NEAR COSTING AS A TEMPLATE FOR FUTURE SMALL SPACECRAFT MISSIONS

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Abstract

On February 17, 1996, NASA solidified its "faster, better, cheaper" guidelines for low cost planetary missions with the successful launch of the Near Earth Asteroid Rendezvous (NEAR) spacecraft. A guide for future small spacecraft missions has now been established. NEAR, the first mission in NASA's Discovery Program for "faster, better, cheaper" planetary exploration and the first asteroid orbiter ever was designed and built at The Johns Hopkins University Applied Physics Laboratory (JHU/APL). The design emphasizes simplicity, reliability, and low cost. Discovery Program criteria include a cost ceiling of $150 million (FY 92 dollars) on spacecraft development to launch plus 30 days and a maximum 36 month development cycle. NEAR was developed and launched in 27 months for approximately $108 million (FY 92 dollars); $3.6 million was actually returned to NASA following launch — the NEAR under-run.

The cost criterion, with reference to NEAR, is the focus of this paper. This paper will discuss the NEAR program cost from the beginning of Phase C/D (December 1993) to launch plus 30 days (March 1996). The NEAR work breakdown structure (WBS) will be presented and each of its 29 cost centers will be discussed in detail with regard to their total cost, manpower required, engineering and fabrication shop hours required, and subcontract cost (with a brief description of the major subcontracts). In addition to the utilization of the WBS, showing the cost make up of each cost center, several other graphs and charts will be presented to show these same cost areas (total cost, manpower, shop hours, and subcontracts) in relation to the phases (design and fabrication, integration and test, launch support, etc.) in which they were expended. Also incorporated in this paper will be discussions on some key cost control techniques—some tried and proven in past programs, and others fairly new to JHU/APL—regarding technical services and subcontract support.

With NASA and its Discovery Program bringing the "faster, better, cheaper" mind-set to the forefront, more pressure is being placed on private and public organizations to find ways to reduce costs of future space systems and to actually achieve the originally estimated cost at the end of the project. The information in this paper will be presented in a way that will be useful as a template or starting point for future small spacecraft programs.

Introduction

In 1992 the National Aeronautics Space Administration (NASA), in an effort to reduce the cost of space science missions, introduced the Discovery Program. The Discovery Program would focus on low-cost satellites (under $150 million in $92), short development time-lines (36 month development phase), and better science and technology. For these qualities and the long and successful track record of The Johns Hopkins University Applied Physics Laboratory (JHU/APL), NASA selected JHU/APL to design, develop, and manage the Near-Earth Asteroid Rendezvous (NEAR) program, the first of its Discovery, low-cost planetary missions.

JHU/APL has been developing low cost satellites, with short development time-lines and better science and technology since the 1950's. Following the invention of the Transit Navy

Navigation Satellite System, the Laboratory's Space Department history has continued to deliver firsts in space exploration and related technologies at low costs and within specified schedules. These accomplishments can be attributed to the fact that the Space Department's "principle focus is to manage the end product of a project which involves delivering a specific technical product, for a specific cost and within a specific schedule."[1]

Over the past 30 years the Space Department has delivered 57 low-cost, short development time-line spacecrafts and over 100 instruments with a reliability record exceeding 95%. In recent history, the Space Department has had seven highly successful satellite launches with program durations ranging from 13 to 36 months, all being completed for their original estimated cost or below. Some of the more recent programs, with similar schedules and cost constraints to the criteria placed on the NEAR Program, include the Delta 180 and the Delta 181, AMPTE, and Polar BEAR.

Scope

This paper presents a history of the NEAR development phase (phase C/D) costing. This information is being made available with the expectation of providing future small satellite project managers with some fiscal guidance with reference to the costing activities they will encounter. The NEAR work breakdown structure (WBS) will be presented and each of its 29 cost centers will be discussed in detail with regard to their total cost, manpower, engineering and fabrication shop hours, and subcontract cost (with a brief description of the major subcontracts). In addition to the utilization of the WBS, showing the cost make up of each cost center, several other graphs and charts will be presented to show these same cost areas (total cost, manpower, shop hours, and subcontracts) in relation to the phases (design and fabrication, integration and test, launch support, etc.) in which they were expended.

Also incorporated in this paper will be discussion on some key cost control techniques (some tried and proven in past programs, and others fairly new to JHU/APL) regarding technical services* and subcontract support.

Overview of the NEAR Mission

NEAR was given congressional approval in the fall of 1993 and began the development phase in December 1993. NEAR is designed to help address global interest and concerns about comets and asteroids. The NEAR mission will make the first quantitative and comprehensive measurements of an asteroid. The spacecraft is equipped with five facility class science instruments that will perform these tasks.

The NEAR spacecraft's three year journey to the asteroid Eros began on February 17, 1996 after a successful launch on a Delta II rocket from Cape Canaveral, Florida. The 27 month development phase, prior to launch, was well within the 36 month limit permitted under the Discovery mission guidelines.

Along with the shortened development phase came a reduced price tag. Originally estimated to cost $112 million (in FY92 dollars), the actual Phase C/D, from December 1993 through launch plus 30 days (March 1996), was approximately $108.4 million (in FY92 dollars), a $3.6 million savings for NASA. This final development cost will be presented and discussed in detail in the same format as that of the NEAR Work Breakdown Structure (WBS) shown in Figure 1.

NEAR Organization

Figure 2 represents the NEAR organizational structure, showing the areas of accountability from NASA to JHU/APL. This organization maps the NEAR WBS and cost centers, a cost control technique which empowers lead engineers

*Technical services can be defined as detailed board design, detail enclosure design, board fabrication, board assembly, board encapsulation, and mechanical fabrication.

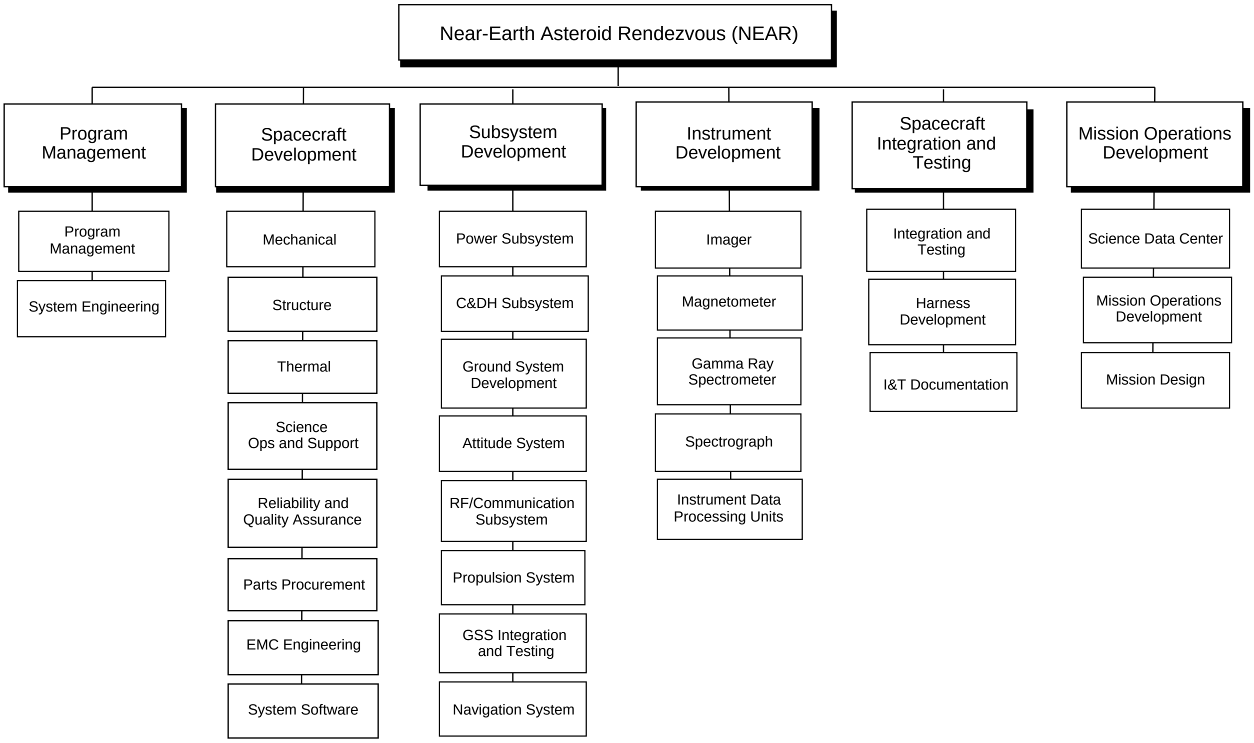

Figure 1. NEAR Work Breakdown Structure

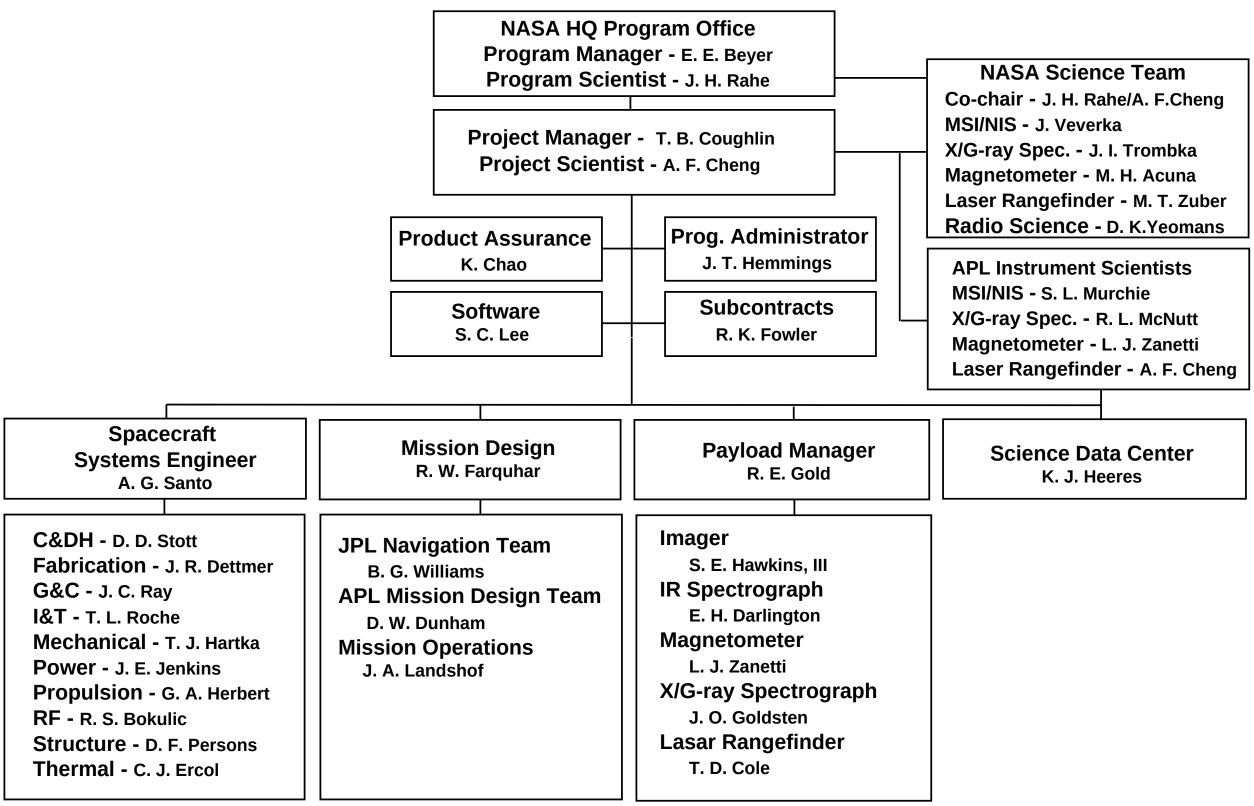

Figure 2. NEAR Organization

with total responsibility for the technical, cost and schedule responsibilities of their technical areas.

NEAR Work Breakdown Structure

The NEAR WBS is typical of those utilized on Space Department programs. The NEAR WBS was modeled from those used on previous programs, and was aligned to JHU/APL Space Department product centers and the program's major cost elements. The NEAR WBS is shown in Figure 1 and mirrors the 29 NEAR cost centers. This WBS can be used to cost down to the 3rd level of the WBS, not only for simplicity of tracking and controlling cost to each center but also for estimating future programs' cost.

Cost Estimate Methodology

Cost estimation of space science missions at JHU/APL is a process that involves interactions among the project management, the JHU/APL organizational unit and the customer. The process consists of five steps: (1) Identify customer requirements; (2) Generation of a project rough-order-of-magnitude (ROM) cost Estimate, initiated by the Project Manager, with the goal of developing at least one acceptable conceptual solution; (3) Generation of a "bottom-up" cost estimate, which is the sum of the detailed cost estimates produced by the individual product center line supervisors, and their technical staff for each technical area; (4) Generation of a top-down cost estimate, generated by the top level managers and technical staff after analyzing the proposed space mission, and comparing to previous missions conducted at JHU/APL; (5) Generation of an Official JHU/APL Cost Estimate, after Project staff meets with the product center supervisors, senior technical staff members and manager to reconcile any differences between the ROM cost estimate, the bottom-up cost estimate, and the top-down cost estimate.[1]

Cost Center Descriptions

The NEAR costs presented, are intended to give a clear accounting of all Phase C/D costs associated with the NEAR program. The element cost summaries include all JHU/APL engineering, science, design, development, fabrication, integration and test, and subcontractor efforts. All of these elements are shown in the cost centers in which they were incurred. Please note Assumptions Section when reviewing all of the figures. This format is utilized in order to aid program managers' planning efforts.

The total cost of each of the NEAR 29 cost centers are initially presented in their raw form in Figure 3 and then finally in a worksheet format (Figure 10), which is very similar to those utilized in on-going cost analysis studies by corporations such as the Aerospace Corporation. These studies are being sponsored by major US organizations including NASA, ARPA, STP, and BMDO, among others, with a common goal of attempting to credibly estimate costs of small low-cost satellites.[2]

As mentioned above, the NEAR WBS is shown in Figure 1. A description of each one of these elements follows:

Program Management

Program management represents all efforts associated with the planning and direction of the entire program from the prime contractor (JHU/APL) level, including all subcontractor interactions. These efforts were supported by: one full-time project manager; one full-time secretary; one full-time program administrator; one full-time scheduler (up to the Integration and Test (I & T) phase only); consulting services as required (for Preliminary Design Review (PDR), Critical Design Review (CDR), etc.); and some extraordinary work regarding a parts archive library (not specific to any one subsystem).

Systems Engineering

System Engineering represents program-level engineering to oversee that all subsystem goals and requirements are met and that payloads are functional. Manpower includes one full-time

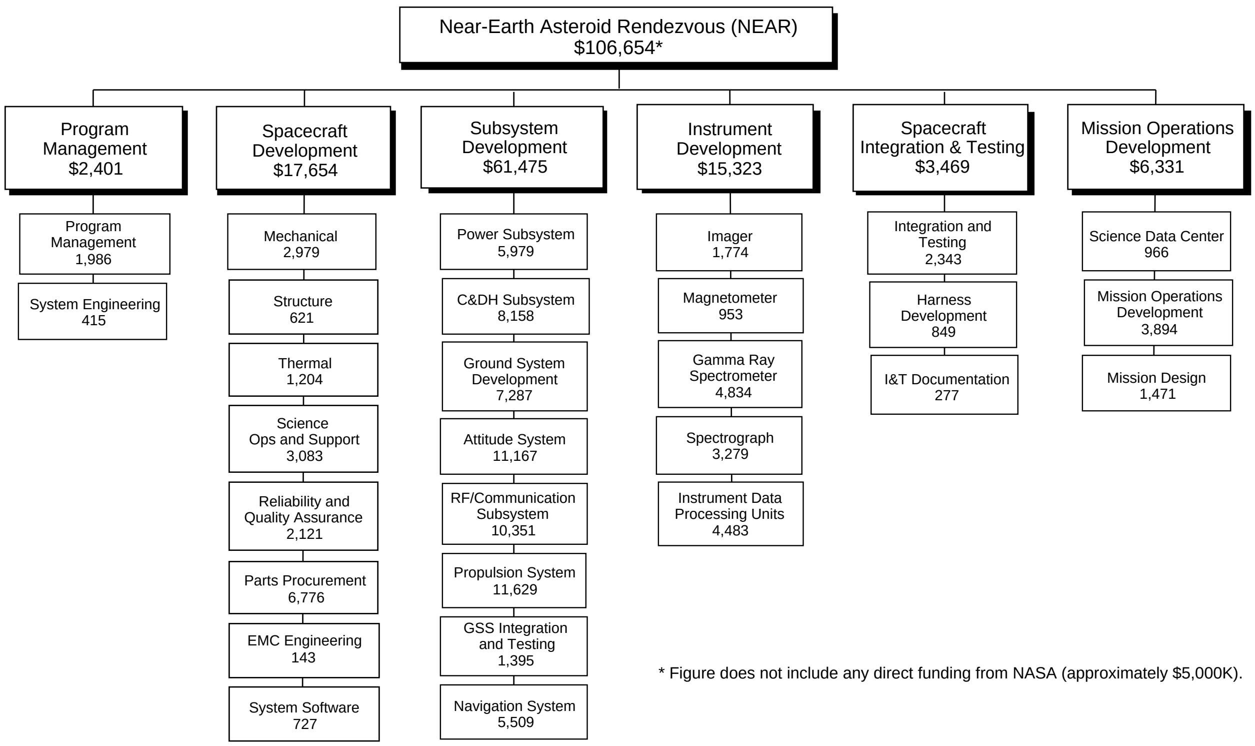

Figure 3. NEAR Cost Data (in K$)

systems engineer. No subcontracts are included in this cost center.

Spacecraft Development

Mechanical Subsystem

The mechanical subsystem is the spacecraft's structure and mechanisms, and provides mounting volume for all spacecraft and instrument packages, antennas, and arrays. The manpower effort includes one full-time mechanical engineer (responsible for the complete spacecraft structure design) with an assistant, and miscellaneous support when interfacing with the different subsystems. Major subcontracts include: substrates/panels, RF reflector, and antenna feed support. The engineering and fabrication (E&F) effort includes mostly structural design, GSE hardware, and solar array hardware.

Structure Subsystem

The structure subsystem effort includes one full-time structural engineer (with support from other subsystems, when necessary), who is responsible for spacecraft environments, factors of safety, design loads, tests and test levels, regarding stress, for the NEAR components, subsystems and integrated spacecraft. There were no major subcontracts.

Thermal Subsystem

The spacecraft thermal subsystem is a combination of radiators, insulation and heaters. The thermal control of the spacecraft is primarily passive, utilizing coated surfaces, radiators and multi-layered insulation (MLI); however heaters (active control elements) are utilized when necessary. Manpower includes one full-time lead engineer and one full-time assistant. Subcontracts includes thermal materials and a resident subcontractor.

Science Operations and Support

The science operations and support represents the management and coordination of all scientific objectives, as well as the management and coordination of all science instrument teams. The outside science team is reflected in the subcontract category of this cost center and/or directly funded by the sponsor (NASA). Manpower includes two scientists. Major subcontracts include the outside science team members.

Reliability and Quality Assurance (R&QA)

The performance assurance engineer represents the single point of contact between R&QA and the NEAR program manager for all R&QA issues. Responsibilities include directing and monitoring the R&QA activities of the NEAR program to assure conformance and the identification of preventive or corrective actions and their implementation as necessary. Manpower includes one lead engineer with several assistants. Major subcontracts includes residential subcontract manpower support for testing. The majority of the E&F effort consists of materials analysis.

Parts Procurement

The purpose of the parts procurement cost center is to initiate and track part procurements, interact with vendors to ensure availability of parts, maintain and manage stock inventory of EEE flight parts, maintain priority test schedules for internal and external testing of parts, inspect and test incoming flight parts, and develop and implement electrical parameter screening procedures. Manpower includes one full-time engineer and several full-time technicians to support procurement and testing of parts/parts packages etc. Major subcontracts include parts procurement, parts testing, and resident subcontractor manpower support.

Electromagnetic Compatibility (EMC) Engineering

The EMC engineer is responsible for the development of a compatible electromagnetic environment for sensitive instruments and spacecraft equipment. Manpower included one part-time EMC Engineer. There were no major subcontracts under this cost center.

System Software

System software is responsible for the management and coordination of the spacecraft flight software, which will allow all aspects of the mission to be carried out and will provide timing, commands, telemetry, and vehicle control. Manpower includes one full-time lead software engineer (with additional manpower support for software). Major subcontracts include Independent Validation and Verification (IV&V).

Subsystem Development

Power Subsystem

The NEAR Power Subsystem is responsible for managing and coordinating the spacecraft power system, which is comprised of a solar array, main bus controller, and battery. Manpower includes one full-time engineer (with additional manpower support). Major subcontracts include spacecraft batteries and solar arrays. The majority of the E&F effort was concentrated around power system electronics.

Command and Data Handling Subsystem (C&DH)

The C&DH subsystem is responsible for spacecraft uplink command processing, stored command management, telemetry data collection and processing, storage of science and engineering data, autonomous fault protection, subsystem intercommunication and spacecraft timekeeping and synchronization. Manpower includes one full-time engineer (with additional manpower for software support). Manpower subcontracts include solid state recorder, flight computer and bench test equipment. The majority of the E&F effort was based around the Command/Telemetry processor and power switching.

Ground System Development

The NEAR ground system consists of the Mission Operations Center (MOC), Integration and Test Operations Segment (ITOGS) of the Ground Support System (GSS), Science Data Center (SDC); and the Deep Space Network (DSN) operated by the Network Operations Control Center at the Jet Propulsion Laboratory (JPL). Manpower includes one full-time lead engineer and several assistants. Major subcontracts include the ground system core computer.

Attitude System

The purpose of the attitude system is to provide attitude control, ΔV control, and attitude determination. The spacecraft's attitude is controlled by three reaction wheels. The attitude determination utilizes inertial measurement units, a star camera and digital sun sensors. Manpower includes one full-time lead engineer with several software engineers. Major subcontracts include reaction wheels, inertia measurement units (IMU's) and a star camera. The majority of the E&F effort was fabrication of the attitude interface unit (AIU).

Radio Frequency (RF) Communication Subsystem

The purpose of RF Communication is to transmit telemetry data, receive spacecraft commands, and provide a frequency coherent ranging capability. Manpower includes one full-time lead engineer and several full-time assistants. Major subcontracts include a transponder, DC/DC converters, and RF ground support equipment. The majority of the E&F effort was based around the X-band power amplifier, the telemetry conditioner unit, the fan beam antenna and the low gain antenna.

Propulsion System

The propulsion pystem consists of a bi-propellant (for large trajectory correction, and asteroid orbit insertion), a ΔV system, a pressurizing gas supply subsystem, and a mono-propellant hydrazine maneuvering subsystem. Manpower includes one full-time lead engineer. Major subcontracts include the propulsion system.

Ground Support System (GSS) Integration and Testing

The purpose of the GSS integration and testing subsystem is to establish procedures nd tools for ground system integration, testing, operation, identification of unexpected interactions among subsystem elements, and to identify failure modes reflecting design weakness and defects in materials, workmanship, and quality control. Manpower includes one full-time lead engineer and part-time assistants throughout the program. Subcontracts include miscellaneous test equipment and software tools for the GSS.

Navigation System

The navigation system consist primarily of the NEAR Laser Rangefinder, which is an incoherent direct-detection laser altimeter designed for high probability of detection in single-pulse operation for reflecting surfaces. Manpower includes one full-time lead engineer with several assistants. Major subcontracts include the laser altimeter. The majority of the E&F effort was concentrated around the fabrication of instrument to spacecraft hardware.

Instrument Development

Imager

The Multispectral Imager (MSI) will determine the overall size, shape, and spin characteristics of 433 Eros and will map the morphology and composition of the surface. Manpower includes one full-time lead engineer and one assistant. Subcontracts include filters and lenses. The majority of the E&F effort was concentrated around the fabrication of instrument to spacecraft hardware.

Magnetometer

The Magnetometer will probe the interior of Eros and help determine whether small asteroids are solid fragments of rock with densities and composition like those of meteorite samples or if they are porous piles of fragmented rubble with considerable void space. Manpower includes one full time leads engineer and support when needed. Subcontracts include flux gate heads. The majority of the E&F effort was concentrated around the fabrication of instrument to spacecraft hardware.

X-Ray/Gamma-Ray Spectrometer

The X-Ray/Gamma-Ray Spectrometer is the primary experiment for determining surface composition of the near-Earth asteroid. Manpower includes one full-time lead engineer with assistants. Subcontracts include high voltage power supply and miscellaneous test equipment, etc. The majority of the E&F effort was concentrated around the fabrication of instrument to spacecraft hardware.

Spectrograph

The Near-Infrared Spectrograph is designed to map the mineralogic composition of the asteroid 433 Eros using the spectrum of reflected sunlight. Manpower includes one full-time lead engineer with miscellaneous support. Major subcontracts include the Spectrograph. The majority of the E&F effort was concentrated around the fabrication of instrument to spacecraft hardware.

Instrument Data Processing Units

The instrument data processing units represent the interface between the spacecraft's instruments and C&DH, commands interpretation and execution, and data acquisition and formatting. Manpower includes one full-time lead engineer and several supporting engineers. Subcontracts include bench test equipment, GSE interface equipment, miscellaneous hardware and software, etc. The majority of the E&F effort was concentrated around the electronic design of the data processing units for all instruments.

Spacecraft Integration and Testing

Integration and Testing (I&T)

The integration and testing subsystem is responsible for the establishment of procedures and tools for spacecraft integration, testing, operation, and assurance that all components are operated beyond their "infant mortality" regime (prior to launch where appropriate), verifying spacecraft design performance (including reliability and life expectancy), and identifying unexpected interactions among system/subsystem elements. Manpower includes one full-time lead engineer and one assistant. Subcontracts include residential subcontractor support, miscellaneous test equipment, etc. The majority of the E&F effort was concentrated around wiring harness components.

Harness Development

Harness development represents all the necessary wiring to connect the spacecraft instrumentation and subsystems. Other components include the terminal boards, the fuse ordnance and battery plug. In addition to the normal RF, signal and power wiring, the NEAR program used the MIL STD 1553 data bus to distribute signals. Manpower includes one part-time engineer. There were no subcontracts.

I&T Documentation

The purpose of the I&T documentation cost center is to maintain all required internal and external engineering documentation with reference to all spacecraft specifications, safety issues, etc. Manpower includes one part-time technician. No subcontracts.

Mission Operations Development

Science Data Center

The purpose of the Science Data Center is to establish a work environment, capable of receiving, analyzing, and distributing the scientific data downloaded for the NEAR spacecraft. Manpower includes one full-time scientist and part-time support. Subcontracts include miscellaneous hardware and software.

Mission Operations Development

The purpose of Mission Operations Development is to establish a work environment capable of: (1) supporting the concurrent engineering of spacecraft, ground system, and mission operations; (2) supporting the design and development of the ground system; and (3) negotiation and development of external interfaces. Manpower includes one full-time lead engineer and several full-time supporting staff. Subcontracts include residential subcontractors and NEAR Mission Operations Center (MOC) facility equipment.

Mission Design

Under the supervision of the Mission manager, the Mission design team interfaces with Mission Operations and the NEAR Science team in reference to: (1) changes in the spacecraft's maneuver design; (2) converting raw data into a tracking schedule; and (3) supporting navigational information. Manpower includes one full-time lead engineer (Mission Manager), one full-time assistant, and one part-time assistant. Subcontracts include trajectory design software.

Cost Center Fiscal Analysis

Figures 3, 4, and 5 show the NEAR cost centers as described above as they represent costs, manpower, and engineering and fabrication efforts, respectively. This format is intended to be of most benefit to the top level managers when comparing to previous missions.

As one might ascertain from reviewing these figures, the major cost driver was the propulsion system. Let it be noted that the propulsion system was one of a few subsystem cost overruns experienced during the program. Other subsystems involving slight overruns include the power subsystem and Mission operations. These overruns, however, were offset by the aggregate savings of the other 27 subsystems, with the majority of savings due to synergism and heritage in the fabrication and instrumentation efforts.

Additional charts are presented to further inform the project manager with reference to costing, manpower, and engineering and fabrication shop efforts relative to the NEAR development time-line (e.g., Design and Fabrication Phase, I&T Phase, GSFC Testing, etc.).

Figures 6, 7, 8, and 9 portray the NEAR spacecraft development costs in different charts, with the NEAR development phase time-line at the top of each chart. The peaks and troughs in Figures 6 and 9 show that the majority of expenditures (representing the programs long lead items) took place in the early part of the design and fabrication phase. Some of the major expenditures in the first six months included the initial funding for the IMU's, the propulsion system, the laser altimeter, the transponder, the star camera, bench test equipment, the solid state recorder, and the flight computer. The final increment of funding to the majority of the subcontractors took place in the first four months of calendar year 1995, as can be seen in Figures 6 and 9, just prior to the start of integration and test.

Again this format can be very beneficial during the "top-down" cost estimation period, when cost estimates are generated by top level managers and technical staff.

For the benefit of anyone wishing to utilize the NEAR costs in a tabular format, Figure 10 depicts the NEAR cost in slightly different categories, which are more in line with industry cost models. All of the costs represented in Figure 10 are in real year dollars and cannot be used in comparison to the GFY 92 costs and saving mentioned in the opening paragraphs of this paper. Real year savings to NASA were approximately $5 million.

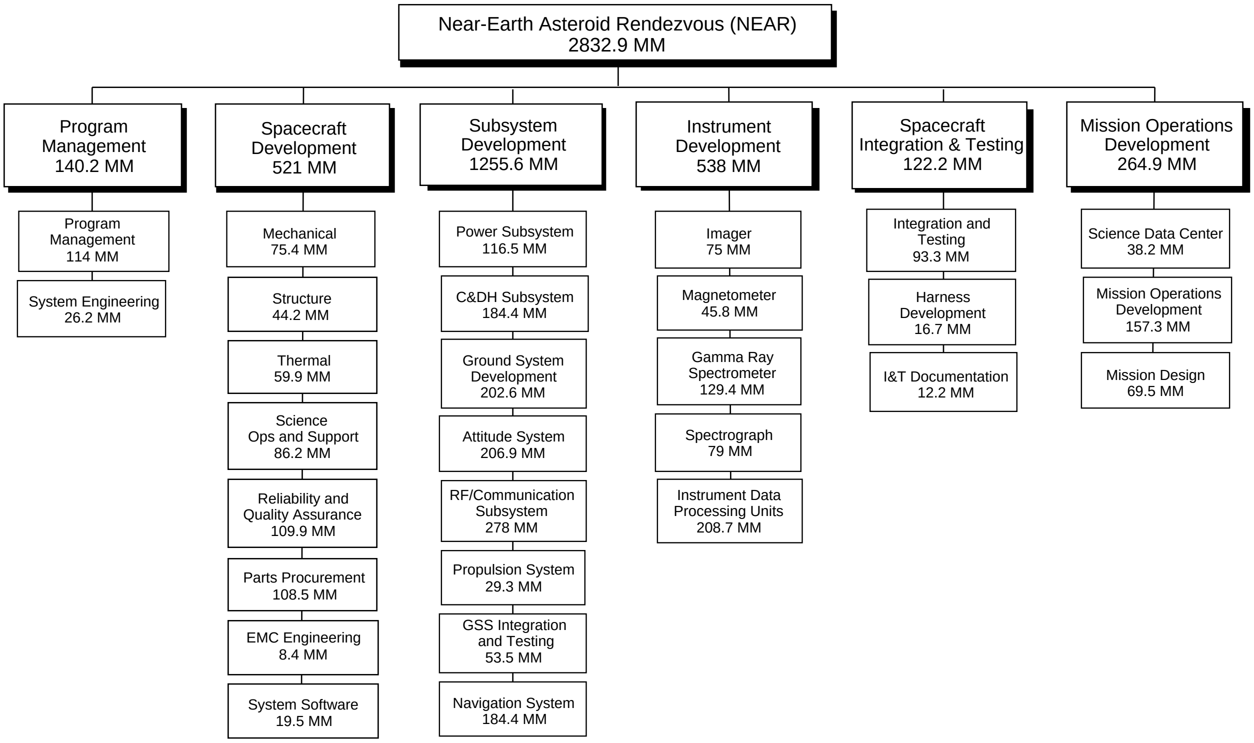

Figure 4. NEAR Manpower Data (in manmonths)

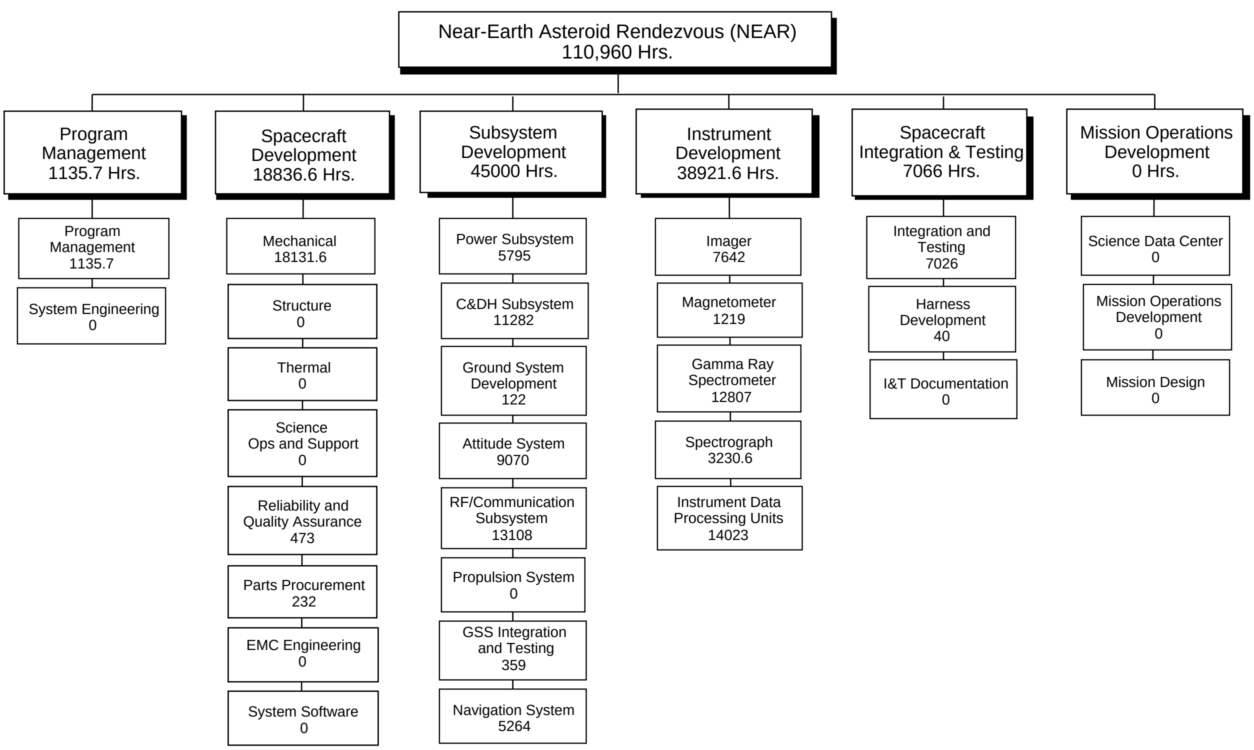

Figure 5. NEAR Engineering and Fabrication Data (in hours)

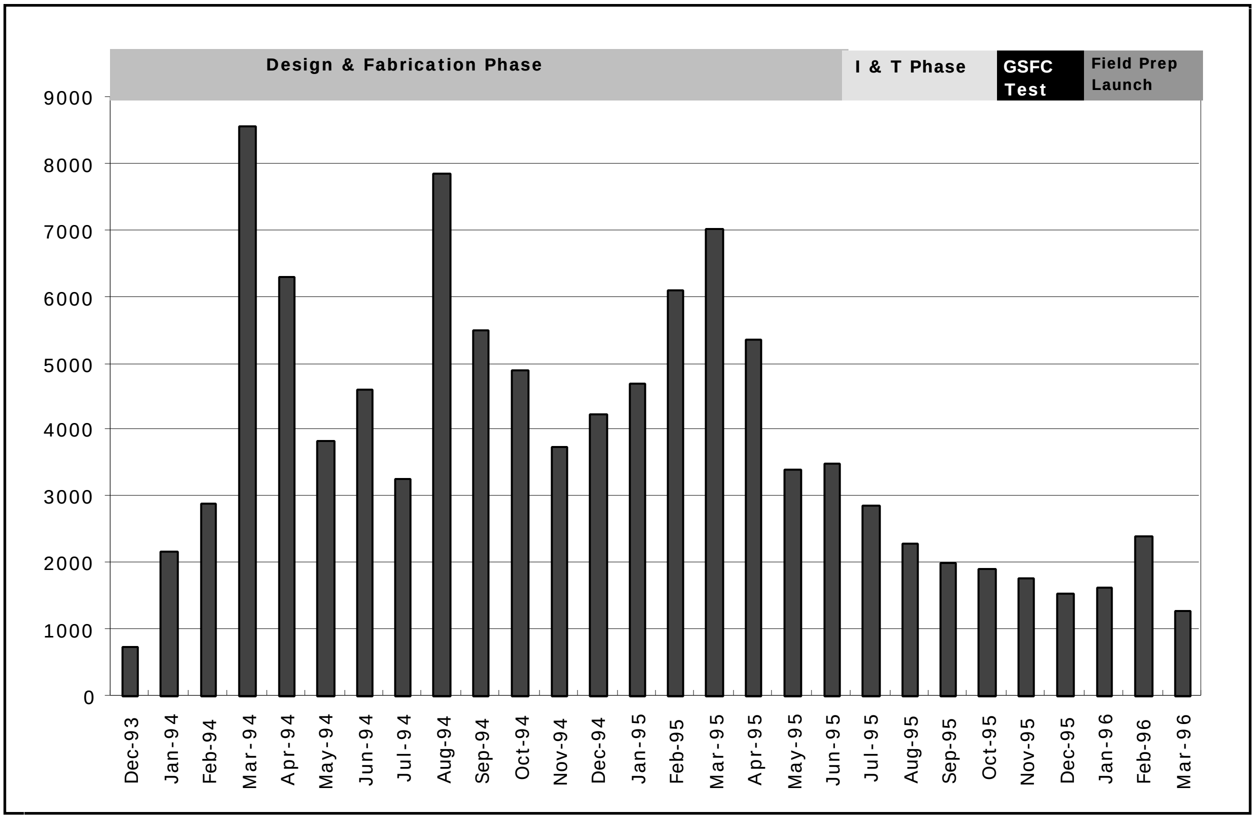

Figure 6. NEAR Cost by Month (in $K)

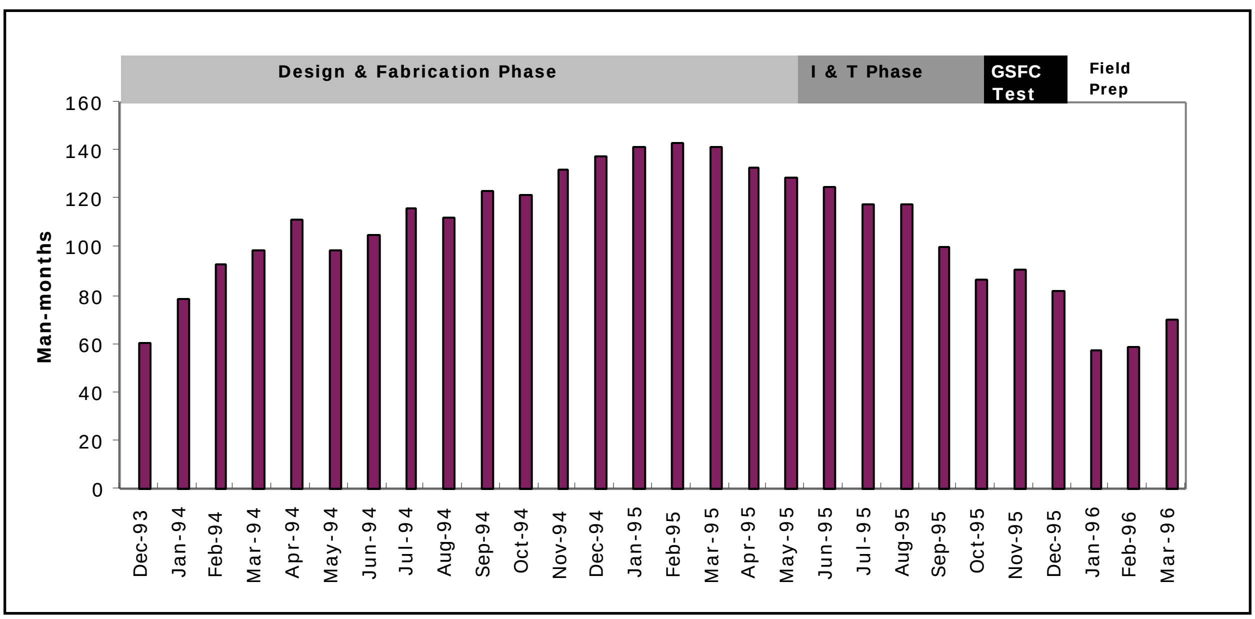

Figure 7. NEAR Manpower by Month

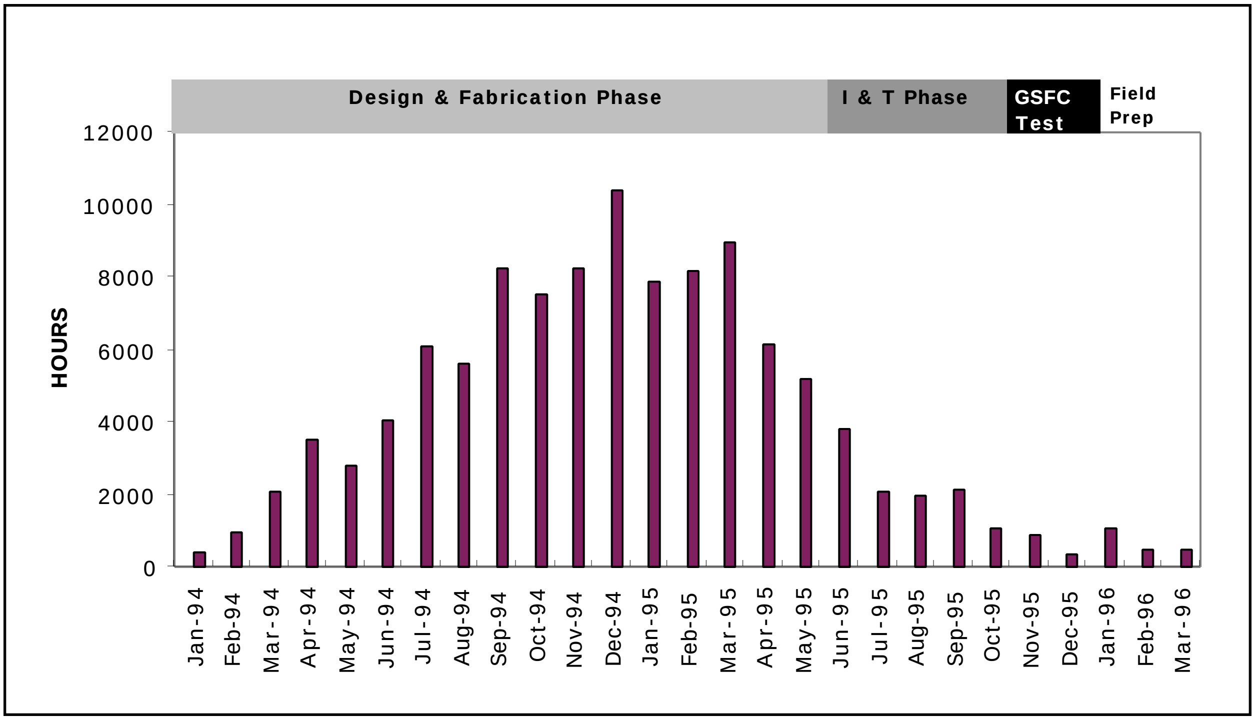

Figure 8. Engineering and Fabrication Hours

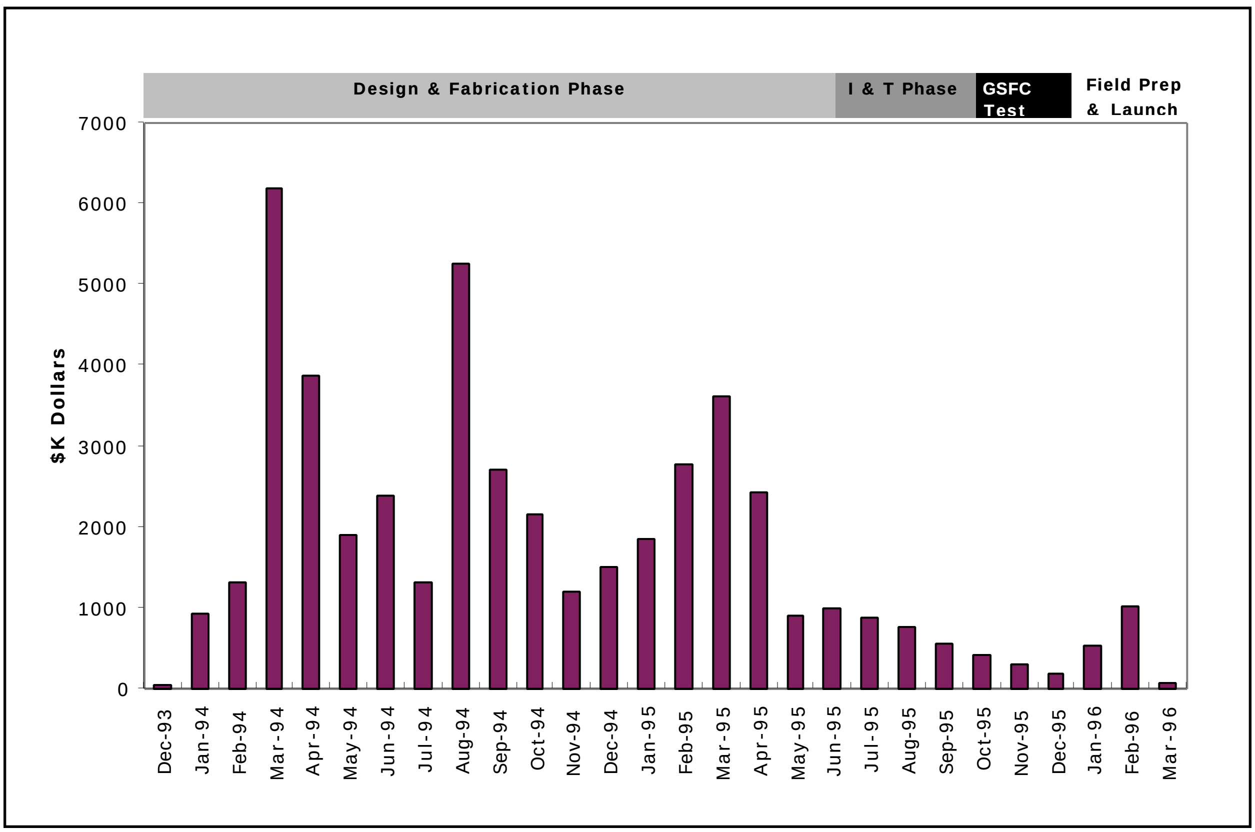

Figure 9. Subcontract Commitments by Month

Program Name: NEAR							
Lead Center: NASA Hqs							
NASA Pt. of Contact: Betsy Beyer							
Prime Contract Center: JHU/APL							
Prime Contractor-Instruments: JHU/APL							
Launch Vehicle: Delta II							
Cost Element (in $K)	**FY: 94**		**FY: 95**		**FY: 96**		**Subtotal by**
	Inhouse	**Contracts**	**Inhouse**	**Contracts**	**Inhouse**	**Contracts**	**Element**
1. Management	719	20	868	119	596	43	2365
2. Planning and Analysis- Phase A	454						454
3. Carrier/Bus							
3a. Structures & Mechanisms	917	568	1124	110			2719
3b. Thermal	132	32	648	186			998
3c. Attitude Control System (ACS)	1177	3225	2488	2500		200	9590
3d. Command & Data Handling (C&DH)	1263	1568	2684	1556		383	7454
3e. Electrical Power System (EPS)	613	342	1376	3074		60	5465
3f. Propulsion	911	5356	1000	3891		221	11379
3g. Flight Software	716	553	1440	595	527	115	3946
3h. Harness	292	90	763	174			1319
3i. Ground Support System (GSS)	207	40	437	284		79	1047
3j. Government Furnished Equipment (GFE)							
3k. Other:							
RF/Communicatons	2250	4341	2775	880		31	10277
Reliablity & Quality Assurance	610	114	805	158		16	1703
4. Spacecraft Integration & Test	648	11	3878	303	1471	193	6504
5. Instruments (5)	6155	4234	8480	2207	1137	52	22265
6. Launch							
6a. Vehicle							
6b. Flight Integration & Checkout					2427	684	3111
7. Operations (Launch + One Year)	1560	1706	2466	1270	410	81	7493
7a. Ground system Software	210	103	869	532	274	325	2313
8. Other:							
Navigation	142	57	318	98		60	675
Science Support	399	8	1185	1395	785	227	3999
Mission Design	445	74	606	-33	321	37	1450
EMC Engineer	60	0	67	2	0	0	129
9. Directly Funded From NASA:							
JPL - Navigation Team		473		731		838	2042
JPL - NAIF				57		49	106
JPL - Radio Science				88		89	177
JPL - Transponder/CDU		2100					2100
GSFC - Science		125		341		390	856
Subtotal by Fiscal Year	19880	25140	34277	20518	7948	4173	111936
Assumptions:							
FY: 96 figures are through Mar. 96 only (Launch + 30 days)							
Launch Vehicle price is not in figures (approximately $50 mil.)							
Payload Software cost is included in S/C instrument cost							

Figure 10. NEAR Development Cost

Cost Control Factors

Having good plans in place that support the generation of accurate project cost estimates must be maintained and adhered to by the subsystem lead engineer. Once the project is under way, the ability to control actual cost can be quite a challenge to the lead engineers, as well as management.

Some cost control techniques incorporated by JHU/APL's management on past and present programs include:

1. Empower lead engineers with total responsibility of this subsystem.

2. Take advantage of synergism among programs being implemented concurrently.

3. Establish single point-of contact in the engineering and fabrication area. This technique worked very well on the NEAR program. As a NEAR team member, the technical services member assigned to the program reported to management on a weekly basis, which expedited all work being routed through the design and fabrication phase.

4. Establish single point-of-contact in subcontract administration. Similar to Technical services, individual subcontract status was reported to program management on a weekly basis. All NEAR subcontracts were under the jurisdiction of one subcontract representative.

5. Establish a baseline technical plan early and assure that it will be adhered to.

6. Establish "Make/Buy" decisions early.

7. Have a well-defined, productive, useful study phase.

8. Utilize off-the-shelf components, parts, etc., whenever possible.

Assumptions

1. All cost centers in Figure 3 include direct labor, overhead, general and administrative burden, and contractors' fees.

2. Regarding figures utilizing the NEAR WBS, the software engineering cost center includes only the lead software engineer and a portion of the independent, validation, and verification subcontract cost. A more accurate representation of software costs can be found in Figure 10.

3. The Navigation subsystem primarily consists of the Laser Transmitter.

4. The Integration and Test (I&T) cost in Figure 3 includes only those costs incurred by the spacecraft manager, with support, throughout the entire development phase. A more precise account of I&T cost is shown in Figure 10, which show total NEAR costs between June 1, 1995 and September 30, 1995 (defined as the I&T Phase), less subcontracts (not pertaining to I&T activities), project management, flight software and ground system software.

5. Total cost does not include launch vehicle or costs for launch site support.

6. Similar to Assumption 4 above, all costs incurred from December 7, 1995 through February 29, 1996 are defined as NEAR launch operations.

7. Direct funds from NASA to JPL, NASA/GSFC, Motorola Inc., totaling approximately $5 million are included in Figure10 only.

8. Due to the comparison of real year dollars to GFY 92 dollars, the exclusion of the NASA direct funding, and documentation costs (not incurred in the development phase), the total NEAR development cost shown in Figure 10 (approximately $112 million, real year dollars) will not equal the NEAR actual total cost mentioned in the opening paragraphs ($108.4 million, GFY 92 dollars).

Summary

For JHU/APL the cost methodology and cost control techniques discussed in this paper, and applied to the NEAR program have been extremely effective, with the by-product being a returned check for $3.6 million to NASA. The ability to generate accurate program cost estimates and control these costs through program completion has become an important attribute to JHU/APL over the years, exceeded only by the Laboratory's technical reputation.

These methods and techniques are continuing to be used on current programs at JHU/APL, and will hopefully provide the same end results as NEAR.

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