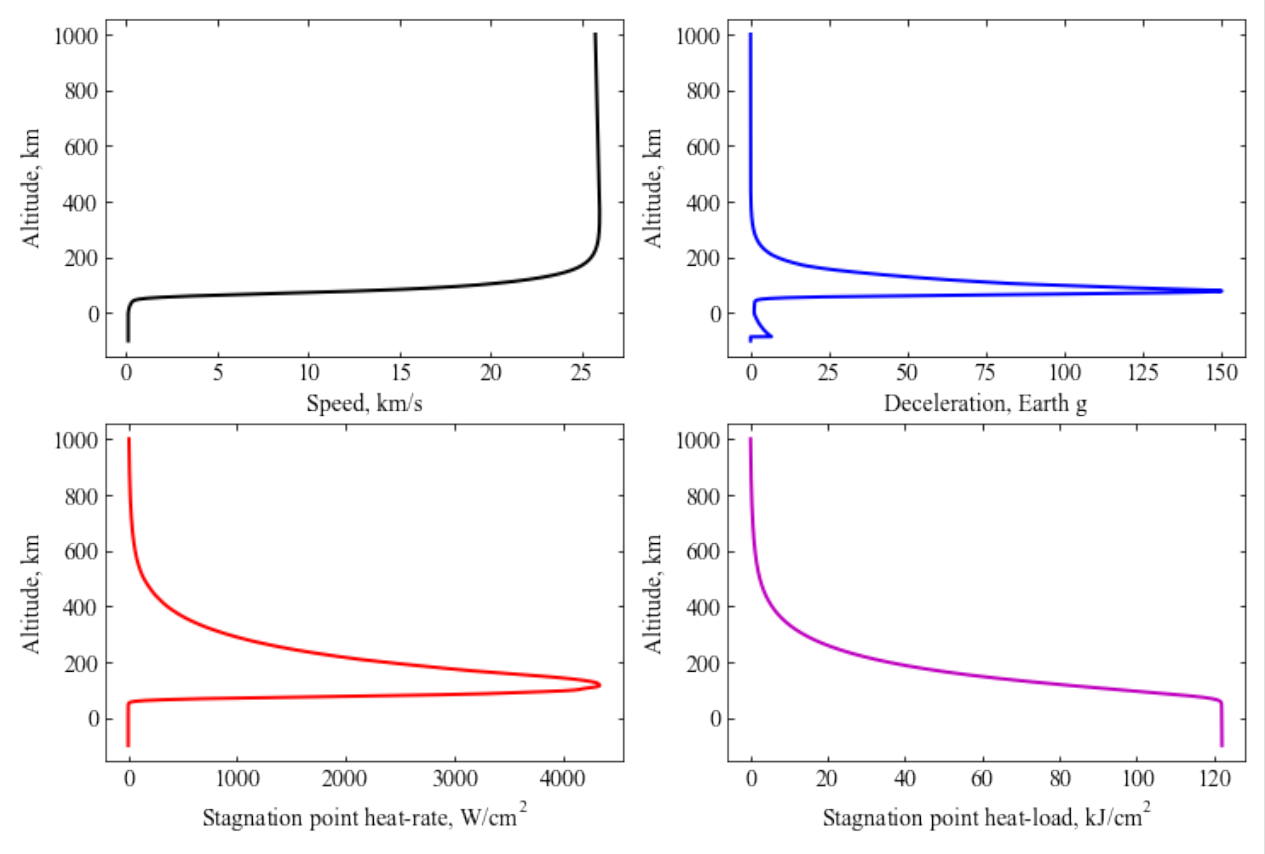
```
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle1.q_stag_total, vehicle1.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle1.heatload/1.0E3, vehicle1.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/igpd-neptune.png',bbox_inches='tight')
plt.savefig('../plots/igpd-neptune.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/igpd-neptune.eps', dpi=300,bbox_inches='tight')

plt.show()
```



Discrepancies are attributed to initial state being not properly converted to planet-relative frame, and different heating relations used in the studies.

4.45 Example - 45 - ADEPT ViTaL - Venus (Concept)

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the ADEPT ViTaL entry system concept. https://ieeexplore.ieee.org/document/6497176

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("VENUS")
planet.h_skip = 200.0E3
planet.h_trap = 20.0E3
planet.loadAtmosphereModel('../atmdata/Venus/venus-gram-avg.dat', 0, 1, 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle1=Vehicle('adept-vital', 1620.0, 38.0, 0.0, np.pi*6.0**2.0*0.25, 0.0, 3.0,␣
↪planet)
```

[5]:
```
# Set up entry parameters
vehicle1.setInitialState(200.0,0.0,0.0,10.8,0.0,-8.25,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle1.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle1.propogateEntry (120.0*60.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle1.v_kmsc, vehicle1.h_kmc, 'k-', linewidth=2.0)

plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle1.acc_net_g, vehicle1.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle1.q_stag_total, vehicle1.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle1.heatload/1.0E3, vehicle1.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
```

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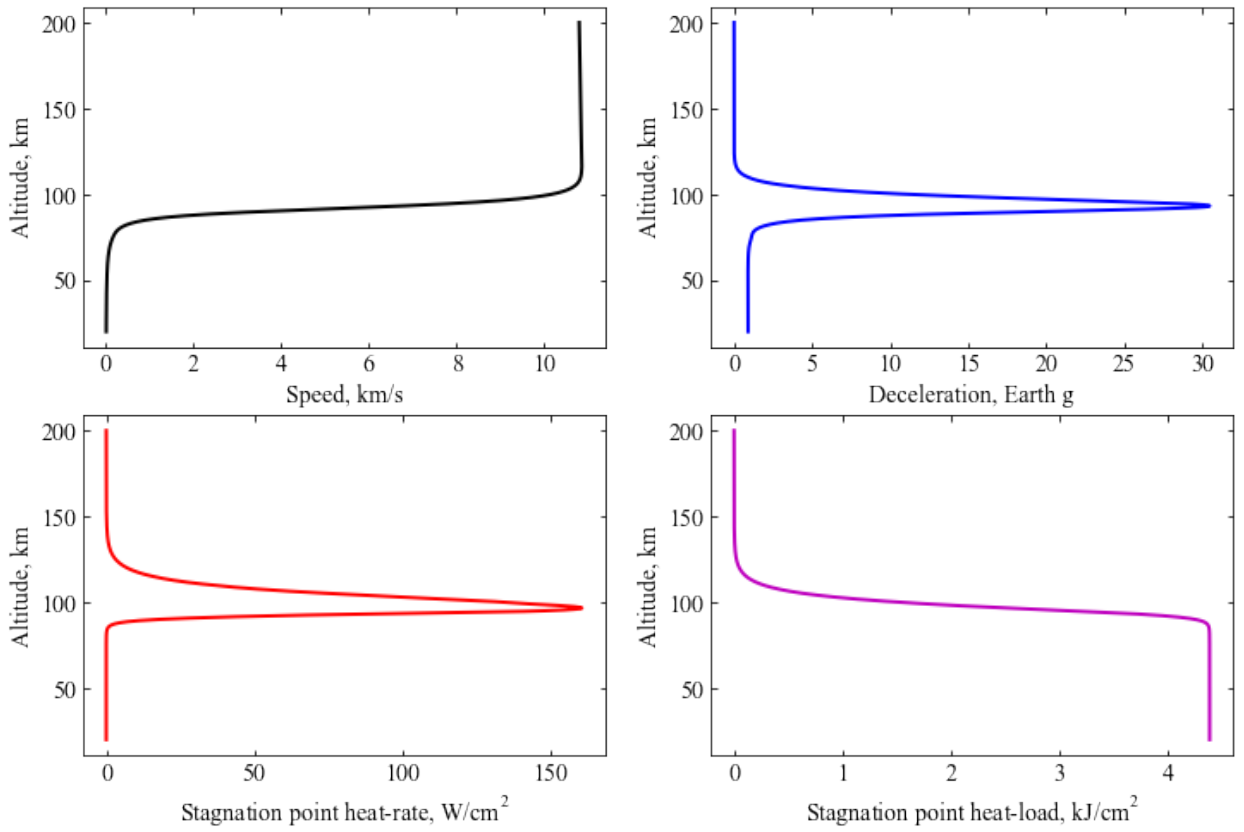
```
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/adept-vital-venus.png',bbox_inches='tight')
plt.savefig('../plots/adept-vital-venus.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/adept-vital-venus.eps', dpi=300,bbox_inches='tight')

plt.show()
```



[20]:
```
plt.figure(figsize=(10,6))
plt.plot(vehicle1.stag_pres_atm[0:1700], vehicle1.q_stag_total[0:1700], 'r-',␣
↪linewidth=2.0)
plt.xlabel('Stagnation pressure, atm',fontsize=14)
plt.ylabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/adept-vital-venus-thermal.png',bbox_inches='tight')
plt.savefig('../plots/adept-vital-venus.thermal.pdf', dpi=300,bbox_inches='tight')
```

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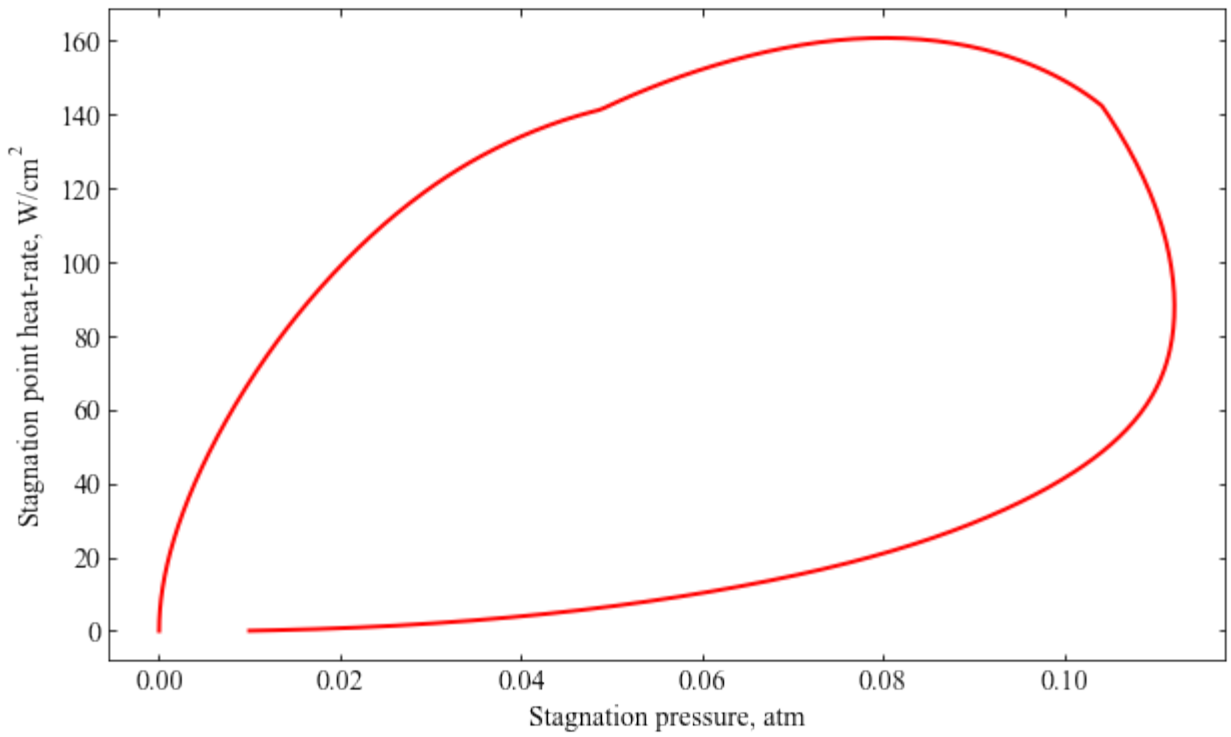
```
plt.savefig('../plots/adept-vital-venus.thermal.eps', dpi=300,bbox_inches='tight')

plt.show()
```



4.46 Example - 46 - Uranus Probe - Decadal Study - 2010 (Concept)

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Uranus entry probe studied during the 2010 Decadal Mission Concept Study (page 42). https://sites.nationalacademies.org/cs/groups/ssbsite/documents/webpage/ssb_059323.pdf

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("URANUS")
planet.h_skip = 500.0E3
planet.h_trap = -100.0E3
planet.loadAtmosphereModel('../atmdata/Uranus/uranus-ames.dat', 0, 1, 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle1=Vehicle('uranus-probe', 88.0, 190.0, 0.0, 0.46, 0.0, 0.19, planet)
```

[5]:
```
# Set up entry parameters
vehicle1.setInitialState(500.0,0.0,0.0,22.3,0.0,-68,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle1.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle1.propogateEntry (120.0*60.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle1.v_kmsc, vehicle1.h_kmc, 'k-', linewidth=2.0)

plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle1.acc_net_g, vehicle1.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle1.q_stag_total, vehicle1.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle1.heatload/1.0E3, vehicle1.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
```

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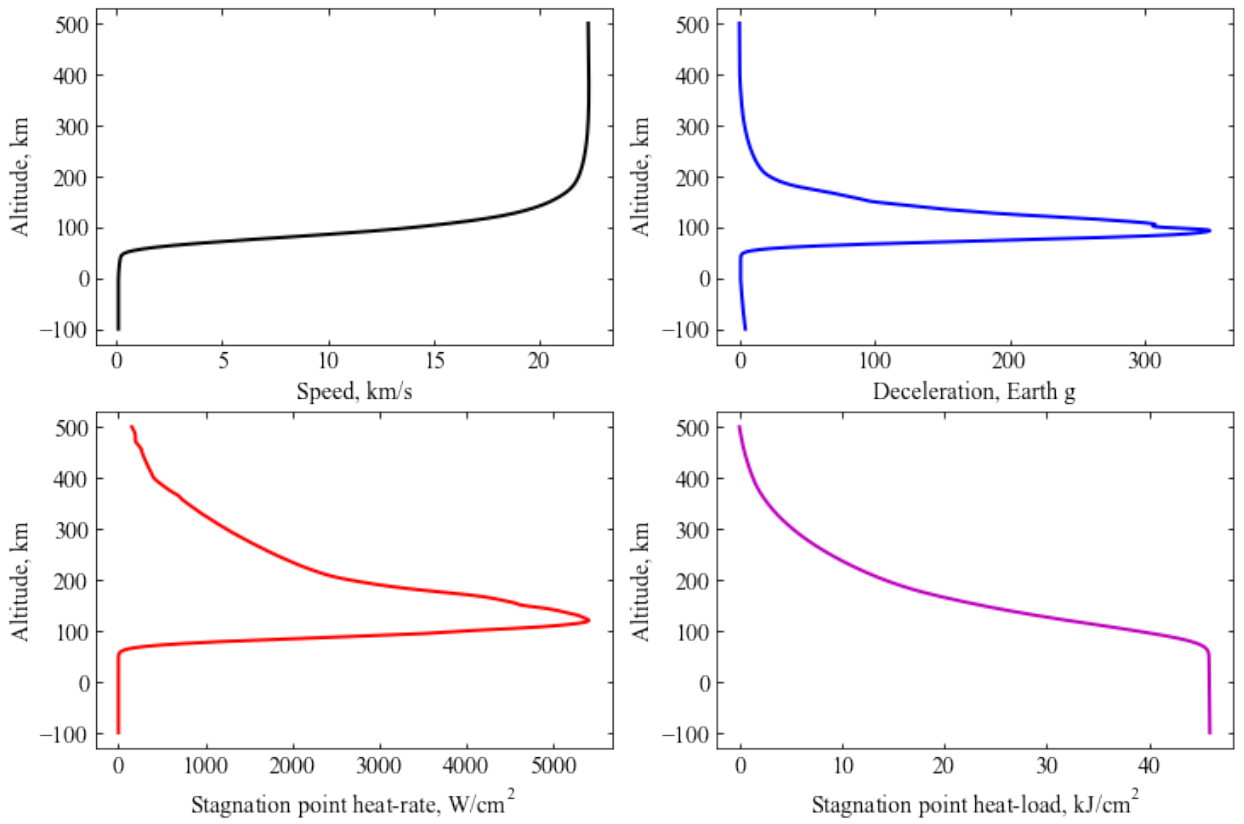
```
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/decadal-2010-uranus-probe.png',bbox_inches='tight')
plt.savefig('../plots/decadal-2010-uranus-probe.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/decadal-2010-uranus-probe.eps', dpi=300,bbox_inches='tight')

plt.show()
```



[10]:
```
plt.figure(figsize=(6,6))
plt.plot(vehicle1.stag_pres_atm[0:1700], vehicle1.q_stag_total[0:1700], 'r-',␣
↪linewidth=2.0)
plt.xlabel('Stagnation pressure, atm',fontsize=14)
plt.ylabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/decadal-2010-uranus-probe-thermal.png',bbox_inches='tight')
plt.savefig('../plots/decadal-2010-uranus-probe-thermal.pdf', dpi=300,bbox_inches=
↪'tight')
plt.savefig('../plots/decadal-2010-uranus-probe-thermal.eps', dpi=300,bbox_inches=
↪'tight')
```

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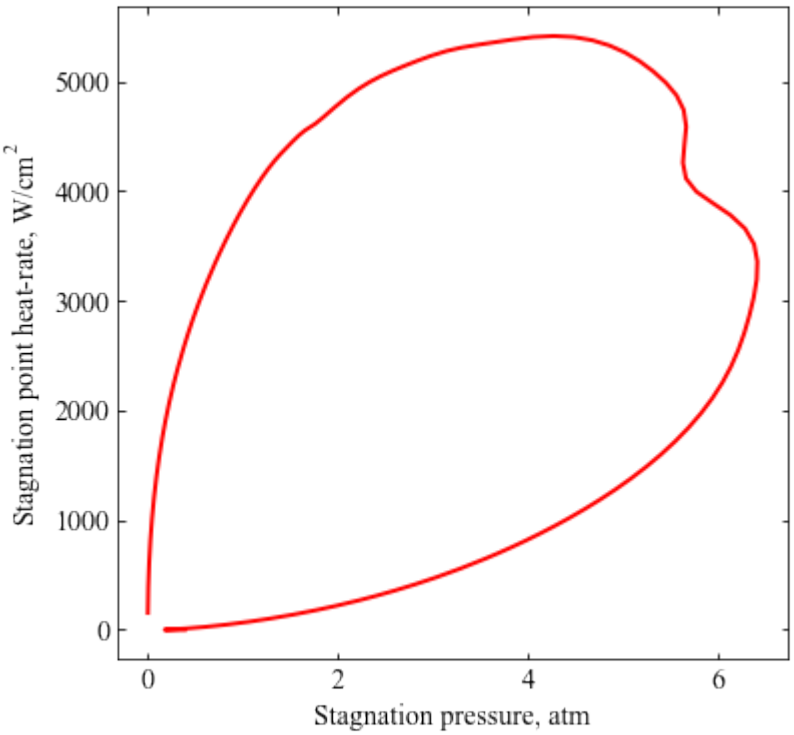
```
plt.show()
```



4.47 Example - 47 - Venus Flagship - Decadal Study - 2010 (Concept)

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Venus Flagship Mission, 2010 Decadal Mission Concept Study (page 159). https://vfm.jpl.nasa.gov/files/Venus+Flagship+Mission+Study+090501-compressed.pdf

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("VENUS")
planet.h_skip = 220.0E3
planet.h_trap = 10.0E3
planet.loadAtmosphereModel('../atmdata/Venus/venus-gram-avg.dat', 0, 1, 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle1=Vehicle('venus-flagship', 2020.0, 349.0, 0.0, np.pi*2.65**2.0*0.25, 0.0, 0.
↪30, planet)
```

[5]:
```
# Set up entry parameters
vehicle1.setInitialState(220.0,0.0,0.0,11.1,0.0,-13.8,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle1.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle1.propogateEntry (120.0*60.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle1.v_kmsc, vehicle1.h_kmc, 'k-', linewidth=2.0)

plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle1.acc_net_g, vehicle1.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle1.q_stag_total, vehicle1.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle1.heatload/1.0E3, vehicle1.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
```

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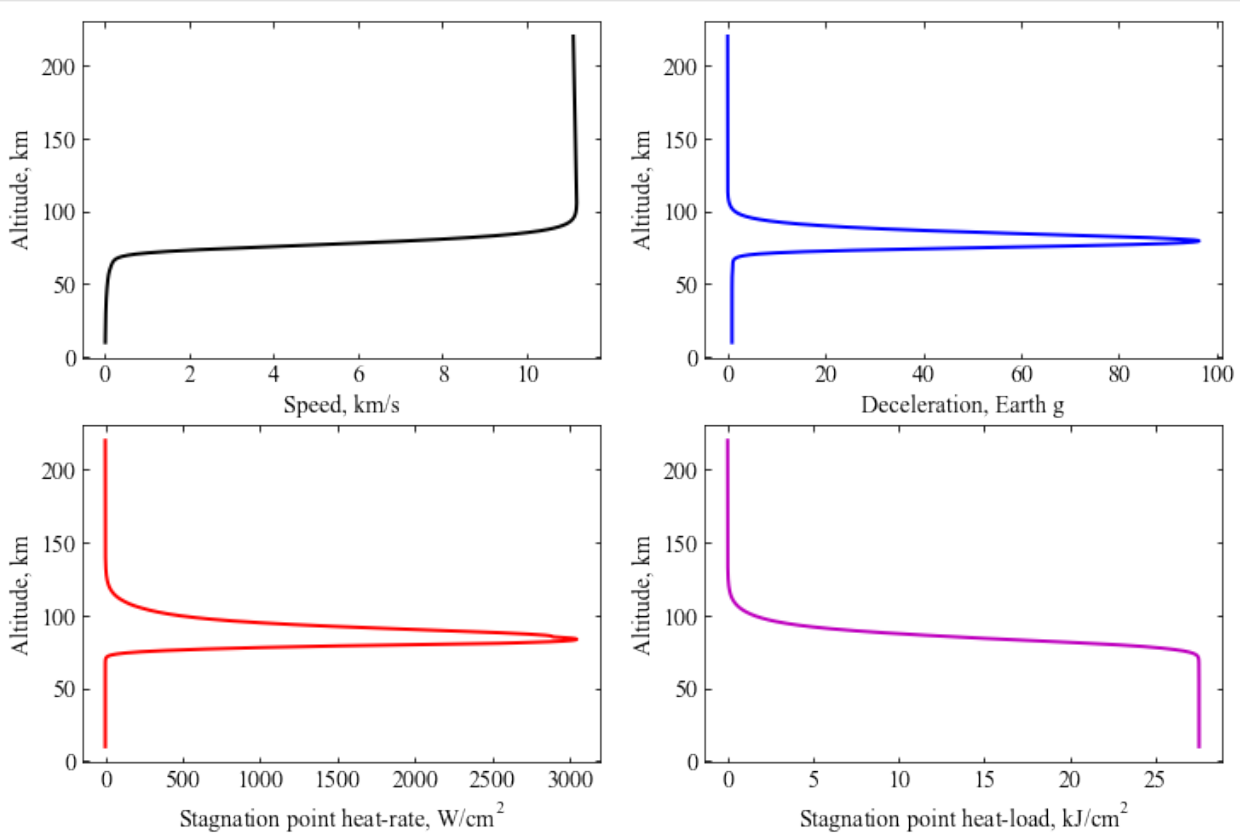
```
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/decadal-2010-venus-flagship.png',bbox_inches='tight')
plt.savefig('../plots/decadal-2010-venus-flagship.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/decadal-2010-venus-flagship.eps', dpi=300,bbox_inches='tight')

plt.show()
```



[10]:
```
plt.figure(figsize=(6,6))
plt.plot(vehicle1.stag_pres_atm[0:1700], vehicle1.q_stag_total[0:1700], 'r-',␣
↪linewidth=2.0)
plt.xlabel('Stagnation pressure, atm',fontsize=14)
plt.ylabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/decadal-2010-venus-flagship-thermal.png',bbox_inches='tight')
plt.savefig('../plots/decadal-2010-venus-flagship-thermal.pdf', dpi=300,bbox_inches=
↪'tight')
plt.savefig('../plots/decadal-2010-venus-flagship-thermal.eps', dpi=300,bbox_inches=
↪'tight')
```

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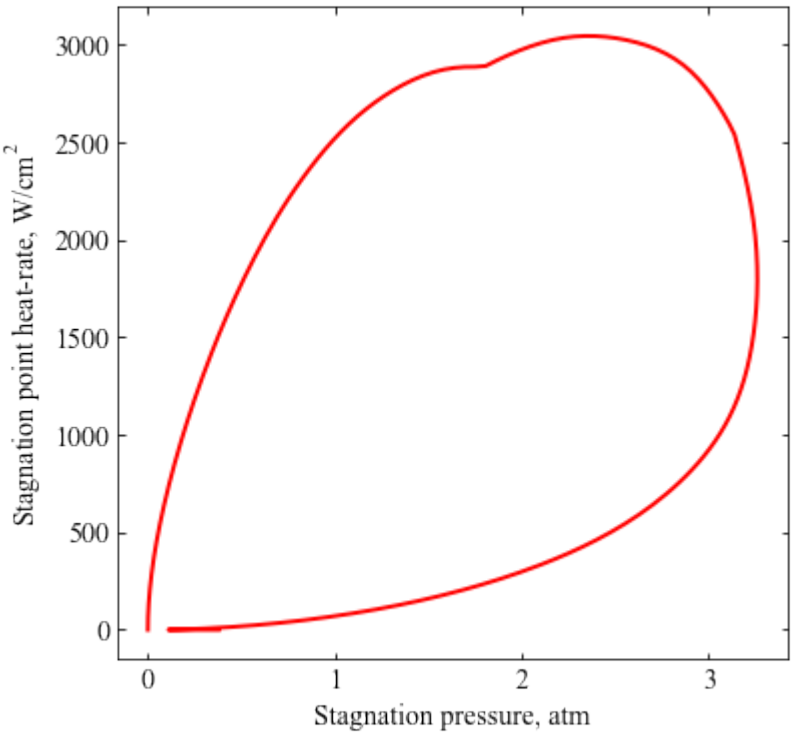
```
plt.show()
```



4.48 Example - 48 - Crew Module Atmospheric Re-entry Experiment

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of Crew Module Atmospheric Re-entry Experiment. https://www.isro.gov.in/sites/default/files/flipping_book/LVM-3/CARE/files/assets/common/downloads/LVM3-brochure.pdf

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("EARTH")
planet.h_skip = 126.0E3
planet.h_trap = 0.0E3
planet.loadAtmosphereModel('../atmdata/Earth/earth-gram-avg.dat', 0, 1, 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle1=Vehicle('care', 3735.0, 350.0, 0.0, np.pi*3.1**2.0*0.25, 0.0, 3.0, planet)
```

[5]:
```
# Set up entry parameters
vehicle1.setInitialState(126.0,0.0,0.0,5.326,0.0,0.0,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle1.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle1.propogateEntry (120.0*60.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle1.v_kmsc, vehicle1.h_kmc, 'k-', linewidth=2.0)

plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle1.acc_net_g, vehicle1.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle1.q_stag_total, vehicle1.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle1.heatload/1.0E3, vehicle1.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
```

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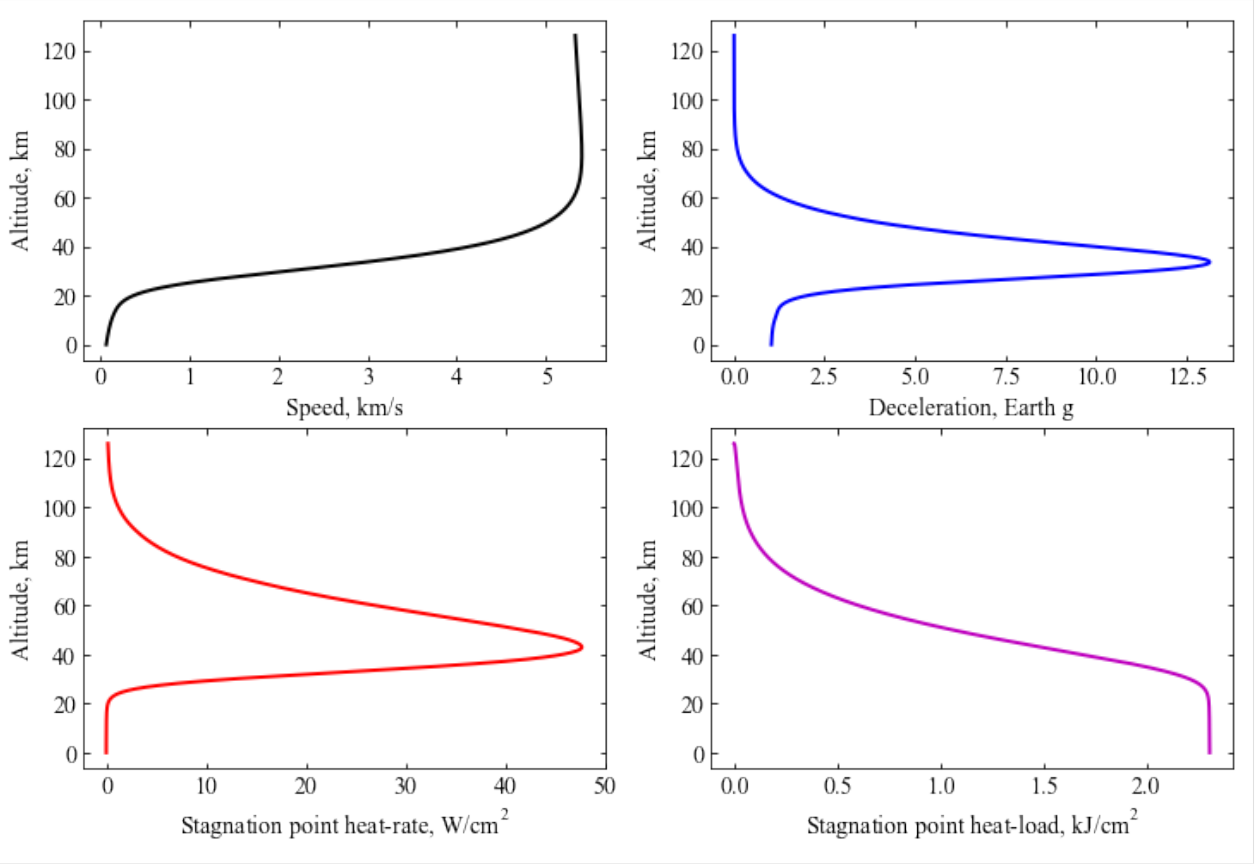
```
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/crew-module-atmospheric-re-entry-experiment-earth.png',bbox_
↪inches='tight')
plt.savefig('../plots/crew-module-atmospheric-re-entry-experiment-earth.pdf', dpi=300,
↪bbox_inches='tight')
plt.savefig('../plots/crew-module-atmospheric-re-entry-experiment-earth.eps', dpi=300,
↪bbox_inches='tight')

plt.show()
```



[10]:
```
plt.figure(figsize=(6,6))
plt.plot(vehicle1.stag_pres_atm[0:2700], vehicle1.q_stag_total[0:2700], 'r-',␣
↪linewidth=2.0)
plt.xlabel('Stagnation pressure, atm',fontsize=14)
plt.ylabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/crew-module-atmospheric-re-entry-experiment-earth-thermal.png',
↪bbox_inches='tight')
```

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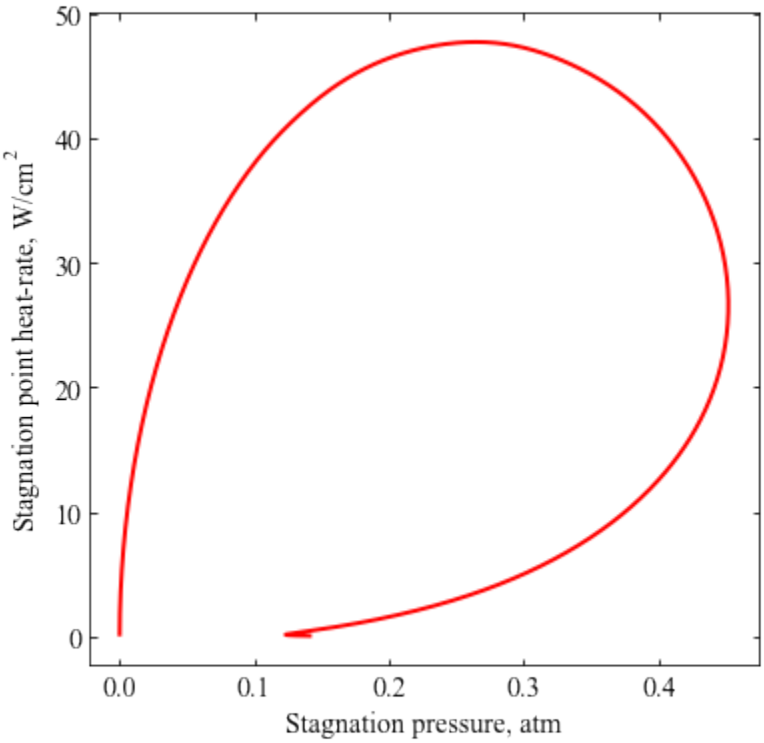
```
plt.savefig('../plots/crew-module-atmospheric-re-entry-experiment-earth-thermal.pdf',␣
↪dpi=300,bbox_inches='tight')
plt.savefig('../plots/crew-module-atmospheric-re-entry-experiment-earth-thermal.eps',␣
↪dpi=300,bbox_inches='tight')

plt.show()
```



4.49 Example - 49 - Earth SmallSat Aerocapture Demonstration - Part 1

This examples reproduces results from M.S.Werner and R.D.Braun, Mission Design and Performance Analysis of a Smallsat Aerocapture Flight Test, Journal of Spacecraft and Rockets, DOI: 10.2514/1.A33997.

[1]:
```
from IPython.display import Image
Image(filename='../plots/werner-smallsat.png', width=500)
```

[1]:

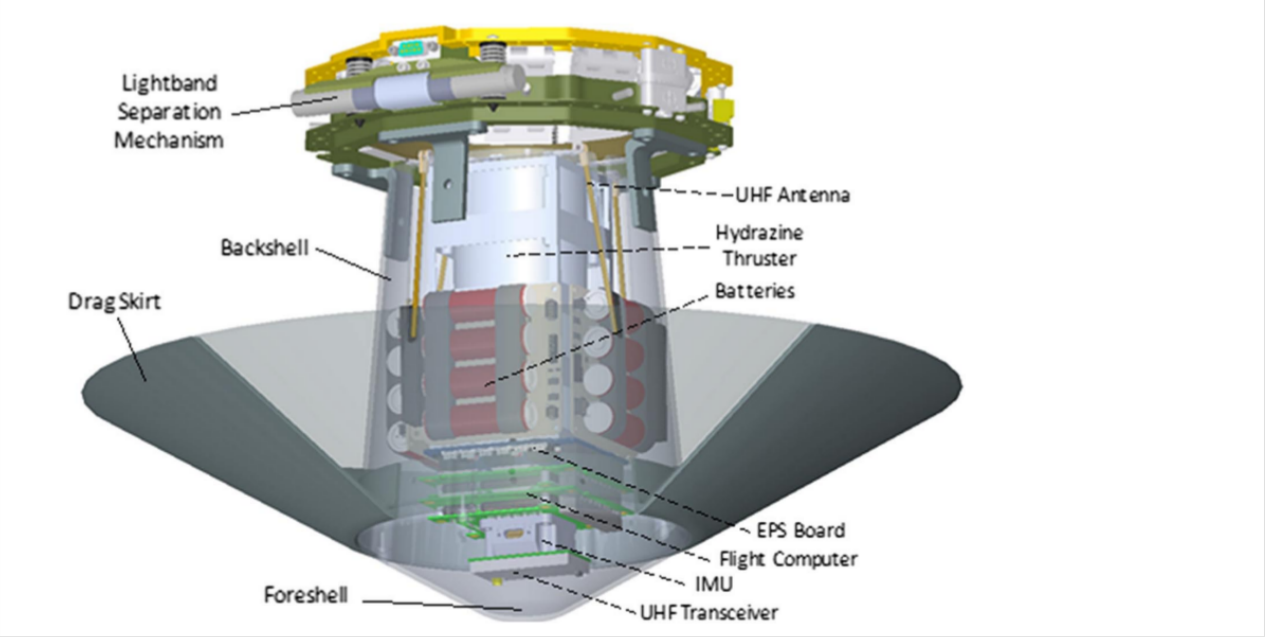


Image credit: M.S.Werner and R.D.Braun

[2]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[3]:
```
import numpy as np
from scipy import interpolate
import pandas as pd

import matplotlib.pyplot as plt
from matplotlib import rcParams
```

[4]:
```
planet = Planet('EARTH')
planet.loadAtmosphereModel('../atmdata/Earth/earth-gram-avg.dat', 0 , 1 ,2, 3)
planet.h_skip = 125.0E3
```

[5]:
```
vehicle=Vehicle('EarthSmallSat', 25.97, 66.4, 0.0, np.pi*0.25**2, 0.0, 0.0563, planet)
vehicle.setInitialState(125.0,0.0,0.0,9.8,0.0,-5.00,0.0,0.0)
vehicle.setSolverParams(1E-6)
vehicle.setDragModulationVehicleParams(66.4,4.72)
```

First, find the corridor bounds to select a target nominal EFPA for a nominal Earth atmosphere.

[6]:
```
underShootLimit, exitflag_us = vehicle.findUnderShootLimitD(2400.0, 0.1, -30.0,-2.0,␣
↪1E-10, 1760.0)
overShootLimit , exitflag_os =  vehicle.findOverShootLimitD(2400.0, 0.1, -30.0,-2.0,␣
↪1E-10, 1760.0)

print(underShootLimit, exitflag_us)
print(overShootLimit,  exitflag_os)
```

```
-5.141069082768809 1.0
-4.649618244053272 1.0
```

It is good practice to see how these corridor bounds vary with minimum, average, and maximum density atmospheres.

We will check how much these corridor bounds change using +/- 3-sigma bounds from EARTH GRAM output files.

Load three density profiles for minimum, average, and maximum scenarios from a GRAM output file.

[7]:
```
ATM_height, ATM_density_low, ATM_density_avg, ATM_density_high, ATM_density_pert =␣
↪planet.loadMonteCarloDensityFile3('../atmdata/Earth/LAT00N.txt', 1, 4, 14, 9,␣
↪heightInKmFlag=True)
density_int_low = planet.loadAtmosphereModel5(ATM_height, ATM_density_low, ATM_
↪density_avg, ATM_density_high, ATM_density_pert, -3.0, 141, 200)
density_int_avg = planet.loadAtmosphereModel5(ATM_height, ATM_density_low, ATM_
↪density_avg, ATM_density_high, ATM_density_pert,  0.0, 141, 200)
density_int_hig = planet.loadAtmosphereModel5(ATM_height, ATM_density_low, ATM_
↪density_avg, ATM_density_high, ATM_density_pert, +3.0, 141, 200)
```

Set the planet density_int attribute to density_int_low

[8]:
```
planet.density_int = density_int_low
```

Compute the corridor bounds for low density atmosphere.

[9]:
```
underShootLimit, exitflag_us = vehicle.findUnderShootLimitD(2400.0, 0.1, -30.0,-2.0,␣
↪1E-10, 1760.0)
overShootLimit , exitflag_os =  vehicle.findOverShootLimitD(2400.0, 0.1, -30.0,-2.0,␣
↪1E-10, 1760.0)

print(underShootLimit, exitflag_us)
print(overShootLimit,  exitflag_os)
```

```
-5.2014596410954255 1.0
-4.72837330459879 1.0
```

Repeat for average and maximum density atmospheres.

[10]:
```
planet.density_int = density_int_avg
```

[11]:
```
underShootLimit, exitflag_us = vehicle.findUnderShootLimitD(2400.0, 0.1, -30.0, -2.0,␣
↪1E-10, 1760.0)
overShootLimit , exitflag_os =  vehicle.findOverShootLimitD(2400.0, 0.1, -30.0, -2.0,␣
↪1E-10, 1760.0)

print(underShootLimit, exitflag_us)
print(overShootLimit,  exitflag_os)
```

```
-5.14605522868078 1.0
-4.6526982840077835 1.0
```

[12]:
```
planet.density_int = density_int_hig
```

[13]:
```
underShootLimit, exitflag_us = vehicle.findUnderShootLimitD(2400.0, 0.1, -30.0, -2.0,␣
↪1E-10, 1760.0)
overShootLimit , exitflag_os =  vehicle.findOverShootLimitD(2400.0, 0.1, -30.0, -2.0,␣
↪1E-10, 1760.0)

print(underShootLimit, exitflag_us)
print(overShootLimit,  exitflag_os)
```

```
-5.096641375908803 1.0
-4.5848947728809435 1.0
```

The above numbers indicate that corridor bounds do not vary that much with atmospheric variations. The corridor is approximately 0.50 deg wide.

[14]:
```
5.09-4.58
```

[14]:
```
0.5099999999999998
```

The mid-corridor is typically a good place to start. We will use the mean of the corridor bounds for the average atmosphere.

[15]:
```
0.5*(-4.65-5.15)
```

[15]:
```
-4.9
```

We will propogate a nominal guided trajectory to reproduce Fig. 5 from the paper.

[16]:
```
# Set planet.h_low to 10 km, if vehicle dips below this level
# trajctory is terminated.
planet.h_low=10.0E3

# Set target orbit = 180 km x 1760, tolerance = 50 km
vehicle.setTargetOrbitParams(180.0, 1760.0, 50.0)

# Set entry phase parameters
# v_switch_kms = 5.0, lowAlt_km = 50.0,
# numPoints_lowAlt = 101, hdot_threshold = -200.0 m/s.
# These are somewhat arbitary based on experience.
vehicle.setDragEntryPhaseParams(5.0, 50.0, 101, -200.0)

# Set beta_1 and beta_ratio
vehicle.setDragModulationVehicleParams(66.4,4.72)

# Set vehicle initial state
vehicle.setInitialState(125.0,0.0,0.0,9.8,0.0,-4.90,0.0,0.0)
```

[17]:
```
# Propogate a single vehicle trajectory
vehicle.propogateGuidedEntryD(1.0,1.0,0.1,2400.0)
```

[18]:
```
plt.figure(figsize=(6,4))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)
plt.plot(vehicle.v_kms_full, vehicle.h_km_full, 'r-', linewidth=2.0)

plt.xlabel('Planet-relative speed, km/s',fontsize=14)
plt.ylabel('Altitude, km',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)
plt.grid(linestyle='dotted', linewidth=0.5)

plt.savefig('../plots/werner-smallsat-nominal-altitude-speed.png',bbox_inches='tight')
plt.savefig('../plots/werner-smallsat-nominal-altitude-speed.pdf', dpi=300,bbox_
↪inches='tight')
plt.savefig('../plots/werner-smallsat-nominal-altitude-speed.eps', dpi=300,bbox_
↪inches='tight')
```

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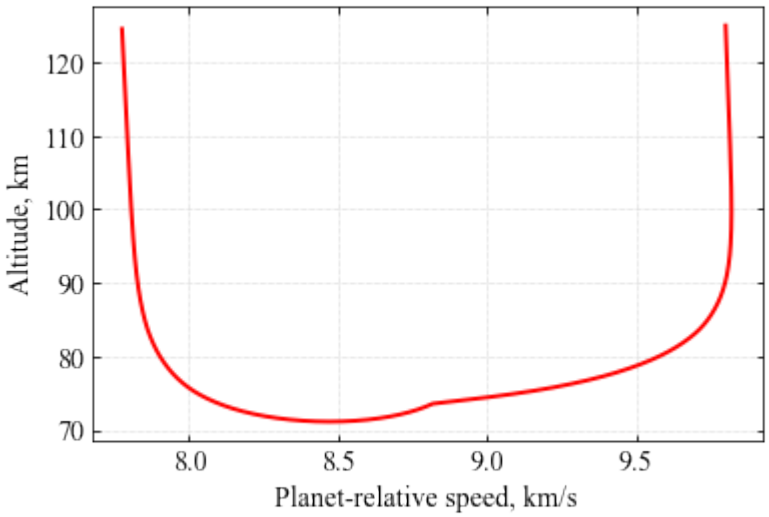
```
plt.show()
```

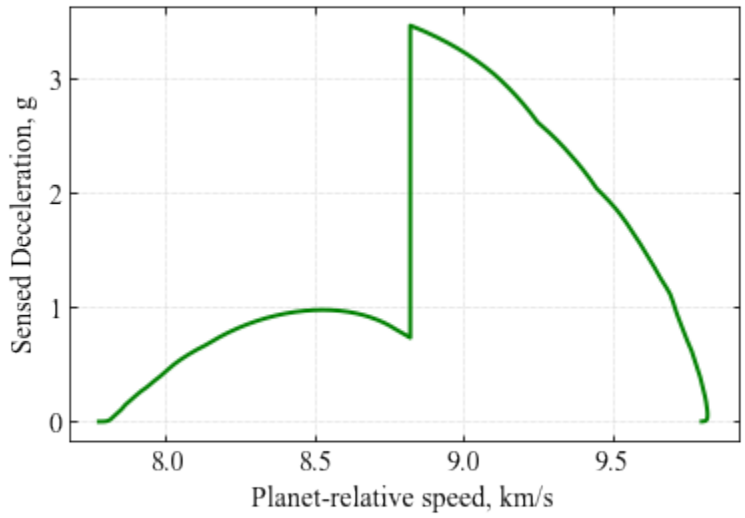


[19]:
```
plt.figure(figsize=(6,4))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)
plt.plot(vehicle.v_kms_full, vehicle.acc_net_g_full, 'g-', linewidth=2.0)


plt.xlabel('Planet-relative speed, km/s',fontsize=14)
plt.ylabel('Sensed Deceleration, g',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)
plt.grid(linestyle='dotted', linewidth=0.5)

plt.savefig('../plots/werner-smallsat-nominal-speed-decel.png',bbox_inches='tight')
plt.savefig('../plots/werner-smallsat-nominal-speed-decel.pdf', dpi=300,bbox_inches=
↪'tight')
plt.savefig('../plots/werner-smallsat-nominal-speed-decel.eps', dpi=300,bbox_inches=
↪'tight')

plt.show()
```

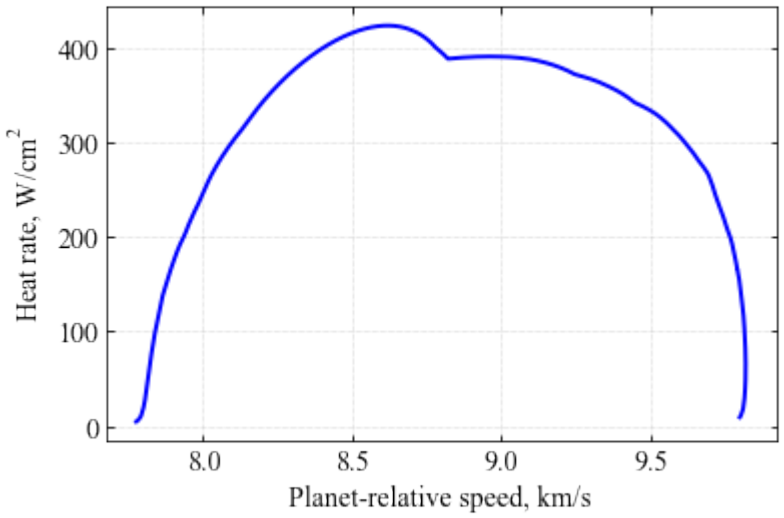


[20]:
```
plt.figure(figsize=(6,4))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)
plt.plot(vehicle.v_kms_full, vehicle.q_stag_total_full, 'b-', linewidth=2.0)


plt.xlabel('Planet-relative speed, km/s',fontsize=14)
plt.ylabel('Heat rate, '+r'$W/cm^2$',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)
plt.grid(linestyle='dotted', linewidth=0.5)

plt.savefig('../plots/werner-smallsat-nominal-speed-heat.png',bbox_inches='tight')
plt.savefig('../plots/werner-smallsat-nominal-speed-heat.pdf', dpi=300,bbox_inches=
↪'tight')
plt.savefig('../plots/werner-smallsat-nominal-speed-heat.eps', dpi=300,bbox_inches=
↪'tight')

plt.show()
```



[21]:
```
vehicle.terminal_apoapsis
```

[21]:
```
1759.9133624138142
```

4.50 Example - 50 - Earth SmallSat Aerocapture Demonstration - Part 2

In this example, we will use Monte Carlo simulations to assess flight performance. Reference: M.S.Werner and R.D.Braun, Mission Design and Performance Analysis of a Smallsat Aerocapture Flight Test, Journal of Spacecraft and Rockets, DOI: 10.2514/1.A33997

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
from scipy import interpolate
import pandas as pd

import matplotlib.pyplot as plt
from matplotlib import rcParams
from matplotlib.patches import Polygon
```

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("EARTH")
planet.loadAtmosphereModel('../atmdata/Earth/earth-gram-avg.dat', 0 , 1 ,2, 3)
planet.h_skip = 125000.0
planet.h_low=10.0E3

# Set up the drag modulation vehicle.
vehicle=Vehicle('EarthSmallSat', 2.82, 66.4, 0.0, np.pi*0.25**2, 0.0, 0.0563, planet)
vehicle.setInitialState(125.0,0.0,0.0,9.8,0.0,-5.00,0.0,0.0)
vehicle.setSolverParams(1E-6)
vehicle.setDragModulationVehicleParams(66.4,4.72)
```

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```
# Set up the drag modulation entry phase guidance parameters.
vehicle.setDragEntryPhaseParams(5.0, 50.0, 101, -200.0)

# Set the target orbit parameters.
vehicle.setTargetOrbitParams(180.0, 1760.0, 50.0)

# Define the path to atmospheric files to be used for the Monte Carlo simulations.
#atmfiles = ['../atmdata/Earth/LAT00N.txt']

atmfiles = ['../atmdata/Earth/LAT00N.txt',
            '../atmdata/Earth/LAT20N.txt',
            '../atmdata/Earth/LAT20S.txt',
            '../atmdata/Earth/LAT40N.txt',
            '../atmdata/Earth/LAT40S.txt',
            '../atmdata/Earth/LAT60N.txt',
            '../atmdata/Earth/LAT60S.txt',
            '../atmdata/Earth/LAT80N.txt',
            '../atmdata/Earth/LAT80S.txt']

# Set up the Monte Carlo simulation for drag modulation.
# NPOS = 141, NMONTE = 200
# Target EFPA = -4.85 deg
# EFPA 1-sigma error = +/- 0.04 deg
# Nominal beta_1 = 66.4 kg/m2
# beta_1 1-sigma = 0.0
# guidance time step for entry = 1.0s (Freq. = 1 Hz)
# guidance time step after jettison = 1.0 s
# max. solver time step = 0.1 s
# max. time used by solver = 2400 s

vehicle.setupMonteCarloSimulationD_Earth(141, 200, atmfiles,1, 4, 14, 9, True,
                                  -4.85,  0.04, 66.4, 0.0,
                                   1.0, 1.0, 0.1, 2400.0)
# Run 200 trajectories
vehicle.runMonteCarloD_Earth(200, '../data/werner2019/MCB1')
```

```
BATCH :../data/werner2019/MCB1, RUN #: 1, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE #:
↪ 107, EFPA: -4.83, SIGMA: 0.22, APO : 1915.51
BATCH :../data/werner2019/MCB1, RUN #: 2, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE #:
↪ 14, EFPA: -4.79, SIGMA: -1.00, APO : 2874.42
BATCH :../data/werner2019/MCB1, RUN #: 3, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE #:
↪ 138, EFPA: -4.84, SIGMA: 0.54, APO : 1901.08
BATCH :../data/werner2019/MCB1, RUN #: 4, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE #:
↪ 126, EFPA: -4.83, SIGMA: 0.10, APO : 1877.14
BATCH :../data/werner2019/MCB1, RUN #: 5, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE #:
↪ 138, EFPA: -4.85, SIGMA: 0.23, APO : 1676.20
BATCH :../data/werner2019/MCB1, RUN #: 6, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE #:
↪ 18, EFPA: -4.99, SIGMA: -1.71, APO : 1533.84
BATCH :../data/werner2019/MCB1, RUN #: 7, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE #:
↪ 22, EFPA: -4.93, SIGMA: 0.05, APO : 1855.16
BATCH :../data/werner2019/MCB1, RUN #: 8, PROF: ../atmdata/Earth/LAT00N.txt, SAMPLE #:
↪ 38, EFPA: -4.89, SIGMA: -0.84, APO : 2005.10
BATCH :../data/werner2019/MCB1, RUN #: 9, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE #:
↪ 187, EFPA: -4.79, SIGMA: -0.30, APO : 2394.91
BATCH :../data/werner2019/MCB1, RUN #: 10, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 123, EFPA: -4.77, SIGMA: 0.85, APO : 2404.43
BATCH :../data/werner2019/MCB1, RUN #: 11, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 143, EFPA: -4.84, SIGMA: -0.55, APO : 2553.98
```

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```
BATCH :../data/werner2019/MCB1, RUN #: 12, PROF: ../atmdata/Earth/LAT00N.txt, SAMPLE
↪#: 82, EFPA: -4.82, SIGMA: -1.59, APO : 1813.22
BATCH :../data/werner2019/MCB1, RUN #: 13, PROF: ../atmdata/Earth/LAT20N.txt, SAMPLE
↪#: 82, EFPA: -4.87, SIGMA: 0.05, APO : 1944.94
BATCH :../data/werner2019/MCB1, RUN #: 14, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 77, EFPA: -4.82, SIGMA: 1.32, APO : 1789.71
BATCH :../data/werner2019/MCB1, RUN #: 15, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 32, EFPA: -4.88, SIGMA: 1.99, APO : 1788.18
BATCH :../data/werner2019/MCB1, RUN #: 16, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 186, EFPA: -4.89, SIGMA: 0.75, APO : 2094.33
BATCH :../data/werner2019/MCB1, RUN #: 17, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 160, EFPA: -4.80, SIGMA: 0.80, APO : 2229.93
BATCH :../data/werner2019/MCB1, RUN #: 18, PROF: ../atmdata/Earth/LAT00N.txt, SAMPLE
↪#: 196, EFPA: -4.91, SIGMA: -0.04, APO : 1757.71
BATCH :../data/werner2019/MCB1, RUN #: 19, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 134, EFPA: -4.87, SIGMA: -1.32, APO : 2048.48
BATCH :../data/werner2019/MCB1, RUN #: 20, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 75, EFPA: -4.83, SIGMA: 0.33, APO : 2973.29
BATCH :../data/werner2019/MCB1, RUN #: 21, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 132, EFPA: -4.88, SIGMA: -0.51, APO : 2467.30
BATCH :../data/werner2019/MCB1, RUN #: 22, PROF: ../atmdata/Earth/LAT20N.txt, SAMPLE
↪#: 177, EFPA: -4.75, SIGMA: -0.25, APO : 1815.59
BATCH :../data/werner2019/MCB1, RUN #: 23, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 107, EFPA: -4.90, SIGMA: 2.15, APO : 1641.88
BATCH :../data/werner2019/MCB1, RUN #: 24, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 77, EFPA: -4.87, SIGMA: 0.79, APO : 2346.24
BATCH :../data/werner2019/MCB1, RUN #: 25, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 56, EFPA: -4.79, SIGMA: 0.52, APO : 2748.76
BATCH :../data/werner2019/MCB1, RUN #: 26, PROF: ../atmdata/Earth/LAT20N.txt, SAMPLE
↪#: 163, EFPA: -4.81, SIGMA: 0.91, APO : 1921.23
BATCH :../data/werner2019/MCB1, RUN #: 27, PROF: ../atmdata/Earth/LAT00N.txt, SAMPLE
↪#: 198, EFPA: -4.85, SIGMA: -1.79, APO : 1978.05
BATCH :../data/werner2019/MCB1, RUN #: 28, PROF: ../atmdata/Earth/LAT40N.txt, SAMPLE
↪#: 180, EFPA: -4.89, SIGMA: -0.43, APO : 1856.87
BATCH :../data/werner2019/MCB1, RUN #: 29, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 171, EFPA: -4.83, SIGMA: 0.45, APO : 1940.96
BATCH :../data/werner2019/MCB1, RUN #: 30, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 38, EFPA: -4.80, SIGMA: 0.23, APO : 1808.58
BATCH :../data/werner2019/MCB1, RUN #: 31, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 1, EFPA: -4.85, SIGMA: -1.00, APO : 2002.24
BATCH :../data/werner2019/MCB1, RUN #: 32, PROF: ../atmdata/Earth/LAT00N.txt, SAMPLE
↪#: 49, EFPA: -4.84, SIGMA: 0.04, APO : 2074.28
BATCH :../data/werner2019/MCB1, RUN #: 33, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 105, EFPA: -4.85, SIGMA: -0.88, APO : 2267.95
BATCH :../data/werner2019/MCB1, RUN #: 34, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 54, EFPA: -4.79, SIGMA: 3.02, APO : 1817.77
BATCH :../data/werner2019/MCB1, RUN #: 35, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 142, EFPA: -4.89, SIGMA: -1.61, APO : 959.84
BATCH :../data/werner2019/MCB1, RUN #: 36, PROF: ../atmdata/Earth/LAT40N.txt, SAMPLE
↪#: 43, EFPA: -4.84, SIGMA: -1.32, APO : 1808.74
BATCH :../data/werner2019/MCB1, RUN #: 37, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 117, EFPA: -4.83, SIGMA: 0.46, APO : 1806.22
BATCH :../data/werner2019/MCB1, RUN #: 38, PROF: ../atmdata/Earth/LAT80N.txt, SAMPLE
↪#: 126, EFPA: -4.97, SIGMA: -0.78, APO : 1885.88
BATCH :../data/werner2019/MCB1, RUN #: 39, PROF: ../atmdata/Earth/LAT20N.txt, SAMPLE
↪#: 73, EFPA: -4.92, SIGMA: 1.39, APO : 2295.27
BATCH :../data/werner2019/MCB1, RUN #: 40, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 41, EFPA: -4.79, SIGMA: -0.06, APO : 1910.13
```

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```
BATCH :../data/werner2019/MCB1, RUN #: 41, PROF: ../atmdata/Earth/LAT00N.txt, SAMPLE
↪#: 29, EFPA: -4.84, SIGMA: 0.12, APO : 1860.60
BATCH :../data/werner2019/MCB1, RUN #: 42, PROF: ../atmdata/Earth/LAT40N.txt, SAMPLE
↪#: 58, EFPA: -4.81, SIGMA: 0.82, APO : 1810.06
BATCH :../data/werner2019/MCB1, RUN #: 43, PROF: ../atmdata/Earth/LAT80N.txt, SAMPLE
↪#: 88, EFPA: -4.86, SIGMA: -0.66, APO : 5832.76
BATCH :../data/werner2019/MCB1, RUN #: 44, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 164, EFPA: -4.82, SIGMA: 0.47, APO : 3232.68
BATCH :../data/werner2019/MCB1, RUN #: 45, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 93, EFPA: -4.84, SIGMA: 0.51, APO : 1893.28
BATCH :../data/werner2019/MCB1, RUN #: 46, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 141, EFPA: -4.87, SIGMA: -0.69, APO : 2347.15
BATCH :../data/werner2019/MCB1, RUN #: 47, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 115, EFPA: -4.82, SIGMA: -2.88, APO : 2131.86
BATCH :../data/werner2019/MCB1, RUN #: 48, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 96, EFPA: -4.84, SIGMA: 0.66, APO : 2325.42
BATCH :../data/werner2019/MCB1, RUN #: 49, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 183, EFPA: -4.83, SIGMA: -0.20, APO : 1924.36
BATCH :../data/werner2019/MCB1, RUN #: 50, PROF: ../atmdata/Earth/LAT20N.txt, SAMPLE
↪#: 14, EFPA: -4.80, SIGMA: 0.36, APO : 1848.65
BATCH :../data/werner2019/MCB1, RUN #: 51, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 148, EFPA: -4.78, SIGMA: 0.50, APO : 2519.58
BATCH :../data/werner2019/MCB1, RUN #: 52, PROF: ../atmdata/Earth/LAT40N.txt, SAMPLE
↪#: 4, EFPA: -4.86, SIGMA: 0.24, APO : 1934.50
BATCH :../data/werner2019/MCB1, RUN #: 53, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 44, EFPA: -4.89, SIGMA: -1.57, APO : 2895.36
BATCH :../data/werner2019/MCB1, RUN #: 54, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 196, EFPA: -4.88, SIGMA: 0.86, APO : 1813.61
BATCH :../data/werner2019/MCB1, RUN #: 55, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 93, EFPA: -4.87, SIGMA: 0.60, APO : 1830.42
BATCH :../data/werner2019/MCB1, RUN #: 56, PROF: ../atmdata/Earth/LAT00N.txt, SAMPLE
↪#: 73, EFPA: -4.92, SIGMA: -0.96, APO : 1713.14
BATCH :../data/werner2019/MCB1, RUN #: 57, PROF: ../atmdata/Earth/LAT40N.txt, SAMPLE
↪#: 175, EFPA: -4.81, SIGMA: 0.65, APO : 1807.05
BATCH :../data/werner2019/MCB1, RUN #: 58, PROF: ../atmdata/Earth/LAT20N.txt, SAMPLE
↪#: 77, EFPA: -4.82, SIGMA: 0.28, APO : 1840.52
BATCH :../data/werner2019/MCB1, RUN #: 59, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 110, EFPA: -4.82, SIGMA: 0.26, APO : 1889.03
BATCH :../data/werner2019/MCB1, RUN #: 60, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 174, EFPA: -4.79, SIGMA: -0.74, APO : 2839.38
BATCH :../data/werner2019/MCB1, RUN #: 61, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 151, EFPA: -4.92, SIGMA: -1.81, APO : 1810.20
BATCH :../data/werner2019/MCB1, RUN #: 62, PROF: ../atmdata/Earth/LAT80N.txt, SAMPLE
↪#: 93, EFPA: -4.82, SIGMA: 1.75, APO : 1809.73
BATCH :../data/werner2019/MCB1, RUN #: 63, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 52, EFPA: -4.87, SIGMA: 0.78, APO : 1810.62
BATCH :../data/werner2019/MCB1, RUN #: 64, PROF: ../atmdata/Earth/LAT00N.txt, SAMPLE
↪#: 67, EFPA: -4.86, SIGMA: -0.45, APO : 1700.97
BATCH :../data/werner2019/MCB1, RUN #: 65, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 12, EFPA: -4.82, SIGMA: 0.32, APO : 2646.75
BATCH :../data/werner2019/MCB1, RUN #: 66, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 183, EFPA: -4.90, SIGMA: -0.44, APO : 333.28
BATCH :../data/werner2019/MCB1, RUN #: 67, PROF: ../atmdata/Earth/LAT00N.txt, SAMPLE
↪#: 59, EFPA: -4.90, SIGMA: -0.17, APO : 1692.33
BATCH :../data/werner2019/MCB1, RUN #: 68, PROF: ../atmdata/Earth/LAT20N.txt, SAMPLE
↪#: 18, EFPA: -4.84, SIGMA: 0.51, APO : 1928.06
BATCH :../data/werner2019/MCB1, RUN #: 69, PROF: ../atmdata/Earth/LAT20N.txt, SAMPLE
↪#: 25, EFPA: -4.85, SIGMA: 0.94, APO : 1940.93
```

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```
BATCH :../data/werner2019/MCB1, RUN #: 70, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 151, EFPA: -4.88, SIGMA: 1.75, APO : 1873.31
BATCH :../data/werner2019/MCB1, RUN #: 71, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 130, EFPA: -4.84, SIGMA: -0.57, APO : 2509.63
BATCH :../data/werner2019/MCB1, RUN #: 72, PROF: ../atmdata/Earth/LAT40N.txt, SAMPLE
↪#: 33, EFPA: -4.90, SIGMA: 0.97, APO : 1824.60
BATCH :../data/werner2019/MCB1, RUN #: 73, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 154, EFPA: -4.88, SIGMA: 0.57, APO : 1485.52
BATCH :../data/werner2019/MCB1, RUN #: 74, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 21, EFPA: -4.82, SIGMA: -1.09, APO : 1833.94
BATCH :../data/werner2019/MCB1, RUN #: 75, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 27, EFPA: -4.85, SIGMA: -0.38, APO : 2849.74
BATCH :../data/werner2019/MCB1, RUN #: 76, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 11, EFPA: -4.90, SIGMA: 0.87, APO : 2129.86
BATCH :../data/werner2019/MCB1, RUN #: 77, PROF: ../atmdata/Earth/LAT40N.txt, SAMPLE
↪#: 149, EFPA: -4.87, SIGMA: 0.24, APO : 1729.69
BATCH :../data/werner2019/MCB1, RUN #: 78, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 20, EFPA: -4.86, SIGMA: 0.11, APO : 1778.55
BATCH :../data/werner2019/MCB1, RUN #: 79, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 61, EFPA: -4.85, SIGMA: -0.36, APO : 1967.42
BATCH :../data/werner2019/MCB1, RUN #: 80, PROF: ../atmdata/Earth/LAT00N.txt, SAMPLE
↪#: 151, EFPA: -4.80, SIGMA: -0.53, APO : 1867.09
BATCH :../data/werner2019/MCB1, RUN #: 81, PROF: ../atmdata/Earth/LAT40N.txt, SAMPLE
↪#: 9, EFPA: -4.87, SIGMA: 0.24, APO : 1780.05
BATCH :../data/werner2019/MCB1, RUN #: 82, PROF: ../atmdata/Earth/LAT40N.txt, SAMPLE
↪#: 78, EFPA: -4.78, SIGMA: -0.15, APO : 4029.84
BATCH :../data/werner2019/MCB1, RUN #: 83, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 14, EFPA: -4.88, SIGMA: -0.21, APO : 124.35
BATCH :../data/werner2019/MCB1, RUN #: 84, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 152, EFPA: -4.80, SIGMA: 0.27, APO : 1906.28
BATCH :../data/werner2019/MCB1, RUN #: 85, PROF: ../atmdata/Earth/LAT40N.txt, SAMPLE
↪#: 141, EFPA: -4.88, SIGMA: -0.44, APO : 1893.22
BATCH :../data/werner2019/MCB1, RUN #: 86, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 171, EFPA: -4.85, SIGMA: 0.90, APO : 706.47
BATCH :../data/werner2019/MCB1, RUN #: 87, PROF: ../atmdata/Earth/LAT40N.txt, SAMPLE
↪#: 87, EFPA: -4.82, SIGMA: 0.13, APO : 1825.07
BATCH :../data/werner2019/MCB1, RUN #: 88, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 70, EFPA: -4.83, SIGMA: -1.14, APO : 1918.20
BATCH :../data/werner2019/MCB1, RUN #: 89, PROF: ../atmdata/Earth/LAT40N.txt, SAMPLE
↪#: 166, EFPA: -4.83, SIGMA: -0.06, APO : 1752.07
BATCH :../data/werner2019/MCB1, RUN #: 90, PROF: ../atmdata/Earth/LAT20N.txt, SAMPLE
↪#: 40, EFPA: -4.84, SIGMA: -0.77, APO : 1837.95
BATCH :../data/werner2019/MCB1, RUN #: 91, PROF: ../atmdata/Earth/LAT40N.txt, SAMPLE
↪#: 189, EFPA: -4.87, SIGMA: -0.62, APO : 1843.50
BATCH :../data/werner2019/MCB1, RUN #: 92, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 127, EFPA: -4.87, SIGMA: -0.79, APO : 2685.77
BATCH :../data/werner2019/MCB1, RUN #: 93, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 131, EFPA: -4.85, SIGMA: 0.13, APO : 1829.54
BATCH :../data/werner2019/MCB1, RUN #: 94, PROF: ../atmdata/Earth/LAT40N.txt, SAMPLE
↪#: 97, EFPA: -4.86, SIGMA: 0.20, APO : 1769.45
BATCH :../data/werner2019/MCB1, RUN #: 95, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 37, EFPA: -4.84, SIGMA: 0.08, APO : 2547.89
BATCH :../data/werner2019/MCB1, RUN #: 96, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 14, EFPA: -4.88, SIGMA: -1.27, APO : 2019.88
BATCH :../data/werner2019/MCB1, RUN #: 97, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 53, EFPA: -4.91, SIGMA: 0.98, APO : 1816.88
BATCH :../data/werner2019/MCB1, RUN #: 98, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 197, EFPA: -4.82, SIGMA: 0.22, APO : 1804.41
```

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```
BATCH :../data/werner2019/MCB1, RUN #: 99, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 195, EFPA: -4.79, SIGMA: 0.75, APO : 1966.88
BATCH :../data/werner2019/MCB1, RUN #: 100, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 107, EFPA: -4.89, SIGMA: -1.37, APO : 2458.49
BATCH :../data/werner2019/MCB1, RUN #: 101, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 1, EFPA: -4.88, SIGMA: -2.25, APO : 5353.50
BATCH :../data/werner2019/MCB1, RUN #: 102, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 40, EFPA: -4.89, SIGMA: -0.66, APO : 2664.62
BATCH :../data/werner2019/MCB1, RUN #: 103, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 114, EFPA: -4.91, SIGMA: 0.64, APO : 1700.72
BATCH :../data/werner2019/MCB1, RUN #: 104, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 13, EFPA: -4.92, SIGMA: -1.19, APO : 22.63
BATCH :../data/werner2019/MCB1, RUN #: 105, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 132, EFPA: -4.78, SIGMA: 0.83, APO : 1815.90
BATCH :../data/werner2019/MCB1, RUN #: 106, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 25, EFPA: -4.88, SIGMA: 0.37, APO : 2613.84
BATCH :../data/werner2019/MCB1, RUN #: 107, PROF: ../atmdata/Earth/LAT40N.txt, SAMPLE
↪#: 184, EFPA: -4.86, SIGMA: -0.02, APO : 1823.35
BATCH :../data/werner2019/MCB1, RUN #: 108, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 52, EFPA: -4.83, SIGMA: 0.86, APO : 2309.78
BATCH :../data/werner2019/MCB1, RUN #: 109, PROF: ../atmdata/Earth/LAT00N.txt, SAMPLE
↪#: 48, EFPA: -4.87, SIGMA: -0.43, APO : 1908.16
BATCH :../data/werner2019/MCB1, RUN #: 110, PROF: ../atmdata/Earth/LAT40N.txt, SAMPLE
↪#: 89, EFPA: -4.84, SIGMA: -1.45, APO : 2984.50
BATCH :../data/werner2019/MCB1, RUN #: 111, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 96, EFPA: -4.83, SIGMA: 0.13, APO : 1895.90
BATCH :../data/werner2019/MCB1, RUN #: 112, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 176, EFPA: -4.90, SIGMA: 1.10, APO : 22.69
BATCH :../data/werner2019/MCB1, RUN #: 113, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 67, EFPA: -4.85, SIGMA: 0.49, APO : 1760.06
BATCH :../data/werner2019/MCB1, RUN #: 114, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 72, EFPA: -4.83, SIGMA: 1.05, APO : 1822.80
BATCH :../data/werner2019/MCB1, RUN #: 115, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 84, EFPA: -4.84, SIGMA: -0.73, APO : 2175.26
BATCH :../data/werner2019/MCB1, RUN #: 116, PROF: ../atmdata/Earth/LAT20N.txt, SAMPLE
↪#: 171, EFPA: -4.83, SIGMA: 1.08, APO : 1878.67
BATCH :../data/werner2019/MCB1, RUN #: 117, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 68, EFPA: -4.86, SIGMA: -1.16, APO : 1808.78
BATCH :../data/werner2019/MCB1, RUN #: 118, PROF: ../atmdata/Earth/LAT20N.txt, SAMPLE
↪#: 200, EFPA: -4.84, SIGMA: 1.32, APO : 1766.54
BATCH :../data/werner2019/MCB1, RUN #: 119, PROF: ../atmdata/Earth/LAT40N.txt, SAMPLE
↪#: 51, EFPA: -4.80, SIGMA: 0.01, APO : 1793.98
BATCH :../data/werner2019/MCB1, RUN #: 120, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 14, EFPA: -4.81, SIGMA: -0.63, APO : 2147.00
BATCH :../data/werner2019/MCB1, RUN #: 121, PROF: ../atmdata/Earth/LAT80N.txt, SAMPLE
↪#: 136, EFPA: -4.87, SIGMA: -0.15, APO : 3850.89
BATCH :../data/werner2019/MCB1, RUN #: 122, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 10, EFPA: -4.80, SIGMA: -0.83, APO : 3750.97
BATCH :../data/werner2019/MCB1, RUN #: 123, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 193, EFPA: -4.91, SIGMA: 0.53, APO : 22.77
BATCH :../data/werner2019/MCB1, RUN #: 124, PROF: ../atmdata/Earth/LAT20N.txt, SAMPLE
↪#: 112, EFPA: -4.84, SIGMA: -0.21, APO : 1965.62
BATCH :../data/werner2019/MCB1, RUN #: 125, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 135, EFPA: -4.89, SIGMA: 0.06, APO : 22.54
BATCH :../data/werner2019/MCB1, RUN #: 126, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 164, EFPA: -4.84, SIGMA: 0.21, APO : 1941.02
BATCH :../data/werner2019/MCB1, RUN #: 127, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 17, EFPA: -4.87, SIGMA: -1.32, APO : 2672.25
```

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```
BATCH :../data/werner2019/MCB1, RUN #: 128, PROF: ../atmdata/Earth/LAT80N.txt, SAMPLE
↪#: 124, EFPA: -4.80, SIGMA: 1.49, APO : 1803.72
BATCH :../data/werner2019/MCB1, RUN #: 129, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 195, EFPA: -4.80, SIGMA: 0.22, APO : 1835.42
BATCH :../data/werner2019/MCB1, RUN #: 130, PROF: ../atmdata/Earth/LAT80N.txt, SAMPLE
↪#: 102, EFPA: -4.80, SIGMA: 1.93, APO : 1835.56
BATCH :../data/werner2019/MCB1, RUN #: 131, PROF: ../atmdata/Earth/LAT80N.txt, SAMPLE
↪#: 18, EFPA: -4.84, SIGMA: -0.79, APO : 1811.93
BATCH :../data/werner2019/MCB1, RUN #: 132, PROF: ../atmdata/Earth/LAT20N.txt, SAMPLE
↪#: 4, EFPA: -4.84, SIGMA: -0.69, APO : 2030.44
BATCH :../data/werner2019/MCB1, RUN #: 133, PROF: ../atmdata/Earth/LAT80N.txt, SAMPLE
↪#: 37, EFPA: -4.86, SIGMA: 0.16, APO : 1812.47
BATCH :../data/werner2019/MCB1, RUN #: 134, PROF: ../atmdata/Earth/LAT00N.txt, SAMPLE
↪#: 181, EFPA: -4.84, SIGMA: -3.70, APO : 1818.59
BATCH :../data/werner2019/MCB1, RUN #: 135, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 4, EFPA: -4.79, SIGMA: -0.71, APO : 1868.37
BATCH :../data/werner2019/MCB1, RUN #: 136, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 184, EFPA: -4.85, SIGMA: -1.87, APO : 1771.29
BATCH :../data/werner2019/MCB1, RUN #: 137, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 102, EFPA: -4.85, SIGMA: -0.48, APO : 2188.19
BATCH :../data/werner2019/MCB1, RUN #: 138, PROF: ../atmdata/Earth/LAT80N.txt, SAMPLE
↪#: 99, EFPA: -4.75, SIGMA: -0.85, APO : 9823.91
BATCH :../data/werner2019/MCB1, RUN #: 139, PROF: ../atmdata/Earth/LAT40N.txt, SAMPLE
↪#: 138, EFPA: -4.86, SIGMA: 0.28, APO : 1777.30
BATCH :../data/werner2019/MCB1, RUN #: 140, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 166, EFPA: -4.83, SIGMA: -0.17, APO : 1900.76
BATCH :../data/werner2019/MCB1, RUN #: 141, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 160, EFPA: -4.89, SIGMA: 0.06, APO : 1798.07
BATCH :../data/werner2019/MCB1, RUN #: 142, PROF: ../atmdata/Earth/LAT00N.txt, SAMPLE
↪#: 196, EFPA: -4.88, SIGMA: 0.33, APO : 1885.40
BATCH :../data/werner2019/MCB1, RUN #: 143, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 19, EFPA: -4.89, SIGMA: 2.38, APO : 1298.20
BATCH :../data/werner2019/MCB1, RUN #: 144, PROF: ../atmdata/Earth/LAT00N.txt, SAMPLE
↪#: 185, EFPA: -4.90, SIGMA: 0.52, APO : 1942.11
BATCH :../data/werner2019/MCB1, RUN #: 145, PROF: ../atmdata/Earth/LAT20N.txt, SAMPLE
↪#: 95, EFPA: -4.83, SIGMA: 2.00, APO : 2038.34
BATCH :../data/werner2019/MCB1, RUN #: 146, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 11, EFPA: -4.85, SIGMA: 0.68, APO : 1814.08
BATCH :../data/werner2019/MCB1, RUN #: 147, PROF: ../atmdata/Earth/LAT00N.txt, SAMPLE
↪#: 187, EFPA: -4.90, SIGMA: -0.51, APO : 1868.46
BATCH :../data/werner2019/MCB1, RUN #: 148, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 81, EFPA: -4.85, SIGMA: 0.87, APO : 1835.14
BATCH :../data/werner2019/MCB1, RUN #: 149, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 67, EFPA: -4.78, SIGMA: 1.77, APO : 2056.58
BATCH :../data/werner2019/MCB1, RUN #: 150, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 47, EFPA: -4.84, SIGMA: 0.08, APO : 2000.82
BATCH :../data/werner2019/MCB1, RUN #: 151, PROF: ../atmdata/Earth/LAT80N.txt, SAMPLE
↪#: 28, EFPA: -4.80, SIGMA: 0.33, APO : 4423.67
BATCH :../data/werner2019/MCB1, RUN #: 152, PROF: ../atmdata/Earth/LAT80N.txt, SAMPLE
↪#: 14, EFPA: -4.89, SIGMA: -0.18, APO : 1826.45
BATCH :../data/werner2019/MCB1, RUN #: 153, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 35, EFPA: -4.83, SIGMA: 0.58, APO : 1913.70
BATCH :../data/werner2019/MCB1, RUN #: 154, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 49, EFPA: -4.83, SIGMA: 0.04, APO : 1839.21
BATCH :../data/werner2019/MCB1, RUN #: 155, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 99, EFPA: -4.85, SIGMA: -1.20, APO : 1911.89
BATCH :../data/werner2019/MCB1, RUN #: 156, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 93, EFPA: -4.91, SIGMA: -2.07, APO : 2050.29
```

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BATCH :../data/werner2019/MCB1, RUN #: 157, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 150, EFPA: -4.82, SIGMA: 0.80, APO : 2043.39
BATCH :../data/werner2019/MCB1, RUN #: 158, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 93, EFPA: -4.85, SIGMA: -0.89, APO : 2905.72
BATCH :../data/werner2019/MCB1, RUN #: 159, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 119, EFPA: -4.87, SIGMA: 1.05, APO : 1762.34
BATCH :../data/werner2019/MCB1, RUN #: 160, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 88, EFPA: -4.86, SIGMA: 0.97, APO : 1768.09
BATCH :../data/werner2019/MCB1, RUN #: 161, PROF: ../atmdata/Earth/LAT00N.txt, SAMPLE
↪#: 137, EFPA: -4.82, SIGMA: 0.27, APO : 1874.13
BATCH :../data/werner2019/MCB1, RUN #: 162, PROF: ../atmdata/Earth/LAT80N.txt, SAMPLE
↪#: 113, EFPA: -4.85, SIGMA: -0.48, APO : 1808.50
BATCH :../data/werner2019/MCB1, RUN #: 163, PROF: ../atmdata/Earth/LAT80N.txt, SAMPLE
↪#: 90, EFPA: -4.82, SIGMA: -0.51, APO : 4621.58
BATCH :../data/werner2019/MCB1, RUN #: 164, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 119, EFPA: -4.93, SIGMA: -0.25, APO : 22.55
BATCH :../data/werner2019/MCB1, RUN #: 165, PROF: ../atmdata/Earth/LAT80N.txt, SAMPLE
↪#: 188, EFPA: -4.80, SIGMA: 0.77, APO : 2672.75
BATCH :../data/werner2019/MCB1, RUN #: 166, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 77, EFPA: -4.93, SIGMA: -0.62, APO : 1391.23
BATCH :../data/werner2019/MCB1, RUN #: 167, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 55, EFPA: -4.88, SIGMA: -0.00, APO : 1905.84
BATCH :../data/werner2019/MCB1, RUN #: 168, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 162, EFPA: -4.86, SIGMA: -0.02, APO : 1887.71
BATCH :../data/werner2019/MCB1, RUN #: 169, PROF: ../atmdata/Earth/LAT20N.txt, SAMPLE
↪#: 6, EFPA: -4.88, SIGMA: 0.29, APO : 2017.17
BATCH :../data/werner2019/MCB1, RUN #: 170, PROF: ../atmdata/Earth/LAT80N.txt, SAMPLE
↪#: 159, EFPA: -4.84, SIGMA: 0.94, APO : 1814.33
BATCH :../data/werner2019/MCB1, RUN #: 171, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 200, EFPA: -4.87, SIGMA: -0.82, APO : 3258.49
BATCH :../data/werner2019/MCB1, RUN #: 172, PROF: ../atmdata/Earth/LAT20N.txt, SAMPLE
↪#: 57, EFPA: -4.93, SIGMA: -1.65, APO : 2096.31
BATCH :../data/werner2019/MCB1, RUN #: 173, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 92, EFPA: -4.90, SIGMA: -0.13, APO : 1450.62
BATCH :../data/werner2019/MCB1, RUN #: 174, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 67, EFPA: -4.85, SIGMA: -1.60, APO : 2194.75
BATCH :../data/werner2019/MCB1, RUN #: 175, PROF: ../atmdata/Earth/LAT20N.txt, SAMPLE
↪#: 20, EFPA: -4.82, SIGMA: -1.65, APO : 1855.57
BATCH :../data/werner2019/MCB1, RUN #: 176, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 111, EFPA: -4.85, SIGMA: 0.13, APO : 2629.28
BATCH :../data/werner2019/MCB1, RUN #: 177, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 86, EFPA: -4.90, SIGMA: -0.57, APO : 1953.92
BATCH :../data/werner2019/MCB1, RUN #: 178, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 200, EFPA: -4.82, SIGMA: 0.17, APO : 3527.15
BATCH :../data/werner2019/MCB1, RUN #: 179, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 73, EFPA: -4.80, SIGMA: 0.96, APO : 1870.57
BATCH :../data/werner2019/MCB1, RUN #: 180, PROF: ../atmdata/Earth/LAT80N.txt, SAMPLE
↪#: 70, EFPA: -4.85, SIGMA: 0.25, APO : 1813.48
BATCH :../data/werner2019/MCB1, RUN #: 181, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 181, EFPA: -4.91, SIGMA: 0.02, APO : 1800.06
BATCH :../data/werner2019/MCB1, RUN #: 182, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 135, EFPA: -4.86, SIGMA: 1.21, APO : 2210.22
BATCH :../data/werner2019/MCB1, RUN #: 183, PROF: ../atmdata/Earth/LAT40N.txt, SAMPLE
↪#: 200, EFPA: -4.83, SIGMA: 0.42, APO : 1796.40
BATCH :../data/werner2019/MCB1, RUN #: 184, PROF: ../atmdata/Earth/LAT40N.txt, SAMPLE
↪#: 34, EFPA: -4.84, SIGMA: 1.11, APO : 1853.91
BATCH :../data/werner2019/MCB1, RUN #: 185, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 136, EFPA: -4.93, SIGMA: 0.08, APO : 1870.74
```

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BATCH :../data/werner2019/MCB1, RUN #: 186, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 144, EFPA: -4.90, SIGMA: 0.93, APO : 1764.16
BATCH :../data/werner2019/MCB1, RUN #: 187, PROF: ../atmdata/Earth/LAT80N.txt, SAMPLE
↪#: 67, EFPA: -4.88, SIGMA: -2.00, APO : 2258.70
BATCH :../data/werner2019/MCB1, RUN #: 188, PROF: ../atmdata/Earth/LAT80S.txt, SAMPLE
↪#: 81, EFPA: -4.92, SIGMA: -0.95, APO : 22.62
BATCH :../data/werner2019/MCB1, RUN #: 189, PROF: ../atmdata/Earth/LAT20N.txt, SAMPLE
↪#: 164, EFPA: -4.84, SIGMA: -1.46, APO : 1904.96
BATCH :../data/werner2019/MCB1, RUN #: 190, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 112, EFPA: -4.87, SIGMA: -1.30, APO : 1737.33
BATCH :../data/werner2019/MCB1, RUN #: 191, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 111, EFPA: -4.88, SIGMA: -1.19, APO : 1818.10
BATCH :../data/werner2019/MCB1, RUN #: 192, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 35, EFPA: -4.83, SIGMA: -0.38, APO : 3184.55
BATCH :../data/werner2019/MCB1, RUN #: 193, PROF: ../atmdata/Earth/LAT60S.txt, SAMPLE
↪#: 184, EFPA: -4.91, SIGMA: -0.57, APO : 1939.20
BATCH :../data/werner2019/MCB1, RUN #: 194, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 96, EFPA: -4.85, SIGMA: 1.09, APO : 1742.70
BATCH :../data/werner2019/MCB1, RUN #: 195, PROF: ../atmdata/Earth/LAT00N.txt, SAMPLE
↪#: 22, EFPA: -4.86, SIGMA: -0.01, APO : 1843.61
BATCH :../data/werner2019/MCB1, RUN #: 196, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 73, EFPA: -4.82, SIGMA: -1.92, APO : 1873.99
BATCH :../data/werner2019/MCB1, RUN #: 197, PROF: ../atmdata/Earth/LAT20S.txt, SAMPLE
↪#: 26, EFPA: -4.84, SIGMA: 0.28, APO : 1885.78
BATCH :../data/werner2019/MCB1, RUN #: 198, PROF: ../atmdata/Earth/LAT40S.txt, SAMPLE
↪#: 122, EFPA: -4.85, SIGMA: -1.06, APO : 1897.63
BATCH :../data/werner2019/MCB1, RUN #: 199, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 114, EFPA: -4.84, SIGMA: -0.12, APO : 3436.07
BATCH :../data/werner2019/MCB1, RUN #: 200, PROF: ../atmdata/Earth/LAT60N.txt, SAMPLE
↪#: 4, EFPA: -4.86, SIGMA: -0.87, APO : 3910.03
```

Load the terminal apoapsis, deceleration and heat rate data.

[85]:
```
apoap = np.loadtxt('../data/werner2019/MCB1/terminal_apoapsis_arr.txt')
peria = np.loadtxt('../data/werner2019/MCB1/terminal_periapsis_arr.txt')
decel = np.loadtxt('../data/werner2019/MCB1/acc_net_g_max_arr.txt')
heatr = np.loadtxt('../data/werner2019/MCB1/q_stag_max_arr.txt')
```

Remove cases which resulted in apoapsis < 1000 km or < 6000 km.

[86]:
```
del_index_low = np.where(apoap < 1000)
print(del_index_low)
```

```
(array([ 34,  65,  82,  85, 103, 111, 122, 124, 163, 187]),)
```

Seven cases resulted in apoapis less than 1000 km, and are considered to crash.

Remove these entries from the data before plotting.

[87]:
```
apoap_clean = np.delete(apoap, del_index_low)
peria_clean = np.delete(peria, del_index_low)
decel_clean = np.delete(decel, del_index_low)
heatr_clean = np.delete(heatr, del_index_low)
```

Also remove cases with apoapsis > 3000 km.

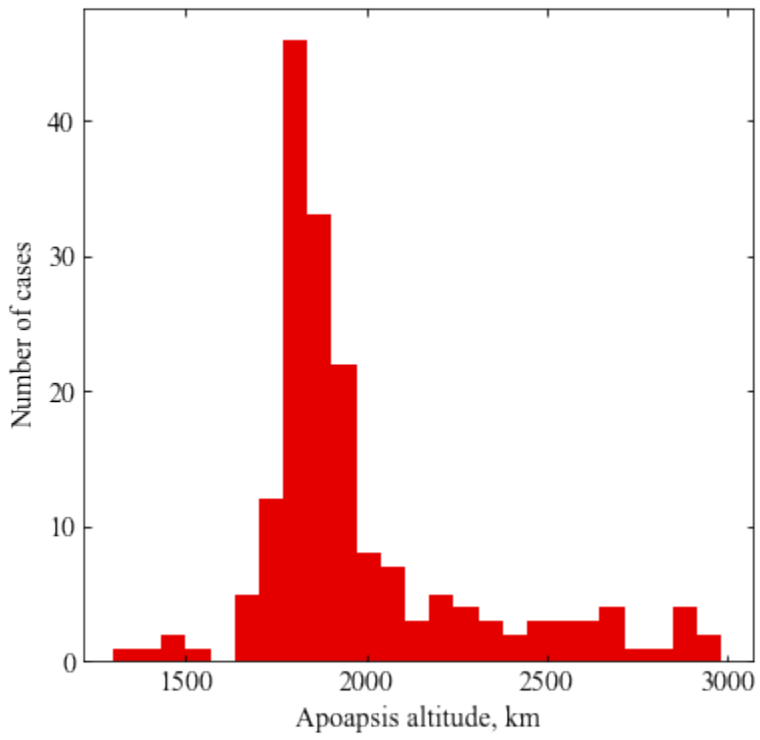
[88]:
```
del_index_high = np.where(apoap_clean > 3000)
print(del_index_high)
```

```
(array([ 41,  42,  79,  96, 114, 115, 129, 142, 154, 161, 168, 181, 188,
       189]),)
```

[89]:
```
apoap_clean2 = np.delete(apoap_clean, del_index_high)
peria_clean2 = np.delete(peria_clean, del_index_high)
decel_clean2 = np.delete(decel_clean, del_index_high)
heatr_clean2 = np.delete(heatr_clean, del_index_high)
```

[95]:
```
plt.figure(figsize=(6,6))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)
plt.hist(apoap_clean2, bins=25, color='xkcd:red')
plt.xlabel('Apoapsis altitude, km',fontsize=14)
plt.ylabel('Number of cases',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/werner-smallsat-apoa-hist.png',bbox_inches='tight')
plt.savefig('../plots/werner-smallsat-apoa-hist.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/werner-smallsat-apoa-hist.eps', dpi=300,bbox_inches='tight')
plt.show()
```



[96]:
```
plt.figure(figsize=(6,6))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
```

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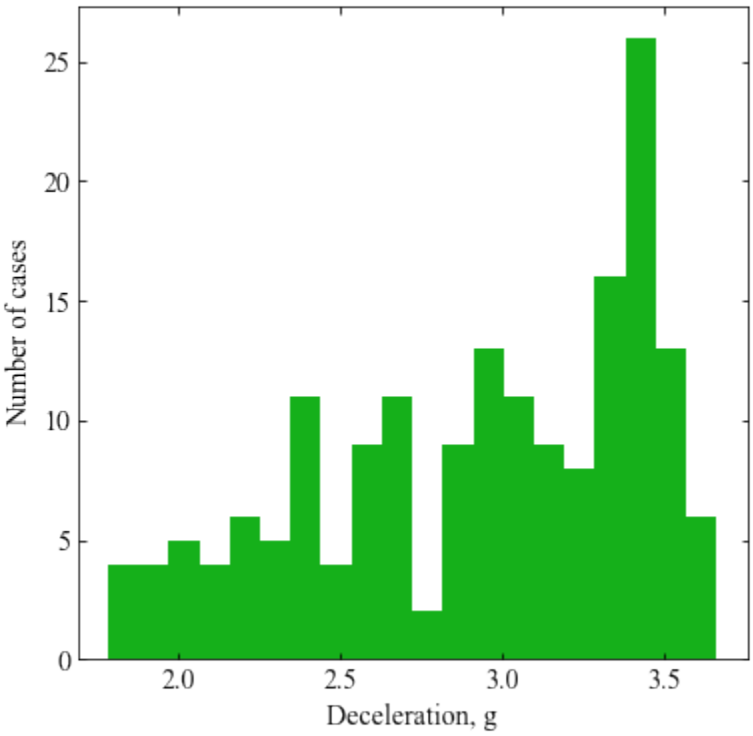
```
plt.rcParams.update(params)
plt.hist(decel_clean2, bins=20, color='xkcd:green')
plt.xlabel('Deceleration, g',fontsize=14)
plt.ylabel('Number of cases',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/werner-smallsat-decel-hist.png',bbox_inches='tight')
plt.savefig('../plots/werner-smallsat-decel-hist.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/werner-smallsat-decel-hist.eps', dpi=300,bbox_inches='tight')
plt.show()
```



[97]:
```
plt.figure(figsize=(6,6))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)
plt.hist(heatr_clean2, bins=20, color='xkcd:blue')
plt.xlabel('Heat rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Number of cases',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)
```

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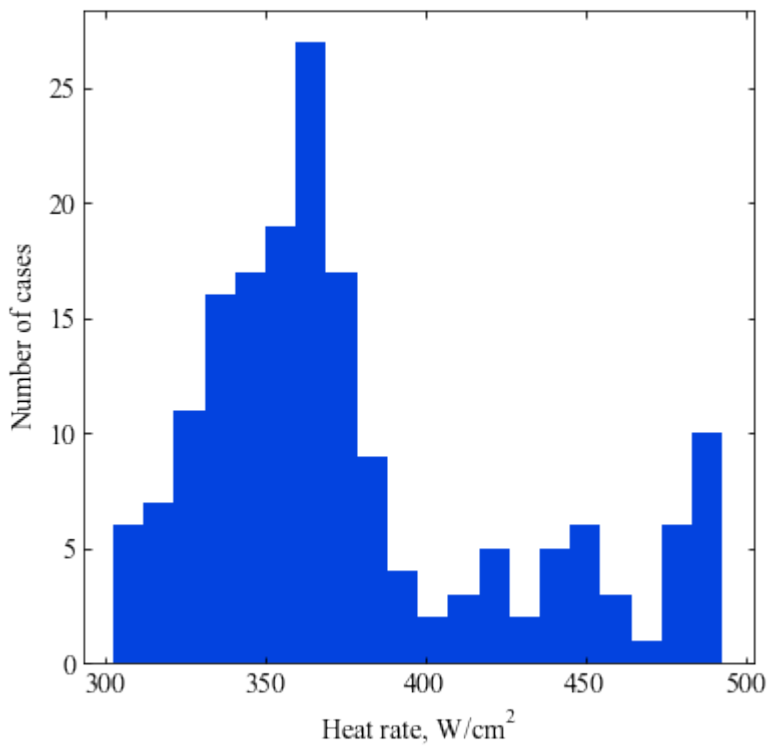
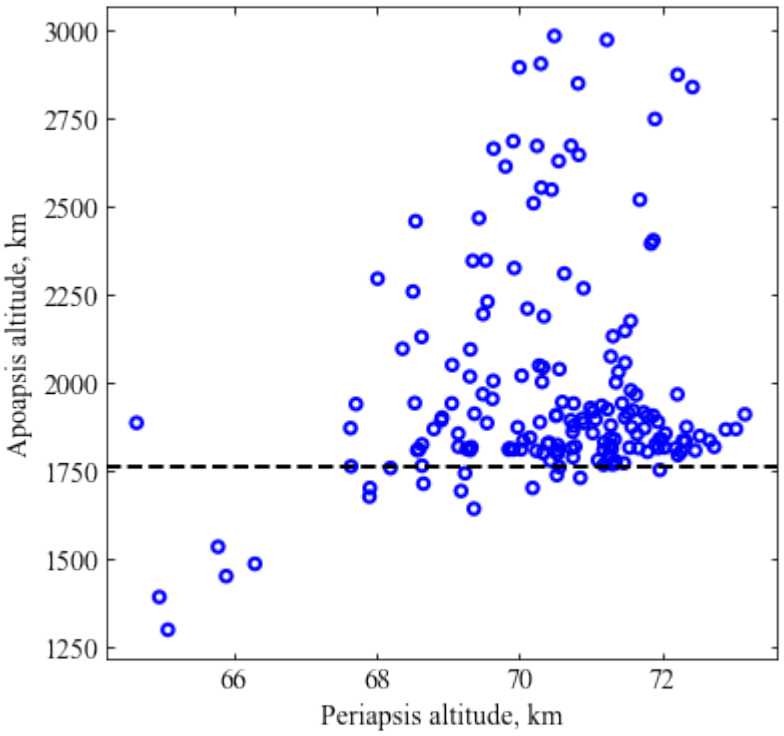
```
plt.savefig('../plots/werner-smallsat-heat-hist.png',bbox_inches='tight')
plt.savefig('../plots/werner-smallsat-heat-hist.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/werner-smallsat-heat-hist.eps', dpi=300,bbox_inches='tight')
plt.show()
```



[98]:
```
plt.figure(figsize=(6,6))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)
plt.scatter(peria_clean2, apoap_clean2, s=30, facecolors='none', edgecolors='b', lw=2)
plt.axhline(y=1760, lw=2.0, ls='dashed', color='k')
plt.xlabel('Periapsis altitude, km',fontsize=14)
plt.ylabel('Apoapsis altitude, km',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/werner-smallsat-apoa-peri.png',bbox_inches='tight')
plt.savefig('../plots/werner-smallsat-apoa-peri.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/werner-smallsat-apoa-peri.eps', dpi=300,bbox_inches='tight')
plt.show()
```



Find the percentage of cases which achieved apoapsis between 1000 and 3000 km.

[94]:
```
(np.size(apoap) - np.size(del_index_low) - np.size(del_index_high))*100/np.size(apoap)
```

[94]:
```
88.0
```

These results are different from those in the paper because of the different guidance schemes used here. This exercide did not attempt to optimize the guidance parameters. Further study can improve the apoapsis targeting.

4.51 Example - 51 - Mars SmallSat Aerocapture Demonstration - Part 1

This examples reproduces results from M.S.Werner and R.D.Braun, Mission Design and Performance Analysis of a Smallsat Aerocapture Flight Test, Journal of Spacecraft and Rockets, DOI: 10.2514/1.A33997.

[1]:
```
from IPython.display import Image
Image(filename='../plots/werner-smallsat.png', width=500)
```

[1]:

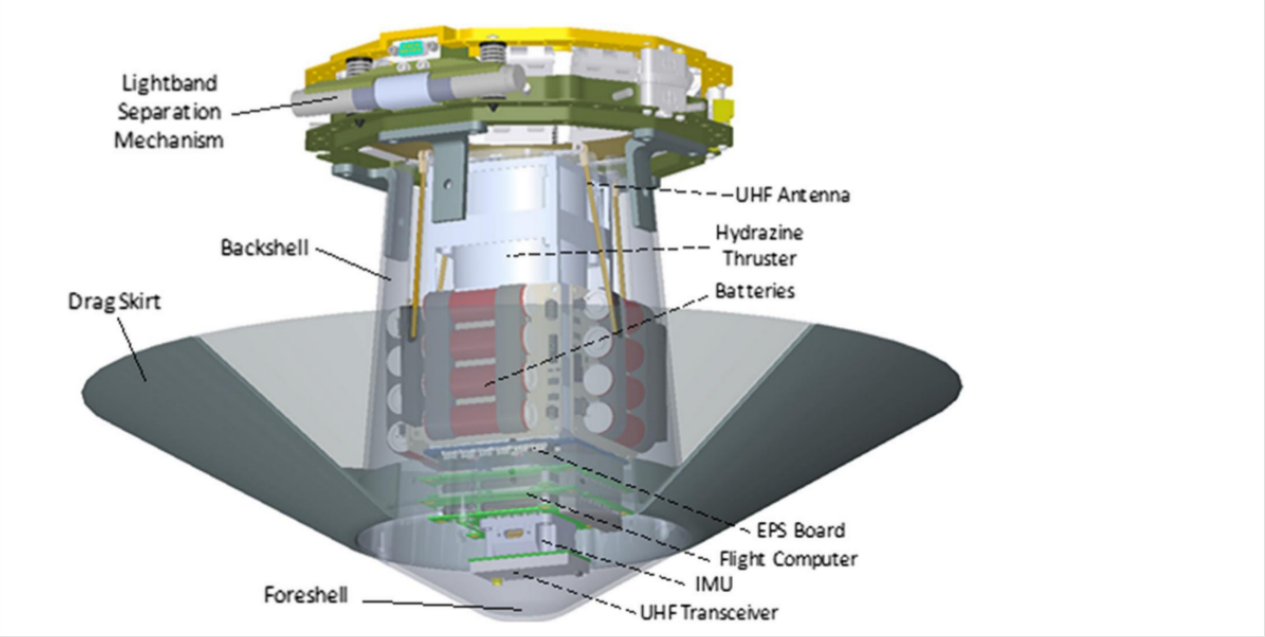


Image credit: M.S.Werner and R.D.Braun

[2]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[3]:
```
import numpy as np
from scipy import interpolate
import pandas as pd

import matplotlib.pyplot as plt
from matplotlib import rcParams
```

[4]:
```
planet = Planet('MARS')
planet.loadAtmosphereModel('../atmdata/Mars/mars-gram-avg.dat', 0 , 1 ,2, 3)
planet.h_skip = 150.0E3
```

[5]:
```
# Set up two vehicle objects, one for 450 km circular, one for 1-sol orbit
vehicle1=Vehicle('MarsSmallSat1', 25.97, 66.4, 0.0, np.pi*0.25**2, 0.0, 0.0563,␣
↪planet)
vehicle2=Vehicle('MarsSmallSat2', 25.97, 66.4, 0.0, np.pi*0.25**2, 0.0, 0.0563,␣
↪planet)

vehicle1.setInitialState(150.0,0.0,0.0,5.74,0.0,-5.00,0.0,0.0)
vehicle2.setInitialState(150.0,0.0,0.0,5.74,0.0,-5.00,0.0,0.0)

vehicle1.setSolverParams(1E-6)
vehicle2.setSolverParams(1E-6)

vehicle1.setDragModulationVehicleParams(66.4,4.72)
vehicle2.setDragModulationVehicleParams(66.4,4.72)
```

First, find the corridor bounds to select a target nominal EFPA for a nominal Mars atmosphere.

[6]:
```
underShootLimit, exitflag_us = vehicle1.findUnderShootLimitD(2400.0, 0.1, -30.0,-2.0,␣
↪1E-10, 450.0)
overShootLimit , exitflag_os = vehicle1.findOverShootLimitD(2400.0, 0.1, -30.0,-2.0,␣
↪1E-10,  450.0)

print("450 km circ.")
print("----------------")
print(underShootLimit, exitflag_us)
print(overShootLimit,  exitflag_os)
print("----------------")
underShootLimit, exitflag_us = vehicle2.findUnderShootLimitD(2400.0, 0.1, -30.0,-2.0,␣
↪1E-10, 33000.0)
overShootLimit , exitflag_os = vehicle2.findOverShootLimitD(2400.0, 0.1, -30.0,-2.0, ␣
↪1E-10,  33000.0)

print("1 sol.")
print("----------------")
print(underShootLimit, exitflag_us)
print(overShootLimit,  exitflag_os)
print("----------------")
```

```
450 km circ.
----------------
-12.472027218049334 1.0
-11.777824826203869 1.0
----------------
1 sol.
----------------
-12.142672350550129 1.0
-11.459108593211567 1.0
----------------
```

It is good practice to see how these corridor bounds vary with minimum, average, and maximum density atmospheres. We will check how much these corridor bounds change using +/- 3-sigma bounds from Mars GRAM output files.

Load three density profiles for minimum, average, and maximum scenarios from a GRAM output file.

[7]:
```
ATM_height, ATM_density_low, ATM_density_avg, ATM_density_high, ATM_density_pert =␣
↪planet.loadMonteCarloDensityFile2('../atmdata/Mars/LAT00N.txt', 0, 1, 2, 3, 4,␣
↪heightInKmFlag=True)
density_int_low = planet.loadAtmosphereModel5(ATM_height, ATM_density_low, ATM_
↪density_avg, ATM_density_high, ATM_density_pert, -3.0, 156, 200)
density_int_avg = planet.loadAtmosphereModel5(ATM_height, ATM_density_low, ATM_
↪density_avg, ATM_density_high, ATM_density_pert,  0.0, 156, 200)
density_int_hig = planet.loadAtmosphereModel5(ATM_height, ATM_density_low, ATM_
↪density_avg, ATM_density_high, ATM_density_pert, +3.0, 156, 200)
```

Set the planet density_int attribute to density_int_low

[8]:
```
planet.density_int = density_int_low
```

Compute the corridor bounds for low density atmosphere.

[9]:
```
underShootLimit, exitflag_us =  vehicle1.findUnderShootLimitD(2400.0, 0.1, -30.0,-2.0,
↪ 1E-10, 450.0)
overShootLimit , exitflag_os =  vehicle1.findOverShootLimitD(2400.0, 0.1, -30.0,-2.0,␣
↪1E-10,  450.0)
```

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```
print("450 km circ.")
print("----------------")
print(underShootLimit, exitflag_us)
print(overShootLimit,  exitflag_os)
print("----------------")

underShootLimit, exitflag_us =  vehicle2.findUnderShootLimitD(2400.0, 0.1, -30.0,-2.0,
↪ 1E-10, 33000.0)
overShootLimit , exitflag_os =  vehicle2.findOverShootLimitD(2400.0, 0.1, -30.0,-2.0,␣
↪1E-10,  33000.0)
print("1-sol.")
print("----------------")
print(underShootLimit, exitflag_us)
print(overShootLimit,  exitflag_os)
print("----------------")
```

```
/home/athul/anaconda3/lib/python3.7/site-packages/AMAT-2.1.2-py3.7.egg/AMAT/vehicle.
↪py:504: RuntimeWarning: invalid value encountered in sqrt
  ans[:]  = 1.8980E-8 * (rho_vec[:]/self.RN)**0.5 * v[:]**3.0
```

```
450 km circ.
----------------
-12.605845816528017 1.0
-11.993464708328247 1.0
----------------
1-sol.
----------------
-12.326484654251544 1.0
-11.651159566965362 1.0
----------------
```

Repeat for average and maximum density atmospheres.

[10]:
```
planet.density_int = density_int_avg
```

[11]:
```
underShootLimit, exitflag_us =  vehicle1.findUnderShootLimitD(2400.0, 0.1, -30.0,-2.0,
↪ 1E-10, 450.0)
overShootLimit , exitflag_os =  vehicle1.findOverShootLimitD(2400.0, 0.1, -30.0,-2.0,␣
↪1E-10,  450.0)

print("450 km circ.")
print("----------------")
print(underShootLimit, exitflag_us)
print(overShootLimit,  exitflag_os)
print("----------------")

underShootLimit, exitflag_us =  vehicle2.findUnderShootLimitD(2400.0, 0.1, -30.0,-2.0,
↪ 1E-10, 33000.0)
overShootLimit , exitflag_os =  vehicle2.findOverShootLimitD(2400.0, 0.1, -30.0,-2.0,␣
↪1E-10,  33000.0)
print("1-sol.")
print("----------------")
print(underShootLimit, exitflag_us)
print(overShootLimit,  exitflag_os)
print("----------------")
```

```
450 km circ.
----------------
```

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```
-12.545852635754272 1.0
-11.894532441678166 1.0
----------------
1-sol.
----------------
-12.250274132129562 1.0
-11.517179594695335 1.0
----------------
```

[12]:
```
planet.density_int = density_int_hig
```

[13]:
```
underShootLimit, exitflag_us =  vehicle1.findUnderShootLimitD(2400.0, 0.1, -30.0,-2.0,
↪ 1E-10, 450.0)
overShootLimit , exitflag_os =  vehicle1.findOverShootLimitD(2400.0, 0.1, -30.0,-2.0,␣
↪1E-10,  450.0)

print("450 km circ.")
print("----------------")
print(underShootLimit, exitflag_us)
print(overShootLimit,  exitflag_os)
print("----------------")

underShootLimit, exitflag_us =  vehicle2.findUnderShootLimitD(2400.0, 0.1, -30.0,-2.0,
↪ 1E-10, 33000.0)
overShootLimit , exitflag_os =  vehicle2.findOverShootLimitD(2400.0, 0.1, -30.0,-2.0,␣
↪1E-10,  33000.0)
print("1-sol.")
print("----------------")
print(underShootLimit, exitflag_us)
print(overShootLimit,  exitflag_os)
print("----------------")
```

```
450 km circ.
----------------
-12.486791579358396 1.0
-11.79002801637398 1.0
----------------
1-sol.
----------------
-12.178909841590212 1.0
-11.394518235101714 1.0
----------------
```

The above numbers indicate that corridor bounds do not vary that much with atmospheric variations. The corridor is approximately 0.70 deg wide for both target orbits.

[14]:
```
12.47 - 11.77
```

[14]:
```
0.7000000000000011
```

[15]:
```
12.14 - 11.45
```

[15]:
```
0.6900000000000013
```

The mid-corridor is typically a good place to start. We will use the mean of the corridor bounds for the average atmosphere.

[16]:
```
0.5*(-12.47-11.77) # 450 km
```

[16]:
```
-12.120000000000001
```

[17]:
```
0.5*(-12.14-11.45) # 1-sol
```

[17]:
```
-11.795
```

We will propogate a nominal guided trajectory to reproduce Fig. 10 from the paper.

[18]:
```
planet.loadAtmosphereModel('../atmdata/Mars/mars-gram-avg.dat', 0 , 1 ,2, 3)
```

[19]:
```
# Set planet.h_low to 10 km, if vehicle dips below this level
# trajctory is terminated.
planet.h_low=10.0E3

# Set target orbit = 450 km x 450 km, tolerance = 50 km
vehicle1.setTargetOrbitParams(450.0, 450.0, 20.0)
vehicle2.setTargetOrbitParams(450.0, 33000.0, 20.0)

# Set entry phase parameters
# v_switch_kms = 2.0, lowAlt_km = 20.0,
# numPoints_lowAlt = 101, hdot_threshold = -200.0 m/s.
# These are somewhat arbitary based on experience.
vehicle1.setDragEntryPhaseParams(2.0, 20.0, 101, -200.0)
vehicle2.setDragEntryPhaseParams(2.0, 20.0, 101, -200.0)

# Set beta_1 and beta_ratio
vehicle1.setDragModulationVehicleParams(66.4,4.72)
vehicle2.setDragModulationVehicleParams(66.4,4.72)

# Set vehicle initial state
vehicle1.setInitialState(150.0,0.0,0.0,5.74,0.0,-12.12,0.0,0.0)
vehicle2.setInitialState(150.0,0.0,0.0,5.74,0.0,-11.80,0.0,0.0)
```

[20]:
```
# Propogate a single vehicle trajectory
vehicle1.propogateGuidedEntryD(1.0,1.0,0.1,2400.0)
vehicle2.propogateGuidedEntryD(1.0,1.0,0.1,2400.0)
```

[21]:
```
plt.figure(figsize=(6,4))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)
plt.plot(vehicle1.v_kms_full, vehicle1.h_km_full, 'r-', linewidth=2.0)
plt.plot(vehicle2.v_kms_full, vehicle2.h_km_full, 'r--', linewidth=2.0)

plt.xlabel('Planet-relative speed, km/s',fontsize=14)
plt.ylabel('Altitude, km',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)
plt.grid(linestyle='dotted', linewidth=0.5)

plt.savefig('../plots/werner-smallsat-nominal-altitude-speed-mars.png',bbox_inches=
↪'tight')
```

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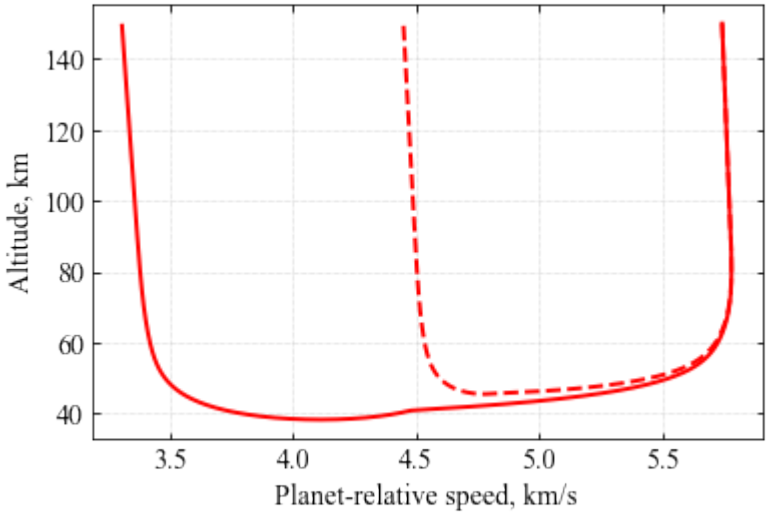
```
plt.savefig('../plots/werner-smallsat-nominal-altitude-speed-mars.pdf', dpi=300,bbox_
↪inches='tight')
plt.savefig('../plots/werner-smallsat-nominal-altitude-speed-mars.eps', dpi=300,bbox_
↪inches='tight')

plt.show()
```

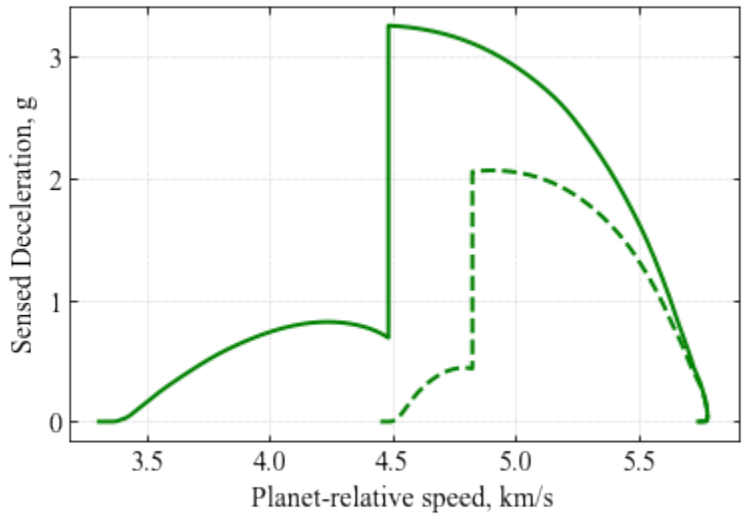


[22]:
```
plt.figure(figsize=(6,4))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)
plt.plot(vehicle1.v_kms_full, vehicle1.acc_net_g_full, 'g-', linewidth=2.0)
plt.plot(vehicle2.v_kms_full, vehicle2.acc_net_g_full, 'g--', linewidth=2.0)

plt.xlabel('Planet-relative speed, km/s',fontsize=14)
plt.ylabel('Sensed Deceleration, g',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)
plt.grid(linestyle='dotted', linewidth=0.5)

plt.savefig('../plots/werner-smallsat-nominal-speed-decel-mars.png',bbox_inches='tight
↪')
plt.savefig('../plots/werner-smallsat-nominal-speed-decel-mars.pdf', dpi=300,bbox_
↪inches='tight')
plt.savefig('../plots/werner-smallsat-nominal-speed-decel-mars.eps', dpi=300,bbox_
↪inches='tight')

plt.show()
```

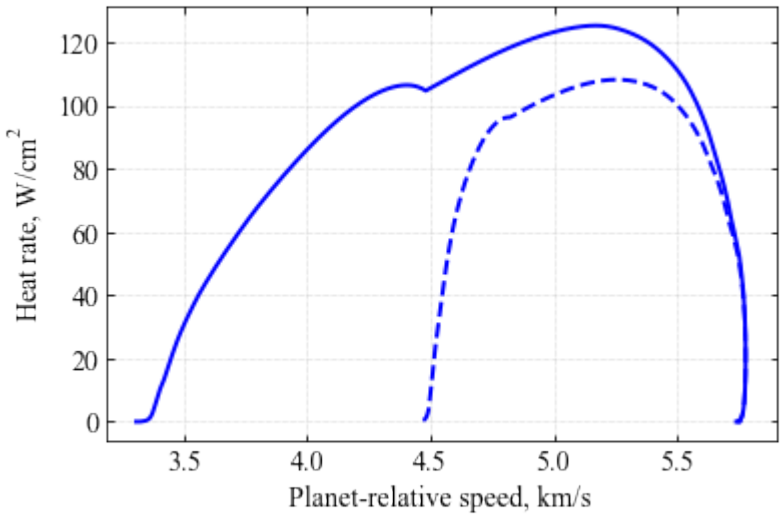


[23]:
```
plt.figure(figsize=(6,4))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)
plt.plot(vehicle1.v_kms_full, vehicle1.q_stag_total_full, 'b-', linewidth=2.0)
plt.plot(vehicle2.v_kms_full, vehicle2.q_stag_total_full, 'b--', linewidth=2.0)


plt.xlabel('Planet-relative speed, km/s',fontsize=14)
plt.ylabel('Heat rate, '+r'$W/cm^2$',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)
plt.grid(linestyle='dotted', linewidth=0.5)

plt.savefig('../plots/werner-smallsat-nominal-speed-heat-mars.png',bbox_inches='tight
↪')
plt.savefig('../plots/werner-smallsat-nominal-speed-heat-mars.pdf', dpi=300,bbox_
↪inches='tight')
plt.savefig('../plots/werner-smallsat-nominal-speed-heat-mars.eps', dpi=300,bbox_
↪inches='tight')

plt.show()
```



[24]:
```
vehicle1.terminal_apoapsis
```

[24]:
```
612.6745425743503
```

[25]:
```
vehicle2.terminal_apoapsis
```

[25]:
```
32890.38040256599
```

4.52 Example - 52 - Mars SmallSat Aerocapture Demonstration - Part 2

In this example, we will use Monte Carlo simulations to assess flight performance. Reference: M.S.Werner and R.D.Braun, Mission Design and Performance Analysis of a Smallsat Aerocapture Flight Test, Journal of Spacecraft and Rockets, DOI: 10.2514/1.A33997

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
from scipy import interpolate
import pandas as pd

import matplotlib.pyplot as plt
from matplotlib import rcParams
from matplotlib.patches import Polygon
```

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("MARS")
planet.loadAtmosphereModel('../atmdata/Mars/mars-gram-avg.dat', 0 , 1 ,2, 3)
planet.h_skip = 150000.0
planet.h_low=10.0E3

# Set up the drag modulation vehicle.
vehicle=Vehicle('MarsSmallSat1', 25.97, 66.4, 0.0, np.pi*0.25**2, 0.0, 0.0563, planet)
```

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```
vehicle.setInitialState(150.0,0.0,0.0,5.74,0.0,-12.12,0.0,0.0)
vehicle.setSolverParams(1E-6)
vehicle.setDragModulationVehicleParams(66.4,4.72)

# Set up the drag modulation entry phase guidance parameters.
vehicle.setDragEntryPhaseParams(2.0, 15.0, 101, -200.0)

# Set the target orbit parameters.
vehicle.setTargetOrbitParams(450.0, 450.0, 20.0)

# Define the path to atmospheric files to be used for the Monte Carlo simulations.
atmfiles = ['../atmdata/Mars/LAT00N-N1000.txt']

# Set up the Monte Carlo simulation for drag modulation.
# NPOS = 156, NMONTE = 1000
# Target EFPA = -12.05 deg
# EFPA 1-sigma error = +/- 0.067 deg
# Nominal beta_1 = 66.4 kg/m2
# beta_1 1-sigma = 0.0
# guidance time step for entry = 1.0s (Freq. = 1 Hz)
# guidance time step after jettison = 1.0 s
# max. solver time step = 0.1 s
# max. time used by solver = 2400 s

vehicle.setupMonteCarloSimulationD(156, 1000, atmfiles, 0 , 1, 2, 3, 4, True,
                                   -12.05,  0.0667, 66.4, 0.0,
                                    1.0, 1.0, 0.1, 2400.0)
# Run 200 trajectories
vehicle.runMonteCarloD(200, '../data/werner2019/MCB1-Mars')
```

```
BATCH :../data/werner2019/MCB1-Mars, RUN #: 1, PROF: ../atmdata/Mars/LAT00N-N1000.txt,
↪ SAMPLE #: 473, EFPA: -12.02, SIGMA: 0.05, APO : 470.71
BATCH :../data/werner2019/MCB1-Mars, RUN #: 2, PROF: ../atmdata/Mars/LAT00N-N1000.txt,
↪ SAMPLE #: 948, EFPA: -12.11, SIGMA: -0.68, APO : 249.09
BATCH :../data/werner2019/MCB1-Mars, RUN #: 3, PROF: ../atmdata/Mars/LAT00N-N1000.txt,
↪ SAMPLE #: 982, EFPA: -12.11, SIGMA: -0.00, APO : 183.77
BATCH :../data/werner2019/MCB1-Mars, RUN #: 4, PROF: ../atmdata/Mars/LAT00N-N1000.txt,
↪ SAMPLE #: 909, EFPA: -12.14, SIGMA: 0.97, APO : 165.56
BATCH :../data/werner2019/MCB1-Mars, RUN #: 5, PROF: ../atmdata/Mars/LAT00N-N1000.txt,
↪ SAMPLE #: 795, EFPA: -11.96, SIGMA: 0.19, APO : 467.54
BATCH :../data/werner2019/MCB1-Mars, RUN #: 6, PROF: ../atmdata/Mars/LAT00N-N1000.txt,
↪ SAMPLE #: 493, EFPA: -12.00, SIGMA: 0.10, APO : 442.98
BATCH :../data/werner2019/MCB1-Mars, RUN #: 7, PROF: ../atmdata/Mars/LAT00N-N1000.txt,
↪ SAMPLE #: 255, EFPA: -12.00, SIGMA: 0.47, APO : 474.19
BATCH :../data/werner2019/MCB1-Mars, RUN #: 8, PROF: ../atmdata/Mars/LAT00N-N1000.txt,
↪ SAMPLE #: 772, EFPA: -12.01, SIGMA: -0.41, APO : 470.02
BATCH :../data/werner2019/MCB1-Mars, RUN #: 9, PROF: ../atmdata/Mars/LAT00N-N1000.txt,
↪ SAMPLE #: 819, EFPA: -12.08, SIGMA: -0.51, APO : 383.96
BATCH :../data/werner2019/MCB1-Mars, RUN #: 10, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 707, EFPA: -12.11, SIGMA: -0.56, APO : 396.13
BATCH :../data/werner2019/MCB1-Mars, RUN #: 11, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 348, EFPA: -12.15, SIGMA: -0.59, APO : 30.81
BATCH :../data/werner2019/MCB1-Mars, RUN #: 12, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 183, EFPA: -12.07, SIGMA: 1.09, APO : 314.32
BATCH :../data/werner2019/MCB1-Mars, RUN #: 13, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 236, EFPA: -12.05, SIGMA: 1.01, APO : 307.66
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BATCH :../data/werner2019/MCB1-Mars, RUN #: 14, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 517, EFPA: -12.05, SIGMA: 1.79, APO : 262.04
BATCH :../data/werner2019/MCB1-Mars, RUN #: 15, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 643, EFPA: -12.15, SIGMA: -0.94, APO : 626.13
BATCH :../data/werner2019/MCB1-Mars, RUN #: 16, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 95, EFPA: -11.93, SIGMA: -0.67, APO : 477.67
BATCH :../data/werner2019/MCB1-Mars, RUN #: 17, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 718, EFPA: -12.02, SIGMA: 0.07, APO : 410.59
BATCH :../data/werner2019/MCB1-Mars, RUN #: 18, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 18, EFPA: -12.07, SIGMA: -1.54, APO : 444.56

/home/athul/anaconda3/lib/python3.7/site-packages/AMAT-2.1.2-py3.7.egg/AMAT/vehicle.
↪py:504: RuntimeWarning: invalid value encountered in sqrt
  ans[:]  = 1.8980E-8 * (rho_vec[:]/self.RN)**0.5 * v[:]**3.0

BATCH :../data/werner2019/MCB1-Mars, RUN #: 19, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 42, EFPA: -12.08, SIGMA: -0.68, APO : 462.32
BATCH :../data/werner2019/MCB1-Mars, RUN #: 20, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 291, EFPA: -11.98, SIGMA: 0.15, APO : 428.46
BATCH :../data/werner2019/MCB1-Mars, RUN #: 21, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 54, EFPA: -12.16, SIGMA: 1.26, APO : 30.55
BATCH :../data/werner2019/MCB1-Mars, RUN #: 22, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 471, EFPA: -12.06, SIGMA: -0.18, APO : 429.90
BATCH :../data/werner2019/MCB1-Mars, RUN #: 23, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 404, EFPA: -11.98, SIGMA: -0.57, APO : 445.32
BATCH :../data/werner2019/MCB1-Mars, RUN #: 24, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 206, EFPA: -11.97, SIGMA: -0.55, APO : 473.24
BATCH :../data/werner2019/MCB1-Mars, RUN #: 25, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 913, EFPA: -12.10, SIGMA: 0.73, APO : 346.17
BATCH :../data/werner2019/MCB1-Mars, RUN #: 26, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 24, EFPA: -12.07, SIGMA: 0.01, APO : 537.43
BATCH :../data/werner2019/MCB1-Mars, RUN #: 27, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 398, EFPA: -12.02, SIGMA: 0.96, APO : 434.48
BATCH :../data/werner2019/MCB1-Mars, RUN #: 28, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 318, EFPA: -12.05, SIGMA: -0.05, APO : 445.43
BATCH :../data/werner2019/MCB1-Mars, RUN #: 29, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 200, EFPA: -12.04, SIGMA: 0.59, APO : 418.05
BATCH :../data/werner2019/MCB1-Mars, RUN #: 30, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 237, EFPA: -12.08, SIGMA: 0.45, APO : 397.03
BATCH :../data/werner2019/MCB1-Mars, RUN #: 31, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 708, EFPA: -12.00, SIGMA: -1.92, APO : 484.91
BATCH :../data/werner2019/MCB1-Mars, RUN #: 32, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 727, EFPA: -12.03, SIGMA: -1.57, APO : 470.89
BATCH :../data/werner2019/MCB1-Mars, RUN #: 33, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 526, EFPA: -11.99, SIGMA: -0.34, APO : 470.23
BATCH :../data/werner2019/MCB1-Mars, RUN #: 34, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 479, EFPA: -12.07, SIGMA: 0.45, APO : 477.59
BATCH :../data/werner2019/MCB1-Mars, RUN #: 35, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 454, EFPA: -12.13, SIGMA: 1.18, APO : 219.58
BATCH :../data/werner2019/MCB1-Mars, RUN #: 36, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 573, EFPA: -11.91, SIGMA: -0.10, APO : 528.42
BATCH :../data/werner2019/MCB1-Mars, RUN #: 37, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 207, EFPA: -12.01, SIGMA: 0.82, APO : 436.65
BATCH :../data/werner2019/MCB1-Mars, RUN #: 38, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 597, EFPA: -12.08, SIGMA: 0.11, APO : 375.03
BATCH :../data/werner2019/MCB1-Mars, RUN #: 39, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 379, EFPA: -12.10, SIGMA: 1.37, APO : 231.86
BATCH :../data/werner2019/MCB1-Mars, RUN #: 40, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 848, EFPA: -12.12, SIGMA: -2.18, APO : 370.00
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BATCH :../data/werner2019/MCB1-Mars, RUN #: 41, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 257, EFPA: -12.01, SIGMA: -0.02, APO : 439.20
BATCH :../data/werner2019/MCB1-Mars, RUN #: 42, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 738, EFPA: -12.01, SIGMA: -1.37, APO : 435.96
BATCH :../data/werner2019/MCB1-Mars, RUN #: 43, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 847, EFPA: -12.06, SIGMA: 0.42, APO : 287.91
BATCH :../data/werner2019/MCB1-Mars, RUN #: 44, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 892, EFPA: -12.12, SIGMA: -0.27, APO : 485.94
BATCH :../data/werner2019/MCB1-Mars, RUN #: 45, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 229, EFPA: -12.05, SIGMA: -1.43, APO : 457.72
BATCH :../data/werner2019/MCB1-Mars, RUN #: 46, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 471, EFPA: -11.96, SIGMA: -0.19, APO : 469.02
BATCH :../data/werner2019/MCB1-Mars, RUN #: 47, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 107, EFPA: -12.00, SIGMA: 0.39, APO : 423.73
BATCH :../data/werner2019/MCB1-Mars, RUN #: 48, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 128, EFPA: -12.03, SIGMA: 1.40, APO : 317.12
BATCH :../data/werner2019/MCB1-Mars, RUN #: 49, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 427, EFPA: -12.10, SIGMA: -0.70, APO : 29.04
BATCH :../data/werner2019/MCB1-Mars, RUN #: 50, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 497, EFPA: -12.07, SIGMA: -0.69, APO : 446.25
BATCH :../data/werner2019/MCB1-Mars, RUN #: 51, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 206, EFPA: -11.99, SIGMA: 0.40, APO : 431.06
BATCH :../data/werner2019/MCB1-Mars, RUN #: 52, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 579, EFPA: -12.04, SIGMA: -0.30, APO : 404.20
BATCH :../data/werner2019/MCB1-Mars, RUN #: 53, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 738, EFPA: -11.97, SIGMA: 0.37, APO : 455.28
BATCH :../data/werner2019/MCB1-Mars, RUN #: 54, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 781, EFPA: -12.11, SIGMA: -1.31, APO : 307.05
BATCH :../data/werner2019/MCB1-Mars, RUN #: 55, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 608, EFPA: -12.09, SIGMA: -0.49, APO : 280.04
BATCH :../data/werner2019/MCB1-Mars, RUN #: 56, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 586, EFPA: -11.89, SIGMA: -0.31, APO : 3114.30
BATCH :../data/werner2019/MCB1-Mars, RUN #: 57, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 170, EFPA: -12.08, SIGMA: 1.99, APO : 359.22
BATCH :../data/werner2019/MCB1-Mars, RUN #: 58, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 555, EFPA: -12.21, SIGMA: 0.20, APO : 30.35
BATCH :../data/werner2019/MCB1-Mars, RUN #: 59, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 870, EFPA: -11.96, SIGMA: -1.26, APO : 2180.48
BATCH :../data/werner2019/MCB1-Mars, RUN #: 60, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 218, EFPA: -12.07, SIGMA: 0.67, APO : 392.25
BATCH :../data/werner2019/MCB1-Mars, RUN #: 61, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 136, EFPA: -12.05, SIGMA: 0.93, APO : 243.16
BATCH :../data/werner2019/MCB1-Mars, RUN #: 62, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 819, EFPA: -12.03, SIGMA: 0.07, APO : 475.63
BATCH :../data/werner2019/MCB1-Mars, RUN #: 63, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 398, EFPA: -11.97, SIGMA: 0.79, APO : 422.55
BATCH :../data/werner2019/MCB1-Mars, RUN #: 64, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 899, EFPA: -12.07, SIGMA: 1.07, APO : 384.39
BATCH :../data/werner2019/MCB1-Mars, RUN #: 65, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 665, EFPA: -12.12, SIGMA: -0.33, APO : 628.14
BATCH :../data/werner2019/MCB1-Mars, RUN #: 66, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 727, EFPA: -12.08, SIGMA: -1.20, APO : 562.68
BATCH :../data/werner2019/MCB1-Mars, RUN #: 67, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 767, EFPA: -11.99, SIGMA: -0.34, APO : 466.43
BATCH :../data/werner2019/MCB1-Mars, RUN #: 68, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 21, EFPA: -11.97, SIGMA: -1.06, APO : 486.86
BATCH :../data/werner2019/MCB1-Mars, RUN #: 69, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 104, EFPA: -12.02, SIGMA: 0.82, APO : 439.20
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BATCH :../data/werner2019/MCB1-Mars, RUN #: 70, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 850, EFPA: -12.08, SIGMA: 0.15, APO : 333.87
BATCH :../data/werner2019/MCB1-Mars, RUN #: 71, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 63, EFPA: -12.14, SIGMA: 0.36, APO : 329.06
BATCH :../data/werner2019/MCB1-Mars, RUN #: 72, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 898, EFPA: -12.12, SIGMA: -1.67, APO : 285.72
BATCH :../data/werner2019/MCB1-Mars, RUN #: 73, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 861, EFPA: -12.00, SIGMA: -0.27, APO : 478.64
BATCH :../data/werner2019/MCB1-Mars, RUN #: 74, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 883, EFPA: -11.98, SIGMA: 0.52, APO : 470.65
BATCH :../data/werner2019/MCB1-Mars, RUN #: 75, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 204, EFPA: -12.07, SIGMA: -0.67, APO : 402.21
BATCH :../data/werner2019/MCB1-Mars, RUN #: 76, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 431, EFPA: -12.09, SIGMA: -1.27, APO : 443.38
BATCH :../data/werner2019/MCB1-Mars, RUN #: 77, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 51, EFPA: -11.99, SIGMA: 1.09, APO : 467.80
BATCH :../data/werner2019/MCB1-Mars, RUN #: 78, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 835, EFPA: -12.16, SIGMA: -0.06, APO : 180.61
BATCH :../data/werner2019/MCB1-Mars, RUN #: 79, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 424, EFPA: -12.20, SIGMA: -1.29, APO : 652.95
BATCH :../data/werner2019/MCB1-Mars, RUN #: 80, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 558, EFPA: -11.91, SIGMA: 0.10, APO : 616.51
BATCH :../data/werner2019/MCB1-Mars, RUN #: 81, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 184, EFPA: -11.96, SIGMA: 0.77, APO : 475.03
BATCH :../data/werner2019/MCB1-Mars, RUN #: 82, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 993, EFPA: -11.97, SIGMA: 0.64, APO : 453.54
BATCH :../data/werner2019/MCB1-Mars, RUN #: 83, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 501, EFPA: -11.99, SIGMA: -0.83, APO : 468.49
BATCH :../data/werner2019/MCB1-Mars, RUN #: 84, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 493, EFPA: -11.99, SIGMA: -0.11, APO : 508.56
BATCH :../data/werner2019/MCB1-Mars, RUN #: 85, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 638, EFPA: -12.14, SIGMA: -0.23, APO : 29.83
BATCH :../data/werner2019/MCB1-Mars, RUN #: 86, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 340, EFPA: -12.22, SIGMA: 1.23, APO : 29.68
BATCH :../data/werner2019/MCB1-Mars, RUN #: 87, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 218, EFPA: -12.07, SIGMA: 0.48, APO : 385.04
BATCH :../data/werner2019/MCB1-Mars, RUN #: 88, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 318, EFPA: -11.93, SIGMA: 1.64, APO : 483.52
BATCH :../data/werner2019/MCB1-Mars, RUN #: 89, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 817, EFPA: -12.13, SIGMA: 0.94, APO : 384.50
BATCH :../data/werner2019/MCB1-Mars, RUN #: 90, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 894, EFPA: -12.07, SIGMA: 0.56, APO : 264.38
BATCH :../data/werner2019/MCB1-Mars, RUN #: 91, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 541, EFPA: -12.09, SIGMA: -0.64, APO : 389.50
BATCH :../data/werner2019/MCB1-Mars, RUN #: 92, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 160, EFPA: -12.12, SIGMA: -1.07, APO : 328.40
BATCH :../data/werner2019/MCB1-Mars, RUN #: 93, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 723, EFPA: -12.07, SIGMA: 1.14, APO : 262.13
BATCH :../data/werner2019/MCB1-Mars, RUN #: 94, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 473, EFPA: -12.03, SIGMA: -1.37, APO : 467.98
BATCH :../data/werner2019/MCB1-Mars, RUN #: 95, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 803, EFPA: -12.08, SIGMA: -0.36, APO : 488.40
BATCH :../data/werner2019/MCB1-Mars, RUN #: 96, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 571, EFPA: -12.01, SIGMA: 0.73, APO : 336.25
BATCH :../data/werner2019/MCB1-Mars, RUN #: 97, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 941, EFPA: -12.13, SIGMA: 0.54, APO : 393.71
BATCH :../data/werner2019/MCB1-Mars, RUN #: 98, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 337, EFPA: -12.08, SIGMA: -0.36, APO : 300.38
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BATCH :../data/werner2019/MCB1-Mars, RUN #: 99, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 870, EFPA: -12.04, SIGMA: -0.65, APO : 485.49
BATCH :../data/werner2019/MCB1-Mars, RUN #: 100, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 740, EFPA: -12.15, SIGMA: -1.16, APO : 672.33
BATCH :../data/werner2019/MCB1-Mars, RUN #: 101, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 261, EFPA: -12.10, SIGMA: 1.70, APO : 28.73
BATCH :../data/werner2019/MCB1-Mars, RUN #: 102, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 139, EFPA: -12.03, SIGMA: -0.76, APO : 477.85
BATCH :../data/werner2019/MCB1-Mars, RUN #: 103, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 828, EFPA: -12.14, SIGMA: 1.64, APO : 29.30
BATCH :../data/werner2019/MCB1-Mars, RUN #: 104, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 523, EFPA: -11.99, SIGMA: 1.19, APO : 299.59
BATCH :../data/werner2019/MCB1-Mars, RUN #: 105, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 86, EFPA: -12.08, SIGMA: -0.91, APO : 391.42
BATCH :../data/werner2019/MCB1-Mars, RUN #: 106, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 650, EFPA: -12.08, SIGMA: 1.97, APO : 302.54
BATCH :../data/werner2019/MCB1-Mars, RUN #: 107, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 819, EFPA: -12.04, SIGMA: 0.84, APO : 351.63
BATCH :../data/werner2019/MCB1-Mars, RUN #: 108, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 567, EFPA: -12.02, SIGMA: 1.34, APO : 565.22
BATCH :../data/werner2019/MCB1-Mars, RUN #: 109, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 826, EFPA: -12.02, SIGMA: 0.21, APO : 449.97
BATCH :../data/werner2019/MCB1-Mars, RUN #: 110, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 814, EFPA: -11.95, SIGMA: -2.35, APO : 470.46
BATCH :../data/werner2019/MCB1-Mars, RUN #: 111, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 383, EFPA: -12.07, SIGMA: 0.18, APO : 438.04
BATCH :../data/werner2019/MCB1-Mars, RUN #: 112, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 966, EFPA: -12.04, SIGMA: 0.45, APO : 346.67
BATCH :../data/werner2019/MCB1-Mars, RUN #: 113, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 121, EFPA: -12.02, SIGMA: 1.17, APO : 311.76
BATCH :../data/werner2019/MCB1-Mars, RUN #: 114, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 470, EFPA: -11.98, SIGMA: -0.82, APO : 491.70
BATCH :../data/werner2019/MCB1-Mars, RUN #: 115, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 43, EFPA: -12.00, SIGMA: -0.37, APO : 445.74
BATCH :../data/werner2019/MCB1-Mars, RUN #: 116, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 363, EFPA: -12.13, SIGMA: -1.66, APO : 401.13
BATCH :../data/werner2019/MCB1-Mars, RUN #: 117, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 592, EFPA: -12.06, SIGMA: -1.24, APO : 404.40
BATCH :../data/werner2019/MCB1-Mars, RUN #: 118, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 27, EFPA: -12.09, SIGMA: -1.55, APO : 332.11
BATCH :../data/werner2019/MCB1-Mars, RUN #: 119, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 825, EFPA: -12.12, SIGMA: 0.23, APO : 308.05
BATCH :../data/werner2019/MCB1-Mars, RUN #: 120, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 483, EFPA: -11.98, SIGMA: 1.25, APO : 429.94
BATCH :../data/werner2019/MCB1-Mars, RUN #: 121, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 8, EFPA: -12.05, SIGMA: 0.07, APO : 345.33
BATCH :../data/werner2019/MCB1-Mars, RUN #: 122, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 343, EFPA: -11.95, SIGMA: 0.18, APO : 484.28
BATCH :../data/werner2019/MCB1-Mars, RUN #: 123, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 311, EFPA: -12.15, SIGMA: 1.17, APO : 30.46
BATCH :../data/werner2019/MCB1-Mars, RUN #: 124, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 426, EFPA: -12.06, SIGMA: -1.71, APO : 422.83
BATCH :../data/werner2019/MCB1-Mars, RUN #: 125, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 369, EFPA: -12.08, SIGMA: 1.58, APO : 270.59
BATCH :../data/werner2019/MCB1-Mars, RUN #: 126, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 291, EFPA: -11.98, SIGMA: -0.21, APO : 440.37
BATCH :../data/werner2019/MCB1-Mars, RUN #: 127, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 328, EFPA: -12.13, SIGMA: -0.21, APO : 252.96
```

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BATCH :../data/werner2019/MCB1-Mars, RUN #: 128, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 107, EFPA: -12.08, SIGMA: 1.50, APO : 481.17
BATCH :../data/werner2019/MCB1-Mars, RUN #: 129, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 398, EFPA: -12.00, SIGMA: 1.43, APO : 381.01
BATCH :../data/werner2019/MCB1-Mars, RUN #: 130, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 472, EFPA: -12.01, SIGMA: -0.72, APO : 469.38
BATCH :../data/werner2019/MCB1-Mars, RUN #: 131, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 860, EFPA: -12.11, SIGMA: 0.83, APO : 252.62
BATCH :../data/werner2019/MCB1-Mars, RUN #: 132, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 64, EFPA: -12.02, SIGMA: 1.19, APO : 448.25
BATCH :../data/werner2019/MCB1-Mars, RUN #: 133, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 113, EFPA: -12.03, SIGMA: 1.44, APO : 379.96
BATCH :../data/werner2019/MCB1-Mars, RUN #: 134, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 996, EFPA: -11.97, SIGMA: -0.72, APO : 458.85
BATCH :../data/werner2019/MCB1-Mars, RUN #: 135, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 496, EFPA: -12.09, SIGMA: -1.28, APO : 404.90
BATCH :../data/werner2019/MCB1-Mars, RUN #: 136, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 975, EFPA: -12.14, SIGMA: -0.21, APO : 845.32
BATCH :../data/werner2019/MCB1-Mars, RUN #: 137, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 196, EFPA: -12.04, SIGMA: 0.75, APO : 290.71
BATCH :../data/werner2019/MCB1-Mars, RUN #: 138, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 398, EFPA: -12.15, SIGMA: -0.36, APO : 356.07
BATCH :../data/werner2019/MCB1-Mars, RUN #: 139, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 798, EFPA: -12.11, SIGMA: -0.45, APO : 407.26
BATCH :../data/werner2019/MCB1-Mars, RUN #: 140, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 850, EFPA: -11.99, SIGMA: -0.63, APO : 429.75
BATCH :../data/werner2019/MCB1-Mars, RUN #: 141, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 364, EFPA: -12.01, SIGMA: -2.51, APO : 470.25
BATCH :../data/werner2019/MCB1-Mars, RUN #: 142, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 497, EFPA: -12.12, SIGMA: -0.11, APO : 197.46
BATCH :../data/werner2019/MCB1-Mars, RUN #: 143, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 942, EFPA: -12.06, SIGMA: -0.13, APO : 392.91
BATCH :../data/werner2019/MCB1-Mars, RUN #: 144, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 292, EFPA: -11.99, SIGMA: -0.16, APO : 462.44
BATCH :../data/werner2019/MCB1-Mars, RUN #: 145, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 457, EFPA: -11.99, SIGMA: -1.14, APO : 474.83
BATCH :../data/werner2019/MCB1-Mars, RUN #: 146, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 202, EFPA: -12.07, SIGMA: 0.95, APO : 352.26
BATCH :../data/werner2019/MCB1-Mars, RUN #: 147, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 411, EFPA: -12.05, SIGMA: -1.34, APO : 439.96
BATCH :../data/werner2019/MCB1-Mars, RUN #: 148, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 926, EFPA: -12.08, SIGMA: 0.69, APO : 339.36
BATCH :../data/werner2019/MCB1-Mars, RUN #: 149, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 341, EFPA: -12.15, SIGMA: 1.01, APO : 177.54
BATCH :../data/werner2019/MCB1-Mars, RUN #: 150, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 897, EFPA: -12.03, SIGMA: 1.11, APO : 248.00
BATCH :../data/werner2019/MCB1-Mars, RUN #: 151, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 759, EFPA: -12.04, SIGMA: -0.16, APO : 424.57
BATCH :../data/werner2019/MCB1-Mars, RUN #: 152, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 736, EFPA: -12.01, SIGMA: -1.08, APO : 476.70
BATCH :../data/werner2019/MCB1-Mars, RUN #: 153, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 367, EFPA: -12.05, SIGMA: -2.00, APO : 439.34
BATCH :../data/werner2019/MCB1-Mars, RUN #: 154, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 715, EFPA: -12.10, SIGMA: -1.63, APO : 444.77
BATCH :../data/werner2019/MCB1-Mars, RUN #: 155, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 196, EFPA: -12.03, SIGMA: 1.02, APO : 334.06
BATCH :../data/werner2019/MCB1-Mars, RUN #: 156, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 822, EFPA: -12.12, SIGMA: -0.38, APO : 251.38
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BATCH :../data/werner2019/MCB1-Mars, RUN #: 157, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 77, EFPA: -12.05, SIGMA: 0.36, APO : 343.02
BATCH :../data/werner2019/MCB1-Mars, RUN #: 158, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 582, EFPA: -11.99, SIGMA: 0.97, APO : 371.69
BATCH :../data/werner2019/MCB1-Mars, RUN #: 159, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 483, EFPA: -12.10, SIGMA: 1.34, APO : 294.31
BATCH :../data/werner2019/MCB1-Mars, RUN #: 160, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 230, EFPA: -12.08, SIGMA: -0.16, APO : 398.86
BATCH :../data/werner2019/MCB1-Mars, RUN #: 161, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 171, EFPA: -12.08, SIGMA: -0.31, APO : 434.57
BATCH :../data/werner2019/MCB1-Mars, RUN #: 162, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 431, EFPA: -12.06, SIGMA: -1.51, APO : 437.77
BATCH :../data/werner2019/MCB1-Mars, RUN #: 163, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 744, EFPA: -12.02, SIGMA: 0.56, APO : 425.09
BATCH :../data/werner2019/MCB1-Mars, RUN #: 164, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 808, EFPA: -12.10, SIGMA: -0.18, APO : 318.38
BATCH :../data/werner2019/MCB1-Mars, RUN #: 165, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 678, EFPA: -11.99, SIGMA: 0.96, APO : 425.24
BATCH :../data/werner2019/MCB1-Mars, RUN #: 166, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 815, EFPA: -12.06, SIGMA: -0.91, APO : 407.80
BATCH :../data/werner2019/MCB1-Mars, RUN #: 167, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 929, EFPA: -12.06, SIGMA: -2.28, APO : 436.81
BATCH :../data/werner2019/MCB1-Mars, RUN #: 168, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 902, EFPA: -12.07, SIGMA: -0.27, APO : 389.17
BATCH :../data/werner2019/MCB1-Mars, RUN #: 169, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 739, EFPA: -12.04, SIGMA: -0.56, APO : 475.41
BATCH :../data/werner2019/MCB1-Mars, RUN #: 170, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 116, EFPA: -12.10, SIGMA: -1.21, APO : 345.25
BATCH :../data/werner2019/MCB1-Mars, RUN #: 171, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 521, EFPA: -12.03, SIGMA: 0.19, APO : 436.42
BATCH :../data/werner2019/MCB1-Mars, RUN #: 172, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 706, EFPA: -12.18, SIGMA: -0.71, APO : 166.46
BATCH :../data/werner2019/MCB1-Mars, RUN #: 173, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 918, EFPA: -12.04, SIGMA: -0.41, APO : 416.91
BATCH :../data/werner2019/MCB1-Mars, RUN #: 174, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 730, EFPA: -12.09, SIGMA: 0.29, APO : 265.49
BATCH :../data/werner2019/MCB1-Mars, RUN #: 175, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 773, EFPA: -12.00, SIGMA: -1.76, APO : 463.55
BATCH :../data/werner2019/MCB1-Mars, RUN #: 176, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 976, EFPA: -12.09, SIGMA: -1.97, APO : 418.32
BATCH :../data/werner2019/MCB1-Mars, RUN #: 177, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 522, EFPA: -11.99, SIGMA: 0.59, APO : 396.80
BATCH :../data/werner2019/MCB1-Mars, RUN #: 178, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 284, EFPA: -12.15, SIGMA: 1.21, APO : 30.75
BATCH :../data/werner2019/MCB1-Mars, RUN #: 179, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 773, EFPA: -11.97, SIGMA: 0.05, APO : 448.87
BATCH :../data/werner2019/MCB1-Mars, RUN #: 180, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 928, EFPA: -11.99, SIGMA: -1.09, APO : 445.25
BATCH :../data/werner2019/MCB1-Mars, RUN #: 181, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 519, EFPA: -12.07, SIGMA: 0.02, APO : 417.03
BATCH :../data/werner2019/MCB1-Mars, RUN #: 182, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 330, EFPA: -12.13, SIGMA: 0.62, APO : 389.94
BATCH :../data/werner2019/MCB1-Mars, RUN #: 183, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 241, EFPA: -12.10, SIGMA: -1.98, APO : 405.54
BATCH :../data/werner2019/MCB1-Mars, RUN #: 184, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 855, EFPA: -11.98, SIGMA: -0.27, APO : 478.47
BATCH :../data/werner2019/MCB1-Mars, RUN #: 185, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 381, EFPA: -12.08, SIGMA: 0.99, APO : 244.64
```

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BATCH :../data/werner2019/MCB1-Mars, RUN #: 186, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 182, EFPA: -11.95, SIGMA: 2.14, APO : 474.76
BATCH :../data/werner2019/MCB1-Mars, RUN #: 187, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 52, EFPA: -12.08, SIGMA: -0.18, APO : 486.57
BATCH :../data/werner2019/MCB1-Mars, RUN #: 188, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 296, EFPA: -12.03, SIGMA: -0.24, APO : 481.16
BATCH :../data/werner2019/MCB1-Mars, RUN #: 189, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 737, EFPA: -12.13, SIGMA: 0.89, APO : 326.65
BATCH :../data/werner2019/MCB1-Mars, RUN #: 190, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 985, EFPA: -11.97, SIGMA: -0.81, APO : 489.30
BATCH :../data/werner2019/MCB1-Mars, RUN #: 191, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 707, EFPA: -12.19, SIGMA: -1.24, APO : 396.14
BATCH :../data/werner2019/MCB1-Mars, RUN #: 192, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 385, EFPA: -12.05, SIGMA: -0.86, APO : 425.49
BATCH :../data/werner2019/MCB1-Mars, RUN #: 193, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 594, EFPA: -12.02, SIGMA: -1.46, APO : 488.71
BATCH :../data/werner2019/MCB1-Mars, RUN #: 194, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 576, EFPA: -12.05, SIGMA: -1.01, APO : 457.67
BATCH :../data/werner2019/MCB1-Mars, RUN #: 195, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 189, EFPA: -12.06, SIGMA: 0.96, APO : 401.33
BATCH :../data/werner2019/MCB1-Mars, RUN #: 196, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 220, EFPA: -12.04, SIGMA: 1.90, APO : 239.64
BATCH :../data/werner2019/MCB1-Mars, RUN #: 197, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 714, EFPA: -12.09, SIGMA: -0.08, APO : 430.14
BATCH :../data/werner2019/MCB1-Mars, RUN #: 198, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 992, EFPA: -12.13, SIGMA: 0.62, APO : 618.85
BATCH :../data/werner2019/MCB1-Mars, RUN #: 199, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 446, EFPA: -12.12, SIGMA: 0.34, APO : 590.72
BATCH :../data/werner2019/MCB1-Mars, RUN #: 200, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 574, EFPA: -12.07, SIGMA: 0.05, APO : 389.68
```

Load the terminal apoapsis, deceleration and heat rate data.

[4]:
```
apoap = np.loadtxt('../data/werner2019/MCB1-Mars/terminal_apoapsis_arr.txt')
peria = np.loadtxt('../data/werner2019/MCB1-Mars/terminal_periapsis_arr.txt')
decel = np.loadtxt('../data/werner2019/MCB1-Mars/acc_net_g_max_arr.txt')
heatr = np.loadtxt('../data/werner2019/MCB1-Mars/q_stag_max_arr.txt')
```

Remove cases which resulted in apoapsis < 100 km or > 800 km.

[5]:
```
del_index_low = np.where(apoap < 100)
print(del_index_low)
```

```
(array([ 10,  20,  48,  57,  84,  85, 100, 102, 122, 177]),)
```

Seven cases resulted in apoapis less than 100 km, and are considered to crash.

Remove these entries from the data before plotting.

[6]:
```
apoap_clean = np.delete(apoap, del_index_low)
peria_clean = np.delete(peria, del_index_low)
decel_clean = np.delete(decel, del_index_low)
heatr_clean = np.delete(heatr, del_index_low)
```

Also remove cases with apoapsis > 800 km.

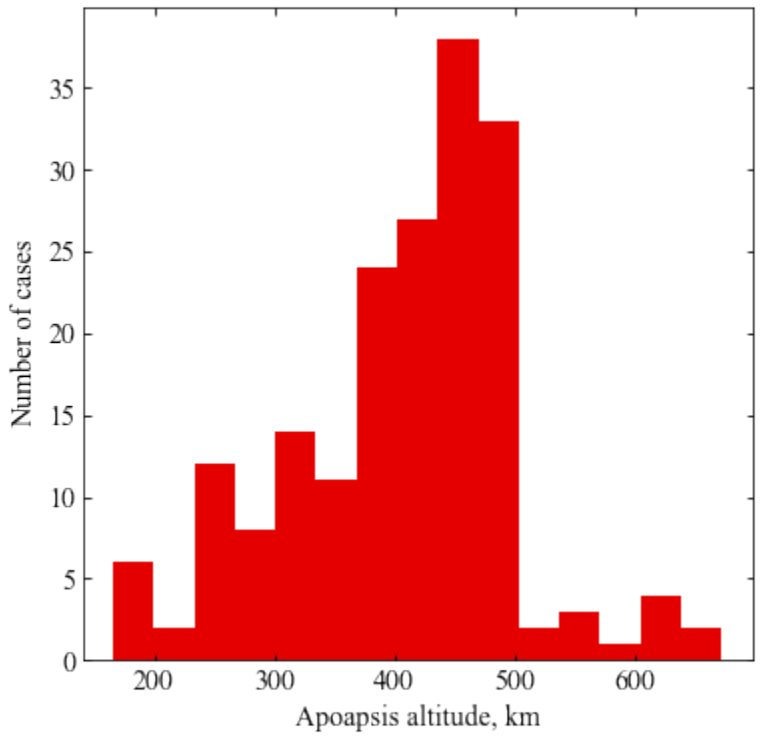
[7]:
```
del_index_high = np.where(apoap_clean > 800)
print(del_index_high)
```

```
(array([ 52,  54, 126]),)
```

[8]:
```
apoap_clean2 = np.delete(apoap_clean, del_index_high)
peria_clean2 = np.delete(peria_clean, del_index_high)
decel_clean2 = np.delete(decel_clean, del_index_high)
heatr_clean2 = np.delete(heatr_clean, del_index_high)
```

[15]:
```
plt.figure(figsize=(6,6))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)
plt.hist(apoap_clean2, bins=15, color='xkcd:red')
plt.xlabel('Apoapsis altitude, km',fontsize=14)
plt.ylabel('Number of cases',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/werner-smallsat-apoa-hist-mars.png',bbox_inches='tight')
plt.savefig('../plots/werner-smallsat-apoa-hist-mars.pdf', dpi=300,bbox_inches='tight
↪')
plt.savefig('../plots/werner-smallsat-apoa-hist-mars.eps', dpi=300,bbox_inches='tight
↪')
plt.show()
```



[10]:
```
plt.figure(figsize=(6,6))
plt.rc('font',family='Times New Roman')
```

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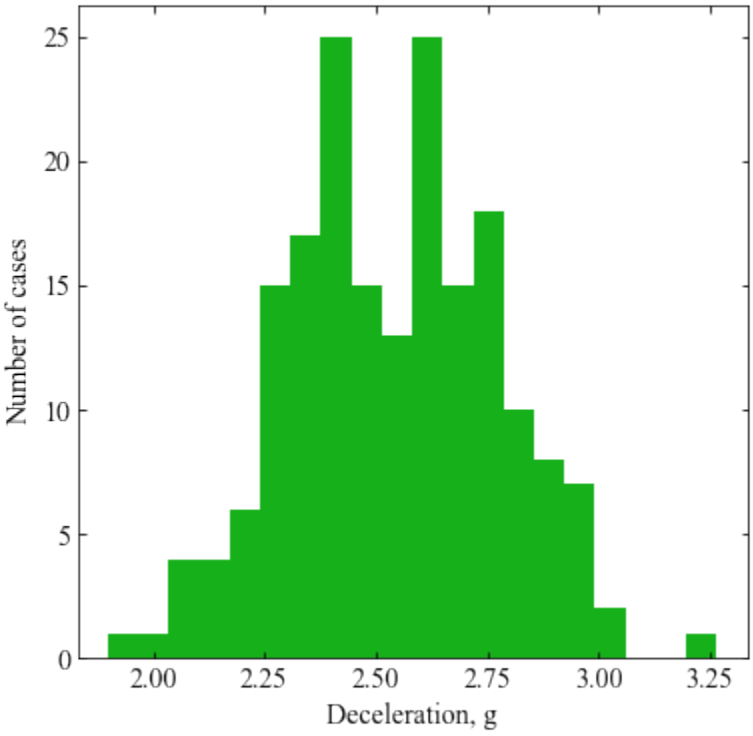
```
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)
plt.hist(decel_clean2, bins=20, color='xkcd:green')
plt.xlabel('Deceleration, g',fontsize=14)
plt.ylabel('Number of cases',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/werner-smallsat-decel-hist-mars.png',bbox_inches='tight')
plt.savefig('../plots/werner-smallsat-decel-hist-mars.pdf', dpi=300,bbox_inches='tight
↪')
plt.savefig('../plots/werner-smallsat-decel-hist-mars.eps', dpi=300,bbox_inches='tight
↪')
plt.show()
```



[11]:
```
plt.figure(figsize=(6,6))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)
plt.hist(heatr_clean2, bins=20, color='xkcd:blue')
plt.xlabel('Heat rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Number of cases',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
```

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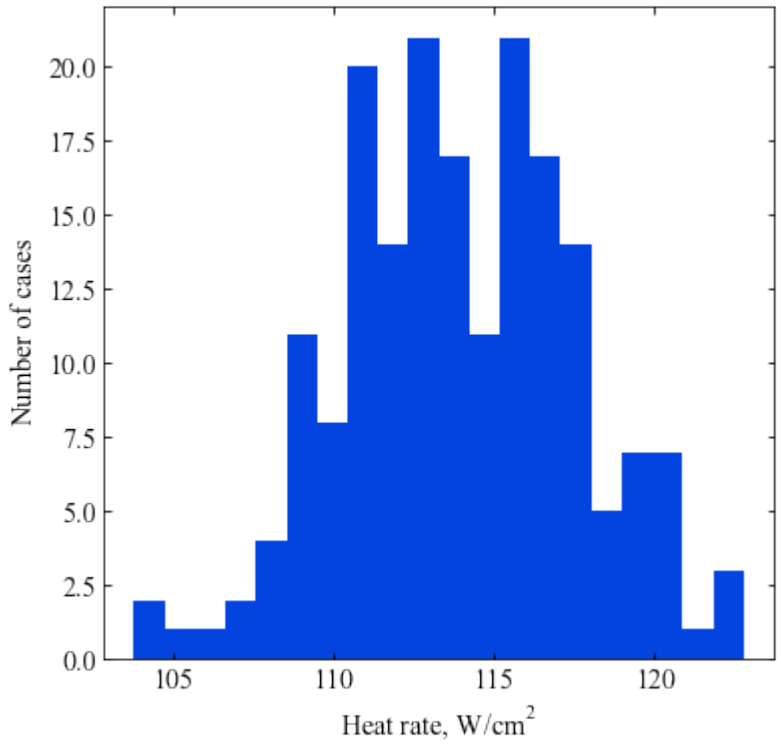
```
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/werner-smallsat-heat-hist-mars.png',bbox_inches='tight')
plt.savefig('../plots/werner-smallsat-heat-hist-mars.pdf', dpi=300,bbox_inches='tight
↪')
plt.savefig('../plots/werner-smallsat-heat-hist-mars.eps', dpi=300,bbox_inches='tight
↪')
plt.show()
```



[14]:
```
plt.figure(figsize=(6,6))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)
plt.scatter(peria_clean2, apoap_clean2, s=30, facecolors='none', edgecolors='b', lw=2)
plt.axhline(y=450, lw=2.0, ls='dashed', color='k')
plt.xlabel('Periapsis altitude, km',fontsize=14)
plt.ylabel('Apoapsis altitude, km',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/werner-smallsat-apoa-peri-mars.png',bbox_inches='tight')
plt.savefig('../plots/werner-smallsat-apoa-peri-mars.pdf', dpi=300,bbox_inches='tight
↪')
plt.savefig('../plots/werner-smallsat-apoa-peri-mars.eps', dpi=300,bbox_inches='tight
↪')
```

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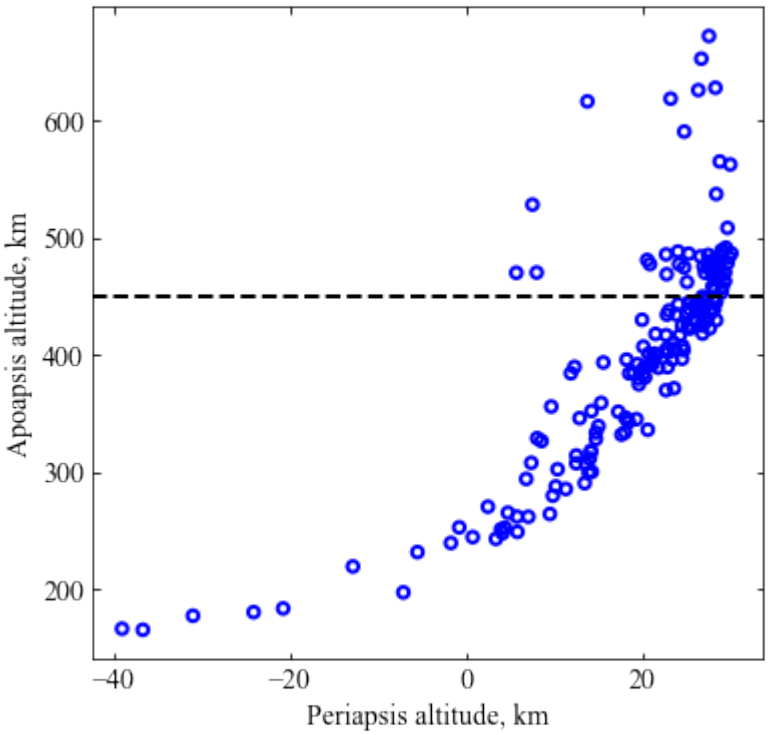
```
plt.show()
```



Find the percentage of cases which achieved apoapsis between 100 and 800 km.

[13]:
```
(np.size(apoap) - np.size(del_index_low) - np.size(del_index_high))*100/np.size(apoap)
```

[13]:
```
93.5
```

These results are different from those in the paper because of the different guidance schemes used here. This exercide did not attempt to optimize the guidance parameters. Further study can improve the apoapsis targeting.

4.53 Example - 53 - Mars SmallSat Aerocapture Demonstration - Part 3

In this example, we will use Monte Carlo simulations to assess flight performance. Reference: M.S.Werner and R.D.Braun, Mission Design and Performance Analysis of a Smallsat Aerocapture Flight Test, Journal of Spacecraft and Rockets, DOI: 10.2514/1.A33997

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
from scipy import interpolate
import pandas as pd

import matplotlib.pyplot as plt
from matplotlib import rcParams
from matplotlib.patches import Polygon
```

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("MARS")
planet.loadAtmosphereModel('../atmdata/Mars/mars-gram-avg.dat', 0 , 1 ,2, 3)
planet.h_skip = 150000.0
planet.h_low=10.0E3

# Set up the drag modulation vehicle.
vehicle=Vehicle('MarsSmallSat1', 25.97, 66.4, 0.0, np.pi*0.25**2, 0.0, 0.0563, planet)

vehicle.setInitialState(150.0,0.0,0.0,5.74,0.0,-12.12,0.0,0.0)
vehicle.setSolverParams(1E-6)
vehicle.setDragModulationVehicleParams(66.4,4.72)

# Set up the drag modulation entry phase guidance parameters.
vehicle.setDragEntryPhaseParams(2.0, 15.0, 101, -200.0)

# Set the target orbit parameters.
vehicle.setTargetOrbitParams(450.0, 33000.0, 20.0)

# Define the path to atmospheric files to be used for the Monte Carlo simulations.
atmfiles = ['../atmdata/Mars/LAT00N-N1000.txt']

# Set up the Monte Carlo simulation for drag modulation.
# NPOS = 156, NMONTE = 1000
# Target EFPA = -12.05 deg
# EFPA 1-sigma error = +/- 0.067 deg
# Nominal beta_1 = 66.4 kg/m2
# beta_1 1-sigma = 0.0
# guidance time step for entry = 1.0s (Freq. = 1 Hz)
# guidance time step after jettison = 1.0 s
# max. solver time step = 0.1 s
# max. time used by solver = 2400 s

vehicle.setupMonteCarloSimulationD(156, 1000, atmfiles, 0 , 1, 2, 3, 4, True,
                                   -11.80,  0.0667, 66.4, 0.0,
                                    1.0, 1.0, 0.1, 2400.0)
# Run 200 trajectories
vehicle.runMonteCarloD(200, '../data/werner2019/MCB2-Mars')
```

```
BATCH :../data/werner2019/MCB2-Mars, RUN #: 1, PROF: ../atmdata/Mars/LAT00N-N1000.txt,
↪ SAMPLE #: 323, EFPA: -11.79, SIGMA: -0.29, APO : 32577.73
BATCH :../data/werner2019/MCB2-Mars, RUN #: 2, PROF: ../atmdata/Mars/LAT00N-N1000.txt,
↪ SAMPLE #: 641, EFPA: -11.81, SIGMA: 0.18, APO : 31263.06
BATCH :../data/werner2019/MCB2-Mars, RUN #: 3, PROF: ../atmdata/Mars/LAT00N-N1000.txt,
↪ SAMPLE #: 120, EFPA: -11.93, SIGMA: -2.68, APO : 32488.87
BATCH :../data/werner2019/MCB2-Mars, RUN #: 4, PROF: ../atmdata/Mars/LAT00N-N1000.txt,
↪ SAMPLE #: 971, EFPA: -11.92, SIGMA: 1.56, APO : 34683.39
```

```
/home/athul/anaconda3/lib/python3.7/site-packages/AMAT-2.1.3-py3.7.egg/AMAT/vehicle.
↪py:504: RuntimeWarning: invalid value encountered in sqrt
  ans[:]  = 1.8980E-8 * (rho_vec[:]/self.RN)**0.5 * v[:]**3.0
```

```
BATCH :../data/werner2019/MCB2-Mars, RUN #: 5, PROF: ../atmdata/Mars/LAT00N-N1000.txt,
↪ SAMPLE #: 165, EFPA: -11.83, SIGMA: -2.05, APO : 33118.19
BATCH :../data/werner2019/MCB2-Mars, RUN #: 6, PROF: ../atmdata/Mars/LAT00N-N1000.txt,
↪ SAMPLE #: 529, EFPA: -11.75, SIGMA: 0.25, APO : 32952.30
BATCH :../data/werner2019/MCB2-Mars, RUN #: 7, PROF: ../atmdata/Mars/LAT00N-N1000.txt,
↪ SAMPLE #: 57, EFPA: -11.88, SIGMA: 0.37, APO : 33138.68
BATCH :../data/werner2019/MCB2-Mars, RUN #: 8, PROF: ../atmdata/Mars/LAT00N-N1000.txt,
↪ SAMPLE #: 158, EFPA: -11.77, SIGMA: 0.27, APO : 31926.75
```

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```
BATCH :../data/werner2019/MCB2-Mars, RUN #: 9, PROF: ../atmdata/Mars/LAT00N-N1000.txt,
 ↪ SAMPLE #: 623, EFPA: -11.76, SIGMA: 0.86, APO : 32279.26
BATCH :../data/werner2019/MCB2-Mars, RUN #: 10, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 335, EFPA: -11.91, SIGMA: -1.30, APO : 34055.62
BATCH :../data/werner2019/MCB2-Mars, RUN #: 11, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 360, EFPA: -11.79, SIGMA: -1.09, APO : 32848.65
BATCH :../data/werner2019/MCB2-Mars, RUN #: 12, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 679, EFPA: -11.77, SIGMA: 1.58, APO : 31324.80
BATCH :../data/werner2019/MCB2-Mars, RUN #: 13, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 820, EFPA: -11.86, SIGMA: -0.50, APO : 34666.91
BATCH :../data/werner2019/MCB2-Mars, RUN #: 14, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 522, EFPA: -11.76, SIGMA: -1.80, APO : 32589.29
BATCH :../data/werner2019/MCB2-Mars, RUN #: 15, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 356, EFPA: -11.81, SIGMA: -0.98, APO : 32025.72
BATCH :../data/werner2019/MCB2-Mars, RUN #: 16, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 400, EFPA: -11.82, SIGMA: -0.93, APO : 32681.15
BATCH :../data/werner2019/MCB2-Mars, RUN #: 17, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 153, EFPA: -11.77, SIGMA: 2.31, APO : 30904.72
BATCH :../data/werner2019/MCB2-Mars, RUN #: 18, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 321, EFPA: -11.83, SIGMA: -1.58, APO : 32500.60
BATCH :../data/werner2019/MCB2-Mars, RUN #: 19, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 243, EFPA: -11.92, SIGMA: -0.53, APO : 32899.73
BATCH :../data/werner2019/MCB2-Mars, RUN #: 20, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 220, EFPA: -11.82, SIGMA: 0.79, APO : 29928.16
BATCH :../data/werner2019/MCB2-Mars, RUN #: 21, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 761, EFPA: -11.74, SIGMA: 0.01, APO : 32632.82
BATCH :../data/werner2019/MCB2-Mars, RUN #: 22, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 518, EFPA: -11.83, SIGMA: 1.50, APO : 30531.60
BATCH :../data/werner2019/MCB2-Mars, RUN #: 23, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 624, EFPA: -11.68, SIGMA: 0.79, APO : 32593.76
BATCH :../data/werner2019/MCB2-Mars, RUN #: 24, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 553, EFPA: -11.74, SIGMA: 0.73, APO : 33146.31
BATCH :../data/werner2019/MCB2-Mars, RUN #: 25, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 824, EFPA: -11.76, SIGMA: -0.21, APO : 32564.92
BATCH :../data/werner2019/MCB2-Mars, RUN #: 26, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 815, EFPA: -11.76, SIGMA: -0.58, APO : 31947.94
BATCH :../data/werner2019/MCB2-Mars, RUN #: 27, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 543, EFPA: -11.84, SIGMA: -1.83, APO : 32945.79
BATCH :../data/werner2019/MCB2-Mars, RUN #: 28, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 855, EFPA: -11.77, SIGMA: -2.10, APO : 33343.44
BATCH :../data/werner2019/MCB2-Mars, RUN #: 29, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 863, EFPA: -11.90, SIGMA: 0.89, APO : 30733.56
BATCH :../data/werner2019/MCB2-Mars, RUN #: 30, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 809, EFPA: -11.72, SIGMA: -0.91, APO : 33349.24
BATCH :../data/werner2019/MCB2-Mars, RUN #: 31, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 805, EFPA: -11.69, SIGMA: -0.54, APO : 32828.30
BATCH :../data/werner2019/MCB2-Mars, RUN #: 32, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 938, EFPA: -11.85, SIGMA: 2.03, APO : 34293.72
BATCH :../data/werner2019/MCB2-Mars, RUN #: 33, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 271, EFPA: -11.90, SIGMA: -0.44, APO : 33137.81
BATCH :../data/werner2019/MCB2-Mars, RUN #: 34, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 579, EFPA: -11.79, SIGMA: 0.83, APO : 32171.64
BATCH :../data/werner2019/MCB2-Mars, RUN #: 35, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 947, EFPA: -11.91, SIGMA: -1.39, APO : 31584.52
BATCH :../data/werner2019/MCB2-Mars, RUN #: 36, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 851, EFPA: -11.67, SIGMA: 0.35, APO : 32554.18
BATCH :../data/werner2019/MCB2-Mars, RUN #: 37, PROF: ../atmdata/Mars/LAT00N-N1000.
 ↪txt, SAMPLE #: 917, EFPA: -11.78, SIGMA: -0.55, APO : 33133.24
```

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```
BATCH :../data/werner2019/MCB2-Mars, RUN #: 38, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 34, EFPA: -11.84, SIGMA: 0.52, APO : 33299.46
BATCH :../data/werner2019/MCB2-Mars, RUN #: 39, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 417, EFPA: -11.82, SIGMA: 1.67, APO : 33257.16
BATCH :../data/werner2019/MCB2-Mars, RUN #: 40, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 905, EFPA: -11.79, SIGMA: -0.99, APO : 32695.03
BATCH :../data/werner2019/MCB2-Mars, RUN #: 41, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 562, EFPA: -11.83, SIGMA: -0.14, APO : 32995.77
BATCH :../data/werner2019/MCB2-Mars, RUN #: 42, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 951, EFPA: -11.82, SIGMA: -0.46, APO : 31976.55
BATCH :../data/werner2019/MCB2-Mars, RUN #: 43, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 572, EFPA: -11.88, SIGMA: -0.50, APO : 33227.59
BATCH :../data/werner2019/MCB2-Mars, RUN #: 44, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 445, EFPA: -11.84, SIGMA: -0.92, APO : 32261.02
BATCH :../data/werner2019/MCB2-Mars, RUN #: 45, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 127, EFPA: -11.75, SIGMA: -0.11, APO : 32204.43
BATCH :../data/werner2019/MCB2-Mars, RUN #: 46, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 834, EFPA: -11.80, SIGMA: -1.26, APO : 32546.44
BATCH :../data/werner2019/MCB2-Mars, RUN #: 47, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 430, EFPA: -11.83, SIGMA: 0.05, APO : 32395.95
BATCH :../data/werner2019/MCB2-Mars, RUN #: 48, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 764, EFPA: -11.78, SIGMA: -2.64, APO : 32847.73
BATCH :../data/werner2019/MCB2-Mars, RUN #: 49, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 428, EFPA: -11.81, SIGMA: 0.65, APO : 33907.42
BATCH :../data/werner2019/MCB2-Mars, RUN #: 50, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 748, EFPA: -11.82, SIGMA: -0.93, APO : 30363.41
BATCH :../data/werner2019/MCB2-Mars, RUN #: 51, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 576, EFPA: -11.78, SIGMA: 0.36, APO : 32627.78
BATCH :../data/werner2019/MCB2-Mars, RUN #: 52, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 621, EFPA: -11.73, SIGMA: 0.33, APO : 32560.41
BATCH :../data/werner2019/MCB2-Mars, RUN #: 53, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 746, EFPA: -11.88, SIGMA: 3.59, APO : 27525.65
BATCH :../data/werner2019/MCB2-Mars, RUN #: 54, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 299, EFPA: -11.83, SIGMA: -0.79, APO : 33239.30
BATCH :../data/werner2019/MCB2-Mars, RUN #: 55, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 757, EFPA: -11.72, SIGMA: 0.41, APO : 33163.05
BATCH :../data/werner2019/MCB2-Mars, RUN #: 56, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 568, EFPA: -11.76, SIGMA: -1.06, APO : 33302.55
BATCH :../data/werner2019/MCB2-Mars, RUN #: 57, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 945, EFPA: -11.66, SIGMA: -0.64, APO : 32926.05
BATCH :../data/werner2019/MCB2-Mars, RUN #: 58, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 729, EFPA: -11.76, SIGMA: 2.08, APO : 32448.62
BATCH :../data/werner2019/MCB2-Mars, RUN #: 59, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 589, EFPA: -11.69, SIGMA: -1.75, APO : 33098.32
BATCH :../data/werner2019/MCB2-Mars, RUN #: 60, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 488, EFPA: -11.80, SIGMA: -0.44, APO : 33247.83
BATCH :../data/werner2019/MCB2-Mars, RUN #: 61, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 193, EFPA: -11.69, SIGMA: -0.68, APO : 32782.73
BATCH :../data/werner2019/MCB2-Mars, RUN #: 62, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 306, EFPA: -11.79, SIGMA: 0.12, APO : 32744.57
BATCH :../data/werner2019/MCB2-Mars, RUN #: 63, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 459, EFPA: -11.97, SIGMA: 1.23, APO : 29849.99
BATCH :../data/werner2019/MCB2-Mars, RUN #: 64, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 478, EFPA: -11.85, SIGMA: -2.99, APO : 32495.06
BATCH :../data/werner2019/MCB2-Mars, RUN #: 65, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 30, EFPA: -11.88, SIGMA: 1.08, APO : 30837.00
BATCH :../data/werner2019/MCB2-Mars, RUN #: 66, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 752, EFPA: -11.69, SIGMA: -1.15, APO : 32767.21
```

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```
BATCH :../data/werner2019/MCB2-Mars, RUN #: 67, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 584, EFPA: -11.80, SIGMA: 0.31, APO : 32557.71
BATCH :../data/werner2019/MCB2-Mars, RUN #: 68, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 632, EFPA: -11.86, SIGMA: -0.36, APO : 32676.39
BATCH :../data/werner2019/MCB2-Mars, RUN #: 69, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 709, EFPA: -11.82, SIGMA: -0.93, APO : 32634.53
BATCH :../data/werner2019/MCB2-Mars, RUN #: 70, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 154, EFPA: -11.87, SIGMA: 0.63, APO : 29549.68
BATCH :../data/werner2019/MCB2-Mars, RUN #: 71, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 468, EFPA: -11.77, SIGMA: 0.31, APO : 33146.20
BATCH :../data/werner2019/MCB2-Mars, RUN #: 72, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 428, EFPA: -11.77, SIGMA: -1.48, APO : 33119.29
BATCH :../data/werner2019/MCB2-Mars, RUN #: 73, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 768, EFPA: -11.83, SIGMA: -1.23, APO : 32376.70
BATCH :../data/werner2019/MCB2-Mars, RUN #: 74, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 447, EFPA: -11.74, SIGMA: -0.32, APO : 32195.44
BATCH :../data/werner2019/MCB2-Mars, RUN #: 75, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 556, EFPA: -11.75, SIGMA: -0.06, APO : 32280.00
BATCH :../data/werner2019/MCB2-Mars, RUN #: 76, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 758, EFPA: -11.79, SIGMA: 0.25, APO : 30210.66
BATCH :../data/werner2019/MCB2-Mars, RUN #: 77, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 168, EFPA: -11.93, SIGMA: 2.43, APO : 27460.65
BATCH :../data/werner2019/MCB2-Mars, RUN #: 78, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 143, EFPA: -11.79, SIGMA: 0.25, APO : 33456.57
BATCH :../data/werner2019/MCB2-Mars, RUN #: 79, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 754, EFPA: -11.80, SIGMA: -0.14, APO : 33714.98
BATCH :../data/werner2019/MCB2-Mars, RUN #: 80, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 180, EFPA: -11.71, SIGMA: -0.71, APO : 33022.70
BATCH :../data/werner2019/MCB2-Mars, RUN #: 81, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 898, EFPA: -11.77, SIGMA: -2.06, APO : 32980.24
BATCH :../data/werner2019/MCB2-Mars, RUN #: 82, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 268, EFPA: -11.87, SIGMA: 0.47, APO : 32306.71
BATCH :../data/werner2019/MCB2-Mars, RUN #: 83, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 774, EFPA: -11.77, SIGMA: -2.42, APO : 32904.05
BATCH :../data/werner2019/MCB2-Mars, RUN #: 84, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 530, EFPA: -11.84, SIGMA: 0.14, APO : 32434.25
BATCH :../data/werner2019/MCB2-Mars, RUN #: 85, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 67, EFPA: -11.67, SIGMA: 1.93, APO : 33094.71
BATCH :../data/werner2019/MCB2-Mars, RUN #: 86, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 461, EFPA: -11.85, SIGMA: -0.61, APO : 30606.20
BATCH :../data/werner2019/MCB2-Mars, RUN #: 87, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 243, EFPA: -11.85, SIGMA: -1.20, APO : 33668.52
BATCH :../data/werner2019/MCB2-Mars, RUN #: 88, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 997, EFPA: -11.86, SIGMA: -0.07, APO : 31123.70
BATCH :../data/werner2019/MCB2-Mars, RUN #: 89, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 722, EFPA: -11.91, SIGMA: 1.14, APO : 30216.72
BATCH :../data/werner2019/MCB2-Mars, RUN #: 90, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 348, EFPA: -11.89, SIGMA: -1.22, APO : 33758.54
BATCH :../data/werner2019/MCB2-Mars, RUN #: 91, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 145, EFPA: -11.83, SIGMA: 1.17, APO : 30788.83
BATCH :../data/werner2019/MCB2-Mars, RUN #: 92, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 62, EFPA: -11.69, SIGMA: -0.52, APO : 33140.54
BATCH :../data/werner2019/MCB2-Mars, RUN #: 93, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 994, EFPA: -11.78, SIGMA: 0.41, APO : 31145.02
BATCH :../data/werner2019/MCB2-Mars, RUN #: 94, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 512, EFPA: -11.75, SIGMA: 0.06, APO : 32627.69
BATCH :../data/werner2019/MCB2-Mars, RUN #: 95, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 222, EFPA: -11.77, SIGMA: 0.23, APO : 32152.49
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BATCH :../data/werner2019/MCB2-Mars, RUN #: 96, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 611, EFPA: -11.58, SIGMA: -2.00, APO : -59599.06
BATCH :../data/werner2019/MCB2-Mars, RUN #: 97, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 30, EFPA: -11.79, SIGMA: -1.34, APO : 33205.77
BATCH :../data/werner2019/MCB2-Mars, RUN #: 98, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 732, EFPA: -11.75, SIGMA: -0.29, APO : 33147.11
BATCH :../data/werner2019/MCB2-Mars, RUN #: 99, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 64, EFPA: -11.68, SIGMA: 0.07, APO : 37376.72
BATCH :../data/werner2019/MCB2-Mars, RUN #: 100, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 343, EFPA: -11.70, SIGMA: 0.99, APO : 32539.10
BATCH :../data/werner2019/MCB2-Mars, RUN #: 101, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 906, EFPA: -11.84, SIGMA: 0.31, APO : 32517.83
BATCH :../data/werner2019/MCB2-Mars, RUN #: 102, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 533, EFPA: -11.76, SIGMA: -1.08, APO : 33033.41
BATCH :../data/werner2019/MCB2-Mars, RUN #: 103, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 329, EFPA: -11.71, SIGMA: 0.74, APO : 32401.12
BATCH :../data/werner2019/MCB2-Mars, RUN #: 104, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 510, EFPA: -11.83, SIGMA: -1.40, APO : 33176.79
BATCH :../data/werner2019/MCB2-Mars, RUN #: 105, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 778, EFPA: -11.77, SIGMA: 0.74, APO : 32348.53
BATCH :../data/werner2019/MCB2-Mars, RUN #: 106, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 555, EFPA: -11.80, SIGMA: -0.74, APO : 32509.25
BATCH :../data/werner2019/MCB2-Mars, RUN #: 107, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 803, EFPA: -11.74, SIGMA: -0.58, APO : 33237.60
BATCH :../data/werner2019/MCB2-Mars, RUN #: 108, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 108, EFPA: -11.83, SIGMA: 1.76, APO : 33437.03
BATCH :../data/werner2019/MCB2-Mars, RUN #: 109, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 906, EFPA: -11.75, SIGMA: -0.77, APO : 32963.40
BATCH :../data/werner2019/MCB2-Mars, RUN #: 110, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 655, EFPA: -11.81, SIGMA: 0.13, APO : 32307.01
BATCH :../data/werner2019/MCB2-Mars, RUN #: 111, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 972, EFPA: -11.75, SIGMA: -0.53, APO : 32921.98
BATCH :../data/werner2019/MCB2-Mars, RUN #: 112, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 651, EFPA: -11.72, SIGMA: 1.04, APO : 33145.04
BATCH :../data/werner2019/MCB2-Mars, RUN #: 113, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 202, EFPA: -11.80, SIGMA: 0.89, APO : 32833.74
BATCH :../data/werner2019/MCB2-Mars, RUN #: 114, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 596, EFPA: -11.78, SIGMA: 0.21, APO : 32579.24
BATCH :../data/werner2019/MCB2-Mars, RUN #: 115, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 911, EFPA: -11.88, SIGMA: -0.81, APO : 35026.98
BATCH :../data/werner2019/MCB2-Mars, RUN #: 116, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 978, EFPA: -11.76, SIGMA: 0.09, APO : 33354.20
BATCH :../data/werner2019/MCB2-Mars, RUN #: 117, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 194, EFPA: -11.80, SIGMA: -1.53, APO : 33170.99
BATCH :../data/werner2019/MCB2-Mars, RUN #: 118, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 63, EFPA: -11.81, SIGMA: -1.53, APO : 31784.22
BATCH :../data/werner2019/MCB2-Mars, RUN #: 119, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 815, EFPA: -11.93, SIGMA: 0.41, APO : 32031.26
BATCH :../data/werner2019/MCB2-Mars, RUN #: 120, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 953, EFPA: -11.76, SIGMA: -0.48, APO : 32281.00
BATCH :../data/werner2019/MCB2-Mars, RUN #: 121, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 288, EFPA: -11.74, SIGMA: -1.51, APO : 32770.89
BATCH :../data/werner2019/MCB2-Mars, RUN #: 122, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 818, EFPA: -11.87, SIGMA: -1.11, APO : 31876.10
BATCH :../data/werner2019/MCB2-Mars, RUN #: 123, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 404, EFPA: -11.80, SIGMA: -0.95, APO : 34060.29
BATCH :../data/werner2019/MCB2-Mars, RUN #: 124, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 231, EFPA: -11.88, SIGMA: 2.04, APO : 28912.72
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BATCH :../data/werner2019/MCB2-Mars, RUN #: 125, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 807, EFPA: -11.86, SIGMA: -0.17, APO : 32252.30
BATCH :../data/werner2019/MCB2-Mars, RUN #: 126, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 873, EFPA: -11.78, SIGMA: 1.00, APO : 30770.96
BATCH :../data/werner2019/MCB2-Mars, RUN #: 127, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 833, EFPA: -11.83, SIGMA: 0.53, APO : 33261.34
BATCH :../data/werner2019/MCB2-Mars, RUN #: 128, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 252, EFPA: -11.87, SIGMA: -0.85, APO : 30178.20
BATCH :../data/werner2019/MCB2-Mars, RUN #: 129, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 565, EFPA: -11.68, SIGMA: -0.44, APO : 33026.39
BATCH :../data/werner2019/MCB2-Mars, RUN #: 130, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 382, EFPA: -11.83, SIGMA: 0.03, APO : 32210.04
BATCH :../data/werner2019/MCB2-Mars, RUN #: 131, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 612, EFPA: -11.73, SIGMA: -1.17, APO : 48514.86
BATCH :../data/werner2019/MCB2-Mars, RUN #: 132, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 937, EFPA: -11.80, SIGMA: 1.55, APO : 31901.56
BATCH :../data/werner2019/MCB2-Mars, RUN #: 133, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 894, EFPA: -11.83, SIGMA: -0.26, APO : 31639.84
BATCH :../data/werner2019/MCB2-Mars, RUN #: 134, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 436, EFPA: -11.78, SIGMA: 1.19, APO : 32842.71
BATCH :../data/werner2019/MCB2-Mars, RUN #: 135, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 856, EFPA: -11.76, SIGMA: 1.05, APO : 31218.55
BATCH :../data/werner2019/MCB2-Mars, RUN #: 136, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 731, EFPA: -11.73, SIGMA: 0.53, APO : 33138.80
BATCH :../data/werner2019/MCB2-Mars, RUN #: 137, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 365, EFPA: -11.91, SIGMA: -0.43, APO : 29544.45
BATCH :../data/werner2019/MCB2-Mars, RUN #: 138, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 131, EFPA: -11.86, SIGMA: -1.29, APO : 32882.69
BATCH :../data/werner2019/MCB2-Mars, RUN #: 139, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 928, EFPA: -11.76, SIGMA: 0.51, APO : 32908.79
BATCH :../data/werner2019/MCB2-Mars, RUN #: 140, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 675, EFPA: -11.84, SIGMA: -0.44, APO : 33420.71
BATCH :../data/werner2019/MCB2-Mars, RUN #: 141, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 771, EFPA: -11.78, SIGMA: -0.55, APO : 32648.17
BATCH :../data/werner2019/MCB2-Mars, RUN #: 142, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 218, EFPA: -11.94, SIGMA: -0.58, APO : 32131.56
BATCH :../data/werner2019/MCB2-Mars, RUN #: 143, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 674, EFPA: -11.75, SIGMA: -1.88, APO : 32942.75
BATCH :../data/werner2019/MCB2-Mars, RUN #: 144, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 526, EFPA: -11.84, SIGMA: 1.02, APO : 32150.60
BATCH :../data/werner2019/MCB2-Mars, RUN #: 145, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 414, EFPA: -11.88, SIGMA: 0.04, APO : 30167.78
BATCH :../data/werner2019/MCB2-Mars, RUN #: 146, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 971, EFPA: -11.83, SIGMA: -0.76, APO : 35221.26
BATCH :../data/werner2019/MCB2-Mars, RUN #: 147, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 644, EFPA: -11.90, SIGMA: 1.13, APO : 31257.53
BATCH :../data/werner2019/MCB2-Mars, RUN #: 148, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 863, EFPA: -11.85, SIGMA: -0.23, APO : 32058.29
BATCH :../data/werner2019/MCB2-Mars, RUN #: 149, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 304, EFPA: -11.77, SIGMA: -0.91, APO : 33121.24
BATCH :../data/werner2019/MCB2-Mars, RUN #: 150, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 202, EFPA: -11.91, SIGMA: -1.65, APO : 32489.36
BATCH :../data/werner2019/MCB2-Mars, RUN #: 151, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 219, EFPA: -11.82, SIGMA: -0.08, APO : 31031.43
BATCH :../data/werner2019/MCB2-Mars, RUN #: 152, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 225, EFPA: -11.82, SIGMA: -1.00, APO : 33058.62
BATCH :../data/werner2019/MCB2-Mars, RUN #: 153, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 298, EFPA: -11.74, SIGMA: -1.00, APO : 32822.08
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BATCH :../data/werner2019/MCB2-Mars, RUN #: 154, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 120, EFPA: -11.72, SIGMA: -0.17, APO : 33055.29
BATCH :../data/werner2019/MCB2-Mars, RUN #: 155, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 73, EFPA: -11.77, SIGMA: -1.34, APO : 33135.85
BATCH :../data/werner2019/MCB2-Mars, RUN #: 156, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 890, EFPA: -11.74, SIGMA: -1.78, APO : 32952.39
BATCH :../data/werner2019/MCB2-Mars, RUN #: 157, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 414, EFPA: -11.82, SIGMA: 0.45, APO : 29928.26
BATCH :../data/werner2019/MCB2-Mars, RUN #: 158, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 522, EFPA: -11.86, SIGMA: 1.85, APO : 34118.29
BATCH :../data/werner2019/MCB2-Mars, RUN #: 159, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 489, EFPA: -11.81, SIGMA: 0.70, APO : 32025.62
BATCH :../data/werner2019/MCB2-Mars, RUN #: 160, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 644, EFPA: -11.76, SIGMA: -0.35, APO : 32760.02
BATCH :../data/werner2019/MCB2-Mars, RUN #: 161, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 764, EFPA: -11.91, SIGMA: -0.32, APO : 29380.60
BATCH :../data/werner2019/MCB2-Mars, RUN #: 162, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 596, EFPA: -11.72, SIGMA: 0.18, APO : 32955.43
BATCH :../data/werner2019/MCB2-Mars, RUN #: 163, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 498, EFPA: -11.88, SIGMA: -1.44, APO : 34005.35
BATCH :../data/werner2019/MCB2-Mars, RUN #: 164, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 615, EFPA: -11.78, SIGMA: 1.76, APO : 32286.27
BATCH :../data/werner2019/MCB2-Mars, RUN #: 165, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 944, EFPA: -11.87, SIGMA: 0.30, APO : 31066.50
BATCH :../data/werner2019/MCB2-Mars, RUN #: 166, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 406, EFPA: -11.83, SIGMA: -0.12, APO : 31599.04
BATCH :../data/werner2019/MCB2-Mars, RUN #: 167, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 829, EFPA: -11.78, SIGMA: -0.43, APO : 34139.57
BATCH :../data/werner2019/MCB2-Mars, RUN #: 168, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 180, EFPA: -11.82, SIGMA: -0.42, APO : 32186.09
BATCH :../data/werner2019/MCB2-Mars, RUN #: 169, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 765, EFPA: -11.70, SIGMA: -1.12, APO : 32991.40
BATCH :../data/werner2019/MCB2-Mars, RUN #: 170, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 267, EFPA: -11.82, SIGMA: 0.33, APO : 32976.77
BATCH :../data/werner2019/MCB2-Mars, RUN #: 171, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 304, EFPA: -11.74, SIGMA: 0.27, APO : 32222.07
BATCH :../data/werner2019/MCB2-Mars, RUN #: 172, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 176, EFPA: -11.86, SIGMA: -1.23, APO : 32461.76
BATCH :../data/werner2019/MCB2-Mars, RUN #: 173, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 303, EFPA: -11.79, SIGMA: 1.18, APO : 30793.02
BATCH :../data/werner2019/MCB2-Mars, RUN #: 174, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 563, EFPA: -11.83, SIGMA: -1.24, APO : 33081.93
BATCH :../data/werner2019/MCB2-Mars, RUN #: 175, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 635, EFPA: -11.77, SIGMA: 0.56, APO : 31688.48
BATCH :../data/werner2019/MCB2-Mars, RUN #: 176, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 59, EFPA: -11.79, SIGMA: -1.15, APO : 32489.12
BATCH :../data/werner2019/MCB2-Mars, RUN #: 177, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 42, EFPA: -11.67, SIGMA: -0.55, APO : 33136.43
BATCH :../data/werner2019/MCB2-Mars, RUN #: 178, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 853, EFPA: -11.77, SIGMA: -1.97, APO : 32841.73
BATCH :../data/werner2019/MCB2-Mars, RUN #: 179, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 367, EFPA: -11.79, SIGMA: -0.33, APO : 32174.99
BATCH :../data/werner2019/MCB2-Mars, RUN #: 180, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 390, EFPA: -11.98, SIGMA: -0.04, APO : 37951.84
BATCH :../data/werner2019/MCB2-Mars, RUN #: 181, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 210, EFPA: -11.85, SIGMA: 0.31, APO : 32692.22
BATCH :../data/werner2019/MCB2-Mars, RUN #: 182, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 185, EFPA: -11.84, SIGMA: 2.36, APO : 30077.14
```

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```
BATCH :../data/werner2019/MCB2-Mars, RUN #: 183, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 710, EFPA: -11.84, SIGMA: -0.56, APO : 31625.02
BATCH :../data/werner2019/MCB2-Mars, RUN #: 184, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 891, EFPA: -11.80, SIGMA: 0.02, APO : 32301.29
BATCH :../data/werner2019/MCB2-Mars, RUN #: 185, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 643, EFPA: -11.82, SIGMA: 0.07, APO : 31366.44
BATCH :../data/werner2019/MCB2-Mars, RUN #: 186, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 414, EFPA: -11.80, SIGMA: -0.10, APO : 30194.61
BATCH :../data/werner2019/MCB2-Mars, RUN #: 187, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 282, EFPA: -11.76, SIGMA: -0.25, APO : 31947.25
BATCH :../data/werner2019/MCB2-Mars, RUN #: 188, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 188, EFPA: -11.83, SIGMA: 1.38, APO : 32456.24
BATCH :../data/werner2019/MCB2-Mars, RUN #: 189, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 365, EFPA: -11.89, SIGMA: 0.36, APO : 30324.04
BATCH :../data/werner2019/MCB2-Mars, RUN #: 190, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 276, EFPA: -11.82, SIGMA: -0.62, APO : 32557.33
BATCH :../data/werner2019/MCB2-Mars, RUN #: 191, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 277, EFPA: -11.78, SIGMA: -1.29, APO : 32861.95
BATCH :../data/werner2019/MCB2-Mars, RUN #: 192, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 397, EFPA: -11.67, SIGMA: 0.77, APO : 32877.94
BATCH :../data/werner2019/MCB2-Mars, RUN #: 193, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 428, EFPA: -11.82, SIGMA: 0.55, APO : 32704.97
BATCH :../data/werner2019/MCB2-Mars, RUN #: 194, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 307, EFPA: -11.87, SIGMA: -0.03, APO : 32033.48
BATCH :../data/werner2019/MCB2-Mars, RUN #: 195, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 191, EFPA: -11.84, SIGMA: -0.11, APO : 32431.21
BATCH :../data/werner2019/MCB2-Mars, RUN #: 196, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 837, EFPA: -11.77, SIGMA: -0.40, APO : 31984.49
BATCH :../data/werner2019/MCB2-Mars, RUN #: 197, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 419, EFPA: -11.74, SIGMA: 1.65, APO : 32412.90
BATCH :../data/werner2019/MCB2-Mars, RUN #: 198, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 922, EFPA: -11.89, SIGMA: -1.35, APO : 33031.33
BATCH :../data/werner2019/MCB2-Mars, RUN #: 199, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 505, EFPA: -11.85, SIGMA: 0.12, APO : 33073.55
BATCH :../data/werner2019/MCB2-Mars, RUN #: 200, PROF: ../atmdata/Mars/LAT00N-N1000.
↪txt, SAMPLE #: 410, EFPA: -11.83, SIGMA: -0.19, APO : 31926.59
```

Load the terminal apoapsis, deceleration and heat rate data.

[14]:
```
apoap = np.loadtxt('../data/werner2019/MCB2-Mars/terminal_apoapsis_arr.txt')
peria = np.loadtxt('../data/werner2019/MCB2-Mars/terminal_periapsis_arr.txt')
decel = np.loadtxt('../data/werner2019/MCB2-Mars/acc_net_g_max_arr.txt')
heatr = np.loadtxt('../data/werner2019/MCB2-Mars/q_stag_max_arr.txt')
```

Remove cases which resulted in apoapsis < 30000 km or > 36000 km.

[15]:
```
del_index_low = np.where(apoap < 28000)
print(del_index_low)
```

```
(array([52, 76, 95]),)
```

Seven cases resulted in apoapis less than 25000 km, and are considered to crash.

Remove these entries from the data before plotting.

[16]:
```
apoap_clean = np.delete(apoap, del_index_low)
peria_clean = np.delete(peria, del_index_low)
```

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```
decel_clean = np.delete(decel, del_index_low)
heatr_clean = np.delete(heatr, del_index_low)
```

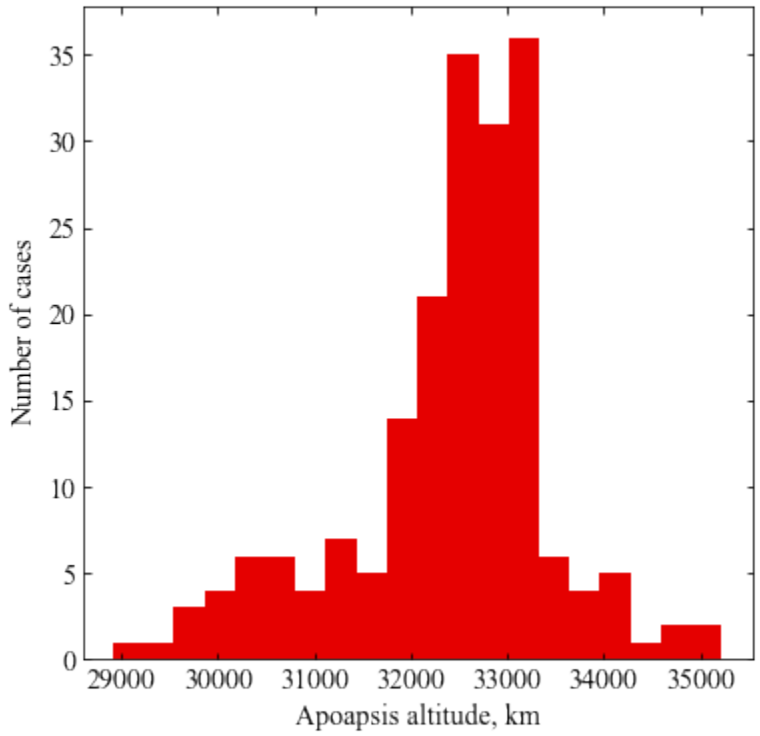
Also remove cases with apoapsis > 36000 km.

[17]:
```
del_index_high = np.where(apoap_clean > 36000)
print(del_index_high)
```

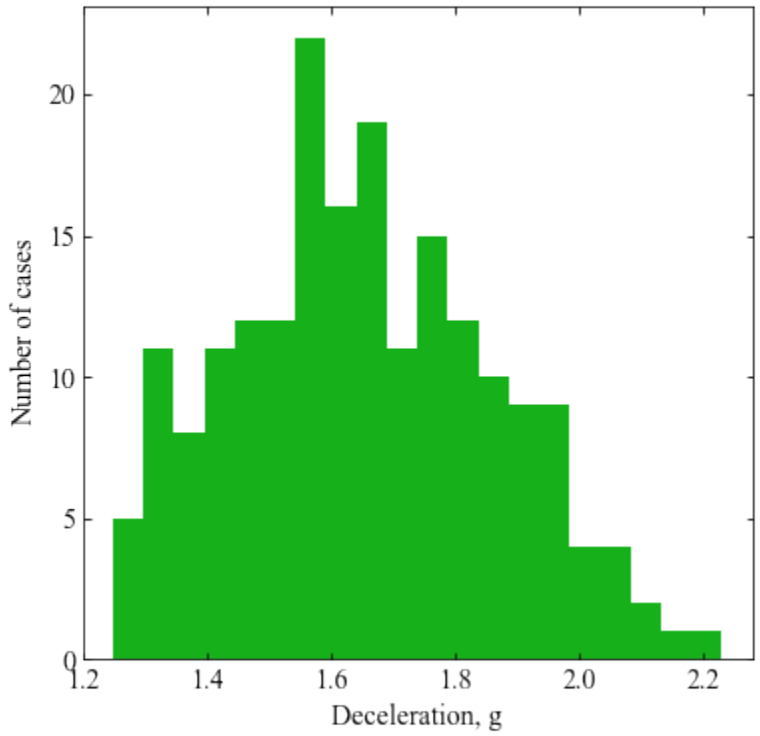
```
(array([ 95, 127, 176]),)
```

[18]:
```
apoap_clean2 = np.delete(apoap_clean, del_index_high)
peria_clean2 = np.delete(peria_clean, del_index_high)
decel_clean2 = np.delete(decel_clean, del_index_high)
heatr_clean2 = np.delete(heatr_clean, del_index_high)
```

[25]:
```
plt.figure(figsize=(6,6))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)
plt.hist(apoap_clean2, bins=20, color='xkcd:red')
plt.xlabel('Apoapsis altitude, km',fontsize=14)
plt.ylabel('Number of cases',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/werner-smallsat-apoa-hist-mars-2.png',bbox_inches='tight')
plt.savefig('../plots/werner-smallsat-apoa-hist-mars-2.pdf', dpi=300,bbox_inches=
↪'tight')
plt.savefig('../plots/werner-smallsat-apoa-hist-mars-2.eps', dpi=300,bbox_inches=
↪'tight')
plt.show()
```

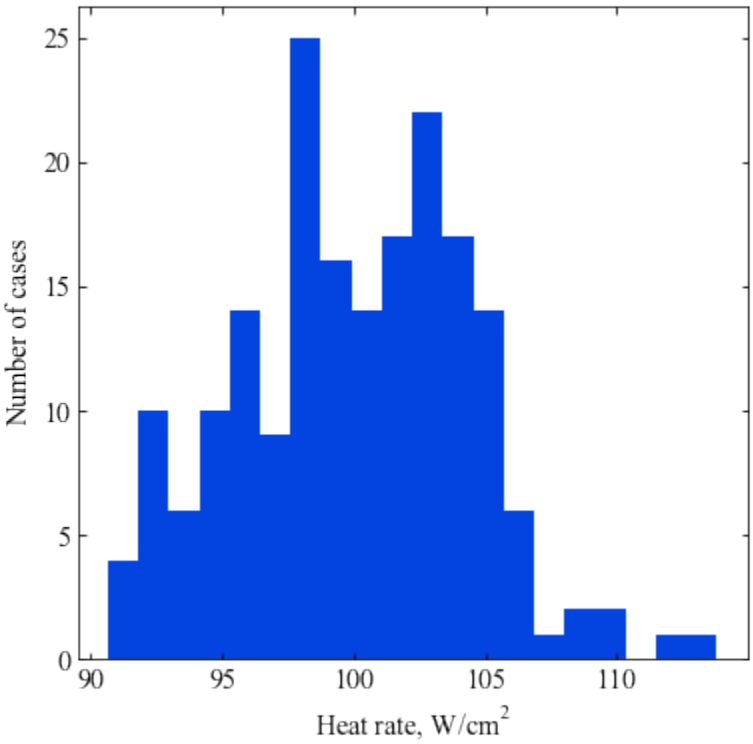


[20]:
```
plt.figure(figsize=(6,6))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)
plt.hist(decel_clean2, bins=20, color='xkcd:green')
plt.xlabel('Deceleration, g',fontsize=14)
plt.ylabel('Number of cases',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/werner-smallsat-decel-hist-mars-2.png',bbox_inches='tight')
plt.savefig('../plots/werner-smallsat-decel-hist-mars-2.pdf', dpi=300,bbox_inches=
↪'tight')
plt.savefig('../plots/werner-smallsat-decel-hist-mars-2.eps', dpi=300,bbox_inches=
↪'tight')
plt.show()
```

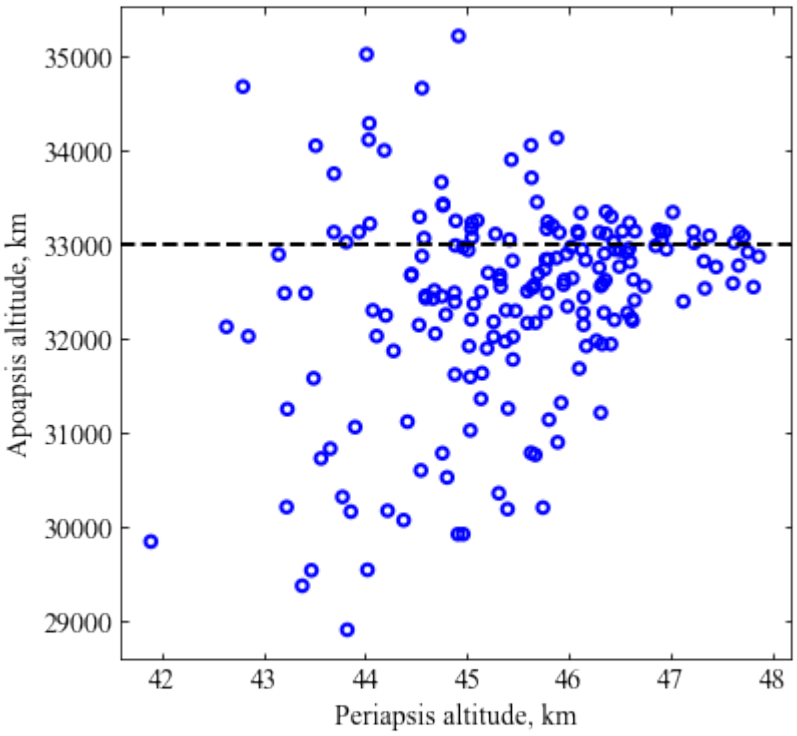


[21]:
```
plt.figure(figsize=(6,6))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)
plt.hist(heatr_clean2, bins=20, color='xkcd:blue')
plt.xlabel('Heat rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Number of cases',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/werner-smallsat-heat-hist-mars-2.png',bbox_inches='tight')
plt.savefig('../plots/werner-smallsat-heat-hist-mars-2.pdf', dpi=300,bbox_inches=
↪'tight')
plt.savefig('../plots/werner-smallsat-heat-hist-mars-2.eps', dpi=300,bbox_inches=
↪'tight')
plt.show()
```

```
/home/athul/anaconda3/lib/python3.7/site-packages/numpy/lib/histograms.py:824:␣
↪RuntimeWarning: invalid value encountered in greater_equal
  keep = (tmp_a >= first_edge)
/home/athul/anaconda3/lib/python3.7/site-packages/numpy/lib/histograms.py:825:␣
↪RuntimeWarning: invalid value encountered in less_equal
  keep &= (tmp_a <= last_edge)
```



[22]:
```
plt.figure(figsize=(6,6))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)
plt.scatter(peria_clean2, apoap_clean2, s=30, facecolors='none', edgecolors='b', lw=2)
plt.axhline(y=33000, lw=2.0, ls='dashed', color='k')
plt.xlabel('Periapsis altitude, km',fontsize=14)
plt.ylabel('Apoapsis altitude, km',fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/werner-smallsat-apoa-peri-mars-2.png',bbox_inches='tight')
plt.savefig('../plots/werner-smallsat-apoa-peri-mars-2.pdf', dpi=300,bbox_inches=
↪'tight')
plt.savefig('../plots/werner-smallsat-apoa-peri-mars-2.eps', dpi=300,bbox_inches=
↪'tight')
plt.show()
```



Find the percentage of cases which achieved apoapsis between 100 and 800 km.

[23]:
```
(np.size(apoap) - np.size(del_index_low) - np.size(del_index_high))*100/np.size(apoap)
```

[23]:
```
97.0
```

4.54 Example - 54 - ExoMars 2016 - Mars

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

This notebook simulates the atmospheric entry of the Schiaparelli EDM, flown in the ExoMars 2020 mission. https://en.wikipedia.org/wiki/Schiaparelli_EDM

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("MARS")
planet.h_skip = 120.0E3
planet.h_trap = 2.0E3
planet.loadAtmosphereModel('../atmdata/Mars/mars-gram-avg.dat', 0 , 1 , 2, 3)
```

[4]:
```
# Set up the vehicle
vehicle=Vehicle('Schiaparelli', 577.0, 75.0, 0.00, np.pi*2.4**2.0, 0.0, 0.6, planet)
```

[5]:
```
# Set up entry parameters
vehicle.setInitialState(120.0,0.0,0.0,5.900,0.0,-12.48,0.0,0.0)
```

[6]:
```
# Set up solver
vehicle.setSolverParams(1E-6)
```

[7]:
```
# Propogate vehicle entry trajectory
vehicle.propogateEntry (30*60.0,0.1,0.0)
```

[8]:
```
# import rcParams to set figure font type
from matplotlib import rcParams
```

[9]:
```
fig = plt.figure(figsize=(12,8))
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

plt.subplot(2, 2, 1)
plt.plot(vehicle.v_kmsc, vehicle.h_kmc, 'k-', linewidth=2.0)
plt.xlabel('Speed, km/s',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 2)
plt.plot(vehicle.acc_net_g, vehicle.h_kmc, 'b-', linewidth=2.0)
plt.xlabel('Deceleration, Earth g',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.subplot(2, 2, 3)
plt.plot(vehicle.q_stag_total, vehicle.h_kmc,'r-', linewidth=2.0)
plt.xlabel('Stagnation point heat-rate, '+r'$W/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)


plt.subplot(2, 2, 4)
plt.plot(vehicle.heatload/1.0E3, vehicle.h_kmc, 'm-', linewidth=2.0)
plt.xlabel('Stagnation point heat-load, '+r'$kJ/cm^2$',fontsize=14)
plt.ylabel('Altitude, km', fontsize=14)
ax=plt.gca()
```

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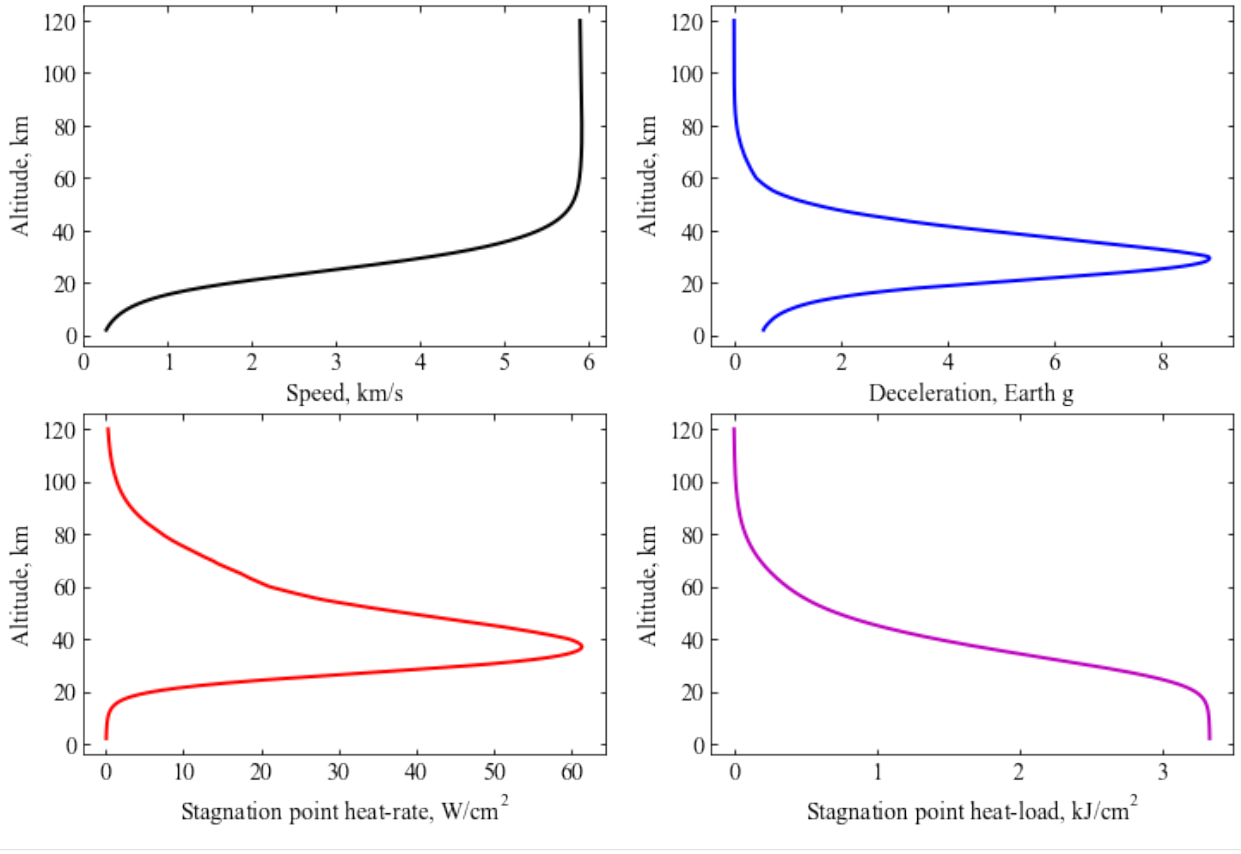
```
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
ax.tick_params(axis='x',labelsize=14)
ax.tick_params(axis='y',labelsize=14)

plt.savefig('../plots/exomars-2016-mars.png',bbox_inches='tight')
plt.savefig('../plots/exomars-2016-mars.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/exomars-2016-mars.eps', dpi=300,bbox_inches='tight')

plt.show()
```



Compare to results from https://doi.org/10.1016/j.actaastro.2018.05.029

4.55 Example - 55 - Titan Aerocapture Systems Study - Part 1

This examples reproduces results from Way, Powell et al., Aerocapture Simulation and Performance for the Titan Explorer Mission, 39th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit 20-23 July 2003, Huntsville, Alabama. https://doi.org/10.2514/6.2003-4951

[1]:
```
from IPython.display import Image
Image(filename='../plots/titan-aerocapture-systems.png', width=500)
```

[1]:

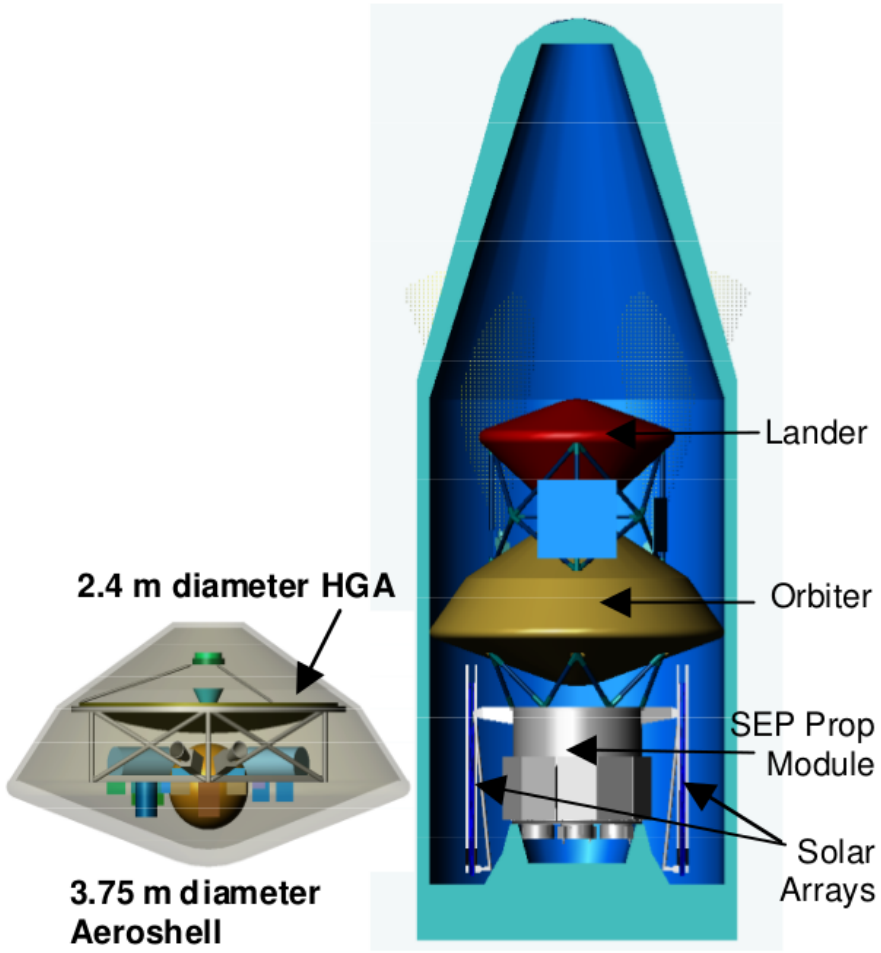


Image credit: Lockwood et al.

[2]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[3]:
```
import numpy as np
from scipy import interpolate
import pandas as pd

import matplotlib.pyplot as plt
from matplotlib import rcParams
```

[4]:
```
planet = Planet('TITAN')
planet.loadAtmosphereModel('../atmdata/Titan/titan-gram-avg.dat', 0 , 1 ,2, 3)
planet.h_skip = 1000.0E3
```

[5]:
```
vehicle=Vehicle('TitanAC', 818.0, 90.0, 0.25, np.pi*0.25*3.75**2, 0.0, 0.91, planet)
vehicle.setInitialState(1000.0,0.0,0.0,6.5,0.0,-25.00,0.0,0.0)
vehicle.setSolverParams(1E-6)
```

First, find the corridor bounds to select a target nominal EFPA for a nominal Mars atmosphere.

[7]:
```
underShootLimit, exitflag_us = vehicle.findUnderShootLimit(60.0*60.0, 1.0, -50.0,-5.0,
↪ 1E-10,  1700.0)
overShootLimit , exitflag_os = vehicle.findOverShootLimit(60.0*60.0,  1.0, -50.0,-5.0,
↪ 1E-10,  1700.0)

print("Corridor bounds for nominal atmosphere.")
print("----------------")
print(underShootLimit, exitflag_us)
print(overShootLimit,  exitflag_os)
print("----------------")
```

```
Corridor bounds for nominal atmosphere.
----------------
-37.83097717905548 1.0
-34.28877212249972 1.0
----------------
```

It is good practice to see how these corridor bounds vary with minimum, average, and maximum density atmospheres. We will check how much these corridor bounds change using +/- 3-sigma bounds from Titan GRAM output files.

Load three density profiles for minimum, average, and maximum scenarios from a GRAM output file.

[9]:
```
ATM_height1, ATM_density_low1, ATM_density_avg1, ATM_density_high1, ATM_density_pert1␣
↪= planet.loadMonteCarloDensityFile2('../atmdata/Titan/FMINMAX-10.txt', 0, 1, 2, 3,␣
↪4, heightInKmFlag=True)
ATM_height2, ATM_density_low2, ATM_density_avg2, ATM_density_high2, ATM_density_pert2␣
↪= planet.loadMonteCarloDensityFile2('../atmdata/Titan/FMINMAX+00.txt', 0, 1, 2, 3,␣
↪4, heightInKmFlag=True)
ATM_height3, ATM_density_low3, ATM_density_avg3, ATM_density_high3, ATM_density_pert3␣
↪= planet.loadMonteCarloDensityFile2('../atmdata/Titan/FMINMAX+10.txt', 0, 1, 2, 3,␣
↪4, heightInKmFlag=True)


density_int_low = planet.loadAtmosphereModel5(ATM_height1, ATM_density_low1, ATM_
↪density_avg1, ATM_density_high1, ATM_density_pert1, -3.0, 201, 1)
density_int_avg = planet.loadAtmosphereModel5(ATM_height2, ATM_density_low2, ATM_
↪density_avg2, ATM_density_high2, ATM_density_pert2,  0.0, 201, 1)
density_int_hig = planet.loadAtmosphereModel5(ATM_height3, ATM_density_low3, ATM_
↪density_avg3, ATM_density_high3, ATM_density_pert3, +3.0, 201, 1)
```

Set the planet density_int attribute to density_int_low

[10]:
```
planet.density_int = density_int_low
```

Compute the corridor bounds for low density atmosphere.

[11]:
```
underShootLimit, exitflag_us = vehicle.findUnderShootLimit(60.0*60.0, 1.0, -50.0,-5.0,
↪ 1E-10,  1700.0)
overShootLimit , exitflag_os = vehicle.findOverShootLimit(60.0*60.0,  1.0, -50.0,-5.0,
↪ 1E-10,  1700.0)

print("Low density atmosphere corridor bounds.")
print("----------------")
print(underShootLimit, exitflag_us)
print(overShootLimit,  exitflag_os)
print("----------------")
```

```
Low density atmosphere corridor bounds.
----------------
-38.47725151913437 1.0
-35.15044797081828 1.0
----------------
```

Repeat for average and maximum density atmospheres.

[13]:
```
planet.density_int = density_int_avg
```

[14]:
```
underShootLimit, exitflag_us = vehicle.findUnderShootLimit(60.0*60.0, 1.0, -50.0,-5.0,
↪ 1E-10,  1700.0)
overShootLimit , exitflag_os = vehicle.findOverShootLimit(60.0*60.0,  1.0, -50.0,-5.0,
↪ 1E-10,  1700.0)

print("Average density atmosphere corridor bounds.")
print("----------------")
print(underShootLimit, exitflag_us)
print(overShootLimit,  exitflag_os)
print("----------------")
```

```
Average density atmosphere corridor bounds.
----------------
-37.86181146377203 1.0
-34.38959433911805 1.0
----------------
```

[15]:
```
planet.density_int = density_int_hig
```

[16]:
```
underShootLimit, exitflag_us = vehicle.findUnderShootLimit(60.0*60.0, 1.0, -50.0,-5.0,
↪ 1E-10,  1700.0)
overShootLimit , exitflag_os = vehicle.findOverShootLimit(60.0*60.0,  1.0, -50.0,-5.0,
↪ 1E-10,  1700.0)

print("High density atmosphere corridor bounds.")
print("----------------")
print(underShootLimit, exitflag_us)
print(overShootLimit,  exitflag_os)
print("----------------")
```

```
High density atmosphere corridor bounds.
----------------
-37.287857468882066 1.0
-33.65637210436944 1.0
----------------
```

The corridor is approximately 3.5 deg wide for the nominal atmosphere.

[17]:
```
37.86 - 34.39
```

[17]:
```
3.469999999999999
```

The mid-corridor is typically a good place to start. We will use the mean of the corridor bounds for the average atmosphere.

[18]:
```
0.5*(-37.86 - 34.39)
```

[18]:
```
-36.125
```

We will propogate a bounding trajectories to illustrate full lift up and full lift down aerocapture trajectories at Titan using this vehicle.

[21]:
```
planet.density_int = density_int_avg
```

[27]:
```
# Reset initial conditions and propogate overshoot trajectory
vehicle.setInitialState(1000.0,0.0,0.0,6.5,0.0,-34.38959433911805,0.0,0.0)
vehicle.propogateEntry (60.0*60.0,1.0,180.0)

# Extract and save variables to plot
t_min_os         = vehicle.t_minc
h_km_os          = vehicle.h_kmc
acc_net_g_os     = vehicle.acc_net_g
q_stag_con_os    = vehicle.q_stag_con
q_stag_rad_os    = vehicle.q_stag_rad

# Reset initial conditions and propogate undershoot trajectory
vehicle.setInitialState(1000.0,0.0,0.0,6.5,0.0,-37.86181146377203,0.0,0.0)
vehicle.propogateEntry (60.0*60.0,1.0,0.0)


# Extract and save variable to plot
t_min_us         = vehicle.t_minc
h_km_us          = vehicle.h_kmc
acc_net_g_us     = vehicle.acc_net_g
q_stag_con_us    = vehicle.q_stag_con
q_stag_rad_us    = vehicle.q_stag_rad

'''
Create fig #1 - altitude history of aerocapture maneuver
'''

fig = plt.figure()
fig.set_size_inches([6.5,6.5])
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)
plt.plot(t_min_os , h_km_os, linestyle='solid' , color='xkcd:blue',linewidth=2.0, ␣
↪label='Overshoot')
plt.plot(t_min_us , h_km_us, linestyle='solid' , color='xkcd:green',linewidth=2.0, ␣
↪label='Undershoot')

plt.xlabel('Time, min',fontsize=14)
plt.ylabel("Altitude, km",fontsize=14)

ax = plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
plt.tick_params(direction='in')
plt.tick_params(axis='x',labelsize=14)
plt.tick_params(axis='y',labelsize=14)
```

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```
plt.legend(loc='lower right', fontsize=14)


plt.savefig('../plots/titan-systems-altitude.png',bbox_inches='tight')
plt.savefig('../plots/titan-systems-altitude.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/titan-systems-altitude.eps', dpi=300,bbox_inches='tight')

plt.show()

fig = plt.figure()
fig.set_size_inches([6.5,6.5])
plt.rc('font',family='Times New Roman')
plt.plot(t_min_os , acc_net_g_os, linestyle='solid' , color='xkcd:blue',linewidth=2.0,
↪  label='Overshoot')
plt.plot(t_min_us , acc_net_g_us, linestyle='solid' , color='xkcd:green',linewidth=2.
↪0,  label='Undershoot')

plt.xlabel('Time, min',fontsize=14)
plt.ylabel("Deceleration, Earth g",fontsize=14)

ax = plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
plt.tick_params(direction='in')
plt.tick_params(axis='x',labelsize=14)
plt.tick_params(axis='y',labelsize=14)

plt.legend(loc='upper right', fontsize=14)


plt.savefig('../plots/titan-systems-deceleration.png',bbox_inches='tight')
plt.savefig('../plots/titan-systems-deceleration.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/titan-systems-deceleration.eps', dpi=300,bbox_inches='tight')

plt.show()

fig = plt.figure()
fig.set_size_inches([6.5,6.5])
plt.rc('font',family='Times New Roman')
plt.plot(t_min_os , q_stag_con_os, linestyle='solid' , color='xkcd:blue',linewidth=2.
↪0,  label='Overshoot convective')
plt.plot(t_min_us , q_stag_con_us, linestyle='solid' , color='xkcd:magenta',
↪linewidth=2.0,  label='Undershoot convective')

plt.xlabel('Time, min',fontsize=14)
plt.ylabel("Stagnation-point heat rate, "+r'$W/cm^2$',fontsize=14)
ax = plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')
plt.tick_params(direction='in')
plt.tick_params(axis='x',labelsize=14)
plt.tick_params(axis='y',labelsize=14)

plt.legend(loc='upper right', fontsize=14)
```

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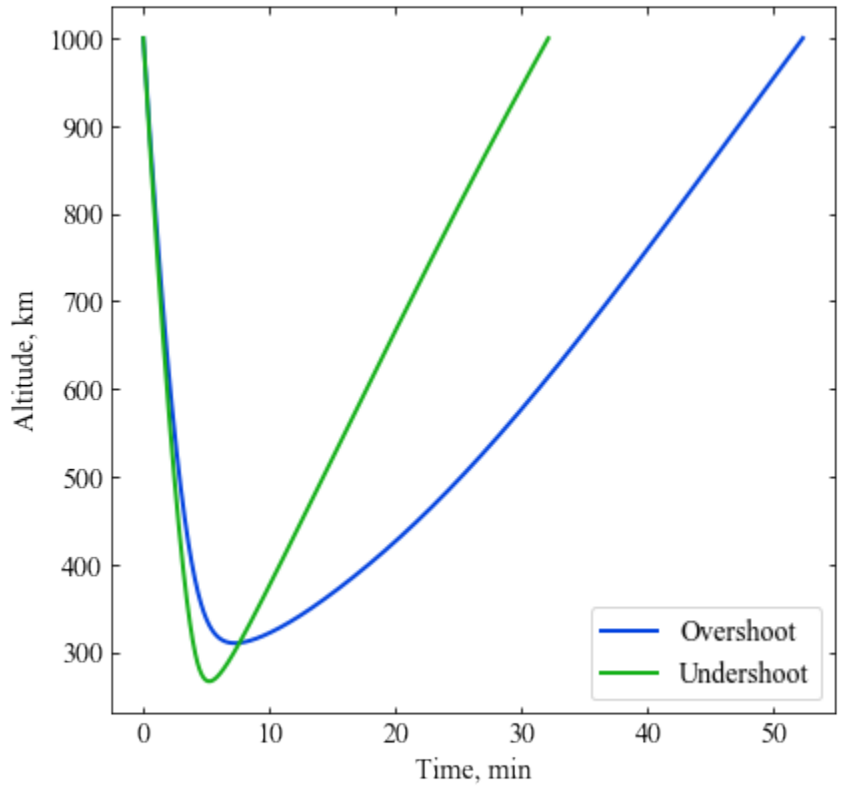
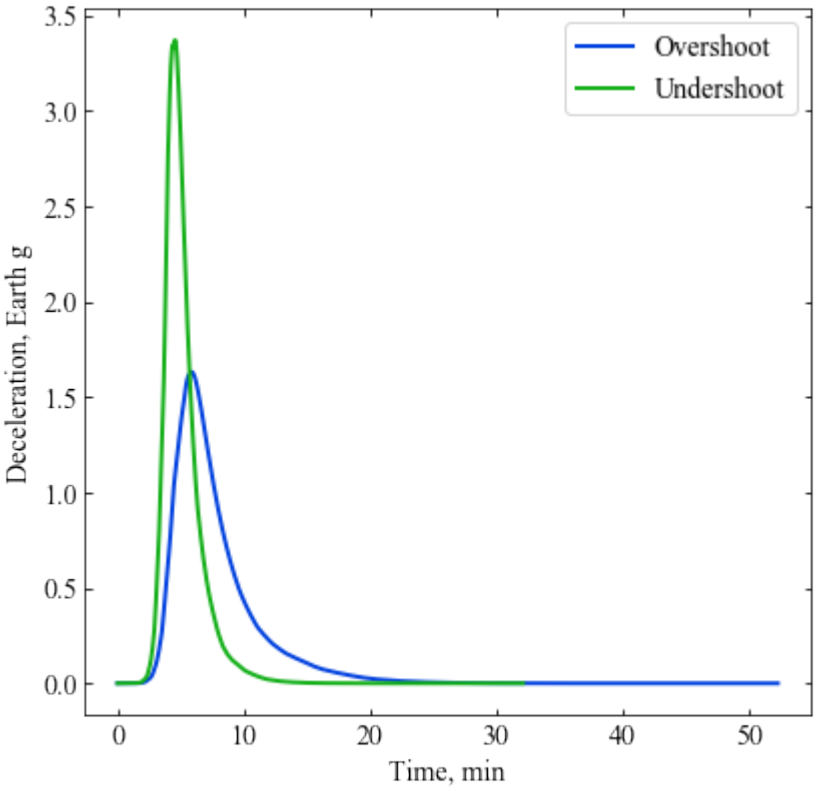
```
plt.savefig('../plots/titan-systems-heating.png',bbox_inches='tight')
plt.savefig('../plots/titan-systems-heating.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/titan-systems-heating.eps', dpi=300,bbox_inches='tight')

plt.show()
```

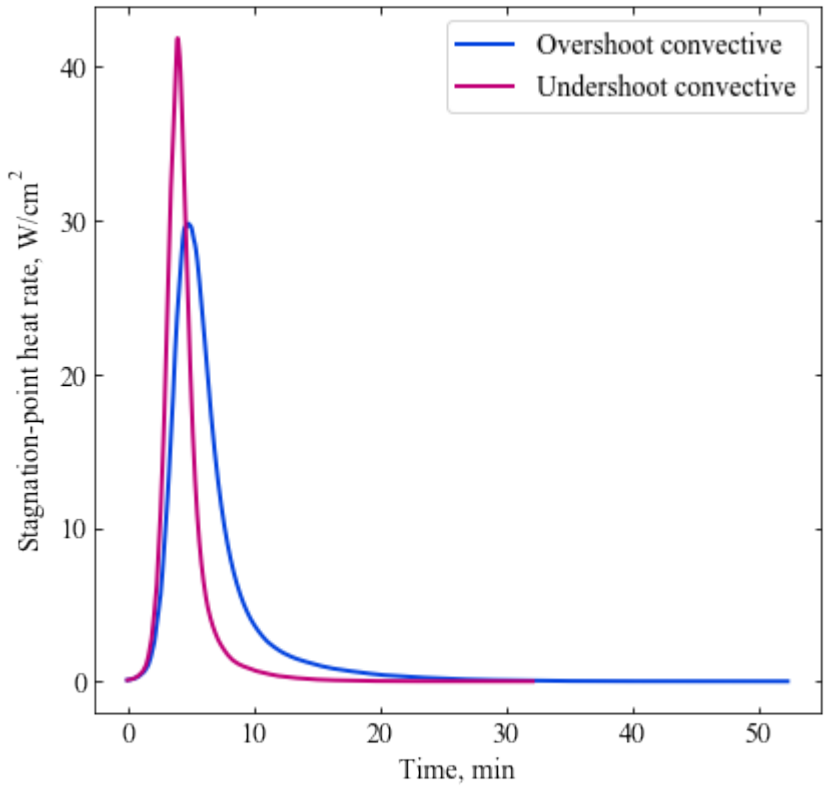
```
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
```




```
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
```




```
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
```



4.56 Example - 56 - Venus Entry Tradespace - Carpet Plot

This example will create an EDL carpet plot showning the trade space for high ballistic coefficient entry systems at Venus

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("VENUS")
planet.loadAtmosphereModel('../atmdata/Venus/venus-gram-avg.dat', 0 , 1 , 2, 3)
```

[4]:
```
betaRange = np.linspace(100,400,11)
gammaRange = np.linspace(-30,-8,11)

acc_net_g_max_array       = np.zeros((len(betaRange),len(gammaRange)))
q_stag_total_max_array    = np.zeros((len(betaRange),len(gammaRange)))
heatload_max_array        = np.zeros((len(betaRange),len(gammaRange)))
dyn_pres_array            = np.zeros((len(betaRange),len(gammaRange)))

for i, beta in enumerate(betaRange):
    for j, gamma in enumerate(gammaRange):
```

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```
        vehicle=Vehicle('vehicle1', 300.0, beta, 0.00, 0.25*np.pi*1.00**2, 0.00, 0.20,
↪ planet)
        vehicle.setInitialState(180.0,0.0,0.0,11.30,0.0,gamma,0.0,0.0)
        vehicle.setSolverParams(1E-6)
        vehicle.propogateEntry (2400.0,0.1,0.0)

        print("G_MAX: "+str("{:.2f}".format(max(vehicle.acc_net_g)))+", Q_MAX: "+str("
↪{:.2f}".format(max(vehicle.q_stag_total)))+", J_MAX: "+str("{:.2f}".
↪format(max(vehicle.heatload/1.0E3)))+", P_MAX: "+str("{:.2f}".format(max(vehicle.
↪dyn_pres_atm))))

        acc_net_g_max_array[i,j]     = max(vehicle.acc_net_g)
        q_stag_total_max_array[i,j]  = max(vehicle.q_stag_total)
        heatload_max_array[i,j]      = max(vehicle.heatload/1.0E3)
        dyn_pres_array[i,j]         = max(vehicle.dyn_pres_atm)
```

```
G_MAX: 272.16, Q_MAX: 3000.63, J_MAX: 10.39, P_MAX: 2.63
G_MAX: 253.65, Q_MAX: 2867.43, J_MAX: 10.69, P_MAX: 2.45
G_MAX: 234.89, Q_MAX: 2728.31, J_MAX: 11.03, P_MAX: 2.27
G_MAX: 215.69, Q_MAX: 2585.18, J_MAX: 11.43, P_MAX: 2.09
G_MAX: 195.63, Q_MAX: 2430.17, J_MAX: 11.91, P_MAX: 1.89
G_MAX: 174.22, Q_MAX: 2261.27, J_MAX: 12.50, P_MAX: 1.69
G_MAX: 151.94, Q_MAX: 2079.58, J_MAX: 13.25, P_MAX: 1.47
G_MAX: 128.85, Q_MAX: 1883.25, J_MAX: 14.24, P_MAX: 1.25
G_MAX: 103.38, Q_MAX: 1655.23, J_MAX: 15.66, P_MAX: 1.00
G_MAX: 74.80, Q_MAX: 1378.07, J_MAX: 18.04, P_MAX: 0.72
G_MAX: 35.61, Q_MAX: 932.10, J_MAX: 24.52, P_MAX: 0.34
G_MAX: 265.99, Q_MAX: 3520.22, J_MAX: 12.28, P_MAX: 3.35
G_MAX: 248.72, Q_MAX: 3365.41, J_MAX: 12.61, P_MAX: 3.13
G_MAX: 230.39, Q_MAX: 3197.74, J_MAX: 13.00, P_MAX: 2.90
G_MAX: 211.15, Q_MAX: 3019.15, J_MAX: 13.45, P_MAX: 2.66
G_MAX: 191.12, Q_MAX: 2830.51, J_MAX: 14.00, P_MAX: 2.40
G_MAX: 170.83, Q_MAX: 2635.39, J_MAX: 14.67, P_MAX: 2.15
G_MAX: 149.45, Q_MAX: 2421.99, J_MAX: 15.51, P_MAX: 1.88
G_MAX: 126.21, Q_MAX: 2182.44, J_MAX: 16.63, P_MAX: 1.59
G_MAX: 101.57, Q_MAX: 1914.77, J_MAX: 18.25, P_MAX: 1.28
G_MAX: 73.11, Q_MAX: 1583.67, J_MAX: 20.98, P_MAX: 0.92
G_MAX: 34.27, Q_MAX: 1061.26, J_MAX: 28.56, P_MAX: 0.43
G_MAX: 261.09, Q_MAX: 4007.68, J_MAX: 14.05, P_MAX: 4.04
G_MAX: 243.61, Q_MAX: 3822.52, J_MAX: 14.42, P_MAX: 3.77
G_MAX: 225.79, Q_MAX: 3628.03, J_MAX: 14.85, P_MAX: 3.50
G_MAX: 207.50, Q_MAX: 3426.40, J_MAX: 15.35, P_MAX: 3.21
G_MAX: 188.32, Q_MAX: 3212.03, J_MAX: 15.95, P_MAX: 2.92
G_MAX: 167.89, Q_MAX: 2979.14, J_MAX: 16.68, P_MAX: 2.60
G_MAX: 146.65, Q_MAX: 2731.82, J_MAX: 17.62, P_MAX: 2.27
G_MAX: 124.52, Q_MAX: 2462.83, J_MAX: 18.86, P_MAX: 1.93
G_MAX: 99.77, Q_MAX: 2150.49, J_MAX: 20.65, P_MAX: 1.55
G_MAX: 71.95, Q_MAX: 1773.14, J_MAX: 23.69, P_MAX: 1.11
G_MAX: 33.21, Q_MAX: 1173.83, J_MAX: 32.28, P_MAX: 0.51
G_MAX: 257.65, Q_MAX: 4478.48, J_MAX: 15.76, P_MAX: 4.74
G_MAX: 240.29, Q_MAX: 4266.81, J_MAX: 16.15, P_MAX: 4.42
G_MAX: 222.38, Q_MAX: 4041.95, J_MAX: 16.61, P_MAX: 4.09
G_MAX: 203.91, Q_MAX: 3806.99, J_MAX: 17.15, P_MAX: 3.75
G_MAX: 185.22, Q_MAX: 3565.21, J_MAX: 17.80, P_MAX: 3.41
G_MAX: 165.72, Q_MAX: 3308.80, J_MAX: 18.60, P_MAX: 3.05
G_MAX: 144.71, Q_MAX: 3026.35, J_MAX: 19.61, P_MAX: 2.66
G_MAX: 122.50, Q_MAX: 2720.55, J_MAX: 20.96, P_MAX: 2.25
```

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```
G_MAX: 98.66, Q_MAX: 2375.37, J_MAX: 22.91, P_MAX: 1.81
G_MAX: 70.90, Q_MAX: 1948.59, J_MAX: 26.23, P_MAX: 1.30
G_MAX: 32.27, Q_MAX: 1276.52, J_MAX: 35.77, P_MAX: 0.59
G_MAX: 254.43, Q_MAX: 4919.54, J_MAX: 17.40, P_MAX: 5.42
G_MAX: 237.40, Q_MAX: 4688.30, J_MAX: 17.83, P_MAX: 5.05
G_MAX: 219.88, Q_MAX: 4444.41, J_MAX: 18.32, P_MAX: 4.68
G_MAX: 201.62, Q_MAX: 4184.25, J_MAX: 18.90, P_MAX: 4.29
G_MAX: 182.64, Q_MAX: 3905.04, J_MAX: 19.59, P_MAX: 3.89
G_MAX: 163.21, Q_MAX: 3616.24, J_MAX: 20.44, P_MAX: 3.48
G_MAX: 143.05, Q_MAX: 3309.04, J_MAX: 21.52, P_MAX: 3.05
G_MAX: 121.02, Q_MAX: 2966.83, J_MAX: 22.97, P_MAX: 2.58
G_MAX: 97.41, Q_MAX: 2585.49, J_MAX: 25.06, P_MAX: 2.07
G_MAX: 69.87, Q_MAX: 2112.27, J_MAX: 28.64, P_MAX: 1.49
G_MAX: 31.52, Q_MAX: 1372.81, J_MAX: 39.06, P_MAX: 0.67
G_MAX: 252.35, Q_MAX: 5353.22, J_MAX: 19.00, P_MAX: 6.11
G_MAX: 235.13, Q_MAX: 5089.09, J_MAX: 19.45, P_MAX: 5.69
G_MAX: 217.49, Q_MAX: 4822.59, J_MAX: 19.97, P_MAX: 5.26
G_MAX: 199.44, Q_MAX: 4543.29, J_MAX: 20.58, P_MAX: 4.83
G_MAX: 180.82, Q_MAX: 4241.77, J_MAX: 21.32, P_MAX: 4.38
G_MAX: 161.27, Q_MAX: 3915.87, J_MAX: 22.22, P_MAX: 3.90
G_MAX: 141.17, Q_MAX: 3577.07, J_MAX: 23.37, P_MAX: 3.42
G_MAX: 119.86, Q_MAX: 3206.83, J_MAX: 24.90, P_MAX: 2.90
G_MAX: 96.13, Q_MAX: 2782.97, J_MAX: 27.13, P_MAX: 2.33
G_MAX: 69.14, Q_MAX: 2271.19, J_MAX: 30.95, P_MAX: 1.67
G_MAX: 30.88, Q_MAX: 1462.05, J_MAX: 42.21, P_MAX: 0.75
G_MAX: 250.31, Q_MAX: 5781.17, J_MAX: 20.57, P_MAX: 6.78
G_MAX: 233.43, Q_MAX: 5491.90, J_MAX: 21.04, P_MAX: 6.33
G_MAX: 215.73, Q_MAX: 5191.43, J_MAX: 21.58, P_MAX: 5.85
G_MAX: 197.61, Q_MAX: 4883.73, J_MAX: 22.23, P_MAX: 5.36
G_MAX: 179.11, Q_MAX: 4562.31, J_MAX: 23.00, P_MAX: 4.85
G_MAX: 159.81, Q_MAX: 4213.52, J_MAX: 23.95, P_MAX: 4.33
G_MAX: 139.55, Q_MAX: 3835.77, J_MAX: 25.16, P_MAX: 3.78
G_MAX: 118.58, Q_MAX: 3435.06, J_MAX: 26.78, P_MAX: 3.21
G_MAX: 95.22, Q_MAX: 2975.82, J_MAX: 29.13, P_MAX: 2.58
G_MAX: 68.52, Q_MAX: 2423.99, J_MAX: 33.18, P_MAX: 1.86
G_MAX: 30.28, Q_MAX: 1544.69, J_MAX: 45.25, P_MAX: 0.82
G_MAX: 248.40, Q_MAX: 6186.87, J_MAX: 22.11, P_MAX: 7.45
G_MAX: 231.77, Q_MAX: 5881.79, J_MAX: 22.59, P_MAX: 6.95
G_MAX: 214.30, Q_MAX: 5559.95, J_MAX: 23.16, P_MAX: 6.43
G_MAX: 196.20, Q_MAX: 5215.47, J_MAX: 23.83, P_MAX: 5.89
G_MAX: 177.53, Q_MAX: 4867.83, J_MAX: 24.64, P_MAX: 5.33
G_MAX: 158.47, Q_MAX: 4498.81, J_MAX: 25.64, P_MAX: 4.75
G_MAX: 138.41, Q_MAX: 4093.45, J_MAX: 26.91, P_MAX: 4.15
G_MAX: 117.26, Q_MAX: 3653.50, J_MAX: 28.60, P_MAX: 3.52
G_MAX: 94.47, Q_MAX: 3165.29, J_MAX: 31.07, P_MAX: 2.83
G_MAX: 67.84, Q_MAX: 2568.86, J_MAX: 35.33, P_MAX: 2.04
G_MAX: 29.70, Q_MAX: 1622.53, J_MAX: 48.18, P_MAX: 0.89
G_MAX: 246.66, Q_MAX: 6590.07, J_MAX: 23.62, P_MAX: 8.12
G_MAX: 230.04, Q_MAX: 6264.13, J_MAX: 24.12, P_MAX: 7.57
G_MAX: 212.88, Q_MAX: 5919.42, J_MAX: 24.72, P_MAX: 7.01
G_MAX: 195.04, Q_MAX: 5550.66, J_MAX: 25.41, P_MAX: 6.42
G_MAX: 176.40, Q_MAX: 5166.63, J_MAX: 26.26, P_MAX: 5.80
G_MAX: 157.18, Q_MAX: 4771.07, J_MAX: 27.29, P_MAX: 5.17
G_MAX: 137.36, Q_MAX: 4344.64, J_MAX: 28.61, P_MAX: 4.52
G_MAX: 116.17, Q_MAX: 3868.27, J_MAX: 30.38, P_MAX: 3.82
G_MAX: 93.67, Q_MAX: 3347.28, J_MAX: 32.97, P_MAX: 3.08
G_MAX: 67.12, Q_MAX: 2707.20, J_MAX: 37.43, P_MAX: 2.21
```

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```
G_MAX: 29.15, Q_MAX: 1697.19, J_MAX: 51.02, P_MAX: 0.96
G_MAX: 245.34, Q_MAX: 6979.82, J_MAX: 25.11, P_MAX: 8.79
G_MAX: 228.57, Q_MAX: 6630.50, J_MAX: 25.63, P_MAX: 8.19
G_MAX: 211.45, Q_MAX: 6263.85, J_MAX: 26.25, P_MAX: 7.57
G_MAX: 193.86, Q_MAX: 5879.23, J_MAX: 26.97, P_MAX: 6.94
G_MAX: 175.45, Q_MAX: 5466.34, J_MAX: 27.84, P_MAX: 6.28
G_MAX: 156.14, Q_MAX: 5036.07, J_MAX: 28.92, P_MAX: 5.59
G_MAX: 136.32, Q_MAX: 4586.26, J_MAX: 30.29, P_MAX: 4.88
G_MAX: 115.36, Q_MAX: 4083.42, J_MAX: 32.13, P_MAX: 4.13
G_MAX: 92.80, Q_MAX: 3522.46, J_MAX: 34.82, P_MAX: 3.32
G_MAX: 66.48, Q_MAX: 2841.40, J_MAX: 39.47, P_MAX: 2.38
G_MAX: 28.67, Q_MAX: 1769.70, J_MAX: 53.79, P_MAX: 1.03
G_MAX: 244.16, Q_MAX: 7371.23, J_MAX: 26.58, P_MAX: 9.45
G_MAX: 227.41, Q_MAX: 6990.31, J_MAX: 27.12, P_MAX: 8.80
G_MAX: 210.19, Q_MAX: 6604.05, J_MAX: 27.76, P_MAX: 8.14
G_MAX: 192.63, Q_MAX: 6199.32, J_MAX: 28.50, P_MAX: 7.46
G_MAX: 174.45, Q_MAX: 5764.68, J_MAX: 29.40, P_MAX: 6.75
G_MAX: 155.36, Q_MAX: 5299.71, J_MAX: 30.52, P_MAX: 6.01
G_MAX: 135.40, Q_MAX: 4819.17, J_MAX: 31.94, P_MAX: 5.24
G_MAX: 114.61, Q_MAX: 4293.05, J_MAX: 33.84, P_MAX: 4.44
G_MAX: 91.97, Q_MAX: 3692.51, J_MAX: 36.63, P_MAX: 3.56
G_MAX: 65.98, Q_MAX: 2974.32, J_MAX: 41.47, P_MAX: 2.55
G_MAX: 28.25, Q_MAX: 1839.89, J_MAX: 56.49, P_MAX: 1.09
```

[5]:
```
from scipy import interpolate
```

[6]:
```
f1 = interpolate.interp2d(betaRange, gammaRange, np.transpose(acc_net_g_max_array),␣
↪kind='cubic')
q1 = interpolate.interp2d(betaRange, gammaRange, np.transpose(q_stag_total_max_array),
↪ kind='cubic')
h1 = interpolate.interp2d(betaRange, gammaRange, np.transpose(heatload_max_array),␣
↪kind='cubic')
s1 = interpolate.interp2d(betaRange, gammaRange, np.transpose(dyn_pres_array), kind=
↪'cubic')

x_new =  np.linspace(100,400, 110)
y_new =  np.linspace(-30,-8,110)

g1_new =  np.zeros((len(x_new),len(y_new)))
q1_new =  np.zeros((len(x_new),len(y_new)))
h1_new =  np.zeros((len(x_new),len(y_new)))
s1_new =  np.zeros((len(x_new),len(y_new)))

for i in range(0,len(x_new)):
    for j in range(0,len(y_new)):

        g1_new[i,j] = f1(x_new[i],y_new[j])
        q1_new[i,j] = q1(x_new[i],y_new[j])
        h1_new[i,j] = h1(x_new[i],y_new[j])
        s1_new[i,j] = s1(x_new[i],y_new[j])

X, Y = np.meshgrid(x_new, y_new)

fig = plt.figure()
fig.set_size_inches([8.00,8.00])
plt.ion()
```

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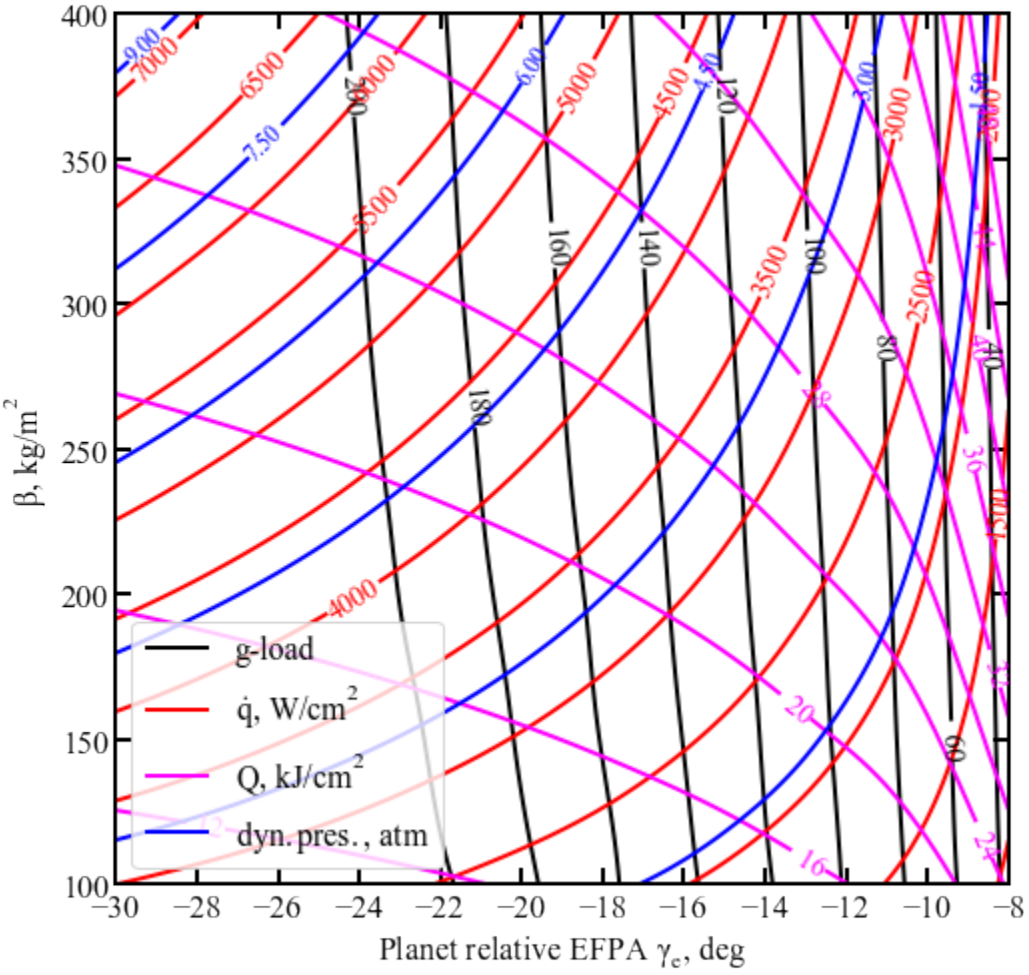
```
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

GCS1 = plt.contour(Y, X, np.transpose(g1_new), levels=np.linspace(40,200,9), ␣
↪linewidths=2.0, colors='black')
plt.clabel(GCS1, inline=1, fontsize=14, colors='black',fmt='%3d',inline_spacing=1)
GCS1.collections[0].set_label(r'g-load')


QCS1 = plt.contour(Y, X, np.transpose(q1_new), levels=np.linspace(1000,7000,13),␣
↪linewidths=2.0, colors='red')
plt.clabel(QCS1, inline=1, fontsize=14, colors='red',fmt='%3d',inline_spacing=1)
QCS1.collections[0].set_label(r'$\dot{q}$'+', '+r'$W/cm^2$')

HCS1 = plt.contour(Y, X, np.transpose(h1_new), levels=np.linspace(12,48,10),␣
↪linewidths=2.0, colors='magenta')
plt.clabel(HCS1, inline=1, fontsize=14, colors='magenta',fmt='%3d',inline_spacing=1)
HCS1.collections[0].set_label(r'$Q$'+', '+r'$kJ/cm^2$')

SCS1 = plt.contour(Y, X, np.transpose(s1_new), linewidths=2.0, colors='blue')
plt.clabel(SCS1, inline=1, fontsize=12, colors='blue',fmt='%.2f',inline_spacing=1)
SCS1.collections[0].set_label(r'$dyn. pres.$'+', '+r'$atm$')

plt.xlabel("Planet relative EFPA "+r'$\gamma_e$'+r', deg' ,fontsize=16)
plt.ylabel(r'$\beta$, '+r'$kg/m^2$' ,fontsize=16)
plt.xticks(np.linspace(-30,-8,12),fontsize=16)
plt.yticks(fontsize=16)
ax = plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')

plt.legend(loc='lower left', fontsize=16, framealpha=0.8)

ax.xaxis.set_tick_params(direction='in', which='both')
ax.yaxis.set_tick_params(direction='in', which='both')

ax.xaxis.set_tick_params(width=2, length=8)
ax.yaxis.set_tick_params(width=2, length=8)

ax.xaxis.set_tick_params(width=1, length=6, which='minor')
ax.yaxis.set_tick_params(width=1, length=6, which='minor')


ax.xaxis.grid(which='major', color='k', linestyle='dotted', linewidth=0.0)
ax.xaxis.grid(which='minor', color='k', linestyle='dotted', linewidth=0.0)

ax.yaxis.grid(which='major', color='k', linestyle='dotted', linewidth=0.0)
ax.yaxis.grid(which='minor', color='k', linestyle='dotted', linewidth=0.0)

for axis in ['top', 'bottom', 'left', 'right']:
    ax.spines[axis].set_linewidth(2)

plt.savefig('../plots/venus-carpet-plot.png', dpi=300,bbox_inches='tight')
plt.savefig('../plots/venus-carpet-plot.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/venus-carpet-plot.eps', dpi=300,bbox_inches='tight')
```

```
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
```



[ ]:

4.57 Example - 57 - Dragnofly (Titan) Entry Tradespace - Carpet Plot

This example will create an EDL carpet plot showning the trade space for Dragnofly entry vehicle at Titan. Based on work presented in "Preliminary Interplanetary Mission Design and Navigation for the Dragonfly New Frontiers Mission Concept, AAS 18-416"

[1]:
```
from AMAT.planet import Planet
from AMAT.vehicle import Vehicle
```

[2]:
```
import numpy as np
import matplotlib.pyplot as plt
```

[3]:
```
# Set up the planet and atmosphere model.
planet=Planet("TITAN")
planet.h_skip = 1270.0E3
planet.h_trap =    0.0E3
planet.loadAtmosphereModel('../atmdata/Titan/titan-gram-avg.dat', 0 , 1 , 2, 3)
```

[4]:
```
speedRange = np.linspace(7  , 9, 11)
gammaRange = np.linspace(-60,-46, 11)


acc_net_g_max_array       = np.zeros((len(speedRange),len(gammaRange)))
q_stag_total_max_array    = np.zeros((len(speedRange),len(gammaRange)))
heatload_max_array        = np.zeros((len(speedRange),len(gammaRange)))
dyn_pres_array            = np.zeros((len(speedRange),len(gammaRange)))

for i, speed in enumerate(speedRange):
    for j, gamma in enumerate(gammaRange):
        vehicle=Vehicle('Dragonfly', 1000.0, 140.0, 0.0, np.pi*3.7**2.0*0.25, 0.0, 0.
↪43, planet)
        vehicle.setInitialState(1270.0,0.0,0.0,speed,0.0,gamma,0.0,0.0)
        vehicle.setSolverParams(1E-6)
        vehicle.propogateEntry (120*60,1.0,0.0)

        print("G_MAX: "+str("{:.2f}".format(max(vehicle.acc_net_g)))+", Q_MAX: "+str("
↪{:.2f}".format(max(vehicle.q_stag_total)))+", J_MAX: "+str("{:.2f}".
↪format(max(vehicle.heatload/1.0E3)))+", P_MAX: "+str("{:.2f}".format(max(vehicle.
↪dyn_pres_atm))))

        acc_net_g_max_array[i,j]     = max(vehicle.acc_net_g)
        q_stag_total_max_array[i,j]  = max(vehicle.q_stag_total)
        heatload_max_array[i,j]      = max(vehicle.heatload/1.0E3)
        dyn_pres_array[i,j]         = max(vehicle.dyn_pres_atm)
```

```
G_MAX: 16.17, Q_MAX: 158.40, J_MAX: 7.08, P_MAX: 0.22
G_MAX: 15.53, Q_MAX: 155.48, J_MAX: 7.20, P_MAX: 0.21
G_MAX: 14.86, Q_MAX: 152.30, J_MAX: 7.34, P_MAX: 0.20
G_MAX: 14.15, Q_MAX: 148.93, J_MAX: 7.49, P_MAX: 0.19
G_MAX: 13.40, Q_MAX: 145.24, J_MAX: 7.67, P_MAX: 0.18
G_MAX: 12.60, Q_MAX: 141.26, J_MAX: 7.87, P_MAX: 0.17
G_MAX: 11.75, Q_MAX: 136.89, J_MAX: 8.10, P_MAX: 0.16
G_MAX: 10.84, Q_MAX: 132.13, J_MAX: 8.37, P_MAX: 0.15
G_MAX: 9.86, Q_MAX: 126.80, J_MAX: 8.70, P_MAX: 0.13
G_MAX: 8.80, Q_MAX: 120.85, J_MAX: 9.10, P_MAX: 0.12
G_MAX: 7.65, Q_MAX: 114.04, J_MAX: 9.60, P_MAX: 0.10
G_MAX: 17.05, Q_MAX: 171.82, J_MAX: 7.48, P_MAX: 0.23
G_MAX: 16.38, Q_MAX: 168.64, J_MAX: 7.61, P_MAX: 0.22
G_MAX: 15.68, Q_MAX: 165.21, J_MAX: 7.75, P_MAX: 0.21
G_MAX: 14.92, Q_MAX: 161.53, J_MAX: 7.92, P_MAX: 0.20
G_MAX: 14.12, Q_MAX: 157.52, J_MAX: 8.10, P_MAX: 0.19
G_MAX: 13.28, Q_MAX: 153.18, J_MAX: 8.32, P_MAX: 0.18
G_MAX: 12.38, Q_MAX: 148.41, J_MAX: 8.56, P_MAX: 0.17
G_MAX: 11.41, Q_MAX: 143.22, J_MAX: 8.85, P_MAX: 0.15
G_MAX: 10.38, Q_MAX: 137.40, J_MAX: 9.20, P_MAX: 0.14
G_MAX: 9.26, Q_MAX: 130.92, J_MAX: 9.62, P_MAX: 0.13
G_MAX: 8.03, Q_MAX: 123.51, J_MAX: 10.16, P_MAX: 0.11
G_MAX: 17.96, Q_MAX: 185.95, J_MAX: 7.89, P_MAX: 0.24
G_MAX: 17.26, Q_MAX: 182.53, J_MAX: 8.02, P_MAX: 0.23
```

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```
G_MAX: 16.51, Q_MAX: 178.80, J_MAX: 8.18, P_MAX: 0.22
G_MAX: 15.71, Q_MAX: 174.81, J_MAX: 8.35, P_MAX: 0.21
G_MAX: 14.87, Q_MAX: 170.48, J_MAX: 8.55, P_MAX: 0.20
G_MAX: 13.97, Q_MAX: 165.73, J_MAX: 8.78, P_MAX: 0.19
G_MAX: 13.02, Q_MAX: 160.59, J_MAX: 9.04, P_MAX: 0.18
G_MAX: 12.00, Q_MAX: 154.90, J_MAX: 9.34, P_MAX: 0.16
G_MAX: 10.91, Q_MAX: 148.62, J_MAX: 9.71, P_MAX: 0.15
G_MAX: 9.72, Q_MAX: 141.56, J_MAX: 10.16, P_MAX: 0.13
G_MAX: 8.42, Q_MAX: 133.48, J_MAX: 10.73, P_MAX: 0.11
G_MAX: 18.90, Q_MAX: 200.88, J_MAX: 8.31, P_MAX: 0.26
G_MAX: 18.16, Q_MAX: 197.08, J_MAX: 8.45, P_MAX: 0.25
G_MAX: 17.36, Q_MAX: 193.07, J_MAX: 8.62, P_MAX: 0.24
G_MAX: 16.53, Q_MAX: 188.83, J_MAX: 8.80, P_MAX: 0.22
G_MAX: 15.63, Q_MAX: 184.12, J_MAX: 9.01, P_MAX: 0.21
G_MAX: 14.69, Q_MAX: 178.97, J_MAX: 9.25, P_MAX: 0.20
G_MAX: 13.68, Q_MAX: 173.42, J_MAX: 9.52, P_MAX: 0.19
G_MAX: 12.61, Q_MAX: 167.28, J_MAX: 9.85, P_MAX: 0.17
G_MAX: 11.45, Q_MAX: 160.45, J_MAX: 10.24, P_MAX: 0.16
G_MAX: 10.20, Q_MAX: 152.76, J_MAX: 10.71, P_MAX: 0.14
G_MAX: 8.82, Q_MAX: 144.00, J_MAX: 11.32, P_MAX: 0.12
G_MAX: 19.86, Q_MAX: 216.50, J_MAX: 8.74, P_MAX: 0.27
G_MAX: 19.07, Q_MAX: 212.61, J_MAX: 8.89, P_MAX: 0.26
G_MAX: 18.24, Q_MAX: 208.27, J_MAX: 9.07, P_MAX: 0.25
G_MAX: 17.36, Q_MAX: 203.47, J_MAX: 9.26, P_MAX: 0.24
G_MAX: 16.42, Q_MAX: 198.44, J_MAX: 9.48, P_MAX: 0.22
G_MAX: 15.43, Q_MAX: 192.96, J_MAX: 9.73, P_MAX: 0.21
G_MAX: 14.37, Q_MAX: 186.92, J_MAX: 10.02, P_MAX: 0.19
G_MAX: 13.23, Q_MAX: 180.27, J_MAX: 10.37, P_MAX: 0.18
G_MAX: 12.01, Q_MAX: 172.88, J_MAX: 10.78, P_MAX: 0.16
G_MAX: 10.69, Q_MAX: 164.59, J_MAX: 11.28, P_MAX: 0.14
G_MAX: 9.23, Q_MAX: 155.08, J_MAX: 11.93, P_MAX: 0.13
G_MAX: 20.85, Q_MAX: 233.07, J_MAX: 9.18, P_MAX: 0.28
G_MAX: 20.02, Q_MAX: 228.84, J_MAX: 9.34, P_MAX: 0.27
G_MAX: 19.14, Q_MAX: 224.14, J_MAX: 9.53, P_MAX: 0.26
G_MAX: 18.21, Q_MAX: 219.09, J_MAX: 9.73, P_MAX: 0.25
G_MAX: 17.23, Q_MAX: 213.61, J_MAX: 9.96, P_MAX: 0.23
G_MAX: 16.18, Q_MAX: 207.62, J_MAX: 10.23, P_MAX: 0.22
G_MAX: 15.06, Q_MAX: 201.11, J_MAX: 10.54, P_MAX: 0.20
G_MAX: 13.87, Q_MAX: 193.95, J_MAX: 10.90, P_MAX: 0.19
G_MAX: 12.58, Q_MAX: 185.96, J_MAX: 11.33, P_MAX: 0.17
G_MAX: 11.19, Q_MAX: 176.98, J_MAX: 11.86, P_MAX: 0.15
G_MAX: 9.66, Q_MAX: 166.73, J_MAX: 12.55, P_MAX: 0.13
G_MAX: 21.86, Q_MAX: 250.41, J_MAX: 9.64, P_MAX: 0.30
G_MAX: 20.99, Q_MAX: 245.89, J_MAX: 9.81, P_MAX: 0.28
G_MAX: 20.07, Q_MAX: 240.82, J_MAX: 10.00, P_MAX: 0.27
G_MAX: 19.09, Q_MAX: 235.40, J_MAX: 10.21, P_MAX: 0.26
G_MAX: 18.05, Q_MAX: 229.44, J_MAX: 10.46, P_MAX: 0.24
G_MAX: 16.95, Q_MAX: 223.06, J_MAX: 10.74, P_MAX: 0.23
G_MAX: 15.78, Q_MAX: 216.02, J_MAX: 11.06, P_MAX: 0.21
G_MAX: 14.52, Q_MAX: 208.27, J_MAX: 11.44, P_MAX: 0.20
G_MAX: 13.17, Q_MAX: 199.71, J_MAX: 11.90, P_MAX: 0.18
G_MAX: 11.70, Q_MAX: 190.02, J_MAX: 12.46, P_MAX: 0.16
G_MAX: 10.09, Q_MAX: 178.96, J_MAX: 13.19, P_MAX: 0.14
G_MAX: 22.90, Q_MAX: 268.79, J_MAX: 10.10, P_MAX: 0.31
G_MAX: 21.98, Q_MAX: 263.74, J_MAX: 10.28, P_MAX: 0.30
G_MAX: 21.02, Q_MAX: 258.36, J_MAX: 10.48, P_MAX: 0.28
G_MAX: 19.98, Q_MAX: 252.50, J_MAX: 10.71, P_MAX: 0.27
```

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```
G_MAX: 18.90, Q_MAX: 246.07, J_MAX: 10.97, P_MAX: 0.26
G_MAX: 17.74, Q_MAX: 239.21, J_MAX: 11.26, P_MAX: 0.24
G_MAX: 16.51, Q_MAX: 231.61, J_MAX: 11.60, P_MAX: 0.22
G_MAX: 15.19, Q_MAX: 223.37, J_MAX: 12.00, P_MAX: 0.21
G_MAX: 13.77, Q_MAX: 214.09, J_MAX: 12.48, P_MAX: 0.19
G_MAX: 12.23, Q_MAX: 203.71, J_MAX: 13.08, P_MAX: 0.17
G_MAX: 10.53, Q_MAX: 191.78, J_MAX: 13.84, P_MAX: 0.14
G_MAX: 23.96, Q_MAX: 287.81, J_MAX: 10.58, P_MAX: 0.32
G_MAX: 23.00, Q_MAX: 282.40, J_MAX: 10.77, P_MAX: 0.31
G_MAX: 21.99, Q_MAX: 276.65, J_MAX: 10.98, P_MAX: 0.30
G_MAX: 20.90, Q_MAX: 270.37, J_MAX: 11.22, P_MAX: 0.28
G_MAX: 19.77, Q_MAX: 263.58, J_MAX: 11.49, P_MAX: 0.27
G_MAX: 18.55, Q_MAX: 256.16, J_MAX: 11.79, P_MAX: 0.25
G_MAX: 17.27, Q_MAX: 248.04, J_MAX: 12.15, P_MAX: 0.23
G_MAX: 15.87, Q_MAX: 239.12, J_MAX: 12.57, P_MAX: 0.22
G_MAX: 14.39, Q_MAX: 229.22, J_MAX: 13.08, P_MAX: 0.19
G_MAX: 12.77, Q_MAX: 218.02, J_MAX: 13.70, P_MAX: 0.17
G_MAX: 10.99, Q_MAX: 205.21, J_MAX: 14.51, P_MAX: 0.15
G_MAX: 25.02, Q_MAX: 307.93, J_MAX: 11.07, P_MAX: 0.34
G_MAX: 24.04, Q_MAX: 302.11, J_MAX: 11.27, P_MAX: 0.33
G_MAX: 22.97, Q_MAX: 295.87, J_MAX: 11.49, P_MAX: 0.31
G_MAX: 21.85, Q_MAX: 289.11, J_MAX: 11.74, P_MAX: 0.30
G_MAX: 20.66, Q_MAX: 281.89, J_MAX: 12.02, P_MAX: 0.28
G_MAX: 19.38, Q_MAX: 273.95, J_MAX: 12.34, P_MAX: 0.26
G_MAX: 18.03, Q_MAX: 265.17, J_MAX: 12.72, P_MAX: 0.24
G_MAX: 16.58, Q_MAX: 255.62, J_MAX: 13.16, P_MAX: 0.22
G_MAX: 15.02, Q_MAX: 245.01, J_MAX: 13.69, P_MAX: 0.20
G_MAX: 13.32, Q_MAX: 233.04, J_MAX: 14.35, P_MAX: 0.18
G_MAX: 11.46, Q_MAX: 219.25, J_MAX: 15.20, P_MAX: 0.16
G_MAX: 26.15, Q_MAX: 328.78, J_MAX: 11.57, P_MAX: 0.35
G_MAX: 25.10, Q_MAX: 322.67, J_MAX: 11.77, P_MAX: 0.34
G_MAX: 23.98, Q_MAX: 315.87, J_MAX: 12.01, P_MAX: 0.32
G_MAX: 22.82, Q_MAX: 308.77, J_MAX: 12.27, P_MAX: 0.31
G_MAX: 21.57, Q_MAX: 300.83, J_MAX: 12.56, P_MAX: 0.29
G_MAX: 20.23, Q_MAX: 292.45, J_MAX: 12.90, P_MAX: 0.27
G_MAX: 18.82, Q_MAX: 283.15, J_MAX: 13.29, P_MAX: 0.25
G_MAX: 17.30, Q_MAX: 272.93, J_MAX: 13.76, P_MAX: 0.23
G_MAX: 15.66, Q_MAX: 261.53, J_MAX: 14.31, P_MAX: 0.21
G_MAX: 13.89, Q_MAX: 248.70, J_MAX: 15.00, P_MAX: 0.19
G_MAX: 11.93, Q_MAX: 233.97, J_MAX: 15.90, P_MAX: 0.16
```

[5]:
```
from scipy import interpolate
```

[6]:
```
f1 = interpolate.interp2d(speedRange, gammaRange, np.transpose(acc_net_g_max_array),␣
↪kind='cubic')
q1 = interpolate.interp2d(speedRange, gammaRange, np.transpose(q_stag_total_max_
↪array), kind='cubic')
h1 = interpolate.interp2d(speedRange, gammaRange, np.transpose(heatload_max_array),␣
↪kind='cubic')
s1 = interpolate.interp2d(speedRange, gammaRange, np.transpose(dyn_pres_array), kind=
↪'cubic')

x_new =  np.linspace(7,9 , 110)
y_new =  np.linspace(-60,-46,110)
```

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```
g1_new =  np.zeros((len(x_new),len(y_new)))
q1_new =  np.zeros((len(x_new),len(y_new)))
h1_new =  np.zeros((len(x_new),len(y_new)))
s1_new =  np.zeros((len(x_new),len(y_new)))

for i in range(0,len(x_new)):
    for j in range(0,len(y_new)):

        g1_new[i,j] = f1(x_new[i],y_new[j])
        q1_new[i,j] = q1(x_new[i],y_new[j])
        h1_new[i,j] = h1(x_new[i],y_new[j])
        s1_new[i,j] = s1(x_new[i],y_new[j])

X, Y = np.meshgrid(x_new, y_new)

fig = plt.figure()
fig.set_size_inches([8.00,8.00])
plt.ion()
plt.rc('font',family='Times New Roman')
params = {'mathtext.default': 'regular' }
plt.rcParams.update(params)

GCS1 = plt.contour(Y, X, np.transpose(g1_new), levels=15, linewidths=2.0, colors=
↪'black')
plt.clabel(GCS1, inline=1, fontsize=14, colors='black',fmt='%3d',inline_spacing=1)
GCS1.collections[0].set_label(r'g-load')


QCS1 = plt.contour(Y, X, np.transpose(q1_new),  levels=15, linewidths=2.0, colors='red
↪')
plt.clabel(QCS1, inline=1, fontsize=14, colors='red',fmt='%3d',inline_spacing=1)
QCS1.collections[0].set_label(r'$\dot{q}$'+', '+r'$W/cm^2$')

HCS1 = plt.contour(Y, X, np.transpose(h1_new), levels=15, linewidths=2.0, colors=
↪'magenta')
plt.clabel(HCS1, inline=1, fontsize=14, colors='magenta',fmt='%3d',inline_spacing=1)
HCS1.collections[0].set_label(r'$Q$'+', '+r'$kJ/cm^2$')

plt.xlabel("Planet relative EFPA "+r'$\gamma_e$'+r', deg' ,fontsize=16)
plt.ylabel(r'Entry speed, km/s' ,fontsize=16)
plt.xticks(fontsize=16)
plt.yticks(fontsize=16)
ax = plt.gca()
ax.tick_params(direction='in')
ax.yaxis.set_ticks_position('both')
ax.xaxis.set_ticks_position('both')

plt.legend(loc='lower left', fontsize=16, framealpha=0.8)

ax.xaxis.set_tick_params(direction='in', which='both')
ax.yaxis.set_tick_params(direction='in', which='both')

ax.xaxis.set_tick_params(width=2, length=8)
ax.yaxis.set_tick_params(width=2, length=8)

ax.xaxis.set_tick_params(width=1, length=6, which='minor')
ax.yaxis.set_tick_params(width=1, length=6, which='minor')
```

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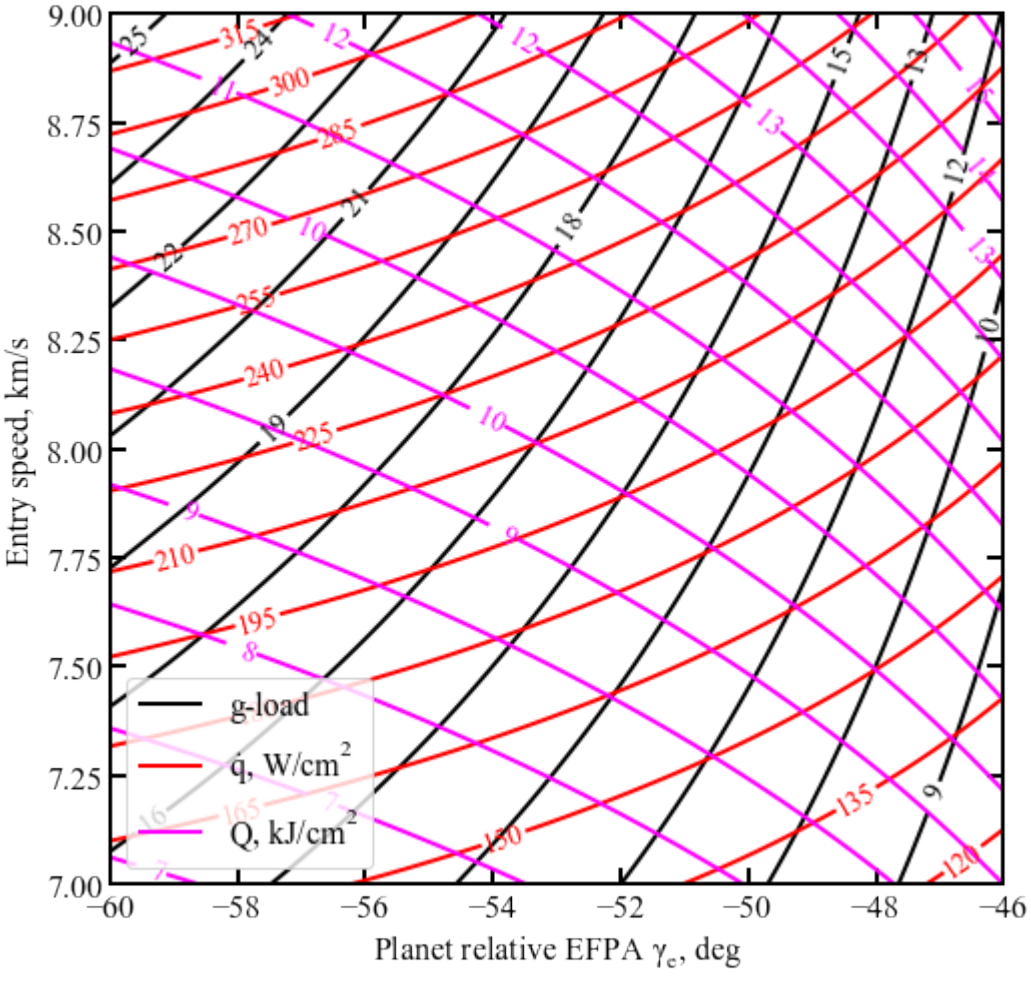
```
ax.xaxis.grid(which='major', color='k', linestyle='dotted', linewidth=0.0)
ax.xaxis.grid(which='minor', color='k', linestyle='dotted', linewidth=0.0)

ax.yaxis.grid(which='major', color='k', linestyle='dotted', linewidth=0.0)
ax.yaxis.grid(which='minor', color='k', linestyle='dotted', linewidth=0.0)

for axis in ['top', 'bottom', 'left', 'right']:
    ax.spines[axis].set_linewidth(2)

plt.savefig('../plots/dragnofly-sweep.png', dpi=300,bbox_inches='tight')
plt.savefig('../plots/dragnofly-sweep.pdf', dpi=300,bbox_inches='tight')
plt.savefig('../plots/dragnofly-sweep.eps', dpi=300,bbox_inches='tight')
```

```
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
The PostScript backend does not support transparency; partially transparent artists␣
↪will be rendered opaque.
```



Compare the figure to Fig. 11 presented in the paper. The heat rate and heat loads are somewhat off (by a factor of about 2 in some cases) because of the simple models heating correlations used. This is an area which could be improved in future versions of AMAT.

CHAPTER 5

Credits

AMAT was developed at the Advanced Astodynamics Concepts (AAC) research group at Purdue University. Parts of the AMAT source code were originally developed in support of contracts between AAC and the Jet Propulsion Laboratory for various aerocapture mission studies between 2016 and 2020. Samples of atmospheric data from Global Reference Atmospheric Model (GRAM) software is used for illustration purpose only, and was developed by NASA Marshall Space Flight Center. The use of these GRAM models does not imply endorsement by NASA in any way whatsoever. A minimal working set of atmospheric profiles is included with AMAT to run the example notebooks. A minimal working interplanetary trajctory dataset is included with AMAT. The dataset was generated at Purdue University using the STOUR software package by Alec Mudek, and is also derived from trajectories published in the NASA Ice Giants Pre-Decadal Mission Study. The author plans to augment the interplanetary dataset with more publicly available information as it becomes available.

5.1 Extras

The AMAT repository includes representative atmospheric profiles for Solar System bodies, an Excel sheet with a comprehensive literature review of aerocapture, sample feasibility charts for aerocapture at all destinations, reference journal articles (by the author), a PDF version of the documentation, and the author's Ph.D. dissertation which provides more details on the methods and algorithms implemented in AMAT.

CHAPTER 6

References

Results from these articles are also used as benchmark examples.

1. Craig, Scott, and James Evans Lyne. Parametric Study of Aerocapture for Missions to Venus. *Journal of Spacecraft and Rockets*, Vol. 42, No. 6, pp. 1035-1038. craiglyne2005
2. Putnam and Braun, Drag-Modulation Flight-Control System Options for Planetary Aerocapture, *Journal of Spacecraft and Rockets*, Vol. 51, No. 1, 2014. putnamBraun2014
3. Lu, Ye, and Sarag J. Saikia. Feasibility Assessment of Aerocapture for Future Titan Orbiter Missions. *Journal of Spacecraft and Rockets*, Vol. 55, No. 5, pp. 1125-1135. luSaikia2018
4. Girija, A. P., Lu, Y., & Saikia, S. J. Feasibility and Mass-Benefit Analysis of Aerocapture for Missions to Venus. *Journal of Spacecraft and Rockets*, Vol. 57, No. 1, pp. 58-73. girijaSaikia2020a
5. Girija, A. P. et al. Feasibility and Performance Analysis of Neptune Aerocapture Using Heritage Blunt-Body Aeroshells, *Journal of Spacecraft and Rockets*, Vol. 57, No. 6, pp. 1186-1203. girijaSaikia2020b

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