Section G. Management, Schedule, & Budget

G.1 Overview

The LISA Project is implemented as a partnership between NASA and ESA wherein both partners are essentially equal contributors. In principle, NASA and ESA assume development responsibility for individual mission elements while sharing in the development of the payload and the science. The NASA focus is on mission management, system engineering, software management, integration (both of the payload and the mission), the launch vehicle, and operations. The European focus is on payload components, the initial payload integration, three spacecraft, three propulsion modules, and the SMART-2 technology demonstration mission. This arrangement provides clean interfaces between familiar mission elements. Payload components are assigned based on capability, past experience, interface complexity, and integration considerations to preserve manageable interfaces while still allowing both partners to share in the payload development. The development responsibility for each mission element or payload component is assigned entirely to either NASA or ESA to preserve clear accountability.

To fairly accommodate each partner's interests, to enhance the focus on the mission elements, and to capitalize on technical expertise and previous investments, the LISA Project uses Integrated Technical Teams (ITTs) throughout Formulation and Implementation. Co-location is essential in this approach to ensure timely decision-making. Both partners are committed to sufficient co-location to provide an on-site presence in each of the more active ITTs. The gravitational wave research community supporting the LISA Mission has naturally formed over the last decade and represents a long-term commitment that provides the continuity to achieve a smooth transition between mission phases.

LISA maps Einstein's relativistic Universe: It is the first space-based gravitational wave observatory
NASA leverages significant European assets, contingent on prompt action: LISA is an approved ESA "Cornerstone Mission", already in Phase A
Our Formulation Phase focuses on technology and mission risk mitigation: The plans, processes, and teams are in place
Our Technology Plan achieves TRL 6 by 2006: A robust approach is defined, with parallel paths and development off-ramps
The Implementation Team is ready for a FY08 start: NASA / ESA agree on contributions, roles and responsibilities

Associated with the ITTs is a System Engineering & Integration (SE&I) Contractor provided by NASA to facilitate the activities of the ITTs both during Formulation and Implementation. Typical tasks include requirements flow down, trade-off studies, design definition, coordination within and between ITTs, resolution of differences between ITTs, definition and maintenance of Interface Control Documents (ICDs), configuration control over evolving ITT products, and the integration of both the payloads and the observatories during Implementation.

NASA and ESA manage the development of all LISA mission elements and payload components through development offices. NASA and ESA individually identify leads for their respective development offices with the concurrence of the other partner. The leads are then accountable for the day-to-day management of their respective offices. If a partner has substantial involvement in a particular office managed by the other

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partner, the non-managing partner provides the Deputy. For activities requiring significant and regular interaction, the Deputy is co-located. Neither partner makes a decision adversely affecting resources of the other partner without consulting the Deputy and/or the appropriate ITT.

The LISA management approach is also planned for the SMART-2 technology demonstration mission to launch in 2006. This provides a test bed opportunity to verify the LISA management approach where the stakes are considerably lower, yet still involve the same principles, relationships, and many of the same people. Moreover, there will be at least a year to incorporate whatever is learned from SMART-2 before significant Phase C/D expenditures.

The LISA management approach also contains parallel, independent but coordinated technology development efforts in the U.S. and Europe. Both NASA and ESA are supporting comprehensive technology development efforts that independently address all of the technology needs of the LISA Mission. These individual efforts are coordinated through an ITT. Within NASA, the effort is managed with the rigor and formality of a flight project including risk management and earned value on the test beds and the test package (DRS). These efforts culminate in each partner producing a test package that is flown in a side-by-side comparison as the primary payload of the SMART-2 technology demonstration mission. The SMART-2 flight data is used to finalize the assignment of LISA payload components and to provide confidence in achieving the performance of the LISA Mission. These parallel technology development efforts assure that the technology needs of the LISA Mission will be met by the end of 2006.

The LISA Project Schedule is driven by two considerations. The first involves the likelihood of FY08 being the earliest year that supports major implementation funding within the NASA Office of Space Science. The second involves the ESA desire to launch by the end of FY11 to mesh well with other ESA missions. These two considerations combine to define the years of major funding for implementation. They also place the PDR and the Non-Advocate Review (NAR) in FY07 and the SMART-2 mission in FY06. Consequently the parallel technology development efforts and their respective test packages also need to be completed in FY06.

The budget is estimated using the GSFC Multi-variable Instrument Cost Model (MICM) and the JPL Team X Model. The models are used to estimate the costs of the instrument payloads, the spacecraft, and the propulsion modules. The remainder of the project cost is estimated using historical experience, quotations based upon statements of work, approved budgets, and reviews by outside experts. These dollar values are then distributed across the Project Schedule. **The European contributions were similarly estimated using these models to determine what they would cost if they were developed in the U.S.** This approach provides a true comparison between the contributions of both partners.

NASA and ESA each provide about half of the total mission cost. Within ESA, the budgets for the LISA Project and the SMART-2 Project are already approved. Within NASA, the technology development funding for the NASA contribution to the LISA Mission and the budget for the ST-7/DRS are both approved. The “Beyond Einstein” Initiative provides the remaining funding for the NASA contribution.

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G.2 Mission Formulation

G.2.1 Management Organization

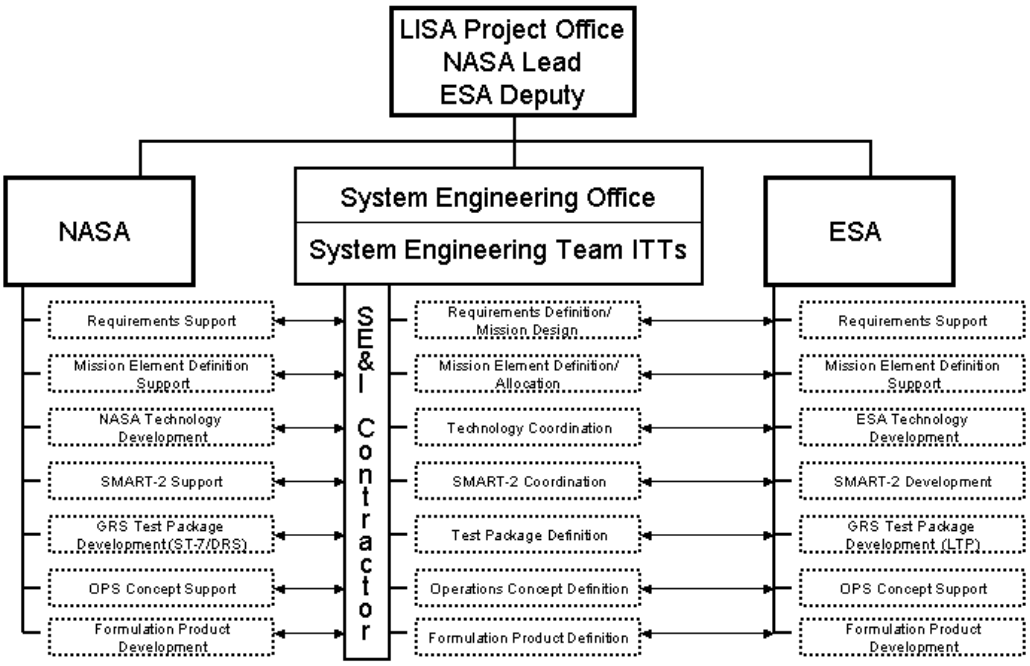

Figure G-1: Formulation Organization

The LISA Project Office has a NASA lead reflecting NASA's responsibility for mission management and an ESA Deputy reflecting ESA's considerable involvement in day-to-day management of the LISA Project (See Figure G-1). The SE&I contractor supports the ITTs and facilitates the formulation process, including the preparation of the Interface Control Documents (ICDs).

G.2.1.1 Teaming Arrangements

LISA involves the best talent in Europe and the U.S. organized into a NASA/ESA partnership that evolved from a decade-long collaboration between U.S. and European scientists. LISA represents a well-studied mission concept as reflected in the *Final Technical Report* published by ESA in April 2000. The scientists involved in LISA are associated with many prominent universities in the U.S. and Europe. A number of these scientists are also intimately involved with the development of ground-based gravitational wave detectors. This technical insight represents a practical risk mitigation that applies to the LISA Mission. The combination of NASA and ESA results in a powerful team to implement the LISA Project. The partners possess the above scientific expertise, as well as the considerable flight experience and extensive facilities of JPL, GSFC, and ESTEC. This combination is ideally suited to proceed with Formulation and Implementation of the LISA Mission.

The most intense collaboration between partners occurs in the requirements and design definition within the System Engineering Team. This includes engineers and scientists from the involved ITTs. During Pre-Formulation and Formulation this Team is co-chaired by the System Engineering managers from NASA and ESA. The System Engineering Office sponsors three Science / Engineering Workshops per year to facilitate the exchange of information among the

scientists and the engineers assigned to the LISA Project. To date, five such workshops have been held. These workshops are compliant with existing International Traffic in Arms Regulations (ITAR). See Appendix H.3, Draft International Participation Plan.

Once the designs are defined to the level of specifications, they are then assigned to NASA or ESA development offices. Three quarters of both partner contributions are spent on routine procurements managed by the procuring partner, working to well-defined ICDs. Integration begins in Europe and is completed in the U.S. with payload integration occurring at JPL, and observatory integration and final end-to-end constellation testing at GSFC.

G.2.1.2 Decision-making Processes

Clear accountability is an essential feature of the LISA management approach. LISA organizes the partners in a way that the decision-making processes guarantee the appropriate influence by each partner while maintaining clear individual accountability. This is accomplished through the use of the ITTs. Programmatic decisions flow through the development offices and technical decisions flow through the ITTs.

NASA and ESA identify leads for their respective development offices. These offices manage the contracts that develop the flight hardware and software. The leads are accountable for the day-to-day management of their offices. If a partner has substantial involvement in a particular office managed by the other partner, the non-managing partner has the opportunity to provide a Deputy. For activities requiring significant and regular interaction, the Deputy is co-located. Neither partner makes a decision adversely affecting resources of the other partner without consulting the Deputy and/or the appropriate ITT.

The development of requirements, the definition and recommended allocation of mission elements, and the coordination of technology represent collaborative roles. These roles are implemented through ITTs reporting to the System Engineering Team, a "team of teams" comprised of the senior system engineers from NASA and ESA. Upon defining the details of the NASA and ESA work packages, assignments are made to appropriate NASA and ESA development offices. The corresponding ICDs are developed and maintained by the System Engineering (SE) Office through the appropriate ITT.

- Technical details that are within the current resource allocations and do not affect other mission elements are decided directly by the ITT.
- Decisions that affect other mission elements are worked through the System Engineering Team and approved by the SE Office.
- Decisions that have significant resource impacts outside of the current resource allocations are developed into decision packages by the SE Office based on the recommendations of the System Engineering Team. The decision packages are presented to the Project Office through the Configuration Control Board (CCB). It is the responsibility of the SE Office to keep the ITTs running smoothly and to resolve differences in an effective and timely fashion.

G.2.1.3 Responsibilities of Team Members Including Contributors and the Status of Commitments

A summary of the management approach and the responsibilities of each partner are reflected in Figure G-2 on the next page.

Partner responsibilities are defined as soon as possible in order to initiate the process of securing ESA Member State contributions. This process continues throughout Formulation and is finalized after the completion of the SMART-2 technology demonstration mission in 2006. Tentative assignment of responsibilities is nearly 90% complete.

Letters of Agreement (LOA) between NASA and ESA authorizing the definition of the LISA Mission and participation in the SMART-2 Mission are both in place. Both of these are replaced with Memoranda of

Understanding (MOUs) once the mission definition is completed. The LISA "Partnership Pathfinder" documents the current understanding of the NASA/ESA partnership. It is periodically updated as new work is accomplished. The initial version documents the basic partnership and is contained in Appendix H.4.

A Management Agreement between GSFC and JPL, signed on November 1, 2000, defines roles for GSFC and JPL, based on a presumed payload allocation between NASA and ESA.

LISA INTEGRATED MANAGEMENT

- Organized around the best talent and facilities in Europe and the U.S. in a partnership between NASA and ESA.
- Based on a decade-long collaboration within the scientific community.
- Conserves budget for both NASA and ESA while capitalizing on earlier ESA technology investments.
- Provides parallel technology development in U.S. and Europe culminating in a technology validation flight (SMART-2) to significantly increase confidence.

NASA RESPONSIBILTIES

- Mission Management
- LIST Co-Chair and U.S. Membership
- Observatory Integration / Final Testing
- Launch Vehicle
- Operations
- SMART-2 Test Package (DRS)
- LISA Payload:
  - Payload Integration
  - Primary & Secondary Structure
  - Optical Benches
  - Interferometer Components
  - Payload Processor
  - Payload Software
  - Associated GSE / Simulators

EUROPEAN RESPONSIBILITIES

- LIST Co-Chair are European Membership
- Three Spacecraft
- Three Propulsion Modules
- Spacecraft Microthrusters
- SMART-2 Technology Validation Flight
- SMART-2 Test Package (LTP)
- LISA Payload (ESA Member States):
  - Gravitational Reference Sensors (GRS)
  - Lasers
  - Telescopes
  - GRS Software
  - Associated GSE

Figure G-2: Partner Responsibilities

G.2.1.4 Rationale for Management Structure

The LISA Project Management uses Integrated Technical Teams (ITTs) throughout Formulation and Implementation to organize the roles of both partners and achieve a sustained focus on the mission elements under development. When combined with the long-term commitments of senior scientists and engineers, this approach provides the flexibility to smoothly and efficiently transition from Formulation into Implementation by restructuring the membership of the ITTs.

G.2.1.5 Approach for Managing Key Risks in Technology Development

The LISA Mission is critically dependent on technology development. Considerable effort has been invested in ensuring technology readiness by the end of 2006. There are five aspects of risk mitigation associated with the technology development effort that ensure a successful outcome.

- Most importantly, the parallel technology development efforts in the U.S. and Europe ensure that mature technologies are available at Mission PDR. This reduces the likelihood that a particular technology significantly delays Implementation. Experience with New Millennium Program missions indicates that prolonged technology development is the most common cause for mission cost overrun.
- Re-assessing maturity is an early warning of a slowly developing technology that could stall the entire effort. By using the error budget to make quarterly predictions of mission performance based on the latest test bed measurements, the Project re-allocates resources to keep overall investments optimally aligned with predicted mission performance. This work is completed by the Integrated Modeling Team and is an essential element of the "Analytical Basis of the LISA Mission", and end-to-end modeling tool that analytically demonstrates the coherence of the design that is available by Mission PDR.

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- The SMART-2 mission demonstrates drag-free flight and reduces the uncertainty as to how well the GRS works in space. These flight results significantly enhance the confidence of achieving the performance of the designs presented at the Mission PDR.
- Reserves are in place to keep the technology development on schedule. The actual values are contained in Appendix H.1 (Budgets). These reserves are preemptively deployed based on the quarterly predictions of mission performance.
- Lastly, the LISA Minimum Mission represents a ten-fold reduction in performance and still achieves important science. This provides significant trade space to accommodate technology development risk. This Minimum Mission has its own error budget used to predict mission performance. Key elements of the Minimum Mission performance are demonstrated by the Test Packages on the SMART-2 Mission.

G.2.1.6 Transition from Technology Program to Flight Program

A smooth transition between Formulation and Implementation is essential to meeting the LISA Project Schedule. To achieve such a transition, the organizational structure for Formulation and Implementation is identical. The Implementation organization is accomplished by gradually evolving the structure of the ITTs late in Formulation. Moreover, the long-term commitment of key science and engineering staff represents continuity that ensures a smooth and seamless transition between Formulation and Implementation. The LISA Project presently resides in the organizational offices within ESA and NASA wherein it remains for its entire existence; there are no organizational hand-offs – ever.

G.2.1.7 Competitive Environment for Acquisitions for Implementation

Qualified SE&I contractors have expressed interest in LISA. The Project utilizes a phased acquisition approach that maximizes competition among the best-qualified offerors. The process begins during Formulation:

- Request for Information (RFI) in March FY03
- Request for Proposals (RFP) in early FY04, award of two parallel contracts Mid-FY04
- Down-select to single prime contractor in Mid-FY05

This proactive approach ensures the contractor is on board before Phase B, reducing project risk. Funding for this acquisition approach is reflected in the budget profiles for Formulation.

G.2.2 Formulation Including Schedule & Budget

G.2.2.1 Formulation Development Strategy

LISA completes all Formulation products consistent with the NASA Program and Project Management Processes and Requirements (NPG 7120.5) and the Space Science Enterprise Management Handbook. Our Formulation applies parallel technology development efforts in the U.S. and Europe to achieve TRL 6 for all required technologies. Furthermore, the SMART-2 Mission demonstrates drag-free flight including key elements of GRS performance and associated noise models. Mission element implementation assignments between NASA and ESA are then finalized based on the outcome of the parallel technology developments.

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G.2.2.2 Formulation Schedule

The Project Team has developed a preliminary integrated schedule for the entire LISA Mission consisting of a 1400+ node logic network that includes:

- Activities that capture the entire scope of work and correlate to the "LISA Project Level 2 Work Breakdown Structure" (See Figure G-3).
- Critical interdependencies among the activities;
- Engineering estimates for activity durations;
- Reserve levels at critical points within the schedule flow.

The integrated schedule provides a framework for more detailed cost and schedule planning in Formulation. Additionally, it is a useful tool for performing "what-if" analyses to evaluate the effect of potential changes and risks on LISA schedule objectives.

Foldout G-1, *"LISA Mission Formulation Summary Schedule,"* contains the Pre-Phase A, Phase A and Phase B portions of the overall LISA schedule. The Formulation schedule is characterized by the planning associated with all WBS elements as well as the transition of the technology development effort into the payload and flight system engineering design. TRL 6 milestones within the Technology schedule are linked to their corresponding subsystem Preliminary Design Reviews (PDRs) within the integrated schedule. As identified by the "red" line in Foldout G-1, the LISA critical path originates with the GRS prototype development within the DRS technology WBS, and continues into the detailed engineering design of the GRS. There are 5.7 months of planned schedule reserve along the critical path prior to GRS TRL 6.

While Foldout G-1 contains the milestones for key Formulation products and reviews, a comprehensive list of these products is contained in Appendix H.2, Supporting, Detailed Schedules.

1.0 LISA Total Project

- 1.1 Project Management
- 1.2 System Engineering
- 1.3 Mission Assurance
- 1.4 Science
- 1.5 Payload System
- 1.6 Flight System
- 1.7 Mission Operations System
- 1.8 Launch System
- 1.9 Technology
- 1.10 Mission Software

Figure G-3: LISA Project Level 2 Work Breakdown Structure

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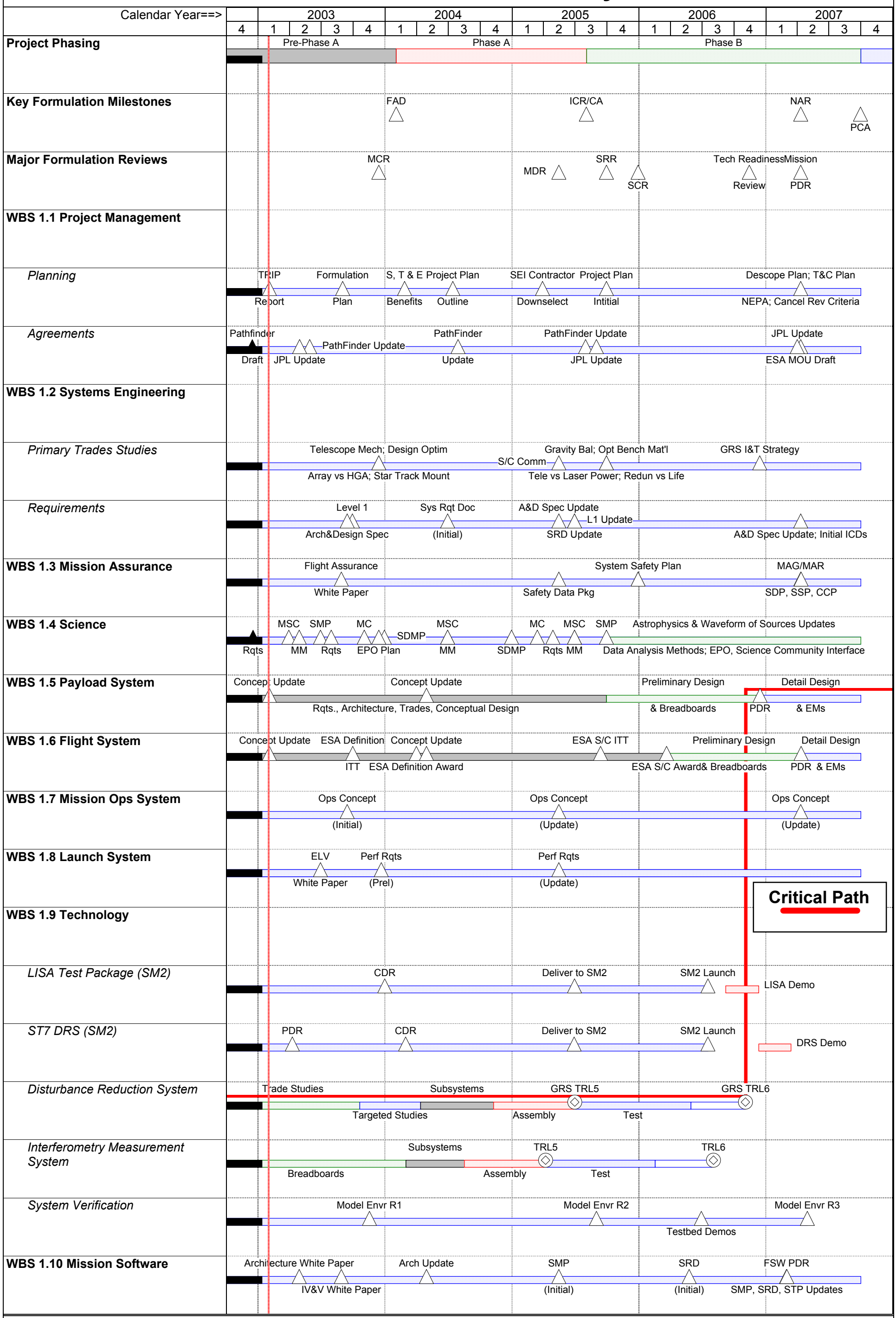
LISA Mission Formulation Summary Schedule



Foldout G-1, "LISA Mission Formulation Summary Schedule"

G.2.2.3 Formulation Budget

Table G-1: Formulation Budget ($M)

SENSITIVE MATERIAL

SENSITIVE MATERIAL

Figure G-4: Formulation Budget with Reserves ($M)

Methodology and Basis of Estimate (BOE)

The budget estimating process utilized two separate parametric models (Team X at JPL and the MICM database from the GSFC Resource Analysis Office (RAO)), historical experience and personal knowledge of comparable past NASA missions, cost quotations from technical organizations derived from statements of work and schedules, approved budgets from contributors, and reviews by outside experts.

The budget is allocated throughout the LISA WBS (Appendix H.1.7) and distributed to support mission activities consistent with the LISA Project Schedule.

The approach first estimates the total cost of the LISA mission in Constant Year Dollars, implemented with a single NASA field center and supported by a single prime contractor. This estimate is then adjusted for dual center participation and the NASA/ESA partnership. Finally, the estimate is converted into Real Year Dollars.

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Table G-2: Methodology/Estimating Process Utilized For The Budget Elements Specified In The Call For Reports

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Checking Process

The budget is checked in two ways. In the first instance, the budget is independently checked within GSFC and JPL by experienced Resource Analysts to look for thoroughness, accuracy, and consistency. In the second instance, an independent cost estimate is developed. There are no significant differences between the proposed Project Budget items and the findings of the independent cost estimate (checking process). The results of this independent cost estimate are discussed in Appendix H.1.3.

Strategy for Managing Budget Reserve

The LISA Project Manager allocates budget reserve directly for NASA and indirectly for ESA through the ESA Deputy Project Manager. The management of budget reserve is intimately related to Risk Management. All of the key risks have an associated risk mitigation plan that is costed and approved by both the Mission System Engineering Manager and the Project Manager. As circumstances trigger the implementation of selected risk mitigation plans, the Project Manager releases the required budget reserve. The current budget reserves are a percentage of the estimated cost of the planned work based on past experience with comparable projects. During Formulation, the budget reserves are based on the expected value of all of the risk mitigation plans associated with the identified risks.

Confidence in Realism of Budget

We have a high confidence in our Formulation budget and the planning that went into developing it.

- There is a clear roadmap, with an accurate estimate, used to gain the knowledge needed to develop high confidence in our Formulation budget.
- Our Formulation plans have sufficient schedule slack so that information will be acquired in time to produce an accurate Implementation estimate.
- Our Formulation budget has adequate programmed reserves to ensure timely completion without needing further augmentation.
- All of the difficult technologies are being investigated through two independent technical paths (NASA and European partners). If one path becomes a money sinkhole while the other looks very promising, the technology effort responds to prevent unnecessary cost growth.
- The Europeans have a strong, well-funded group of gravitational wave scientists currently working on investigations complementary to activities in the U.S.
- There are confidence building flight tests planned by both the U.S. (ST-7) and Europe (LTP, SMART-2), which demonstrate drag-free flight, and provide

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confidence to undertaking Implementation.

G.2.3 Technology Development Including Schedule & Budget

Technology development is normally considered as a part of Formulation. However, in the case of the LISA Project, technology development was started in FY01 and Formulation does not formally begin until February of 2004. Consequently, the management approach for technology development is essentially a precursor of the organizational approach described in Section G.2.1.

G.2.3.1 Technology Development Strategy

The technology development effort successfully completes:

- Parallel technology development efforts in the U.S. and Europe by reaching TRL 6 for all required technologies prior to the end of 2006. The partners produce the same technology products but based on different providers and frequently on different technological approaches. The variety of parallel technology evaluations is summarized in Table G-3 and the associated milestones are contained in Appendix H.2, Schedules. The down-selection process is complete by Mission PDR.
- The "Analytical Basis of the LISA Mission" prior to the Mission PDR.
- The flight demonstration of the U.S. and European GRS Test Packages on the SMART-2 Mission prior to LISA PDR.

NASA technology development started in 2001 and runs through 2006, while Formulation formally begins in February 2004 and runs through September 2007. Consequently, technology development spans both Pre-Formulation and Formulation. During Pre-Formulation, a skeleton of the organization planned for Formulation (see Section G.2.1) is projected into Pre-Formulation to support technology development. This approach ensures a smooth transition between Pre-Formulation and Formulation by simply adding more people and a single, additional ITT (See Figure G-1).

Table G-3: The critical technology development products are all completed by 2006. Multiple independent coordinated development paths provides robustness against technical, cost, and schedule risk.

Product	TRL 4	TRL 6	Comment
GRS	Current	2006	Three independent development efforts, two of which are flown on SMART-2 to verify performance and models. Targeted laboratory studies to identify and eliminate disturbance effects. Precision ground measurements coupled to integrated modeling complement flight demonstration.
μN-Thrusters	Current	2006	Three different thruster technologies supported. Aggressive ground measurements in addition to flight demonstration on SMART-2. Early lifetime testing and critical performance measurements.
Laser System	Current	2006	Three independent development efforts, using two different approaches. One approach is very mature, but requires performance enhancements. The other approach is immature, but satisfies performance requirements. Early lifetime testing.
Phase Meter	2004	2006	Four independent development efforts. Early tests nearly meet performance requirements. Space qualified as part of the prototype IMS.

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Product	TRL 4	TRL 6	Comment
Laser Stabilization	2003	2006	Five independent stabilization developments. Early tests nearly meet performance requirements. Space qualified as part of the prototype IMS.
Prototype IMS	2004	2006	Two independent prototypes developed using most promising phase meter, laser stabilization, etc. Full performance verified in the laboratory. Space qualification straightforward
Integrated Models	NA	NA	Phased approach with regular short-term products and long-term goals. Strong connection to system engineering, technology test beds, and flight demonstrations. Adapts to support different Project phases.
Test Bed Technology	NA	NA	Regular reviews and coordinated design with system engineering, technology development, and modeling insure testable hardware and test bed approaches that address critical system-level performance metrics.

Technology development is managed with the same rigor and formality of a traditional flight project. Maturity milestones are periodically placed in the flow of each technology to demonstrate progress. In addition to monitoring TRL transitions, we monitor noise performance and its relationship to the error budget for the entire measurement scheme. Noise performance is the largest contributor to the error budget. By periodically reviewing the status of the error budget based on the most recent measurements in our test beds, we readily see where additional effort is most needed.

ESA completed a Phase A Mission Concept Study *(Final Technical Report)* in April 2000. All of the technology needs are identified and technology development has been underway since 2000 in Europe and 2001 in the U.S. The university laboratories and test beds associated with the LISA Project are used to support the infusion of the technologies into the contractors who will build the flight hardware and software. All of the contractors are in place and the technology infusion is completed by the LISA PDR.

Relative to technology development, the SMART-2 Mission serves to exercise the U.S. and European GRS Test Packages by demonstrating drag-free flight. The NASA contribution to the SMART-2 Mission is the New Millennium Program's ST-7/DRS. This effort is organizationally independent of the LISA Project but it is linked in that the ST-7 Project Manager is also the LISA Deputy Project Manager. The New Millennium Program's objectives for the ST-7/DRS are a superset of the LISA objectives.

G.2.3.2 Technology Development Schedule

Technology development is integrated into the overall LISA Project schedule. Activities and critical milestones highlighting the schedule for each key technology are defined in Foldout G-2, *"LISA Technology Development Summary Schedule."* The technology schedules also indicate the relationship of the LTP and ST-7/DRS schedules to the LISA Project Schedule.

As described previously in Section G.2.2.2, the critical path for technology readiness is the development of a prototype GRS. This is indicated by the "red" line on Foldout G-2. Specifically, the Sensing and Forcing Subsystem trade studies pace the subsequent subsystem development, assembly, and test of the GRS prototype. TRL 6 is achieved in 2006, prior to the corresponding Payload Subsystem PDRs. Moreover, approximately six months of schedule reserve are incorporated into the technology schedule prior to each TRL 6 milestone.

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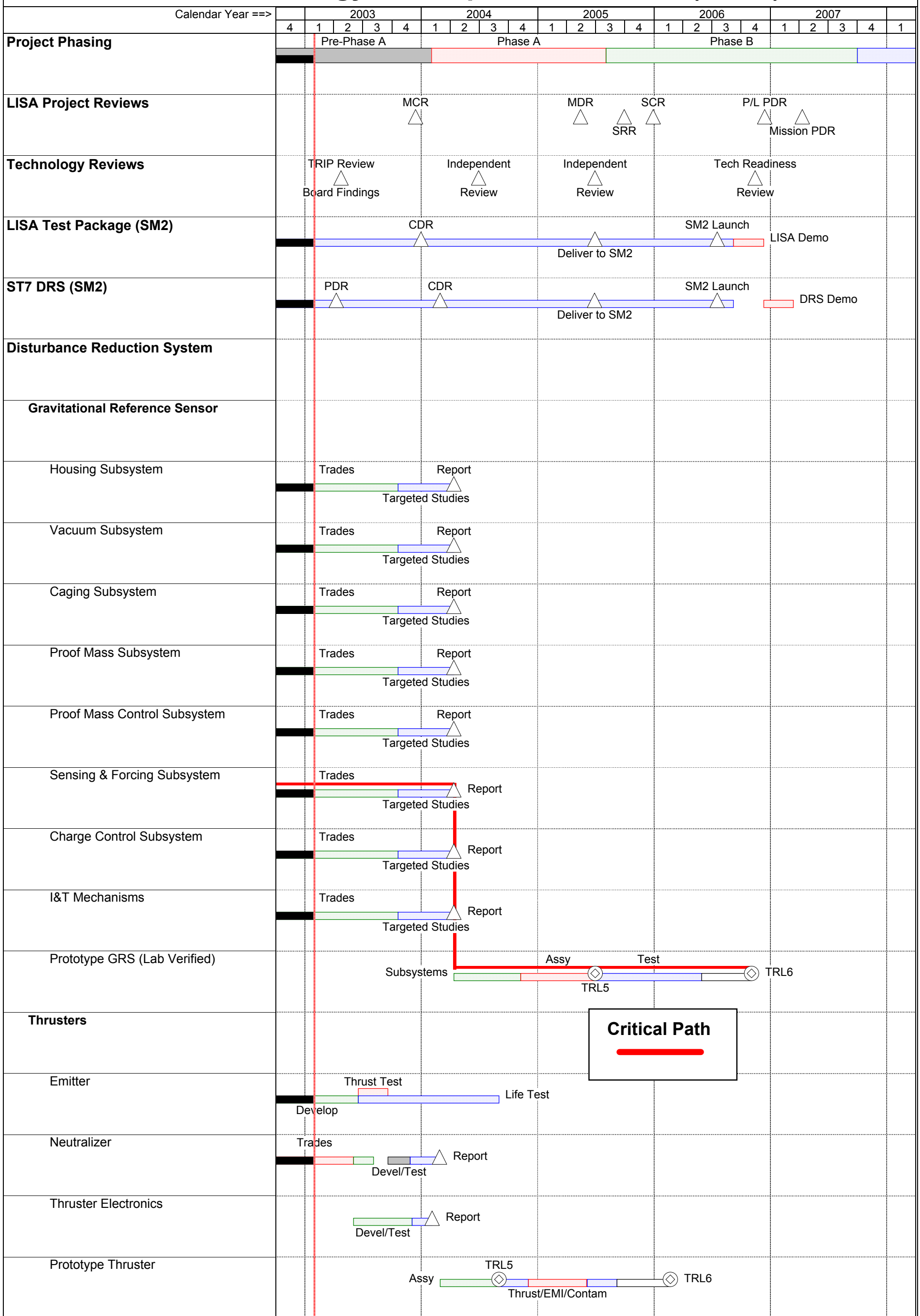
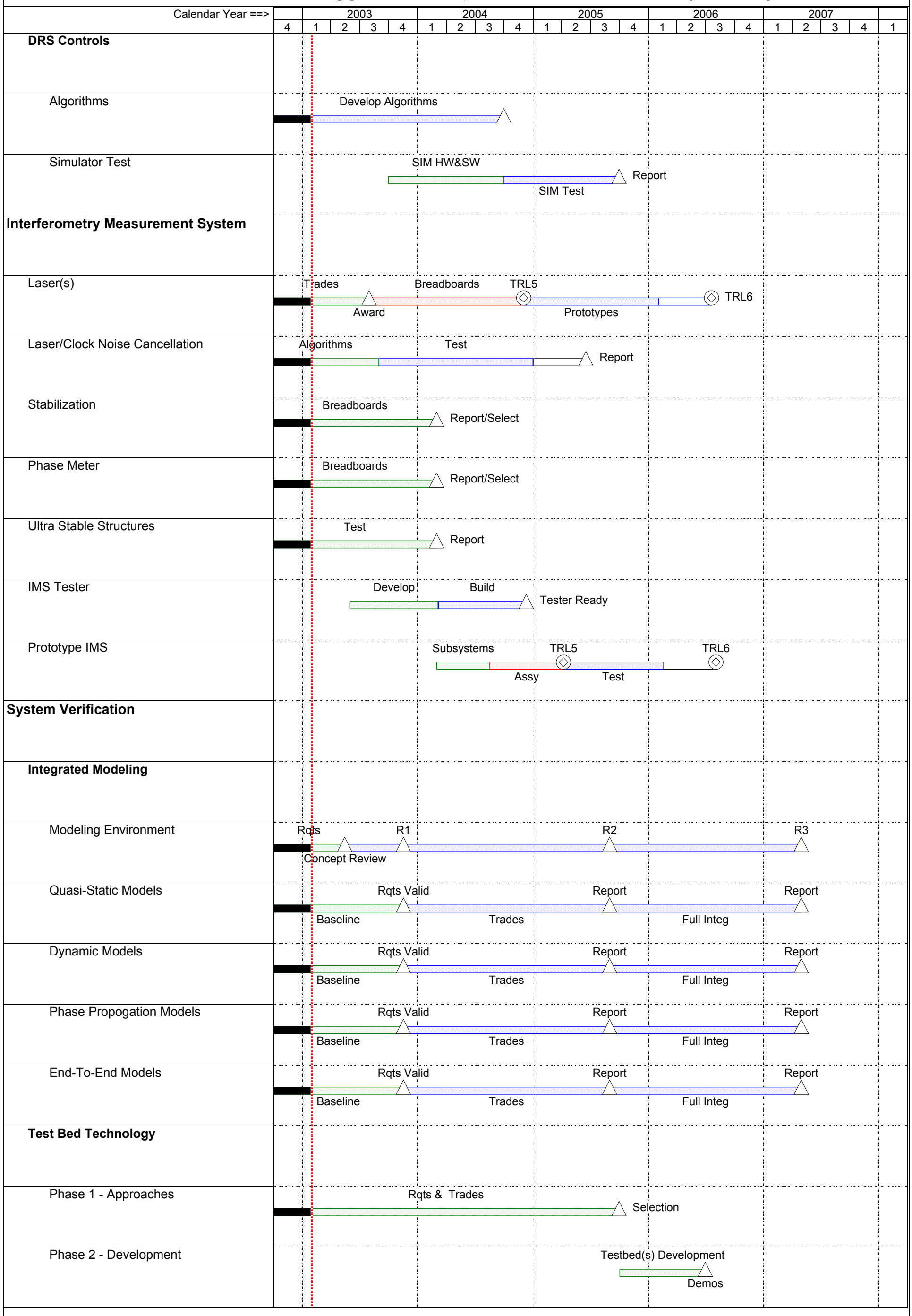
LISA Technology Development Schedule (1 of 2)



Foldout G-2 "LISA Technology Development Summary Schedule"

LISA Technology Development Schedule (2 of 2)



Foldout G-2 "LISA Technology Development Summary Schedule"

G.2.3.3 Technology Development Budget

Table G-4: Technology Development Budget ($M)

SENSITIVE MATERIAL

The **estimating methodology, checking process, and strategy for managing budget reserves** during the Technology Development Phase are the same as described in Section G.2.2.3.

Since the Technology Development effort is a part of Formulation, the reasons for our **confidence in the realism** of the technology development budget are the same as those cited in Section G.2.2.3.

SENSITIVE MATERIAL

Figure G-5: Technology Development Budget with Reserves ($M)

G.3 Mission Implementation

During Implementation, NASA and ESA develop, launch, and operate the LISA Mission. LISA then becomes the first space-based gravitational wave observatory, enabling scientists to map Einstein's relativistic Universe.

NASA and ESA are implementing the LISA Mission as a partnership that engages the best talent and facilities in the U.S. and Europe. Flight hardware and software are developed both in Europe and the U.S. ESA provides three spacecraft and propulsion modules while ESA Member States provide payload components. This arrangement facilitates European Member State contributions and capitalizes on previous ESA technology investments. NASA provides mission management, payload components, payload and observatory integration, final constellation testing, the launch vehicle, and operations. This arrangement capitalizes on NASA's broad experience in instruments, integration, system engineering, and mission management. The integration and test flow of the LISA Mission has been reviewed by the NASA Manager of International Technology Transfer Policy at NASA Headquarters and is ITAR-compliant.

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G.3.1 Management Organization

The Implementation organization is in place prior to the Mission PDR. The incremental restructuring of the ITTs late in Formulation provides a smooth and efficient transition into Implementation.

The ITTs depicted in Figure G-6: operate in the same way as during Formulation (see Section G.2.1). During Implementation the emphasis is on monitoring the progress of development, evaluating potential changes, and maintaining ICDs. The SE&I contractor is intimately involved in assessing proposed changes to the ICDs in preparation for I&T.

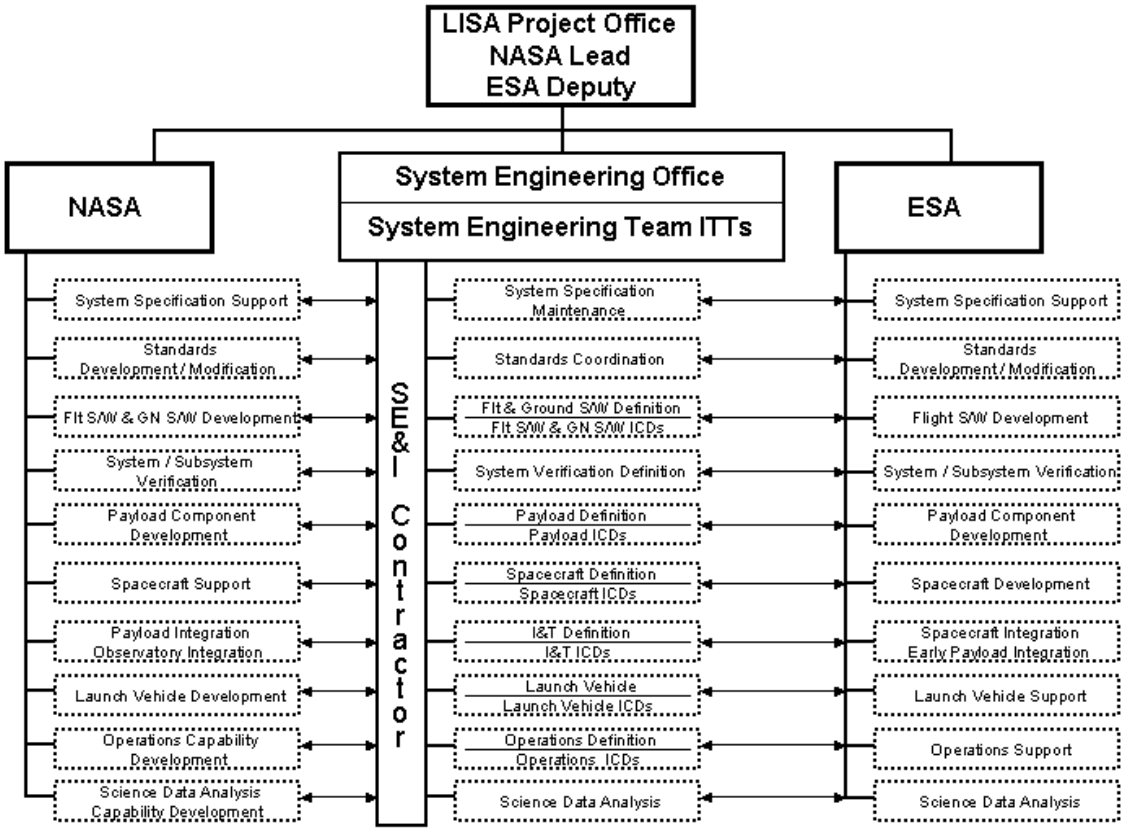

Figure G-6: Implementation Organization

G.3.1.1 Teaming Arrangements

The teaming arrangements are tentatively defined in Pre-Formulation to initiate the process of defining ESA Member State contributions. During Formulation these are further defined and finalized at the end of Formulation. This process is described in Section G.2.1.1. The teaming arrangements at the beginning of Implementation are stable throughout the development of all of the flight hardware and software in the LISA Mission.

G.3.1.2 Decision-making processes

The basic decision-making process used in Formulation is carried into Implementation as described in Section G.2.1.2. The essential change is a gradual transformation of the ITTs from those representing the beginning of Formulation as shown in Figure G-1 to those representing Implementation as shown in Figure G-6. This gradual transformation occurs late in Formulation. During Implementation the emphasis moves from the ITTs to the development offices. In Implementation, the ITTs focus on assessing progress, on the

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maintenance of ICDs, and on the evaluation of proposed changes to baselined requirements. The SE&I contractor focuses on integration, first with the payload, then supporting the spacecraft, the three observatories, and finally the constellation.

Table G-5: LISA Team Member Responsibilities

NASA		European	
GSFC	JPL	ESA	ESA MEMBER STATES
Mission Management NASA Business Management Technology Development System Engineering Integrated Modeling Payload Software Observatory Integration Final End-to-End Testing Launch Campaign Launch Vehicle On-Orbit Check-Out	Payload Management Technology Development ST-7 / DRS Science Office Operations Payload Components: – Test Mass – GRS Electrode Housing – Phase Meter – Actuator – Structure – Optical Benches – Interferometer Optics – Simulators – Ground Support Equipment Payload Integration	European Business Mgmt Spacecraft Management – Three Spacecraft – Three Propulsion Modules – Ground Support Equipment – Simulators Manage Member State Contributions Technology Development System Engineering SMART-2 Mission	LTP Payload Components: – GRS Front-End Electronics – Charging System – GRS Vacuum & Str – GRS Software – Beam Acquisition Sensor – Laser Stabilization Bench – Lasers – Telescopes – Ground Support Equipment Initial Payload Integration Science Support

The allocation of mission elements is currently 90% complete. These assignments are finalized after the completion of the SMART-2 Mission in 2006 when the flight demonstration data from the U.S. and European test packages are available.

The NASA/ESA partnership captures the best scientific talent needed to accomplish LISA. Many of the LISA International Science Team (LIST) scientists are also involved in ground-based gravitational wave detectors and have gained considerable experience in the building of these instruments. The flight hardware and software experience as well as the integration capability of the SE&I contractor complements the NASA/ESA Team to support the overall development.

A draft of the NASA/ESA MOU is presented at the LISA PDR. This draft is finalized after the PDR and is ready for signature at the Approval Review. The Management Agreement between GSFC and JPL is updated for the Approval Review.

G.3.1.3 Rationale for Management Structure

The use of ITTs provides each partner the opportunity to participate fully in the definition of the design and to follow that design through development, integration, and test. This approach is already familiar to both NASA and ESA. Moreover, this approach allows both NASA and ESA development offices to pursue business as usual and facilitates a smooth transition between Formulation and Implementation. Three quarters of the entire budget of both partners flows through the NASA and ESA development offices. Contractors are ISO certified and use the ISO process to reconcile standards through the ITTs devoted to this purpose.

G.3.1.4 Team Members' Capabilities (Including Past Experience)

The NASA/ESA partnership captures the best scientific talent needed to accomplish LISA. Many of the LIST scientists are involved in ground-based gravitational wave

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detectors and have gained considerable experience in the building of the instrument capabilities required by the LISA Mission. LISA is the first space-based gravitational wave mission. The experience and capability of the SE&I contractor complements the NASA/ESA Team to support the development.

G.3.1.5 Assignment of Technical Responsibility Between NASA and ESA

See Sections G.3.1.1 and G.3.1.3 for the partners' responsibilities. The current assignment of team members' responsibilities is reflected in Table G-5.

G.3.1.6 Risk Management and Risk Mitigation Plans (Top 3-5 Risks)

The four most significant risks are shown in Table E-6. There are specific mitigation plans for these reflected in the same table. However, there are a number of other risks that require a broader, more strategic approach to risk mitigation.

There are four major components to the LISA Project's risk mitigation for Implementation:

- The LISA Project is committed to early risk retirement through comprehensive technology development during Formulation. More specifically, NASA and ESA are supporting parallel technology development efforts that culminate in a technology demonstration mission in 2006 (SMART-2). Both of these efforts are comprehensive and address all of the technologies necessary to achieve the LISA Mission. They are coordinated through an ITT to maximize the benefit of each partner's investments. This parallel approach ensures that the necessary technologies are at TRL 6 in 2006 and technology risk is thereby retired by the LISA PDR. This enables a Project Commitment Agreement (PCA) for the LISA Project in FY08.
- The LISA Project is committed to Integrated Modeling providing the capability to extend the design definition to a level of detail not otherwise available. Achieving this greater depth of design definition early in the definition process lowers the implementation risk. This work is summarized in the "Analytical Basis of the LISA Mission" that is available at the LISA PDR.
- The LISA Minimum Mission represents a ten-fold reduction in performance. This provides significant trade space to accommodate development risks. The Minimum Mission has its own error budget used to predict mission performance. Key aspects of the Minimum Mission performance are demonstrated by the two GRS Test Packages on the SMART-2 Mission.

  The sensitivity to be demonstrated by the SMART-2 Mission is identical to the sensitivity required by the Minimum Mission and is only one order of magnitude better than current ground-based performance. Moreover, the error tree enables the definition of a family of descope options, putting the reduced sensitivity where it would provide the greatest relief. When the allocation of the mission elements within the payload are agreed upon specific descope options are developed and their savings estimated. This approach provides meaningful descope options throughout development with decreasing value later in the development cycle.
- Budget reserves are maintained to support proactive risk mitigation both during technology development and during Implementation.

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G.3.1.7 Strategy for Release of Resources

See Section G.2.2.3 for a discussion of the management of budget reserves. During Formulation, specific risks are identified and specific mitigations are developed, generally within the broad areas discussed in the previous section. Trigger points in the schedule are established and the status of the primary development path and the mitigations are reviewed monthly. Each mitigation identifies not only the budget requirements but also all of the other technical resources such as mass, power, computer cycles, memory, etc. The Mission System Engineer recommends that mitigation be implemented and the LISA Project Manager concurs before the resources are released. The implementation of risk mitigation in Europe is proposed by the ESA Deputy Mission System Engineer, concurred upon by the ESA Deputy Project Manager, and approved by the LISA Project Manager. The goal in Implementation is that the budget reserves are largely determined by the expected value of all of the risk mitigations presently active.

G.3.2 Schedule (Including Slack Policy, and Activities On And Near Critical Path)

Foldout G-3, *"LISA Mission Implementation Summary Schedule"* summarizes Phase C/D of the LISA Project schedule. After completion of the detailed engineering design and build of the Engineering Model (EM) payload and spacecraft hardware, a full EM observatory is integrated and tested. This is followed by the integration and test of the three flight observatories, constellation testing, culminating in the launch campaign in 2011.

The critical path for Implementation, which originated with the GRS technology development and GRS preliminary design in Formulation, continues into Implementation with the detailed engineering design of the GRS and build/test of the Engineering Model and Flight Units. The third GRS Flight Unit paces integration of the Flight Model 3 Payload, which, in turn, drives the integration of the third Flight Unit. Finally, the critical path continues through constellation testing and the launch campaign.

The LISA Project incorporates schedule reserve into the Project Schedule at key points, such as prior to TRL 6 milestones or the end of key test activities. The Project maintains the NASA guideline of one month of schedule reserve for each year, between time-now and launch, throughout the project life cycle. The preliminary schedule reserve levels, as well as total slack, for key elements of LISA are summarized in Table G-8, "LISA Schedule Reserve & Total Slack Summary." Schedule reserve levels and locations within the integrated schedule are continuously evaluated throughout both Formulation and Implementation. Allocation of schedule reserves are examined as the LISA integrated schedule evolves and the risk management process matures. Finally, schedule reserve can only be allocated by the LISA Project Manager.

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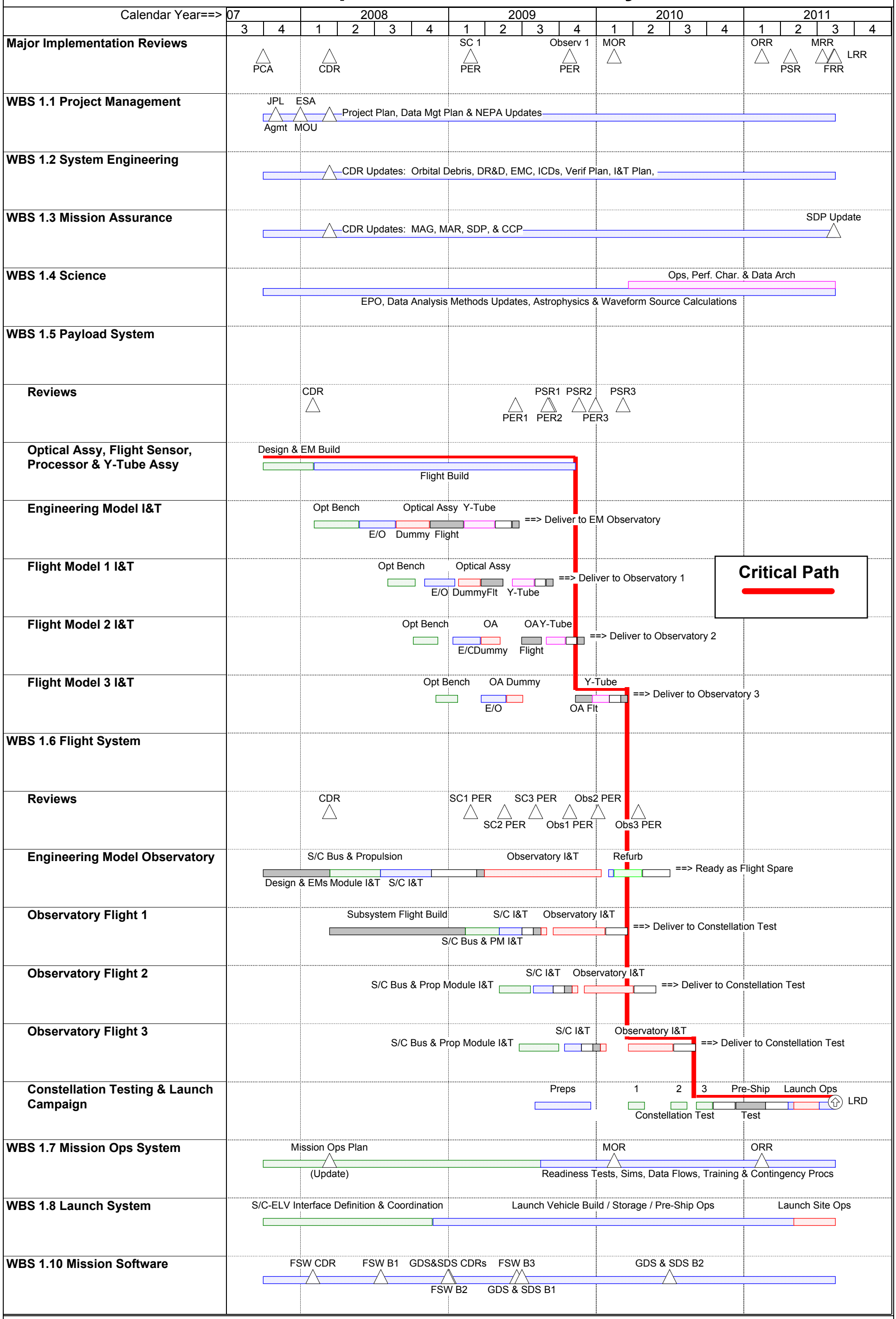
LISA Mission Implementation Summary Schedule



Foldout G-3, LISA Mission Implementation Summary Schedule

G.3.3 Budget

Table G-6: Implementation Budget ($M)

SENSITIVE MATERIAL

Table G-7: Use of NASA Facilities & Equipment ($M)

SENSITIVE MATERIAL

SENSITIVE MATERIAL

Figure G-7: Implementation Budget with Reserves ($M)

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Since we are in Pre-Phase A, our Implementation cost is a Rough Order of Magnitude (ROM). Recognizing this, we have included significant reserves on the hardware and software. Some key points that help mitigate risk are:

- There is an order of magnitude difference in sensitivity between the nominal mission and the minimum mission. This allows us to trade-off the cost of solving technical problems versus decreasing sensitivity.
- Technology Development/Formulation retires all of the near-term risks and ensures that the requisite technologies are at TRL 6 prior to Implementation.
- We have created a strong project team by distributing work between the partners based on their strengths. NASA is responsible for the mission management of this endeavor.
- NASA/ESA work assignments are finalized based on demonstrated performance in the parallel technology efforts prior to Implementation.
- Much of the U.S. effort is directed toward assembly, integration and test, developing models and algorithms, and mission operations – all activities that occur later in Implementation. Therefore, we limit the size of the contractor workforce, postponing expansion until the prerequisite activities are completed.
- LISA does not have an external schedule driver, other than the meshing of NASA and ESA programs. Therefore, there is nothing that would force significant budget augmentations to meet fixed launch dates or maintain data continuity.

The **estimating methodology, checking process, and strategy for managing budget reserves** are the same as described in Section G.2.2.3.

The **rationale for confidence** provided in Section G.2.2.3 also applies to Implementation. In addition:

- The greatest uncertainty during Implementation is the cost of designing and fabricating hardware. For LISA these costs are primarily ESA's responsibility.
- Staffing of NASA SE&I contractor is controllable. The contract does not "ramp up" until hardware is actually delivered.
- The LISA investment through end of Formulation is $XXXM ($XXXM NASA, $XXXM ESA), including a highly robust technology development effort that retires risk prior to beginning Implementation.

G.4 Whole Program Summary

G.4.1 Schedule

Foldout G-4 summarizes the schedule for the entire LISA effort based on the preliminary logic network which:

- Provides a fully integrated schedule for all elements of the project;
- Identifies an initial critical path originating with the GRS development; and,
- Establishes reserve estimates that exceed NASA planning guidelines by nearly 50%.

Appendix H.2 contains the supporting, detailed schedules for LISA. Additionally, the MS Project file for the entire schedule has been submitted on CD-ROM with this report.

Table G-8 shows a summary of schedule reserve and total slack.

Table G-9 gives a whole program budget summary.

Table G-10 shows budget contingency and reserves as a function of mission phase. Reserve levels vary between WBS level 2 elements. The table shows the average at WBS level 1.

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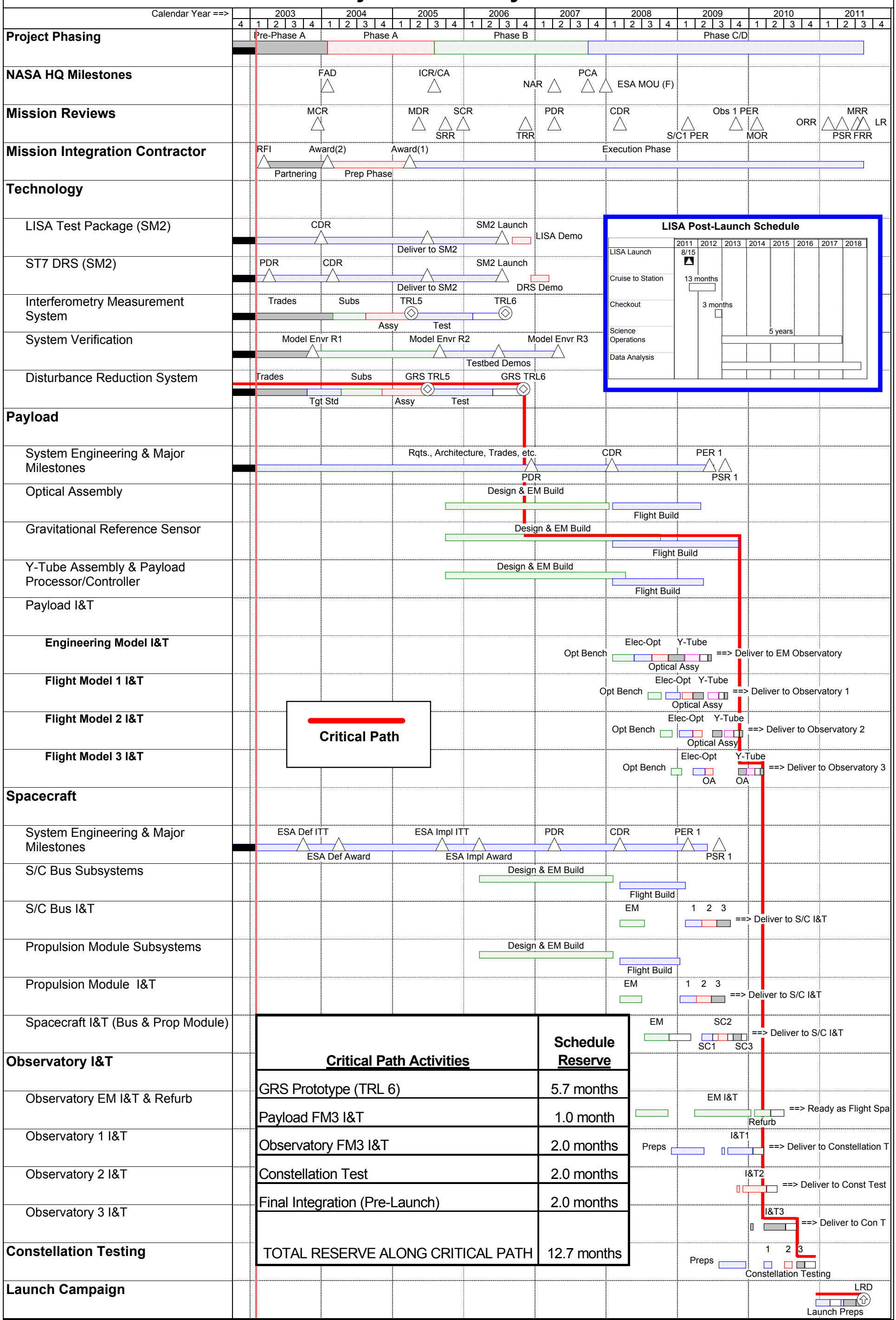
LISA Project Summary Schedule



Critical Path Activities	Schedule Reserve
GRS Prototype (TRL 6)	5.7 months
Payload FM3 I&T	1.0 month
Observatory FM3 I&T	2.0 months
Constellation Test	2.0 months
Final Integration (Pre-Launch)	2.0 months
TOTAL RESERVE ALONG CRITICAL PATH	12.7 months

Foldout G-4 "LISA Project Summary Schedule"

Table G-8: LISA Schedule Reserve & Total Slack Summary

ELEMENT	FINISH DATE	SCHEDULE RESERVE (MONTHS)	TOTAL SLACK (MONTHS)	RESERVE + TOTAL SLACK (MONTHS)
GRS TRL 6	***11/3/2006***	***5.7***	***0***	***5.7***
Thrusters TRL 6	2/21/2006	6	16	22
Laser TRL 6	7/20/2006	6	5.7	11.7
IMS TRL 6	8/3/2006	6	5.2	11.2
Payload EM	6/5/2009	1.5	0.8	2.3
Payload FM1	8/28/2009	1	0.8	1.8
Payload FM2	11/13/2009	1	0.8	1.8
Payload FM3	***3/2/2010***	***1***	***0***	***1***
Spacecraft EM	3/11/2009	4	1.5	5.5
Spacecraft Flight 1	7/29/2009	1	1.4	2.4
Spacecraft Flight 2	10/14/2009	1	1.4	2.4
Spacecraft Flight 3	12/23/2009	1	2	3
Observatory EM (Refurb as flight spare)	7/2/2010	2.5	0.8	3.3
Observatory Flight 1	3/19/2010	2	3	5
Observatory Flight 2	5/18/2010	2	2	4
Observatory Flight 3	***9/3/2010***	***2***	***0***	***2***
Constellation Testing	***12/10/2010***	***2***	***0***	***2***
Final Integration (Pre-Launch)	***4/20/2011***	***2***	***0***	***2***
RED = Critical Path				

Critical Path: the longest sequential path of activities through the LISA logic network, from beginning to end, that defines the earliest LISA can launch; Path with the longest overall duration; Path with the least amount of Total Slack

Total Slack: the amount of duration an activity can be delayed without impacting the project's completion date (e.g., launch).

Schedule Reserve: a pre-planned amount of schedule duration incorporated into the logic network at critical points and/or prior to the completion point of the project; used for management control purposes such as recovery from technical problems that impact the schedule.

[Ref G-1] "Understanding the Project Scheduling Process." NASA/GSFC Code 400 Seminar Work Book, April 2002.

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G.4.2 Budget – Summary Budget

Table G-9: LISA Summary Budget

SENSITIVE MATERIAL

Table G-10: Budget Contingency/Reserve Levels as a Function of Mission Phase

SENSITIVE MATERIAL

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