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GRAVITY PROBE B PAYLOAD VERIFICATION AND TEST PROGRAM

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ABSTRACT

Most of the Flight Payload hardware for the Gravity Probe B Relativity Mission is currently being manufactured. The design, fabrication, and integration of this hardware has already been subjected to an extensive program of full scale prototyping and testing in order to provide maximum assurance that the payload will meet all requirements. Full scale prototyping is considered to be a crucial aspect of the payload development because of the complexity of the payload, the stringency of its requirements, and the necessity for integration of a warm cryostat probe into a dewar maintained at liquid helium temperature. This latter requirement is derived from the fact that the dewar contains a superconducting ultralow magnetic field shield which provides an ambient magnetic field environment for the probe of < 10 pT (0.1 μG)

INTRODUCTION

The Gravity Probe B (GP-B) Relativity Mission will provide a controlled test of Einstein's General Theory of Relativity by making observations of the precession of nearly perfect gyroscopes in Earth orbit with respect to the line of sight to a guide star. A discussion of the mission objectives and the experiment design can be found in the accompanying paper by Turneaure *et al.* (this volume) as well as in Everitt, *et al.* (1993).

The experiment design is based on a London moment readout of the gyro spin direction. This approach requires that the ambient magnetic field at the gyros be low enough to limit the trapped flux density in the gyro rotors to ≤ 0.1 nT (1 μG). This requirement is necessary because the trapped flux will be detected by the SQUID-based readout at the rotor spin frequency (Muhlfelder, this volume) and, if too large, can interfere with accurate readout of the London moment. In order to meet this requirement, a superconducting Pb-foil shield (T_c = 7.2 K) is installed in the central well of the dewar and provides an ambient field of ≤ 10 pT (0.1 μG) in the region of the gyros. (See Taber *et al.*, 1994, for a description of the shield installation process and Parmley, 1996 for a description of the GP-B Science Mission Dewar.) In addition, extreme care is taken in the selection of materials and screening of components used in the probe and the Science Instrument Assembly (SIA, the integrated assembly which includes the telescope, gyroscopes, and the readout subsystems) in order to insure that the remanent fields of these components do not exceed our requirements.

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The existence of the superconducting shield in the dewar has significant consequences for the probe-dewar integration process. In particular, the probe and the components of the SIA (~ 40 kg mass) must be cooled by insertion into the cold dewar while the superconducting shield is kept below its transition temperature by continuous immersion in liquid helium. This in turn means that the integration process must be carried out via a purged airlock with a sliding piston seal in order to avoid convective mixing of the helium vapor with atmospheric gases and the formation of frozen air inside the dewar well. A large-scale integration of this sort is unique to GP-B. The portion of the probe that is inserted in the dewar is approximately 0.25 m dia. by 2.5 m long; the airlock is 1.5 m dia. by 3.4 m long.

Once the probe is fully inserted into the dewar, the integration process is completed by operating a set of three deployable dogging mechanisms in the dewar which engage the probe below the neck region and clamp the probe into the dewar well. This process also causes spring mechanisms located at heat stations on the probe neck to engage the dewar vent-gas heat exchangers. The result of this is to mechanically and thermally couple the probe to the dewar. Once the dogging has been completed, the residual liquid helium in the dewar well is depleted, the well is evacuated, and the helium in the main tank pumped to 1.8 K.

GP-B INTEGRATED SYSTEM TEST PROGRAM

In addition to the challenges associated with the probe-dewar integration process and the achievement of low trapped flux in the gyro rotors, there are numerous other challenges at the payload-system level. Some of these include: 1) spinning up and operating multiple gyros, 2) meeting vacuum and thermal performance specifications, 3) verifying compatibility of the gyro electrostatic suspension system and the SQUID readout, 4) achieving reliability of a large number of mechanical, electrical, and optical components (many of them made of fused silica) subjected to thermal cycling and vibration, 5) meeting the ac magnetic shielding requirement, and 6) verifying adequate immunity to external electromagnetic interference. Given the number and complexity of these challenges, we adopted the process of "incremental prototyping" in conjunction with a series of full-scale system tests (Turneaure *et al.*, this volume).

The GP-B integrated-test program has evolved into a series of five tests utilizing three cryostat probes and two dewars. This program and the major hardware subsystems are summarized in Table 1. It should be noted that the first dewar (Engineering Development Dewar) and the first probe (Probe-A) were full-scale development systems that did not have full functionality but were accurately prototypical with regard to the probe-dewar interface. They were primarily intended to assist in resolution of many of the challenges noted above, particularly the integration issues. Probe-B was constructed as a potential flight spare (after refurbishment) and the Science Mission Dewar (SMD) together with Probe-C will constitute the flight payload.

CURRENT STATUS OF THE INTEGRATED SYSTEM TEST PROGRAM

The third of the five full-scale tests, Ground Test Unit 1 (GTU-1), was completed in November 1995 and involved the test of Probe-B in the EDD. The tests completed to date have been not only useful in helping to resolve anticipated issues, but also in raising some unanticipated ones. The designs of all the major subsystems and our integration and operations procedures have been significantly improved as a result. Some examples of the lessons that have been learned and the issues that have been resolved as a result of our system tests to date are presented in Table 2.

The next full-scale system test, GTU-2, is scheduled to start in January 1997. GTU-2 is noteworthy for several reasons: 1) it will be the first integrated-system test using the Science Mission Dewar (with Probe-B); 2) the SMD will allow operation in the horizontal orientation which will be useful for testing of multiple gyros to high spin speed and for some thermal tests; and 3) all subsystems will be fully functional with the exception of the telescope. This will be the last full-scale test before integration and test of the actual flight payload.

Table 1. Key Hardware Subsystems and Test Objectives in the GP-B Integrated System Test Program

TEST	DEWAR	PROBE	SCIENCE INSTRUMENT ASSEMBLY (SIA)	KEY FEATURES / OBJECTIVES
FIST	ENGINEERING DEVELOPMENT DEWAR (EDD): • *Prototypical interface to probe* • *Non-flight design with less liquid helium capacity & lifetime* • *1 μT ambient magnetic field in well*	PROBE-A: • *No cryopump* • *Cabling and spinup plumbing for 2 gyroscopes* • *Metal radiation baffles instead of windows*	• *Quartz block #1* • *Two gyroscopes* • *One rf SQUID per gyro readout* • *SQUID Magnetometer* • *No telescope*	• *Warm probe-dewar integration* • *Verification of interfaces and integration procedures & hardware* • *Measurement of spin-up gas flow pressure drops and vacuum performance* • *Verification of multiple gyroscope compatibility*
GTU-0	EDD • ~ *Ultralow field (10 pT, 0.1 μG) ambient field in well*	PROBE-A: • *Prototype windows instead of metal baffles*	• *Same as FIST + one dc SQUID readout*	• *Installation of ultralow magnetic field shield* • *Verification of probe insertion procedure while maintaining lead shield in its superconducting state* • *Operation of gyro(s) in ultralow magnetic field with low trapped flux* • *Verification of subatmospheric LHe transfer equipment and procedure*
GTU-1	EDD • *Unmodified from GTU-0* • *Flight lead shield retainer*	PROBE-B: • *Flight spare unit* • *Support for full SIA* • *Sintered Ti cryopump*	• *Quartz block #1 with four gyros* • *Full complement of dc SQUIDs* • *Telescope mass model* • *No caging*	• *Vacuum performance with cryopump* • *Achieve ≤ 0.1 nT trapped dipole in gyro rotor* • *Test of fully coupled dc SQUID readout* • *EMI test*
(Probe-B Shake Test)	–	PROBE-B: • *In shake fixture at room temperature*	• *Same as GTU-1 + gyro caging*	• *Mode identification* • *Verification of design and workmanship (protoqual level)*
GTU-2	SCIENCE MISSION DEWAR (SMD)	PROBE-B	• *Full functionality except:* •*Telescope mass model or partially functional telescope*	• *Verification of payload integration and test procedures using SMD* • *Full functional test of all subsystems (SIA, probe, and dewar)*
Payload	SMD	PROBE-C	• *Full functionality*	• *Full Payload functional test*

Table 2. Examples of Lessons Learned and Issues Resolved from Completed Payload System Tests

ISSUE	COMMENTS
Integration of probe into dewar while maintaining ultralow field in dewar well	Demonstrated in GTU-0 after two full-scale integration rehearsal tests
Achievement of 0.1 pT (1 μG) uniform field equivalent trapped flux in gyro rotor	Demonstrated in GTU-1 for one gyro; need to improve reproducibility and demonstrate with multiple gyros
Operation of all four gyros with nominal performance	Demonstrated in GTU-1
Achievement of Science Mission readout noise performance with fully coupled SQUID	Demonstrated in GTU-1
Achievement of $< 10^{-9}$ Pa (10^{-11} torr) vacuum in probe after low temperature bakeout	Unable to achieve in GTU-0, but was demonstrated in GTU-1 (to a level of 2×10^{-11} Pa) after addition of sintered Ti cryopump
Need to improve immunity to internal and external EMI	Deficiencies identified in GTU-0,-1; fixes to be tested in GTU-2

CONCLUSIONS

The GP-B program is in the process of fabricating and, in some cases, testing flight hardware for the Relativity Mission. The design, fabrication and integration of this hardware have been supported by an incremental prototyping process involving a sequence of four full-scale payload-level tests. Three of these tests have been completed and the fourth is scheduled for January of 1997. The lessons that have been learned and the heritage that has been acquired as a result of these tests give us substantial confidence in the success of the flight payload verification tests due to start in 1998.

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