A Systems Engineering Approach for a Multi-Destination Human Space Flight Architecture

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Abstract - *The systems engineering approach traditionally employed by NASA has generally resulted in a large, contracted workforce for human spaceflight projects that generally requires significant development schedules and acquisition budgets. This has limited NASA human spaceflight to Low Earth Orbit since 1972. This paper will discuss how the NASA systems engineering process can be applied to a small team, low cost, in-house structure to develop multi-destination human spaceflight architectures. This will include enabling financial structures, the role of requirements and other standards, balancing the utilization of technology development against existing technology or commercial off the shelf technology, and the management of schedule and design and production milestones.*

Keywords: Systems Engineering, NASA, Moon, Mars, space exploration, destinations, NSBE Visions for Human Space Flight Working Group.

1 Introduction

The Space Special Interest Group of the National Society of Black Engineers has commissioned a *Visions for Human Space Flight Working Group* to investigate technical challenges surrounding NASA human space flight and to identify an alternative path for the direction of United States human space flight. Research conducted by working group participants and documented in this paper represents volunteer labor executed on behalf of NSBE, a 501(c)3 nonprofit headquartered in Alexandria, VA. NSBE coordinates the inputs of aerospace industry experts to propose innovative solutions to complex technical challenges facing the United States. This paper, in coordination with six other Working Group papers, collectively encompasses the product of the Working Group's efforts. Recommendations, results, and conclusions in this paper do not reflect NASA policy or programmatic decisions.

1.1 The Modern Challenge for Systems Engineering

Systems engineering perhaps saw its greatest development and emergence as a discipline in the 1960s, during the height of the Cold War. The military and NASA were both faced with the need to rapidly develop systems of staggering complexity that involved technologies that did not exist in the previous decade. Management of these endeavors developed into systems management, defined as "a set of organizational structures and processes to rapidly produce a novel but dependable technological artifact within a predictable budget." [21]

Within this innocent-sounding definition lies a key problem. An initial constraint during the formation of what would become known as systems engineering was the reality (at the time) that "congressional leaders in the 1960s did not mind high costs, but they would not tolerate unpredictable costs or spectacular failures." [21] While much of this remains true, Congress is no longer tolerant of high costs. Even Congressional offices from states with NASA centers have expressed a desire to see NASA make good progress even without requested budgets. [8]

Thus, the modern challenge for systems engineering is that the discipline was designed under the constraint that it must produce reliable systems at a predicted budget, regardless of how high that budget may be. However, the new reality is flat or declining budgets, an environment in which systems engineering was never intended to operate. The initial conditions, under which systems engineering was designed, have now changed.

This challenge has revealed itself in numerous projects since World War II. North American produced more than 15,000 P-51 Mustang fighters [5] at a 1945 unit cost of \$50,985 [16], which equates to a labor cost of \$1,310,000 in 2012 dollars, assuming production worker compensation. [6] Table 1 shows that since World War II, the cost of developing fighters has grown to more than more than 150 times the cost of the P-51 per aircraft for the F-35 B and C variants. [1], [2], [3], [4], [5], [6], [7], [10], [11], [13], [16], [22], [24], [25]

Table 1 also shows how Congress has become more critical in recent years with respect to the cost of aerospace systems. The F-22 was so widely criticized for cost that production was halted prior to completion of the desired number of fighters. However, when normalized to FY2012 dollars, the F-22 was noticeably less expensive than the F-14 Tomahawk.

Table 1. Cost Growth in US Military Fighters

Fighter	Year Introduced	Unit Cost (FY12)	# Built	Total Cost (FY12)	Growth
P-51 Mustang	1942	$ 1,310,000	15000	$ 19,650,000,000	1.0
F-84 Thunderjet	1947	$ 4,950,000	7524	$ 37,243,800,000	3.8
F-86 Sabre	1949	$ 4,080,000	9860	$ 40,228,800,000	3.1
F-100 Super Sabre	1954	$ 9,600,000	2294	$ 22,022,400,000	7.3
F-105 Thunderchief	1958	$ 24,300,000	899	$ 21,845,700,000	18.5
F-4 Phantom	1960	$ 25,600,000	5195	$ 132,992,000,000	19.5
A-7 Corsair	1967	$ 23,600,000	1569	$ 37,028,400,000	18.0
F-111 Aardvark	1967	$ 85,000,000	563	$ 47,855,000,000	64.9
F-14 Tomcat	1974	$ 190,000,000	712	$ 135,280,000,000	145.0
F-15 Eagle	1976	$ 121,000,000	1198	$ 144,958,000,000	92.4
F-16 Falcon	1978	$ 58,300,000	4500	$ 262,350,000,000	44.5
F/A-18 Hornet	1983	$ 104,000,000	1480	$ 153,920,000,000	79.4
F-22 Raptor	2005	$ 170,000,000	195	$ 33,150,000,000	129.8
F-35A Lighting	2016	$ 153,100,000	1623	$ 248,481,300,000	116.9
F-35B Lighting	2015	$ 196,500,000	340	$ 66,810,000,000	150.0
F-35C Lighting	2019	$ 199,400,000	480	$ 95,712,000,000	152.2

1.2 A Systems Engineering Approach for Human Space Flight

NASA has developed a systems engineering framework very similar to the DOD framework that produced the fighters mentioned in Table 1. In NASA's case this framework has enabled successful operation of the Apollo lunar landings, decades of space shuttle operations, and has assembled the International Space Station. But in the meanwhile, nearly two dozen human space flight projects have been initiated and cancelled, most often for reasons related to budget.

If there is to be any significant future for human space flight, it must be an accompanied by a modification in systems engineering processes. The framework that has produced modern aerospace systems is no longer sustainable. Apollo, shuttle, and ISS were major, focused efforts that consumed the vast majority of the NASA human space flight budgets, yet only led to point solutions for human space activity. A systems engineering approach is needed that requires significantly less budget to deliver human space flight systems capable of supporting exploration to numerous destinations and space environments.

2 NASA 7123 Tailoring for Short Development Life Cycle

NASA has established a set of mandatory systems engineering processes for the execution of NASA projects. This process is applicable to all elements of a system (hardware, software, human systems integration) over the complete project life cycle. NASA defines a project as, "a specific investment having defined goals, objectives, requirements, life-cycle cost, a beginning, and an end… Projects may be performed wholly in-house; by Government, industry, or academia partnerships; or through contracts with private industry." [17]

NASA recommends tailoring or customization of these systems engineering processes as appropriate, suggesting the following considerations: "scope and visibility (e.g., organizations and partnerships involved, international agreements); risk tolerance and failure consequences; system size; system complexity (e.g., human spaceflight vs. flagship science vs. subscale technology demonstration, number of stages and interfaces, technology readiness level); impact on other systems; longevity; serviceability (including on-orbit); constraints (including cost, schedule, degree of insight/oversight permitted with partnerships or international agreements, etc.); safety; technology base; and industrial base." [17] With this in mind, a tailoring is recommended to achieve cost savings in the organization of in-house human spaceflight projects.

2.1 Congressional Decision Points

The standard Key Decision Points (KDPs) recommended by NASA 7123 [17] will be incorporated into the development schedule, as shown later in this paper. However, the Program will also include Congressional Decision Points (CDPs). This Program assumes a fixed budget with unlimited fiscal year rollover [20], which enables the program to reduce costs that would be incurred in an annual appropriations cycle. However, such an approach negatively impacts the governmental balance of power by eliminating the ability of the Legislative branch of government to exert control over the Program. This limitation is corrected by means of the CDPs. Serving as a form of a KDP, the CDPs enable Congress to maintain oversight over the Program and exert controls, even with the fixed annual budget with unlimited fiscal year rollover. This paper introduces the idea of two CDPs, an Authorization CDP and an Appropriations CDP.

An Authorization CDP is to be held bi-annually in the first and third quarters of the fiscal year as a joint hearing of the House Science Subcommittee on Space and the Senate Commerce Subcommittee on Science and Space. The first quarter hearing is chaired by the chair of the House Science Subcommittee on Space. The third quarter hearing is chaired by the chair of the Senate Commerce Subcommittee on Science and Space. These hearings examine Program and Project technical performance and policy compliance in light of relevant Congressional Authorization Acts. Program and Project personnel will provide testimony to this hearing as requested by the chair. The Authorization CDP will result in a joint subcommittee report that will identify any deficiencies or redirection that have been agreed to by majority vote of both the House and Senate Subcommittees. The Program must correct these deficiencies as entrance criteria to the next major systems engineering design review.

Similarly, an Appropriations CDP is to be held in the second and fourth quarters of the fiscal year. This is also a joint hearing, held by the House and Senate Subcommittees on Commerce, Justice, Science, and Related Agencies. Chaired by the Senate in the second quarter and the House in the fourth, these hearings examine Program performance in light of budget and schedule. Like the Authorizations CDP, the Appropriations CDP will result in a joint subcommittee report with deficiencies and redirection agreed to by majority vote of both House and Senate Subcommittees. The Program must also correct these deficiencies as entrance criteria to the next major systems engineering design review.

2.2 Civil Servant Expertise

Burt Rutan was quoted in reference to his company Scaled Composites as saying, "I get my hands dirty. And I insist that all of our engineers do that. The general rule here is that you don't get the privilege of designing something unless you have the capability of building it with your own hands." [9]

By comparison, NASA civil servants have historically had few opportunities for hands-on technical work. A recent report by the NASA Office of Inspector General observed that, "NASA engineers are primarily operating as overseers of work performed by contractors rather than gaining experience building instruments and spacecraft in-house." The report further stated that an, "increased reliance on contractors to design and build projects has led to a decline in Agency personnel with development experience." [18]

One of the key purposes of this program is to combat that decline in civil servant expertise by conducting spacecraft development as a hands-on, in-house activity. Similar to the Scaled Composites approach, all program scientific and engineering personnel will be involved in hands-on, in-house fabrication and assembly.

2.3 Training for Hands-On, In-House Acquisition

The previously mentioned Office of Inspector General report demonstrates the need for in-house, civil servant development activity. However, this institutional lack of experience also indicates the need for significant training to be incorporated into this development cycle. Civil servant training will be provided in multiple phases, based on upcoming project-related activity. For instance, relatively basic machining skills will need to be taught in preparation for low fidelity mockups, while advanced machining and potentially composites fabrication training will be required for flight hardware production.

Each project office will build a proto-flight unit in-house for each configuration of the spacecraft within their respective domains. Proto-flight hardware is hardware that will be used operationally in space, but first undergoes a qualification and acceptance test program. [13] For those with nine or fewer follow-on spacecraft of that configuration (inclusive of flight articles, one crew trainer/simulator, and one integration test unit), in-house labor will be used. For those with greater than nine follow-on units, production contracts will be used.

2.4 Role of Requirements, Standards, and Team Member Expertise

In many government spacecraft programs involving a prime contractor, there is a tendency for the government to specify requirements at the lowest level possible before issuing a contract. The reason most often cited for this is that once the contract has been signed, the contractor is only required to meet terms explicitly specified in the requirements. Any changes or additional details could be considered scope creep and the contractor would require additional fees from the government for implementation. Unfortunately, the contract is often awarded before the design can be at a sufficient level of maturity for the government to know what the requirements should be at that level of detail.

Because the proposed multi-destination human space flight program is an in-house effort, this driver does not exist. Thus, requirements will be allowed to evolve throughout the vehicle's development cycle. Rather than requirements driving the design, the design and requirements will iterate with one another. The team members' expertise will drive both, with the use of analysis, analog missions, tests, and simulations for validation and refinement. Further, there are extensive standards in the spacecraft industry that are also applicable. Designs and requirements are expected to comply with applicable standards. Any deviations from these standards must be justified with validity proven in appropriate analog missions, testing, or simulations. All standards are applicable from program initiation, but official requirements are not baselined until the System Requirements Review (SRR) [17]. Between SRR and Critical Design Review (CDR) [17] requirements can be changed by each project as a result of mission, testing, or simulation results. At CDR requirements are made binding for purposes of flight vehicle production and the design is effectively frozen.

2.5 Utilization of Technology Development, Existing Technology, and Commercial Off the Shelf Technology

A key best practice from the X-38 project is that the V201 space flight test vehicle pursued maximum feasible re-use of existing equipment, holding new development to a strict minimum. [23] This approach will be followed by the multi-destination human space flight program.

In order to control costs, it is important for the systems engineering approach to carefully regulate the utilization of technology development, existing space technology, and commercial off the shelf technology.

The default choice is to use existing space technology and deviation from this requires justification. In order to justify use of technology development, an engineer must demonstrate that one of the following is true:

- No other option can satisfy mission performance envelope;
- Life cycle cost of technology development is within budget and is less than the life cycle cost of using existing or COTS technology;
- Resulting improvement to system performance is accepted by project as worth the additional cost; or
- Enables new mission objectives deemed by project sufficiently important to justify additional cost.

In order to justify the use of COTS, either of the following justifications must be satisfied:

- Any resulting improvement to system performance is accepted by project as worth any additional cost; or
- Any resulting decrement in system performance is accepted by project as worth the resulting cost benefit.

Technology usage decisions are first vetted within an applicable community of practice [20] and ultimately approved by the project Chief Engineer for technology decisions with single project impact and in the Program Systems Engineering Forum [20] for decisions that apply to multiple projects.

3 Design and Production Paradigm

3.1 Ten Year Development Schedule

Project work is scoped within a ten year development schedule, measured from project initiation to delivery of first proto-flight hardware unit to the launch facility. The development schedule incorporates extensive prototyping into the design cycle. This timeframe is divided into three periods, as shown in Table 2, a Concept Development Phase, System Development Phase, and Production Phase. Each phase will be discussed in greater detail later in this paper.

Table 2. Ten Year Development Schedule

Phase	Duration	Primary Development Activities
Concept Development Phase	0 – 0.5 yrs	Training I & 6DR & Design
	0.5 – 1 yrs	Design & SIR & Low Fi Fab & TRR(LoFi) & Analog(s)/Test(s)
	1 – 1.5 yrs	Training II & TER & Design & SIR & IDR & Med Fi Fab
	1.5 – 2 yrs	Med-Fi Fab
	2 – 2.5 yrs	Med-Fi Fab & TRR(MedFi) & 180-Day Analog(s)/Test(s)
	2.5 – 3 yrs	Training III & 180-Day Analog(s)/Test(s) & Detail Design & TER & SIR & MCR
System Development Phase	3 – 3.5 yrs	TER & HiFi Simulator(s) Fab
	3.5 – 4 yrs	HiFi Simulator Fab(s) & TRR(HiFi)
	4 – 4.5 yrs	860-Day Analog(s)/Test(s) & Design Maturity
	4.5 – 5 yrs	860-Day Analog(s)/Test(s) & Design Maturity
	5 – 5.5 yrs	860-Day Analog(s)/Test(s) & Design Maturity
	5.5 – 6 yrs	860-Day Analog(s)/Test(s) & Design Maturity
	6 – 6.5 yrs	860-Day Analog(s)/Test(s) & TER & Design Maturity & SRR/MDR/SDR
Production Phase	6.5 – 7 yrs	Training & TER & Design Maturity & PDR
	7 – 7.5 yrs	Training & Final Design
	7.5 – 8 yrs	Final Design & CDR/PRR & Flight Vehicle Production
	8 – 8.5 yrs	Flight Vehicle Production
	8.5 - 9 yrs	Flight Vehicle Production
	9 – 9.5 yrs	SIR & Flight Vehicle Integration
	9.5 - 10 yrs	SAR & Delivery to KSC

3.2 Concept Development Phase (3 yr)

3.2.1 0 - 0.5 yrs

The first six months focus on organization of the project team and initial design work. One of the earliest activities will be a series of training courses to provide project members the hands-on skills necessary for fabrication and testing during the Concept Development Phase. This phase will also include compilation of design data from previous programs. The 60-Day Review [15] is the first major project milestone. It will also be combined with a technical review encompassing design work completed during the first two months.

3.2.2 0.5 - 1 yrs

Initial design and mission architecture work concludes during the second half of the first year. This design work should produce a complete concept for evaluation across the various projects within the program. The mockups and test units are fabricated in time to support Test Readiness Reviews and testing before the end of the fiscal year.

3.2.3 1 - 1.5 yrs

A System Integration Review (SIR) is conducted for test hardware, which may include test chambers, breadboards, low fidelity mockups, analog habitats, etc.

This review is the milestone prior to initiation of hardware fabrication. An Initial Design Review (IDR) is also conducted for the overall system as a precursor to a Preliminary Design Review (PDR) [17] that will occur much later. The IDR sets informal requirements, identifies cost and schedule constraints, establishes a preliminary identification of interfaces, describes the risk management methodology, establishes the basis for evaluation of design options and describes validation and verification methods. The IDR is intended to establish early program structure and allow delay of Mission Concept Review (MCR) [17], SRR, System Design Review (SDR) [17], and PDR in order that an early, extensive design and testing phase can mature vehicle concepts prior to these reviews, thus reducing overall programmatic risk.

Training during this period will expand to include test preparation. Program personnel will be trained to conduct a variety of subsystem and analog tests.

A Test Evaluation Review (TER) [17] is held to assess the scope of medium fidelity and analog testing for the concept development phase. The intent of this testing is to validate the multi-destination architecture and ensure the proper design assumptions have been made throughout the program.

3.2.4 1.5 - 2 yrs

The next six months is focused on fabrication for testbeds, software, prototypes, and medium fidelity analogs. Fabrication and associated support activity is expected to fully occupy the program and project offices. SIRs are held prior to subsystem integration for each medium fidelity spacecraft prototype.

3.2.5 2 - 2.5 yrs

Fabrication work concludes during the first six months of year two and a Test Readiness Review is conducted for all testing. A 180-day analog mission is then initiated for appropriate spacecraft elements. This mission may include integration of multiple elements and parallel tests of different missions. Additional standalone subsystem testing of spacecraft subsystems is also conducted during this period.

3.2.6 2.5 - 3 yrs

While the six-month testing continues, training begins for relevant personnel, with a focus on the skills needed to design, fabricate, integrate, and test high fidelity spacecraft subsystems. Additionally, program and project personnel not directly involved in full time test support will begin to process test data and incorporate preliminary findings into detailed design work for high fidelity subsystems.

Testing work and analog missions conclude during this period and a Test Evaluation Review is held to review results of all tests and disposition any decisions necessitated by test results.

Detailed design work continues at a rapid pace to incorporate test results into high fidelity hardware and software designs, which may include crew trainers, integrated tests, test chambers, operational subsystems, etc. This review is the milestone prior to initiation of high fidelity fabrication.

A MCR is held for the overall project to conclude the concept development phase. By delaying the MCR until after a 180-day medium fidelity testing period, including analog missions and subsystem tests with high fidelity hardware, there is ample opportunity to gain confidence in the mission concept before locking into fixed configurations. As an example of the value of this approach, the NASA Constellation Program had determined essentially at the beginning of the program that the lunar lander and lunar surface habitat would be separate vehicles developed by separate project offices, despite some engineering analysis that suggested the possibility of converting used lander descent stages into a surface habitat. [14] Had their MCR been delayed, there could have been more engineering effort devoted to this integrated lander/outpost concept, potentially saving millions, if not billions of effort that would have been needed had the program continued.

3.3 System Development Phase (3.5 yr)

3.3.1 3 – 4 yrs

The first year of the system development phase begins with a TER to examine test objectives, plans, and scope for an 860-day test period that will occur later in the system development phase. The bulk of the year is devoted primarily to fabrication of high fidelity hardware, including simulators, testbeds, and analog spacecraft prototypes. SIRs are scheduled for each high fidelity spacecraft prototype as they are prepared for subsystem integration. This year concludes with a TRR for the upcoming testing.

3.3.2 4 – 6.5 yrs

The balance of the system development phase is used to conduct the previously mentioned 860-day test period. This duration allows analog mission testing to examine a complete, end-to-end Mars mission concept, including the outbound and inbound cruise periods. In addition to an examination of human performance issues, this will also allow continuous use of subsystem components to reveal lifetime-related issues. In parallel, standalone subsystem testing will also occur during this phase. While testing work continues, design engineers will continue to mature spacecraft designs. A TER will be conducted at the conclusion of this 860-day test period. Lessons learned from testing will feed into requirements development.

The system development phase will conclude with a combined Mission Definition Review (MDR) [17], SRR, and SDR. Essentially, the projects will have by this time determined the desired final system configuration and the requirements are written to reflect what has been designed

These reviews are positioned after an extensive design and testing period to the program to combat important issues that frequently occur in major aerospace and defense acquisitions. A 2006 investigation by the Government Accounting Office determined that billions of dollars in cost growth in DOD space acquisitions were primarily due to a pattern of starting programs before knowing if requirements could be achieved within available resources. They further noted that this pattern was primarily due to pressures the DOD faced to secure funding. [26] This is a key problem throughout aerospace and defense acquisitions. The traditional paradigm for a major, multi-billion dollar program is to issue a contract, which provides the lobbying base to protect funding in Congress. In order to award a contract, there must be a set of requirements upon which to base the contract, hence the rush. But because the requirements are developed so early, there are usually inherent flaws in the requirements that require cost growth to accommodate. This program will instead design to available resources and will have sufficient insight by the time of SRR to give high confidence that the requirements can be met within available resources.

3.4 Production Phase (3.5 yr)

3.4.1 6.5 – 7 yrs

The first six months of the production phase begin with training related to manufacture of flight hardware in parallel with a design maturity cycle leading up to PDR at the end of year seven.

Typically, the PDR is employed at a point in a program where it cannot possibly satisfy its intended objectives. A PDR should show that the proposed design is expected to achieve its objective. In 2009, NASA completed the PDR for the Orion capsule. [12] Despite the fact that the PDR assessed a vehicle design that was described as “much more mature than you might see on many programs at the PDR checkpoint,” [12] the overall architecture surrounding the use of Orion was not stable. It has since changed and none of the three missions it was evaluated to perform (flights to the International Space Station, weeklong missions to the Moon, and missions to the Moon for up to 210 days) exist today. Further, many Orion systems still lack definition. An example of this is the crew exercise system and it has never been clear that Orion can accommodate exercise needs for any mission other than the extremely short duration flights to the International Space Station that the vehicle will no longer support.

More recently, NASA recently completed a successful PDR for the Space Launch System [19]. The SLS is intended to provide the flexibility to launch spacecraft for crew or cargo missions, including to an asteroid or Mars. However, there are basic questions that cannot be answered at this point. What are the dimensions, mass, and c.g. of the various spacecraft that would need to be launched as cargo for a Mars surface base? A Mars transit vehicle? An asteroid transit vehicle? Do they launch as a single unit or are they integrated at some location in space? How many SLS launches are required for each manned expedition? These questions are unknowable because these vehicles and their associated architectures have not yet been baselined. So while the SLS is an impressive rocket in its own right, there is no way of knowing if it is the right rocket for the job.

Placing the PDR of an integrated architecture closer to the initiation of actual production allows more design iteration and component and integrated testing, thus increasing the probability that the requirements and design will be appropriate to the mission.

3.4.2 7 – 8 yrs

Year seven of the development schedule completes final design activity. Design work will mature the high fidelity products tested in the System Development Phase into their flight configurations. Flight hardware training programs conclude by the end of the second quarter.

In the third quarter a CDR is held in conjunction with a Production Readiness Review (PRR) [17] for the in-house production of proto-flight hardware. At this point the design is frozen and flight vehicle production begins. In the fourth quarter additional PRRs are held for all companies awarded production contracts for follow-on flight hardware units.

3.4.3 8 – 10 yrs

Manufacture of proto-flight hardware continues in year eight and concludes within year nine. Each spacecraft is subjected to qualification and acceptance tests as it proceeds through production. SIRs will also be held for each spacecraft as it is ready to begin integration of subsystems and components. The final six months are used to conduct System Acceptance Reviews (SAR) [17] for each proto-flight spacecraft and begin shipment to Kennedy Space Center for launch processing.

4 Operations

Operational Readiness Reviews (ORRs) [17] and Flight Readiness Reviews (FRRs) [17] are held for each spacecraft prior to launch.

Flight operations may include up to two surface outposts (Lunar and Mars Outposts), two deep space transit vehicles (Mars Transfer Vehicle and Deep Space Vehicle), one space station (captured NEA), and one or more transfer spacecraft (lunar or Mars lander or Earth launch vehicles delivering component spacecraft) in operation at any given time. Because these systems are composed of common spacecraft elements, Mission Control operations will be less complex than if all of these were unique developments.

A mission control team involving a combination of Flight Control Rooms (FCRs), Multi-Purpose Support Rooms (MPSRs), and a single Mission Evaluation Room (MER) provides operational support. Due to the commonality in elements and subsystems, given personnel may be able to support multiple vehicles.

The MER is largely staffed by project engineers and maintains subsystem performance data for incorporation into future design iterations as additional spacecraft are manufactured, whether internally or via production contracts. The MER also maintains configuration records for each spacecraft.

Project engineers continue in-house production until all in-house follow-on units have been delivered for launch processing.

5 Termination

5.1 NASA Data Archival

Both the program and individual project offices include personnel responsible for archiving lessons learned throughout the life of the program. [20] This data is continuously maintained such that when the program reaches the end of its life cycle a complete data package will exist to fully document the program from inception through termination.

5.2 Hardware Disposition

Any items identified as critical for support of active flight operations will be retained on-site for utilization. Items not deemed critical will be assessed for disposition options.

Items with identified value for companies awarded production contracts will be transitioned to the associated companies. Remaining items with identified value for new NASA programs will be transitioned to those programs. Remaining items identified as useful for hardware training will be transitioned to relevant NASA divisions. Remaining items will be available to NASA facilities for selection of display items. Remaining items with historic or educational value will be transitioned to museums and schools. Remaining items will be transitioned to excess and disposal.

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