Satellite Test of the Equivalence Principle STEP

Final Technical Report

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Paul Worden
Stanford University
Stanford, CA 94305-4085

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Final Report on Grant NAGW-2793
Satellite Test of the Equivalence Principle-STEP

This grant provided support for the STEP (Satellite Test of the Equivalence Principle) program between October 1991 and September 1993. STEP, previously supported by NASA under Grant NAG8-837 "A Satellite Test of the Equivalence Principle", was selected by the European Space Agency for a Phase A Study as a candidate for ESA's next medium size mission (M2). STEP was conceived as a joint NASA/ESA mission with equal participation by both agencies. ESA's contribution to the program would be the spacecraft; NASA would provide the launcher and half of the instrument, while the other half of the instrument would be provided by various European agencies.

STEP was in competition with three other programs, INTEGRAL, PRISMA, and MARSNET. The Phase A study, which was conducted jointly by NASA and ESA, began in January 1992, and was conducted by ESTEC in Holland. There were six STEP Study Team meetings held at different locations in Europe and the United States, and two scientific conferences were held on STEP. There were also numerous meetings of the five subgroups on Hardware, Theory, and the Geodesy, Aeronomy, and Gravitational Constant Co-Experiments. During the period of the study the Stanford team participated in all of the Study Team meetings, and organized or attended the meetings of the Hardware subgroup, which were held near the Study team meetings to minimize travel.

Scientific collaborators included representatives from ONERA (Office National d'Etudes et de Recherches Aerospatiales) and BIPM (Bureau International des Poids et Mesures) in Paris; The University of Strathclyde, University of Birmingham, Imperial College, the Rutherford Appleton Laboratory, and the Mullard Space Science Laboratory in Great Britain; the University of Delft, in Holland; the Universita degli Studi dell'Aquila, the University of Pisa, and the Istituto di Astrofisica Spaziale in Italy; the Paul Scherrer Institute in Switzerland, the University of Maryland, and Montana State University in the United States, and many others.

The final selection of a single mission for M2 took place in April 1993. STEP was not selected for M2 but made a very close second. The program is continuing in modified form.

Work performed under this grant was divided between production of necessary documentation for the Phase A study, coordination of experiment design with European prepare the documentation. Our research and technical activity at Stanford during this period was almost entirely planning and paper studies, since we were constrained by the effort required for the Phase A study. Subjects studied included topics related to the technical and scientific issues of the STEP program, such as the helium tide, particle radiation effects, drag-free and attitude control performance, and the like. We were aided in the payload design by a study performed by Lockheed Corporation on the STEP dewar and thermal environment, assisted by some Lockheed internal funding.

Documentation produced for the Phase A study included major portions of the ESA Phase A study report (Appendix 1, the "Red Report"), and a number of other study documents including baseline and final design reports, payload requirements, and interface requirements documents. Published papers on STEP and related topics, which originated under this grant, are listed in the bibliography, Appendix 2.

The *Report on the Phase A Study* (red report) gives a reasonably detailed description of the STEP program. The STEP satellite designed in the Phase A study was a very complex one. It included five co-experiments in addition to independent American and European versions of the basic Equivalence Principle experiment: These were the Gravitational Constant, $1/R^2$ dependence of Gravity, Spin Coupling, Geodesy, and Aeronomy co-experiments. STEP was to be launched in 2002 for a total cost of nearly $500 million.

In summary, the Satellite Test of the Equivalence Principle (STEP) was one of four finalists in the selection of ESA's M2 mission during 1989-1993. Although STEP was not selected for M2, it was very highly rated and is a candidate for the M3 mission. If selected for M3, STEP would be launched in 2005 for (presumably) about the same cost.

Appendix 2
Publications Under this Grant

STEP Report on the Phase A Study (European Space Agency, document SCI(93)4, March 1993)

P. Worden, M. Bye,``The Stanford Equivalence Principle Experiment'', Proceedings of the STEP Symposium, Pisa, Italy, April 1993

Torii, R. H. "Gravitational Disturbance due to the Tidal Motion of Helium", Proceedings of the STEP Symposium, Pisa Italy, April 6-8 1993

Torii, R. H. , Worden, P.W. Jr., "Superfluid Helium in an Annular Free-Falling Vessel", Proceedings of the STEP Symposium, Pisa Italy, April 6-8 1993

Mason, P. V. et. al., "Technical Challenges of Satellite Test of the Equivalence Principle Mission", *Cryogenics*, Vol 33, #4 (1993)

STEP Cryogenic Payload Interface Requirements Document (NASA 2-008) Ref. WBS 3.6.1, 3.6.3, 3.6.4

STEP...An International Collaboration in Fundamental Physics ("STEP brochure" Ed. Monica Jarnot, Stanford, 1993)