

**Guidance for Distributed Satellite  
System (DSS) Architectures Proposed  
in Response to Science Mission  
Directorate (SMD) Announcements of  
Opportunity (AOs)**

**Version 2.0**

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# Introduction

The availability of smaller satellites has created the opportunity to propose mission concepts with Distributed Satellite System (DSS) architectures. A DSS is a mission architecture consisting of multiple space elements that collectively accomplish the mission's objectives. Science requirements flow down to the distributed architecture and then to the individual flight elements. DSS architectures may be categorized by a variety of names including constellations, trains, clusters, swarms, etc.

The requirements and evaluation criteria for proposals and Phase A Concept Study Reports (CSRs) are the same for DSS mission concepts as they are for non-DSS missions. However, these DSS missions offer both opportunities and challenges that must be considered in the development approach. This document provides additional guidance for proposal teams to create stronger proposals and CSRs when DSS missions are proposed. Proposal teams are advised to consider the guidance in this document during the proposal process. This document is supplemental; it does not create new requirements, nor does it remove any existing requirements in the Announcement of Opportunity (AO) or Guidelines and Criteria for the Phase A Study. Guidance related to deferred material is included in this document so that proposal teams may consider it as the mission concepts are defined. Deferred material should not be included in proposals.

Additional guidance for DSS missions is provided for the following ten topics.

- Consistent Terminology
- Systems Engineering Approach
- Pre-Production Testing Approach
- Multiple Unit Development
- Instrument System Calibration
- Development Schedule Resiliency
- Development Costs
- Resource Availability
- Operations and Ground Systems
- Mission Level Reliability

# Consistent Terminology

## Background

To avoid miscommunication between the proposing team and Technical, Management and Cost (TMC) evaluation team, a consistent set of terminology is necessary for DSS proposals.

## Potential Issues for DSS Missions

Given a DSS mission consisting of multiple flight elements (e.g., satellites) needed to meet the full science objectives of the mission, combined with a plan to launch more flight elements than is needed to meet those full science objectives in order to support reliability expectations through redundancy, the proposal or CSR could assume one of two definitions of the “Baseline Science Mission:”

- the number of satellites to be launched to support both the full science objectives and redundancy
- only the number of satellites needed to meet the full science objectives.

## Additional Guidance for DSS Missions

To avoid ambiguous terminology, the following definitions are provided:

- **Baseline Science Mission:** The mission that, if fully implemented, would fulfill the Baseline Science Requirements, which are the performance requirements necessary to achieve the full science objectives of the mission. A DSS Baseline Science Mission consists of multiple satellites operating as an integrated system to fulfill the Baseline Science Requirements. Multiple DSS scenarios may achieve the Baseline Science Mission.
- **DSS Launched Mission:** The planned number and configuration of satellites to be launched and the associated science measurements obtained if these satellites operated for their nominal lifetime.
- **Baseline Science DSS Resiliency:** The ability of the mission to tolerate flight system and instrument failures while still meeting the Baseline Science Mission. This resiliency may include the ability to collect the science measurements with less than the DSS Launched Mission or reconfiguration and other changes to the concept of operations that can be accomplished within the proposed resources.

# **Systems Engineering Approach**

## **Background**

All proposals are expected to describe the unique aspects of systems engineering that apply to the proposed mission. All proposals are expected to provide traceability matrices showing the instrument and mission requirements that the science goals and objectives impose on the mission design elements.

## **Potential Issues for DSS Missions**

A DSS mission architecture may have additional complexity that is caused by the required geometric configuration of flight elements and the dynamic evolution of the configuration. DSS-related features of this complexity should be included in the definition, decomposition, and flow-down of science and mission requirements for the proposed mission.

## **Additional Guidance for DSS Missions**

The systems engineering approach should address the unique challenges of the DSS mission consisting of multiple space elements that interact, cooperate, and communicate with each other. This systems engineering approach should address configuration and interoperability of multiple flight elements.

The proposal should address the requirements decomposition and flow-down from science goals to top-level science and mission requirements to DSS configuration, architecture, number of flight units, and observation strategy.

Sufficient technical and operational margins should be available to manage development of individual flight systems and provide resiliency at the DSS or constellation level.

Identification of requirements for any mission unique launch services pertaining to the accommodation and deployment of multiple space elements is expected.

# **Pre-Production Testing**

## **Background**

All proposals are expected to describe the approach to ensuring that the instrument design is mature enough to begin production. The appropriate level of pre-production analysis and testing will vary based on instrument requirements, heritage, production complexity and other factors.

## **Potential Issues for DSS Missions**

DSS missions will need to develop multiple copies of each instrument. The production plans will often require production on subsequent units to begin before production and testing of the previous unit has been completed. This concurrent or parallel production approach increases the difficulty of addressing issues that are discovered during production.

## **Additional Guidance for DSS Missions**

DSS mission proposals should provide a description of the approach to prototypes, engineering models, qualification models or any other planned builds that enable the project to begin production of multiple copies of flight units. The approach to pre-production testing should be justified in relation to the heritage and TRL of the proposed instruments and any heritage related to the production of multiple units.

If the approach includes an Engineering Test Unit (ETU):

- Proposals should identify the development and testing path of the ETU. Early end-to-end testing and calibration verification and validation of an ETU should be reflected in the build schedule
- The proposal should describe any differences between the planned ETU and the flight units. Justification should be provided for any planned differences between the planned ETU and the flight units.

If the approach does not include an ETU:

- The proposal should include information that shows that the risks associated with discovering build issues during production are mitigated through other means.

# Multiple Unit Development

## Background

All missions must provide plans for developing the instrument and flight system hardware. DSS missions by nature require development of multiple units of various systems and subsystems. Development of multiple similar units offers both opportunities and challenges that must be considered in the development approach. When developing multiple identical copies of hardware or software systems, elements of Human Systems Integration (HSI) can have significant impact on development, integration, and test processes.

## Potential Issues for DSS Missions

Manufacturing and Assembly, Integration, Test, and Verification (AITV) of DSS missions have additional challenges compared to single space vehicle missions. The proposal must address the logistics management challenges of planning, developing, integrating, and testing many similar flight elements on a time scale similar to single spacecraft missions.

Specifically, the greater number and relative development timing and delivery schedules of multiple copies of systems or subsystems can place unique requirements on items such as the AITV approach, vendor capabilities, facilities, and Ground Support Equipment (GSE).

## Additional Guidance for DSS Missions

The DSS mission proposal should demonstrate the ability to build, test, and integrate the required number of flight elements (spacecraft buses, instruments, etc.) from various government, contractor, academic, and foreign organizations with repeatable quality and performance standards on the required schedule. The proposal should describe the organization of the fabrication, assembly, test and calibration flow, and specify planned serial vs. parallel activities. The facilities and staffing needed for the production of multiple units should be specified. The proposal should address the availability of these facilities. Any plans for automation of production, assembly and integration activities should be described. The proposal should either describe any institutional heritage of producing multiple flight units or describe the approach to developing the institutional capability to produce multiple units.

Proposals should summarize the plan for configuration management of the manufacturing, testing, and calibration of all units from initial prototypes through the complete set of flight units. If an institutional configuration management process will be used, proposals should describe how that plan will be applied to the project. Proposals should describe any institutional heritage with complex configuration management tasks.

Planning should demonstrate resiliency to the discovery of single unit anomalies and the associated impact on various AITV approaches. This resiliency might include unique sparing plans, serial versus parallel assembly and test flows, schedule margins at critical processing steps, GSE, and unique test chamber contingency planning.

The overall unit test philosophy should be described. If different build units have different test requirements, the proposal should fully justify the differences.

Proposals should include descriptions of and justification for any planned automation of test and/or calibration processes and procedures. A description of any relevant heritage or institutional experience with automation of test and calibration activities should be included if automation is planned.

The DSS mission proposal should include the impact of the flight element's design on the repeat manufacturability, the quality assurance program implementation, the proposer's management of any subcontracted manufacturer, and the ability to capture and apply lessons learned for the effective production of subsequent units. If storage of completed flight units is required, the storage facilities and any necessary planned maintenance of the flight units should be described in the CSR.

# Instrument System Calibration

## Background

Most NASA observations from space require stringent and well-defined ground and on-orbit calibration and validation plans. NASA expects each proposal to describe the requirements for calibration and validation.

## Potential Issues for DSS Missions

DSS instrument calibration for individual instruments as well as across an expanded architecture of many distributed instruments creates additional complexities compared to instruments on non-DSS missions. Non-DSS missions typically do not need to intercalibrate among multiple identical instruments.

A DSS instrument system is any group of multiple instruments that must be operated together to produce science data analysis products. An instrument system is designed to achieve measurement requirements flowed down from Level 1 Requirements and can only achieve them as a system. Examples of DSS instrument systems include:

1. A set of identical instruments on multiple satellites. For example, a DSS mission may use three-axis magnetometers on all satellites to map the magnetic field of the Coronal Mass Ejection (CME) as it passes the DSS. The final product could be a time-dependent, three-dimensional “movie” of the CME magnetic field. The same mission may use Faraday Cups on each satellite to measure the in-situ plasma density. The final product is a time-dependent three-dimensional “movie” of the CME plasma density.
2. Instruments that use different techniques that produce overlapping physical measurements. For example, a DSS mission may use Magneto-Resistant Magnetometers (MRMs) to measure low frequency magnetic fields, and Superconducting QUantum Interference Device (SQUID) Magnetometers to measure high frequency magnetic fields. The two instruments overlap at mid-frequencies, and both instrument types are required to generate the final three-dimensional, three-axis CME magnetic field movie.
3. Instruments whose components are distributed across multiple satellites and/or ground assets. A DSS mission may utilize radio frequency transceivers at two frequencies to measure line of sight plasma rotation measure between all possible pairs of satellites using polarization direction. These measurements are used along with the plasma density measurements and in-situ magnetic field measurements to tomographically derive three-dimensional maps of the time-dependent magnetic field as the CME passes the DSS.

## Additional Guidance for DSS Missions

DSS mission proposals should describe the requirements and approach for calibration and validation of the instrument system distributed over the mission architecture. Proposals should demonstrate that sufficient Ground Support Equipment (GSE) and facilities are planned to support the mission’s approach to calibration. Proposers should discuss the instrument cross calibration requirements and identify the implementation plans for any required cross calibration

tasks. While calibration is often performed one unit at a time, proposals should describe plans for parallel activities if calibration will be performed in parallel. Proposals should describe plans for automating calibration if portions of calibration will be automated.

In addition, CSRs should discuss the resiliency of the plan for multiple instrument calibration. This resiliency discussion should address backup facilities including the availability of these facilities. Any planned backup personnel or the plan to obtain additional personnel should be described. The resiliency of the schedule to issues or delays in calibration should be addressed.

To clarify the full range of requirements, the following DSS-specific terminology is helpful:

1. **Inter-calibration:** Calibration between multiple copies of the same instrument. For example, consider a mission where each satellite employs an MRM to measure the low-frequency three-axis magnetic field. Uncalibrated sensitivity variations between MRMs will imprint spatio-temporal artifacts in the three-dimensional, three-axis magnetic field movies. The inter-calibration plan that allows science requirements to be met by sufficiently mitigating these artifacts should be described.
2. **Cross-calibration:** Calibration between different instruments making overlapping measurements. For example, consider a mission where each satellite employs an MRM and a SQUID Magnetometer to measure intermediate frequency magnetic fields. Proposals should indicate how the two instrument types are cross-calibrated consistently in the overlapping frequency range.
3. **Distributed calibration:** When an instrument consists of components that are distributed across multiple satellites and/or ground assets, the ground and flight calibration plans should address the unique challenges of validating and calibrating distributed instruments. For example, consider a mission where a Radio Frequency (RF) transmitter on satellite A illuminates an RF receiver on satellite B at two frequencies. The polarization difference is a measure of the density-weighted line-of-sight magnetic field. The transmitter polarization accuracy and the receiver sensitivity together determine the final accuracy of the measured rotation measure and derived magnetic field maps. Distributed calibration may be achieved by separately calibrating the transmitter and the receiver or more ideally, by calibrating the transmitter and receiver simultaneously in a flight-like fashion. In practice the latter may only be possible in-flight. Note that the derived magnetic field maps also depend on the plasma density and in situ magnetic field measurements, so that the final map quality depends on the calibration of the complete transmitter/receiver/plasma density/magnetometer measurement system.

# Development Schedule Resiliency

## Background

All missions must demonstrate that the schedule supports the planned mission development approach. The required nominal schedule duration and the amount of schedule reserve needed to provide resiliency will depend on mission unique factors. These factors include the maturity of the hardware, steps required for production, plans for I&T, and the level of experience of the project institutions.

## Potential Issues for DSS Missions

AOs specify the same starting date and the same launch period constraints for all missions. DSS missions must develop, integrate, and test additional flight units within this time allocation. DSS missions may experience schedule pressure in cases where the testing of subsequent units requires rework of previous units.

## Additional Guidance for DSS Missions

Additional schedule foldout pages are allowed for DSS missions due to the increased complexities and interdependencies associated with those missions. The foldouts should include aspects of DSS development including parallel versus serial production and testing activities, how the ETU development (if applicable) leads to the first flight unit, how the flight model builds are delivered to testing, how single facilities (e.g., TVAC chamber or calibration fixture) are used to test the flight units, the flight system delivery sequences, shipment(s) to the launch range, etc.

All proposals should demonstrate that adequate Funded Schedule Reserve (FSR) is available to provide resiliency. Compliance with institutional guidelines is not necessarily sufficient. Greater FSR is typically warranted for DSS missions due to the project complexities and quantity of flight elements. Increased schedule margin, including that margin beyond institutional guidelines, should be addressed in the proposal to address procurement, development, production, redesign, rebuild, I&T, and calibration. The use of schedule slack should be justified with regard to its impact on overall FSR.

The CSR and associated schedule should describe the resources and plans required for the production, I&T, and launch of the entire DSS. The CSR and associated schedule should also provide discussion of alternative production/I&T flows and resources in case work-arounds are required due to anomalies or failures of any given flight vehicle or unit. The CSR should provide information that demonstrates the production schedule is resilient to an anomaly late in production or I&T, or a late delivery of key vendor units. Work-arounds and backup options should be described in the CSR if an anomaly threatens to delay the entire AI&T flow. The flexibility in resources, personnel, facilities, and processes to accommodate these types of issues without significantly impacting the entire production and AI&T flow should be provided in the CSR.

# Development Costs

## Background

All missions must demonstrate the adequacy and robustness of the cost plan. The proposals must provide a basis of estimate and demonstrate that adequate funding and reserves are available for each phase of the project.

## Potential Issues for DSS Missions

The cost of developing and operating multiple flight units do not generally scale linearly with the number of flight elements. DSS missions may benefit from cost efficiencies for follow on units. The viability of the cost plans associated with a DSS mission will often depend on the accuracy with which the mission has estimated these efficiencies.

## Additional Guidance for DSS Missions

The Basis of Estimate (BOE) for proposed DSS missions should describe and quantify the non-recurring cost investment and the assumptions and factors used to minimize the recurring cost. Where cost efficiencies are assumed, the presented costs should be supported by a discussion of key technical and programmatic factors having the greatest impact on cost reduction (automation, fabrication process, the cost of the spacecraft as a function of the reliability of the spacecraft, heritage, etc.). For instruments and spacecraft, BOEs should indicate whether the total proposed cost assumes any reduction in fabrication, assembly and I&T cost for units following the first flight unit. If cost efficiencies and lower costs are assumed for follow-on units, the BOE should indicate and justify the level of cost reduction that is used. If proposed savings are derived using standard industry learning curve calculations, the BOE should indicate the learning curve percentage that is used, and which flight unit is assumed as the start of learning. A discussion of the fabrication plan, to include staffing, use of automation, and fabrication process (i.e., serial vs parallel) should be presented to include assumptions regarding how these parameters influence any recurring cost efficiencies.

For vendor quotes for major flight hardware elements, adequate supporting detail should be included to provide insight into the vendors costing assumptions associated with the multiple units. Adequate support is needed whether the quote is Firm Fixed Price (FFP) or another contract type. A BOE based on a vendor quote without supporting information does not demonstrate estimate credibility.

Comparison of Phase E costs for the proposed DSS mission to operations costs for previous DSS mission(s) should be provided if this data is available. Alternatively, a comparison of the Phase E costs for the proposed DSS mission to operations costs for previous single spacecraft mission(s) may be provided. If a comparison with a single spacecraft mission(s) is provided, the operational differences between the DSS and single spacecraft mission(s) should be identified, and the cost differences should be justified.

# **Resource Availability**

## **Background**

All missions must demonstrate that sufficient resources are available to support any mission unique aspects of the proposed approach to instrument and flight system development. These mission unique needs may include aspects such as parts, processes, facilities, ground support equipment, and staffing.

## **Potential Issues for DSS Missions**

DSS missions often require additional resources during development to support multiple unit development. DSS missions may require significant procurements of flight-quality parts much earlier than is normally planned for a mission with only one flight unit. Multi-unit develop may require additional facilities and different approaches to staffing. The approach to multi-unit build, I&T, and calibration may require a higher quantity of simulators than single satellite missions.

## **Additional Guidance for DSS Missions**

If early procurements of flight-quality parts are required to build a high-fidelity ETU early in the project, proposals should describe the necessary procurements. The proposal should describe any related cost and schedule risk from early procurement of parts that may turn out not to be what is needed. If large quantities of flight-quality parts are required for a DSS mission, the timing of parts procurement should be described and justified.

The proposal should provide suitable information that demonstrates the production facilities are adequate to support the project's build, I&T, and calibration plans. The proposal should discuss existing and planned facilities for the DSS production requirements. Any planned use of new facilities within project institutions should be described.

Flexibility in the planned facilities, and alternative facilities, planned as backups, should be discussed in the CSR to demonstrate that adequate facilities are available for the development of multiple flight units. For example, the CSR should demonstrate how I&T processes or integration plans could move forward even if a key facility is unavailable because the facility is occupied by another flight unit in the DSS production flow.

The proposal should summarize the existing and planned support equipment and resources that will support the planned DSS development approach. If applicable, duplication of support equipment and resources at multiple institutional locations should be described with regard to the overall facilities and the planned production activities.

The proposal should demonstrate that the quantity and type of planned simulators is adequate for the build, I&T, and calibration plans for the multiple builds. Information regarding the use of simulators at multiple institutional locations should be described with regard to the overall production and verification activities. Delineation of project-funded and existing simulators should be provided and supported by the cost information in the proposal.

The planned size and organization of the staff responsible for manufacturing, assembly, test and calibration of multiple flight units should be described. The proposal should describe how the team will be organized to support the planned serial and parallel workflows.

# Operations and Ground Systems

## Background

All missions must be operated in a manner that enables science requirements to be met. Proposals are expected to fully describe the operational approach, capabilities, and ground systems (including software) that will be used in all phases of deployment, commissioning, commanding, monitoring, fault/anomaly response and resolution, decommissioning, and end of life operations. Some aspects of these expectations are deferred until the CSR for a two-step evaluation.

## Potential Issues for DSS Missions

Operations of DSS missions have additional challenges compared to single space vehicle missions. These missions must fully consider the mission operations approach, capabilities, and resources to execute the deployment commissioning, commanding, and monitoring of all satellites in the DSS launched mission.

Specifically, the greater number and relative timing of total operational events can place a greater strain on the mission operational approach, capabilities, and facilities than simple linear scaling may predict. For example, multiple launches, “simultaneous” deployments, critical events, or faults on multiple spacecraft may require more resources (ground contacts, operator, and Subject Matter Expert (SME) support) to resolve than a non-DSS mission. Plans to address failures of individual space vehicles or instruments through reconfiguration of the remaining vehicles must be accounted for in delta-V budgets and overall mission schedule margins.

## Additional Guidance for DSS Missions

The DSS mission proposal should provide a description of the plan for mission and science operations for all satellites in the DSS launched mission.

The DSS mission proposal should clearly demonstrate the ground systems and mission operations approach/capabilities/resources to accommodate all satellites in the DSS launched mission during deployment, commissioning, commanding, monitoring, fault/anomaly response and resolution (including any reconfiguration), decommissioning, and end of life operations.

The Space System Protection Standard (NASA-STD-1006A) defines the command stack as the end-to-end command chain from initial command transmission at the operations center to receipt and execution on the platform. DSS missions that relay commands via a hub spacecraft should show that their plans provide protection throughout the full command stack. If the requirements related to the Space System Protection Standard are deferred until Step-2, these plans should not be addressed in the proposal.

NPR 2570.1C defines maximum channel bandwidth requirements as applying to satellite systems. A satellite system includes one or more artificial satellites. If maximum channel

bandwidth requirements are applicable to the AO, DSS missions should show that the plans for the entire DSS comply with these maximum bandwidth requirements.

# Mission Level Reliability

## Background

All missions are required to comply with NASA Procedural Requirements (NPR) 8705.4A. NPR 8705.4A defines expectations for risk tolerance for each class of mission. The objectives for each class are specified in Appendix D of NPR 8705.4A. Step 1 proposals and Step 2 CSRs are expected to demonstrate that the proposed missions have a reasonable probability of successfully meeting the risk tolerance expectations in NPR 8705.4A during Phases B-D.

Deviations in the recommended requirements in Science Mission Directorate (SMD) Policy Document (SPD)-39, *Science Mission Directorate Policy: SMD Standard Mission Assurance Requirements For Payload Classification D* and in Appendix C of NPR 8705.4A must not result in tailoring below SPD-39, even for individual flight elements within a DSS. If the AO specifies requirements related to a MAR document other than SPD-39, all proposed missions and flight elements should comply with those requirements. The guidance in this document is not meant to waive any AO requirements.

## Potential Issues for DSS Missions

The approach to demonstrating appropriate risk tolerance with a DSS mission requires a more rigorous approach than non-DSS missions, due to the increased number of space vehicles. Proposed DSS missions may become infeasible when mission assurance and system reliability are considered. Even when all required flight elements individually meet the defined risk tolerance, the overall mission may not meet the system reliability expectations. For example, a mission that requires numerous space vehicles to all survive over the mission lifetime in order to meet the science observation requirements may not meet the system reliability expectations even if each flight element meets reliability expectations.

Furthermore, the total number of space vehicles expected to survive over the mission lifetime may well exceed the overall number required, but the configuration of the surviving space vehicles may not meet the science observation requirements.

## Additional Guidance for DSS Missions

Performing a thorough mission assurance analysis is beyond the scope of both Step 1 proposals and Step 2 CSRs. However, all proposals are expected to show that the proposed approach to systemic and random errors meets the mission level reliability expectations for the specified mission class.

Systemic errors are common across all space vehicles and can result from defects in workmanship and testing standards, parts control processes, environmental effects, and relevant component heritage, among other causes. The evaluation of these areas is the same for both DSS and non-DSS proposals. Strengths and weaknesses are evaluated by SMEs in the appropriate factor areas (e.g., instruments, flight systems, systems engineering, etc.)

Random errors are all other stochastic failure modes of an individual space vehicle that impact the mission. Although the probability of these random errors may be low for an individual space vehicle, the combined probability across the total number of space vehicles in a DSS mission may prevent the DSS mission requirements from being satisfied.

Recognizing that this effect of random errors both has a potentially greater negative effect on DSS missions and that providing detailed analysis to prove resiliency against these effects is a burden on organizations that propose DSS missions, a Preliminary Mission Architecture Survivability Estimate may be provided to demonstrate that the DSS mission has a reasonable probability of successfully meeting the risk tolerance expectations in Phases B-D. Projects that do not provide a Preliminary Mission Architecture Survivability Estimate in the proposal must use other methods to demonstrate that the DSS mission will meet mission level reliability expectations. This preliminary estimate is not a replacement or supplement for SMA oversight of missions during formulation and implementation.

The Preliminary Mission Architecture Survivability Estimate only focuses on estimating the likelihood that the proposed mission assets will survive for sufficient time to achieve the science objectives. Survivability typically depends on individual space vehicle reliability, mission duration, and mission/orbit design. Proposers may use any methodology to demonstrate sufficient survivability.

To reduce the burden on organizations that propose DSS missions, projects may assume a 0.8% monthly failure rate for individual satellites without further justification in the proposal. If any individual satellites are built to Class C risk tolerance, projects may assume a 0.45% monthly failure rate for those satellites. Projects are free to use a different value for individual satellite reliability, but any deviations must be justified and well-supported in the proposal.

DSS proposals that utilize the 0.8% monthly failure rate for satellites that are not built to Class C standards and a 0.45% monthly failure rate for satellites built to Class C risk tolerance in the Preliminary Mission Architecture Survivability Estimate are eligible for “safe-harbor” treatment. DSS proposals for missions that demonstrate Preliminary Mission Architecture Survivability Estimates greater than

- 60% for a Step 1 proposal for a Class D mission
- 65% for a Step 1 proposal for a Class C mission
- 75% for a Step 2 CSR for a Class D mission
- 80% for a Step 2 CSR for a Class C mission

will not have TMC/Form C weaknesses written against the impact of random errors on mission level reliability. DSS proposals that have Preliminary Mission Architecture Survivability Estimates below these values, or that use a different monthly failure rate, may or may not have weaknesses written against the impact of random errors on mission level reliability depending on the information provided in the proposal.

Note that the impact of systemic errors on mission level reliability is not covered by the Preliminary Mission Architecture Survivability Estimate and is not eligible for “safe-harbor” treatment. Systemic issues are evaluated by SMEs in the appropriate factor areas and can generate strengths or weaknesses independent of the Preliminary Mission Architecture Survivability Estimate presented in the proposal.

## **Preliminary Mission Architecture Survivability Estimate Examples**

Two examples, one analytical and one numerical, for calculating the Preliminary Mission Architecture Survivability Estimate are presented. These examples are representative of the types of analyses that are expected, but individual proposal teams may utilize alternative methods.

### **Analytical Example**

#### **Mission Design**

The DSS launched mission consists of 12 satellites split evenly between two planes. Each satellite will be built to Class C risk tolerance standards. The mission is being developed as a Class C mission. All mission requirements can be met as long as at least five satellites are fully operational over the 21-month science period in each of the orbital planes.

Mission design has accounted for individual satellite failure within an orbit plane. The time required for reconfiguration after a satellite failure is accounted for in the estimated instrument duty cycle. However, satellites do not have sufficient propellant to move between planes.

Launch and Early Operations (LEOP) requires three months before science operations can begin.

#### **Preliminary Mission Architecture Survivability Estimate**

The mission requires five of six satellites to survive in each orbital plane for 24 months (three months of LEOP plus 21 months of science operations). A 0.45% monthly failure rate, results in an individual satellite reliability of ~89.7% at the end of the science mission.

For a single plane, the mission assumes a binomial distribution with six events that requires five successes where each probability of success is ~89.7%.

For a single plane, the binomial distribution has an ~88.1% likelihood of having at least five of six satellites survive for 24 months.

Since both planes must have five operational satellites, the Preliminary Mission Architecture Survivability Estimate is  $(88.1\%)^2$  or ~77.5%.

This mission design qualifies for “safe-harbor” treatment for a Step 1 proposal. The mission design does not qualify for safe-harbor treatment for a Step 2 CSR because the Preliminary Mission Architecture Survivability Estimate is less than 80% for a Class C mission.

## **Numerical Example**

### **Mission Design**

The mission is a Class C mission. The AO permits individual flight elements that are not built to Class C risk tolerance. All space vehicles are 12 kg satellites with a single instrument. The individual space vehicle (CubeSat plus instrument) reliability uses the “safe-harbor” monthly failure rate of 0.8%.

The DSS launched mission consists of 20 type A satellites and 12 type B satellites. All science requirements can be met with at least 3500 measurement units during the mission. The number of measurement units in a given month is  $n_A * n_B$  where  $n_A$  is the number of operational type A satellites and  $n_B$  is the number of operational type B satellites.

LEOP requires three months before science operations can begin. Science operations are planned for 24 months after LEOP.

### **Preliminary Mission Architecture Survivability Estimate**

The mission does a Monte Carlo analysis with 100,000 runs to determine the probability of achieving 3500 measurements. The number of runs should be selected to ensure that statistical sampling is not significantly impacting the results.

For each mission run, the simulation loops through the 27 months of mission operations.

#### ***Monte Carlo Details***

The number of type A satellites available at the end of the first science month ( $n_{A1}$ ) is obtained by sampling one discrete event for each of the 20 type A satellites. The probability that a satellite is alive at the end of first month of science operations is  $(100\% - 0.8\%)^4$ . The probability is raised to the fourth power because there are three months of LEOP in addition to the single month of science operations.

The number of surviving type B satellites at the end of science month 1 ( $n_{B1}$ ) is determined in the same manner.

The number of collected observations in the first science month is the product of  $n_{A1}$  and  $n_{B1}$ .

The number of type A satellites available at the end of the second month ( $n_{A2}$ ) is obtained by sampling one discrete event for each of the  $n_{A1}$  type A satellites that were alive at the end of the first month. The probability that a satellite is alive at the end of second month of science operations given that it was alive at the end of the first month is  $(100\% - 0.8\%)$ .

The number of surviving type B satellites at the end of science month 2 ( $n_{B2}$ ) is determined in the same manner.

The number of collected observations in the second science month is the product of  $n_{A2}$  and  $n_{B2}$ .

The process is repeated for all 24 months of science operations.

The total number of observations for the single run is the summation over  $i$  of  $nA_i \times nB_i$  for all values of  $i$  from one to 24.

If the total number of observations for the run exceeds the required number of observations, increment the number of successes by one.

The Preliminary Mission Architecture Survivability Estimate is the number of successes divided by the total number of runs. The Preliminary Mission Architecture Survivability Estimate is ~97.3% for this scenario.

This mission design meets the “safe-harbor” requirements for a Class C mission for both a Step 1 proposal and a Step 2 CSR.