Tailoring Systems Engineering Projects for Small Satellite Missions

Stephen Horan and Keith Belvin
NASA Langley Research Center
Hampton, VA 23681
UNITED STATES

stephen.j.horan@nasa.gov / w.k.belvin@nasa.gov

ABSTRACT

NASA maintains excellence in its spaceflight systems by utilizing rigorous engineering processes based on over 50 years of experience. The NASA systems engineering process for flight projects described in NPR 7120.5E was initially developed for major flight projects. The design and development of low-cost small satellite systems does not entail the financial and risk consequences traditionally associated with spaceflight projects. Consequently, an approach is offered to tailoring of the processes such that the small satellite missions will benefit from the engineering rigor without overly burdensome overhead. In this paper we will outline the approaches to tailoring the standard processes for these small missions and describe how it will be applied in a proposed small satellite mission.

1.0 INTRODUCTION

The National Aeronautics and Space Administration (NASA) project management requirements for space flight projects is described in the NASA Procedural Requirements (NPR) document NPR 7120.5E [1]. This document outlines the necessary design reviews and project documentation required for flight projects conducted by the Agency. The process prescribes design and development activities that depend upon the criticality of the mission type with those missions of highest criticality requiring the most extensive engineering rigor. While the cost of applying all the processes of NPR 7120.5E is acceptable for human-rated missions or missions with significant national investment, the use of all the processes is often viewed as excessive for smaller, higher-risk mission designs. With smaller missions often having a technology development emphasis, such as a microsatellite mission with short development time and short mission duration, mission designers question the NPR 7120.5E process even further.

Small satellite missions frequently have mission life cycle costs and mission durations that are inconsistent with NPR 7120.5E requirements. The engineering and flight project community at Langley Research Center (LaRC) has been working to develop a method to tailor the NPR 7120.5E processes to meet the needs of these smaller missions and still provide adequate oversight over mission design and execution [2]. As part of this activity, LaRC has defined project "Types" described in Figure 1 that take into account not only project costs, but also acceptable risk. In this paper, we will look at the process used at LaRC to tailor the engineering and design activities to smaller missions; the Type A through Type C missions are not subject to this process.

	Type A	Type B	Type C	Type D	Type E	Type F
Description of the Types of Mission	Human Space Flight or Very Large Science/Robotic Missions	Non-Human Space Flight or Science/Robotic Missions	Small Science or Robotic Missions	Smaller Science or Technology Missions (ISS payload)	Suborbital or Aircraft or Large Ground based Missions	Aircraft or Ground based technology demonstrations
Priority (Criticality to Agency Strategic Plan) and Acceptable Risk Level	High priority, very low (minimized) risk	High priority, low risk	Medium priority, medium risk	Low priority, high risk	Low priority, high risk	Low to very low priority, high risk
National Significance	Very high	High	Medium	Medium to Low	Low	Very Low
Complexity	Very high to high	High to Medium	Medium to Low	Medium to Low	Low	Low to Very Low
Mission Lifetime (Primary Baseline Mission)	Long. >5 years	Medium. 2-5 years	Short. <2 years	Short. <2 years	N/A	N/A
Cost Guidance (estimate LCC)	High (greater than ~$1B)	High to Medium (~$500M - $1B)	Medium to Low (~$100M - $500M)	Low (~$50M - $100M)	(~$10-50M)	(less than $10-15M)
Launch Constraints	Critical	Medium	Few	Few to none	Few to none	N/A
Alternative Research Opportunities or Re-flight Opportunities	No alternative or re-flight opportunities	Few or no alternative or re-flight opportunities	Some or few alternative or re-flight opportunities	Significant alternative or re-flight opportunities	Significant alternative or re-flight opportunities	Significant alternative or re-flight opportunities
Achievement of Mission Success Criteria	All practical measures are taken to achieve minimum risk to mission success. The highest assurance standards are used.	Stringent assurance standards with only minor compromises in application to maintain a low risk to mission success.	Medium risk of not achieving mission success may be acceptable. Reduced assurance standards are permitted.	Medium or significant risk of not achieving mission success is permitted. Minimal assurance standards are permitted.	Significant risk of not achieving mission success is permitted. Minimal assurance standards are permitted.	Significant risk of not achieving mission success is permitted. Minimal assurance standards are permitted.
Examples	HST, Cassini, JIMO, JWST, MPCV, SLS, ISS	MER, MRO, Discovery payloads, ISS Facility Class payloads, Attached ISS payloads	ESSP, Explorer payloads, MIDES, ISS complex subrack payloads, PA-1, ARES 1-X, MEDLI, CLARREO, SAGE III, Calipso	SPARTAN, GAS Can, technology demonstrators, simple ISS, express middeck and subrack payloads, SMEX, MISSE-X, EV-2	IRVE-2, IRVE-3, HiFIRE, HyBoLT, ALHAT Earth Venture I	DAWNAir, InFlame, Research, technology demonstrations

Figure 1: NASA mission classification types from highest to lowest criticality [2].

2.0 TAILORING PROCESS

It is NASA policy that all prescribed requirements of NPR 7120.5E are complied with unless relief is formally granted. Policy also recognizes that each program or project has unique aspects that must be accommodated to achieve mission success in an efficient and economical manner. Tailoring is the process used to adjust or seek relief from a prescribed requirement to meet the needs of a specific program or project. Tailoring is both an expected and accepted part of establishing proper requirements. The request for relief from a requirement includes the rationale, a risk evaluation, and reference to all material that provides the justification supporting acceptance.

The shift in emphasis from large missions with long development cycles to small missions with rapid development cycles requires a shift in philosophy towards a "lean thinking" approach as recommended in [3]. This does not mean throwing out engineering processes but appropriately adapting them to the needs of the small mission environment.

The tailoring process described herein attempts to balance the needs and scope of the smaller mission with the need for management oversight and adequate engineering discipline. The process starts with the required steps in the NPR 7120.5E process and then suggests levels of compliance based on the mission type. The levels of tailoring compliance are listed in Table 1. While the tailoring tool has pre-suggested levels of compliance, none of these levels is automatically granted. The project team will need to justify that the suggested compliance level for each project is appropriate and either engineering management or the project may require greater rigor if it is believed that the oversight level is necessary to assure project success.

Table 1: Basic tailoring definitions to apply to the process (based on [2]).

Tailoring Term	Meaning
Blank/Empty	Required Element for the project.
Tailor Down	Decrease the level of detail, formality, and rigor required based on the project’s size, complexity, and acceptable risk or the requirement may be captured/met by the fulfilment of another requirement.
Tailor Out	Seek relief from the requirement based on the project’s size, complexity, and acceptable risk. This may require a waiver.
N/A	Not applicable. The requirement is not relevant to the project type.
Project Plan	The intent of the requirement can be met and documented within the project plan.
TOR	The intent of the requirement can be documented within the project Terms of Reference.
HQ/Center	Used to identify the recommended level of decision authority.

The suggested tailoring levels for the NPR 7120.5E processes are given in Table 2 and Table 3. The technical and management work products are given first by mission type and then decision points and flight system management plans. In both tables, if the entry under the mission type is blank, then that element is still required in the tailored process. The non-blank entries show where a tailoring down or tailoring out of the usual requirement is suggested. For some mission types, entries may even be suggested to be not applicable for the mission. As mentioned above, these are suggested starting points but the final tailoring level must be justified by the project.

The Key Decision Points (KDPs) typically found in a project have split responsibility between NASA Headquarters (HQ) and the implementing NASA Center rather than all being at HQ as in the larger projects. Because HQ funding is the usual initiator of a project, the initial Key Decision Point (KDP), A, remains with the responsible HQ Directorate for sponsoring the project.

The NASA process requires several formal reviews tied to the KDPs and the flight process. The tailoring of these review levels is shown in Table 4. This includes the KDP reviews and the technical reviews found in a typical process. In these reviews, the project peer reviews are required and not tailored down. As with the technical work products, the tailoring of the reviews is suggested and negotiated with engineering management. A project may, for example option to hold a combined System Requirements Review and Mission Definition Review in place of tailoring out the MDR if engineering management and the project believe that this will lead to a higher probability of mission success.

Table 2: Suggested tailoring levels for the 7120 management processes [2].

Project Technical Products	Type D	Type E	Type F
1. Mission Concept Report	Tailor Down	Tailor Down	Tailor Down
2. System Level Requirements			Tailor Down
3. Preliminary Design Report		Tailor Down	Tailor Down
4. Mission Operations Concept		Tailor Down	Tailor Down
5. Technology Readiness Assessment	Tailor Out	N/A	N/A
6. Missile System Pre-Launch Safety Package			N/A
7. Detailed Design Report		Tailor Down	Tailor Out
8. As-Built Hardware and Software Documentation			Tailor Down
9. Verification and Validation Report	Tailor Down	Tailor Down	Tailor Down
10. Operations Handbook		Tailor Down	Tailor Out
11. Orbital Debris Assessment		N/A	N/A
12. Mission Report	Tailor Down	Tailor Down	Tailor Down
Project Planning, Cost, and Schedule Products			
1. Work Assignment for next phase		Tailor Down	Tailor Out
2. Integrated Baseline	Tailor Down	Tailor Down	Tailor Out
3. Project Plan		Tailor Down	Tailor Down
4. CADRe	Tailor Out	N/A	N/A
5. Planetary Protection Plan		N/A	N/A
6. Nuclear Safety Launch Approval Plan		N/A	N/A
7. Business Case for Infrastructure	N/A	N/A	N/A
8. Range Safety Risk Management Plan		N/A	N/A
9. Systems Decommissioning/Disposal Plan		N/A	N/A

Table 3: Suggested tailoring levels for the 7120 management processes (cont.) [2].

Key Decision Points (KDP)	**Type D**	**Type E**	**Type F**
KDP A	HQ	HQ	HQ
KDP B	Center	Center	Center
KDP C	HQ	HQ	Center
KDP D	Center	Center	Center
KDP E	Center	Center	Center
KDP F	Center	Center	Center
Project Planning, Cost, and Schedule Products			
1. Technical, Schedule, and Cost Control Plan	Project Plan	Project Plan	Tailor Out
2. Safety and Mission Assurance Plan		Tailor Down	Tailor Out
3. Risk Management Plan	Project Plan	Project Plan	Tailor Out
4. Acquisition Plan	Project Plan	Project Plan	Tailor Out
5. Technology Development Plan	Project Plan	Tailor Out	Tailor Out
6. Systems Engineering Management Plan	Tailor Down	Tailor Down	Tailor Down
7. Software Management Plan		Project Plan	Tailor Down
8. Review Plan	Project Plan	TOR	Tailor Out
9. Mission Operations Plan		Tailor Down	Tailor Down
10. Environmental Management Plan	Project Plan	Project Plan	Tailor Down
11. Logistics Plan	Project Plan	Review Material	Tailor Out
12. Science Data Management Plan	Project Plan	Project Plan	Tailor Out
13. Information and Configuration Management Plan	Project Plan	Project Plan	Tailor Down
14. Security Plan	Project Plan	Project Plan	Tailor Down
15. Export Control Plan	Project Plan	Project Plan	Tailor Down

Table 4: Suggested tailoring of project technical reviews [2].

Technical Review	Type D	Type E	Type F
LaRC 60-day review			
Mission Concept Review	Tailor Down	Tailor Down	Tailor Down
System Requirements Review	Tailor Down	Tailor Down	Tailor Down
Mission Definition Review	Tailor Out	Tailor Out	Tailor Out
System Definition Review	N/A	N/A	N/A
Preliminary Design Review		Tailor Down	Tailor Out
Critical Design Review		Tailor Down	Tailor Out
Production Readiness Review	Tailor Out	Tailor Out	Tailor Out
System Integration Review	Tailor Down	Tailor Out	Tailor Out
Test Readiness Review		Tailor Out	Tailor Out
System Acceptance Review		Tailor Down	Tailor Out
Operational Readiness Review	Tailor Down	Combine with FRR	Combine with FRR
Flight Readiness Review		Combine with ORR	Combine with ORR
Post-Launch Assessment Review	Tailor Down	N/A	N/A
Critical Event Readiness Review		N/A	N/A
Post-Flight Assessment Review	N/A	N/A	N/A
Decommissioning Review		N/A	N/A
Periodic Technical Review			
Technical Peer Reviews			
LaRC Lessons Learned Outbrief			

3.0 APPLICATION EXAMPLE

An example of applying this process is currently under development at LaRC where we are developing a scientific microsatellite project to advance modelling of cosmic ray effects. A key component of the mission design is to instruct engineers, scientists, and support staff in the relevant design and review processes from NPR 7120.5E but tailored for the mission context.

The particular mission is called the *Radiation Dosimetry Experiment* (*RaD-X*) and it is competing as part of NASA's Hands-On Project Experience (HOPE) program for early-career professionals. *RaD-X* will fly a test mission on a high-altitude balloon to advance the space readiness of the technology involved in the science measurement and prepare the basic microsatellite infrastructure for an eventual space operation. We are basing this process on a similar mission described in [4]. If NASA selects the mission for implementation, then the total mission cost will be approximately $2.25M, the mission total life cycle time will be 18 months, and the flight time will be one day. This description fits with mission Type E or Type F, with the latter being the preferred classification. The final determination will be negotiated as part of the selection in the proposal competition.

As part of the mission development process, the *RaD-X* team needs to review the tailoring process outlined here and make suggestions to Center management for the approach that will apply to their mission. This process will start with a 4-hour seminar on the tailoring approach conducted by the Chief Engineer's office from the Engineering Directorate. Because of the short development time, the instruction and starting the tailoring process will occur before NASA HQ announces the mission award. Because one of the goals of the HOPE program is to provide early-career professionals experience with this type of smaller flight project that will give them the basis to understand the needs of larger missions, the tailoring process is one of the key educational points in the *Rad-X* development concept.

4.0 CONCLUSION

With continuing advances in technology, low cost small satellite systems could perform many of the missions currently achieved by large expensive spacecraft and instruments. To realize the full cost benefits of small spacecraft, the engineering and development processes must be appropriate to the risks (cost, technical and schedule). The challenge is to use risk-informed decision making to select the technical and management processes such that the small satellite missions will benefit from the engineering rigor without overly burdensome overhead.

Instead of developing new systems engineering processes from the bottoms-up, this paper suggests that tailoring of tried-and-true methods such as those found in NPR 7120.5E is a more rational approach. Specific steps to tailoring of the "normal" systems engineering activities for small satellite missions are offered. This tailoring approach is now being used for the proposed *Radiation Dosimetry Experiment* (*RaD-X*) which is competing for selection as part of NASA's Hands-On Project Experience (HOPE) program for early-career professionals.

5.0 REFERENCES

[1] National Aeronautics and Space Administration, *NASA Space Flight Program and Project Management Requirements*, NPR 7120.5E, August 14, 2012, http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7120&s=5E .

[2] Langley Research Center, *LaRC NPR7120.5D and NPR7123.1A Tailoring Guidelines (Baseline 1)*,

http://engineering.larc.nasa.gov/ .

[3] Hunyadi, G., Ganley, J., Berenberg, L., and Henrikson, E., *The AFRL/STP Nanosat-2 Mission on Delta IV Heavy: A Demonstration of Current Responsive Space Capabilities*, Proc. 2005 IEEE Aerospace Conference (Paper #1169), Big Sky, MT, March 2005.

[4] Horan, S., Hull, R., and Alvarez, L., *Using a Balloon Flight for End-to-End Testing of a Nanosatellite Mission*, Journ. Small Satellites, Vol. 1, No. 1, January 2012.