

# Deep Space Systems Technology Program Future Deliveries

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## Abstract

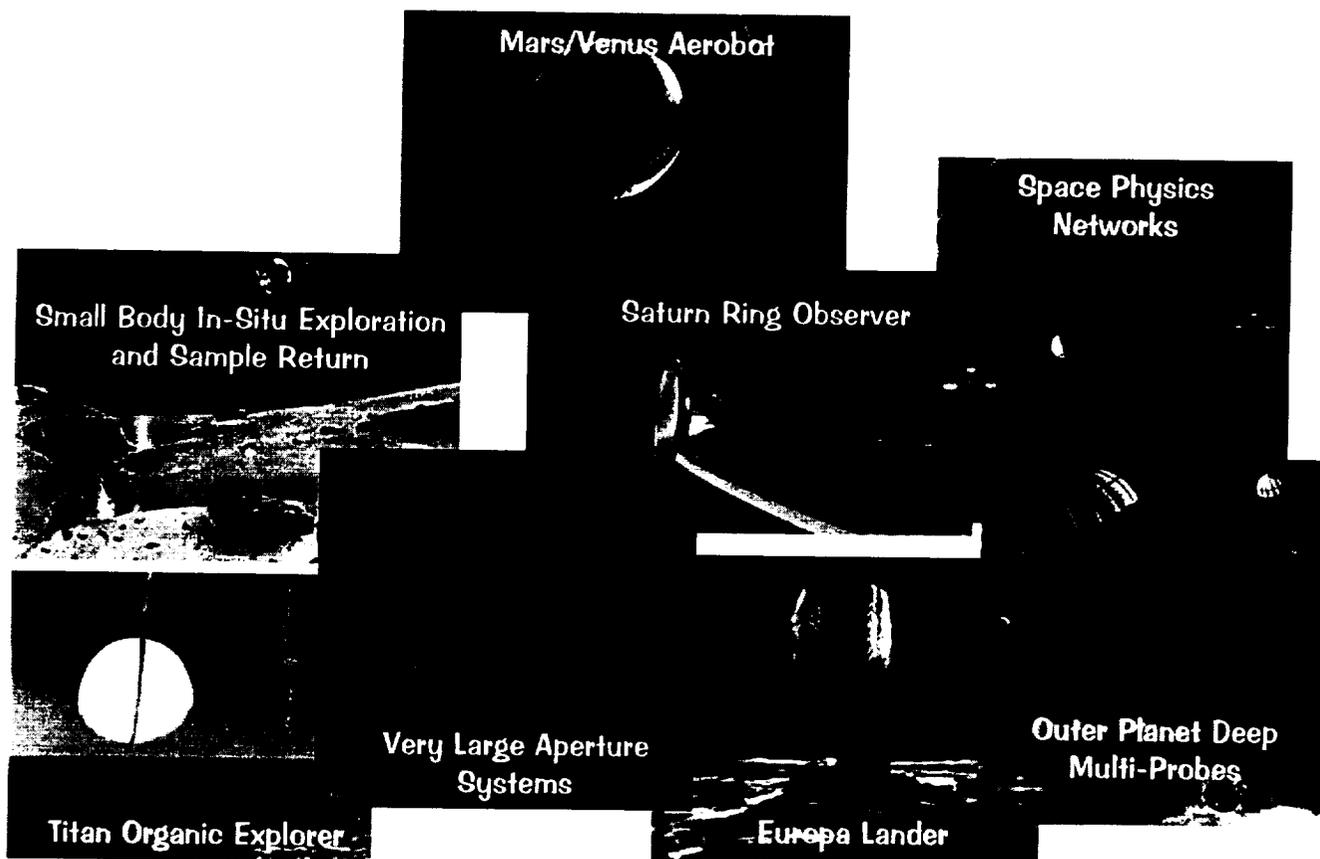
NASA is in a period of frequent launches of low cost deep space missions with challenging performance needs. The modest budgets of these missions make it impossible for each to develop its own technology, therefore, efficient and effective development and insertion of technology for these missions must be approached at a higher level than has been done in the past. The Deep Space Systems Technology Program (DSST), often referred to as X2000, has been formed to address this need. The program is divided into a series of "Deliveries" that develop and demonstrate a set of spacecraft system capabilities with broad applicability for use by multiple missions. The First Delivery Project, to be completed in 2001, will provide a one MRAD-tolerant flight computer, power switching electronics, efficient radioisotope power source, and a transponder with services at 8.4 GHz and 32 GHz bands. Plans call for a Second Delivery in late 2003 to enable complete deep space systems in the 10 to 50 kg class, and a Third Delivery built around Systems on a Chip (extreme levels of electronic and microsystems integration) around 2006. Formulation of Future Deliveries (past the First Delivery) is ongoing and includes plans for such developments as highly miniaturized digital/analog/power electronics, optical communications, multifunctional structures, miniature lightweight propulsion, advanced thermal control techniques, highly efficient radioisotope power sources, and a unified flight ground software architecture to support the needs of future highly intelligent space systems. All developments are targeted at broad applicability and reuse, and will be commercialized within the US.

## Introduction

NASA has entered an era of frequent low cost planetary science missions. Gone are the days of multi-billion dollar efforts launched at a rate of one or two per decade. The path to deep space is clearly to be marked by many planetary launches each year, with some projections reaching an average of one per month in the near future. In fact, for short bursts NASA has already reached that rate with the recent launches of Stardust, Mars Polar Lander, Mars Climate Orbiter, Deep Space 2 (Mars Microprobe), and Deep Space 1; five deep space missions in about a five month span starting in October, 1998. In addition to the increased frequency, there has been and will continue to be a dramatic reduction in cost for planetary missions. Mission costs now range from about three hundred million dollars all the way down to a few tens of millions.

Even as mission frequency is going up and costs are coming down, the performance requirements of missions are getting more ambitious. With the exception of the planet Pluto (which would be visited by the planned 2004 Pluto/Kuiper Express mission), all the planets have been encountered at least briefly by a robotic spacecraft. Some bodies have been visited many times. The types of exploration that must be done next require not simply flying by and snapping pictures, but observing many processes at many locations for long periods of time, exploring the atmospheres and under the surfaces of planets and other bodies, and analyzing in detail the rocks, gases, ices, and other materials that make up our solar system.

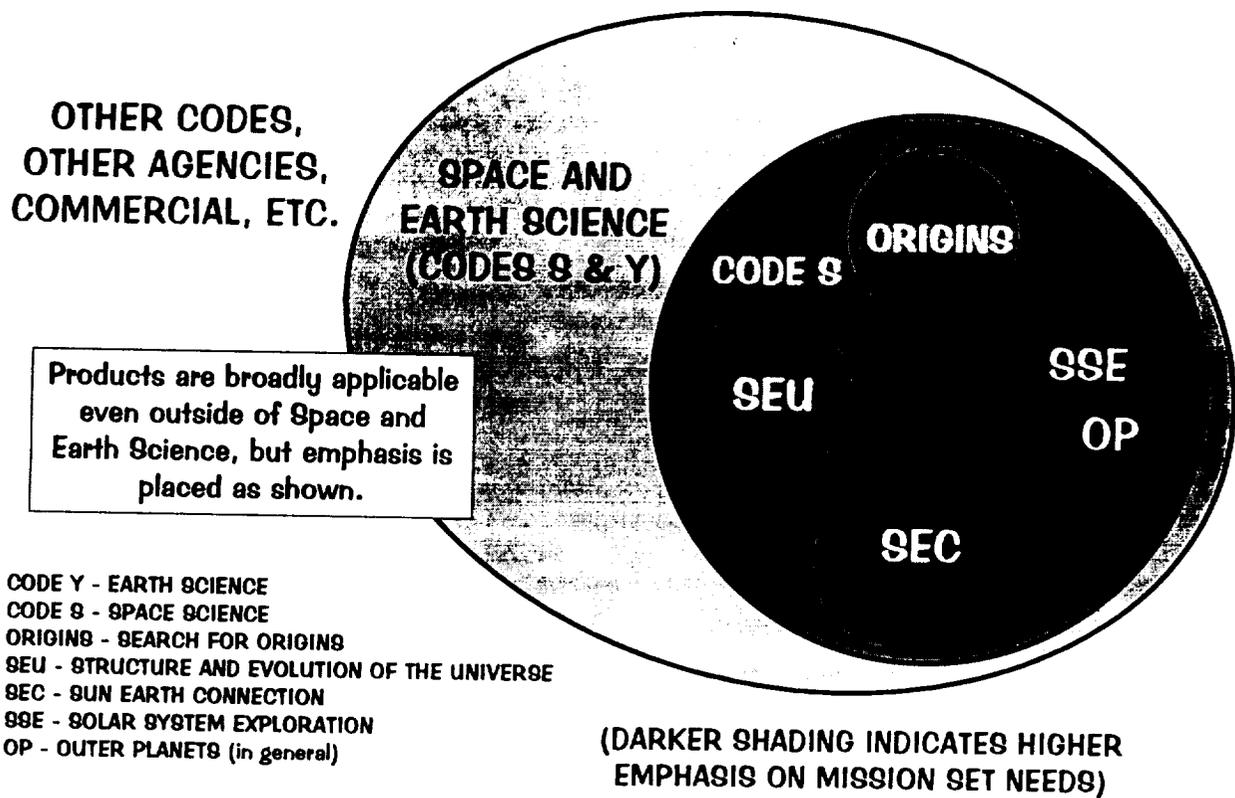
Figure 1 shows some missions that are envisioned for the future. These missions will use landers, rovers, and burrowing systems to dig into rocks, soil, and ice. There will be submarines to explore potential oceans on other planets and their moons. There will be aircraft and balloons on other planets to explore the atmospheres and cover great distances on the surfaces. Networks of tiny data-gathering stations will be scattered across, around and within the planets and other bodies, to perform long term monitoring. There will be systems which seek out interesting samples in the solar system and return them to Earth. There will be all of these things, as well as more capable orbiters for observing from space, and providing communications and navigation services.



**Figure 1. Some Envisioned Future Science Missions**

To meet the technology development needs of this wide range of modestly funded missions, there is a need for a broad-based, deep space focused technology development program. Historically, missions have assessed their needs for new technology, and if they required something that was not available, they reached into their own budgets to find the funds to bring innovations from the research laboratories into flight readiness. The large budgets and long development cycles of past missions allowed for this. The smaller, faster missions of today do not have sufficient time or dollars for technology development, yet they require advanced technology to meet mission objectives. Common capabilities that multiple missions can use must be developed centrally, and only slightly ahead of the user missions. While this has been attempted in the past with limited success, the larger number of missions in development at the same time makes it practical and efficient to do so now. The Deep Space Systems Technology (DSST) Program was formed in response to this need, and it is chartered to provide the necessary breakthroughs in spacecraft functionality, and spacecraft architecture to

enable these faster, better, cheaper missions of the future to succeed. As shown in Figure 2, the primary focus is on the Solar Systems Exploration science theme within NASA's Office of Space Science, but the program will strive to be as broadly applicable as possible and will surely provide useful developments for missions in other themes and outside of NASA.



**Figure 2. Mission Set Focus By NASA Organization**

Figure 3 presents the relationship among technology sources, flight demo programs, mission customers, and the two main parts of DSST (X2000). DSST has two main activities. The first is a technology planning, fusion, and development activity. This contains the long term formulation in the program and the ongoing development activities like Systems on a Chip (electronics integration and miniaturization), Revolutionary Computing Technologies (advanced computing techniques for the future), Advanced Radioisotope Power Source (more efficient, miniature radioisotope power sources), and Mission Data System (complete flight and ground software architecture for reuse and evolution of capabilities). Technology is advanced cooperatively with other providers (shown at the top of the figure) in other programs, other parts of NASA, other agencies, and in industry and academia. The other DSST element contains the delivery projects. Periodically (at about three year intervals), the state of technology development within the program and outside is evaluated against the needs of future missions, and a delivery of needed capabilities is formulated. This delivery is then managed like a flight project, and proceeds to deliver a suite of capabilities on a fixed schedule within a fixed budget. A delivery consists of a system demonstration on the ground in a relevant environment greatly reducing the risk of infusion of the technology into flight missions. If flight validation is needed on some of the technology products, other programs like New Millenium are chartered to

perform this, but most products will go directly to missions from DSST demonstration. All products are commercialized within the US so that mission customers can purchase them directly from industry suppliers.

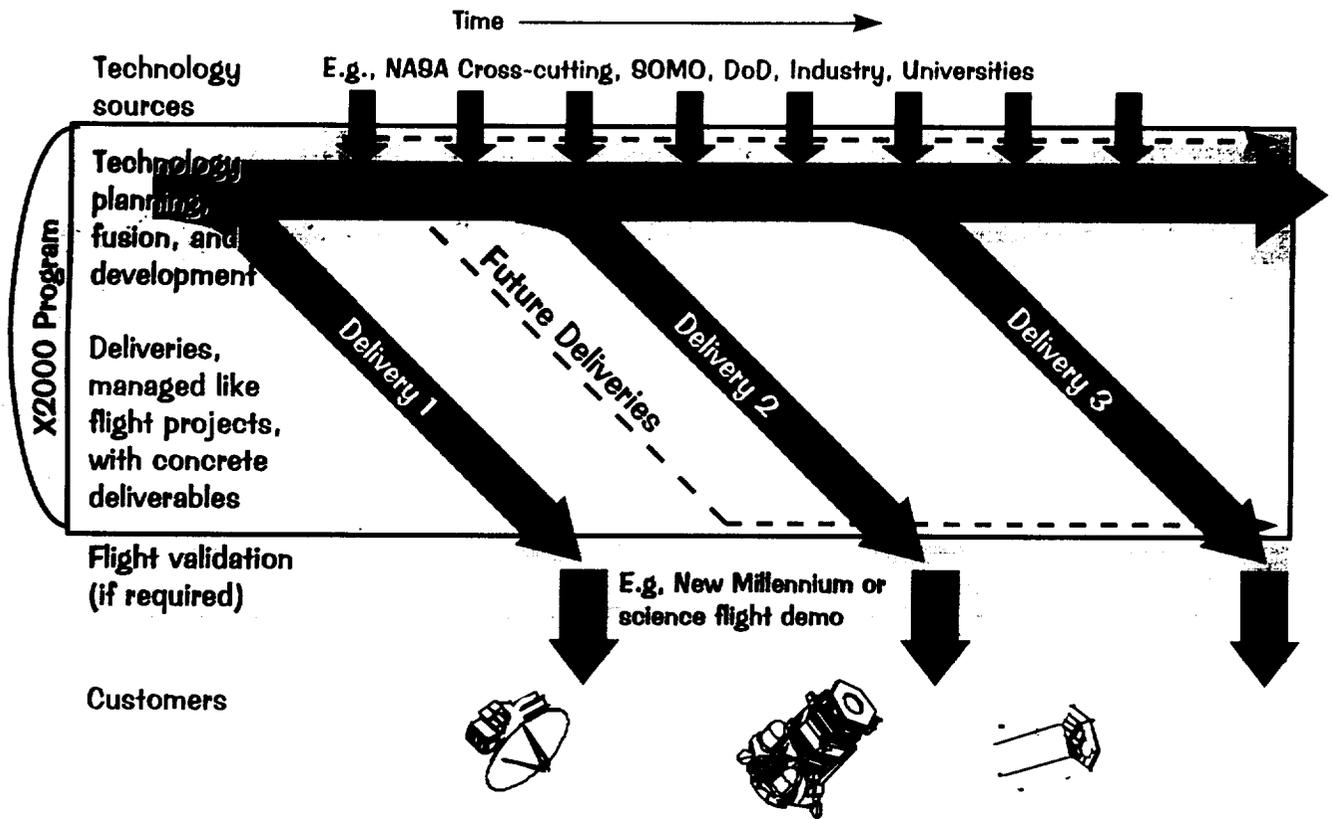


Figure 3. Supplier and Customer Relationship for DSST (X2000)

### Program Technology Focus

The driving themes in technology development for this program are based on cost. This translates to many things in turn. Systems are driven to lower mass due to constraints on launch vehicle capabilities, especially for missions with large propulsive needs. Large launch vehicles are expensive, and vehicles large enough to carry out some missions with current technology don't even exist. Power consumption must also be driven down and the efficiency of power sources improved to reduce the mass and expense of spacecraft power systems. Shorter development cycles contribute to cost reduction directly, and can be achieved through the use of such things as modularity, flexibility, and reuse of designs. Modular architectures reduce integration and test time. Flexible architectures that are reconfigurable to accommodate broad requirements reduce the necessary design analysis and improve the chances of recovering from unforeseen difficulties. Reuse of hardware and software reduces development times and contributes directly to lower cost by reducing non-recurring engineering. High performance computing reduces costs by allowing the use of layered software architectures and commercial off the shelf software components, both of which reduce design complexity and test time. Automation of functions in software is also enabled, allowing migration of functions from ground to space thus reducing operations cost. All of these things and other approaches which directly address the cost of building individual components guide the technology development of the program.

With these thoughts in mind, the program has formed technology paths in all the major spacecraft functional areas. Some areas have dedicated program elements which guide and coordinate efforts inside and outside the program for specific technical areas. The Center for Integrated Space Microsystems (CISM) is the element in the program that addresses many important areas of avionics and computing development with its Systems on a Chip, and Revolutionary Computing Technologies tasks. The Advanced Radioisotope Power Source (ARPS) element drives development of thermal-to-electric conversion technologies and system architectures for radioisotope power sources. The Mission Data System (MDS) element focuses on the advancement of flight/ground software system architectures. All of these activities are funded by the program and work across the spectrum of technology maturity to make key advances in these specific areas. The program also has plans to focus technologies from providers outside the program and infuse them into mission use through inclusion in delivery projects. This teamwork among research elements and delivery projects in the program and technology sources outside of the program (e.g. NASA's Cross Enterprise Technology Development Program, efforts in DARPA, Air Force, etc.) is essential to maximize the capabilities of products demonstrated by DSST within cost constraints.

In the area of avionics, the main drive is toward miniaturization and power reduction. This area will draw upon work in CISM (particularly Systems of a Chip) and move forward in two ways. First, the program will continue to take advantage of advances in smaller integrated circuit feature size and lower voltages to miniaturize and lower power consumption. Second, a push will be made toward combining functionality to achieve fewer nodes and extensive use of bus-based distributed architectures to reduce demands for point-to-point connections and associated cabling. Other microsystem developments include miniature solid state gyros and accelerometers and miniature imagers for star camera and wide angle imaging functions. Advances in the technology for rapid reliable integration of circuits and microsystems into systems on chips will result in very capable miniature systems that can be stamped out cheaply on integrated circuit fabrication lines. Scalable, distributed, miniature avionics systems will be used both to achieve complete spacecraft and other systems of unprecedented size (i.e. microspacecraft, nanospacecraft), and as distributed nodes of functionality throughout larger space systems. As the technology for miniaturization and chip thinning continues, avionics will be completely integrated into the structures and skins of other components.

In the area of propulsion, miniature valve work in DSST's First Delivery Project, lightweight tank work in the Mars Exploration Program, will be combined with other component miniaturization work internal to DSST's Future Deliveries. This will enable in the Delivery 2 time frame propulsion systems for attitude control and maneuvers consistent with the mass and power constraints of a microspacecraft. Deeper into the next decade, further dry mass reduction will be seen through component miniaturization and lightweight tank technologies, as well as MEMS-based (Micro-ElectroMechanical Systems) propulsion to meet the tiny thrust levels and impulse bits needed for microspacecraft systems or very fine pointing of larger systems. Other advanced propulsion concepts may also be explored based on the special needs of missions late in the next decade.

In telecommunications, activity will include development of devices for combined optical communications and narrow angle science imaging capabilities. The Delivery 2 product will be the first real deep space capable optical communications/imaging device. Integration into the spacecraft avionics of shorter range relay communications is also being pursued. Further advancement in these areas and others will follow later in the next decade. As in avionics, miniature, high performance telecommunications devices help to enable microspacecraft systems and contribute to increased functionality of larger systems.

In structures, efforts will focus on combining cabling, circuit cards, and structure to reduce total spacecraft mass and integration time for Delivery 2. Further advances in embedding functions and components within the structure are also envisioned, including batteries, power modules, and thermal control devices. Such multifunctional architectures are applicable to a diversity of space systems, large and small.

In thermal control the emphasis will be on flexibility. Technologies include miniature loop heat pipes which would move heat from one panel to another as needed without requiring detailed analyses in the design phase. Also part of this thermal energy management architecture is the use of electrochromic materials which can change their emissive properties electronically for active control of radiation to space. The large dynamic range of these two devices allows great flexibility in both spacecraft configuration and operations environment. In addition to enabling microspacecraft, thin electrochromic radiators could also be used for active surface thermal control of large space structures, allowing fine control of structural distortion due to temperature gradients. In the further future, miniature pumped fluid loop systems are envisioned that would allow complete thermal energy management. These systems would move thermal energy from sources to sinks, and to and from storage reservoirs as needed to minimize heater power demands and maximize flexibility.

In power there is an ongoing Advanced Radioisotope Power Source (ARPS) activity that will build on current work in the Delivery 1 time frame to produce the next generations of power sources for the Delivery 3 time frame. Reduction of the amount of radioisotope material is the main driver due to its cost. Increasing the efficiency of the thermal to electric conversion reduces the amount of radioisotope needed, and as a result reduces cost and mass. Highly efficient power sources of different output levels (50W, 10W, 1W, even milliwatt levels) are being pursued using such conversion technologies as Alkali Metal Thermal to Electric Conversion (AMTEC), and thermionics. These lower power levels will expand the suite of available power sources for use with smaller systems in environments that make other power sources impractical.

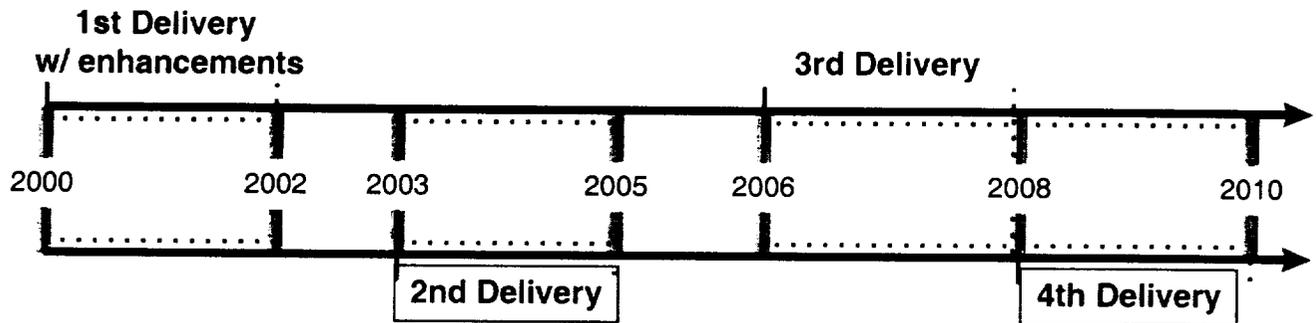
In software, the Mission Data System (MDS) element of the program will continue to develop a unified flight/ground software system architecture that is increasingly reusable and integrates capabilities for the use of higher levels of autonomy in the future. It will draw heavily on commercial capabilities, especially at lower layers like the operating system and in development tools and code generators. Delivery 2 will demonstrate reuse and broad applicability by using the MDS product from Delivery 1 with minimal modification, and will add selected new capabilities consistent with the Delivery 2 hardware. Additional functionality will be pursued as the MDS technology development continues, including increased autonomy and other new applications modules. MDS will be applicable to a broad set of space systems.

## **Program Schedule and Budget**

Figure 4 shows a high level timeline for the program. Major deliveries occur on 4 to 6 year centers and represent revolutions in spacecraft capabilities across system metrics of mass, volume, power, cost, and performance. Delivery 1 around 2001 is the first major delivery and is currently a fully funded project in the implementation phase. Delivery 3 will be the next major delivery in about 2006. Plans for Delivery 3 are currently limited to technology planning and development. Delivery 2 is in the early stages of formulation and may be considered a developmental step towards Delivery 3. Many of the technologies envisioned for Delivery 3 will be brought to some intermediate level of maturity and turned into products for Delivery 2.

The First Delivery Project is of about the same funding magnitude as a Discovery class mission, and Delivery 3 will be a little larger. Delivery 2 is a much more modestly funded effort with

a current allocation of approximately one-quarter of Delivery 1. These budgets are through system demonstration of delivery hardware and software in ground test. They do not include subsequent flight buys by mission customers, nor do they include the advanced technology development performed in the other elements of the program (CISM, ARPS, MDS) or by other technology providers or partners.



**Figure 4. Program Timeline**

The schedule for Delivery 2 is shown in more detail in Figure 5. It is currently in an early formulation phase, and has not yet been designated a project. Activities in FY99 include technology seed efforts in several key areas (microgyro characterization, laser transmitter evaluation, laser communications acquisition and tracking breadboard, micro pressure regulator development, zero debris isolation valve evaluation, multifunctional structures evaluation, and thermal control technologies evaluation). FY99 is also focussed on definition of the Delivery 2 system and implementation planning. In FY00 the effort is expected to form into a recognized project and continue with key technology work and more detailed definition and implementation planning. Around mid year FY00 a mission partner would be selected. This would ideally be a technology demonstration mission of some sort which would provide detailed requirements for Delivery 2 and make direct use of the delivered system. Further work would lead into a Preliminary Design Review early in FY01. The next 3 years would be characterized by design, build, and test, respectively, resulting in a completed Delivery 2 late in the calendar year 2003.

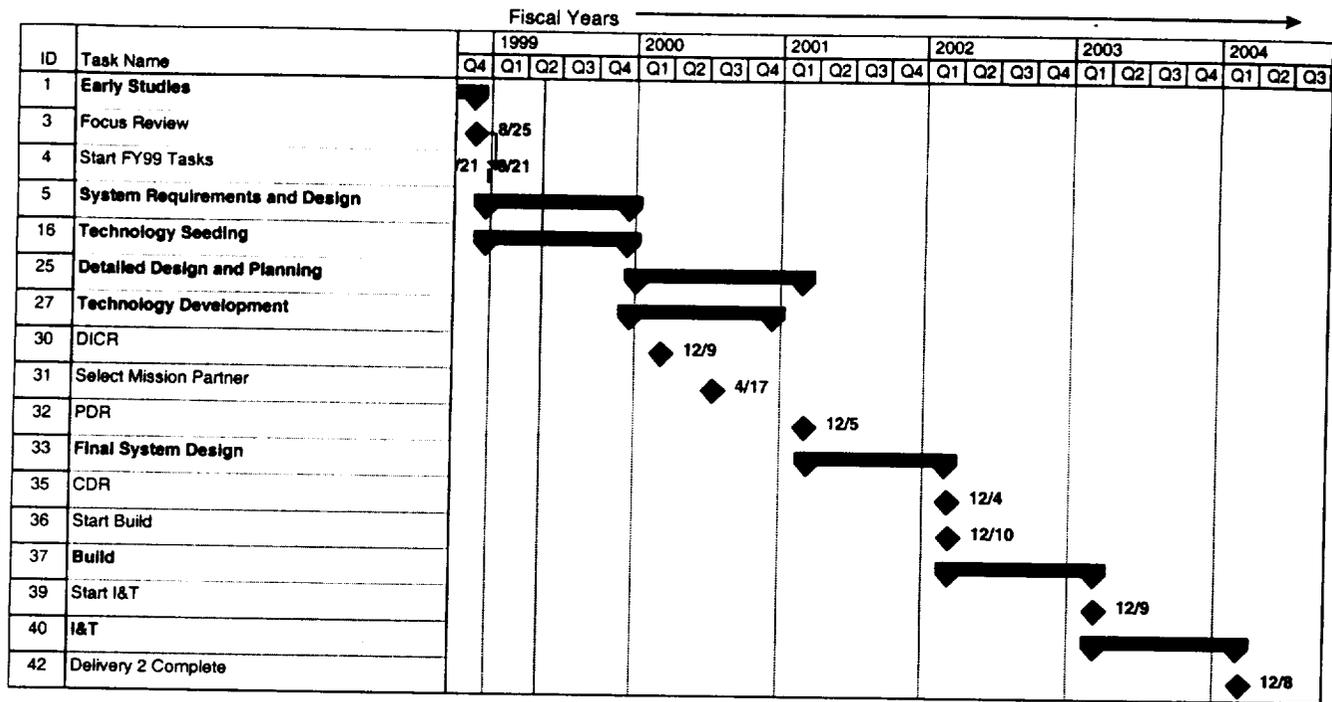


Figure 5. High Level Schedule for Delivery 2

### Delivery 2 Overview

As stated earlier, the two main goals of the DSST program are to advance technology, and to create common, multi-use systems for deep space missions. Fortunately, these two objectives can often aid one another. That is to say, high performance can often compensate for the inherent inefficiencies of multi-use systems. Technology has produced incredibly light, fast, and low power electronics, light-weight composite structures, new ways of communicating from the depths of space, and so on and so forth. Has this solved the inherent mass and power inefficiencies of multi-use systems? No, but they are much *smaller!* This is particularly important to the deep space exploration community given the traditionally tight resource margins of a deep space mission.

The First Delivery of DSST is the crucial first step where key systems are being developed for use in what could be termed 'flag-ship' missions – mainline science platforms designed to collect vast and detailed amounts of data. The Third Delivery will again be a development of this type, but will seek unparalleled levels of integration to achieve extraordinarily low masses and powers in combination with exceptional performance. Poised between these two grand-scale efforts, and a critical link in the development path, is the Second Delivery.

### Design Objectives:

Now more so than ever there are missions that either by design or necessity are aiming for more focused goals. In other cases, the tasks traditionally allocated to a large spacecraft might be performed by swarms of smaller ones. In both of these cases, and in many others, the need for small or *micro* systems has manifested itself. It is addressing this need while making advances along the path to 3<sup>rd</sup> Delivery that has become the system focus of Delivery 2. In addition to addressing the

specific needs of microspacecraft systems, several 'universal' objectives must also be considered. The following list comprises the high level guidelines for Delivery 2.

- 1) **The delivery shall enable deep space microspacecraft in the 10 to 50 kilogram class.** This also serves as the definition for a micro-class spacecraft for the purposes of this paper. In some cases, this definition may exclude certain subsystems, such as propulsion in the case of missions with large delta-V requirements.
- 2) **The design shall incorporate new, innovative, and exciting technologies.**
- 3) **The system shall use, and where possible advance, the developments of DSST First Delivery.** For example, in the area of Avionics, First Delivery is taking the first step of integrating high performance into a package that is lighter, more RAD hard, and that uses less power than anything else available. It is essential for future deliveries to build upon this work. However, First Delivery has been driven to focus on achieving both high performance *and* low mass and power. In 2<sup>nd</sup> Delivery's case, a further increase in performance is not the primary focus. Rather, it will be our focus to achieve significantly lower mass and power while at least maintaining the performance achieved by First Delivery.
- 4) **The system, and parts thereof, must be broadly applicable.** This means 2nd Delivery should be able to satisfy in whole or in part and with little or no modification the needs of most future deep space missions of the micro-class. This whether they be space, ground, or air, or from Venus to the Main Belt Asteroids.
- 5) **The system shall be modular.** This is actually a subset of the broad applicability objective. It is of importance not only in allowing potential mission customers to create semi-custom configurations of the full system delivery, but also in allowing use of individual subsystem deliveries separate from the others. This would be key to certain mission types where some subsystems may be considered unnecessary.
- 6) **The performance of the spacecraft shall be scaleable.** To ensure broad applicability the most stringent anticipated requirements must often be met. This means that for most customer missions the system would tend to "over-perform." Scalability is necessary so that any detrimental side effects of over-performance can be avoided, or so that savings in other resources resulting from "scaled-down" performance can be realized.
- 7) **Where practical, instrument functions shall be designed coexistent with engineering functions.** A key aspect of the development paths for many technologies seems to be greater and greater levels of integration. With the potential for considerable mass savings and the ever-growing need for micro-systems to fit into smaller packages, integrated instrumentation should not be left unconsidered.

#### *Design Approach:*

The design approach comprises two major efforts. The first is requirement definition; the second is the formulation of a representative design case.

*Requirement definition* is complicated due to the fact that there is not just one set of customer specifications to design to. In fact, at the early stages of design, real customers (approved missions) are lacking period. While this is beneficial from the aspect that it leaves the freedom to be innovative,

it also leaves no solid guidelines, and presents the danger that the resulting design may be something that no one will want to use. The approach to avoid this is three fold.

First the objectives that I have already enumerated were documented as the project's high level requirements. These are the words the design team lives by.

Second, for what would normally be termed lower level requirements, a "Capabilities Catalog" is being created. This document lists the various performance characteristics of the system such as processor speed, transmit data rate, imaging resolution, etc. The term capabilities is used to emphasize that the team's intention at the outset is to probe the limits of what can be achieved; that is, exploring capabilities not setting requirements. The main purpose is to give potential missions an idea of what 2<sup>nd</sup> Delivery can provide them – advertisement if you will. Eventually, once the project settles upon a firm design, or enters into an agreement with a customer mission, these capabilities will develop into third and fourth level requirements.

Finally, a survey of mission requirements from future deep space missions is being compiled. This has drawn mostly from missions lying within the Solar System Exploration science theme of NASA, but also includes missions from the Sun-Earth Connection science theme. In addition, the team is working with other NASA system development programs, such as rovers or aerobots, to capture their requirements. The purpose of this compilation of 'user' requirements is to compare with 2<sup>nd</sup> Delivery's internal requirements and capabilities and ensure their relevance to prospective customer missions.

The second part of the design approach involves the creation of a *representative design point*. Design coherency is difficult to achieve without a system/mission context to focus requirements. The approach in this early phase of Delivery 2 is to devise a generic mission for this purpose. To be effective it has to be something that taxes all the spacecraft functional areas, and is free of special concerns (severe environments, unusually long life, etc.). Also, the representative design and its hypothetical mission has to represent not only a potential but *probable* usage of the Second Delivery system. That is, the representative case needs to reflect real demand in the deep space community.

### *Representative Design:*

As a result, an orbiter/fly-by based system has been chosen as our representative design. The hypothetical mission assigned to the representative design, in order to give it form, is that of an orbiter around Mars. This represents a feasible future mission, which also lacks any unique constraints; thus a perfect design point for the purpose of designing a generic, broadly applicable system.

A quick look at the likely missions in the 2004-2006 time frame indicated additional systems that may find use for the products of 2<sup>nd</sup> Delivery, and that is being kept in mind. Activities are ongoing to assess the impact on these systems of Delivery 2 developments. Brief descriptions of the most notable of these systems follow:

- Orbiter/fly-by systems: These have been the mainstay of space exploration in the past and will be with us in the future. The potential destinations of such systems are incalculable. A few examples include Mars, Venus, near earth asteroids, comets, etc. Their purpose can vary from imaging platform to relay communications link between earth and other planetary assets (e.g., Mars).
- Planetary Aerobots: This relatively new concept (for the deep space community) allows for intimate study of a target body. By descending to low altitude, aerobots can produce images of the surface with much greater resolution than orbital platforms. In addition, their continual immersion in the atmosphere of the target body can allow numerous chemistry and weather

experiments. Principal targets for aerobots in the near term include Venus and Mars. In the far term, concepts exist for Titan and outer planet aerobots.

- **Planetary Rovers:** Made famous by the recent Mars Pathfinder mission, these systems are currently integral parts of numerous planned missions to Mars and near earth asteroids.
- **Daughter Spacecraft:** This is defined for purposes of this paper as a spacecraft accompanying a larger spacecraft to its science target for the purpose of performing either a supplemental or wholly separate mission from that of the 'mother craft'. Many concepts of this type have been bred with the hope of defraying the enormous launch costs typically associated with deep space missions.

*Design Characteristics:*

The resulting design has a mass of 32kg (see Table 1). The power consumption of some components is still being determined. As a result, a precise estimate cannot be given for power at this time. In addition, power profiles are very mission specific. However, it is estimated that the average power for the operational phases of most missions using our system will fall within the range 20-50W.

Characteristics of the constituent subsystems are as follows:

- **Avionics:** This includes a flight computer with peak performance at between 100 & 150 MIPS, mass memory of about 10 Gigabits, a distributed data & power bus architecture, micro-IMU, and an advanced miniaturized star tracker. This subsystem relies on high levels of integration to achieve its mass and power objectives.
- **Optical Communications:** This technology promises to greatly increase the transmit data rates of deep space missions. Second Delivery plans to serve as the first deep space demonstration for this system, and the current design incorporates a laser terminal with a 10-cm aperture. At 14W input the communications engineer expects such a system to achieve 40kbps or better from a range of 2 A.U. using a ground based 10-m optical receiver.
- **Propulsion:** The propulsion system uses a hot gas concept, which operates by running Helium with trace amounts of Hydrogen and Oxygen over a catalyst. The result is hot Helium as exhaust and a performance rivaling Hydrazine. In addition, this design incorporates a micro-regulator development. This system will provide 200m/s delta-V and all necessary attitude control impulse.
- **Structures:** This design uses bonded composite, multi-functional panels of a standard design in order to significantly reduce mass and cost.

**Table 1. System Mass Accounting**

<b>Subsystem Masses</b>	<b>(kg)</b>
<b>Instruments</b>	<b>2.0</b>
<b>ADACS</b>	<b>0.6</b>
<b>C&amp;DH</b>	<b>2.1</b>
<b>Power</b>	<b>2.5</b>
<b>Propulsion</b>	<b>6.0</b>
<b>Structures</b>	<b>5.8</b>
<b>Telecommunications</b>	<b>4.0</b>
<b>Thermal</b>	<b>0.6</b>
<b>Spacecraft-Dry w/o Instr.:</b>	<b>21.6</b>
<b>Instruments:</b>	<b>2.0</b>
<b>Contingency: (30%)</b>	<b>7.1</b>
<b>Propellant (Helium/H2+O2)</b>	<b>2.1</b>
<b>Total:</b>	<b>32.8</b>

- **Thermal:** This design is taking the first steps toward a flexible thermal management system through use of loop heat pipes and variable emissivity radiator technologies. This should allow a wide range of thermal environments to be endured as well as provide tremendous flexibility in spacecraft configuration.
- **Instrument Multi-functionality:** In addition to a 2kg allocation (for which the project has not specified instruments) there are two multifunctional instruments in the current design. The first is a narrow field imager designed to share the optics of the optical communications terminal. This combined system also has the capability of performing optical navigation. The second is a wide field imager designed to share the star camera's optics.

### *Benefits to Other Systems:*

The final step in this discussion is to revisit the potential systems described earlier, and see how well the representative design case formulated serves them. In general it appears that all of the systems previously discussed will find useful developments from a 2<sup>nd</sup> delivery design based on the representative case described.

As a matter of course the orbiter/flyby systems will be addressed – that is, the design is an orbiter design, and it is thus the expectation of the project that the whole of the development will be applicable to an orbiter/flyby mission. Due to the similarities between the two systems, daughter spacecraft would be served in a similar fashion.

The greatest benefits to aerobots and rover systems will likely come from the avionics, structural, and thermal developments. It is possible that optical communications could be of use as well – particularly if an optical relay capability was developed. Technologies from the propulsion developments may also find use in aerobot systems for inflation, and attitude control.

### **Delivery 3 and Beyond**

Details of Delivery 3 are difficult to specify, but it will bring together all of the technology areas to demonstrate spacecraft performance and miniaturization that will revolutionize planetary exploration. It will be driven by the mission set that is selected for late next decade which will most certainly contain very demanding missions. The work in the CISM element in Systems on a Chip will be a cornerstone, providing high performance avionics in a small, low power package. New power sources from the ARPS element will almost certainly be required for some future missions to outer planets, and will be included in Delivery 3. The next generation of highly reusable software will be included from the MDS, and it will include levels of performance and autonomy never before seen. In addition to these areas, further development of propulsion, telecommunications, structures, and thermal technologies will be pursued building on the success of Delivery 2. Advances from CISM's Revolutionary Computing Technologies may also begin to find their way into deliveries in Delivery 3 time frame. Deliveries beyond the Third are even more difficult to specify, but the program will continue to address the common needs of deep space systems at about \$75M each year through at least the end of the next decade. One can only imagine what can be achieved in this time frame.

### **Summary**

The Deep Space Systems Technology Program has been formed to provide multi-use technology development for future deep space missions. The program produces system

demonstrations of ripe technologies to bridge the gap between technology development and flight, and it has long term development plans across all the major spacecraft functional areas. Future demonstrations are in an early formulation phase. The Future Deliveries team is currently engaged in key technology seed activities, technology roadmap tasks, and implementation planning for Deliveries 2 and 3. Delivery 2 will make advancements toward the more long term objectives of Delivery 3, while also producing products that near term mission customers can use. Planning and seed tasks for deliverables in avionics, attitude sensors, optical communications, micropropulsion, multi-functional lightweight structures, advanced thermal control, and flight/ground software are underway for the Delivery 2 (2003) time frame. In the Delivery 3 (2006) time frame, further advances in all of these areas are planned, plus the next generation of advanced radioisotope power sources, and revolutionary computing technologies. The Program is planned to continue indefinitely at \$75 M per year, with deliveries about every 3 years. For up to date information, visit the Deep Space Systems web site frequently, at <http://dsst.jpl.nasa.gov>.

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