Minutes of SPIRE CQM BDA Kevlar Failure Non-Conformance Review Board

1 October 2007

Present:

At RAL: UK Project Team:		Matt Griffin, Eric Sawyer, Doug Griffin, Eric Clark, Pete Hargrave
	ESA:	Carsten Scharmberg, Chris Jewell (from item 6)
At JPL:		Ulf Israelsson, Jamie Bock, Marty Herman, Jim Newell, Mark Weilert

Contents

1. Objectives of the review

The objectives circulated before the review were agreed:

1. Assess the cause of failure of the CQM BDA Kevlar support
2. Identify all relevant differences between that unit and the FM and FS BDAs
   - design, manufacturing or assembly processes and procedures
   - operational history (thermal cycles, vibration tests, etc.)
3. Assess any relevant information on the mechanical behaviour of systems with a similar design (e.g., BDA units used in other projects; the development of the 300-mK thermal strap supports for SPIRE)
4. Assess the possible impact on SPIRE and/or Herschel scientific performance of a similar failure of an FM BDA
5. Assess the risk of such a failure pre-launch or during/after launch
6. Identify the options, if any, to remove or mitigate such risk
7. Identify any special requirements/recommendations for testing or other activities at system level

2. Document list

The document set for the review was as follows

1	Document list, Objectives and Agenda
2	Herschel-Planck/SPIRE CQM BDA Kevlar Failure Report, Mark Weilert (JPL D-40353, Revision B, 28 September, 2007)
3	NCR Report Failure of KEVLAR Tension Cord on CQM PLW detector (HR-SP-RAL-NCR-172v3, Sept. 27 2007)
4	CQM Thermal Strap Kevlar Failure Documentation • SPIRE - 300mK strap supports – PFM EIDP, Peter Hargrave (14 October 2007) • Inspection Report: STM/CQM Photometer Light Baffle Assembly, Peter Hargrave (8 May 2003) • Cardiff Components Vibration Qualification Report, RAL SST Dept.

The documents are attached as Annexes 1 - 4.

3. Run-through of the JPL report

Mark Weilert summarised the key points from his report using a PowerPoint presentation (attached as Annex 5). All material in the presentation is in the report.

- Comments and points made during Mark's presentation.
- The CQM unit had been inspected carefully after known fraying; bottom braid had been in good shape at that stage
- Marty: Note that CQM was designated as non-flight.
- Slide 3: Note solid touch of 300-mK assembly to 2-K stage is apparent.
- Slide 4: Pete: Kevlar looks like it comes off at a slight angle, so looks like its in strong contact with the hex face.
- Slide 5: The kind of abrasion that's seen here is not very apparent until the Kevlar is removed
- Slide 6: Green areas correspond to Kevlar fluorescence signature
- Kevlar broke very close to where it came of the hex face
- Slides 8/9: CQM vs. other units
  - Key hardware differences

    - Pulley design changed for qual. and all subsequent units - polished everywhere the Kevlar touches (barrel and hex face) and rounded on the hex face
    - Kevlar routing changed on the QM and flight BDAs – but on the top braid only
    - The other changes noted on Slide 9 are probably not relevant to this failure
- Slide 10: Mass table – failed BDA has high 300-mK mass, but not especially so
- Slide 11:
  - CQM BDA vibration exposure
    - Comparable to Qual unit but less than flight units
  - All flight units had similar vibration exposure at JPL; less at RAL (noting that S/C vibration to come)
  - Qual unit is roughly as old as CQM, has had many more thermal cycles, been stored for long period at room temperature, with no problems.
  - Bakeout:
    - The CQM did not have a vacuum bakeout – discussions to whether this might affect its mechanical properties
      - Not likely to have an influence on this kind of failure.
      - Mark: It did have some bakeout in dry nitrogen atmosphere.
- Slide 12: Polished and unpolished pulleys.
  - Polishing was finished carefully by hand; included rounding off of all corners and edges at the hex face
- Slide 14: UV-illuminated pictures of Kevlar residue after 30-minutes vibration
  - Significantly better for the polished pulley
  - No residue on hex face in either case as Kevlar was not touching it
- Slide 15: Shake to failure of unpolished pulley
  - Failure at the pulley after 7.7 minutes at max level
  - Qualitatively looks like the broken Kevlar on the CQM
- Slide 16: Shake to failure of unpolished pulley
  - Failure at highest level after 36 minutes
  - Broke not at pulley but at bottom tie-off – looks like a more localised break than the distributed fraying seen on the CQM and on the 300-mK strap support system
- Slides 17 and 18:
  - More Kevlar residue on the unpolished pulley
  - Residue looks "continuous" rather than fibrous – maybe cold welding or heating effects associated with change in structure of the Kevlar as it sticks
- Slide 20: Conclusions
  - Failure was due to abrasion at unpolished pulley
  - Has been addressed already in flight standard BDAs
  - A small risk of similar failure on FM or FS
- Section 4 of report
  - Failure would likely make SPIRE inoperable
  - Not likely to cause a problem with the other instruments
- Slide 21: Risk mitigation
  - Root cause already addressed
  - Exact circumstances of the failure are not known, but careful handling and transport are advised
  - Avoid high humidity and temperature where possible

- Speculation
  - Very little unwrapping of the Kevlar around the pulley when it was first seen
  - Over the course of next few days it appeared to unwrap a bit more
  - This would imply that it broke late in the process of transportation from ESTEC – RAL
- FM BDAs have not been inspected since PFM-4 integration

4. CQM thermal strap failure

In May 2003, a similar Kevlar failure occurred during vibration testing of the SPIRE Structural-Thermal Model (STM). The relevant documents are contained in Annex 3. A brief summary of key points was given by Pete:

- Inspection report
  - Partial failure of a Kevlar cord – led to overall extension of the Kevlar suspension and loss of alignment
  - Page 7, Figure 8:
    - Shows poor machining quality on the guide holes
    - One and a half of the three bundles broken
    - Figure 9 shows a similar phenomenon happening to another braid at the machining edge
    - Marty question: What was pre-tension?
    - Pete will check (but load is lower than for BDAs)
  - Figure 10
    - Fretting at the other end, but no evidence of cutting – holes were much smoother
    - Figures 11 and 12: Design shape for guide holes and as manufactured with flat top leading to sharp edge
- MRB minutes (Page 50 of EIDP in Annex 3)
  - Agreed on failure mode and redesign
  - Sharp edge acts as initial point at which fraying can occur and effect is cumulative
    - Re-routing Kevlar for larger bend radius + careful polishing to get rid of machining marks
    - See photos on pp. 63, 64
    - Pete regards the polishing as more important in addressing the problem
- For the 300-mK strap development, it was found that although parallel strand Kevlar was better mechanically, braided Kevlar was used as it is easier to handle.

5. Flight standard BDAs environmental history

PowerPoint summary by Eric Sawyer (Annex 6)

- Cool-down rates at RAL: max rate of change is about 15/5 K hr^{-1} for spectrometer/photometer
- Warm-up rates: much slower
- At CSL:
  - Strictly controlled rate < 5 K hr^{-1} to avoid stressing other parts of the instrument
  - Rate inside the instrument even slower
- STM cooldown information: still need that from Chris Jewell
- Slide 5: Transport
  - Lowest level shock monitor is 15 g for flight instrument-level transport (always warm)
  - None have tripped
  - Spacecraft level
    - Plan is for cold transport with continuous shock monitoring
    - Carsten: level for the STM-2 transport (with the CQM inside) level was always < 0.5 g
    - Transport from ESTEC to FN (06.03.2007)
    - 141 hrs duration
    - OBA was at ~130 K at the start and 292 K on arrival
    - So there was nothing unusual or potentially problematic about the transport from a vibration or thermal point of view
- Slide 6: Humidity control
  - Pump-down of the flight cryostat is planned for late October

- Vacuum bakeout for 48 hrs (adhering to the 5-K per hour limit)
    - Bake-out temperature will be limited to 60^{o} C at the instruments; bakeout will be under vibrationally quiescent conditions (the procedure is described in ASED-TP-0070_Issue 1 23 May 2007)
    - Warm Functional Test (WFT) before bakeout
    - SPIRE desire for a WFT after bakeout is noted by ESA
- Only one cooldown is planned for the Herschel cryostat

6. Discussion

- Impact on SPIRE and/or Herschel scientific performance of a similar failure of an FM BDA
    - Such a failure would most probably result in a strong thermal contact between the 300-mK level and the 2-K level. This would lead to a large thermal load on the cooler making it inoperable or drastically reducing the hold time. This should therefore be regarded as a single-point failure for the SPIRE instrument.
    - The risk to the other instruments is very low. Some small particles of debris may be released, but would be confined inside the SPIRE FPU.
- Risk of such a failure pre-launch or during/after launch
    - The conclusion from Mark's report is that risk is "low" but difficult to quantify)
    - It is noted that the BLAST detectors survived very harsh treatment during and after the landing, when the balloon gondola was dragged over the ice for many hours.
        - The BLAST BDAs were strung up at U. Penn, and from an even earlier batch, with stainless steel pulleys (vs. Invar for FM)
    - High humidity and high temperature cause the Kevlar tension to increase, and so should be avoided (especially the combination of the two)
- Options, if any, to remove or mitigate risk
    - Be careful in cooldown, bakeout, transport and vibration
        - Cooldown, bakeout, and transport: OK – no significant stresses to BDAs
    - Vibration
        - System-level vibration qualification testing is likely to take place in early 2008
        - The detailed strategy and vibration levels are not yet defined, and will be the subject of discussions between ESA, Industry and the instrument teams
        - The need to protect the instrument subsystems will be an important consideration
        - The SPIRE Project Team will keep JPL informed via the weekly telecons, and ensure that JPL can be involved in these discussions
- SPIRE FS testing
    - The current plan for FA testing is that a cold vibration test will be done in between two cooldowns at RAL – care will be taken to characterise the 300-mK thermal system before and after.
- Special requirements/recommendations for system level activities
    - The SPIRE Cold Functional Test will be the first opportunity to notice such a failure – there will be such a test before and after system-level vibration
- What would be the options if a similar failure occurred at FM level?
    - Diagnosing the problem
        - Thermal signature = inability to operate, or severe difficulty in operating, the cooler
        - Optical alignment – could check with any signal capability
        - Test occasions

IST1/SPT	Friedrichshafen	End 2007
TV test	ESTEC	March 08
IST2/SPT	ESTEC	March +

- SPIRE has already drawn up a list of failure modes that would require (in SPIRE's view) a warm-up of the Herschel cryostat so that the problem could be fixed. A BDA Kevlar failure, or any other fault that would cause the cooler to become inoperable, falls into this category.

- SPIRE would therefore propose to ESA that the cryostat be warmed up and the instrument be repaired or replaced. The proposed approach is a "return-to-base" repair scheme in which the instrument would be returned to RAL, the faulty unit replaced by its twin from the Flight SPARE, the FM FPU subjected to a quick cold test, and returned for re-installation in the cryostat. The necessity or otherwise for a workmanship cold vibration would be discussed with ESA.
- Time needed to warm up the cryostat: if the failure occurred at Friedrichshafen, it would take at least two months to warm up and open up the cryostat (longer if the cryostat were at ESTEC)
- A spare unit from the FS could be made available on that timescale regardless of what stage FS testing might be at.
- Persuading ESA of the need for and wisdom of such a repair strategy might require support from the instrument funding agencies, especially NASA

7. Conclusions and recommendations

1. An extremely thorough and careful investigation of the failure has been carried out by JPL.
2. The root cause of the Kevlar cord failure has been identified as Kevlar fraying due to abrasion at an unpolished pulley
3. The proximate cause is not clear since the time and circumstances of the failure are not fully known. It appears to have happened between warm-up of the Herschel cryostat after the completion of the STM-2 test campaign, and the disassembly of the returned CQM FPU at RAL. Since none of the operations involved significant vibration exposure, it is presumed that the Kevlar had frayed previously and was in a condition such that a small disturbance caused it to break.
4. The root cause of the failure has already been addressed in the design and manufacture of the flight standard BDAs. The review team is satisfied that the design changes have been appropriate, properly executed, and should reduce the risk of similar Kevlar fraying to a very low level.
5. A similar failure occurred in the case of the 300-mK thermal strap support unit, and was resolved in a similar way.
6. The risk of a similar failure of a FM or FS BDA is regarded as low, but difficult to quantify.
7. There is no case for recalling the FM instrument for inspection as a result of this failure – the outcome of this investigation is to use the instrument "as is".
8. Should a similar failure occur during FM system-level testing, SPIRE's proposed approach would be to warm up the Herschel cryostat and return the FPU to RAL for replacement of the faulty BDA.

8. List of Annexes

8.1 Document list, Objectives and Agenda

8.2 Herschel-Planck/SPIRE CQM BDA Kevlar Failure Report, Mark Weilert

8.3 NCR Report Failure of KEVLAR Tension Cord on CQM PLW detector

8.4 CQM Thermal Strap Kevlar Failure Documentation

SPIRE - 300mK strap supports – PFM EIDP, Peter Hargrave (14 October 2007)
Inspection Report: STM/CQM Photometer Light Baffle Assembly, Peter Hargrave (8 May 2003
Cardiff Components Vibration Qualification Report, RAL SST Dept.

8.5 Presentation by Mark Weilert on the JPL report

8.6 Presentation by Eric Sawyer on the Environmental History of the PFM BDAs

Annex 1: SPIRE CQM BDA Kevlar Failure NRB

1 October 2007, 15:00 – 18:00 UK time

Objectives, Document List, and Agenda

1. Objectives of the review

1. Assess the cause of failure of the CQM BDA Kevlar support
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6. Identify the options, if any, to remove or mitigate such risk
7. Identify any special requirements/recommendations for testing or other activities at system level

2. Document list

1	Document list, Objectives and Agenda (this document)	Final version attached
2	Herschel-Planck/SPIRE CQM BDA Kevlar Failure Report, Mark Weilert	Draft version attached – may be some updates before the meeting
3	NCR Report Failure of KEVAR Tension Cord on CQM PLW detector (HR-SP-RAL-NCR-172v3, Sept. 27 2007)	Final version attached
4	CQM Thermal Strap Kevlar Failure Documentation • SPIRE - 300mK strap supports – PFM EIDP, Peter Hargrave (14 October 2007) • Inspection Report: STM/CQM Photometer Light Baffle Assembly, Peter Hargrave (8 May 2003) • Cardiff Components Vibration Qualification Report, RAL SST Dept.	Final versions attached
5	SPIRE/CQM Historical Record (27 June 07)	Final version attached
6	Environmental History of the PFM BDAs (PPT Presentation)	Draft version attached – will be updated before the meeting

3. Agenda

1.	Objectives of the meeting - Matt	15:00
2.	List of documents and presentations available – Matt/Eric	15:10
3.	Summary of NRB process so far (review of NCR document) - Matt	15:20
4.	Run-through of JPL Investigation Report - Mark	15:30
5.	Relevant aspects of thermal strap support system design and development -Pete	16:30
6.	FM BDA environmental history - Eric	16:45
	Discussion	17:00
7.	Impact on SPIRE and/or Herschel scientific performance of a similar failure of an FM BDA	
8.	Risk of such a failure pre-launch or during/after launch	
9.	Options, if any, to remove or mitigate such risk	
10.	Special requirements/recommendations for system level activities	
11.	Conclusions and recommendations	17:45
	End	18:00

Annex 2: Herschel/Planck

SPIRE

CQM BDA Kevlar Failure Report

Prepared By:
Mark Weilert

JPL D-40353
Revision B
28 September, 2007

Jet Propulsion Laboratory
California Institute of Technology

DOCUMENT CHANGE LOG

CHANGE LETTER	**CHANGE DATE**	**PAGES AFFECTED**	**CHANGES/ NOTES**	**GENERAL COMMENTS**
A	2007/9/18	All	Initial Release	
B	2007/9/28	All	Reformatted, changed based on JPL and RAL comments, added new abrasion test pictures and final conclusion.	

Table of Contents

1 Introduction

On 29 May, 2007, during the disassembly of the SPIRE CQM instrument at RAL, the CQM PLW BDA was discovered to have a broken lower Kevlar braid. A photograph of the failed braid is shown Figure 1. The break allowed the 300mK section of the detector assembly to touch the outer housing of the BDA, which explains an anomalous short to chassis ground discovered later during the instrument disassembly process. The CQM BDA was assembled at JPL in mid 2003, and when the break was discovered the unit had been through the entire planned testing program (almost 3-1/2 years of testing at RAL / ESA). The BDA had been operating normally during the last cold testing, indicating that the touch, and therefore very probably the broken braid, did not exist then. Thus this failure occurred somewhere during the warm-up, de-integration, or transportation of the SPIRE instrument between the last cold testing at ESA (the STM2 campaign) and the electrical testing of the instrument at RAL. This failure is captured in RAL NCR HR-SP-RAL-NCR-172v2 and JPL PFR 6308. This report documents the investigation of the failure.

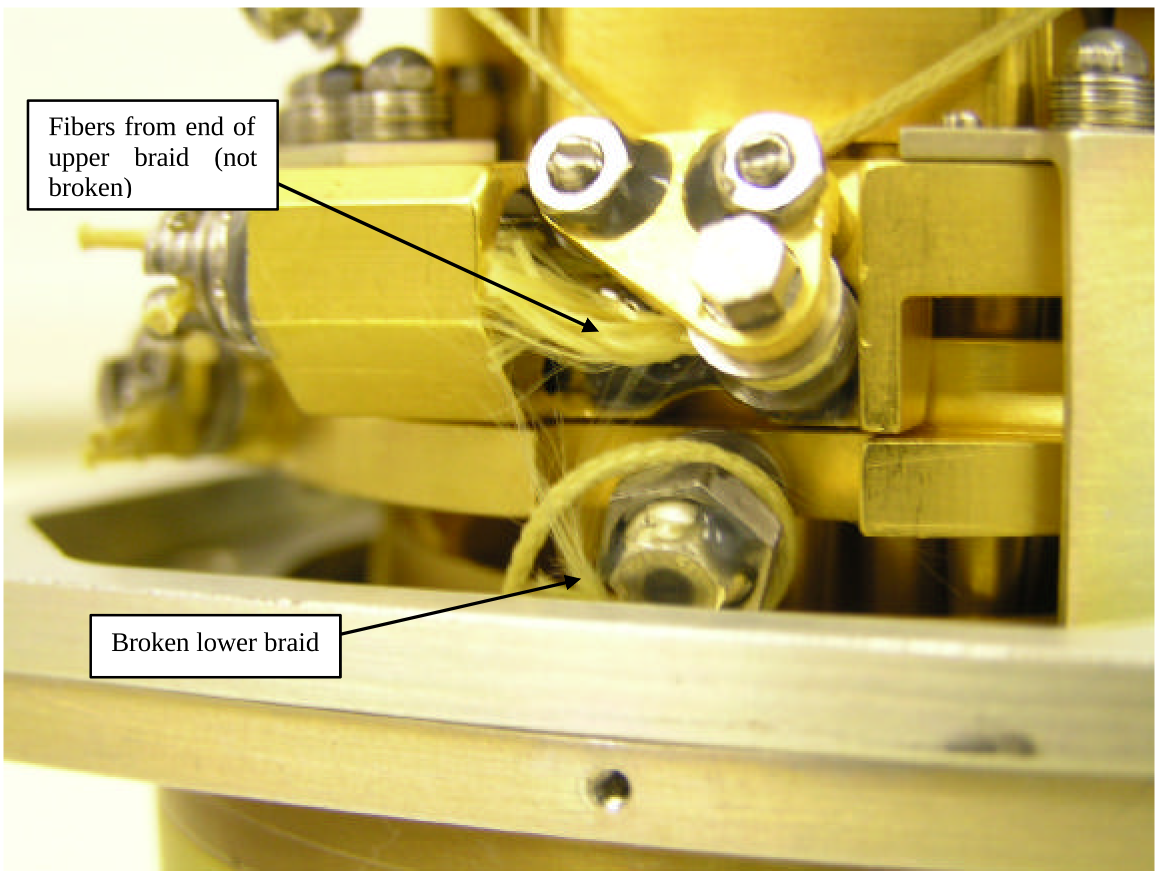


Figure 1: Picture of broken Kevlar on CQM PLW taken shortly after discovery (29/05/2007). The Upper frayed bundle of fibers is one of the terminations of the upper braid. The broken lower braid is seen still partially wrapped around the pulley.

2 CQM BDA Background

2.1 Hardware Identification

The unit that experienced the failure being investigated is the CQM (Cryo-Qual-Model) PLW (Photometer Long-Wave) BDA (Bolometer Detector Assembly), JPL part # 10209800-1 SN006. This unit was delivered from JPL to RAL in August 2003 and is documented in HRCR package JPL D-26491 and JPL final-ship IR 919282. The RAL receiving IR is SPIRE-RAL REP-001773.

2.2 Build Standard

The CQM PLW BDA was built using the same JPL flight processes, Quality Assurance and traceability as the FM and FS units. The Kevlar suspension component parts were from the same lots as used for the Qual BDA and several of the flight and flight spare units (those with suspension SN's 3, 5 & 14). The Kevlar used in stringing the CQM was from the same flight spool used for all the BDAs. There were some design changes between the CQM and the later units as noted below. Despite the flight-like build standard, the CQM was delivered with a not-for-flight disposition due to Kevlar fraying on the upper braid discovered after assembly, see below.

2.3 CQM BDA Historical Record

2.3.1 Assembly and Pre-Existing Fraying

The CQM BDA was assembled at JPL beginning with the stringing of the Kevlar suspension during May 2003. Due to delivery schedule constraints, the CQM BDA was assembled first of all the shipped BDAs, and notably also before the Qual model BDA, which was not shipped.

After shake testing at JPL, an area of fraying on the top Kevlar braid of the CQM BDA was discovered. Photographs showed that this fraying had existed prior to the shake, and had been introduced during Kevlar stringing. At the time, this known fraying caused the CQM BDA to be dispositioned as not-for-flight in the HRCR package. The discovery of the fraying also motivated several slight design changes between the CQM and the Qual and all subsequent BDAs which will be discussed below. Note that the failure in the CQM BDA Kevlar did not occur at the location of the pre-existing fraying, or indeed even on the same Kevlar braid.

2.3.2 Test / Operations

Copies of the detailed operations logs for the CQM BDA from JPL and RAL are given in Appendix A. To summarize the detailed logs, the CQM BDA went through a total of 12 thermal cycles (6 each at JPL and post-shipment), including two cold vibration tests. A single Y-axis cold random vibration test was done at JPL, and a 3-axis cold test was performed as part of instrument testing at CSL, including both high-level sine and random vibration for each axis. The 3-axis testing was completed in May 2004, during the 9^{th} (of 12) cool down of the CQM BDA. The BDA was removed and inspected after this shake test and it was not visibly damaged. Metrology showed no large suspension shift had occurred. It should be noted, however, that an

RAL NCR (HR-SP-RAL-NCR-075) was generated due to an over test during one axis of sine vibration.

The CQM BDA performance was normal during functional and performance testing for three subsequent cool downs over the next ~3 years, and then the Kevlar failure was discovered during the disassembly of the instrument at RAL. The problem was initially found by visual inspection of the BDA during instrument disassembly, and further testing revealed a resultant 300mK electrical short to chassis.

No room temperature electrical tests, which might have helped pinpoint the time of failure, were performed during the several steps involved in dewar warm-up and shipping, removal of the SPIRE instrument, and packing/shipping the instrument back to RAL. Shock monitors installed during the instrument shipping showed only the 5g monitor tripped. (The next higher monitor was 10g, all three axes were monitored.)

2.4 Differences between the CQM and Other BDAs

2.4.1 Hardware differences

Table 1 below shows a list of all known hardware differences between the CQM and later units of the same (PLW) type. Additional differences which exist between the CQM and other BDAs are due to the different detector types, (PLW, PMW, SLW, etc). As the BDA has a modular design with different detector assemblies within a common Kevlar suspension, the most relevant difference between the different types the total mass and the suspension sub-type. These build details for all the BDAs are shown in Table 2.

The suspension sub-type difference between the PLW and other BDA types is a small additional cutout in the top ring of the PLW BDAs to provide clearance for the larger PLW feedhorn. This difference would not be expected to affect the lower braid where the CQM failure occurred.

2.4.1.1 Background on Pulley Changes

Of all the detailed differences between the CQM and the other BDAs, the only differences seemingly pertinent to the CQM Kevlar failure are possibly the change to the Kevlar routing and the change in polishing and rounding of the pulleys.

The routing changes concern the starting point of the Kevlar wraps on a given pulley, which can begin at the inside end of the pulley barrel (near the structure) or at the outside end (near the hexagonal pulley face). The routing design was changed after the CQM fraying was discovered, in order to reduce abrasion of the Kevlar against the hex face were the fraying was discovered. Only the top braid routing was changed between the CQM and the final design, so this is not expected to impact the CQM lower braid failure.

Table 1

Hardware Difference List

Part	CQM PLW	Later Hardware	Notes:
10209860 suspension	chamfered pulleys per redlined dwg 5/2/03	Fully rounded & polished pulleys per released dwgs	changed on Qual and subsequent units to address CQM PLW fraying
10209860 suspension	preliminary Kevlar routing	final (Qual BDA type) Kevlar routing	changed on Qual and subsequent units to address CQM PLW fraying (note: only upper braid routing was changed from CQM to final design)
10209860 suspension assy.	no side screws into invar spacers	side spacer screws were used	screws had been eliminated in error when the vespel safety spacer was eliminated from the design. Units after SN009 (PFM SSW) have screws installed.
10209890 middle ring (part of suspension)	suspension Ring-A is pinned to flexure mounting plate with both old pins and smaller new invar pins.	suspension Ring-A is pinned to flexure mounting plate with only new invar pins.	Old pins were partially machined away after assembly in early suspension units (up to 10209860 sn006). Final design used only the new pins.
10209860 suspension assy.	no epoxy on capstan-1	versamid epoxy at capstan-1 end of kevlar.	epoxy added to final design to strengthen tie-off at capstan-1 and reduce fraying of free end.
Detector Assembly	bare copper thermal strap interface	gold plated thermal strap interface	FM and FS units gold plated to meet ICD requirements.

Table 2

BDA Build Details

BDA				Suspension		
Nomenclature	S/N	type	Mass (g)	S/N	type	Date Strung
CQM PLW BDA	6	-1	596	2	-2	2003-05-14
Qual BDA	7	-8	614	6	-1	2003-07-17
PFM SLW BDA	8	-4	542	3	-1	2003-09-03
PFM SSW BDA	9	-5	482	5	-1	2003-10-20
PFM PMW BDA	12	-2	603	10	-1	2004-06-04
PFM PSW BDA	13	-3	579	11	-1	2004-07-08
PFM PLW BDA	14	-1	602	12	-2	2004-08-15
FS SLW BDA	15	-4	527	7	-1	2004-01-16
FS SSW BDA	16	-5	485	13	-1	2004-10-22
FS PSW BDA	17	-3	574	14	-1	2004-12-10
FS PLW BDA	18	-1	601	8	-2	2004-03-11
FS PMW BDA	19	-2	605	9	-1	2004-05-06

NOTES:

-1 / -2 suspensions differ only in top ring cutout details for PLW feedhorn clearance.

SN 10 and 11 BDAs were noisy and were re-built into SN 18,19.

The changes to the pulleys were implemented in part due to the CQM fraying and also due to abrasion of the Kevlar against the pulley barrel discovered during attempts to string the Qual BDA. Photographs of a CQM-type pulley and a polished pulley typical of all the other BDAs are shown in Figure 2 and Figure 3, respectively. The CQM pulley design incorporated a chamfer on the hex face as an early attempt to prevent damage to the Kevlar by the points of the pulley hex. Unfortunately this chamfer left a sharp edge on the pulley face. It was likely this edge that caused the pre-existing fraying discovered on the CQM. In the final design, the entire pulley end face and barrel is rounded off and polished. This final design was used on BDAs from the Qual onward, including all the FM and FS units.

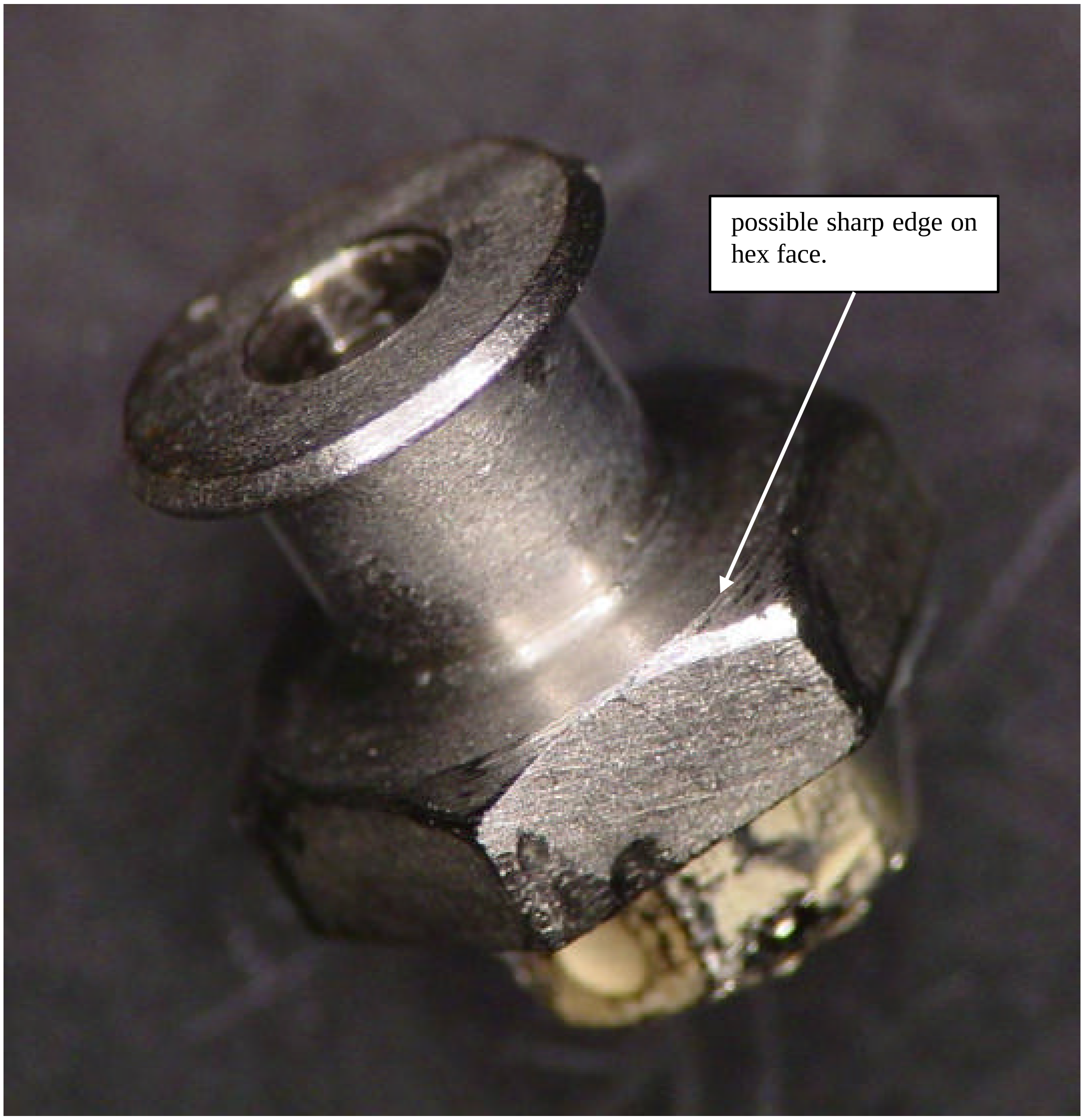


Figure 2: Unpolished pulley as used on CQM BDA. Note possible sharp edge on hexagonal face.

Figure 3: Polished pulley typical of those used in later BDAs.

2.4.2 Operation / Test Differences

Table 3 shows a summary of the environmental exposure (bakeouts, thermal cycles and shake tests) of the various BDAs. Also included in the table are the environmental exposures expected in the future for the FM and FS units. Further details of post-delivery environmental history can be found in RAL documentation.

Table 3

BDA Environmental Exposures

BDA	**Vac. Bake (80C) JPL**	**Thermal Cycles JPL**	**RAL**	**Expected**	**Shake Tests (all cold) JPL**	**RAL**	**Expected**
CQM PLW BDA	none	6	6	0	1 axis PF random	3 axis, Qual level random+sine	none
Qual BDA	120 hrs	29	NA	NA	3 axis PF random	NA (not shipped)	NA
PFM SLW BDA	24 hrs	5	5	1	1 axis PF random	3-axis, 2 min/axis FA; 1 axis, 1 min FA (workmanship)	S/C-level test +launch
PFM SSW BDA	24 hrs	5	5	1	1 axis PF random		
PFM PMW BDA	24 hrs	5	5	1	1 axis PF random		
PFM PSW BDA	24 hrs	5	5	1	1 axis PF random		
PFM PLW BDA	24 hrs	5	5	1	1 axis PF random		
FS SLW BDA	24 hrs	5	0		1 axis PF random		
FS SSW BDA	24 hrs	6	0		1 axis PF random		
FS PSW BDA	24 hrs	5	0		1 axis PF random		
FS PLW BDA	12 + 24 hrs	9	0	TBD	1 axis PF, 1 axis FA random	None	TBD
FS PMW BDA	2 x 24 hrs	12	0		1 axis PF, 1 axis FA random		

NOTES:
PF = proto-flight levels, FA = flight acceptance levels. JPL tests were all 2 min/axis, as was the CQM instrument test.
FS PLW and FS PMW were tested twice due to re-build caused by initially noisy detectors.
Final expected thermal cycle on FM units is cooldown only (remaining cold to end of mission).

2.4.2.1 Comparison of Qualification and CQM Vibration Testing

To aid in evaluating the CQM failure, it is particularly pertinent to compare the environmental exposure of the CQM and the Qual BDA which was used to prove out the final design. For thermal cycles this is straightforward, but the comparison of the vibration testing is more complicated. The Qual unit was vibration tested to the agreed upon detector qualification levels. The CQM was instead shaken as part of a qualification test at the instrument level with a very different input spectrum and a complicated transfer function between the input and the BDA exposure.

Referring to the vibration test reports for the Qual and the CQM tests, both reports characterize the exposure in terms of equivalent g-rms at the detector suspended mass. The JPL Qualification report claims a goal g-level of 16 g-rms and achieved levels of 16.8, 16.5, and 19.9 g's RMS for X, Y, Z axes, respectively. These values were determined by a combination of data from accelerometers on the suspended mass and force transducers on the BDA support.

The CQM instrument level test was notched to achieve >10grms equivalent at the detector suspended mass, and the calculated achieved values for the photometer box ranged from 13.1 to

14.3 g-rms, though the values are reported as being suspect. Thus it seems that the Qual BDA was given a harder random vibe test, but not by a large amount. Note also that the Qual unit did not see the additional high level sine test and that the CQM had also seen the 1 axis protoflight test at JPL.

3 Evaluation of CQM BDA Failure

3.1 Circumstances of the Failure

It is unlikely that the Kevlar could have failed without leading to a thermal short between the 300mK section and the outer warm parts of the BDA. Such a short would have compromised the performance of the CQM PLW and indeed the whole SPIRE instrument. Since the BDA and instrument were functioning normally through the end of the last cold test, the failure must have happened during warm-up or during the shipping of the unit back to RAL. This shipping process did involve several steps as the dewar was first shipped, the SPIRE instrument was removed, and then the instrument was packed and shipped. The most likely scenario is that the proximate cause of the failure was vibration or shock sometime during the shipping of the unit. Since the available evidence does not indicate any excessively rough handing (only the 5g shock monitor tripped during instrument shipping, none of the 10g monitors tripped in any axis), it is expected that some other factor is the root cause of the failure.

3.2 Inspection of the CQM BDA

3.2.1 Initial inspection at RAL

After removal of the CQM BDA from the instrument, the broken Kevlar braid was clearly visible, and the 300mK portion of the BDA was seen to be significantly tilted. The photograph shown in Figure 1 captures the unit soon after the failure was discovered. This picture is probably the best direct photographic evidence of the location of the Kevlar break, since the braid becomes progressively more disturbed during subsequent handling and inspection. Electrical tests had indicated a 300mK to BDA chassis touch, but the location of this touch was not evident.

3.2.2 JPL Disassembly / inspection on site at RAL

Mark Weilert from JPL visited RAL in June 2007 for additional inspection of the BDA. An electrical test was initially performed. This showed that apart from one previously known bad pixel, the only anomalous reading was the short between the 300mK section and the BDA mounting flange. This result is not greatly significant to the cause of the failure, but it does seem to indicate that the unit did not experience any extreme shock or rattle around after the Kevlar broke.

The BDA light can was removed to allow for improved access to the lower Kevlar braid and investigation of the touch. Photographs are shown below. With the can removed the touch between the 300mK coverplate and the connector bracket was immediately visible; see Figure 5 and Figure 6. The suspended portion of the BDA was still fairly rigid as the tension in the intact upper braid and the residual tension in the lower braid pushed the coverplate against the bracket.

This strong touch between the detector mounting coverplate and the aluminum connector bracket within the warm parts of the BDA would certainly have caused a significant thermal short if it had been present during the previous functional tests.

The break is seen at the end of a wrap around pulley #2 and the Kevlar is still fully wrapped around pulley #3. (Pulleys are numbered following the Kevlar path starting at the "capstan-3" Kevlar termination.) From the disposition of the Kevlar, it was clear that the failure had occurred somewhere in the vicinity of pulley #2, probably either where the Kevlar was on the pulley or in the span between the 2nd and the 3rd pulley. Visual inspection of pulley near the break did not show any obvious defects that would have caused the failure. Since the Kevlar springs back after the break, a more exact determination of the failure location was not possible without detailed inspection of the Kevlar. It was decided to perform that inspection after shipping the unit to JPL.

At RAL, the pre-existing fraying on the top braid was also inspected. This fraying was still visible and not obviously altered from when it was originally discovered in 2003. The pre-existing fraying was clearly not directly related to the current failure.

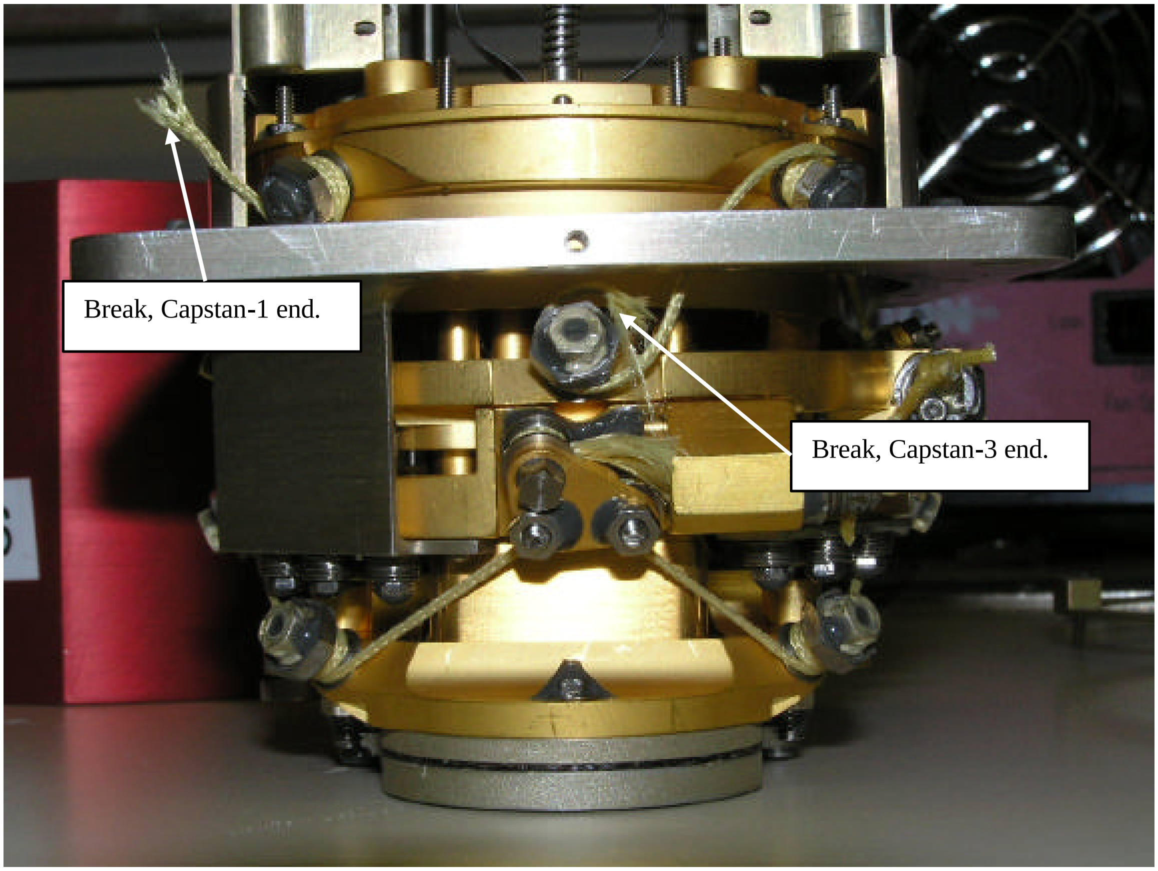


Figure 4: CQM PLW at RAL with light can removed, showing the both ends of the broken lower braid.

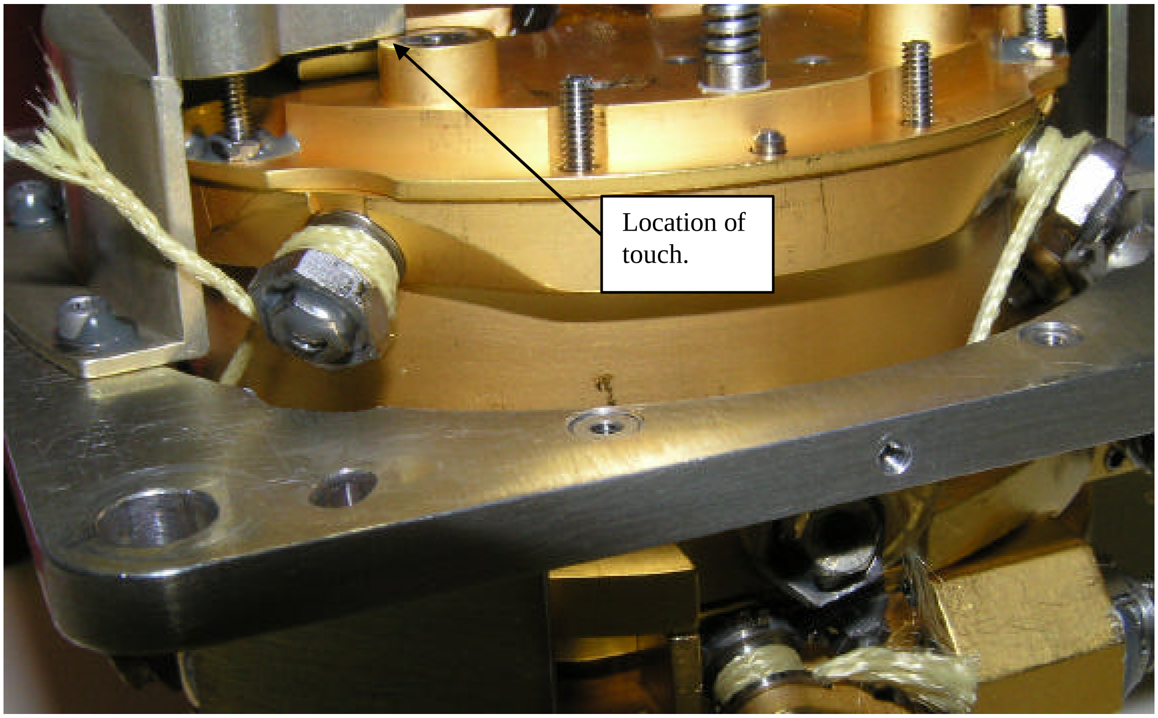


Figure 5: CQM PLW inspection at RAL, showing location of 300mK to connector bracket touch. Note slack in Kevlar on pulleys adjacent to the one near the break.

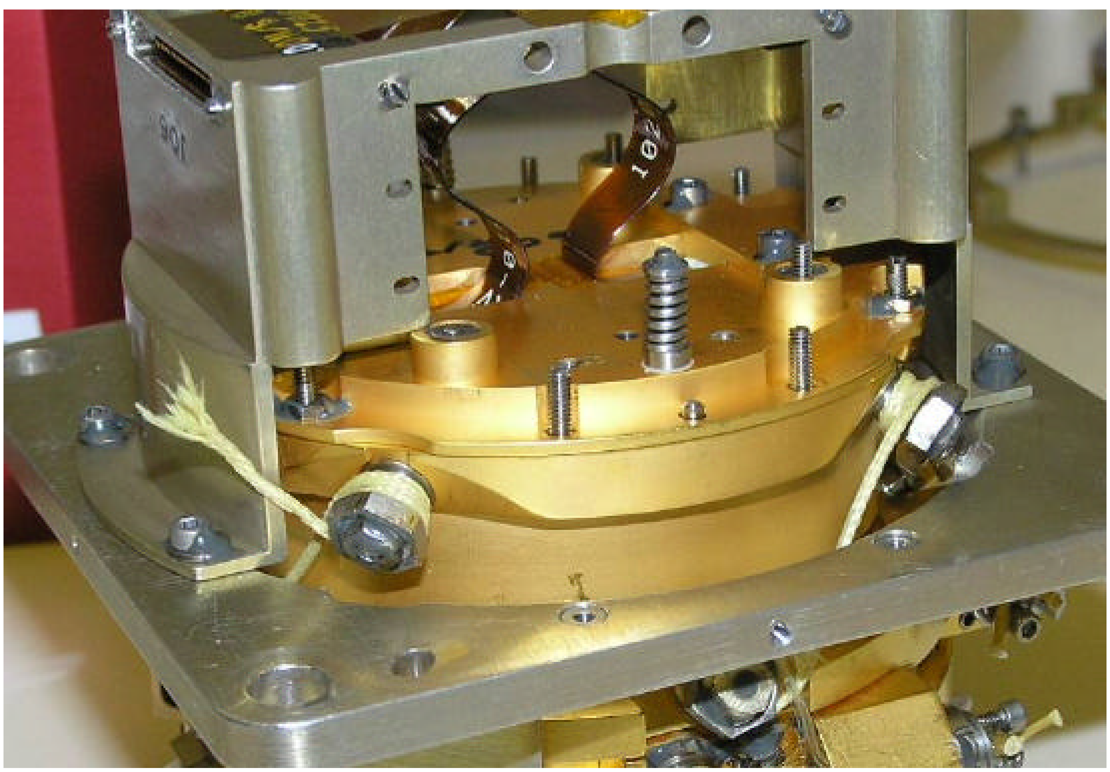


Figure 6: Another CQM BDA view with the light can removed.

3.2.3 Disassembly / Inspection at JPL

After the partial disassembly at RAL, the CQM BDA was protected for shipping, re-assembled, packed and shipped back to JPL for further investigation of the failure. The BDA was protected for shipping by hand-fitting Teflon spacers between the 300mK section and the surrounding housing to prevent any rattling of the structure. Lacing cord was tied around the 1st and 3rd lower-braid pulleys to retain the broken Kevlar in position as much as possible. The re-assembled BDA was then shipped back to JPL in the original red shipping fixture (aka. "bowling ball") and padded containers. The Teflon spacers were still tightly in place on receipt at JPL and the upper braid was intact, indicating that the unit had survived shipping without being further compromised. None of the 10, 15 or 20g shock monitors installed on the red shipping container were tripped.

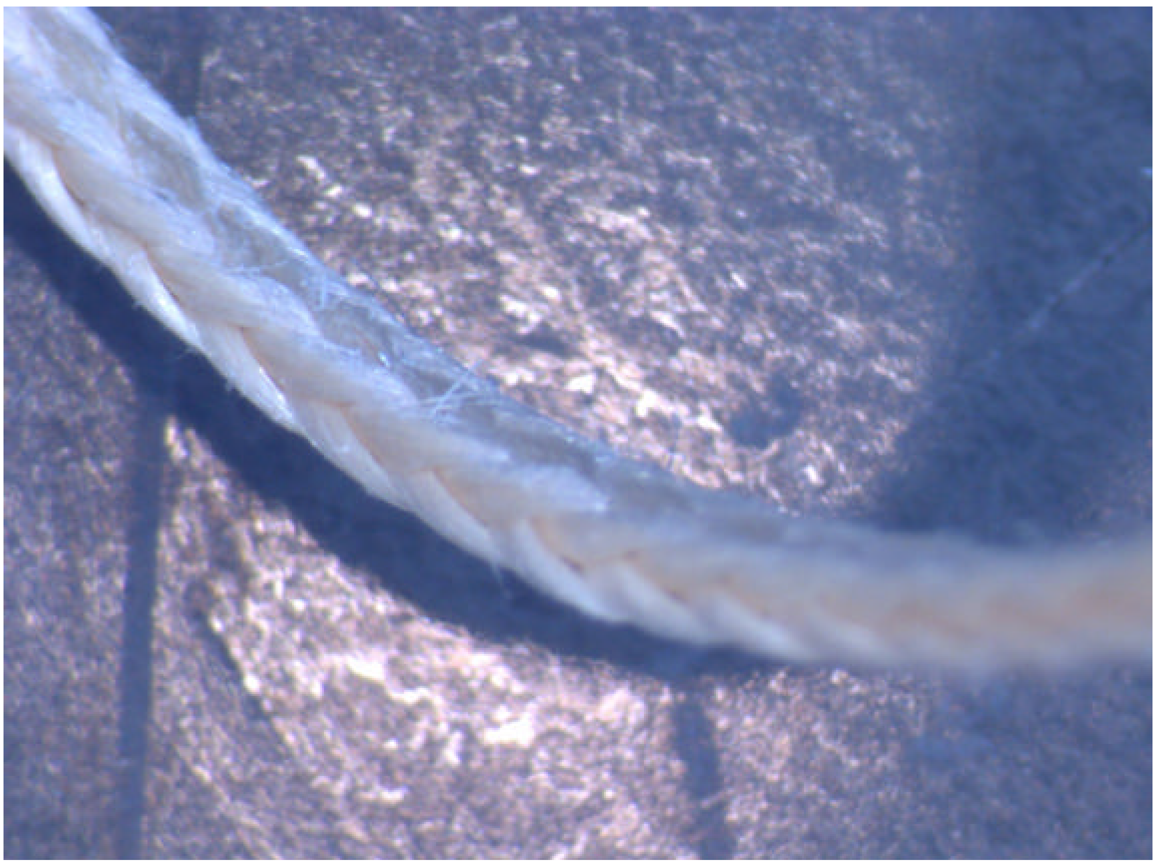


Figure 7: Microscopic view of abraded Kevlar from pulley #2 area.

3.2.4 Determination of Failure location

During disassembly at JPL, the lower Kevlar braid was marked with a permanent marker at each of the pulleys and removed from the CQM BDA. Extrapolation of the distance between the pulleys and the inspection of the surface finish of the Kevlar showed that the failure area was very near where the Kevlar was leaving the 2nd pulley in the span between the 2nd and 3rd pulley. The Kevlar routing was such that at this point the braid was near the outer hexagonal face of the pulley. The suspension design does not pull the Kevlar braid against the hex face of the pulley, but the ~2-¼ wraps of Kevlar around the pulley fills the available space on the pulley barrel and typically leaves the braid in contact with the hex face. Clear abrasion was seen on the Kevlar surface where it had been in contact with the pulley barrel; See Figure 7. Similar abrasion was seen near the other pulley locations, with the worst abrasion being on the first few pulleys near the Capstan-3 termination. This is typical of abrasion from the stringing process since the Kevlar slack is pulled out of capstan-3 during stringing.

Figure 8: CQM BDA Kevlar break, Capstan-3 end.

Figure 9: CQM lower braid Kevlar from pulley #2 area, showing abrasion where the Kevlar was against the pulley barrel.

3.2.5 Check for pre-existing damage

With the failure location determined, several old pictures of the failure area were located and are shown in the figures below. These images range in time from the stringing of the unit through the first installation of the CQM BDA into the SPIRE instrument at RAL. There is no obvious damage to the Kevlar braid in the area that ultimately failed. Detecting Kevlar damage in photographs is always difficult, so it should be noted that the CQM BDA was also carefully inspected for visible Kevlar damage after the pre-existing fraying was discovered. At that time the lower braid was determined to be undamaged. The photographs and inspections show that there was no pre-existing gross external damage to the Kevlar at the failure location, but note that abrasion at the pulley surface would not be visible.

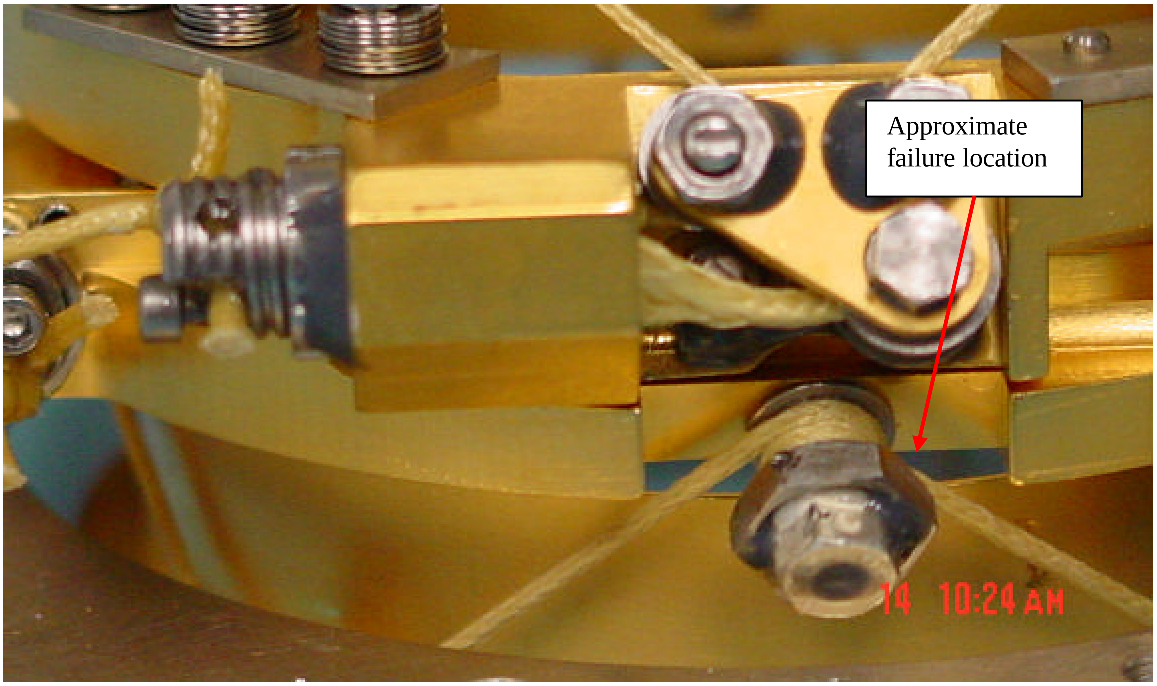


Figure 10 View of the ultimate failure location on the CQM BDA from the period of suspension stringing, May 2003

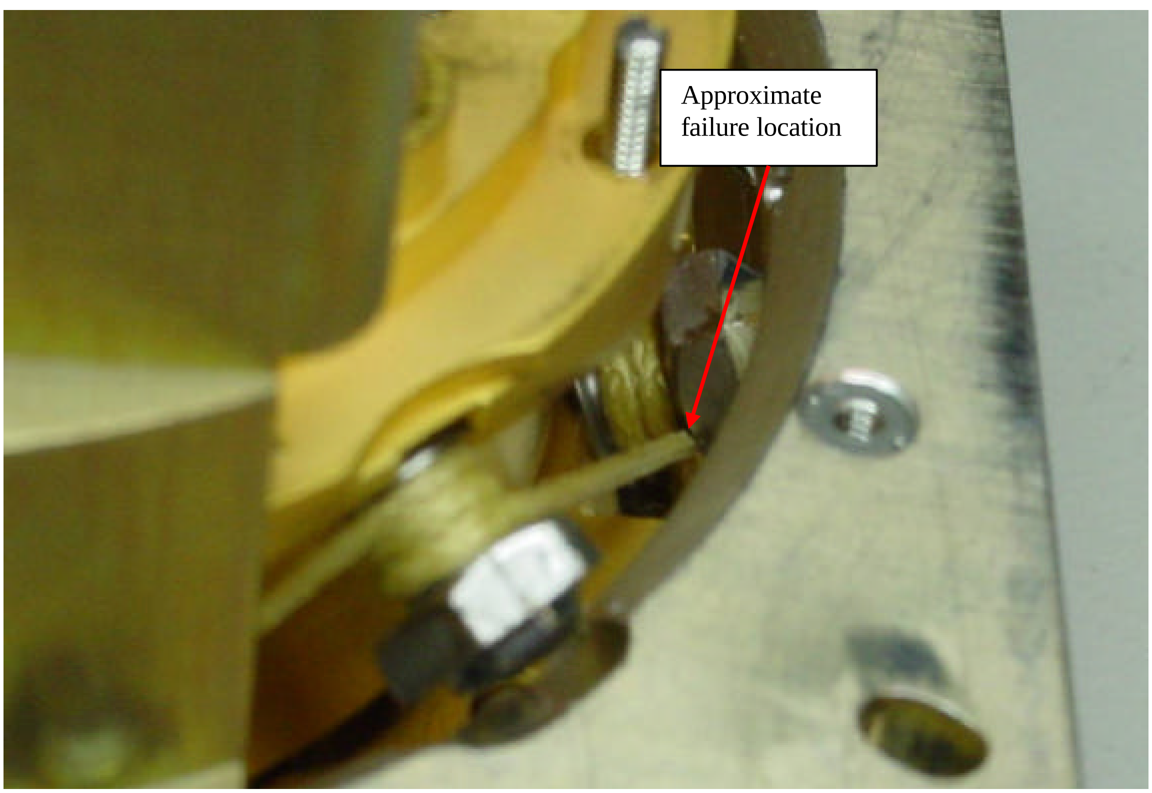


Figure 11 View down the Kevlar braid to the failure location taken during post-vibe inspection at JPL.

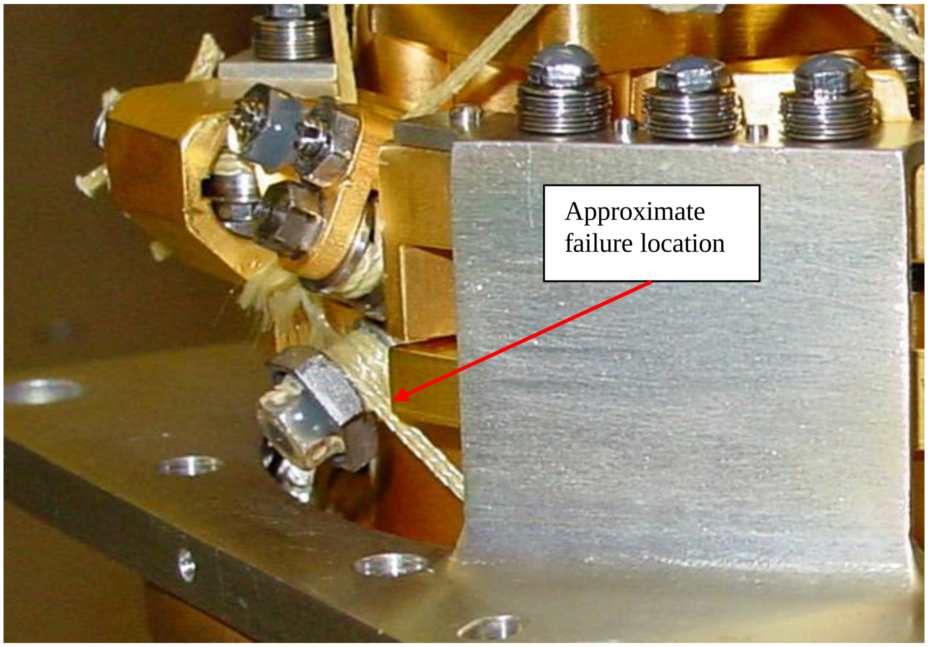


Figure 12 View of failure location taken at RAL before installation into the CQM instrument, Sept. 2003.

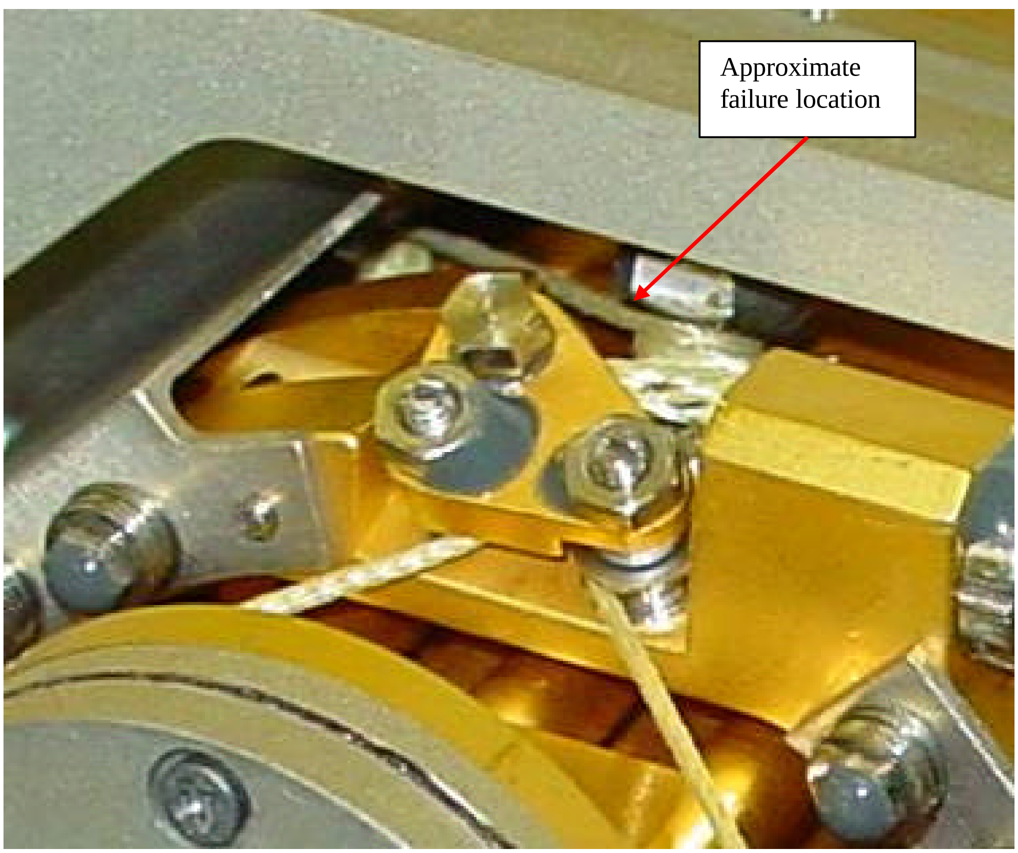


Figure 13 View of failure location after installation into CQM instrument, Sept. 2003.

3.2.6 Pulley inspection / Kevlar residue

After the removal of the Kevlar, all of the lower-braid pulleys were removed from the suspension assembly for microscopic inspection. Pulley #2 is shown above in Figure 2. The only defects seen are the known roughness and somewhat sharp edge on the hex face. The other pulleys are similar. More informative pictures were obtained by viewing the pulleys under UV illumination. Pulley #2 and Pulley #1 are shown below. Both pulleys show strong fluorescence on the barrel and hex face due to Kevlar residue. (In a separate test, a piece of Kevlar was confirmed to have the same color of fluorescence.)

Using this method, Kevlar residue was detected on all of the bottom braid pulleys to varying extent. Note that Pulley #2 was in the same condition in the UV photograph as in the previous white-light picture in which the residue is not at all obvious.

These images and the photos of the braid make it clear that the rough surfaces of the pulleys are doing damage to the Kevlar. This had been evident from Kevlar removed during stringing of the Qual unit before the time that the polished pulley design change was implemented. It is not surprising that the CQM had this abrasion at the pulley surfaces which are not visible during external inspection. At the time of the Qual assembly it was determined that the polished pulleys reduced the amount of abrasion, but there is no quantitative documentation of this conclusion.

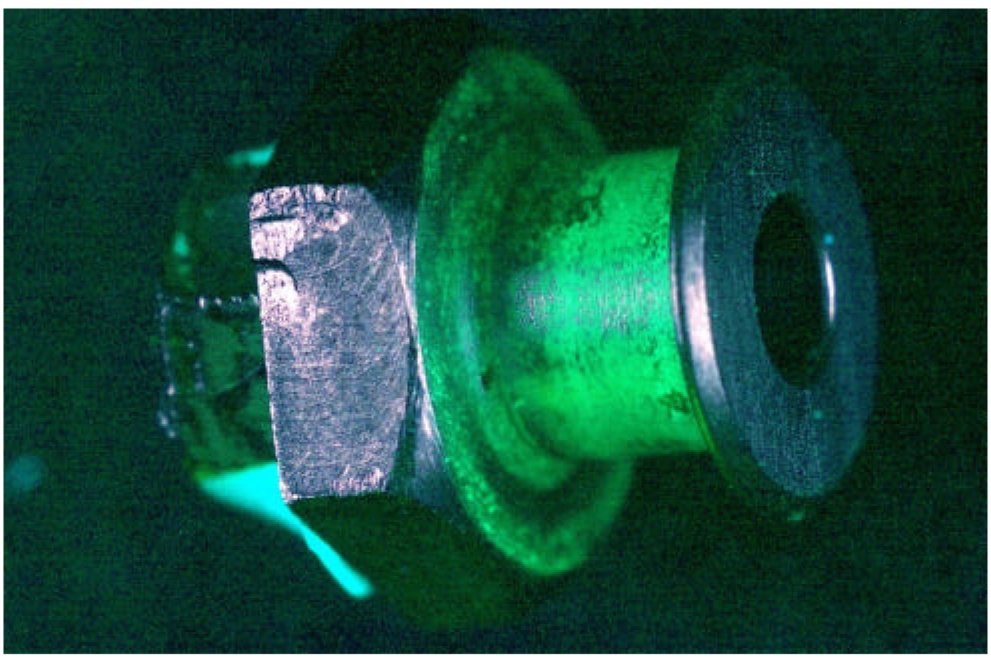


Figure 14: CQM BDA pulley #2 (pulley near failure) under UV light. Green fluorescence is Kevlar residue. Blue fluorescence on the left is from pulley staking epoxy. Note the Kevlar debris on the hex face up to the sharp edge.

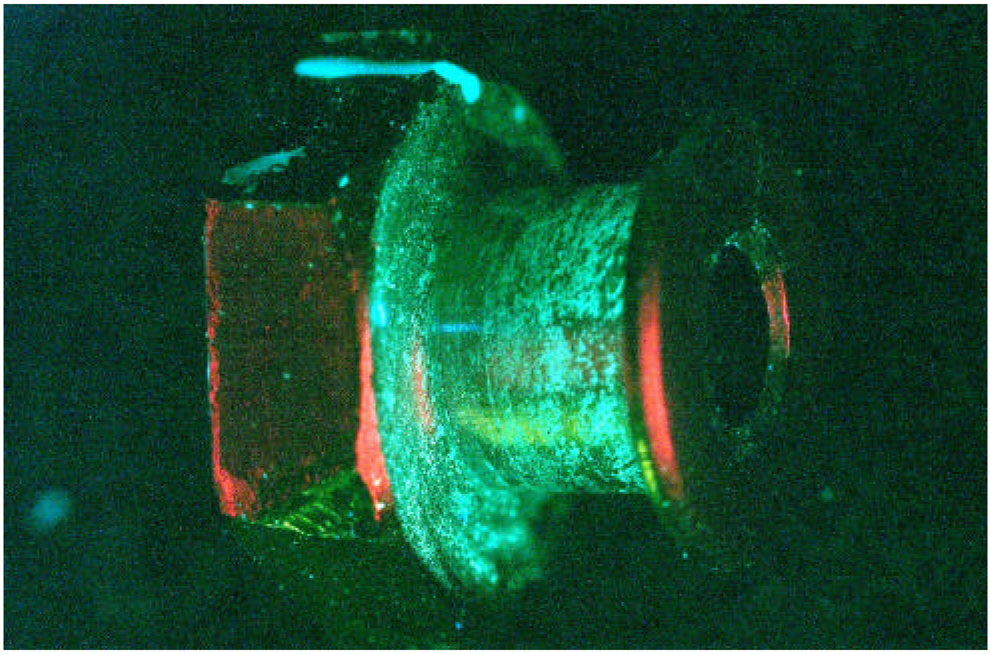


Figure 15: CQM BDA pulley #1 under UV lighting. Red areas are stray reflections from light source. Other fluorescent colors are as in the previous figure.

3.3 Shake Test evaluation of abrasion from Pulleys

While it seems that the likely root cause of the CQM failure is the abrasion of the Kevlar by the unpolished pulleys, it is difficult to quantitatively asses the impact of the abrasion. In order to make a more quantitative comparison of the performance of the polished and the unpolished pulleys, we performed a shake test using the setup shown in Figure 16 and Figure 17.

Using the pictured setup, we arranged to rapidly modulate the length (and tension) of a short piece of Kevlar by hanging a weight from the Kevlar while vibrating the upper end of the braid vertically on a shake table. The upper Kevlar support used a linear stringing test fixture made early in the JPL SPIRE development. We tested with a polished or unpolished pulley in the last location before the vertical weighted Kevlar span. The unpolished pulley used was the actual CQM BDA pulley #2 near which the Kevlar broke. The attachment of the Kevlar to the weight used a 2-pin tie-off from the BDA stringing fixture. A 51.2 lb weight approximated the 55 lbf tension used to string the BDAs, and both the stringing fixture and the weight were instrumented with vertical accelerometers. The Kevlar used for all tests was from the same flight spool used to string all BDAs, though the braid was not preconditioned as it had been for stringing.

At the chosen drive frequency of 200Hz the weight stays essentially stationary, typically moving only 1-2% as much as the top end of the Kevlar. Thus the length of the hanging span of Kevlar is modulated essentially by the amplitude of the oscillation of the top support. The variation in the tension in the Kevlar is conveniently determined from the measured acceleration of the weight multiplied by its mass.

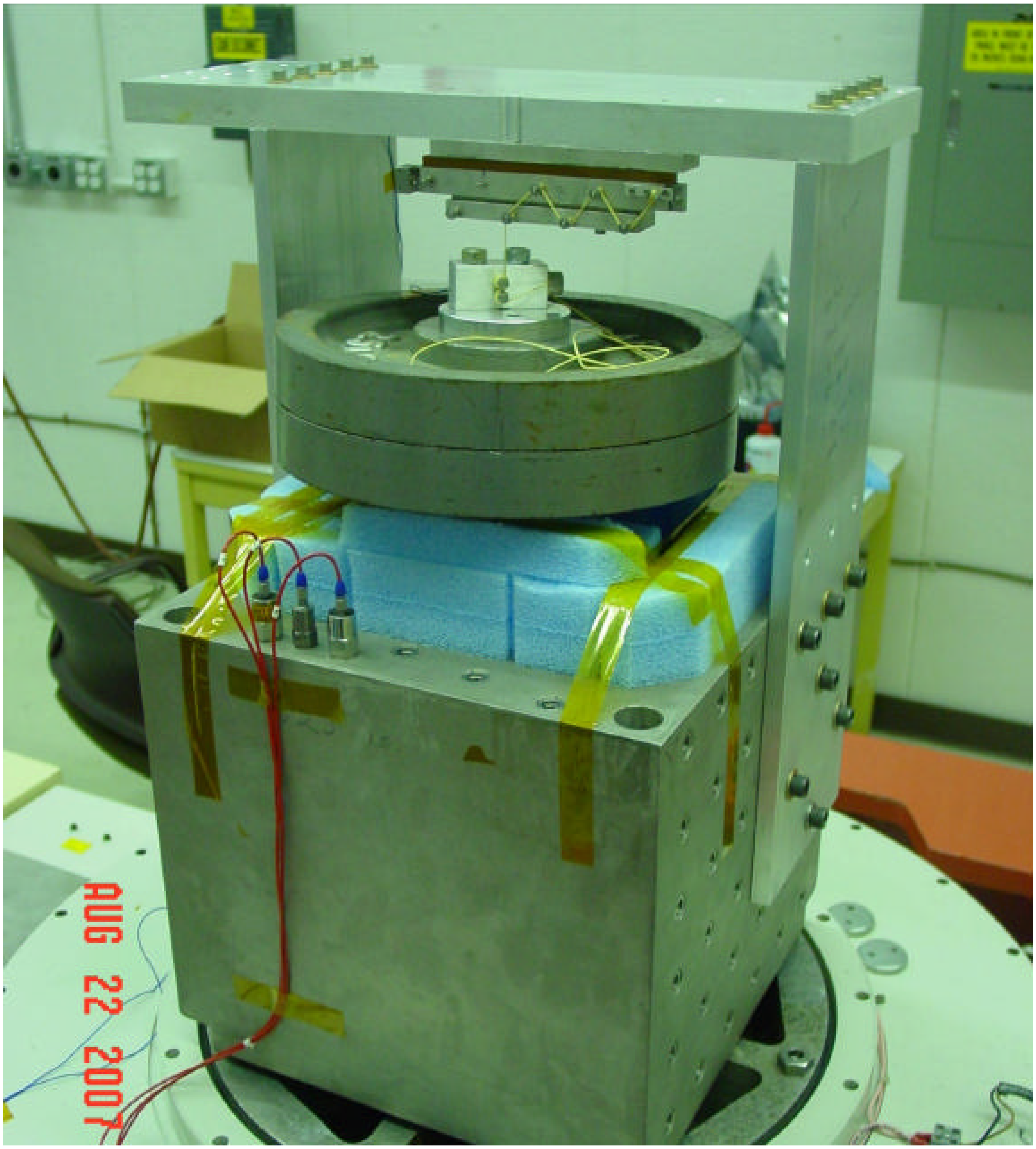


Figure 16: Kevlar abrasion shake test setup. The blue foam below (and not touching) the weight is to catch the weight when the Kevlar breaks. The whole fixture vibrates vertically.

Two sets of tests were performed with this setup. In the first set, an ~3" length of Kevlar was shaken with a 200Hz sine dwell for 30 minutes at a peak-peak drive amplitude of 0.010". This exposure did not break the Kevlar using the unpolished pulley, so we repeated the same exposure using the polished pulley. The pulleys, which had been cleaned of any Kevlar residue before the test, were then compared using UV illumination as above. As can be seen in Figure 18 through Figure 21, the shaft of the unpolished pulley is clearly covered with Kevlar debris from abrasion, while the polished pulley shows only a few isolated fibers and a bit of abrasion at some particularly deep grooves which were apparently not adequately smoothed in the hand polishing process. Note that the Kevlar in these tests was not in contact with the hexagonal end face of the pulley, so no Kevlar residue is seen there, in contrast to the earlier inspections of the pulleys as removed from the CQM.

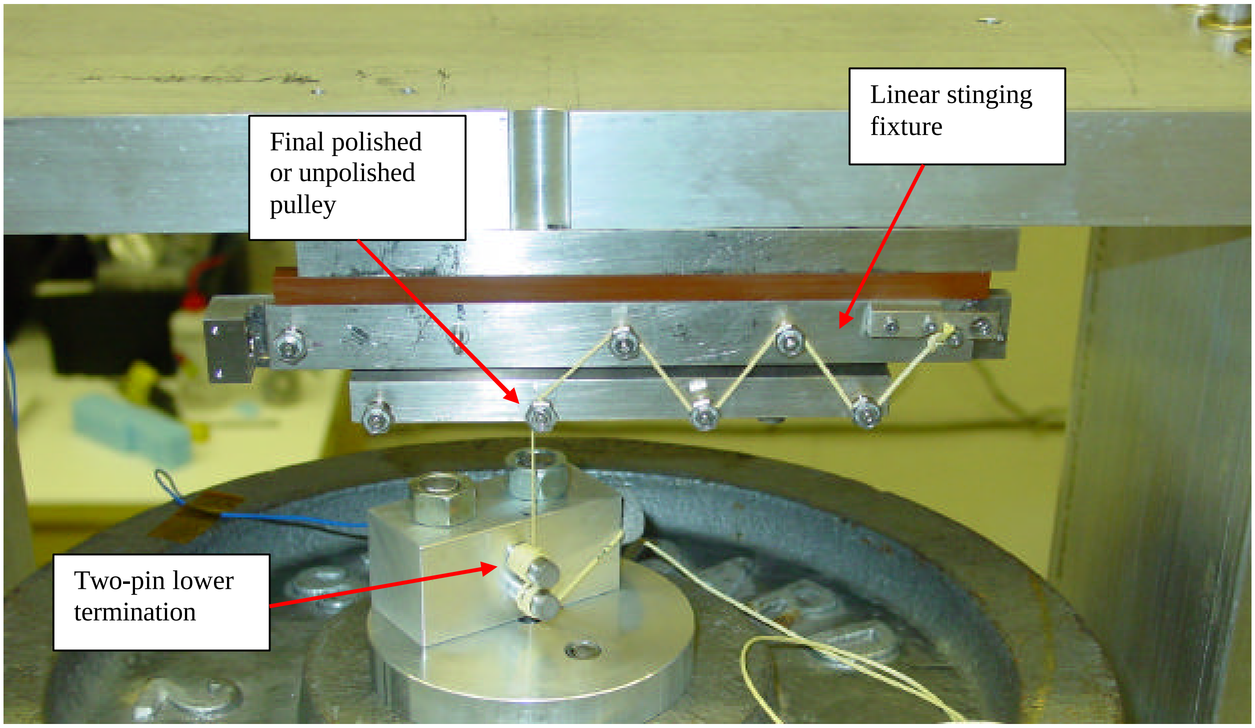


Figure 17: Detail of abrasion shake test setup.

The second set of Kevlar shake tests were tests to failure using both a polished and an unpolished final pulley. During this test the Kevlar on the unpolished pulley was shaken for 15 minutes per run and the amplitude of the shaker oscillation was steadily stepped up each run until the Kevlar failed. A new Kevlar sample was installed with a polished final pulley and run through the same sequence of levels. Testing was continued at the highest level until the Kevlar failed.

The result of this test was that the Kevlar failed on the unpolished pulley after 7.7 minutes at the highest level, at which time it broke at the unpolished pulley (just at the top of the hanging span). With the polished pulley the Kevlar survived for a total of 36.5 minutes at the same high level, at which time the Kevlar failed not at the pulley but near the bottom termination. Pictures of the failed braid immediately after the tests are shown in Figure 22 and Figure 23.

Magnified visible light and UV-illuminated pictures of the pulleys from the two tests are shown in Figure 24 through Figure 27. These pictures show a large amount of Kevlar residue on the unpolished pulley, but a much smaller amount on the unpolished pulley, even after a significantly longer total test time.

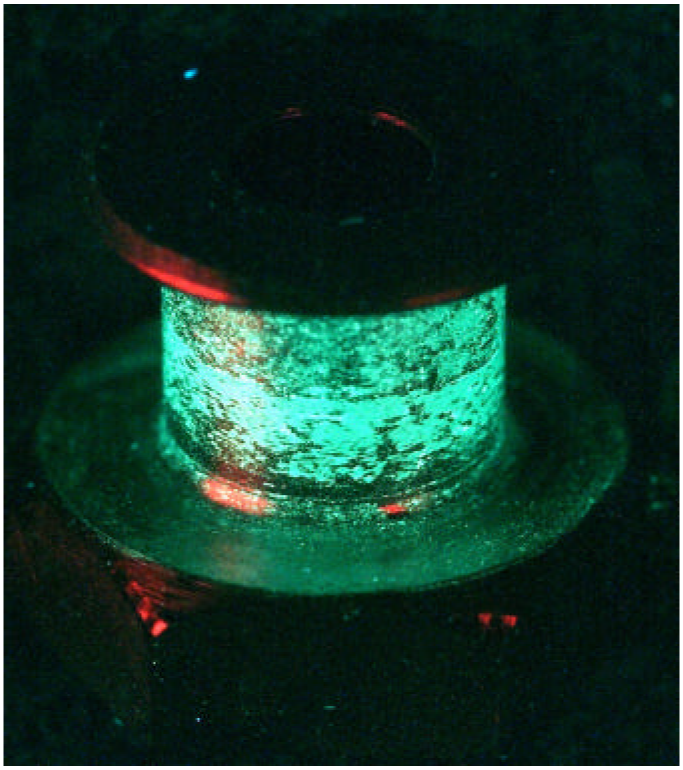


Figure 18: Unpolished pulley after initial (no failure) abrasion shake test. Viewed under UV light, showing green fluorescence from Kevlar debris.

Figure 19: Unpolished pulley from Figure 18 under ordinary illumination. Kevlar debris is barely visible.

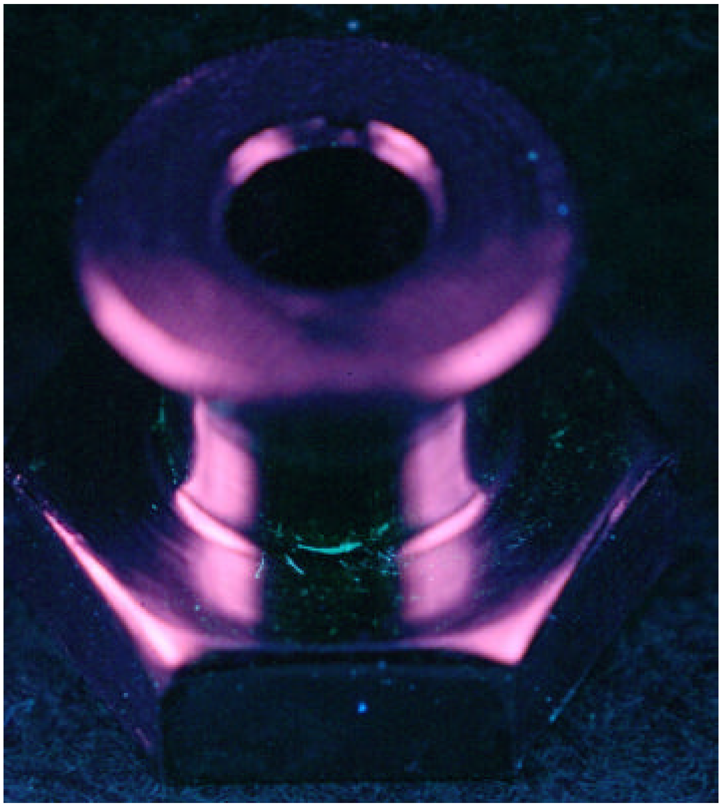


Figure 20: Polished pulley after initial abrasion shake test. Viewed under UV light.

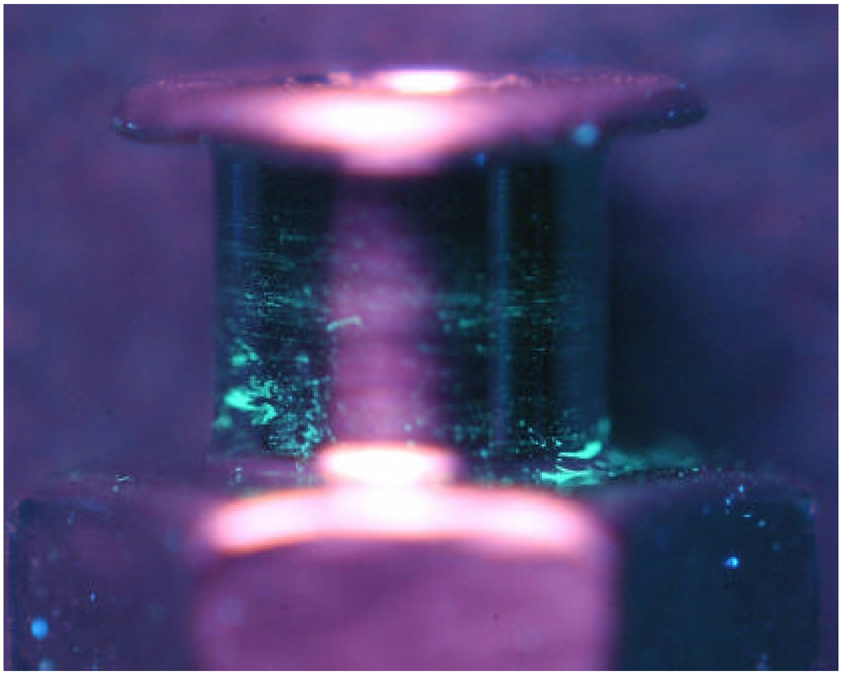


Figure 21: Another view of polished pulley shown above.

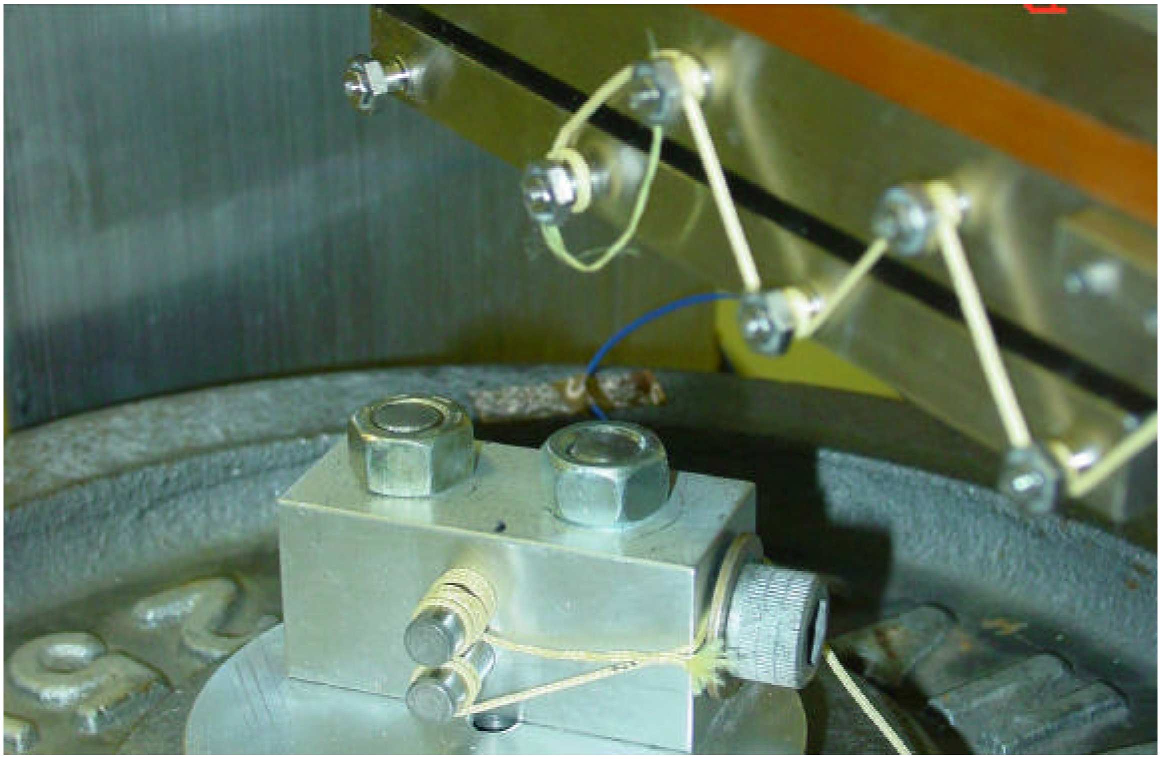


Figure 22: failure from shake with unpolished pulley.

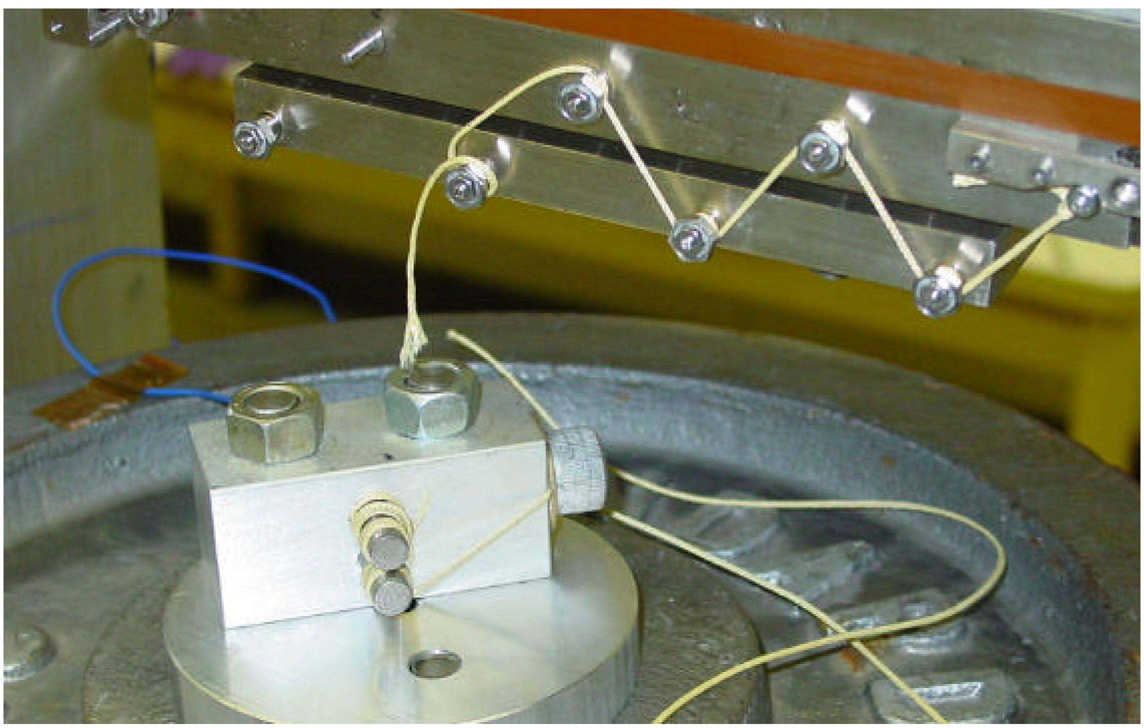


Figure 23: failure from shake with polished pulley.

Figure 24: Unpolished pulley under visible illumination after shake-to-failure test.

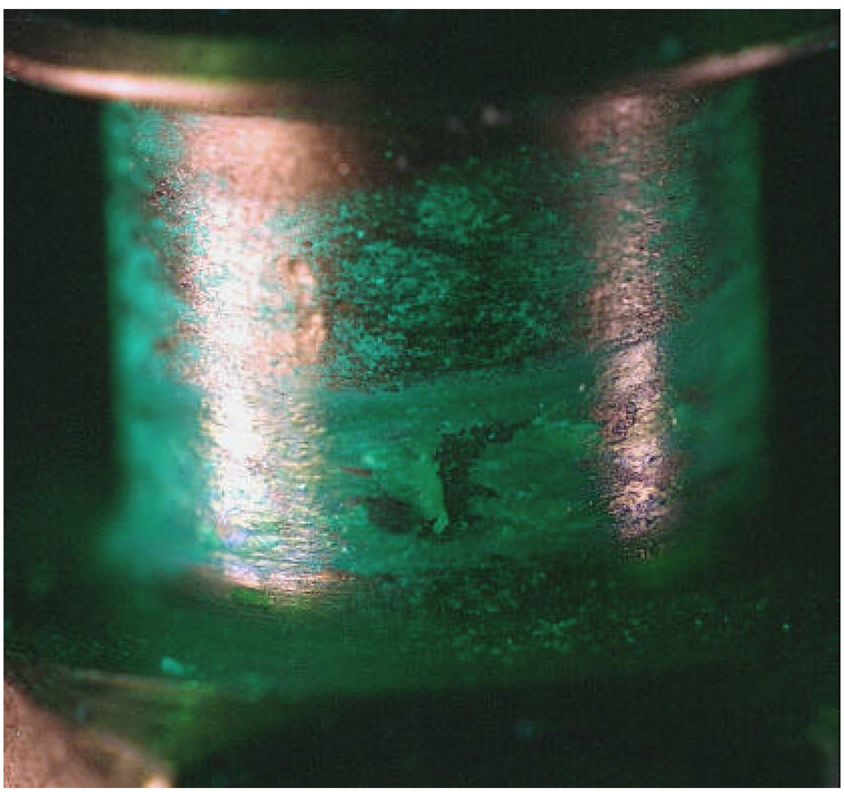


Figure 25: Unpolished pulley from previous figure under UV illumination.

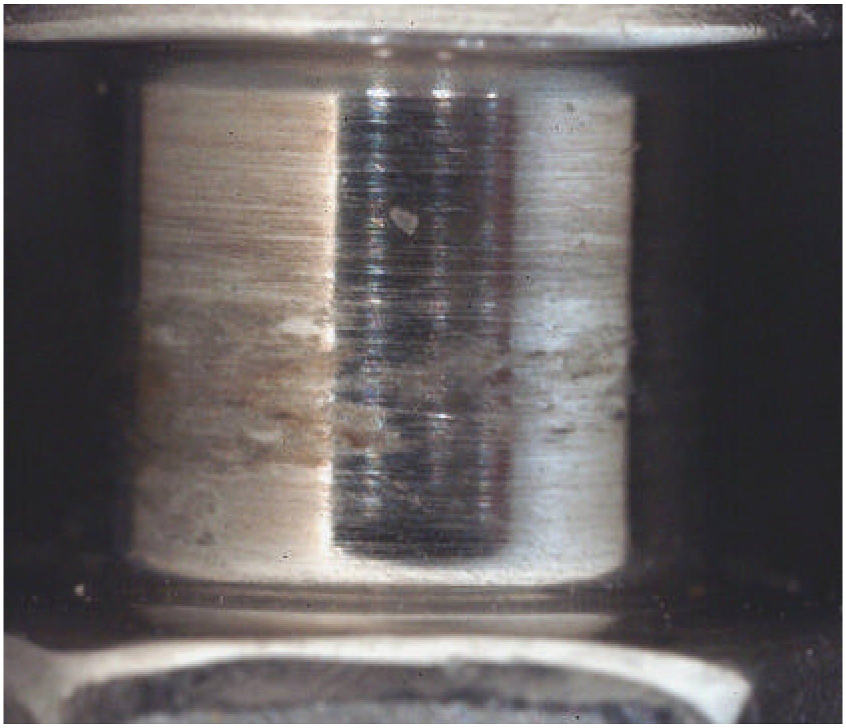


Figure 26: Polished pulley under visible illumination after shake-to-failure test.

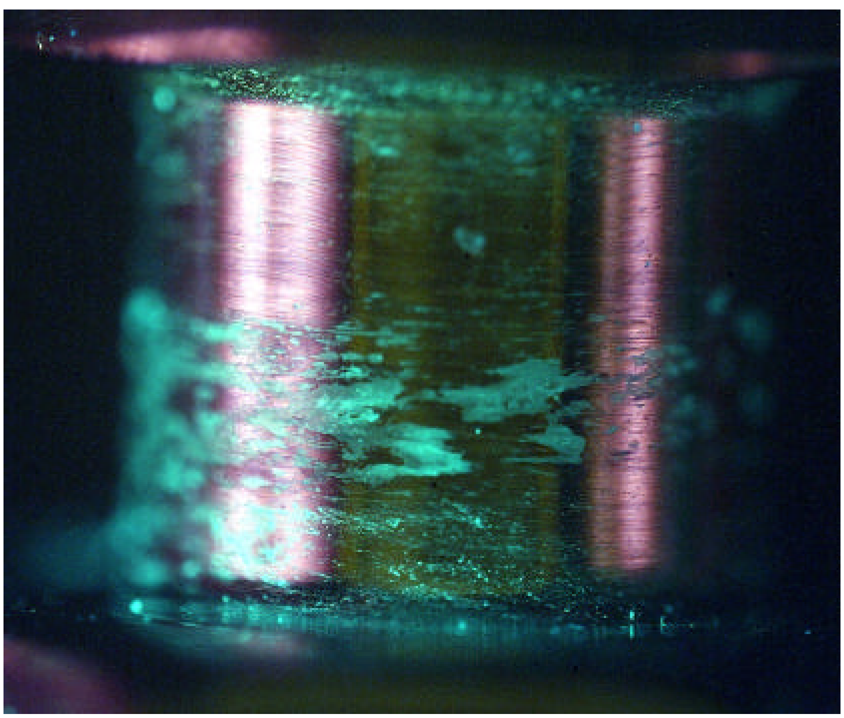


Figure 27: Polished pulley from previous figure under UV illumination.

The details of the shake runs for this test and the previous one are shown in **Error! Reference source not found.**. The result of the last test, a factor of more than 4 times longer lifetime at the highest level with the polished pulley, is tempered by the fact that the last few shakes were all probably contributing damage to the Kevlar. The proper way to account for this is not known, but in any case the test shows that the unpolished pulley significantly degraded the life of the Kevlar.

Table 4: Summary of Kevlar Abrasion Shake Testing

duration min	kevlar length (inches) after run	drive (inch pk-pk)	control (g rms)	top (g rms)	weight (g rms)	kevlar stretch (inch pk-pk)	kevlar force (lbf, peak)
Abrasion Shake Tests (No Failure)							
Unpolished pulley, 3.07" free length initially							
30 min		0.01	14.65	17.51	0.1786	0.0121	12.9
Polished Pulley, 3.44" free length initially							
30 min		0.01	14.63	17.4	0.1605	0.0120	11.6
Shake to Failure:							
Unpolished Pulley, 1.40" free length initially							
15	1.4	0.007	10.122	11.85	0.2167	0.0083	15.7
15	1.42	0.009	13.015	15.28	0.2459	0.0107	17.8
15	1.42	0.011	15.907	18.75	0.2896	0.0132	21.0
15	1.42	0.013	18.799	22.3	0.3223	0.0156	23.3
7.7	Broke at pulley	0.015	21.691	25.72	0.3726	0.0180	27.0
Polished Pulley, 1.48" free length initially							
15	1.5	0.007	10.122	11.87	0.2074	0.0084	15.0
15	1.51	0.009	13.015	15.31	0.2375	0.0108	17.2
15	1.52-1.53	0.011	15.907	18.78	0.281	0.0132	20.3
15	1.53-1.54	0.013	18.799	22.29	0.3316	0.0156	24.0
15	1.55-1.56	0.015	21.691	25.76	0.3699	0.0181	26.8
21.5	Broke at lower end	0.015	21.691	25.76	0.3744	0.0181	27.1
36.5	total at max level						

3.4 Inspection of Other BDAs

In order to rule out any possible degradation of the Kevlar suspensions over time, this failure investigation included inspections of all available BDA suspensions. As the flight units are inaccessible, this leaves the flight spare and Qual BDAs.

3.4.1 Flight Spare BDAs

While at RAL for the CQM inspection, Mark Weilert performed a visual inspection of all of the flight spare BDAs which have been in storage since delivery from JPL. These units had been stored in shipping containers sealed at room humidity. The visual inspections were limited because of the BDA light can which was not removed. The table below shows notes on the inspection taken at the time. No indication of degradation was detected.

Table 5 FS BDA Inspection Notes.

FS SLW SN 015	Visual inspection	OK Slight fraying seen (see photo) this was likely there before, took photo to check.
FS SSW SN 016	Visual inspection	OK Slight fraying seen (see photo) -
FS PSW SN 017	Visual inspection	BDA had been replaced in bowling ball incorrectly screws were not adjacent to cut outs. Some Strands on top pulley (see photo)
FS PLW SN 018	Visual inspection	No indication of degradation, Kevlar looks very good.
FS PMW SN 019	Visual inspection	OK, few fibers showing on top ring, first pulley from capstan-3 termination. This looks like the kind of slight defect that would have passed originally. Took photo.

In general the flight spare units looked very good. The Kevlar is not perfect, but it never was. The slight defects that were seen look like they would have been accepted at initial stringing. There is no indication of degradation.

3.4.2 Qual BDA

The Qual BDA was strung with Kevlar only about 2 months after the CQM PLW. During the SPIRE effort at JPL, the Qual BDA had been stored in a nitrogen purged drybox except while being tested. Since ~Sept. 2005 the Qual BDA had been stored in a sealed shipping container, likely filled with room air. To give the Qual BDA a detailed inspection, the light can was removed to allow better access to the lower braid. A visual inspection of both Kevlar braids under bright light and magnification (magnifying goggles) showed no visible damage to the Kevlar or any signs of degradation. Only the occasional broken fiber could be seen and this was typical of the units even immediately after stringing. The 300mK portion is mechanically rigid (by feel) and an electrical test shows no connection between the 300mK suspended portion and the BDA mounting flange, indicating no touch.

3.5 Failure Analysis Conclusion

The root cause of the failure of the CQM unit appears to be abrasion of the Kevlar braid on the unpolished pulleys. This failure only occurred after inevitable abrasion during the stringing process, qualification level vibration testing and many thermal cycles on the compromised hardware. There is no evidence that intrinsic degradation of the Kevlar over time contributed. Assuming there was no undetected extreme handling during the final shipping, the failure of the unit at the particular instant at the very end of its testing program can only be attributed to the accumulation of wear and tear from the previous testing, thermal cycles and ordinary shipping environments.

4 Impact of Similar Failure on SPIRE / Herschel

The CQM BDA Kevlar failure resulted in a strong touch between the detector-mounting plate within the 300mK portion of the BDA and the aluminum connector bracket in the warm section of the BDA. This would almost certainly create a thermal short large enough to prevent the proper operation of the SPIRE ^{3}He cooler leaving the detectors too warm to operate effectively. Although it is conceivable that a Kevlar break might result in a smaller, less catastrophic, thermal short the most likely case seems to be a strong metal-to-metal touch held in contact by residual Kevlar tension. Such a failure would essentially result in the loss of the SPIRE instrument.

A Kevlar failure would not be expected to compromise the other Herschel instruments. The Kevlar-suspended sub-assembly within the BDA is captured so it cannot move more than a few millimeters even with no Kevlar present. Complete Kevlar failure during vibration might result in rattling of the 300mK portion of the BDA. This could make the detector wafer break and produce some silicon debris, but this would likely be trapped within the SPIRE detector box.

5 Assessment of Risk of Failure of Flight BDAs

The Qual BDA and all subsequent units including the FM and FS BDAs used polished pulleys, which have been shown to produce much less Kevlar damage. In addition, because of the pre-existing fraying which was discovered on the CQM BDA, all later units were inspected during stringing much more closely for any evidence of abrasion or other damage to the Kevlar. In several cases stringing was redone with new Kevlar after damage was discovered. The Qual BDA, which was strung only shortly after the CQM has been subjected to higher level vibration testing and many more thermal cycles and has survived intact. **These facts make it unlikely that a similar failure would occur on the flight units before or during launch.** A failure after launch is even less likely since the environment at that stage will be more benign and the Kevlar tension is lower when the unit is cold.

6 Mitigations to Reduce Residual Risk

The residual risk of the FM BDAs experiencing a similar failure is in large part associated with the uncertain circumstances of the actual CQM failure event. Therefore we suggest the following mitigations.

6.1 Monitoring / Control of Shipping Environment

Although some monitoring was in place during shipping, and it seems to indicate the dynamic environment was benign, it is still likely that the failure occurred during shipping. It is prudent to take additional care in controlling and monitoring the vibration and shock environment during transportation of the BDA or any higher-level assembly.

6.2 Monitoring / Control of Humidity & Temperature

As stated in the BDA handling document (JPL D-26653) delivered with the hardware, the BDA is humidity and temperature sensitive. Units should be stored or shipped in a dry environment.

High humidity or temperature both result in increased tension in the Kevlar which should particularly be avoided during shipping of the BDA or any higher level of assembly.

7 Conclusion

The failure of the Kevlar braid on the CQM BDA probably occurred during shipping, but the root cause was very likely the abrasion of the Kevlar at the surfaces of the unpolished pulleys used on that BDA. The consequences of a similar failure on the SPIRE instrument would be dire; however, the flight, Qual and flight spare BDAs already incorporate a design change to eliminate the root cause. The abrasion at the pulleys had been discovered in 2003, shortly after the assembly of the CQM, and the polishing of the pulleys to reduce the problem was implemented at the time for all subsequent BDAs. The improved design was successfully flight qualified, and testing during this failure investigation showed that the BDAs with the polished pulleys should be much more robust than the unit that failed. Thus, while it is prudent to take additional care in the shipping of the instrument, the chance of a similar failure on a flight unit is very low.

Appendix A: CQM PLW Operations Log (JPL) and Historical Record (RAL)

Operation Log Compilation
CQM
PLW
10209800-1 S/N 006

starting after assembly complete

Date	Operation
28-May-2003	Assembly Complete electrical resistance test
29-May-2003	Installation in Cold Shake Facility
29-May-2003	Pump Out
30-May-2003	Backfill with 300 torr GN2
30-May-2003	Cooled to 100K and Shake Tested
30-May-2003	Warmup
2-Jun-2003	Vent
2-Jun-2003	Remove from Cold Shake Facility
3-Jun-2003	Post-Vib electrical resistance test
11-Jun-2003	Installation in Cold Alignment Facility
11-Jun-2003	Pump Out
12-Jun-2003	cooled to 4K
-	cold alignment and continuity tests
14-Jun-2003	Warmup
15-Jun-2003	Vent
15-Jun-2003	remove from CAF for metrology
16-Jun-2003	Installation in Cold Alignment Facility
16-Jun-2003	Pump Out
16-Jun-2003	cooled to 4K
-	cold alignment and continuity tests
17-Jun-2003	Warmup
18-Jun-2003	Vent
18-Jun-2003	Remove from Cold Alignment Facility
25-Jun-2003	CQM PLW filter installation
26-Jun-2003	Installation in BoDAC test facility
27-Jun-2003	Pump Out
29-Jun-2003	cool to 77K/4K/300mK
-	BDA functional / performance tests
4-Jul-2003	Warmup
7-Jul-2003	Vent
7-Jul-2003	Pump Out
8-Jul-2003	cool to 4K / 300mK

-	BDA functional / performance tests
22-Jul-2003	Warmup
24-Jul-2003	Vent
25-Jul-2003	Pump Out
26-Jul-2003	cool to 4K / 300mK
-	BDA functional / performance tests
6-Aug-2003	Warmup
18-Aug-2003	vent
18-Aug-2003	Removal from BoDAC test facility

DESCRIPTION OF ACTIVITY / EVENT	REMARKS/ REF. DOC.	OPERATING TIME	DATE	SIGNATURE
Delivery of BDA to RAL			August 2003	
BDA incoming inspection	SPIRE-RAL REP-001773		12-Sep-2003	
CQM Integration				
PLW BDA Fitted			16-Sep-2003	
FPU Moved to cryolab for WFT			12-Dec-2003	
Harness Integration			12-Dec-2003	
Warm functional test performed			14-Dec-2003	
FPU Returned to G56			15-Dec-2003	
1st Cold Thermal Verification				
FPU Moved to cryolab			23-Dec-2003	
Cooldown Started	FIRST COOL DOWN		24-Jan-2004	
Cold Functional Tests Performed			29-Jan-2004	
Cooler Recycled for 1st time			02-Feb-2004	
PLW on			03-Feb-2004	
PCAL on – 1st light			04-Feb-2004	
Warm up started			15-Feb-2004	
FPU at room temp, tank vented, WFT performed			20-Feb-2004	
FPU Removed from cryostat and returned to clean room			25-Feb-2004	
Preparations for Cold Vibration				

Spacecraft/Project	**Herschel**	**Document**			
Instrument/Model	**SPIRE/CQM**	**Issue No**		**REV**	
Subsystem	**FPU**	**Date**	**27 June 07**		

DESCRIPTION OF ACTIVITY / EVENT	REMARKS/ REF. DOC.	OPERATING TIME	DATE	SIGNATURE
SCAL Removed and sent to Cardiff for test			05-Mar-04	
Mass dummy and accelerometer fitted to spectrometer det box, to replace the STM BDAs	THE CQM BDA REMAINED IN POSITION		11-Mar-04	
Mass dummy and accelerometers fitted to photometer box, to replace the STM BDAs			13-Mar-04	
Cold Vibration Tests				
CQM packed in transport container			27-Mar-04	
CQM shipped for cryogenic vibration at CSL			28-Mar-04	
Cold Vibration Test at CSL	FIRST COLD VIBE TEST THIS INCLUDED TWO COOL DOWN			
FPU Returned to RAL –			07-May-2004	
Incoming Inspection			07-May-2004	
Detector boxes removed from SOB			14-May-2004	
PLW detector removed from Photometer Detector Box			04-Jun-2004	
Inspection and metrology of BDA				
CQM Re-Integration				
CQM PLW Integrated			20-July-2004	

DESCRIPTION OF ACTIVITY / EVENT	REMARKS/ REF. DOC.	OPERATING TIME	DATE	SIGNATURE
Detector Boxes Integrated			03-Aug-2004	
Completed integration			11-Aug-2004	
2nd Cold Thermal Verification				
FPU Moved to cryolab			11-Aug-2004	
Cooldown Started	FOURTH COOL DOWN		04-Sep-2004	
Cold Functional Tests Performed			10-Sep-2004	
1st Cooldown to 276mK			17-Sep-2004	
Performance Testing Started			21-Sep-2004	
JFET-2 Failed			13-Oct-2004	
Warm-Up Started			15-Oct-2004	
FPU Removed from cryostat and returned to clean room			26-Oct-2004	
Preparations for Delivery				
SPIRE CQM packed for transport			13-Nov-2004	
SPIRE CQM shipped to Ottobrunn			14-Nov-2004	
At Ottobrunn				
FPU Unpacked			22-Nov-2004	
PLW JFET replaced			22-Nov-2004	
Connected to FPU warm electronics for functional tests			23-Nov-2004	
FPU Returned to RAL			23-Dec-2004	

Spacecraft/Project	**Herschel**	**Document**			
Instrument/Model	**SPIRE/CQM**	**Issue No**		**REV**	
Subsystem	**FPU**	**Date**	**27 June 07**		

DESCRIPTION OF ACTIVITY / EVENT	REMARKS/ REF. DOC.	OPERATING TIME	DATE	SIGNATURE
FPU Unpacked and Inspected			23-Dec-2004	
L1 strap to FPU short investigated			23-Dec-2004	
FPU packed and returned to Ottobrunn			16-Jan-2005	
FPU integrated to OBA				
EQM test campaign, one cooldown	FIFTH COOL DOWN			
Removed form EQM cryostat				
FPU packed and returned to RAL			23/2/06	
FPU updated for Stray light tests etc				
FPU packed and shipped to Friedrichshafen			16/5/06	
Fitted to FM cryostat for the STM2 test campaign				
Cool down	SIXTH COOL DOWN			
Transport to ESA				
STM 2 test campaign.				
Warm up and transport to Friedrichshafen				
Remove from cryostat				
Pack and return to RAL			23/4/07	
Strip CQM for refurbish to FS, remove PLW BDA			29/5/07	

NCR Number:	HR-SP-RAL-NCR-172v2

Spacecraft / Project	**Herschel / SPIRE**	**Originator's Name**	Dion Dawson	
Experiment / Model	SPIRE	**Signature**		
Sub-System	CQM	**Date**	**v3 23 September 2007**	
Assembly	Phot box	**Level** (Highlight if applicable)	**Major**	Minor
Sub-Assembly	PLW BDA			
Item		**NRB Reference**		
Serial Number	006			

NCR Occurred During (Highlight if applicable)	Manufacture	**Inspection**	Test	Integration	Other

NCR Title	**Failure of KEVAR Tension Cord on CQM PLW detector**

NCR Description

Prior to refurbishment of the CQM phot box for the FS Programme, the CQM PLW BDA was removed.
On inspection, the Kevlar tension cord on the PLW BDA was found to have severed.
(See Photos Below of first and second inspections respectively)

Cause of NCR

JPL stated that this BDA had some slight damage to the cords before shipment and as part of the CQM it has seen greater environmental testing than flight units which may of contributed to problem.
However none could be seen on the areas of cord visible on this assembly except for the top cord on the opposite side to the broken lower one.

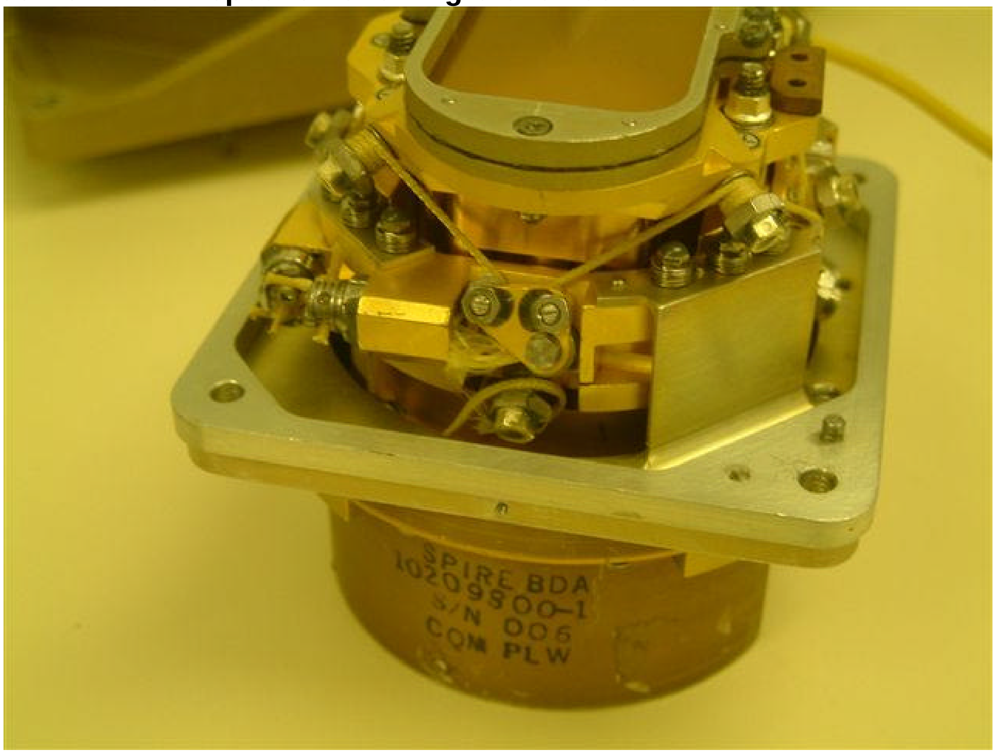
Disposition / Corrective Action

- **See Minutes of JPL-SPIRE Telecons 29 May 2007 – Sept. 25 copied below**
- **JPL investigations are documented in document *CQM BDA Kevlar Failure Report*, by Mark Weilert**
- **Review meeting to be held by videoconference on Oct. 1 – minutes and documentation to be attached**
- **Conclusions: TBW after review meeting**

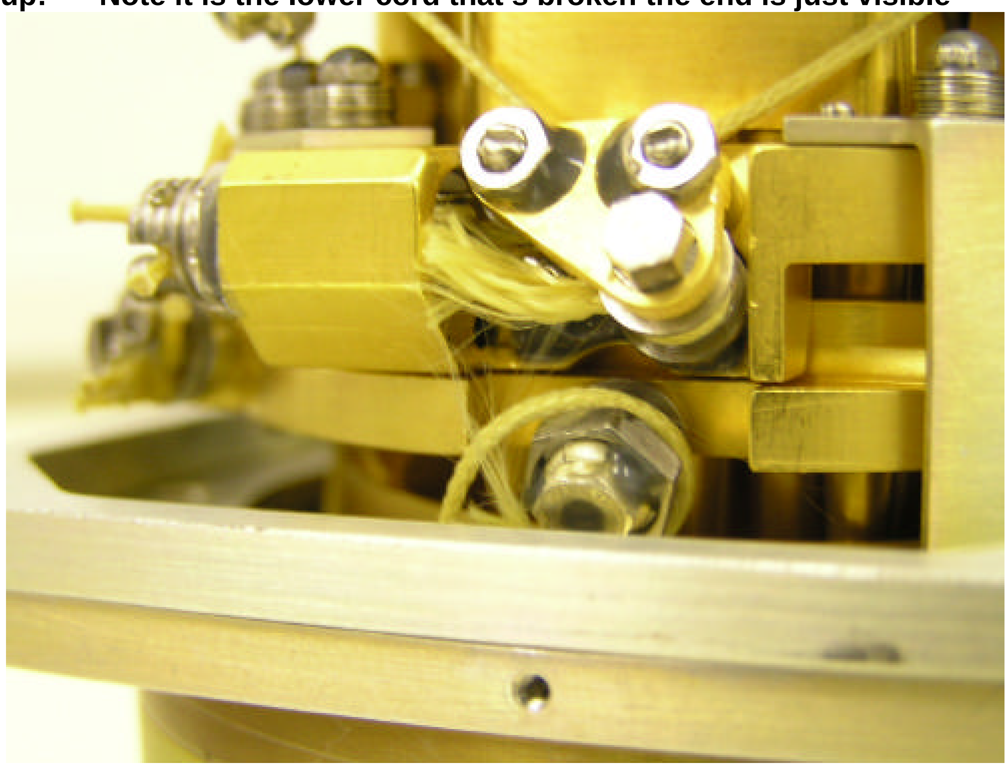
Document or Drawing Affected (Title, Number & Issue)	**Estimated COST OF NCR (cost of : correction, Materials, Resource, and delay to Project etc.)**

NCR CLOSED	**Name**	**Sign & Date**	
		Approved	**Rejected**
Project Manager	**Eric Sawyer**		
Product Assurance:	**Eric Clark**		
Principle Investigator	**Matt Griffin**		
Product Assurance:	**Jim Newell**		
Co-Investigator			
ESA Product Assurance	**Jan Rautakoski**		
ESA Project Office	**Carsten Scharmberg**		

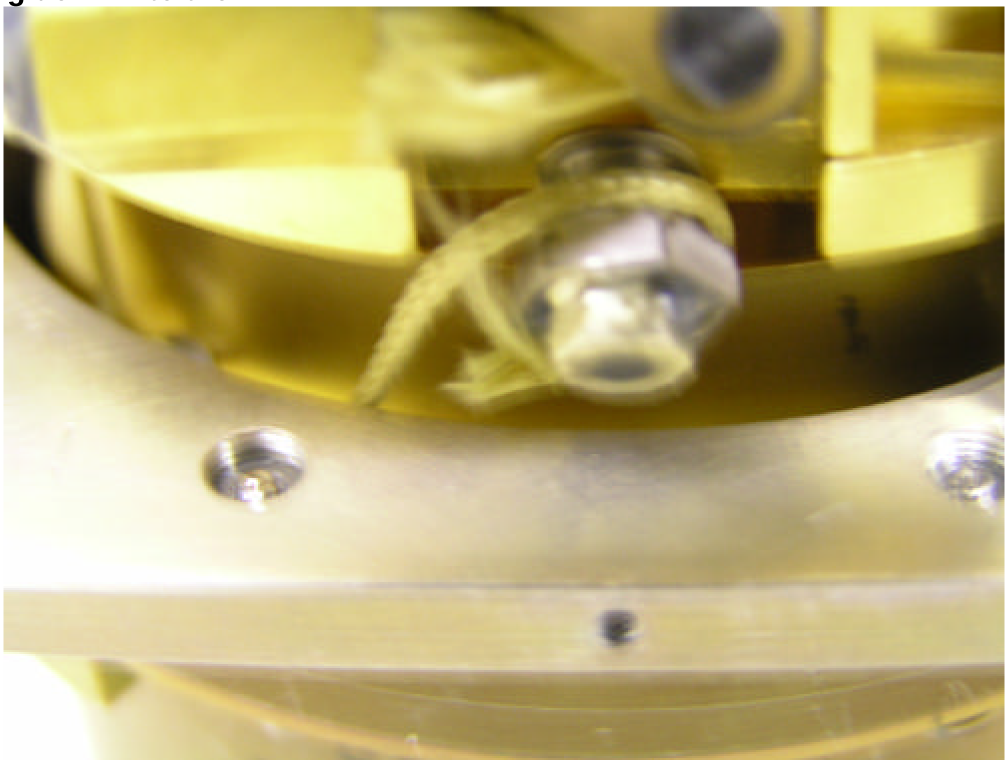
Photos from first inspection showing broken cord

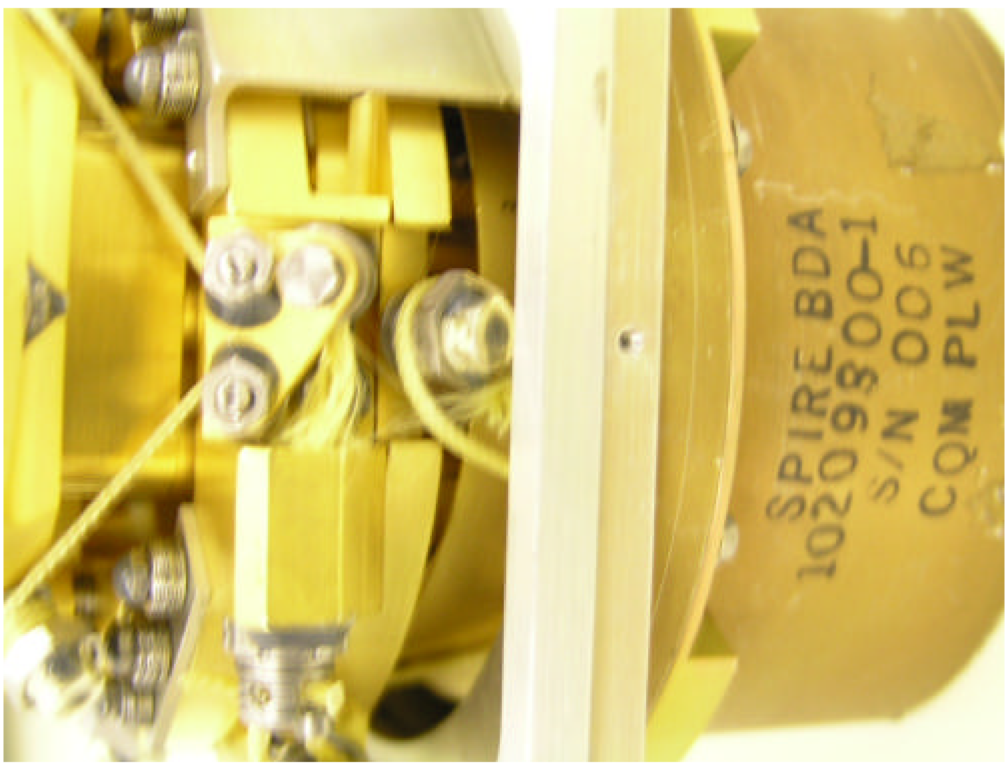


Close up: Note it is the lower cord that's broken the end is just visible

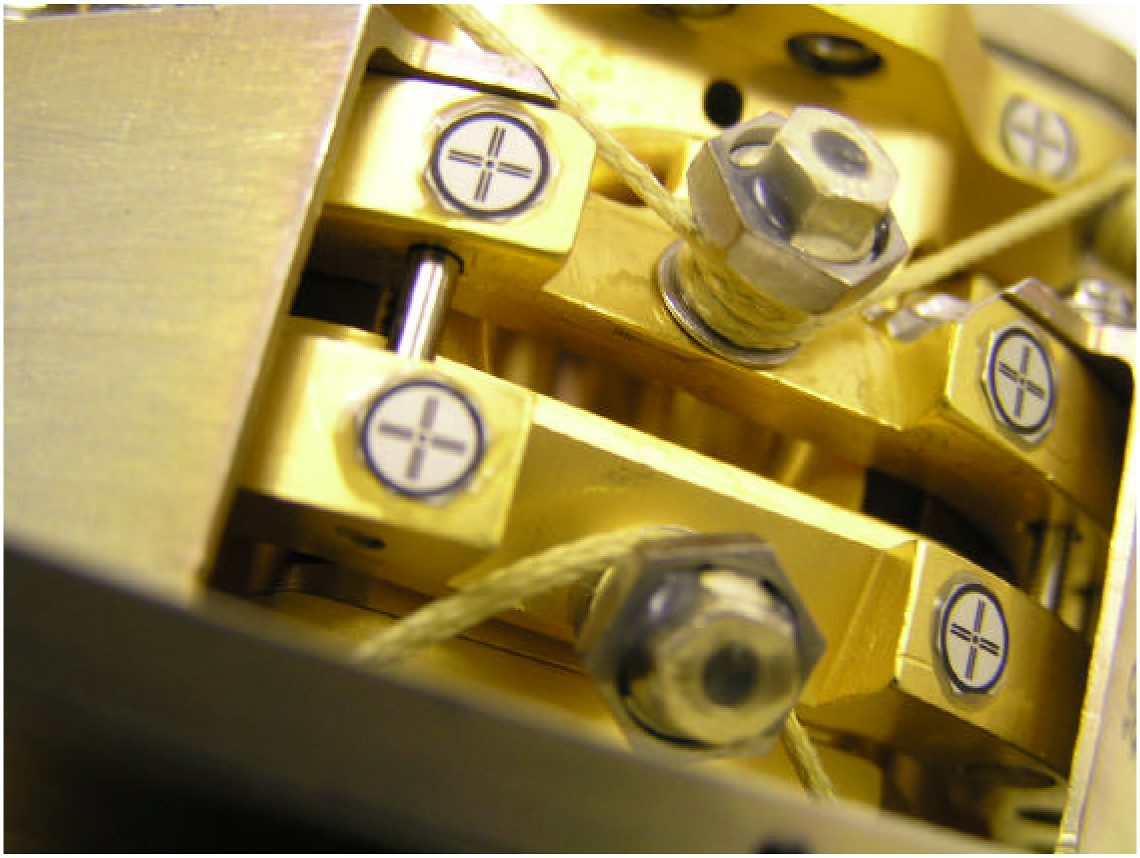


Photos from Second inspection following JPL telecon on 5th June 07
Looking down into the BDA





View Opposite side to the Break when viewed under x15 magnification the upper cord is starting to fray



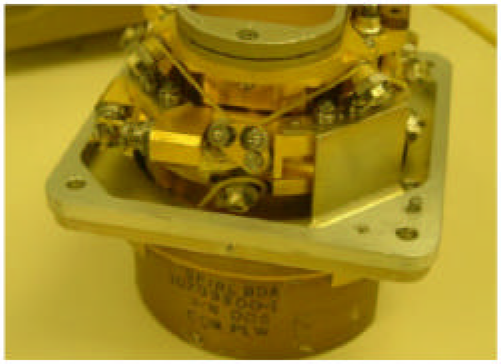
Comments

Other than the broken cord no cuts nicks or damage to the Kevlar cords was seen using x15 magnifier except for the fraying on the top cord not quite visible in the photo above

It is planned to take higher magnification Photos of this problem shortly they will be added to the updated NCR form when available.

Extract from Minutes of JPL-SPIRE Telecon 29 May 2007

3. CQM BDA inspection



- On inspection of CQM BDA at RAL, a Kevlar cord was seen to be broken on CQM BDA (see picture)
- No other evidence of any damage inside the FPU
- Sequence of events:
  - Last vibration was instrument-level cold vibration in June 2004
  - BDA was inspected and some metrology done, reinstalled in July 2004
  - CQM closed up
  - Second cold verification in August 2004
  - Delivered to Astrium in November 2004
  - Installed and tested in the EQM cryostat at Ottobrunn
  - Cooled down only once
  - EQM programme finished and cryostat warmed up in early 2006 (TBC)
  - Returned to RAL
    - Some work done on the FPU
      - Installation of black tiles etc.
      - Detector box not opened
  - Then shipped to Friedrichshafen in mid-2006
    - Installed in the STM2
    - Cooled down at Friedrichshafen
    - Transported cold to ESTEC
    - Returned "cool"
  - FPU removed
  - FPU transported by MSSL driver in back to RAL March
  - BDA 300-mK stage is shorted to case – seems to be touching
  - If Kevlar breaks, it's unlikely not to get a touch (Jamie will confirm with Mark)
  - Eric: looks like a recent breakage – Kevlar is wrapped around the capstan
- Jamie: a fray had been noted on this assembly
  - Can check the documents and check that
- Transportation box shock monitors
  - Mounted on baseplate rather than the FPU
  - Baseplate is on an antivibration mount
  - Trip switches were not activated (5-g tripped, but higher levels didn't – nothing unusual)
- Process for inspection
  - BDA will be left alone at RAL for now - could be dangerous to ship
  - Jamie will get in touch with Marty and Ulf to decide on how to proceed
  - Next telecon Tuesday 5 June – will be used as NCR update
  - Action: Eric to start an NCR form for the CQM BDA before he goes on holiday at the end of this week

Extract from Minutes of JPL-SPIRE Telecon 5 June 2007

3. CQM BDA

- These notes will be incorporated into the NCR document by Eric C.
- Further visual inspection: Doug has looked at the Kevlar under the microscope
  - Section of Kevlar near detector disappeared
  - It's broken near the capstan
  - ~ 5 mm from the end the cord is intact
  - It's a frayed break - individual fibres broken over a length of about 5-mm
- BDA is now back in storage in the clean room
- Jamie has been in contact with Mark Weilert (who's on vacation at present)
  - Mark says top braid was frayed not the bottom one that broke; also thinks it's very unlikely that the unit could maintain thermal isolation
  - Mark will be back on June 18th – could take part in June 19 telecon
- Doug will look at top cord to see if the "nick" location can be seen and distribute any additional photos
- Bruce: All evidence from EQM and STM 2 is that the unit was thermally OK and consistently aligned; certainly no change between EQM and STM2.
- Next inspection stage:
  - Agreed that it should be inspected at RAL
  - JPL will start making arrangements for Mark to visit (could be in the week of the 18th)
- Other points noted and to be considered later if appropriate:
  - All five FS BDAs have been inspected and all appear to be fine
  - BDA manufacturing process for later BDAs may have been better in some important respects
  - The CQM BDA has been tested and exercised more than others – may have some relevance

Extract from Minutes of JPL-SPIRE Telecon 12 June 2007

3. CQM BDA

- Mark Weilert will be coming to RAL – travel plans have been made for him and he will be at RAL during the detector meeting.

Extract from Minutes of JPL-SPIRE Telecon 26 June 2007

3. CQM BDA

- Inspection
  - Mark Weilert inspected the unit at RAL last week
  - Also inspected all FS BDAs – no apparent damage
  - CQM BDA has been shipped back to JPL (arriving LAX tomorrow) with some PTFE spacers to restrain it
  - Inspection to continue at JPL – further reports in the next telecons
  - **Action: Eric to provide a timeline of what happened to the CQM pre-delivery after its initial delivery to RAL.**
- Analysis
  - Bruce presented some analysis on hold time at the RAL meeting.
  - PFM-5 cooler hold time not so clear – no dedicated test, although hold time was OK – max. seen is 55 hrs – but conditions non-nominal. There will be cooler hold-time test in IST.
  - PFM-3 hold-time and strap ΔT were anomalous: smaller ΔT (10 mK) and lower hold time.
  - PFM-2 had same ΔT as in 4 and 5.
  - Jamie: useful to see if delta-T was the same throughout PFM-3. Hien can check that –Bruce will specify which OBSIDs to look at.
  - **Action: Bruce to send PFM-2 thermometry/load curve data to Hien, and specify a set of OBSIDs to check for consistency of ΔT during PFM-3**
  - Jamie has PFMM-5 PTC load curves – not analysed yet. Hien will also look at those.

Extract from Minutes of JPL-SPIRE Telecon 3 July 2007

3. CQM BDA

- Not yet received by Jamie at JPL
- Eric has distributed the CQM Historical Record document (see Annex 1)

Extract from Minutes of JPL-SPIRE Telecon 17 July 2007

4. CQM BDA

- Update on inspection status and plans from JPL
  - BDA has arrived at JPL and Marc has started inspection
  - Internal JPL meeting tomorrow to discuss the plan
  - Marty may (or may not) be available – it would be excellent if he were to be able to lead this activity
  - Jamie will be away for three weeks from tomorrow
- Plan for continuing investigation and formal NRB meeting (discussed with Ulf after Agencies meeting)
  - Could be videocon or telecon if deemed acceptable but a face-to-face meeting preferred
  - Needs to be very thorough as it's a potential single point failure for SPIRE
  - Key points/objectives
  - Inspection of CQM and other BDAs
    - Especially flight standard, but all other relevant units should be considered
  - Manufacture, test history of the CQM unit and FS and FM BDAs
    - Other units can be considered if relevant to building up a picture of the properties and reliability of the units
  - Differences between CQM and FM/FS manufacturing or assembly processes and procedures
  - The possible impact of a similar failure of an FM BDA
    - Impact on operation/performance of other BDAs and the cooler
    - Implications for scientific performance of SPIRE
  - Assessment of the risk of such a failure pre-flight or in-flight
  - What are the options, if any to remove or mitigate such risk?
  - Any special requirements/recommendations for testing at system level
  - Preliminary date, location: TBD - possibly end September

Extract from Minutes of JPL-SPIRE Telecon 24 July 2007

3. CQM BDA

- JPL Tiger Team kick-off meeting 18 July
  - Mark Weilert will lead the team with assistance from Marty Herman
- BDA received on July 12 – Mark's ruggedisation seems to have worked
- Bottom braid taken out and inspected
  - Break seems to have happened at second pulley from staked end
  - A lot of abrasion near the break
- JPL are assembling documentation on history of the unit
- Formulation of review topics and objectives as summarised in last weeks minutes OK for now

Extract from Minutes of JPL-SPIRE Telecon 31 July 2007

3. CQM BDA

- Tiger Team now fully formed – similar make-up to JFET team
- Mark Weilert has located break at exit of wrap-around on a pulley
- Will look in detail at that particular pulley with a fibre-scope to check for imperfections etc.
- May also do some SEM inspection
- Documentation and paperwork being prepared
- Break symptoms being compared with other historical breakages from the development phase.
- September still feasible for the review meeting
- Eric: any pull tests planned on the Kevlar from this unit?
  - Ulf: will bring this up at tomorrow's meeting

Extract from Minutes of JPL-SPIRE Telecon 14 August 2007

3. CQM BDA

- All pulleys removed on lower Kevlar,
- SEM investigations
- Pulley 2 (the one where the break occurred) is worse than the rest
- Has sharp corner and scratches.
- Vibration test planned for this week, one set up with suspect pulley to compare with a pristine pulley.
- Features like these should have been detected on FM, but investigations continue.
- Can we SEM pulleys on the CQM, Ulf, SEM of spare pulleys has been done.
- Will investigation of FS units be required; no as full disassembly would be required.
- Detailed SEM of failed Kevlar to be carried out this week.

Extract from Minutes of JPL-SPIRE Telecon 23 August 2007

3. CQM BDA

- JPL update
  - Vibration test of two pulleys
    - One high quality and one unpolished with some nasty grooves (like the CQM)
    - Shaken in vertical direction for about 30 minutes
    - No breakage
    - Inspection to be done to look for Kevlar damage
  - UV pictures of CQM pulleys
    - A lot of Kevlar attached to pulleys – consistent with surface abrasion
- Date for the NCR review meeting
  - Monday 24 Sept. by videocon; start 3 pm UK time
  - TBC at next week's telecon
    - Action: Eric and Ulf to check availability of videocon facilities
  - ESA to be invited to participate (preferably by sending someone to RAL)
  - Agenda and documentation to be considered at next week's telecon

Extract from Minutes of JPL-SPIRE Telecon 28 August 2007

3. CQM BDA

- E-mail summary by Ulf on 25 Aug:

1. Mark reported on the vibration tests performed. The initial test at TBD displacement showed no breakage with either pulley even after 30 minutes of testing. A second test sequence was run with new Kevlar braids at 200 Hz amplitude and 51 lbs tension. Vibration runs of 15 minutes duration were performed starting with a displacement of 0.007" , and increasing by .002" after each 15 minute interval. The Kevlar broke at CQM pulley #2 after 7 minutes of testing at 0.015" displacement. In contrast, the Kevlar wrapped around the pristine pulley broke after 35 minutes of testing at 0.015" displacement in a location far removed from the pulley.

2. Saverio showed UV pictures of CQM pulley #2 and the polished pulley after the initial 30 minutes of vibration testing. The CQM pulley had significantly larger amounts of Kevlar rubbed off on it in contrast to the polished pulley.
[Did we take a picture of how pulley#2 looked after it was cleaned?]

3. Pictures will be taken of the two pulleys after the second vibration test. Pictures will also be taken of the various broken Kevlar braids to search for consistency of breakage.
[Was pulley #2 cleaned after the first vibration test? Was a picture taken?]

4. A Video conference meeting will be held with RAL to complete the NCR action. It will likely take place on October 1. The 3 hour meeting will start at 7 AM PDT.

5. Mark will start drafting the report.

The final meeting will be held Thursday 8/23 at 9 AM in 301-429. Only Mark, Marty and Ulf is available that day.

I want to express my gratitude for your excellent support in bringing this activity to a quick completion.

- Evidence is accumulating linking the failure to the particular surface condition of the CQM pulley (much rougher than for the FM units)
- Mark is compiling a test report for the review
- Plan for review videocon
  - New date = Oct 1; 3 – 6 PM UK time
  - Detailed agenda will be discussed at next weeks telecon

Extract from Minutes of JPL-SPIRE Telecon 4 September 2007

3. CQM BDA

3.1 JPL update

- Investigation report under preparation
- Detailed photos to be taken this week of the two pulleys tested
- Internal JPL review of the report planned
  - Maybe some minor additional activities but not much

3.2 Objectives and key questions for the review meeting on Oct. 1

- Discussion has been summarised below in the form of proposed review objectives and draft agenda

- Proposed Review Objectives (to be iterated in future telecons)

1. Assess the cause of failure of the CQM BDA Kevlar support
2. Identify all relevant differences between that unit and the FM and FS BDAs
   - design, manufacturing or assembly processes and procedures
   - operational history (thermal cycles, vibration tests, etc.)
3. Assess any relevant information on the mechanical behaviour of systems with a similar design (e.g., BDA units used in other projects; the development of the 300-mK thermal strap supports for SPIRE)
4. Assess the possible impact on SPIRE and/or Herschel scientific performance of a similar failure of an FM BDA
5. Assess the risk of such a failure pre-launch or during/after launch.
6. Identify the options, if any, to remove or mitigate such risk
7. Identify any special requirements/recommendations for testing at system level

   - Items 4, 5 and 6 are the key issues for the review – difficult questions but need to be considered as thoroughly as possible.
   - **These topics need to be discussed and (preliminary) conclusions written up before the review meeting – to be discussed in next two telecons**
   - Some preliminary points
     - Impact of failure: is most likely to be hard thermal short between 2 K and 300 mK, probably making SPIRE inoperable. Milder scenarios are a softer short resulting in degraded ^{3}He hold time and violation of the grounding scheme, or no physical short but misalignment of the affecte array. We should assume the worst
     - Risk of failure occurring on FM: this will need to take into account the planned vibration testing (levels and durations) that the BDAs will be exposed to before and during launch. Will be difficult to be definitive as the CQM unit failed under unknown circumstances.

- Draft agenda (for iteration in next couple of telecons)

1. Objectives of the meeting (Matt/Eric)
2. List of documents and presentations available (Eric)
3. Summary of NRB process so far (review of NCR minutes to date) (RAL)
4. Run-through of JPL Investigation Report (JPL)
   - to include
     a. CQM build standard and history; differences wrt FM/FS units
     b. analysis of failure event and failure mode(s)
     c. assessment of any other relevant data on similar units
5. Relevant aspects of thermal strap support system design and development (Cardiff)
6. Details of planned thermal cycling and vibration tests (BDA levels and lengths of tests) for system-level tests (RAL)
7. Impact on SPIRE and/or Herschel scientific performance of a similar failure of an FM BDA
8. Risk of such a failure pre-launch or during/after launch
9. Options, if any, to remove or mitigate such risk
10. Special requirements/recommendations for testing at system level
11. Conclusions and recommendations

Extract from Minutes of JPL-SPIRE Telecon 11 September 2007

3. CQM BDA

3.1 JPL update

- Additional Tiger Team meeting held
- Pictures of the tested pulleys still to be done
- Review objectives as defined in last week's minutes: all OK (noting that JPL and UK team need to work together on some of the issues)
- Mark Weilert's draft report will be available at JPL this week – will review internally at JPL before making it available

3.2 Objectives, documents and agenda for review meeting on Oct. 1

- Review Objectives as listed in last week's telecon are agreed:
  1. Assess the cause of failure of the CQM BDA Kevlar support
  2. Identify all relevant differences between that unit and the FM and FS BDAs
     - design, manufacturing or assembly processes and procedures
     - operational history (thermal cycles, vibration tests, etc.)
  3. Assess any relevant information on the mechanical behaviour of systems with a similar design (e.g., BDA units used in other projects; the development of the 300-mK thermal strap supports for SPIRE)
  4. Assess the possible impact on SPIRE and/or Herschel scientific performance of a similar failure of an FM BDA
  5. Assess the risk of such a failure pre-launch or during/after launch
  6. Identify the options, if any, to remove or mitigate such risk
  7. Identify any special requirements/recommendations for testing at system level

- Draft agenda also agreed – to be finalised when Eric is back

  1. Objectives of the meeting (Matt/Eric)
  2. List of documents and presentations available (Eric)
  3. Summary of NRB process so far (review of NCR minutes to date) (RAL)
  4. Run-through of JPL Investigation Report (JPL)
  5. Relevant aspects of thermal strap support system design and development (Cardiff)
  6. Details of planned thermal cycling and vibration tests (BDA levels and lengths of tests) for system-level tests (RAL)
  7. Impact on SPIRE and/or Herschel scientific performance of a similar failure of an FM BDA
  8. Risk of such a failure pre-launch or during/after launch
  9. Options, if any, to remove or mitigate such risk
  10. Special requirements/recommendations for testing at system level
  11. Conclusions and recommendations

- Additional information needed for the review (as summarised in Jamie's e-mail)
  - Briefly discussed as indicated below – Eric to compile relevant information prior to the review

  - *PFM BDA vibration and cool-down exposure to date and expected through launch. This will allow a comparison the exposure already encountered on the CQM and make an assessment of risk.*
    - OK – Eric to compile

  - *Thermal strap Kevlar failure documentation. This will allow a comparison with an almost identical failure mode in the history of SPIRE.*
    - Pete has compiled relevant documentation – see Annex:
      1. CQM Kevlar failure inspection report
      2. Flight unit EIDP (see esp. pp. 47 – 64)
      3. Vibration qualification report

- *Cold ship temperature versus time. We are concerned that Kevlar stress could be maximized during the cool down and warm up cycle which depends on the thermal profile.*
  - Max 5 K per hour as measured on 2-K or 4-K box down to 80 K
  - No expedited warm-ups
  - Cold transport was from ESTEC to Friedrichshafen
    1. Was it warming up while under transport?
    2. What were the transport conditions? (shock monitors etc.)

- *History of FM dewar warm ups (i.e. warm up times, and were any accelerated due to inadvertent exchange gas). Particular interest here is in the last warm up.*

- *What monitoring was used for vibration during shipment past and planned? This is an area to reduce risk.*
- SPIRE has used standard shock monitors
- Not sure about spacecraft plans

- *What procedures have been in place to reduce exposure to humidity? This is also an area to reduce risk.*
- FM is in the clean room at Astrium – standard clean room conditions (Eric to document)

Extract from Minutes of JPL-SPIRE Telecon 25 September 2007

3. CQM BDA

3.1 JPL document

- Draft of Marc's report has been distributed
  - A few additions to be made before the final version, but nothing major
  - Some questions for RAL highlighted in blue
    - Details of environmental exposures for BDAs

    - CQM vs Qual model vibration levels?
    - o Berend: Qual model saw higher levels than CQM (about 16 vs. 14) – Berend will check figures
  - Doug comment:
    - o Electrical short at RAL was found after the BDA damage was seen
  - Berend comments
    - o Good report
    - o Maybe needs more clear-cut conclusions

3.2 Document list for the review

1. Mark's report – JPL to distribute final version before end of this week
2. NCR document – Matt to produce updated version incorporating all the telecon notes
3. Pete's NCR docs – already distributed
4. CQM Operational Record – already distributed by Eric
5. Eric's PPT presentation – currently in draft form – see below

- Action: Matt to distribute document list by Friday Sept. 28

- Quick run-through of Eric's draft ppt (attached)
  - Ship of CQM instrument where 5-g shock monitor went off
  - Next level was 10-g (in all three axes)
  - Vibration levels
    - o CQM – 2 minutes in three axes at Qual level
    - o PFM first test – 1 minute in three axes, Acceptance level (= 1.4 less in g2 Hz-1)
    - o PFM workmanship test – 1 minute, X-axis only, Acceptance level
    - o PFM system level tests – levels likely to be lower; 1 minute duration; acoustic (3-axes) and sine (3-axes at once)
  - Question from Chris Jewell– BDA had anomalously low temperature during STM-2 – could it have broken without actually touching
    - o Would have been only a small reduction in the heat load on the CQM
    - o Small fraction of about 2 uW per BDA
    - o Not very likely as an explanation

3.3 Final review agenda

1. Objectives of the meeting (Matt/Eric)
2. List of documents and presentations available (Eric)
3. Summary of NRB process so far (review of NCR minutes to date) (RAL)
4. Run-through of JPL Investigation Report (JPL)
5. Relevant aspects of thermal strap support system design and development (Cardiff)
6. FM BDA environmental history (Eric)
7. Impact on SPIRE and/or Herschel scientific performance of a similar failure of an FM BDA
8. Risk of such a failure pre-launch or during/after launch
9. Options, if any, to remove or mitigate such risk
10. Special requirements/recommendations for testing at system level
11. Conclusions and recommendations

Annex 4: Inspection Report

STM/CQM Photometer Light baffle Assembly

SPIRE Ref.: SPIRE-UCF-
Cardiff Ref.: HSO-CDF-RP-047

8 May 2003

Prepared by: Peter Hargrave

Approved by:

Distribution list

RAL	Bruce Swinyard		

1. Test Article ID

SPIRE STM/CQM photometer light baffle assembly – LTS-CQM-400

2. Characteristics & Design Criteria to be Tested

Inspection report of light baffle assembly following warm vibration in SPIRE-STM.
An NCR was raised (HR-SP-RAL-NCR-038) following apparent misalignment post-shake.
This report records the inspection.

3. Sequence of Operations & Inspections

3.1. Inspection prior to de-integration from STM

The bus-bar section was non-concentric with the hole in the baffle, as shown in Figure 1. The displacement is in a plane perpendicular to the SPIRE optical bench. Using a multimeter, 15 Ω continuity was measured from the 300mK portion to the light baffle cover & SPIRE structure.

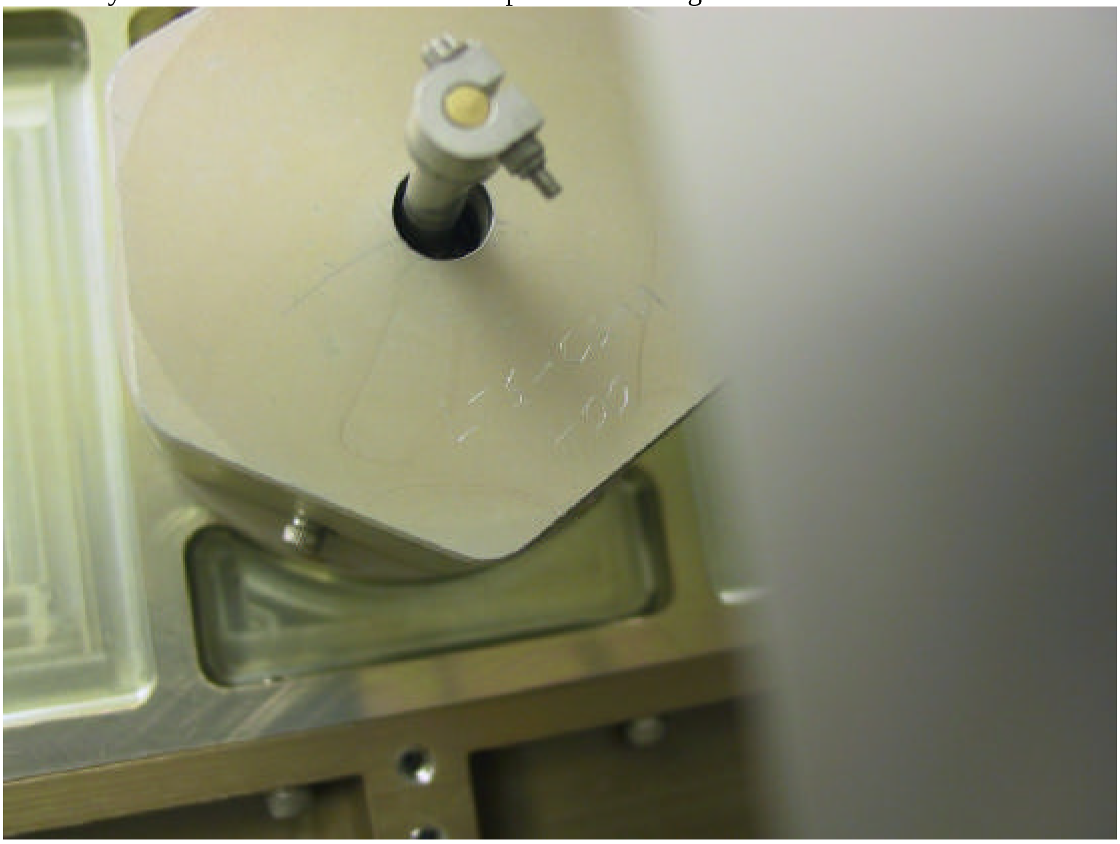


Figure 1 View of photometer light baffle post-STM warm vibration.

The photometer 2-K box was de-mounted from the SOB, and the base removed to allow access to the box interior. Figure 2 shows a damaged Kevlar cord. Partial failure of this cord will result in an extension of this section, with a resulting misalignment of the central hub.

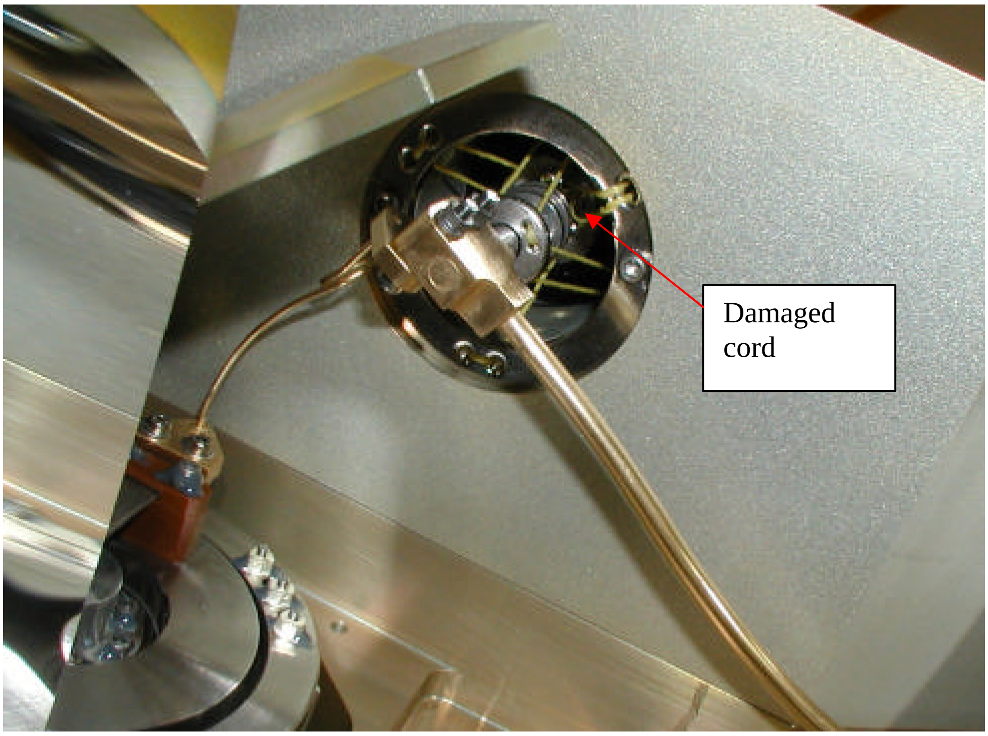


Figure 2 View from inside 2K box showing damaged cord.

The light baffle cover was then removed. Figure 3 shows the baffle assembly after removal of the outer cover. The damaged cord is evident.
Another view from inside the 2-K box is shown in Figure 4.

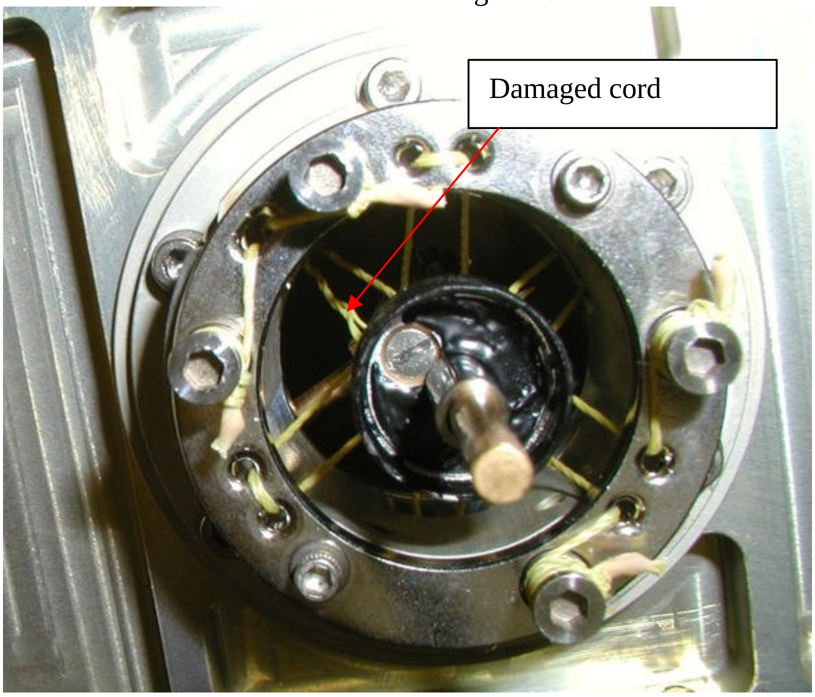


Figure 3 Light baffle on 2-K photometer box, after removal of baffle cover.

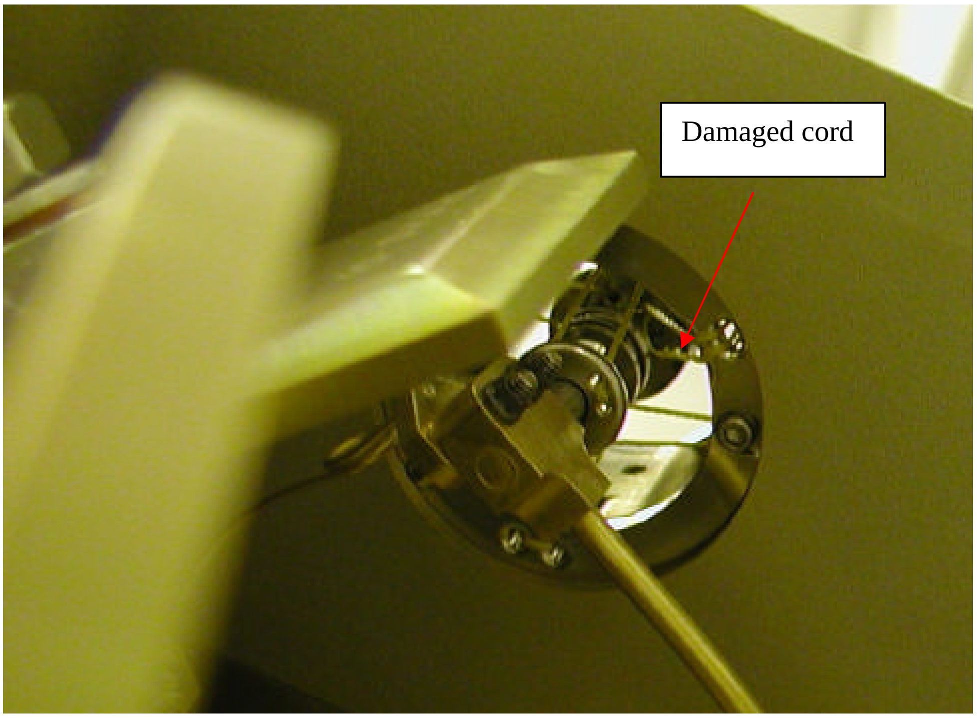


Figure 4 View from inside 2-K box with outer light baffle cover removed

In addition, the hub and cover were inspected for damage to the black coating. There was no evidence of damage to the coating, as shown in Figure 5 and Figure 6.

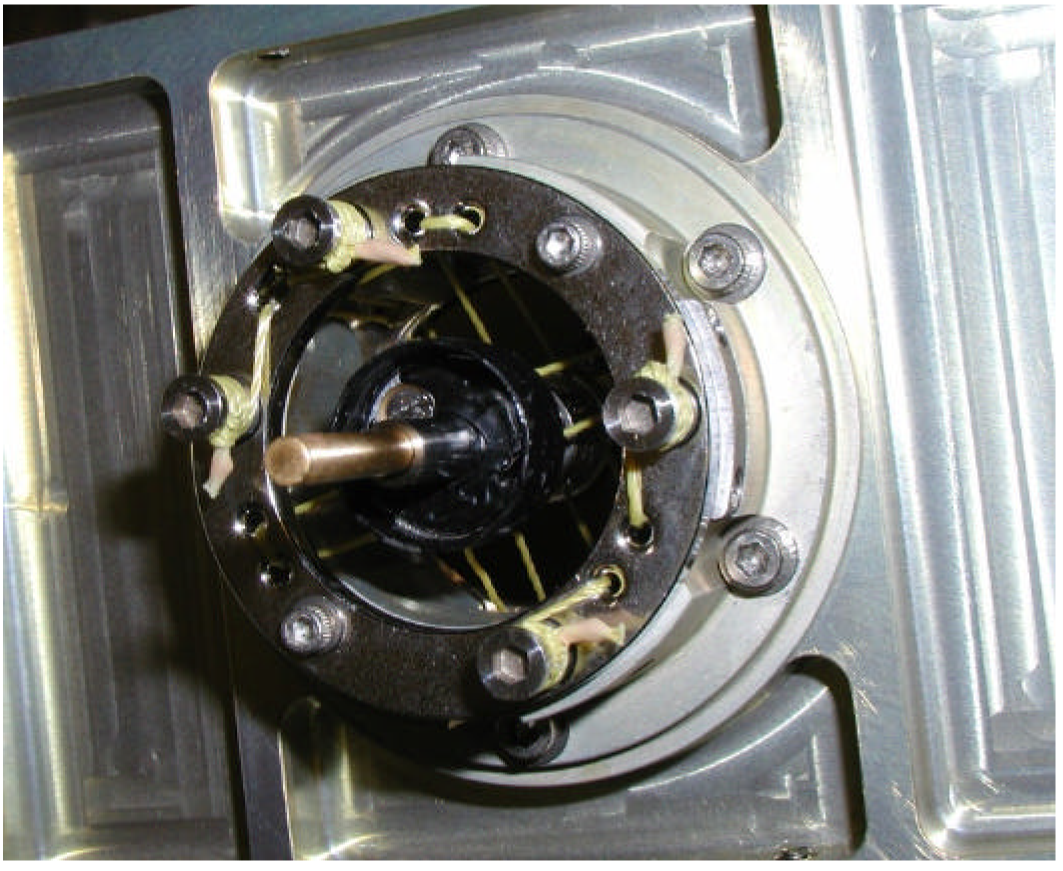


Figure 5 Preliminary inspection for integrity of black coating on hub

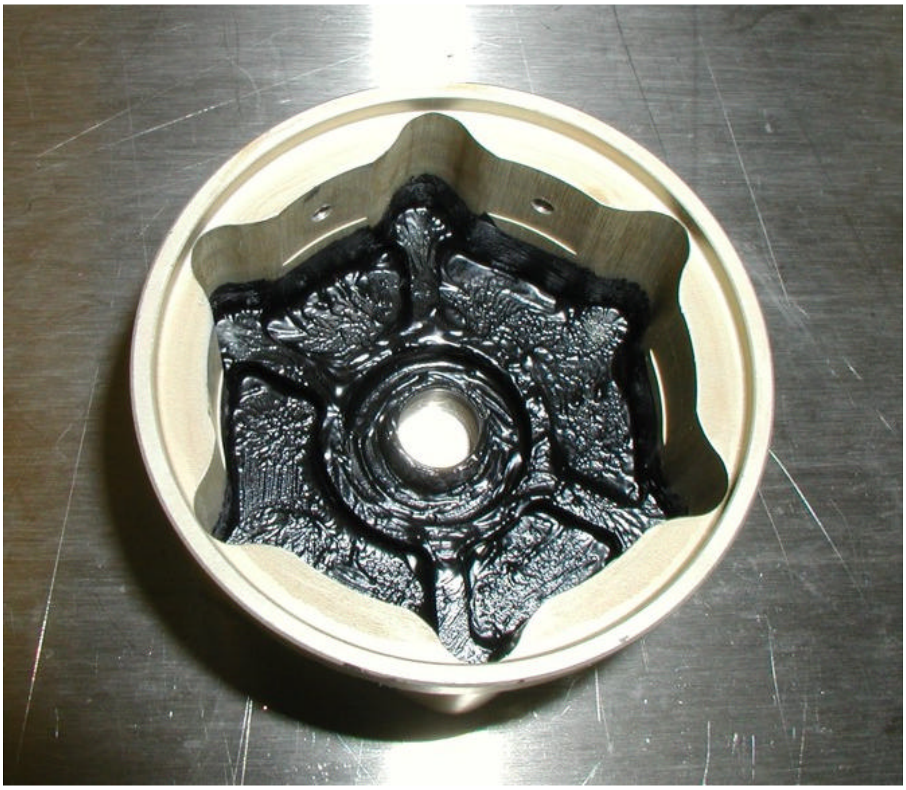


Figure 6 Preliminary inspection for integrity of black coating on cover

3.2. De-mounting from STM & Inspection at unit level at RAL

The light baffle assembly was de-mounted from the 2-K photometer box spine, and inspected further in the RAL clean room. The baffle cap was also removed at this point to examine the Kevlar underneath it, as shown in Figure 7. The Kevlar seems to have failed at the point, indicated in Figure 7, where the Kevlar passes over the guide between the radiused holes in the central hub.

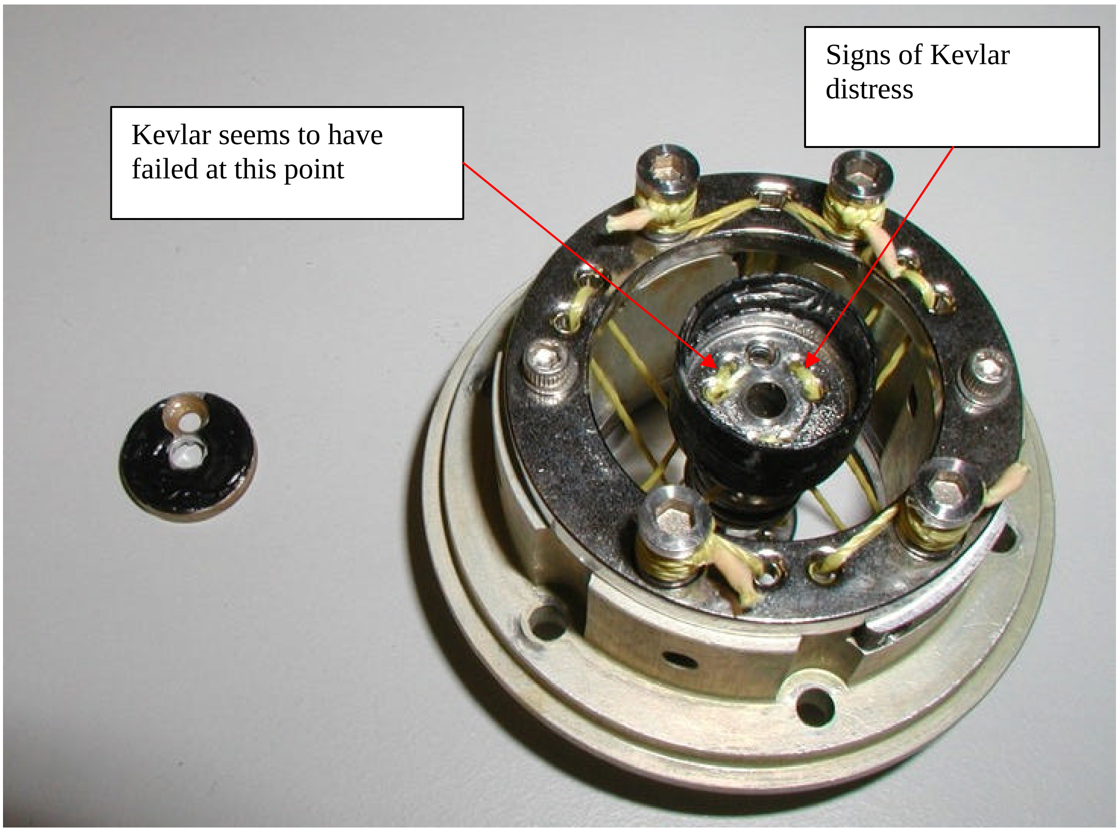


Figure 7 Unit after initial de-mounting from structure at RAL (baffle cap removed).

3.3. Disassembly & inspection at Cardiff

The unit was brought back to Cardiff University, and inspected under a microscope in the SPIRE clean room.

The failure has occurred at the apex of one of the radiused guide hole pairs on the light baffle end of the central hub, as shown in Figure 8. There was also evidence of serious Kevlar distress around another guide-hole pair on this end of the hub, as shown in Figure 9.

The Kevlar around the inner hub was also examined (Figure 10). Mild abrasion was evident. However, this may have been caused by incorrect handling. Slight surface abrasion may result from the light baffle assembly being placed temporarily on a bench in the wrong orientation (with the inner hub in contact with the bench).

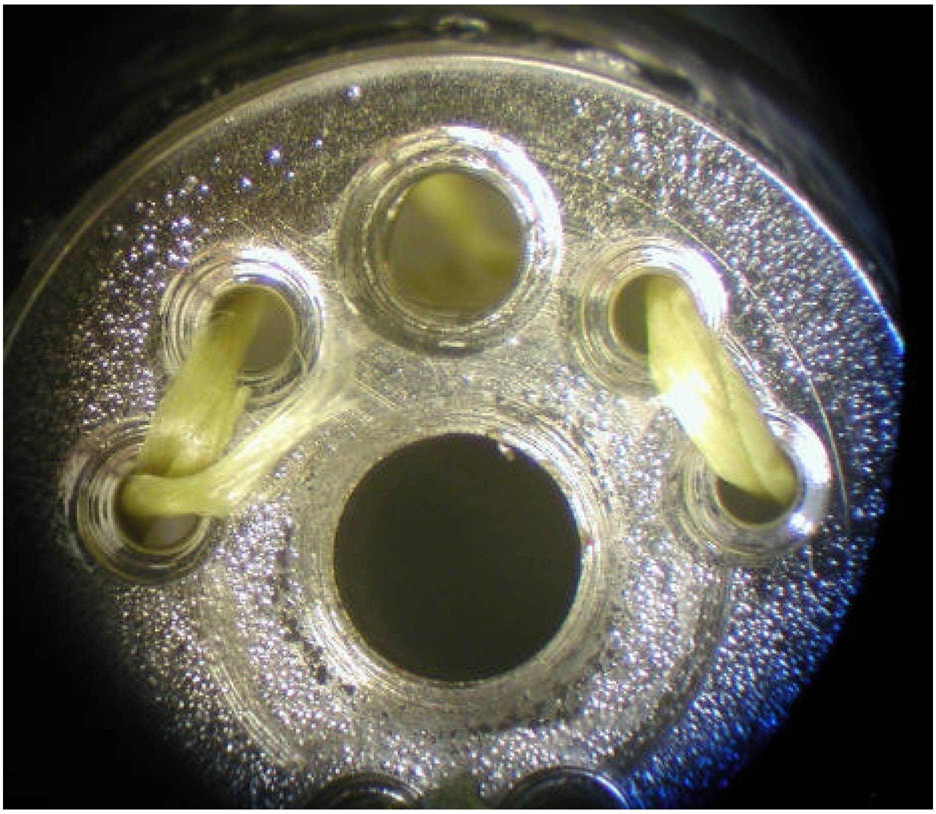


Figure 8 Close-up of light-baffle end of central hub, showing failed Kevlar section

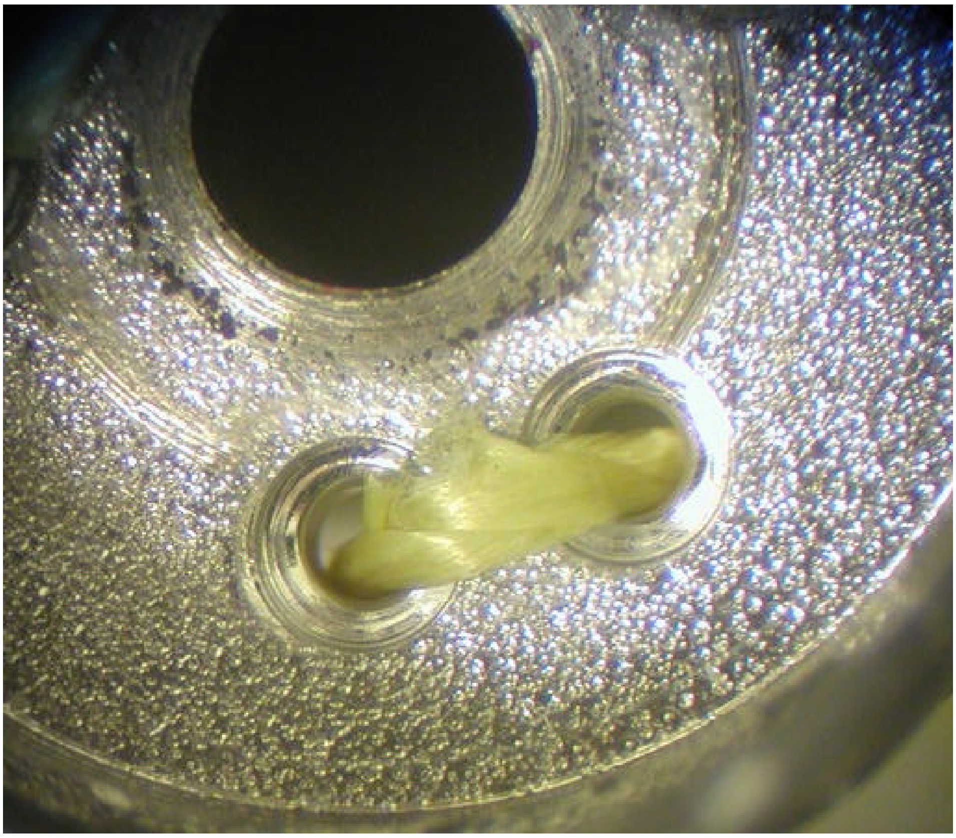


Figure 9 Another view of the light baffle end of the central hub, showing Kevlar distress at another guide-hole pair.

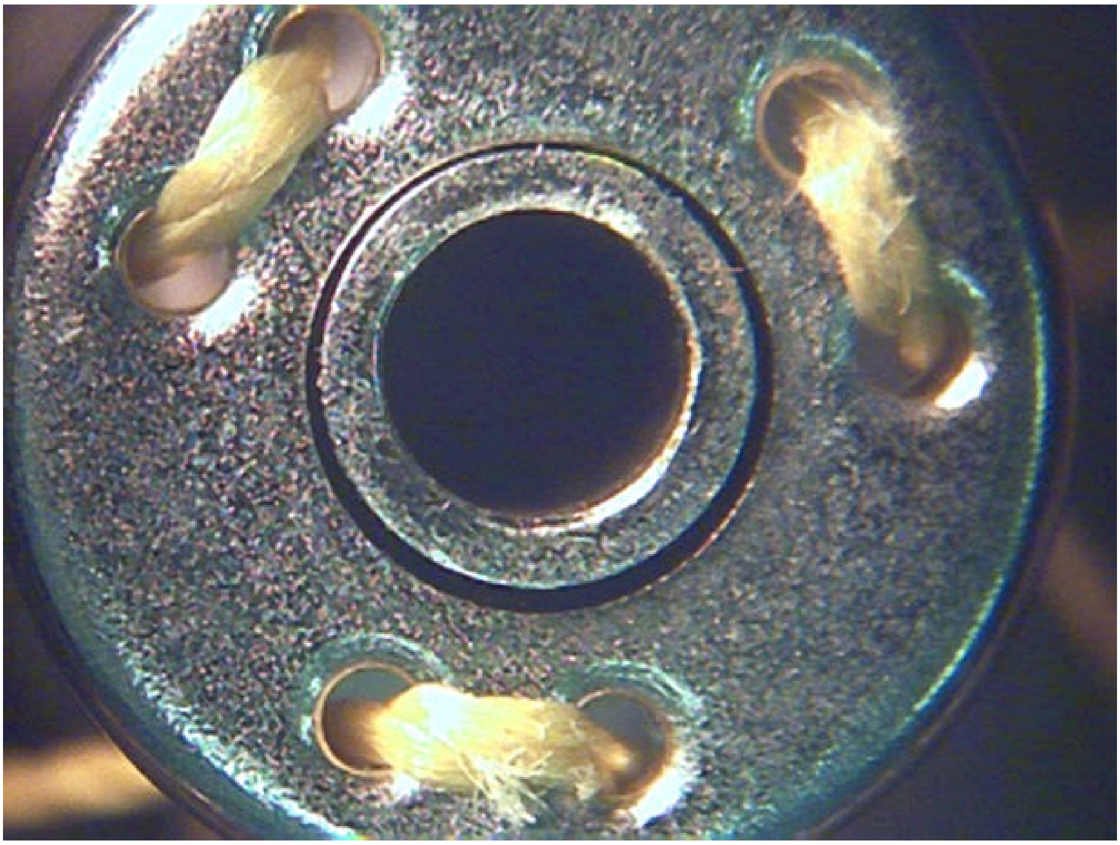


Figure 10 View of inner hub, showing signs of mild Kevlar abrasion

4. Test Results & conclusions

- The failure occurred at the apex of one of the radiused guide hole pairs on the light baffle end of the central hub, with signs of severe distress at one of the other apices on this end.
- There were signs of slight surface abrasion on the inner hub end. This may have been due to incorrect handling.
- There appear to be differences in the quality of machining of the radiused guide holes on the inner hub and the light baffle end. The guide holes were designed to be arranged such that the Kevlar bends around a smooth radius of 0.75mm, as shown in Figure 11. However, initial examination appears to show poor quality of machining of the guide holes on the light baffle end.

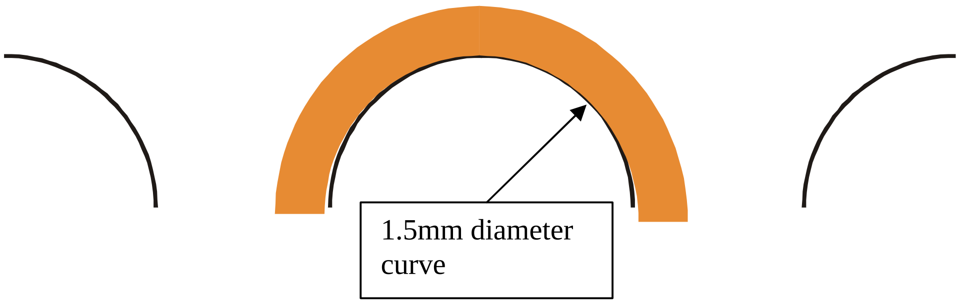


Figure 11 Designed guides for Kevlar on central hub

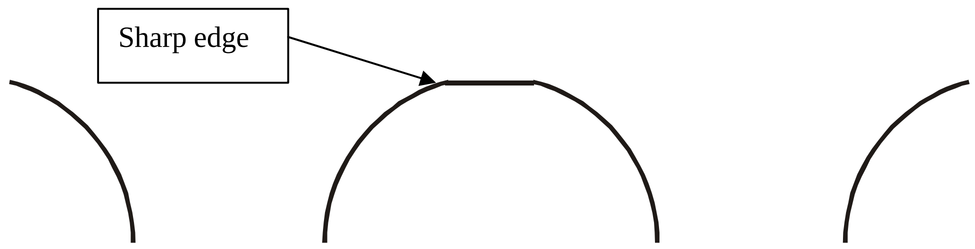


Figure 12 Appearance of radiused holes on light baffle end of central hub as inferred from figure 9. Note the flattened tops due to incorrect machining. This will be confirmed using the 3-D co-ordinate measuring machine at Cardiff.

- The incorrect machining indicated in Figure 9 and Figure 12 would cause increased compressive stress in the Kevlar at the "sharp" edges indicated in Figure 12.
- The hubs were initially designed for a much lower Kevlar pre-load than was finally used for the STM.
- An FEA analysis is in progress at the time of writing to confirm the suspected marginality of the design of the guide holes.

End Item Data Package (EIDP)

SPIRE - 300mK strap supports- PFM

SPIRE Ref.: SPIRE-UCF-
Cardiff Ref.: HSO-CDF-EIDP-072 Issue 1.0
14 October 2004

Prepared by: Peter Hargrave
Cardiff SPIRE Technical Manager

Approved by: Ian Walker
Cardiff AIG Programme Manager

Distribution list

RAL	Eric Sawyer		
	Eric Clark		
	Judy Long		
	Bruce Swinyard		
	Doug Griffin		
Cardiff	Peter Ade		
	Matt Griffin		
	Ian Walker		

Change Record

Issue	Section	Date	Changes
0.1		23/07/04	First issue for DRB
1.0		13/10/04	Flight model released version

Table of contents

SECTION 01 - Shipping Documents

The 300mK strap support system was hand-carried to the Rutherford Appleton Laboratory by Peter Hargrave on 14th October 2004.

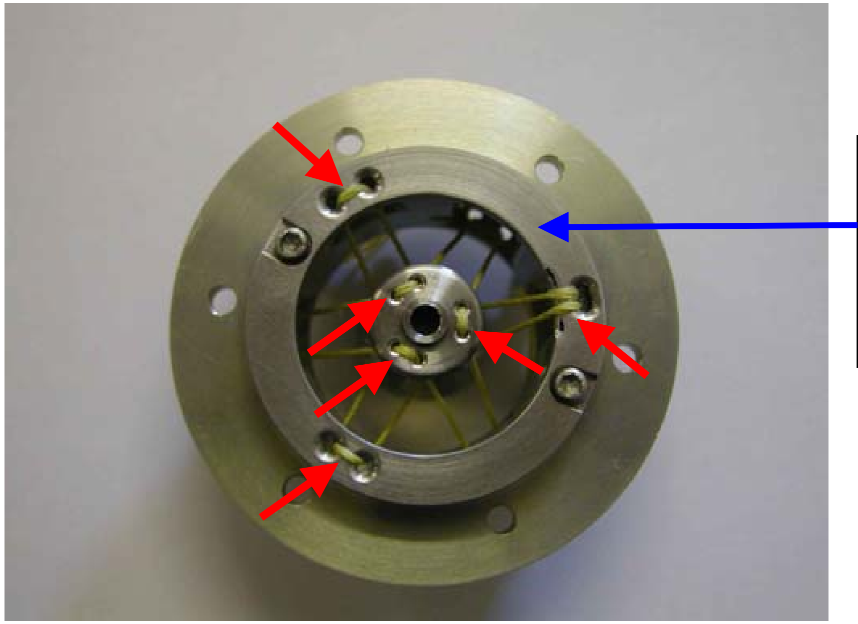
Delivery review board minutes

The delivery review for the 300mK strap support system was held at Cardiff on 29th July 2004. The minutes of this meeting are attached as Appendix F (on CD-ROM).

SECTION 02 – Transportation, Packing, Handling & Integration Procedures

Handling

- Inspection may be carried out in class-100 clean air cabinet.
- The light baffle covers must not be removed unless by an authorised member of the SPIRE AIV team.
- Outer surface may be cleaned using a clean-room wipe impregnated with iso-propyl alcohol.
- The light baffle may only ever be placed on a bench in the orientation shown in Figure 1. Any other orientation may damage the Kevlar cords, and this must be avoided at all costs.



This face must NEVER be placed in contact with a bench, or similar, otherwise the Kevlar cords may be damaged at the points indicated by the red arrows.

Figure 1 The light baffles may only be placed on a bench in the orientation shown here. On no account must the face indicated by the blue arrow be placed in contact with any surface. N.B. The image shown above is of an STM unit, NOT a flight model design assembly.

Storage

- The 300mK strap support assemblies must be stored in the transport container provided.
- Store in a dark place. Exposure to light should be kept to a minimum wherever possible.

Installation

- The 300mK strap support assemblies should be installed by trained MSSL or RAL technicians, according to the MSSL integration procedure –SPIRE Structure integration & Handling – MSSL/SPIRE/SP011.04 – section 10.2
- If any part of the 300mK strap system has to be forced or bent in order to fit through the light baffles or supports, integration should be halted, an NCR should be raised, and Cardiff should be informed immediately.

SECTION 03 – Certificate of Conformance

Cardiff University Astronomy Instrumentation Group hereby certifies that the following equipment,	
Spacecraft / Project:	**Herschel**
Instrument:	**SPIRE**
Model:	**PFM**
Subsystem:	**300mK Strap Support System**
Serial No:	**LTS-PFM-100, LTS-PFM-200, LTS-PFM-300, LTS-PFM-400**
As described in this End Item Data Package: **HSO-CDF-EIDP-072**	
Complies with the requirements set out in: **SPIRE-RAL-PRJ-000034 – SPIRE Instrument Requirements Document** **SPIRE-RAL-PRJ-001323 – Thermal Strap Requirements Document Draft 0.1**	

Responsible Authority		***Signature***
Cardiff Product Assurance	Dr I.Walker	
Cardiff SPIRE Management	Dr P.Hargrave	

SECTION 04 – Qualification Status List / Compliance Matrix

Test	Status	Applicable document / Test reference	Test Institute
Dimension and tolerances to specification	Compliant	HSO-CDF-RP-086	UWC
Visual inspection (internal & external)	Passed	Lab book – “300mK log – 1” HSO-CDF-RP-086	UWC
Mass	Requirements document is only in draft form (0.1), and out-of date. A change request will be placed against this document.	SPIRE-RAL-PRJ-001323 STRAP-REQ-05 “285g (includes mass of photometer and spectrometer straps & stray light baffles)”	
Thermal / vacuum cycles	Passed	Lab book – “300mK log – 1” HSO-CDF-RP-086	UWC
Power consumption	N/A		
Vibrations 300K	Passed	HSO-CDF-RP-078, AIV-2003-008-VIB, AIV-2003-091-VIB	RAL
Vibrations 4K	Passed	HSO-CDF-RP-078, AIV-2003-008-VIB, AIV-2003-091-VIB	RAL
Environmental condition – Vacuum $3x10^{-1}$mBar	Passed	Lab book – “300mK log – 1” HSO-CDF-RP-086	UWC
Differential pressure (a pumping-out rate of 10mB/sec)	Compliant	Lab book – “300mK log – 1” HSO-CDF-RP-086	UWC
Pre-bake out (not exceeding 80˚C)	Completed	Lab book – “300mK log – 1” HSO-CDF-RP-086	UWC
Outgassing	Compliant	By design	
Cleanliness checks, by visual inspection.	Passed	Lab book – “300mK log – 1” HSO-CDF-RP-086	UWC
Degradation due to high energy radiation.	Compliant	By design	

Compliance with IRD and 300mK Strap System Requirements

There are no specific requirements in the IRD for the 300mK strap supports.
Requirements stated below, which are relevant to the 300mK supports are stated in “300mK Strap System requirements”, SPIRE-RAL-PRJ-001323 draft 0.1.

<table>
<tr><th>Requirement ID</th><th>Description</th><th>Value</th><th>Compliant?</th></tr>
<tr><td>IRD-COOL-R01</td><td>Temperature at the detectors</td><td>The ^{3}He cooler, in conjunction with the associated 300 mK architecture, shall maintain all bolometer detector assemblies at less than 310 mK – goal 300 mK.</td><td>This requirement is not complete. The base temperature achievable depends heavily on the level-0 temperature, and the resulting parasitic heat load to the 300mK system.
There is no specific requirement on the parasitic heat load, or more correctly, the thermal conductance, of the support system as a function of level-0 temperature.</td></tr>
<tr><td>IRD-COOL-R08</td><td>Hold time</td><td>Minimum 46 hours</td><td>This requirement places design constraints on the cooler, the 300mK support system, and the overall thermal design of SPIRE.</td></tr>
<tr><td>IRD-COOL-R10</td><td>Mechanical interface</td><td>Preferred interface is with the instrument common structure</td><td>Compliant</td></tr>
<tr><td>STRAP-REQ-02</td><td>Strap support and stray light baffles parasitic heat load</td><td>Maximum of 2μW</td><td>Parasitic load depends on level-0 temperature. According to data from Duband, we are compliant, according to Ventura, we are not.
<table>
<tr><th rowspan="2">Level-0 temperature</th><th colspan="2">Parasitic load to cooler tip from 300mK strap suspension (μW)</th></tr>
<tr><th>Duband model</th><th>Ventura model</th></tr>
<tr><td>1.8K</td><td>1.42</td><td>2.65</td></tr>
<tr><td>2.0K</td><td>1.87</td><td>3.54</td></tr>
</table></td></tr>
<tr><td>STRAP-REQ-04</td><td>Accomodation</td><td>The 300-mK Strap system is to be supported entirely from the Level-0 Photometer and Spectrometer Detector Boxes.</td><td>Compliant</td></tr>
<tr><td>STRAP-REQ-05</td><td>Mass</td><td>285g (includes mass of photometer and spectrometer straps & stray light baffles)</td><td>Not compliant. This is a strap system level requirement.
Requirements document is only in draft form (0.1), and out-of date.
The mass of the assemblies has been accepted by the project.
A change request will be placed against this document.</td></tr>
<tr><td>STRAP-REQ-06</td><td>First mode of vibration</td><td>>300Hz, goal >400Hz</td><td>This requirement is for the whole system, including the bus-bar, and can only be checked by analysis followed by system level vibration in SPIRE. MSSL are responsible for this analysis.</td></tr>
<tr><td>STRAP-REQ-07</td><td>Qualification level random vibration loads</td><td>0.5g^2/Hz 100Hz – 400Hz, 6dB/octave roll-off below & above this</td><td>Compliant</td></tr>
<tr><td>STRAP-REQ-08</td><td>Qualification level sine vibration loads</td><td>40g between 5Hz and 110 Hz</td><td>Compliant</td></tr>
</table>

STRAP-REQ-17	Stray light baffling effectiveness	The photometer and spectrometer stray light baffles are to provide at least four reflections for the shortest optical path between the level-1 environment and the level-0 environment inside the detector boxes.	Not compliant. It is possible for a photon to penetrate the inside of the detector box from the level-1 environment following three reflections. Increasing the effectiveness of the light trap would compromise the safety of the system, making a thermal short from 300mK to level-0 more likely. The fewer reflections are not such an issue, as the whole light trap is coated with a high emissivity coating.
STRAP-REQ-18	Stray light baffle opacity	The photometer and spectrometer stray light baffles are to be opaque (99.9%) in the wavelengths 0.5μm to 670μm	Compliant.

SECTION 05 – Top Level Drawings (Inc. Family Tree)

Hardware tree

The hardware tree for the 300mK is shown in Figure 2. Note that the part numbers are given by the general form "LTS-XXX-nnn", where "XXX" is the model designation (CQM, PFM etc) and "nnn" is the number given in the hardware tree (LTS stands for "Low Temperature System"). For instance, the part number for the 300mK flight model adjustable capstan for photometer support A is "LTS-PFM-108".

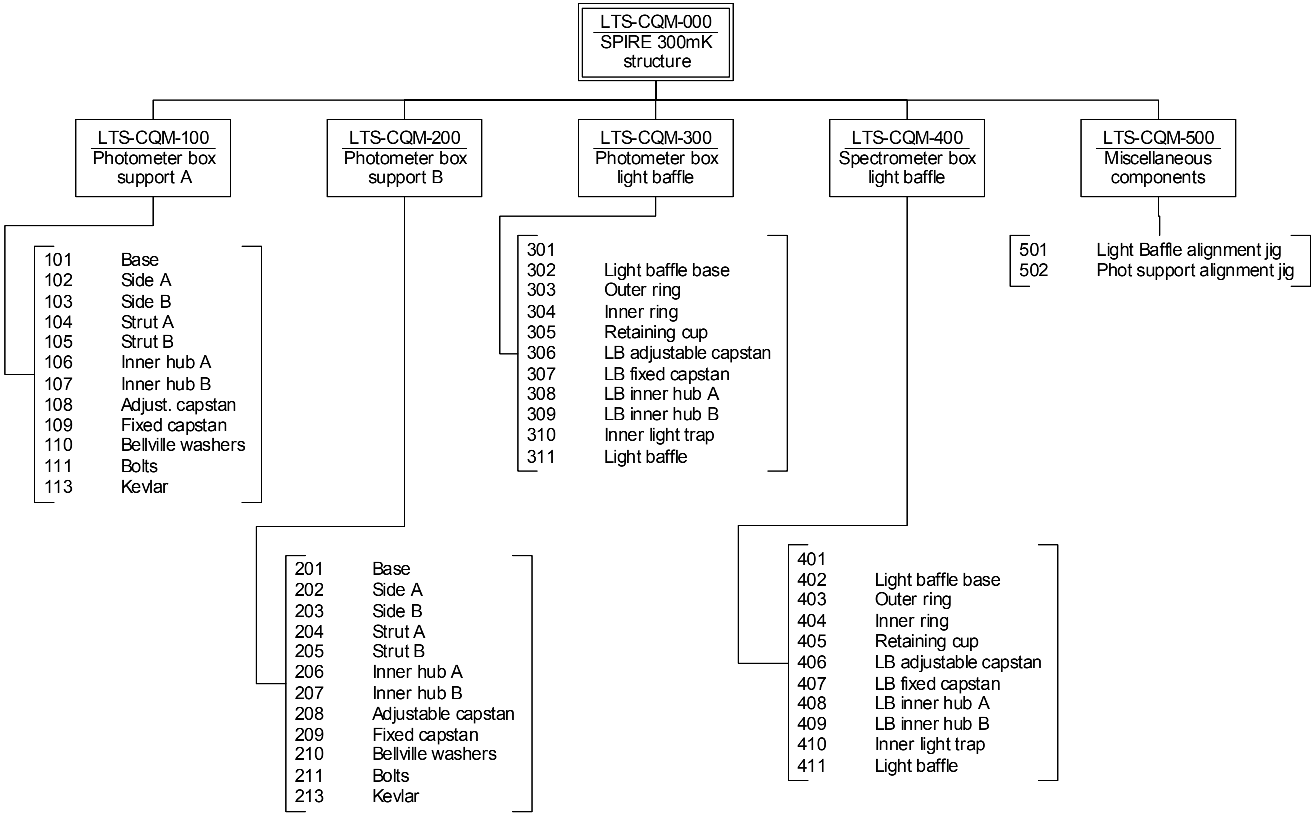


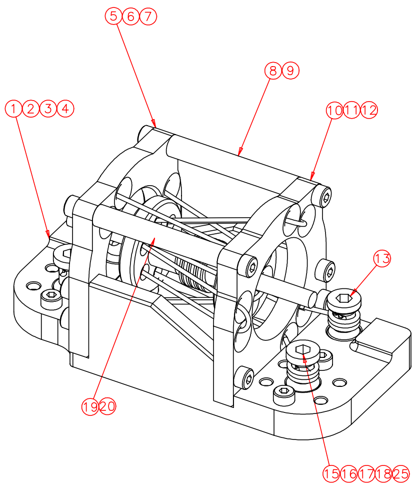
Figure 2 Hardware tree for 300mK support system. Note that the tree shown is for the CQM model. The PFM tree is identical to this, with all instances of "CQM" replaced by "PFM" for the part numbers.

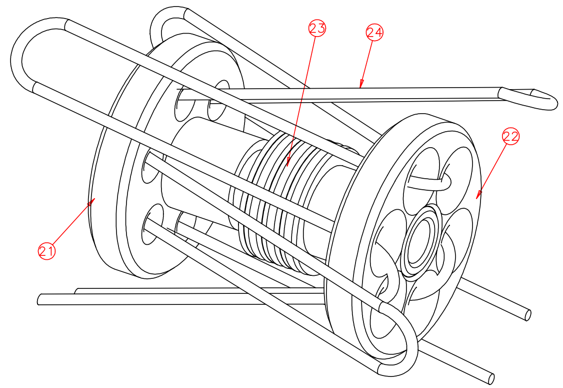
TOP LEVEL DRAWING LIST

Note that the drawings below, although labelled CQM, CQM2, are the drawings used for flight model manufacture.

Drawing No.	Title
LTS-CQM-100/200	Photometer Support (Figure 3) Issue 1.0
LTS-CQM2-300/400	300mK Light Baffle (Figure 4) Issue 1.0

CLEAN & BREAK ALL SHARP EDGES





ITEM NO.	DRAWING No.	DESCRIPTION	No. OFF	REMARKS
25	N/D	EPOTEK 920FL (CORD TERMINATION)	A/R	
24	N/D	UNWOVEN KEVLAR CORD.	A/R	
23	N/D	BELLEVILLE SPRING WASHER	12	PT. NO. S105204
22	LTS-CQM-107/207	INNER HUB B	1	ST. STEEL
21	LTS-CQM-106/206	INNER HUB A	1	ST. STEEL
20	N/D	HELICOIL SCREWLOCK INSERTS 256 UNC x 1.5D	2	PT. NO. 3585-02 CNX.129
19	LTS-CQM-204/205	STRUT B	1	ST. STEEL
18	N/D	HELICOIL SCREWLOCK INSERTS 256 UNC x 1.5D	24	PT. NO. 3585-02 CNX.129
17	N/D	BELLEVILLE SPRING WASHER	2	PT. NO. D6-20
16	N/D	SCREW, 2-56UNC CP HD. 6.35 LG.	2	ST. STEEL
15	LTS-CQM-108/208	ADJUSTABLE CAPSTAN	2	ST. STEEL
14	N/D	Ø2.0mm DOWEL x 10.0 LG.	2	ST. STEEL
13	LTS-CQM-109/209	FIXED CAPSTAN	2	ST. STEEL
12	N/D	BELLEVILLE SPRING WASHER	5	PT. NO. D6-20
11	N/D	SCREW, 2-56UNC CP HD. 6.35 LG.	5	ST. STEEL
10	LTS-CQM-202/203	SIDE B	1	ST. STEEL
9	N/D	HELICOIL SCREWLOCK INSERTS 256 UNC x 1.5D	2	PT. NO. 3585-02 CNX.129
8	LTS-CQM-104/105	STRUT A	1	ST. STEEL
7	N/D	BELLEVILLE SPRING WASHER	5	PT. NO. D6-20
6	N/D	SCREW, 2-56UNC CP HD. 6.35 LG.	5	ST. STEEL
5	LTS-CQM-102/103	SIDE A	1	ST. STEEL
4	N/D	HELICOIL SCREWLOCK INSERTS 256 UNC x 1.5D	13	PT. NO. 3585-02 CNX.129
3	N/D	BELLEVILLE SPRING WASHER	4	PT. NO. D6-20
2	N/D	SCREW, 2-56UNC CP HD. 6.35 LG.	4	ST. STEEL
1	LTS-CQM-101/201	MAIN BASE	1	AL-6082

CONTRACT NO.		AMENDMENT
APPROVALS	DATE	
DRAWN BJK	15.09.03	
CHECKED BY: IT	16.09.03	
APPROVED BY: PCH	17.09.03	
ISSUE	1	

MATERIAL & SPEC : AS LISTED

FINISH: AS LISTED — ESTD WT. 100.0g

QUANTITY: 2 — ACTL WT. 110.0g

CAD FILE
CONFIGURED-DOCUMENTS/300mK/PFM-BUILD/MANUFACTURE/ARCHIVE FILE

SCALE 2:1

DIMENSIONS IN MM

PROJECT
SPIRE

TOLERANCES UNLESS OTHERWISE STATED
LINEAR +/- 0,10
ANGULAR +/- 0,15°

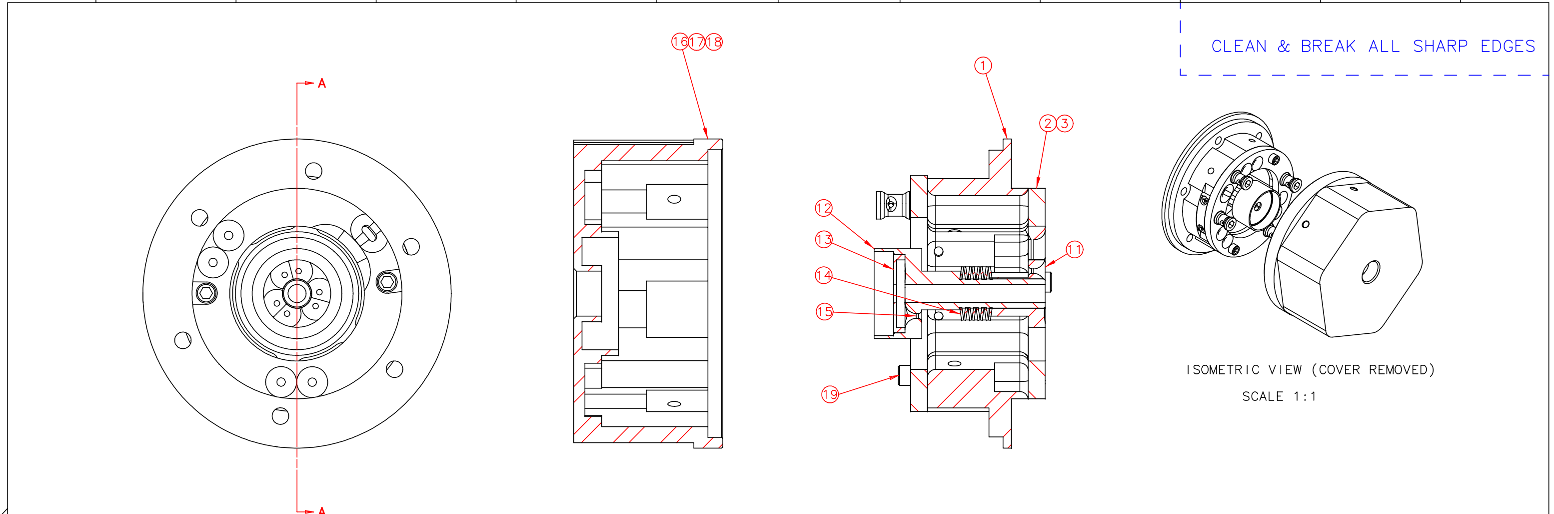
TITLE
PHOTOMETER SUPPORT ASSEMBLY

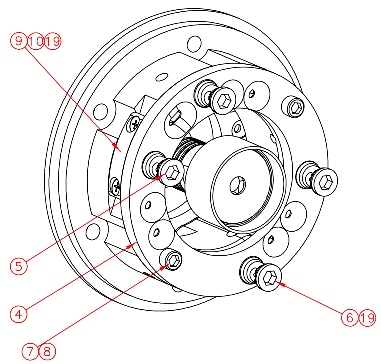
ASTRONOMY & INSTRUMENTATION GROUP
CARDIFF UNIVERSITY
QUEENS BUILDING 5 THE PARADE
NEWPORT ROAD CARDIFF CF24 3YB
TEL 02920 876269 FAX 02920 874056
E-MAIL Brian.Kiernan@astro.cf.ac.uk

DRAWING NO LTS-CQM-100/200

SHEET 1 OF 1 — A2

Figure 3 Photometer support assembly





20	N/D	EPOTEK 920FL (CORD TERMINATION)	A/R	
19	N/D	HELICOIL SCREWLOCK INSERTS 256 UNC x 1.5D	10	PT. NO.3585-02 CNX,129
18	N/D	SCREW, 2-56UNC CP HD. 6.35 LG	4	ST.STEEL
17	N/D	BELLEVILLE SPRING WASHER	4	PT. NO. D6-20
16	LTS-CQM2-311/411	COVER	1	AL 6082 - ALUCHROM
15	N/D	UNWOVEN KEVLAR CORD.	A/R	
14	N/D	BELLEVILLE SPRING WASHER	12	PT. NO. S105204
13	LTS-CQM2-310/410	INNER LIGHTRAP	1	TORLON - BG1
12	LTS-CQM2-308/408	INNER HUB A	1	ST.STEEL
11	LTS-CQM2-309/409	INNER HUB B	1	ST.STEEL
10	N/D	SCREW, M1.6CSK.HD. 5.0 LG.	4	ST.STEEL
9	LTS-CQM2-305/405	RETAINING CUP	2	ST.STEEL
8	N/D	BELLEVILLE SPRING WASHER	2	PT. NO. D6-20
7	N/D	SCREW, 2-56UNC CP HD. 6.35 LG.	2	ST.STEEL
6	LTS-CQM2-307/407	FIXED CAPSTAN	2	ST.STEEL
5	LTS-CQM2-306/406	ADJUSTABLE CAPSTAN	2	ST.STEEL
4	LTS-CQM2-303/403	OUTER RING	1	ST.STEEL
3	N/D	SCREW, 2-56UNC CP HD.	2	ST.STEEL
2	LTS-CQM2-304/404	INNER RING	1	ST.STEEL
1	LTS-CQM2-302/402	MAIN BASE	1	AL 6082 - ALUCHROM
ITEM NO.	DRAWING No.	DESCRIPTION	No. OFF	REMARKS

CONTRACT NO.

APPROVALS	DATE
DRAWN BJK	09.09.03
CHECKED BY: IT	15.09.03
APPROVED BY: PCH	15.09.03
ISSUE	1

AMENDMENT

ø33.50 PCD FOR OUTER RING RETAINING BOLTS TO ø35.50.

MATERIAL & SPEC : AS LISTED

FINISH: AS LISTED — ESTD WT. 140.0g

QUANTITY: 2 — ACTL WT. 137.0g

SCALE 2:1

DIMENSIONS IN MM

TOLERANCES UNLESS OTHERWISE STATED

LINEAR +/- 0,10
ANGULAR +/- 0,15°

ASTRONOMY & INSTRUMENTATION GROUP
CARDIFF UNIVERSITY
QUEENS BUILDING 5 THE PARADE
NEWPORT ROAD CARDIFF CF24 3YB
TEL 02920 876269 FAX 02920 874056
E-MAIL Brian.Kiernan@astro.cf.ac.uk

CAD FILE
CONFIGURED-DOCUMENTS/300mK/PFM-BUILD/MANUFACTURE/ARCHIVE-FILE

PROJECT
SPIRE

TITLE
300mK LIGHTBAFFLE ASSEMBLY

DRAWING NO LTS-CQM2-300/400

SHEET 1 OF 1

A2

Figure 4 Light baffle assembly

SECTION 06 – Interface Drawings

INTERFACE DRAWING LIST

Note that the drawings below, although labelled CQM, CQM2, are the drawings used for flight model manufacture.

Drawing No.	Title	Notes
LTS-CQM-ICD-100/200	300mK support interface	Issue 1.0 (Figure 5)
LTS-CQM2-ICD-300/400	Light baffle interface	Issue 2. (Figure 6)

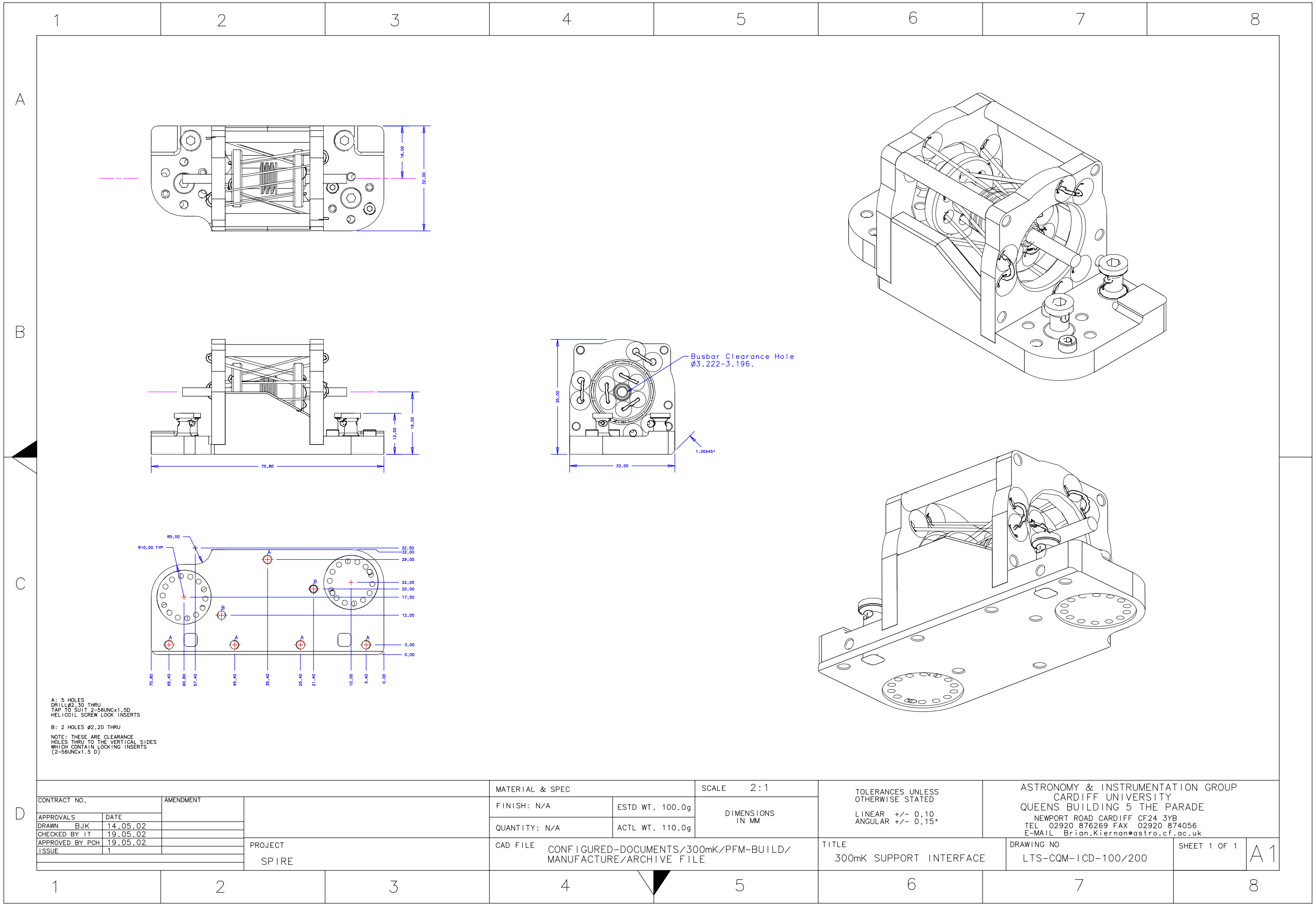


Figure 5 Photometer support A and B interface drawing

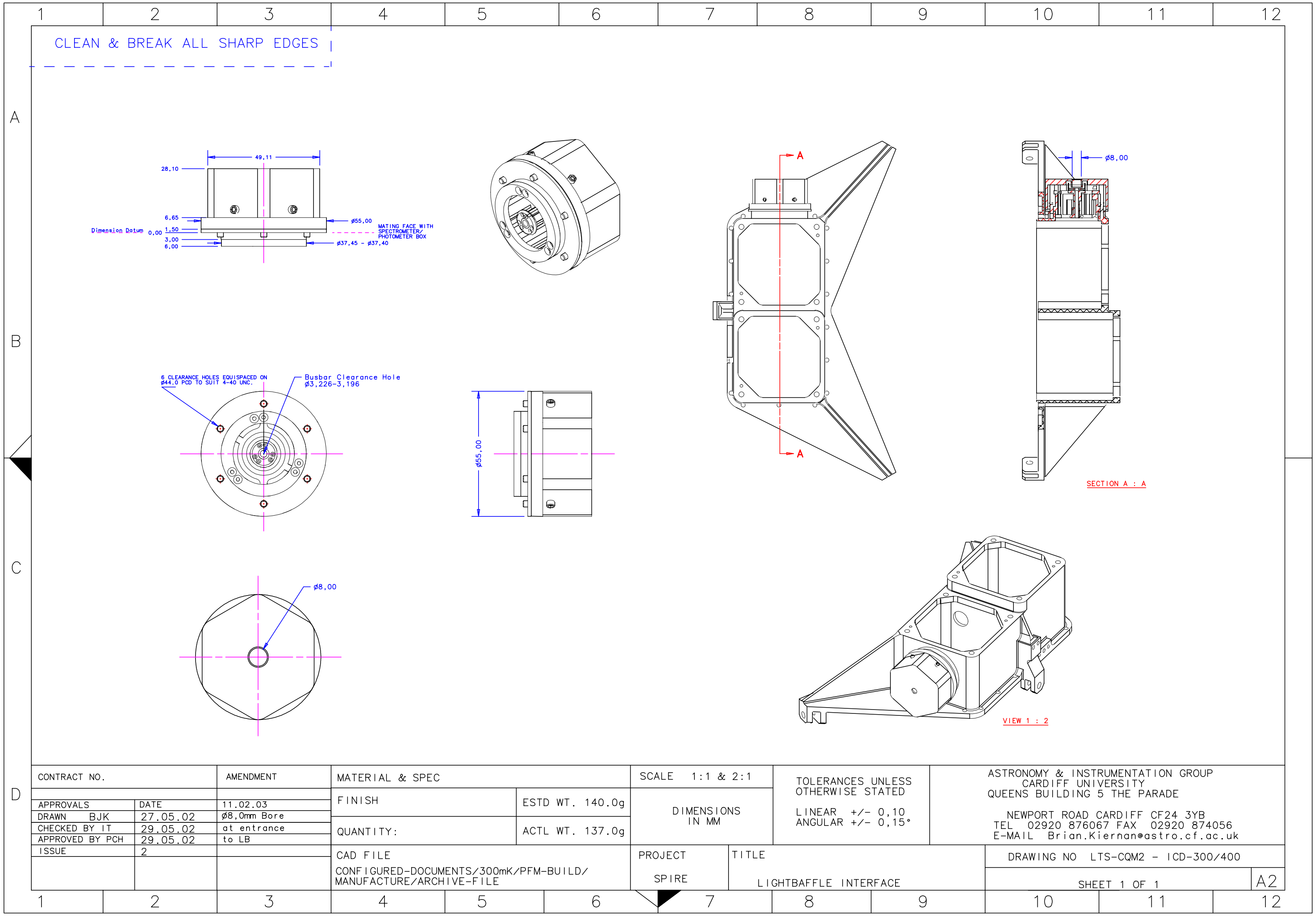


Figure 6 Light baffle A and B interface drawing

SECTION 07 – Functional, Block & Mechanical Drawings

Component drawings are given in this section.

FUNCTIONAL & BLOCK DRAWING LIST

Drawing No.	Title

MECHANICAL COMPONENT DRAWING LIST

Note that the drawings below, although labelled CQM, CQM2, are the drawings used for flight model manufacture.

Drawing No.	Title	Notes
LTS-CQM-101/201	PHOTOMETER SUPPORT BASE	
LTS-CQM-102/103-202/203	PHOTOMETER SUPPORT: SIDES A & B	
LTS-CQM-104/105-204/205	PHOTOMETER SUPPORT: STRUT A & B	
LTS-CQM-106/206	PHOTOMETER SUPPORT: INNER HUB A	
LTS-CQM-107/207	PHOTOMETER SUPPORT: INNER HUB B	
LTS-CQM-108/208	PHOTOMETER SUPPORT: ADJUSTABLE CAPSTAN	
LTS-CQM-109/209	PHOTOMETER SUPPORT: FIXED CAPSTAN	
LTS-CQM2-302/402	300mK LIGHTBAFFLE MAIN BASE	2 SHEETS
LTS-CQM2-303/403	300mK LIGHTBAFFLE OUTER RING	
LTS-CQM2-304/404	300mK LIGHTBAFFLE INNER RING	
LTS-CQM2-305/405	300mK LIGHTBAFFLE RETAINING CUP	
LTS-CQM2-306/406	300mK LIGHTBAFFLE ADJUSTABLE CAPSTAN	
LTS-CQM2-307/407	300mK LIGHTBAFFLE FIXED CAPSTAN	
LTS-CQM2-308/408	300mK LIGHTBAFFLE INNER HUB A	
LTS-CQM2-309/409	300mK LIGHTBAFFLE INNER HUB B	
LTS-CQM2-410/510	300mK LIGHTBAFFLE INNER LIGHT TRAP	
LTS-CQM2-411/511	300mK LIGHTBAFFLE COVER	2 SHEETS

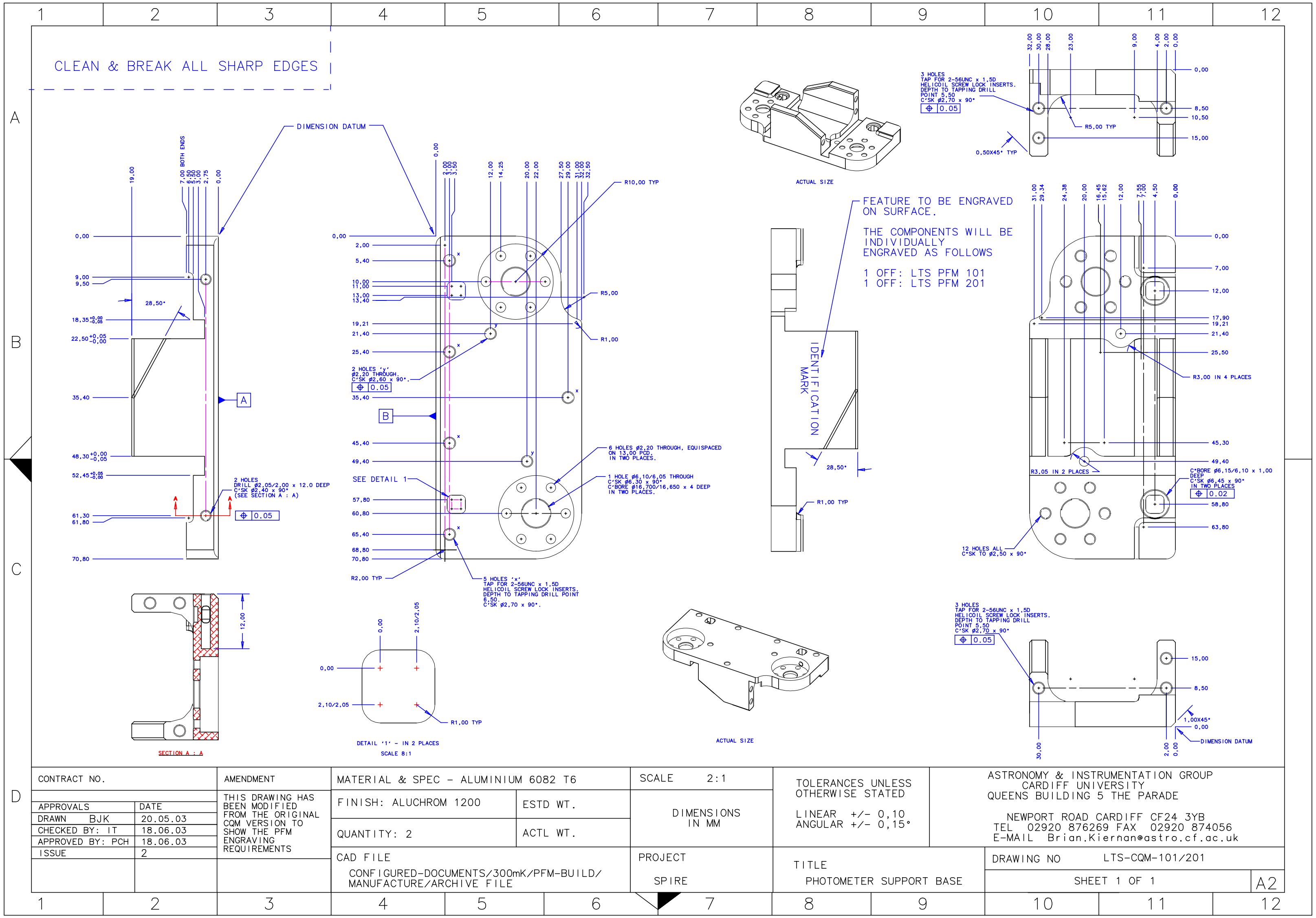


Figure 7 Photometer support base

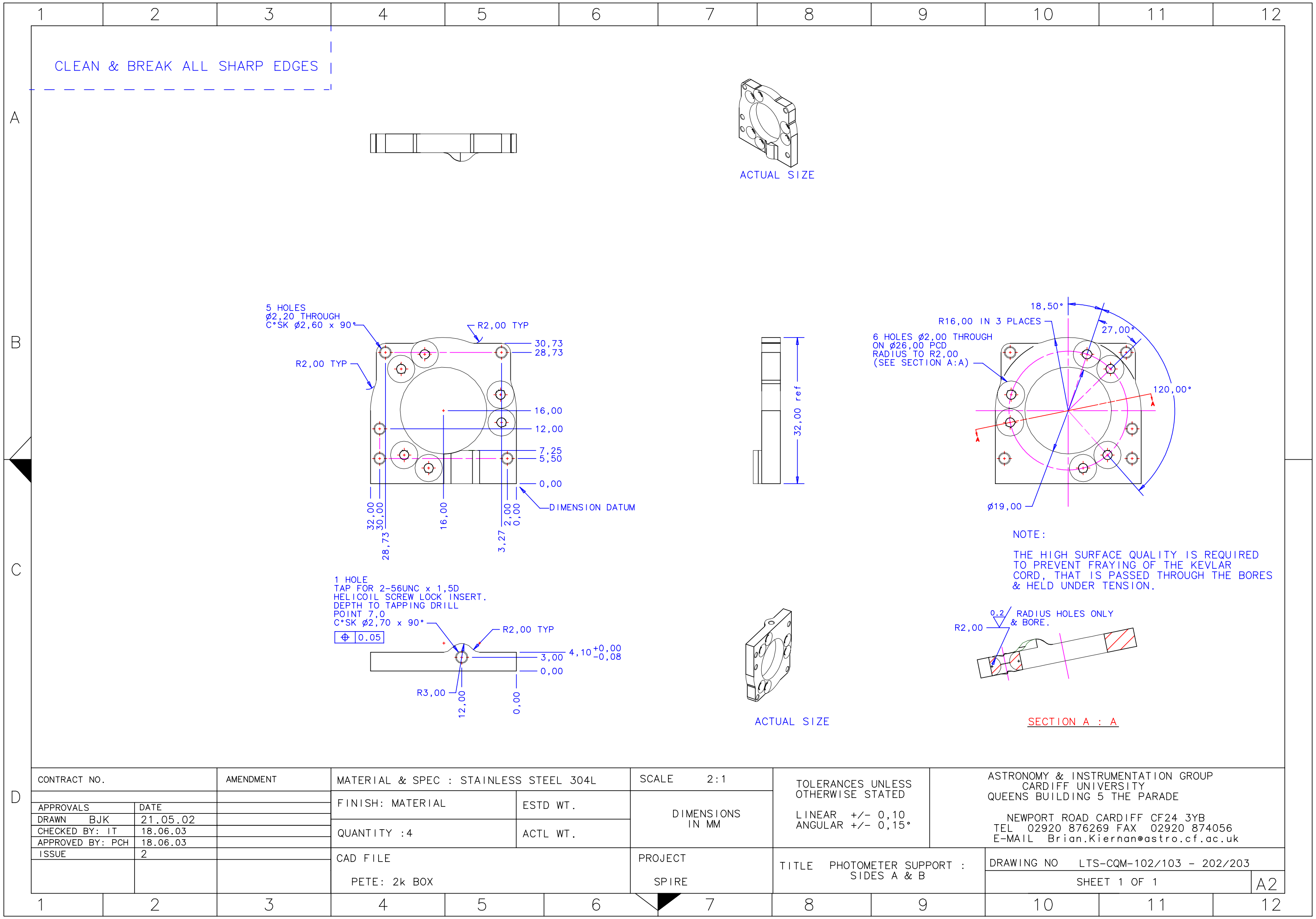


Figure 8 Photometer support sides A & B

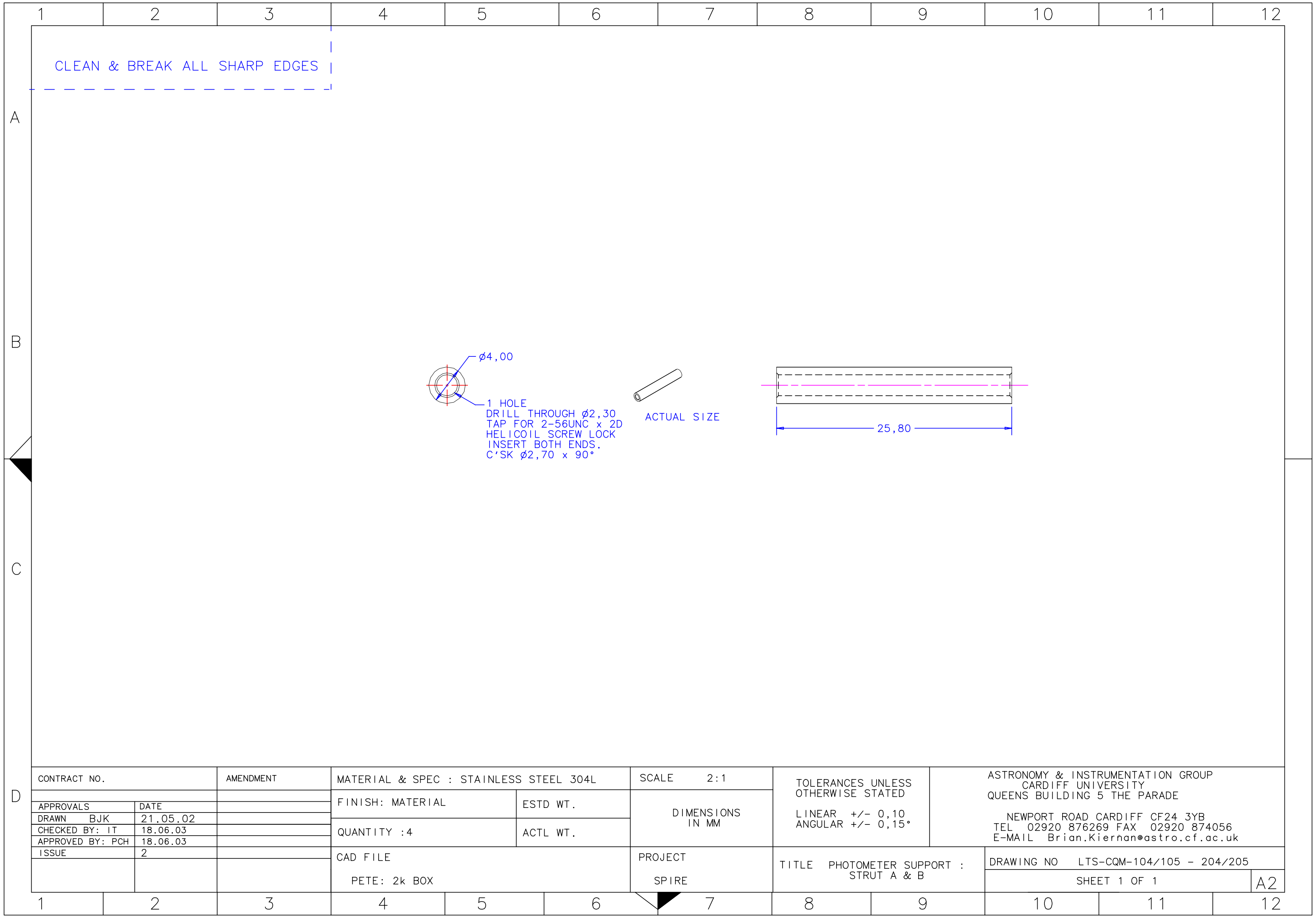


Figure 9 Photometer support strut A & B

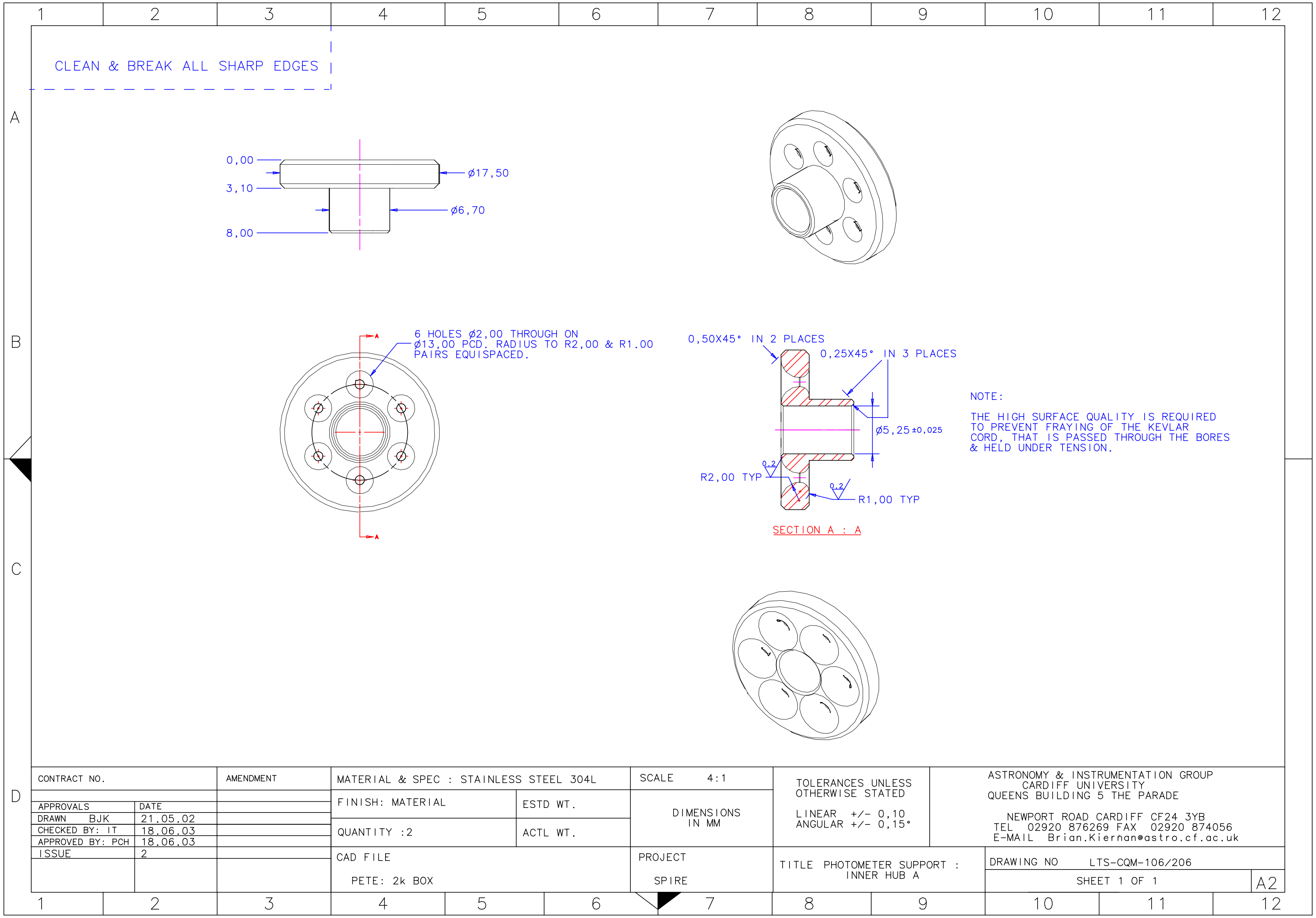


Figure 10 Photometer support inner hub A

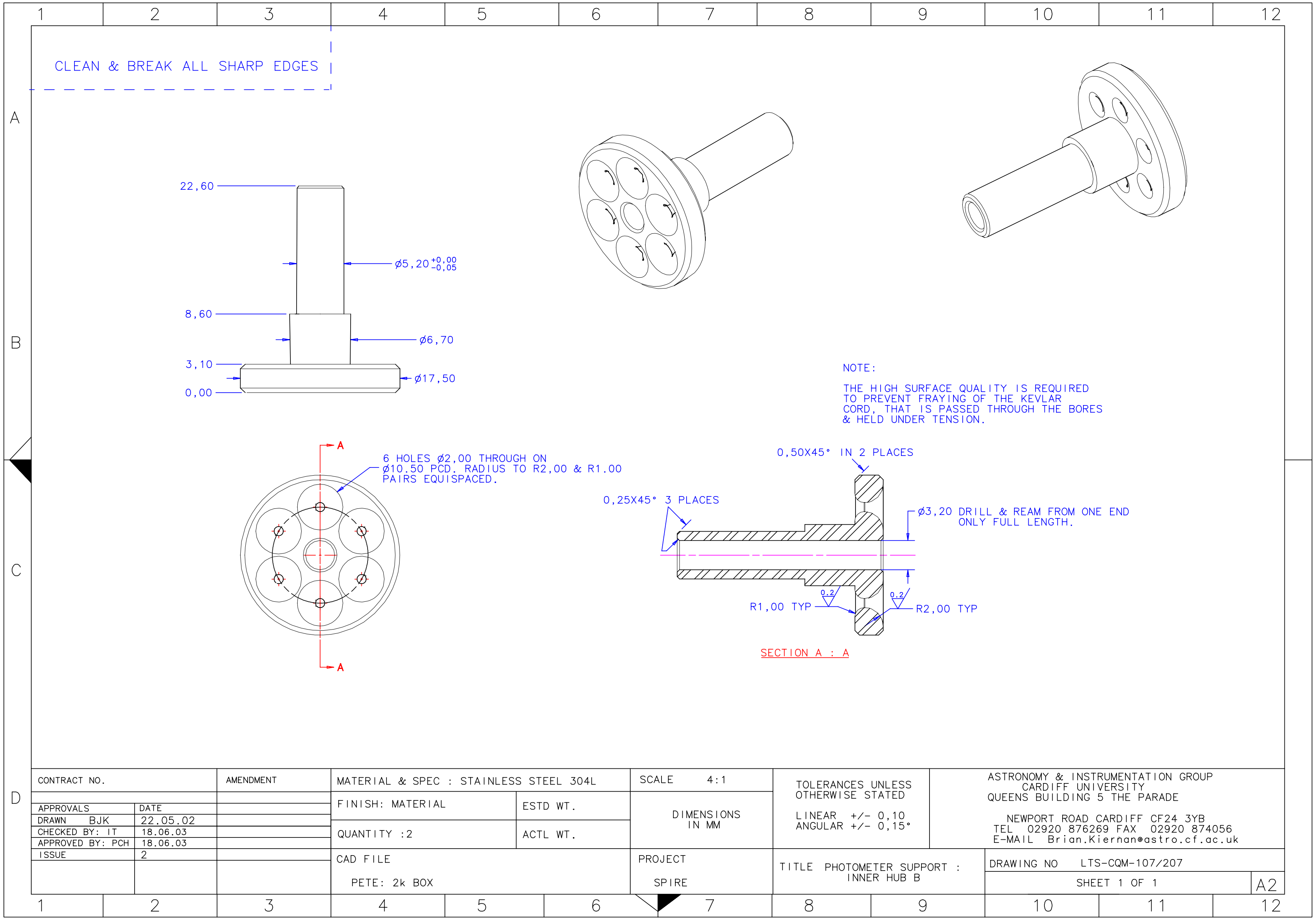


Figure 11 Photometer support inner hub B

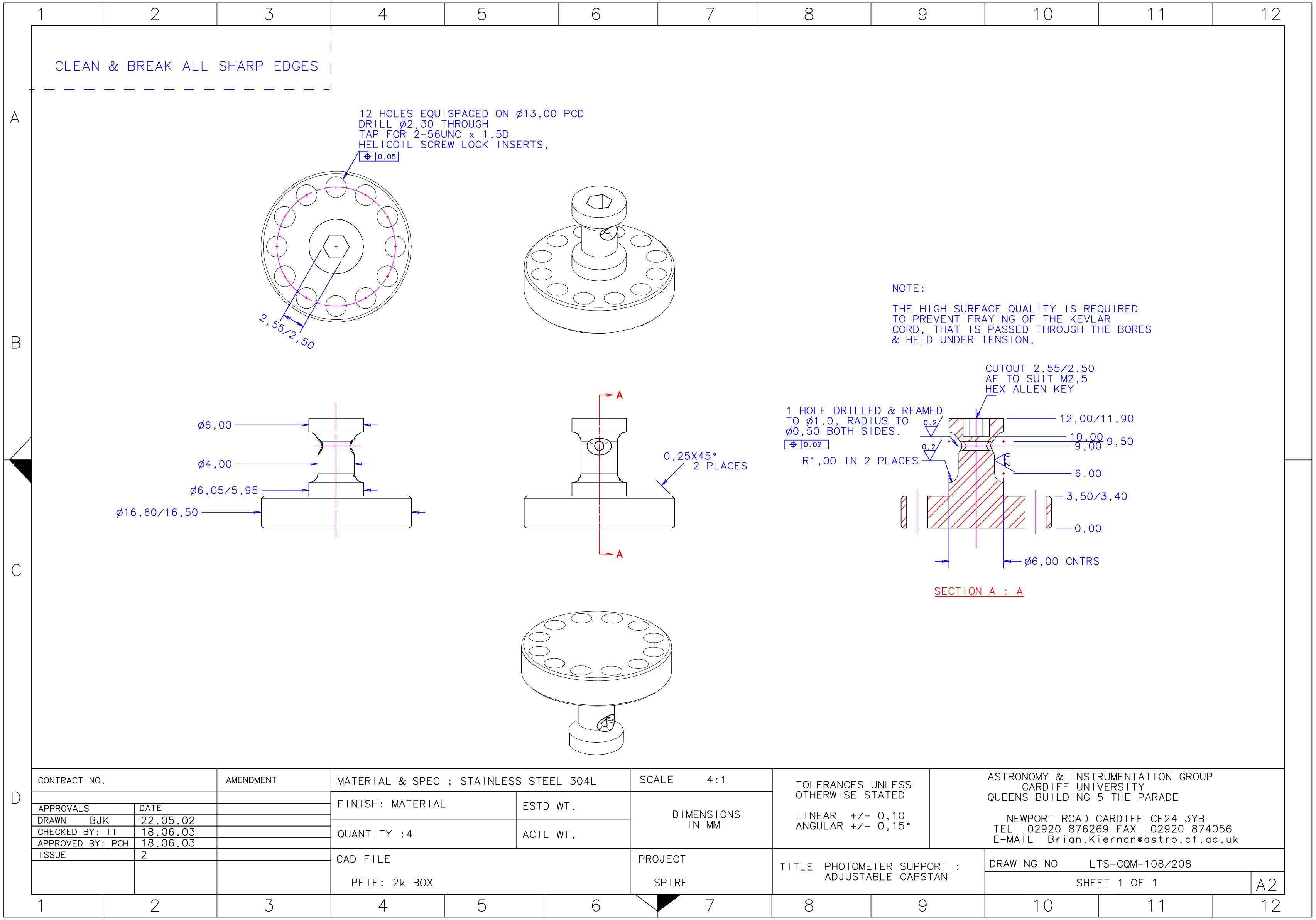


Figure 12 Photometer support adjustable capstan

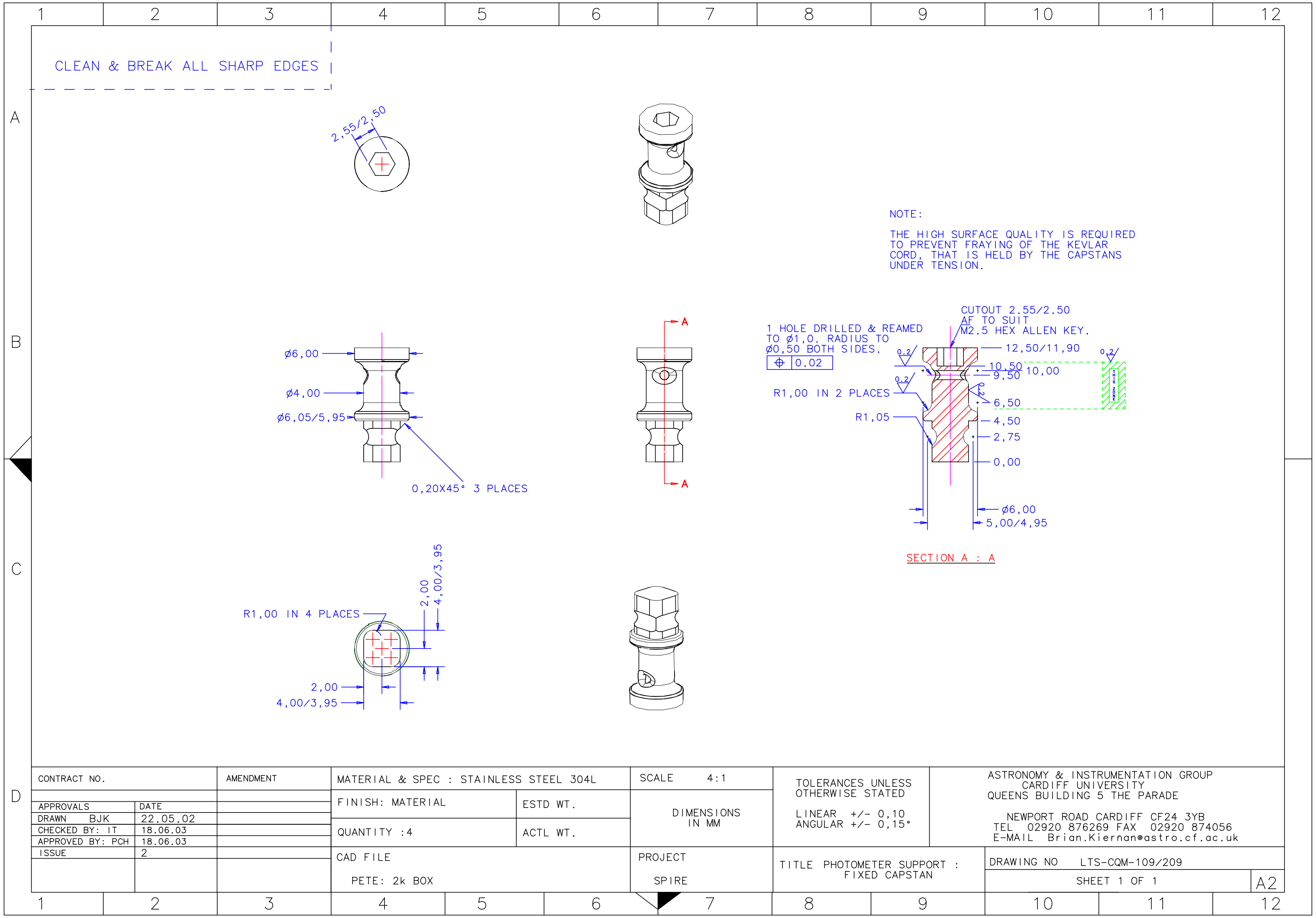
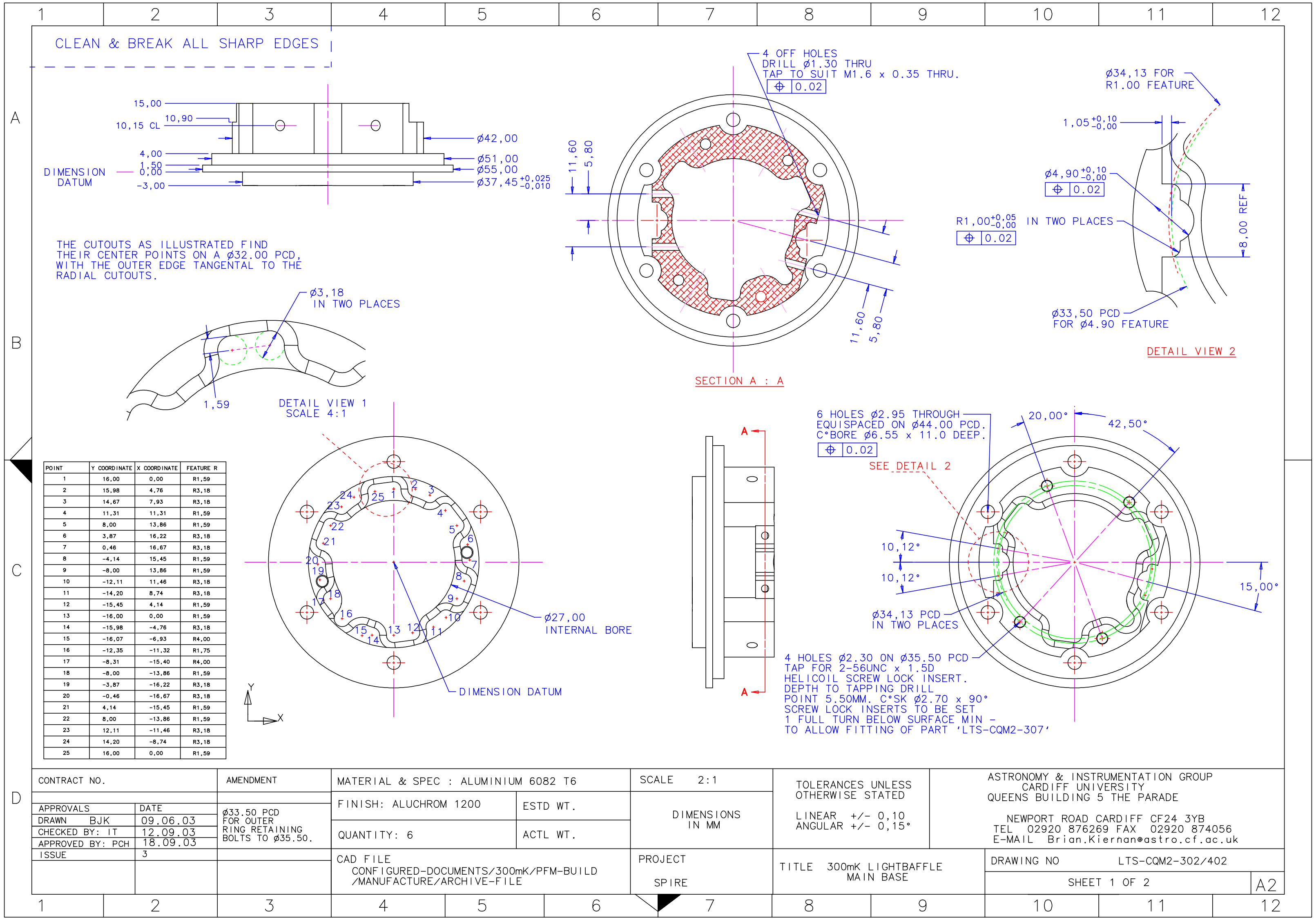


Figure 13 Photometer support fixed capstan



POINT	Y COORDINATE	X COORDINATE	FEATURE R
1	16,00	0,00	R1,59
2	15,98	4,76	R3,18
3	14,67	7,93	R3,18
4	11,31	11,31	R1,59
5	8,00	13,86	R1,59
6	3,87	16,22	R3,18
7	0,46	16,67	R3,18
8	-4,14	15,45	R1,59
9	-8,00	13,86	R1,59
10	-12,11	11,46	R3,18
11	-14,20	8,74	R3,18
12	-15,45	4,14	R1,59
13	-16,00	0,00	R1,59
14	-15,98	-4,76	R3,18
15	-16,07	-6,93	R4,00
16	-12,35	-11,32	R1,75
17	-8,31	-15,40	R4,00
18	-8,00	-13,86	R1,59
19	-3,87	-16,22	R3,18
20	-0,46	-16,67	R3,18
21	4,14	-15,45	R1,59
22	8,00	-13,86	R1,59
23	12,11	-11,46	R3,18
24	14,20	-8,74	R3,18
25	16,00	0,00	R1,59

Figure 14 300mK light baffle main base – sheet 1

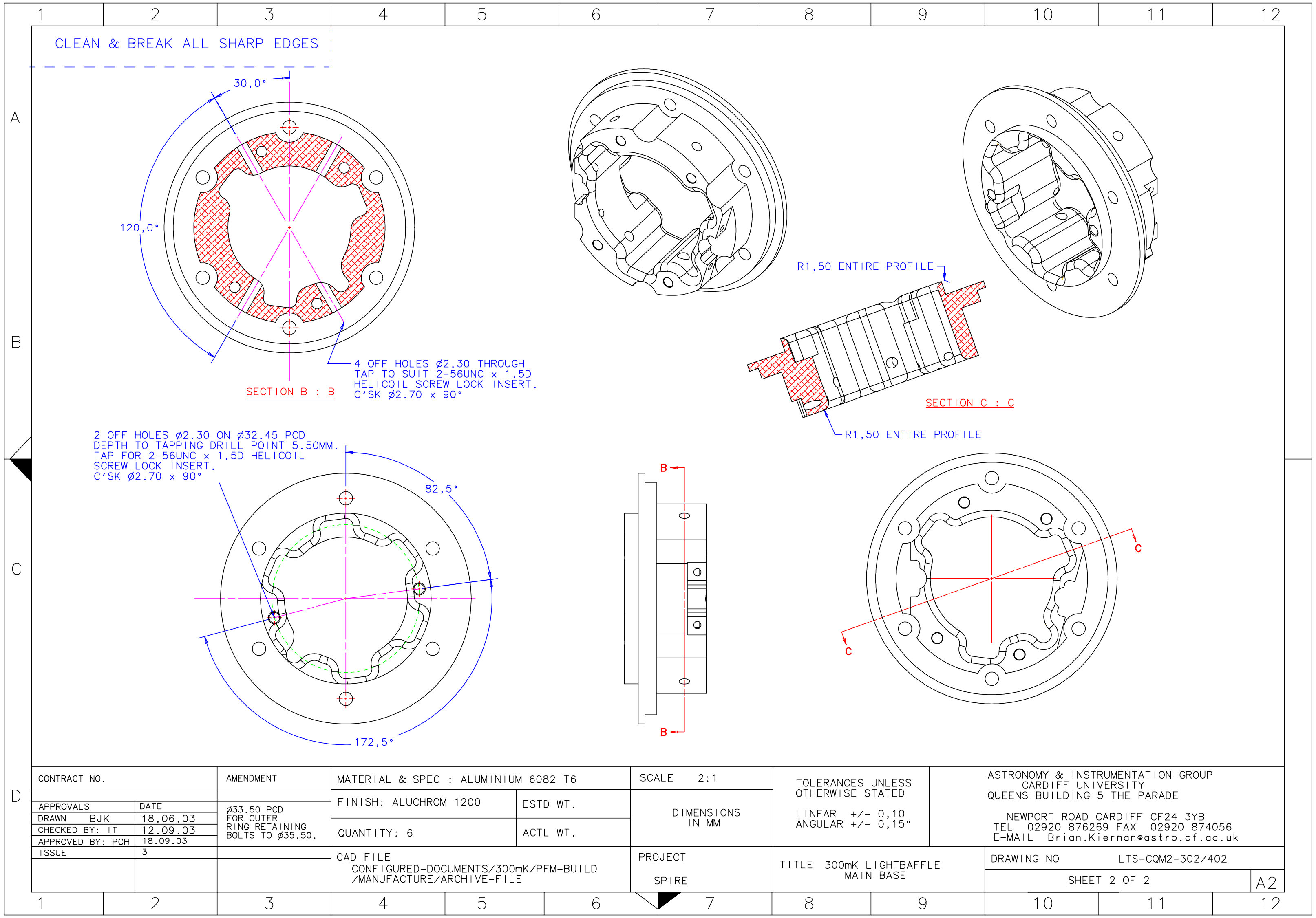


Figure 15 300mK light baffle main base – sheet 2

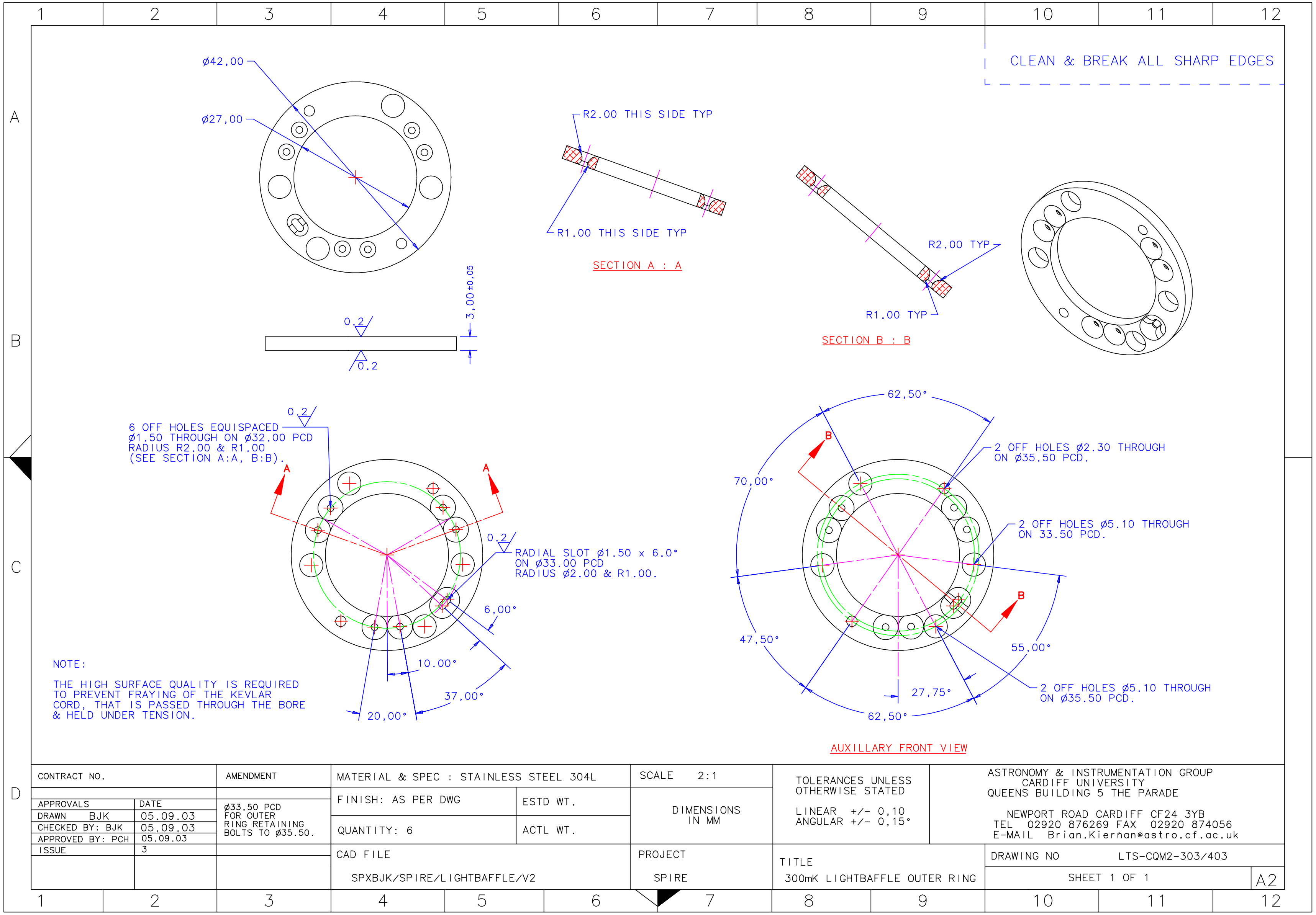


Figure 16 300mK light baffle outer ring

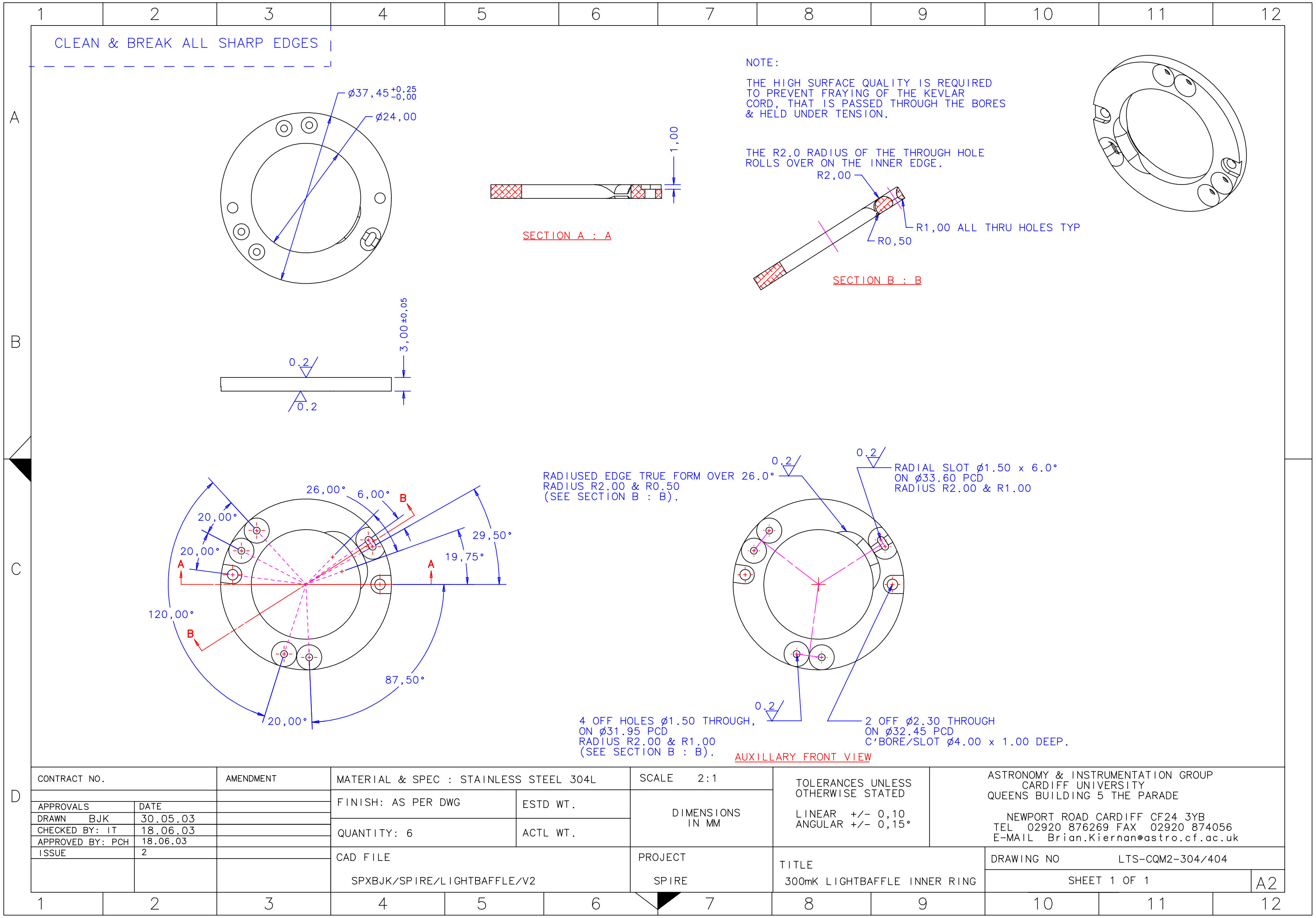


Figure 17 300mK light baffle inner ring

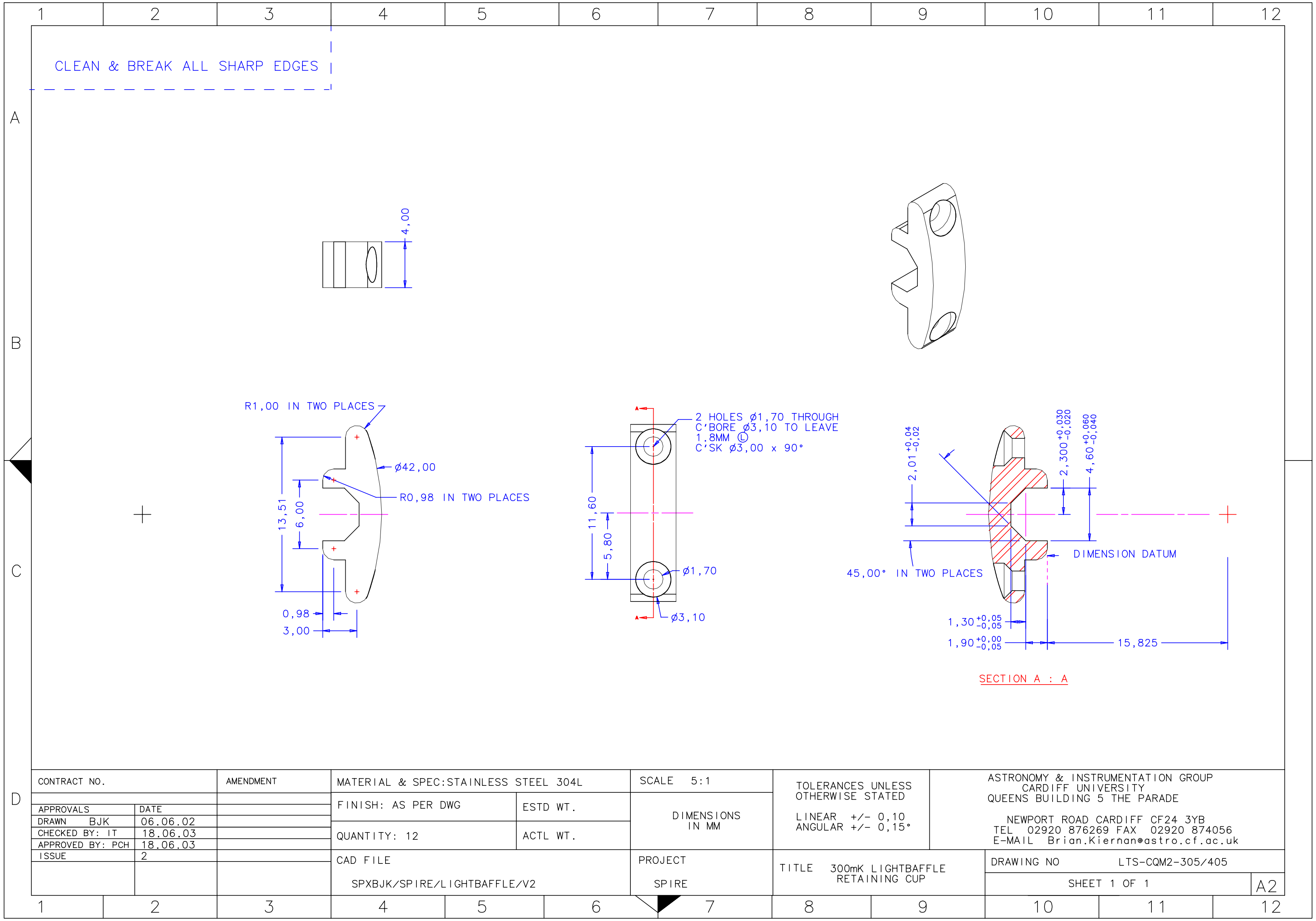


Figure 18 300mK light baffle retaining cup

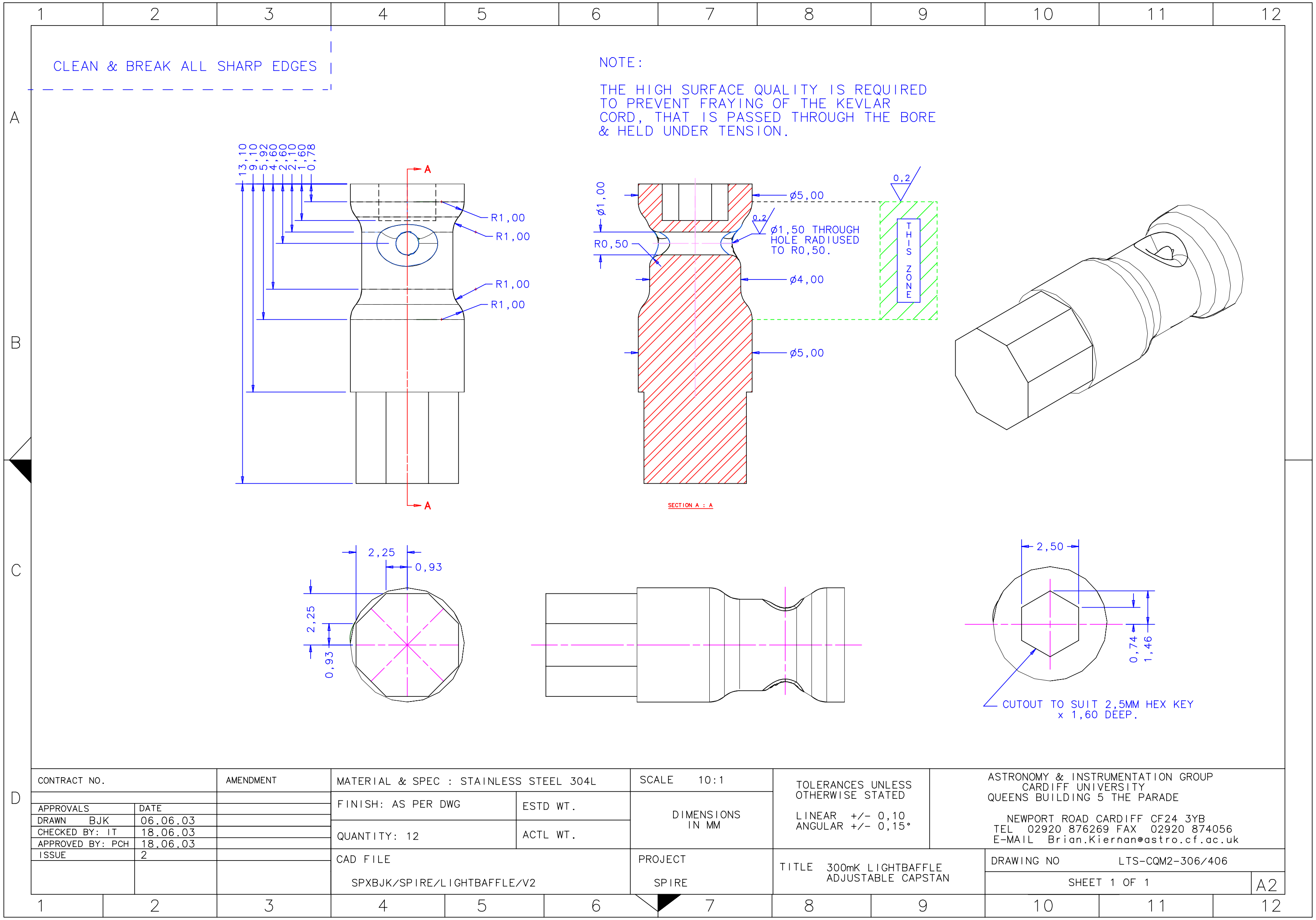


Figure 19 300mK light baffle adjustable capstan

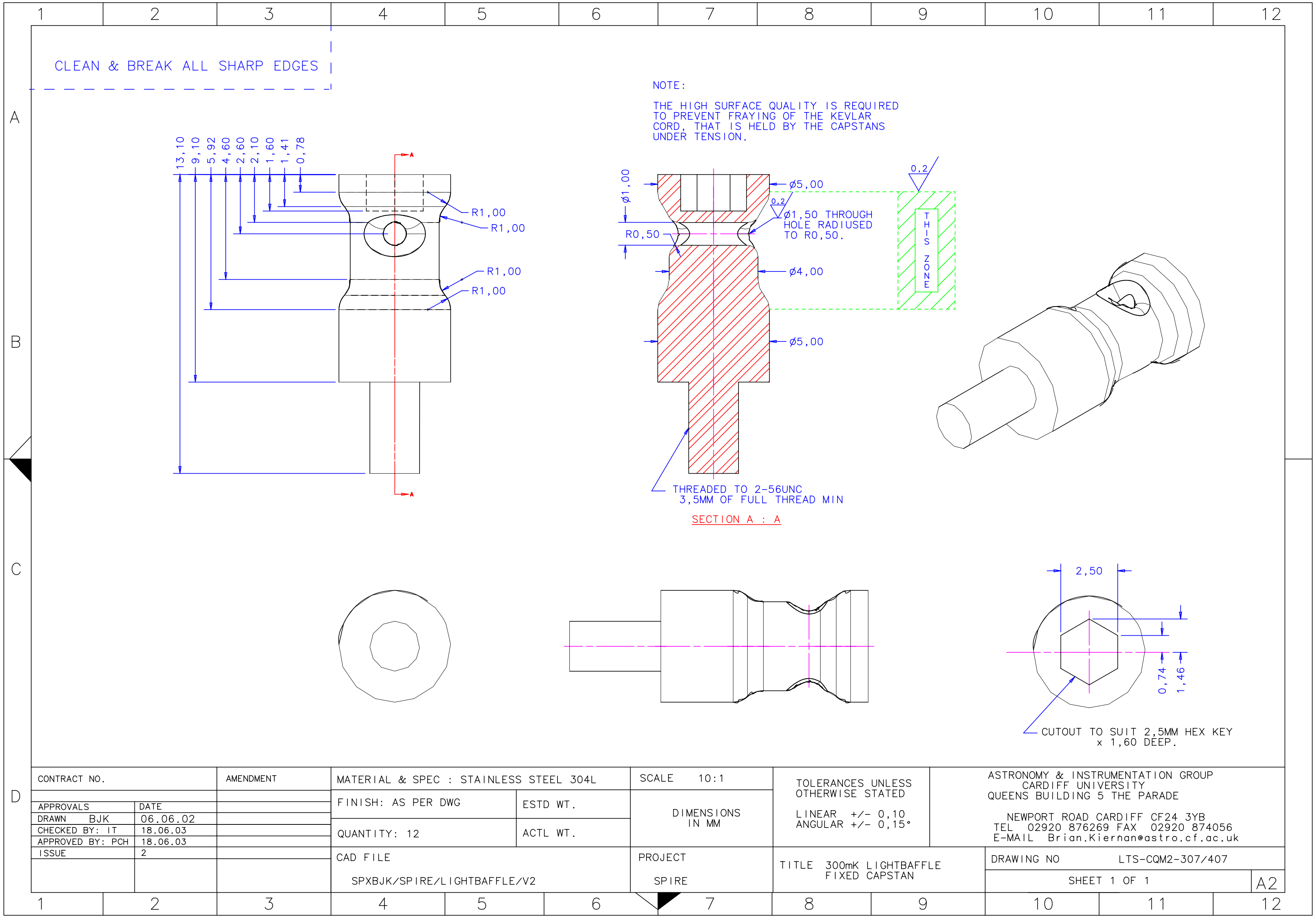


Figure 20 300mK light baffle fixed capstan

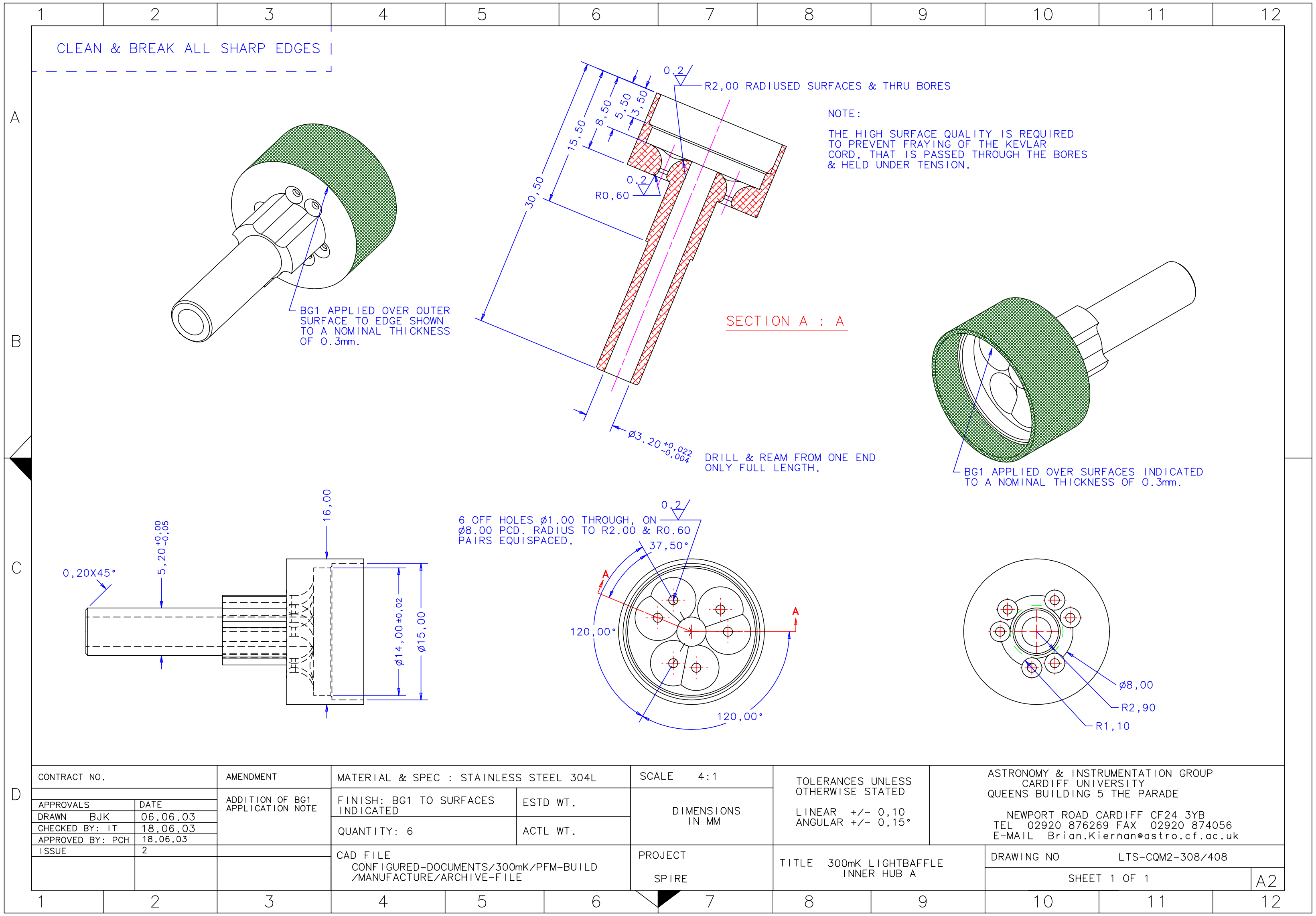


Figure 21 300mK light baffle inner hub A

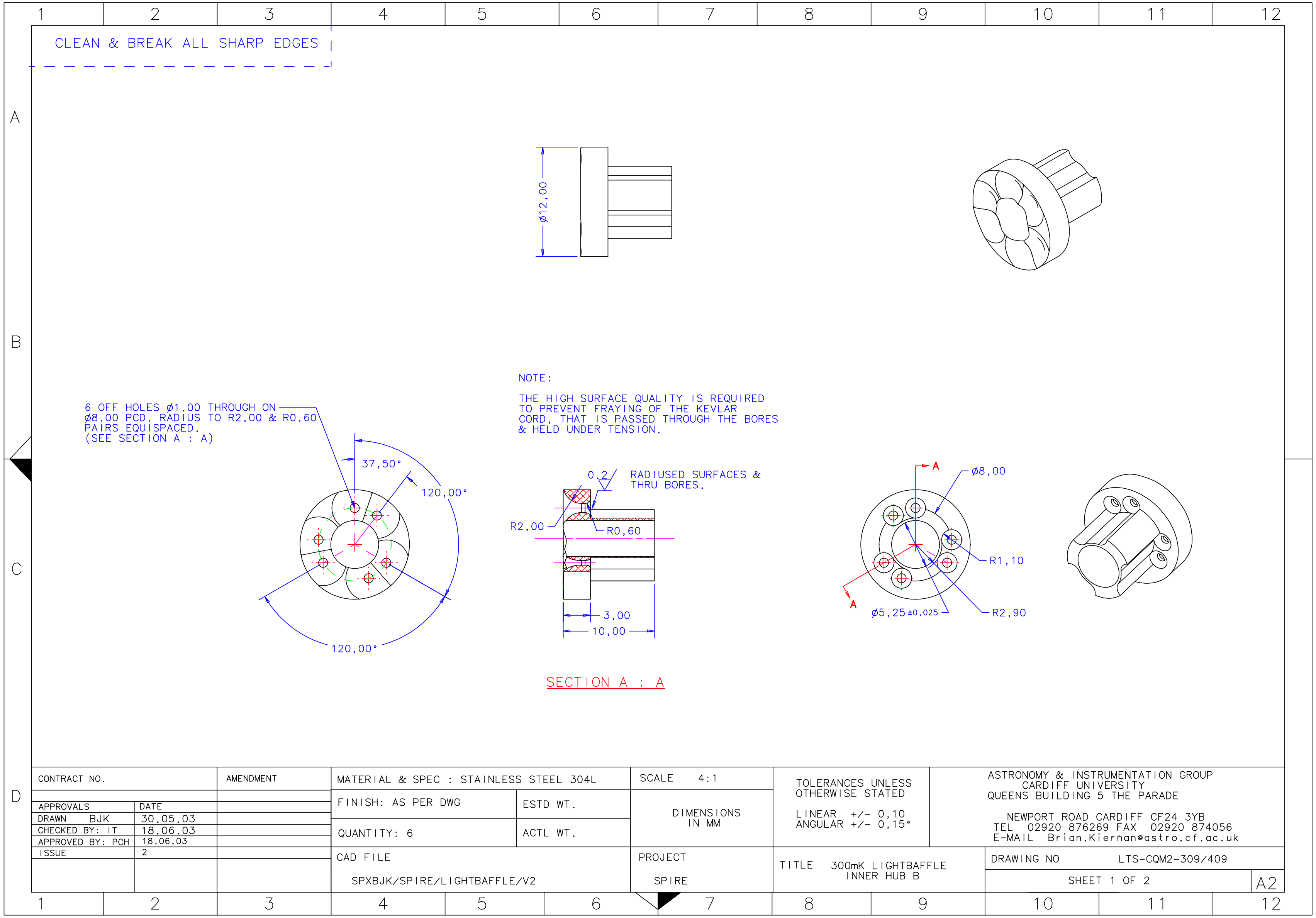


Figure 22 300mK light baffle inner hub B

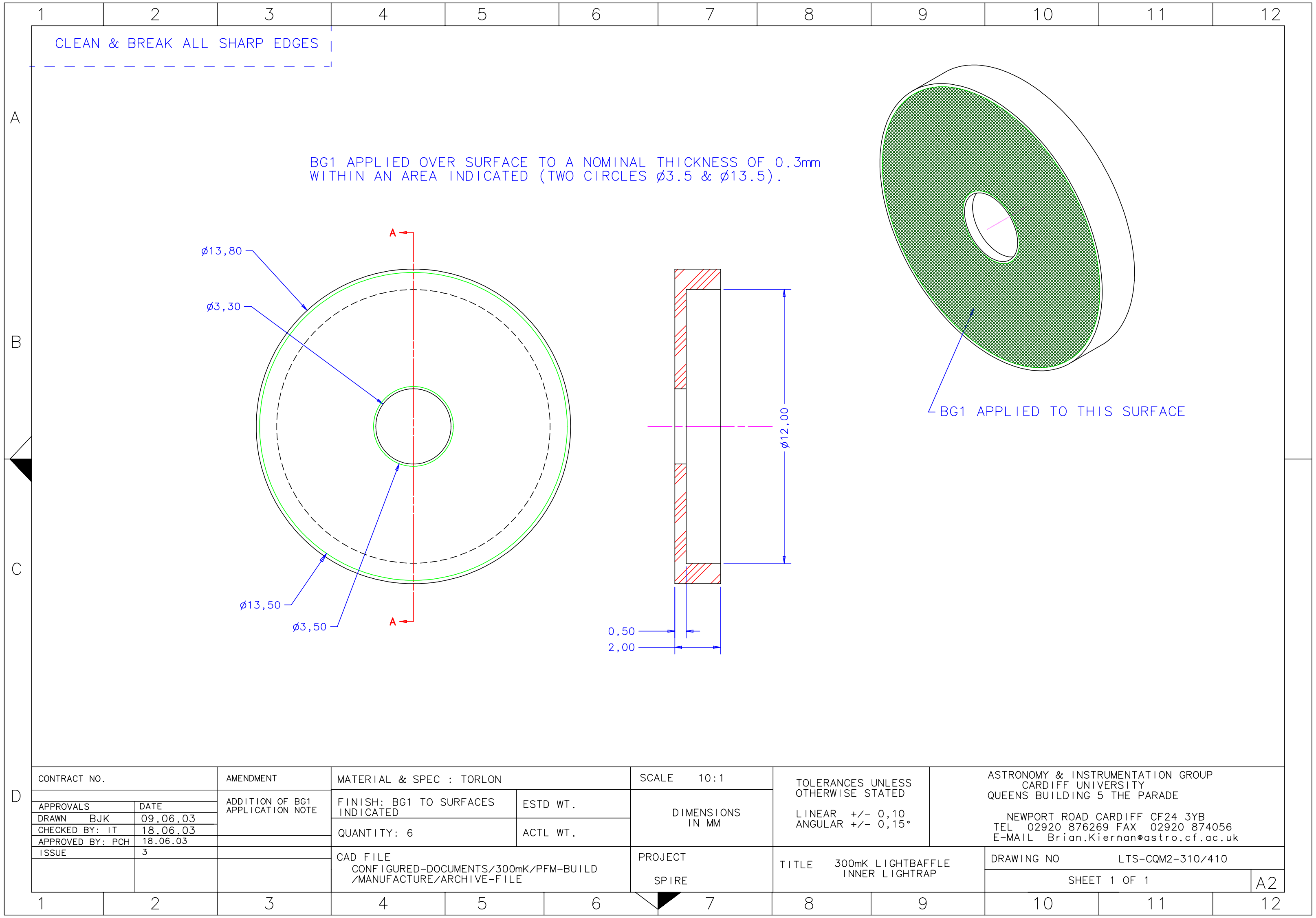
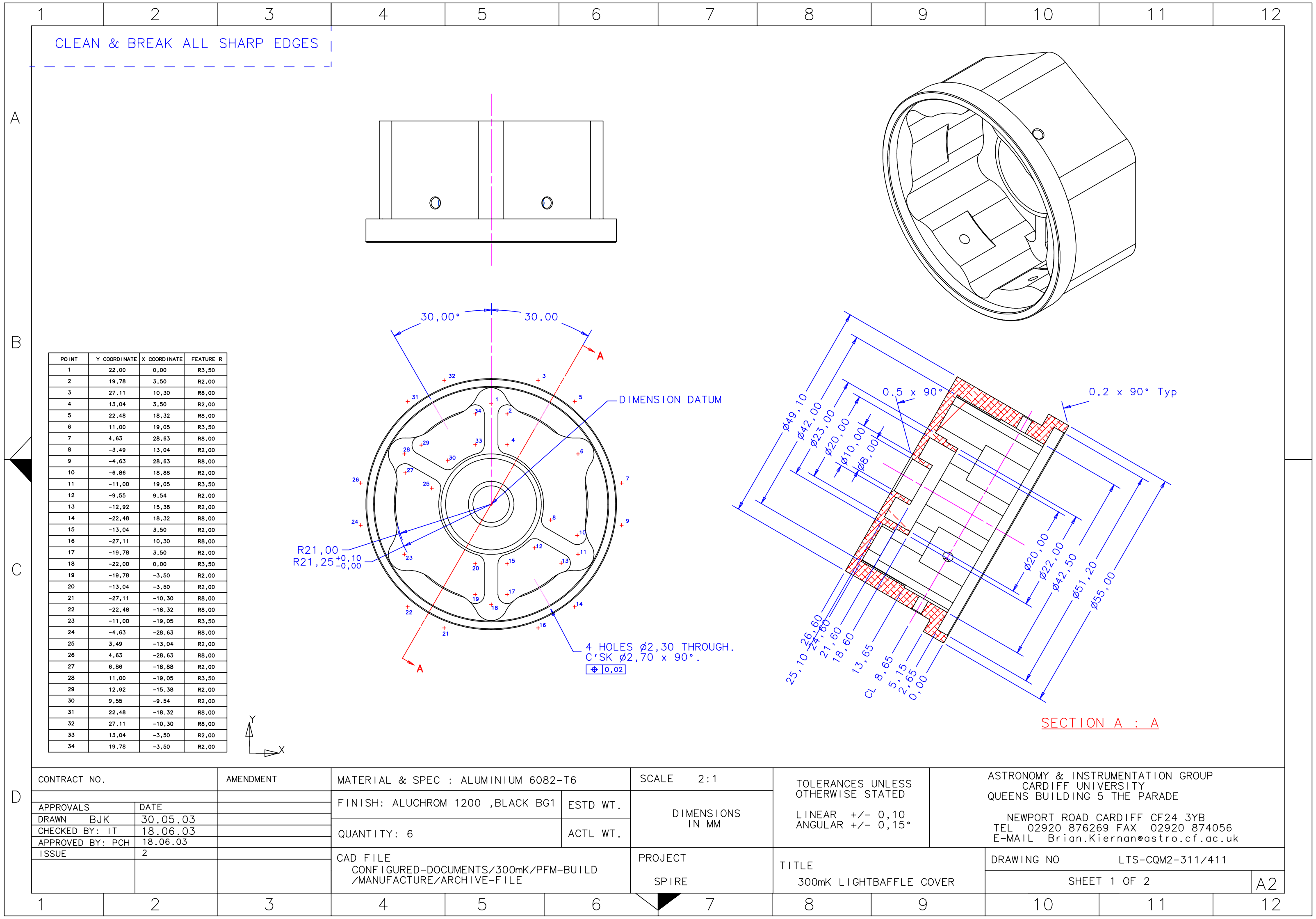


Figure 23 300mK light baffle inner light trap



POINT	Y COORDINATE	X COORDINATE	FEATURE R
1	22,00	0,00	R3,50
2	19,78	3,50	R2,00
3	27,11	10,30	R8,00
4	13,04	3,50	R2,00
5	22,48	18,32	R8,00
6	11,00	19,05	R3,50
7	4,63	28,63	R8,00
8	-3,49	13,04	R2,00
9	-4,63	28,63	R8,00
10	-6,86	18,88	R2,00
11	-11,00	19,05	R3,50
12	-9,55	9,54	R2,00
13	-12,92	15,38	R2,00
14	-22,48	18,32	R8,00
15	-13,04	3,50	R2,00
16	-27,11	10,30	R8,00
17	-19,78	3,50	R2,00
18	-22,00	0,00	R3,50
19	-19,78	-3,50	R2,00
20	-13,04	-3,50	R2,00
21	-27,11	-10,30	R8,00
22	-22,48	-18,32	R8,00
23	-11,00	-19,05	R3,50
24	-4,63	-28,63	R8,00
25	3,49	-13,04	R2,00
26	4,63	-28,63	R8,00
27	6,86	-18,88	R2,00
28	11,00	-19,05	R3,50
29	12,92	-15,38	R2,00
30	9,55	-9.54	R2,00
31	22,48	-18.32	R8,00
32	27,11	-10,30	R8,00
33	13,04	-3,50	R2,00
34	19,78	-3,50	R2,00

Figure 24 300mK light baffle cover – sheet 1

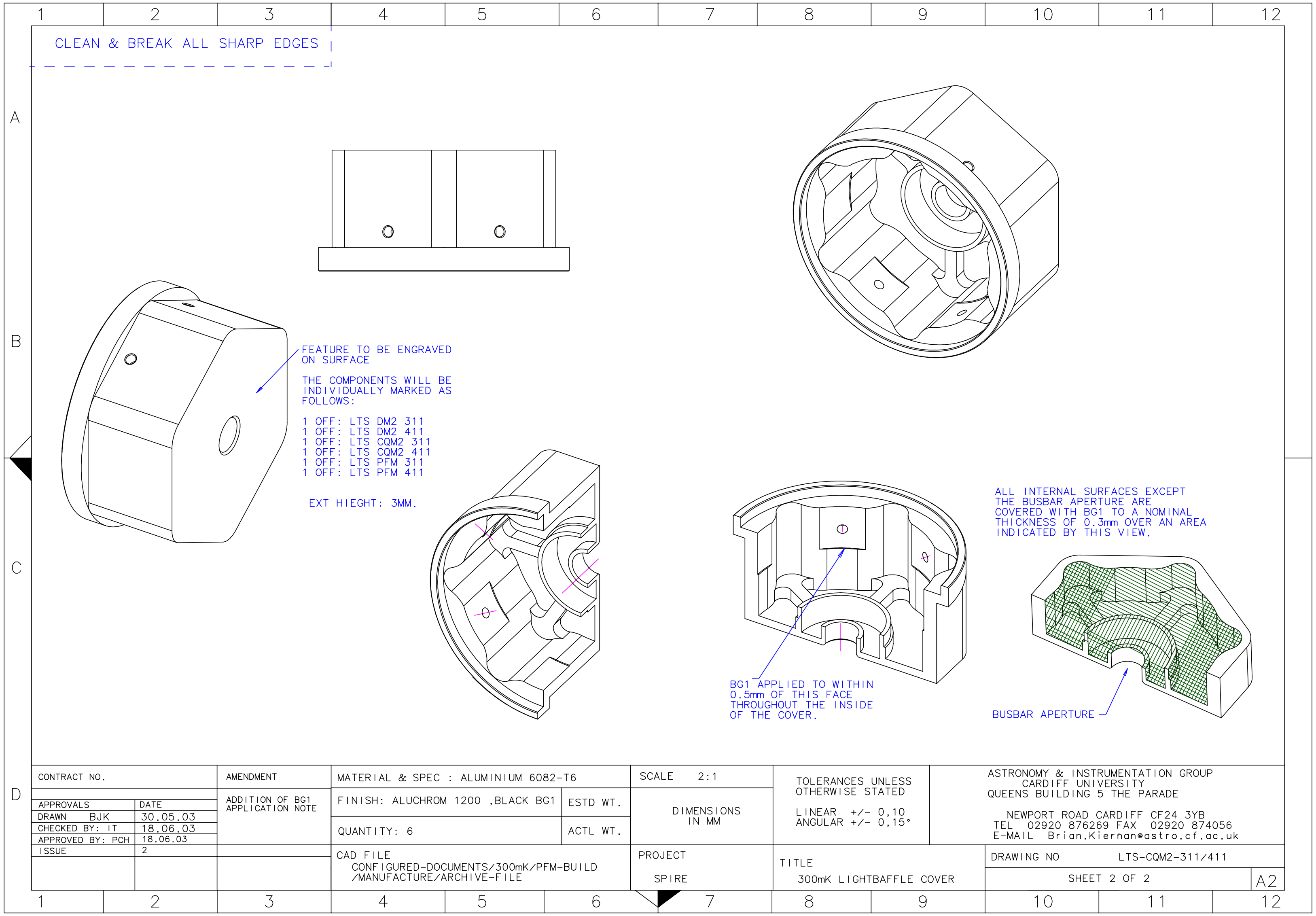


Figure 25 300mK light baffle cover – sheet 2

SECTION 08 – Electrical Circuit Diagrams

N/A

SECTION 09 – As Built Configuration Items Status List

Item	Reference / batch number / serial number	Quantity	Assembly / Location	Manufacturer / supplier	C of C #	Notes
BASE	LTS-PFM-101	1	**PHOTOMETER SUPPORT A LTS-PFM-100**	EMEC	23654 / 29472	
SIDE A	LTS-PFM-102	1		TMC	13755	
SIDE B	LTS-PFM-103	1		TMC	13755	
STRUT A	LTS-PFM-104	1		TMC	13755	
STRUT B	LTS-PFM-105	1		TMC	13755	
INNER HUB A	LTS-PFM-106	1		TMC	13755	
INNER HUB B	LTS-PFM-107	1		TMC	13755	
ADJUSTABLE CAPSTAN	LTS-PFM-108	1		TMC	13755	
FIXED CAPSTAN	LTS-PFM-109	1		TMC	13755	
BELLVILLE WASHERS	Part#3105204	12		PTC	Batch #19135	
BOLTS 2-56 X ¼		2		PTC	17953	
BOLTS 2-56 X 5/16		8		PTC	13734	
KEVLAR	0816-1000 Lot# K0971			CFILT		
BASE	LTS-PFM-201	1	**PHOTOMETER SUPPORT B LTS-PFM-200**	EMEC	23654 / 29472	
SIDE A	LTS-PFM-202	1		TMC	13755	
SIDE B	LTS-PFM-203	1		TMC	13755	
STRUT A	LTS-PFM-204	1		TMC	13755	
STRUT B	LTS-PFM-205	1		TMC	13755	
INNER HUB A	LTS-PFM-206	1		TMC	13755	
INNER HUB B	LTS-PFM-207	1		TMC	13755	

ADJUSTABLE CAPSTAN	LTS-PFM-208	1		TMC	13755	
FIXED CAPSTAN	LTS-PFM-209	1		TMC	13755	
BELLVILLE WASHERS	Part#3105204	12		PTC	Batch #19135	
BOLTS 2-56 X ¼		2		PTC	17953	
BOLTS 2-56 X 5/16		8		PTC	13734	
KEVLAR	0816-1000 Lot# K0971					
LIGHT BAFFLE BASE	LTS-PFM-302	1		EMEC	23654 / 29472	
OUTER RING	LTS-PFM-303	1		TMC	13755	
INNER RING	LTS-PFM-304	1		TMC	13755	
RETAINING CUP	LTS-PFM-305	1		TMC	13755	
LB ADJUSTABLE CAPSTAN	LTS-PFM-306	1		TMC	13755	
LB FIXED CAPSTAN	LTS-PFM-307	1		TMC	13755	
LB INNER HUB A	LTS-PFM-308	1	**PHOTOMETER BOX LIGHT BAFFLE LTS-PFM-300**	TMC	13755	
LB INNER HUB B	LTS-PFM-309	1		TMC	13755	
INNER LIGHT TRAP	LTS-PFM-310	1		TMC	13755	
LIGHT BAFFLE	LTS-PFM-311	1		EMEC	23654 / 29472	
BOLTS – 2-56 X ¼		4		PTC	17953	
BOLTS – 2-56 X 5/16		4		PTC	13734	
BELLVILLE WASHERS	Part#3105204	12		PTC	Batch #19135	
KEVLAR	0816-1000 Lot# K0971			CFILT		
LIGHT BAFFLE BASE	LTS-PFM-402	1	**SPECTROMETER BOX LIGHT BAFFLE LTS-PFM-400**	EMEC	23654 / 29472	
OUTER RING	LTS-PFM-403	1		TMC	13755	
INNER RING	LTS-PFM-404	1		TMC	13755	
RETAINING CUP	LTS-PFM-405	1		TMC	13755	
LB ADJUSTABLE CAPSTAN	LTS-PFM-406	1		TMC	13755	
LB FIXED CAPSTAN	LTS-PFM-407	1		TMC	13755	
LB INNER HUB A	LTS-PFM-408	1		TMC	13755	
LB INNER HUB B	LTS-PFM-409	1		TMC	13755	

INNER LIGHT TRAP	LTS-PFM-410	1		TMC	13755	
LIGHT BAFFLE	LTS-PFM-411	1		EMEC	23654 / 29472	
BOLTS – 2-56 X ¼		4		PTC	17953	
BOLTS – 2-56 X 5/16		4		PTC	13734	
BELLVILLE WASHERS	Part#3105204	12		PTC	Batch #19135	
KEVLAR	0816-1000 Lot# K0971					
Photometer support & light baffle – Assembly drawings and ICDs	300mK-PFM-top-level-DRAWINGS.doc		\\SPIRE\Cardiff_workpackages\Configured_Documents\300mK\PFM-BUILD\Manufacture			
Photometer support – Component drawings	300mK-SUPPORT-PFM-components.doc		\\SPIRE\Cardiff_workpackages\Configured_Documents\300mK\PFM-BUILD\Manufacture			
Light baffle – component drawings	300mK_Light-Baffle-PFM-components.doc		\\SPIRE\Cardiff_workpackages\Configured_Documents\300mK\PFM-BUILD\Manufacture			
300mK support system EIDP	HSO-CDF-EIDP-078		\\SPIRE\CARDIFF-WORKPACKAGES\deliverables\shipped\300mK\PFM\EIDP			
300mK support PFM design description	HSO-CDF-DD-038 issue 3.0					
Inspection record	Photographs		\\SPIRE\Cardiff_workpackages\Configured_Documents\300mK\PFM-BUILD\LTS-PFM-inspection \\SPIRE\Cardiff_workpackages\Configured_Documents\300mK\PFM-BUILD\LTS-PFM-inspection\COMPONENTS			

Suppliers & manufacturers:-

TMC	PTC	EMEC	CFILT
The Machining Centre, Pembroke Lane, Milton Village, Abingdon, Oxon, OX14 4EA 01235 831343	Precision Technology Supplies LTD, The Birches Industrial Estate, Imberhorne Lane, East Grinstead, West Sussex. RH19 1XZ 01342 410758	Electro-mec (Reading) LTD, 28 Portman Road, Reading, Bershire, England. RG30 1EA 0118 958 2035	Cousin Filterie, 8 rue Abbé Bonpain, BP 6 Wervicq Sud, 59558 Comines Cedex France

SECTION 10 – Serialised Components List

See above

SECTION 11 – List of Waivers

No waivers.

SECTION 12 – Copies of Waivers

N/A

SECTION 13 – Operations Manual

No operating manual is supplied.

SECTION 14 – Historical Record

The following table contains *brief* historical details of the manufacture, assembly and testing of the PFM 300mK strap support system
A *full* historical record of every stage of manufacture for each component is traceable at UWC, in both hard copy log-book format and on a Microsoft Access database.

Date	Event	Notes
28/07/03	PFM aluminium components delivered (manufacturer EMEC)	
07/08/03	PFM aluminium components accepted	
15/08/03	Stainless steel components delivered (manufacturer TMC)	
20/08/03	Stainless steel components rejected – sent back for re-work / re-build	Machining quality not to drawing spec.
02/09/03	Stainless steel components accepted	
08/03/04	Photometer support assembly	
10/03/04	Light baffle assembly	
11/03/04	Thermal shock cycles – supports & baffles	
04/05/04	Thermal cycle #1 to 4K	
10/05/04	Thermal cycle #2 to 4K	
04/05/04	Monitoring period starts	
22/07/04	Monitoring period ends	
08/07/04	Pre-delivery inspections	
22/07/04	Final cleaning & bakeout	
	Delivery to RAL	

SECTION 15 – Logbook / Diary of Events

Not provided – available from subsystem provider upon request.

SECTION 16 – Operating Time / Cycle Record

Post assembly, the four PFM assemblies (LTS-PFM-100/200/300/400) underwent five thermal shock cycles (350K – 77K – 350K) over the course of two days (11th/12th March 2004) as part of the Kevlar conditioning procedure.

They subsequently underwent two controlled thermal cycles to 4K, with a 6Hr soak at 4K before warming up.

- Cycle #1 – 4th May 2004
- Cycle #2 – 10th May 2004

SECTION 17 – Connector Mating Record

N/A

SECTION 18 – Age Sensitive Items Record

N/A

SECTION 19 – Pressure Vessel History / Test Record

N/A

SECTION 20 – Calibration Data Record

N/A

SECTION 21 – Temporary Installation Record

N/A

SECTION 22 – Open Work / Deferred Work / Open Tests

None.

SECTION 23 – List of Non-Conformance Reports

Number	Non-Conformance Details	Status	Raised Date
HR-SP-RAL-NCR-038	Failure of Kevlar cord on CQM1 photometer light baffle after STM warm shake	Major. Closed – CQM2 design used for CQM & PFM	April 2003

SECTION 24 – Copies of Non-Conformance Reports

NCR number HR-SP-RAL-NCR-038 is attached below.
The minutes from the resulting MRB are also attached, after the NCR.

NCR Number:	HR-SP-RAL-NCR-038v2

Spacecraft / Project	HERSCHEL	**Originator's Name**	Doug Griffin
Experiment / Model	SPIRE	**Signature**	
Sub-System	Structure	**Date**	6th May 03
Assembly	300-mK Strap	**Level** (Highlight if applicable)	Major / **Minor**
Sub-Assembly	Photometer SLB		
Item		**NRB Reference**	
Serial Number			

NCR Occurred During (Highlight if applicable)	Manufacture	**Inspection**	Test	Integration	Other

NCR Title	**300-mK Thermal Short during STM Programme**

NCR Description

It was observed that the Ø3mm copper bus-bar that passes through the Photometer Detector Box was misaligned. An Ohmmeter measured a resistance of 15Ohm between the bus-bar and the Photometer Detector Box which indicated that a short had occurred.

It was noted that there was a degree of misalignment of the bus-bar during integration.

The structure had undergone a warm random vibration test.

The link between the Stray-light baffle and the cooler was not present.

Attachments:

1 – Image of the partially assembled SLB prior to the vibration test
2 – Image of the SLB after the vibration test

Cause of NCR

Undetermined: It is unclear if the misalignment was increased during the vibration test as quantitative measurements were not made during initial integration

Disposition / Corrective Action

1. De-integrate the components from the Instrument and inspect for signs of mechanical interference during the test. **Action: RAL/MSSL/Cardiff**
   a. This action has been completed. Figures 3 and 4 indicate the precise location within the stray-light baffle where the cord commenced to fail.
2. Create an alignment budget for the 300-mK SLB and Supports. **Action: Cardiff**
3. Insert into 300-mK Integration Procedure an inspection point for measuring the misalignment. **Action: MSSL/Cardiff**

Item 1-Doug to issue a check list to cover Key integration Point including this one.
Items 2 & 3 no longer valid Delete. NCR Closed

Document or Drawing Affected (Title, Number & Issue)

	PA Manager (Or Deputy)	Project Manager (Or Deputy)	Date
NCR CLOSED (Signatures Required)	Digitally signed by Eric Clark Date: 2004.05.14 10:19:00 +01'00'		Digitally signed by Eric Sawyer Date: 2004.05.17 11:00:12 +01'00'

NCR Number:	HR-SP-RAL-NCR-038

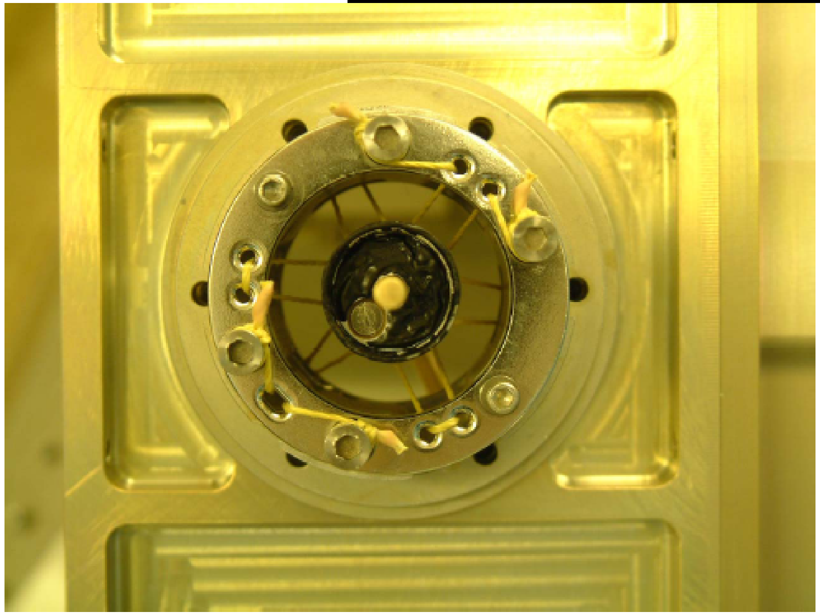


Figure 1 - Image of the SLB prior to the Warm Vibration

Figure 2 - Image of the outside of the SLB after warm vibration. This view is partially obscured by the presence of the cooler.

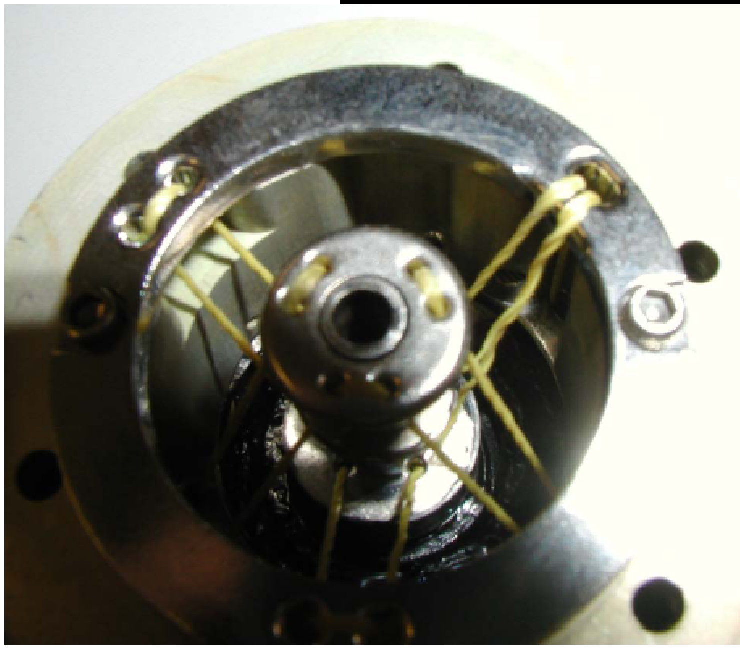


Figure 3 - View of the partially failed Kevlar cord

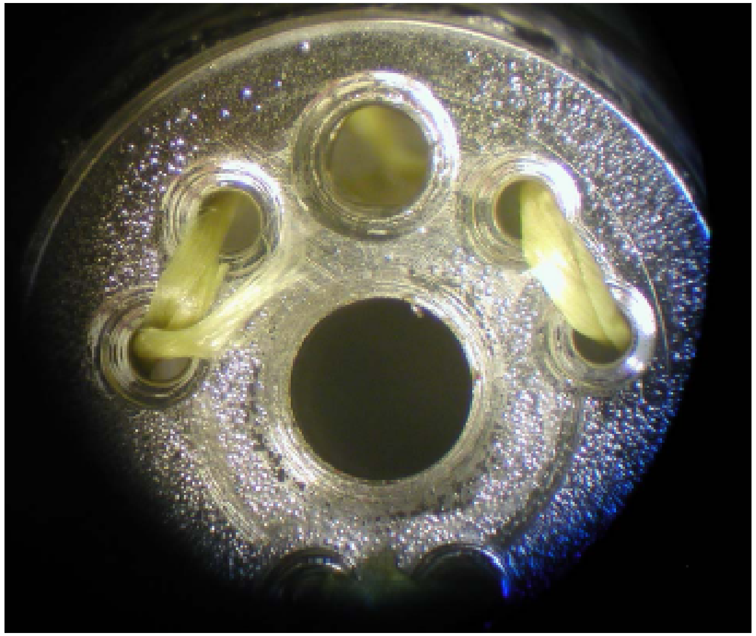


Figure 4 - View of the cord fraying around the tight bend radius.

MRB minutes – following NCR number HR-SP-RAL-NCR-038

300-mK STM vibration Kevlar failure MRB

Summary by Pete of his document of May 8

- Unit was central when delivered from Cardiff
- Before vibration: not exactly central but not touching by visible inspection.
- After vibration: not touching on visible inspection outside but touching inside as measured electrically.
- Kevlar cord visibly damaged – two of three cords broken – asymmetry leading to misalignment
- Black coating undamaged
- Close inspection showed cord failure as radiused hole – badly machined with slight discontinuity instead of smoothly radiused transition from one hole to another
- Signs of minor Kevlar fibre abrasion on inner hub – scuffing during handling? – but this is not the failure mode. Handling and jigging procedures may be revised.
- Unit was originally designed for lower preloads – bends are too tight for higher preload now being used to prevent the Kevlar from slipping and make the unit stiff.
- Manufacturers used ball-ended cutter but profiled cutter was requested.- will be addressed at rebuild – processes will be specified and inspected.

Proposed Redesign (presentation by Pete)

- Kevlar diameter 0.5 mm to be retained (needed to accommodate the pre-load)
- Larger radiused holes (4-mm dia bend) on both the inner and outer parts (even though inner part is less critical) with some rerouting of the Kevlar
- No change to interfaces or volume envelope
- Small (advantageous) increase in Kevlar angles
- 1-mm radiused sections where Kevlar exits
- Disk thickness will be increased from 2 mm to 3 mm
- Disk now to be threaded instead of using a locked screw - still to be detailed

Options – keep existing design or redesign?

- Berend: It was a workmanship/inspection failure, but approve of redesign to provide more margin.
- Doug: Agree.
- Bruce: Agree provisionally, but need to inspect the spectrometer baffle unit. Danger of bringing in unforeseen phenomena in a new design – e.g., will it slip more?
- Berend: New design should slip less.

- Doug: Larger radiused hole should reduce compressing stress if the cord goes over a raised feature.
    - *Note: Inspection of spectrometer side light baffle support by Berend later in the day showed it to exhibit no anomalies*.

Conclusions

- Failure is attributed to sharp edges at radiused holes (workmanship/inspection) combined with too-small radiused holes (vulnerability to such workmanship errors)
- Very careful inspection will be needed of the new units

Proposed plan (assuming redesign goes ahead)

- Already slipped by a few days wrt Pete's plan as distributed in the note.
- Review of drawings of new unit after ~ 1 week preparation - internal Cardiff review but to be circulated to MSSL
- 4-week manufacture (est.) – MIPS need to be included in the plan.
- Six sets of outer rings and central hubs to be procured
- A few days needed for acceptance – RAL Talysurf machine to be used.
- Assemble DM2 to all procedures for unit-level test (mid-July) at MSSL
- Pete's plan has CQM delivery end July
- Cold shake with analogue of photometer 2-K box at RAL would be ideal next test.
- PLW BDA goes in 20 July – so there's no time for this cold test.
- 2-K box would need 400-mm envelope – too big for the cryostat.
- John: Note that Kevlar touching other side of radiused hole needs to be considered in the new design.
- Non-Cardiff effort needed to implement the recovery plan:
    - MSSL: support from for review of drawings, warm shake, definition of integration and handling procedures
    - RAL: Talysurf facility; manufacturing/advice (John Spencer's team)
- Doug: Suggest implementing an imbalance in the warm shake to make the test more severe.
- Action: Pete to updated plan to include the following, timetabled appropriately:
    - Document handling procedures and review with MSSL (Chris)
    - Provide (by repolishing/inspection and choice of the best units) a unit of the existing design as well as a fallback.
    - Test how much torque needed to misalign and restore the alignment of the unit.
    - Include workmanship shake of the unit that goes into the CQM

MRB to be reconvened before installation of new unit into the CQM.

SECTION 25 – Test Reports

Vibration test report

Warm and cold vibration testing was carried out to full qualification levels on the DM versions of the 300mK support system. These components were built in the same batch as the PFM components, and assembled to the same procedure.
The test report, HSO-CDF-RP-078, may be found on the accompanying CD-ROM

Post-assembly monitoring

Post-assembly, the PFM deliverables were monitored over the course of three months, at two-week intervals. The monitoring consisted of:-

- Visual inspection of the Kevlar
- Metrology of the suspended hubs
- Alignment of the suspended hub

Suspended hub metrology

Figure 26 The dimensions marked "A" and "B" are used for monitoring hub extension as a function of time for the photometer supports and light baffles respectively

Hub alignment

Hub alignment was checked by fitting the alignment caps to each module. These caps form a close fit between the bodies and the suspended hubs, and any difficulty in re-fitting them would indicate a hub mis-alignment.

Monitoring results

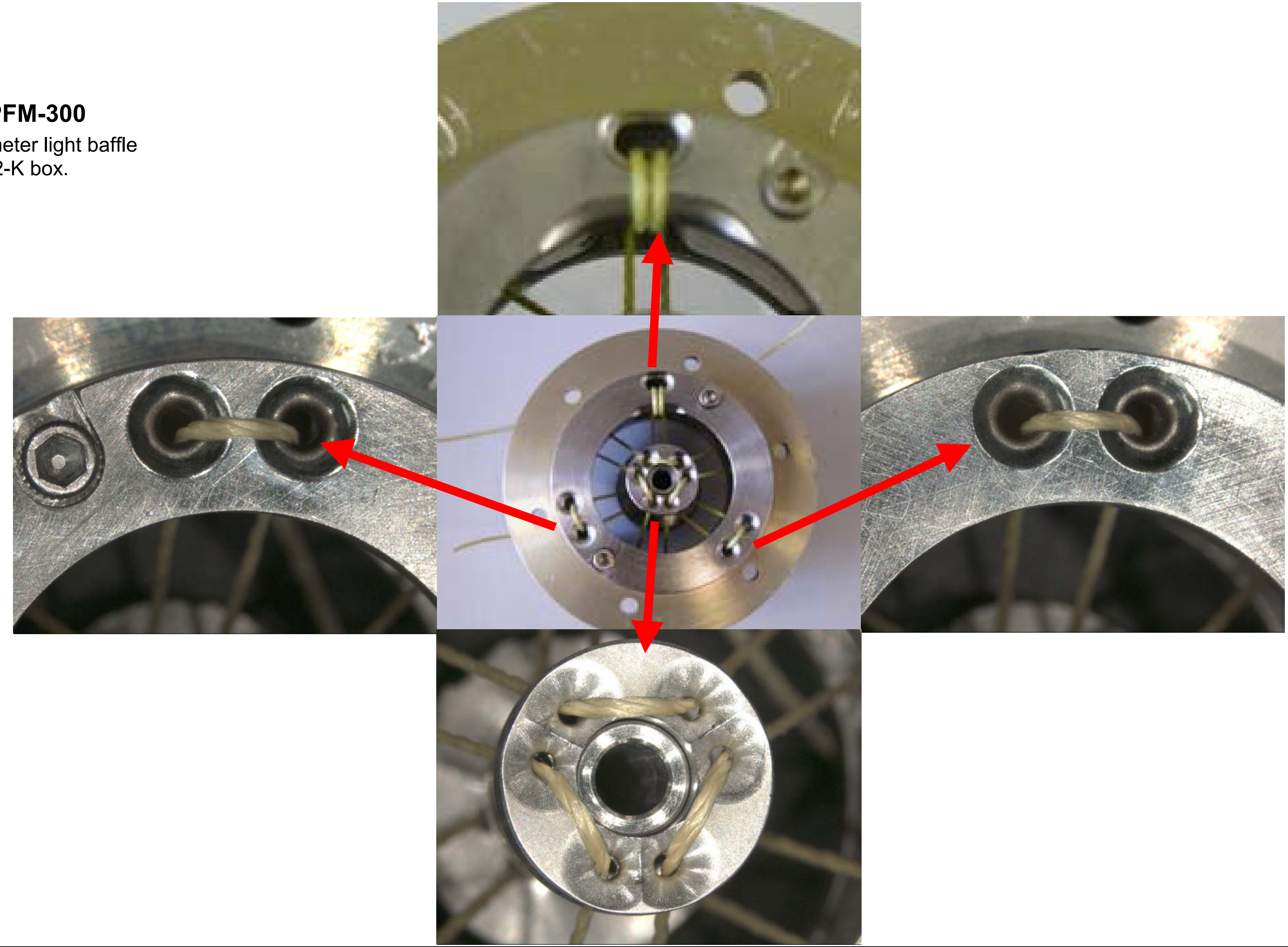
Date	LTS-PFM-100		LTS-PFM-200		LTS-PFM-300		LTS-PFM-400		Checked by:
	Hub length (mm ±0.05 mm)	Cap fit?	Hub length (mm ±0.05 mm)	Cap fit?	Hub length (mm ±0.1 mm)	Cap fit?	Hub length (mm ±0.1 mm)	Cap fit?	
04/05/04	15.78	Yes	15.57	Yes	22.20	Yes	22.71	Yes	P.Hargrave
18/05/04	15.80	Yes	15.61	Yes	22.27	Yes	22.79	Yes	P.Hargrave
31/05/04	15.81	Yes	15.61	Yes	22.28	Yes	22.80	Yes	P.Hargrave
18/06/04	15.80	Yes	15.61	Yes	22.26	Yes	22.78	Yes	P.Hargrave
06/07/04	15.81	Yes	15.60	Yes	22.25	Yes	22.81	Yes	P.Hargrave
22/07/04	15.81	Yes	15.61	Yes	22.29	Yes	22.80	Yes	P.Hargrave

Pre-delivery inspection

All Kevlar routings were photographically recorded prior to delivery, as shown on the next six pages.

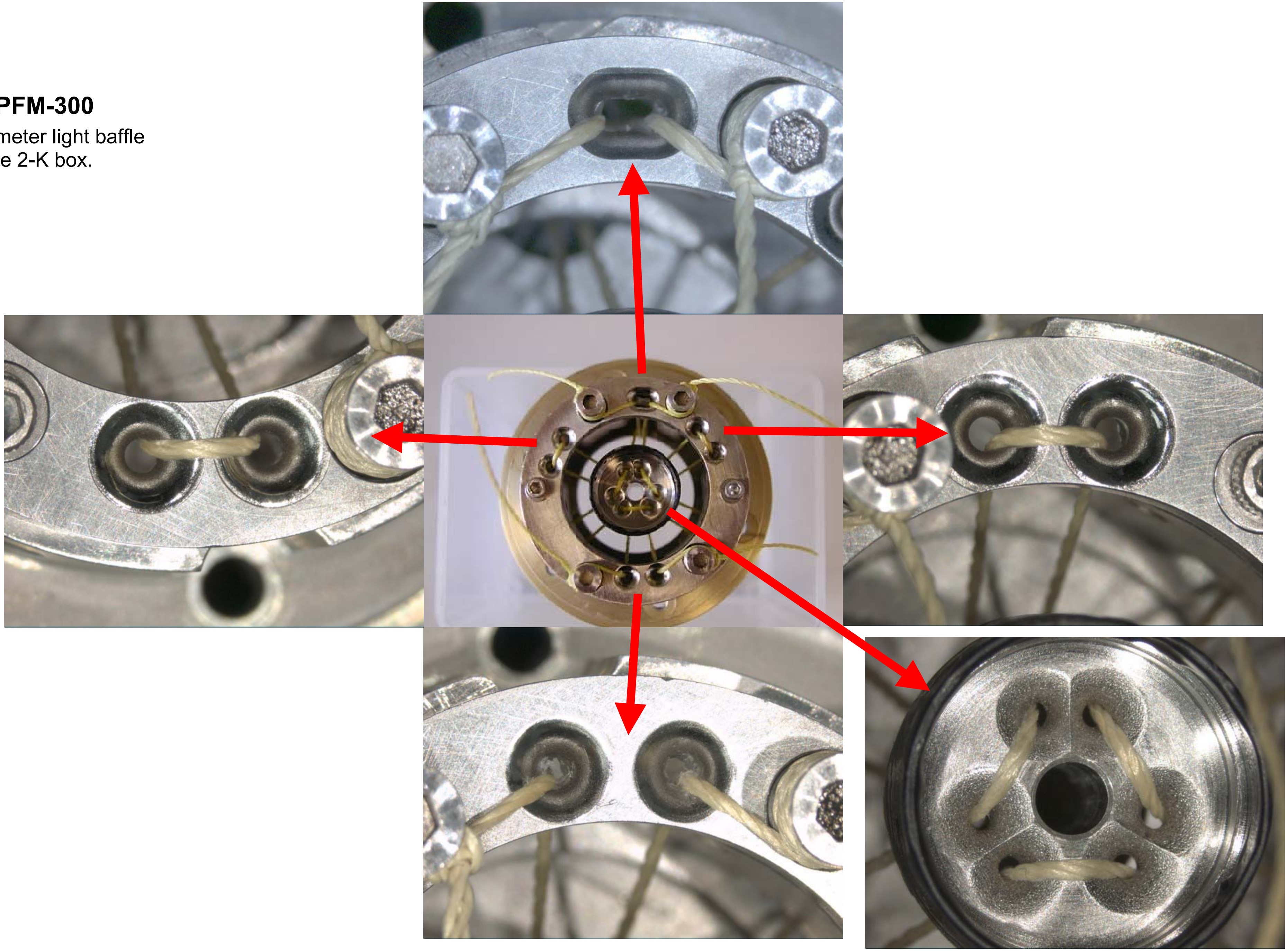
LTS-PFM-300

Photometer light baffle
Inside 2-K box.



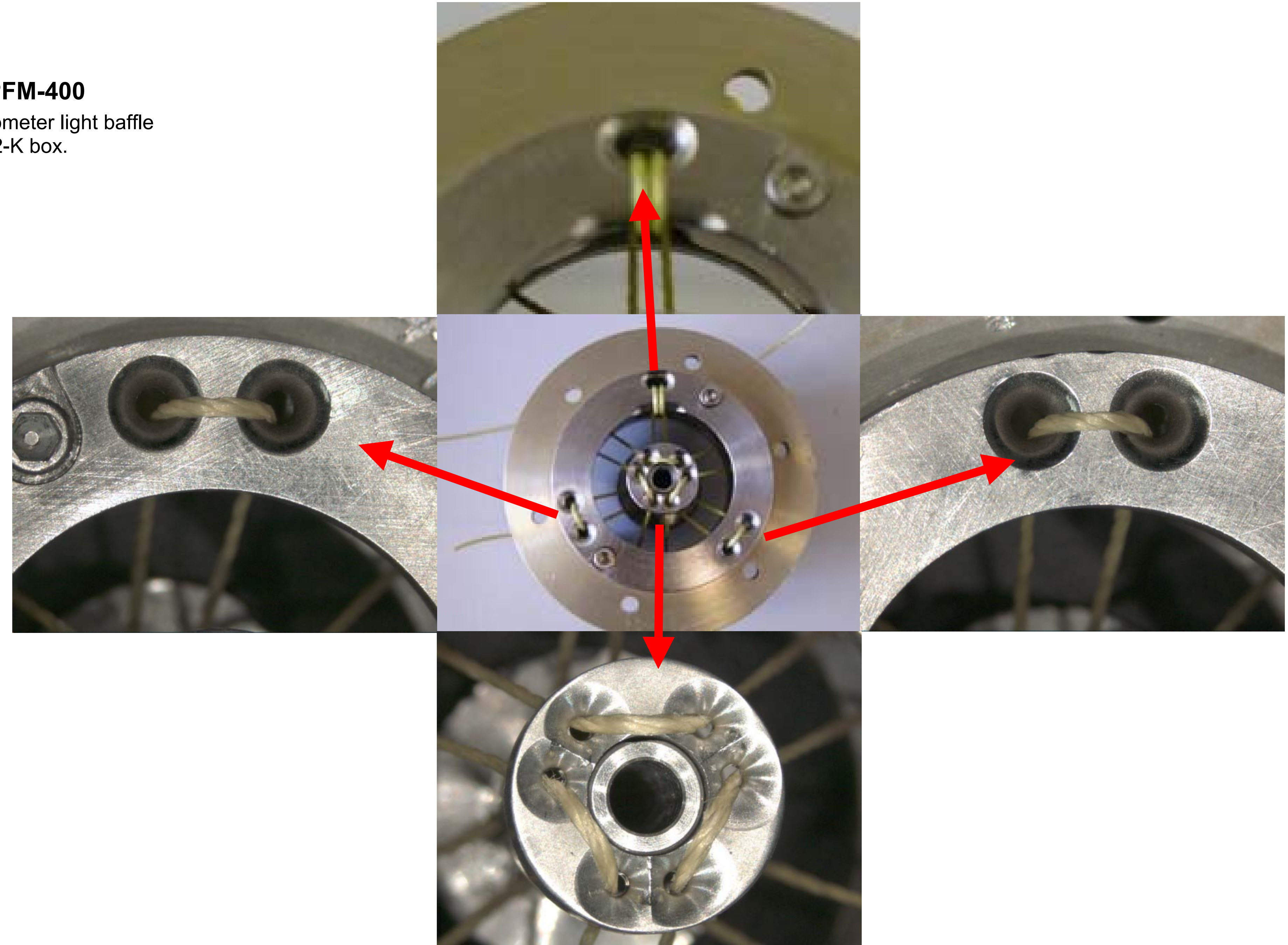
LTS-PFM-300

Photometer light baffle
Outside 2-K box.



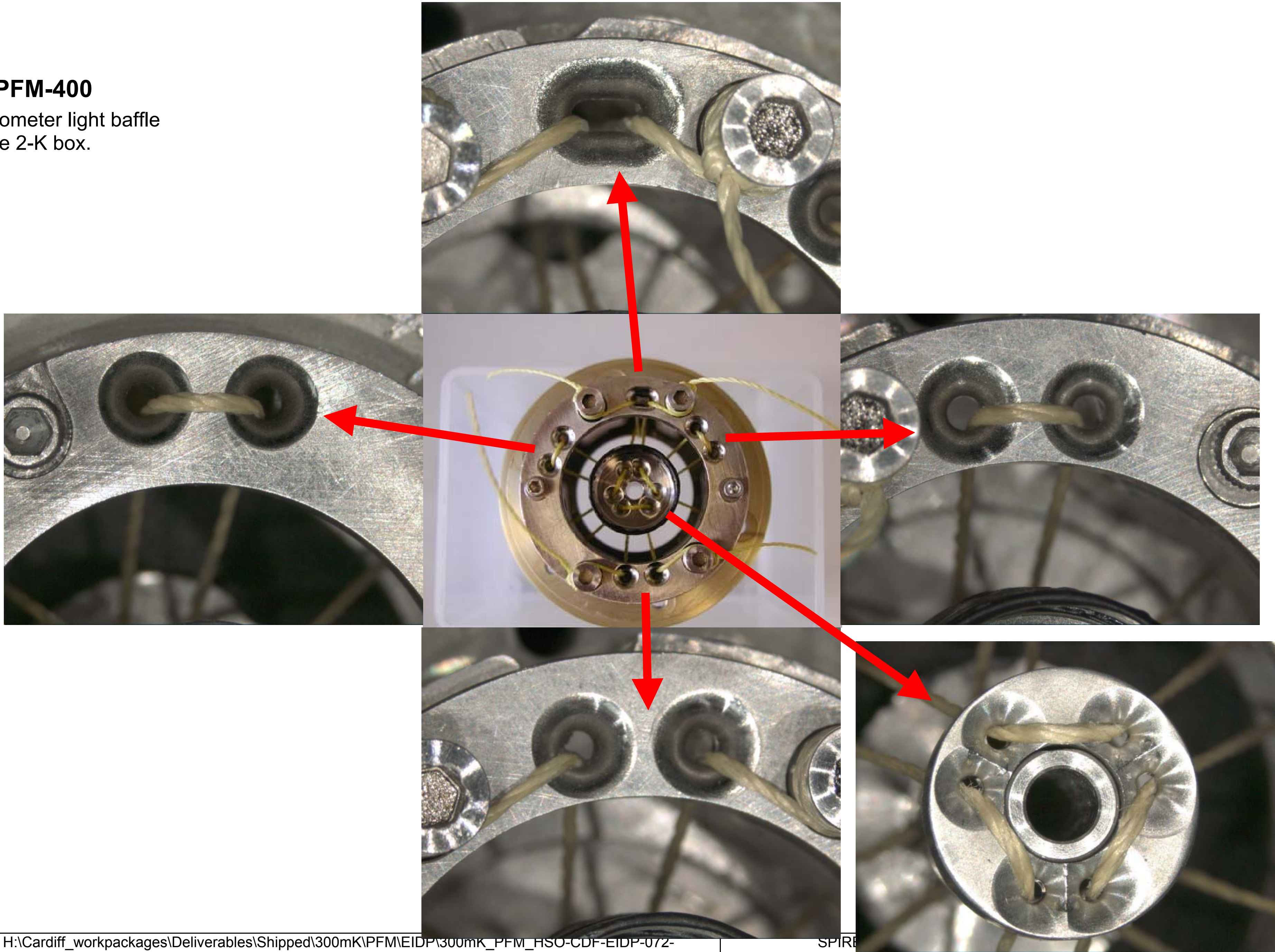
LTS-PFM-400

Spectrometer light baffle
Inside 2-K box.



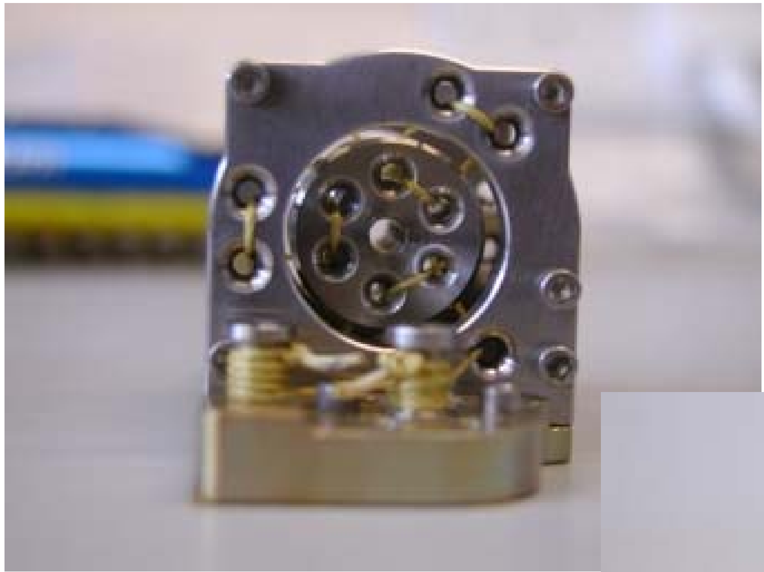
LTS-PFM-400

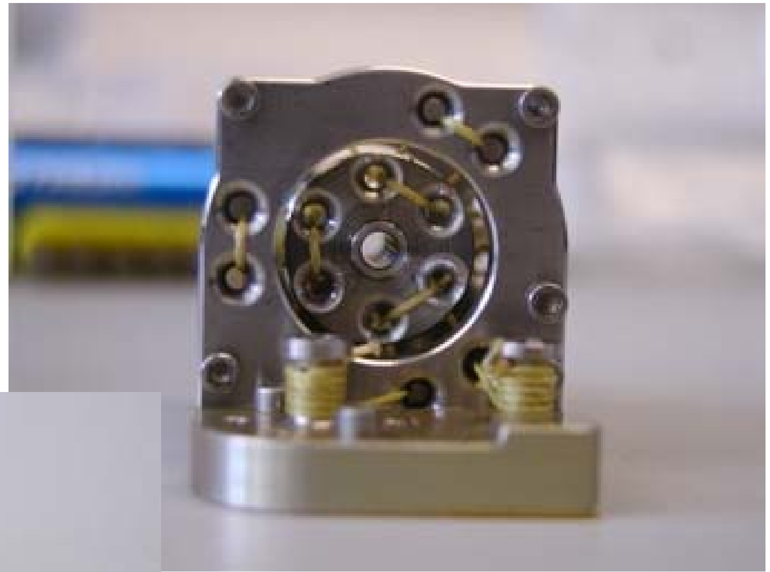
Spectrometer light baffle
Outside 2-K box.



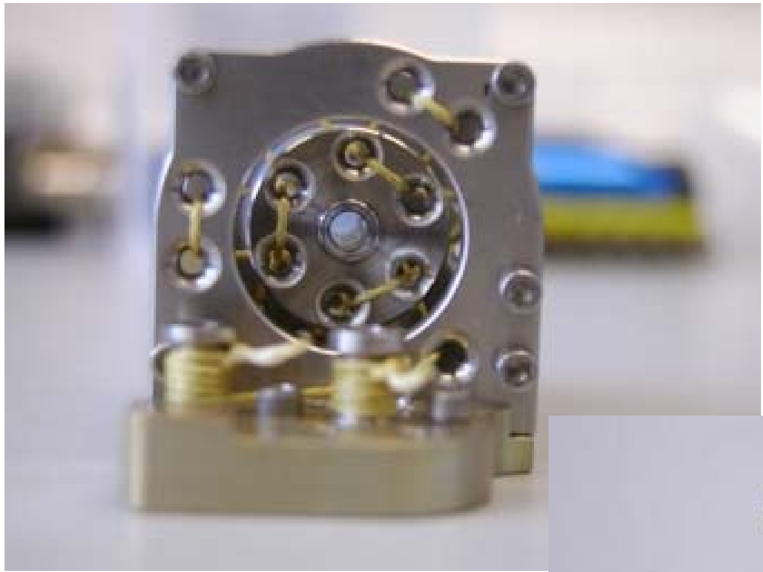
LTS-PFM-100

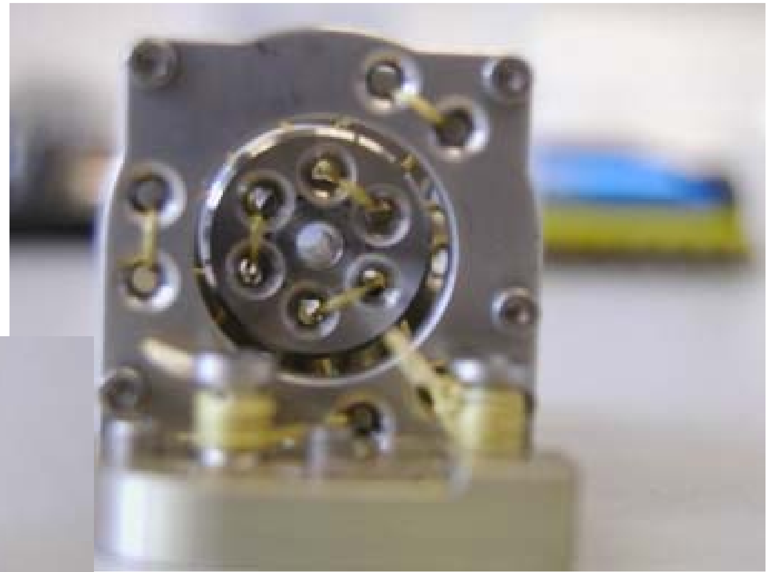
Photometer support A





LTS-PFM-200





SECTION 26 – Assembly record

08/03/04 – Photometer supports (LTS-PFM-100, LTS-PFM-200) assembled according to photometer support assembly procedure – HSO-CDF-PR-044
10/03/04 – Light baffles (LTS-PFM-300, LTS-PFM-400) assembled according to light baffle assembly procedure – HSO-CDF-RP-045

SECTION 27 – Reference List of EIDP's

Associated

Title (Listed in alphabetical order)	**ID** (Serial No.)	**Acronym**	**Document No.**	**Issue**	**Date**
MSSL PFM Structure EIDP			MSSL/SPIRE/PA012.01		

Lower Level

Title (Listed in alphabetical order)	**ID** (Serial No.)	**Acronym**	**Document No.**	**Issue**	**Date**

SECTION 28 – Mass Records

Assembly	Final measured mass (g)
LTS-PFM-100 – PHOTOMETER SUPPORT A	109.3
LTS-PFM-200 – PHOTOMETER SUPPORT B	109.6
LTS-PFM-300 – PHOTOMETER LIGHT BAFFLE	137.3
LTS-PFM-400 – SPECTROMETER LIGHT BAFFLE	137.0

SECTION 29 – Cleanliness Statement

Statement

The PFM 300mK strap support assemblies (LTS-PFM-100, -200, -300, -400) have been cleaned, assembled and tested within a class 1000 clean room to meet the requirements of the Cardiff PA plan (HSO-CDF-PL-007).

Signed ……………………………………………Peter Hargrave, Technical Manager, Cardiff-SPIRE deliverables.

Signed ……………………………………………Ian Walker, Programme Manager, Cardiff AIG.

Date …14th October 2004…………..

Extra Information

A dedicated Herschel-Planck clean room is available in the Cardiff AIG labs, class 1 000, with class 100 laminar flow cabinets.
For cooldown tests (thermal cycles) the PFM assemblies were integrated to the Cardiff test dewar within the clean room annex (approx. Class 10,000 – exposure ~15 minutes per thermal cycle).

SECTION 30 – Other Useful Information

SECTION 31 – DPL/DML

Refer to the Cardiff-SPIRE PFM deliverables lists.

Cardiff-SPIRE-DML	HSO-CDF-LI-074
Cardiff-SPIRE-DMPL	HSO-CDF-LI-075
Cardiff-SPIRE-DPL	HSO-CDF-LI-076

SECTION 32 – List of Appendices/Attachments

Appendix #	Title (Listed in alphabetical order)	Document No.	Issue	Date	Notes
A	300mK strap supports detailed design description	HSO-CDF-DD-038	3.0		On accompanying CD-ROM
B	300mK photometer support assembly procedure	HSO-CDF-RP-044	1.0		On accompanying CD-ROM
C	300mK light baffle assembly procedure	HSO-CDF-RP-045	1.0		On accompanying CD-ROM
D	Vibration test report – Herschel: Cardiff components	HSO-CDF-RP-078	1.0		On accompanying CD-ROM
E	Qualification report	HSO-CDF-RP-086	1.0		On accompanying CD-ROM
F	Minutes of DRB meeting				On accompanying CD-ROM

References

End of document

SPIRE flight model deliverables

Cold vibration qualification report – HSO-CDF-RP-078

P. Hargrave. 5th October 2004

Introduction

This document records the warm and cold vibration qualification tests carried out on the following hardware deliverables for SPIRE:-

- 300mK strap supports and light baffles LTS-DM-100, LTS-DM-300 – flight design.
- SCal reduced power version – SCAL-FS-000. Note that this item has since been accepted as the actual flight model unit.
- Pcal DM – this unit is the Pcal lifetest source mounted in the DM structure. This test was performed after the lifetest cycle had been successfully completed.
- Two additional Pcal sources in sealed chambers – one mica-based device, and one sapphire-based unit. The sapphire unit is a flight-replica design.
- Beam divider unit in CQM mount – flight design.
- Sample of blackened tile – flight design

Test configuration

300mK strap support components

The 300mK strap support components were mounted in the configuration shown in Figure 1. A bus-bar replica was manufactured, with an accelerometer mounted at the apex, to replicate the mechanical loading expected on the Kevlar-suspended 300mK parts of the system.

SCal unit

This unit, at the time of the test, was designated the flight spare unit. It was built to a revised design to the already qualified flight model unit, following a change request from the project to reduce power dissipation.
It was mounted on a bracket off the shaker plate as shown in Figure 2. The unit was sealed with vented bags for cleanliness.

Pcal unit

The Pcal unit comprised the lifetest source (HB-27) mounted in the DM structure. This vibration test was performed after HB-27 had successfully completed the lifetest qualification tests. The unit was mounted on a bracket off the shaker plate as shown in Figure 3.

Additional PCal sources

Two additional PCal sources were mounted as shown in Figure 4.
These sources were HB-21 (sapphire – flight type) and HB-25 (mica – non-flight design).

Beam divider unit

A flight replica beam divider unit was mounted off the shaker plate in a flight-design (CQM) mount, as shown in Figure 5. This component was bagged for cleanliness, as the mount was from the CQM instrument.

Blackened tile sample

An aluminium tile was manufactured and blackened according to the flight design and procedure. It was mounted according to the RAL procedure to an aluminium box, as shown in Figure 6. The tile sample was bagged so that if any particles were dislodged during the shake, they would be contained.

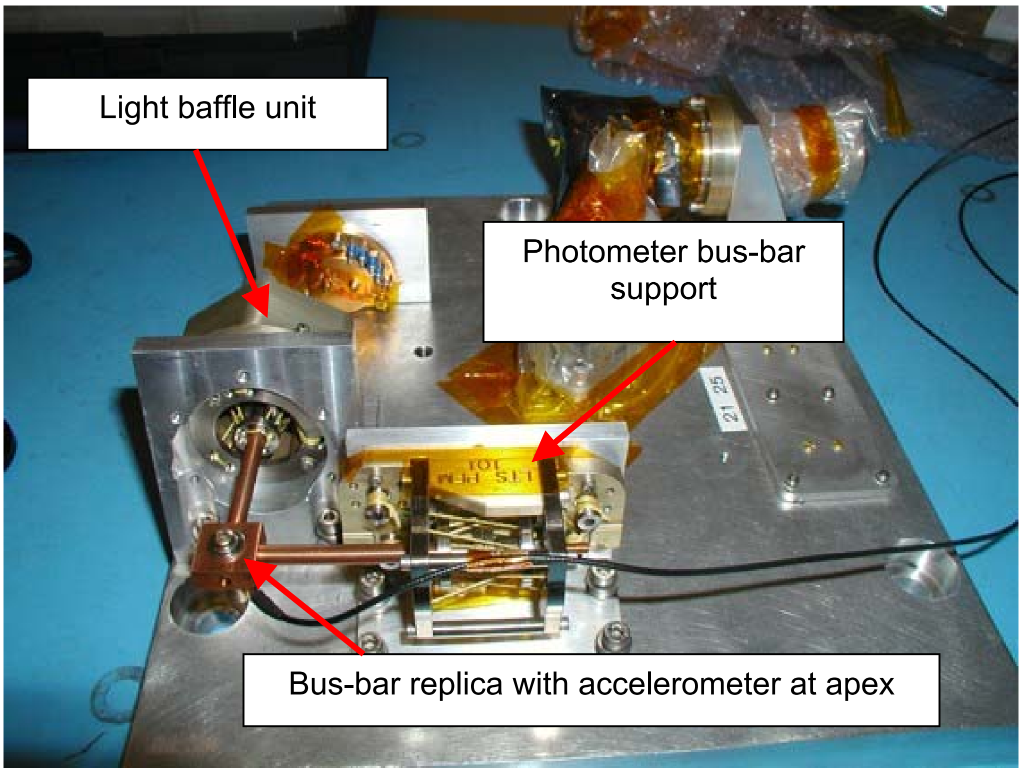


Figure 1 Configuration used for vibration testing of 300mK strap support components. Note the accelerometer mounted on the suspended copper bus-bar replica.

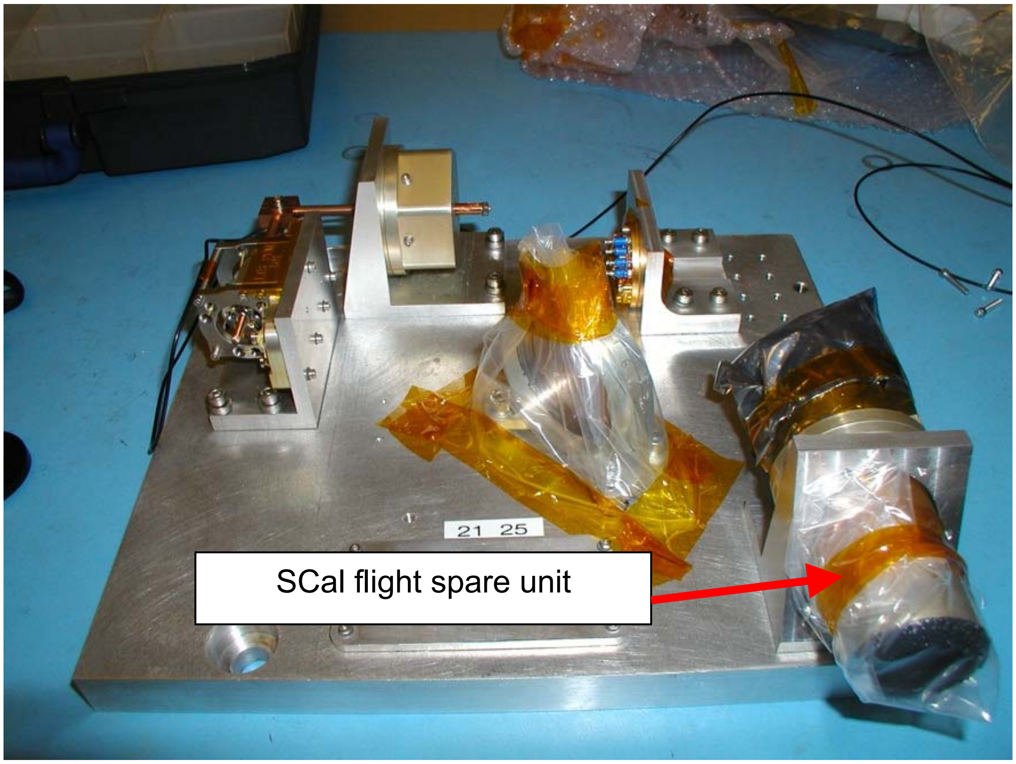


Figure 2 SCal flight spare model on shaker plate.

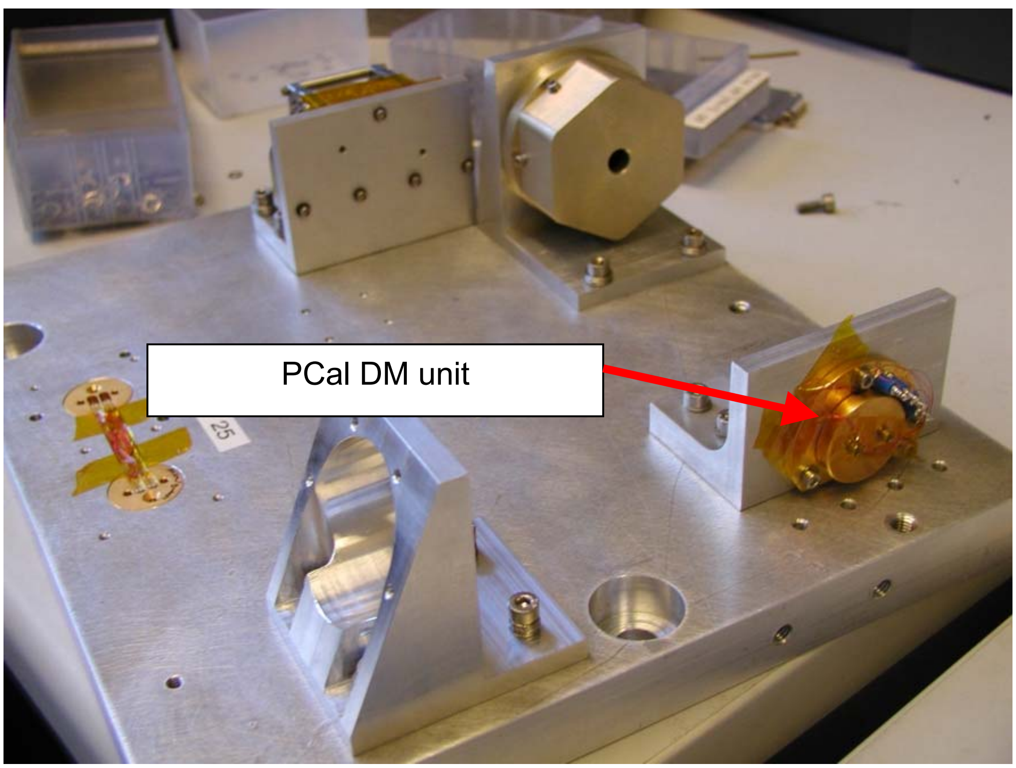


Figure 3 PCal DM in mounting bracket.

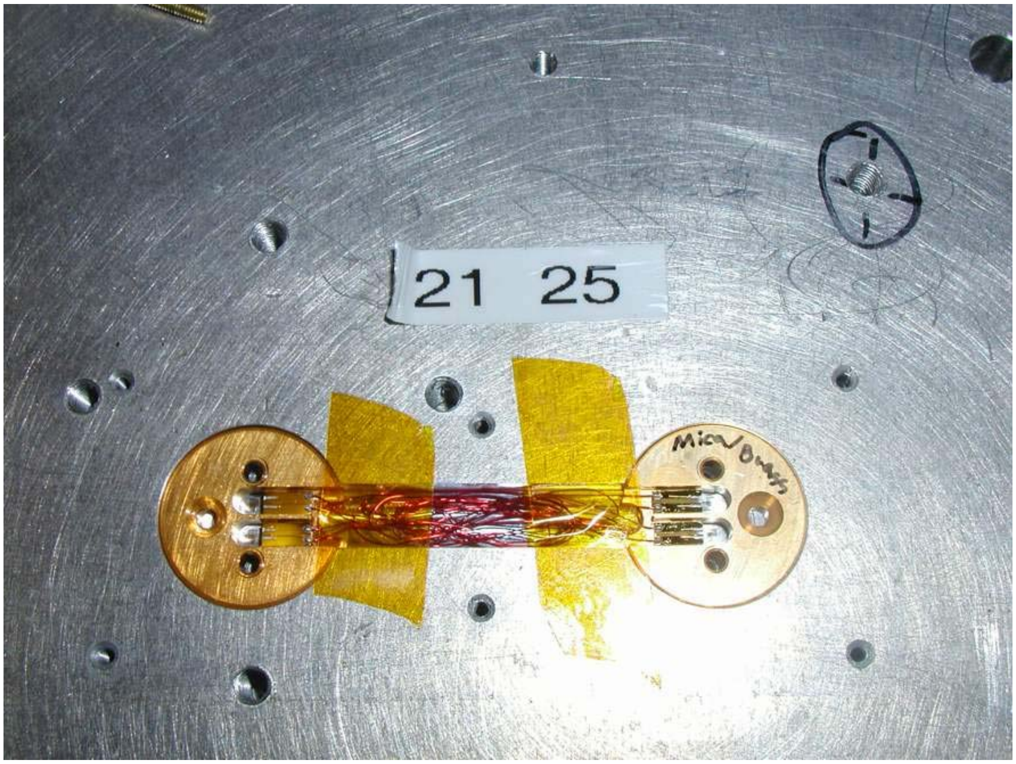


Figure 4 Additional PCal-type sources, prior to covering with aluminium plate.

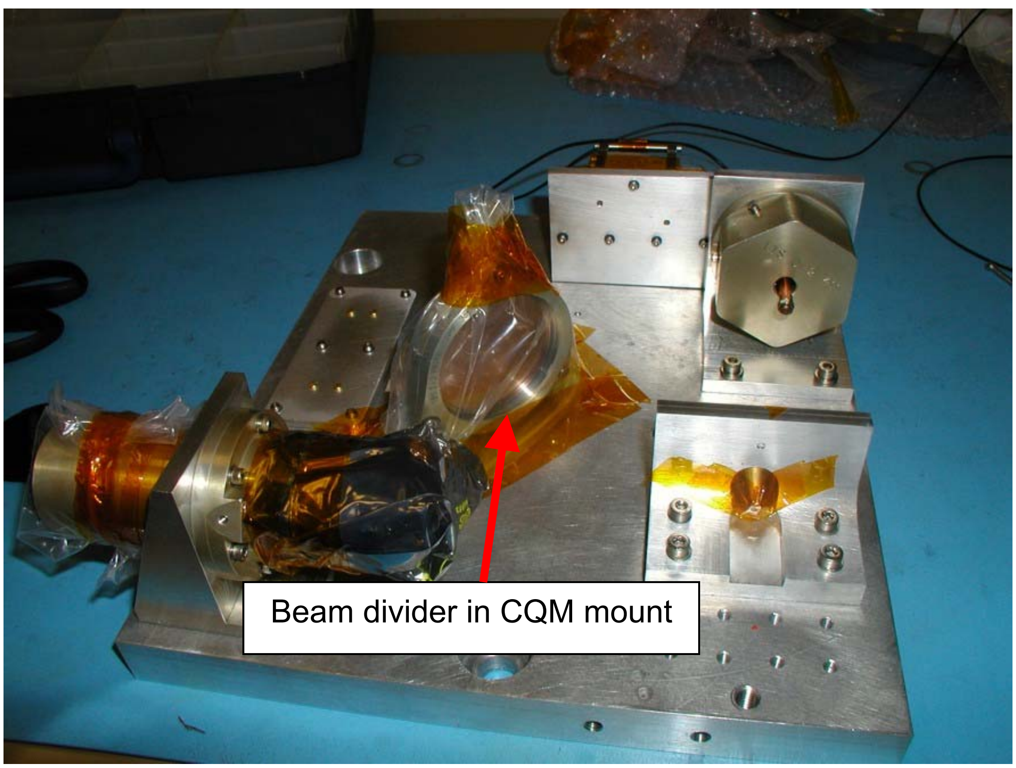


Figure 5 Beam divider in CQM mount.

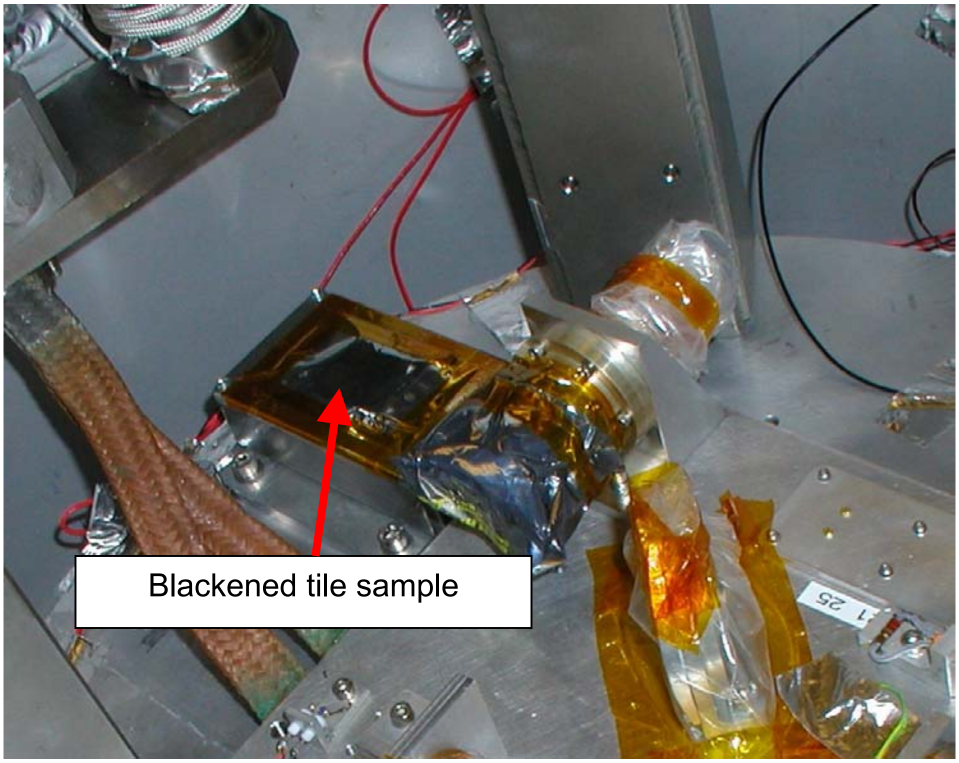


Figure 6 Tile mounted on aluminium box – bagged for cleanliness and for capture of any particles which may be dislodged.

Test report

Full details of the warm and cold vibration test are contained in the RAL vibration test report, AIV-2003-091-VIB, attached to this document as Appendix A.

Post-test inspections

300mK strap support components

Following removal of the shaker plate from the cold vibration test facility, the 300mK strap support components were examined for any sign of damage or movement. The location of the bus-bar apex with respect to the supports and the shaker plate had not changed following the shake. Therefore the bus-bar replica was removed and the support and light baffle were examined individually. There were no signs of Kevlar distress on either unit, nor any sign of particulate contamination from e.g. the black coating on the light baffle. No movement of the suspended hubs was discernable for either unit, as the alignment caps fitted each unit perfectly both before and after the shake.

SCal unit

Visual inspection of the unit revealed no visible damage.
The unit was subsequently re-calibrated at Cardiff, and no difference was observed in its' performance compared to the equivalent test before vibration.

Pcal unit

Visual inspection of the unit revealed no visible damage.
The unit was subsequently re-calibrated at Cardiff, and no difference was observed in its' performance compared to the equivalent test before vibration.

Additional PCal sources

Visual inspection of the sources revealed no visible damage.
The sources were subsequently re-calibrated at Cardiff, and no difference was observed in their performance compared to the equivalent test before vibration.

Beam divider unit

Visual inspection revealed no damage.
The beam divider was measured spectrally following the vibration test and showed identical performance to the pre-shake measurements.

Blackened tile sample

The bag containing the tile sample was carefully removed, and no debris was noted.
Careful microscopic examination of the tile sample shows no sign of cracking.

SST DEPARTMENT

VIBRATION TEST FACILITY

REPORT REF: AIV-2003-091-VIB

HERSCHEL : CARDIFF COMPONENTS

RUTHERFORD APPLETON LABORATORY
Vibration Facility
Chilton, Didcot,
Oxfordshire OX11 OQX

Tel: 44 (0) 1235 446617

CONTENTS

1) TEST ITEM DESCRIPTION

The test items consisted of :-

- Scal-B - nominal flight spare, reduced power option - SCAL-FS-000-FLIGHT COMPONENT
- Pcal DM – lifetest source in DM structure – non-flight, but flight replica
- 300mK System – 1 photometer support & 1 light baffle – both DM, but flight replica. Configuration as per previous shake.
- 2 additional Pcal sources (in sealed chambers). One mica device, one sapphire device.
- Beam divider in CQM Mount (flight replica)
- Black tiles
- Representative hot-pressed filter material in SPIRE-type mount

Testing would be carried out on the head of the shaker within the Cryostat.

2) TEST SPECIFICATION

The components were to be tested to Spire Qualification levels. A sine survey was to be initially carried out at ambient temperature/atmospheric pressure. A further sine survey followed by a random and post random sine survey would be carried out at sub 10 Kelvin/ Vacuum. A final sine survey at ambient temperature/atmospheric pressure would be undertaken.

A single axis accelerometer was to be used for monitoring.

SINE SURVEY TEST

One sweep @ 0.25g from 10 Hz to 2000 Hz at 2 octaves per minute.

RANDOM

FREQUENCY (Hz)	TEST LEVEL
20 - 100	+3 dB/oct
100 – 138.5	0.06 g^2 / Hz
138.5 - 170	0.06 – 0.7 g^2 / Hz
170 - 200	0.7 g^2 / Hz
200 - 220	0.7 – 0.1 g^2 / Hz
220 - 300	0.1 g^2 / Hz
300 - 2000	-9 dB/oct

Overall Test Level = 8.0 g rms. for 30 Seconds

3) ACCELEROMETER CALIBRATION STATUS

SINGLE AXIS - ENDEVCO 2272 & B&K 4393

SERIAL NUMBER	CALIBRATION PC/g	Date	SIGNAL CONDITIONER
A66B	12.67	11/03/04	ENDEVCO 2775A
YG32	13.77	11/03/04	
1434587	3.16	N/A	

NOTE

Due to the temperature effects, a reduction of 10% in the sensitivity values was used during all cold testing.

See test summary for details on S/N 1434587

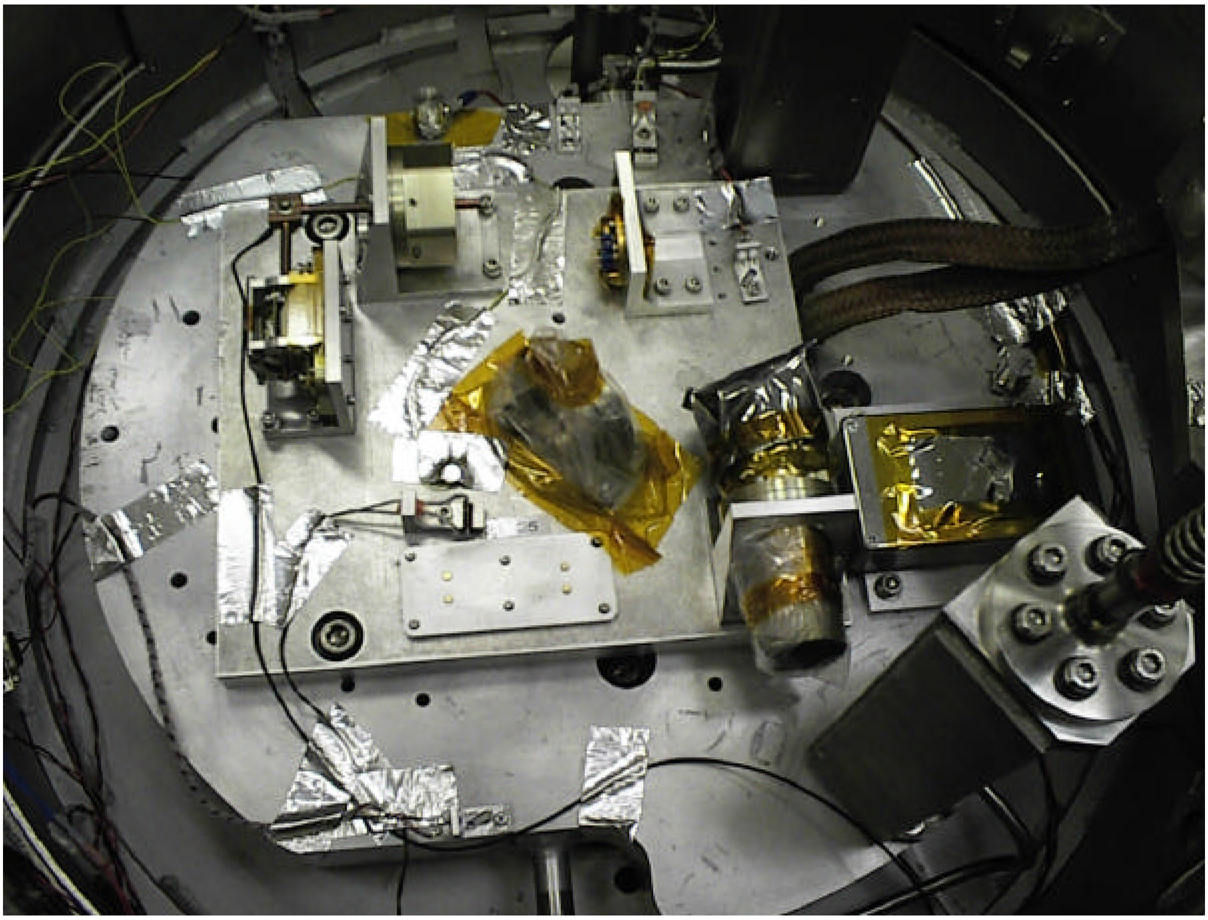
Signal Conditioners: Endevco 2775A
Calibrated on**:** September 2002

4) CLEANLINESS

Approved cleanroom gloves to be worn when handling the test items.

5) FIXTURE DETAILS

FIXTURE CONFIGURATION



A view of the test items mounted on their vibration fixture. The control strategy implemented involved taking the average response from the two accelerometers attached to the fixture.

6) TEST SUMMARY

Test Dates: 23 March 2004 to 25 March 2004

Observers: Dr. Peter Hargrave and Facility Staff

Organisation **:** Cardiff University

CHANNEL ALLOCATION:

CONTROL:-

Channel No.	Accelerometer Type/Serial No.	Testing Axis	Mounting Position
1	Endevco A66B	**N/A**	Fixture
2	Endevco YG32	**N/A**	Fixture

MONITORING:-

Channel No.	Accelerometer Type/Serial No.	Testing Axis	Mounting Position
3	B&K 1434587	**N/A**	300mK Busbar

NOTE

Accelerometer B&K 1434587 was an uncalibrated unit, which was not specified to have a working temperature range at the low temperatures it would be subjected too. As such the data collected should only be viewed as an indication of frequency response. The amplitude data has no relevance.

ACTION	DATE	TIME
Pumpdown Started	23/03/04	16:45
Cooldown Started	23/03/04	21:30
Cold Vib. Testing	24/03/04	11:30
Start Warm Up	24/03/04	12:00
Ambient Testing	25/03/04	08:40
Test Item Removed	25/03/04	11:00

ACCELEROMETER TEST PLOTS

ATMOSPHERIC/AMBIENT TEST CONDITIONS 23/03/04

RUN 00002 SINE SURVEY *FIG 1*

COLD TEST CONDITIONS 24/03/04

RUN 00003 SINE SURVEY *FIG 2*

RUN 00001 RANDOM *FIG 3*

RUN 00005 SINE SURVEY *FIG 4*

ATMOSPHERIC/AMBIENT TEST CONDITIONS 25/03/04

RUN 00006 SINE SURVEY *FIG 5*

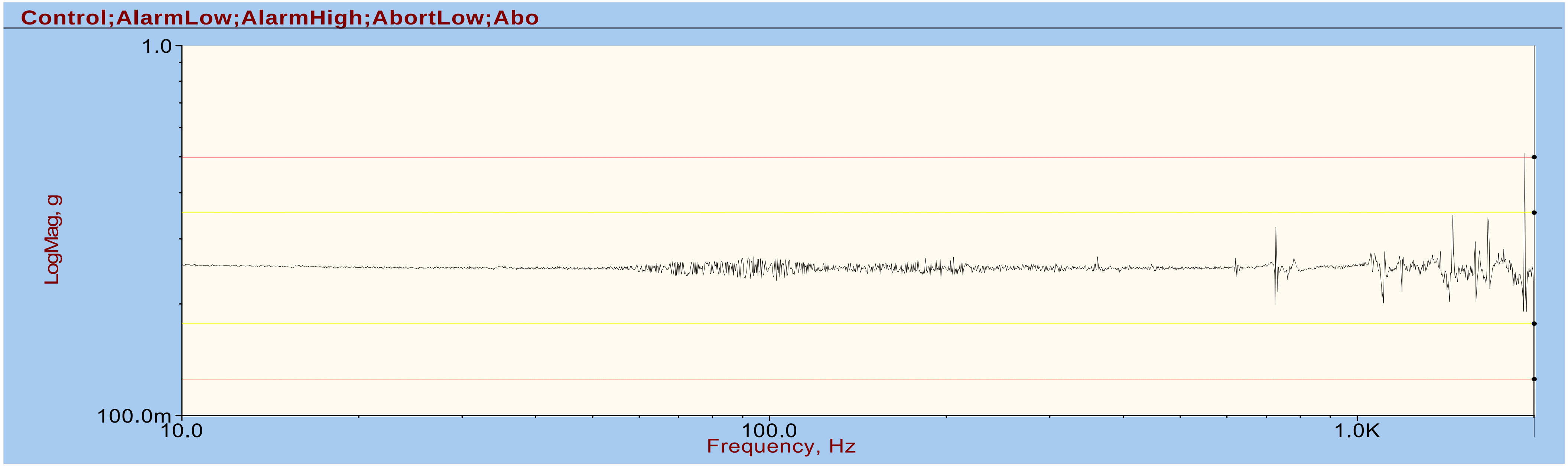
7) CONCLUSION

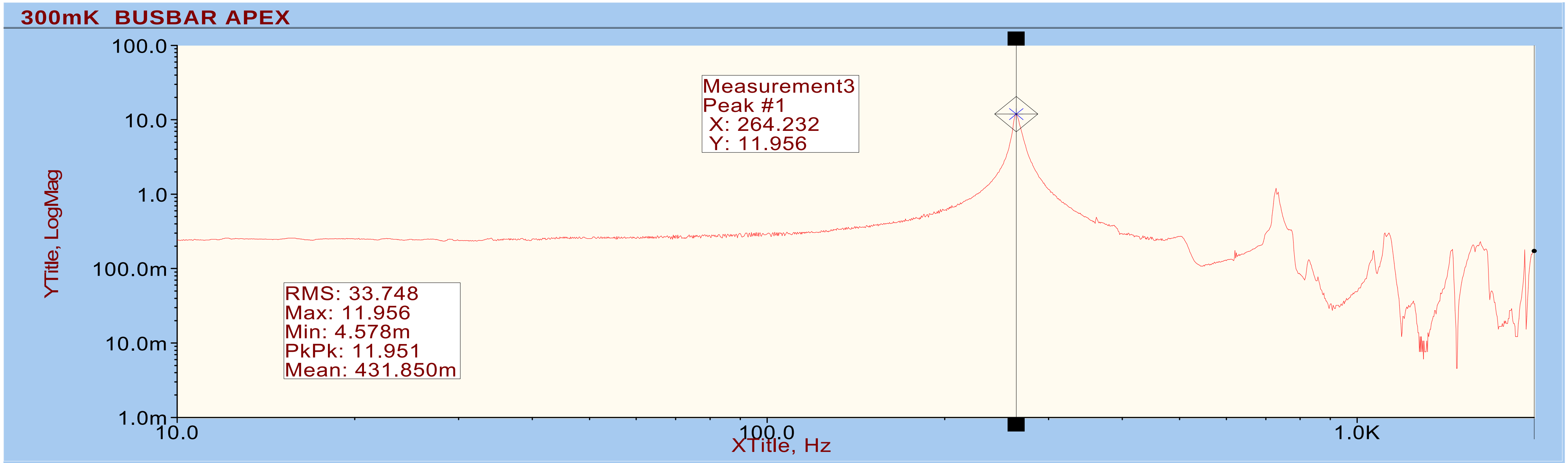
The test items were subjected to the Spire Qualification levels of vibration. On inspection, post vibration testing, it was discovered that 3 of the 4 fasteners securing the photometer support to the fixture were loose. These had been torqued too 0.2 NM prior to testing.

A visual inspection revealed no further problems with any other components.

FACIL ITY OPERATOR: -

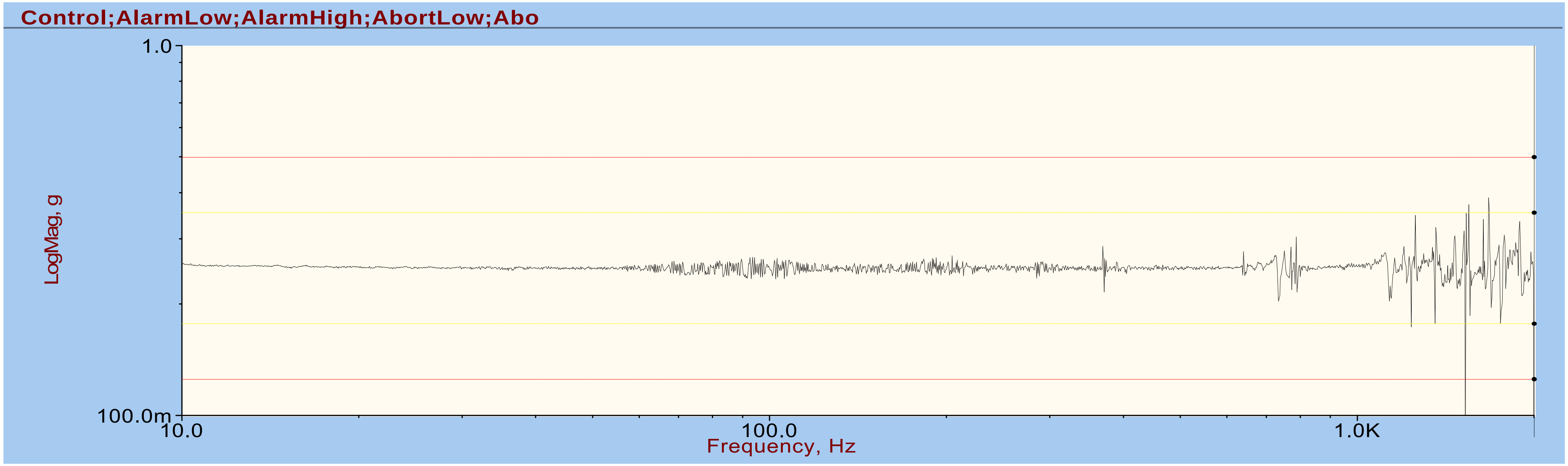
ANNEX: A   ACCELEROMETER PLOTS
ANNEX: B   COOLDOWN/WARM-UP GRAPH

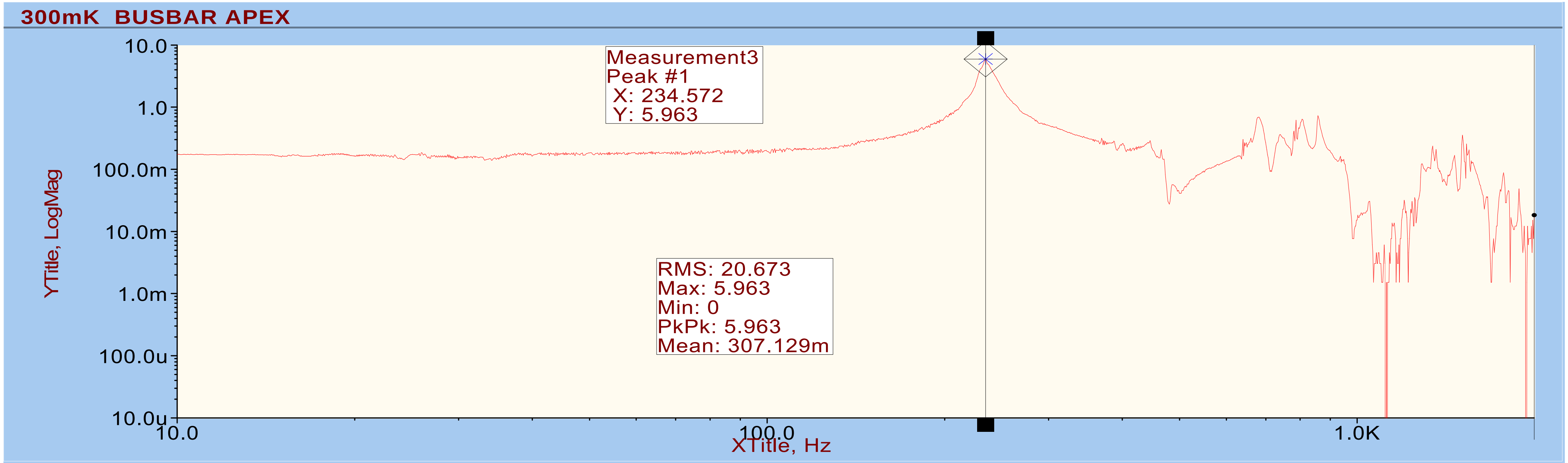




SPIRE CARDIFF COMPONENTS SINE SURVEY AMBIENT/ ATMOSPHERE
RUN 00002
N/A AXIS 16:01:23 23/03/2004

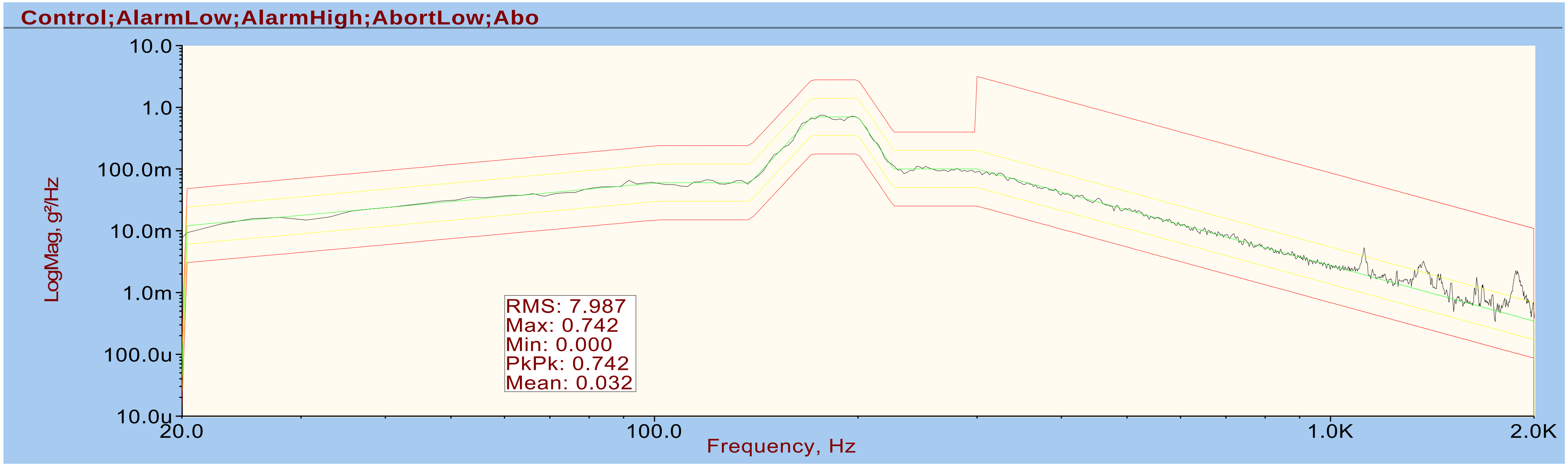
Fig 1

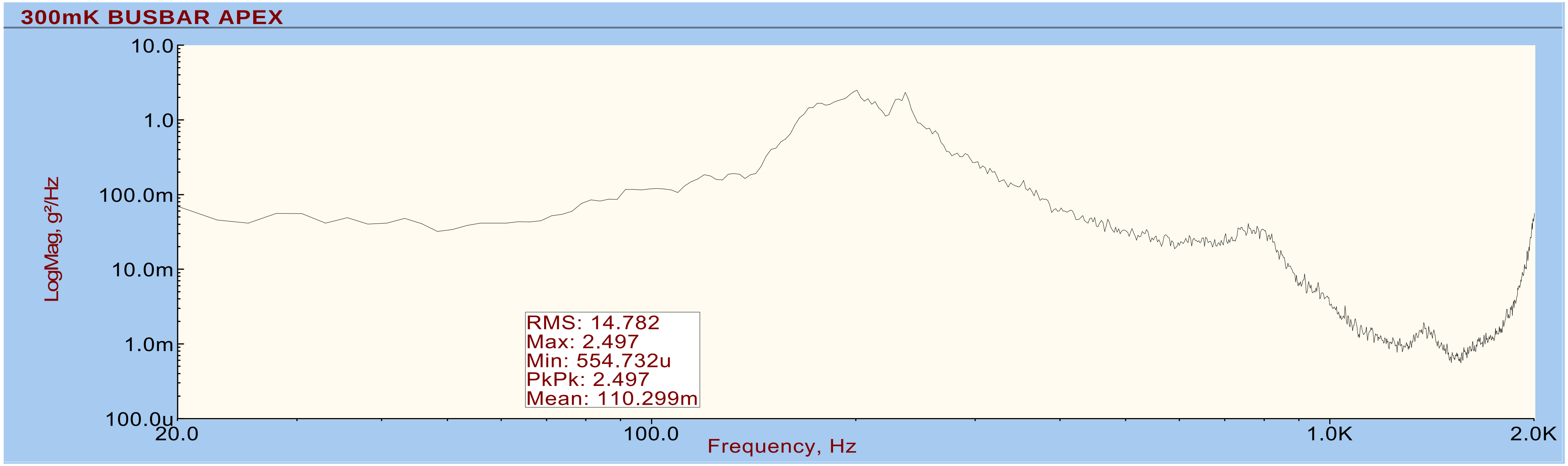




SPIRE CARDIFF COMPONENTS SINE SURVEY 7 Kelvin 5.8E-6mBAR
RUN 00003
N/A AXIS 11:37:40 24/03/2004

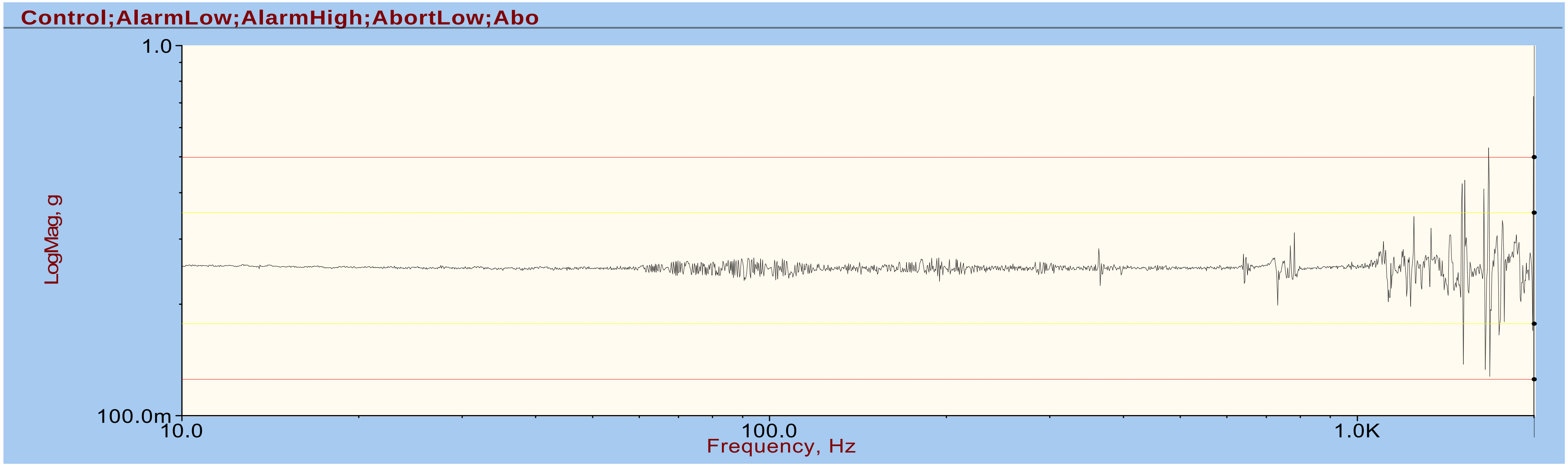
Fig 2

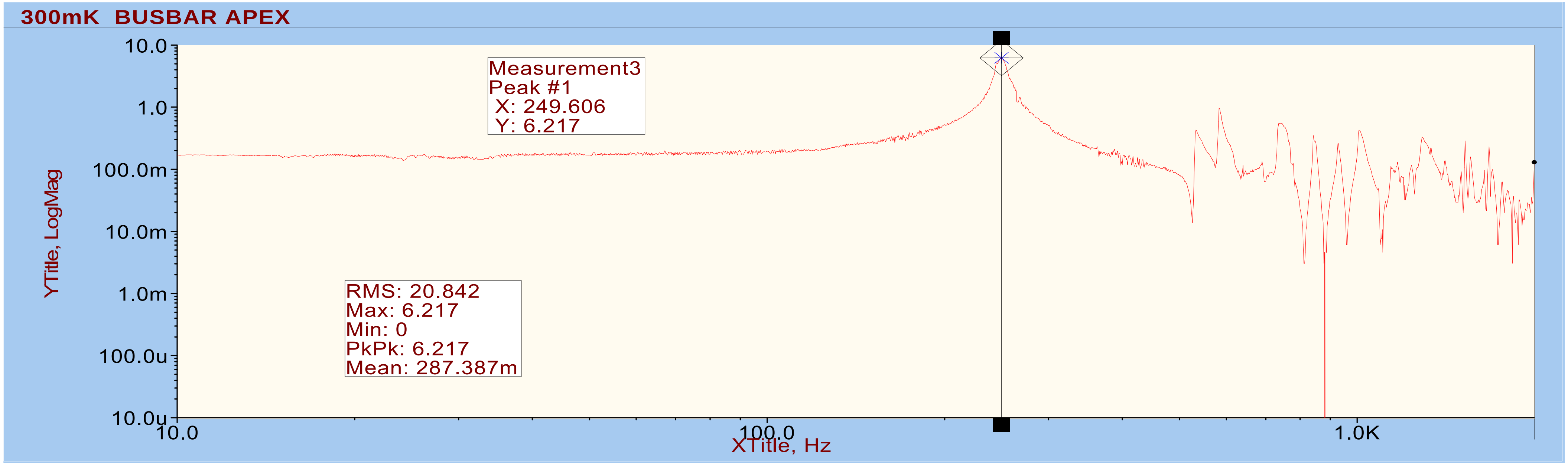




SPIRE CARDIFF COMPONENTS   RANDOM 7 KELVIN @ 5.6e-6mBAR
RUN 00001
N/A AXIS 11:46:44   24/03/2004

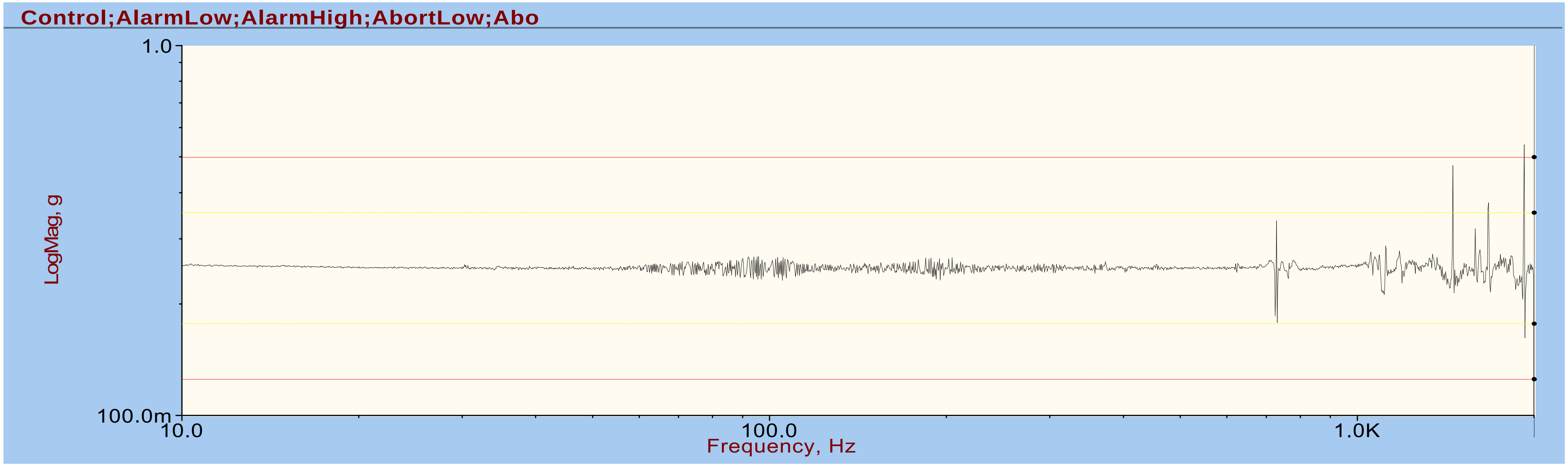
Fig 3

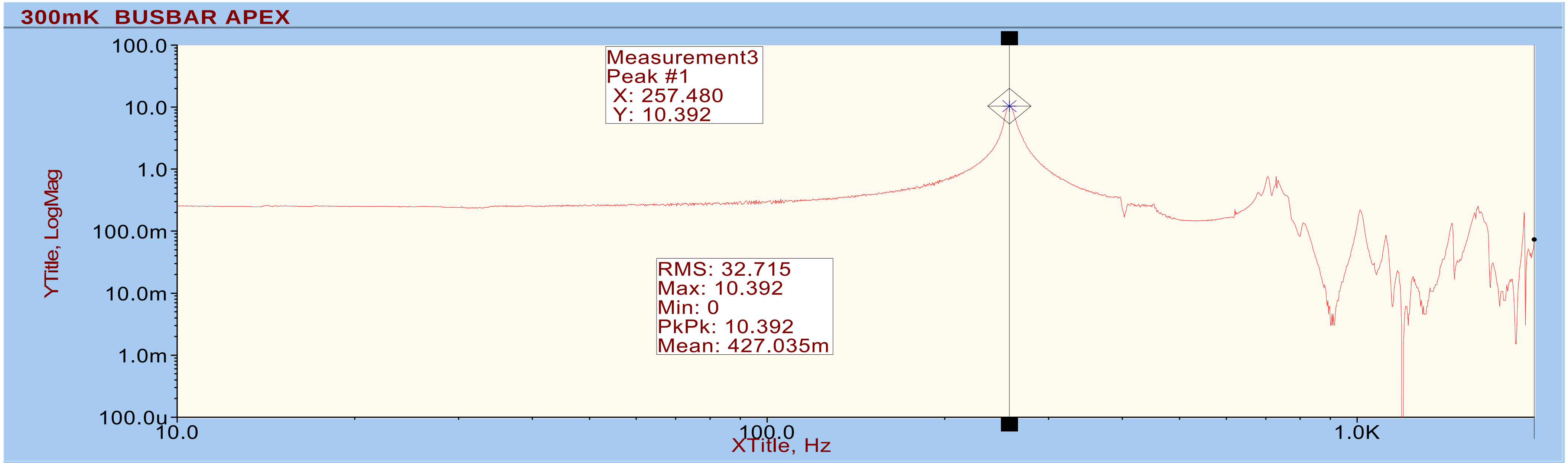




SPIRE CARDIFF COMPONENTS POST RANDOM SINE SURVEY 7 Kelvin 5.8E-6mBAR
RUN 00005
N/A AXIS 11:55:48 24/03/2004

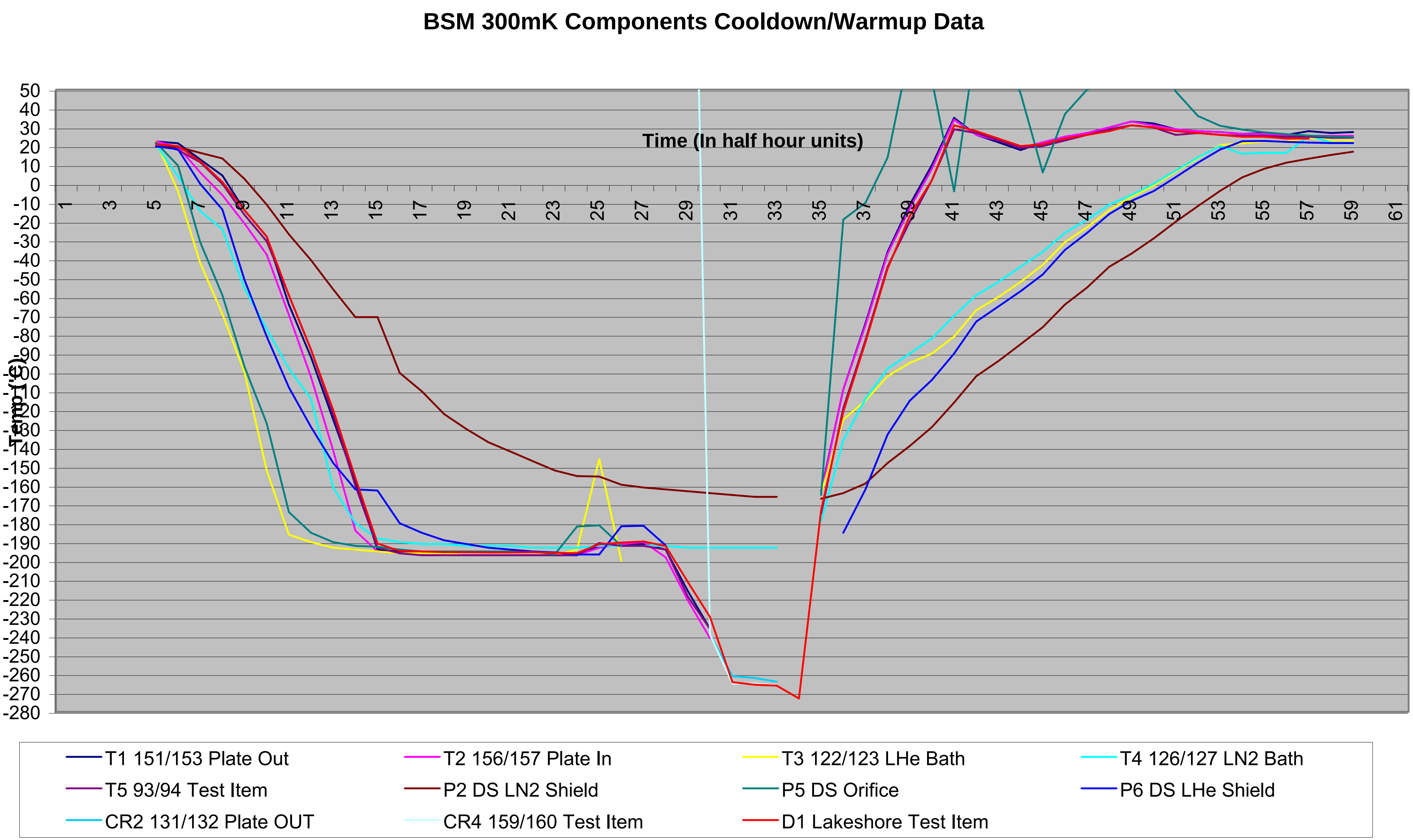
Fig 4





SPIRE CARDIFF COMPONENTS POST RANDOM SINE SURVEY AMBIENT/ATMOSPHERE
RUN 00006
N/A AXIS 08:38:48 25/03/2004

Fig 5



BSM 300mK Components Cooldown/Warmup Data
Time (In half hour units)
Temp (°C)
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
-180
-190
-200
-210
-220
-230
-240
-250
-260
-270
-280
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61
T1 151/153 Plate Out
T2 156/157 Plate In
T3 122/123 LHe Bath
T4 126/127 LN2 Bath
T5 93/94 Test Item
P2 DS LN2 Shield
P5 DS Orifice
P6 DS LHe Shield
CR2 131/132 Plate OUT
CR4 159/160 Test Item
D1 Lakeshore Test Item

Annex 5

SPIRE
CQM BDA
Kevlar Failure Report

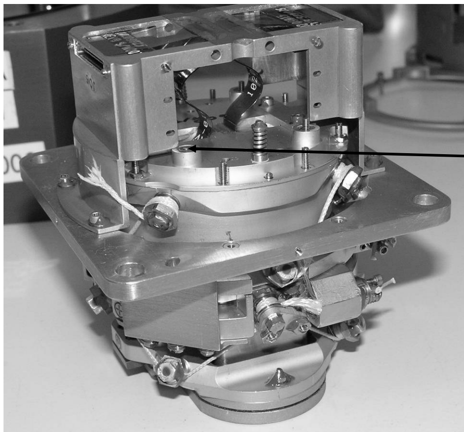
1 Oct 2007

CQM Failure

CQM PLW BDA, 10209800-1 SN006

- Lower Kevlar braid broken
- Discovered during tear-down of CQM instrument, May 2007
- Found after shipping back from STM2 testing – BDA had been working normally
- Break discovered visually, also internal touch (electrical short)
- CQM delivered to RAL Sept. ’03
- Break after 3½ years of post-delivery testing
- Shipping apparently benign – only 5g monitors tripped.

Disassembly At RAL- Touch Location



- JPL inspection at RAL
- Light can removed
- Touch identified:
  - coverplate to connector bracket
- Break ~near pulley#2
  - no obvious smoking-gun
- Shipped back to JPL for more investigation

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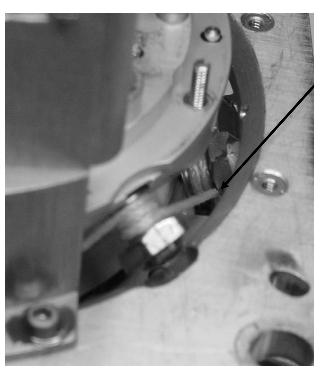
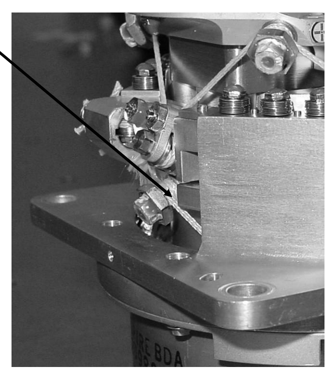
Failure Area

- Inspection determined failure just where kevlar leaves pulley #2
- No obvious pre-existing defect (also had been inspected carefully at JPL)



JPL, June ‘03



RAL, Sept. ‘03

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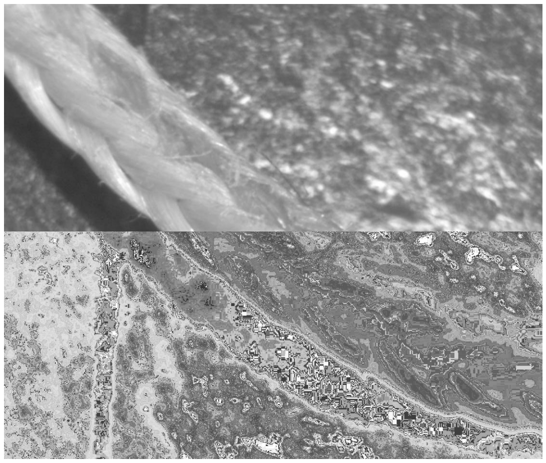
Kevlar Abrasion



- Abrasion damage at all pulleys
- Worse near Capstan-3 (pulleys 1,2…)
- Braiding exposes different parts to damage

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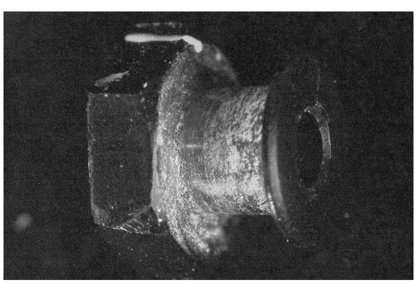
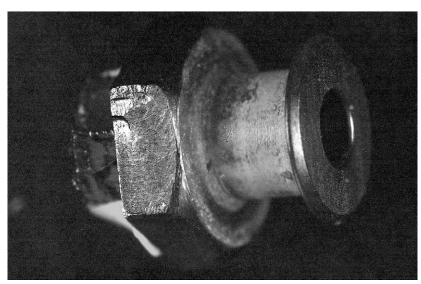
Kevlar Residue on Pulleys

UV light illumination reveals fluorescence from extensive kevlar residue on CQM pulleys.



Pulley 1



Pulley 2

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Failure Conclusion

- Kelvar likely failed during shipping (proximate cause)
- Root cause is kevlar abrasion damage at the pulley

CQM background / differences

(will this failure happen on other units?)

- Hardware differences
- Environmental exposures

Hardware Difference List

Part	CQM PLW	Later Hardware	Notes:
10209860 suspension	**chamfered pulleys per redlined dwg 5/2/03**	**Fully rounded & polished pulleys per released dwgs**	**changed on qual and subsequent units to address CQM PLW fraying**
10209860 suspension	preliminary kevlar routing	final (Qual BDA type) kevlar routing	changed on qual and subsequent units to address CQM PLW fraying (note: only upper braid routing was changed from CQM to final design)
10209860 suspension	no side screws into invar spacers	side spacer screws were used	screws had been eliminated in error when the vespel safety spacer was eliminated from the design. Units after SN009 (PFM SSW) have screws installed.
10209890 middle ring (part of suspension)	suspension Ring-A is pinned to flexure mounting plate with both old pins and smaller new invar pins.	suspension Ring-A is pinned to flexure mounting plate with only new invar pins.	Old pins were partially machined away after assembly in early suspension units (up to 10209860 sn006). Final design used only the new pins.
10209860 suspension assy.	no epoxy on capstan-1	versamid epoxy at capstan-1 end of kevlar.	epoxy added to final design to strengthen tie-off at capstan-1 and reduce fraying of free end.
Detector Assembly	bare copper thermal strap interface	gold plated thermal strap inteface	FM and FS units gold plated to meet ICD requirements.

BDA build details

BDA				Suspension		
Nomenclature	**S/N**	**type**	**Mass (g)**	**S/N**	**type**	**Date Strung**
CQM PLW BDA	6	-1	596	2	-2	2003-05-14
Qual BDA	7	-8	614	6	-1	2003-07-17
PFM SLW BDA	8	-4	542	3	-1	2003-09-03
PFM SSW BDA	9	-5	482	5	-1	2003-10-20
PFM PMW BDA	12	-2	603	10	-1	2004-06-04
PFM PSW BDA	13	-3	579	11	-1	2004-07-08
PFM PLW BDA	14	-1	602	12	-2	2004-08-15
FS SLW BDA	15	-4	527	7	-1	2004-01-16
FS SSW BDA	16	-5	485	13	-1	2004-10-22
FS PSW BDA	17	-3	574	14	-1	2004-12-10
FS PLW BDA	18	-1	601	8	-2	2004-03-11
FS PMW BDA	19	-2	605	9	-1	2004-05-06

-1 / -2 suspensions differ only in top ring cutout details for PLW feedhorn clearance.
SN 10 and 11 BDAs were noisy and were re-built into SN 18,19.

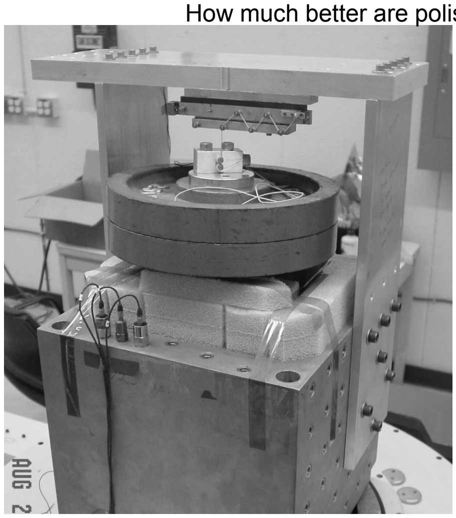
BDA Environmental Exposures

BDA	Vac. Bake	Thermal Cycles			Shake Tests (all cold)		
	(80C) JPL	JPL	RAL	Expected	JPL (2min/axis)	RAL	Expected
CQM PLW BDA	none	6	6	0	1 axis PF random	3 axis, Qual level, 2min/ax random+sine	none
Qual BDA	120 hrs	29	NA	NA	3 axis PF random	NA	NA
PFM SLW BDA	24 hrs	5	5	1	1 axis PF random	3-axis, 2 min/axis FA; 1 axis, 1 min FA (workmanship)	S/C-level test +launch
PFM SSW BDA	24 hrs	5	5	1	1 axis PF random		
PFM PMW BDA	24 hrs	5	5	1	1 axis PF random		
PFM PSW BDA	24 hrs	5	5	1	1 axis PF random		
PFM PLW BDA	24 hrs	5	5	1	1 axis PF random		
FS SLW BDA	24 hrs	5	0	TBD	1 axis PF random	None	TBD
FS SSW BDA	24 hrs	6	0		1 axis PF random		
FS PSW BDA	24 hrs	5	0		1 axis PF random		
FS PLW BDA	12 + 24 hrs	9	0		1 axis PF, 1 axis FA random		
FS PMW BDA	2 x 24 hrs	12	0		1 axis PF, 1 axis FA random		

Polished vs Unpolished pulleys

Kevlar Abrasion Testing

How much better are polished pulleys?



- Hang weight on kevlar
- Last pulley is polished or unpolished
- Shake vertically
- 2 tests:
  - 30 min .010”p-p no failure
  - Step up level till failure

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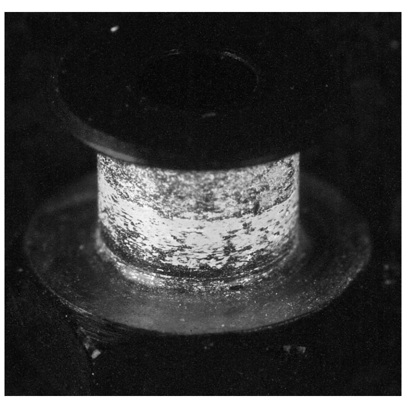
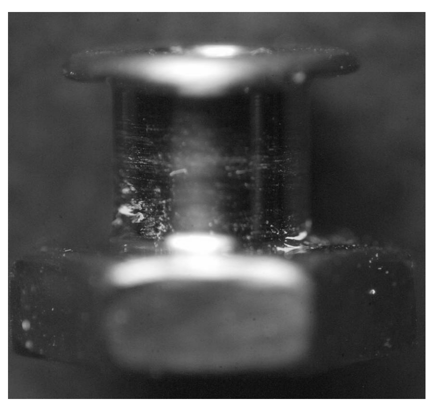
Pulleys after 1st abrasion test (no failure)





unpolished Same shake exposure polished

UV light

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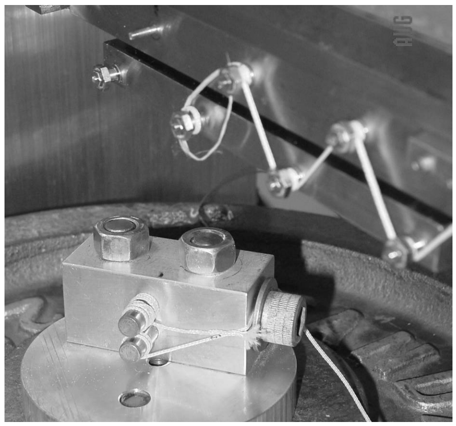
shake-to-failure with unpolished pulley



- Failed after 7.7 min at highest shake level
- Failed at pulley

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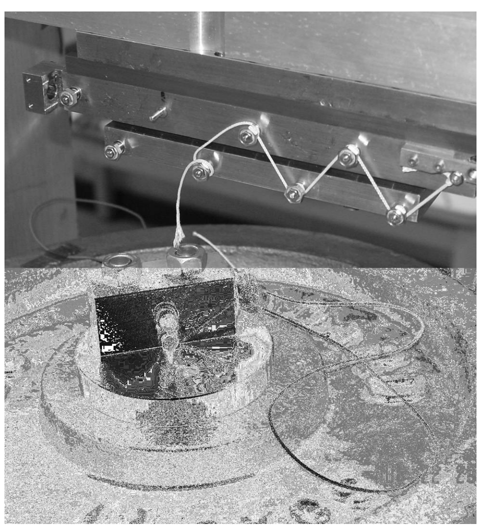
shake-to-failure with polished pulley



- Failure after 36 minutes at max shake level
- Failed at lower tie-off

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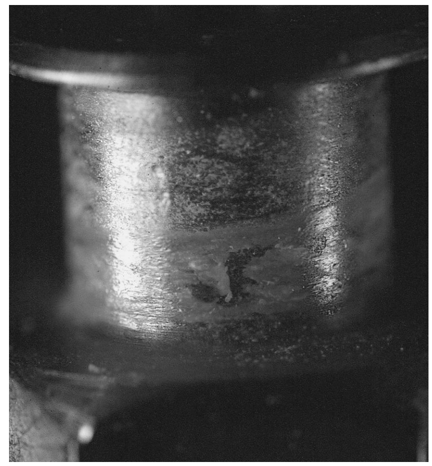
Unpolished Pulley after shake-to-failure



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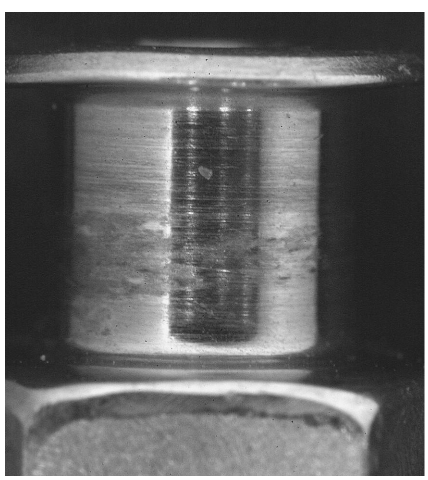
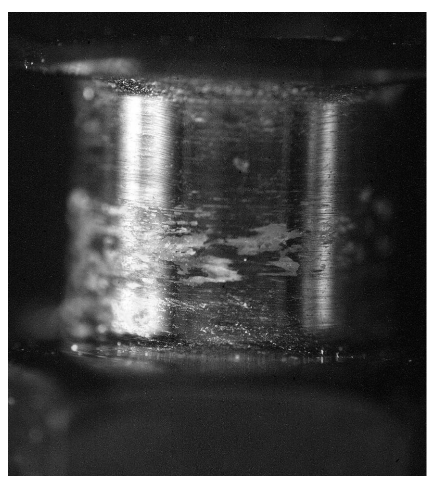
Polished Pulley after shake-to-failure





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Abrasion Shake Details

duration	kevlar length	drive	control	top	weight	kevlar stretch	kevlar force
min	(inches) after run	(inch pk-pk)	(g rms)	(g rms)	(g rms)	(inch pk-pk)	(lbf, peak)
Abrasion Shake Tests (No Failure)							
Unpolished pulley, 3.07" free length initially							
30 min		0.01	14.65	17.51	0.1786	0.0121	12.9
Polished Pulley, 3.44" free length initially							
30 min		0.01	14.63	17.4	0.1605	0.0120	11.6
Shake to Failure:							
Unpolished Pulley, 1.40" free length initially							
15	1.4	0.007	10.122	11.85	0.2167	0.0083	15.7
15	1.42	0.009	13.015	15.28	0.2459	0.0107	17.8
15	1.42	0.011	15.907	18.75	0.2896	0.0132	21.0
15	1.42	0.013	18.799	22.3	0.3223	0.0156	23.3
7.7	Broke at pulley	0.015	21.691	25.72	0.3726	0.0180	27.0
Polished Pulley, 1.48" free length initially							
15	1.5	0.007	10.122	11.87	0.2074	0.0084	15.0
15	1.51	0.009	13.015	15.31	0.2375	0.0108	17.2
15	1.52-1.53	0.011	15.907	18.78	0.281	0.0132	20.3
15	1.53-1.54	0.013	18.799	22.29	0.3316	0.0156	24.0
15	1.55-1.56	0.015	21.691	25.76	0.3699	0.0181	26.8
21.5	Broke at lower end	0.015	21.691	25.76	0.3744	0.0181	27.1
36.5	total at max level						

Conclusion

- Failure due to abrasion at unpolished pulleys
- Polished pulleys shown to be much more robust
- This problem was fixed already for all units after the CQM (including the Qual)
- Chance of failure on FM is small
- Just to be safe, be more careful with shipping / environment

Risk Mitigations

- Root Cause has already been fixed
- Failure circumstances somewhat uncertain – be more careful
  - Shipping (monitor and control)
  - Environment (Humidity, Temperature)

Annex 6: Environmental history of thePFM BDAs

Eric Sawyer

Post delivery of PFM BDAs to RAL

• Integration	Spectrometer BDAs 30/11/04
• Cool down 1	23/2/05
• Warm up 1	9/4/05
• Integration	Photometer BDAs 3/6/05
• Cooldown 2	5/9/05
• Warm up 2	2/10/05
• Vibration test – cold	23/11/05 to 25/1/06
• Cooldown 3	21/3/06
• Warm up 3	28/6/06
• Vibration test – workmanship	22/8/06 to 13/09/06
• Cooldown 4	28/10/06
• Warm up	16/12/06
• Cooldown 5	30/1/07
• Warm up 5	9/3/07

Cooldown and warm up profiles

- ILTs at RAL.
  - L0 connected to 2K pot
  - when filled the 2K stage cools rapidly, first to 77K then to 4K.
  - Spectrometer box cools much faster than the photometer box.
  - Temperature sensors not close to BDA interface.
  - Estimated max dT/dt 15k/hour for spectrometer, 5K/hour for the photometer.
  - Warm ups much slower, not accelerated.
- Cold vibration at CSL
  - L0, L1, L3 connected.
  - strict limit on dT, dT/dt less than 5K/hour, ambient to 200K, 10K/hour 200K to 100K, 20k/hour below 100K
- Spacecraft level testing.
  - limits placed on dT/dt less than 5K/hour, ambient to 200K, 10K/hour 200K to 100K, 20k/hour below 100K
  - Only one cooldown planned
  - Bruce – is there any data available from the STM cooldown? – Action on Bruce to ask Chris Jewell for the information

Vibration history and proposed S/C level tests

- All vibration tests are conducted <20K
- 1st test
  - Inputs based on CQM results
  - PFM tests should result in lower levels (X1.25) at the subsystems than those seen during the CQM testing.
  - BDAs were instrumented during the CQM tests
  - Input notched to protect subsystems
  - Levels at the suspended mass limited to 10g rms
  - Accelerometers fitted to both detector boxes
- Workmanship test
  - Repeat of PFM tests in X axis only
- S/C level test
  - Information to follow
  - Test spec is available
  - There will be extensive discussion about the levels and test details, especially for the acoustic tests
  - Need to discuss this at the review
- Transport
- Instrument level
  - Transported warm, in our own transport
  - Container has vibration isolators
  - Inner container as 15 and 25g monitors in 3 axis – none tripped
- S/C level
  - Transported cold (by road)
  - Vibration monitoring is standard for such transport
  - Carsten and Chris are looking up information on transport of STM from ESTEC to Friedrichshafen (while warming up) – should have information by Monday

STM S/C transport (SPIRE CQM)

- Thermal environment
  - On the transport from Friedrichshafen to ESTEC (24.08.2006) the OBA was at 312 K and on the arrival 304 K.
  - The transport from ESTEC to FN (06.03.2007): the OBA was at ~130 K and on the arrival ~292 K.
- Shock environment
  - Information to follow

Humidity control

- All PFM have been subject to same environment.
- Stored in JPL bowling balls until integration (nitrogen atmosphere)
- Then exposed to Clean room (RH 50%) environment for several months
- Under vacuum during tests
- Re-pressurised with nitrogen
- Transit container inner bag purged with nitrogen before packing, but no continuous purge
- At Astrium, stored in clean room on the spacecraft controlled humidity (50%)
- 6 months between delivery to Astrium (March 2007) and pumpdown