

# Implementing Effective Mission Systems Engineering Practices During Early Project Formulation Phases

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***Abstract** - Developing and implementing a plan for a NASA space mission can be a complicated process. The needs, goals, and objectives of any proposed mission or technology must be assessed early in the Project Life Cycle. The key to successful development of a space mission or flight project is the inclusion of systems engineering in early project formulation, namely during Pre-phase A, Phase A, and Phase B of the NASA Project Life Cycle. When a space mission or new technology is in pre-development, or “pre-Formulation”, feasibility must be determined based on cost, schedule, and risk. Inclusion of system engineering during project formulation is key because in addition to assessing feasibility, design concepts are developed and alternatives to design concepts are evaluated. Lack of systems engineering involvement early in the project formulation can result in increased risks later in the implementation and operations phases of the project. One proven method for effective systems engineering practice during the pre-Formulation Phase is the use of a mission conceptual design or technology development laboratory, such as the Mission Design Lab (MDL) at NASA’s Goddard Space Flight Center (GSFC). This paper will review the engineering process practiced routinely in the MDL for successful mission or project development during the pre-Formulation Phase.*

*Keywords:* Systems Engineering Team, Formulation Phase, Mission Design Lab, MDL, collaborative engineering

## 1 Introduction

Incorporating systems engineering input early, during pre-Formulation, allows for effective technical planning, decision-making, and agreement among various contributors, laying the groundwork for positive working relationships at critical times during development and helping to ensure mission success. The MDL of GSFC’s Integrated Design Center (IDC), managed by the Mission Engineering and Systems Analysis Branch, is a mechanism that introduces effective project pre-Formulation during the Project Life Cycle. (See Figure 1.) This facility provides a collaborative technical environment in which scientists, systems engineers and engineers of various disciplines examine all technical aspects of a proposed mission or technology and develop an initial point design, that can iterated upon as changes for a more refined design later.

In this engaging environment, a Lead Systems Engineer establishes the systems design process by getting involved early in initial negotiations with scientists, engineers, project managers (and other stakeholders) and

utilizes the skills of relevant engineers pertinent to the concept development phase. The scientists and engineers work interactively in an intense design environment to reach a solution to a proposed science mission concept or technology in a short timeframe, typically one week. The result of the intense study is usually a roadmap for a successful mission or technology proposal. This systems engineering driven design process provides an orderly transformation of science, mission, or technology objectives into a system architecture as groundwork for effective project development and implementation.

The IDC also consists of the Instrument Design Lab (IDL), which is the facility in which the instrument systems necessary for a mission are designed or selected from prior heritage instrument system components. Most MDL studies that are presented have already been through the IDC for the instrument systems design or assume heritage instruments or components as precursor for the design. There may be no need for instruments, as in the case in which the study goal is exclusively technology development.

## 2 The MDL Study Process

The inception of an MDL study begins when a potential study Customer, mission or technology developer contacts the IDC Lead and requests a design study. Subsequently, the IDC Lead, the MDL Team Lead, and the MDL Systems Engineer (SE) meet several times to discuss and plan the specifics that the Customer would like to explore in the study. A mission or technology description, complete with requirements and goals, is established. Mission or technology requirements flow down from scientific goals and objectives which address all required scientific observations and instrument specifications that have usually been determined during instrument design studies, ground testing, or previous heritage flight experiments. If the product is specific to technology development only, the goals and requirements are established based on the developer’s desire to improve on current state-of-the-art technology or to produce innovative game-changing technology. Regardless of whether a successful outcome is a mission design or technology development, the objective of the MDL Team is to best accommodate the requirements and best satisfy the expectations of each Customer.

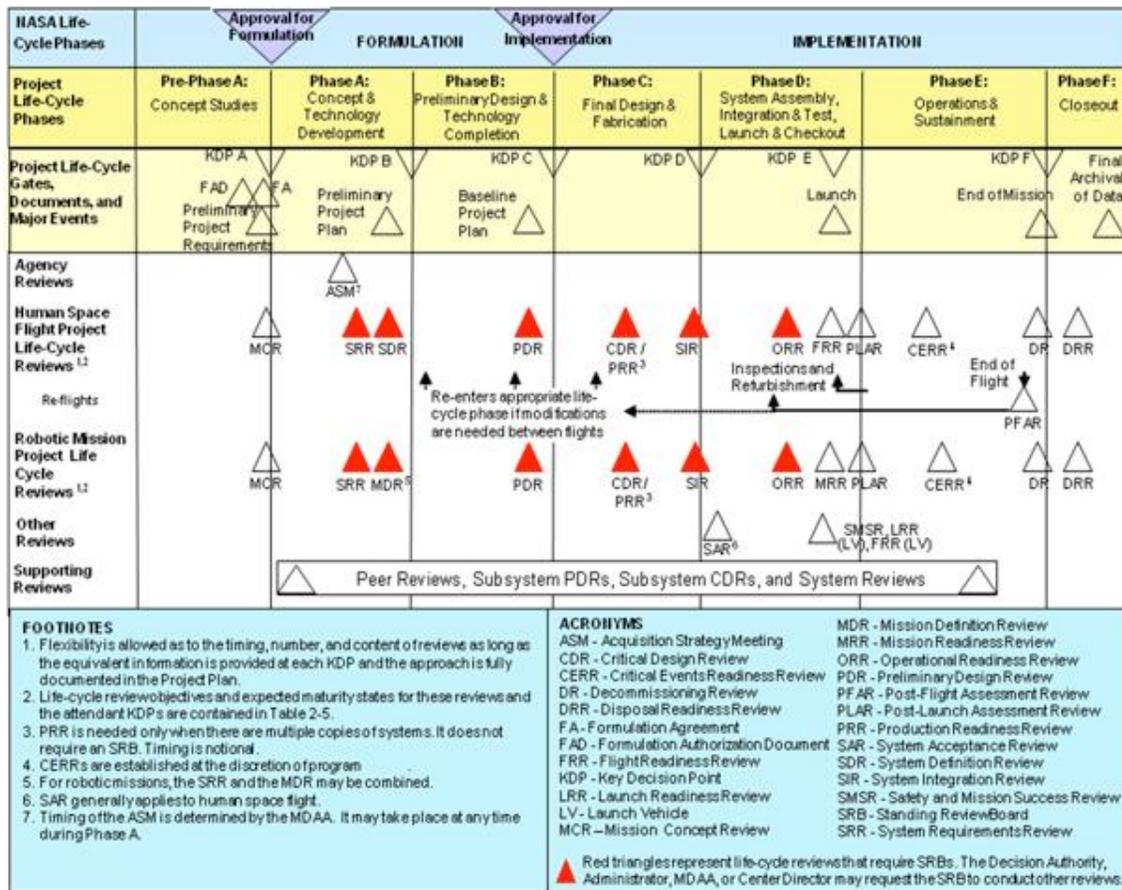


Figure 1. NASA Project Life Cycle (Courtesy of NASA.gov)

To assure the best study results possible, due consideration is given to the unique requirements and specifics of each study. Accordingly - considering the extraordinary variety in studies – the process, while flexible in scope, is rigorously adhered to in every design session during an MDL study. Figure 2 is a snapshot taken of a sample MDL Team during a design session.

study preparations and staffing with the most appropriate discipline engineers for the study.



Figure 2. Sample MDL Team Design Session (Courtesy of NASA.gov)

To further understand the scope of the proposed MDL study, the MDL Team Lead and the MDL Systems Engineer interact with the mission developer and carefully review requirements and parameters such as instrument mass, power, data volume, and clear fields of view. Initial trades such as orbits, trajectories, and launch vehicle capabilities are performed. Flight dynamics is involved at this time for any mission concept requiring a complex trajectory. Spacecraft capabilities, Mission Operations Center/Science Operations Center (MOC/SOC) locations, data downlink methodology, and other requirements of the opportunity are also explored. This process is 2-4 weeks long, to ensure that a proper level of definition of the mission or technology goals and constraints are developed prior to the start of the study. A questionnaire addressing these items is sent to the customer who is encouraged to bring the answers to the initial MDL Planning Meeting. This meeting occurs about one month prior to the study date, allowing time for adequate

In the Planning Meeting, all parties reach a mutual understanding of major parameters for the study, such as primary study objectives, ground rules applicable to the study, sensitive issues which the MDL Team should be aware of during the study, and any other matters that would be helpful in planning and executing the study. Once the

study is approved, a schedule is set and a team of discipline engineers is selected to carry out the week-long study. The MDL systems engineers and discipline engineers comprise the MDL Engineering Team (Table 1) for the proposed study.

Table 1. MDL Engineering Team

MDL Engineering Team	
Attitude Control	Launch Vehicle
Avionics	Mechanical Designer
Communications	Mechanical Systems
Costing	Mission Ops
Debris Analysis/EOM	MSE (2)
Electro-Mechanical	Propulsion
Elect. Power	Radiation
Flight Dynamics	Reliability
Flight Software	Thermal
Integration & Testing	Team Lead

The week prior to the MDL study, a 2-hour Pre-Work meeting is held with the MDL Team and the Customer Team,

in which both teams are introduced and the mission or technology to be studied is presented in detail. The results of the Pre-Work meeting are tabulated by the Team Lead and SE and presented in order to give the MDL Team sufficient time to line up any extra resources they may need.

The study week starts with a brief recap of the mission requirements, drivers, and science goals (Figure 3). The MDL Team then begins to develop a notional mission. The first required product is the definition of the Concept of Operations (ConOps). This is done as soon as possible on the first day, usually Monday, as things like mission duration, power load profiles, delta V budgets, required ACS equipment and many more subsystems rely on the concept of operations (ConOps) to guide them in mission design.

During the week of the MDL study, regular tag-ups are held twice daily, at 9:30 AM and 1:30 PM. During these tag-ups, the overall mission design is discussed with each engineering discipline. The tag-ups ensure that all engineers are in sync and designing with the same mission objectives. During tag-ups, problems requiring more in-depth discussion are identified and a sidebar discussion is scheduled. Sidebar discussions are technical discussions among a subset of the Customer and members of the MDL Team which help facilitate decisions relative to the baseline approach. The sidebar discussions involve only the necessary discipline engineers and SEs to enable the rest of the team to continue working. This helps the team to be decisive in order to close the baseline design in a few days. The results of each sidebar are usually documented and presented at the next tag-up.

MDL Study Plan	
<ul style="list-style-type: none"> <li> <b>Monday</b>            AM: Introduce team members and mission developers (customer team);            Review study expectations and identify key issues            PM: 1) Define concept of operations (ConOps)            2) Discuss derived subsystem requirements and ask questions            3) Input initial estimates of mass, power for each subsystem into system bookkeeping software         </li> </ul>	
<ul style="list-style-type: none"> <li> <b>Tuesday</b>            AM: 1) Initial mechanical design report – sketch of S/C showing key elements, FOV's, etc.            2) Develop S/C block diagram – "architecture"            PM: 1) Subsystems status            2) Input initial component info into system bookkeeping software by COB         </li> </ul>	
<ul style="list-style-type: none"> <li> <b>Wednesday</b>            AM: 1) Initial Observatory mass/power rack-up is input and presented by SE            2) I&amp;T flow discussion            PM: 1) Review design concerns            2) Finalize design         </li> </ul>	
<ul style="list-style-type: none"> <li> <b>Thursday</b>            AM: Prepare presentations            PM: 1) Check presentations for consistency            2) Finish presentations         </li> </ul>	
<ul style="list-style-type: none"> <li> <b>Friday</b> Presentation with mission developers/customers, including remote customer team         </li> </ul>	
<ul style="list-style-type: none"> <li> <b>Monday following</b>            1) Lessons learned, process improvements, lab status, etc.            2) Finalize presentations and wrap up the study for electronic production         </li> </ul>	

Figure 3. MDL Week-Long Study Plan

### 3 MDL Study Products

The design process is iterative in nature, and by the end of the first study day, each discipline engineer is expected to list their expected mass and power values, which are book-kept in a master equipment list (MEL) and summarized in a mass summary table. This allows the other discipline engineers to proceed with a systems-oriented design. Design decisions have to be made based on the information at hand, in real-time. Over the course of the next three days, the design is refined to meet requirements. When the engineering team identifies a requirement that can't be met through the current resources available to the mission, a subsequent sidebar is held with the mission developers to find the best solutions for their needs.

The study results are presented to the mission developer on the last day. Systems resource tables, rationale for the current design and discipline specific presentations are made to the mission developer. Careful notes are taken about any errata or Customer concerns.

A MEL is presented as a key development to capture the mission flight segment design. Finally, a mass summary and launch vehicle capability table is presented which illustrates the viability of the proposed mission or technology concept (Table 2).

After presenting the findings to the customer team, a final meeting of the MDL team is held to address any errata or concerns. Lessons learned from the study are also recorded. After all team members have updated their presentations, the final study products are delivered to the mission developers in an electronic format (typically on DVDs). If costing has been requested, the study data is forwarded to GSFC's costing branch for their evaluation. Study results are only provided to the designated Study Customer Lead and are not divulged to anyone else, or used in subsequent studies, unless designated by the Customer.

Table 2. Mission Mass Summary and Launch Vehicle Capability Table

Mission X MASS Summary			
Payload Mass			
Mission X Payload Dry Mass	CBE	Cont.	MEV
Instrument 1	4.8 kg	30%	6.2 kg
Instrument 2	11.0 kg	30%	14.3 kg
Instrument 3	25.9 kg	30%	33.7 kg
Instrument 4	2.5 kg	30%	3.3 kg
Instrument 5	54.0 kg	30%	70.2 kg
Instrument 6	47.5 kg	30%	61.8 kg
<b>Total Payload Mass</b>	<b>145.7 kg</b>		<b>189.41 kg</b>
Bus Dry Mass			
Mission X Spacecraft Bus Dry Mass	CBE	Cont.	MEV
Mechanical	332.0 kg	30%	431.6 kg
Thermal	40.0 kg	30%	52.0 kg
Attitude Control	60.4 kg	30%	78.5 kg
Propulsion	243.7 kg	30%	316.8 kg
Power	441.5 kg	30%	574.0 kg
Avionics	25.0 kg	30%	32.5 kg
Communications	47.1 kg	30%	61.2 kg
<b>Spacecraft Bus Dry Mass Total</b>	<b>1189.7 kg</b>	<b>30%</b>	<b>1546.6 kg</b>
Observatory Mass			
Mission X Observatory Mass	CBE	Cont.	MEV
Payload Total	145.7 kg	30%	189.4 kg
Spacecraft Bus Dry Mass	1189.7 kg	30%	1546.6 kg
<b>Observatory Dry Mass</b>	<b>1335.4 kg</b>	<b>30%</b>	<b>1736.0 kg</b>
Propellant + Hydrazine + Gas	870.4 kg	0%	870.4 kg
<b>Observatory Launch Mass</b>	<b>2205.8 kg</b>		<b>2606.4 kg</b>
Launch Vehicle Evaluation			
LV Throw Mass Margin** (Dry Mass) %			4%
Launch Vehicle Capability (Atlas V 431, C3 of 30.62 km <sup>2</sup> /sec <sup>2</sup> )			2715 kg
LV Throw Mass Margin**			109 kg
<b>Key:</b>	<b>Notes:</b>		
CBE - Current Best Estimate	* "Not to exceed" value; no margin		
Cont. - Contingency			
MEV - Maximum Expected Value			

## **4 Conclusion**

The MDL team performs technically sound and accurate state of the art systems engineering design work in a professional, productive, and cooperative environment. The MDL embodies the integration of the technical disciplines' efforts into the systems engineering process, summarizes each technical discipline effort, and cross references each of the specific and relevant mission or technology objectives. During this interactive systems design process, design decisions are made based on the information at hand, which sometimes is not complete. Considering the limited study timeframe, the MDL team works efficiently to converge on the best solution based on established design objectives, guidelines, and resources. The result of the intense study is a high quality systems engineering product which may serve as a roadmap for a successful mission or technology proposal, thus laying the groundwork in the Formulation Phase. The fidelity and integrity of the MDL study is preserved for use only by the mission developer or Customer for the proposal or development of future work. The MDL study process continues to evolve with the state of the art in concurrent and collaborative engineering design and to reflect changes in applicable rules, guidelines, and standards for the production of viable proposed mission or technology concepts.

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