LOCKHEED MARTIN

Gravity Probe B Relativity Mission

Risk Assessment of Most Critical GP-B Mission Failure Modes

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This document was originally submitted in accordance with (and as part of) DRD 802PA-08.

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Revision History

Rev	Release Date	Status and Changes
A	29 July 1998	Initial Draft generated following first GP-B review meeting.
B	17 December 1999	Minor changes to text – no assessments have been changed. A summary table has been inserted into Section 2.0.
C	27 January 2000	Failure mode list and assessments have been updated to take into account DR's since mid-1998. The distinction between "primary" and "secondary" failure modes has been removed. Analysis procedures are outdated and have been removed (this includes Section 5.0, which has also been deleted).

1.0 Introduction

As part of the FMECA submissions intended to satisfy Data Requirements Description (DRD) number 802PA-08, "Failure Modes and Effects Analysis and Critical Items List," the following risk assessment of the ten most critical failure modes for the GP-B Relativity Mission is presented. For these ten failure modes, a detailed analysis of the uncertainty in the operating environment is compared to the uncertainty in the performance of the relevant GP-B equipment to assess the likelihood of failure due to the design margins being insufficient. This is not meant to comprehensively measure the reliability of the GP-B Relativity Mission. Instead, it is meant to demonstrate that GP-B has adequate design margins for the failure modes considered most threatening to the GP-B Relativity Mission.

Rather than selecting exactly ten failure modes, a larger list of failure modes of significant concern has been developed and has been successively revised as mitigating steps are implemented and as new information has become available. The latest list incorporates GP-B discrepancy reports (DR's) since the last major revision of this list (in mid-1998), and it has been given a separate document number (S 0408, Rev. C).

2.0 Summary of Ranked Failure Modes

The following table summarizes, in rank order, the 16 GP-B failure modes identified in more detail in Section 3.0.

FM Rank	System	Failure Mode	Source
1	SIA – Gyro	gyro contamination/particulates	design, rework
2	Gyro Suspension System	forward electronics/electrodes	design, DR 279
3	SIA – Gyro Readout	SQUID readout broken	design, **DR 278**
4	Payload	caging/spinup leaks	design, DR 216/272/ 285/288/293/295/297
5	SIA – Science Telescope	hardware bonds fail	design
6	SIA – Gyro	excessive trapped flux	**DR 283**, rework
7	SIA – Science Telescope	sunshade fails closed	design
8	Spacecraft	CCCA	design
9	Spacecraft	SSR box	design
10	Spacecraft	ACE box	design
11	Mission Operations	software or controller error	design
12	Spacecraft	solar array/ARP deployment	design
13	Spacecraft	attitude control thrusters	design
14	SIA – Probe-C	anomalous cryopump temp.	**DR 282**, rework
15	Spacecraft	mass trim mechanism	design
16	Spacecraft	Transponder/telemetry	design

Note: DR's of "major" severity are indicated in **boldface.**

3.0 Details of the Top Sixteen GP-B Failure Modes

(in approximate order of decreasing risk)

1.) *SIA – Gyro*: Entry of particulates or other contaminants into the gyro housing, leading to damage to one or more gyros, has always been a primary concern (see DR's 293 and 297, which may have been caused by impure spinup gas). This risk has been increased by the need to recycle the probe, which introduces another opportunity for particle contamination to occur.

Mitigation Steps: Careful contamination controls for original probe assembly and for rework have been implemented, and the subsequent Probe-C room-temperature and low-temperature testing should verify that contamination has been kept to acceptable levels. Additional steps will be taken to insure that the caging and spinup gas is free from impurities. For more details, see risk items 15 and 16 of the document titled "GP-B Recycle Risk Mitigation," Document S 0355 Rev. B, 7 January 2000.

Responsible Person: Sasha Buchman

2.) *Gyro Suspension System*: Failure of the single-string electronic parts in the forward GSS assembly, including analog arbiter, voltage amplifiers, and position bridge, which could lead to a gyro crash (see DR 279).

Mitigation Steps: Stringent qualification tests have been implemented on all forward GSS components. The apparent insulation failure reported in DR 279 does not pose a significant increase in mission risk.

Responsible Persons: Bill Bencze, Rob Brumley

3.) *SIA – Gyro Readout*: Open failure (including poor or intermittent connections, as has apparently happened to gyro #4 – see **DR 278**) or short circuit in SQUID readout connections.

Mitigation Steps: The SQUID loop in gyro #4 will be repaired during the upcoming probe recycle, although the remaining redundancy provided by the other three gyros makes it feasible to launch without repair. For more details, see risk items 17 and 27 of "GP-B Recycle Risk Mitigation," Document S 0355 Rev. B, 7 January 2000.

Responsible Person: Barry Muhlfelder

4.) *Payload*: Leaks in the caging and spinup gas lines and/or RAV's, leading to unacceptable loss of helium or failure of the caging or spinup systems (see DR's 216, 272, 285, 288, 293, 295, and 297).

Mitigation Steps: New gas relief valves will be added to all caging system lines before the probe removal procedure, and leaking valves will be replaced. Contingency plans are being developed to address the risk of continuing leaks. For more details, see Appendix B of "GP-B Recycle Risk Mitigation," Document S 0355 Rev. B, 7 January 2000.

Responsible Persons: John Turneaure, Sasha Buchman

5.) *SIA – Science Telescope*: Mounting-to-baseplate, image-divider-assembly, and detector/preamplifier assembly bond failures.

Mitigation Steps: Telescope qualification and acceptance procedures have been designed to verify the adequacy of these bonds with reasonable strength margin.

Responsible Person: John Turneaure

6.) *SIA – Gyro*: Excessive trapped flux (exceeding the requirement of 3 μGauss maximum) leading to degradation of science measurements (see **DR 283**).

Mitigation Steps: The trapped-flux anomaly reported in **DR 283** will be corrected during the upcoming probe recycle. Recent analysis has confirmed that sufficient margin exists to meet the science measurement accuracy requirements under trapped flux levels significantly higher than 3 μGauss. For more details, see the presentation in Section 3.2 of the Independent Assessment Review package titled "Trapped Flux Level in Gyro #1" and risk item 3 of "GP-B Recycle Risk Mitigation," Document S 0355 Rev. B, 7 January 2000.

Responsible Person: Sasha Buchman

7.) *SIA – Science Telescope*: On-orbit telescope sunshade/shutter fails closed or fails open during Earth passage

Mitigation Steps: The shutter is designed such that a spring will hold it open unless power is applied to keep it closed; thus failing closed is very unlikely. The mechanism to apply power to close the shutter is redundant, and remaining open during Earth passage does not produce unacceptable thermal loads. For more details, see LMMS/P480211, 20 April 1999.

Responsible Person: Hugh Dougherty

8.) *Spacecraft*: R6000 computer processor failure in CCCA (internally redundant; SRI reliability estimate ≅ 0.99).

Mitigation Steps: The CCCA failure risk has been reduced by limiting duty cycling during storage (prior to launch), and extensive vehicle testing should be sufficient to detect any problems. For more details, see LMMS/P480211, 20 April 1999.

Responsible Person: Hugh Dougherty

9.) *Spacecraft*: Solid State Recorder (SSR) box failure (internally redundant; vendor reliability analysis gives 18-month reliability ~ 0.993)

Mitigation Steps: In the event of complete SSR failure, it may be feasibile to provide a backup data conduit to minimize the loss of science data received by the ground station. LMMS testing should be sufficient to detect any problems.

Responsible Person: Hugh Dougherty

10.) *Spacecraft*: Attitude Control Electronics (ACE) box failure (internally redundant; vendor reliability analysis gives 18-month reliability ~ 0.988)

Mitigation Steps: The vendor reliability assessment appears conservative. ACE box and ATC system testing should be sufficient to detect any problems.

Responsible Person: Hugh Dougherty

11.) *Mission Operations*: Software error or faulty commands leading to mission loss.

Mitigation Steps: An extensive set of safeguards and contingencies has been developed and integrated into the mission operations procedures to protect against software errors and to ensure that all commands uplinked from the ground are verified beforehand.

Responsible Person: Gaylord Green

12.) *Spacecraft*: Solar Array or ARP deployment failure (each mechanism is redundant, but all must deploy)

Mitigation Steps: In addition to being redundant, all release and deployment mechanisms used on GP-B are heritage units that have been extensively tested on older spacecraft and have sufficient margins against the loads expected on GP-B. For more details, see LMMS/P480211, 20 April 1999.

Responsible Person: Hugh Dougherty

13.) *Spacecraft*: Thruster failures leading to loss of attitude control (with redundancy, reliability estimated at > 0.996 for each of four clusters).

Mitigation Steps: The LMMS thruster qualification and acceptance tests should be sufficient to detect any significant problems.

Responsible Person: Hugh Dougherty

14.) *SIA – Probe-C*: Anomalous temperatures within Probe-C leading to reduction of dewar helium lifetime and potential degradation of science measurements (see **DR 282**).

Mitigation Steps: The cryopump-and-window reported in **DR 282** will be corrected during the upcoming probe recycle. For more details, see risk item 26 and Appendix B of "GP-B Recycle Risk Mitigation," Document S 0355 Rev. B, 7 January 2000.

Responsible Person: Sasha Buchman

15.) *Spacecraft*: Mass trim failures leading to loss of CG control (all 3 axes are redundant and have estimated reliabilities > 0.997)

Mitigation Steps: The risk of failure of units that pass ground tests is small. The LMMS mass trim qualification and acceptance tests should be sufficient to detect any problems existing prior to launch.

Responsible Person: Hugh Dougherty

16.) *Spacecraft*: Transponder or telemetry failure (redundant units on both; reliability estimates > 0.998)

Mitigation Steps: The risk of failure of units that pass ground tests is small. LMMS CTU qualification and acceptance tests should be sufficient to detect any problems existing prior to launch.

Responsible Person: Hugh Dougherty