New Millennium Program (NMP) Earth Observing – 1 (EO-1) Orbital Debris Assessment

December 1999

NASA/GSFC

SIGNATURE PAGE

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Scope

This report documents the compliance of the Earth Observing –1 (EO-1) satellite with the requirements of NASA Safety Standard 1740.14, 'Guidelines and Assessment Procedures for Limiting Orbital Debris.' EO-1 is co-manifested with the Argentine satellite, SAC-C, and two other payloads, and launched on a Delta 7320. The debris assessments for SAC-C and the two other payloads are not included here and are the responsibility of their respective program offices. The Delta Dual Payload Attach Fitting (DPAF) and the second stage assessments will be included, based on data provided by the Kennedy Space Center Expendable Launch Vehicle Office. Data provided by KSC was obtained from the following sources:

EO-1/SAC-C DTO, Doc. # A3-L230-M-99-089
Boeing memorandum #A3-L262-LEPO-98-036, Dated 10 February 1998, from D. M. Yano/H012-C204 to R.W. Pudil/H012-C207, Titled "Reentry Analysis Of Delta Second Stage".
E-mail from Boeing, Mission Integration – Delta Programs, Dated July 31, 1999, Subject: Standard DPAF

1 EO-1 Program Background and Program Management

1.1 Project Objectives

The Earth Observing-1 Mission is the first of the New Millennium Program Earth Observing missions. This spacecraft, managed by the Goddard Space Flight Center, will validate revolutionary technologies contributing to the reduction in cost and increased capabilities of future land imaging missions. Three revolutionary land imaging instruments, the Advanced Land Imager (ALI), the Atmospheric Corrector (AC) and the Hyperion on EO-1 will collect multi-spectral and hyperspectral scenes over the course of its one year mission in coordination with the Enhanced Thematic Mapper Plus (ETM+) on LANDSAT 7.

Breakthrough technologies in lightweight materials, high performance integrated detector arrays and precision spectrometers will be demonstrated in these instruments. The EO-1 mission will provide for the on-orbit validation of several spacecraft technologies to enable this transition. Key technology advances in communications, power systems, propulsion systems, thermal technology and data storage are also included on the EO-1 Purpose

1.2 Mission Description

The planned orbit of the EO-1 spacecraft is associated with that of Landsat 7. The Landsat 7 orbit has an altitude of 705 km at an inclination of 98.2 degrees. It is sun-synchronous with a nominal equatorial crossing of 10 AM. The EO-1 spacecraft will fly in a sun-synchronous orbit at the same altitude but approximately 1-minute behind Landsat 7. To achieve the desired orbit, EO-1 will be launched from the United States Air Force Western Test Range aboard a Delta 7320 launch vehicle. The mass for the EO-1 satellite is 588 kg, which includes some contingency.

The duration of the mission is 12 months, which includes sufficient time to complete technology and science validation objectives. Beyond this period, the mission would enter extended operations depending on funding and the health of the spacecraft and instruments. The hardware must meet a one-year life requirement and the spacecraft is required to provide at least 18 months of expendables and propellant for deorbit.

Following EO-1 deployment, the DPAF will separate, and the separable portion will remain in an orbit of 704.316 km x 686.760 km. The Delta II will then perform several maneuvers to insert the SAC-C and the first secondary payload into their respective orbits. Finally, the Delta II second stage will perform a depletion burn, followed by the deployment of MUNIN, the last payload. Following the depletion burn and MUNIN separation, the Delta II second stage will be left in a 1700 km x 705.816 km orbit.

1.3 Project Schedule

The launch of EO-1 is scheduled for December 15, 1999. The Preliminary Design Review was held in December 1996, and was referred to as the "Design Convergence Review". The Critical Design Review occurred in June 1997.

1.4 Project Management

The EO-1 project manager is Mr. Dale Schulz at the Goddard Space Flight Center.

2 EO-1 Mission Design and Operation Factors

2.1 EO-1 Spacecraft Hardware

The spacecraft primary structure is of all aluminum construction, in the shape of a hexagonal right prism, with dimensions of 1.25m across flats, and 0.73 m high. The top and bottom decks (zenith and nadir) are machined aluminum skin/rib plates, with a skin thickness of 2.03mm. The six sides of the spacecraft are 25.4mm thick honeycomb plates, with .508mm thick facesheets, and 4.76mm cell size core. All the spacecraft electronics boxes are mounted to the inside surfaces of these plates, which also serve as radiators. See Figure 1 below for clarification. The EO-1 website (http://eo1.gsfc.nasa.gov) can be accessed for additional information and views of the satellite.

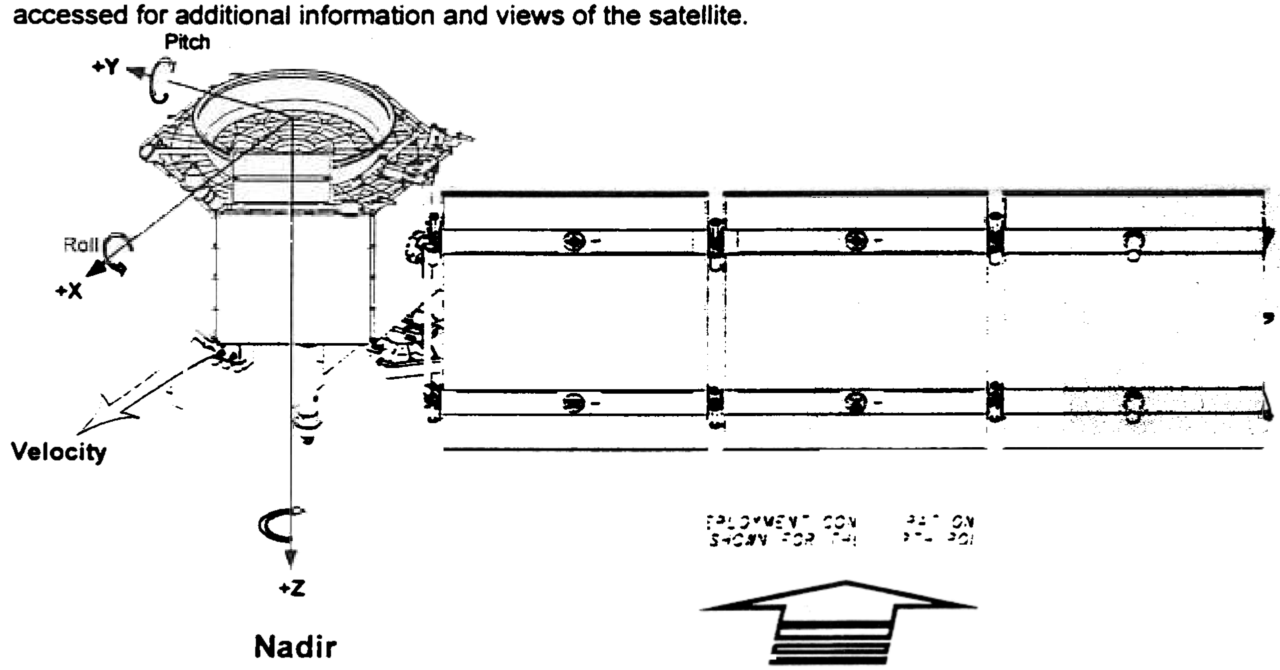


Figure 1 EO-1 Deployed Spacecraft With Solar Array in North Pole Orientation

The critical spacecraft control items are the Attitude Control and Data System (ACDS) box, the Power System Electronics (PSE) box, the Battery, the Battery Electronic Control Unit (ECU), the S-band Transponder, the Inertial Reference Unit, and the Propulsion tank and lines. The star tracker, which is mounted to the exterior of one of the equipment panels, is not include in the above list since it is not critical for maintaining attitude control for disposal purposes. The propulsion tank is a PSI-80389-1 Titanium tank, mounted to the Zenith deck, and located in the center of the spacecraft. A 19.3cm diameter area of the tank is exposed directly to space through a hole in the Zenith deck; the tank is recessed and the hole is covered with MLI. This pressurized Hydrazine tank contains a rubber diaphragm and uses Nitrogen as a pressurant. Fuel is transported to the four Zenith mounted thrusters through fuel lines on the interior of the Zenith deck. Three momentum wheels are onboard, and are mounted to the interior of the Zenith Deck near the Solar Array mounting panel. There are no range safety systems on board the spacecraft. Attached to the Nadir deck are the ALI, Hyperion, and AC instruments. These are not critical to the operation of the spacecraft, but are large masses that are considered for impact area.

2.2 EO-1 Mission Parameters

The spacecraft will be launched on December 15, 1999 into a 98.2 degree inclination, circular sun-synchronous orbit at 705 km, with a descending nodal crossing time of 10:01 a.m. The Delta 7320 with the 10-foot fairing is the EO-1 launch vehicle. EO-1 is co-manifested with SAC-C (Argentina), which will be mounted below EO-1 inside a Dual Payload Attach Fitting (DPAF) that surrounds the SAC-C satellite.

Spacecraft attitude during the mission will primarily be as shown in Figure 1, with the solar array rotating about the Pitch axis to follow the sun. Occasionally, the spacecraft will slew to point the +Z axis at the Sun, Moon, or Deep Space for calibration purposes. This will mostly be a pitch maneuver so as to maintain sun on the solar array.

3 Assessment of Debris Generation During Normal Operations

EO-1 Observatory operation scenarios preclude debris generation during any phase of operations. This includes staging, payload separation, payload deployment, and mission operations. EO-1 uses High Output Paraffin Actuators (HOPS) instead of pyrotechnic devices, since they result in lower shock loads, and do not generate debris.

Following EO-1's deployment from the second-stage/DPAF, the DPAF upper portion will separate from the second stage to allow for SAC-C to deploy. This separation produces one piece of debris, which is approximately a cylinder measuring 2.8 m in diameter, 2.68 m long, and having a mass of 185.77 kg. Using data provided by the ELV office at KSC, and the DAS program menu 3.1.2, the de-orbit time was calculated, and is shown in Figure 2.

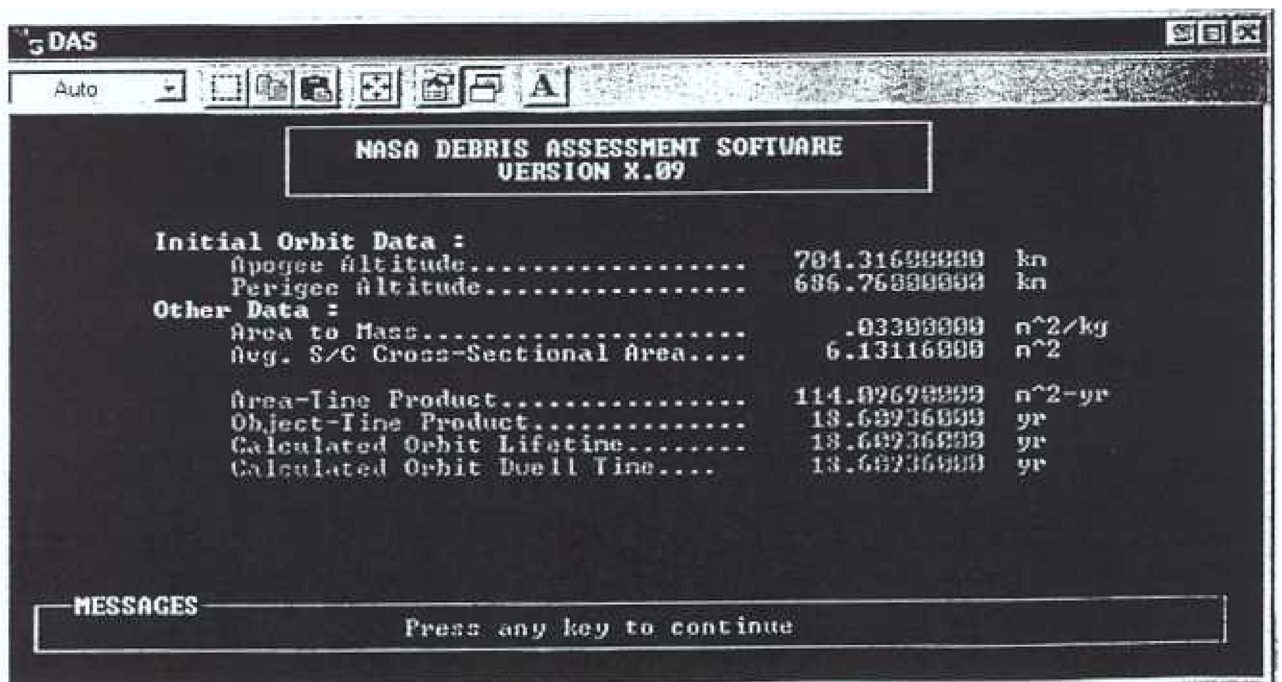


Figure 2 DAS Calculation of DPAF Orbit Lifetime

This result shows that the DPAF will de-orbit in less than 25 years. For the area calculation shown above, the area of the end of the cylinder was chosen since it provides a more conservative orbit lifetime estimate.

Following the deployment of the DPAF upper section, SAC-C and the two other payloads will deploy from the Delta second stage. The EO-1 program has no knowledge of any debris that may be generated by any of these other structures during these or any other operations.

4 Assessment of Debris Generated by Explosions and Intentional Breakups

4.1 Accidental Explosions

Accidental explosion of any EO-1 components during flight is highly unlikely. Three items were considered in this analysis: batteries, propulsion, and reaction wheels. A formal FMEA analysis has not been performed on this program since it is a single string design, and therefore no quantitative numbers are available.

The NiCad Battery is the same basic design, which has been used for the past 35 years: this particular battery is identical to the unit that is currently on orbit in the TRMM spacecraft. With increased lifetime it is possible for over heating and venting of gas to occur from an individual cell. This will result in degradation to the battery, but not in the release of debris or damage to other structures. Given the short duration of the EO-1 mission, 12 months, and the use of an oversized battery that will not be overly stressed during the mission, we are confident that the risk of accidental explosion of the battery has been successfully mitigated.

The propulsion tank, PSI model 80389-1, has been designed to leak before burst. Following mission completion, EO-1 will be de-orbited until all fuel is expended, thus eliminating all on-board fuel. A small amount of pressurant will remain in the tank at 70 psi, and cannot be vented.

The reaction wheels are Ithaco Type A's, and have a MTBF of 2 million hours. It has been shown through analysis that the wheel housing will contain the wheel, should a catastrophic failure of a wheel occur. This analysis was performed for the Bremsat mission, which was launched from the Space Shuttle. In addition, drive motor back EMF limits the wheel speed to less than the rated speed. The wheel has been analyzed at the rated speed and shown to have a positive margin with a safety factor of 2. Following de-orbit, the wheels will be de-spun to remove all kinetic energy.

Accidental explosion of the DPAF is not possible since it does not contain any fuel or pressure vessels.

The Delta second stage will be passivated using a depletion burn, as is standard practice. All pressurants will be depleted as part of this burn. The batteries will be passivated by default since they are not rechargeable, and have a very short life.

Intentional Breakups

EO-1 Observatory operations scenarios preclude intentional breakups, as do Delta II operations, thus debris generation due to intentional breakups does not apply.

5 Assessment of Debris Generated by On-Orbit Collision

Assessment of Collisions with Large Objects During Mission Operations

The probability of an EO-1 collision with large objects is less than 0.00003, as calculated by the Debris Orbit Assessment (DAS) Program, version X.09, shown in Figure 3. This probability of failure meets the guideline specified in document 1740.14 of being less than 0.001. The average cross sectional area was calculated by env ping the components in eac iew in o gest possible area, which provides the ost conservative analysis.

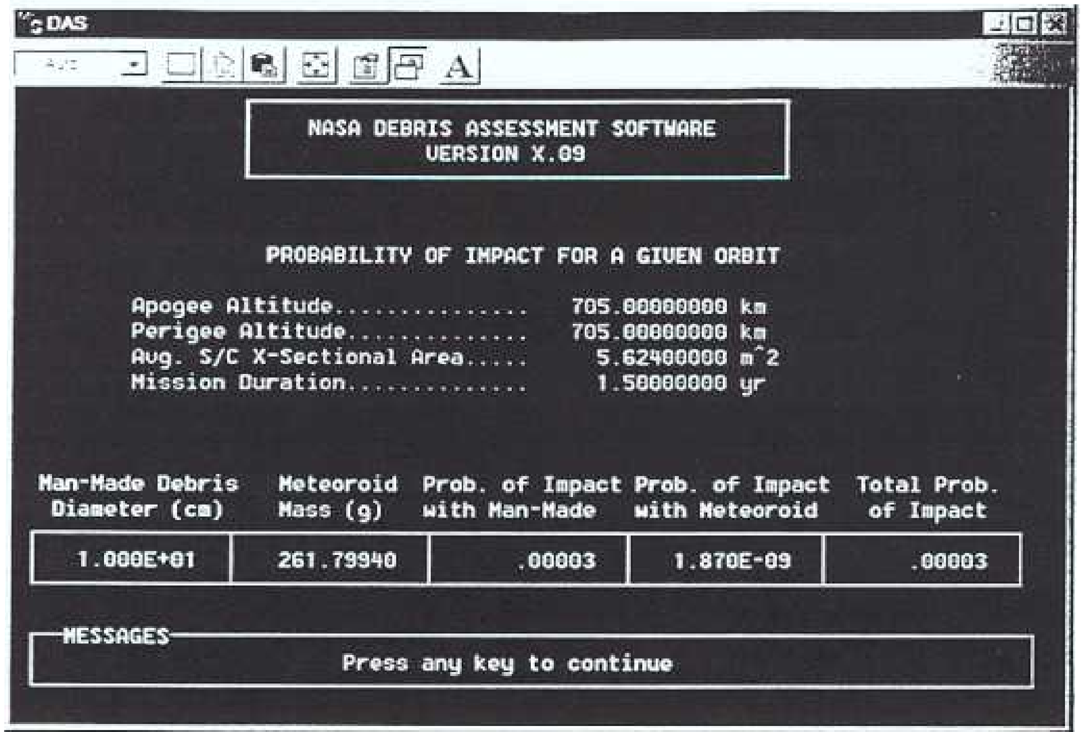


Figure 3 DAS Probability of EO-1 Collision With Large Debris for a Given Orbit

For the DPAF this calculation was repeated, as shown in Figure 4 below, with the probability of collision with large debris being an acceptable 2.222E-8 during mission operations. The area used was the largest cross-sectional area, which is a side view of the cylinder.

Figure 4 DAS Probability of DPAF Collision With Large Debris for a Given Orbit

For the Delta second stage, this calculation was repeated, as shown in Figure 5 below, with the probability of collision with large debris being an acceptable 3.945E-8 during mission operations. The area used was the largest cross-sectional area, which is a side view of the cylinder.

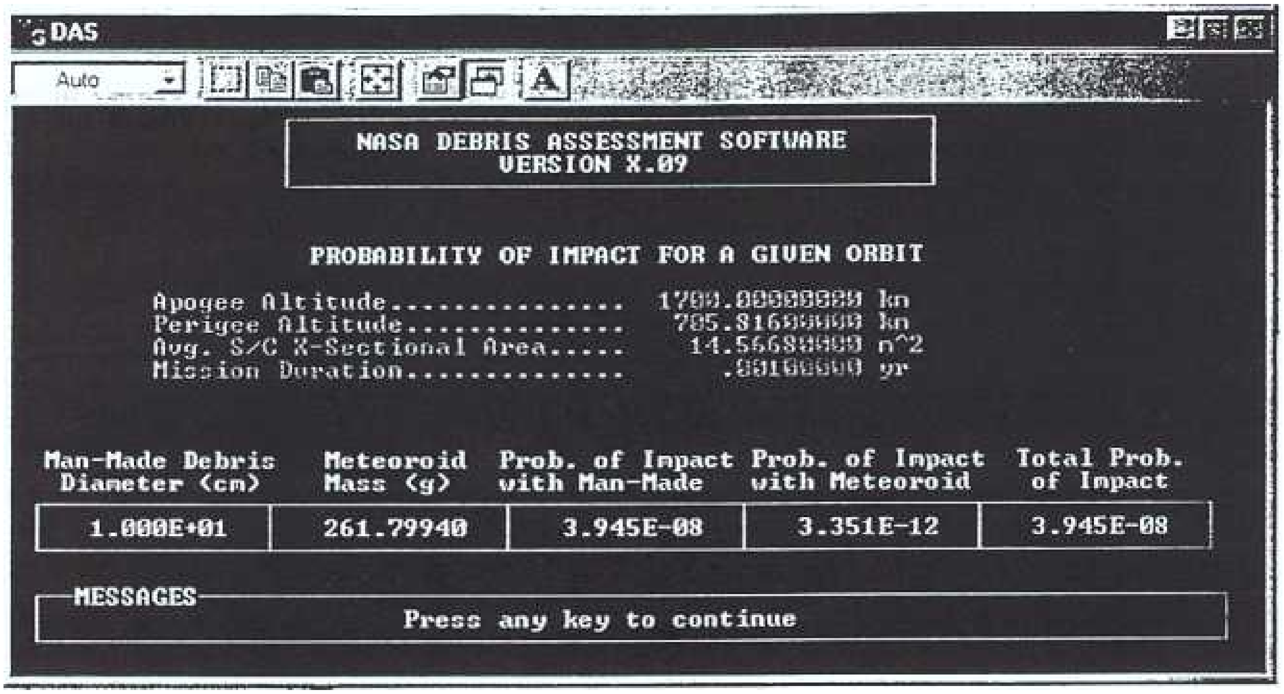


Figure 5. DAS Probability of Delta Second Stage Collision With Large Debris for a Given Orbit

5.2 Assessment of Collisions with Small Debris During Mission Operations

The DAS Program was initially used for this failure probability calculation, but was found to not contain the proper material. Instead, the "Guideline 5-2" methodology described in the document "NASA Safety Standard 1740.14" was used. The details of this calculation are provided Figure 6 below. Several points need to be made about the calculations contained in the figure. First, the "Debris Diameter" was calculated by multiplying the "Shield Den(sity)" by a "K" value of 0.35, which corresponds to a Whipple shield. This is justified since all boxes are internal to the spacecraft, and are thus protected by honeycomb panels.

	X (in)	Y (in)	Area (cm^2)	Shield Den. (g/cm^2)	Debris Dia (cm)	Area Flx Man (#/m^2/yr)	Area Flx Met (#/m^2/yr)	Life yr	Lman Factor	Lmet Factor	Num. Of Failures
ACDS	11	16	1135.2	0.62059	0.2172065	0.0018	0.00037	1	3	1	0.00066
PSE	11	16	1135.2	0.62059	0.2172065	0.0018	0.00037	1	3	2	0.00070
Sband	7	4.3	194.15	0.62059	0.2172065	0.0018	0.00037	1	0.02	0.2	0.00000
SIRU	12	4	309.6	0.44444	0.155554	0.0046	0.0014	1	3	2	0.00051
Battery	12	19	1470.6	0.62059	0.2172065	0.0018	0.00037	1	3	2	0.00090
Battery ECU	4.8	7.3	241.49	0.62059	0.2172065	0.0018	0.00037	1	3	2	0.00015
Porpellant Tank. Zen. Hole	1.3	radi	55.653	0.456	0.1596	0.0046	0.00128	1	0.01	2	0.00002
Propellant Tank Zen. Deck	7.7	radi	1132.6	0.64353	0.2252355	0.00044	0.00012	1	0.01	2	0.00003
Propellant Lines	0.4	30	193.5	0.43089	0.1508115	0.0049	0.0016	1	0.01	2	0.00006

Total Number of Failures 0.0030 Probability of Failure 0.0030

Figure 6. Calculation of Probability of EO-1 Failure Due to Small Debris, During Mission Operations

The propellant tank is calculated on two lines since most of the tank is protected, but there is a small hole on the zenith deck mounting surface, which is only covered by MLI. This hole is 19.3cm in diameter, but due to the geometry of the tank relative to the hole, this diameter is effectively smaller. The hole is located 0.17 meters from the tank, and thus a meteoroid coming in through the hole at an angle of greater than 45 degrees from the zenith will totally miss the tank. That reduces the potential meteor origin to roughly only 30 percent of the total solid angle of the hemisphere. In other words, less than 30% of the meteors that penetrate the hole will strike the tank - that corresponds to about a factor of 2 smaller effective hole diameter. In addition, the MLI covering the hole provides shielding equivalent to 0.456 grams/cm^2, with a "K" of 0.35. The Orbital Debris Program Office at JSC provided these numbers.

The result of the calculation is that there is a probability of failure during the nominal 1-year mission life of 0.003. This probability of failure meets the guideline specified in document 1740.14 of being less than 0.01. This analysis assumes that any box penetration causes a failure of that box; since not all penetrations will cause loss of control of the spacecraft (not all functions are critical) there is an inherent conservatism in these calculations.

The DPAF was not assessed under this guideline since there are no controls required for re-entry.

A conservative assessment of the Delta second stage probability of failure due to small debris was performed, as shown in the following two figures. The probability of impact with a 0.5 mm debris object is 0.0042, which is well less than the guideline of 0.01 or less. Due to the lack of information on the Delta system, this analysis was performed assuming that the total second stage area was critical, and that particles less than one half of a millimeter were critical. In addition, it was assumed that the second stage was traveling sideways, thus presenting the largest surface area possible in the velocity direction. Due to the limitations of the DAS program, the time period used is five times longer than the time required to complete the depletion burn of the stage, thus adding additional conservatism.

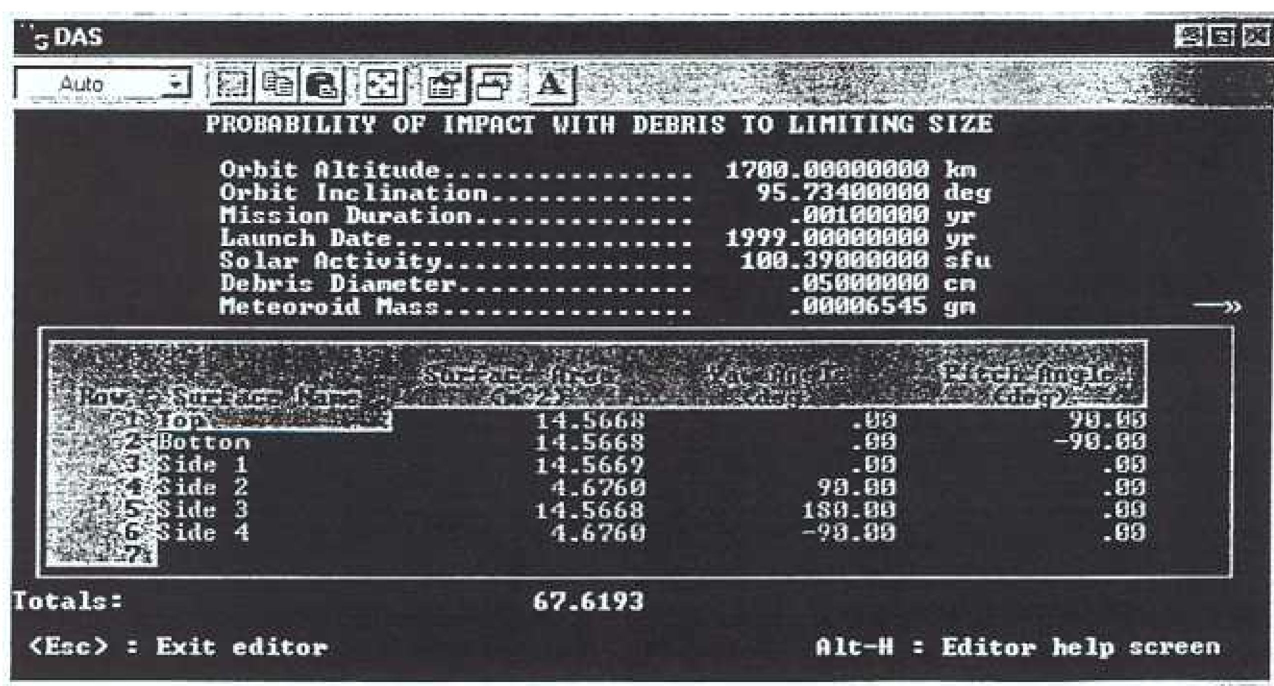
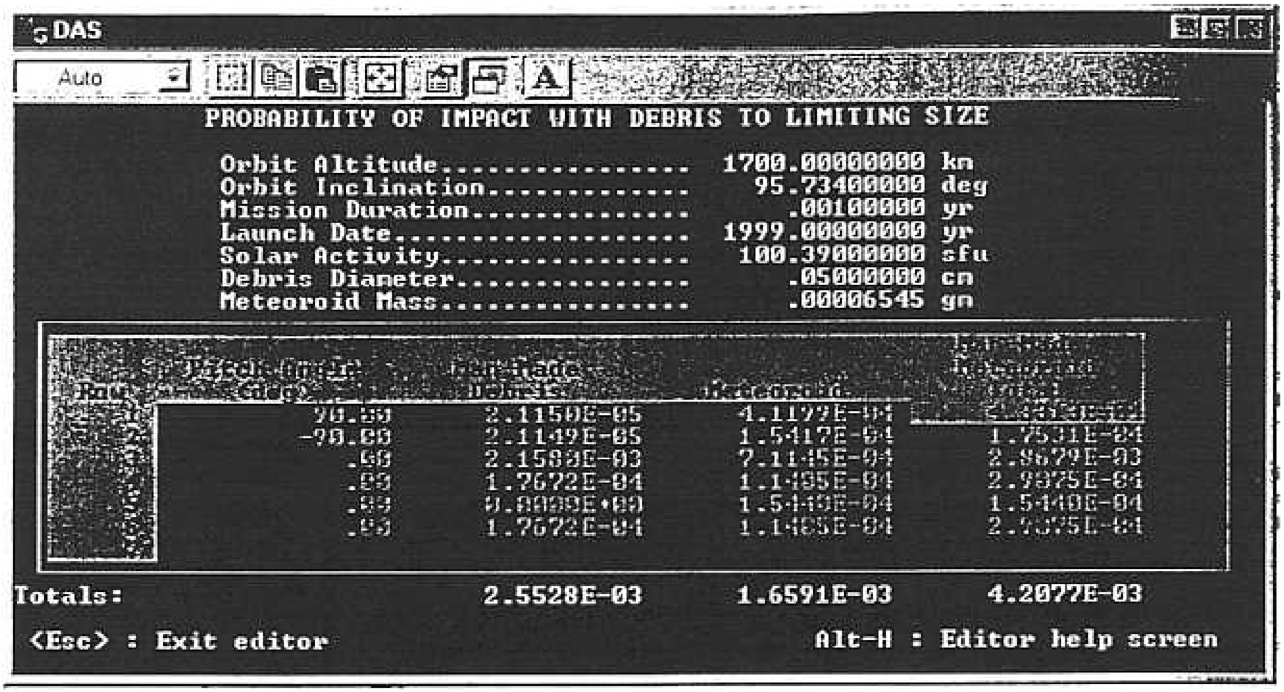


Figure 7. DAS Calculation of Probability of Delta Second Stage Failure Due to Small Debris, During Mission Operations (Part A)



DAS

PROBABILITY OF IMPACT WITH DEBRIS TO LIMITING SIZE

Orbit Altitude.................	1700.00000000	km
Orbit Inclination.............	95.73400000	deg
Mission Duration..............	.00100000	yr
Launch Date...................	1999.00000000	yr
Solar Activity................	100.39000000	sfu
Debris Diameter...............	.05000000	cm
Meteoroid Mass................	.00006545	gm

[illegible]	Debris	Meteoroid	[illegible]
90.00	2.1150E-05	4.1179E-04	[illegible]
-90.00	2.1149E-05	1.5417E-04	1.7531E-04
.00	2.1580E-03	7.1145E-04	2.8679E-03
.00	1.7672E-04	1.1405E-04	2.9075E-04
.00	0.0000E+00	1.5440E-04	1.5440E-04
.00	1.7672E-04	1.1405E-04	2.9075E-04
Totals:	2.5528E-03	1.6591E-03	4.2077E-03

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Figure 8 DAS Calculation of Probability of Delta Second Stage Failure Due to Small Debris, During Mission Operations (Part B)

6 Assessment of Postmission Disposal Procedures and Systems

6.1 Description of Postmission Disposal Option and Disposal System

The EO-1 program has chosen to dispose of the spacecraft through atmospheric reentry within 25 years by transferring to a reentry orbit. Area to mass was calculated using three orthogonal cross-sectional areas calculated from the Pro-Engineer model of the spacecraft with the solar array deployed. The results of the area calculation for each view are presented in Figures 9, 10, and 11, with Figure 9 showing Amax, and Figures 10 and 11 showing the other two orthogonal views.

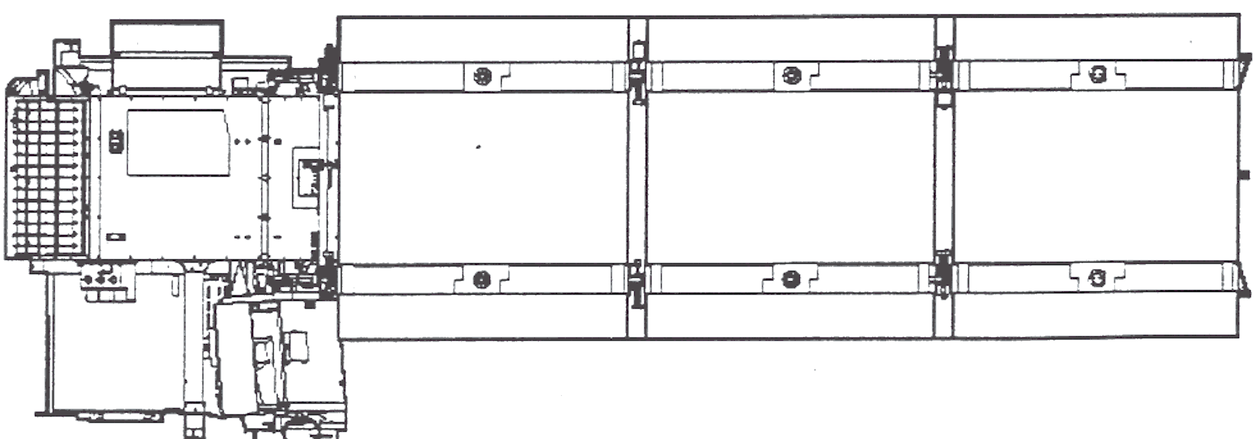
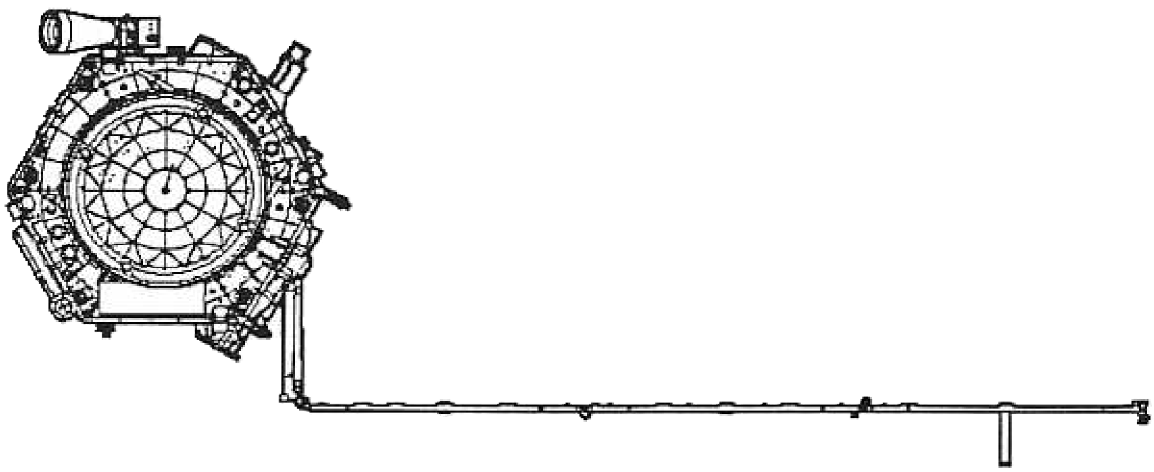
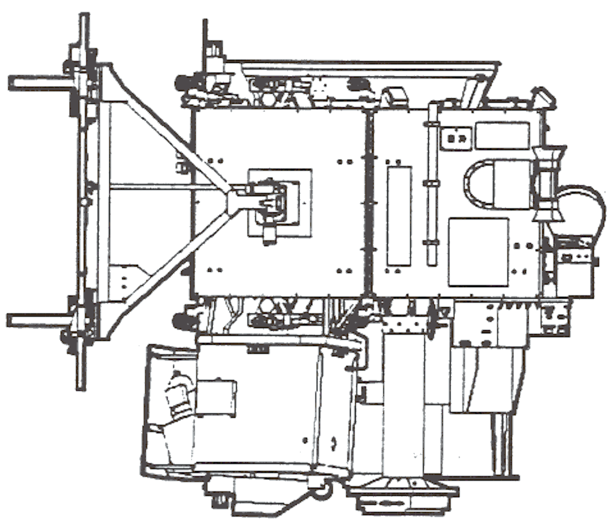


Figure 9 View of Maximum Cross-sectional Area (A_{max}) of The EO-1 Spacecraft



SURFACE AREA = 3,026.70 sq in

Figure 10. View of Cross-sectional Area (A_1) Orthogonal to A_{max}



SURFACE AREA = 4,146.75 sq in

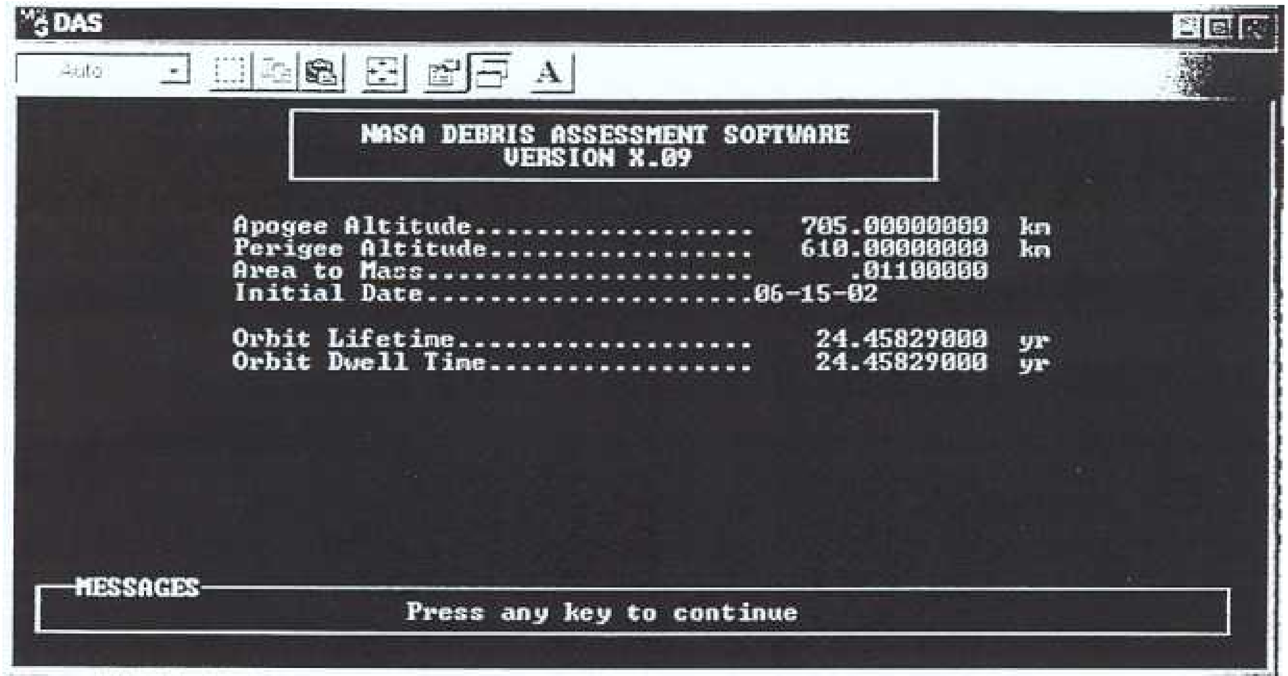
Figure 11. View of Cross-sectional Area (A_2) Orthogonal to A_{max} and A_1

These areas were then used in the following equation to calculate the average cross-sectional area:

$$(A_{max} + A_1 + A_2) / 2 = A_{average}$$

$$(12334 + 3027 + 4147) / 2 = 9754 \text{ in}^2 \cdot (.0006452\text{m}^2/\text{in}^2) = 6.2933 \text{ m}^2$$

Final disposal mass was calculated to be 570 kg (including 60% disposal orbit fuel margin, see below), which results in an area-to-mass ratio of 0.011 m^2/kg. Results from menu 8.1.3.1 of the DAS program, provided in Figure 12 below, show that reentry will occur within the 25 year requirement by transferring to an elliptical orbit with an apogee of 705 km, and perigee of 610 km.



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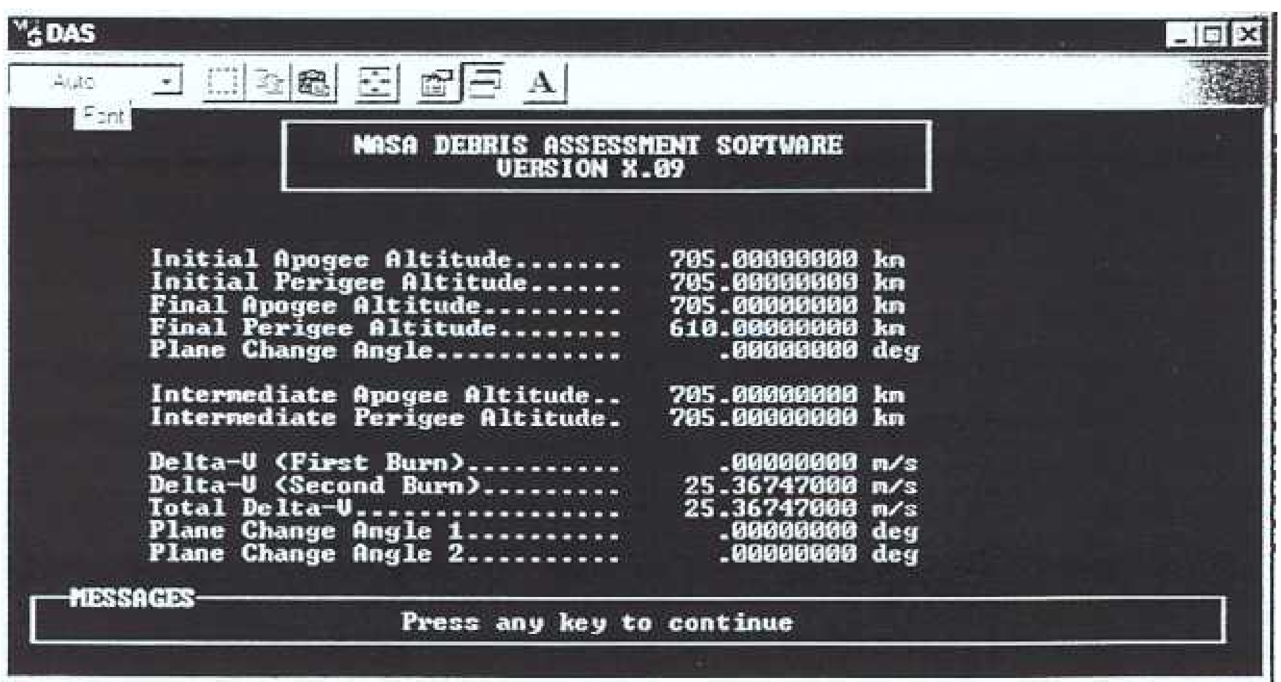

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As was shown in Section 3, the DPAF lifetime will be 18.6 years, which meets the guideline.

The calculation for the Delta second stage is provided in Figure 14, and clearly fails the guideline. This calculation was performed in DAS menu 8.1.3.1. Changing the Area to Mass ratio had no effect on the calculation of orbit lifetime.

Figure 14 DAS Orbit Lifetime Calculation For Delta Second Stage With Time-Varying Solar Activity

6.2 Assessment of Potential Failures that Prevent Successful Postmission Disposal

The EO-1 project has limited all credible failure modes that could prevent postmission disposal through use of conservative design practices and quality assurance requirements. Due to the lack of FMEA and Reliability analyses, no quantitative measure exists for the reliability of this spacecraft. The quality assurance program is defined in GSFC-426-EO-001, 'Mission Assurance Requirements for the Earth Obiter (EO-1) Program.' EO-1 is a technology validation mission and, as such, is not required to be fault tolerant. However, GSFC-426-EO-001 requires extensive box and system level testing that provides confidence that the spacecraft will be capable of performing the deorbit maneuver at the end of the mission.

A reliability prediction of 0.9939 for the propulsion system was provided by Primex Technologies Inc. (formerly Olin Aerospace Company), and documented in the Technical/Management portion of their Proposal. Document #96-P-1804, dated November 22, 1996. In section 3.4.1, they state that "A reliability prediction was prepared using the methodology in MIL-HDBK-217F and MIL-STD756B as a guide for this proposal. It is predicted that the EO-1 propulsion system has a reliability of 0.9939 for the following mission profile", which is summarized here:

1 year storage
10 minutes of launch environment
2 Years on orbit
7 Hours operation of thrusters
10,000 Thruster valve cycles

Post mission disposal of the DPAF is only effected by operations of the launch vehicle, such as failure to deploy from the second stage. Once deployed, the DPAF will re-enter without further action.

There are no known Delta second stage failure modes which can prevent the final depletion burn.

7 Assessment of Survival of Debris from the Postmission Disposal Atmospheric Reentry Option

This analysis was performed with the help of the JSC Orbital Debris Program Office (JSC). A list of all major components of the spacecraft with dimensions and weights was provided to JSC for calculation of survivability. An initial case was run using the given dimensions, total mass, and provided material of each object. A second run was performed (Figure 15) using a "fake material" for the objects which were shown to survive in the first run. This "fake material" was used to represent the effective density of the object, and was used by creating a material in the materials database for each surviving object, keeping the original material properties with the exception of the density, specific heat, and heat of fusion. These three quantities were calculated as follows:

Effective Density: $\rho_{eff} = m/V$

where **m** is equal to the total mass of the object and **V** is equal to the volume calculated from the given *outer* dimensions (i.e., doesn't take into account thickness).

Heat of Fusion: $L = L_{mat} * (\rho_{eff} / \rho_{mat})$

where L_{mat} is equal to the original heat of fusion of the material, ρ_{eff} is equal to the above calculated effective density, and ρ_{mat} is the original density of the material.

Specific Heat: $C_P = C_{Pmat} * (\rho_{eff} / \rho_{mat})$

where C_{pmat} is the specific heat of the material

Objects that were still shown to survive after this second run, which were the Battery and Propellant Tank, will definitely survive. The ones which originally survived but were now shown to demise were looked at more carefully, with attention to the contents of each object. The ACDS, WARP, and PSE boxes are all aluminum boxes with nothing but circuit cards inside, all of which are less than the 0.25m dimension on any side, and should ablate along with the housings. The Solar Array Assembly is a honeycomb structure with composite facesheets (0.015" thick) on an aluminum honeycomb core, which will breakup during re-entry, and don't contain any piece-parts greater than 0.25m in any dimension. The Hyperion instrument contains many parts and materials, but all are smaller than 0.25m in any dimension. In the ALI instrument, there are three parts larger than 0.25m, and these are the three main mirrors. These parts are made of Silicon-Carbide (SiC), with a sublimation temperature of ~2500 K (various maximum temperature values were found for SiC, but they all ranged between 1900 and 2500 Kelvin). For comparison, the melting temperatures of titanium and steel are ~1940 K and ~1650 K, respectively, and these types of objects are the ones which typically surviye reentry. Therefore, there's no doubt that the mirrors will also survive. Therefor, the impact area for the mirrors was calculated separately, as shown here, per NSS 1740.14:

ALI Mirror M1: Volume = 0.3327m x 0.1676m x 0.019m = $0.00106m^2$,
Debris Area = $(0.6+\sqrt{(0.00106)})^2 = 0.400m^2$
ALI Mirror M3: Volume = 0.2972m x 0.1346m x 0.019m = $0.00076m^2$
Debris Area = $(0.6 + \sqrt{(0.00076)})^2 = 0.394m^2$
ALI Mirror F1: Volume = 0.2743m x 0.08636m x 0.019m = $0.00045m^2$
Debris Area = $(0.6 + \sqrt{(0.00076)})^2 = 0.386m^2$
Total Mirror Debris Casualty Area: = $1.180m^2$

Adding this area to the debris area calculated in Figure 15, yields a total of 3.145 m^2, which is less than the upper limit of 8 m^2 as set forth in the guidelines. Therefore the casualty risk for postmission disposal from reentry of the EO-1 spacecraft is acceptable.

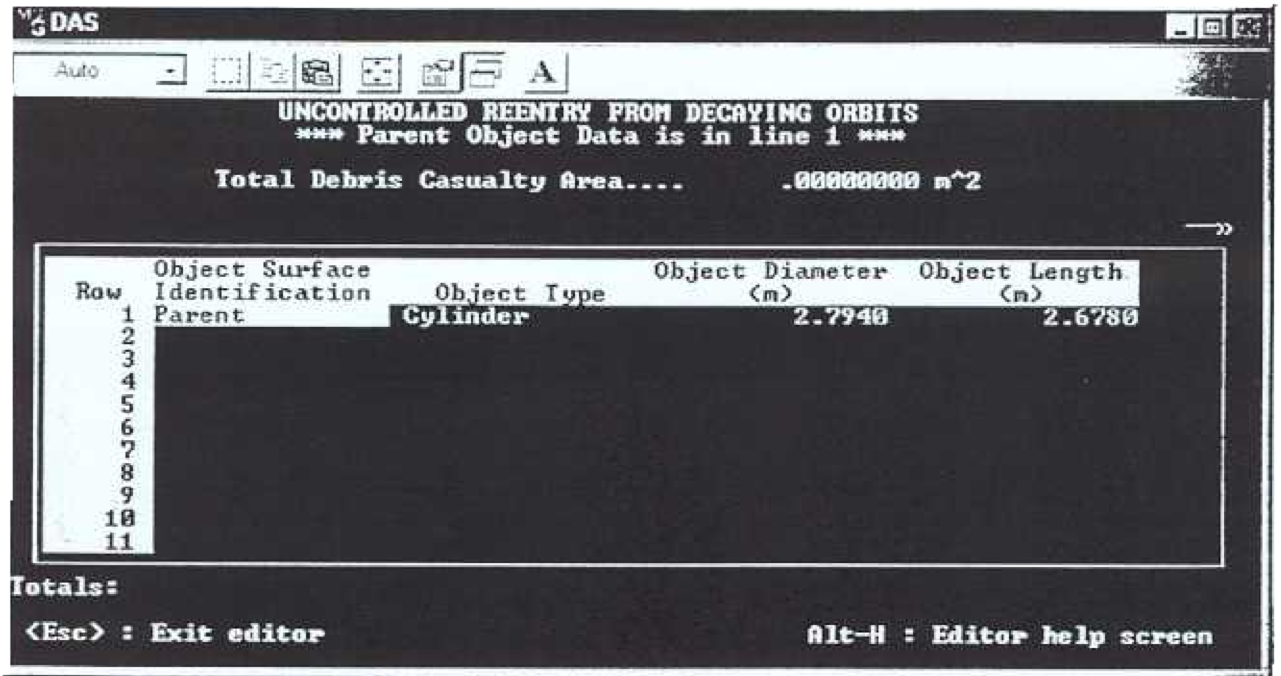
UNCONTROLLED REENTRY FROM DECAYING ORBITS

*** Parent Object Data is in line 1 ***

Total Debris Casualty Area 1.96525400 m^2

Object Surface Identification	Object Type	Object Diameter (m)	Object Length (m)	Object Height (m)	Object Mass (kg)	Material Type	Demise Altitude (km)	Casualty Area (m^2)
Parent	Cylinder	1.4351	.7264	.0000	96.0500	Al 2024-T8xx	77.9860	.0000
ACDS	Box	.3937	.2819	.2192	17.1320	ACDSMat	74.2531	.0000
Star Coupler	Box	.2032	.0889	.0190	1.8370	Al 2024-T8xx	61.6928	.0000
Star Coupler	Box	.2032	.0889	.0190	1.8370	Al 2024-T8xx	61.6928	.0000
GPS Power Conv.	Box	.1651	.1333	.0474	1.0387	Al 2024-T8xx	71.4332	.0000
GPS Pre-Amp.	Box	.1379	.0711	.0508	.5488	Al 2024-T8xx	71.1122	.0000
GPS Receiver	Box	.2750	.1689	.0401	1.8551	Al 2024-T8xx	69.8555	.0000
Mag. Elect.	Box	.1308	.0914	.0259	.4309	Al 2024-T8xx	73.7066	.0000
RWDE	Box	.1826	.1539	.0825	2.1273	Al 2024-T8xx	66.6383	.0000
SIRU	Box	.3022	.2044	.0952	4.8398	Al 2024-T8xx	60.5414	.0000
Star Tracker	Box	.3477	.1531	.1729	6.1688	Al 2024-T8xx	46.6813	.0000
Tri-Ax.Mag.Head	Box	.0571	.0444	.0307	.3084	Al 2024-T8xx	69.4485	.0000
X-Re.WheelAsse.	Cylinder	.2032	.0635	.0000	2.4856	Al 2024-T8xx	68.9476	.0000
X-Torque Bar	Cylinder	.0279	.6375	.0000	1.5558	Al 2024-T8xx	72.7624	.0000
X-Re.WheelAsse.	Cylinder	.2032	.0635	.0000	2.4856	Al 2024-T8xx	68.9476	.0000
X-Torque Bar	Cylinder	.0279	.6375	.0000	1.5558	Al 2024-T8xx	72.7624	.0000
X-Re.WheelAsse.	Cylinder	.2032	.0635	.0000	2.4856	Al 2024-T8xx	68.9476	.0000
X-Torque Bar	Cylinder	.0279	.6375	.0000	1.5558	Al 2024-T8xx	72.7624	.0000
S-BandOAN+Boom	Cylinder	.0762	.6769	.0000	2.3859	Al 2024-T8xx	73.8527	.0000
S-BandOAZ	Cylinder	.0762	.1181	.0000	.1496	Al 2024-T8xx	76.8399	.0000
S-Band Trnspndr	Box	.1963	.1333	.1282	3.8101	Al 2024-T8xx	56.1048	.0000
WdBandAdvReProc	Box	.3886	.3606	.2438	21.9538	WdBndAdvMat	74.5532	.0000
X-BandPhArrBoom	Box	.3302	.2794	.5461	12.2606	Al 2024-T8xx	42.8652	.0000
AdvLndImagInstr	Box	.9144	.9144	.7112	89.5209	AdvLndImMat	77.0910	.0000
LEISA AtmCorEle	Box	.2794	.2319	.1778	4.3907	Al 2024-T8xx	63.9083	.0000
LEISA AtmCorIns	Box	.1905	.1348	.1612	3.4926	Al 2024-T8xx	57.8954	.0000
Hyperion Instru	Box	.7498	.6461	.3850	34.9266	HyperionMat	76.7527	.0000
Hyperion CEA	Box	.2222	.1905	.1704	6.9853	Al 2024-T8xx	50.7438	.0000
Hyperion HEA	Box	.2438	.2286	.1295	6.9853	Al 2024-T8xx	55.0875	.0000
DeplLtWtFlxSoAr	Box	.5003	.1905	.0508	1.5966	Al 2024-T8xx	72.3636	.0000
PulPlasThrMtnPl	Box	.3439	.2839	.1920	5.9874	Al 2024-T8xx	62.4247	.0000
Battery	Box	.4864	.3048	.2308	63.0085	SSBatteryMat	.0000	.9830
BatEnablRelUnit	Box	.2090	.1397	.0840	1.0432	Al 2024-T8xx	72.1217	.0000
DeplSolArrAssem	Box	3.9116	1.4414	.0254	42.0000	SolarArrayMat	77.4300	.0000
PwrSupplyElectr	Box	.3939	.2832	.2192	13.6123	PowSupElecMat	75.6900	.0000
SolarArrayDrive	Cylinder	.2032	.2540	.0000	7.7110	Al 2024-T8xx	65.5881	.0000
SolarArrayDrEle	Box	.1587	.0889	.0342	.9661	Al 2024-T8xx	68.6348	.0000
PropellantTank	Box	.3911	.3911	.3911	3.7195	PropTankMat	.0000	.9823
Totals:					472.8040			1.9653

Figure 15. DAS Debris Casualty Area Calculation Results For EO-1, Not Including Box Contents Calculation



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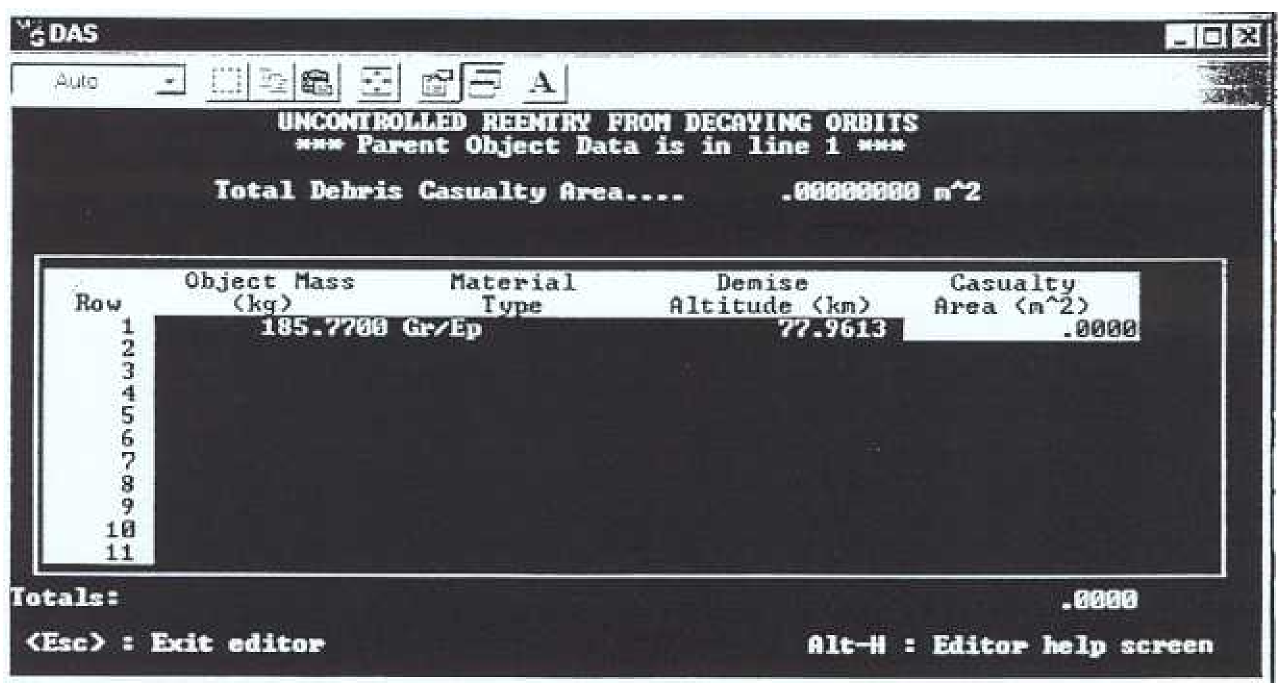

Debris casualty area calculations for the Delta second stage will exceed the guideline, as documented in a Boeing memorandum #A3-L262-LEPO-98-036, dated 10 February 1998, from D. M. Yano/H012-C204 to R.W. Pudil/H012-C207, titled "Reentry Analysis Of Delta Second Stage".

8 Assessment of Tether Missions

This mission contains no tethered devices