The NASA Exploration Design Team: Blueprint for a New Design Paradigm

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Abstract—To meet the Nation's goal[1,2] of a new direction in human and robotic space exploration, the National Aeronautics and Space Administration (NASA) must rapidly develop concepts, architectures, and requirements for the next generation of space exploration systems. This requires a rapid architectural design capability, quick access to the vast expertise distributed throughout NASA centers and external partners, and impartial analysis of options. To accomplish these goals, the NASA Exploration Design Team (NEDT) has been established to provide the infrastructure, tools and processes to evaluate exploration program, mission and technology trade studies in a collaborative, distributed, real-time environment.

Experience with JPL's Team X studies of robotic space missions (there have been over 650 designs to date) demonstrates that significant efficiencies can be captured in performing these complex studies in a collaborative environment with common tools and processes. Team X has reduced per-study costs by a factor of 5 and per-study duration by a factor of 10 compared to conventional design processes. The Team X concept has spread to other NASA centers, industry, academia, and international partners. The goal for NEDT at project completion is to achieve a study turn-around time of as low as 2 weeks.

In this paper, we present an extension of the JPL Team X process to the NASA-wide collaborative design team. We describe the architecture and approach for such a process and elaborate on the implementation challenges of this process. We further discuss current ideas on how to address these challenges.

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1. INTRODUCTION

To meet the Nation's goal of a new direction in human and robotic space exploration, the National Aeronautics and Space Administration (NASA) must rapidly develop concepts, architectures, and requirements for the next generation of space exploration systems. This requires a rapid architectural design capability, quick access to the vast expertise distributed throughout NASA centers and external partners, and impartial analysis of options. To accomplish these goals, the NASA Exploration Design Team (NEDT) has been established to provide the infrastructure, tools and processes to evaluate exploration program, mission and technology trade studies in a collaborative, distributed, real-time environment. NASA's Exploration Systems Mission Directorate (ESMD) will select the trade studies to be performed and the study will be led by ESMD or individual NASA Centers.

NEDT will consist of teams at NASA centers, NASA Headquarters (HQ) and industry partners, collaborating in real-time and will be supported by integrated communication and engineering tools (see Figure 1). This concurrent engineering paradigm is expected to provide results in much less time and cost than the traditional serial design team process. The goal is for NEDT to provide a study turn-around time of as low as 2 weeks.

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[1] 0-7803-8870-4/05/$20.00© 2005 IEEE
[2] IEEEAC paper #1627, Version 8, Updated January 3, 2005

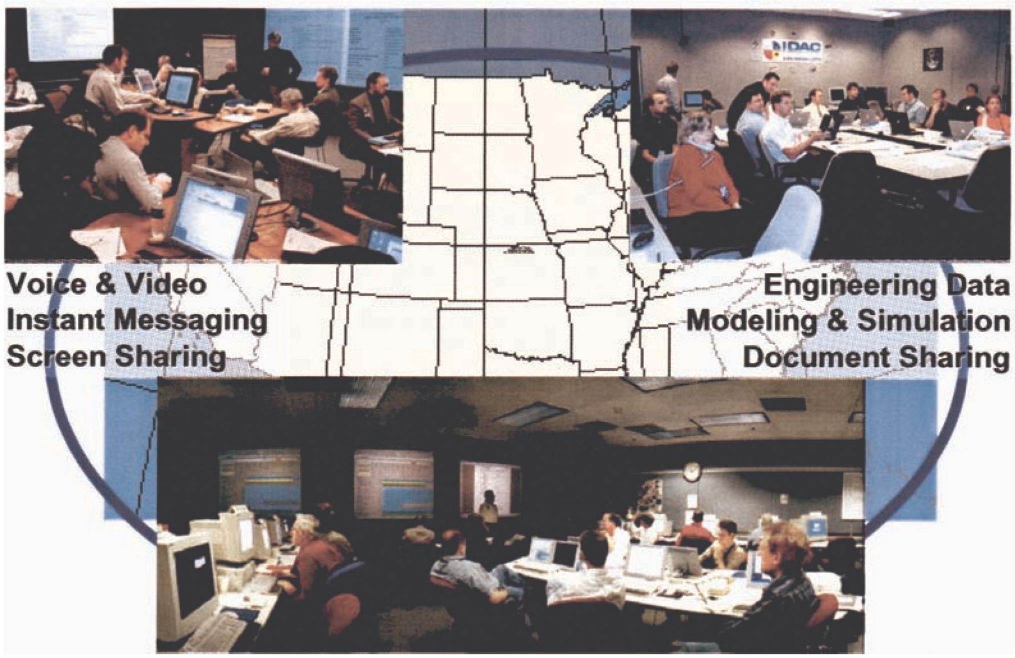

Figure 1. Distributed Concurrent Engineering Design

To provide this capability the following activities are planned:

(1) Connect NASA centers, NASA HQ and partners via collaboration infrastructure, including:

  a. Secure network connectivity through firewalls.

  b. Integrate and upgrade existing collaboration tools (i.e. voice, video, and data sharing).

(2) Train personnel in concurrent engineering techniques.

(3) Identify and integrate engineering tools, including:

  a. Adoption of existing engineering design tools.

  b. Connections to trade-space and simulation-based acquisition models.

  c. Inter-center engineering parameter exchange.

(4) Execute studies and deliver needed study results to ESMD as early as possible.

During Phase 1 of this project, NEDT will integrate NASA HQ, the Jet Propulsion Laboratory (JPL), the Johnson Space Center (JSC), and the Aerospace Corporation concentrating on a basic engineering collaboration capability. It will provide a training study and a pilot study, and deliver study results to ESMD. During Phase 2, several operational studies will be selected by ESMD for analysis and collaborative designs will be performed. Further, additional NASA Centers can be added to the set of participating organizations in Phase 2 (e.g., the Marshall Space Flight Center (MSFC), Glenn Research Center (GRC), Goddard Space Flight Center (GSFC), Ames Research Center (ARC), and Langley Research Center (LRC)).

In order to rapidly make informed decisions on next generation space exploration system concepts, architectures and requirements, ESMD faces daunting fundamental questions: what are the impacts and risks of a certain technology, in what sequence should missions occur to optimally leverage technology developments, how much will a certain architecture cost, etc. Answering these questions requires the consistent, agile, and cost-effective execution of large numbers of conceptual space system design and trade studies, drawing on expertise across NASA and industry. ESMD needs in this area are listed in Table 1.

Need	Definition
Agility	Rapid turnaround, rapid change of direction, ability to address disparate regimes, e.g., human & robotic.
Completeness & consistency	Standard products that are consistent between studies and organizations.
Cost effectiveness	Predictable cost per study, reduction in costs from current paradigm
Access to expertise	Access to world-class experts for reliable results.
Trade spaces	Must be able to assess a wide range of options to insure selection of optimal architectures.
Collaboration	Quickly include input from all pertinent organizations, inside and outside of NASA.
Access to Capability	HQ, and any NASA center, can exercise NASA-wide design capabilities.

Table 1. ESMD Needs Defined

The NASA Exploration Design Team (NEDT) will meet these needs by providing the necessary framework, tools and processes. It will perform real-time concurrent engineering on mission and system architecture, design, and technology trade studies, including design trades, costs, and risks. These results will be used by ESMD in designing and assessing specific missions, and in developing strategic program technology roadmaps and investment strategies.

2. NEDT ARCHITECTURE AND APPROACH

NEDT will utilize the concurrent engineering paradigm to create an environment for performing studies in much less time and expense than conventional design. The conventional design process is shown in Figure 2. This process is generally characterized by cycles of issue resolution as shown in Figure 3, which can take days, weeks, or months. By comparison, with concurrent engineering (shown in Figure 4) all participants can work together in real-time, with physical or virtual collocation. Issues are identified and resolved quickly because all information is at hand and all personnel are present. Meeting cycles are eliminated. The entire design team can quickly change direction to instantly react to new information.

JPL has been at the forefront of real-time collaborative engineering beginning with the launch of Team X nine years ago. Team X study statistics (shown in Table 2) have resulted in adoption of this concept by other NASA centers, industry, academia, and international partners.

Studies Performed	650
Study Time Reduction	10x
Study Cost Reduction	5x

Table 2. Concurrent Engineering Results Demonstrated by Team X

Neither Team X nor any other single design team can currently adequately serve ESMD due to the nature of their specializations (e.g. robotic missions, manned missions). NEDT will draw on the expertise of all NASA centers and external partners in this regard. NASA Headquarters will select study topics and study leaders, with field centers and partners enlisted according to the needs of each study. Through real-time distributed collaboration, NEDT will effectively bring the field centers into a real-time study environment with NASA Headquarters. For the first time, NASA HQ will be able to initiate and conduct mission studies directly.

The development team will consist of leaders of Team X, Team Prometheus, and collaborative design facilities and teams across NASA. It is intended to gather all available experience within NASA to synthesize a world-class facility as well as organizational structure to provide distributed concurrent space system engineering.

The NEDT Project is planned to be executed over a period of three years in phases of incremental capability. The first phase delivers an initial operating capability to demonstrate the concept and a set of requirements for Phase 2 implementation. Phase 2 delivers the full multi-center collaborative design capability for NASA.

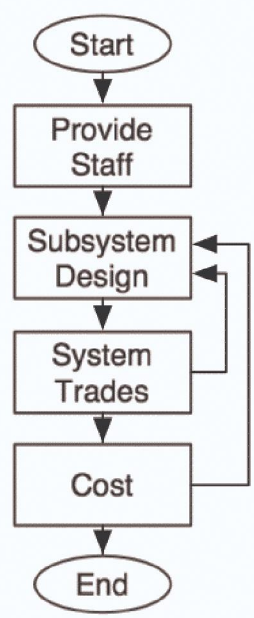

Figure 2.
Traditional Serial Design Process

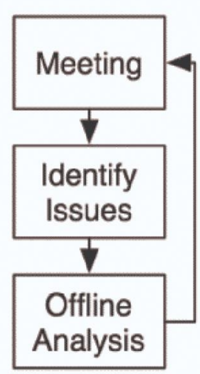

Figure 3.
Meeting & Issue Process

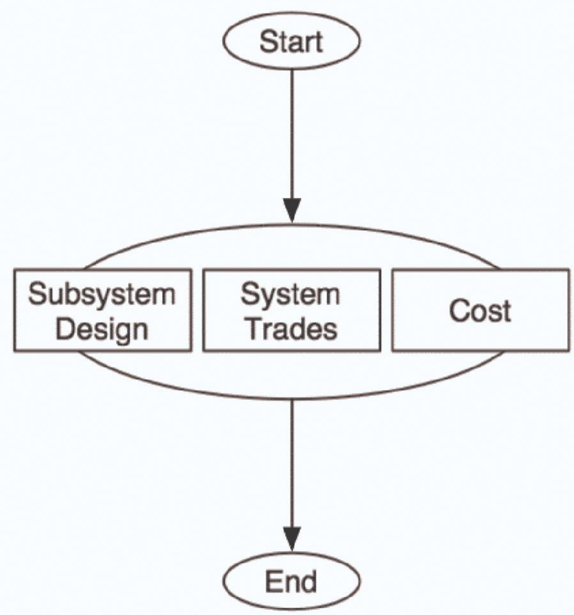

Figure 4.
Concurrent Engineering Process

The Phase 1 development concentrates on assembling existing resources and infrastructure to demonstrate the feasibility and functionality of the NEDT team. NASA Headquarters, JPL, JSC and the Aerospace Corporation will participate in the Phase 1 feasibility demonstration. NASA Headquarters will select the pilot study to validate the NEDT 's Initial Operating Capability (IOC). Phase 1 activities will culminate in requirements and a plan for Phase 2 that extends the capability demonstrated in Phase 1 to include the integration of additional NASA centers.

Key Activities during Phase 1 (FY 2005)

(1) Establish a basic operations process

(2) Connect NASA HQ, JSC, JPL, and Aerospace Corporation using existing infrastructure with minimal upgrades necessary for basic engineering collaboration. Complete new infrastructure installation at NASA HQ, if not available.

(3) Identify and incorporate existing communication and engineering tools into the Initial Operational Capability.

(4) Train distributed teams and conduct a training study.

(5) Perform a pilot study on a Headquarters'-selected topic. Complete pilot study report and verify study products.

(6) Generate requirements for Phase 2 implementation.

Phase 2 - Full Operational Capability (FY 2006 - 2007)

Phase 2 will expand the capability by enabling additional NASA Centers to integrate with the NEDT and expand the infrastructure and tools available to complete a design activity. To the maximum extent possible, analytical tools, techniques or information infrastructures developed by the Systems & Infrastructure Analysis Tools Committee (SIAT) or Simulation Based Acquisition (SBA) activity will be integrated into the collaborative environment utilized by the NEDT team. At least two operational studies will be performed by the NEDT during phase 2. In phase 2, HQ will determine the specific role of each organization on a study-by-study basis, and in particular will decide which centers will lead and facilitate each study. Completion of these efforts will result in a Full Operational Capability (FOC) to address relevant ESMD design or SBA assessment activities.

Key Activities during Phase 2

(1) Connect additional NASA Centers (e.g., MSFC, GRC, GSFC, ARC, LRC)

(2) Upgrade collaboration infrastructure to enable full engineering collaboration, including full data connectivity through firewalls.

(3) Upgrade engineering tools. Enable inter-center engineering parameter exchange. Connect to SIAT or SBA-developed technologies (e.g., tradespace exploration tools, modeling and simulation tools, collaboration technologies, simulation-based acquisition modeling tools, etc.) as appropriate and available.

(4) Execute operational studies; provide useful design results to ESMD.

3. Thrust Areas

NEDT development will be based on the following thrusts:

Concurrent Engineering Paradigm: JPL will start with the distributed team paradigm, as pioneered by Team X and Team Prometheus, and evolve it according to the capabilities of the various centers and requirements of ESMD.

Organizational Participation: Phase 1 will include HQ, JSC, JPL, and Aerospace Corporation in design studies. Aerospace Corporation will serve as a pathfinder for collaboration with industrial partners, will provide technical expertise as appropriate, and may eventually serve as an independent technical assessor. Additional Centers will be involved in requirements development, consulting, and tool preparation during phase 1. The NASA Integrated Services Network (based at MSFC) will be utilized for infrastructure provisioning. Phase 2 will add the capability to incorporate other NASA Centers (e.g., GSFC, ARC, GRC, MSFC, LRC) into the design studies. In phase 2, HQ will determine the specific role of each organization on a study-by-study basis, and in particular will decide which centers will lead and facilitate each study.

Infusion: The NEDT will perform design studies on an ongoing basis throughout the 3 years of this task. The studies will be directly applicable to ESMD; their content will be decided by ESMD. The project will solicit and incorporate feedback from ESMD on tailoring the process and products to ESMD needs. Operational Studies are planned to be co-funded by the customer.

Process: JPL will define the initial Team operating process and standard products in the draft Operations Concept. This draft will be refined in a collaborative Workshop involving all the future participants, with a final version released soon afterwards. The initial Operations Concept will be the basis for developing the training plan and associated materials, as well as the training and pilot studies. The operations concept will be refined continuously based on customer feedback and lessons learned from studies.

Baseline Operating Process:

(1) HQ/ESMD identifies study need and provides study request to NEDT.

(2) ESMD and NEDT leaders formulate study requirements in pre-session videoconference(s).

(3) ESMD and any co-funding sponsors will designate the study lead and participating NASA centers and partners.

(4) NEDT performs the design study.

(5) The Lead center will be responsible for rolling up key engineering data from the supporting Centers as well as completion of the final study report with support from the NEDT study participants. The baseline study results are illustrated below.

Baseline Standard Study Products:

- Mission objectives
- Key drivers & challenges
- Key components to be used
- Estimated cost, performance, risk, mass, power
- Estimated schedule & programmatic
- Operations overview
- Trajectory
- Design assumptions & trades conducted
- Launch vehicle
- Ground systems and networks
- Descriptions of structure, communication, propulsion, life support, power, & thermal systems

Infrastructure: The NEDT effort will be significantly enhanced by improving and expanding the existing infrastructure. Significant challenges are data communications through firewalls and voice communications. JPL, with support from Headquarters, will establish through-firewall data communications paths between study participants and use these paths to connect existing engineering tools and collaboration infrastructure. Voice and video communications will use existing capabilities.

Phase 1 will use existing infrastructure, with minimal modifications, to connect the initial centers; the emphasis will be on speed of deployment and obtaining minimum essential connectivity at the expense of permanence and robustness. In Phase 2, a more robust infrastructure based on requirements and technologies developed by SAIT and SBA in Phase 1 will be implemented. Phase 2 will involve more complete engineering data exchange, voice and tool connectivity, video (depending on location), and connections to simulations (see below).

Commercial (COTS) infrastructure solutions will be preferred; however, selected technology will be developed where COTS options are not adequate. Standards for collaboration infrastructure will be adopted consistent with SAIT specifications (e.g., firewall/security standards, data protocols, engineering data formats) or from COTS sources, or other NASA organizations, as appropriate (e.g., ESMD CIO led collaboration infrastructure, or other advanced engineering environments being developed by NASA). JPL will work with external partners to establish their compatibility with these standards.

Figure 5. JPL Project Design Center


Figure 6. JSC Collaborative Engineering Center


Figure 7. MSFC Collaborative Engineering Center

Figure 8. GRC Integrated Design & Analysis Center

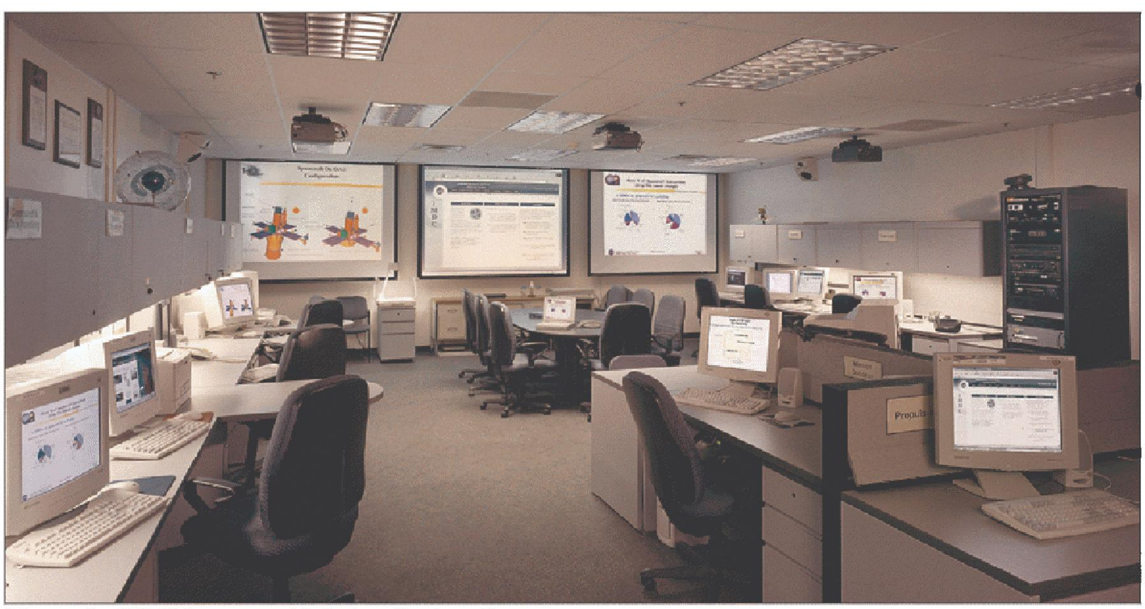
Figure 9. GSFC Integrated Mission Design Center

Engineering Tools: The project will begin with the engineering tools currently in use at the NASA centers and Aerospace Corporation. In Phase 2, the project will connect NEDT with externally developed models (model-based design, simulation-based acquisition models, trade-space tools, etc.) so that the Team can provide driving design parameters to the models and evaluate the results. In addition, during phase 2 the project will incorporate advanced engineering tools and technologies being developed under SAIT and SBA initiatives and provide user feedback to the developers of such tools.

Training & Team Building: JPL will train study session participants in collaborative engineering methodologies. Training in concurrent engineering techniques will be provided "offline" via instruction from experienced personnel and "online" via participation in training and pilot studies. While it is likely that the existing concurrent engineering paradigm will initially be adopted, process developers will actively solicit feedback and discussions among team participants concerning the optimal team composition, process, and environment. By using the training studies as team building exercises, it is intended that the core of the rapid design process can be retained while encouraging the team to evolve its own optimized process for operating in a distributed environment. By addressing actual ESMD problems in these studies the team will provide early results, address pressing needs, and demonstrate the Team's value.

4. IMPLEMENTATION CHALLENGES

Many implementation challenges are anticipated during the development of the NEDT. In addition to the technical challenges involved with setting up the infrastructure and team processes, significant organizational challenges are also anticipated.

Some of the infrastructure, tools and team process challenges anticipated:

(1) Demonstration of effective and efficient team collaboration across multiple geographically distributed NASA and industry partner sites

(2) NASA communication infrastructure limitations (e.g., hardware may be incompatible or incomplete, infrastructure may not be capable of handling peak loads, etc.)

(3) Incompatible collaboration software tools across the agency

(4) Design and analysis tools require sufficient agility to support the rapid design and assessment paradigm

(5) Security approaches for handling data access at the various NASA Centers may be inconsistent

(6) NASA Headquarters may have space restrictions that impact the location of the planned HQ design center

(7) Multi-user facilities may not be available when needed and support to these centers may be limited

Organizational challenges facing the NEDT development team include:

(1) Center priorities may interfere with timely implementation

(2) Domain specialists or other key personnel may not be available for studies when needed

(3) Inter-center cooperation limitations in the world of competed missions

One final challenge is that of customer involvement and training. The NEDT capabilities will evolve to meet the customer's needs only if there is active engagement.

Ideas on how to address these challenges

The NEDT development team has spent considerable effort to address the anticipated challenges.

Some of these challenges will be mitigated by the fact that the capability development will be done using an incremental, evolutionary approach. The initial capability will be based on Team X concurrent design experience. Recent activities with Team Prometheus (based on Team X experience, including JPL, MSFC and GRC and U.S. Department of Energy participation) provide additional confidence in the viability of this approach. The NEDT plan involves integration of one NASA center at a time, so that lessons can be learned before large investments of resources are made. In addition, all centers will participate in the initial requirements analysis so that there are few surprises late in the implementation. The use of existing infrastructure wherever possible as well as COTS tools will help the team contain costs and will allow them to focus attention on other development priorities.

Training and team building are central to our approach. In addition, our test and validation approach involves a series of tests executing a series of incrementally more challenging tests, verifying the functionality and processes that are developed. The test program culminates in the Pilot study, which is the proof of concept activity that demonstrates the Phase 1 capability. Phase 2 test activities will be similar and will depend on the requirements generated during Phase 1.

To meet the anticipated organizational challenges, the NEDT Project will secure commitments from supporting Centers and participating non-NASA organizations to act as responsible Partners and/or Suppliers, meeting agreed-to objectives with products produced on time and delivered on budget. These supporting Centers and/or other organizations will establish their own management *structure to develop Task Plans to deliver this commitment to the Project. The Project will audit the plans and progress of the supporting Centers and/or other organizations in order to integrate their contributions into the overall objectives of the Project. All Partners and Suppliers will participate fully in day-to-day programmatic input to all integration activities as deemed appropriate by the Project management.*

5. CONCLUSIONS

Although facing significant implementation challenges, the architectural approach and organization structure for the NEDT will effectively bring the rapid, collaborative design capability to all participating NASA Centers, NASA HQ and industry partners. Each participant will be able to initiate and conduct mission studies directly. The real-time distributed collaboration approach has been shown to be both cost effective and timely based on Team X experience. Because of this, NASA participants will be able to explore the mission trade-space in a much more comprehensive manner than could have been done with a conventional design methodology.

Because it will draw on NASA-wide expertise and resources, the NEDT will have be able to address all ESMD missions, both human and robotic, and all Strategic Technical Challenges and technologies applicable to such missions. The team will be able to support NASA Headquarters in addressing both mission-specific and program-level issues. Studies will be designed to generate mission and system requirements and architectures, including designs, costs, and risk estimates. Study results will be used by Headquarters in designing and assessing specific missions, and in developing strategic program technology roadmaps and investment strategies.

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BIOGRAPHY

***Robert Oberto** is Project Manager of the Advanced Projects Design Team at JPL. These teams pioneered concurrent engineering methodologies for conceptual spacecraft, instrument, ground system and in-situ payload/instrument design. A total systems approach is utilized, with multi-disciplinary design teams and interconnected state-of-the-art design tools. He has led the design teams in the development of over 450 concepts for space system exploration missions. He has also developed cost-effective engineering design processes for space mission architecture development. The design capabilities are currently being extended to include multiple NASA centers. Previous JPL assignments have included Project Manager of the Interferometer Program Experiment II and Spacecraft System Engineer for interplanetary space missions. He has a BS in Aerospace Engineering from the University of Southern California and an MS in Aerospace Engineering from the University of Colorado at Boulder.*

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