NEW HORIZONS: PLUTO'S FIRST VISITOR FROM EARTH

by

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ABSTRACT

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The National Aeronautics and Space Administration (NASA) conducts planetary exploration using a three step process: (1) fly-by reconnaissance; (2) orbital study and (3) landing operations. *New Horizons* is the latest in a decades-long series of missions to visit each of the planets in the Solar System – in this case, Pluto. Designed as a fly-by mission, it was launched in January 2006 and will reach Pluto in July 2015. The probe will then conduct extensive study of the Kuiper-Belt. Onboard remote sensing will collect images of several planetary objects, measure the effects of solar wind near Pluto, analyze the neutral atoms that are escaping from Pluto's atmosphere and will count and measure the dust particles encountered throughout the spacecraft's trajectory.

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CHAPTER I

BACKGROUND

Exploring the Planets

Since its earliest days, the National Aeronautics and Space Administration (NASA) has explored the Solar System with an ambitious series of probes. The agency has expanded human knowledge of our heavenly neighbors using several steps: (1) initial reconnaissance (i.e., fly-by) of the planetary body; (2) orbital missions to study specific features; and (3) surface landings (by either robotic probes or humans). With Earth's moon, the entire process was demonstrated, culminating with the *Apollo* landings. The landmark *Mariner*, *Pioneer* and *Voyager* missions all helped to show that NASA can ultimately gather information from all of the planets and other sub-planetary bodies within our Solar System (Peters, 2004; Sellers, 2000).

Such exploration requires missions which utilize remote sensing, defined by Lillesand and Kiefer as "the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation" (Lillesand & Kiefer, 2000, p.1). In this framework, Pluto provides an extraordinary challenge for planetary explorers. The shear distances and time required for travel and data transmission have long prevented NASA from collecting detailed information about the outer planets. In fact, the trip to Pluto and Charon has been in the planning stages since at least 1989 (Guo & Farquhar, 2002; Applied Physics Laboratory [APL], n.d.).

Interplanetary probes have already visited eight of the planets. Robotic landing craft have returned images from the surface of Venus and Mars (and, arguably, Jupiter).

Multiple probes have entered orbit around Venus, Mars, Jupiter and Saturn. *Voyager 2* provided the only (limited) detailed images of Uranus (1986) and Neptune (1989) after passing Jupiter and Saturn (Sellers, 2000). NASA planned the *New Horizons* mission to complete the initial fly-by exploration of the ninth planet before its reclassification as an “ice dwarf” in 2006 (APL, n.d.).

Pluto – Charon – Kuiper-Belt

A trip to Pluto will span nearly three billion miles. With the fastest spacecraft previously utilized, this mission would still take decades. NASA mission planners had to create a new kind of spacecraft to ensure the mission could quickly reach its destination while still providing useful data (APL, n.d.). Time was also a factor, since Pluto has been moving farther away from the Sun since 1989. During this phase, the planet has been observed to be changing significantly. Problems that would affect a mission to the Pluto-Charon system that arrived after 2020 would be an inability to collect data on the (currently) gaseous atmosphere and the presence of more shadows on Pluto’s surface. Mission planners realized early on that the *New Horizons* mission needed to launch as soon as possible to take advantage of the conditions available (Guo & Farquhar, 2002).

In addition to Pluto and Charon, the Kuiper-Belt is of great interest to planetary explorers. This region of space is full of “cometary impactors,” thought to be the cause of the extinction of the dinosaurs. Scientists have long wanted to determine their composition and study their motion. A probe could be directed beyond Pluto and Charon to study objects in this area. Scientists anticipate that the region may extend out to 50 Astronautical Units (AU), requiring nearly ten years for a probe to complete the study after passing Pluto (APL, n.d.).

Mission Objectives

New Horizons will take the first close-up photos of Pluto and other Kuiper-Belt Objects (KBOs). Its speed will not allow for an orbital entry of any of the planetary bodies it passes. Despite this, the Pluto-Charon fly-by should provide breakthrough knowledge for the scientific community (APL, n.d.). Science objectives have been categorized into three groups: (1) Group 1 (highest priority); (2) Group 2 (desirable); and (3) Group 3 (optional). Group 1 objectives include the characterization of Pluto geology and the morphology of Pluto and Charon, mapping of Pluto and Charon and characterization of the atmosphere of Pluto and its escape rate (Guo & Farquhar, 2002).

CHAPTER II

DESIGN AND DEVELOPMENT

Management Team

The Principal Investigator for the *New Horizons* mission is Dr. S. Alan Stern of the Southwest Research Institute (SwRI). The Project Manager is Glen Fountain of the Johns Hopkins University (JHU) Applied Physics Laboratory (APL) and the Payload Manager is Bill Gibson of SwRI (Aviation Week, 2006; APL, n.d.). The spacecraft was designed and is operated by JHU/APL. Sensors were developed in collaboration with SwRI, the University of Colorado and Stanford University. NASA's Goddard Space Flight Center and Ball Aerospace assisted with the science payload development. The Jet Propulsion Laboratory (JPL) will provide Deep Space Network (DSN) services (Guo & Farquhar, 2002).

Development Schedule

This program is the final version of a Pluto mission first envisioned in 1989. Mission names before *New Horizons* included "Pluto 350," "Pluto Fast Flyby," Pluto Express," and "Pluto Kuiper Express" (Guo & Farquhar, 2002). The program was approved in 2001 under NASA's New Frontiers Program. The contract was awarded in January 2002 at a cost of less than $600 million (Bowman, Chacos, DeBoy, Furrow & Whittenburg, 2004). Target dates for launch were narrowed to January 2006 due to a combination of gravity assist potentials and an earlier arrival time (2015 vice 2020) at Pluto (Guo & Farquhar, 2002). Using a variety of previously developed sensors, the probe was completed and launched on time (Aviation Week, 2006).

Launch Vehicle

A Lockheed-Martin Atlas V 551 rocket provided first stage launch capabilities. This version of the Atlas V is the first to use five Aerojet solid rocket boosters (SRBs) and has a 2 g acceleration off the launch pad. The second stage was a Pratt & Whitney RL10 Centaur oxygen/hydrogen rocket. The third stage was an integrated Boeing/ATK Thiokol Delta II spin table and Star 48B solid rocket (Aviation Week, 2006). The spacecraft maneuvering package, used for course corrections and pointing, includes 16 hydrazine thrusters (APL, n.d.; Guo & Farquhar, 2002).

Electrical Power Supply

Like many of the recent deep space probes, *New Horizons* uses a radioisotope thermoelectric generator (RTG) as the main source of energy for its Electrical Power Supply (EPS) and distribution subsystems. While photo-voltaics and battery systems have shown great potential for missions closer to the Sun, solar energy availability will significantly diminish as the probe travels farther from Earth. For this reason, a mission to Pluto requires the longer lasting and consistently reliable power that can be produced using nuclear energy sources. Plutonium isotope 238 is used for the *New Horizons* RTG. Energy is generated using the natural radioactive decay to produce heat and, consequently, electricity (Jet Propulsion Laboratory [JPL]), n.d.). Used for the *Voyager* missions and other probes to Jupiter and Saturn, the RTG can easily power spacecraft EPS for many decades (National Aeronautics and Space Administration [NASA], 2005).

Despite a nearly flawless safety record, RTGs are surrounded by significant controversy during each launch. Even though no nuclear fission occurs, the association with nuclear energy has caused anti-nuclear public opposition against many deep space probes, including *New Horizons* (CNN, 2006). Interestingly, the public appears to be unaware about the difference between the nuclear reactions used for nuclear power plants and those used for an RTG. Most respondents who are questioned about whether RTGs are dangerous devices provide answers indicating they do not understand the concepts relating to this kind of energy. However, NASA Fact Sheets have been shown to alleviate these concerns (Coogan, 2007; NASA, 2005).

Payload Elements

Several payload elements have been incorporated in the *New Horizons* mission to ensure that the probe can study as much of Pluto, Charon and any KBO as possible. Mission planners also ensured that there are backups for all major electronics, navigation elements and data recorders. In fact, many of the payload elements are themselves backups for other sensors. Contained within the 1,054 pound (fuel included) spacecraft are the following seven science payload elements (APL, n.d.):

Ralph

Perhaps the most important sensor is the visible and infrared imager and spectrometer, called "Ralph" (APL, n.d.). It weighs 10.5 kilograms and requires 7.1 watts for operation. Ralph uses panchromatic and color imaging capabilities and can combine these with infrared (IR) imaging spectroscopy. Its main function is to map the surface of all planetary objects encountered by the spacecraft. Ralph uses a single telescope (with 75 millimeter aperture) and two focal planes: (1) the Multi-spectral Visible Imaging Camera (MVIC) and (2) the Linear Etalon Imaging Spectral Array (LEISA). MVIC (a visible and near IR imager with four filters) and LEISA (an IR imaging spectrograph) are designed to create maps of surface features and use color capabilities to show different elements (e.g., gasses). In the case of LEISA, the resolution of these images is expected to be ten kilometers (Reuter et al., 2006; APL, n.d.). Ralph is part of the Pluto Exploration Remote Sensing Investigation (PERSI) package (Guo & Farquhar, 2002).

Alice

New Horizons will use an ultraviolet (UV) imaging spectrometer (i.e. imaging spectrograph) called “Alice” for the study of Pluto’s atmosphere (APL, n.d.). This payload component weighs 4.4 kilograms and only requires 4.4 watts for operation. Alice is designed to survey the surfaces of Pluto, Charon and any Kuiper-Belt Objects using ultraviolet (UV) energy between 52 and 187 nanometers. From this evaluation, scientists hope to characterize the atomic composition of the atmosphere around these planetary bodies (Stern et al., 2005). Alice is part of the PERSI package (Guo & Farquhar, 2002).

REX

The Radio Science Experiment (REX) is part of the telecommunications system of the spacecraft and acts as a relay for all uplink and downlink signals. In this capacity, it does not act as a sensor. However, its other modes allow it to help to indirectly determine the atmospheric temperature and composition of Pluto’s atmosphere. When *New Horizons* passes Pluto and Charon, REX’s radio transmissions will be “bent” by the atmosphere of Pluto. This effect will provide information on the molecular weight of the elements in Pluto’s atmosphere (APL, n.d.). This sensor can also act as a thermal (i.e. passive) radiometer (Stern et al., 2005). In this capacity, also called a “radiometry mode,” REX will be able to measure the night-side temperature of Pluto (APL, n.d.).

LORRI

The Long Range Reconnaissance Imager (LORRI) works with Ralph and Alice to provide further visible light images of Pluto and Charon during *New Horizons'* extremely fast (13.77 kilometer per second) fly-by. It is capable of obtaining high-resolution monochrome images with low light conditions (Conard et al., 2005). LORRI uses a narrow angle (field of view 0.29 degrees) telescope with an 8.2 inch aperture (20.8 centimeter) to scan Pluto throughout the closest approach (APL, n.d.). Another important function of this sensor is to collect navigation images for use by mission controllers in course corrections (Conard et al., 2005; Miller, Stanbridge & Williams, 2004).

SWAP

The Solar Wind Analyzer around Pluto (SWAP) sensor is designed to analyze charged particles from the solar wind near Pluto and Charon. It will also provide scientists with information about Pluto's escaping atmosphere (APL, n.d.). This payload element can be characterized as plasma sensor. SWAP is part of the Plasma and high-energy particle spectrometer (PAM) suite (Guo & Farquhar, 2002).

PEPSSI

The Pluto Energetic Particle Spectrometer Science Investigation (PEPSSI) sensor will measure the density and composition of plasma escaping from Pluto's atmosphere. PEPSSI will also allow scientists to examine how these neutral atoms are affected (i.e. charged) by the solar wind (APL, n.d.). This payload element can be characterized as plasma sensor. PEPSSI is part of the PAM suite (Guo & Farquhar, 2002).

SDC

The Student Dust Counter (SDC) is designed to study the number and sizes of dust particles along the entire flight path of *New Horizons*. Scientists believe that some of this dust was shed by comets and KBOs and hope to learn more about their properties. Findings made with this sensor will be significant because the spacecraft is traveling in areas of space where no other probe has ever been. This sensor was primarily designed by students at the University of Colorado at Boulder (APL, n.d.).

CHAPTER III

LAUNCH AND OPERATIONS

Launch Services

New Horizons was launched from Pad 41 at Cape Canaveral Air Force Station in Florida on January 19, 2006. Atlas Control was responsible for providing launch services for the probe (APL, n.d.). The combined rocket packages described above provided 2.4 million pounds of thrust for *New Horizons*, ensuring it was the fastest man-made object ever to leave Earth's atmosphere. After 47 minutes of flight, the spacecraft had attained speeds of 10.07 miles per second (Aviation Week, 2006).

Trajectory

New Horizons' timing for launch was critical since its arrival at Pluto could be affected by months, or even years, if the launch windows were not properly utilized. With a well-designed launch platform, the speed required for the mission still mandated the use of a gravity assist maneuver. After evaluating several options (considering the potential benefits in fuel savings, payload size and arrival date at Pluto), the Jupiter gravity-assist (JGA) was chosen (Guo & Farquhar, 2002). An additional benefit of using the JGA maneuver is that it provided *New Horizons* with an opportunity to collect data and images of Jupiter and its moons. Not only was such information invaluable to the understanding of this planet, the JGA also gave NASA the opportunity to test all remote sensing equipment (APL, n.d.).

The probe successfully completed its gravity assist maneuver with Jupiter in February 2007. It actually passed closer to the planet than the *Cassini-Huygens* probe, providing scientists with significantly detailed images. Some of the important discoveries and evaluations included information about the “Little Red Spot,” closer detail of Jupiter’s “shepherd moons” and evidence of a new volcano (Reuters, 2007). Ironically, more data and images were collected near Jupiter than will be possible during the Pluto fly-by due to the difference in distances from Earth (Aviation Week, 2006).

In March 2007, *New Horizons* entered the “Interplanetary Cruise” phase of its mission. This period will last until June of 2015. During this phase, the probe will enter a modified hibernation state, used as an overall mission cost-savings measure. All spacecraft systems will be annually checked and trajectory changes can still be made during this hibernation mode (Bowman, Chacos, DeBoy, Furrow & Whittenburg, 2004; APL, n.d.)

Before *New Horizons* arrives in the Pluto-Charon system, the onboard sensors will be used to ensure the earliest possible detection of Pluto or Charon. MVIC and LORRI are designed to detect objects using their relative brightness. Mission controllers will gradually adjust the spacecraft’s trajectory to ensure closest approach by comparing this brightness to that of other heavenly bodies in the image. This will require significant and constant monitoring during the two years prior to arrive in the Pluto-Charon system (Miller, Stanbridge & Williams, 2004).

Five months before *New Horizons* reaches Pluto, observations will begin. Closest approach to Pluto will occur on July 14, 2015. The trajectory of the mission at this point (see above) should take the spacecraft in between Pluto and the orbit of Charon and then allow for remote sensing along the Pluto-Sun occultation. It will take more than nine months for all data from the Pluto fly-by to be transmitted to Earth (APL, n.d.).

The final phase of the mission is designed to allow *New Horizons* to explore the Kuiper-Belt. The spacecraft will most likely take more than five years to navigate this huge area of space. NASA hopes that there will be opportunities for at least one KBO to be closely studied. The closest approach sequence described for Pluto-Charon will be utilized each time the probe encounters a KBO (APL, n.d.).

Tracking and Commands

Important for effective communication with *New Horizons* is the relative attitude of the spacecraft in space. An advanced guidance and control (G&C) system was designed for the spacecraft. This system, coupled with an inertial measurement unit (IMU) and star tracker cameras, keeps the telescopes and antenna pointed in the appropriate directions. Maneuvering thrusters keep the antenna pointed at Earth when required (APL, n.d.).

NASA’s DSN will provide tracking services (APL, n.d.). This network is comprised of three separate locations on the planet, roughly 120 degrees of longitude apart (Peters, 2004). Using radiometric tracking data, DSN will be able to monitor the spacecraft’s trajectory. Range data can provide further details on the line-of-sight distance of *New Horizons* from Earth (Miller, Stanbridge & Williams, 2004).

The Science Operations Center (SOC) at JHU/APL is responsible for developing the precise commands that will be transmitted to *New Horizons*. These commands are tested thoroughly and then transmitted by the Mission Operations Center (MOC) to DSN, operated by the JPL, for transmission (APL, n.d.). X-band transmissions are sent through a digital receiver to the spacecraft (Haskins & Millard, 2004). The spacecraft receives all commands with its 83-inch diameter radio antenna (APL, n.d.)

As described above, one important phase of the mission involves a hibernation state for the spacecraft. During this time, the mission planners must be able to command *New Horizons* to ensure that it does not remain dormant indefinitely. A successful test was completed near the end of June 2007 (APL, n.d.). Tests of the “sleep-cycle” will continue through the mission. A series of eight beacon tones are used to transmit the probe’s status during the hibernation phases (Bowman, Chacos, DeBoy, Furrow & Whittenburg, 2004; APL, n.d.).

Data Collection

Even though most of the nine-year mission will involve long periods of inactivity, *New Horizons* has several important data collection opportunities. Throughout the trajectory, the SDC will collect and measure dust samples. During the JGA, all onboard sensors – especially Ralph, Alice and LORRI – will be tested and examined for their performance during data and image collection near Jupiter. After Pluto or Charon are identified by either MVIC or LORRI, the mission planners will determine the most feasible time for the rest of the sensors to begin data collection. Due to its extreme speed during the closest approach, there will actually be a very small window of opportunity for procuring high-resolution images. This will also be true of encounters with any KBO (APL, n.d.)

Data Transmission and Archiving

One problem with the extreme distances involved is the slow downlink rate that will exist, especially when the spacecraft passes Pluto (and beyond). It actually takes radio signals 4.5 hours to reach Earth from Pluto. And, while the downlink rate during the JGA will be 38 kilobytes per second, the rate near Pluto is only 300-600 bytes per second. At that rate, the entire data set from the Pluto-Charon closest approach would take nearly 40 consecutive days of downlink to complete the transfer. Since DSN capabilities cannot normally be monopolized in this fashion, the *New Horizons* mission team had to use a method involving compressed "browse" data. Some of the original data may be lost during this process, but it will give mission planners a better idea of what data needs to be downlinked later using a "losslessly compressed" method (APL, n.d.).

New Horizons will transmit all images and other data back to the DSN using its 83-inch antenna (APL, n.d.). Data is filtered through a highly sophisticated RF telecommunications system using the X-Band (Deboy et al., 2004). Data received by DSN will be sent to the APL for further use. The MOC is responsible for evaluating all data in order to monitor *New Horizons'* performance. Meanwhile, the SOC will convert the data from instrumental units (used by the spacecraft instruments) to scientific units using calibration keys created for each sensor (APL, n.d.). The *New Horizons* teams, especially the Mission Science Team (MST), will evaluate all data and eventually distribute it for scientific use through the Small Bodies Node of NASA's Planetary Data System (PDS). There are instrument teams for each of the onboard sensors. Consequently, all data will be archived into data set collections that correspond to each detector (Southwest Research Institute, 2005).

CHAPTER IV

CONCLUSIONS

Summary

New Horizons has already proven to be a probe with great potential. The launch window goal was met and the closest approach date will occur in mid 2015 – well before the originally predicted 2020 arrival. Sensors all proved effective during the JGA, providing NASA with significant opportunities for examination of Jupiter's moons and surface activity. Hibernation tests have thus far proceeded according to plan.

Future Outlook

During the nearly eight years remaining before the *New Horizons* spacecraft reaches its destination, scientists will hopefully have further opportunities to attain improved images of Pluto and Charon using telescopes in Earth orbit. Data obtained from each of the spacecraft's onboard sensors (especially Ralph, Alice and LORRI) will provide greater knowledge of the Solar System. Further areas of study will undoubtedly be identified. Further missions will most likely be discussed, but time and distance will continue to impact decisions concerning additional probes to Pluto.

Barring a catastrophe, the probe will succeed in becoming the first to take high-resolution images of Pluto, Charon and KBOs. Study of the Kuiper-Belt will provide more information about extinction level disasters caused by the so-called "cometary impactors." Solar wind and particle studies will allow scientists to further develop theories on deep space physics. *New Horizons* not only become the first visitor from Earth to Pluto, it will answer many of the important questions about the origins of the Universe.

CHAPTER V

RECOMMENDATIONS

Several areas for further research and exploration can easily be gleaned from the *New Horizons* mission. Images and data should be used to improve our planetary database. Technology used during the trip to Pluto should be evaluated and improved upon, ensuring that future missions can achieve even better results. Perhaps most importantly, the mission should open discussions into the possibility for further probes.

Prior to the spacecraft's arrival, NASA should attempt to use the Hubble Space Telescope (and further variations of orbiting telescopes) to learn as much as it can about the Pluto-Charon system. *New Horizons* will study Pluto and Charon during a significant transition stage for this system. This may be the last time observers from Earth will have the opportunity to collect such data. All possible corrections of *New Horizons* trajectory to ensure proper planetary intercept should be made to give probe the closest possible fly-by.

In July 2015, when data first becomes available from the *New Horizons* mission, the DSN should be utilized to the maximum extent possible to ensure that all available data is down-linked from the fly-by. Despite the slow bit rate and the corresponding required monopolization of DSN time, the loss of any data collected in this previously unexplored system could be disastrous. Additional employees should be contracted by APL and NASA, as required, to ensure maximum success for this program.

As with the *Voyager* probes and the Mars Rovers, *New Horizons* will most likely prove to have an exceptional transmitting life-span – possibly well beyond the mission requirements. This quality should be exploited to ensure that all available information is collected by the probe in this rare fly-by opportunity. *New Horizons* should be sent to as many KBOs as possible to ensure that its usefulness can be extended for as long as possible. If mission planners and operations staff continued to utilize the spacecraft as long as it is transmitting, even more spectacular discoveries could be made.

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