National Aeronautics and Space Administration

NASA Case Study

GSFC-1032C-2
Rev. 04/14/10

The DART Mission: Hard Decisions in a Changing Environment

Attempting to Forge the Future of Space Exploration

Many space missions depend on the rendezvous of different space capsules with each other. The first such technology had been tested as far back as Gemini, NASA's second manned space-flight program, in the 1960s. It later played a central role in the Apollo moon missions, enabling the lunar module to dock with the command surface module. In all these missions, rendezvous between spacecraft had been performed by astronauts.

By the 21st century, however, NASA envisioned technology using only computers and sensors to guide the approach and link-up among objects. This envisioned a new era of space exploration, and DART, for Demonstration of Autonomous Rendezvous Technology, emerged as the standard bearer. The DART spacecraft, six feet long and three feet in diameter, would be propelled into orbit on a Pegasus rocket, culminating years of development of rendezvous technology.

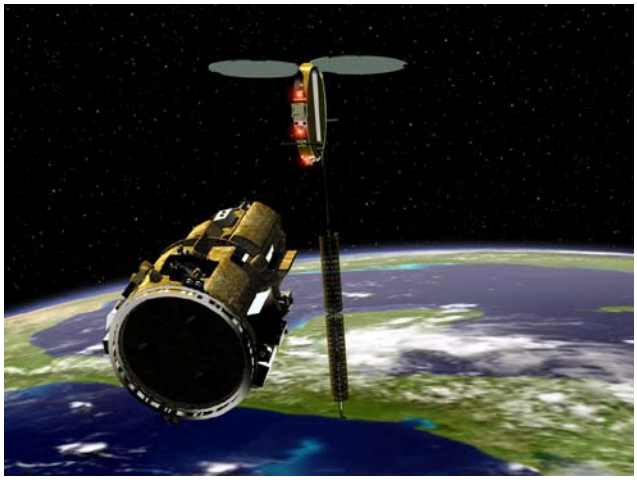

Figure 1: An artist's conception of the DART spacecraft as it approaches the MUltiple-path, Beyond Line-of-site COMmunications (MUBLCOM) satellite.

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DART's genesis was rather humble. DART originated as a low-profile, high-risk experimental demonstration project. Its goal was to demonstrate that a spacecraft could autonomously rendezvous with a satellite. The satellite in question was the MUltiple-path, Beyond Line-of-site COMmunications (MUBLCOM) satellite. DART was to link up with the satellite by employing its Advanced Video Guidance Sensor and a global positioning system (GPS), which receive signals from other spacecraft, allowing it to move close to its target.

Originally one of several parts to a larger program, within a few years DART had been selected as the mission at the center of NASA's transition to the new vision. By 2004, DART was being depicted as a key to the door of future space exploration. Successful application of the rendezvous technology would have implications for missions ranging from servicing the International Space Station to assembling objects beyond Earth's orbit.

Leading up to its launch, the spacecraft was being described by NASA as the "shining example of technology that will move the Agency toward safer, more reliable, and affordable access to space." It would be NASA's first test of rendezvous technology involving no human intervention, and the first flight test in support of President George W. Bush's "Vision for Space Exploration"—to the Moon, Mars, and beyond. With its new high visibility came great expectations, and high stakes.

The Early Days

NASA had chosen DART as one of several technology demonstration projects in the 2nd Generation Reusable Launch Vehicle (2GRLV) Program. Under a broad NASA Research Announcement (NRA), NASA awarded the contract to Orbital Sciences Corporation (OSC) in 2001. A year later, 2GRLV was reorganized into two new programs. DART was being passed about from program to program, rather like an orphan and ended up as a component of the Orbital Space Plane (OSP) program. The OSP program was meant to develop the entire space transportation system. This encompassed ground operations and all supporting technologies needed to conduct missions to and from the International Space Station. Yet DART's star soon began to rise in recognition of the promising role of automated rendezvous technology in the space station program.

By the time President George W. Bush had announced the new space exploration vision, in January 2004, NASA's ambitious Orbital Space Plane (OSP) had been cancelled. DART, though, was continued, due to its potential for contribution to "in-space assembly of certain exploration architecture concepts." And because DART had been in the pipeline for several years, with an original target launch date in 2004, the project jumped into the lead position as NASA's "first flight demonstration of new exploration capability."

The Technology behind the Mission

DART was designed to demonstrate that an unaided spacecraft could autonomously, with no assistance from ground personnel, meet up with a non-maneuvering satellite. In its initial mission the target would be a military satellite called MUBLCOM, also developed by OSC, which had completed its primary mission. Some 27 objectives for the DART mission were identified and divided among four phases: 1) launch and early orbit, 2) rendezvous, 3) proximity operations, and 4) departure.

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The DART spacecraft would comprise two sections. The first was a forward segment with DART-specific systems. These included the Advanced Video Guidance Sensor (AVGS), one of DART's key demonstration technologies, and the successor to the Video Guidance Sensor system created at Marshall Space Flight Center and licensed by OCS. Developed by OSC in collaboration with Marshall, the AVGS was a sophisticated system capable of calculating the precise measurements between objects in space needed to navigate in proximity operations. Essentially, the AVGS served as the "eyes" behind the maneuvers.

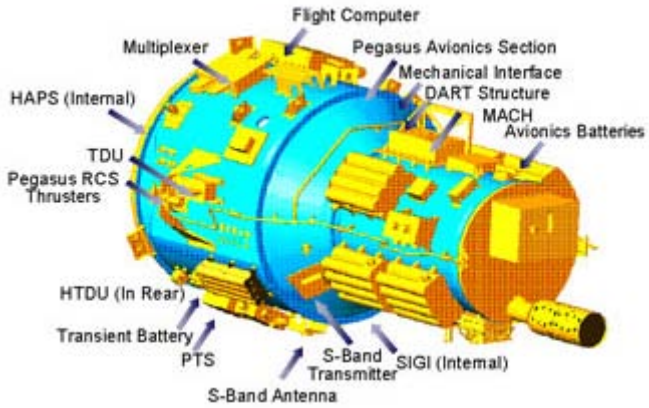

Figure 2 – The DART Spacecraft. NASA image.

The second portion of DART was also the fourth stage of the Pegasus rocket; the shared section would provide avionics and propulsion for the spacecraft.

After launching on Pegasus from a U.S. Navy carrier in the Pacific, DART would spend the first eight hours circling the Earth, searching for MUBLCOM using a GPS receiver and catching up to the satellite. Once it gained a "station keeping" position, staying at an equal distance from a MUBLCOM traveling at 17,000 mph, it would begin a series of maneuvers around the satellite, holding a distance anywhere from 1,000 meters to five meters.

By then DART would have switched over from GPS to AVGS, or Advanced Video Guidance Sensor--DART's "eyes"--to execute its close-range operations. Eventually it would go through these maneuvers two or three times to demonstrate the proximity maneuvers. After completing its mission, the spacecraft would go into a "retirement burn," launching itself into orbit where it would burn up in the atmosphere sometime over the next 10 years.

If everything went off without a hitch, DART would have achieved all its objectives—including 14 designated as critical—and engineers would have reached the next level of rendezvous technology. In accord with the philosophy of the mission, DART had no uplink capabilities—it was not designed to receive commands from the ground. The spacecraft's flight computer alone would determine how to accomplish the mission objectives. It was rather like an autonomous robot in space.

Synchronizing for Success

For a mission this complex to succeed--involving technology as sophisticated as any space project involving an autonomous system thus far--the science, technology, and human components would have to be precisely aligned, and would have to operate flawlessly. The key players in the mission were: Marshall Space Flight Center, the managing center for the project; OSC, or Orbital Sciences Corporation, the prime contractor, spacecraft designer, and co-developer of the AVGS; NASA HQ; and several international companies, including a British firm providing the primary GPS receiver.

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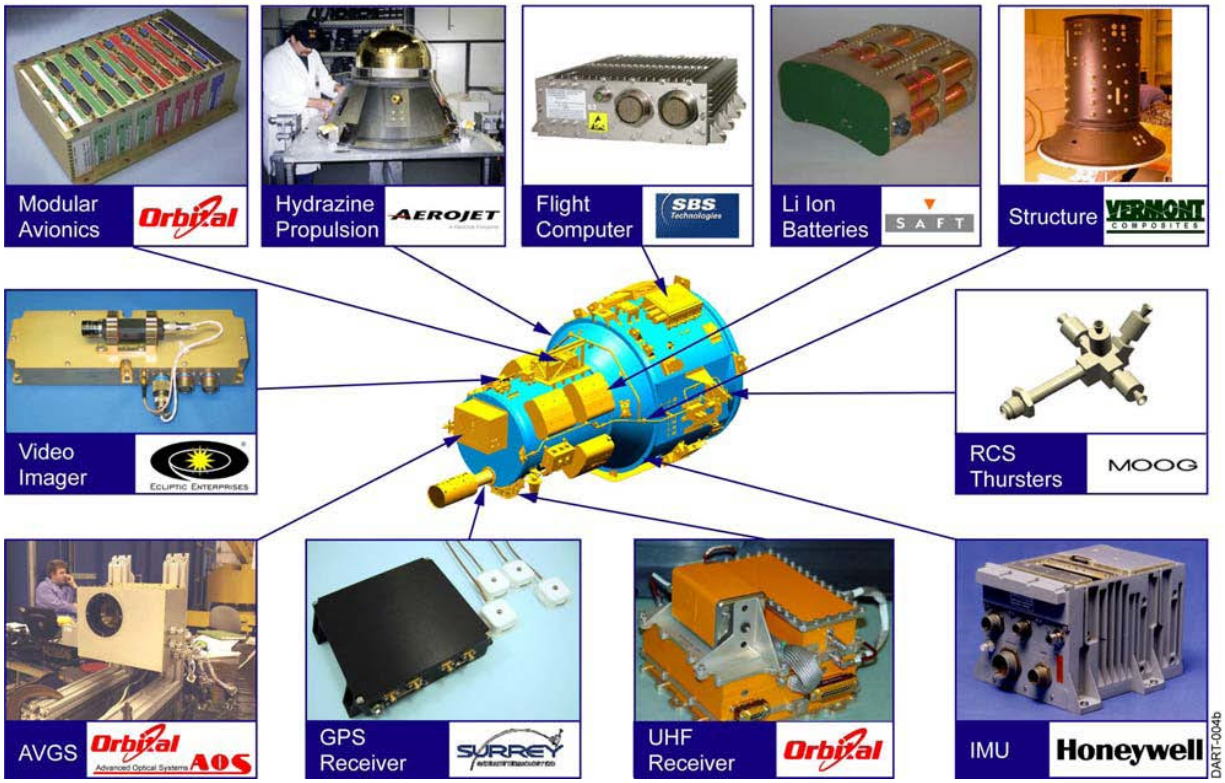

Figure 3 – The DART spacecraft and its major components and manufacturers.

Mission Concerns

Yet, after the work of the DART mission began, a number of problems with the project arose.

Some of these were contractor-related. Most of the detailed design decisions about how to meet mission requirements were left to the discretion of the contractor, OSC. NASA procured the data, while setting broad requirements. It left most of the detailed design decisions about meeting requirements to the contractor.

OSC had carried over to the DART project, from the Pegasus launch vehicle, many of the design features from the development of Pegasus. For example, DART's software architecture consisted primarily of a pre-programmed, timed sequence of fixed commands. This had worked adequately for Pegasus. However, for DART, it was questionable whether such software architecture would be able to respond adaptively while performing autonomous in-space operations.

Further, the contractor retained control over the mission's spacecraft design, development, and operations--as opposed to a more predominant role by the government, via detailed government specifications. More broadly, a challenge in management coordination resulted from different vendors providing the integration of guidance, navigation, and control (GN&C) technology.

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Further, communication lapses were occurring between project managers and an international vendor. This was due in part to perceived restrictions in export control regulations over some of the mission's sophisticated technology. Several international vendors involved in the project were subject to the International Traffic in Arms Regulations, or ITAR. This had the potential to exacerbate related management and technology issues.

The mission also struggled to strike a balance between some of its own engineers gaining hands-on experience in flight system design, testing, and operation, and relying on subject matter experts with previous experience in those arenas. The NASA design team worried about the risks and benefits of putting into practice some of the recommendations for altering the project that it was receiving from the experts. The team's lack of experience, meantime, was leading to compromises in portions of the system design and testing.

This spilled over into the software development process. A change to DART's navigation software--involving the measured velocity of its GPS--was made without the knowledge of most of the DART team. Technicians discovered a math model-related units conversion omission after most of the hardware-in-loop testing of the system was completed.

The concerns over design and testing were part of a bigger worry--over risk management. Over time, DART had become a higher-profile project for NASA, one with less tolerance for risk.

At the Marshal Space Flight Center, there was considerable turnover in the important position of systems engineer, who in effect is in charge of systems integration. Analysts focused on the effect of a complete loss of functionality of components of the navigation system, but not the effect of an incomplete loss of functionality of components. Further, the performance requirements for critical capabilities, for example, collision avoidance, were not as detailed as they could have been. Another area of concern was one important in any mission: money. Project costs were rising, nearly doubling by this point. DART had operated under NASA's "faster-better-cheaper" paradigm, which in this case seemed to be coming up short, particularly with expenses. Top management wished to bring costs under control. This influenced decisions on whether to conduct more testing and when to proceed with launch.

Case Study Decision Time: Critical Choices

The DART mission has been delayed due to issues with the launch vehicle. DART is therefore in stand-down mode for six months.

You are DART project manager. There is time to assess what has worked and what's gone wrong. There is also time to conduct some systems integration testing that perhaps should be done. There may also be time to consider whether schedule and budget allow for a final "look around the corner" for obstacles that could prevent a successful launch.

The mission has faced some challenges that you believe could still threaten the integrity of the project. You've noted some of these, as well as some other concerns:

- After the late discovery of a units error in a software simulator for the GPS receiver, a software change has been made to improve performance. It has not been tested with the GPS receiver in

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the loop. The program is already well over budget. Now you must weigh the cost vs. the risk of not testing the software change with hardware in the loop. What critical criteria do you need to factor into your consideration?

- Based on a careful review of design changes suggested by a subcontractor with a long history of rendezvous experience, you suspect that lack of training and experience in the design team may have led to inadequate navigation system design and testing. But again, cost is a consideration in whether to investigate.

- Systems-level integration is worrisome. At the Marshall Space Flight Center, the person in the systems engineering job is seen as an integrator of systems, almost like a chief engineer. However, the position has undergone considerable turnover in the past few years. What potential effects of this flux might occur with DART, and what effects might have been anticipated?

- The technical-risk assessment and management teams have some concern that overall responsibilities may not have been clearly defined.

- There are clearly some conflicting "personalities" on the DART team. Beginning about a year ago, there was a growing awareness on the team that more was at stake on this project than originally planned. Many new people had been brought in, and some problems had been solved by this influx of help. Still, interpersonal and working relationship issues have helped prevent fully investigating all the suspected problems. What measures might help to break down these obstacles?

- The International Traffic in Arms Regulations (ITAR) restrictions appeared to have caused some inadequate technical communications between the project and the British vendor supplying the GPS equipment. Were there implications from this that could have been anticipated? Is it too late now to catch any surprises?

- Finally, looking back to the beginning of the project, you having nagging doubts about the possible effects on the mission of the launch vehicle approach. The high-risk, low-budget nature of the procurement under the NASA Research Announcement meant that most of the detailed design decisions about how to meet the project requirements were left to the contractor. For DART, OSC had carried over many of the spacecraft's design features from the Pegasus launch vehicle approach. Will the software architecture that worked for Pegasus adapt properly to perform autonomous in-space operations?

Mulling over these issues, you try to prioritize and pick your battles. What are your primary responsibilities? Where can your resources as program manager best be applied—and how?

At this rather late point, how can you make the mission work?

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Related Resources

- NASA DART web site:
  http://www.nasa.gov/mission_pages/dart/main/index.html
- Overview of the DART Mishap Investigation Results:
  http://www.nasa.gov/pdf/148072main_DART_mishap_overview.pdf
- Fender Bender: NASA's DART Spacecraft Bumped Into Target Satellite:
  http://www.space.com/missionlaunches/050422_dart_update.html

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