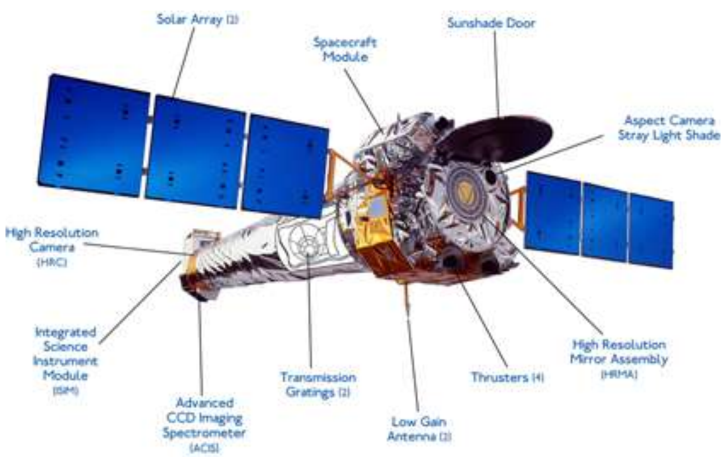
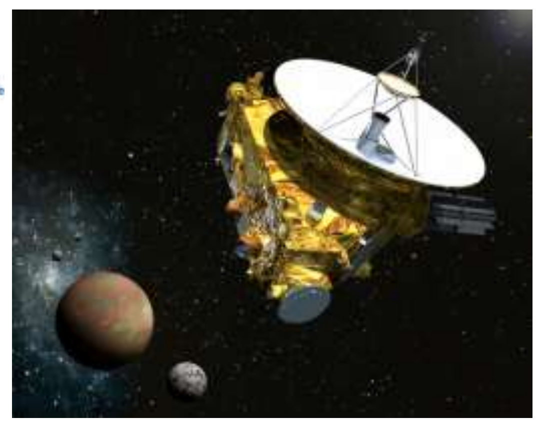
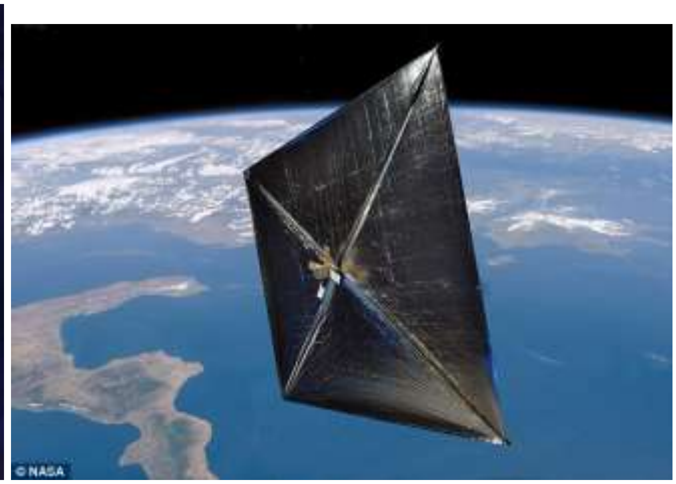
EAE-298 - Spacecraft Engineering – W2016







EAE-243a - Spacecraft Engineering (4 units)

(EAE-298) Winter 2016 – Robinson V3

Course Description: Principles, governing equations, theoretical and empirical predictive approaches to spacecraft design. Integration of engineering disciplines including dynamics, astrodynamics, heat transfer, structures, propulsion, and sensors. Weekly homework plus team design/analysis project.

Req'd Text: Spacecraft Systems Engineering (4thEd.) – *Fortescue, Swinerd, Stark*
Req'd Text: NASA Systems Engineering Handbook – *SP2007-6105 (free)*
Reference: Fundamentals of Space Systems – *Pisacayne*
Reference: Space Vehicle Design (2^{nd} Ed.) – *Griffin and French*
Reference: Space Mission Engineering: The New SMAD – *Wertz et al*

Pre-requisites: EAE-141 (Space Mission Design) or EAE-198 (Intro to Space Vehicles) or equivalent undergraduate spacecraft course.

Student Expectations:

40%: Individual Bi-Weekly homework (analysis of assigned subsystem)
60%: Team Project: - Satellite design for launch/rendezvous/docking/reboost with HST
- or CubeSat design to dock with and provide attitude control for existing LEO satellite

No final exam – presentations of projects during final exam time

Week1

Spacecraft Systems Engineering
Intro to Principles of Systems Engineering
NASA Systems Engineering Handbook
Case Study: ISS Environmental & Life Support System

Introduction to Spacecraft Systems
Payloads and Missions
A System View of Spacecraft

Homework: Project mission requirements and flowchart

Week 2

The Space Environment and Its Effect on Vehicle Design
Pre-Operational Spacecraft Environments
Operational Spacecraft Environments
Radiation – measurements and modeling
MMOD - measurements and modeling (NASA software)
Environmental Effects on Design

Spacecraft Structures
Pressure shell design parameters

Debris (MMOD) impact modeling and shielding techniques

Homework: Radiation and MMOD stochastic modeling for mission intended orbit

Week 3

Dynamics of Spacecraft

Trajectory Dynamics

General Attitude Dynamics

Attitude Motion of Specific Types of Spacecraft

Oscillatory Modes

Homework: Quad-reaction wheel dynamic analysis

Week 4

Celestial Mechanics

The Two-body Problem—Particle Dynamics

Specifying the Orbit

Orbit Perturbations

Spacecraft Rendezvous – Hill & Clohessy-Wiltshire eqns

Homework: Rendezvous, prox ops, and docking trajectory plan and delta-V requirements

Requirements Review

Week 5

Mission Analysis & Design

Keplerian Orbit Transfers

Mission Analysis

Polar LEO/Remote-Sensing Satellites

Geostationary Earth Orbits (GEO)

Highly Elliptic Orbits

Interplanetary Missions

Homework: Orbital transfer analysis for re-boost propulsion requirements

Week 6

Propulsion Systems

Systems Classification

Chemical Rockets

Spacecraft Propulsion

Electric Propulsion

Mission-based propulsion selection process: mass vs volume vs performance

Homework: Design cold-gas thruster system for project

Week 7

Launch Vehicles

Basic Launch Vehicle Performance and Operation

Spacecraft Launch Phases and Mission Planning

US Crewed Launch Systems
Launch Sites
Today's Available Launchers
Specific Launch Costs and Reliability

Homework: Trade study of launchers: performance vs cost/schedule

Week 8

Attitude Control

ACS Overview
Spacecraft Attitude Response
Torques and Torquers
Attitude Measurement
ACS Computation/Models

Homework: Attitude control requirements for mission phases, including RW desaturation predictions

Week 9

Electrical Power Systems and Thermal Control of Spacecraft

Power System Elements
Power Management, Distribution and Control
Power Budget – Apollo 13 example
The Thermal Environment
Thermal Balance & Analysis
Thermal Technology

Homework: Finalizing system element designs/analyses

Week 10

Systems Integration – Prelim Design Review

Final project presentations

EAE-243b - Spacecraft Engineering for Human Spaceflight (4 units)

(EAE-298) Spring 2017? – Robinson

Course Description: Requirements and theoretical/empirical predictive approaches to human spacecraft design. Mission design and operations, life support and safety systems, robotics, and extravehicular activity. Weekly homework, research paper review, plus team design/analysis project.

Req'd Text: Human Spaceflight – Mission Analysis and Design (4thEd.) – *Larson et al*
Req'd Text: Human-Rating Requirements for Space Systems– *NASA NPR 8705.2B (free)*
Reference: Spaceflight Life Support and Biospherics– *Eckart*

Pre-requisites: EAE-243a (Spacecraft Systems Engineering)

Student Expectations:

- Weekly homework (analysis of assigned subsystem)
- Research Papers as Assigned
- Team Project: Lunar lander design, including trajectory simulator
- No final exam – presentations of projects during final exam time

Week1

- **Introduction to Human Spaceflight**
  - Mission concepts and architectures
- **Designing Human Space Missions**
  - Systems Engineering – Objectives & Requirements
  - Constraints

Week 2

- **The Space Environment - Hazards and Effects on Humans**
  - Vacuum & Human Pressure Requirements
  - Plasma and Spacecraft Charging
  - Radiation and Human Risk
  - MicroMeteoroid Damage (MMOD) Risk
- **Physiology of Spaceflight**
  - Environmental Parameters: micro-g
  - Metabolic input/output
  - Fluid shift, neurovestibular, cardiovascular, musculo-skeletal, ocular changes
  - Partial gravity: planetary surfaces, centrifugation effects on physiology

Week 3

- **Safety, Human Rating, & Human Factors of Crewed Spaceflight**
  - Design and Analysis for Human Life Support/Survival

Entry, Descent, Landing, and Ascent

Atmospheric entry: heating, guidance, navigation, control
Capsules vs Wings: Cross-range and G-Loading Considerations
Descent and Landing: Wings vs Parachutes & Retro Rockets
Lunar Ascent – Numerical Integration of Eqns of Vehicle Motion for State-Vector Simulation

Week 4

Designing and Sizing Space Elements for Habitation

Requirements & Constraints
Habitat Subsystem Critical Choices
Baseline and Alternative Configurations; Concept Engineering Assessment

Week 5

Transfer, Entry, Landing, and Ascent Vehicles

Vehicle Concepts and Evaluation

Spacecraft Thermal Control for Humans – Overview

Thermal Environments
Hardware Design for Thermal Control
Thermal Analysis Tools
Passive vs Active Thermal Control

Week 6

Human Environmental Control and Life Support Systems (ECLSS)

Example: ISS ECLSS systems – design, redundancy, reliability, repair
Human Requirements
Pressurization, Leaks
Atmospheric Revitalization (N2, O2, CO2, humidity)

Week 7

Human Environmental Control and Life Support Systems (ECLSS) (con't)

Thermal Control Systems
Water Supply and Recycle
Waste Management

Week 8

Extravehicular Activity (EVA) Systems

System Requirements: pressure, comm, mobility, tools
Self-Rescue (SAFER example)
Micro-g vs Surface EVA – ISS vs Lunar Example

Week 9

Space Robotics

Human vs Robotics
Functional, Operational, and Design Requirements

Selecting Launch and Transfer Vehicles

Engineering Specs of Launch and Transfer Vehicles
Selection Criteria for Launchers

Week 10

Mission Operations for Crewed Spaceflight

Planning & Analysis for: Mission Design, Data Transport, Navigation, Payloads, Communication, Crew Timeline Planning

Command, Control, and Communications Architecture

Analyzing Requirements & System Design

Mars Design Example

Spacecraft Design - Course Goals:

- **Foundation of systems engineering as applied to spacecraft systems integration**
- **Introduction to spacecraft design considerations/trades**
- **Broad look at spacecraft environments, missions, orbits, launchers, and design considerations**
- **Practice with subsystem analyses (individual HW)**
- **Significant spacecraft design to meet specific mission requirements (team effort)**
- **Introduction to modern software tools for orbit, mission, and subsystem design**
- **Deep immersion in online information sources**
- **Engineering Skills:**
    - **Systems engineering**
    - **Dynamics**
    - **Physics**
    - **Orbital mechanics**
    - **Propulsion**
    - **Fluid dynamics**
    - **Thermodynamics**
    - **Optimization**

Spacecraft, Launchers, News, and Policy – Online Knowledge Resources:

- **NASA websites**
- **SpaceX, Boeing CST-100, Sierra Nevada, Blue Origin**
- **ULA, Boeing, Lockheed Martin, Space Systems/Loral**
- **https://en.wikipedia.org/wiki/List_of_spacecraft_manufacturers**
- **Space news websites (examples):**
  - **http://www.space.com/**
  - **http://spacenews.com/**
  - **http://www.nbcnews.com/science/space**
  - **http://news.discovery.com/space**
  - **http://phys.org/space-news/**
  - **http://www.livescience.com/space/**
  - **http://www.universetoday.com/**
- **NASASpaceflight.com:** (Thanks to Chris Bergin)
  http://www.nasaspaceflight.com/
  Username: UCDavisSpaceflight
  Password: ucdavisaggies

Weekly Lecture Plan:

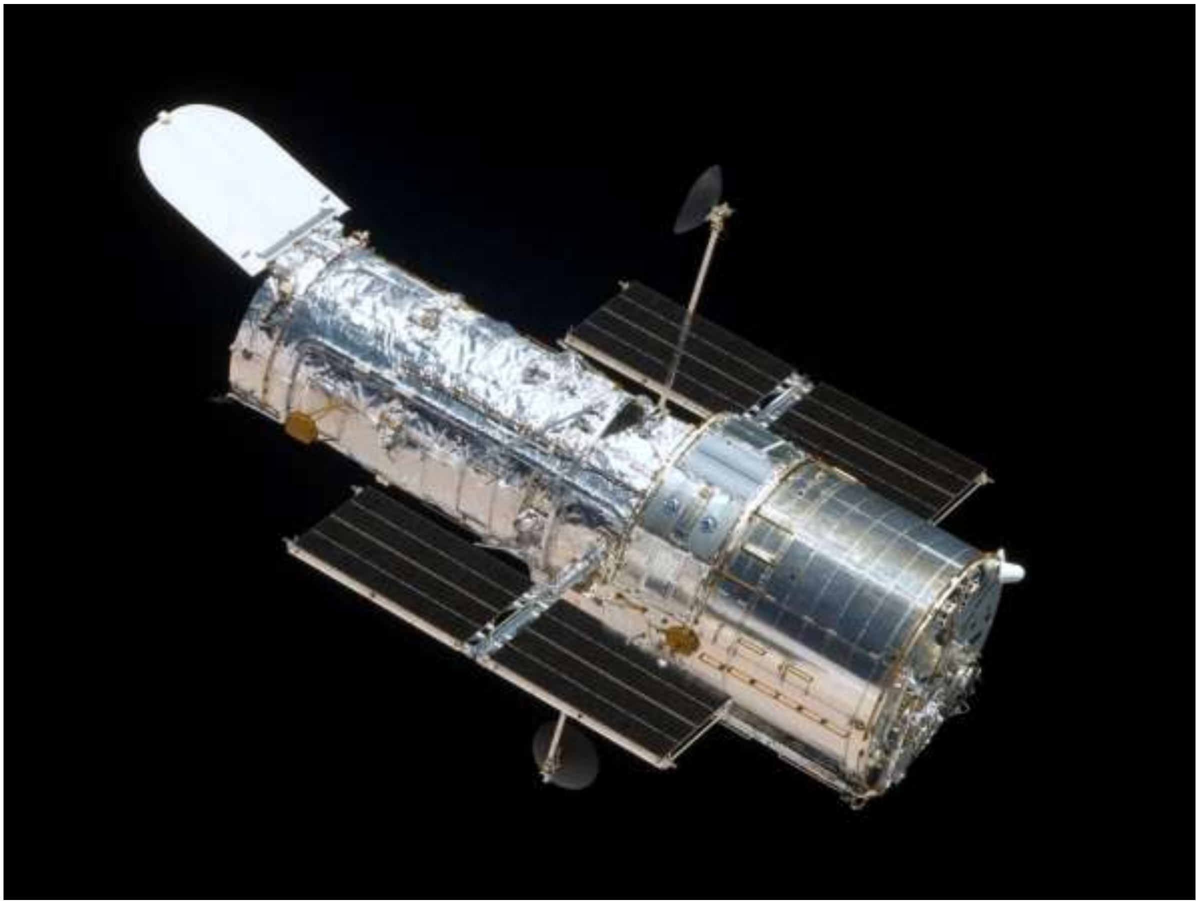
- **Tuesdays 2:10-4pm**
  - **Space news**
  - **Lecture**
  - **Homework assignment**
  - **Homework due next Tuesday 8pm SmartSite**
- **Thursdays 2:10-4pm**
  - **Lecture 2:10-3pm**
  - **In-class project group work 3-4pm**
- **Occasional guest lectures**
- **Weekly text reading assignments**
- **Individual weekly homework (40% grade): mix of problems and subsystem trade studies**
- **Matlab or Python plus existing packages and apps**
- **Team project (60% grade): (more details later)**
  - **Every Thursday in class 3-4pm**
  - **Requirements review ~4 weeks**
  - **Preliminary design review – finals week**
  - **Written report**

Team Project: You are a satellite startup

- **You have venture capital for one year of planning, potentially followed by five years for a market-busting demo**
- **Must accomplish a needed mission that has never been done before to impress market and future investors**
- **10 weeks to generate mission design, spacecraft design, and budget – up to Preliminary Design Review**
- **Three potential missions to choose from**
- **No guarantee than any one mission is do-able (nobody has yet done them!)**
- **NASA systems engineering principles will provide your development framework**

Group Design Project: we will choose one

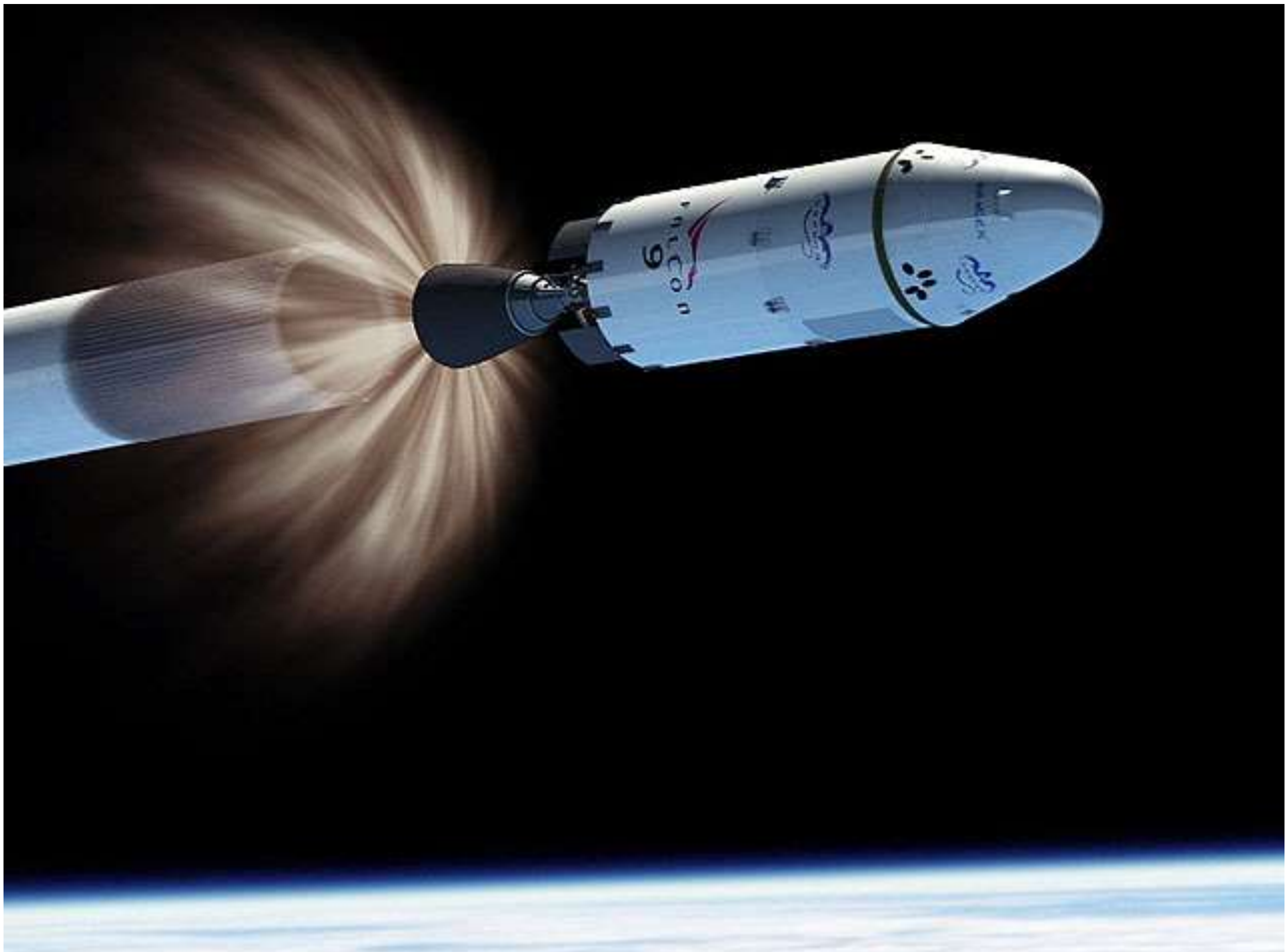
#1 Project ***Hubble-Boost***:



- **Launch from KSC**
- **Rendezvous, dock with HST (grapple fixture?)**
- **Reboost to higher orbit – 2-burn Hohmann xfer**
- **De-orbit booster vehicle**

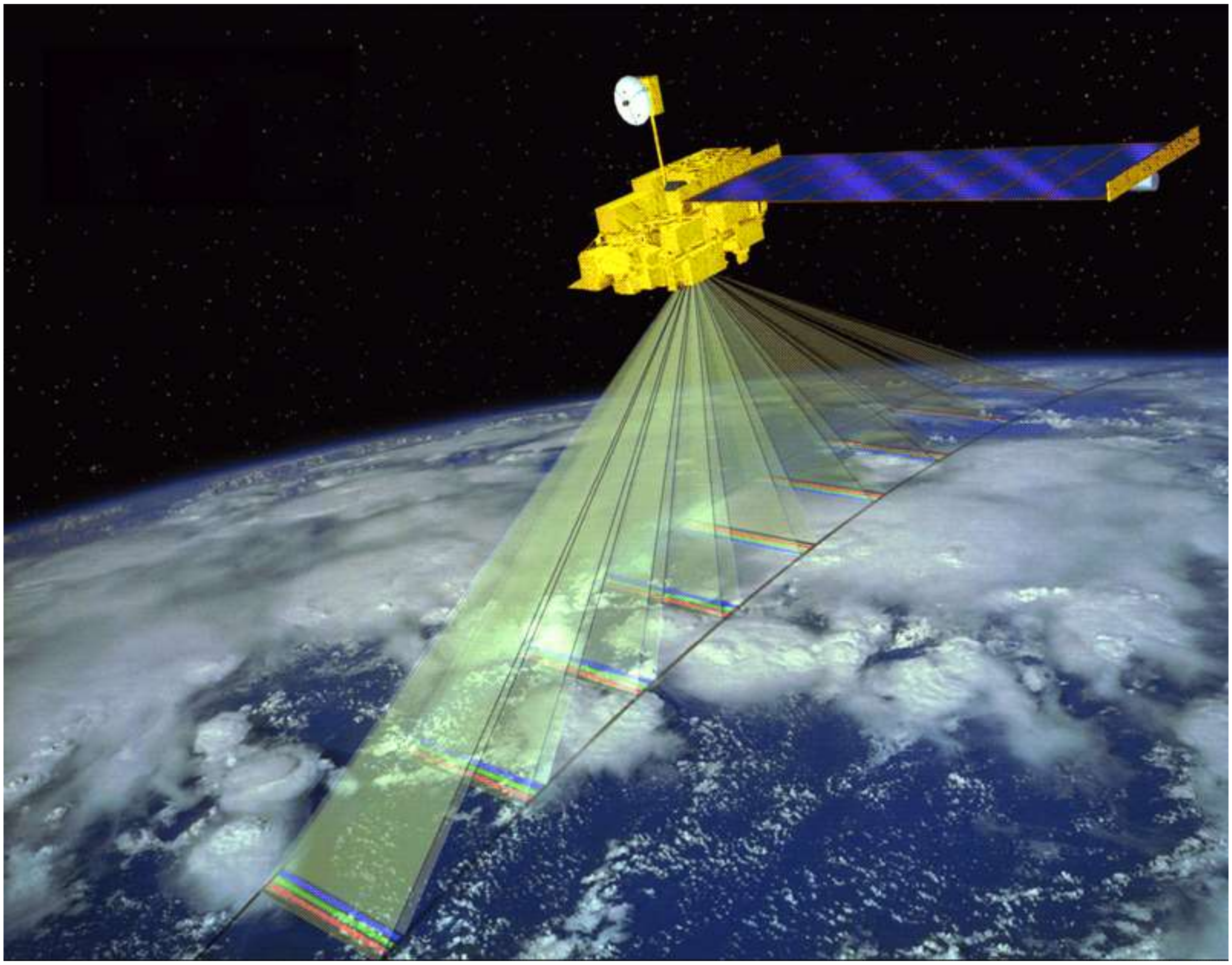
#2 Project ***De-orbit SpaceX Junk:***

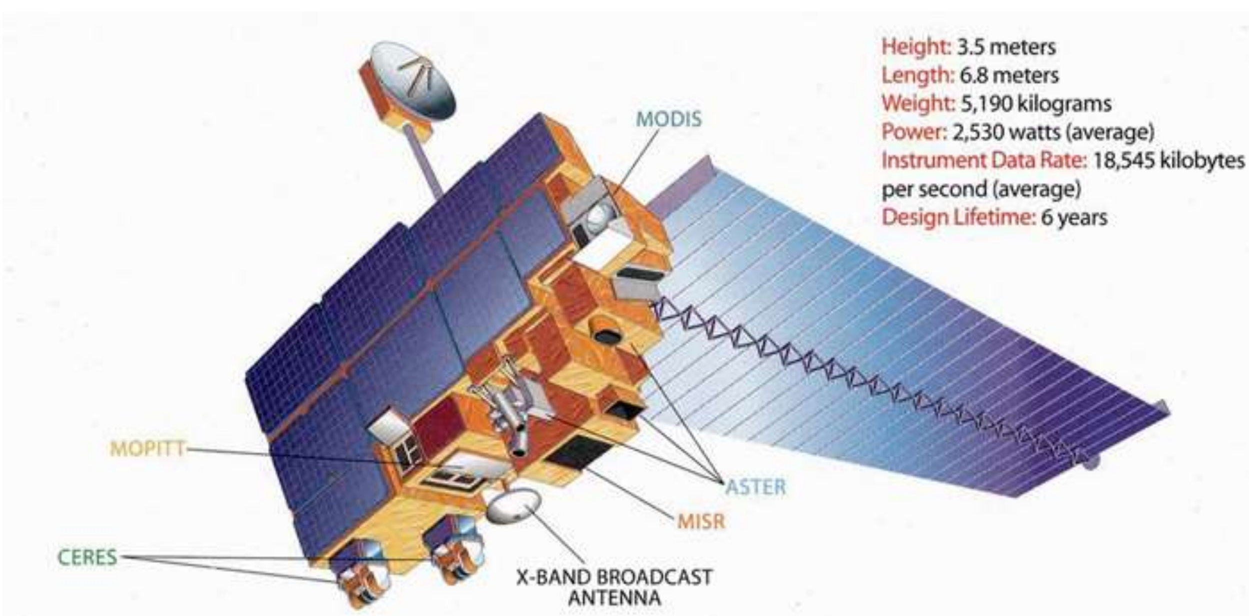
http://stuffin.space/ Falcon 9 R/B 2015-023



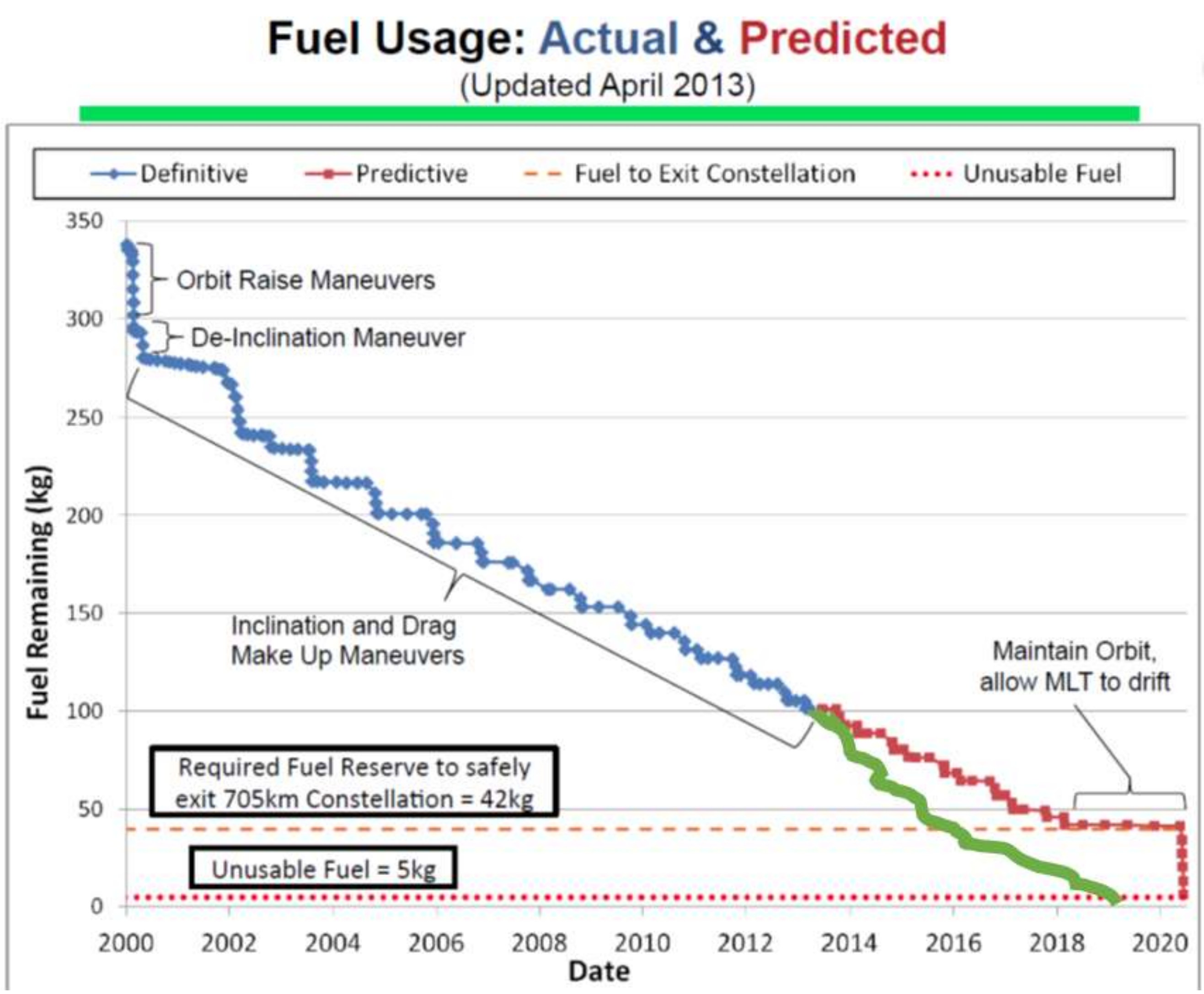
- **Launch from KSC**
- **Rendezvous, dock with spent upper stage**
- **De-orbit junk and clean-up vehicle**

#3 Project ***Save Terra***:



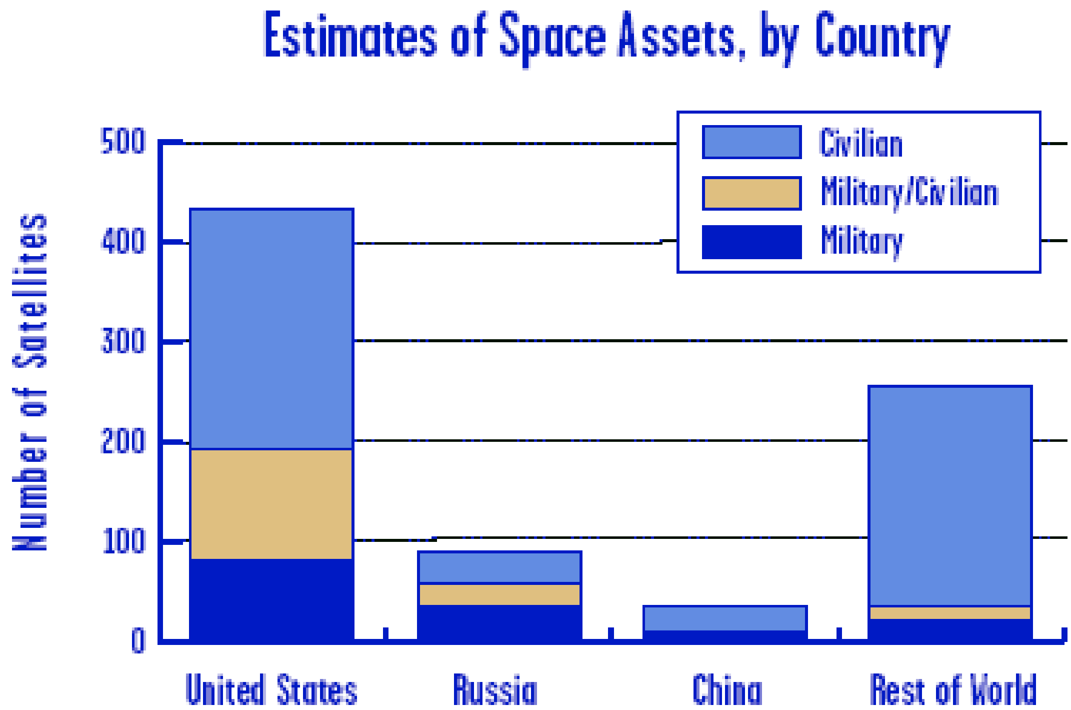


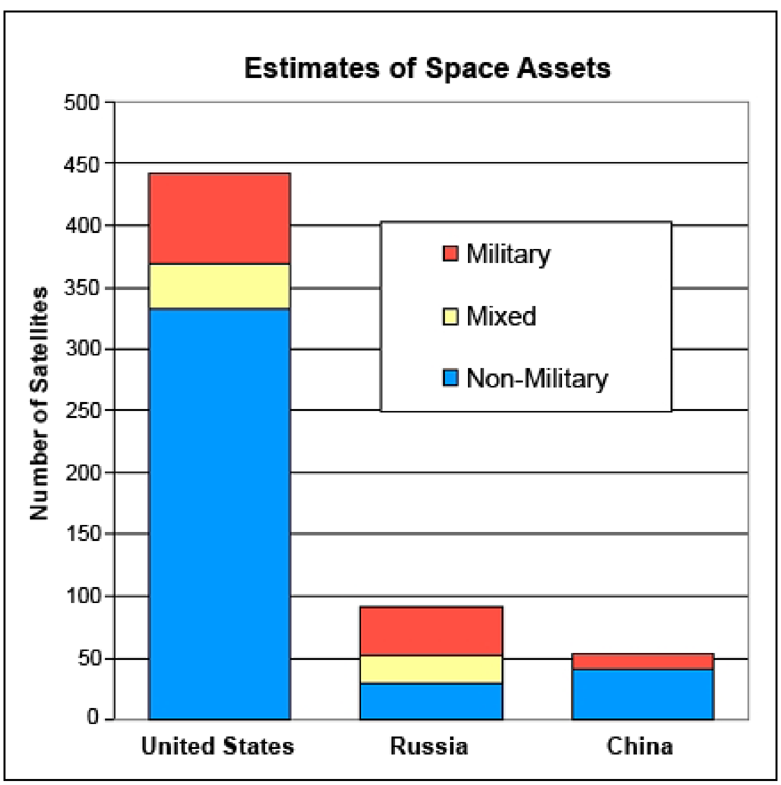
- **Save Terra Earth Observing Satellite**
  http://terra.nasa.gov/
- **Fuel leak will leave it unable to maneuver**
- **Launch from KSC**
- **Rendezvous, dock with TERRA**
- **Provide external attitude control module + propellant to complete mission**

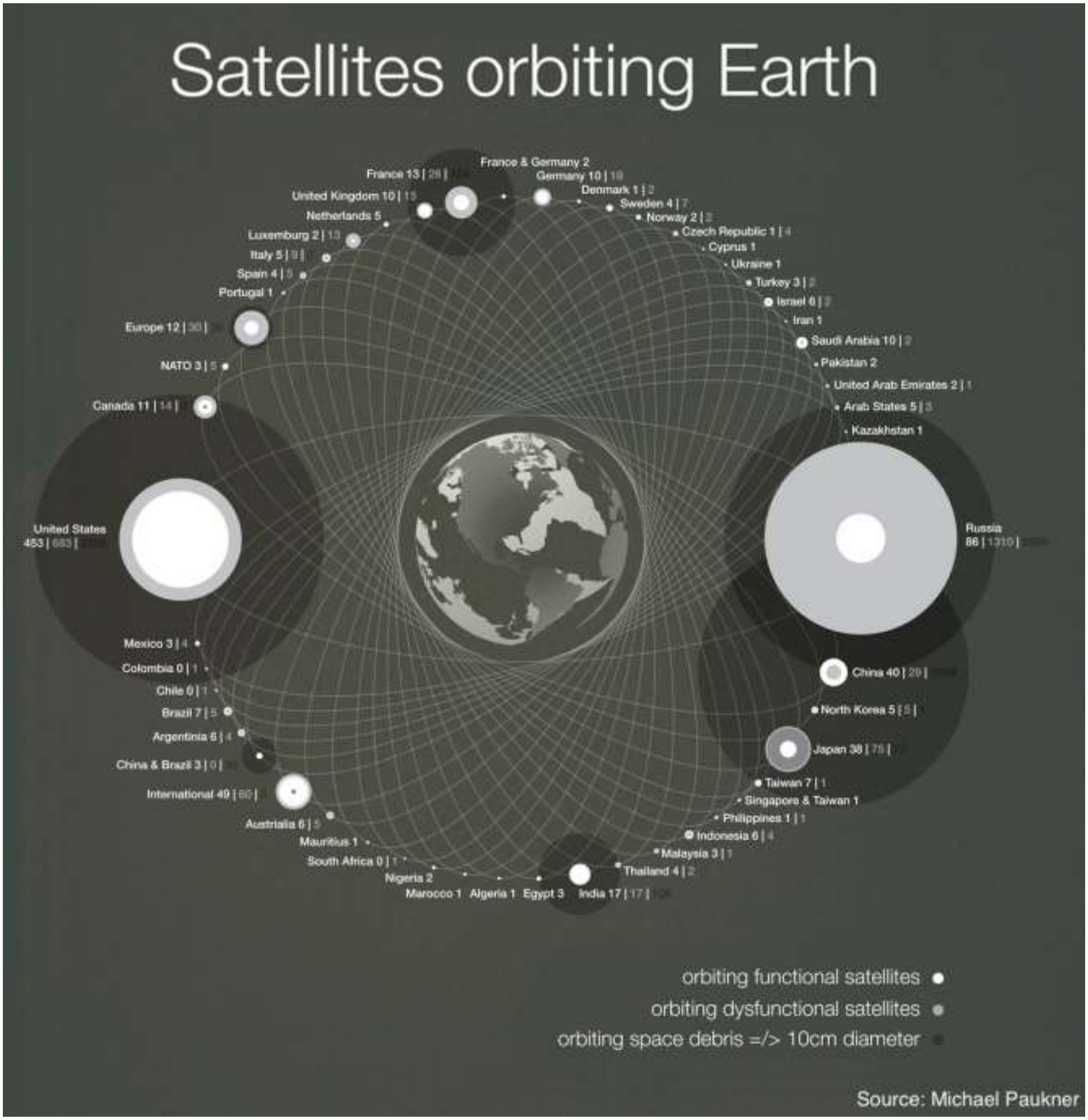


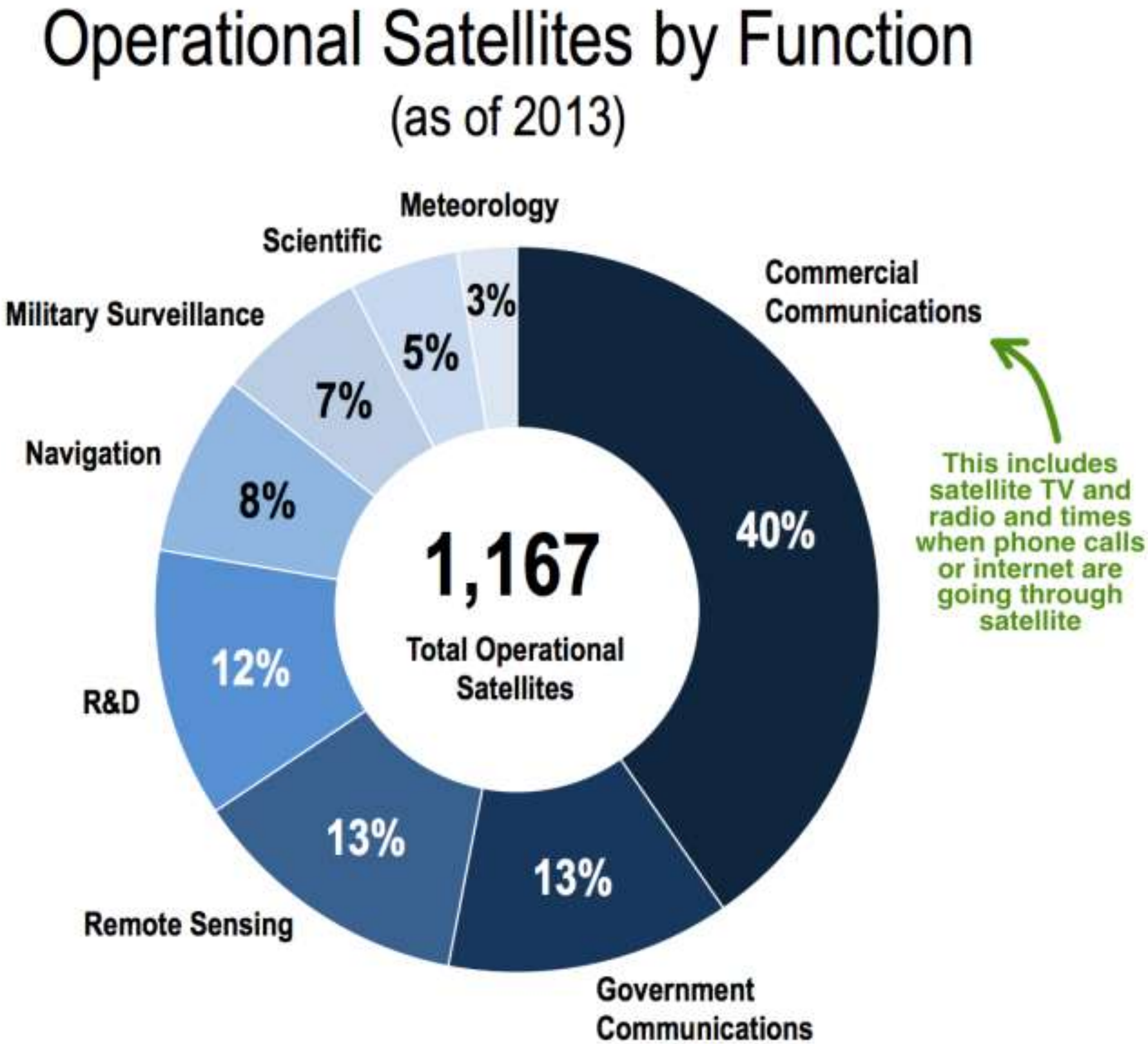

EVERY SINGLE SATELLITE ORBITING THE EARTH

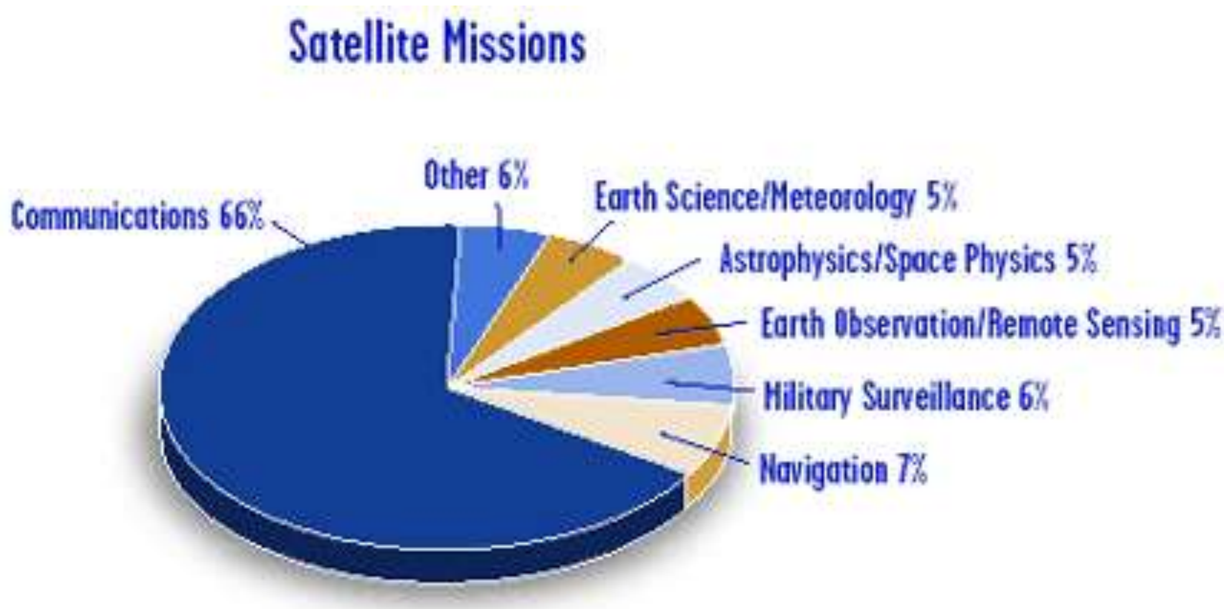
State of the Spacecraft






Satellites orbiting Earth
France & Germany 2
France 13 | 28 |
Germany 10 | 19
United Kingdom 10 | 15
Denmark 1 | 2
Sweden 4 | 7
Netherlands 5
Norway 2 | 2
Luxemburg 2 | 13
Czech Republic 1 | 4
Cyprus 1
Italy 5 | 9 |
Ukraine 1
Spain 4 | 5
Turkey 3 | 2
Portugal 1
Israel 6 | 2
Iran 1
Europe 12 | 30 |
Saudi Arabia 10 | 2
NATO 3 | 5
Pakistan 2
United Arab Emirates 2 | 1
Canada 11 | 14 |
Arab States 5 | 3
Kazakhstan 1
United States
453 | 683 |
Russia
86 | 1310 |
Mexico 3 | 4
Colombia 0 | 1
China 40 | 29 |
Chile 0 | 1
North Korea 5 | 5 |
Brazil 7 | 5
Argentinia 6 | 4
Japan 38 | 75 |
China & Brazil 3 | 0 |
Taiwan 7 | 1
International 49 | 60 |
Singapore & Taiwan 1
Philippines 1 | 1
Austrialia 6 | 5
Indonesia 6 | 4
Mauritius 1
Malaysia 3 | 1
South Africa 0 | 1
Thailand 4 | 2
Nigeria 2
Marocco 1
Algeria 1
Egypt 3
India 17 | 17 |
orbiting functional satellites
orbiting dysfunctional satellites
orbiting space debris =/> 10cm diameter
Source: Michael Paukner


Operational Satellites by Function
(as of 2013)
Meteorology
Scientific
Military Surveillance
Navigation
R&D
Remote Sensing
Government Communications
Commercial Communications
3%
5%
7%
8%
12%
13%
13%
40%
1,167
Total Operational Satellites
This includes satellite TV and radio and times when phone calls or internet are going through satellite



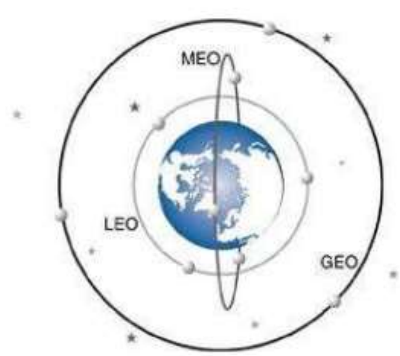
U.S. Earth Science Satellites

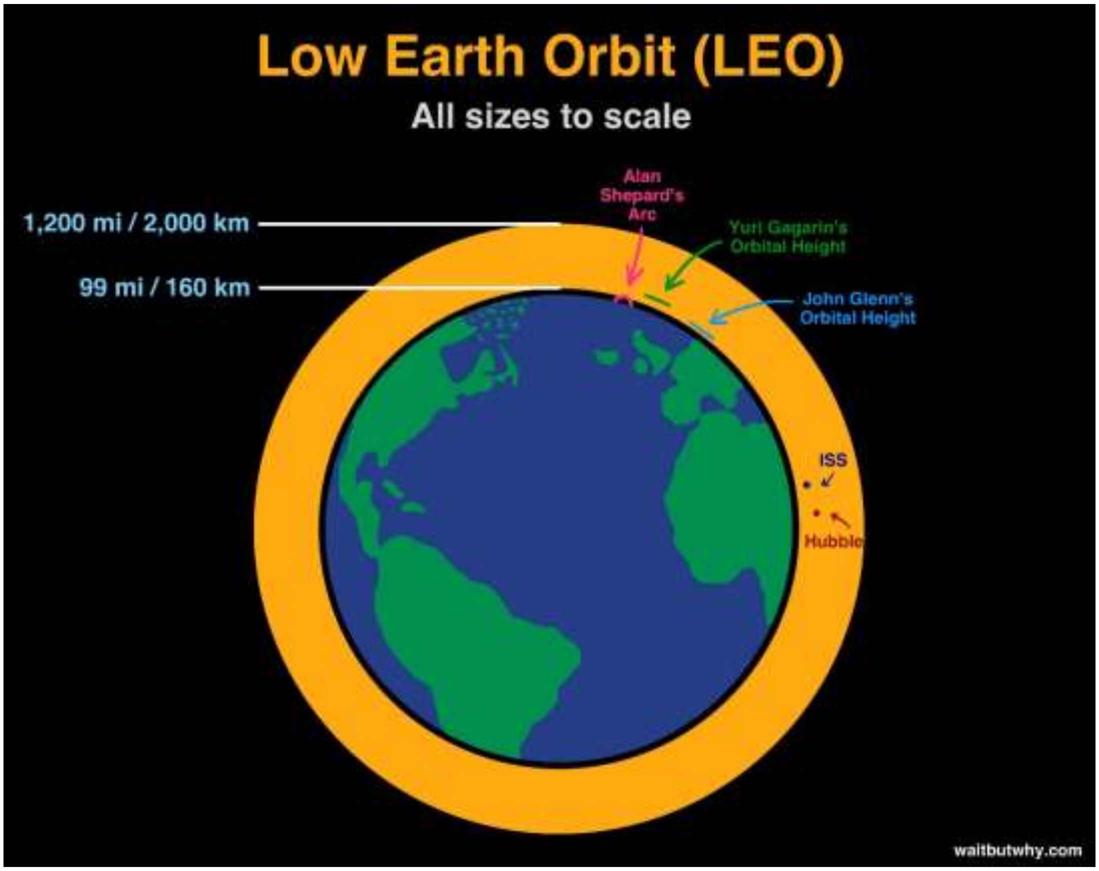
Classes of Satellite Orbits

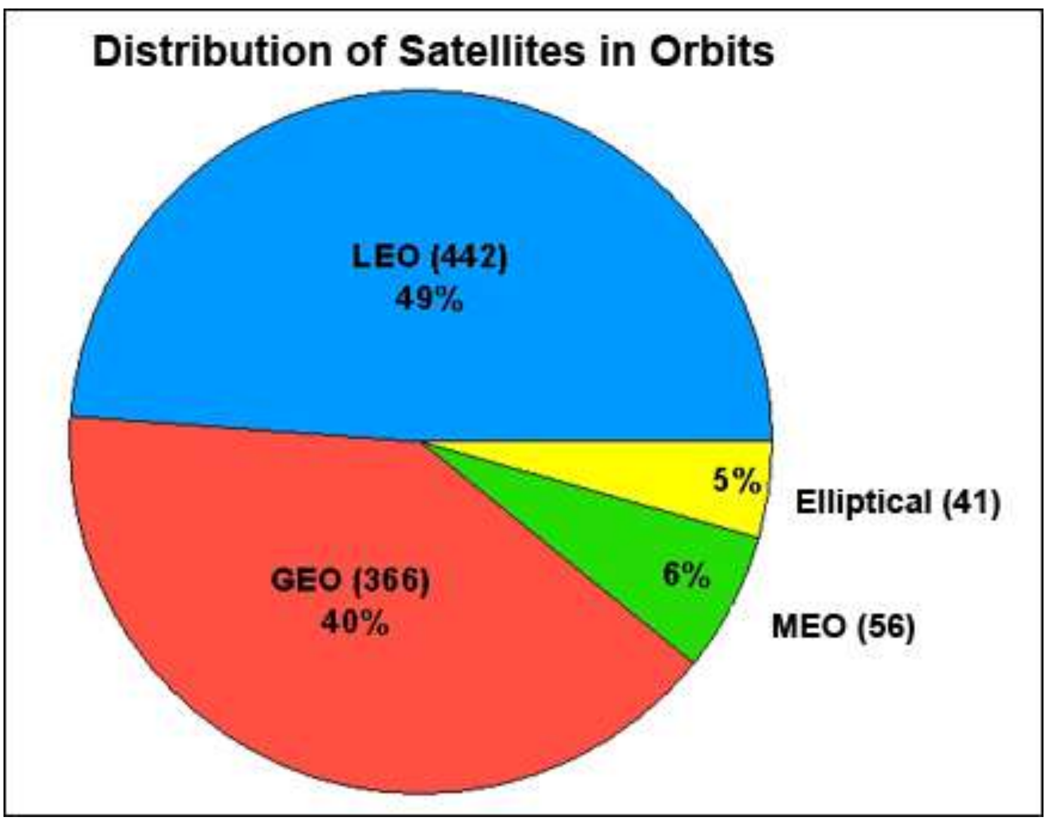
- **Low Earth Orbit (LEO) --- defined as having altitude < 2000 km**
  - Circular, e.g., Iridium, Globalstar, Orbcomm; also many scientific, weather spacecraft
  - For comm use, a constellation of satellites is usually required to achieve reasonable visibility to users
  - A number of standard constellations of multiple satellites have been defined to meet certain objectives:
    - Walker constellations, etc.
    - Usually specified as, e.g., 7 spacecraft in each of 9 orbital planes at a specified inclination angle, equally spaced around the equator
- **Medium Earth Orbit (MEO)**
  - Circular, with altitudes from ~ 2,000 km out to 35786 km,
  - e.g., GPS is ~ "half-synchronous" with altitude of ~ 20,200 km
  - Not many communications satellites in this regime; also Van Allen belts are in MEO
- **Highly Elliptical Orbit (HEO)**
  - Elliptical orbits, e.g., Molniya, Tundra, primarily at 63.4^{0} inclination
  - Achieves good visibility with high average elevation angles for users at high latitudes
- **Geosynchronous Earth Orbit (GEO)**
  - Circular, with altitude such that the orbital period exactly equals one sidereal period of the earth's rotation
  - If excellent station-keeping is maintained, this could be called a "geostationary" orbit
  - By far the dominant orbit for communications satellites

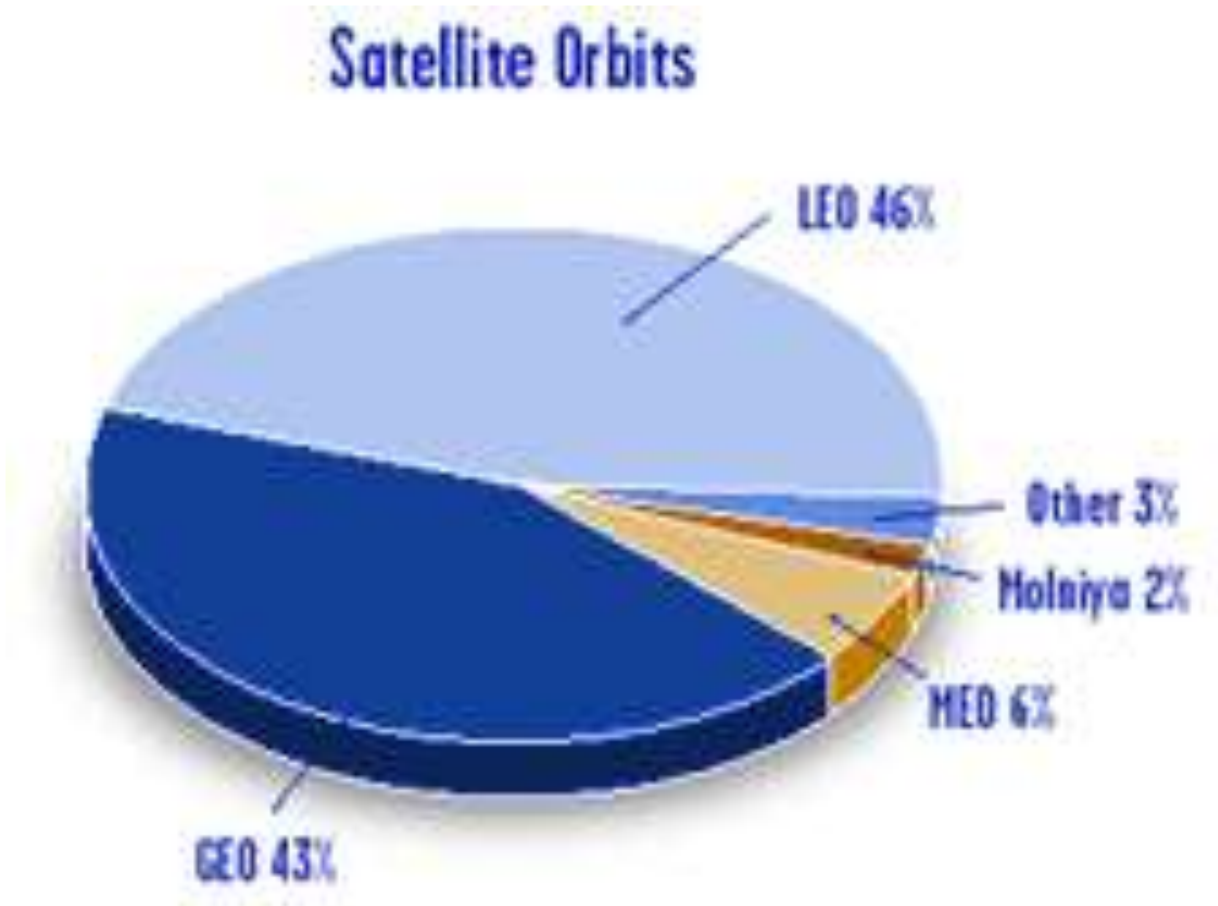
<u>LEO (Low Earth Orbit)</u>

- Circular/slightly elliptical orbit, 2000km
- Orbit period: 1.5 -2 km
- Diameter of coverage: 8000 km
- Signal propagation delay: <20 ms
- Maximum satellite visible time:20 min
- Atmospheric drag results in orbital deterioration.




Low Earth Orbit (LEO)
All sizes to scale
1,200 mi / 2,000 km
99 mi / 160 km
Alan Shepard's Arc
Yuri Gagarin's Orbital Height
John Glenn's Orbital Height
ISS
Hubble
waitbutwhy.com


Distribution of Satellites in Orbits
LEO (442)
49%
GEO (366)
40%
6%
MEO (56)
5%
Elliptical (41)



- **Low Earth orbits (LEO)-about 80 kilometers (km) to 2000 km above Earth Includes: military intelligence satellites, weather satellites**

- **Geosynchronous orbits (GEO)-36,000 km above Earth Includes: commercial and military communications satellites, satellites providing early warning of ballistic missile launch**

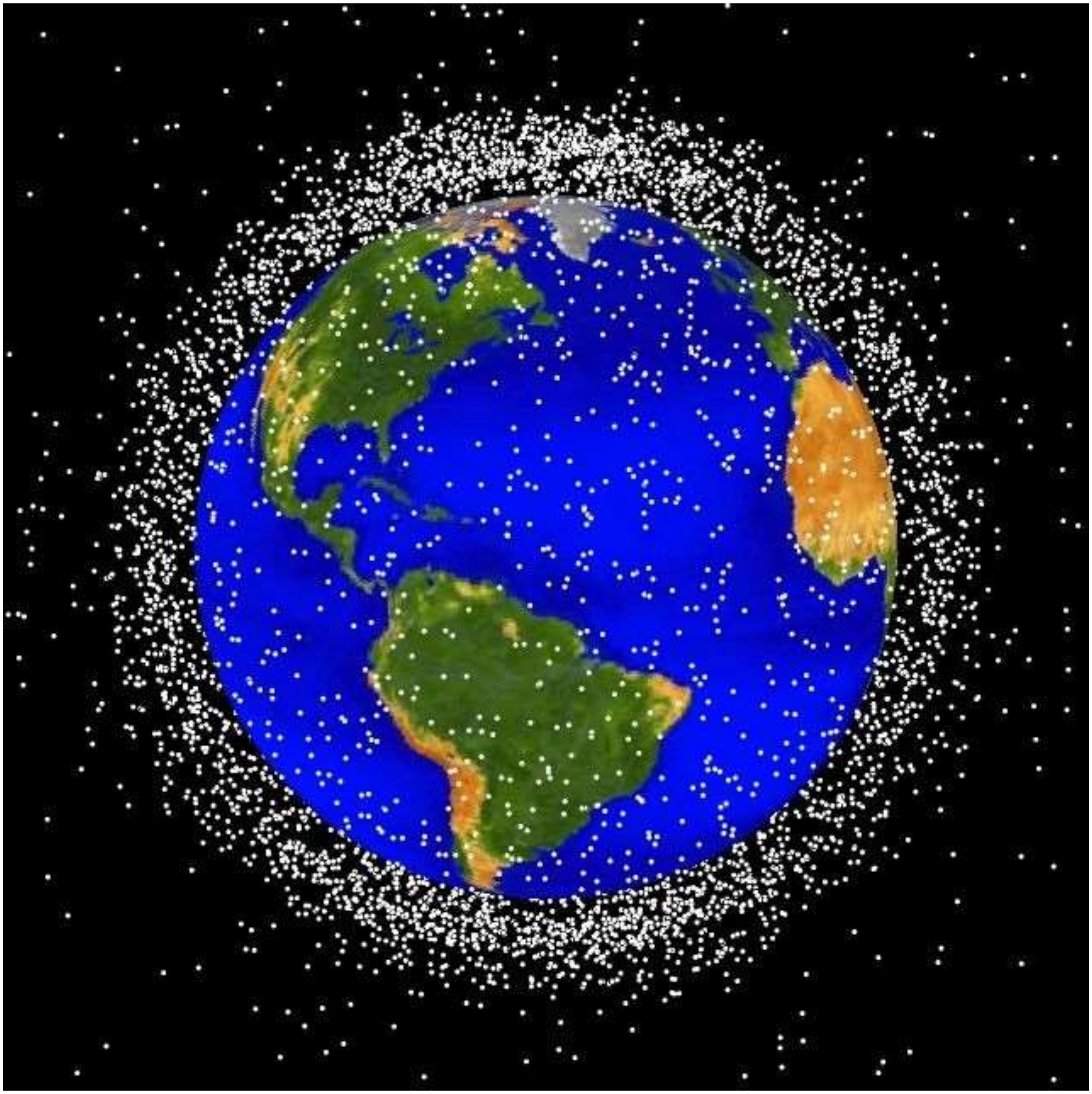
- **Medium Earth orbits (MEO)-between LEO and GEO Includes: navigation satellites (Navstar, Glonass)**

- **Molniya orbit-a highly elliptical orbit with a 12-hour period Includes: communication satellites for regions near the North Pole**

Low Earth Orbit Advantages/Disadvantages

- Advantages:
  - Reduced launch costs to place in low Earth orbit
    - e.g., airplane/booster launched
  - Reduced pass loss
  - Lower Power, Lower cost satellite ($0.5-2M)
  - Much shorter transmission delays
- Disadvantages:
  - Short visibility from any point on earth, as little as 15 minutes
    - Potentially large constellations
  - Radiation effects reduce solar cells and electronics lifetimes
    - Van Allen radiation belts limit orbit placement
      - Belt 1: 1500-5000 km
      - Belt 2: 13000-20000 km -

Crowded Sky:

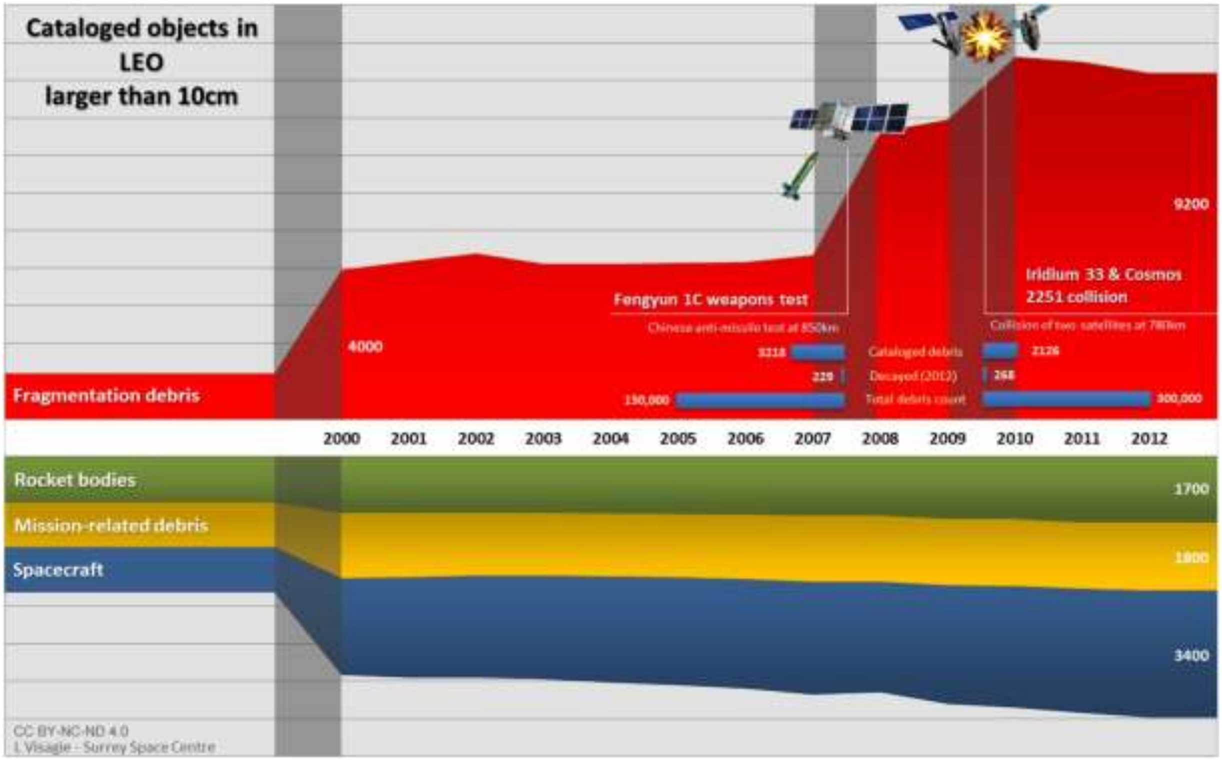


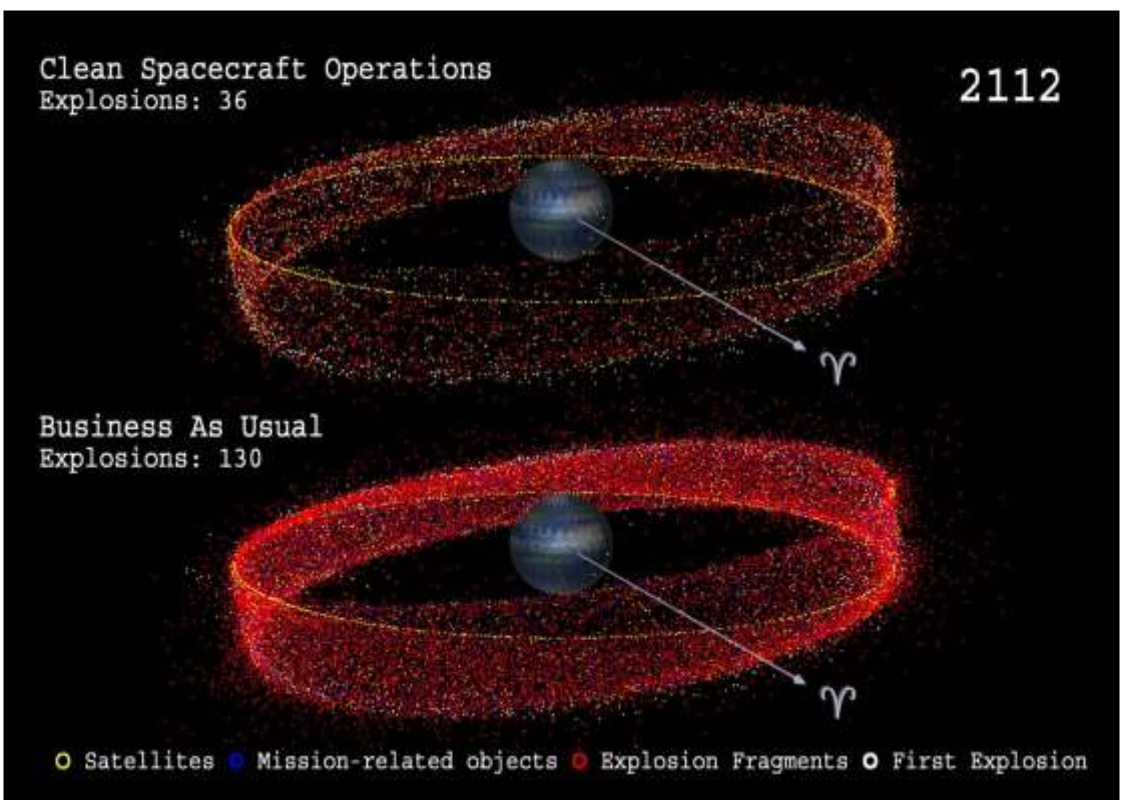
Thousands of manmade objects—95 % of them “space junk”— occupy low Earth orbit. Each black dot in this image shows either a functioning satellite, an inactive satellite, or a piece of debris. Although the space near Earth looks crowded, each dot is much larger than the satellite or debris it represents, and collisions are extremely rare. (NASA illustration courtesy Orbital Debris Program Office.)

http://orbitaldebris.jsc.nasa.gov/

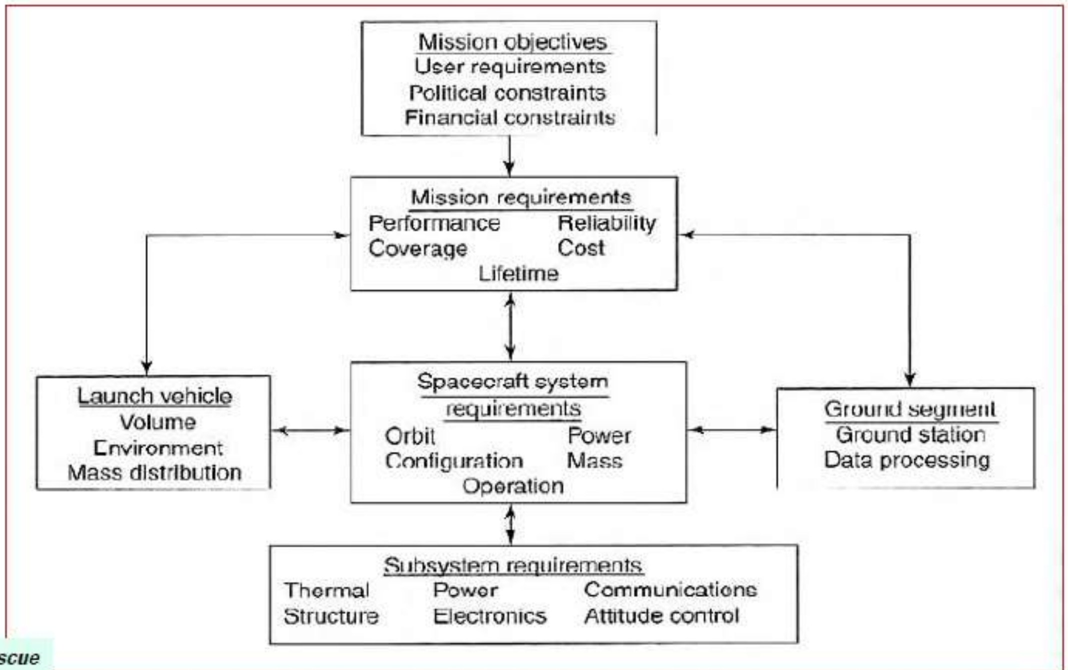
A Growing Problem – Risk of Collision

http://www.vox.com/2015/1/20/7558681/space-junk





Spacecraft Mission Objectives and Requirements

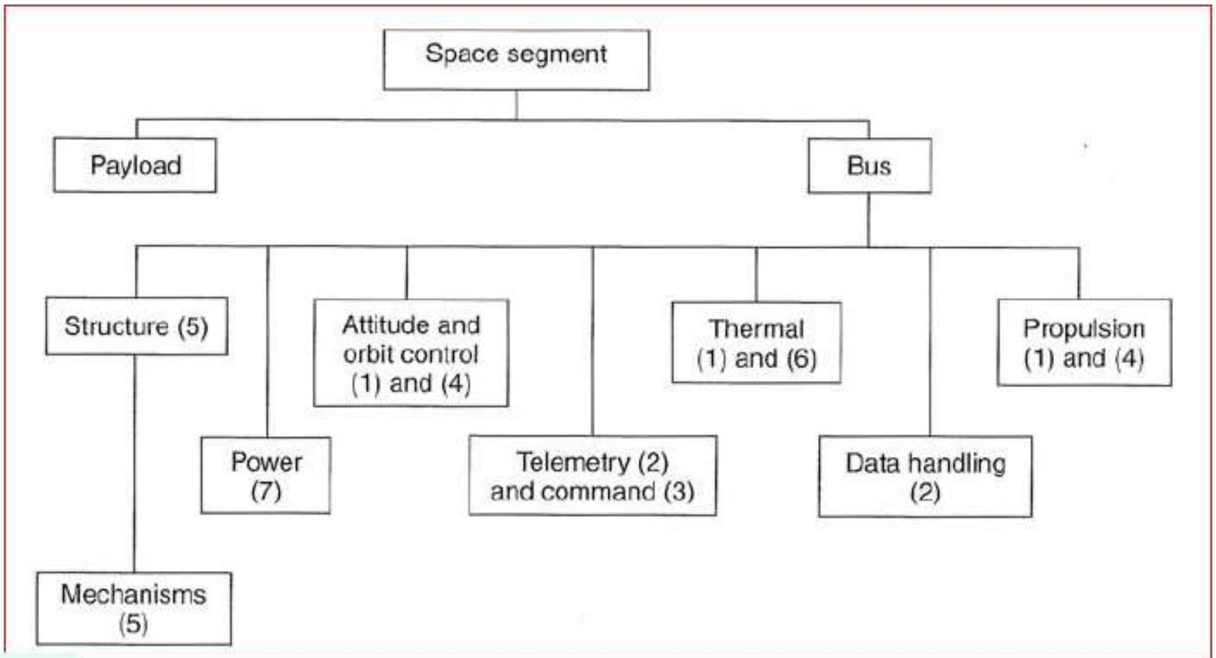


Fortescue

Functional Requirements of Spacecraft Subsystems

1. Payload must be pointed in the right direction
2. Payload must be operable
3. Data must be communicated to the ground
4. Desired orbit for the mission must be maintained
5. Payload must be held together and mounted on the spacecraft structure
6. Payload must operate reliably over some specified period
7. Adequate power must be provided

Spacecraft Subsystems

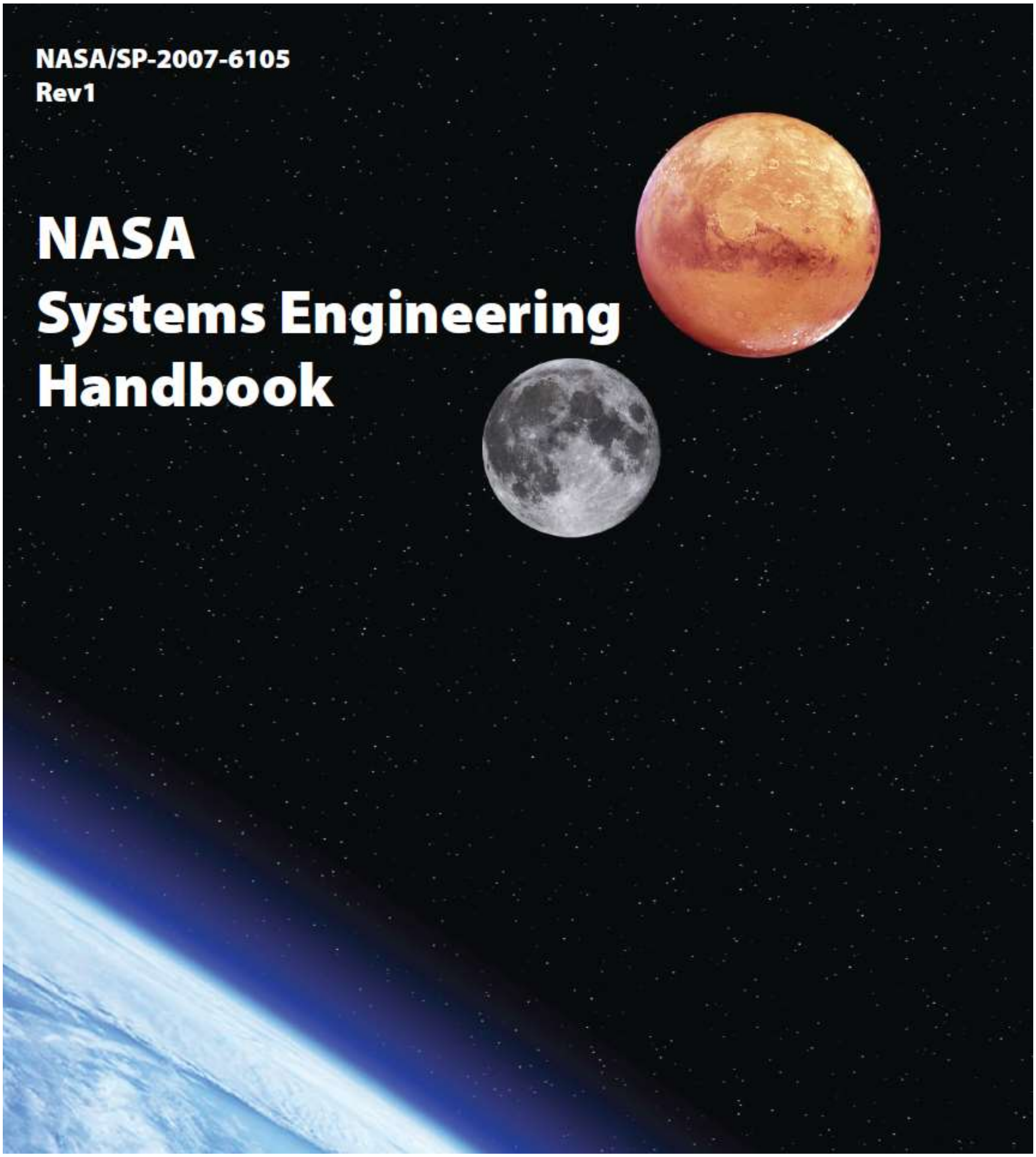


Fortescue

- **Numbers refer to mission functions**

How do we design and integrate the satellite subsystems to meet the mission requirements?

Spacecraft Systems Engineering



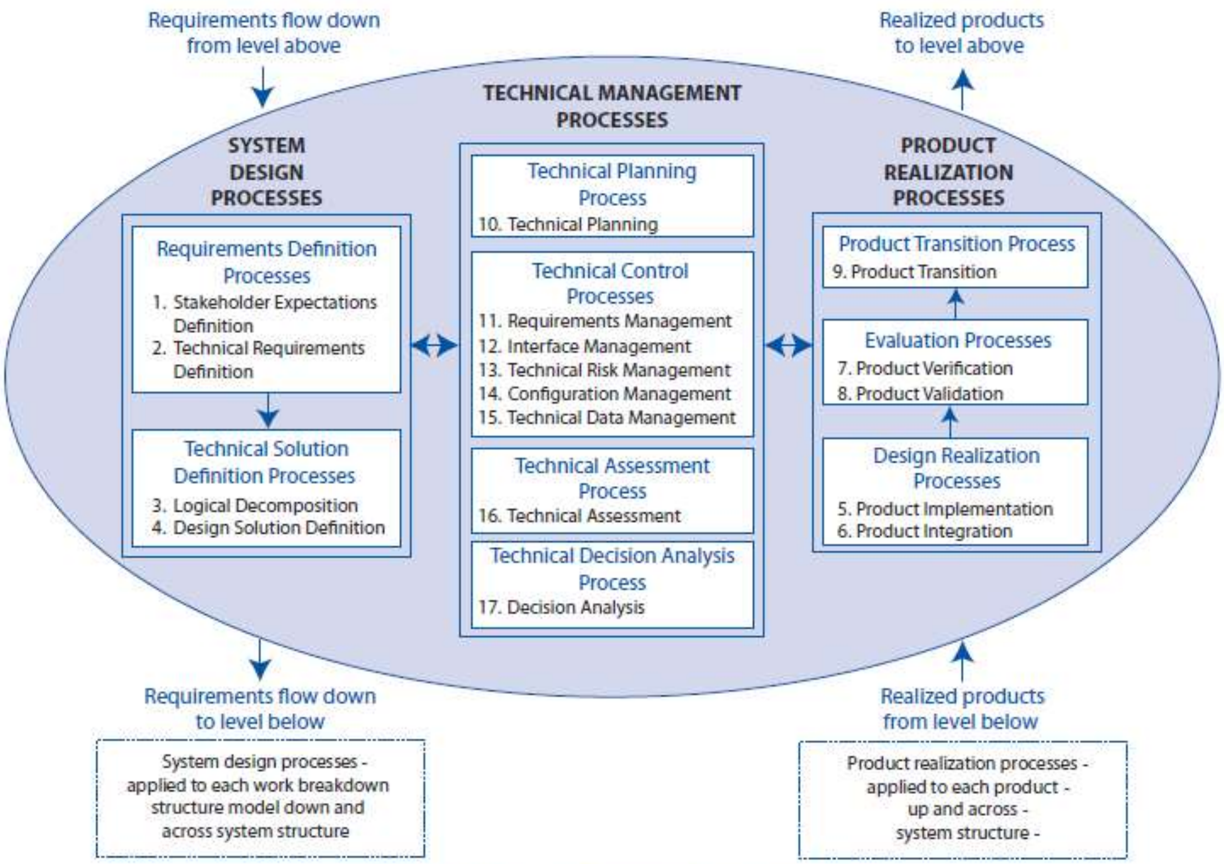


Figure 2.1-1 The systems engineering engine

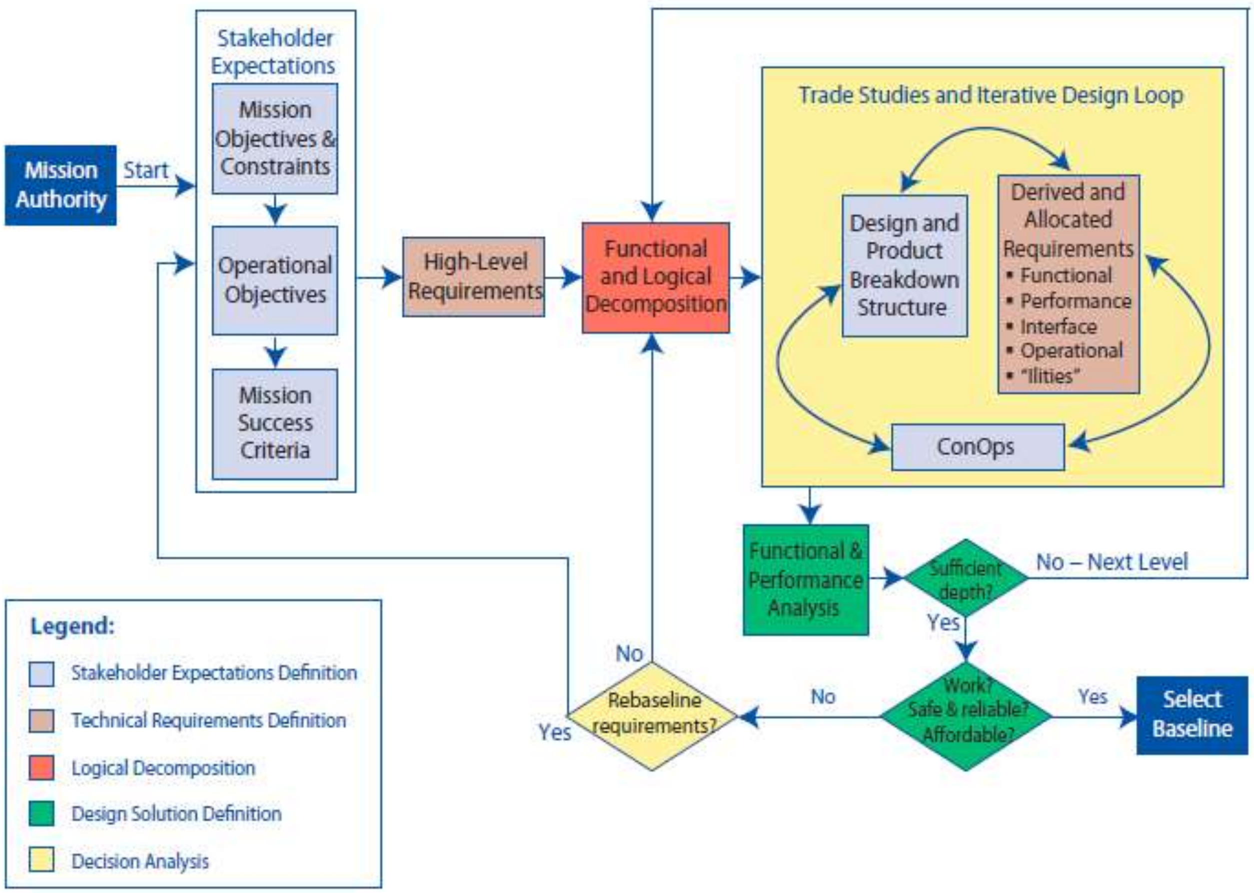


Figure 4.0-1 Interrelationships among the system design processes

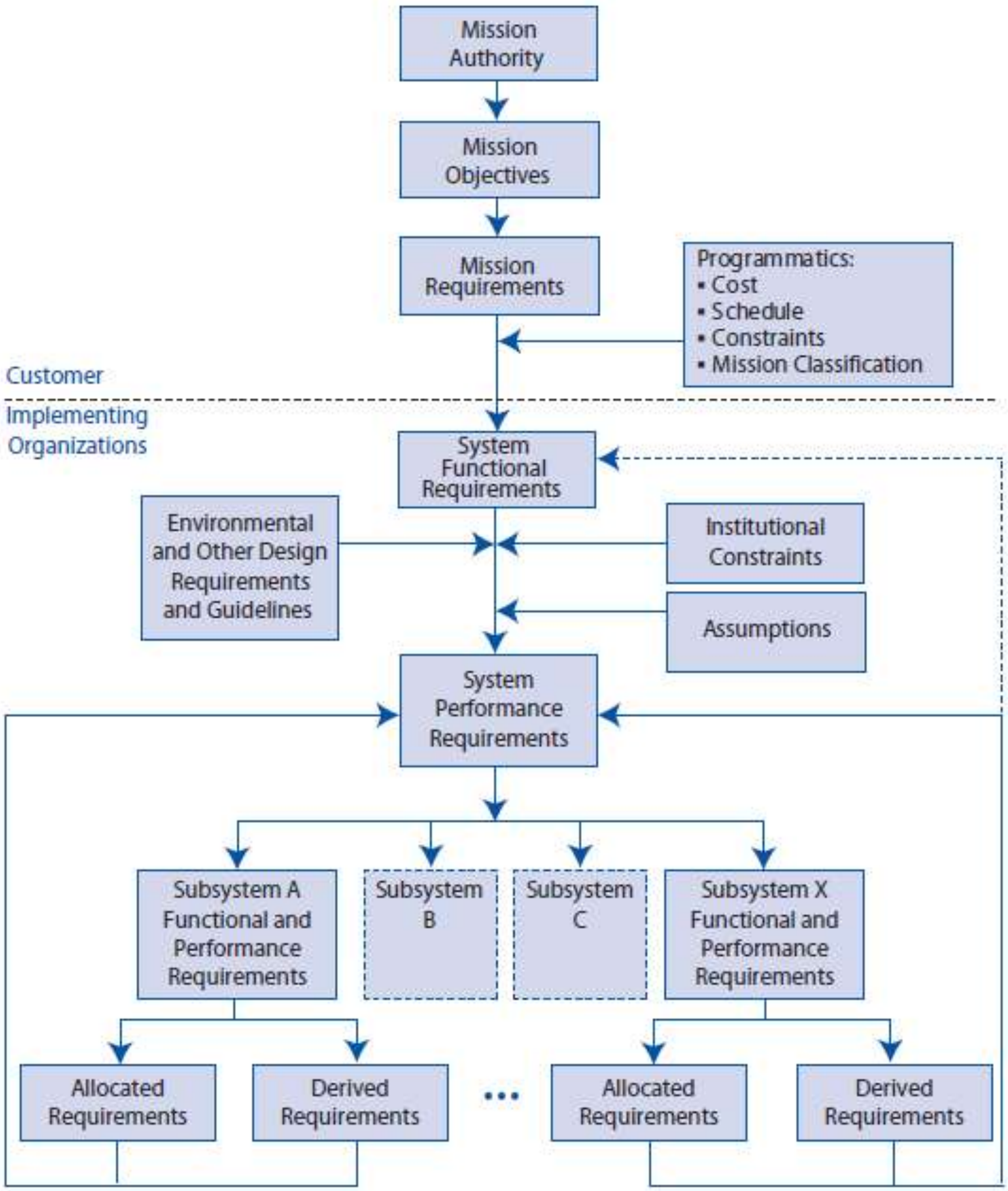


Figure 4.2-3 The flowdown of requirements

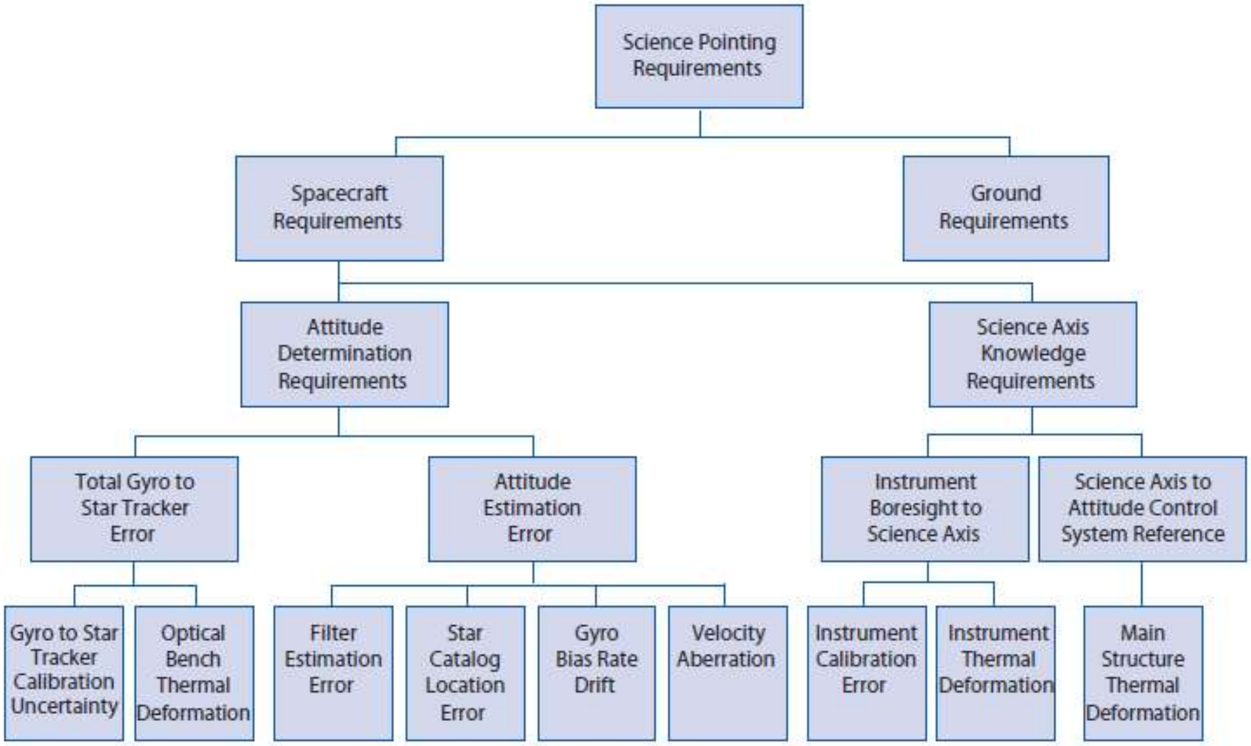


Figure 4.2-4 Allocation and flowdown of science pointing requirements

Product Breakdown Structure (PBS):

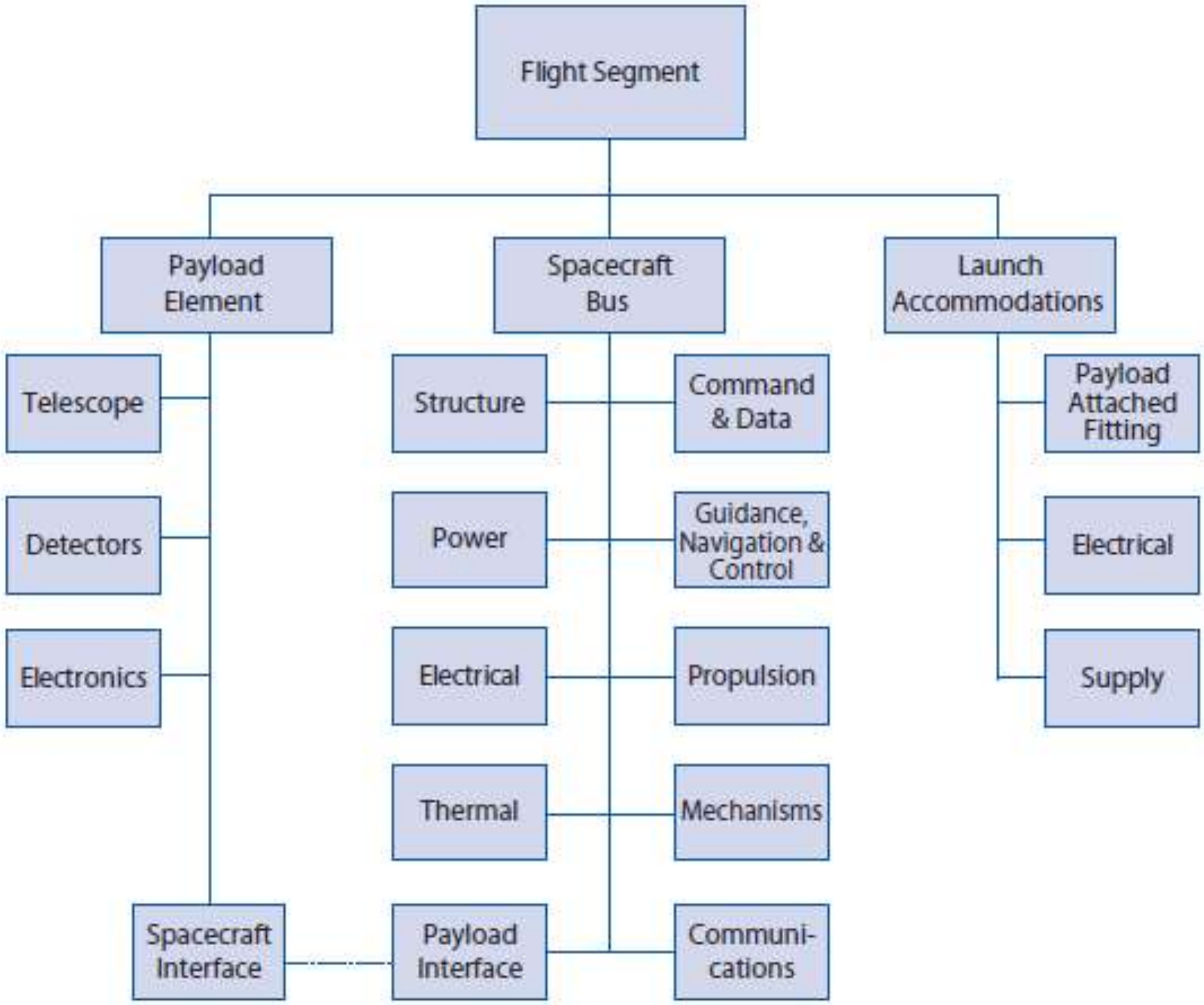


Figure 4.3-2 Example of a PBS

Homework #0: Choose mission by Thurs 1/7 7pm

- **Send email to Prof. Robinson**

Homework #1: due Tues 1/11/2016 8pm on SmartSite

- **Read text pp 3-10**
- **Read NASA Systems Engineering Handbook pp 1-69**
- **Stakeholder expectations (Fig 4.0-1) will be provided on Sat 1/9**

Version 1 of the following:

- **Technical requirements list and flowchart (Fig 4.2-4)**
- **Product breakdown structure for vehicle (Fig. 4.3-2)**
- **List of required analyses**