Space Missions: Modelling and Analysis

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. 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. Further, many Earth related activities e.g. communication, etc. also are found to be better performed with instruments positioned at higher altitudes. These have resulted in the concept of space objects 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. These were used for detecting x-rays and study of upper atmosphere structure, including aurorae, magnetosphere, ionosphere, Von Allen belts etc. It should be noted that till this time it was believed that only rockets could perform such tasks. However, launch of Sputnik-1 by USSR in 1958 established that satellites could also be used effectively. Luna 3, launched in 1959, was the first among many space probes, that were launched to photograph moon. April 1962 is a landmark as Yuri Gagarin established an orbit around Earth, leading to competition, which culminated in USA putting a man on the Moon in 1969. USSR, not to be left behind, launched Salyut-1 in 1971, which was a kind of space station. USA closely followed this with Skylab in 1973. India entered the space age in 1967, with participation in the sounding rocket programme and raised the level with establishment of 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. The period of 1970-2000 witnessed many milestones e.g. space station, space shuttle, missions to Mars, Jupiter, Saturn, Venus, Mercury etc. India has not only consolidated its position in launcher segment with PSLV & GSLV, but also has embarked on Moon & Mars missions, including human spaceflight. Globally, SpaceX has emerged as a major player in launch systems with heavy launchers and launch-to-orbit missions & fully reusable technology. The renewed interest of many other countries in Moon & Mars is expected to significantly scale up the space activities in the next decade.

Space Mission Configuration

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 which consist of satellites, probes, landers etc. as per the specific role assigned to these objects. Transportation of these objects is done through rockets which are also termed launch vehicles and burn a large amount of propellant to impart the required energy. Further, 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.

Space Mission Segments

Objective of ascent mission is to provide potential (altitude) & kinetic (velocity) energy to desired payload, so that it can remain at a specified altitude above earth. This is made possible through burning of a large quantity of propellant. It should be mentioned that ascent missions are designed to perform the above task in a safe and optimal manner. Objective of orbital segment is to perform spacecraft related tasks and is broadly grouped as follows. 1. Manoeuvres to achieve desired earth orbit. 2. Manoeuvres to achieve desired inter-planetary path. 3. Manoeuvres to achieve desired orbit around planets. Re-entry or return is the reverse of the ascent mission, that involves recovery of space objects, without damage. The main challenge is the dissipation of large amount of energy, imparted during ascent & orbital mission phases. Problem is further complicated by the requirement of precise positioning during landing phase.

Space Mission Design Strategy

Space missions aim to carry out scientific/ technological tasks so that their design is driven by the intended role of the spacecraft. However, for spacecraft to carry out the tasks, it needs to be placed at the correct location and hence, the need for a launch vehicle, for which spacecraft is just a mass. In most mission design activities, we first design the spacecraft, followed by suitable launch vehicle.

Broad Course Objectives

To understand fundamental principles governing ascent mission design.

To provide exposure to basic concepts of spacecraft orbital mechanics and interplanetary travel.

To highlight issues concerning entry/reentry phase and their conceptual understanding.

Course Contents

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. Basic concept of staging, staging solution & its sensitivity, series and parallel staging, optimal staging. Concept of orbits, 2-body problem & Kepler's laws, orbital parameters, orbit from initial conditions, types of orbits. Orbit raising, Hohmann and low thrust transfers, orbit inclination / perigee change, rendezvous and docking manoeuvres. Interplanetary motion basics, non-Keplerian formulation, launch window, departure and arrival solutions, gravity assist trajectories. Concept of re-entry, orbit decay solution, ballistic and other reentry concepts.

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

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