Space Interferometry Mission Reliability Modeling

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ABSTRACT

The Space Interferometry Mission, part of NASA's Origins Program, uses a 10m-baseline space-based optical Michelson interferometer to measure the positions of stars to an accuracy of 4 μas (about a billionth of a degree of angle). With this two order of magnitude improvement in accuracy over current capability, one can infer the orbital characteristics of planets down to about three earth masses circling nearby stars. Using astrometry — measurement of star positions — SIM will perform a wide range of scientific observations. SIM will directly measure the distance to any star in our galaxy to an accuracy of 10% by using triangulation from opposite points in its orbit around the sun (that is, by parallax). These measurements will improve the calibration of several other astronomical distance estimators, extending their range of applicability much further. Proper motion measurements of many stars throughout the galaxy will tell us the rotation rate as a function of distance from the galactic center. In turn, these measurements will allow us to infer the mass distribution within the galaxy. Using SIM, we will improve our understanding of stellar and galactic dynamics tremendously. SIM is slated for launch in 2009.

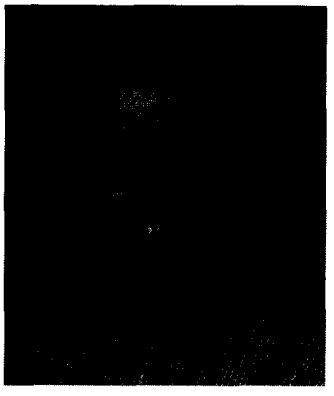
SIM faces many incredible technological challenges. For instance, SIM uses a laser metrology system to measure displacements of optical elements with sub-angstrom precision. The diameter of a hydrogen atom is about one angstrom. SIM measures the phase of optical fringes to about $1/10{,}000^{th}$ of a wavelength of visible light. Some components in SIM's error budget are allocated less than 20 picometers. A picometer (1 pm = 10^{-12} m) is one hundredth of an angstrom. To meet these challenges, SIM is developing many new technologies. Overall mission success depends on many interacting factors, and reliability is a major consideration.

Although SIM is still in the conceptual design phase, we have developed some high-level (i.e. coarse) reliability models to help guide the configuration development for SIM. The complex geometry of SIM (particularly the logical connectivity of the three-dimensional metrology truss) does not lend itself to the use of commercially available reliability modeling tools. Therefore, we developed a Monte Carlo modeling approach using Microsoft Excel, but which can be applied to more conventional configurations quite easily. This tool was applied to several competing SIM configurations and the results were used in the selection process. For two cases, closed-form probability relations were also developed. The results of these analytic solutions agreed well with the predictions using the Monte Carlo approach. The agreement effectively confirmed both methods. (Strictly speaking, both models could have been wrong and still agreed, but the approaches used were so different that this is very unlikely.) The closed-form approach was quite complex and it is difficult to imagine extending it. On the other hand, having confirmed the basic approach, one could easily include greater detail in the Excel model. It is also easier to develop new Excel models when the SIM configuration changes drastically, as it has tended to do over the past several years.

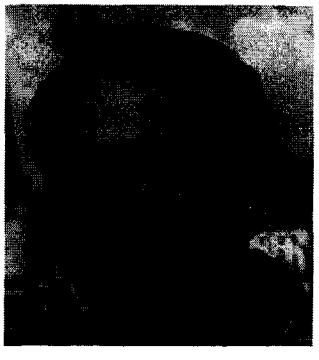
The presentation will provide an overview of SIM, followed by brief descriptions of both the closed-form solution and the Excel modeling approach. A comparison of predictions using both approaches will be shown.

A 30 minute time slot is requested (and was agreed to by Noel Hinners by telephone).

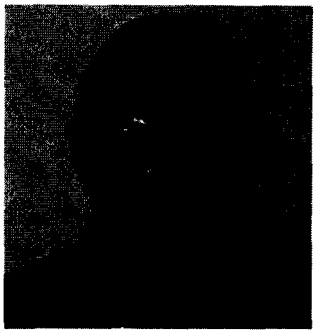
BIOGRAPHIES



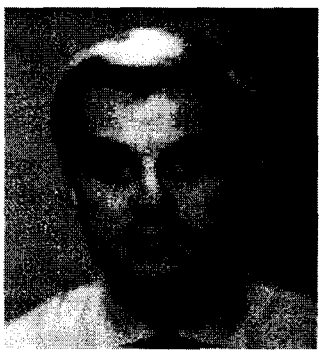
Kim Aaron has worked on the SIM project for almost six years and is now the SIM Flight System Architect. In this role, he is responsible for the overall configuration of the SIM Flight System, which involves many different areas. He has become involved in understanding various reliability aspects and how they affect the configuration of the SIM Flight System in order to assure the eventual success of the mission. During his 17-year tenure at JPL, he has been involved in the conceptual design phase of about thirty different space missions. On a recent project, he designed and flight-qualified a vibration isolation system to operate at 2 kelvin for a superfluid helium experiment. Earlier, he was responsible for hardware design, fabrication and assembly of portions of the Rocky 4 microrover, predecessor to the Mars Pathfinder Sojourner rover. He developed probabilistic models for the response of the Galileo and Cassini spacecraft to various hypothetical failure scenarios. Early in his career at JPL, he developed nozzles to inject artificial rain into a wind tunnel while matching the drop size distribution observed in natural rain. In 1985, he graduated from Caltech with a Master of Science and PhD in Aeronautics. He earned a Bachelor of Engineering degree in Honors Mechanical Engineering from McGill University in Montreal, Canada in 1979.



Don Ebbeler is an analyst at JPL. He has been involved in the modeling and analysis of both the engineering reliability and economic aspects of solar energy, war-gaming, cost prediction, aerospace propulsion, electro-optical, structural, mechanical, chemical and advanced automobile air bag systems and, for SIM, the optical interferometer system designs. Before coming to JPL in 1980 he worked as an aerospace research engineer for General Motors, served as an assistant and associate professor of economics at Georgia Tech, Claremont Graduate School and Iowa, and as an economist at Southern California Edison. He was on the editorial board of the Journal of Macroeconomics from 1977 - 2002. He graduated from Purdue University in 1970 with an MS and PhD in Economics. In 1964 he earned a BS in Electrical Engineering in the R&D option, with concentrations in physics and mathematics, and in 1965 earned an MS in Electrical Engineering, specializing in statistical communication theory with a concentration in statistics, both from Purdue University.



George Fox: Engineers used slide rules when George entered Caltech as a Freshman in 1965. After certification as a Quantum Mechanic & Micro Economist (Caltech PhD, Applied Physics and Economics, 1979) George joined JPL to determine the value of solar cell power for the national PV solar energy program. When Ronald Reagan killed the program George changed sides, doing military acquisition policy analysis & war-gaming modeling for the highly successful JESS, validated during the Gulf War. As an original developer of the Space Station System Design Tradeoff Model and an analyst for JPL's Project Design Center, George failed in educating NASA about cost performance tradeoffs. He currently does reliability modeling of complex systems (SIM, NEPTUNE) for hire and is entering the quagmire of cost-risk modeling to convince management that it can be done without (irrelevant) historical data and (inappropriate) regression models.



W. John Walker received the B.Sc. degree in Electrical and Electronic Engineering from Queen's University, Belfast, Northern Ireland in 1980 and the M.S. degree in Aeronautics and Astronautics from MIT in 1990.

His previous employers include GEC Marconi in Scotland and Litton Guidance & Control in California.

Since 1990, he has been a technical staff member at the Jet Propulsion Laboratory in Pasadena, California, and has contributed to the design and integration of attitude control hardware for the Cassini Mission to Saturn, Deep Space 1 and Europa Orbiter spacecraft.

He is currently involved with the development of real-time control systems for the Space Interferometry Mission.