Research project meeting summary: Trajectory Module for Launcher MDAO

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Plan:

1. Review of previous work
2. Key points discussed and future actions

Review of previous work

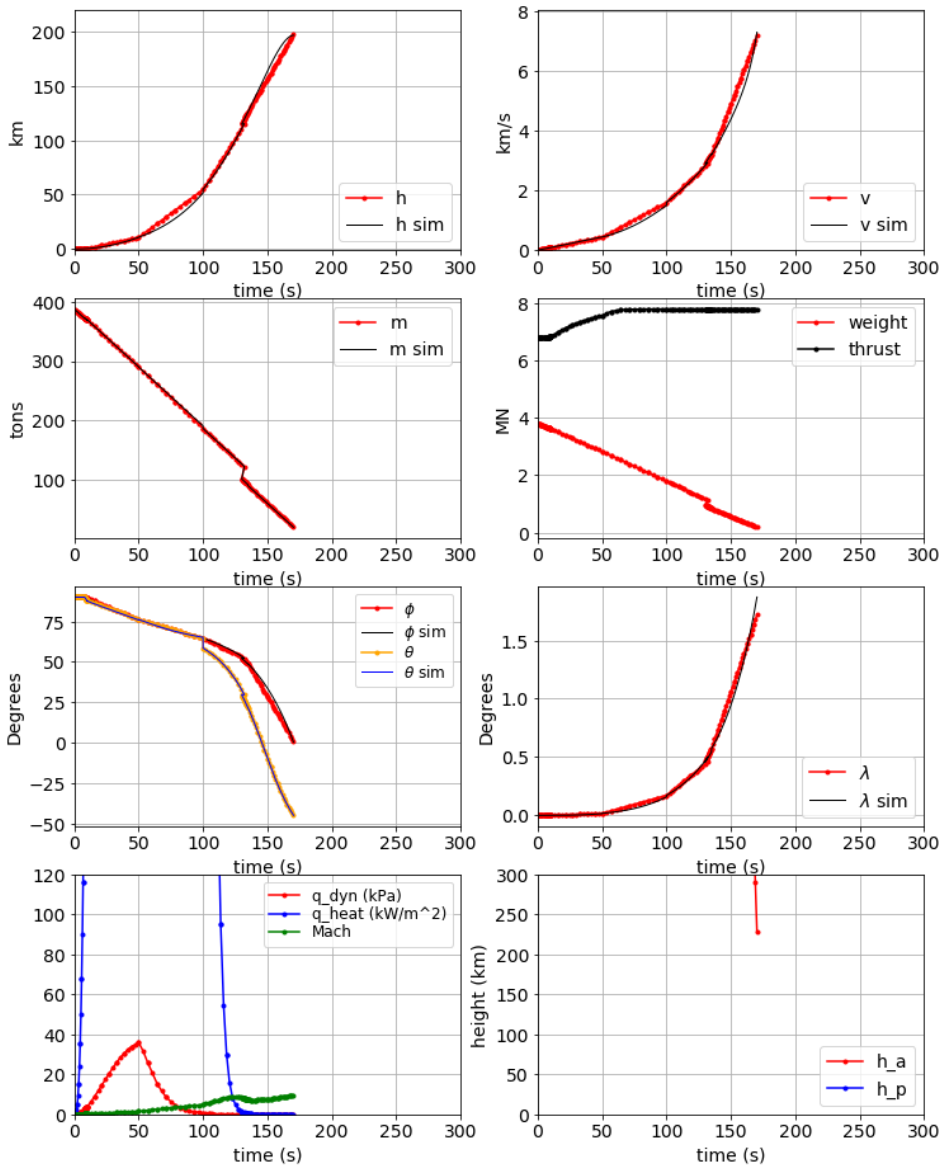
- In the last weeks I've been working with optimization of 2D trajectories for 2 stage vehicles in DYMOS. They work fine for an imaginary rocket but still have trouble when I try to include the fairing jettison.
- I tried using the 3 independent optimization variables for mass of propellants, but I found a simpler approach to the optimization of propellant mass. No need to use any extra optimization variable.

  Before I was constraining the initial and final values of mass for a jettison event. Now I'm constraining the difference between those values (i.e. the amount of mass being jettisoned). The optimization of mass is then performed in the same way as for any other state in Dymos, without the extra component outside the "phases" group.

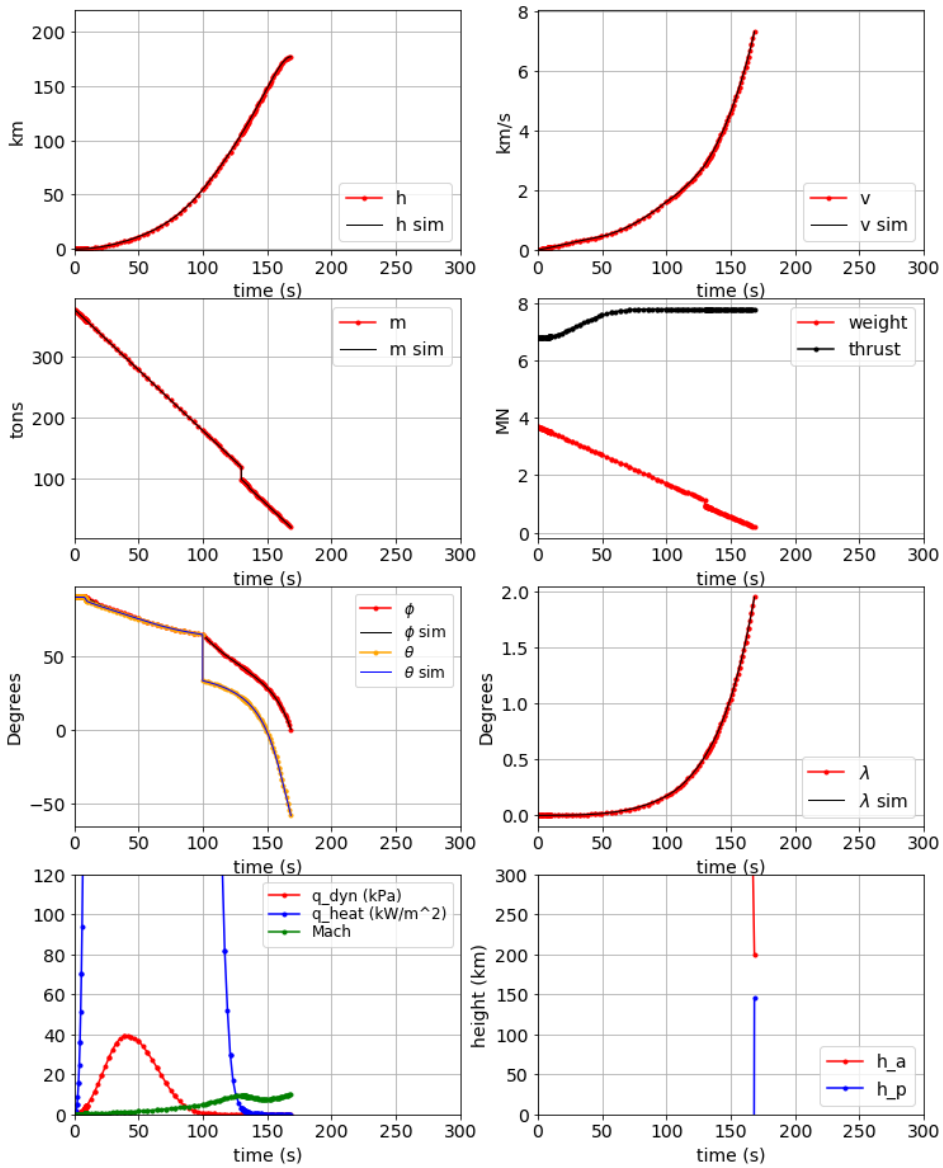
Review of previous work

- The initial guess I use is based on the results of a previous iteration.
- Already implemented Hohmann Transfer Ascent. It works nicely.
- Still problems for SLQSP to converge when fairing jettison is considered, although the trajectories look fine even after only 10 iterations. Now I frequently get the message 'Inequality constraints incompatible'. The following is an analysis of that.

Initial guess



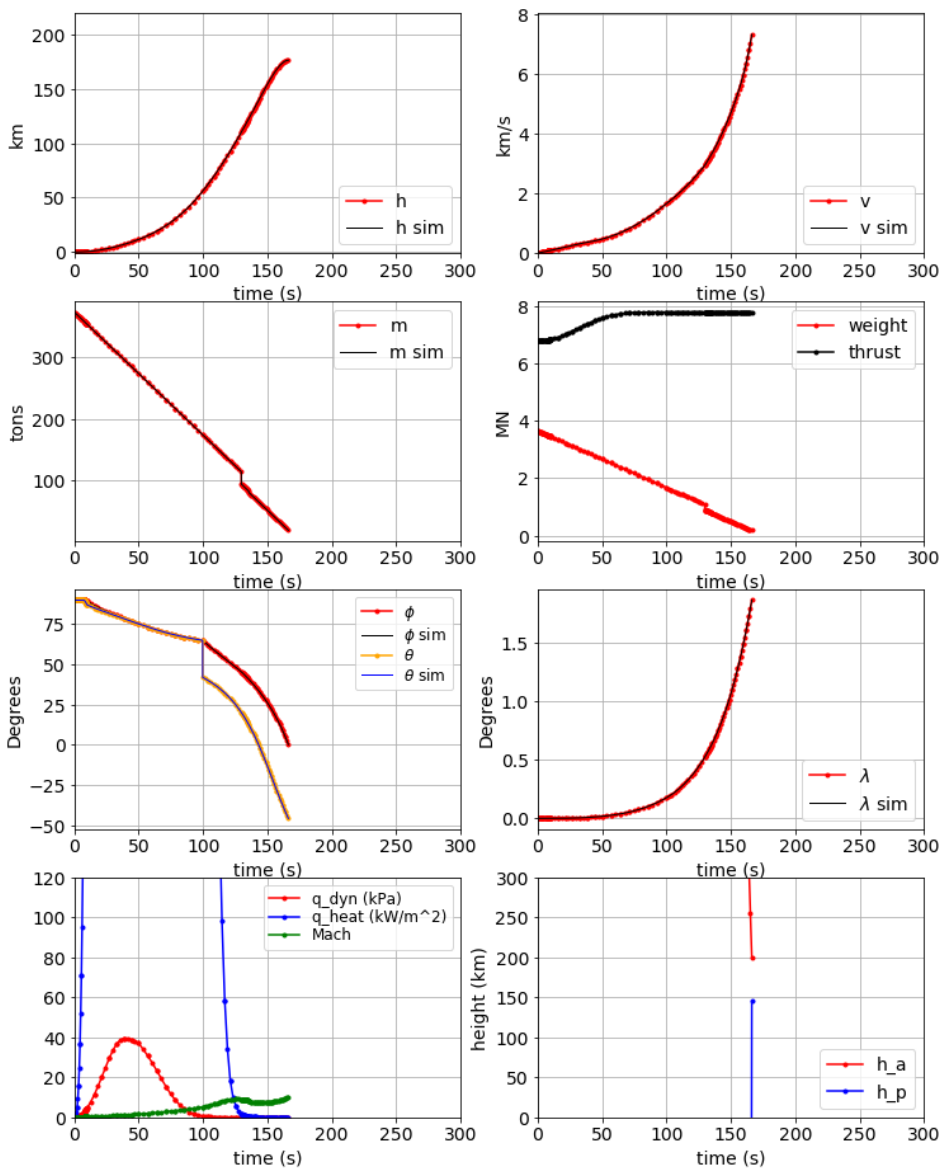
10 iterations




```
----------------------------------------
h lift_off (m):                 271.87
q_dyn gravity_turn (pa):        798.93
q_heat exoatmos_b (w/m^2):      885.39
h apogee (m):                   200001.53
h perigee (m):                  144998.18
m end of Hohmann (kg):          20000.16
m start of Hohmann (kg):        20083.81
ms_1 (kg):                      20000.0
mplf (kg):                      2000.0
--------------------- Objective --------
m full at t=0 (kg):             377146.5
```

Figure: Constraints and objective

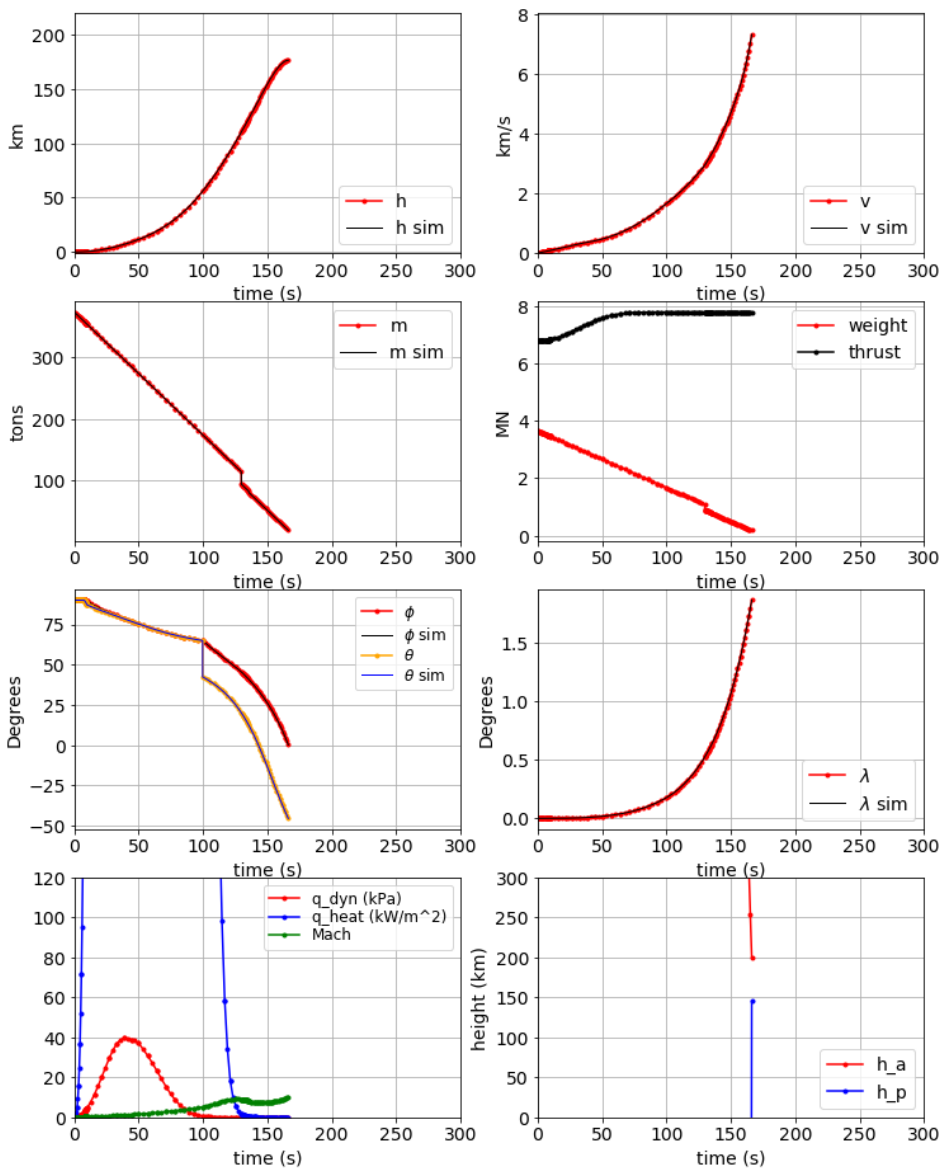
50 iterations




```
----------------------------------------
h lift_off (m):                 266.81
q_dyn gravity_turn (pa):        727.14
q_heat exoatmos_b (w/m^2):      461.57
h apogee (m):                   200000.14
h perigee (m):                  145007.92
m end of Hohmann (kg):          20000.0
m start of Hohmann (kg):        20083.63
ms_1 (kg):                      20000.0
mplf (kg):                      2000.0
-------------------- Objective --------
m full at t=0 (kg):             372918.13
```

Figure: Constraints and objective

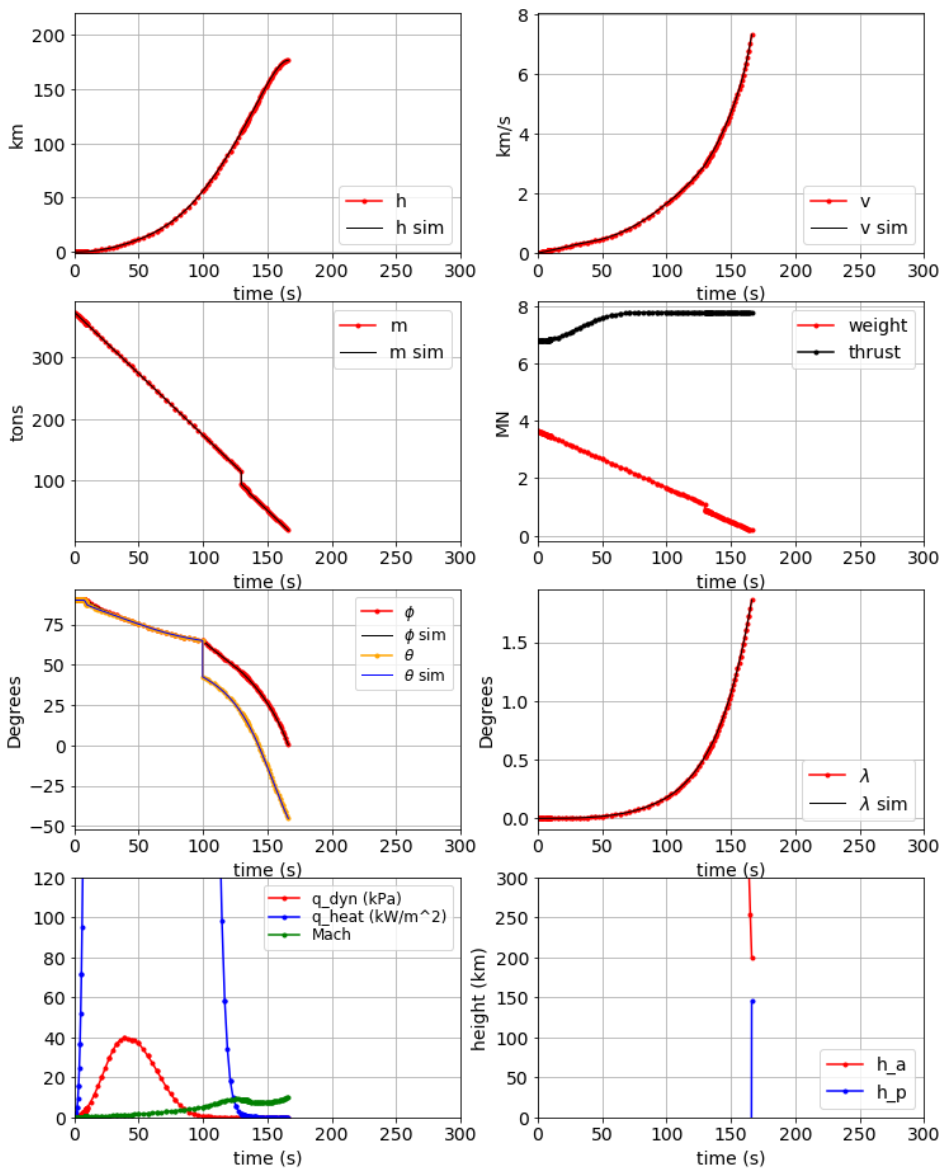
100 iterations




```
----------------------------------------
h lift_off (m):                 266.91
q_dyn gravity_turn (pa):        728.09
q_heat exoatmos_b (w/m^2):      456.06
h apogee (m):                   200000.14
h perigee (m):                  145026.68
m end of Hohmann (kg):          20000.0
m start of Hohmann (kg):        20083.6
ms_1 (kg):                      20000.0
mplf (kg):                      2000.0
---------------------- Objective --------
m full at t=0 (kg):             372797.79
```

Figure: Constraints and objective

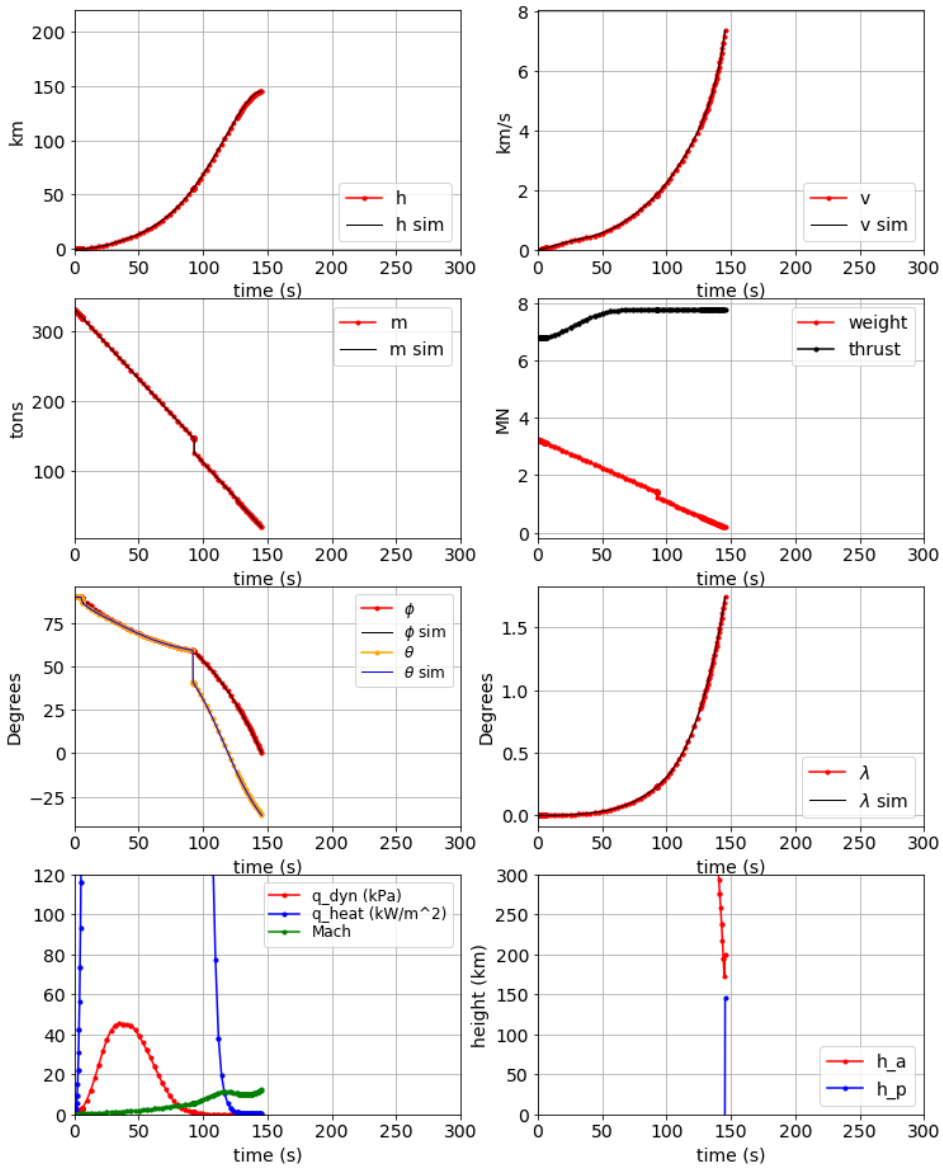
200 iterations (crashed at 120)




```
----------------------------------------
h lift_off (m):                 267.49
q_dyn gravity_turn (pa):        728.09
q_heat exoatmos_b (w/m^2):      455.13
h apogee (m):                   200000.14
h perigee (m):                  145033.07
m end of Hohmann (kg):          20000.0
m start of Hohmann (kg):        20083.59
ms_1 (kg):                      20000.0
mplf (kg):                      2000.0
-------------------- Objective --------
m full at t=0 (kg):             372767.97
```

Figure: Constraints and objective

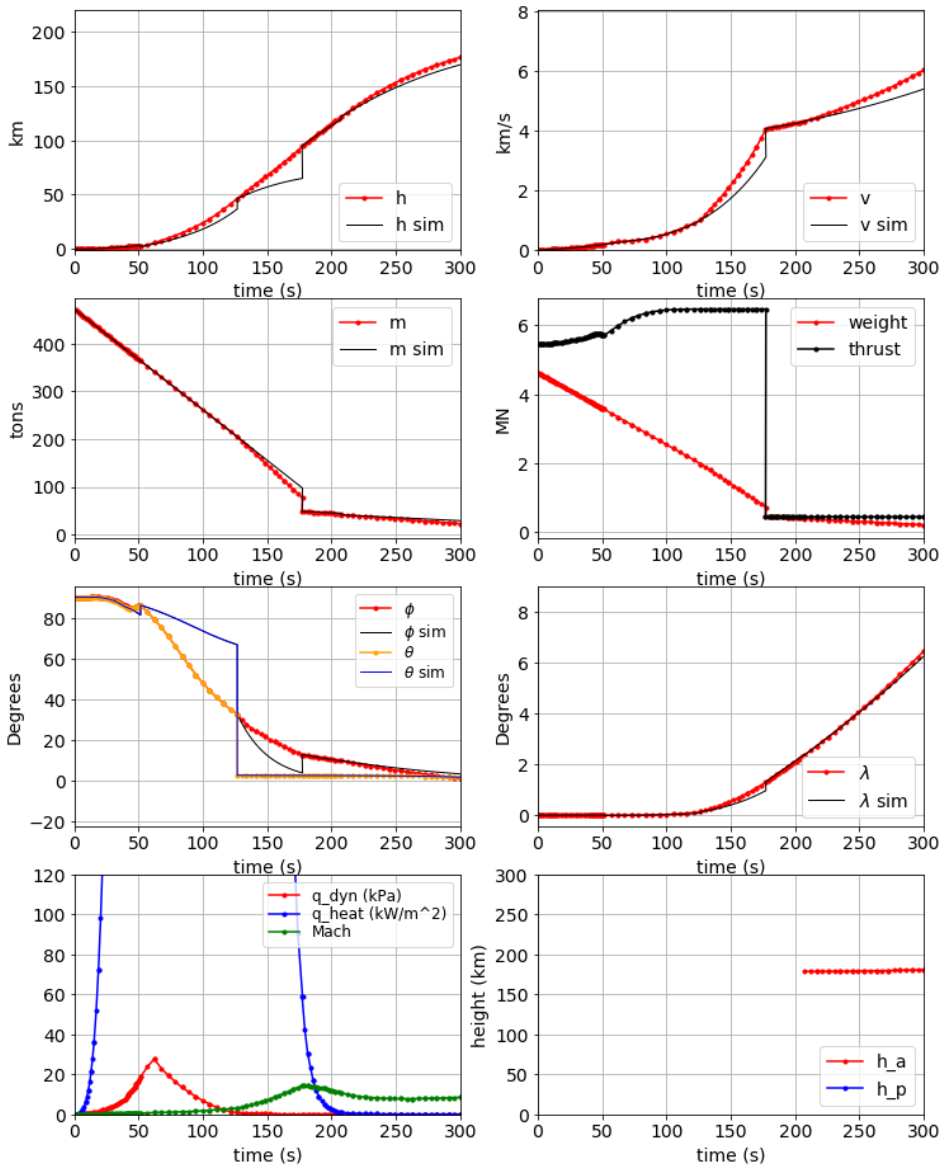
crashed at 196 iterations 1m tol in apogee



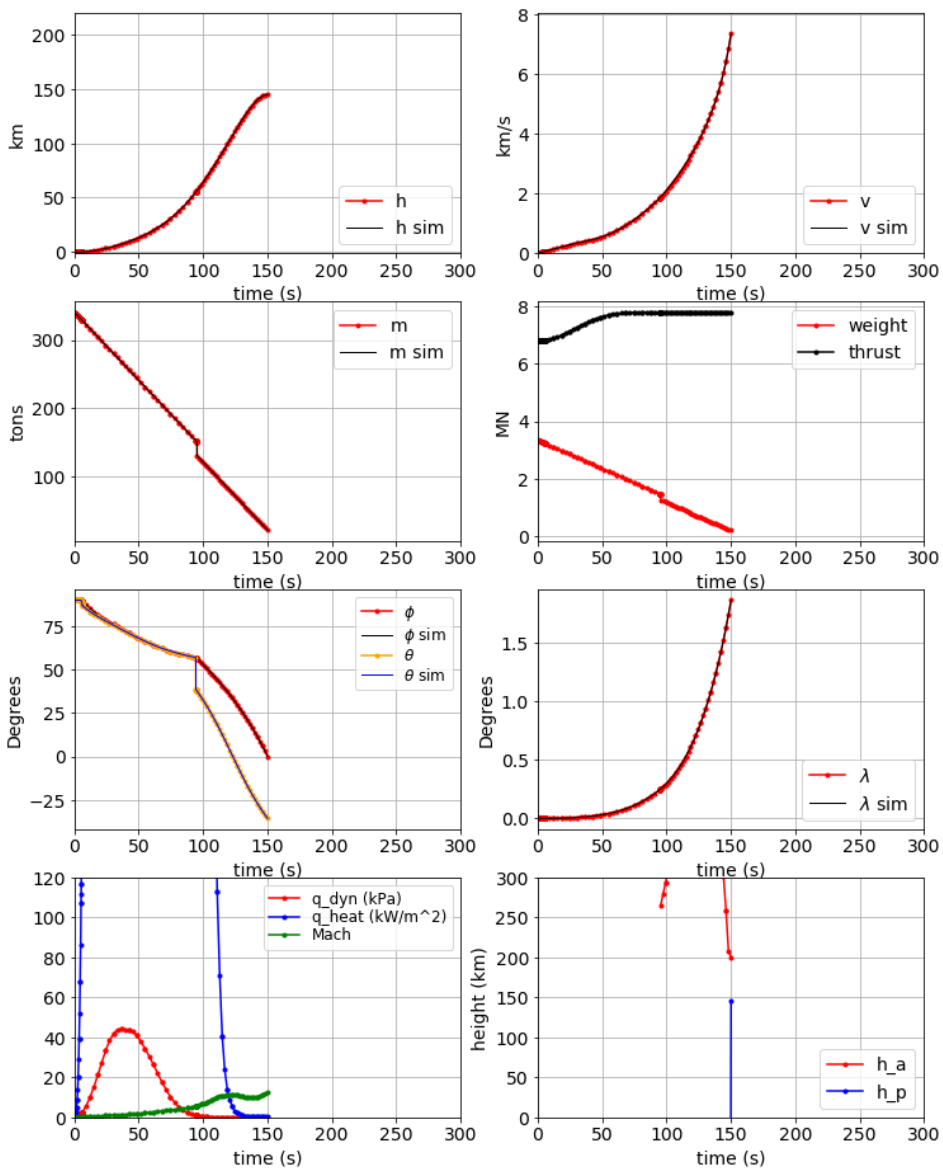

```
----------------------------------------
h lift_off (m):                  150.0
q_dyn gravity_turn (pa):         1000.0
q_heat exoatmos_b (w/m^2):       1135.0
h apogee (m):                    199999.0
h perigee (m):                   145000.0
m end of Hohmann (kg):           20000.0
m start of Hohmann (kg):         20083.64
ms_1 (kg):                       20000.0
mplf (kg):                       2000.0
--------------------- Objective --------
m full at t=0 (kg):              331660.74
```

Figure: Constraints and objective

Falcon 9 - first attempt



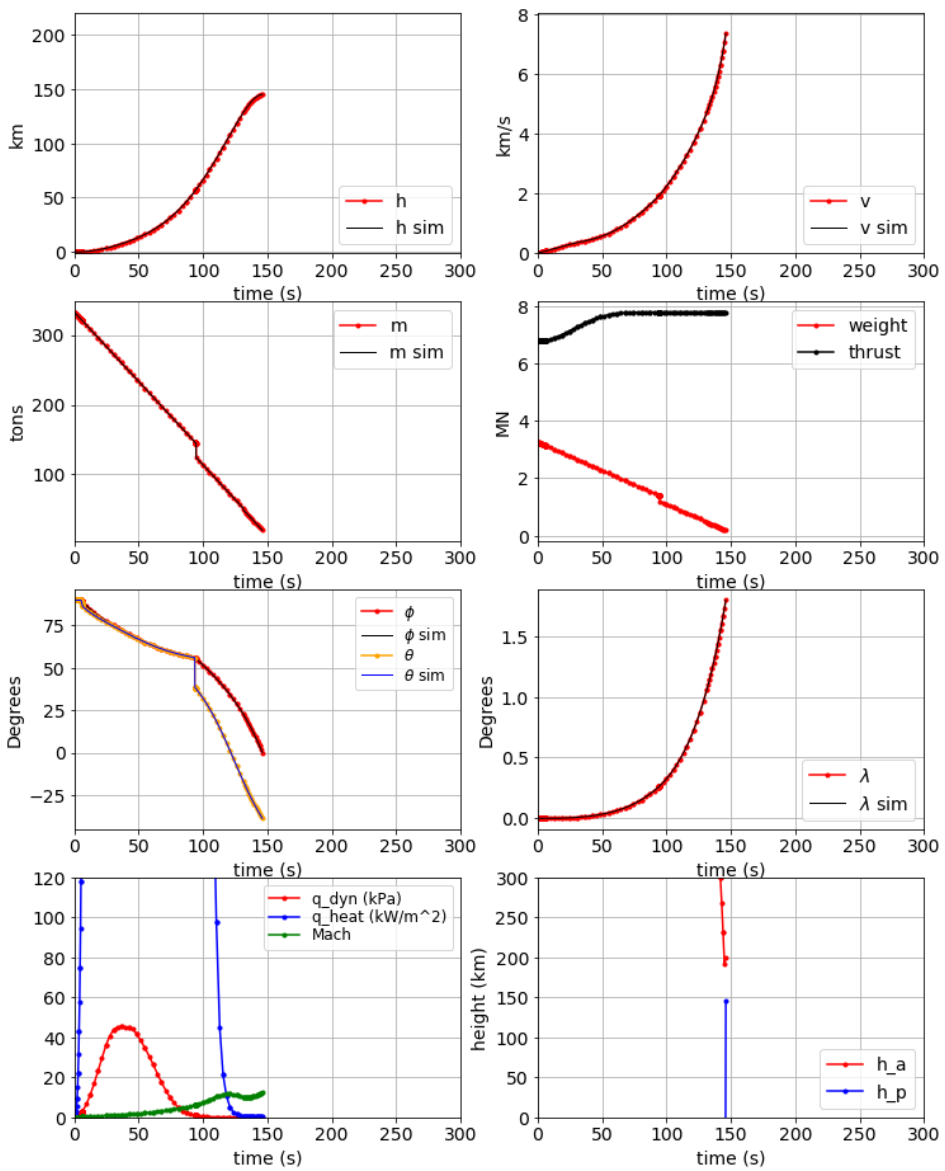
131 iterations. No PLF Jettison. Converged!




```
----------------------------------------
h lift_off (m):                  150.0
q_dyn gravity_turn (pa):         1000.0
h apogee (m):                    199999.0
h perigee (m):                   145000.0
m end of Hohmann (kg):           22000.0
m start of Hohmann (kg):         22092.0
ms_1 (kg):                       20000.0
--------------------- Objective --------
m full at t=0 (kg):              340855.83
```

Figure: Constraints and objective

30 iterations crash. Initial guess from previous slide




```
-----------------------------------------
h lift_off (m):                  152.64
q_dyn gravity_turn (pa):         961.53
q_heat exoatmos_b (w/m^2):       675.94
h apogee (m):                    199999.41
h perigee (m):                   144999.59
m end of Hohmann (kg):           20000.0
m start of Hohmann (kg):         20083.64
ms_1 (kg):                       20000.0
mplf (kg):                       2000.0
--------------------- Objective ----------
m full at t=0 (kg):              332748.53
```

Figure: Constraints and objective

Key points discussed

- Convert equality constraints into inequality constraints with wide margins.
- Continue to optimize Falcon 9, instead of the imaginary rocket, with a realistic mission. It could be LEO at 400km with payload increasing progressively up to 15 ton.
- Explore if Dymos allows to propagate the ODE's for the Coasting phase of the Hohmann transfer.