PAYLOAD FLIGHT HAZARD REPORT

PAYLOAD FLIGHT HAZARD REPORT		a. NO:	AMS-02-F06
b. PAYLOAD	Alpha Magnetic Spectrometer-02 (AMS-02)	c. PHASE:	II
d. SUBSYSTEM: Pressure Systems, Magnet	e. HAZARD GROUP: Collision	f. DATE:	May 22, 2006
g. HAZARD TITLE:	Excessive Thrust/Overturning Moments	i. HAZARD CATEGORY:	CATASTROPHIC X CRITICAL
h. APPLICABLE SAFETY REQUIREMENTS:	NSTS 1700.7B, ISS Addendum, 200.1b		
j. DESCRIPTION OF HAZARD:	The AMS-02 has the potential due to the presence of stored gases and magnetic fields to generate excessive loads on the vehicles (Orbiter, ISS) or robotic manipulators (SRMS, SSRMS).		

k. CAUSES

(list)

1. Planned/Controlled Venting
2. Inadvertent/Emergency Venting of Gases
3. Gas Loss by the TRD
4. Excessive Magnetic Fields
5. Sloshing of Superfluid Helium

o. APPROVAL	PAYLOAD ORGANIZATION	SSP/ISS
PHASE I		
PHASE II		
PHASE III		

PAYLOAD FLIGHT HAZARD REPORT	a. NO: AMS-02-F06
b. PAYLOAD Alpha Magnetic Spectrometer-02 (AMS-02)	c. PHASE: II

l. HAZARD CONTROL (CONTROL), m. SAFETY VERIFICATION METHODS (SVM), n. STATUS OF VERIFICATIONS (STATUS)	OPS CONTROL
1. CAUSE: Planned/Controlled Venting	
1.1 CONTROL: Helium gas is vented from the Cryomagnet system through non-propulsive (24 staggered circumferential ports) vents. The nominal vent rate is 3.2 liters/min @ STP (approximately 0.6 grams per minute). The non-propulsive vent path utilized on the ground in conjunction with the vacuum pump is isolated by two valves and limited in flow potential due to the pump design. These valves will be closed prior to flight (approximately T-9 minutes). 1.1.1 SVM: Review of design for implementation of non-propulsive vents on helium vent paths. 1.1.2 SVM: Inspection of as built hardware for implementation of non-propulsive vents on helium vent paths. 1.1.3 SVM: Review of design for implementation of valves for propulsive vent path through vent pump. 1.1.4 SVM: Inspection for installation of valves to isolate pump vent path 1.1.5 SVM: Review of preflight procedures to close valves. 1.1.1 STATUS: Open 1.1.2 STATUS: Open 1.1.3 STATUS: Closed. Memo ESCG-4390-06-SP-MEMO-0004, "Cryosystem External Interfaces" Dated 6 March 2006, from AMS-02 Chief Engineer Chris Tutt. 1.1.4 STATUS: Open 1.1.5 STATUS: Open	
1.2 CONTROL: The TRD utilizes a mixing process to establish the working gas for Box C. Should the gas within Box C be deemed unacceptable for use in the sensing straws, the TRD may release the gas contained within the Box C and straw manifolds through zero-thrust "T" vents through commanding V4 (a, b) and V18 (a, b) to open. 1.2.1 SVM: Review of Design for implementation of non-propulsive vents on TRD Box C vents. 1.2.2 SVM: Inspection of as build hardware for implementation of non-propulsive vents on TRD Box C vents. 1.2.1 STATUS: Open 1.2.2 STATUS: Open	
2. CAUSE: Inadvertent/Emergency Venting of Gases	

PAYLOAD FLIGHT HAZARD REPORT	a. NO: AMS-02-F06
b. PAYLOAD Alpha Magnetic Spectrometer-02 (AMS-02)	c. PHASE: II

2.1 CONTROL: All emergency venting locations connecting to gas sources will be equipped with non-propulsive vents. Vents will be located and oriented to preclude impingement effects that could result in unbalanced thrusts from the non-propulsive vents.

2.1.1 SVM: Review of design for implementation of non-propulsive vents on all pressure relief ports.

2.1.2 SVM: Inspection of as built hardware for implementation of non-propulsive vents on all pressure relief locations.

2.1.1 STATUS: Open

2.1.2 STATUS: Open

2.2 CONTROL: There are burst discs associated with discrete volumes in the cryomagnet design that may experience pressure buildup from entrapment of cryogenics that subsequently warm up. These locations are not considered to be flight concerns as they have a very low thrust potential.

2.2.1 SVM: Analysis of entrapped volume thrust potential and vector.

2.2.2 SVM: ISS acceptance of entrapped volume thrust potential.

2.2.1 STATUS: Open

2.2.1 STATUS: Open

2.3 CONTROL: The Fill and Drain ports on the gas supply tanks (TRD CO2, TRD Xenon, Superfluid Helium, Warm Helium Gas Supply) will utilize a valve and dual seal caps to preclude a gas release.

2.3.1 SVM: Review of design for implementation of fill and drain port check valves and cap seals.

2.3.2 SVM: Inspection of as built hardware for implementation of fill and drain port check valves and cap seals.

2.3.1 STATUS: Open

2.3.2 STATUS: Open

2.4 CONTROL: GSE Ports on the Cryomagnet System are isolated by dual manual valves to preclude leakage through the GSE Interfaces. All valves will be closed on the ground prior to launch. The vacuum case GSE interface is only isolated with a single manual valve, but the vacuum case can not experience a pressure build up without a pressure system failure.

2.4.1 SVM: Review of Design

2.4.2 SVM: Inspection of as built hardware

2.4.3 SVM: Inspection to confirm closure of manual valves. 2.4.1 STATUS: Closed. Memo ESCG-4390-06-SP-MEMO-0004, "Cryosystem External Interfaces" Dated 6 March 2006, from AMS-02 Chief Engineer Chris Tutt. 2.4.2 STATUS: Open 2.4.1 STATUS: Open	
2.5 CONTROL: TRD GSE interfaces will utilize valves and dual seal caps to preclude a gas release. 2.5.1 SVM: Review of design for implementation of GSE port valves and cap seals. 2.5.2 SVM: Inspection of as built hardware for implementation of GSE valves and cap seals. 2.5.1 STATUS: Open 2.5.2 STATUS: Open	
3. CAUSE: Gas Loss by the TRD	
3.1 CONTROL: The TRD is could lose up to 7 liters of xenon/carbon dioxide gas mixture a day from its collection of proportional tube sensors. This gas will permeate through the TRD structure supporting the proportional tubes and surrounding MLI and exit in a non-propulsive fashion from the multitude of exit paths of the TRD and its surrounding MLI. 3.1.1 SVM: Analysis of design to confirm multi-path diffusion release of TRD leaked gases. 3.1.1 STATUS: Open	
4. CAUSE: Excessive Magnetic Fields	
4.1 CONTROL: While installed on the ISS, the magnetic field of the AMS-02 will interact with the geomagnetic field of the Earth and produce a torque to the ISS through the structural interface with the S3 truss. The factors involved in generating this torque include field strength and area of field. The field strength of the AMS-02 magnetic fields are insufficient to create hazardous loads or orbit affects, but could have the potential for affecting the microgravity environment of the ISS. Torquing potential will be shown to be compatible with CMG Momentum Manager (MM) capabilities to preserve CMG MM operational capabilities. 4.1.1 SVM: Analysis of magnetic torque potential 4.1.2 SVM: Acceptance of calculated torque by ISS Program	

PAYLOAD FLIGHT HAZARD REPORT	a. NO: AMS-02-F06
b. PAYLOAD Alpha Magnetic Spectrometer-02 (AMS-02)	c. PHASE: II

4.1.3 SVM: Measurement of actual magnetic fields to confirm predicted magnetic fields of AMS-02 4.1.1 STATUS: Closed. Documented in Boeing Memo TM-990018-05, September 29, 1999 4.1.2 STATUS: Closed. Documented in Boeing Memo TM-990018-05, September 29, 1999 4.1.3 STATUS: Open.	
4.2 CONTROL: The magnet will not be charged in the Orbiter or on any robotic manipulator. While in the Orbiter the power from the APCU is not routed to the magnet charging circuits. While on the robotic arms, ISS power feeds will be selected to power the “B” bus~~,~~. This bus~~that~~ is unable to charge the magnet, only SSRMS Bus A is capable of supplying power to the magnet charging circuit. Charging commands will not be sent while the AMS-02 is on the SSRMS and cannot be received by the AMS-02 as there is no 1553 bus connected through the SSRMS. There are no stored commands present in AMS-02 computer s~~S~~ystems capable of enacting a magnet charge. ~~, r~~Randomly generated “blind” commands originating from within a malfunctioning computer system can not initiate charging as process is operationally complex and is process and timing dependent. The superconducting magnet will be discharged prior to any removal from the ISS and handling by robotic systems. Charging of the magnet to full strength takes approximately 1.5 hours. 4.2.1 SVM: Review of design and as built hardware to confirm magnet cannot be powered while in the Orbiter payload bay. 4.2.2 SVM: Review of operational procedures to confirm that magnet will not be charged while on the SSRMS (appropriate power line applied.) 4.2.3 SVM: Review of Design to assure that no command path and command operability exists while on the SSRMS. 4.2.4 SVM: Review of operational procedure requirements to confirm the magnet will be discharged prior to removal from the ISS berthing location. 4.2.1 STATUS: Open 4.2.2 STATUS: Open 4.2.3 STATUS: Open 4.2.4 STATUS: Open	I
5. CAUSE: Sloshing of Superfluid Helium	

PAYLOAD FLIGHT HAZARD REPORT	a. NO: AMS-02-F06
b. PAYLOAD Alpha Magnetic Spectrometer-02 (AMS-02)	c. PHASE: II

5.1 CONTROL: The design of the superfluid helium tank limits the amount of sloshing forces that can develop during nominal operations of the tank while being handled by the SSRMS as the internal support ribs act as baffles. During nominal deployment handling the tank is essentially full and sloshing is at a minimum. At end of life the SFHe tank will be empty, eliminating the sloshing potential.

NOTE: There are no plans to move the AMS-02 ~~before end of life~~ once installed on the ISS truss, and in the event that the AMS-02 is required to be moved ~~prior to end of life~~, a specific analysis may be required to establish the potential sloshing effects based on the load at the time of operation.

NOTE: The suspension straps for the Cryomagnet provide a dampening function minimizing induced loads.

5.1.1 SVM: Review of Mission Profile and Operations to verify no planned SSRMS operations of AMS-02 prior to end of life.

5.1.1 STATUS: Open

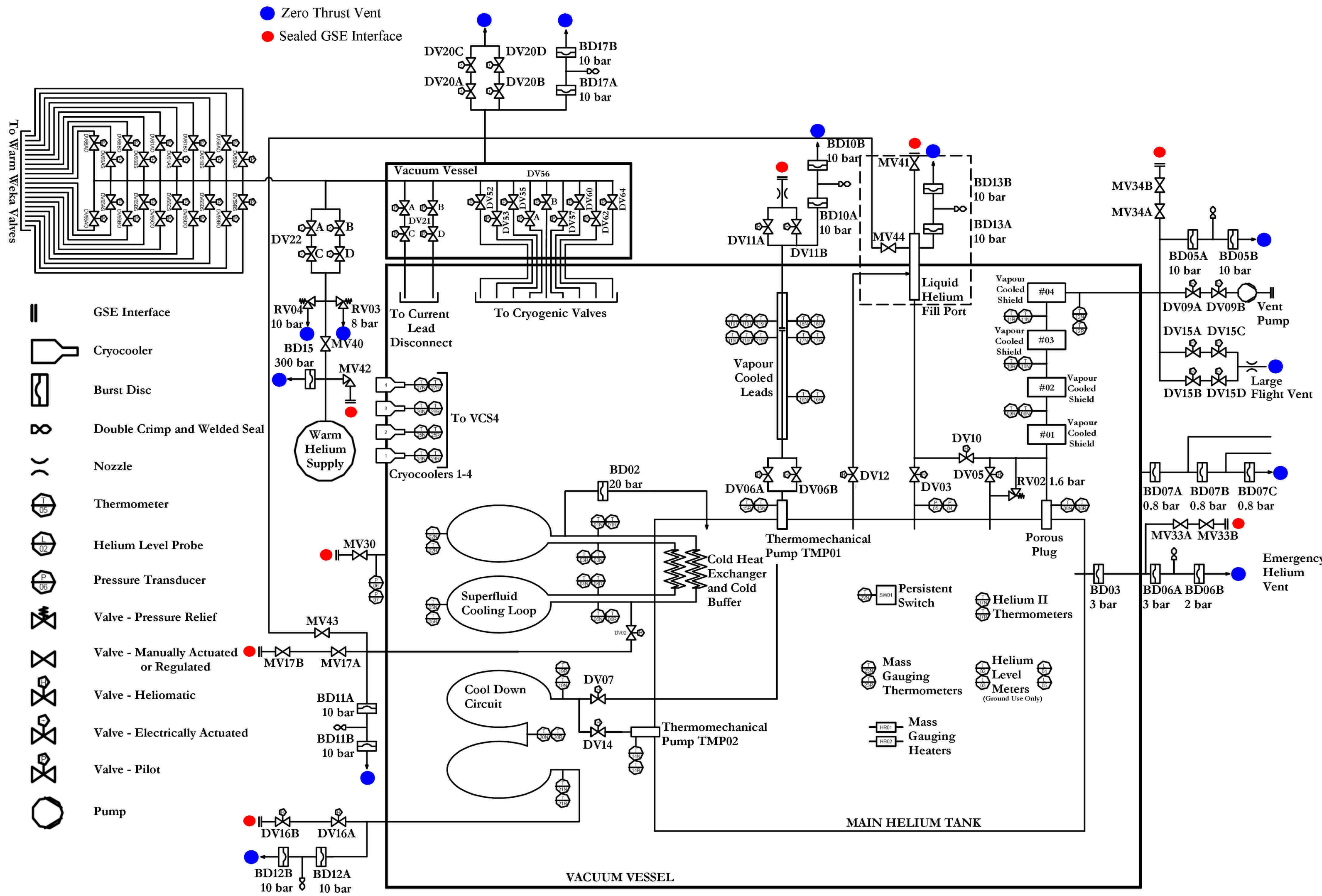
Notes:

ACRONYMS	
°C – degrees Centigrade (Celsius)	mm – millimeter
amp-m^2 – Amperes per square meter	psi – Pounds per square inch
AMS-02 – Alpha Magnetic Spectrometer - 02	SFHe – Superfluid Helium
APCU – Auxillary Power Control Unit	SRMS – Shuttle Remote Manipulator Mechanism
CAB – Cryomagnet Avionics Box	SSRMS – Space Station Remote Manipulator Mechanism
CMG – Control Moment Gyroscope	STP – Standard Temperature and Pressure
CO_2 – Carbon Dioxide	SVM – Safety Verification Method
GSE – Ground Support Equipment	TRD – Transition Radiation Detector
He – Helium	TTCS – Tracker Thermal Control System
MDP – Maximum Design Pressure	USS-02 – Unique Support Structure 02
MLI – Multilayer insulation	Xe – Xenon
MM – (CMG) Momentum Manager	

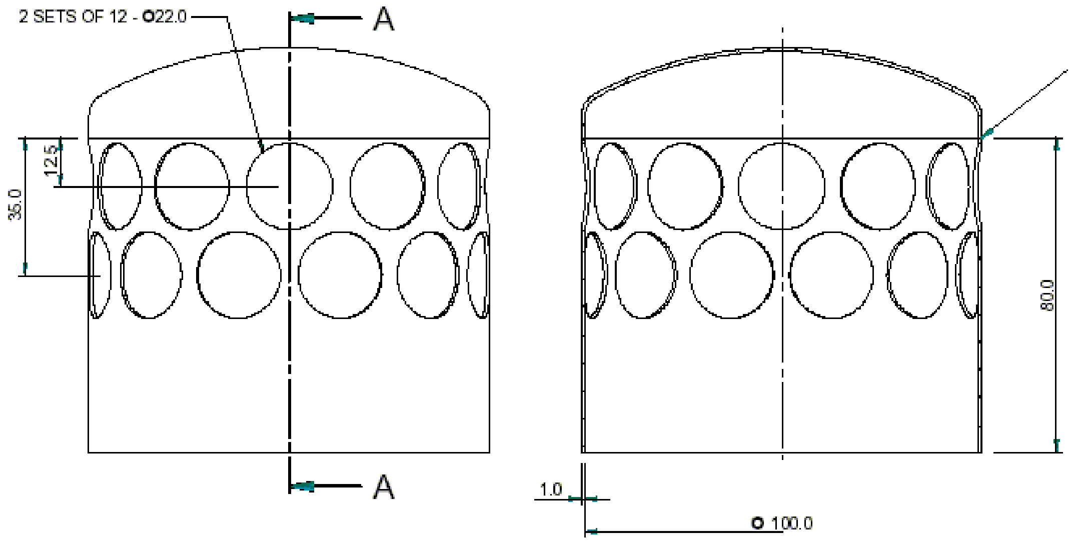
~~NEED Diagram showing SSRMS inhibit structures for charging magnets.~~

NEED Diagrams showing GSE Vents or Interfaces (with caps.)

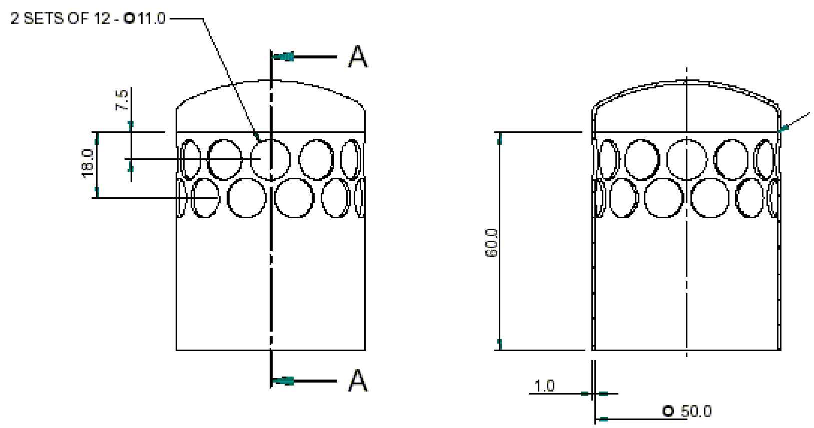
NEED Diagrams of Fill and Drain cap with seals (cutaway best) for each application.



Cryomagnet System – Vent paths



Cryomagnet Large Nonpropulsive Vent

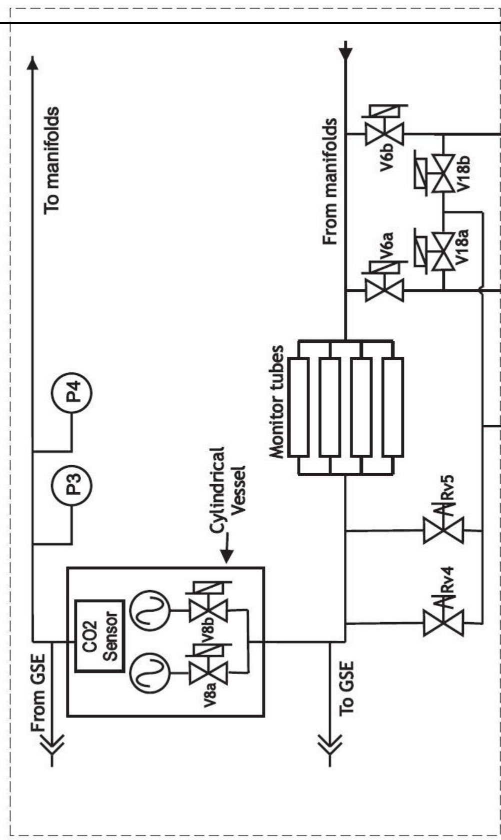


Cryomagnet Small Nonpropulsive Vent

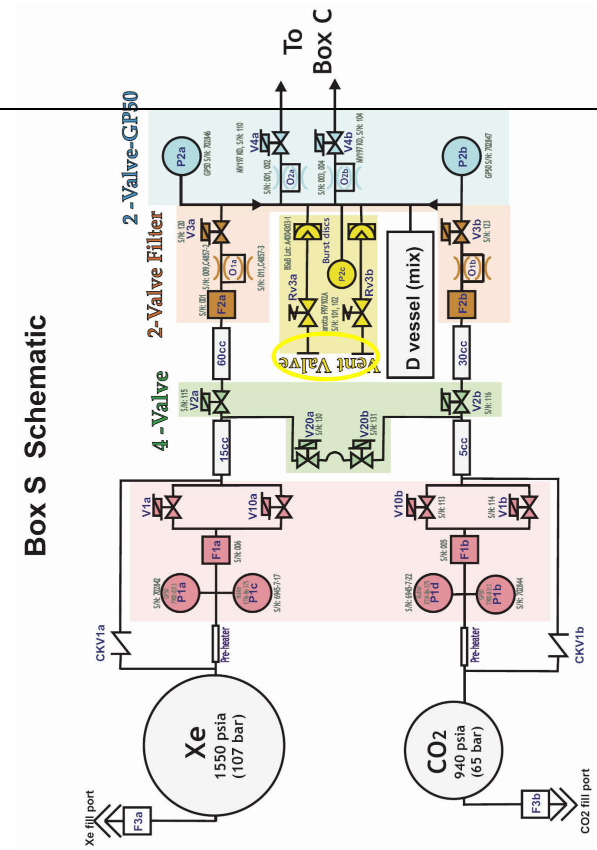
Location of Zero Thrust Vents for Cryosystem (Example)

TBS Graphic

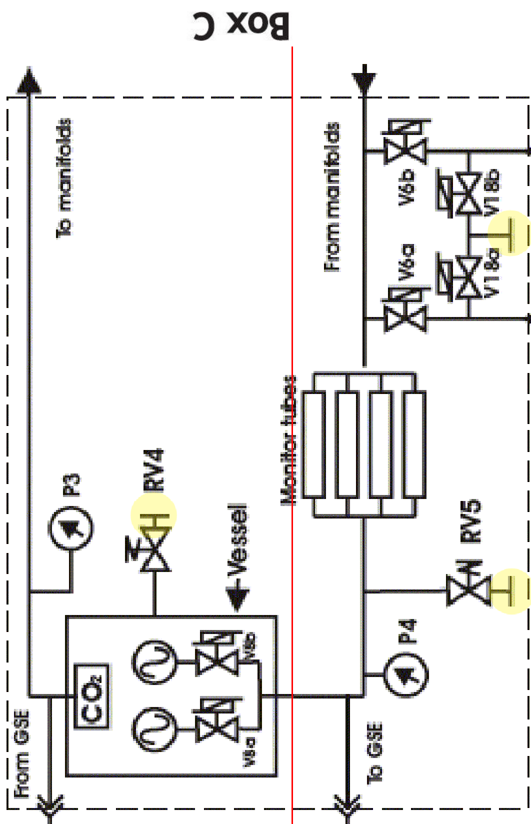
49978



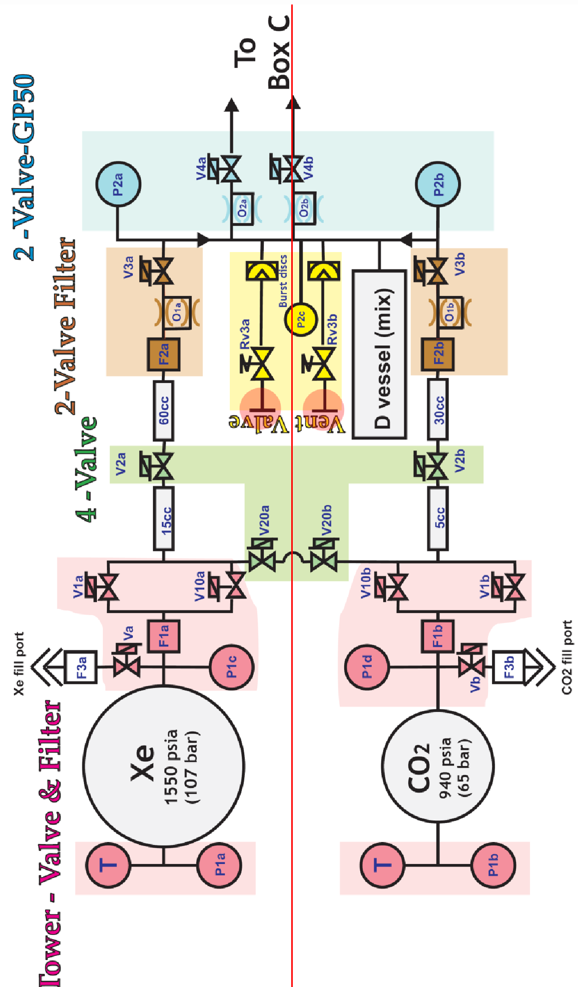
To manifolds
From manifolds
P3
P4
Cylindrical Vessel
Monitor tubes
CO2 Sensor
V8a
V8b
Rv4
Rv5
V6a
V6b
V18a
V18b
From GSE
To GSE
Vent
From S
From S



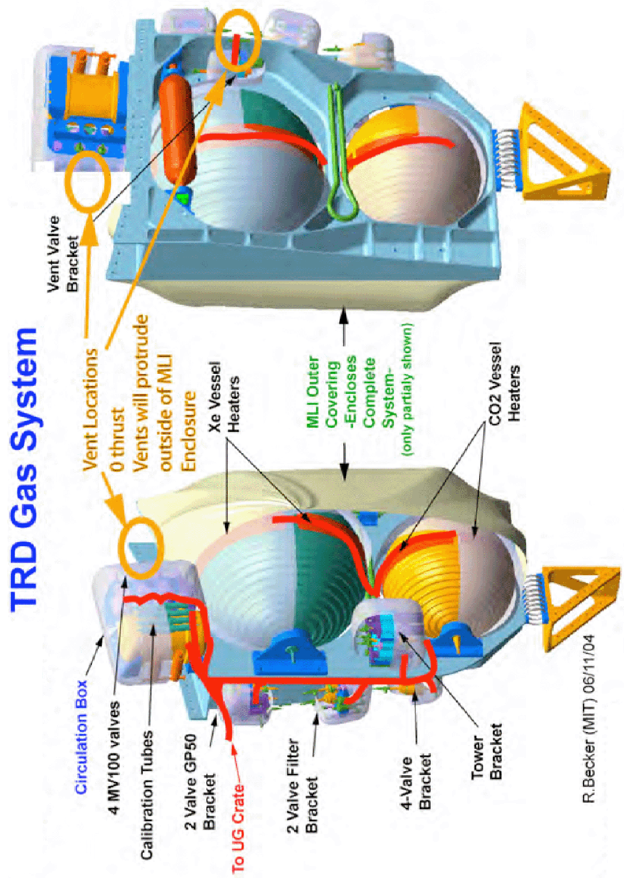
Box S Schematic
To Box C
2-Valve-GP50
2-Valve Filter
4-Valve
Vent Valve
Burst discs
D vessel (mix)
Xe
1550 psia
(107 bar)
CO2
940 psia
(65 bar)
Xe fill port
CO2 fill port
CKV1a
CKV1b
Pre-heater



Box C
To manifolds
From manifolds
P3
P4
RV4
RV5
Vessel
Monitor tubes
From GSE
To GSE
From S
From S
V6a
V6b
V18a
V18b



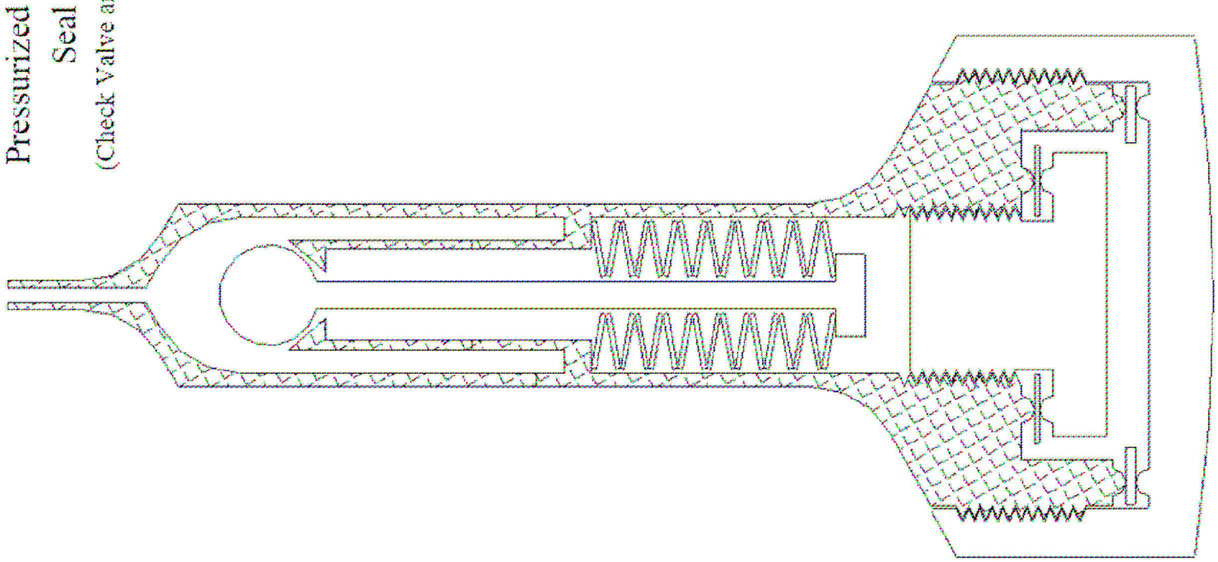
Tower - Valve & Filter
To Box C
2-Valve-GP50
2-Valve Filter
4-Valve
Vent Valve
Burst discs
D vessel (mix)
Xe
1550 psia
(107 bar)
CO2
940 psia
(65 bar)
Xe fill port
CO2 fill port
60cc
30cc
15cc
5cc



TRD Gas System
Circulation Box
4 MV100 valves
Calibration Tubes
2 Valve GP50 Bracket
To UG Crate
2 Valve Filter Bracket
4-Valve Bracket
Tower Bracket
R.Becker (MIT) 06/11/04
Vent Locations
0 thrust
Vents will protrude outside of MLI Enclosure
Xe Vessel Heaters
MLI Outer Covering -Encloses Complete System-
(only partialy shown)
CO2 Vessel Heaters
Vent Valve Bracket

TRD Vent Locations on TRD Assembly (Box S and Box C)
and
Example of non propulsive “T” vents used in Box S

Pressurized Vessel Fill Port Seal - Sketch
(Check Valve and Two Screw Caps)



Summation of Findings as Documented in Boeing Memo TM 990018-05

To Meet the CMG Momentum Manager
Magnetic Fields for any payload must be less than:

100,000 amp-m^2 if parallel to the ISS x-axis
40,000 amp-m^2 if parallel to the ISS y-axis
190,000 amp-m^2 if parallel to the ISS z-axis

The values of that the AMS-02 generates supplied by Stephen Harrison of Space Cryomagentics Ltd. based on the final configuration of the superconducting magnet are:

0 amp-m^2 if parallel to the ISS x-axis (AMS-02 y-axis)
8,200 amp-m^2 if parallel to the ISS y-axis (AMS-02 x-axis)
0 amp-m^2 if parallel to the ISS z-axis (AMS-02 z-axis)

From: Stephen Harrison [stephenharrison@spacecryo.co.uk]
Sent: Tuesday, March 01, 2005 1:25 AM
To: Hill, Leland D
Cc: Tutt, John C
Subject: RE: Magnetic Field Confirmation

Leland

What I said at KSC was:

We can supply the dipole moments of the magnet based on the finished geometry.

AMS x-axis	8.2 kAm^2	(spec <40 kAm^2)
AMS y-axis	0	(spec <100 kAm^2)
AMS z-axis	0	(spec <190 kAm^2)

Here the dipole moment specs are given in terms of the AMS axes, which are the same as the Orbiter axes but different from the ISS axes. We expect the measured values to be 8,200 Am2 along the AMS x-axis, but zero along the other two axes. The other two values (136,000 and 27,200) look like earlier versions of the spec, which has undergone some evolution over the last 5 years. The spec values I quoted are the same ones you found on the Boeing document.

I hope this makes everything clear.

Steve

-----Original Message-----
From: Hill, Leland D [mailto:Leland.Hill@escg.jacobs.com]
Sent: 28 February 2005 18:57
To: stephenharrison@spacecryo.co.uk
Subject: Magnetic Field Confirmation

I have reviewed a memo from Boeing where the torquing of the AMS-02 and its impact on the ISS CMG momentum manager. The bottom line was a bit vague and I was wondering if you can confirm.

To summarize,
To Meet the CMG Momentum Manager
Magnetic Fields for any payload must be less than:

100,000 amp-m^2 if parallel to the ISS x-axis
40,000 amp-m^2 if parallel to the ISS y-axis
190,000 amp-m^2 if parallel to the ISS z-axis

The pitch put the AMS-02 fields at 136,000 amp-m^2 while the cover memo indicated that the number was 27,200 amp-m^2 , can you confirm which is the number (or different one) we expect to be correct when we actually measure the fields?

Leland D. Hill
Hernandez Engineering Inc.
AMS-02 System Safety
Leland.Hill@escg.jacobs.com
281-461-5701 - Office
Mailing Address: 2224 Bay Area Blvd, MC B2SC, Houston TX 77058
Physical Address: 2222 Bay Area Blvd, 2S-817

(email reformatted for ease of inclusion in this document)

THE BOEING COMPANY — *Boeing – Houston*

TRANSMITTAL MEMO

SUBJECT: ALPHA MAGNETIC SPECTROMETER / CMG MOMENTUM MANAGER INTERACTION ASSESSMENT

ENCL: 1) AMS TIM Presentation charts

TM NO.	**TM-990018-05**
DATE	**29 Sept 1999**
CONTRACT NO.	**NAS9-19100**
SUBCONTRACT NO.	**02C0100001**
LTD NO.	**MDA-99-0018**
STO NO.	**9HECEG4AA**

TO — **NASA/LYNDON B. JOHNSON SPACE CENTER**
2101 NASA ROAD 1
HOUSTON, TEXAS 77058
ATTN: Tuyen. Hua/EG

REMARKS:

The Alpha Magnetic Spectrometer (AMS) is an ISS attached payload/experiment used to detect anti-matter, matter, and dark-matter in space. It is currently planned to be manifested on flight UF-4 and mounted on the inboard upper payload attach point on the S3 or P3 truss (location is TDB). The original AMS design (AMS-01) contained a permanent magnet with a magnetic dipole moment of about 13,600 amp-m^2. The currently designed AMS (AMS-02) is a super conducting electromagnet with a worst-case magnetic dipole moment of 136,000 amp-m^2 (10 times the AMS-01 value). Although the AMS magnet can be "turned off", it will take about 4 hours to complete the shutdown cycle. There is a strong desire to maintain continuous operation since recooling the system to cryogenic temperatures requires approximately 1500 liters of super fluid helium. It is planned to operate the AMS on the ISS until it has accumulated 4 years of operation.

Since the AMS magnetic field will interact with the earth's magnetic field, disturbance torques will be produced which will affect the performance of the CMG Momentum Manager (ISS average attitude, attitude variations, and CMG momentum usage). Per request from John Shebalin/Payloads Integration and James Bates/AMS Mission Manager, an assessment was made of the effects of the AMS magnetic disturbance torques on the CMG Momentum Manager (MM) performance and ISS attitude. Bob Henscheid/GN&C presented the assessment results at the AMS Technical Interchange Meeting (TIM) on Sept 13, 1999. It was decided at the TIM, that the magnetic dipole moment would be aligned parallel to the ISS y-axis. Also at the AMS TIM, Prof. Hans Hofer stated that the expected magnetic dipole moment should be only 27,200 amp-m^2 (2 times the AMS-01 value). After the AMS TIM, additional analysis was performed to (a) determine the CMG MM performance with the expected AMS magnetic dipole moment, and (b) determine the maximum AMS magnetic dipole moment, which would allow the CMG MM system to meet its performance requirements (thereby supporting the microgravity requirements). The enclosure of this Transmittal Memo (TM) contains the AMS TIM presentation charts modified to include the analysis performed after the AMS TIM.

James Bates/AMS Mission Manager considers the issue closed based on Prof. Hans Hofer's prediction that the magnetic dipole moment will be only 2 times the AMS-01 value. It is planned to review the issue after the fringe field data is available in October 1999.

Prepared by: ______________________________ ______________________________

R.B. Henscheid/C70B/HEI	**C.D. Chlouber/C70B**
Engineer III	**Senior Principal Engineer**
ISS Dynamics & Control	**ISS Dynamics & Control**

13100 Space Center Blvd, Houston, TX 77059-3556 (281) 244-4000

Boeing Transmittal Memo No. TM-990018-05
29 September 1999
Contract No. NAS9-19100
Subcontract No. 02C0100001

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Engineering, Test, and Analysis Contract

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Alpha Magnetic Spectrometer / CMG Momentum Manager Interaction Assessment

Contents

ISS CMG Momentum Manager Overview

- Purposes of CMG Momentum Manager (MM)
  - Minimize propellant usage for long term attitude control
  - Minimize disturbances to microgravity in laboratories during microgravity operations
    - ✓ Provides continuous proportional non-propulsive attitude control torques

Control Moment Gyro (CMG)

- **Control Moment Gyros (CMGs) are double-gimbaled constant speed devices which can produce control torques about 2-axes**
  - At least 2 CMGs are required for 3-axis control
- **CMGs can produce torques in 2 ways:**
  - **CMG gimbal rotations** redirect the angular momentum vector of the rotor creating short-term control torques
    - ✓ When CMG rotors become aligned (parallel), control torques can no longer be produced in all axes (condition known as "saturated")
  - **CMG roll / yaw gyroscopic torques** are produced when CMG system angular momentum is non-zero due to ISS motions (primarily rotations about ISS pitch axis to maintain LVLH attitude)
    - ✓ If a constant CMG system angular momentum is maintained, a constant gyroscopic torque is produced which can be used to modify the "natural" TEA (known as a "biased" attitude)

MM Control Strategy

- **MM must maintain the ISS near a Torque Equilibrium Attitude (TEA) to avoid CMG saturation**
  - TEA is an attitude at which all orbit average environmental torques (aerodynamic, gravity-gradient, magnetic, gyroscopic) are balanced
  - Results in orbit average control torques near zero and zero CMG momentum accumulation
  - MM makes small attitude changes about the TEA adjusting gravity-gradient torques to maintain the desired CMG momentum state (usually zero)
- **If a TEA is poorly defined (e.g., Iy~Iz) or falls outside the allowable attitude envelope, a biased attitude control strategy may be used in the roll and/or yaw axes**
  - Maintains a constant CMG momentum offset which combined with the ISS attitude rate (relative to inertial space) creates a constant gyroscopic torque to maintain the desired (biased) attitude

MM Control Strategy (cont'd)

- **Disturbance filtering is provided to allow tradeoff of attitude variations with CMG momentum usage at certain frequencies**
  - 1* orbit frequency (primarily aerodynamic disturbances due to the atmospheric diurnal bulge **and the AMS**)
  - 2* orbit frequency (primarily aerodynamic disturbances due to the rotating solar arrays)
  - Selectable frequency

Assembly Complete Requirements

- **Microgravity Requirements**
  - ISS shall provide the following microgravity performance for at least 50% of the internal payload locations for 180 days/year for 30 continuous days
    - ✓ Acceleration magnitude < 1 μg
    - ✓ Perpendicular component < 0.2 μg
- **Momentum Manager Requirements**
  - Provide non-propulsive only attitude control for 30 continuous days
    - ✓ ISS attitude must be within +/- 15 deg roll/yaw and +15/-20 pitch
    - ✓ ISS attitude rate < 0.002 deg/sec during microgravity operations (transient disturbances are exempt)
    - ✓ ISS attitude variation / orbit < 2.5 deg peak-peak
    - ✓ Must be 1-fault tolerant (i.e., 3 CMG capability)

System / Payload Disturbances Requirement (SSCN 2664)

Para 3.2.1.1.4.4 Capability: Support microgravity mode

Para 3.2.1.1.4.4.1 Limit Disturbance Induced ISS Attitude Rate

When the ISS is in the microgravity mode, any **non-transitory** disturbance induced on the ISS by individual ISS systems or payloads (including vent impingement on ISS structure) shall have an angular momentum impulse during any continuous 9 minute period less than the per axis values shown in Table IX.

Table IX: Maximum Angular Momentum Impulse (ft-lb-sec)

Hx	Hy	Hz
930	1277	2876

Where Hx, Hy, Hz are the components of the disturbance angular momentum impulse in the ISS analysis coordinate system (specified in SSP 30219, Figure 4.0-1) which shall normally be calculated as the integral of the disturbance torque relative to the ISS center of mass over the specified period of time.

Notes:
[1] For sinusoidal disturbances with a single frequency greater than **2** times orbital frequency, the angular momentum impulse shall be calculated for 1/4 cycle. (H imp=Torque Amplitude * Period / 2π).
[2] For constant, steadily increasing, or steadily decreasing disturbance torques over adjacent periods, the difference in angular momentum impulse of the adjacent periods should be used.
[3] All disturbances are assumed non-transitory unless determined to be transitory by the Microgravity AIT
[4] External robotic operations or EVAs are not allowed during microgravity operations

System / Payload Disturbances Requirement (Cont'd)

Para 3.2.1.1.4.4.2 Limit Disturbance Induced CMG Momentum Usage
When the ISS is in the microgravity mode, any disturbance induced on the ISS
by individual ISS systems or payloads (including vent impingement on ISS structure)
shall have an angular momentum impulse during any continuous **110** min period
which produces an estimated CMG momentum less than **10,000** ft-lb-sec using the following equation:
Hcmg_est = SQRT((1.25*Hx+1069)**2 + (1.25*Hy+6885)**2 + (1.25*Hz+779)**2)
Where Hx, Hy, Hz are the components of the disturbance angular momentum impulse in the
ISS analysis coordinate system (specified in SSP 30219, Figure 4.0-1) which shall normally
be calculated as the integral of the disturbance torque relative to the ISS center of mass
over the specified period of time.
Notes:
[1] For sinusoidal disturbances with a single frequency greater than **0.2** times orbital frequency,
the angular momentum impulse shall be calculated for 1/4 cycle.
(H imp=Torque Amplitude * Period / 2π).
[2] For constant, steadily increasing, or steadily decreasing disturbance torques over adjacent periods,
the difference in angular momentum impulse of the adjacent periods should be used.
[3] External robotic operations or EVAs are not allowed during microgravity operations

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AMS Requirements Compliance Assessment

(SSCN 2664)

- **Used Space Station Multi-Rigid Body Simulator (SSMRBS) to determine magnetic torques time profiles**
  - ISS Mass Properties
    - ✓ Stage c112_16a (Assembly Complete) of the DAC-6 Rev C Assembly Sequence
  - Geomagnetic Field Model
    - ✓ International Geomagnetic Reference Field (IGRF) up to degree 10 and order 10 (used degree 4 and order 4 in analyses)
    - ✓ IGRF year 1995
  - AMS Magnetic Model
    - ✓ Assumed worst case magnetic dipole moment is 136,000 amp-m²
    - ✓ Magnetic dipole moment aligned along ISS x or y axis
  - Atmospheric Density Model
    - ✓ Marshall Engineering Thermosphere (MET) – Nominal conditions
- **Calculated angular momentum impulse from magnetic torque time profiles and applied as specified in SSCN 2664**
- **Determined maximum magnetic dipole moment which provides compliance with requirements, as necessary**

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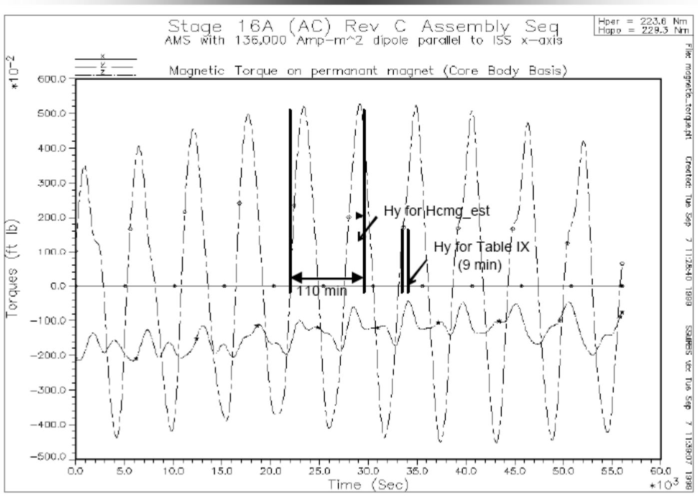

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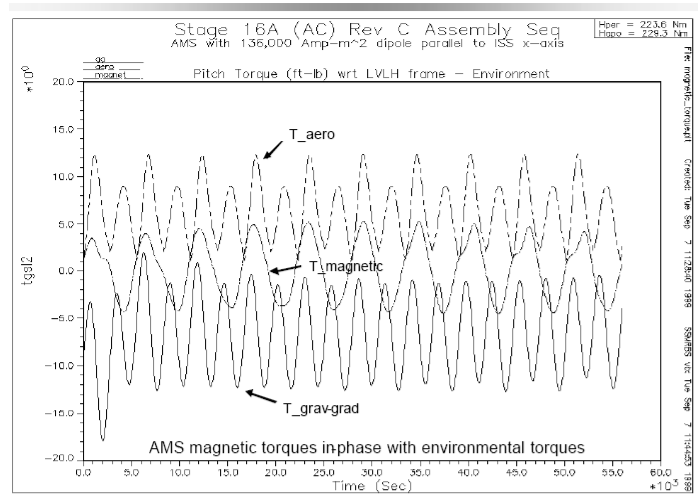

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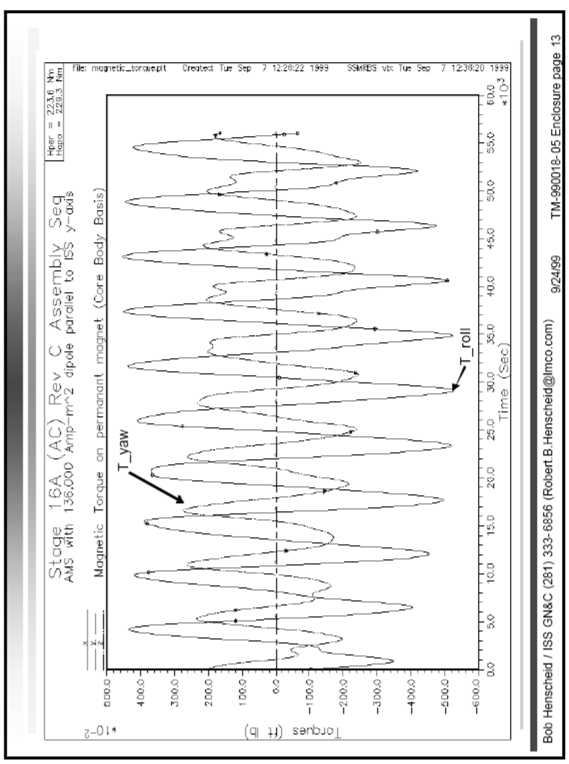
Stage 16A (AC) Rev C Assembly Seq
AMS with 136,000 Amp-m^2 dipole parallel to ISS y-axis
Magnetic Torque on permanent magnet (Core Body Basis)
T_yaw
T_roll
Torques (ft lb)
Time (Sec)
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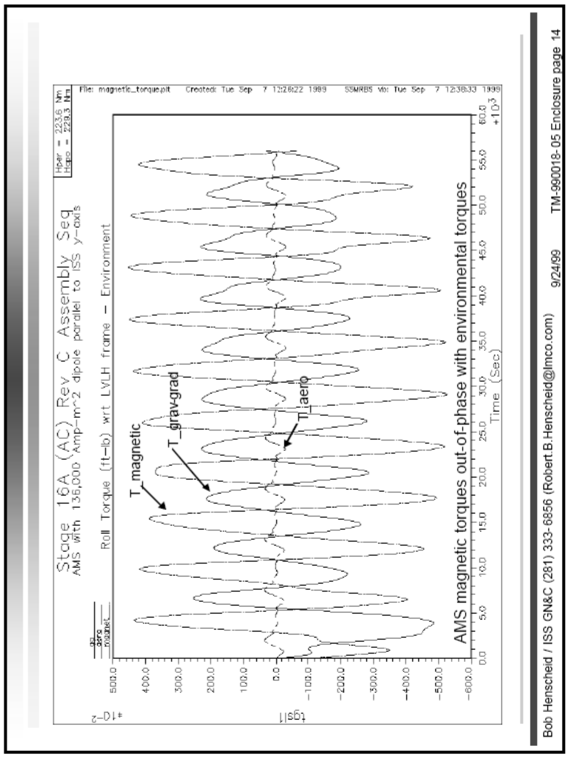
Stage 16A (AC) Rev C Assembly Seq
AMS with 136,000 Amp-m^2 dipole parallel to ISS y-axis
Roll Torque (ft-lb) wrt LVLH frame - Environment
T_magnetic
T_grav-grad
T_aero
AMS magnetic torques out-of-phase with environmental torques
Time (Sec)
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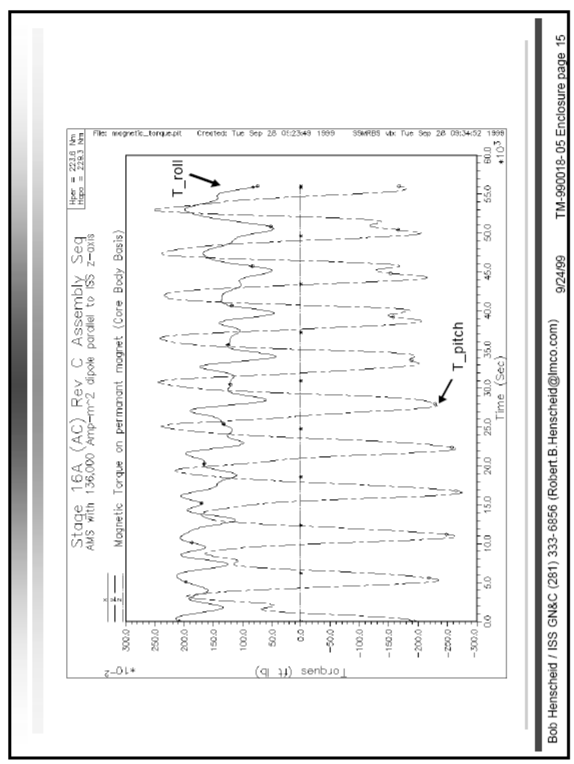
Stage 16A (AC) Rev C Assembly Seq
AMS with 136,000 Amp-m^2 dipole parallel to ISS z-axis
Magnetic Torque on permanent magnet (Core Body Basis)
T_roll
T_pitch
Torques (ft lb)
Time (Sec)
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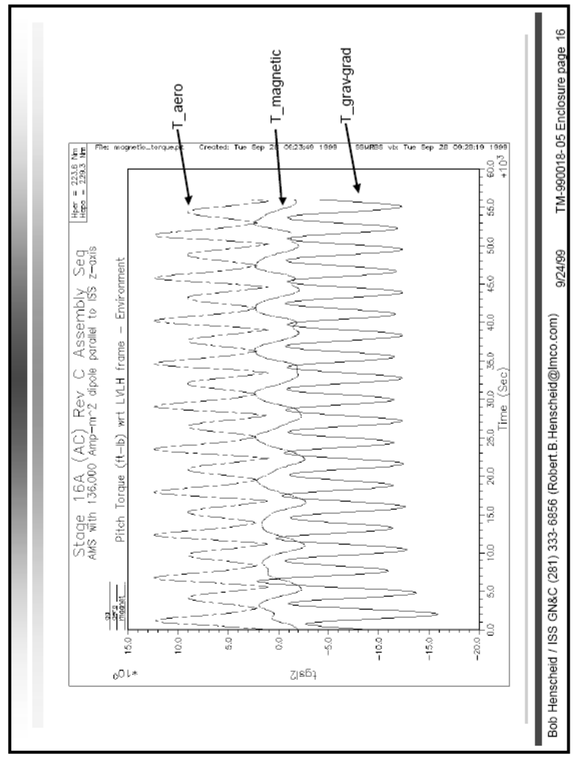
Stage 16A (AC) Rev C Assembly Seq
AMS with 136,000 Amp-m^2 dipole parallel to ISS z-axis
Pitch Torque (ft-lb) wrt LVLH frame - Environment
T_aero
T_magnetic
T_grav-grad
Time (Sec)
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Systems/Payloads Requirements Compliance (SSCN 2664)

System / Payload Disturbance	9 min period Hx	9 min period Hy	9 min period Hz	Hcmg Est	110 min period** Hx	110 min period** Hy	110 min period** Hz
SPP Solar Arrays - Reset*	0	0	1,126	7,302	0	0	1,126
SM Solar Arrays - Reset	0	10	0	7,023	0	10	0
SPP Thermal radiator	138	138	0	7,208	138	138	0
RSA-4 Vozdukh Vent	1	0	62	7,020	1	0	62
RSA-5 MAU Vent	1	0	63	7,020	1	0	63
RSA-6 Elektron Vent	4	44	0	7,066	4	44	0
Thermal Radiators (S1,P1)*	1,082	0	0	7,340	1,082	0	0
Treadmill Gyro Spinup (Lab)	42	0	124	7,041	47	0	138
ACES Flywheel (S3)	0	1,162	0	8,442	0	1,162	0
LAB-1 VES Vent*	41	158	71	7,223	41	158	71
LAB-4 CO2 Vent	27	62	65	7,863	245	564	599
HAB-1 CO2 Vent	tbd	tbd	tbd	tbd	tbd	tbd	tbd
ESA-1 Experiment Vent	32	393	395	7,567	32	393	395
JEM-1a,b Waste Gas Vent*	538	42	757	7,358	538	42	757
JEM-4a,b PM Airlock Vent	4	1	22	7,016	4	1	22
AMS Y-dipole= 136,000 amp-m^2	788		410	9,908	4,125		2,149
AMS X-dipole= 136,000 amp-m^2		739	181	**11,930**		3,867	945
AMS X-dipole= 77,500 amp-m^2		421	103	9,967		2,363	322
Centrifuge Spinup/Spindown (TBD allocated)	775	0	2,862	8,398	775	0	2,862
SSCN 2664 requirements (max values):	**930**	**1,277**	**2,876**	**10,000**			

* Transient disturbances (shaded requirements do not apply)
**Hcmg estimates assume one occurrence per 110 min period

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Momentum Manager Requirements Compliance

- Approach using SSMRBS
  - Determine Baseline MM performance
  - Determine delta performance due to parameter uncertainties
  - Determine delta performance due to system / payload disturbances
  - Estimate worst case MM performance
    - = Baseline MM performance
    - + Continuous system/payload disturbance performance deltas
    - + Root Sum Squared (RSS'd) parameter uncertainty performance deltas
    - + RSS'd system/payload disturbance performance deltas (non-continuous)
  - Compare with Momentum Manager Performance Requirements
- Assess worst case AMS magnetic dipole moment (along ISS x or y-axis)
- Determine maximum allowable magnetic dipole moment (along all axes)
- Assess expected AMS magnetic dipole moment (along y-axis)

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Uncertainty / Disturbance Description	TEA / Average Attitude (degrees) Roll	Pitch	Yaw	Attitude Variation (peak-peak deg/orbit) Roll	Pitch	Yaw	Max Attitude Rate (mdeg/sec) Roll	Pitch	Yaw	Peak CMG Momentum (ft-lb-sec)
Integrated Vehicle Requirements:	15.0	-20.0	15.0	3.5	3.5	3.5	2.0	2.0	2.0	10500
Flex/thermal Allocation:	0.5	-0.5	0.5	1.0	1.0	1.0				
MM Performance Allocations:	**14.6**	**-18.6**	**14.6**	**2.6**	**2.6**	**2.6**	**2.0**	**2.0**	**2.0**	**10000**
Nominal performance with environmental disturbances										
Nominal performance	0.99	-10.09	-2.09	1.17	0.16	0.19	0.63	0.24	0.1	4943
Parameter Uncertainties (performance deltas)										
Atmospheric density	0.05	1.12	0.00	0.04	1.00	0.02	0.03	0.19	0.01	1456
Diurnal Bulge / Orbit Phasing (DAC7)	0.10	1.43	0.02	0.81	0.08	0.11	0.57	0.23	0.29	561
Aerodynamic model (%diffuse)	0.00	0.12	0.00	0.02	0.03	0.01	0.03	0.08	0.00	323
Projected surface areas (+/- 20%)	0.00	0.03	0.00	0.00	0.01	0.00	0.01	0.01	0.00	37
Mass properties (+/- 2000 lbm)	0.06	0.33	0.01	0.01	0.00	0.00	0.01	0.00	0.00	44
Momentum knowledge error	0.09	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	498
RSS'd Uncertainties	0.16	1.85	0.02	0.81	1.00	0.11	0.57	0.31	0.29	1670
Estimated Worst MM Performance with Parameter Uncertainties:										
Nominal + RSS'd Uncert's	1.15	-11.94	-2.11	1.98	1.16	0.30	1.20	0.55	0.39	6613
Environmental Allocations:	**13.6**	**-18.6**	**13.6**	**2.0**	**1.6**	**1.6**	**1.3**	**0.8**	**0.6**	**7000**
Continuous System / Payload Disturbances (performance deltas)										
Electrical current loops	0.00	0.00	0.00	0.05	0.00	0.01	0.01	0.00	0.01	20
AMS X-dipole=136,000 amp-m^2	0.08	-0.06	-1.49	0.31	0.52	0.01	0.13	0.24	0.03	1996
Transient System / Payload Disturbances (performance deltas)										
Crew pushoff (US-Hab / Lab)	na	na	na	0.00	0.00	0.00	0.24	0.40	0.19	13
Crew pushoff (RS-SM)	na	na	na	0.00	0.00	0.00	0.00	1.14	0.54	1
Crew pushoff (JEM-PM)	na	na	na	0.00	0.00	0.00	0.29	0.76	0.37	24
Crew pushoff (APM)	na	na	na	0.00	0.00	0.00	0.22	0.77	0.37	25
ADS string failure	0.00	0.01	0.08	0.08	0.27	0.13	0.28	0.61	0.20	850
Lab-1 VES vent (US-Lab)	0.00	-0.01	0.00	0.02	0.03	0.01	0.05	0.09	0.01	74
JEM-1 waste gas vent (JEM-PM)	0.00	0.00	0.00	0.27	0.03	0.07	0.33	0.08	0.30	64
ESA-1 experiment vent (APM)	0.01	0.00	0.00	0.04	0.01	0.02	0.04	0.01	0.01	0
SARJ (RS-SPP) - reset event	0.00	0.00	0.00	0.00	0.20	0.00	0.10	0.19	0.72	321
TRRJ (S1/P1)	0.00	0.00	0.00	0.00	0.02	0.02	0.93	0.05	0.20	976
Quasi-steady System / Payload Disturbances (performance deltas)										
Lab-4 CO2 vent (US-Lab)	0.00	-0.02	0.00	0.10	0.07	0.02	0.05	0.07	0.01	160
RSA-6 vents (RS-SM)	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
SARJ - rewind event (RS-SM)	0.00	0.02	0.00	0.00	0.03	0.00	0.00	0.00	0.00	88
SARJ - rewind event (RS-FGB)	na	na	na	na	na	na	na	na	na	na
Treadmill gyro spinup/down (RS-SM)	0.01	0.00	0.00	0.02	0.00	0.01	0.01	0.00	0.01	142
TRRJ (RS-SPP)	Not Assessed - need model									
JEM-4 airlock vent (JEM-PM)	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	22
Hab-1 CO2 vent (US-Hab)	0.00	-0.02	0.00	0.03	0.06	0.01	0.02	0.04	0.01	155
Centrifuge (z-axis)(CAM)	0.53	0.02	0.09	0.19	0.01	0.10	0.21	0.28	0.87	1227
Total System/Payload Disturb's	0.61	0.11	1.62	0.58	0.62	0.12	0.36	0.53	0.91	3852
Systems / Payloads Allocations:	**1.0**	**1.0**	**1.0**	**0.6**	**1.0**	**1.0**	**0.7**	**1.4**	**1.6**	**3000**
Estimated Worst MM Performance with Parameter Uncertainties and System / Payload Disturbances										
Excluding transient disturbances	1.76	-12.05	-3.73	2.56	1.78	0.42	1.56	1.07	1.30	10486
MM Performance Allocations:	**14.6**	**-18.6**	**14.6**	**2.6**	**2.6**	**2.6**	**2.0**	**2.0**	**2.0**	**10000**

Momentum Manager Performance Budget With ***Worst Case*** *AMS dipole moment* ***along ISS X-axis*** *(136,000 amp-m^2)*

Bob Henscheid / ISS GN&C (281) 333-6856 (Robert.B.Henscheid@lmco.com) 9/24/99 TM-990018-05 Enclosure page 19

Uncertainty / Disturbance Description	TEA / Average Attitude (degrees) Roll	Pitch	Yaw	Attitude Variation (peak-peak deg/orbit) Roll	Pitch	Yaw	Max Attitude Rate (mdeg/sec) Roll	Pitch	Yaw	Peak CMG Momentum (ft-lb-sec)
Integrated Vehicle Requirements:	15.0	-20.0	15.0	3.5	3.5	3.5	2.0	2.0	2.0	10000
Flex/thermal Allocation:	0.5	-0.5	0.5	1.0	1.0	1.0				
MM Performance Allocations:	**14.6**	**-18.6**	**14.6**	**2.6**	**2.6**	**2.6**	**2.0**	**2.0**	**2.0**	**10000**
Nominal performance with environmental disturbances										
Nominal performance	0.99	-10.09	-2.09	1.17	0.16	0.19	0.63	0.24	0.1	4943
Parameter Uncertainties (performance deltas)										
Atmospheric density	0.05	1.12	0.00	0.04	1.00	0.02	0.03	0.19	0.01	1456
Diurnal Bulge / Orbit Phasing (DAC7)	0.10	1.43	0.02	0.81	0.08	0.11	0.57	0.23	0.29	561
Aerodynamic model (%diffuse)	0.00	0.12	0.00	0.02	0.03	0.01	0.03	0.08	0.00	323
Projected surface areas (+/- 20%)	0.00	0.03	0.00	0.00	0.01	0.00	0.01	0.01	0.00	37
Mass properties (+/- 2000 lbm)	0.06	0.33	0.01	0.01	0.00	0.00	0.01	0.00	0.00	44
Momentum knowledge error	0.09	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	498
RSS'd Uncertainties	0.16	1.85	0.02	0.81	1.00	0.11	0.57	0.31	0.29	1670
Estimated Worst MM Performance with Parameter Uncertainties:										
Nominal + RSS'd Uncert's	1.15	-11.94	-2.11	1.98	1.16	0.30	1.20	0.55	0.39	6613
Environmental Allocations:	**13.6**	**-18.6**	**13.6**	**2.0**	**1.6**	**1.6**	**1.3**	**0.8**	**0.6**	**7000**
Continuous System / Payload Disturbances (performance deltas)										
Electrical current loops	0.00	0.00	0.00	0.05	0.00	0.01	0.01	0.00	0.01	20
AMS Y-dipole=136,000 amp-m^2	0.03	0.00	-0.02	0.87	0.01	0.18	0.84	0.02	0.07	32
Transient System / Payload Disturbances (performance deltas)										
Crew pushoff (US-Hab / Lab)	na	na	na	0.00	0.00	0.00	0.24	0.40	0.19	13
Crew pushoff (RS-SM)	na	na	na	0.00	0.00	0.00	0.00	1.14	0.54	1
Crew pushoff (JEM-PM)	na	na	na	0.00	0.00	0.00	0.29	0.76	0.37	24
Crew pushoff (APM)	na	na	na	0.00	0.00	0.00	0.22	0.77	0.37	25
ADS string failure	0.00	0.01	0.08	0.08	0.27	0.13	0.28	0.61	0.20	850
Lab-1 VES vent (US-Lab)	0.00	-0.01	0.00	0.02	0.03	0.01	0.05	0.09	0.01	74
JEM-1 waste gas vent (JEM-PM)	0.00	0.00	0.00	0.27	0.03	0.07	0.33	0.08	0.30	64
ESA-1 experiment vent (APM)	0.01	0.00	0.00	0.04	0.01	0.02	0.04	0.01	0.01	0
SARJ (RS-SPP) - reset event	0.00	0.00	0.00	0.00	0.20	0.00	0.10	0.19	0.72	321
TRRJ (S1/P1)	0.00	0.00	0.00	0.00	0.02	0.02	0.93	0.05	0.20	976
Quasi-steady System / Payload Disturbances (performance deltas)										
Lab-4 CO2 vent (US-Lab)	0.00	-0.02	0.00	0.10	0.07	0.02	0.05	0.07	0.01	160
RSA-6 vents (RS-SM)	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
SARJ - rewind event (RS-SM)	0.00	0.02	0.00	0.00	0.03	0.00	0.00	0.00	0.00	88
SARJ - rewind event (RS-FGB)	na	na	na	na	na	na	na	na	na	na
Treadmill gyro spinup/down (RS-SM)	0.01	0.00	0.00	0.02	0.00	0.01	0.01	0.00	0.01	142
TRRJ (RS-SPP)	Not Assessed - need model									
JEM-4 airlock vent (JEM-PM)	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	22
Hab-1 CO2 vent (US-Hab)	0.00	-0.02	0.00	0.03	0.06	0.01	0.02	0.04	0.01	155
Centrifuge (z-axis)(CAM)	0.53	0.02	0.09	0.19	0.01	0.10	0.21	0.28	0.87	1227
Total System/Payload Disturb's	0.56	0.05	0.14	1.14	0.11	0.29	0.86	0.31	0.95	1888
Systems / Payloads Allocations:	**1.0**	**1.0**	**1.0**	**0.6**	**1.0**	**1.0**	**0.7**	**1.4**	**1.6**	**3000**
Estimated Worst MM Performance with Parameter Uncertainties and System / Payload Disturbances										
Excluding transient disturbances	1.70	-11.99	-2.26	3.12	1.27	0.59	2.06	0.86	1.34	8502
MM Performance Allocations:	**14.6**	**-18.6**	**14.6**	**2.6**	**2.6**	**2.6**	**2.0**	**2.0**	**2.0**	**10000**

Momentum Manager Performance Budget With ***Worst Case*** *AMS dipole moment* ***along ISS Y-axis*** *(136,000 amp-m^2)*

Bob Henscheid / ISS GN&C (281) 333-6856 (Robert.B.Henscheid@lmco.com) 9/24/99 TM-990018-05 Enclosure page 20

Uncertainty / Disturbance Description	TEA / Average Attitude (degrees) Roll	Pitch	Yaw	Attitude Variation (peak-peak deg/orbit) Roll	Pitch	Yaw	Max Attitude Rate (mdeg/sec) Roll	Pitch	Yaw	Peak CMG Momentum (ft-lb-sec)
Integrated Vehicle Requirements:	15.0	-20.0	15.0	3.5	3.5	3.5	2.0	2.0	2.0	10000
Flex/thermal Allocation:	0.5	-0.5	0.5	1.0	1.0	1.0				
MM Performance Allocations:	**14.5**	**-19.5**	**14.5**	**2.5**	**2.5**	**2.5**	**2.0**	**2.0**	**2.0**	**10000**
Nominal performance with environmental disturbances										
Nominal performance	0.99	-10.09	-2.09	1.17	0.16	0.19	0.63	0.24	0.1	4943
Parameter Uncertainties (performance deltas)										
Atmospheric density	0.05	1.12	0.00	0.04	1.00	0.02	0.03	0.19	0.01	1456
Diurnal Bulge / Orbit Phasing (DAC7)	0.10	1.43	0.02	0.81	0.08	0.11	0.57	0.23	0.29	561
Aerodynamic model (%diffuse)	0.00	0.12	0.00	0.02	0.03	0.01	0.03	0.08	0.00	323
Projected surface areas (+/- 20%)	0.00	0.03	0.00	0.00	0.01	0.00	0.01	0.01	0.00	37
Mass properties (+/- 2000 lbm)	0.06	0.33	0.01	0.01	0.00	0.00	0.01	0.00	0.00	44
Momentum knowledge error	0.09	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	498
RSS'd Uncertainties	0.16	1.85	0.02	0.81	1.00	0.11	0.57	0.31	0.29	1670
Estimated Worst MM Performance with Parameter Uncertainties:										
Nominal + RSS'd Uncert's	1.15	-11.94	-2.11	1.98	1.16	0.30	1.20	0.55	0.39	6613
Environmental Allocations:	**13.5**	**-18.5**	**13.5**	**2.0**	**1.5**	**1.5**	**1.3**	**0.6**	**0.5**	**7000**
Continuous System / Payload Disturbances (performance deltas)										
Electrical current loops	0.00	0.00	0.00	0.05	0.00	0.01	0.01	0.00	0.01	20
Max X-dipole=100,000 amp-m2	0.03	0.04	-1.49	0.22	0.43	0.04	0.10	0.22	0.02	1204
Transient System / Payload Disturbances (performance deltas)										
Crew pushoff (US-Hab / Lab)	na	na	na	0.00	0.00	0.00	0.24	0.40	0.19	13
Crew pushoff (RS-SM)	na	na	na	0.00	0.00	0.00	0.00	1.14	0.54	1
Crew pushoff (JEM-PM)	na	na	na	0.00	0.00	0.00	0.29	0.76	0.37	24
Crew pushoff (APM)	na	na	na	0.00	0.00	0.00	0.22	0.77	0.37	25
ADS string failure	0.00	0.01	0.08	0.08	0.27	0.13	0.28	0.61	0.20	850
Lab-1 VES vent (US-Lab)	0.00	-0.01	0.00	0.02	0.03	0.01	0.05	0.09	0.01	74
JEM-1 waste gas vent (JEM-PM)	0.00	0.00	0.00	0.27	0.03	0.07	0.33	0.08	0.30	64
ESA-1 experiment vent (APM)	0.01	0.00	0.00	0.04	0.01	0.02	0.04	0.01	0.01	0
SARJ (RS-SPP) - reset event	0.00	0.00	0.00	0.00	0.20	0.00	0.10	0.19	0.72	321
TRRJ (S1/P1)	0.00	0.00	0.00	0.00	0.02	0.02	0.93	0.05	0.20	976
Quasi-steady System / Payload Disturbances (performance deltas)										
Lab-4 CO2 vent (US-Lab)	0.00	-0.02	0.00	0.10	0.07	0.02	0.05	0.07	0.01	160
RSA-6 vents (RS-SM)	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
SARJ - rewind event (RS-SM)	0.00	0.02	0.00	0.00	0.03	0.00	0.00	0.00	0.00	83
SARJ - rewind event (RS-FGB)	na	na	na	na	na	na	na	na	na	na
Treadmill gyro spinup/down (RS-SM)	0.01	0.00	0.00	0.02	0.00	0.01	0.01	0.00	0.01	142
TRRJ (RS-SPP)	Not Assessed - need model									
JEM-4 airlock vent (JEM-PM)	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	22
Hab-1 CO2 vent (US-Hab)	0.00	-0.02	0.00	0.03	0.06	0.01	0.02	0.04	0.01	155
Centrifuge (z-axis)(CAM)	0.53	0.02	0.09	0.19	0.01	0.10	0.21	0.28	0.87	1227
Total System/Payload Disturb's	0.56	0.09	1.61	0.49	0.52	0.15	0.32	0.51	0.90	3060
Systems / Payloads Allocations:	**1.0**	**1.0**	**1.0**	**0.5**	**1.0**	**1.0**	**0.7**	**1.4**	**1.5**	**3000**
Estimated Worst MM Performance with Parameter Uncertainties and System / Payload Disturbances										
Excluding transient disturbances	1.70	-12.03	-3.73	2.47	1.69	0.46	1.53	1.06	1.29	9674
MM Performance Allocations:	**14.5**	**-19.5**	**14.5**	**2.5**	**2.5**	**2.5**	**2.0**	**2.0**	**2.0**	**10000**

Momentum Manager Performance Budget with ***Maximum Allowable*** *magnetic dipole moment* ***along ISS X-axis*** *(100,000 amp-m²)*

Uncertainty / Disturbance Description	TEA / Average Attitude (degrees) Roll	Pitch	Yaw	Attitude Variation (peak-peak deg/orbit) Roll	Pitch	Yaw	Max Attitude Rate (mdeg/sec) Roll	Pitch	Yaw	Peak CMG Momentum (ft-lb-sec)
Integrated Vehicle Requirements:	15.0	-20.0	15.0	3.5	3.5	3.5	2.0	2.0	2.0	10000
Flex/thermal Allocation:	0.5	-0.5	0.5	1.0	1.0	1.0				
MM Performance Allocations:	**14.5**	**-19.5**	**14.5**	**2.5**	**2.5**	**2.5**	**2.0**	**2.0**	**2.0**	**10000**
Nominal performance with environmental disturbances										
Nominal performance	0.99	-10.09	-2.09	1.17	0.16	0.19	0.63	0.24	0.1	4943
Parameter Uncertainties (performance deltas)										
Atmospheric density	0.05	1.12	0.00	0.04	1.00	0.02	0.03	0.19	0.01	1456
Diurnal Bulge / Orbit Phasing (DAC7)	0.10	1.43	0.02	0.81	0.08	0.11	0.57	0.23	0.29	561
Aerodynamic model (%diffuse)	0.00	0.12	0.00	0.02	0.03	0.01	0.03	0.08	0.00	323
Projected surface areas (+/- 20%)	0.00	0.03	0.00	0.00	0.01	0.00	0.01	0.01	0.00	37
Mass properties (+/- 2000 lbm)	0.06	0.33	0.01	0.01	0.00	0.00	0.01	0.00	0.00	44
Momentum knowledge error	0.09	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	498
RSS'd Uncertainties	0.16	1.85	0.02	0.81	1.00	0.11	0.57	0.31	0.29	1670
Estimated Worst MM Performance with Parameter Uncertainties:										
Nominal + RSS'd Uncert's	1.15	-11.94	-2.11	1.98	1.16	0.30	1.20	0.55	0.39	6613
Environmental Allocations:	**13.5**	**-18.5**	**13.5**	**2.0**	**1.5**	**1.5**	**1.3**	**0.6**	**0.5**	**7000**
Continuous System / Payload Disturbances (performance deltas)										
Electrical current loops	0.00	0.00	0.00	0.05	0.00	0.01	0.01	0.00	0.01	20
Max Y-dipole= 40,000 amp-m2	0.01	0.00	-0.01	0.25	0.00	0.05	0.14	0.01	0.01	8
Transient System / Payload Disturbances (performance deltas)										
Crew pushoff (US-Hab / Lab)	na	na	na	0.00	0.00	0.00	0.24	0.40	0.19	13
Crew pushoff (RS-SM)	na	na	na	0.00	0.00	0.00	0.00	1.14	0.54	1
Crew pushoff (JEM-PM)	na	na	na	0.00	0.00	0.00	0.29	0.76	0.37	24
Crew pushoff (APM)	na	na	na	0.00	0.00	0.00	0.22	0.77	0.37	25
ADS string failure	0.00	0.01	0.08	0.08	0.27	0.13	0.28	0.61	0.20	850
Lab-1 VES vent (US-Lab)	0.00	-0.01	0.00	0.02	0.03	0.01	0.05	0.09	0.01	74
JEM-1 waste gas vent (JEM-PM)	0.00	0.00	0.00	0.27	0.03	0.07	0.33	0.08	0.30	64
ESA-1 experiment vent (APM)	0.01	0.00	0.00	0.04	0.01	0.02	0.04	0.01	0.01	0
SARJ (RS-SPP) - reset event	0.00	0.00	0.00	0.00	0.20	0.00	0.10	0.19	0.72	321
TRRJ (S1/P1)	0.00	0.00	0.00	0.00	0.02	0.02	0.93	0.05	0.20	976
Quasi-steady System / Payload Disturbances (performance deltas)										
Lab-4 CO2 vent (US-Lab)	0.00	-0.02	0.00	0.10	0.07	0.02	0.05	0.07	0.01	160
RSA-6 vents (RS-SM)	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
SARJ - rewind event (RS-SM)	0.00	0.02	0.00	0.00	0.03	0.00	0.00	0.00	0.00	83
SARJ - rewind event (RS-FGB)	na	na	na	na	na	na	na	na	na	na
Treadmill gyro spinup/down (RS-SM)	0.01	0.00	0.00	0.02	0.00	0.01	0.01	0.00	0.01	142
TRRJ (RS-SPP)	Not Assessed - need model									
JEM-4 airlock vent (JEM-PM)	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	22
Hab-1 CO2 vent (US-Hab)	0.00	-0.02	0.00	0.03	0.06	0.01	0.02	0.04	0.01	155
Centrifuge (z-axis)(CAM)	0.53	0.02	0.09	0.19	0.01	0.10	0.21	0.28	0.87	1227
Total System/Payload Disturb's	0.54	0.05	0.13	0.62	0.10	0.16	0.37	0.29	0.89	1864
Systems / Payloads Allocations:	**1.0**	**1.0**	**1.0**	**0.5**	**1.0**	**1.0**	**0.7**	**1.4**	**1.5**	**3000**
Estimated Worst MM Performance with Parameter Uncertainties and System / Payload Disturbances										
Excluding transient disturbances	1.68	-11.99	-2.24	2.60	1.26	0.46	1.57	0.84	1.28	8478
MM Performance Allocations:	**14.5**	**-19.5**	**14.5**	**2.5**	**2.5**	**2.5**	**2.0**	**2.0**	**2.0**	**10000**

Momentum Manager Performance Budget with ***Maximum Allowable*** *magnetic dipole moment* ***along ISS Y-axis*** *(40,000 amp-m²)*

Uncertainty / Disturbance Description	TEA / Average Attitude (degrees) Roll	Pitch	Yaw	Attitude Variation (peak-peak deg/orbit) Roll	Pitch	Yaw	Max Attitude Rate (mdeg/sec) Roll	Pitch	Yaw	Peak CMG Momentum (ft-lb-sec)
Integrated Vehicle Requirements:	15.0	-20.0	15.0	3.5	3.5	3.5	2.0	2.0	2.0	10000
Flex/thermal Allocation:	0.5	-0.5	0.5	1.0	1.0	1.0				
MM Performance Allocations:	**14.5**	**-19.5**	**14.5**	**2.5**	**2.5**	**2.5**	**2.0**	**2.0**	**2.0**	**10000**
Nominal performance with environmental disturbances										
Nominal performance	0.99	-10.09	-2.09	1.17	0.16	0.19	0.63	0.24	0.1	4943
Parameter Uncertainties (performance deltas)										
Atmospheric density	0.05	1.12	0.00	0.04	1.00	0.02	0.03	0.19	0.01	1456
Diurnal Bulge / Orbit Phasing (DAC7)	0.10	1.43	0.02	0.81	0.08	0.11	0.57	0.23	0.29	561
Aerodynamic model (%diffuse)	0.00	0.12	0.00	0.02	0.03	0.01	0.03	0.08	0.00	323
Projected surface areas (+/- 20%)	0.00	0.03	0.00	0.00	0.01	0.00	0.01	0.01	0.00	37
Mass properties (+/- 2000 lbm)	0.06	0.33	0.01	0.01	0.00	0.00	0.01	0.00	0.00	44
Momentum knowledge error	0.09	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	498
RSS'd Uncertainties	0.16	1.85	0.02	0.81	1.00	0.11	0.57	0.31	0.29	1670
Estimated Worst MM Performance with Parameter Uncertainties:										
Nominal + RSS'd Uncert's	1.15	-11.94	-2.11	1.98	1.16	0.30	1.20	0.55	0.39	6613
Environmental Allocations:	**13.5**	**-18.5**	**13.5**	**2.0**	**1.5**	**1.5**	**1.3**	**0.6**	**0.5**	**7000**
Continuous System / Payload Disturbances (performance deltas)										
Electrical current loops	0.00	0.00	0.00	0.05	0.00	0.01	0.01	0.00	0.01	20
AMS Z-dipole=190,000 amp-m²	-0.27	0.00	0.05	0.22	0.10	0.01	0.06	0.15	0.01	445
Transient System / Payload Disturbances (performance deltas)										
Crew pushoff (US-Hab / Lab)	na	na	na	0.00	0.00	0.00	0.24	0.40	0.19	13
Crew pushoff (RS-SM)	na	na	na	0.00	0.00	0.00	0.00	1.14	0.54	1
Crew pushoff (JEM-PM)	na	na	na	0.00	0.00	0.00	0.29	0.76	0.37	24
Crew pushoff (APM)	na	na	na	0.00	0.00	0.00	0.22	0.77	0.37	25
ADS string failure	0.00	0.01	0.08	0.08	0.27	0.13	0.28	0.61	0.20	850
Lab-1 VES vent (US-Lab)	0.00	-0.01	0.00	0.02	0.03	0.01	0.05	0.09	0.01	74
JEM-1 waste gas vent (JEM-PM)	0.00	0.00	0.00	0.27	0.03	0.07	0.33	0.08	0.30	64
ESA-1 experiment vent (APM)	0.01	0.00	0.00	0.04	0.01	0.02	0.04	0.01	0.01	0
SARJ (RS-SPP) - reset event	0.00	0.00	0.00	0.00	0.20	0.00	0.10	0.19	0.72	321
TRRJ (S1/P1)	0.00	0.00	0.00	0.00	0.02	0.02	0.93	0.05	0.20	976
Quasi-steady System / Payload Disturbances (performance deltas)										
Lab-4 CO2 vent (US-Lab)	0.00	-0.02	0.00	0.10	0.07	0.02	0.05	0.07	0.01	160
RSA-6 vents (RS-SM)	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
SARJ - rewind event (RS-SM)	0.00	0.02	0.00	0.00	0.03	0.00	0.00	0.00	0.00	83
SARJ - rewind event (RS-FGB)	na	na	na	na	na	na	na	na	na	na
Treadmill gyro spinup/down (RS-SM)	0.01	0.00	0.00	0.02	0.00	0.01	0.01	0.00	0.01	142
TRRJ (RS-SPP)	Not Assessed - need model									
JEM-4 airlock vent (JEM-PM)	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	22
Hab-1 CO2 vent (US-Hab)	0.00	-0.02	0.00	0.03	0.06	0.01	0.02	0.04	0.01	155
Centrifuge (z-axis)(CAM)	0.53	0.02	0.09	0.19	0.01	0.10	0.21	0.28	0.87	1227
Total System/Payload Disturb's	0.80	0.05	0.17	0.49	0.20	0.12	0.28	0.44	0.89	2301
Systems / Payloads Allocations:	**1.0**	**1.0**	**1.0**	**0.5**	**1.0**	**1.0**	**0.7**	**1.4**	**1.5**	**3000**
Estimated Worst MM Performance with Parameter Uncertainties and System / Payload Disturbances										
Excluding transient disturbances	1.95	-11.99	-2.29	2.47	1.36	0.43	1.48	0.99	1.28	8915
MM Performance Allocations:	**14.5**	**-19.5**	**14.5**	**2.5**	**2.5**	**2.5**	**2.0**	**2.0**	**2.0**	**10000**

Momentum Manager Performance Budget with ***Maximum Allowable*** *magnetic dipole moment* ***along ISS Z-axis*** *(190,000 amp-m²)*

Uncertainty / Disturbance Description	TEA / Average Attitude (degrees) Roll	Pitch	Yaw	Attitude Variation (peak-peak deg/orbit) Roll	Pitch	Yaw	Max Attitude Rate (mdeg/sec) Roll	Pitch	Yaw	Peak CMG Momentum (ft-lb-sec)
Integrated Vehicle Requirements:	15.0	-20.0	15.0	3.5	3.5	3.5	2.0	2.0	2.0	10000
Flex/thermal Allocation:	0.5	-0.5	0.5	1.0	1.0	1.0				
MM Performance Allocations:	**14.5**	**-19.5**	**14.5**	**2.5**	**2.5**	**2.5**	**2.0**	**2.0**	**2.0**	**10000**
Nominal performance with environmental disturbances										
Nominal performance	0.99	-10.09	-2.09	1.17	0.16	0.19	0.63	0.24	0.1	4943
Parameter Uncertainties (performance deltas)										
Atmospheric density	0.05	1.12	0.00	0.04	1.00	0.02	0.03	0.19	0.01	1456
Diurnal Bulge / Orbit Phasing (DAC7	0.10	1.43	0.02	0.81	0.08	0.11	0.57	0.23	0.29	561
Aerodynamic model (%diffuse)	0.00	0.12	0.00	0.02	0.03	0.01	0.03	0.08	0.00	323
Projected surface areas (+/- 20%)	0.00	0.03	0.00	0.00	0.01	0.00	0.01	0.01	0.00	37
Mass properties (+/- 2000 lbm)	0.06	0.33	0.01	0.01	0.00	0.00	0.01	0.00	0.00	44
Momentum knowledge error	0.09	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	498
RSS'd Uncertainties	0.16	1.85	0.02	0.81	1.00	0.11	0.57	0.31	0.29	1670
Estimated Worst MM Performance with Parameter Uncertainties:										
Nominal + RSS'd Uncert's	1.15	-11.94	-2.11	1.98	1.16	0.30	1.20	0.55	0.39	6613
Environmental Allocations:	**13.5**	**-18.5**	**13.5**	**2.0**	**1.5**	**1.5**	**1.3**	**0.6**	**0.5**	**7000**
Continuous System / Payload Disturbances (performance deltas)										
Electrical current loops	0.00	0.00	0.00	0.05	0.00	0.01	0.01	0.00	0.01	20
AMS Y-dipole= 27,200 amp-m2	0.01	0.00	0.00	0.17	0.00	0.03	0.10	0.01	0.00	5
Transient System / Payload Disturbances (performance deltas)										
Crew pushoff (US-Hab / Lab)	na	na	na	0.00	0.00	0.00	0.24	0.40	0.19	13
Crew pushoff (RS-SM)	na	na	na	0.00	0.00	0.00	0.00	1.14	0.54	1
Crew pushoff (JEM-PM)	na	na	na	0.00	0.00	0.00	0.29	0.76	0.37	24
Crew pushoff (APM)	na	na	na	0.00	0.00	0.00	0.22	0.77	0.37	25
ADS string failure	0.00	0.01	0.08	0.08	0.27	0.13	0.28	0.61	0.20	850
Lab-1 VES vent (US-Lab)	0.00	-0.01	0.00	0.02	0.03	0.01	0.05	0.09	0.01	74
JEM-1 waste gas vent (JEM-PM)	0.00	0.00	0.00	0.27	0.03	0.07	0.33	0.08	0.30	64
ESA-1 experiment vent (APM)	0.01	0.00	0.00	0.04	0.01	0.02	0.04	0.01	0.01	0
SARJ (RS-SPP) - reset event	0.00	0.00	0.00	0.00	0.20	0.00	0.10	0.19	0.72	321
TRRJ (S1/P1)	0.00	0.00	0.00	0.00	0.02	0.02	0.93	0.05	0.20	976
Quasi-steady System / Payload Disturbances (performance deltas)										
Lab-4 CO2 vent (US-Lab)	0.00	-0.02	0.00	0.10	0.07	0.02	0.05	0.07	0.01	160
RSA-6 vents (RS-SM)	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
SARJ - rewind event (RS-SM)	0.00	0.02	0.00	0.00	0.03	0.00	0.00	0.00	0.00	83
SARJ - rewind event (RS-FGB)	na	na	na	na	na	na	na	na	na	na
Treadmill gyro spinup/down (RS-SM)	0.01	0.00	0.00	0.02	0.00	0.01	0.01	0.00	0.01	142
TRRJ (RS-SPP)	Not Assessed - need model									
JEM-4 airlock vent (JEM-PM)	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	22
Hab-1 CO2 vent (US-Hab)	0.00	-0.02	0.00	0.03	0.06	0.01	0.02	0.04	0.01	155
Centrifuge (z-axis)(CAM)	0.53	0.02	0.09	0.19	0.01	0.10	0.21	0.28	0.87	1227
Total System/Payload Disturb's	0.53	0.05	0.13	0.44	0.10	0.14	0.32	0.29	0.88	1861
Systems / Payloads Allocations:	**1.0**	**1.0**	**1.0**	**0.5**	**1.0**	**1.0**	**0.7**	**1.4**	**1.5**	**3000**
Estimated Worst MM Performance with Parameter Uncertainties and System / Payload Disturbances										
Including transient disturbances	na	na	na	2.71	1.60	0.60	2.64	2.59	2.41	8475
Excluding transient disturbances	1.68	-11.99	-2.24	2.42	1.26	0.45	1.52	0.84	1.27	na
MM Performance Allocations:	**14.5**	**-19.5**	**14.5**	**2.5**	**2.5**	**2.5**	**2.0**	**2.0**	**2.0**	**10000**

Momentum Manager Performance Budget with ***Expected*** *AMS dipole moment* ***along ISS Y-axis*** *(27,200 amp-m²)*

Requirements Compliance Summary

- For AMS dipole = 136,000 amp-m^2 parallel with ISS Y-axis
  - MM exceeds "Roll Attitude Variation / Orbit" requirement
  - MM exceeds "Roll Attitude Rate" requirement
- For AMS dipole = 136,000 amp-m^2 parallel with ISS X-axis
  - AMS exceeds "Limit CMG Momentum" requirement (SSCN 2664)
  - MM exceeds "1-fault tolerant CMG momentum" requirement
  - MM exceeds "Roll Attitude Variation / Orbit" requirement
- All MM requirements are met if magnetic dipole moment is less than
  - 100,000 amp-m^2 if parallel to ISS X-axis
  - 40,000 amp-m^2 if parallel to ISS Y-axis
  - 190,000 amp-m^2 if parallel to ISS Z-axis

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MM / AMS Interaction Summary

- AMS dipole aligned along ISS X-axis
  - Large pitch magnetic torque in-phase with large pitch aero torque
    - ✓ Produces high CMG momentum usage
      - Requires "momentum emphasis" MM controller design
    - ✓ Pitch axis has **least** CMG momentum margin for disturbances
- AMS dipole aligned along ISS Y-axis
  - Large roll magnetic torque out-of-phase with roll gravity-gradient torque and small roll aero torque
    - ✓ Produces large roll attitude variations / rates
    - ✓ Roll axis has **least** attitude rate margin for disturbances
- AMS dipole aligned along ISS Z-axis
  - Medium pitch magnetic torque out-of-phase with large pitch aero torque

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Recommendations

- AMS and other magnetic systems/payloads should have magnetic dipole moments less than:
  - 100,000 amp-m^2 if parallel to ISS X-axis
  - 40,000 amp-m^2 if parallel to ISS Y-axis
  - 190,000 amp-m^2 if parallel to ISS Z-axis
- Incorporate above in appropriate AMS requirements document(s)
- Re-assess AMS/MM requirements compliance when actual magnetic dipole moment is known

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