Space Missions: Modelling, Analysis and Design

Introduction

Space has always been of keen interest to mankind as it is believed to contain information relevant to formation, existence and continued sustenance of our planet. In this regard, astrophysics, which is an important space science, employs the principles of physics and chemistry to provide information about nature of space & objects in it. Similarly, astronomy, an old natural science, provides information about origin & evolution of celestial objects e.g. planets, stars, galaxies etc. using observed data. However, as terrestrial instruments have a limited reach, concept of objects in space for such tasks has evolved in order to address terrestrial and space exploration needs.

History & Current Status of Space Programmes

Since early fifties, there have been continued efforts to create space objects for various purposes. These efforts were initially simultaneous in Russia, USA & Germany. However, after World War II, USA & USSR created their own space research programmes and it is instructive to trace their evolution and growth. Chinese are acknowledged pioneers of space technology, through development of fireworks. However, it is only at the start of 1900 that study of space as a formal discipline began, with development of rockets that overcame Earth's gravity. During the decade 1948-1958, most developments were in the context of rocket technology, which saw the evolution of German V-2 rockets & USA's sounding rockets. However, launch of Sputnik-1 by USSR in 1958 established that satellites could also be used effectively. April 1962 is a landmark as Yuri Gagarin established an orbit around Earth, leading to USA putting a man on the Moon in 1969 and USSR launching Salyut- 1 in 1971, a kind of space station. India entered the space age in 1967, with participation in the sounding rocket programme and established satellite centre in 1973. European space programmes were initiated in 1975 with setting up of ESA, an inter-governmental initiative of 22 countries, while ArianeSpace came up in 1980. Recently, SpaceX has emerged as a major player in launch systems with heavy launchers, launch-to-orbit missions and fully reusable technology. The renewed interest of many other countries in missions to Moon and Mars is expected to significantly scale up the space activities in the next decade.

Space Mission Definition, Classification and Design Strategy

Space mission is defined as an act of transporting a space object to its designated spot and then carrying out the scientific / technological activities. In general, space objects are termed spacecraft whose transportation is done through rockets. This is typically achieved by burning a large amount of propellant to impart the required energy. In this regard, space mission is broadly classified in terms of ascent, orbit /inter-planetary and entry/reentry missions. Ascent mission is the part in which space object is imparted sufficient energy to form an orbit around earth. Orbital mission pertains to the part where the object is placed in a desired orbit / put on a path to other planets. Reentry mission is that segment in which the object is brought to planet surface in a controlled manner. In the context of the design of space missions, primary requirement is the nature of task to be carried out by spacecraft and, hence, in most mission design activities, we first design the spacecraft, followed by the design of applicable launch vehicle.

Broad Course Objectives

To understand fundamental principles governing ascent mission design.
To provide exposure to basic concepts of spacecraft orbital mechanics.
To describe the basic methodology for setting up interplanetary missions.
To highlight issues concerning entry/reentry phase and their conceptual understanding.

Course Contents

Module-1: Basic Ascent Mission Analysis - Space missions and role of launch vehicles and spacecraft. Ascent mission objectives, mathematical models, rectilinear & gravity turn trajectories, effect of drag and gravity on mission performance. (**8 Hours**).

Module-2: Launch Vehicle Configuration Design Strategies – Basic concept of series or restricted staging, staging formulation and solution, including optimal methods for arriving at rocket configuration, sensitivity of the design and concept of variants, concept of parallel staging. (**8 Hours**).

Module-3: Basics of Orbital Mechanics - Concept of orbits, N-body formulation and solution, solution of 2-body problem and its relation with Kepler's laws, types of orbits, orbital parameters in geographical context, orbit from initial conditions. (**6 Hours**).

Module-4: Orbital Manoeuvres - Orbit raising manoeuvre with single impulse, Hohmann and low thrust transfers, orbit inclination & perigee change. (**6 Hours**).

Module-5: Interplanetary Motion Basics - Non-Keplerian formulation and restricted three-body problem, concept of sphere of influence and setting up of departure and arrival solutions, concepts of gravity assist trajectories and fast transfers e.g. launch to orbit, rendezvous / docking solution and launch window concept. (**8 Hours**).

Module-6: Return Mission Models - Concept of entry/re-entry, orbit decay solution, ballistic, lifting and other reentry concepts. (**4 Hours**).

Module-7: Advanced Topics – Air-breathing propulsion concept, ballistic missile trajectory models, jet damping effect in rockets and missiles. (**4 Hours**).

Pre-requisites

Course does not have any formal pre-requisites. However, good familiarity with basic Newtonian mechanics and mathematical / numerical techniques for solving differential equation, is desirable. Further, some understanding of basic aerodynamics and propulsion, as applicable to space vehicles, will be useful.

Texts / References

Thompson, 'Introduction to Space Dynamics', Dover Publications, New York, 1986.
Hale, 'Introduction to Space Flight', Prentice Hall, 1994.
Wiesel, 'Spaceflight Dynamics', McGraw-Hill, 1997.
Curtis, 'Orbital Mechanics for Engineering Students', 2nd Ed., Elsevier, 2010.
Walter, 'Astronautics: The Physics of Space Flight', Wiley-VCH, 2012.

Mode of Conduct and Delivery

The course is planned to be conducted fully in the on-line format, with two hours per week engagement. Further, it will be run in a module-wise sequence.