# NASA'S FIRST NEW MILLENNIUM DEEP-SPACE TECHNOLOGY VALIDATION FLIGHT

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Planned for launch in 1998, the first flight of NASA's New Millennium Program will validate selected breakthrough technologies required for future low-cost, low-mass space science missions. The principal objective is to validate these advanced technologies thoroughly enough that subsequent users may be confident of their performance, thus reducing the cost and risk of science missions in the 21st century. Although this flight will be driven by the requirements of the technology validation, it also will be an opportunity to conduct science during the cruise and encounters with an asteroid and comet. Advanced technologies selected for validation include solar electric propulsion, high power solar concentrator arrays, autonomous on-board operations including navigation, an integrated imaging spectrometer, and a variety of microelectronics and telecommunications devices. Where advanced 'technologies are not included in the design, low-cost, commercially available space hardware will be used.

## INTRODUCTION

NASA's vision of space and Earth science in the early years of the next century comprises frequent, affordable, exciting, scientifically compelling missions. Microspacecraft, small enough to be launched on low-cost launch vehicles, with highly focused objectives, will execute many of these missions.

The New Millennium Program (NMP) is designed to help enable these missions by developing and validating some of the key technologies they need.[1] With one to two launches per year starting in 1998, NMP will flight validate some of the high risk technologies that will help enable these missions. Background on the definition of the NMP mission set is given elsewhere.[2] Using dedicated deep-space and Earth-orbiting flights, the program combines advanced technologies needed to provide the capabilities of the future missions with current state-of-the-practice technologies. The spacecraft flown by NMP are not intended to be fully representative of the spacecraft to be flown in future missions, but the advanced technologies they incorporate are.

Although the objective of the NMP technology validation missions is to enable future science missions, the NMP missions are not science-driven. They are technology-driven missions, with the principal requirements coming from the needs of the advanced technologies that form the "payload." The missions will be high risk because, by their nature, they will incorporate unproven technologies that, in general, will not have functionally equivalent back-ups. Indeed, if an advanced technology does not pose a high risk, validation by NMP is not required.

The first flight of NMP will be a deep-space mission, currently known as DS1. It is being developed by JPL, in partnership with Spectrum Astro, Inc. Advanced technologies are provided by NMP's integrated product development teams (IPDTs), composed of representatives from NASA and other government agencies, industry, and universities. The IPDTs and details on the technologies, including those described in the following pages for DS1, are described elsewhere.[3,4,5,6]

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## DS 1 ADVANCED TECHNOLOGIES

Sixteen advanced technologies are under consideration for DS 1. These have been selected on the basis of how relevant they are to 21st-century science missions, how revolutionary they are, and how much the risk of their subsequent use is reduced by validating them in flight. In addition, more practical issues such as schedule, likelihood of funding, and compatibility with the basic DS 1 mission contributed to their selection. Each technology is a milestone on one of the technology roadmaps developed by the IPDT's.

Once the technologies are selected as DS 1 candidates, they are grouped into three categories according to how the mission depends on them. The primary purpose of including any technology is, of course, to validate it, but the functional capability some provide to DS 1 make them indispensable to this mission, while others are less critical.

- Category I technologies are essential to conducting the mission. Without them, the basic profile of the planned technology validation mission will require major redesign. If one of these technologies does not pass its readiness gates, thus leading to its removal from the flight, a significant change in the mission will result. As an example, the inclusion of solar electric propulsion as the primary propulsion system necessitates a low-thrust trajectory. If this technology is not included in the flight, it will require a fundamental redesign of the mission.

- Category II technologies provide a capability that, while critical for the mission, could be offered by an existing technology that does not require a new development. Thus, if one of these technologies fails to be ready for the flight, a substitute can be found that prevents the mission from undergoing a major redesign. Clearly some redesign will be necessary, but the capability lost with the removal of the advanced technology will not be irreplaceable.

- Category III technologies are not required for the execution of the mission, although they may be enhancing. If the technology is not ready for flight, its removal will not require the substitution of another technology to replace lost functionality; the mission can be conducted without the lost capability. These technologies will be critical for future science missions, but, in contrast to the Category I and II technologies, the functionality they provide will not be enabling for DS 1.

The DS 1 advanced technologies and their classification into the categories described, are listed in Table 1. Overviews of some of the technologies are given in the next section in the order in which they appear in the table.

| DS 1 Advanced Technology | Category |
|---|---|
| Solar electric propulsion | I |
| Solar concentrator array | I |
| Integrated camera/spectrometer | I |
| Integrated space physics package | III |
| Autonomous remote agent | II |
| Autonomous optical navigation | II |
| Small deep-space transponder | I |
| Composite high gain antenna | II |
| Beacon mode operations | III |
| 3D stack processor | II |
| Ka-band solid state power amplifier | III |
| Tiny exciter | III |
| Power high density interconnect | III |
| Power activation and switching module | III |
| Low power electronics | III |
| Multifunctional structure | III |

Table 1. DS 1 Advanced Technologies.

Each of these technologies must pass three future gates before final inclusion on DS 1 can be assured. A technology readiness review (TRR) will be conducted to assess the status of the development and the cost required to deliver it on time for integration. Plans for testing the technology on the ground and validating it in flight will be covered at the TRR as well. At the Key Technology Hardware/Software Demonstration, each technology will be required to demonstrate its performance to show that it is meeting its design objectives and is on schedule for providing the intended capability. Finally, a Subsystem Hardware/Software Demonstration will aid in establishing whether the technology performs as required and will be ready for delivery.

The success of DS 1 depends upon determining how well any of these technologies will work on future missions. If an advanced technology product fails on DS 1, even if it leads to the termination of the mission, as long as the failure can be diagnosed, the objective of validating the technology will be accomplished. If DS1 could prove that an advanced technology is not appropriate for future missions, that is a valuable result. This information would achieve the goal of reducing the cost and risk to candidate future users of the technology. Of course, it is likely that such a determination would lead to modifications to the implementation of the technology, thus restoring its potential value to future space science missions.

## TECHNOLOGY OVERVIEW

Overviews of some of the technologies that play key roles in DS 1 follow. The mission in which these technologies will be validated is discussed in the next section. Further details on all technologies are given in IPDT overviews[3,4,5,6] and specific references below.

### Solar electric propulsion

Solar electric propulsion (SEP) offers tremendous mass savings for future deep-space and Earth-orbiting missions with high $\Delta v$ requirements. The objective of the NSTAR (NASA SEP Technology Applications Readiness) program[7], to validate low-power ion propulsion, fits well with NMP's goals. The joint JPL/Lewis Research Center effort, which was started in November 1992, has been building and ground testing ion propulsion hardware in parallel with building flight hardware for DS 1.

The NSTAR-provided ion propulsion system (IPS) will use a hollow cathode to produce electrons to collisionally ionize xenon. The $Xe^+$ is electrostatically accelerated through a potential of 1280 V and emitted from the 30-cm thruster through a molybdenum grid. A separate electron beam is emitted to neutralize the main beam. The spacecraft provides up to 2.5 kW to the IPS power processing unit (PPU), and the peak thruster operating power is 2.31 kW. At this power, the thrust is about **90** mN. Throttling is achieved by balancing thruster and Xe feed system parameters at lower power levels, and at the lowest PPU input, 500” W, the thrust is about 20 mN. The specific impulse decreases from > 3300 s at peak power to about 2?,()() s at the minimum throttle level.

Because the purpose of flying NSTAR's IPS is to validate it for future flights, a diagnostic system will be included. This will aid in quantifying the interactions of the IPS with the remainder of the spacecraft, including science instruments, and validating models of those interactions. Measurements will include the rate and extent of contamination around the spacecraft from the $Xe^+$ plume and the sputtered Mo from the grid, electric and magnetic fields, and the density and energy of electrons and ions in the vicinity of the spacecraft.

### Solar concentrator array

Because of the high power needs of the IPS, DS1 needs a high power solar array. The Ballistic Missile Defense Organization, working with NASA's Lewis Research Center and AEC-Able, wants space validation of its Solar Concentrator Array with Linear Element Technology (SCARLET II)[8], so flying SCARLET on DS 1 is mutually beneficial. A 180-W SCARLET 1 array, using similar technology, was included on the METEOR commercial experiment platform, which was destroyed in a failed launch in October 1995.

SCARLET uses cylindrical Fresnel lenses to concentrate sunlight onto GaInP/GaAs/Ge cells arranged in strips with an expected average efficiency of at least 24%. By combining the lenses with a reflector below the cells, a total concentration ratio of 7.5:1 is achieved. With relatively small area actually covered by solar cells then, thicker cover glass becomes practical, thus greatly reducing the susceptibility to radiation. The pair of arrays will produce 2.6 kW at 1 AU at the beginning of life. Each array comprises four panels that are folded for launch, and a single-axis gimbal guarantees pointing in the more sensitive longitudinal axis.

### Integrated camera/spectrometer

Low-mass science instruments clearly are critical for future space science missions. One of the advanced technologies DS1 will validate is the Miniature Integrated Camera-Spectrometer (MICAS), conceived and developed by a team from the United States Geological Survey, SSG, Inc., the University of Arizona, and JPL in one 7-kg package, this derivative of the original concept for a Pluto Integrated Camera Spectrometer[9] includes two visible imaging channels, an ultraviolet imaging spectrometer, and an infrared imaging spectrometer plus all the thermal and electronic control. All sensors share a single 10-cm-diameter telescope. Two visible detectors, both operating between about 500” and

**1000** nm, are planned: a CCD and a CMOS active pixel sensor, which includes the timing and control electronics on the chip with the detector. With a field of view of 0.78°, each pixel will be 10 μrad. The imaging spectrometers operate in push-broom mode. The UV imaging spectrometer will span 80 to 185 nm with 1 nm spectral resolution. The IR will cover the range from 1300 to 2600 with 7 nm spectral resolution.

MICAS will serve three functions on DS 1. First, as with all the advanced technologies, tests of its performance will establish its applicability to future space science missions. Second, it will collect valuable science data during this mission at the asteroid and comet. Although science is not the primary goal of the mission, returning science data is an important part of the overall demonstration that all technologies are consistent with a mission that conducts science. Third, MICAS will be used to gather images for the on-board autonomous optical navigation system (see below). Indeed, the MICAS design originally intended for validation on DS 1 used an 8-bit analog to digital converter. To satisfy optical navigation requirements, the design was changed to 12-bits; this provides the important ancillary benefit of improving the performance so that a more useful instrument is validated and thus available to future users.

Integrated space-physics package

Future missions will require compact instruments for measurements other than the kinds made by MICAS. Using the same approach of integrating several different measurement capabilities into one low-mass package, the integrated space physics package will serve three functions on DS 1. It will validate the design for a suite of space physics instruments in one package.; it will assist in determining the effects of the IPS on spacecraft surfaces and instruments and the space environment, including interactions with the solar wind; and it will make scientifically interesting measurements during the cruise and the encounter with the comet (and possibly asteroid). Indeed, a key demonstration will be that space physics measurements can be made from a spacecraft operating with an ion propulsion system to assure future users that there are no incompatibilities.

The 3-kg package on DS 1, to be built by Southwest Research, inc.. and Los Alamos National Laboratory, will measure the energy spectrum of electrons and ions in the range of 1-30 keV and perform mass analysis on the ions. It also will determine the till.cc.-(l ir~~c. r~sior~:il plasma distribution over its $2.8\pi$ sr field of view. The instrument may include a microcalorimeter to help understand the plasma/sw-face interactions.

Small deep space transponder/Beacon mode operations

One of the telecommunications technologies DS 1 will validate is a small deep space transponder (SDST) under development by Motorola. In addition to its application to the. kinds of science missions NASA envisions for the 21st century, the use of the SDST is under consideration by missions with starts likely in the next few years. Because of its importance to these near-term missions, the SDST's development is shared by a consortium of programs and projects. Allowing X-band uplink and X-band and $K_a$-band clown link, the SDST combines the receiver, command detector, telemetry modulation, exciters, beacon tone generation (see below), and control functions into one package of about 2.8 kg. This unit supports both uplink and downlink radio science modes of operation, and it provides coherent and non-coherent operation for radio navigation purposes (in addition to basic communications). To achieve the same functionality without a new technology development would require about 6.6 kg. This compact, low-mass transponder is enabled by the use of advanced GaAs monolithic microwave integrated circuits, high density packaging techniques, and silicon ASICs. The SDST can collect analog telemetry signals from its own internal and external diagnostics, and it can support 1553, RS422 (using 1553 protocol), and 1773 interfaces.

The SDST generates the four tones needed for beacon mode operations. This Category III advance.d technology is designed to reduce the. tremendous load that would be expected on the Deep Space Network (DSN) if many missions were in flight simultaneously, as envisioned by NASA. in beacon mode, smart spacecraft will send one of four tones to small receivers on Earth to indicate to ground operations what action, if any, is necessary. The four tones correspond to the spacecraft not needing any assistance because all is well; informing the ground that the.re was a problem that the spacecraft resolved; alerting the ground that the space.craft has data that are ready to be transmitted, so a DSN pass should be

**scheduled;** and requesting assistance because the spacecraft has encountered a problem it was unable to solve.

### Autonomous remote agent

Because operations are a significant cost in NASA science missions, NASA explicitly included autonomy in its guidelines to NMP. The team developing the autonomous system is drawn from JPL, Amex Research Center, the USAF Phillips Laboratory, TRW, and elsewhere. DS 1 will validate not only a specific on-board autonomous operation capability, but, through careful design, it will represent an entire architectural approach that is expected to be applicable to a wide range of future science missions. The architecture is illustrated in Figure 1. The system incorporates a planning and scheduling engine which, by incorporating comprehensive knowledge of the spacecraft state, constraints on spacecraft operations, and the high-level goals provided by the ground, generates a set of time-based and event-based activities, known as tokens, that are delivered m the executive. The executive expands the tokens to a sequence of commands that are issued directly to the appropriate destination on the spacecraft. The executive monitors the response to these commands and reissues or modifies them if the response is not what was planned.

The design is flexible enough to handle a variety of unexpected situations onboard, and its access to a much more complete description of the spacecraft state. than would be available. to ground controllers in a traditional operations concept allows it to make better use of on-board resources. A failure detection, identification, and recovery engine. allows recovery or work -arounds in the. presence of faults without requiring help from the ground except in extraordinary cases.

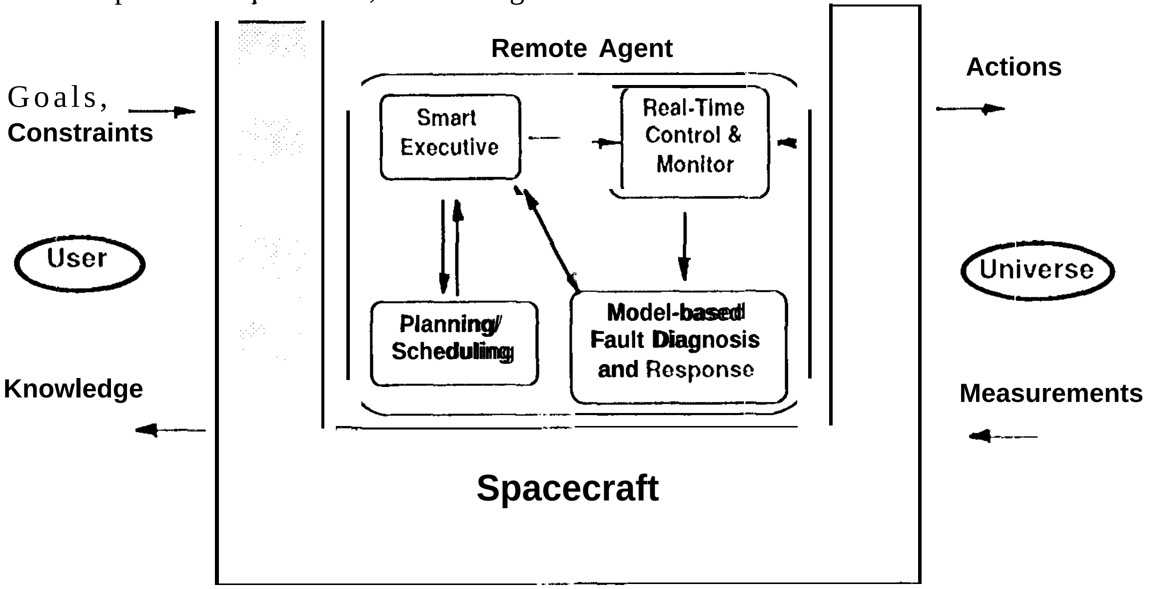

Figure 1. Remote. agent architecture. The concept of a remote agent is that instead of using remote. control (from Earth), there will be an agent of the. controllers located on the spat.cxrak '1 bus, the ground defines what the desired result is, and the onboard agent has the freedom to determine how and when to achieve it.

### Autonomous optical navigation

A significant reduction in requirements for DSN tracking of spacecraft will come from the placement of a complete navigation capability onboard the spacecraft.[10] The autonomous system to be validated on DS1 will navigate the spacecraft from shortly after injection through the encounters with the asteroid and comet using data already resident on the spacecraft or acquired and processed onboard. It determines when MICAS visible-channel images, each with a selected asteroid (certain to be visible from the spacecraft) and known background stars, need to be acquired and delivers its requests to the remote agent described above. The images will be collected along three to five lines of sight approximately every other day. Onboard image processing allows accurate. extraction of the apparent positions of the asteroids with respect to the stars. With asteroid ephemerides and star catalogs resident in the autonomous navigator, the spacecraft three-dimensional position is estimated.

The heliocentric orbit is computed with a sequence of these position determinations. The trajectory them is propagated to the encounter targets (an asteroid and comet), and course changes are generated by the maneuver design element. in general, those course changes will be implemented through changes in the IPS thrust profile, but in certain cases described below, the maneuvers may be achieved with the small chemical propulsion system.

Composite high gain antenna

The high gain antenna on DS 1 is to be a 1.5-m graphite-composite parabola provided by Boeing.[11] At only 2.9 kg, it is less than 30% the mass of a comparable aperture. cassegrain antenna used for the Mars Global Surveyor. The antenna incorporates a dual central feed for X-band and $K_a$-band operation, and it has the high surface accuracy required for the higher frequency. Achieving this high performance with low mass is crucial for missions of the 21st century.

3D stack processor

To reduce the packaging volume and mass of the electronics, DS 1 will validate three-dimensional stacked multichip modules (MCM). A processor MCM will have a RAD6000 processor fabricated with Loral's “51 .” rad-hard processing line and 2 MB of SRAM. Another MCM will use stacked DRAM die. to provide 160 MB of extended memory. At 45 MHz (approximately 50 RISC MIPS) with 160 MB of main memory, this will be the most capable rad-hard processor flown. The solid state recorder resides on another slice, with 192 MB of non-volatile flash memory and 64 MB of DRAM. A fourth MCM contains a bridge between the PCI bus used to communicate within the stack and the spacecraft's VME bus. A 1773 bus interface is also included in this interface MCM.

The four MCMs are mounted with some ancillary electronics on printed circuit boards which are then combined to form a "3D electronics stack." The stack is approximately 12 cm x 12 cm x 3 cm and is under 2. kg. For compatibility with DS 1 packaging, this stack is mounted on a VME board and resides in a VME card cage.

The validation of this unit on DS 1 is a result of a cooperation between NMP, the USAF Phillips Laboratory, and a number of industrial partners including Loral, TRW, Lockheed Martin, Boeing, and SCC.

MISSION

It was decided early in NMP that a complete validation of the technologies would require. flying them on missions that bore strong resemblance to science missions of the future. DS1's mission was focused on small bodies because of the great interest in exploring them in many future missions, the ease in reaching some for this validation fright, the desire to avoid overlap with other programs such as the ongoing set of Mars missions, and the interest in conducting a mission that NASA's principal customer (the US taxpayers) would find exciting. Because DS 1 is a technology-driven mission, formulation of candidate mission types was dependent upon some of the. technologies that were selected. The principal mission-driving technology is the ion propulsion system. In order to keep costs down, force the development of new management and design tools, and get results to users quickly, a launch between January and July 1998 was chosen.

Another constraint on the mission derives from the need to return results promptly to the future users. Except for tests of lifetime. most technologies could be evaluated on short missions as well as long ones, so it was decided that the primary mission should last no longer than about two years. This would allow sufficient time to conduct an exciting mission and to exercise the technologies under a wide range of conditions without forcing eager potential users to wait unreasonably long before being confident about the technologies. NASA has strongly supported a high risk mission for DS1 (and the other NMP missions), and it advocates a particularly bold and exciting extended mission.

Four mission types were identified: launch into Earth orbit, followed by a spiral out to escape (possibly using a lunar gravity assist) and eventual flyby of a near-Earth asteroid; a combination asteroid and comet flyby; an asteroid rendezvous; and an asteroid flyby followed by a comet rendezvous. The last mission would require that the comet rendezvous be conducted during the extended mission because of the long flight time. Examples of each mission type were developed and comparisons were elucidated for evaluation by NASA. The combined asteroid and comet flyby was selected.

The final mission has not been chosen yet, but candidate pairs of targets are under study. The selection of a specific mission will depend upon how well it suits the needs of those technologies that are dependent upon the encounters for their validation, the negotiated capabilities of the spacecraft, and the capability of an affordable. launch vehicle. Once those criteria are satisfied, the relative scientific interest of the targets is evaluated so that, m the extent that it does not interfere with the primary goals, as much science is extracted from the mission as possible.

The technologies that depend upon the encounters for their validation are MICAS and the encounter portion of the optical navigation. MICAS needs an extended source that is visible throughout its spectral range. The autonomous navigation system needs bodies that can be seen in enough time that the spacecraft propulsion allows sufficient control authority to enable the accurate delivery the system is designed to achieve. The candidate missions are being evaluated for how well each asteroid and comet combination satisfies the requirements of these technologies.

An example mission is shown in Figure 2. in this case, the launch date is 11 February 1998, although the low $C_3$'s for all of these missions and the great flexibility of the IPS allow launch opportunities of many months. This example is used to illustrate the kind of mission DS1 will fly and to provide. a context for describing some of the key activities during the mission. Other candidate missions will vary in the specific durations of different mission phases, but will be essentially the same from the perspective of overall technology validation and mission profile. Ground-based determination of the. injected state will be used to generate and optimize an updated low-thrust trajectory that will be transmitted to the spacecraft. Thereafter, all navigation will be accomplished exclusively by the onboard autonomous navigation system. After thrusting for 124 days, the IPS is turned off to allow the spacecraft to coast for 71 days. During the cruise, approximately every other day the spacecraft will turn to collect its optical navigation images. During times of IPS thrusting, this will require being off the thrust vector only for one to two hours; this is included in the trajectory calculations, which assume only an 85% duty cycle for the IPS thrusting. The remainder of the time off the thrust vector is allocated to one 6-hour pass per week for communications with the DSN, thrusting to correct errors trajectory accumulated during scheduled thrust times, and faults during which the spacecraft may not be able to thrust. The IPS thruster gimbal allows pointing of the thrust vector through the spacecraft center of mass, but the spacecraft attitude in two axes during IPS thrust is fixed by the need to achieve thrust in a particular direction.

Throughout the cruise, most of the technologies will exercised. Some simply will require regular activation and checks of their health. Others, such as the solar arrays and telecommunications technologies, will require spacecraft maneuvers to evaluate their performance under different Sun or Earth viewing angles and thermal conditions. The remote agent will be responsible for the planning and execution of these tests.

On 13 September 1998, the spacecraft will fly by asteroid 60531993 BW3 at about 18 km/s. This body is estimated to be 2.100 m in radius, and its spectral type has not been determined. In all missions under consideration, the deterministic thrust will be suspended from 10 days before closest approach (C/A) until 1 day after. This will allow more time for optical navigation images of the target before C/A and for validating MICAS. (MICAS is fixed on the spacecraft, so in general it cannot be pointed at the target while the IPS is thrusting in the needed direction.) It also allows more time for collecting science data. This hiatus is important because the accumulation of trajectory error from the small noise in the IPS thrust will be eliminated, thus allowing the navigation system to deliver the spacecraft to a flyby distance of about 50 km, with a likely error of less than 20 km. During the final approach, the navigation system will generate trajectory correction maneuver plans. If it determines that a maneuver needs to be executed for which the IPS does not provide enough control authority (approximately 10 m/s/day) or which requires the IPS to thrust in an attitude that is unacceptable (because, for example, it violates Sun pointing for MICAS or thermal constraints on the IPS power processing unit), it can request a small maneuver (-10 m/s) from the hydrazine attitude control system.

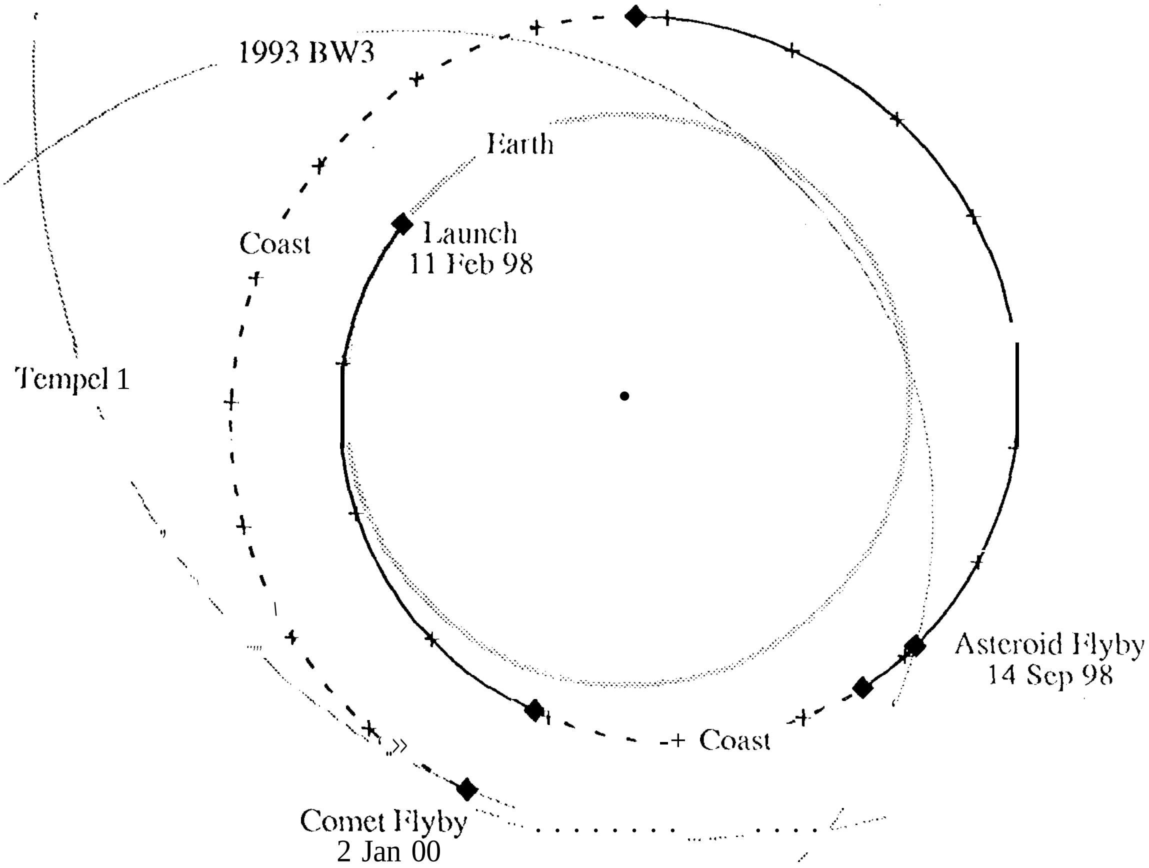

Figure 2. Example DS1 trajectory. The solid line shows when the IPS thrust is on. The tic marks are at 30-day **intervals.**

The asteroid encounter will allow an opportunity to gather science data on the size, shape, spin state, geomorphology, and the chemical composition of the surface material. It may also be possible to constrain the interaction of the body with the solar wind.

The deterministic thrust on this mission terminates **427 days** after launch. By then, the spacecraft will have used about 52 kg of Xe to provide a total velocity change of over 4 km/s. Shortly after the beginning of the new millennium, after 690 days of flight, the spacecraft encounters comet P/Tempel 1. The encounter occurs on 2 January 2000, just one month after the comet's perihelion. The flyby speed is about 8 km/s, and the navigation system will use images of the coma and finally the nucleus to calculate corrections to the trajectory for a close flyby. Science data at the comet that may be collected include the structure and composition Of the coma and tail, interaction with the solar wind, and the same kind of characterization of the nucleus as at the asteroid.

The primary mission ends with the completion of the comet encounter. Most mission candidates allow another encounter, usually with another asteroid, within 4 years of launch. In some cases, a comet encounter is possible, and a return to the Earth/moon may be possible. impacts with the small bodies may be attempted.

In addition, during the extended mission, extremely stressing tests may be conducted of the advanced technologies that are not reasonable during the primary mission. The operation of the. spacecraft that is under ground control may be turned over to students.

## SPACECRAFT

Clearly there are not enough advanced technologies to compose an entire spacecraft. Because the focus of DS 1 is on the validation of these technologies for future missions, not on building a complete spacecraft representative of those to be used in future science missions, the remainder of the spacecraft utilizes existing low-cost components. As part of the agreement with NASA that this will be a high risk, low-cost mission, the spacecraft is principally single string with Class B parts. Wherever possible, standard interfaces are used. The design is driven by the needs of the advanced technologies and the technology-driven mission.

The spacecraft structure is an aluminum space frame base. on the three Miniature Seeker '1'ethnology integration (MSTI) spacecraft built by Spectrum Astm for BMDO. With most of the components and boxes mounted on the exterior of the bus, their accessibility simplifies replacement during ATLO. Thermal control is accomplished with standard multilayer insulation, heaters, and radiators,

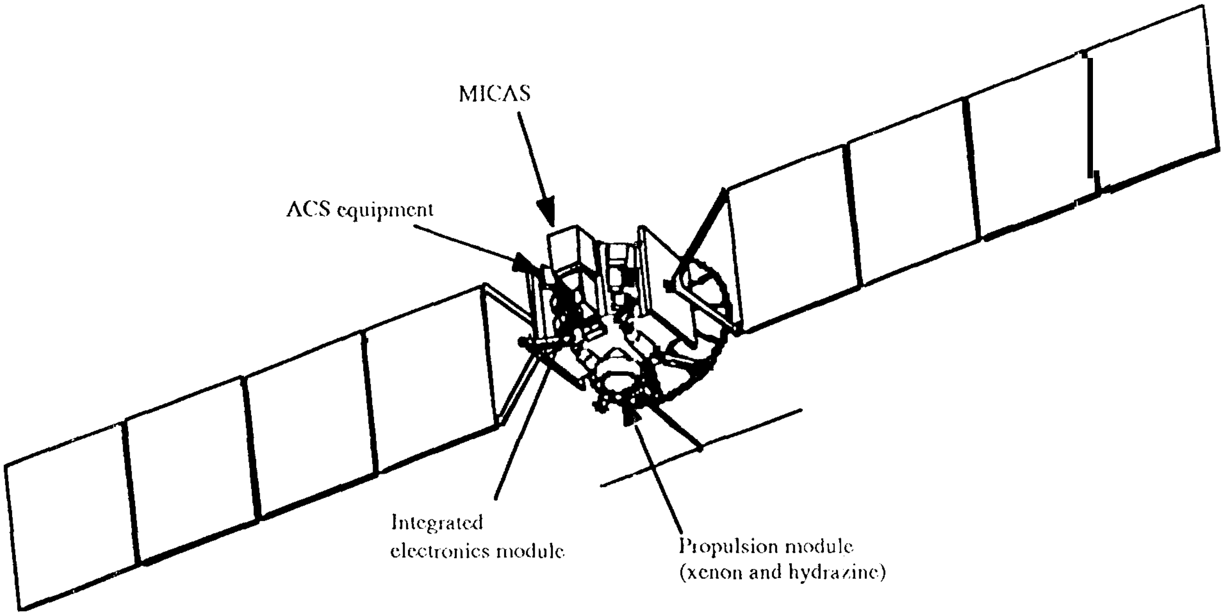

Figure 3. DS 1 in flight configuration.

Attitude control sensors include five Sun sensor heads distribute] to provide near] y 4π sr coverage; two inertial reference units, each sensitive in two axes; and one wide field of view star tracker. A hydrazine reaction control system provides three-axis stabilization.

Most of the electronics, including the advanced technology microelectronics, [illegible] enclosed in the integrated electronics module with a VME backplane.

The spacecraft is launched on an LMLV2-class launch vehicle with a Star 48 upper stage. The injected mass will be approximately 365 kg, including 50 kg of Xe and 20 kg of hydrazine. A view of the deployed spacecraft is in Figure 3.

## ACKNOWLEDGMENTS

The members of the DS 1 team, including the JPL and Spectrum Astro members of the flight team and the technologists, are gratefully acknowledged for their fine work in developing the material on which this overview is based.

Some of the research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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