SMALL SPACECRAFT CONCEPTUAL DESIGN FOR A FAST PLUTO FLYBY MISSION

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Abstract

The P uto Fast Flyby mission is a pre-Phase A mission development activity being pursued at the Jet Propulsion laboratory and funded by NASA's Code SL. Its objective is to conduct first reconnaissance level science at Pluto before its atmospheric collapse in the next two to three decades. The design approach is driven by the consideration of cost, schedule, and performance, in that order. This requires a combination of science requirements driven top-down design and cost and capability driven bottoms-up design, The result of this approach has been the 1992 baseline design that is strongly supported by the Outer Planets Science Working Group (OPSWG). The objective is to deliver two 164 kg spacecraft to Pluto for less than $400 M development cost. An Advanced Technology Insertion (ATI) activity is being conducted in fiscal 1993 funded by Code C and Code S1. to produce a new baseline design with a reduced spacecraft mass through the insertion of new technology.

Introduction

The Pluto Fast Flyby mission development activity is being pursued at the Jet Propulsion laboratory and funded by NASA's Solar System Exploration Division (Code SL). It is in a pre-Phase A conceptual design mode which began in January of 1992. The objective is to conduct an initial reconnaissance of the ninth planetary system in our solar system, Pluto and its large moon Charon. Scientific objectives include study of the surface morphology and composition of both bodies, and characterization of Pluto's neutral atmosphere, including identification of the major constituents and determination of the temperature and pressure profile down to the surface. Completion of this mission in a timely manner is very important since a collapse of Pluto's tenuous atmosphere is eminent. Pluto continues to move away from the sun after its 29.7 AU perihelion in 1989, towards a 49.5 AU aphelion to be reached in 2113. As a result its atmosphere, which is believed to exist for only about the warmest few decades around perihelion, will begin to condense onto the surface of Pluto, thus ending the opportunity for scientific study of Pluto's atmosphere for another -200 years. [1]

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Design Approach

The design of the mission has been mainly driven by three requirements embodying cost, schedule, and performance, in that order:

1) Total mission development cost not including launch vehicle or operations after launch plus 30 days, but including NASA's cost for the RTG, must not exceed $400 M measured in FY92 dollars,
2) Arrival at Pluto must be achieved as soon as possible.
3) The minimum set of necessary scientific observations for an initial reconnaissance of the Pluto/Charon system as defined by the Outer Planets Science Working Group (OPSWG) must be achieved.

The first driver, cost, is clearly the most important. If at any time during the course of the mission development it becomes apparent to NASA that the $400 M cost cap is going to be exceeded, the Pluto Fast Flyby Team can expect that further activity will be canceled. "l'his attitude is not only Understood, but advocated by the Pluto Fast Flyby Team. It is clear that NASA cannot continue along the trend towards fewer and fewer larger and more expensive missions. This must change.

The typical accounting of mission costs must also change. Currently, launch vehicles and operations costs arc not added to the mission development cost to arrive at a total mission cost which the project is responsible for, 'l'his allows decisions to be made during the mission development without any regard for their cost impacts during operations. Problems during development arc often resolved by pushing them downstream into operations driving up operations costs. Pluto Fast Flyby is including operations impacts in its design consideration to ensure that decisions arc made which reduce the combined cost of development and operations.

The second mission driver is the need to get to Pluto as quickly as possible. This vaguely worded requirement stems from three different motivations. The first is the scientific desire to arrive at Pluto before the atmospheric collapse, expected sometime around 2015-202.0. This leaves only a couple of decades for the definition, development, and execution of a Pluto mission. The second motivation is onc born of a need for excitement and inspiration in the planetary program. Few people could get enthusiastic about a program which require.s 15 years of uneventful cruise (a typical duration from past studies of missions to Pluto) before the encounter takes place. Some reasons for this arc boredom of all personnel (what dots onc do during]5 years of interplanetary cruise?); attrition of those people interested in the results (many scientists will retire or expire. during a cruise period of this magnitude!); and reliability of the spacecraft (a critical failure after 14.9 years of fruitless cruise would be a very bitter experience). 'l'he. third, but certainly not the least important motivation for an early arrival date is that it will imply a short development cycle, and a lower cost. Time is money during development. Time also implies cost during operations of a spacecraft in cruise. The desire to have an early arrival date dictates a short flight time and fewer years of operations costs.

The third mission driver, the scientific objectives, is the obvious motivation for even wanting to conceive the mission. The scientific objectives of the mission define what the spacecraft has to be capable of doing. From these objectives come performance requirements on the spacecraft. These include electrical power generation, data storage volume, communications capability, propulsive capability, thermal control, pointing control, and a long list of other resources or capabilities which the spacecraft must provide to the instruments.

These three drivers (cost, schedule, performance) arc not independent variables. If two arc held fixed the other must be allowed to vary. In many past science missions, the science objectives (performance) and the schedule have been defined first and held fixed. Since the science objectives arc defined without regard to cost and they arc often ambitious, this generally results in very expensive missions. Given the cost-schedule-performance priority in the Pluto activity, the approach must be different from that of the typical top-down, science requirements driven mission. The Pluto Fast Flyby design approach holds a tight upper limit on total development cost. Schedule must be flexible where cost considerations require it to be, and performance must yield to both. This requires more of a bottoms-up approach where capability within cost and schedule defines the performance, in this case the science return, This has already taken place in the definition by the Outer Planets Science Working Group of the minimum science objectives. The objectives arc focussed and the resulting baseline payload is modest; a result of cost driven design.

In reality a solely bottoms-up,

capability driven design process is as flawed as the top-down, science requirements driven approach. Just as the top-down process with overly ambitious science goals will likely result in a program that is too expensive, the bottoms-up process with overly frugal cost constraints will likely result in performance that is too poor to accomplish anything useful. In fact both approaches must be used in a complementary, iterative fashion. In this way science requirements and cost-driven capabilities can find a sort of middle ground where adequate performance can be achieved for a reasonable cost. This is what has been attempted in Pluto Fast Flyby with good results so far.

The balancing Of performance against cost and capability, and the reduction of development time add up to only half the battle in controlling cost, Also kcy to Pluto Fast Flyby's design approach is concurrent engineering. Representatives from all aspects of the mission are included in the design process from start to finish. The team includes people from ground operations, integration and test, product assurance, safety, launch approval, procurement, and many other areas to help eliminate surprises downstream in the process. This will keep costs down and help to hold a steady schedule as well.

PlUto Fast Flyby Conceptual Flight System Current 1992 Baseline

The flight system in the current 1992 baseline design consists of the spacecraft, the solid injection stages, and all structural adapters above the separation plane of the Titan IV/Centaur (or Proton), The injection stages consist of two solid rocket motors, a Star 48B and a Star 27 from Thiokol. This upper stage set on a Titan IV/Centaur gives the spacecraft an injection energy (C_3) of about 260 km^2/s^2, resulting in a flight time to Pluto of about 8 years.

The spacecraft has been conceived as a high reliability, fault tolerant system. A large amount of component internal fault tolerance has been used to achieve high reliability with block redundancy used where internal redundancy was not appropriate.

The Pluto Fast Flyby spacecraft has a three-axis attitude control subsystem utilizing cold gas attitude control. The baseline features a small RTG for electrical power augmented by capacitors for short peak loads. Telecommun cations arc X-band uplink and downlink with a nominal downlink rate of about 40 b/s at encounter range to a 34 m DSN station, The command and data subsystem has a central computer for all commanding, sequencing, and computations and can store 400 Mbits of science data. A blowdown monopropellant hydrazine propulsion subsystem is included to perform delta-V maneuvers. The cold gas attitude control uscs pressurant from the monopropellant tank.

The instrument package in the baseline design satisfies the three main science objectives defined by the OPSWG. The imaging camera addresses the surface geology and morphology. The in fra-red imaging instrument provides for surface compositional mapping. Analysis of the neutral atmosphere is addressed by the ultra-violet spectrometer for composition and the uplink radio occult ation experiment to map temperature and pressure down to the surface.

Figures 1 and 2 show isometric views of the Pluto Fast Flyby spacecraft. The high gain antenna (HGA) shown is about 1.5 m in diameter. Overall spacecraft dimensions arc -1.6 m maximum width and -1.? m height, The bus has a 0,5 m maximum diameter. Dry spacecraft mass is 140.1 kg including 29,4 kg contingency for expected mass growth during detailed design. The spacecraft is loaded with 24.0 kg of monopropellant hydrazine to perform 350 m/s delta-V, resulting in a total wet spacecraft mass of 164.1 kg. Additional mass margin exists in the form of incrcascd flight time with increased spacecraft mass.

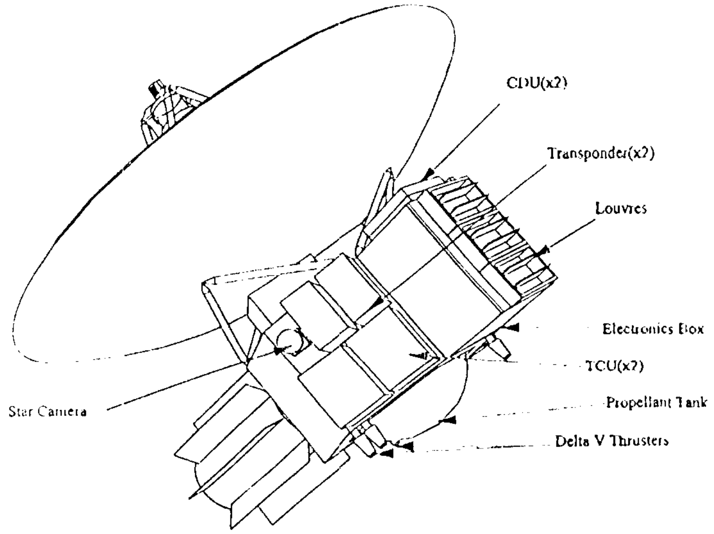


Figure 1. Spacecraft CYuisc/Encounter Configuration (+Z Isometric View)

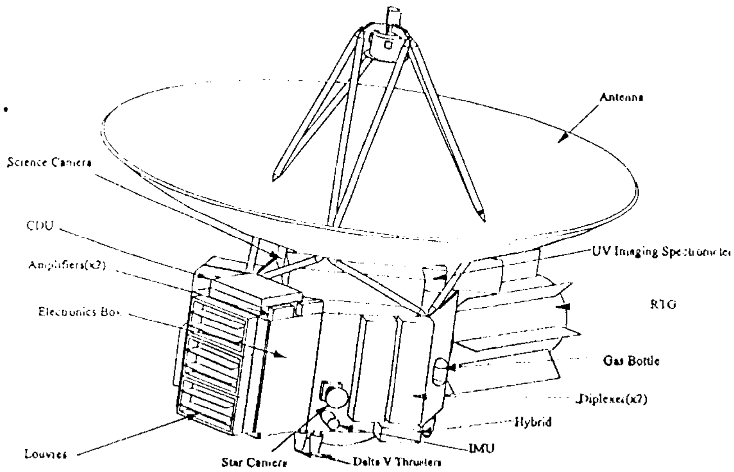


Figure 2. Spacecraft Cruise/I{ncountcr Configuration (-Z Isometric View)

Power output from the RTG (Radioisotope Thermoelectric Generator) is 65 Watts at encounter and 63.8 Watts at the end of the mission -10 years after launch. Power consumption of 60.8 Watts during the encounter mode includes 30% contingency. Losses for voltage conversion and regulation arc included in the electrical power subsystem. The current best estimate for power consumption during downlinking post-encounter is 49.3 Watts leaving a 29.50/o contingency and margin within the 63.8 watts,

The flight system has been designed to execute the following mission scenario. The Centaur spins the flight system up to -10 rpm prior to separation. Additional spin-up to -60 rpm, SRM burns and separations, nutation control, and yo-yo spin-down arc sequenced by the stack sequencer on the Star 27. After release from the Star 27, the spacecraft acquires an inertial star reference, turns the HGA to Earth and establishes communications. After performing an injection error correction maneuver, the spacecraft cruises with the HGA Earth-pointed and uscs onc 8 hour DSN pass pcr week. At distant encounter optical navigation images arc taken by the sciencc camera and returned to the ground for processing. Near encounter science is stored in solid-state memory for post-encounter playback at 40 b/s. During post-encounter cruise the spacecraft uscs onc 8 hour 34 m DSN pass pcr day to downlink 400 Mbits of data in less than a year. Data can be returned faster using increased DSN coverage or the 70 m net.

Design History

The first exercise of the iterative process between science objectives and cost driven mission capabilities came long before the Pluto Fast Flyby concept. Many flight system concepts had been studied for a Pluto flyby mission including a concept based on the extremely capable, multi-thousand kilogram Mariner Mark 11 spacecraft. Studies such as the MMII concept heightened the expectations of the sciencc community for a Pluto mission. However, fiscal realities dictated that science appetites be limited. Onc of the early results of this need for a limited appetite was a moderately sized (~500 kg) mission to perform a Pluto flyby. Eventually, even this was seen as less desirable than the fast, first reconnaissance science mission that now enjoys the outer Planets Sciencc Working Group's support; the Pluto Fast Flyby.

The Pluto Fast Flyby mission concept began in the fall of 1991 as a trajectory study by Stacy Weinstein and Rob Stachle of NASA's Jet Propulsion laboratory (JPL) to determine how quickly a minimal mass could be delivered to a flyby of Pluto. It also included consideration of the feasibility of placing a spacecraft in orbit around Pluto. The spacecraft mass assumed for these initial studies was 35 kg, based on conceptual micro spacecraft designs for other missions that had been studied at JPL. Initial estimates determined that given a Titan IV/Centaur plus Star 48 and Star 27 solid upper stages, a 35 kg spacecraft could be placed on a -5.5 year flyby trajectory. Alternatively, the Titan IV/Centaur could be used to place the spacecraft on a ~16 year trajectory to Pluto at which time the solid stages could be used to achieve orbital insertion.[2]

This trajectory study led to a brief period of proposal preparation which included consideration of spacecraft conceptual design, mission operations concept, integration and test, procurement, and many other aspects of the entire mission. The two primary guidelines during this period were cost and speed. The goal was to get to Pluto very quickly and for a cost much lower than the multi-billion dollar price tags of other space missions. It was also assumed that the launch date would be February of 1998. In January of 1992, a proposal was made to NASA Code SL for funds to further pursue a fast Pluto flyby mission development.

The spacecraft concept for this proposal, shown in Figure 3, was based around a Viking Orbiter residual 1.47 m high gain antenna (HGA). It featured a main structural backbone mounted to the antenna to accommodate an electronics box, an imaging camera, and a small RTG (Radioisotope Thermoelectric Generator) power source. This 3-axis stable spacecraft concept was conceived as a low cost, low mass, largely single-string spacecraft to conduct bare minimum imaging and radio science of the Pluto/Charon system.

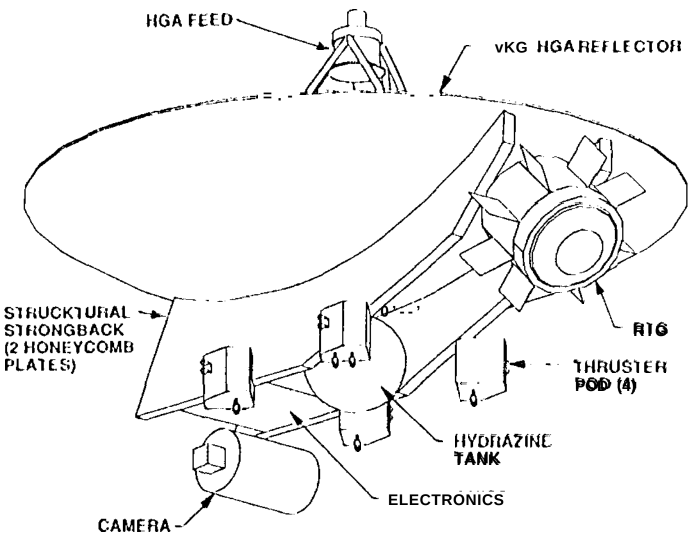
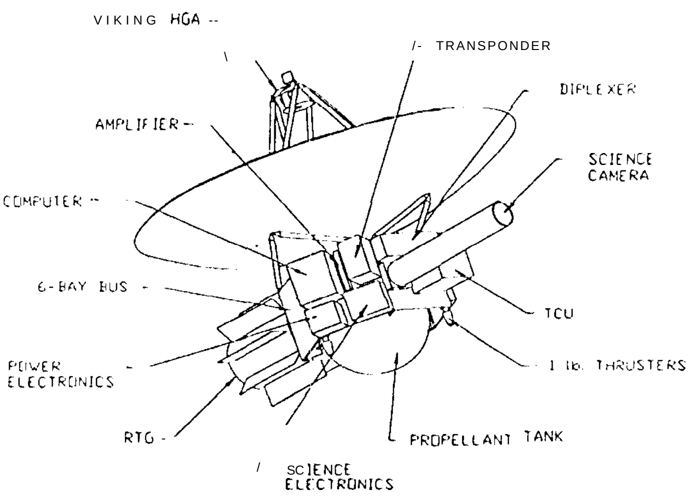


Figure 3. January 1992 Pluto Fast Flyby Spacecraft Configuration

The proposal was well received and Rob Stachle proceeded to set up a mission development team to expand upon the concept, It was at this time that the high level requirements for the mission were agreed upon by NASA Code SL and the Pluto team as described above, including the need to address the minimum science as defined by the Outer Planets Science Working Group. In January of 1992 the Pluto team had not yet met with the OPSWG and therefore the minimum science was not yet defined. The conceptual design activity went forward with internal JPL science input assuming an imaging camera and a radio.

From January to April of 1992, detailed design and a need to keep costs down quickly drove the spacecraft mass up to about 80 kg. The microspacecraft concept in the January proposal was not consistent with the mission constraints of low cost and launch in 1998. Even though new technology was allowed into the design as long as it could be space qualifiable in 1994, much of the projected microspacecraft subsystem hardware that allowed J} 'I, microspacecraft concepts to be so small could not be assumed for a low cost program with a launch as early as 1998. As a result, heavier, more power hungry equipment that required lcss dcvclopmcnt was placed in the baseline design.

In April of 1992 the Pluto Fast Flyby concept was prcscntcd to the outer Planets Sciencc Working Group. At that timc thc basclinc consistcd of a single-st]ing spacccraft, shown in Figurc 4, with a dry mass of 83 kg. The single-string approach was being considered in the context of multiple spacecraft on onc or more launches as an approach to fault tolcrancc. Bcsidcs being single-string, the baseline in April was very much like the current baseline with a fcw cxccptions. Tclccommunications were X-band uplink, Ka-band downlink, and assumed lighter, lowcr power components than could bc included in the current 1992 baseline, Power was supplied by a 38 W RTG and supplcmcntcd by primary batteries for peak modes. The sciencc consisted of only imaging and radio scicncc. Variations on the baseline were briefly considered to address the possibility of an orbiter spacecraft and to explore the mass implications of a more fault tolerant spacecraft with many dual-string subsystems. At this point it was becoming apparent that an orbiter mission was not desirable duc to the scvcrc risk of the -20 year flight time resulting from an 80-100 kg dry spacecraft mass, and further consideration of an orbiter was dropped.



Figurc 4. April 1992 Pluto Fast Flyby Spacecraft Configuration

The sciencc working group had two main concerns about the Pluto Fast Flyby after the April meeting. They felt that it did not accomplish enough sciencc, and they were conccrncd about the risky prospect of a single-string spacecraft. For these reasons, the majority of opinions held that a mission with a larger more capable spacecraft would bc more attractive, and they favored an alternative concept in the -500 kg range. Despite its much longer flight time, the modcratcly sized Pluto mission could addrcss more sciencc objectives and was more fault tolerant.

Two things happcncd after the April OPSWG to bring the Pluto Fast Flyby to its current baseline with OPSWG support. First, the environment continued to get more hostile towards large, very long duration missions. The ncw approach of the faster, better, chcapcr Pluto Fast Flyby mission began to win favor within NASA. Second, the Pluto team continued to update the mission and flight systcm conceptual design to include the robust sciencc package and fault tolcrancc of the current 1992 baseline dcscribcd previously. Thcsc two factors lcd to the strong support of the Pluto Fast Flyby mission by the Outer Planets Sciencc Working Group in August of 1992.

Currcnt/Futurc Activity

At the beginning of fiscal 1993 the Pluto Fast Flyby team was dircctcd by NASA to utilize more advanced technology to dccrcasc the mass of the spacecraft. Dccrcascd spacecraft mass allows a shorter flight time to Pluto. This Advanced Technology Inscrtion (ATI) activity is funded by NASA's Code C (formcrly Code R) in cooperation with mission dcvclopmcnt activities for fiscal 1993 funded by Code SL. Thc object is to transfer ncw technology into the Pluto design from sources in industry, universities, other FFRDC's (Federally Funded Research and Dcvclopmcnt Facilitics) and update the baseline design accordingly. The 1992 baseline is to bc used as a collection of subsystcm fallback positions to mitigate incrcascd dcvclopmcnt risk. Thc goal is to bring the dry spacecraft mass down to lcss than 100 kg while still remaining within the $400 M cost cap.

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