Independent Review of the Outer Planet Flagship Mission Studies

Curt Niebur
OPF Program Scientist
NASA Headquarters

R. Brad Perry
Director, Science Support Office
NASA Langley Research Center

Presentation to the
Decadal Survey
August 25, 2009

Study Background and Purpose

- NASA and ESA are using a multistep downselection process to carefully select their next “flagship” missions
  - Multiple studies in this process intended to inform decisionmakers on science value, implementation risk/issues, cost and cost risk, and technology needs
- Step 1 (2007): NASA and ESA operated independently of one another
  - PSD conducted detailed studies for several flagship missions (Europa, Titan, Enceladus, and Jovian System Observer)
    - AA Stern selected two of these concepts (Europa and Titan) for further study/evaluation in 2008
  - ESA solicited Cosmic Vision Class L proposals
    - ESA selected Laplace and Tandem proposals (as well as IXO and LISA)
- Step 2 (2008): NASA and ESA began a closer collaboration
  - Europa and Laplace concepts combined into Europa Jupiter System Mission with Europa Orbiter contributed by NASA and Ganymede Orbiter by ESA
  - Titan and Tandem concepts combined into Titan Saturn System Mission with Titan Orbiter contributed by NASA and balloon and lake lander by ESA
- Step 3 (2009): Single concept moves forward for further work
  - NASA will focus on risk mitigation
  - ESA will conduct industry studies of 3 Class L concepts (OP, IXO, an LISA) for downselect beyond 2010

Review Process

- NASA conducted its standard independent review for pre-phase A concepts submitted in response to an AO for both the 2007 and 2008 studies
  - TMC panel evaluated feasibility of science implementation and mission implementation of NASA contributions - Jupiter Europa Orbiter (JEO) and Saturn Titan Orbiter STO
  - Science panel addressed the scientific merit of full international mission (EJSM and TSSM) and feasibility of science implementation of NASA contributions (JEO and STO)
- ESA conducted its own independent review process
  - Board of Technical Experts conducted a relative evaluation between the ESA contributions - Jupiter Ganymede Orbiter (JGO) and Titan In Situ Explorer (TISE)
  - Solar System Working Group evaluated science of full international missions (EJSM and TSSM)
- NASA and ESA provided observers for each other's reviews

Review Process

- Once Study Reports were submitted they were distributed to the TMC and Science panels (~50 panelists total)
- Panels spent 1 month reviewing reports in preparation for site visits with Study Teams
- Panels spent one day with each Study Team for discussions and presentations
  - Panels provided written questions to Study Teams ~1 week prior to site visits and had the opportunity to ask additional questions at site visit
- Panels spent day following each site visit in closed session
- TMC Panel held 3 day plenary session the following week
- Final package provided to Program Scientist ~3 weeks later

Principles for NASA Evaluation

- The basic assumption for the review was that the Study Team is the expert on their mission concept study
  - Study Teams’ task was to provide evidence that the project is Low Risk; TMC panel task was to validate this assertion
- The TMC Risk Assessment was based on a pre-Phase A concept with appropriate benefit of the doubt given to the Study Team
- Both Study Reports were reviewed to identical standards to the extent possible and without comparison to the other Study Report
- The Cost Analysis was integrated into overall mission implementation risk on Form C
- TMC and Science panels were composed of evaluators that were experts in the areas of the studies that they evaluated
- TMC and Science panels developed findings for each Study Report that are the product of the entire panel and provided adjectival ratings
  - Only major strengths and weaknesses were used to determine ratings
- Studies were funded by NASA as a directed activity and the evaluation was a Non-Competitive Process

Output of NASA Review

- TMC and Science panels populated standard review forms
  - Form A: evaluated the scientific merit of full international mission (EJSM and TSSM) and NASA-only missions (JEO and STO)
  - Form B: evaluated the science implementation by assessing the level of risk of accomplishing the scientific objectives with the measurements provided by the instrument suite
  - Form C: evaluated the mission implementation by assessing the level of risk of accomplishing the scientific objectives of the investigation, through the described mission implementation, on time and within cost
- Forms B and C rated as Low, Medium, or High Risk
  - Low Risk: There are no problems in the study that cannot be normally solved within the time and cost described. Problems are not of sufficient magnitude to doubt the project's capability to accomplish the investigation.
  - Medium Risk: Problems have been identified, but are considered within the project's capabilities to correct with good management and application of effective engineering resources. Mission design may be complex and resources tight.
  - High Risk: Problems are of sufficient magnitude such that failure is highly probable.

NASA Review Results - Summary

Study	Form A: Science Merit (EJSM & TSSM)	Form B: Science Implementation Risk (JEO & STO)	Form C: Mission Implementation Risk (JEO & STO)
Europa Jupiter System Mission	Excellent	Low Risk	Low Risk
Titan Saturn System Mission	Excellent	Low Risk	High Risk

Form A Significant Findings for EJSM (1) Rating: Excellent

- +The Europa Jupiter System Mission (EJSM) brings together a diverse, well-focused suite of measurements designed to investigate Europa as well as the environment in which it formed and evolved.
- +The science objectives of the EJSM are highly responsive and consistent with the 2003 NRC Decadal Survey goals and NASA's Solar System Exploration Roadmap.
- +The Jupiter Europa Orbiter (JEO) fills critical gaps in our understanding of Europa's interior (and especially its ocean and ice shell) and makes fundamental progress beyond Voyager and Galileo.
- +The joint EJSM represents an outstanding advance for satellite science and comparative planetology.
  - + The final phase of the Jupiter Ganymede Orbiter (JGO) mission, an orbital tour of Ganymede, will investigate the gravitational field, internal structure, surface features, and especially the intrinsic and induced magnetic fields of Ganymede.

Form A Significant Findings for EJSM (2) Rating: Excellent

- +JGO also provides complimentary Jupiter system science, including a sub-millimeter wave sounder of Jupiter's atmosphere.
- +EJSM is a mission of considerable breadth and is a superb example of Flagship science.
- +The Study demonstrated the ability to distinguish between competing models of Europa's interior, constraining the thickness of the icy crust and the volume of liquid water below, using a combination of geophysical measurements (electromagnetic induction, gravity and topography, and radar sounding).
- +Thoroughly exploring Europa from orbit will feed forward to any future landed mission.
- -There were no significant weaknesses
- The NASA-only JEO mission represents a highly capable mission that retains essentially all of the components for the study of Europa, and some of those for the study of Jupiter, that the full EJSM provides.

Form B Significant Findings for JEO Rating: Low Risk

+The Traceability Matrix (TM) is very well done and comprehensive, particularly for Europa investigations.

– Science Objectives are clearly flowed to Science Investigations, to detailed Measurement Requirements in Table 2.4-2, and finally to Instruments in F/O-1. A very thorough discussion is provided of the rationale for measurements and measurement requirements needed to support each science investigation. Hypotheses, Questions and their corresponding Hypotheses Tests are listed in Tables 2.4-4, 2.4-5, 2.4-10, 2.4-11 and 2.4-12, following the various Science Investigations given.

-There were no significant weaknesses.

Form C Significant Findings for JEO Rating: Low Risk

+ The overall discussion of mission operations is excellent, and the operations impact on the design of the flight segment has clearly been considered, which is indicative of an appreciation of the importance of operations considerations early in the mission lifecycle.
+ The current JEO baseline builds upon a large body of previous studies to produce the current design concept, resulting in a relatively mature flight system concept for pre-Phase A and substantially reducing implementation risk.
+ The report presents a technical approach to risk identification and mitigation that demonstrates an excellent understanding of the major risks and the actions required to effectively mitigate those risks.
- The JEO ability to meet a stringent stability requirement in Europa orbit is not supported.
- The proposed funding profile for the Payload System (WBS 5) is too back-loaded to allow for efficient mitigation of issues and adequate early understanding of design details and requirements.

Form A Significant Findings for TSSM (1) Rating: Excellent

+ The goals of the Titan and Enceladus exploration are clear, concise, and important.
+ The baseline TSSM is highly responsive to the NASA Solar System Roadmap and the 2003 NRC Decadal Survey.
+ The Enceladus science included in the TSSM mission is substantial and significant.
+ The synergistic approach of the baseline TSSM is ideal for making fundamental progress well beyond the Cassini Mission.
+ TSSM is a mission of considerable breadth and is a superb example of Flagship science.
+ The measurement set is well-defined and appropriate for meeting the scientific objectives of the mission.

Form A Significant Findings for TSSM (2) Rating: Excellent

+ The descoped version of the international mission, in which the SEP is eliminated, maintains the full science capability of the mission in terms of instruments and measurements, although the time in Titan orbit will be reduced by 30%, from 20 to 14 months.

- There were no significant weaknesses

• The NASA-only mission, consisting of only a Titan orbiter as described in the Final Report, clearly makes fundamental advances in our understanding of Titan and Enceladus. However, in the absence of an in situ element, the mission falls short of providing the fundamental advances expected of flagship missions such as Galileo and Cassini.

Form B Significant Findings for STO Rating: Low Risk

+ The Traceability Matrix and associated discussions clearly show the connection between objectives and measurements and further show the priorities involved.
  + A detailed science traceability matrix is provided that clearly flows from the three mission goals to science objectives, to proposed science investigations, to the required payload, to a planned measurement approach, leading on to a strong planning payload. Excellent discussion with detailed background is provided describing the rationale for the science payload measurements and the measurement requirements.

- There were no significant weaknesses.

Form C Significant Findings for STO (1)
Rating: High Risk

+ The report provides an excellent technical basis for the estimates and assumptions related to payload accommodation, with a thorough description of the individual instruments in the planning payload.
- The dry mass margin is too low for a pre-Phase A mission concept with significant technical challenges.
- The design drivers resulting from the inclusion of aerobraking in the TSSM mission have not been adequately defined and their resulting impact to the design has not been assessed.
- The changes for TIRS from the heritage CIRS instrument on Cassini are large, and the ability to successfully implement these changes is not well supported.
- The HGA pointing budget is extremely optimistic with little justification of the improvements presented.
- The TSSM ability to meet the stringent pointing stability requirement is not supported.

Form C Significant Findings for STO (2) Rating: High Risk

- Analysis, engineering, and test of the TSSM thermal subsystem will be challenging and the report does not acknowledge the complexity of the task to address the substantial thermal design constraints posed by solar insolation, Venus albedo, the Montgolfière Multimission Radioisotope Thermoelectric Generator (MMRTG) waste heat, capillary pumped heat pipes (CPHPs), and aeroheating.
- Systems Engineering (SE) lacks the rigorous approach necessary for this highly complex mission, which leads to substantial technical, cost and schedule risk in both design and implementation.
- The complexity of the SEP stage development and lack of technical maturity are not reflected in the project cost estimate.
- The cost impact to accommodate the in situ elements seems unrealistically low.
- The allocated budget for Project System I&T appears insufficient.

Decision & Rationale

NASA and ESA have assigned the highest priority to the Europa Jupiter System Mission for a late next decade launch.

- Science value was not a discriminator between the two missions.
  - If flown, either mission would conduct outstanding science of significant breadth and depth that could be expected to dramatically advance our understanding of their targets.
  - The NASA Science Panel rated both the EJSM and TSSM science as Excellent.
  - The ESA SSWG concluded that the relative scientific merits of the two missions could not be separated and gave the missions equal priority for implementation.
- The EJSM is more technically mature, with the flight elements, their supporting technologies, and associated risks well understood and at a relatively high level of flight readiness.
  - The JEO mission concept was a medium to low risk development that effectively built upon many years of previous work to produce a relatively mature flight system concept for pre-phase A. This substantially reduces implementation risk and demonstrated excellent understanding of the major risks and the actions required to effectively mitigate those risks.
  - The ESA Board of Technical Experts concluded that established heritage and pathways are available to address radiation issues in a timely manner.
- The TSSM is a complex mission that possesses several technical challenges requiring significant study and technology development, and this increases the uncertainty that this mission can meet its schedule, cost, and science goals.
  - The STO mission concept was a high-risk development with significant technical challenges ahead.
  - ESA Board of Technical Experts concluded the TISE portion of the mission required multiple new technologies that would require a significant development effort. In addition, the thermal control system for the Multi-Mission Radioisotope Thermoelectric Generator and the complexity of the interfaces were a shared concern.

Backup Slides

"Sweet Spot" Mission – June 2008

- At the Second Interim Review in June 2008 NASA changed its strategy
  - Strict cost cap strategy with science as the only free variable was dropped since the $2.1B cost capped mission was not compelling
  - A new strategy to seek the "sweet spot" was adopted: optimize balance between science and cost to better respond to the Decadal Survey
- The study teams were directed to identify a "sweet spot" mission consistent with this new strategy
- An assessment of science value vs. cost was developed based on science goals set down by the Decadal Survey
- Following the second interim briefing to HQ management in June 2008 the study teams were directed to:
  - Focus the remaining study efforts on the "sweet spot" mission
  - Defer the nominal launch date from nlt 2017 to 2020 (with evaluation of launch options from 2018-2022)
  - Assess the impact of ASRG and MMRTG power sources and select the preferred system
- This slipped the original study schedule and increased study costs

Form B Evaluation Factors and Subfactors

The degree to which studies address the following factors directly relates to the Science Implementation Risk Rating of Low, Medium, or High Risk:

- **Technical Approach**
  - Methods and Procedures for Implementation
  - Innovative Technologies and Fallbacks
- **Instrumentation**
  - Data needed to achieve Science Objectives and Measurement Margins
  - Design and Performance Characteristics
  - Requirements Traceability
- **Science Operations Plan and Data Acquisition**
  - Science Payload Operational Profile
  - Operations and Data Acquisition Plan
- **Science Descope Plan**
  - Performance Floor/Degradation to Performance Floor
  - Descope Decision Points and Costs
- **Data Analysis and Archiving**
  - Data Reduction and Analysis Plan
  - Delivery of Data Products to PDS or Public Archive

Form C Evaluation Factors and Sub-Factors

The degree to which studies address the following factors directly relates to the Mission Implementation Risk Rating of Low, Medium, or High Risk:

- **Instrumentation**
  - Technology Readiness
  - Instrument Design, Accommodation, and Interface
  - Design Heritage
  - Environment Concerns
- **Mission Design and Operations**
  - Mass Margins
  - Trajectory Analysis
  - Launch Services
  - Concept of Mission Operations
  - Ground Facilities – New/Existing
  - Telecom
- **Spacecraft/Flight Systems**
  - Development of New Technology
  - Hardware/Software Design**
  - Design Heritage
  - Spacecraft Systems Design
  - Design Margins and Contingencies
  - Assembly, Test, and Launch Operations
- **Management* and Schedule**
  - Project-Level Schedule
  - Risk Assessment
  - Work Breakdown Structure (WBS)
  - Systems Engineering
- **Cost**
  - Basis of Estimate (BOE)
  - Cost Realism and Completeness
  - Cost Reserves by Phase
  - Comparison with TMC Estimates (Including Parametric Models/Analogies)

**Not to be fully evaluated for these studies*

***MMRTG vs. ASRG selection is not to be evaluated, as it will be a programmatic decision made by NASA HQ*

- Scientific Evaluation (SSWG)
  - No preference for either mission was given
  - EJSM & TSSM were rated at equivalent science value
- Technical Evaluation Panel (Mandate)
  - Relative evaluation between the 2 missions
  - Design Maturity and Development risks
  - Likelihood of Technology Readiness for a 2020 launch
  - Only European mission elements have been evaluated by ESA

<u>Major concerns/risks raised by technical panel for EJSM-JGO:</u>

1. **Radiation environment**
2. **Complexity of navigation**

- Major issue for EJSM-JGO is the radiation environment. This is considered critical, but radiation issues have been dealt with before at ESA

- Further reduction of total dose by
(1) use of improved and more shielding material
(2) shielding by Ganymede (mass and magnetic field, when in orbit around Ganymede)

- The degradation of the solar panels is assumed to be <u>of no major concern</u>, existing cells seem compliant to expected radiation environment

- EJSM-JGO has to perform a larger number of manoeuvres,
needs to be addressed during the potential next study phases with appropriate attention.

Major concerns/risks raised by technical panel for TSSM-ISE:

1. **Balloon deployment** (complexity of deployment)
2. **Balloon inflation** via limited opening (when balloon is still suspended from the parachute)
3. **Thermal control system** for MMRTG during cruise and coast phase
4. **Complexity of interfaces**

- TSSM (balloon, thermal control) are new & innovative designs
- Deployment of balloon and multiple interfaces with parachute, MMRTG & gondola are complex
- Development and verification to be handled in co-operation of three agencies
- Development of lake lander is considered less challenging, as heritage from Huygens exists
- Main lander instrument (Titan Lander Chemical Analyser) has 23kg of 27kg (allocated P/L mass):
  TCLA is estimated at TRL 2, presenting a **mass growth risk**

Technical Evaluation – Conclusion

- Technical Panel considers EJSM-JGO (Laplace) less critical than TSSM-ISE (Tandem) for a launch in 2020
- TSSM-ISE includes new technologies with a significant development effort
- EJSM-JGO - although complex from design point of view – requires less development effort.

The panel believes that timely addressing of radiation damage mitigations could achieve the required result, in particular as established heritage and pathways are available.