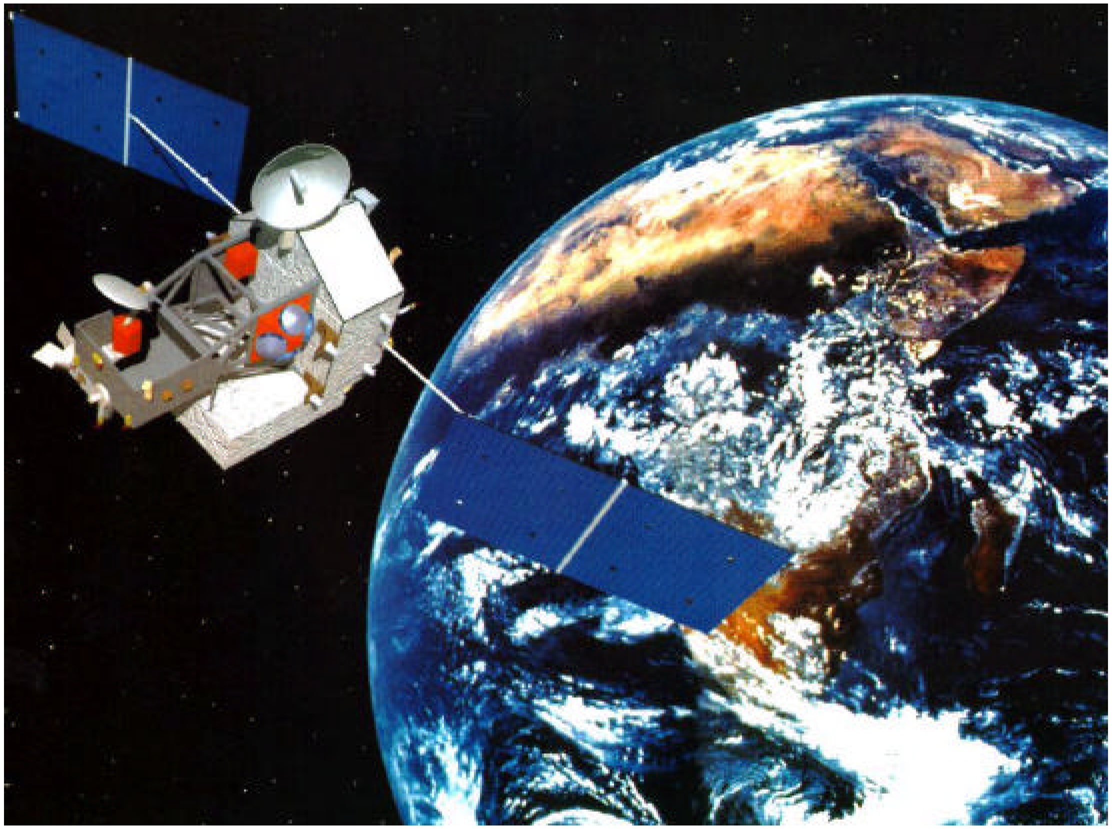
TRMM De-Orbit Alternatives

NASA/Goddard Space Flight Center

Presentation to NCAR/UCAR June 18, 2001



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NASA Orbital Debris Guidelines

NASA Orbital Debris Guidelines

- NASA Policy Directive 8710.3 outlines NASA Policy for Limiting Orbital Debris Generation
  - Directive covers orbital debris due to collisions, malfunctions, normal operations, and post mission disposal
- NASA Safety Standard 1740.14 gives guidelines and assessment procedures for conducting Orbital Debris Assessments (ODA)
  - Debris released during normal operations
  - Debris generated by explosions / intentional breakups
  - Debris generated by on-orbit collisions
  - Safe disposal of upper stages and spacecraft
  - Debris surviving reentry and impacting populated areas
  - Collision hazards posed by tethered systems

NASA Orbital Debris Guideline
Survival of Orbital Debris

- Limiting the risk of human casualty from debris surviving uncontrolled reentry
  - Total Debris Casualty Area for spacecraft components surviving natural reentry should not exceed 8 m^2
  - Upper limit of 8 m^2 derived assuming an average risk of human casualty of 1 in 10,000 per reentry event
  - Risk of reentry may be lower since no correction made for protection of people inside buildings or vehicles
- If amount of debris surviving reentry exceeds the guideline, then the impact area should be controlled by performing a controlled reentry
  - Reentry debris footprint should be no closer than 200 nautical miles from foreign landmasses and 25 nautical miles from U.S. territories and the Continental United States
  - Authorities for shipping lanes and airline routes will be notified of the event

Orbital Debris Analysis Methodology

- Model parent body as sphere or cylinder
- Determine altitude, velocity and flight path angle at breakup
- Identify components within parent body
  - All components larger than 0.25 m in any dimension must be identified
- Model each component as equivalent spheres or cylinders and determine predominant material and reference area
- Determine integrated heat load experienced by each component
- Determine specific heat of ablation of predominant materials
- Determine reentry survivability of each component
- Compute total debris casualty area, D_A
  - Add 0.3 m "man border" to average cross-sectional area (A_i) of components at ground impact
  - $D_A = \text{sum}\,(0.6 + \text{sqrt}\,(A_i))^2$
- If Debris Casualty Area exceeds 8 m^2, then decrease the amount of debris or control the ground impact point for the debris

NASA Orbital Debris Guideline
Debris Mitigation Measures

- Perform a controlled reentry
- Use materials that are less likely to survive
- Decrease the effective drag at reentry interface by decreasing the frontal area of the object
- Cause a structure to break up at a higher altitude
- Maneuver the structure to a disposal orbit where reentry will not occur

GSFC Orbital Debris Mitigation Status

Orbital Debris Mitigation
Why is this important to GSFC?

- GSFC has vested interest in limiting generation of orbital debris
- Both on-orbit and missions in development at GSFC are affected by Orbital Debris Assessment guidelines
- Adherence to guideline can have major impact to mission cost & schedule
  - Additional spacecraft propulsion system hardware
  - Additional spacecraft fault tolerance
  - Engineering support for safe disposal planning, trajectory design, flight ops training and simulations
  - Shortened mission life & science products

On-Orbit GSFC Missions

Mission	Orbit	Atmospheric Reentry?	On-orbit Mass (kg)	Debris Casualty Area (m**2)	Controlled reentry possible?	Shuttle return possible?	< 25 yr disposal possible?	Launch Date	Earliest Reentry
ACE	L1	No	665		N/A	N/A	N/A		N/A
ACRIMSAT	685 km	Yes	115		No	No		Dec-99	
EO-1	705 km	Yes	562	6.2	No	No	Yes	Nov-00	
ERBS	573 km, 57 deg	Yes	1965	6.7?	No	Yes	Yes	Oct-84	2024
FAST	351 x 4175 km	Yes	187		No	No		Aug-96	2027
FUSE	760 km	Yes	1335		No	No			
GEOTAIL	9Re x 30Re	No			N/A	N/A	N/A		N/A
GOES-8	35,790 km	No	2105		N/A	N/A	N/A		N/A
GOES-10	35,790 km	No	2105		N/A	N/A	N/A	Apr-97	N/A
GOES-11	35,790 km	No	2105		N/A	N/A	N/A	May-00	N/A
HETE-2	600 x 650 km	Yes	123		No	No		Oct-00	
HST	600 km	Yes	11063	TBD	No	Yes	Yes	Apr-90	2011
IMAGE	1000 x 7000 km	No	494	10.9#	N/A	N/A	N/A	Mar-00	N/A
IMP-8	35Re	No			N/A	N/A	N/A	Oct-73	N/A
Landsat-4	705 km, 98.2 deg	Yes	1900		**No**	No	Yes	Jul-82	2027
Landsat-5	705 km, 98.2 deg	Yes	1900		**No**	No	Yes	Mar-84	2027
Landsat-7	705 km, 98.2 deg	Yes	2200	**20**	**No**	No	Yes	Apr-99	2027
NOAA-10	802 km, 98.6 deg	Yes	1475	**TBD**	No	No	**No**	Sep-86	
NOAA-11	844 km, 99 deg	Yes	1475	**TBD**	No	No	**No**	Sep-88	
NOAA-12	810, 98.5 deg	Yes	1475	**TBD**	No	No	**No**	May-91	
NOAA-14	847 km, 99.1 deg	Yes	1475	**TBD**	No	No	**No**	Dec-94	
NOAA-15	811 km, 98.6 deg	Yes	1475	**TBD**	No	No	**No**	May-98	
NOAA-16	853 km, 98.8 deg	Yes	1475	**TBD**	No	No	**No**	Sep-00	
POLAR	2Re x 9Re	No	1040		N/A	N/A	N/A		N/A
QuikSCAT	800 km	Yes	830	7.6	No	No	**No**	Jun-99	
RXTE	560 km	Yes	3031		**No**	No	Yes		2011
SAMPEX	520 x 670 km, 82 deg	Yes	161	0	No	No	Yes	Jul-92	Nov-08
SeaWiFS	705 km	Yes			No			Aug-97	
SOHO	L1	No	1753		N/A	N/A	N/A		N/A
TDRS-H	35,790 km	No	3180		N/A	N/A	N/A	Jun-00	N/A
SWAS	640 km	Yes	283		No	No			2027
Terra	705 km, 98.2 deg	Yes	4400	**33**	**No**	No		Dec-99	2027
TOMS-EP	730 km	Yes	220		No	No	**No**	Jul-96	2027
TRACE	607 km	Yes	214		No	No			2020
TRMM	350 km	Yes	3220	**12**	Yes	No	Yes	Nov-97	Jan-03
UARS	583 km	Yes	5968	TBD	No	Yes	Yes	Oct-91	2012
WIND	5Re x 185Re	No	1008		N/A	N/A	N/A	Nov-94	N/A
WIRE	540 km, 97.5 deg	Yes	238	5.8	No	No	Yes	Mar-99	Mar-08

Orbital Debris Assessment
GSFC On-Orbit Mission Status

- STS retrieval possible for very few on-orbit missions (UARS, ERBS, HST)
- TRMM, Landsat-4, Landsat-5, Landsat-7, RXTE, Terra, UARS and HST have debris casualty area above 8 m^2
  - Of all GSFC on-orbit missions, TRMM is the only mission capable of performing a controlled reentry
  - Landsat-4 and Landsat-5 operational prior to 1993
  - UARS and HST reliant on Shuttle retrieval to meet guideline
  - Landsat-7, RXTE and Terra in violation of guideline
- Currently working implementation of Landsat-4 & 5 disposal to orbit < 25 years
- TOMS-EP, QuikSCAT and all NOAA series missions cannot meet disposal to orbit < 25 year guideline

GSFC Missions in Development

Mission	LRD	Orbit	Atmospheric Reentry?	On-orbit Mass (kg)	Debris Casualty Area (m**2)	Controlled reentry possible?	Shuttle return possible?	< 25 yr disposal possible?
HESSI	May-01	600 km, 38 deg	Yes	290	3.3	No	No	
MAP	Jun-01	L2 Lagrange	No	800	4.3	N/A	N/A	N/A
QuikTOMS	Jun-01	800 km	Yes	196		No	No	Yes*
GOES-M	Jul-01	35,790 km	No			N/A	N/A	N/A
Aqua	Jul-01	705 km, 98.2 deg	Yes	2808	**18.2**	**No**	No	Yes*
NOAA-M	Aug-01	830 km	Yes	1475	TBD	No	No	**No**
TIMED	Aug-01	625 km, 74.1 deg	Yes	600	5.2	No	No	Yes
GRACE	Oct-01	500 km, 89 deg	Yes	466	3.6	No	No	Yes
TDRS-I	Nov-01	35,790 km	No			N/A	N/A	N/A
CATSAT	Dec-01	550 km	Yes	170		No	No	
Icesat	Dec-01	592 km, 94 deg	Yes	915	3.6	No	No	Yes
GALEX	Jan-02					No	No	
INTEGRAL	Apr-02	10000 x 153000 km	No			N/A	N/A	N/A
SORCE	Jul-02	640 km, 40 deg	Yes	268	8.2	No	No	Yes
CHIPS	Aug-02	600 km	Yes			No	No	
TDRS-J	Oct-02	35,790 km	No			N/A	N/A	N/A
GOES-N	Jan-03	35,790 km	No			N/A	N/A	N/A
TWINS	Mar-03					No	No	
Picasso	Apr-03	705 km	Yes	587	5.4	No	No	
VCL	May-03		Yes			No	No	
Coudsat	May-03	705 km	Yes	700		No	No	
Aura	Jun-03	705 km, 98.2 deg	Yes	2967	TBD	**No**	No	Yes*
CINDI	Jul-03					No	No	
ST-5	Dec-03	GTO?	No	10		N/A	N/A	N/A
SWIFT	Dec-03	600 km, 18 deg	Yes	1453	**10.9**	**No**	No	Yes
NOAA-N	Dec-03	830 km	Yes	1475	TBD	No	No	**No**
FAME	Oct-04					No	No	
Stereo	Dec-04	Heliocentric	No			N/A	N/A	N/A
NPP	Oct-05	824 km	Yes	3000		Yes	No	Yes
GLAST	Mar-06	500 km, 28.5 deg	Yes	4460	20	Yes	No	Yes
GPM	Jan-07	400 km, 70 deg	Yes	2000		**?**	No	Yes
NOAA-N'	Mar-08	830 km	Yes	1475	TBD	No	No	**No**
Triana	?	L1 Lagrange	No	490		N/A	N/A	N/A

yes* < 25 yr disposal possible; however, not documented in end-of-life plan

Orbital Debris Assessment
GSFC Challenges

- On-orbit missions not in compliance with guidelines
- Missions in development not in compliance with guidelines
  - Aqua, Aura and SWIFT can not perform controlled reentry without substantial modification/development
  - NOAA-M, NOAA-N and NOAA N’ can not meet 25 year disposal
- Backlog of Missions requiring ODA
  - Some GSFC on-orbit missions have not completed ODA
  - Some development mission ODA behind schedule

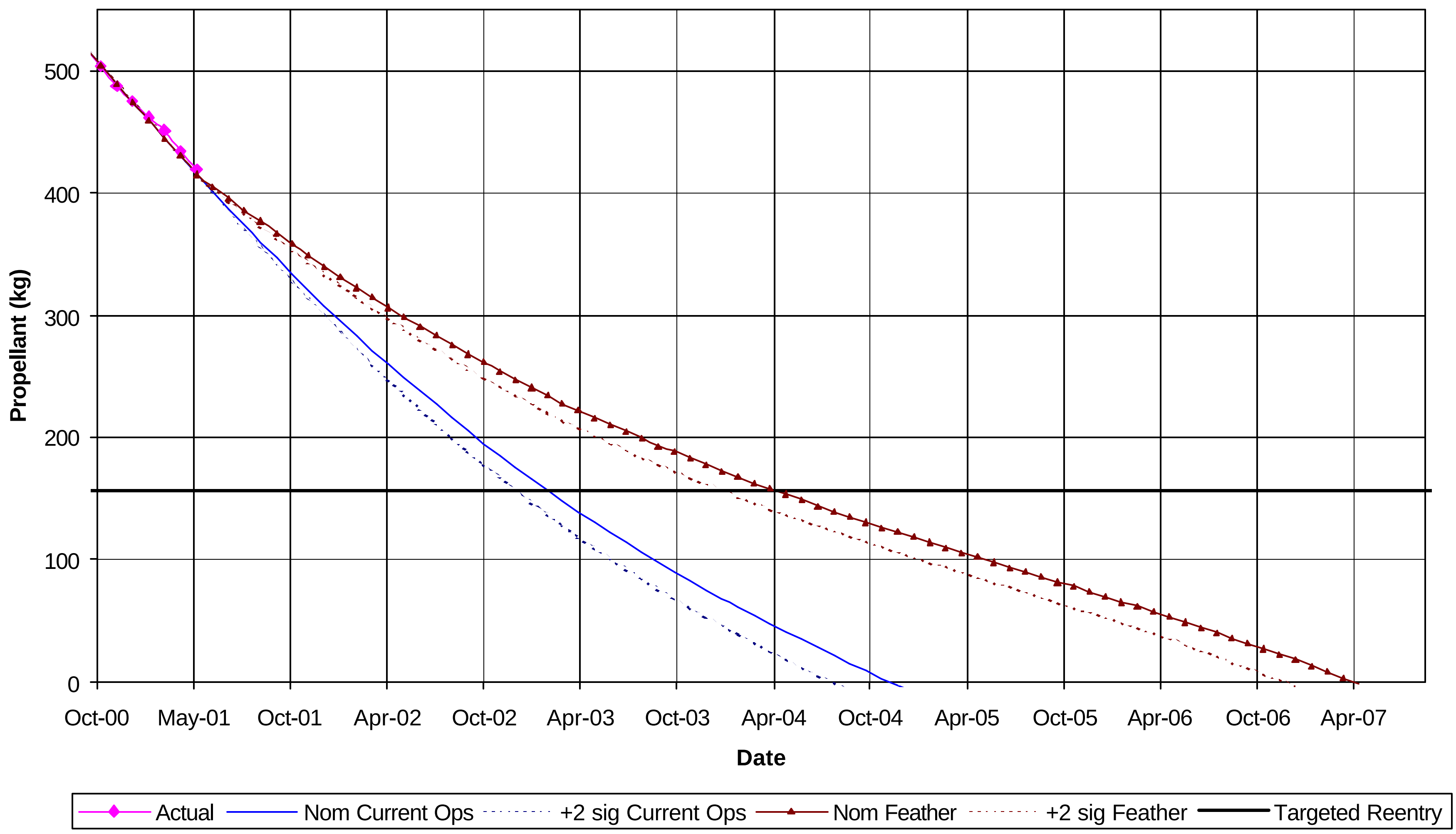
Orbital Debris Assessment
GSFC Challenges (cont.)

- Inconsistency in analysis
  - NASA Safety Standard allows interpretation & subjectivity in analysis
  - Multiple support contractors performing analysis
  - Multiple software analysis packages
- GSFC policy in preparation
  - Triggers for safe disposal / controlled reentry
    - » Is zero fault tolerance for controlled reentry a trigger for controlled reentry (GRO paradigm)?
  - Analysis requirements for on-orbit missions
- Limited GSFC experience
  - GRO controlled reentry was GSFC first experience
  - Limited number of GSFC individuals cognizant of ODA or safe disposal issues

TRMM Status (Cont.)

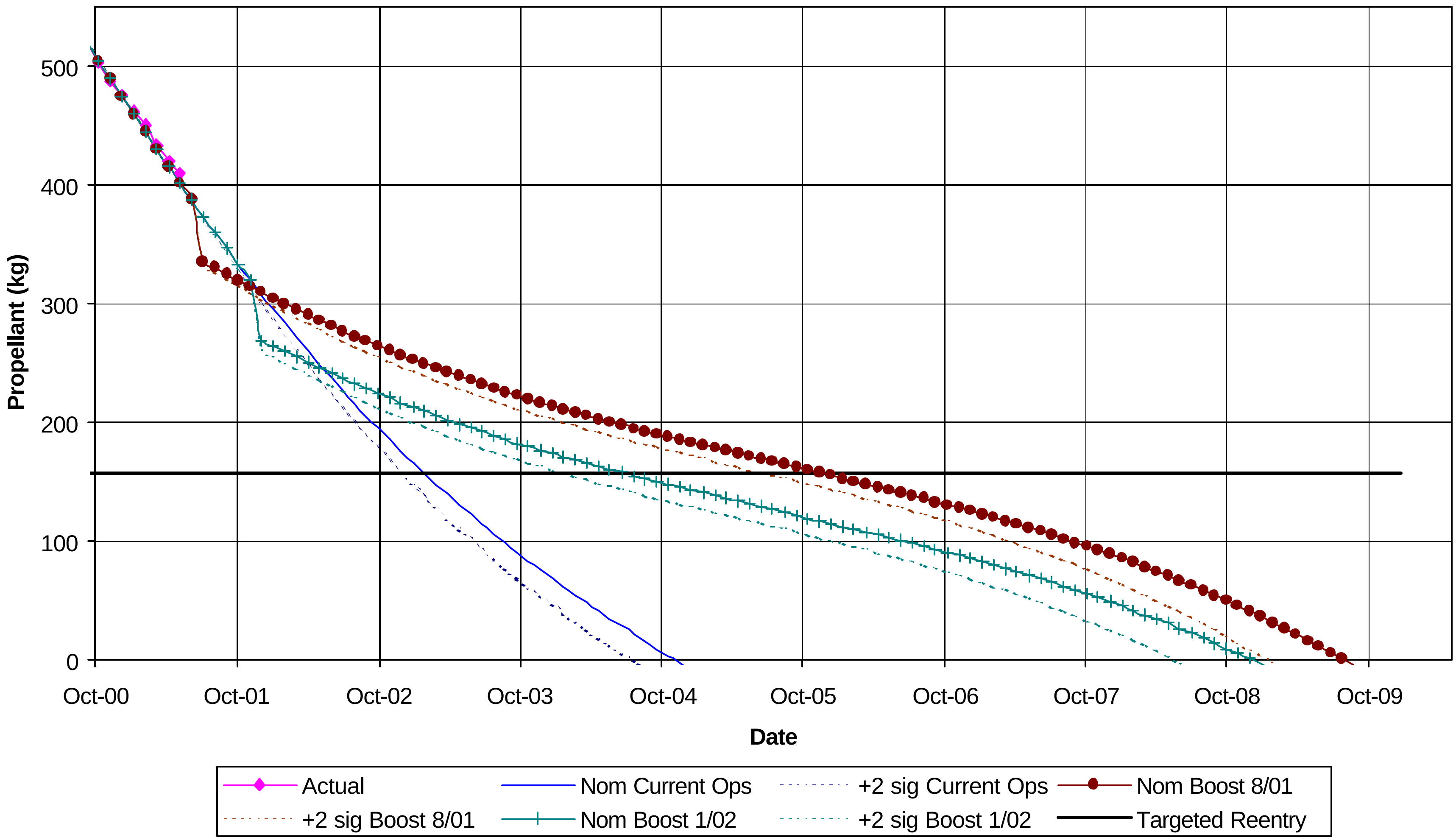
TRMM Mission Life

Nominal, +2 sigma Schatten Predicts



TRMM Mission Life Increase by Boosting to 400 km

Nominal, +2 sigma Schatten Predicts



TRMM Orbital Debris Assessment

Orbit Debris Assessment

- A reentry assessment of TRMM was performed in January 1999 by B.S. Kirk and W.C. Rochelle of Lockheed Martin using the Miniature-Object Reentry Analysis Tool (MORSAT).
- Only 8 components were analyzed for the MORSAT reentry study, and of those 5 survived producing a total debris casualty area of 13.844 m^2 for both targeted and decaying orbits.
- NASA JSC Orbital Debris Program Office was asked to perform an uncontrolled reentry study of the TRMM spacecraft using the Object Reentry Survival Analysis Tool – Version 5.0 to determine feasibility of an uncontrolled reentry option.

ORSAT – Version 5.0

- Heat Conduction
  - Only applicable to spheres and cylinders
  - Allows division of object into layers using nodes. One node represents each layer and a maximum of 50 nodes can be used
  - Enables the modeling of hollow objects
  - Permits layers to be melted away during reentry
- Surface Chemical Heating (Oxidation)
  - Amount of heat transfer to the surface wall of the object can be controlled using a chemical heating efficiency factor, τ
  - τ can range from 0 to 1.0, where τ equal to 0 represents no heating to the surface due to oxidation.
- Emissivity
  - Emissivity is the ratio of thermal energy emitted by an object over the thermal energy emitted by a perfect blackbody
  - Emissivity can range from 0 to 1.0, where an emissivity of 1.0 represents a blackbody and implies that all radiation heat absorbed is also emitted by the object
  - In ORSAT, the emissivity varies based on the material type

ORSAT Model Validation

- Good comparisons made with Sandia Corporation's fuel rod reentry flight measurements taken during the Sandia Reentry Flight Demonstration (RFD) test
  - The fuel rods were tracked using optical instruments during the reentry from a suborbital trajectory.
  - The altitude at which the barium tracer material located in the cylinder core of the fuel rods was exposed was obtained through flight data.
  - ORSAT predicted the barium exposure altitude to within a few kilometers of the actual observed altitude.
- Benchmark calculations of reentering 1 m diameter hollow spheres of varying materials compared well with similar studies by the European Space Agency (ESA) using their Spacecraft Atmospheric Reentry and Aerothermal Reentry and Aerothermal Break-up (SCARAB) code
- Reentry studies performed for Delta second stage for validation
  - Both the titanium sphere and the stainless steel cylinder were predicted to survive
  - Predicted sphere impact point 146.4 km downrange of predicted cylinder impact point; relative distance between Seguin, TX and Georgetown, TX (landing sites of the sphere and cylinder, respectively) is approximately 135 km
- Aeroheating calculations compare within 10% of results of higher fidelity BLIMP boundary layer code and CFD codes.

Orbit Debris Assessment

- The total mass analyzed using ORSAT was 76% of the total spacecraft mass
  - 76% analyzed
  - 6% components less than 0.25 m
  - 1% residual propellant/gas
  - 17% harness, cabling, MLI, paint, plumbing, solar array booms
- 37 different structures, including the “Parent Object”, were evaluated
- Reentry assumed at 122 kilometers with breakup occurring at 78 kilometers
- Parent object modeled as a 2632 kg aluminum box with approximate 5.1 m x 3.5 m x 3.0 m dimensions.
- Initial relative flight path angle assumed to be -.07 degrees and relative velocity set at 7350 m/s based on orbit inclination
- For surviving components, oxidation heating efficiency factor was set to 0.5; components still predicted to survive are assumed to survive

TRMM Model Input

Item (Qnty)	Quantity	Shape	Material	Diam. (m)	Lngth. (m)	Hght. (m)	Thk (m)	Mass (kg)	Object Details from GSFC
PARENT OBJECT	1	Box	Aluminum 6061-T6	5.1	3.5	3	0	2632	
CERES	1	Box	Aluminum 6061-T6	0.58	0.57	0.57	0	46.591	
LIS Electronics	1	Box	Aluminum 6061-T6	0.274	0.222	0.311	0	13.4	
LIS SENSOR	1	Cylinder	Aluminum 6061-T6	0.214	0.369	0	0.003	6.343	LIS sensor has Aluminum housing 0.125 in thick. It contains 0.9 kg of Titanium, 0.5 kg of glass, with the rest Aluminum.
Precipitation Radar	1	Box	Graphite Epoxy Honeycomb	2.3	2.3	0.65		464.9	Most of the structure of the PR is Graphite epoxy honeycomb face sheets 0.012 in thick (density was 0.061 lb/in^3) with aluminum core (density varied from 1.0 lb/ft^3 to 4.0 lb/ft^3).
TMI	1	Cylinder	Aluminum 6061-T6	0.969	0.761	0		54.07	The TMI housing was Aluminum, but the BAPTA is constructed of titanium
VIRS Electronics	1	Box	Aluminum 6061-T6	0.487	0.256	0.255		21.2	
VIRS Scanner	1	Box	Aluminum 6061-T6	0.422	0.97	0.575		30.85	
ACE	1	Box	Aluminum 6061-T6	0.508	0.356	0.324		27.363	
Earth Sensor Assem.	1	Cylinder	Aluminum 6061-T6	0.185	0.343	0	0.00127	4.5	The ESA has an A356-T6 aluminum housing 0.05 in thick.
Engine Valve Driver	1	Box	Aluminum 6061-T6	0.363	0.25	0.2		10.75	
IRU	1	Box	Aluminum 6061-T6	0.35	0.29	0.27		13.56	
Reaction Wheels	4	Cylinder	Titanium / Stainless Steel with Aluminum housing	0.394	0.172	0		10.751	The TRMM wheels have a titanium flywheel (0.358 m dia x 0.018 m length), a stainless steel shaft (0.025 m dia x 0.115 m length), with an Aluminum housing (thickness varies from 0.031 in through 0.385 in, but most of the housing thickness is 0.063 in). Roughly 75% of the mass is titanium, with the rest mostly stainless steel.
Torquer Bars	3	Cylinder	Iron / Cobalt core with Copper windings	0.076	1.1	0		8.1836667	The TRMM torquer bars are cylindrical with a vanadium permendur alloy (2% vanadium, 49% cobalt, 49% iron) core, copper windings and an Aluminum collar. The core has 0.0178 m dia, length of 1.09 m and mass of 2.21 kg. The inner copper winding is #26 wire (0.019" square). The outer copper winding is #25 wire (0.022" square). The copper is wound around the core extending from a radius of 0.00889 m to 0.01702 m. Total mass of the copper windings is 5.4 kg. The Aluminum brackets are 0.6 kg.

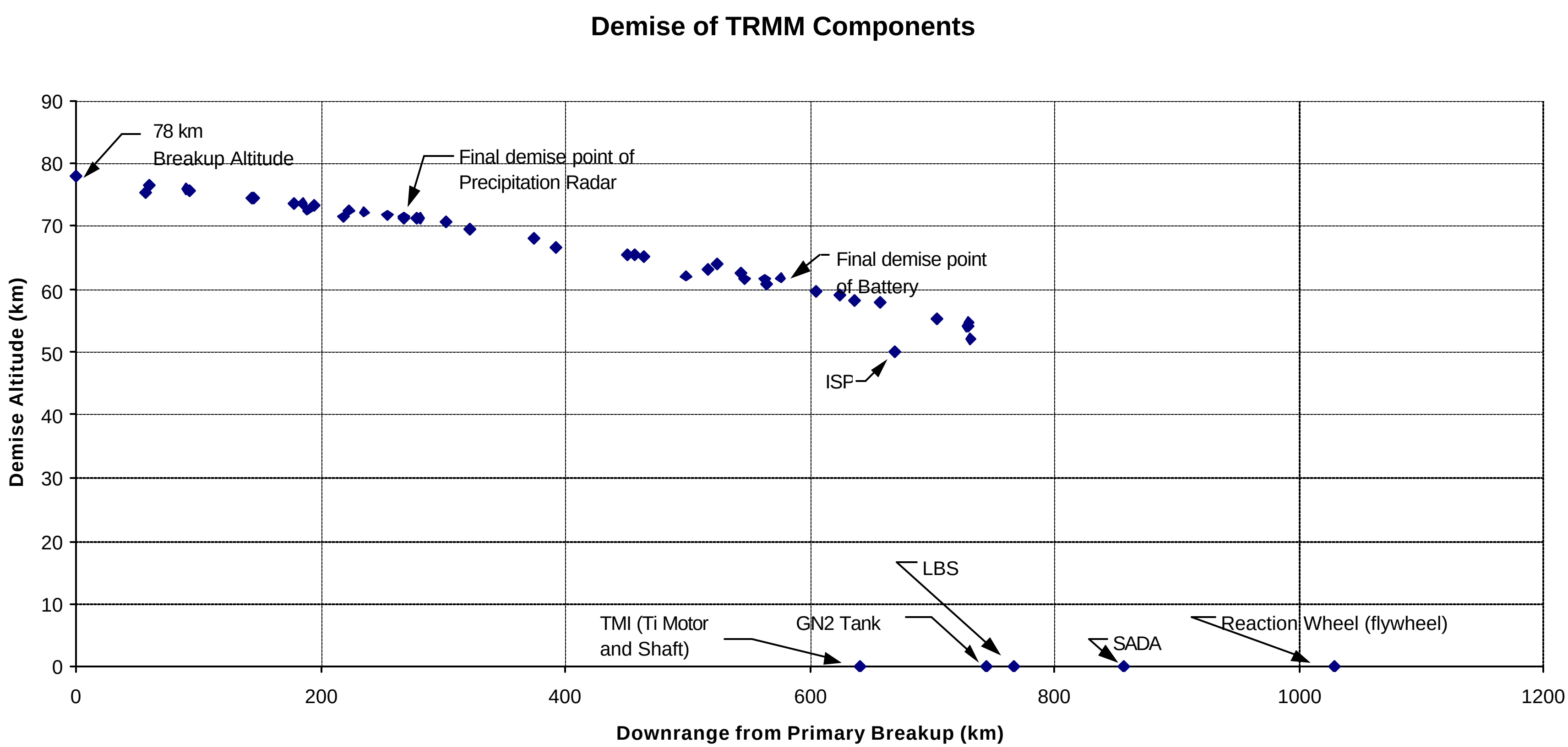
TRMM Model Input (cont.)

Item (Qnty)	Quantity	Shape	Material	Diam. (m)	Lngth. (m)	Hght. (m)	Thk (m)	Mass (kg)	Object Details from GSFC
SDS A	1	Box	Aluminum 6061-T6	0.579	0.343	0.201		37.997	SDS A and SDS B are separate boxes.
SDA B	1	Box	Aluminum 6061-T6	0.579	0.343	0.201		38.211	
High Gain Antenna	1	Cylinder	Aluminum F.S. /Al Honeycomb	1.303	0.25	0		5.9	0.01" thk Aluminum face sheets with 3.1 lb/ft^3 Al honeycomb core
NASA Stnd Transp.	2	Box	Aluminum 6061-T6	0.353	0.162	0.143		6.1305	
IPSDU	1	Box	Aluminum 6061-T6	0.464	0.224	0.215		17.727	
SPSDU	1	Box	Aluminum 6061-T6	0.483	0.224	0.215		21.364	
GSACE	1	Box	Aluminum 6061-T6	0.47	0.262	0.215		16.71	
Battery	2	Box	Nickel / Aluminum	0.494	0.305	0.193		59.8	The battery is ~45% nickel
PBIU	1	Box	Aluminum 6061-T6	0.43	0.309	0.161		18.15	
PSIB	1	Box	Aluminum 6061-T6	0.364	0.267	0.19		12.636	
Stnd Pwr Reg Unit	1	Box	Aluminum 6061-T6	0.706	0.235	0.185		19.09	
GN2 Tank	1	Sphere	Titanium 6Al-4V	0.559	0	0	0.00508	14.04	Wall thickness is 0.2 in.
Main Tank	2	Cylinder	Titanium 6Al-4V	1.016	0.813	0	0.00127	32.28	There are 2 tanks. Wall thickness is 0.05 in.
PCM Module	1	Box	Aluminum 6061-T6	0.78	0.44	0.26		14.16	
Thrusters (1-8)	8	Box	Stainless Steel	0.15	0.165	0.325		1.6445	
Thrusters (9-12)	4	Box	Stainless Steel	0.115	0.165	0.377		1.6125	
SADA	2	Cylinder	Aluminum 6061-T6	0.23	0.406	0		11.175	There are 2 SADAs, mostly made of Aluminum.
Solar Arrays	4	Flat Plate or Box	Aluminum 6061-T6	2.168	2.13	0.02		27.65	
ISP	1	Box	Aluminum 6061-T6	1.522	1.22	0.925		136.773	
LBS	1	Box	Aluminum 6061-T6	1.8	2.442	1.67		416.476	
LISP	1	Box	Aluminum 6061-T6	0.425	0.482	2.092		37.27	
UISP	1	Box	Aluminum 6061-T6	1.238	0.69	1.22		64.91	

Orbit Debris Assessment Results

- 6 objects in analysis were determined to survive, though only 5 contributed to the total debris casualty area (the main tanks were housed within the LBS, which was also determined to survive)
- The 5 surviving objects which contributed to the total debris casualty area are the following:
  - TMI → Debris Casualty Area (x1) = 0.657 m^2
  - Reaction Wheels → Debris Casualty Area (x4) = 1.784 m^2
  - GN2 Tank → Debris Casualty Area (x1) = 1.200 m^2
  - SADA → Debris Casualty Area (x2) = 1.640 m^2
  - LBS → Debris Casualty Area (x1) = 7.067 m^2
- *TOTAL DEBRIS CASUALTY AREA = ~ 12.35 m^2*

TRMM Component Demise Altitude vs. Downrange



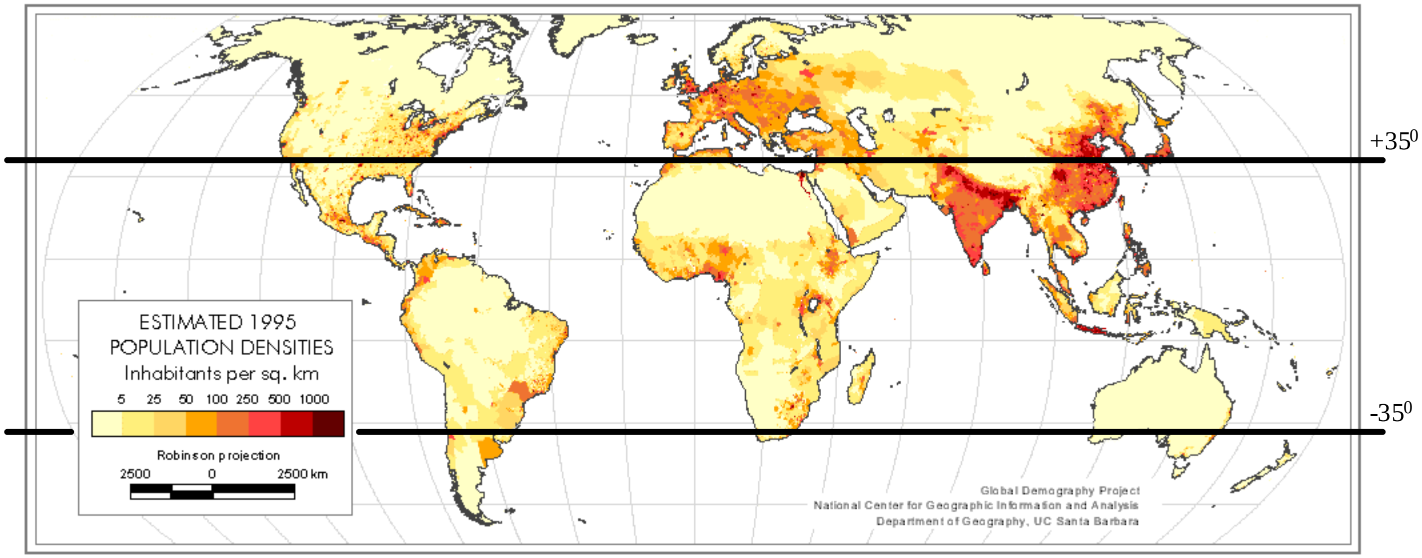
TRMM Reentry Options

TRMM Reentry Options

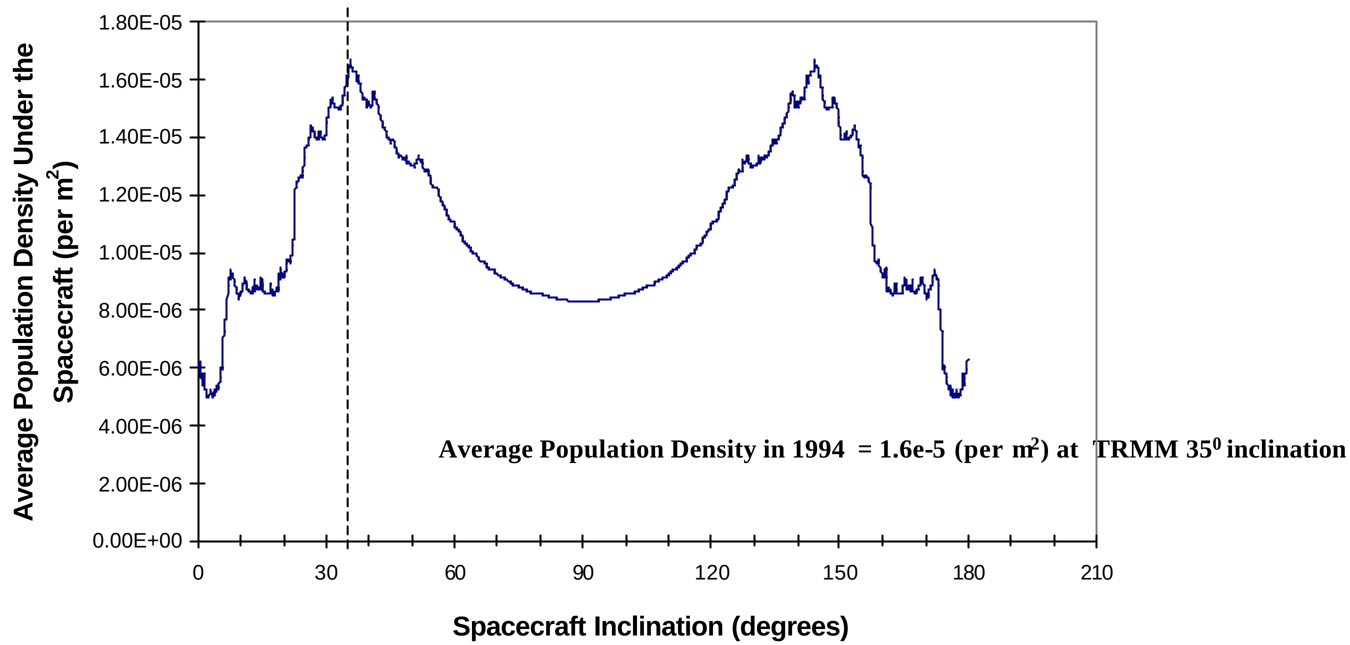
- Uncontrolled Reentry
  - Allow TRMM spacecraft orbit to naturally decay due to atmospheric drag
  - Location of debris footprint is undetermined
- Controlled Reentry
  - Perform spacecraft propulsion burns to precisely target location of debris footprint

Uncontrolled Reentry

- JSC Orbital Debris Program Office ORSAT Debris Casualty Area estimate (4/9/01) for TRMM = 12.3 sq m
- Following guideline, probability of casualty associated with an Uncontrolled Reentry is approximately 0.021% (~2 in 10,000)
- NSS 8719.4 Guideline: Perform Targeted Reentry if Debris Casualty Area is greater than 8 sq m. This corresponded to a probability of casualty greater than 0.01% (1 in 10,000)



Uncontrolled Reentry



- Average population predicted to increase by 11% from 1994 to 2004
- TRMM Uncontrolled Reentry Probability of Casualty in 2004

= 1.6e-5 (per m sq) x 1.11 x 12.3 (sq m)

= 0.021 % **(~2 in 10,000**)

TRMM Targeted Reentry Challenges

- Low available Delta V thrust
  - TRMM propulsion system will enter blowdown at ~220 kg remaining fuel
  - Delta V thruster force will decrease from 3.2 lbf to ~2.6 lbf during Delta V reentry operations
- High aerodynamic torques
  - TRMM ACS can not maintain pointing without thruster operation at altitudes below ~280 km
- No thruster based Earth pointing mode
  - TRMM ACS does not have a on-board ACS mode which will keep the spacecraft Earth pointing under the control of thrusters

TRMM Reentry Independent Analysis

- Aerospace Corporation involved with GRO reentry and other missions
- Aerospace Corporation given study task to perform independent analysis of TRMM reentry
  - Determine disposal concept
  - Determine trajectory design / burn plan
  - Quantify 'skip-out' potential
  - Determine break-up altitude
  - Determine debris footprint sensitivity
- Report received 1/29/2001
- Analysis is consistent with GSFC mission design
- Future work: Aerospace retained to perform end-to-end simulation to independently verify final burn plan and target predictions

TRMM Targeted Reentry Philosophy

- Keep it simple
- Plan must be robust
- Use spacecraft as designed
- Allow for contingencies

TRMM Targeted Reentry Mission Design

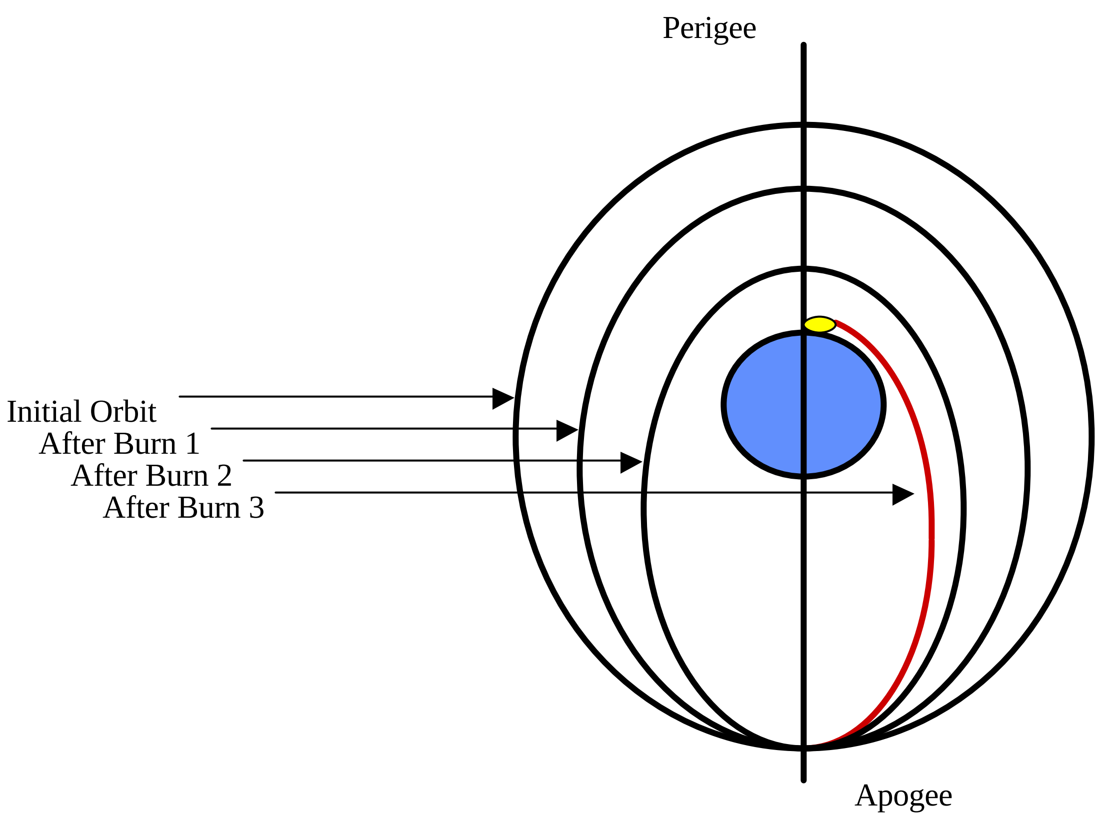
- Sequence of events designed to provide simplest, most robust approach with adequate time provided for contingencies
- Nominal reentry orbit selected to place worst case debris footprint furthest from land and provide a backup reentry opportunity on the following orbit
- Spacecraft used as originally designed and tested

TRMM Reentry Mission Design Factors

- ACS Operational Constraints
- ACS Fuel
- Characterization of Burns prior to Final Burn
- Delta V Pointing Control
- Contingency prior to Final Burn
- Footprint

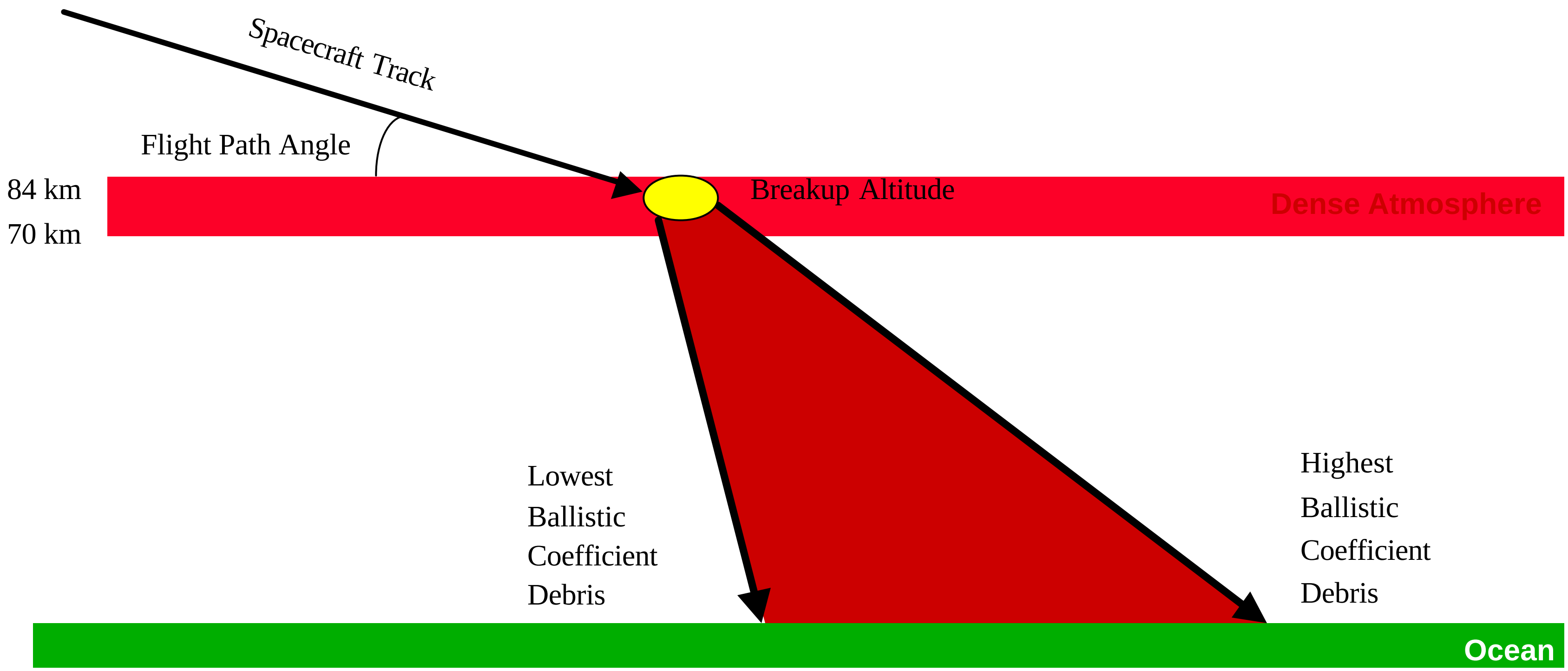
Nominal Maneuver Scenario

Incrementally Drop Perigee Until Spacecraft Hits Dense Atmosphere and Re-enters on Target



Spacecraft Re-entry / Impact Footprint

Spacecraft Hits Atmosphere at a Steep Angle, Dramatically Slows Down, Breaks Up, and Falls into Ocean



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TRMM Targeted Reentry Sequence

- Spacecraft Configuration / Checkout
  - Turn off instruments
  - Configure FDC
  - Configure power system
  - Load software patches
  - Perform Delta H Checkout
  - Transition to omni antennas
  - Minimize drag
    - Feather solar arrays
    - Feather HGA
    - Spacecraft projected area = 9.4 sq m
  - Orbit lifetime 6 months

TRMM Targeted Reentry Sequence (cont.)

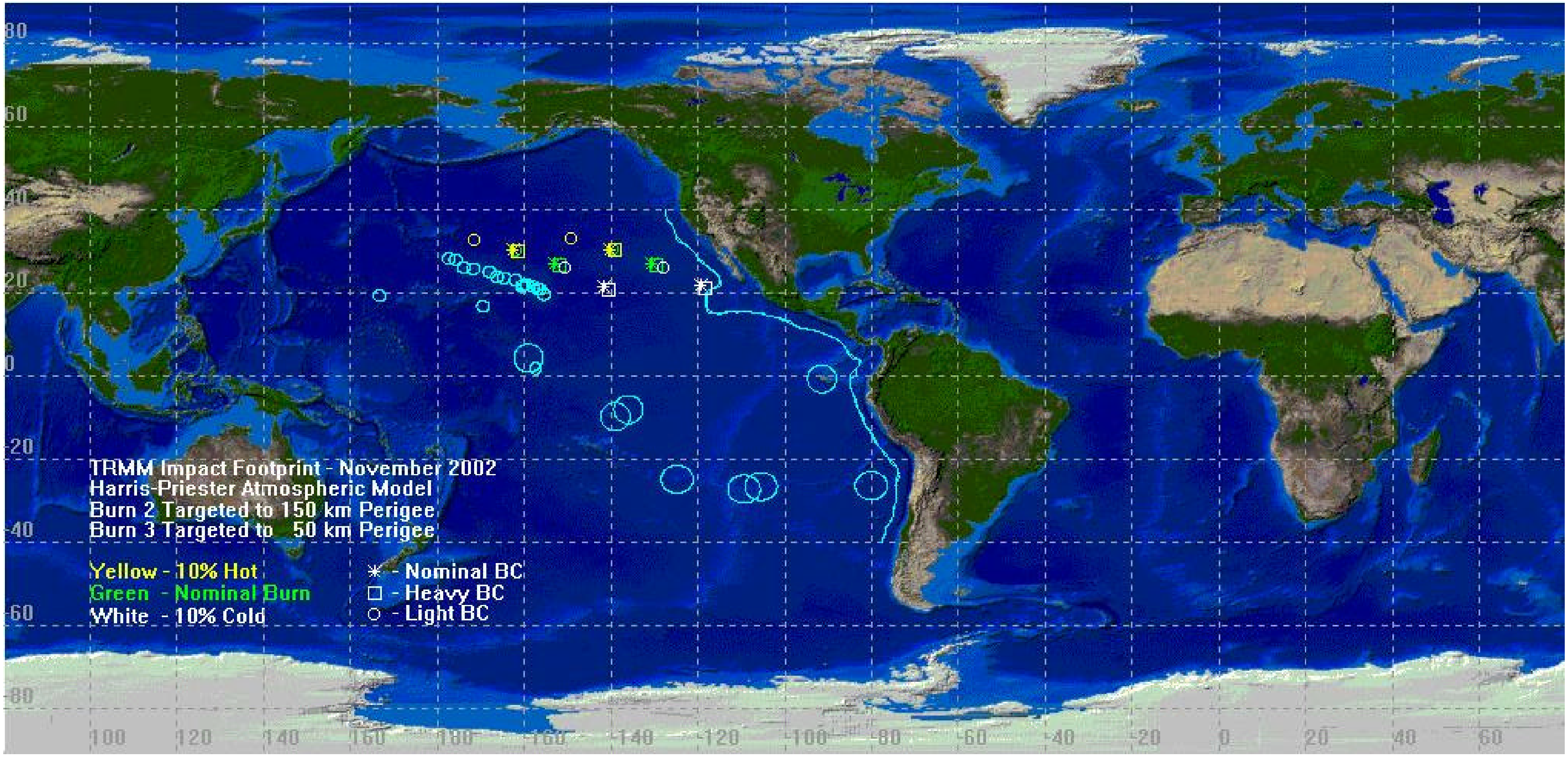
- Perform Burn 1
  - Lower perigee from 350 km to 250 km
  - Perform Delta H centered at perigee as required
  - Perform Orbit Determination
  - Prior to Burn 2, configure FDC
  - Orbit lifetime 45 days
- Perform Burn 2
  - Approximately 24 hours later, perform Burn 2 to lower perigee from 250 km to 150 km
  - Perform Delta H at perigee
  - Orbit lifetime 3 days
- Perform Burn 3
  - Next orbit, perform Burn 3 to reenter

TRMM Targeted Reentry Propellant Budget

TRMM Reentry Fuel Budget - Nominal Mission design

	Fuel Required Estimate (kg)	Reserve (Percentage)	Reserve (kg)	Estimate with Reserve (kg)
Burn 1 (350km to 250km)	36.1	5%	1.81	37.91
Burn 2 (250km to 150km)	38.3	3%	1.15	39.45
Burn 3 (150km to reentry)	39	5%	1.95	40.95
Attitude Control	10.00	15%	1.50	11.50
Unusable (tank & lines)	13.00	5%	0.65	13.65
Totals	136.4		7.05	143.45
Total Resource (kg)	**157**	-8%	-12.00	145.00
Margin (kg)	20.6			1.54
Margin (resource - requirement)/requirement	15%			1%

TRMM Impact Footprint

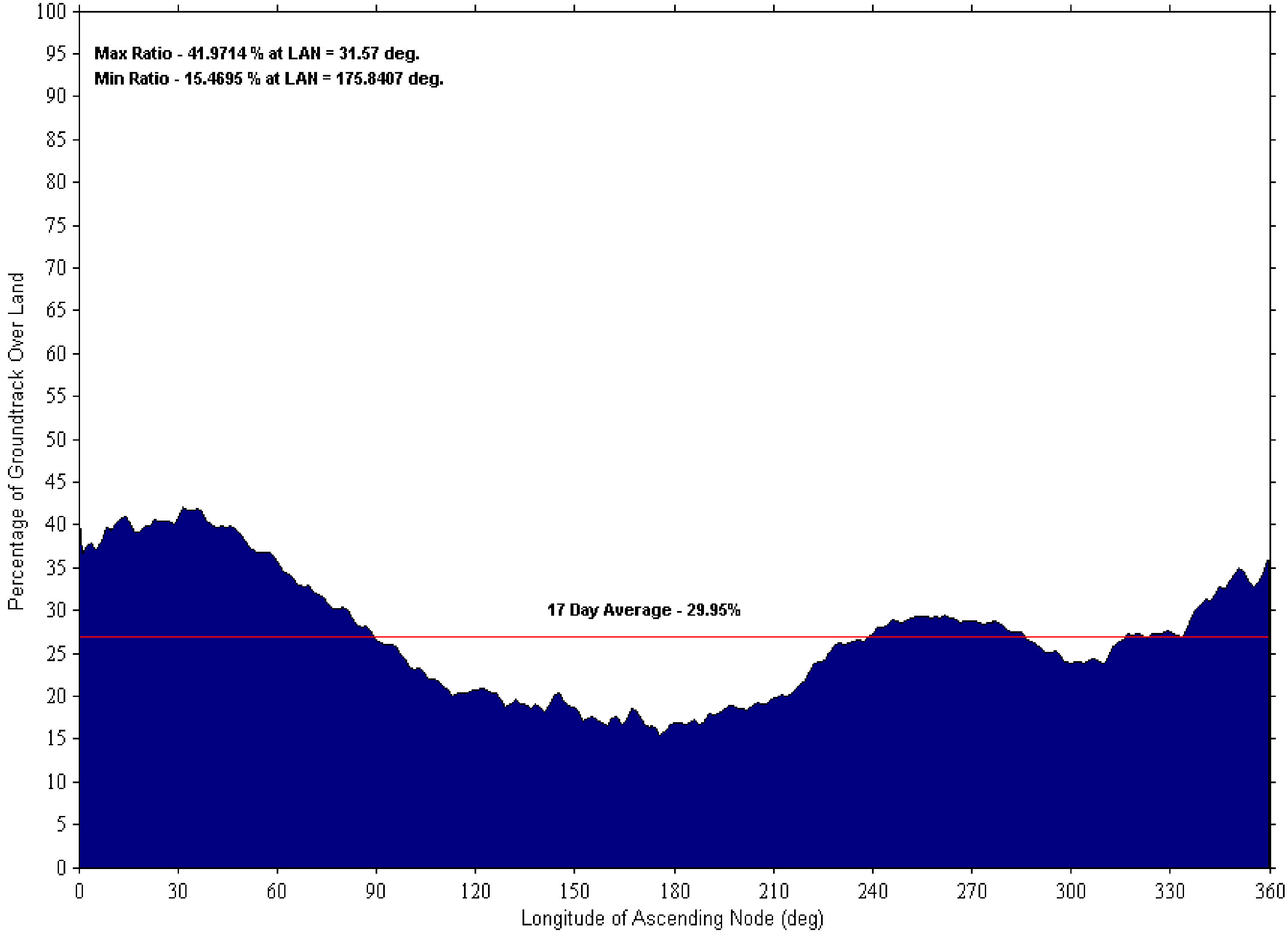


In Summary…

- TRMM Debris Analysis shows $12m^2$ (2 in 10,000) vs. $8m^2$ (1 in 10,000) limit requiring TRMM to perform a controlled reentry and limiting the current mission to the first quarter of CY 2003.
- Shortened TRMM mission is not desired since TRMM provides important data for scientific analysis and "Real Time" severe weather predictions. It is estimated that 240 lives per year are saved through the use of TRMM data in tropical cyclone forecasts.
- The TRMM spacecraft is healthy and can currently support an extended mission and provide for a controlled reentry.
- A "Controlled Reentry Plan" is in process
- An option to raise the orbit altitude to 400km is under review and extends the mission significantly

Backup Charts

TRMM Land Mass Coverage vs. Initial Longitude of Ascending Node 3 Orbit Average Over 17 Days



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