Small Spacecraft Technology Program Guidebook for Technology Development Projects

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TABLE OF CONTENTS

REFERENCE DOCUMENTS:

Doc No SSTP.PP.01	Small Spacecraft Technology Program Plan
GPR 8705.4	Risk Classification Guidelines
GSFC-HDBK-8007	Mission Success Handbook for Cubesat Missions
GSFC-STD-7000	General Environmental Verification Standard (GEVS)
LSP-Req-317.01	Launch Services Program Program Level Dispenser and CubeSat Requirements Document
NASA/SP-2016-6105	NASA Systems Engineering Handbook
NASA-HDBK-6022	NASA Handbook for the Microbiological Examination of Space Hardware
NASA-STD-8719.14	Process for Limiting Orbital Debris
NASA-STD-8719.24	NASA Expendable Launch Vehicle Payload Safety Requirements
NASA-STD-8739.6	Implementation Requirements for NASA Workmanship
NASA-STD-8739.8	Software Assurance and Software Safety Standard
NID 8020.109	Planetary Provisions for Robotic Extraterrestrial Missions
NPD 8020.7G	Biological Contamination Control for Outbound and Inbound Planetary Spacecraft
NPD 8700.1	NASA Policy for Safety and Mission Success
NPD 8730.5	NASA Quality Assurance Program Policy
NPR 8715.6	NASA Procedural Requirements for Limiting Orbital Debris and Evaluating the Meteoroid and Orbital Debris Environments
NPR 2570.1	NASA Radio Frequency Spectrum Management Manual
NPR 7120.5	NASA Space Flight Program and Project Management Handbook
NPR 7120.6	Knowledge Policy for Programs and Projects
NPR 7120.8	NASA Research and Technology Program and Project Management Requirements
NPR 7123.1	NASA Systems Engineering Processes and Requirements
NPR 7150.2	NASA Software Engineering Requirements
NPR 8705.6	Safety and Mission Assurance (SMA) Audits, Reviews, and Assessments
NPR 8715.3	NASA General Safety Program Requirements
NPR 8735.1	Exchange of Problem Data Using NASA Advisories and the Government-Industry Data Exchange Program (GIDEP)
NPR 8735.2	Hardware Quality Assurance Program Requirements for Programs and Projects

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Introduction

The Small Spacecraft Technology (SST) program expands the ability to execute unique missions through rapid development and demonstration of capabilities for small spacecraft applicable to exploration, science and the commercial space sector. SST seeks to embrace promising technologies in the public and private sectors, taking advantage of the fast pace of developments and driving innovation in the nation's small spacecraft industry. SST invests in efforts within the Agency, at academic institutions, private entities, and in public-private partnerships. Faster timelines and lower costs allow greater risk tolerance, providing opportunities to introduce new technologies and iterate through failures to create new capacities or recreate existing capabilities at a fraction of the traditional cost.

Mirroring an approach pioneered by the Air Force Research Laboratory, SST can employ "constraint driven" approaches for small spacecraft missions. In this approach, missions are largely driven by technical and non-technical constraints rather than mission requirements. The objective in a constraint driven mission is to produce as much of the desired capability as possible within a fixed cost and schedule.

This Space Technology Mission Directorate (STMD) SST Program Guidebook for Technology Development Projects (hereby called Guidebook) is a collection of recommended practices and ready references to expedite research and technology (R&T) development projects. It offers guidance for efficiency, best practices and improved success based on SST and NASA experience and SST policies. It does not reproduce or contradict existing requirements nor add new requirements. The Guidebook is aimed at projects implemented at NASA Centers as well as SST contracts and grantees. Though based on experience and policies at NASA, much of the recommended practices here are general and could be useful for technology development projects conducted by organizations in academia or the private sector.

SST Program formulates and manages its projects as outlined in NPR 7120.8 (Chapter 4, R&T Project Requirements) and the SST Program Plan (Doc No SSTP.PP.01). Waivers to, or any requirements in addition to, NPR 7120.8 must be approved by SST Program.

7120.8 Program Management is for Research and Technology projects:

- Research projects: performing basic research or applied research with unpredictable outcomes.
- Technology projects: attempting to solve a specific problem or address a practical need.
- Technology Gaps: Supports NASA's strategic efforts to identify future investment.

Success, Failure, Risk:

- Mission Success can be defined as creating a new capability, investigating the feasibility of a new architecture, discovering capability limits, or exploring the trade space.
- Mission Failure is defined as flight test data not obtained.
- Independent assessments at key decision points replace reviews in accordance with a risk-tolerance approach. Economically appropriate efforts are made to understand risks, but cost and schedule are not used to eliminate all uncertainty in technical risks. SST invests in projects that have high-risk/high-reward, acknowledging only a minority will be transformative.

1. Purpose and Audience of this Guidebook

This Guidebook for Technology Development Projects (Guidebook) provides recommended practices for the research and technology (R&T) development projects sponsored by NASA STMD's Small Spacecraft Technology (SST) Program. Many of the recommended practices derive from lessons learned by small spacecraft developers over the course of many R&T projects. Lessons and best practices include such things as: various work processes that help to execute projects more effectively, methods and practices that advance technology more reliably and affordably, and experiences to help project members recognize, avoid and overcome pitfalls commonly encountered in technology development projects. The intent of this Guidebook is to capture successful experiences to make them available for the benefit of others. NASA and industry have published other excellent standards, processes and guidebooks with the more high-profile, costly, and risk-averse robotic and human spaceflight missions in mind. In contrast, this Guidebook aims to improve likelihood of project success within the greater risk tolerance and tighter budgetary and schedule constraints typical of R&T projects. This Guidebook is not intended to contradict existing NASA, legal or contractual requirements nor is it intended to add any new requirements; rather, where relevant standards and requirements do exist the Guidebook may provide guidance for interpreting and tailoring requirements or may suggest waivers where requirements are not relevant to R&T projects.

The Guidebook is primarily for R&T projects sponsored by NASA's SST Program. Some R&T projects demonstrate technologies in the lab environment, and some R&T projects are formulated for technology demonstration in spaceflight. Most recommended practices in this Guidebook are relevant to both lab and spaceflight demonstrations.

Some SST R&T projects are executed at NASA Centers while others are executed under contract, grant, or cooperative agreement in the private sector or academia. Where best practices are relevant only to projects executed at NASA Centers, those best practices are denoted as such, and include the role of Technical Authority and some Safety and Mission Assurance (S&MA) practices. Projects executed outside NASA typically follow the entity's internal safety, quality and mission assurance practices as applicable. Federal Acquisition Regulations, contractual and various legal requirements apply to projects executed on contracts or grants. See the body of the Guidebook for explicit denotation.

Though this Guidebook is primarily for NASA SST projects, many of the recommended practices in it may be helpful for technology development and demonstration projects that are sponsored by other NASA Programs, other Government Agencies, or other organizations.

2. Scope and Layout

The SST Program and all of its projects are formulated and executed in accordance with NPR 7120.8 NASA Research and Technology Program and Project Management Requirements. Material captured in this Guidebook will be updated when relevant new topics arise and as the experience base grows.

For each topic in Section 4 of this Guidebook, the following layout is as follows:

- *Brief Purpose for inclusion of the Topic (italic font)*
- Topic background, guidelines, and external references, where applicable
- List of Recommended Practices (blue-colored font)
- Applicability Key – best practice relevance for which types of projects
    - ***** = SST-NC – guidance applies to SST projects implemented at a NASA Center

- ****** = SST-PS – guidance applies to SST projects implemented in Academia or Private Sector
- ******* = SST-SpaceDemo – guidance applies to SST technologies to be demonstrated in space

3. SST Program Charter, Goals, and NPR 7120.8 Requirements *SST-NC, **SST-PS

Purpose of Section: SST project personnel – whether on projects executed at a NASA Center or on a grant or contract - need to be familiar with the SST Program Plan and the NPR 7120.8 NASA Research and Technology Program and Project Management Requirements in order to avoid errors due to not adhering to requirements or by applying unnecessary practices not needed for NPR 7120.8 projects. This section highlights a few important requirements for SST projects under NPR 7120.8 that contrast with NPR 7120.5 and that may be unfamiliar to those coming from experience with NPR 7120.5. For other R&T projects that are not sponsored by SST Program, this section may be useful especially if the project is formulated elsewhere under the requirements of NPR 7120.8.

The SST Program Plan (Doc. No. SSTP.PP.01) provides projects guidance on the program's policies for project management and execution. SST program and projects are formulated and managed in accordance with the structure and requirements of NPR 7120.8 for R&T projects. NPR 7120.8 governs all aspects of R&T project formulation, requirements, roles, and management principles. See subsequent later chapters in this Guidebook for respective details.

SmallSat R&T projects typically are formulated with small budgets and short schedules when compared to NPR 7120.5 Spaceflight projects, so quality and mission assurance practices should be scaled down proportionally and optimized appropriately. SST program has greater tolerance for technical and programmatic risk than typical for programs managed under NASA NPR 7120.5 NASA Space Flight Program and Project Management Requirements. For its policy regarding project risk see SSTP.PP.01 Small Spacecraft Technology Program Plan.

All SST R&T development projects are managed in consideration of two guiding principles:

"<u>No Compromise to Safety</u>" - Safety and protection of high-valued assets are paramount. Projects adhere to all relevant NASA, or company/university, launch service provider and range safety policies and practices. These apply in the lab, to personnel, to property, to procured services and elements, and during integration with the launch vehicle, on-orbit operations, limitation of orbital debris, and disposal. These policies are frequently referred to as "do no harm". Projects are to comply with all legal, NASA safety, or launch provider safety requirements. Projects comply with Quality Assurance requirements for all identified safety-critical items.

"<u>Apply Systems Engineering and Quality Assurance Practices as Informed by Risk</u>" – *For non-safety-critical items,* projects apply common industry and/or NASA best practices that enhance likelihood of technical success and do so with consideration of programmatic and technical risks. Acting as good stewards of the taxpayer's dollars, SST project managers determine the best approach for developing, and demonstrating technologies without unnecessarily spending time and money where not likely to enhance technical success. Application of every known mission assurance edict at any cost to eliminate all technical risk does not support constraint driven missions. SST projects develop and demonstrate technology - in the lab or on orbit - using "**risk-informed assurance**"; i.e. projects assess technical and programmatic risks and selectively apply engineering, mission, and quality assurance processes balanced with technical, cost and schedule consequences. This approach is sometimes called “right-sized quality assurance”.

Guidance for risk management and quality assurance are given in later sections.

4. R&T Project Guidelines and Recommended Practices

Projects executed under contract, grant, or cooperative agreement are not required to deliver a Project Plan, Systems Engineering Management Plan (SEMP), or Safety and Mission Assurance Plan (SMAP) unless explicitly required in the terms of the contract, grant or cooperative agreement. Unless otherwise stated in the contract, the Systems Engineering, Quality, Safety and Mission Assurance standards, processes and requirements should be those commonly used within the contractor/grantee organization. Systems Engineering, Quality, Safety, and Mission Assurance requirements in the contract/grant take precedent.

4.1. SST Project Planning – Life Cycle. *SST-NC, **SST-PS

Purpose of Section: The SST recommended approach to project planning and execution according to requirements of NPR 7120.8 is in contrast to the approach of projects formulated under NPR 7120.5. SST projects are typically smaller, leaner, executed faster, and require less formal documentation. Particularly important is the distinction between R&T project reviews versus spaceflight project reviews. 7120.8 project reviews are internal to the project and less formal than 7120.5 project reviews. Project managers and members familiar with 7120.5 process frequently plan projects and their review in ways that are more formal, more complex, and with more external reviewers than needed by SST Program. The consequence of this is unnecessarily increasing cost and schedule for project plans and reviews. Projects executed outside NASA are encouraged to pattern their project life cycle and plan according to NPR 7120.8 in the absence of other policies at their institution of origin.

SST projects are formulated according to the R&T project life cycle defined in NPR 7120.8 Sect. 4.1.2. SST projects typically have a total life cycle of approximately two years. R&T projects include three phases: Pre-Formulation and Authority to Proceed; Formulation and Project Approval; and Implementation and Closeout. SST projects generally do not include Pre-Formulation phase and simply begin at Authority to Proceed. SST projects with Technology Demonstration in space add an Operations phase.

The R&T project phases, Key Decision Points (KDPs), reviews and planning documents are defined in NPR 7120.8 Sect. 4.1.2.1 (see its figure 4-1 and 4-2) and are fewer in comparison to NPR 7120.5 projects.

During the Pre-Formulation phase, an initial negotiation between the Program and Project manager determines the purpose and scope of the project (e.g., type, size, complexity, etc). Typically R&T projects capture this determination in a Formulation Authorization Document (FAD). Note: SST projects often do not include this step but proceed at ATP.

R&T Projects develop Project Plans per the template provided in NPR 7120.8 (Appendix G), omitting elements that are not applicable to the specific project. Projects executed under a grant, cooperative agreement or contract the Statement of Work (SOW) and contractual requirements may not require a Project Plan; the contract, grant or cooperative agreement may serve as the Project Plan.

<u>Project Planning Recommended Practices (*SST-NC, **SST-PS):</u>

- Negotiate project expectations early in the life cycle of the project. To understand and keep project objectives clear, and to avoid project "scope creep", document clear objectives in the "Purpose" section of the project FAD and/or in the "Goals, Objectives, and Metrics" of the Project Plan. This will also guide subsequent technical implementation trades, risk, and quality management decisions. SST projects typically don't include a Pre-Formulation phase but begin at ATP.[*,**]
- Project Plans describe technical and management approach in sufficient detail so stakeholders recognize and achieve agreement on just how the project executes the project within cost and schedule. Project plans should avoid unnecessary, unimportant details or "boilerplate" cut-and-paste to avoid confusion and costly or unnecessary practices. [*,**]
- Specific goals, milestones, deliverables, a complete schedule of project reviews, and relevant policies for each respective SST project need to be defined in the Project Plan, for awareness and reference of managers, NASA TAs (for projects implemented at NASA Centers) and project members, preventing ambiguity. [*,**]
- For clarity and brevity, the project SEMP is preferably included within the Project Plan. This reduces replication of objectives and other text. See Sect. 4.5 of this Guidebook for SEMP details. [*,**]
- An often overlooked but critical element of project plans is quantitative goal (or floor and stretch values) of the Key Performance Parameters (KPPs) or Measures of Effectiveness (MOEs) to be demonstrated (in the lab or in-space). Stakeholders need these metrics to understand the extent the project will fulfill a future purpose or technology gap. The values may be updated in the Project Plan in the case the project scope or unexpected technical constraints arise. SST program understands that according to the nature of research projects, not all planned values (especially stretch values) will be achieved. See NPR 7120.8 Sect 4.2.7.7 or NASA/SP-2016-6105 for explanation of KPPs and MOEs. [*,**]
- Planned dates for ATP and Project Closeout KDPs should be included in the Project Plan approved by the SST Program. Keeping these important milestones up-to-date in the Plan in case of change is a visible record for internal and external stakeholders.
- SST may give smaller projects the Authority to Proceed (ATP) without the Pre-Formulation or Formulation phases. Consult with the SST Program Manager to establish KDP expectations and include them in the Project Plan. [*,**]
- Closeout KDP and Report - Includes the final (lab or in-space) demonstrated performance measures of the research and/or technology under development, lessons learned (NPD 7120.6), a measure of the Technology Readiness Level (TRL) advancement, list of papers published, and New Technology Reports. [*,**]

4.2. Project Reviews. *SST-NC, **SST-PS, ***SST-SpaceDemo

Purpose of Section: KDPs are "gates" – typically ATP and Closeout – and they are run by the SST Program. Project reviews, called "Periodic Project Reviews" (PPRs) in NPR 7120.8, are run by the project for the project. Spaceflight demos typically plan to run SRR/SDR, CDR, and MRR/FRR. Lab projects may have very infrequent and informal reviews. Do not conduct project reviews with excessive formality or assign reviewers unnecessary approval authority; this costs time and money without return on investment. Reviews under NPR 7120.8 are not at all like those under NPR 7120.5.

Periodic Project Reviews are not KDPs. The SST program will schedule ATP and Closeout KDPs. See NPR 7120.8 4.1.2 for project life cycle and KDPs.

Periodic Project Reviews (PPR) are scheduled by the project and overseen by the project as the project determines beneficial. Understanding the distinction between PPRs of NPR 7120.8 and NPR 7120.5 may help a project establish and conduct more efficient and effective reviews without unnecessary overhead. PPRs for projects executed under NPR 7120.8 may be informal discussions or can be in the form of "life-cycle reviews" with entrance and success criteria as described in NPR 7123.1, Appendix G. Whether informal or formal, PPRs are planned by, and internal to, the Project. They are not approval "gates". SST projects may also schedule their own Independent Assessments if the project determines beneficial.

NPR 7120.8 R&T projects do not have Standing Review Boards nor are they governed by a Program Management Council, unlike NPR 7120.5 projects.

For definitive information on PPRs and Independent Assessments (IAs), review NPR 7120.8 Sect. 4.2.10.

Launch vehicle operators or launch service managers (and some NASA Centers) require a "pre-ship review" (which is not defined in NPR 7123.1) to determine flight readiness for R&T projects demonstrating technology in space. The SST Program does not require Certificate of Flight Readiness (CoFR) reviews.

Project Reviews Recommended Practices (*SST-NC, *SST-PS, ***SST-SpaceDemo):

- R&T projects plan and conduct reviews that include external subject matter experts (SMEs) who bring "fresh eyes" to identify risks and issues that may require further work. [*,**]
- For SmallSat Technology Partnerships and similar grants (particularly for projects involving technology demonstration in the lab), PPRs are typically quarterly or other periodic status reviews, conducted by telecon and using a status "quad chart". [**]
- For large projects, particularly those demonstrating technology in space, PPRs may be structured like the technical reviews of NPR 7123.1 Appendix G. Often, new SST Flight Demonstration Projects initially plan to exceed the necessary scope for technical reviews of R&T projects. This is especially true for projects and managers familiar with review requirements of NPR 7120.5. Adhere to the NPR 7120.8 sect. 4.2.10 generic guidance for reviews for scope and formality appropriate for R&T projects (even for technology demonstrations in space) to avoid time-consuming, expensive, unnecessary review formality. [***] The SST program recommends these reviews:
    - Combined Systems Requirements Review/Systems Definition Review (SRR/SDR)
    - Critical Design Review (CDR)
    - Mission Readiness Review/Flight Readiness Review (MRR/FRR).
- For projects or elements that involve a rebuild of a previously-flown component, "Delta" reviews should be held in lieu of CDRs to represent any changes from previous designs or manufactures, the past history of success, failures, and anomalies, and any project lessons learned. [***]
- In general, the technology under development should be the subject of the review. For example, if a new payload will be integrated on a spacecraft bus that has flown, the development of the payload and the integration plan would be reviewed. Bus characteristics may be reviewed, if necessary in a secondary capacity, from the point of view of demonstrating that the bus meets the payload requirements that flow down to the bus from the payload. Unique, one-time alterations to the bus may be reviewed as an "altered item" of a commercially available bus. [***]

Phase	Activity	Output(s)
Pre-formulation	Preliminary planning (NPR 7120.8 Sect 4.2.5). Often omitted from SST projects which proceed from ATP	Scope, from SST Program
ATP (KDP)	SST approval of proposed project to enter Formulation Phase (NPR 7120.8 Sect 4.2.6)	Approval, Preliminary Project Plan
Formulation	NPR 7120.8 Sect 4.2.7	
Project Approval (KDP)	SST approval to enter Implementation Phase (NPR 7120.8 Sect 4.2.8)	Approval, Final Project Plan
Implementation	NPR 7120.8 Sect 4.2.9	Life cycle reviews per approved Project Plan
Continuation Assessments (if in plan/contract/grant, or upon subsequent direction)	NPR 7120.8 Sect 4.2.10.3	Continuation approval, if required
Independent Assessments (if required, or upon subsequent direction)	NPR 7120.8 Table 4-1	Independent assessments, if required
Status telecons, quad charts (for small lab demo projects)	NPR 7120.8 Sect. 4.2.10.2 informal reviews for lab projects	Quad charts (typical) as planned
SRR/SDR*** (large flight demo projects)	Internal review conducted by project. Tailored from NPR 7123.1 Appendix G-4	NPR 7123.1 success criteria, as in approved project plan
CDR*** (large flight demo projects)	Internal review conducted by project. Tailored from NPR 7123.1 Appendix G-7	NPR 7123.1 success criteria, as in approved project plan
MRR/FRR*** (large flight demo projects)	Internal review conducted by project. Tailored from NPR 7123.1 Appendix G-13	NPR 7123.1 success criteria, as in approved project plan
Closeout Review (KDP)	NPR 7120.8 Sect 4.2.11	Closeout Report, New Technology Report

*** These reviews ("life cycle reviews") are for flight demonstration projects only. They are internal reviews, conducted by the project, to review the project cost, schedule, and technical performance. Details on these reviews are determined by the project manager in coordination with the SST Program and documented in the approved Project Plan.

Table 1. SST Project Life Cycle and Reviews

4.3. Project Resources and Cost Estimation Resources and Tools

Purpose of Section: R&T projects benefit by efficient programmatic processes optimized to reduce time and cost in balance with their higher risk tolerance, smaller size, and lower complexity - in contrast to processes applied to NASA NPR 7120.5 Spaceflight projects.

The Project Plan should document a high level cost breakdown and costs for each participating Center/Org, as applicable, in alignment with the schedule and performance parameters/milestones.

SST projects follow the ideology of constraint driven missions. Once a project is awarded, budgets are managed internally by said project. The goal of SST projects are to maintain schedule (preferably two years) and to complete the mission at no additional funding from the NASA SST program after award funds are granted. The Project Plan should include in-depth analysis of how the resources allotted will align with scheduling.

Project Costing Estimation Resources and Tools:

- CubeSat or MicroSat Probabilistic and Analogy Cost Tool (COMPACT)
  - Available to NASA users for early lifecycle CubeSat cost estimates. The tool currently contains analogs only. The main goals are to provide a sanity check on cost estimates and a database of CubeSat and SmallSat cost information.
  - COMPACT is located on the ONCE database website (NASA users only): https://oncedata.hq.nasa.gov. Users must apply for access via a NAMS request. Instructions to access ONCE can be found at: http://www.nasa.gov/sites/default/files/atoms/files/_once_user_access_request_form_tagged.pdf. Within ONCE, users can navigate to COMPACT via the left panel tab by clicking "ONSET" and then "COMPACT" once the tool has loaded. There is currently no option for users outside of NASA to access COMPACT, its data, or its models.
- NASA Instrument Cost Model (NICM)
  - Costing tool for science instruments.
  - Directions to access NICM can be found at: https://www.nasa.gov/offices/ocfo/functions/models_tools/nicm. Within ONCE, users can navigate to NICM download by clicking "Model Portal" on the left panel, and then "NICM" at the top of the model portal. Users outside of NASA can access the limited version (hidden data but models included) at: https://software.nasa.gov/software/NPO-51529-1.

4.4. Risk, Safety, Quality, and Mission Assurance. **SST-NC

Purpose of Section: NASA policies for Risk, Safety, Quality, and Mission Assurance are frequently conflated, sometimes with unfortunate results for low-cost, risk-tolerant R&T projects. For R&T projects, safety requirements are absolute, while mission assurance and quality practices need to be evaluated using risk analyses, scaled and applied in proportion to the project's programmatic constraints, goals, and tolerance for risk. Quality and Mission Assurance practices must not be applied blindly in a blanket fashion. Doing so would inflate project costs and decrease productivity disproportionately relative to the increase in reliability. SST projects use "risk-informed quality assurance/mission assurance". Safety of public, personnel, *infrastructure, or high-valued equipment shall never be compromised. For the purposes of this Guidebook, risk and safety will be discussed separately and quality and mission assurance will be combined.*

Risk, Safety and combined Quality/Mission Assurance best practices are given in the three subsections. Project personnel should consult source documents (required by NASA and/or their home institution). Information and guidance here does not supersede relevant NASA, institutional or contractual requirements.

NPD 8700.1 NASA Policy for Safety and Mission Success establishes NASA's policies and roles for safety and mission success. As stipulated in NPD 8700.1 paragraph f.(1) the SST Program establishes safety and mission success requirements within its projects and does so conjunction with NASA Center-designated Technical Authority (TA). SST program accepts any residual safety and mission success risk for SST projects (see NPD 8700.1 paragraph f.(3)). Per this policy, SST requires projects adhere strictly to safety requirements and best practices. Less clearly relevant are phrases "Mission success risk" and "mission success requirements" of NPR 8700.1 for R&T projects; NPR 8700.1 references NPR 7120.5 but does not reference NPR 7120.8. For this reason, this Guidebook does not discuss "mission success" or "mission assurance" in this context.

<u>The SST program does not authorize projects to take every effort to eliminate every possible uncertainty in technical risk, even for technology demonstrations in space. Reasonable and informed acceptance of technical risk are an accepted characteristic of R&T development and demonstration</u>.

Below is a summary of the SST Program approach to Risk, Safety, Quality and Mission Assurance for SST projects (explained in the next three sub-sections in further detail):

1. Analyze and identify all safety hazards in the R&T project elements and work processes. Document safety hazards in project SMAP. This should be done early as possible in the project design phase. At NASA Centers, consult with an SMA TA for inputs and analysis regarding safety hazards.
2. For every safety hazard, identify and document in the SMAP the risk levels and the appropriate safety and quality standards and processes to mitigate safety risks to acceptable levels. For projects at NASA Centers, consult the Center SMA TA to review mitigation processes for safety-critical elements.
3. Analyze and identify all other (non-safety-critical) technical hazards and hazards to project success. These may be documented in a project SMAP or in another risk list.
4. For identified technical and project hazards that are <u>not safety</u> related, the project should quantify the technical and programmatic risk levels, then select and apply appropriate quality assurance processes to reduce risks to acceptable to agreed-upon levels. Use best engineering judgement to determine which processes to apply and appropriately tailor processes to the scale of the budget and technical goals of the project.

SST program accepts that there will be some degree of technical risk and programmatic risk associated with its R&T projects, including technology demonstrations in space.

4.4.1. Risk Management. *SST-NC, **SST-PS, ***SST-SpaceDemo

Purpose of Section: Aid with establishment and documentation of project risk assessment, management, plans and practices. Provides successful examples and guidance on risk and risk policies, within the context of the SST (and other) R&T project risk policies.

The SST Program policies regarding project technical and programmatic risk management and mission assurance are given in the SST Program Management Plan Section 3.6.

SST program accepts that its R&T projects will identify a degree of technical and programmatic risk. Some technologies will not perform as expected during flight demonstrations – in fact, this is the reason for technology flight demonstrations. Nevertheless, SST program expects projects to follow best practices for quality assurance aligned with the available budget, schedule, and technical resources.

SST projects (including those with technology demonstration in space) are executed under NPR 7120.8 and so are **not** given an NPR 8705.4 risk classification, as that NPR applies only to NPR 7120.5 missions. SST technology demonstrations are not “sub-Class D” projects, rather, they have no NPR 8705.4 risk classification at all.

Specific technology demonstration mission hazards can be identified by projects by employing reliability analyses, such as Failure Modes and Effects Criticality Analyses (FMECAs) and single-point failure (SPF) analyses. The general principle is that all SST projects apply *appropriate* elements of mission assurance with an eye toward “right-sizing” practices commensurate with the risk profile, budget and schedule of the technology development or demonstration project. This principle for tailoring or requesting waiver of NASA practices is called “Risk-Informed Mission Assurance”.

Mission hazards may arise from any of several elements during a project life cycle. Projects are encouraged to consider application of standards and processes to mitigate mission risks to acceptable levels. Hazards and mitigations to consider:

- Selection of appropriate materials to increase reliability/robustness
- Software design, coding and test to mitigate and detect errors
- Design trades (redundancy, reliability, radiation tolerance) to reduce probability or consequence of failure
- Inspection, measurement and test processes, to detect manufacture and assembly errors
- Workmanship and assembly processes – training and inspection for critical manual processes
- Operations and command and control concepts for manual work-arounds of off-nominal conditions

In accordance with NPR 7120.8 Sect. 4.2.7.9, if a project determines through analysis that it does not include elements, systems, or processes that could result in harm to personnel, the public, or property, the project is **not** required to (but may) produce a risk management plan.

Risk Management Recommended Practices (*SST-NC, **SST-PS):

- Identify technical and programmatic hazards and quantify risks in a risk management list. Projects that actively identify, track and apply appropriate mitigations can increase likelihood of technical success within budgets.[*,**]
- The formality of NPR 8000.4 and NPR 7123.1 Sect. 3.2.14 Technical Risk Management Process are not required but offer excellent guidance. [*,**]

4.4.2. Safety. *SST-NC, **SST-PS, ***SST-SpaceDemo

Purpose of Section: Never compromise on safety. "Mission assurance" is often conflated with safety in NASA organizations. But mission assurance practices, like quality assurance practices, should be considered separately using analytical risk management processes described elsewhere in this document. This section provides successful examples and guidance on safety. To reiterate, <u>safe practices are never to be compromised</u>.

*SST-NC, **SST-PS: All SST projects shall conduct a project safety analysis and document the results. The project safety analysis shall list every safety-critical element, or, shall indicate that analysis has identified no safety-critical elements if there are none. The safety analysis must be completely documented in the SMAP as early as possible and preferably before SRR/SDR review. If the project analysis concludes that there are no credible safety hazards, then projects are *not* required to produce SMA Plans or Risk Management Plans (unless otherwise directed to do so by the program or determined for some other reason by the project).

*SST-NC: Projects implemented at NASA Centers must follow NPR 8715.3 NASA General Safety Program Requirements.

*SST-NC: In accordance with NPR 7120.8 Sect. 4.2.7.9, if any technology development project is determined to contain elements, systems, or processes that could result in harm to personnel, the public, or property, the project plan must include:

- A SMAP in accordance with NPRs 8715.3 NASA General Safety Program Requirements and 8705.6. Safety and Mission Assurance (SMA) Audits, Reviews, and Assessments
- A risk management plan in accordance with NPR 8000.4. The risk management plan must address relevant safety and health risks, but not technical or programmatic risks unless determined by the project or directed by SST program.

*SST-NC: Consult NPR 8715.3 NASA General Safety Program Requirements and the Center S&MA office regarding safety reviews and audits.

**SST-PS: Projects implemented in academia or private sector must follow their respective entities' established safety policies.

*SST-NC, **SST-PS: For all project-identified safety-critical items, the project must comply with all relevant NASA or other institutional safety, quality and mission assurance requirements. Safety concerns for SST technology development projects are often considered in two areas: 1) safety of personnel and property in the lab, and 2) avoiding harm to personnel, launch vehicle, or to other payloads during integration, launch pad and operation in space, through end-of-life. Typical examples of technology flight demonstration elements that could result in harm to personnel or property:

- Test or shipment of spacecraft bus with stored energy in form of batteries, springs, compressed gas
- Storage or use of caustic or toxic fuel or other toxins
- Operation of high-powered RF systems or lasers
- RF transmissions, recontact or other hazards to launch vehicles and their payloads
- Generation of orbital debris and de-orbit requirements

*SST-NC, **SST-PS: For the most part, safety-critical items should tie strictly to items in hazard reports (or risk-informed safety cases for those who use them instead) or the launch-provider's "do no harm" interface and safety requirements.

*SST-NC, **SST-PS: The SMA Plan and risk management plan, if required, is best incorporated into the Project Plan to reduce redundant documentation and to encourage brevity. But stand-alone plans are acceptable. Plans address credible safety and health hazards.

*SST-NC, **SST-PS, ***SST-SpaceDemo: Projects that include technology demonstration in space must also abide by launch services restrictions and requirements. The particular launch vehicle or provider will determine requirements for a the launch, but common examples include: LSP-Req-317.01 (for LSP hosted CubeSats), ISS safety requirements (for ISS-launched CubeSats), do no harm requirements from other launch providers, orbital debris requirements in NASA-STD-8719.14 (as called from NPR 8715.6), and range safety requirements in NASA-STD-8719.24 (as called from NPR 8715.3).

***SST-SpaceDemo: Limitation of Orbital Debris and the End of Mission Plan (EOMP) are addressed in Section 4.13 of this Guidebook.

Safety Recommended Practices (*SST-NC, **SST-PS, ***SST-SpaceDemo):

- Safety-critical elements are specifically derived in a focused way from a safety analysis (hazard analysis, probabilistic safety assessment (PSA), or risk-informed safety case for those who use such an approach). Address safety-critical elements and processes in accordance with NASA, contractual, legal, and other applicable requirements. (The term “focused” is used here to avoid broad determinations such as “the cryocooler has safety implications, thus each part inside is safety critical” in comparison to the determination from a hazard analysis that the inhibits on the cryocooler are controls against a safety incident and thus the inhibits (whether hardware or software) and the interfaces of the inhibits are safety critical, while other elements of the cryocooler are not). *,**
- NASA projects should coordinate early with the Center TA to consider the project-identified safety-critical mitigations and processes. The TA’s role is to ensure that proper quality practices and attention go to the safety critical items (as opposed to making the determination of criticality). *
- R&T projects should determine (in consultation with the cognizant TA or SMA TA) which (if any) NASA quality and mission assurance requirements are relevant to project-identified safety-critical elements. Quality and mission assurance of non-safety-critical items should be considered separately and as informed by risk (discussed in a later sub-section). *
- For R&T projects that are determined by analysis that they do not include safety hazards, NPR 7120.8 does not require a SMAP or an RMP; however, it is best practice to identify technical and programmatic hazards and quantify risks in a risk management list or plan. Projects that actively identify, track and apply appropriate mitigations can increase the likelihood of technical success within constrained budgets. The formality of NPR 8000.4 and NPR 7123.1 Sect. 3.2.14 Technical Risk Management Process aren’t required but offer excellent guidance. *,**
- For projects implemented at NASA Centers, consult NPR 8715.3 NASA General Safety Program Requirements and the Center S&MA office regarding safety reviews and audits. These independent assessments of safety hazards are considered vital to increased confidence in safety. *
- For projects implemented in academia or private sector, projects are expected to follow the entities’ established safety policies. **

4.4.3. Quality and Mission Assurance. *SST-NC, **SST-PS, ***SST-SpaceDemo

Purpose of Section: Provides guidance for establishing and documenting project mission- and quality- management. Recommended practices are applied as informed by risk within programmatic and risk-tolerance constraints. This section also provides guidance and examples of successful quality and mission assurance policies, tailoring and waiver requests where appropriate, within the context of the SST (and other) R&T project risk policies.

The SST Program (and Center TAs) should assume that requirements not explicitly described or itemized in the Project Plan, SMAP or RMP will not be applied.

*SST-NC, **SST-PS, ***SST-SpaceDemo: SST projects select and apply quality management and mission assurance requirements when appropriate and as based on quantitative risk analysis. Technical hazards may be identified through reliability analyses, such as Failure Modes and Effects Criticality Analyses (FMECAs) and single-point failure (SPF) analyses. Technical hazards may arise from any of several elements during a project life cycle.

*SST-NC: NPD 8730.5B NASA's Quality Assurance Program Policy is relevant to technology development projects executed under NPR 7120.8 at NASA Centers. Please note: Language in Attachment A of 8730.5B regarding "critical and complex" work may be revised. Please contact the relevant SMA authorities regarding questions about potential changes and applicability.

*SST-NC: NPD 8730.5 Table 2 lists workmanship standards. For elements not identified as safety-critical, SST projects are not required to apply workmanship standards but – as informed by their project risk analysis – *should consider and select specific, relevant* workmanship practices in from NPD 8730.5 Table 2. SST projects may consider specific and selected practices from SAE AS9100 Quality Management Systems – Requirements for Aviation, Space and Defense Organizations. As stated above, all the requirements that projects choose to flow down from NPD 8730.5 or AS9100 should be explicitly listed and described in the project PMP, SMAP, SEMP or RMP.

*SST-NC: R&T projects implemented at NASA Centers must select relevant requirements of NPR 8735.2 NPR 8735.2 NASA's Hardware Quality Assurance Program Requirements for Programs and Projects for safety-critical elements. R&T projects may also (but are not required to) apply selected requirements appropriate for non-safety-critical hardware and software if the project determines beneficial based on technical risk analysis (on a "risk-informed" basis) and regard to project goals, risk posture and cost/schedule constraints. See NPR 8735.2 P.1.g.

**SST-PS: SST projects implemented outside of NASA (in academia or the private sector) follow the quality and mission assurance practices at their respective entity. SST program may inquire about the entity's policies and procedures and may include additional quality and mission assurance requirements in a contract, grant or cooperative agreement.

Quality and Mission Assurance Recommended Practices (*SST-NC, **SST-PS, *-SST-SpaceDemo):**

- Avoid assuming requirements on "mission assurance" are relevant to R&T projects. The relevance for those requirments may be limited to NPR 7120.5 space flight projects. When encountering "mission assurance" requirements, review them selectively for non-safety-critical elements and considering tailoring or customizing or requesting waiver. Consult the cognizant Engineering TA or SMA TA at NASA Centers for further guidance. *

- GPR 8705.4 Risk Classification Guidelines and Risk-Based SMA Practices for GSFC payloads and Systems Table 1, *Guidelines for Safety and Mission Success Activities at Each Mission Classification,* provides good recommendations for risk-informed mission assurance and quality assurance standards and processes relevant to NPR 7120.8 research and technology projects. *,**,***
- Explicitly document *all* the project-specific implementation of quality practices in either the project plan (preferably for brevity of project documentation) or in a stand-alone SMAP or Risk Management Plan (RMP) or SEMP. This is so no false assumptions are made about risk mitigations to be taken or to be omitted by the project. This will avoid causing confusion or worse, requiring re-work or resulting in later problems. *,**,***
- **SST Program (and Center TAs) should assume that requirements not explicitly described or itemized in the Project Plan, SMAP or RMP will not be applied.** *
- Simply calling out a standard's document number and title (e.g. "NASA STD 8739.4") does not imply that the project intends to comply with any of the requirements in that standard; particular requirements selected from within a standard must be explicitly listed to avoid false assumptions or later confusion or errors. For projects developing a series of products, each of which have different hazards or mission assurance requirements, the project may append a table to the SMA Plan (or other method of denotation) that indicates applicability of requirements to respective products. This can streamline the additions and retain relevant information about applicability of requirements to respective configurations of an item. *,**,***

4.5. Systems Engineering. *SST-NC, **SST-PS, ***SST-SpaceDemo

Purpose of Section: Systems engineering is defined as a logical approach to systems to ensure products meet customer's needs. Systems engineering processing of NPR 7123.1 are methodical and based on NASA's legacy of spaceflight experience; SST recommend those processes be utilized for R&T projects in more expedient and less formal ways than for NPR 7120.5 Spaceflight projects. Guidance is given here. A SEMP template tailored to SST R&T projects is planned.

*SST-NC: NPR 7123.1 NASA Systems Engineering Processes and Requirements is owned by the NASA Office of the Chief Engineer. It includes systems engineering policies and requirements for NASA projects including R&T projects. It lists requirements for 17 "Common Technical Processes". Large and small projects employ these processes in more formal or less formal ways. Projects are expected to "tailor" and "customize" (which mean different things) depending on project size, complexity or accepted risk posture, as described in NPR 7123.1 Sect. 2.2 and throughout.

*SST-NC: The NASA Center's Engineering Technical Authority (ETA) is responsible for ensuring risks are considered and good engineering practices are followed in technical development and implementation, and assist the program or project in making risk-informed decisions that properly balance technical merit, cost, schedule, and safety across the system (ref. NPR 7123.1C 1.3.1.c and 2.6.1.2.d). More on balancing risk when considering systems engineering processes is found in NPR 7123.1C 1.3.1.c and throughout that document.

*SST-NC, *SST-PS, *SST-SpaceDemo: NASA Systems Engineering Handbook (NASA-HDBK-6105) is a useful reference for details, examples and best practices for implementing systems engineering processes. A SEMP template is given in NASA-HDBK-6105.

*SST-PS: For projects not managed at a NASA Center, the company or university best practices for systems engineering apply.

<u>Systems Engineering Recommended Practices (*SST-NC, **SST-PS, ***SST-SpaceDemo):</u>

- Project life-cycle and technical review requirements are included in NPR 7123.1 Chapter 5 and Appendix G; SST recommended practices for life-cycle and technical reviews (called "Periodic Project Reviews" in NPR 7120.8 for R&T projects) are given in 4.2 of this Guidebook.
- Include a project SEMP within the SST Project Plan (as it encourages brevity and reduces redundant descriptions of the project goals and other characteristics). Though the SEMP may be prepared as a separate stand-alone document, this is not preferred.[*,**,***]
- Tailor and customize systems engineering practices appropriately by considering the typically modest budgets, schedules and acceptable risk profile of R&T projects. Efforts to document and implement engineering processes that are disproportionately elaborate or formal relative to the benefit they provide to the project may not contribute to increased success or excellence and may not be best use of resources. Avoid the route of implementing processes unnecessarily due to precedence of some other larger, more complex, less risk tolerant project. Risk tolerance of R&T projects under NPR 7120.8 are typically higher in contrast to NPR 7120.5 Spaceflight Programs and Projects for science or exploration programs. [*,**,***]
- Refer to NPR 7123.1 regarding specific guidance on the 17 common technical processes. [*,**,***]

4.6. Configuration Management. *SST-NC, **SST-PS, ***SST-SpaceDemo

Purpose of Section: R&T projects benefit by efficient technical processes optimized to reduce time and cost in balance with their higher risk tolerance, smaller size, and lower complexity - in contrast to processes applied to NASA NPR 7120.5 Spaceflight projects.

Projects briefly describe how they will manage configuration of documents and hardware and software in the project SEMP, whether the SEMP is stand-alone or an internal part of the Project Plan. Entities outside of NASA (universities, private sector, other Government Agencies) will use their own best practices for CM. Projects approve configuration changes and track configuration items as they determine most efficiently and effectively for the project.

If there is a discrepancy between project documentation and products, a Non-Conformance Report should be created and rework/repair documented.

<u>CM Guidelines and Recommended Practices (*SST-NC, **SST-PS, ***SST-SpaceDemo):</u>

- Projects manage configuration items as necessary to ensure assembly, integration, test, and operational considerations are correct and traceable, to avoid errors. [*,**,***]
- Test as you fly, fly as you test. Thorough understanding of the configuration changes throughout the lifecycle of the project is critical. [***]
- Project closeout should include complete documentation of the final configuration with notation of changes. [*,**,***]
- The project plan or SEMP should describe the project's configuration management process and identify which documents and products will be placed under configuration control. [*,**,***]
- Safety-critical items must be kept under a rigorous configuration control process. [*,**,***]

4.7. Software Engineering, Assurance and Management

Purpose of Section: Software assurance and compliance with NPR 7150.2 is required of R&T projects; however NPR 7150.2 requirements are often selected and applied unnecessarily or with excessive formality for R&T projects because project personnel who are more familiar with complex software development projects or are more familiar with NPR 7120.5 Spaceflight projects are tempted to parrot methods used in those projects. R&T technology demonstrations often occur in the lab, on suborbital flights, or as secondary payloads on technology demonstrations in space with low safety and technical risk. NPR 7150.2 software classifications were not developed with these circumstances at the forefront. R&T projects benefit by efficient software assurance processes optimized to reduce time and cost in balance with their higher risk tolerance, smaller size and lower complexity - in contrast to processes applied to NASA NPR 7120.5 spaceflight projects.

**SST-PS: SST projects executed in commercial or academic sectors comply with their respective internal best practices and software management policies.

*SST-NC: Software developed or acquired for NASA (internally or externally) is subject to Software Assurance Standard NASA-STD-8739.8. SST projects executed at a NASA Center that include software will comply with NPR 7150.2 NASA Software Engineering Requirements.

*SST-NC: SST projects implemented at NASA Centers typically generate a stand-alone Software Management Plan to document their methods for compliance with processes of NPR 7150.2. Software developed for technology demonstration in space is classified as Class C Mission Support Software, as defined in the NASA-wide software classification structure of NPR 7150.2. Note that software Class C is not to be confused with Mission Risk Classification. Projects should apply the processes of NPR 7150.2 tailored in accordance to the modest budgets and risk tolerant approach of the SST Program.

Software Engineering Recommended Practices (*SST-NC, **SST-PS, ***SST-SpaceDemo):

- The software and computing architecture should be designed to minimize or eliminate the need of safety critical software. For example, consider maintaining a minimal set of software that protects the ability to (1) maintain communication with the ground, (2) upload new software, and (3) place and maintain the spacecraft in a safe mode. [*,**]
- SST projects that include technology demonstration in space that are executed at NASA Centers are classified as Software Class C. [***]
- SST technology development projects demonstrated in the lab at NASA Centers are classified as Software Class D or E. [*,**]
- Projects executed at NASA Centers should refer to their respective Center's Process Asset Library and the respective repository for resources regarding Software Management Plans and NPR 7150.2 compliance. [*]
- The GRC software.grc.nasa.gov has examples of Software Management Plans and tailoring appropriate for technology demonstration project software. [*]
- SST projects are encouraged to develop their NPR 7150.2 compliance matrix (or Software Management Plan) to their best effort; then if there are remaining questions they may contact their Center software assurance lead or the NASA Software Tech Fellow's designated representative for NPR 7150.2. [*]

4.8. Procurement Quality Assurance. *SST-NC

Purpose of Section: Recommended practices for procurement of components, subsystems and services for R&T projects – especially for projects to demonstrate technology in space. When applying the requirements of the FAR and of NPR 8730.5 and of the previous revision NPR 8735.2B, NASA projects, procurement personnel and procurement SMA TA often apply requirements in ways disproportionate to R&T project size, complexity and risk tolerance. This happens in their pursuit of project excellence because of a lack of familiarity with procurement requirements for R&T projects and greater familiarity with NPR 7120.5 Spaceflight projects. This often results in unnecessary procurement delay, complexity and cost. R&T projects benefit from efficient procurement processes optimized to reduce time and cost in balance with their higher risk tolerance, smaller size and lower complexity.

For SST R&T projects demonstrating technology in space that are implemented at NASA Centers and that include safety-critical hardware or software delivered to the NASA Center, it is NASA policy to prescribe requirements for independent assurance of compliance through Government contract quality assurance functions as required by Federal Acquisition Regulation (FAR) Part 46, FAR Part 12, NASA FAR Supplement (NFS) Part 1846, and NPD 8730.5, NASA Quality Assurance Program Policy. The purpose of Government contract quality assurance is to ensure that supplies and services acquired under Government contract conform to contract requirements. Procurement quality assurance requirements should be levied only in consideration of the project risk, scope, and worst credible consequence of safety-critical element failure. This process is called risk-informed quality assurance.

Procurement Quality Assurance Recommended Practices (*SST-NC):

- Procurement Quality Assurance personnel at NASA Ames Research Center are in the process of establishing a web-based, menu-driven approach to establish appropriate mission assurance clauses for procurement contracts.* See https://q.arc.nasa.gov/pqa_app/home

4.9. Technical Authority. *SST-NC

Purpose of this Section: Technical Authority is defined at the highest level of NASA policy. TA serves as independent oversight of projects at NASA Centers. The SST program recommends R&T projects executed at NASA Centers read NPR 7120.8 to understand the role of TA in R&T projects and avoid confusion with the way TA applies to NPR 7120.5 spaceflight projects. Ultimately the SST Program is responsible for the test readiness (for lab) and the flight readiness (for orbital or suborbital demonstrations) of its projects, not the Center TA. Projects may proceed at risk if SST or its project determine that is in the best interest of the project and program while dissenting opinions are resolved. Dissenting opinions between Project and Center TA are elevated to the next higher authorities for resolution.

Technical Authority (TA) for engineering and safety and mission assurance are established through NASA's Office of the Chief Engineer (OCE) and Office of Safety and Mission Assurance (OSMA), respectively.

The role of the TAs for technology development projects is identified in NPR 7120.8 Sect. 5.4. The SST Program works with each relevant Center TA to articulate the SST Program technology demonstration goals, the program's degree of risk tolerance, and to ensure reasonable project oversight that is in line with those goals and risk posture. The SST Program understands that (as is stated in NPR 7120.8 Sect. 5.4.4), "Due to the nature of R&T, the technical authority requirements for R&T projects are not as specific as for projects managed under NPR 7120.5." TA roles are not predefined in NPR 7120.8 because they vary greatly depending on the nature and level of effort of R&T programs.

The mission assurance strategy for SST flight demonstration projects has a different aim compared to that of science or exploration missions. SST is chartered to invest in a wide array of emerging, high-risk / high-reward technologies and to rapidly mature them to flight with the understanding that a minority will prove to be transformative. Economically appropriate efforts are made to ensure that space flight demonstrations yield useful results; mission failure in this context means that flight test data was not obtained, rather than whether all performance metrics were completely achieved. As such, the SST philosophy is to not expend cost and schedule to eliminate all uncertainty in technical risk as doing so would jeopardize future opportunities for achieving the desired results.

For SST projects managed at a NASA Center, the Center technical authority may make recommendations to the SST program office. Projects may invite TA's to participate in periodic project reviews for efficiency in their oversight roles. TA involvement in project activities should ensure that any significant views from the TA be made available to the program in a timely manner and should be handled during the normal project processes. However, ultimate responsibility for project success, in conformance with governing requirements, remains the responsibility of the SST program and the SST project manager. Authority for system acceptance for flight resides with the SST Program Office. Unresolved disagreements are elevated to the SST Program Executive and STMD Chief Engineer. See NPR 7120.8 Sect. 5.4.7.

Technical Authority Recommended Practices (*SST-NC, ***SST-SpaceDemo):

- For efficiency in TA oversight, Center-designated TAs may be invited by NASA technology flight demonstration projects to attend the project's internal technical reviews. Projects may accept and disposition TA comments within consideration of the project risk posture. Responsibility for project success in conformance with governing requirements remains the responsibility of the SST program and SST project manager. *
- Projects executed at NASA Centers should request their Center Engineering TAs to review and approve the project SEMP, or the SEMP paragraphs of the Project Plan. *
- Projects executed at NASA Centers should request their Center Safety and Mission Assurance TAs to review and approve the project SMAP (if the project has determined that the project contains safety-critical elements). *
- NASA technology flight demonstration projects are encouraged to involve a Safety and Mission Assurance TA early in the project, for cognizance and oversight of project-identified safety-critical items. *,***
- SMA mission assurance TAs should be consulted by NASA projects when tailoring their Mission Assurance and Quality processes. SMA TAs must approve waiver of any processes *required* by NASA Procedural Requirements. *

4.10. Obtaining a Launch

Purpose of this Section: Useful references to commonly available suborbital and orbital launch service providers are given here to aid NASA and non-NASA projects seeking flight demonstrations.

4.10.1. Launch opportunities and POCs

- NASA Launch Opportunities: https://s3vi.ndc.nasa.gov/launchportal/
- NASA CubeSat Launch Initiative (CSLI): https://www.nasa.gov/content/announcement-of-opportunity-for-cubesat-launch-initiative
- Commercial Lunar Payload Services (CLPS): https://www.nasa.gov/content/commercial-lunar-payload-services-overview
- Science Mission Directorate Heliophysics Rideshare: https://www.nasa.gov/sites/default/files/atoms/files/a.mendoza-hill-smd_rideshare_nasatownhall_2020.pdf
- Space Technology Mission Directorate Flight Opportunities: https://www.nasa.gov/directorates/spacetech/flightopportunities/opportunities

Example of Commercial Rideshare Organizations

- NanoRacks: https://nanoracks.com/products/rideshare-launch/
- SpaceX rideshare: https://www.spacex.com/rideshare/
  - SpaceX Rideshare Payloads User's Guide (November 2020): https://storage.googleapis.com/rideshare-static/Rideshare_Payload_Users_Guide.pdf
- Space Systems/Loral, LLC (SSL): https://www.maxar.com
- Spaceflight: https://spaceflight.com/services/

4.11. Verification, Validation, and Expedited Spaceflight Qualification Testing

Purpose of Section: Clarify SST Program's objectives and approach to technology demonstration (including demonstration in space) as distinct from NPR 7120.5 Spaceflight product V&V. Describe efficient qualification requirements and approaches for technology demonstrated in space.

R&T products under NPR 7120.8, including those demonstrated in space, are not verified and validated as would be for an NPR 7120.5 Spaceflight mission. Technology developed for demonstration in space should, however, be qualified per the launch service provider's requirements. The SST Program may also impose requirements, which should be documented in the project plan or SEMP. Technology demonstrations in space typically undergo environmental qualification for the expected range of storage, transport, launch and space operational environments. Particular qualification requirements depend on the characteristics of the launch vehicle and launch providers generally establish qualification requirements, with Thermal Vacuum testing (TVAC) parameters generally driven by the expected on-orbit operational environment. Launch providers also give safety and interface requirements design requirements which must be verified as being met by the project. Launch providers require verification artifacts provided by the project that qualification requirements have been met before delivery or may approve certain waivers in some circumstances.

Other than the R&T product, hardware and software that will support the technology (spacecraft bus or spacecraft subsystems not part of the R&T technology under development) can be verified and validated for the space environment. If multiple copies of the bus or subsystems are built to be re-flown without configuration change, they only need to be verified and qualified once, with the first unit typically undergoing (proto-)qualification testing, and subsequent ones acceptance testing. In some instances a dedicated non-flight qualification unit can be used to qualify the design, with all flight units undergoing acceptance testing.

Differences Between Verification, Qualification, Acceptance and Certification

Crosscutting with Verification are the Acceptance and Qualification processes. Below are excerpts from the NASA/SP-6105 NASA Systems Engineering Handbook.

Verification: Verification is a formal process, using the method of test, analysis, inspection or demonstration, to confirm that a system and its associated hardware and software components satisfy all specified requirements. The Verification program is performed once regardless of how many flight units may be generated (as long as the design does not change).

Qualification: Qualification activities are performed to ensure that the flight unit design will meet functional and performance requirements in anticipated environmental conditions. A subset of the verification program is performed at the extremes of the environmental envelope and will ensure the design will operate properly with the expected margins. Qualification is performed once regardless of how many flight units may be generated (as long as the design does not change).

Acceptance: A smaller subset of the verification program is selected as criteria for the acceptance program. The selected Acceptance activities are performed on each of the flight units as they are manufactured and readied for flight/use. An Acceptance Data Package is prepared for each of the flight units and shipped with the unit. The acceptance test/analysis criteria are selected to show that the manufacturing/workmanship of the unit conforms to the design that was previously verified/qualified. Acceptance testing is performed for each flight unit produced.

Certification: Certification is the audit process by which the body of evidence that results from the verification activities and other activities are provided to the appropriate certifying authority to indicate the design is certified for flight/use. The Certification activity is performed once regardless of how many flight units may be generated.

See also NPR 7123.1 for more formal definitions of Verification and Validation.

Proto-Qualification is a hybrid strategy between Acceptance and Qualification; it consists of testing the first flight hardware to Proto-Qualification requirements to verify design while maintaining its flight worthiness, then testing subsequent flight hardware (if any) to acceptance levels to screen workmanship defects.

The following figure is provided as an example of the Integration and Test (I&T) Flow. This particular sequence is not mandatory but should serve as an adequate case of speedy qualification testing and is tailorable.

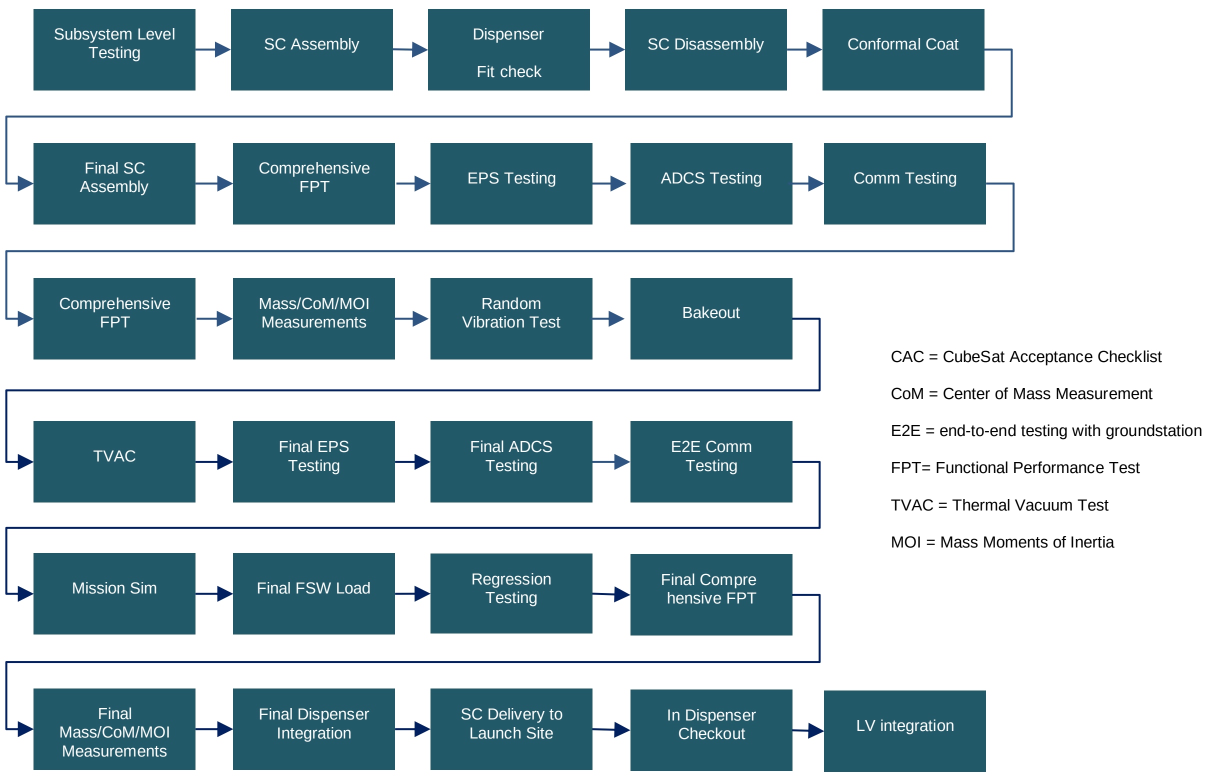

Figure 1. Generic I&T Flow – Baseline

Expedited Qualification Sequence – a.k.a. “Minimum Compressible Test Flow”

This represents a baseline set of tests to be performed to meet launcher and mission requirements by a project within the acceptable risk posture of the program, that a project will revert to if it needs to free up schedule margin. It is good practice for teams to establish this set prior to the start of the I&T campaign and get concurrence from applicable stakeholders, to ensure that this minimum set does indeed meet all the necessary requirements.

The General Environmental Verification Standard (GEVS) for GSFC Flight Programs and Projects (GSFC-STD-7000) is frequently used for flight projects at NASA Centers as well as the private and academic sectors. The Mission Success Handbook for CubeSat Missions (GSFC-HDBK-8007) also includes a version of the GEVS that is tailored for CubeSats in Appendix A, “Environmental Test for CubeSats”. Both of these references may be on the conservative side for small spacecraft technology demonstration flights and developers are encouraged to tailor the environment and test plan appropriately for the scope and risk profile of the flight project. However, developers are also reminded that small spacecraft are predominantly launched as secondary payloads, and a conservative approach on launch loads and environments is often warranted to preserve the greatest set of launch opportunities.

Verification, Qualification, Acceptance and Certification Recommended Practices:

- “Test as you fly, fly as you test”: following this philosophy helps ensure that the testing campaign and planned operations are commensurate with one another and the expected environments, increasing the likelihood of success.

- Plan early (during system concept, preliminary and detail design phases) and follow a schedule for tests to be conducted during spacecraft element procurement, fabrication, assembly and integration phases to screen and ensure hardware and software function as intended. Finding problems early gives more time for correction or alternatives.
- Schedule margin and contingency should be planned for each test to ensure sufficient time, budget and alternatives to mitigate unplanned test results. Tests are meant to detect problems; neglecting contingency plans may result in schedule problems.
- Nominal values and margin for thermal, vibration, and shock environmental qualification should be selected depending on the anticipated environments for launch, ascent environment of the particular launch vehicle, and expected on-orbit environment. If the particular launch vehicle is unknown at the time of qualification testing, the generic GEVS environment may be used. Even if the launch vehicle is known, it may still be prudent to use the generic GEVS environment as the majority of SST missions to date have switched launch vehicles at least once during development to mitigate the effects of changes in launch vehicle schedule or availability on the mission schedule and cost. (On rare occasions – such as for atypical launchers and/or launch configurations – the launch envelopes can sometimes exceeed that of the typical GEVS profiles; projects should be on the lookout for such circumstances and use best engineering judgement when proceeding forward).
- Environmental stress during storage and during shipment to the integration or launch site can damage hardware just as the launch environment would. Include design test for all known environmental exposure for qualification.
- Qualify your batteries for ISS deployment as that is the most restrictive case and will drive LV selection. Refer to the NanoRack Battery Guidance/requirements for ISS requirements.
- End (pusher) plate switches are, typically, preferred over rail switches.
- LV's will require materials lists for various purposes, such as the Orbital Debris Assessment Report (ODAR), and Outgassing assessments. These are NOT typically the same list as they have different criteria.

4.12. Spectrum Management and Radio Licensing. *SST-SpaceDemo

Purpose of Section: SST projects to be demonstrated in space need to be aware of approval authorities and long lead times for radio licensing. Projects implemented at NASA Centers typically are licensed through NTIA. Projects implemented in the private sector and academia typically are licensed through FCC. For both licensing agencies, licensing process may take more than a year after application.

4.12.1. Spectrum Management Introduction

Domestic (U.S.-based) small spacecraft radio licensing and documentation differ depending on whether the spacecraft operator is a federal (military or civilian) agency, or non-federal (commercial or academic) entity. In the US, two federal agencies have responsibilities for management of spectrum. For federal spectrum, the National Telecommunications and Information Administration (NTIA) is the lead authority. For non-federal spectrum, the Federal Communications Commission (FCC) has regulatory purview.

A. Projects Managed by Universities or other Non-Government Entities

For spacecraft managed, developed, and operated by non-government entities, the FCC will approve spectrum allocation and license the space station and any non-government-operated ground stations. In addition to licensing the radio, the FCC will not grant launch approval without Orbital Debris Assessment Report (ODAR) approval. Radio licensing will include requirements that spacecraft command and control include a provision for silencing the spacecraft radio in case of radio interference.

B. NASA and Other Government Agencies (OGA) Demonstrations in Space

NASA Center Spectrum Management Offices coordinate spectrum allocation and interface with the NTIA. For NASA missions that are being operated by non-government entities, the NTIA requires that NASA maintain “effective control” through contractual or other means to silence the spacecraft radio in case of radio interference.

4.12.2. Lead times

Begin planning for spectrum allocation as soon as possible, even before the project has selected the exact radio models and settled on a choice of spectrum. Inputs from NASA spectrum management, FCC and other licensing authorities may influence design trades. It’s also best to give the authorities notice of the upcoming mission so they can begin their planning. Typically, the licensing authorities should be contacted at least two years in advance of delivery of the spacecraft for launch. This is a challenge for the rapid tempo of small spacecraft and SST missions should start the process as soon as the project is in pre-planning (Pre-Phase A).

Many projects hire experienced consultants, or spectrum engineers, to guide them through the licensing process. Consultants may have access to points of contact within the licensing agency, insight derived from previous missions, as well as experience and understanding of the types and details of data needed for the RFA Application or spectrum filing form.

4.12.3. References: Organizations and POCs

ITU - International Telecommunication Union is the United Nations specialized agency for information and communication technologies (ICTs).

https://www.itu.int/en/about/Pages/default.aspx

NTIA - National Telecommunication and Information Administration is the Executive Branch agency that is principally responsible for advising the President on telecommunications and information policy issues. NTIA’s programs and policymaking focus largely on expanding broadband Internet access and adoption in America, expanding the use of spectrum by all users, and ensuring that the Internet remains an engine for continued innovation and economic growth.

https://www.ntia.doc.gov

FCC - The Federal Communications Commission regulates interstate and international communications by radio, television, wire, satellite, and cable in all 50 states, the District of Columbia and U.S. territories. An independent U.S. government agency overseen by Congress, the Commission is the federal agency responsible for implementing and enforcing America’s communications law and regulations.

Part 25- CFR-2015-title47-vol2-part25.pdf

FCC Office of Engineering and Technology, Experimental Licensing System (ELS)

https://apps.fcc.gov/oetcf/els/index.cfm

https://www.fcc.gov

NASA Center's Spectrum Managers -

For projects executed at NASA Centers, the updated list of NASA Center Spectrum Managers is found at:

https://www.nasa.gov/directorates/heo/scan/spectrum/txt_NASA_Spectrum_Personnel.html

- NPR 2570.1 – NASA Radio Frequency Spectrum Management Manual
- Spectrum Considerations for Interplanetary SmallSat Missions, William Notley, Interplanetary Small Satellite Conference, Santa Clara, CA, April 2015
- Spectrum 101 - An Introduction to National Aeronautics and Space Administration Spectrum Management, February 2016
- Spectrum Guidance for NASA Small Satellite Missions, Version 1.0 (2015.08.27)

Spectrum Management / RF Licensing Recommended Practices (*SST-NC, **SST-PS, ***SST-SpaceDemo):

- For projects managed at a NASA Center, during pre-Phase A, before a project has authorization to proceed (ATP), or as soon as possible after ATP, contact the local Center Spectrum Manager to discuss spectrum management issues and regulations that could influence / be influenced by mission design, choice of orbit, and technical trades for transponder(s).[*,***]
- For projects managed outside NASA Centers, during pre-Phase A, before a project has authorization to proceed (ATP), or as soon as possible after ATP, consult an FCC licensing consultant, review the FCC ELS web site, and make initial contacts with the relevant FCC authorities to discuss spectrum management issues and regulations that could influence / be influenced by mission design, choice of orbit, and technical trades for transponder(s). [**,***]
- The lead time for planning and licensing spectrum can take a year or longer. The NTIA process is time consuming. The process involves coordination with other missions, NASA-wide coordination, interagency coordination, coordination with international authorities; aspects of the spectrum management process cannot be expedited by a project or NASA line management. [*,**,***]
- Projects should identify a member of the project team who will serve as the project's spectrum engineer (i.e. the project's single point of contact to the spectrum management authority). The spectrum engineer will coordinate with the Center Spectrum manager (or with the FCC) as the single POC for communicating project design information impacting spectrum management. The spectrum engineer should be embedded within the project to facilitate timely dissemination of latest mission design information. [*,**,***]
- Considerations include orbit selection (or, range of orbit considerations in the case of a ride-share launch that has yet to be identified). [*,**,***]
- It is best for projects to include a spectrum engineer experienced in the process, who understands the detail of the data required, and how it needs to be formatted, and the importance of providing complete and precise design data in planning and in the spectrum filing form. [*,**,***]
- Projects managed at NASA Centers communicate to their Spectrum Management Office the design information needed for spectrum management in a standardized "RFA Application" spectrum filing form. [*,***]
- The NASA RF Allocation and Assignment Process and Procedures is found in NPR 2570.1C Chapter 3. [*,***]

4.13. ODAR and EOMP

Purpose of Section: Convey ODAR and EOMP lessons-learned. Reminder that all projects submit ODAR and EOMP. Explanation of submittal routing (from project through SST Program approval; Program relays them to NASA OSMA).

To ensure compliance with international law, all SST projects implemented at a NASA Center or in the private sector or academia must follow the orbital debris requirements in NASA-STD-8719.14 Process for Limiting Orbital Debris, NPR 8715.6 NASA Procedural Requirements for Limiting Orbital Debris and Evaluating the Meteoroid and Orbital Debris Environments, and the Orbital Debris Mitigation Standard Practices (ODMSP).

ODAR and EOMP Recommended Practices:

- For secondary payloads, a full ODAR package may require approval at PDR or a PDR-equivalent. Teams are encouraged to have the ODAR package pre-reviewed by the NASA Centers OSMA Representative.
    - For LSP launches, ODARs should be consolidated and submitted by LSP for all its payloads prior to FRR. There is no ODAR responsibility from payloads to OSMA in this scenario.
    - For commercial launch vehicles licensed by the FAA or orbital vehicles licensed by the FCC, there are currently no ODAR responsibilities from payloads to OSMA. However, OSMA still reviews the abbreviated debris assessment when/if NASA contributes an instrument or other element to a mission led by another space agency, to ensure that the agency does not deliver hardware known to violoate orbital debris mitigation principles.

To accelerate the process, ODAR and EOMP templates are available in NPR 8719.14 Appendix A and B, respectively. Note that ODAR sections 9 through 14 for the launch vehicle are typically not covered for CubeSat Secondaries.

4.14. Planetary Protection

Purpose of Section: For SST technology demonstrations beyond Earth orbit, the project shall take measures to address forward contamination (transmittal from Earth to a targeted Solar System body) and backward contamination (transmittal to Earth from the targeted body) with respect to other Solar System bodies.

The following documents apply:

- NPD 8020.7G, Biological Contamination Control for Outbound and Inbound Planetary Spacecraft
- NID 8020.109, Planetary Protection Provisions for Robotic Extraterrestrial Missions
- NASA-HDBK-6022, NASA Handbook for the Microbiological Examination of Space Hardware

Planetary Protection Recommended Practices:

- Note that forward contamination is of particular concern for Mars, Europa, Enceladus, and other icy satellites with possible liquid water bodies within.
- For additional information, developers should contact the NASA Planetary Protection Officer while the requirements are in development.

4.15 References to S3VI, other portals and sources for best practices

- The Small Spacecraft Systems Virtual Institute (S3VI): www.nasa.gov/smallsat-institute
- S3VI Reliability Initiative:https://www.nasa.gov/smallsat-institute/reliability-initiative
- Space Mission Design Tools: https://www.nasa.gov/smallsat-institute/space-mission-design-tools
- The SmallSat Parts On Orbit Now (SPOON) database: https://s3vi.ndc.nasa.gov
- Trajectory Design and Optimization Tools: https://trajbrowser.arc.nasa.gov
- The Astrogator's Guild: https://astrogatorsguild.com
- General Mission Analysis Tool (GMAT): https://opensource.gsfc.nasa.gov/projects/GMAT/index.php
- Debris Assessment Software (DAS): https://orbitaldebris.jsc.nasa.gov/mitigation/debris-assessment-software.html
- Copernicus: https://www.nasa.gov/centers/johnson/copernicus/index.html
- Mission Analysis Low-Thrust Optimization program (MALTO): https://www1.grc.nasa.gov/space/?ref=spaceSSPO/ISPTProg/LTTT/
- Spacecraft Planet Instrument Camera-matrix Events (SPICE): https://naif.jpl.nasa.gov/naif/toolkit.html
- Open Mission Control Technologies (MCT): https://nasa.github.io/openmct/getting-started/
- Space Environment Information System (SPENVIS): https://www.spenvis.oma.be
- NASA Tech Transfer Program**:** https://software.nasa.gov
- NASA Engineering Network communities of practice: https://www.nasa.gov/content/nasa-engineering-network-communities-of-practice/index.html
- NASA Launch Services Program (LSP) Performance Web Site https://elvperf.ksc.nasa.gov/Pages/Default.aspx
- State of the Art of Small Spacecraft Technology https://www.nasa.gov/smallsat-institute/sst-soa-2020
- NASA and Smallsat Cost Estimation Overview and Model Tools https://www.nasa.gov/smallsat-institute/nasa-and-smallsat-cost-estimation-overview-and-model-tools
- NASA Public Lessons Learned System https://llis.nasa.gov/
- Government-Industry Data Exchange Program (GIDEP) https://www.gidep.org/
- NASA Online Directives Information System (NODIS) Library https://nodis3.gsfc.nasa.gov/main_lib.cfm
- NASA Technical Standards System https://standards.nasa.gov/
- NASA Software Engineering and Assurance Handbook (living document) https://swehb.nasa.gov/display/SWEHBVC
- ODARs and EOMPs https://orbitaldebris.jsc.nasa.gov/mitigation/debris-assessment-software.html https://sma.nasa.gov/news/articles/newsitem/2018/06/26/complying-with-od-mitigation-requirements

https://www.federalregister.gov/documents/2020/08/25/2020-13185/mitigation-of-orbital-debris-in-the-new-space-age

The following sections may be incorporated in future revisions of the Guidebook:

- Technology Transition – Demonstration in Space, NASA Infusion, and Commercialization
- Streamlined Procurement, COTS Elements and Commodity Items including Spacecraft Bus – NASA
- Cybersecurity and Command Link Protection
- Launch Provider's Safety and Interface Requirements Compliance