APPENDIX F
Burst Disk Testing Report Excerpt

National Aeronautics and
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Reply to Attn of: EA3-09-030

TO: AMS Records

FROM: EA3/NASA AMS Project Manager

SUBJECT: AMS Burst Disk Vent Duct Redesign and Certification

On July 9, the Alpha Magnetic Spectrometer (AMS) Collaboration Magnet design team experienced a failure of the AMS Superfluid Helium Tank Burst Disk duct system. Over the next three months, the collaboration in conjunction with the AMS Project Office at JSC went through an extensive redesign and recertification process. This letter summarizes the results of this extensive effort. This letter is an attempt to provide closeout verification documentation for Safety Data Package verification items as well as Acceptance Data Package verification items.

A design change effort began soon after the test failure. The test report from the failed test can be found in Enclosure 1 of this letter. Once a new design concept was developed, the AMS Project Office requested a meeting with the Payload Safety Review Panel (PSRP). That meeting was held on August 13. The minutes from that meeting can be found in Enclosure 2. At that meeting, a series of eight certification tests were outlined. The following is a summary of the results of those tests. Although an eight-test certification approach was accepted by the PSRP, the AMS team actually performed more than eight tests. The team learned something new in just about every test, and based on the test results, several changes were made in the final flight design as well as in the test setups and procedures. The final design is shown in the following figures :

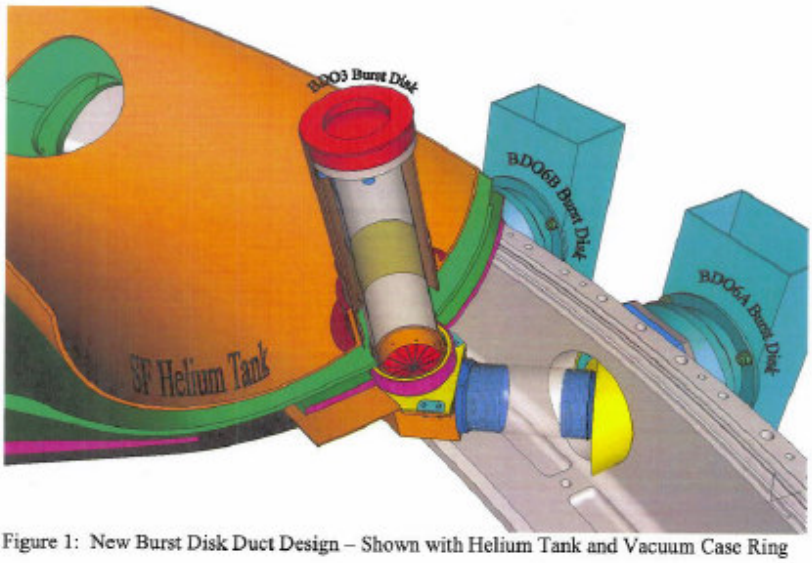

Figure 1: New Burst Disk Duct Design – Shown with Helium Tank and Vacuum Case Ring

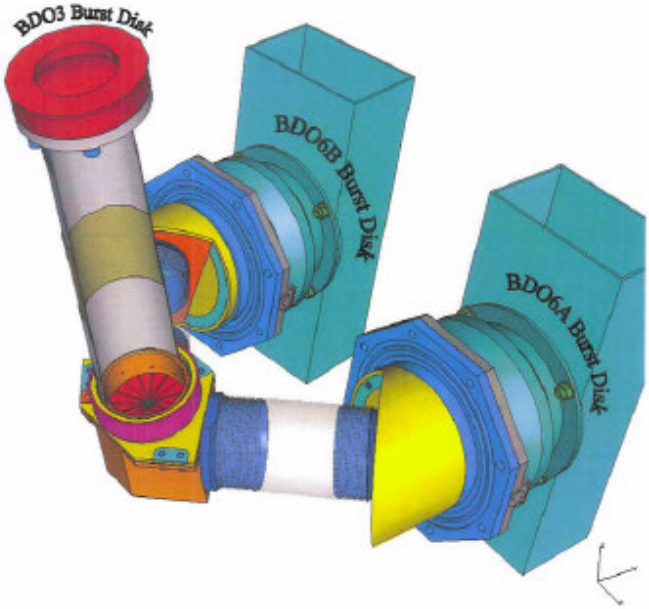

Figure 2: New Burst Disk Duct Design – Duct Only

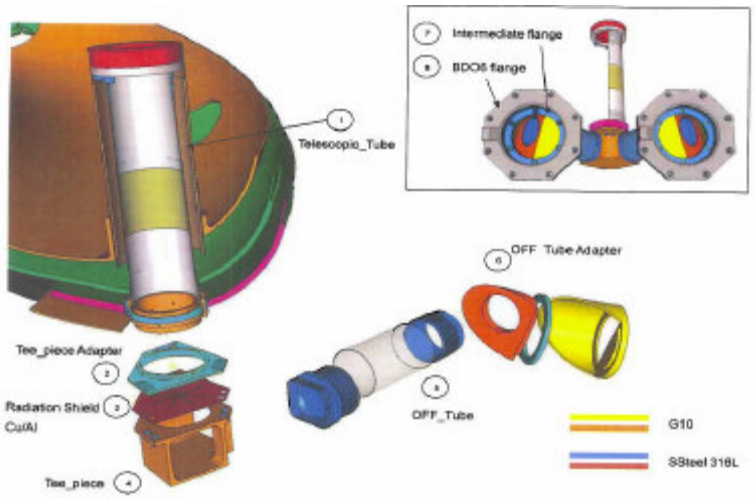

Figure 3: Cut away showing materials

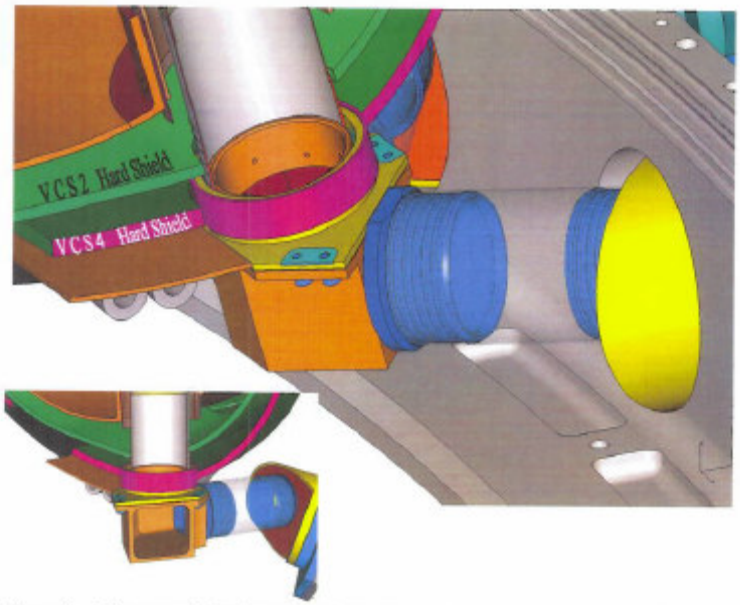

Figure 4: Close up of Tee-Box including cut-away

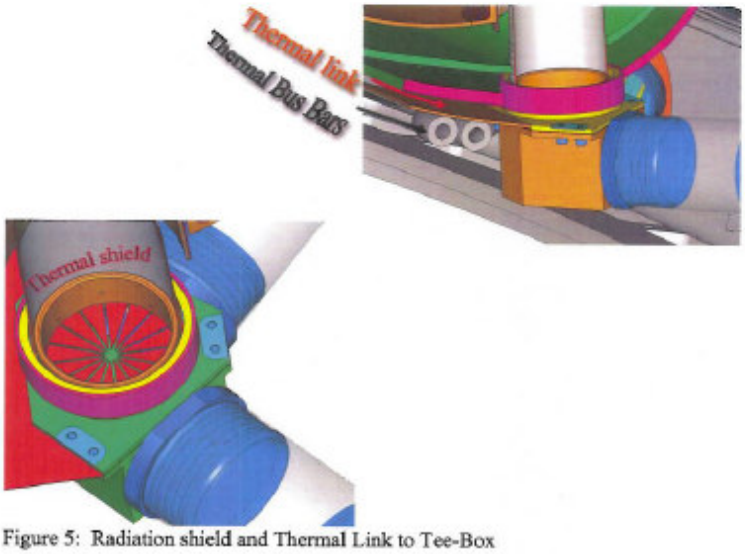

Figure 5: Radiation shield and Thermal Link to Tee-Box

1. The first tests were on the Telescoping Tube of the new design. The telescoping tube was subjected to two static tests. The first was done at room temperature and the tube held together up to 24 bar. A subsequent static test was performed with the burst disk in a liquid nitrogen bath. The tube was submerged in an LN2 Styrofoam dewar and connected to a gaseous helium supply and then pressurized. The pressure rose from 1 to 30 bar in 13 seconds. The last part of the test went from 30 bar to 36 bar in 2 seconds. At 36 bar, the end cap used for pressure testing blew off, but the tube had not failed. In fact, the tube never failed. This gave the team adequate confidence in the telescoping tube design to proceed.

2. The second major portion of the new design presented to the PSRP in August was a stainless steel bellows. The second test was done on August 12 on the 72 mm (Outside Diameter) (OD) / 52 mm Inside Diameter Stainless Steel (ID SS) Bellows in a LN2 bath. The video of the test indicates the Bellows began to yield around 3-4 bar, became unstable around 5-7 bar, and failed at 9.3 bar. The Bellows also failed in a way that it blocked the BD03 to BD06A & B flow path. The failure and its mode were not unexpected since edge-welded bellows like these are normally used in vacuum service and are not pressurized without an "anti-squirm" sleeve; typically a SS wire braid. Unfortunately, the extremely tight space and flexibility requirement in the system over a relatively short length does not allow for a sleeve. Based on this test, it became obvious that some new system would be required for this portion of the duct.

3. The team then started testing the Ortho-fabric Flexible Tube in a LN2 bath on August 14. Ortho-fabric is a Kevlar Nomex weave material used in the Space Suits. This material is very porous so it requires some sort of bladder to retain the helium gas while the Ortho-fabric provides the structural support. The third test indicated the Flexible Tube reached ~14 bar before the bladder and test fixture developed an unsustainable leak. There appeared to be no detrimental effects on the tube or its stitching which remained flexible even at ~77 K. The test setup used ~10 meters of 6 mm OD tube so there was quite a large pressure drop from the helium supply to the test article. The pressure was read from a gauge located just upstream and near the Flexible Tube. Thus, judging by the audible callouts in the video and the gauge visible in the video, the pressure in the tube was likely a bar or so lower due to the leak in the bladder. This test showed the team that the Ortho-fabric Flexible Tube configuration was extremely promising.

4. The fourth test using the same Ortho-fabric Flexible Tube was done on August 15th using a similar bladder with different assembly techniques. The bladder failed again at an indicated pressure of 19.7 bar while the Ortho-fabric remained flexible and intact.

5. The fifth test was conducted on the same Flexible Tube immediately after the bladder failed above. The flow was increased significantly in an effort to fail the Ortho-fabric Flexible Tube. The indicated pressure reached ~24 bar before the cloud caused by the rapidly dispersing LN2 obscured the view from the video cameras. The actual pressure probably only reached ~20 bar for the same reasons cited in #3 above. The Ortho-fabric *still* would not fail.

6. The team then reconfigured the setup to read the pressure directly on the tube by drilling and tapping the other end of the test fixture. This placed the local pressure gauge at the opposite end of the He supply line – and downstream of any leaks in the Flexible Tube bladder. The team utilized ~0.005" thick teflon sheet. Unfortunately, it was only enough to go around ~1½ times inside the Ortho-fabric – so the overlap was poor and the team suspected this would lead to an even larger leak. The test proved this assumption to be accurate. This created more nitrogen clouds during testing. However, the team did get some readings from brief glimpses between the clouds. Even with the much larger leak in this test, the pressure in the tube still reached ~15 bar as read on the gauge downstream of the leak when the gauge at the supply cylinder read ~30 bar. Judging from the call-outs at higher pressures while the gauge was obscured, the configuration reached in excess of ~20 bar again – still without failing the Flexible Tube. Post-test examination indicated the teflon sheet was very wrinkled at installation and was even folded under one of the test fixture hose clamps. This contributed to the excessive leakage. This test proved that a seamless tube without wrinkles and holes was clearly needed.

Based on the Ortho-fabric Flexible Tube tests, the team agreed that it appeared to have the strength to meet the pressure requirements while remaining flexible at 77 K. Even after installing it ~10 times (it took multiple attempts on some occasions), clamping it four times at each end with 9 mm wide hose clamps, thermal cycling it three times, and pressure cycling it four times, there are minimal signs of abrasion, wear, or fraying.

7. At this point, the testing shifted from Center European Research Nuclear (CERN) to Texas A&M where a large test chamber had been built and readied for the next round of full system tests. Numerous burst disks were ordered or retrieved from storage. Numerous Cryogmagnet Ground Support Equipment (CGSE) burst disks were used during preliminary tests. Test #4 (Enclosure 5) was conducted with all CGSE disks at room temp and warm gas pressurization: September 6th. All three disks opened properly but the pressurization rate was well below the target. The flight pressurization rate is based on analysis of the maximum expected heat load from a complete vacuum failure driving the pressure in the Superfluid Helium Tank.

8. Test #5 (Enclosure 6) was conducted with all CGSE disks with LHe and warm gas pressurization: September 11. The CGSE BD03 disk simulator reversed at the proper pressure but did not open. The pressurization rate was still ~53% below the target of 6.2 psi/second. The test hardware reached 100+ psig because it was provided with a helium gas supply that had no means of turning it off. Then it reached 100+ psig due to self-pressurization of the liquid helium. Post test evaluation eventually determined that the most likely cause of the burst disk failure to open was a faulty burst disk.

9. Test #6 (Enclosure 7) with flight-like BD03 and one BD07A/B (B disk removed; no BD06B) and warm gas pressurization: September 18. Both disks opened properly and the pressurization rate was 6.17 psi/second – within 0.3% of the target. However, it was determined that this over-tested the hardware. This is because at the time the burst disk opens, essentially the test setup was adding pressure via the test system, and also adding pressure due to the increase of the pressure in the vacuum space. The team decided to pressurize via loss of vacuum through a 0.5" orifice. Analysis showed that a 0.5" orifice is equivalent to a complete loss of vacuum on the flight system.

10. It was determined that since the test configuration was being changed to a loss of vacuum test, the next test should be performed with CGSE burst disks instead of flight burst disks to make sure that the test setup was accurate. Test #7A (Enclosure 8) with CGSE disks with LHe and self-pressurization from loss of vacuum: September 25. All disks opened properly and testing data was much closer to expected results.

11. Once the team had proven that the test setup was correct, Test #7B (Enclosure 9) was performed with a flight-like BD03 and one BD07A/B (B disk removed), one flight-like BD06 and self-pressurization from loss of vacuum: September 29. All disks opened properly and testing data looked very good. During this test, the team intentionally sabotaged the test by putting a burst disk membrane that was torn free in the original failed test in July into the flow path. The team also made the assumption that one of the BD06 burst disks fails to open; this was accomplished by removing one of the disks and replacing it with a cover.

12. PSRP representatives were invited to the final test, which was a complete replica of the flight system from the helium tank burst disk to the zero thrust vents. Test #8 (Enclosure 10) was performed with flight-like BD03 and two flight-like BD06a and self-pressurization from a simulated complete loss of vacuum: October 5. All disks opened properly and testing data looked very good.

During the testing process, the flight duct system was built identical to the final test configuration and installed in the flight magnet. This testing should give everyone the confidence that should there be a complete loss of vacuum on the AMS magnet, the system will vent safely without over-pressurizing the AMS Superfluid Helium tank or the AMS Vacuum Case.

Trent D. Martin
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Enclosure 1: Test report from July 9, 2009 – Failure of original design
Enclosure 2: PSRP meeting minutes from August 13, 2009
Enclosure 3: Cryogenic Testing of the Telescoping Tube
Enclosure 4: Final Flight Configuration of Ortho-Fabric Flexible Tube
Enclosure 5: BD Test #4 Report
Enclosure 6: BD Test #5 Report
Enclosure 7: BD Test #6 Report
Enclosure 8: BD Test #7A Report
Enclosure 9: BD Test #7B Report
Enclosure 10: BD Test #8 Report
Enclosure 11: Analysis of Complete Loss of Vacuum