Formulation of NASA Space Flight Investigations:
A Framework to Enable Discussions

This document discusses the different ways that NASA SMD can formulate space flight investigations. It discusses the different types of space flight investigations, what pre-formulation information NASA requires, and what pre-formulation efforts NASA would need to undertake. (Note that the discussion of pre-formulation efforts excludes any acquisition process, such as solicitations.)

These investigation types and associated processes arise from the set of regulations, policies, and procedures that SMD projects are solicited and developed within.

The terms and definitions of consist of those drawn from NASA documents (sometimes in a simplified form), those terms used within the heliophysics community, and those plain-English terms that capture key attributes. This document was drafted to provide a common understanding and language for the clear communication around the 2024 Solar and Space Physics Decadal Survey.

Introduction

SMD space flight investigations can be classified based on three characteristics. These characteristics are determined during formulation and lead to the project's requirements.

1. Completion of investigation-specific science objectives
2. Reliance on resources of specific, non-infrastructure capabilities outside of the project for completion of investigation-specific science objectives
3. Direct leading to the completion of science objectives beyond the investigation-specific science objectives

Completion of investigation-specific science objectives

An investigation is defined by the existence of science objectives for completion. SMD requires that its space flight investigations complete science objectives within the scope of the supporting project. Therefore, this characteristic is uniform across all investigations described within this document.

Note: While not discussed in this document, there are heliophysics investigations that would be cost prohibitive to complete within a single project. These generally require large ranges of spatial and/or temporal coverage. Many projects could make relevant observations, but completion of the science objective(s) require compilation of observations across multiple projects. (This is analogous to how completion of a science objective is achieved by an investigation, but major progress on a science goal requires completion of objectives across multiple investigations.)

For these science needs, community discussions have centered around data buys, contributed instruments, and hosted payloads. Space flight projects that meet these needs would not be acquired through SMD solicitations (e.g. Announcement of Opportunity).

Reliance on resources outside of the project

An investigation's reliance on resources or capabilities outside of its project's control is limited for legal and risk-based reasons. (Note that a resource or capability contributed by an investigation partner or otherwise acquired directly by the investigation is within the investigation's control.)

Legally, the primary restriction is 51 U.S.C. §30504, which mandates a triennial review of SMD space flight missions that exceed their planned mission lifetime. SMD primarily meets this requirement through its Senior Review process, in which every mission proposes for an additional three-year extended mission. Permitting an investigation to be formulated with the reliance on another SMD mission late in (or past) its planned lifetime would lead to a conflict with this legal mandate as it would presume an outcome of that mandated review.

With regards to risk, the restrictions are programmatic. Restricting extra-investigation reliances avoid predictable situations where a SMD would need to A) permit an investigation to proceed with the understanding that it would not reach a successful completion, B) terminate a mission before it can launch, or C) commit a significant amount of additional funding to fill a capability gap.

Since this restriction is based on risk, situations where risk is minimized to an acceptable level are those where SMD accepts a reliance on extra-investigation capabilities. The two most common are 1) existing, widely accessible infrastructure, and 2) decentralized or non-provider specific capabilities.

Infrastructure are those systems that have a very high likelihood of continued existence, either due to a strong Government guarantee or societal need. For instance, global navigation satellite systems (GNSS) are an integral part of many Government and civilian technologies. It is highly unlikely that these systems, once available, would be decommissioned or become otherwise unaccessible during a mission's development lifecycle.

Decentralized or non-provider specific capabilities are those where the information they provide are not temporally or spatially sensitive, and can be provided by a moderate or large number of sources. A common example in solar and space physics is contextual measurements of the solar wind or geomagnetic activity. These contextual measurements would not be sufficient to perform detailed, high-resolution (in space and time) analyses, but provide insights into the general space environment during times of interest.

Situations where SMD might accept the risk of an investigation relying on specific capabilities outside of its control include where NASA or another Government Agency (e.g. NOAA, USGS) has a mandate for or commitment to operate a specific project/platform (either ground- or space-based). For these, the two most obvious conditions SMD would consider are 1) whether the

Agency is mandated/committed to operating it until/past an investigation's planned completion date, and 2) whether use of the capability is restricted or otherwise limited. A restricted or limited capability would be one where the data is not publicly available, or where use by one party reduces or precludes use by another part (such that the investigation may not have full anticipated use; e.g. an observatory that makes targeted observations).

Directly lead to completion of science objectives beyond the investigation

Every mission acquires measurements that can be used in research beyond the scope project investigation. That does not imply that the mission makes a direct contribution to the objectives beyond the investigation's objectives, as discussed by this document.

A mission that directly leads to the completion of objectives beyond the investigation is one where NASA formulates a mission with the intention to meet requirements that flow down from objectives the beyond the investigation.

Independent investigation

Independent investigations are those

1. formulated to complete a set of science objectives by a single space flight project, and
2. formulated to complete that set of science objectives without relying on specific resources or capabilities provided by any concurrently operating space flight mission.

Example: The typical NASA project. It has a set of project-specific objectives that are completed using data from a stand-alone mission developed and operated by the project.

Pre-formulation inputs

- For NASA-defined investigations (e.g. New Frontiers, Solar Terrestrial Probes/IMAP), NASA requires defined scopes for one or more potential investigations. These may be developed within the Agency, recommended by a non-government stakeholder (e.g. decadal survey), or directed by a government stakeholder (e.g. Congress).
- For PI-defined projects, NASA does not require any specific input.

Pre-formulation efforts: NASA typically only engages in pre-formulation efforts for NASA-led projects. After defining the scope of the investigation, NASA frequently supports community-based pre-formulation work to refine the objectives and to define high-level investigation and mission requirements (e.g. Science and Technology Definition Team). Then a pre-project office is stood up to move the project through a successful KDP A.

Dependent investigation

Dependent investigations are those

1. formulated to complete a set of science objectives by a single space flight project, and

2. formulated to complete at least one objective in the set of science objectives with a reliance on specific resources or capabilities provided by one or more concurrently operating space flight missions.

The limitations on dependent investigations are primarily legal and risk-based (as described in the Introduction). Although NASA encourages the leveraging of the full Heliophysics System Observatory for science investigations supported through its research programs, it is challenging to permit a particular mission's use for a new mission investigation.

The missions that could be relied on with less risk would be those 1) being developed at the same time as the mission leveraging their resources or capabilities, or 2) that NASA or a partner Agency are mandated to continue operating.

Example: DYNAMIC. SMD announced an intention to formulate DYNAMIC as a small mission that would depend on measurements acquired by the concurrently launching GDC mission to complete the DYNAMIC-specific science objectives. (Note that, in this scenario, while DYNAMIC is a dependent investigation, GDC remains an independent investigation as it does not require DYNAMIC for its own success.)

Pre-formulation inputs

- For PI-defined/PI-led investigations, NASA requires knowledge of the resources and capabilities of the space flight missions that the dependent investigation will rely on.
- For NASA-defined/PI-led investigations (e.g. New Frontiers, Solar Terrestrial Probes [2017 AO]), NASA requires defined scopes for one or more potential investigations. These may be developed within the Agency, recommended by a non-government stakeholder (e.g. decadal survey), or directed by a government stakeholder (e.g. Congress).
    - Note: Certain forms of input received from outside the Agency may provide challenges to NASA formulating a dependent investigation. For instance, a recommendation that specifies a particular mission implementation (e.g. spacecraft, mission design, schedule) instead of just a focused scope of scientific investigation could make it difficult for NASA to be formulate the project on a schedule that permits it to leverage another space flight mission's capabilities.

Pre-formulation efforts

- For all investigations, NASA documents the resources and capabilities that a dependent investigation could rely on. This documentation is released with the solicitation.
- For NASA-defined investigations, NASA documents the project scope that is being solicited. This includes the scientific requirements for the investigation and the programmatic constraints (e.g. cost, schedule, mission technical specifications [e.g. size, mass, power]).

Coupled investigation

Coupled investigations are those

1. formulated to complete a set of science objectives by a single space flight project, and
2. formulated to directly lead to the completion of additional science objectives when the space flight project's resources or capabilities are combined with those of one or more concurrently operating space flight missions.

[It should be noted that this definition of a coupled investigation is agnostic to whether an investigation relies on resources or capabilities outside of its control. Coupled investigations are defined by the formulation to complete science objectives. They could require resources or capabilities outside of their control, and any required resources or capabilities could be provided by investigations that they are coupled to or not. There are differences in the strength of coupling that are a level of detail not informative for decadal survey discussions.]

Coupled investigations are unlikely to be part of PI-defined projects. Coupled projects have the two-directional coupling (i.e. Project A required Project B and Project B requires Project A) that requires coupled pre-formulation.

Example: The Afternoon Constellation ("the A-Train") aligns with the spirit of this investigation type. Each satellite in the constellation has its own separate investigation objectives, but the spacecraft are closely spaced in a single orbit so that near-simultaneous observations of Earth's surface and atmosphere could be combined to enable additional Earth system research. Note, however, that A-Train projects are not truly loosely coupled due to the lack of coupled formulation for the completion of specific science objectives beyond the investigation-specific objectives completed by each project.

Pre-formulation inputs: NASA requires either 1) the sets of investigation objectives (one set per project) that, when combined, would enable the completion of the additional set of objectives, or 2) a single investigation that could be separated into multiple investigations that, when combined, would still complete the parent investigation's objectives.

Pre-formulation efforts: NASA engages in the same pre-formulation efforts as for an independent investigation. However, there are addition components exclusive to the loosely coupled investigations.

- When starting with a single investigation, it needs to be separated into multiple investigations. Depending on the original investigation's particular nature, this could be accomplished early in the process (if the investigation requires a clearly separable heterogenous constellation) or a late in the process (if there are scientific and technical trades necessary to maximize the return of coupled investigation and the set of investigations).
- For all investigations, the pre-formulation efforts need to establish requirements that are flowed down to each of the coupled investigations and to manage the trades between the investigations. This could be done by a single group developing the concepts in parallel or multiple groups developing the concepts under the outside management.
- For all investigations, NASA would need to study the trades of mission cost, complexity, and lifetime to identify the optimal development schedules for the projects.
    - For example, assume that NASA decides to split a single investigation with a heterogenous constellation. If all of the satellites are developing along the same

schedule, the funding requirements would all align and create significant budgetary pressure. However, a more consistent overall budget profile could be achieved by 1) staggering similarly sized projects, or 2) lining up start or stop times of dissimilarly sized projects.

- Staggering similarly sized project: In the simplest case, imagine two missions. If one has a long Phase E cruise phase before prime science operations, NASA could start that one first and time the other so that both start prime science operations at the same time. Alternatively, if they had the same time between launch and prime science operations, they could be staggered and the first mission could be designed for a longer Phase E (where the trade would be increased development cost of the first against the budget risk of aligning the budget profiles of the two).
- Lining up dissimilarly sized projects: In the simplest case, imagine two missions (one larger, one smaller). Assuming the same time between launch and prime science operations for the two, NASA could start the smaller project later such that the both launch at the same time.