Program Organization of a Multi-Destination Human Space Flight Architecture

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Abstract - *One of the greatest sources of cost for any engineering enterprise is the labor cost of the associated workforce. Organization of a family of spacecraft within a low-cost, in-house, multi-destination, short development cycle framework requires a highly efficient program structure. This paper describes the composition of a proposed program office and subordinate project offices capable of executing such an initiative. It will describe at a high level the working relationships between the various project offices and the program office, as well as between the program and key external NASA programs. It further defines roles and methods for commercial collaboration and international participation.*

Keywords: Program management, systems engineering, human spaceflight, Moon, Mars, Asteroids, 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 Program and Project Offices in Human Spaceflight

NASA institutes program and project offices in order to organize its implementation of national priorities through the Agency's Mission Directorates as shown in figure 1. [9]

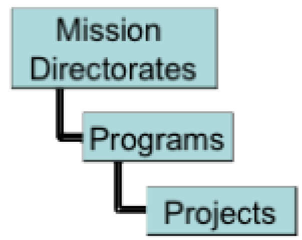

Figure 1. NASA Programmatic Authority Organizational Hierarchy

In the final days of the Constellation program, the Planetary Society criticized Constellation as being bloated. [6] However, this is not a new sentiment for NASA programs. President Eisenhower criticized President Kennedy's decision to approve the Apollo program in the 1960s, stating "This swollen program, costing more than the development of the atomic bomb, not only is contributing to an unbalanced budget; it also has diverted a disproportionate share of our brain-power and research facilities from other equally significant problems, including education and automation." [5] This critique has persisted throughout NASA's existence and it is common to see perceptions in space-related editorials that NASA has become a "bloated government program." [16]

Incumbent with this perception of NASA programs as having become bloated is an infighting where any given human spaceflight proposal is immediately resisted by space advocates who have their sights on any other destination, because they believe any human spaceflight pursuit will be at the expense of all others. The *Bay Area Houston Today* claimed in an editorial that "It's been estimated that such a lunar base [referring to the US House sub-committee on Space's proposal for NASA to return to the Moon] would cost up to $500B, and with current funding levels it would take half a century, effectively ending our dreams of going to Mars." [10]

This is at root a program management and systems engineering problem. It can be shown that there are credible rationales for all of the primary human space flight destinations [8], [13], [17] but if each destination forces the abandonment of the others then there can be no solution. Any attempt to pursue any destination will immediately trigger intense attacks from advocates of the others, seeking to discredit the program. Thus, the program management challenge is to develop a program organization strategy that can effectively manage multi-destination human spaceflight architectures. Inherent to this approach is an acquisition strategy that involves NASA building systems in-house, with production contracts only used for follow-on hardware. [12]

While this paper may propose unique program and project management structures, it is by no means an attempt to replace or deviate from NPR 7120, NASA Space Flight Program and Project Requirements. This NPR is applicable to all NASA space flight programs, but contains guidance that allows extensive tailoring to meet the needs of specific programs and projects. [9]

1.2 Program Structure

This paper proposes a Multi-Destination Human Space Flight Program Office (MDHSF-PO) as the program body that organizes the multiple destination approach for exploration of Near Earth Asteroids, the lunar surface, Mars, and its moons.

Each project is organized around a family of spacecraft. [11] The following five project offices will produce the spacecraft used to execute the multi-destination program. Each project office is an in-house team

- Power, Thermal & Propulsion Project Office (PTPPO)
- Habitat Project Office (HPO)
- Scout Vehicle Cabin Project Office (SVCPO)
- Destination Propulsion Project Office (DPPO)
- Resource Utilization Project Office (RUPO)

2 Program and Project Staffing

2.1 Program Office Staffing

The Working Group recommends a Program Office staff of 86 full time equivalent (FTE) persons, as indicated in table 1. For purposes of this paper, FTE is inclusive of all employees, whether civil servant, contractor, international, or other. It indicates the number of full time equivalent persons for a given program office function, which could suggest either a single person at 100% of their time or a combination of people at fractional elements of time. (1 FTE could equal one person working 40 hours per week on a given position or two people each working 20 hours per week on that same position.)

A significant percentage of the Program Office (35 FTE) is dedicated specifically to manage program interaction with external entities, particularly oversight and partnering entities.

Another significant attribute is that 10 FTE are dedicated to training instructors. As will be described later in this paper and in other papers, the approach for this program involves significantly more hands-on work from program and project staff, which implies a need for skills development within the workforce.

Also, 15 FTE are dedicated to test and verification. While there will be some test and verification staffing at the project level, including both dedicated staff as well as test and verification work performed by project engineers, the program provides test and verification expertise for the entire architecture.

Table 1. Program Office Staffing

FTE	Position
1	Program Manager
2	Deputy Program Manager
1	Chief Engineer
1	Chief Scientist
3	Systems Engineering & Integration
5	Risk Managers
1	Safety Lead
10	Training Instructors
15	Test & Verification
2	Budget Analysts
3	Secretaries
3	Facilities Coordinators
4	Mission Directorate Liaisons
6	Industry Liaisons
1	International Liaison
8	Congressional Liaisons
10	Center Liaisons
1	Mission Operations Liaison
1	Ground Operations Liaison
1	Partnerships Liaison
1	MPCV Liaison
1	SLS, Commercial and International Launch Vehicle Liaison
1	Launch Services Liaison
1	Education / Outreach Coordinator
1	Attorney
1	Lessons Learned Archivist
1	Marketing Coordinator

As should be obvious at this point, this paper attempts to characterize a workforce size and accompanying management approach through a bottoms-up accounting of personnel. One could easily argue for variations in how the FTE are allocated. It is important to not attach a religious dogma to the exact accounting of personnel. One might argue, for instance, that the relative ratio of Systems Engineering and Integration personnel to the number of Risk Managers should shift in one direction or another. Or one might have a differing argument for the exact number of electrical engineers. What is more important is to understand that the costs of the program are driven by the personnel costs and an effective bottoms-up analysis is needed to define the program workforce size and enable trades when necessary to remain within cost margins. Rigorous task analyses should be used to ultimately draft final workforce allocations. Until such time, the NSBE recommendations stand as an example allocation that can be used to implement the multi-destination human space flight architecture.

2.2 Project Office Staffing

Each project office is composed of a management team and up to 17 spacecraft discipline teams. On the average, this sums up to a total workforce of 184 FTE per project. The project office management team is described in table 2.

Table 2. Project Office Management Team

FTE	Position
1	Project Manager
1	Deputy Project Manager
1	Chief Engineer
1	Systems Engineering & Integration
2	Risk Managers
3	Training Instructors
2	Test & Verification
2	Budget Analysts
2	Secretaries
1	Lessons Learned Archivist

Each project office will also be staffed with science and engineering technical experts organized into spacecraft discipline teams, representing the spacecraft subsystems. In some cases a particular discipline may not apply to a project and will therefore not be included in that project office's discipline teams. The following are the nominal discipline teams:

- Thermal Control
- Environmental Control and Life Support
- Crew Equipment
- Guidance Navigation and Control
- Power
- Spacecraft Module or Bus Shell/Frame
- Extravehicular Activity
- Robotics
- Propulsion
- Docking
- Command and Data Systems
- Communications
- Exercise
- Stowage and Cargo
- Science
- Workstations
- Crew Stations

Each team is staffed as relevant with engineers and scientists from the following list of knowledge domains: materials, structures, mechanisms, fluids, electrical, electromagnetic, human factors, safety, software, dynamics/controls, radiation, flight controllers, MMOD, medicine, life science, physical science, space science, psychology, physiology, and orbital mechanics.

2.2.1 Funding Profile

In concert with a fixed development timeframe, the budget is tightly controlled. It is a myth that anything designed to go into space must cost billions of dollars.

From the late 1990s to early 2000s, NASA pursued development of the X-38 project in an effort to prove this point. The X-38 employed an in-house, rapid prototyping strategy to achieve development of a human-rated spacecraft faster and at a fraction of the cost of previous projects. The NASA Independent Program Assessment Office and NASA Office of Inspector General both concurred that this approach was high risk but achievable, with the potential to save up to $1 billion over traditional approaches. [14]

The small team of 220 engineers and technicians [7] was responsible for most aspects of the vehicle's development with some items outsourced via small contracts. For instance, Aerojet was awarded a contract of only $16.4 million to design and build the de-orbit propulsion module. Options for a second test unit and five operational units would have had a total value of $71.9 million. [4] At the point of the X-38's cancellation, it had spent approximately $500 million (approximately $646 million in 2012 dollars [15] based on production worker compensation) and was months shy of its first orbital spaceflight test. [2] This lean, low cost approach will be mirrored by the multi-destination human spaceflight program office.

The Program will receive a flat annual budget of $300 million, adjusted annually for inflation and labor cost of living adjustments. This budget is divided evenly between the Program Office and its five constituent Project Offices, each receiving $50 million a year.

As previously discussed, the Program Office has a staff of 86 FTE, which equates to $17.2M. The Program Office retains a $0.172M procurement allocation. (Procurement only denotes purchases and other non-labor fees.) The remaining $32.628M is a Program reserve budget that can be allocated within the Program Office or to any Project as needed.

Each Project Office has a staff of 184 FTE, equating to $36.8M. This leaves $13.2M available for Project Office procurement. This ratio reflects the nature of each project as an in-house development effort. The personnel reflected by the 184 FTE are not managers of contracting teams, but are in fact the actual individuals engaged in the design, fabrication, and testing.

A somewhat "out of the box" funding measure is the recommendation for the Program Office and each Project Office to have unrestricted rollover capability. This denotes a financial process whereby the program or project retains control over all of its funds, regardless of whether they are spent by the end of the fiscal year. Any unspent funds can be retained for as long as necessary, allowing projects to "bank" funding to augment more expensive future years. This rollover is indefinite through the program life cycle (there is no limit to the number of years funds may roll over) and may not be used as justification to reduce the annual funding. For instance, if a project spends only $30M each of the first four years, it has banked $80M and therefore has available $130M in the fifth year. In effect, each project is guaranteed a total ten-year budget of exactly $500M and will receive $50M of which per year. This empowers a project manager to "save up" for some of the greater expenses incurred closer to flight and reduces the tendency to "spend out" the budget at the end of the fiscal year to prevent the loss of budget in future years.

Rollover will also help to curtail inefficient end of year spending. A recent study of $130 billion of federal information technology contracts revealed that spending in the last week of the fiscal year was 4.9 times greater than the weekly average. [3] This spending is actually necessary for Federal agencies under current budgeting policies because an agency that fails to spend its entire budget is subject to having that budget reduced in subsequent fiscal years. However, a pattern of such spending inherently increases the cost of any complex endeavor such as human spaceflight.

This funding profile deviates from the traditional NASA annual appropriations cycle, which requires some additional systems engineering practices to avoid bypassing the legislative oversight powers of Congress. These are detailed in a systems engineering approach for the Program involving Congressional Decision Points (CDPs). [12]

3 Commercial and International Collaboration

While this Program is described as an in-house effort, that does not exclude commercial and international direct collaboration and involvement.

An open development approach is pursued, whereby vehicle development data is shared openly with all companies and countries eligible to receive US technical data. This includes open access to all US companies eligible to participate in federal contracting and grant programs and to all countries not barred by Congress or the State department from exchanging dual use technologies with United States.

However, given that a key purpose of the program is to build skills of the NASA workforce, NASA civil servants are directly involved in all aspects of the program and no elements or subsystems are completely outsourced to international or commercial partners. Engagement of commercial and international partners is instead achieved by integrating both into program and project teams.

3.1 Mixed Government, Industry, International Program Staffing

The program operates in a relatively "badgeless" environment with NASA civil servants, corporate employees, and international space agency employees working side by side. A baseline staffing percentage allocation is defined to ensure participation levels as follows:

- 60% NASA Civil Servants

- 10% NASA institutional contractors

- 10% Commercial companies (including a mandatory 30% US small businesses as a forcing function to grow the commercial spaceflight industry)
- 20% International government partners

Allocation of specific positions is a function of NASA negotiation with commercial and international partners, subject to the limitation that the Program Manager is a NASA civil servant, one Deputy Program Manager is commercial, and the other Deputy Program Manager is international. It is a safe assumption that not all project managers will be NASA civil servants. All program and project staff will be answerable to the Program Manager, not to their institutional line management, for the duration of their involvement with the Program.

English is the official design language and the design work of international partners must be completed in English. Translators are not provided by Program Office funding, but international partners may supply translators at their own expense to replicate design data into native languages.

With respect to English or metric units, design and manufacturing concerns will drive the use of specific units, but design data will be documented in all applicable units of both standards.

3.2 Production Contract Potential

While the Program is primarily an in-house development activity, the potential does exist for some production contracts. Depending on the total number of flight units of any given spacecraft element, the Program may build all units in-house or may issue production contracts for some additional flight articles. [12] Such a contract could be issued to either US companies or international partners.

The Project Offices most likely to issue production contracts due to the relatively large number of vehicles needed include the Scout Vehicle Cabin, Destination Propulsion, and Resource Utilization offices. Additionally, the Program will contract a significant number of commercial logistics modules.

Regardless of whether production contracts are issued or not, all companies and nations employed within the Program will have access to sufficient design data to produce any units desired for unrelated initiatives. This would, for instance, enable a participating company to spin off a commercial asteroid mining venture, leveraging design data for the Deep Space Vehicle to produce spacecraft to be used by potential mining companies. With the development work conducted by the Program and lessons learned from initial NASA expeditions, the operational risks will be greatly reduced for any commercial ventures to the Moon, Mars, or Near Earth Asteroids.

3.3 Program Personnel Location

Program personnel will be primarily located at NASA centers. The specific location of individual team members strategically maximizes use of existing NASA facilities and is consistent with anticipated program needs (e.g. fabrication or testing facilities, etc.). In some cases this may require some civil servant extended TDY in cases where a period of activity involves fabrication not at the civil servant's home center. This is especially true during periods of activity at remote NASA facilities (e.g. Michoud, White Sands, Wallops, etc.). Commercial and international partners are responsible for relocation of their Project personnel to the assigned NASA center. Non-NASA facilities will only be used when equivalent functionality does not exist at NASA facilities or where significant cost or schedule benefits result from the use of the facility.

4 Coordination within Program

Obviously, with five different Project Offices each developing a family of component spacecraft to operate in multiple space environments coordinating within the Program is of the highest priority. Several mechanisms are recommended for the Program's use to maintain open lines of communication and coordination.

4.1 Program Management Forum

The highest level coordination is the Program Management Forum. This is led by the Program Manager and includes the Deputy Program Managers along with the Project Manager and Deputy Project Manager from each project.

This forum meets weekly to monitor the overall progress of the program and negotiate any actions across project interfaces. It effectively serves as a control board for any formal decisions that impact multiple projects.

4.2 Program Systems Engineering Forum

The Program Systems Engineering Forum is led by the Program Chief Engineer. It meets monthly and includes all Chief Engineers and SE&I personnel across projects and program office. The forum monitors systems engineering performance of the Program and polices compliance with NASA standards, procedures, and applicable regulations.

4.3 Program Risk Management Forum

The Program Risk Management Forum is led by the Lead Risk Manager. It meets monthly and includes all Risk Management personnel across projects and program office.

Subject matter experts, outside personnel, and program and project office staff are also invited where warranted by topic. The forum monitors all forms of risks across the program and ensures appropriate measures are put in place for their management. [1]

4.4 Communities of Practice

Engineers within the program will all belong to Communities of Practice, organized by knowledge domains – the same domains from which each Project Office's Spacecraft Discipline Teams draw their personnel. For instance, the Human Factors Community of Practice consists of all of the human factors engineers working in the various subsystems of all five projects. The same is true for Materials, Fluids, Safety, Risk Management, Software, Orbital Mechanics, etc.

The role of the Communities of Practice is to promote commonality across programs. Using the Human Factors Community of Practice again as an example, they will establish common standards, techniques, approaches, and tools across the Program. This ensures, for instance, that Human Factors approaches, procedures, paradigms, etc. in the Scout Vehicle Cabin Project are not fundamentally alien to those in the Habitat Project.

The community provides a forum for peer-to-peer sharing of best practices and lessons learned and discussion of technical challenges. It also provides a gateway for the engagement of domain subject matter experts from outside the program (e.g. other NASA, international, commercial, academia, etc.). Each Community of Practice meets bi-weekly and in addition to its assigned personnel, it is attended by relevant program or project office staff as needed.

4.5 Training Forum

The Training Forum is composed of program and project level training instructors. It is responsible for monitoring and evaluating workforce readiness for upcoming technical activity. It also organizes and implements a workforce training curricula to ensure such readiness. It should be noted that this forum is focused specifically on training related to hands-on development skills such as soldering, welding, CAD Modeling, wiring installation, metalworking, etc., as compared with an institutional training office that would typically be more focused on leadership or management classroom-setting instruction. The Training Forum meets monthly and is attended by relevant program or project office staff as needed.

4.6 Test and Verification Forum

The Test and Verification Forum is composed of test and verification personnel across the Program Office and all Projects. This forum establishes the overall Program strategy for testing. It develops or approves all test and evaluation protocols used within the Program. It also oversees all Test Readiness Reviews and coordinates Institutional Review Board (IRB) approvals for Program activity. The forum meets monthly, but can meet more frequently for special actions surrounding major test phases or test anomaly investigations.

4.7 Program Technology Review Forum

The Program Technology Review Forum is a multi-day forum held quarterly. It is co-chaired by the Deputy Program Managers. The forum provides program-wide technical updates including reviews of current configurations, upcoming work, and identified technical challenges. The forum includes mandatory peer review by external stakeholders. The primary purpose of the forum is to identify areas of technical risk and ensure proper attention is applied to resolution of technical issues.

5 Conclusions

This paper proposes an organizational structure for a NASA Program Office to manage an international, multi-destination human spaceflight architecture that includes missions to the Moon, Mars, and Near Earth Asteroids. It tackles the challenge of labor costs with a tightly controlled, small, in-house workforce that is responsible for direct performance of developmental activity instead of providing management oversight to contractor teams. It provides a structure for both internal and external communication and coordination, devoting significant manpower to maintaining an open flow of information to stakeholders. It further demonstrates how a NASA in-house program can also serve commercial and international interests.

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