Assessment of the CRAF and Cassini Science Missions: Letter Report

Committee on Planetary and Lunar Exploration, Space Science Board, Commission on Physical Sciences, Mathematics, and Resources, National Research Council

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On September 1, 1988, Dr. Robert O. Pepin, chair of the Committee on Planetary and Lunar Exploration, sent the following letter to Dr. Geoffrey A. Briggs, director of NASA's Solar System Exploration Division.

At its June 1988 meeting, the Space Science Board's Committee on Planetary and Lunar Exploration (COMPLEX) carried out a detailed assessment of the combined Comet Rendezvous-Asteroid Flyby (CRAF) and Titan Probe-Saturn Orbiter (Cassini) missions, which are proposed for new start status in FY1990. This assessment included science objectives, mission profiles, and engineering considerations for both missions, and was made with the assistance of presentations by representatives of the mission Science Working Groups and the engineering study team.

As you know, it is the practice of COMPLEX to assess the science content of missions, as they near proposal as new start candidates, in order to measure how well the agency has responded, in a mission context, to the committee's relevant exploration strategies. The conclusions of these assessments are measures of the support of the committee and the Space Science Board for the proposed planetary missions. The committee also carries out further reviews during the development periods of the missions leading to launch.

In two previous letter reports, dated May 31, 1985, and May 27, 1987, COMPLEX has commented on the mission plans and the strawman and selected instrument payloads for the CRAF mission, and evaluated these plans and instrumental capabilities in the light of results from investigation of Comet Halley. The present report again reviews the CRAF mission, this time in the context of the combined CRAF/Cassini initiative. It also contains our first assessment of the agency's mission strategy and strawman payload for Cassini, at a time prior to the issuance of the Announcement of Opportunity for Cassini instrument selection, now scheduled for December 1989, and instrument confirmation, anticipated in March 1991. This report does not review the CRAF and Cassini missions in the broader context of NASA's overall priorities.

ASSESSMENT SUMMARY

The committee has not revised its earlier positive assessment of the overall ability of the CRAF mission as currently designed to implement the COMPLEX strategy

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for exploration of comets and reconnaissance of asteroids. In the discussion that follows we address a number of specific points, including progress in CRAF instrument development, the prime and backup cometary targets, and changes in spacecraft capabilities resulting from commonality in the Mariner Mark II design that now supports both the CRAF and the Cassini components of the combined program.

The committee finds that the science planning for the Cassini mission is proceeding within the guidelines recommended by COMPLEX in its 1986 strategy for the next phase of outer planet exploration. The strawman science instrument payload and the preliminary mission profile are fully responsive, within the defined scope of the mission, to the first priority of that strategy, a balanced multidisciplinary investigation of the Saturnian planet-ring-magnetosphere-satellite system. Within this balance, there is appropriate emphasis on Titan. Only in the area of detailed characterization of Saturn's atmosphere, which lies beyond the scope of Cassini, does the mission fail to address the primary science objectives set out by the committee. We note that advantage of the opportunity for primitive body reconnaissance has been taken by the inclusion of flyby measurements on at least one asteroid in the current mission plan.

In the view of COMPLEX, the current status of Cassini as a joint NASA-ESA venture is one of its major strengths. European fabrication of the Titan probe and sponsorship of central scientific instruments and teams represent an unprecedented and effective international sharing of the science payload, data analysis, mission operation, and fiscal responsibilities of a planetary exploration mission.

In the body of this report, we comment specifically on certain aspects of Cassini science planning, and emphasize that attainment of mission objectives ultimately depends on adequate support for development of capable science instruments. A later assessment will readdress these issues, and deal in more detail with the objectives and capabilities of the selected instruments in the context of the measurement requirements recommended in the COMPLEX strategy report.

COMET RENDEZVOUS-ASTEROID FLYBY (CRAF)

A detailed summary of the rationale and goals of the COMPLEX strategy for primitive body exploration, the specific comet and asteroid science objectives identified by the committee, and the types and precision of measurements required to implement these objectives, is given in our earlier letter reports on the CRAF mission and will not be repeated here. In this assessment of the mission, the committee reiterates its perception that the baseline objectives and measurement capabilities of the selected science instrument payload are both congruent with the prioritized scientific objectives recommended by COMPLEX for in situ comet exploration and asteroid reconnaissance, and responsive to the specific measurement requirements established by the committee to meet these objectives.

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We have previously focused some specific attention on two of the payload instruments, the penetrator and the scanning electron microscope and particle analyzer (SEMPA), both of which represent high-order advances in flight instrument concept and design, sampling and measurement strategy, and analytic techniques. Neither of these instruments has flight inheritance, and for these reasons they were regarded as involving a relatively high degree of risk in fulfilling primary mission science objectives. This concern has been addressed in part, as expressed in our May 1987 letter report, by the identification of appropriate backup capabilities in other instruments for characterizing solid materials in or from the cometary nucleus.

The committee is pleased to note the following developments since its last review of the CRAF mission:

The penetrator experiment. COMPLEX recognizes the unique ability of the penetrator instruments to address in situ the highest priority science objective identified in its strategy report, namely determination of the dust and volatile composition, state, and physical properties of the nucleus. For this reason we endorsed continued development of this experiment in our 1985 and 1987 letter reports, while cautioning that substantial development work remained to be performed during the accommodation study to demonstrate the reliability of penetrator deployment and instrument function. We are informed that specific tests have now been carried out to demonstrate the ability of the penetrator to implant successfully in a range of materials representative of cometary nucleus models, and that the project has switched from a solid to a liquid fueled penetrator rocket to allow adjustment of penetration velocity based on assessment of nucleus material properties derived by remote sensing from the main spacecraft. Additional tests show that the gamma-ray spectrometer crystal can withstand the penetration acceleration. In view of these results we extend our endorsement of penetrator development for the mission. We are also informed that the project is building a second penetrator for inclusion in the payload if spacecraft mass and performance margins permit. The advantages of a second unit are evident, both as a fully competent backup in the event of penetration or instrument failure in the first deployment and as a means to assess the heterogeneity of the nucleus if both are successful.

Scanning electron microscope and particle analyzer (SEMPA). The committee's perceptions of this instrument and of the penetrator have been similar. Both are technologically advanced, sophisticated, untested by flight experience, and in concept uniquely capable of satisfying primary cometary science objectives, in SEMPA's case the detailed chemical, mineralogic, and morphologic characterization of individual cometary dust particles emitted from the nucleus. We have endorsed the effort to develop SEMPA and to demonstrate its viability in the spacecraft and cometary environments during accommodation study, and are encouraged to learn that an engineering/research prototype of the flight instrument has been constructed and is operating successfully in the laboratory.

Target comets and asteroids. Adoption of the CRAF/Cassini plan and the current

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schedule for the CRAF mission have necessitated a change in target comet from P/Tempel 2 to P/Wild 2. In addition, several backup flight opportunities have been identified, involving both P/Wild 2 and P/Kopff as potential targets. We have previously commented (May 1985) on the suitability of P/Wild 2 for comet investigations. From available data, the properties of both P/Wild 2 and P/Kopff appear to be appropriate for achieving the scientific objectives of the CRAF mission. The identified asteroid encounter for the prime mission, with Eunomia—the largest S-type object in the belt, with unusual metal-rich and metal-poor surface exposures according to Earth-based observation—appears admirably suited for asteroid reconnaissance studies. It is our understanding that planned flyby measurements include imaging at 165-m/pixel resolution, IR spectral mapping and thermal mapping, and mass and density determinations. Although the full suite of COMPLEX science objectives for asteroid exploration can be satisfied only by multiple rendezvous missions, these measurements are in accord with objectives for the reconnaissance phase.

Mariner Mark II spacecraft. We note that the only major engineering changes in the previously planned CRAF mission resulting from the cRAF/Cassini combination are in the area of spacecraft capabilities, and that they are very positive changes for CRAF. Enhancements to the CRAF spacecraft resulting from commonality of spacecraft design for CRAF and Cassini include addition of a second RTG, doubling the power originally available at aphelion, and use of a larger Voyager-class antenna in place of the smaller Viking-orbiter antenna. Resulting increases in power and data rate will provide markedly superior measurement capabilities during the initial reconnaissance, rendezvous, and penetrator deployment phases of the mission. The committee wishes to commend the efforts of the engineering development team in implementing a Mariner Mark II design philosophy of high inheritance, judicious use of new technology, standardization, and modular design, which we may expect will minimize both cost and risk without compromising mission science objectives.

TITAN PROBE-SATURN ORBITER (Cassini)

Recommendations of the COMPLEX Strategy Report

In its 1986 report *A Strategy for Exploration of the Outer Planets: 1986-1996,* COMPLEX has identified the highest priority for outer planet exploration within this period to be the intensive study of Saturn—the planet, satellites, rings, and magnetosphere—as a system. Major science objectives, unprioritized by the committee, are exploration and intensive study of *Titan's atmosphere* and surface and of *Saturn's atmosphere, rings, small satellites, and magnetosphere.* Specific objectives for Titan include measurement of the composition, structure, and circulation of the atmosphere, and characterization of atmosphere-surface interactions; and reconnaissance of the physical properties and geographic variability of the surface (solid or liquid, rough or smooth), with emphasis given to any information needed ot guide the design of a lander vehicle. Specific objectives for the Saturn system include determination of atmospheric elemental composition, dynamics, and cloud composition and structure, to a level well below the H_2O cloud base; measurement of ring particle composition and variety, spatial distribution of ring particles, and the evolution of dynamic structures; comparative determinations of satellite surface compositions, densities, geologic histories, and geomorphological processes; and specification of magnetospheric structure, dynamics, and processes, and of the mutual interactions of the magnetosphere with Saturn's atmosphere, rings, icy satellites, Titan, and the solar wind.

The committee's preferred strategy was to implement most of these major objectives in a single mission that would comprehensively address the top priority of intensive, multidisciplinary study of the Saturn system and the interrelationships among its individual phenomena. For missions of lesser scope—a category that includes Cassini since it does not carry the probe required to address the first-order objectives of Saturn atmosphere investigations—COMPLEX emphasized that the interrelated nature of the system must be kept in mind in defining mission objectives, and that the first such mission should include a reconnaissance of Titan's surface for guidance of future exploration as well as for its scientific importance.

Assessment of the Cassini Mission

The committee's preliminary assessment, based on expected Mariner Mark II design and performance characteristics, the proposed mission profile, and the objectives and measurement capabilities of the strawman science payload instruments on both the Titan probe and the orbiter, is that the Cassini mission as currently planned (1) reflects well the intrinsically high degree of importance, excitement, and potential for major scientific return associated with the opportunity to explore the Saturn system, and (2) is responsive to most of the specific COMPLEX science objectives and to the necessity for a balanced approach, across the broad range of multidisciplinary phenomena offered by the individual components of the system, in meeting these objectives. The only primary objective set out by COMPLEX that is not implemented by Cassini is detailed in situ investigation of the composition, structure, and dynamics of Saturn's atmosphere and clouds by an instrumented probe; we note, however, that remote atmospheric investigations are effectively addressed by planned payload instruments, for example by the capability of a new (non-Voyager) microwave radiometer to enable studies of ammonia distribution and atmospheric temperatures near the ammonia cloud level. Opportunities for satellite science measurements during the currently planned 4-year orbital tour appear excellent: some 30-40 passes of Titan within 3000 km, and encounters with most satellites close enough to enable achieving primary magnetospheric and ring science objectives by careful planning of the orbital tour. Titan atmosphere objectives appear to be well addressed by current plans for probe instrumentation and deployment. Specific comments relating to current planning for asteroid science, Titan surface science, ring and plasma investigations, and the science instrument payload are given below.

Asteroid science. We are pleased to note that the prime Cassini mission plan includes encounter prior to Earth flyby with 66 Maja, a 39-km C-type asteroid, in keeping with the policy of the planetary exploration program to construct flight profiles of outer solar system mission that enable close flybys of asteroids for reconnaissance measurements. The project is encouraged to continue its efforts to identify other possible encounter opportunities on the Earth-Saturn outbound leg of the mission.

Titan surface science. COMPLEX was informed of the project's plans to conduct surface science experiments on Titan in the event the probe survives landing. With the exception of the possible addition of a 3-axis accelerometer package to measure impact signature and assess surface properties, the current surface science plan utilizes instruments already on the prove for atmospheric measurements during descent, and is therefore achievable with minimal incremental cost. The planned surface investigations—mass spectrometer and gas chromatograph analyses of surface material, in addition to the accelerometer measurements—could provide much more definitive information on surface composition than that inferred from orbiter or probe-descent measurements. such investigations exceed the 1986 report requirements for remote reconnaissance of the surface from the orbiter or descending probe, and anticipate lander studies envisioned for an advanced post-Cassini phase of exploration. Consequently, we endorse the project's plan for surface measurements of this nature, but on an opportunistic basis (i.e., if the probe survives, and if surface materials are successfully introduced into the GC/MS and analyzed during the at most 15 minutes of available post-landing communication with the orbiter). At this time CoMPLEX does not advocate major modifications to the probe to ensure survival, nor addition of instruments beyond the accelerometer package specifically to do surface science. Probe survival in its present design appears sufficiently likely, and its instrument complement sufficiently competent, to carry out the project's present surface science plan with some reasonable chance of success.

Ring and plasma studies. The committee finds that the objectives for ring science will be effectively addressed by the strawman payload on the Cassini orbiter, with substantial improvements over Voyager capabilities. Major direct contributions will come from imaging, near and mid-far IR spectrometers, the UV imaging spectrometer, the microwave radiometer/spectrometer, and the high-speed photometer. Auxiliary but important ring-related data will be provided by the dust analyzer and plasma instruments, and perhaps by the Titan radar.

The time period around Saturn orbit insertion provides a unique opportunity to achieve important science objectives that will not recur later in the mission profile as currently designed. The committee recognizes that the primary mission responsibility at this time is the successful execution of the orbit insertion maneuver, and that spacecraft configuration and power resource allocation must be dictated by this priority. We recommend, however, that the mission plan include science observations to the maximum extent feasible during the time when the spacecraft is inside 2.3 Saturn radii, particularly on magnetic field ring and plasma measurements may prove to be possible. Ideally these would include imaging the F, A, and B rings at resolutions that may approach 100 m, spectroscopic measurements at otherwise unattainable spatial resolutions, and in situ measurements of the plasma and the ring atmosphere. Also worthy of consideration, although probably more difficult to implement, would be radar observations of the rings using the Titan imaging radar and/or sounder. The period of time around orbital insertion is also the most favorable for measurements of the cosmic-ray albedo neutron environment and the atomic hydrogen ring atmosphere. It additionally provides the only possible opportunity to study the plasma environment of the main rings, which bears on mechanisms for spoke formation and has implications for Saturn's ionosphere. The ring plane crossings also represent a unique opportunity to study dust and plasma populations and electrostatic plasma waves that are known to be localized near the ring plane.

Science instruments. The selected instrument complement for CRAF and the strawman payload for Cassini are comprehensive and well balanced, and can be expected to implement the science objectives for both missions as set out in the relevant COMPLEX exploration strategies. The committee urges that appropriate levels of funding be made available to support development of these science instruments for flight. We emphasize that our scientific assessments of both missions are predicated, in the final analysis, on the actual availability of the instruments and associated measurement capabilities upon which those assessments have been based.

Please feel free to contact the committee with any questions you may have regarding this report, or for further discussion.