SECTION II. SPACE FLIGHT PROJECTS

Chapter 7. Overview of Mission Inception

Objectives: Upon completion of this chapter you will be able to describe activities typical of the following mission phases: conceptual effort, preliminary analysis (proof of concept), definition, design, and development. You will be conversant with typical design considerations included in mission inception.

In this discussion, we will consider projects suitable for sponsorship by the U.S. National Aeronautics and Space Administration (NASA). Many JPL projects have different sponsors. This discussion considers a hypothetical example. In reality, there may be many deviations from this nominal process.

There is no single avenue by which a mission must be initiated. An original concept may come from members of the science community who are interested in particular aspects of certain solar system bodies, or it may come from an individual or group, such as a navigation team, who show a unique opportunity approaching from an astronomical viewpoint. As a project matures, the effort goes through different phases:

- Pre-Phase A, Conceptual Study
- Phase A, Preliminary Analysis
- Phase B, Definition
- Phase C/D, Design and Development
- Operations Phase

Formal reviews are used as control gates at critical points in the full system life cycle to determine whether the system development process should continue, or what modifications are required.

Conceptual Study

A person or group petitions NASA with an idea or plan. The proposal is studied and evaluated for merit, and, if accepted, the task of screening feasibility is delegated to a NASA Center. In the case of unmanned deep space exploration, that center has historically been JPL in many cases.

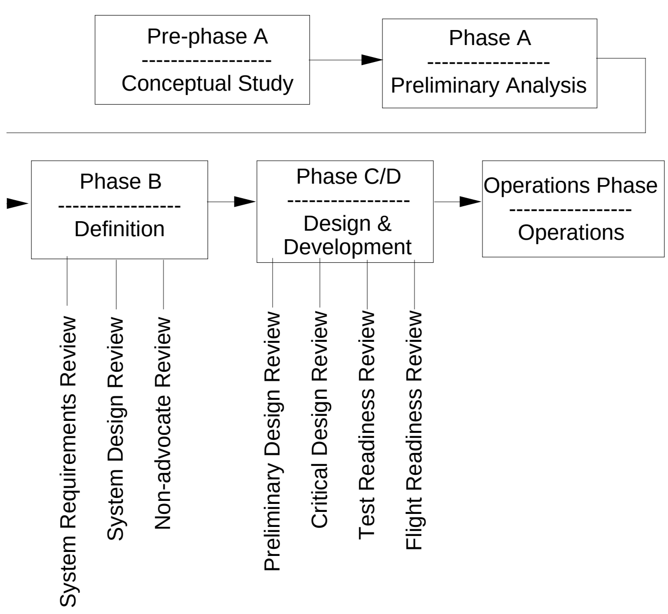
Prior to Phase A, the following activities typically take place: NASA Headquarters establishes a Science Working Group (SWG). The SWG develops the science goals and requirements, and prepares a preliminary scientific conception of the mission. Based on the high-level concept and the work of the SWG, a scientific document called the “Announcement of Opportunity” (AO) is sent out by NASA Headquarters to individuals (scientists) at universities, NASA centers, and science organizations around the world. The AO defines the existing concept of the mission and the scientific opportunities, goals, requirements, and system concepts. The AO specifies a fixed amount of time for the scientific community to respond to the announcement. All proposals for new experiments are reviewed for science merit as related to the goal of the mission. Items such as mass, power consumption, science return, safety, ability to support the mission from the "home institution" are key issues. JPL develops a library of launch possibilities which becomes available to the project. Depending on the nature of the tasks at hand, they will be delegated to various sections within JPL.

A project is started by making funding available to Section 312 (Mission Design). The Mission Design Section then tasks personnel from appropriate divisions or sections as needed, for example:

- Section 313 (Spacecraft Systems Engineering) for Spacecraft Design
- Section 314 (Navigation Systems) for Navigation Design
- Section 317 (Mission Information Systems Engineering) for Ground Data System Design
- Division 390 (Information Systems Development and Operations) for Mission Operations

Usually the presentation of the study concept to NASA Headquarters by JPL personnel and NASA's approval to proceed to Phase A signify the end of Conceptual Study.

Full System Life Cycle



Phase A: Preliminary Analysis (Proof of Concept)

The Project creates a preliminary design and project plan specifying what to build, when to launch, the course the spacecraft is to take, what is to be done during cruise, when the spacecraft will reach the target, and what operations will be carried out. The preliminary plan also addresses build-versus-buy decisions, what spacecraft instruments are needed, where system tests will be performed, who performs mission operations, what Ground Data System (GDS) capabilities are required, and who the experimenters are. Generally speaking, publication of the preliminary plan with costing data marks the completion of Phase A: Preliminary Analysis.

Phase B: Definition

The definition phase converts the preliminary plan into a baseline technical solution. Requirements are defined, schedules are determined, and specifications are prepared to initiate system design and development. Major reviews commonly conducted as part of the definition phase are: System Requirements Review, System Design Review, and Non-advocate Review. The proposed experiments are divided into two classes based on facilities and experimenters. The facilities form teams around a designated set of hardware. Facilities are selected based on existing resources and past performance. Experimenters were specified in the preliminary plan. However, individuals are encouraged to respond with modifications and to step forward with their own ideas. These ideas could include the addition of another experiment.

A NASA peer group reviews all new proposals and "grades" them. After that, a sub-committee from NASA Headquarters' Office of Space Science and Applications (OSSA) Steering Committee (SC) makes the final experiment selection, based on scientific value, cost, management, engineering, and safety.

Personnel teams are established to build and operate the instruments and evaluate the data returned. There is usually one team for each experiment, with one individual from that team chosen as the team leader and Principal Investigator (PI). In most cases, the Non-Advocate Review marks the end of Phase B: Definition.

Recap

1. As a project matures, the effort goes through different phases (including) Pre-Phase A ___________________ ________________ .
2. Formal ________________ are used as control gates at critical points in the full system life cycle to determine whether the system development process should continue...
3. The SWG, or_________________ ________________ ________________ develops the science goals and requirements, and prepares a preliminary scientific conception of the mission.
4. The AO, or ____________________ _____ _______________________ defines the existing concept of the mission and the scientific opportunities, goals, requirements, and system concepts.
5. Publication of the preliminary plan with ____________________ data marks the completion of Phase A: Preliminary Analysis.
6. The definition phase converts the preliminary plan into a baseline _______________ solution.

1. conceptual study *2. reviews* *3. Science Working Group* *4. announcement of opportunity*
5. costing *6. technical*

Phase C/D: Design and Development

During the design and development phase, schedules are negotiated, and the space flight system is designed and developed. Then, in a process called ATLO (Assembly, Test, and Launch Operations), it is integrated, tested, launched and/or deployed, and verified. The design and development phase begins with the building and integration of experiments into a single spacecraft. The complete spacecraft science package is tested together in a simulated space environment prior to launch. Ground systems to support the mission are also developed in parallel with the spacecraft development. Phase C/D typically lasts until 30 days after launch. Reviews commonly conducted as part of the design and development phase include: Preliminary Design Review, Critical Design Review, Test Readiness Review, and Flight Readiness Review.

Operations Phase

The long-term operations phase, that is flying the spacecraft and obtaining science data for which the mission was designed, is described in later sections of this training module: Chapters 14 through 17 present details of Launch, Cruise, Encounter, Extended Operations, and Project Closeout.

Design Considerations

The process by which a mission is conceived and brought through the phases described above includes consideration of many variables. The remainder of this chapter touches upon a few of them.

Budget

Trajectories are constrained by the laws of celestial mechanics, but the realities of budgets constrain the desires and needs of project science to determine the final choices. Should the mission use a quick, direct path that can be achieved only with a massive upper stage, or an extended cruise with gravity assists for “free” acceleration? Can significant science be accomplished by going only a few weeks out of the way? Which options can be justified against the cost in personnel and time? This task of balancing the political and the physical is ordinarily resolved before most project personnel are assigned.

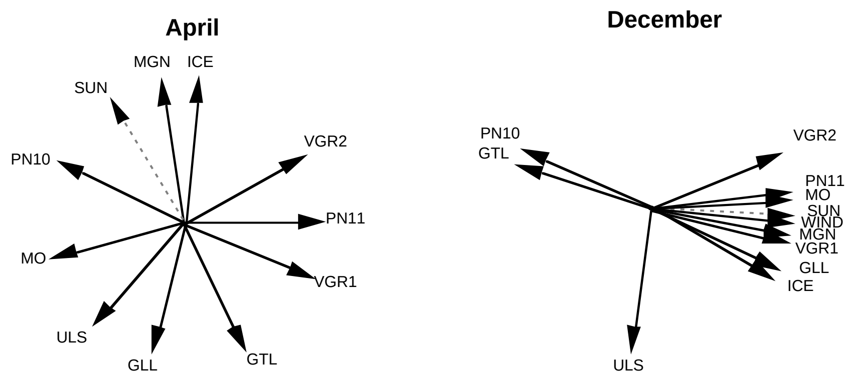
Design Changes

The purpose, scope, timing and probable budget for a mission must be clearly understood before realistic spacecraft design can be accomplished. But even a final, approved and funded design may be altered when assumed conditions change during its lifetime. Design changes are always costly. The Galileo mission design, for example, underwent many significant and costly changes before it was finally launched. The Space Station Freedom spent tens of billions of dollars over several years prior to having comprehensive design changes imposed.

Resource Contention

Timing for many JPL missions is affected most directly by solar system geometry, which dictates optimum launch periods. It correspondingly implies the “part of the sky” that the proposed spacecraft will occupy and how many other spacecraft it may have to compete with for DSN antenna time. If possible, it is very advantageous to fly a mission toward an area where the spacecraft will share little or none of its viewperiod with other missions (viewperiod is the span of time during which one DSS can observe a particular spacecraft above its local horizon). Years before launch, mission designers request a “what-if” study by Section 391’s Resource Analysis Team to determine the probable degree of contention for DSN tracking time during the mission. Such a study can assist project management in the selection of launch date and mission profile with the least contention for external resources, and maximized science return for the mission.

Spacecraft Right Ascension, 1993



Abbreviations defined in Glossary

The diagram above illustrates how viewperiods may cause different spacecraft to compete for DSN resources. When spacecraft occupy different areas of the sky, as in the April 1993 example, contention is at a minimum. However, when several spacecraft are bunched together in the same part of the sky, as they are for December, contention for DSN resources within heavily populated bunches may be formidable. Diagrams such as those shown above are produced by the Resource Allocation Team for ten year periods. They represent the situation on the 15th of the month shown. The arrow indicates the center of a spacecraft view from Earth. Extend 60 degrees on both sides of an arrow to describe an 8-hour viewperiod for a spacecraft.

Tracking Capabilities

DSN tracking capabilities must be considered when designing on-board storage, telemetry rates, trajectory and launch periods. Magellan, for example, acquired radar data at 800 kilobits per second. Since it used its high-gain antenna for both mapping and high rate communications, it required on-board storage sufficient to record its data during each mapping pass. The project needed assurance that it could count on DSN tracking time nearly 24 hours a day for the duration of the mission. The data for each orbit had to be downlinked immediately after being acquired or it would be lost, overwritten by data from the next orbit. This scheme made good use of the highly elliptical orbit that Magellan occupied during mapping phase. High-rate data acquisition took place during the 20 or 30 minutes near periapsis, and the hour-long outbound and inbound legs of each orbit were necessary to transmit the data to Earth at the lower rate of 268.8 kbps.

The Mars Global Surveyor spacecraft also has limited on-board storage that will require at least one tracking pass daily to avoid data loss. The high transmission rate and the maximum distance to Mars must be taken into account when designers determine such things as transmitter power and high-gain antenna size.

Data Complexity

The proposed volume and complexity of the mission's telemetry influences the cost of ground processing. If telemetry does not present significant differences from recent missions, it may be economical to use an adaptation of the existing Advanced Multimission Operations System (AMMOS) rather than develop one that is mission-specific.

Recap

1. During the _____________ and _____________ phase the system is designed, developed, integrated, tested, launched and or deployed, and verified.
2. Phase C/D: Design & Development typically lasts until 30 days after _______________ .
3. DSN ___________________ capabilities must be considered when designing on-board storage, telemetry rates, trajectory and launch periods.

1. design and development *2. launch* *3. tracking*

Chapter 8. Experiments

Objectives: Upon completion of this chapter you will be able to identify what is referred to as the scientific community, describe the typical background of principal investigators involved with space flight, and describe options for gathering science data. You will be aware that radio science applies sensing techniques to planetary atmospheres, rings, and mass, solar corona, and gravitational wave searches. You will be able to describe avenues for disseminating experiment results.

Obtaining information about a particular aspect of the solar system is the primary reason for launching a robotic deep-space mission. Information is obtained by conducting an experiment under controlled conditions to collect and analyze data. After extensive analysis, that information is made available to the science community and at the same time, to the public at large. Frequently, however, JPL imaging data are released to the media by the Public Information Office shortly after collecting them, before long-term analysis has been accomplished and published within the scientific community.

The Scientific Community

The scientific community involved in JPL's experiments is worldwide, and typically is composed of PhD-level scientific professionals tenured in academia and their graduate students, similar-level professional scientists and their staff from industry, scientific institutions, and professional societies.

Gathering Scientific Data

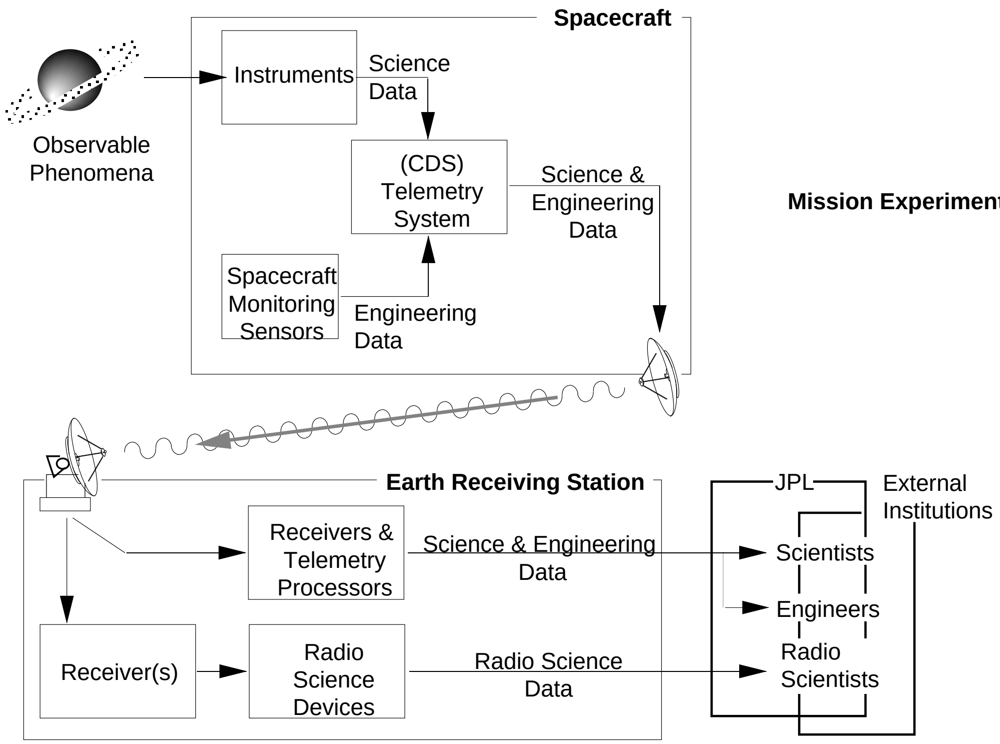
Some experiments have a dedicated instrument aboard the spacecraft to measure a particular physical phenomenon, and some do not. A designated principal investigator (PI), and in many cases a team, determines or negotiates the experiment's operation, and decides who will analyze its data and publish the scientific results. Members of these teams may have been involved in the design of the instrument. Some examples of this kind of experiment are

- the Radar Sensor on the Magellan spacecraft and the associated Radar Investigation Group of 26 scientists worldwide headed by a PI at MIT;
- the Photopolarimeter experiments on the Voyager spacecraft and their PI at JPL;
- the Solid State Imaging experiment on the Galileo spacecraft, and the imaging team headed by a PI at the University of Arizona.

Details of individual instruments aboard spacecraft which are used to gather data for these experiments appears in Chapter 11.

Other experiments are undertaken as opportunities arise to take advantage of a spacecraft's special capabilities or unique location or other circumstance. Some examples of this kind of experiment are

- the gravitational wave search using the DSN and telecommunications transceivers aboard the Ulysses, Mars Observer, and Galileo spacecraft (the PI is at Caltech);
- the UV spectral observations of various astronomical sources using the Voyager UV spectrometer by various members of the astronomical community; and
- Venus atmospheric density studies using the attitude reaction wheels aboard the Magellan spacecraft by the PI at Langley.



Mission Experiments

Science and Engineering Data

Data acquired by the spacecraft's scientific instruments and telemetered to Earth, or acquired by ground measurements of the spacecraft's radio signal, in support of scientific experiments, are referred to as "science" data. The other category of data telemetered from a spacecraft, its health and status data, are referred to as "engineering" data. The latter are normally more of a repetitive nature, and if some are lost, the same measurements can be seen again in a short time. Except in cases of spacecraft anomalies or critical tests, the science data are always given a higher priority than engineering data, because the former is a mission's end product, while the latter is the data used in carrying out spacecraft operations involved in obtaining the science data.

The Science Data Pipeline

Science data from on-board instruments, once received at the antennas of the DSN, flows through a string of computers and communications links known collectively as the Ground Data

System (GDS). The functions of the GDS can be viewed as generally divided into two high-level segments: front end and back end. Front end processing consists of frame synchronizing the data stream, restoring the formats created by the spacecraft computers, and providing real-time visibility of engineering and tracking data for analysts and science instrument teams. Back end processing consists of data management, data products production, and data access systems. While there typically is some front-end visibility into the science data in real time, it is mainly through the back end systems that science teams (for whom the missions are flown) are formally given access to complete sets of their science data.

When science telemetry data are first received by the data management system, they are stored in a time-ordered data base. It is common for significant segments of this preliminary data to be missing. A data management team must first determine what gaps exist and ascertain whether or not those data are recoverable. Data that are easily recoverable are data that reached the ground and were recorded either at a DSN station or at some intermediate subsystem in the GDS front end, but were missing from the back end due to some failure in the pipeline.

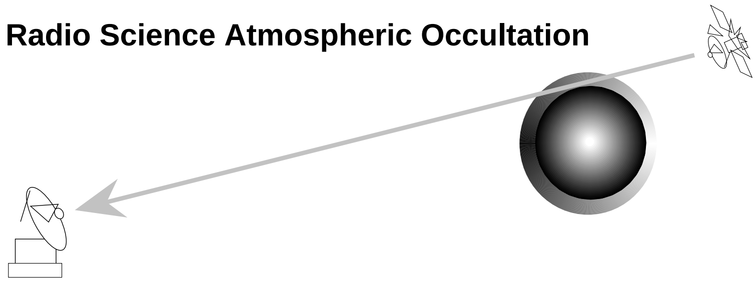
Once identified and located, recovered data are transferred to data management system storage and integrated with data received earlier. The problem is more time consuming if DSN station problems or sudden rain over a station prevented reception of the data. In such cases, if the data are of great value, the project may be able to recover them by commanding the spacecraft to replay a specific portion of the tape before it is overwritten.

Final science data products usually consist of time-ordered, gap controlled sets of instrument-specific data records known as Experiment Data Records (EDRs). Other products that support analysis of the science data include collections of DSN monitor data which indicates the performance of DSN receivers, tracking and telemetry equipment, selected spacecraft engineering data, spacecraft ephemeris and pointing data. These are known as Supplementary Experiment Data Records (SEDRs) or the equivalent. SEDRS track the history of pointing of the instruments (discussed in Chapter 12), which details the instrument's "footprint" on the object being imaged.

While data products are produced within the Data Management Systems of some projects, Cassini is an example of a new plan calling for its science teams to produce all the science data products that are the result of data compilation and analysis. The Advanced Multimission Operations System (AMMOS) that supports Cassini will perform some data management functions, but will not produce the basic science products.

Radio Science

It was mentioned in the beginning of this chapter that not all science experiments use dedicated instruments aboard the spacecraft. Radio science experiments use the spacecraft radio and the DSN as their instrument. They are interested in the attenuation, refraction, Doppler shifts, and other modifications of the signal as it is occulted by the atmosphere of a planet, moons, or by structures such as planetary rings. From these data, radio scientists are able to derive a great deal of information about the structure and composition of an atmosphere and particle sizes in rings. The "atmosphere" of the sun is another target of great interest which can be observed by radio science. The solar corona causes a scintillation of the spacecraft's radio signal which can be measured while a spacecraft is within a few tens of degrees from the sun as viewed from Earth. When a spacecraft is near superior conjunction with the sun, radio science experiments may be conducted to quantify the general-relativistic gravitational bending imposed on the spacecraft's radio link as it grazes the sun. Such bending results in a slight increase in the apparent distance to the spacecraft.



Another Radio Science experiment is the gravitational wave search. Gravitational waves are predicted by Einstein's general theory of relativity, but as of 1995 they have never been detected. Measuring minute Doppler shifts of a spin-stabilized spacecraft in interplanetary space over long periods of time might yield the discovery. The spacecraft’s distance would be observed to increase and then decrease on the order of millimeters as a gravitational wave passes through the solar system. Even if these gravitational wave searches have negative results, this information is useful, in that it places limits on the magnitude of gravitational waves at long wavelengths.

Gravity Field Surveys

Another science experiment, like radio science, does not use an instrument aboard the spacecraft. Gravity field surveys (not to be confused with gravitational wave searches) use the spacecraft’s radio and the DSN to measure minute Doppler shifts of a vehicle in planetary orbit. After subtracting out the Doppler shifts induced by planetary movement, the spacecraft’s primary orbital motion, and small force factors such as the solar wind and atmospheric friction, the residual Doppler shifts are indicative of small spacecraft accelerations and decelerations. These are evidence for variations in the planet’s gravity field strength associated with high and low concentrations of mass at and below the planet’s surface. Mapping the planet’s mass distribution in this way yields information that complements other data sets such as imaging or altimetry in the effort to understand geologic structure and processes at work on the planet.

Dissemination of Results

Publication of the results of the experiments takes place in the literature of the scientific community, notably the journals *Science* (American Association for the Advancement of Science, AAAS), *Nature*, the international weekly journal of science, *JGR* (*Journal of Geophysical Research*), and *Icarus*. Presentations are made at virtually every annual convention of various scientific societies, such as the American Astronomical Society (AAS) by experimenters who use JPL’s spacecraft. The news media and several magazines keep a close eye on all these journals and proceedings and report items of discovery from them. The thin weekly magazine *Science News* is a notable example, as is the amateur astronomers’ monthly *Sky & Telescope* magazine. Splendid photography from JPL’s missions occasionally appears in *National Geographic* magazine, and many a JPL mission has enjoyed very good treatment in public television’s science series *Nova*.

Regional Planetary Imaging Data Facilities (RPIF) are operated by NASA at over a dozen sites around the United States and overseas. Each maintains a complete photographic library of images from NASA’s lunar and planetary missions. They are open to members of the public by appointment for browsing, and their staff can assist individuals in selecting and ordering materials. All of NASA's planetary imaging data is made available for researchers who are funded by NASA, in photographic format and digital data format, via the Planetary Data System (PDS). The PDS consists of a central on-line catalog at JPL, and a number of nodes located at various research facilities from which data may be retrieved on line.

Educators may obtain a wide variety of materials and information from NASA's flight projects through the network of Teacher Resource Centers (TRC) in cooperation with educational institutions around the country. Each TRC also supports a center for distribution of audiovisual materials called the Central Operation of Resources for Educators (CORE). Members of the public may purchase photographic images and videotapes through contractor facilities associated with JPL's Public Information Office (PIO). The PIO can serve as a clearinghouse for information about access to all of the various avenues for dissemination. Increasing use is being made of the World-Wide Web to disseminate scientific results.

Recap

1. Most experiments have an associated ___________________ on board the spacecraft to measure a particular physical phenomenon.
2. The data produced by the spacecraft instrument suite in support of the experiments are generally referred to as _______________ data.
3. _____________ ____________ experiments use the spacecraft radio and the DSN as their instrument.
4. The ___ ___ ___ (at JPL) can serve as a clearinghouse for information about access to all of the various avenues for dissemination.

---

1. instrument 2. science 3. radio science 4. PIO
