Terrestrial Planet Finder: Technology Development Plans and Progress

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Abstract— One of humanity's oldest questions is whether life exists elsewhere in the universe. The Terrestrial Planet Finder (TPF) mission will survey stars in our stellar neighborhood to search for planets and perform spectroscopic measurements to identify potential biomarkers in their atmospheres. TPF is currently planned for launch around 2015.

Two major classes of mission have been identified as likely to meet the TPF goals: Visible-light Coronagraphs, and Infrared Interferometers. Within the interferometer class are options for using separated spacecraft or a connected structure. TPF is now in the midst of an intensive period of technology development, design study, and scientific investigation to make a selection in 2006 for Phase A development. Substantial funding has been committed for development in these three areas, with the largest portion going to support demonstration of key technologies. Efforts underway through industry and university contracts and at JPL include a number of system and subsystem testbeds, as well as devices and numerical modeling capabilities. The science, technology, and design efforts are all closely coupled to ensure that requirements and capabilities will be consistent and meet the science goals.

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1. INTRODUCTION

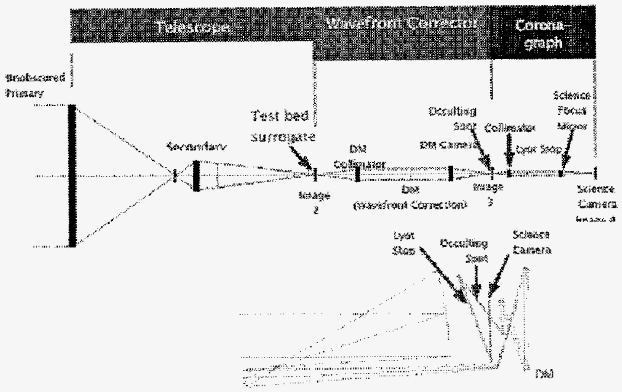
The Terrestrial Planet Finder is among the most ambitious science missions ever proposed by NASA. TPF will search for earthlike planets around a statistically significant number of stars in our stellar neighborhood and characterize the atmospheres of detected planets to determine if they are capable of supporting life as we understand it. Subsequent missions, such as Life Finder and Planet Imager, will further refine our knowledge of extrasolar planetary systems.

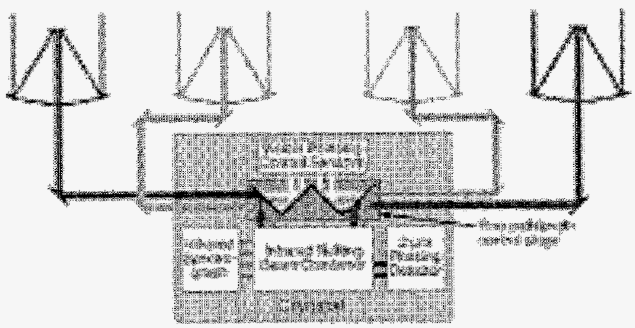
The basic problem of TPF is to separate the light of a planet from the light of the star that it orbits. In the infrared portion of the spectrum, the star is ~10^6 times brighter than the planet's emitted radiation, and in the visible portion of the spectrum the star is ~10^9 times brighter than the reflected light of the planet. The situation is further complicated by the proximity of the planet to the star—given that the planet is likely to be on the order of 1 AU from its parent star, the angular separation will be very small—on the order of 0.1 arcsecond. Looking only at the required contrast, the problem looks substantially more tractable in the infrared than the visible. When one includes additional complications such as exozodiacal light and the need for larger apertures or interferometer baselines at long wavelengths, the choice is much less obvious. The TPF project is in the process of determining the best approach to developing a space mission to meet the science requirements.

Infrared vs. Visible

Science studies [1] have determined that there are suitable biomarkers in both the visible (0.7 μm to 1.0 μm) and infrared (8.5 μm to 20 μm) portions of the electromagnetic spectrum, and that technical feasibility should be used to determine the best approach to the mission development. JPL commissioned a set of mission studies in 2000 to explore and refine the trade space for possible mission designs. Four teams, led by Ball Aerospace, Lockheed Martin, Boeing, and Northrop Grumman and composed of scientists, technologists, and engineers from academia and industry each explored the possible trade space of missions capable of performing the TPF science. Two major classes of mission were identified in these studies as feasible for the TPF mission[2]: Visible-light coronagraphs and Infrared Interferometers. The IR interferometers are further separated into subclasses of structurally connected interferometers and separated spacecraft interferometers.

A visible light coronagraph would be based on a high-perfomance optical telescope, with a diameter, or at least one semi-major axis, of 4 to 8 meters, depending on ultimate capabilities of the downstream optics. The coronagraphic instrument would use some combination of masks and stops to control diffracted light so as to block out the light of the star and allow the light of the planet, at close angular separation, through the system. Because the system is very





sensitive to scattered light, a high precision deformable mirror is also required. A schematic of this type of system is shown in **Figure 1a.**

Figure 1. a) Schematic of a coronagraphic system. b) Schematic of an interferometer system.

An infrared interferometer would be based on a small number (4 to 6) of moderate sized (2 to 4 meter) infrared telescopes, with the entire optical system cooled to less than about 40 K. To obtain the angular resolution required to distinguish a planet from the central star, the telescopes would be arranged to create optical baselines of 30 to 70 meters, with longer baselines offering higher angular resolution. The positions of the telescopes could be maintained either with a large deployable structure or by mounting each of the telescopes on its own spacecraft. The interferometer would then combine the light from the telescopes in such a way that the on-axis light from the star is cancelled, and the light from the nearby planet is transmitted to the focal plane. A schematic of a nulling interferometer is shown in **Figure 1b.**

Both the visible-light coronagraphs and the IR interferometers are challenging missions to build with currently available technology. Using results from the various studies that have been done, the TPF project at JPL has identified the key technologies that are required for each of the architectures and embarked on an intensive technology development program to demonstrate by the end of 2006 sufficient capability to implement one or more of the mission concepts for launch around 2015.

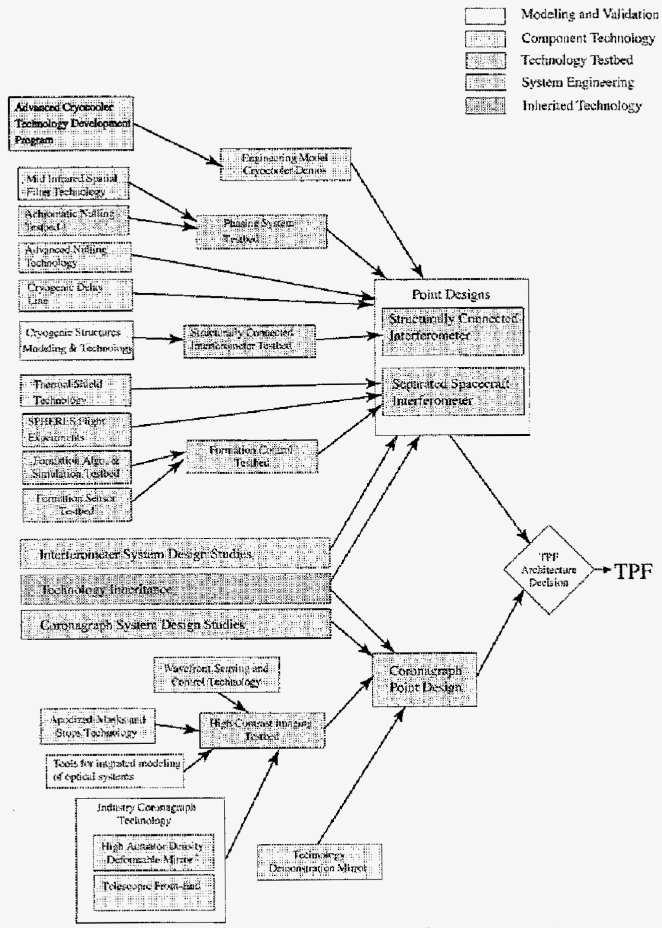


Figure 2. TPF Technology Roadmap.

2. TECHNOLOGY DEVELOPMENT APPROACH

The TPF project is taking an approach that keeps the science goals, mission design, and technology development closely coupled throughout the technology development period [3]. Science requirements were generated from inputs from a number of sources, including the TPF Science Working Group (SWG), prior industry studies, JPL studies, the inputs of multiple review panels, and newly published science results. These inputs, including technology development recommendations, were used to identify technology needs for the TPF architectures under study. Performance requirements for the technologies were determined from the industry/academia architecture studies and additional subsequent study efforts. The science requirements are being further refined through regular meetings of the TPF SWG, leading to further refinements of the system design concepts and the resulting technology requirements.

The project is organized into competing teams for the interferometer and coronagraph that will develop the two concepts in parallel. The architecture development teams are each composed of mission design and technology development teams. The mission design teams develop and improve the mission designs to determine performance requirements and technology needs, and also perform trades and design changes based on inputs from the technology development teams. The technology development teams work to reduce mission risk by identifying key technologies for further development to meet mission needs, and then arranging to develop those technologies through a combination of JPL, NASA, and subcontracted industry and university efforts. Throughout the development program, the design and technology teams are closely coupled to ensure that the system designs are consistent with the available technologies.

The process described above led to the technology roadmap, shown in Figure [Roadmap] and the published technology plan [3]. The technology roadmap shows the relationships between the various development tasks, and how they integrate with the design studies to lead to at least one technically feasible design by 2006. The technology plan provides a full description of the requirements for each technology and the approach for achieving it. The technology plan was reviewed by the Navigator program independent review team (IRT), which reports to NASA HQ, prior to publication. The plan will be updated annually, with a new edition released each spring.

Tracking Technology Development Progress

For each technology development task within the TPF project, a set of objective milestones and performance targets has been developed. The milestones represent specific work to be accomplished, but do not include technical performance levels. The performance goals are quantitative estimates of the level of performance that is expected to be achieved with the corresponding milestone. Each of the key technologies is planned to be developed to TRL~5 by late 2006. Progress against the plan is tracked in monthly management reviews, and checked at least annually by an external technology review panel.

Industry and University Involvement

The TPF project is maintaining close involvement with universities and industry by incorporating them into the various teams. Each of the design teams has members from both industry and academia with expertise in areas that are relevant to the system and instrument designs. The technology development efforts include several major component and testbeds that are being done under subcontract to industry and industry/university teams, as well as a number of smaller system and component development efforts that are being done primarily at universities. Among the larger efforts are the Technology Development Mirror, the Structurally Connected Interferometer Testbed, and the Telescope Front End. The individual component efforts include coronagraphic mask and stop development, deformable mirror development, and high performance modeling software.

The entire technology development and system design program is connected as shown in figure [tech roadmap]. Each of the technology efforts feeds into other technology advances or testbeds, and ultimately into the system designs. Each task has a set of annual milestones and performance goals that are reviewed periodically to ensure that they remain closely tied to the mission development as science requirements and mission concepts are refined.

Technology Inheritance

One of the keys to a successful technology development program is recognition of other sources of of technology development, whether it directly meets the technology need, provides a lower level of capability that can be enhanced with small additional investments, or provides a general knowledge and experience base that can be exploited to avoid repeating earlier basic research and development. Much of this inheritance comes in through the expertise of experienced engineers who have done prior related work, such as wavefront sensing and control, or ground-based interferometer development, but because there is such a range of potential sources for technology, TPF has made an effort to explicitly identify and catalog sources of technology inheritance. Some examples of planned inheritance from within the Origins program are wavefront sensing and large cryogenic sunshields from JWST, as well as collaborative development of cryocoolers with JWST, and Constellation-X. The formation flying technology program also derives substantial heritage from the former StarLight formation flying interferometer mission.

Technology Legacy

In addition to providing technologies to enable TPF, the TPF technology development program also considers the technology legacy that will be left by TPF. TPF is only the first of what will likely be a series of missions to detect and characterize extrasolar planets that may be capable of supporting life. Subsequent missions will require even higher spatial and spectral resolution, which leads to much larger collecting areas spread over much larger baselines or telescope diameters. In selecting technologies for development for TPF, the project seeks to ensure that the developments can be further extended to support these follow on missions.

3. Conclusions

The TPF project is in a period of intensive technology development in anticipation of an architecture selection in late 2006. The technology development program is closely coupled to the science requirements and the system design activities to ensure that the technology developments are consistent with the system and science requirements, and will lead to the development of at least one viable mission concept to enter into Phase A around 2007. Further information, including current versions of the TPF Technology plan and Science Roadmap, is available in the library section of the TPF website [4].

ACKNOWLEDGEMENT

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BIOGRAPHY

Chris Lindensmith *is the Terrestrial Planet Finder Project Technologist. Prior to this he was the lead system engineer on TPF during the development of earlier mission concepts leading to the present two. He started at JPL in 1996, working on development of cryogenic technologies, including magnetostrictive actuators. Since then he has supported development of missions and instruments, including the Planck mission, the JWST mid-IR instrument, and a next generation microwave limb sounder. He also led the development and demonstration of 6 K sorption cryocoolers at JPL. He has a Ph.D. in physics from the University of Minnesota, where he did research on the nucleation of quantized vortices in superfluid helium, and a BS in physics from the University of Michigan. In between his BS and PhD, he spent two years at American Superconductor, in Cambridge, MA working on the early development of high-temperature superconducting wire.*