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ORBITAL DEBRIS ENVIRONMENT

AND DATA REQUIREMENTS

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ORBITAL DEBRIS, CURRENT NASA INVOLVEMENT

NASA is involved with orbital debris in 4 major areas: 1. Characterizing the environment. This is accomplished with a program of measurements and modeling. This work is mostly conducted at JSC. 2. Examining implications of the environment. This is accomplished by conducting hypervelocity impact tests, determining possible failure modes for spacecraft systems, and evaluating the required shielding to obtain a desired spacecraft reliability. This work is conducted at MSFC, JSC, ARC. and LaRC. In addition, other agencies and contractors conduct independent research. 3. Developing an Agency technical plan. JSC has put together a technical plan for the review of other centers. 4. Developing Policy. NASA Headquarters has the responsibility of developing policy, with other centers providing the technical background.

- **CHARACTERIZING THE SPACE ENVIRONMENT**
- **EXAMINING IMPLICATIONS FOR FUTURE USE OF SPACE**
- **DEVELOPING AN AGENCY TECHNICAL PLAN**
- **DEVELOPING AGENCY POLICY**

METEOROID BACKGROUND

The natural meteoroid environment has historically been a design consideration for spacecraft. Meteoroids are part of the interplanetary environment, and sweep through Earth orbital space at an average speed of 20 km/sec. At any one instant, a total of 200 kgm of meteoroid mass is within 2000 km of the Earth's surface. Most of this mass is concentrated in 0.1 mm meteoroids, with only a small fraction of the mass in sizes as large as 1 cm.

- Meteoroid orbits pass through Earth orbital space

- Less than 500 lbs at altitudes below 2000 km at any one time (most approximately 0.1 mm in diameter)

- In the past, meteoroids have occasionally been a spacecraft design consideration
  - Apollo, Skylab
  - size range 0.3 mm to 3 mm most important

- In the future, meteoroids are expected to be more important
  - larger spacecraft
  - longer exposure
  - lighter weight construction
  - size range 0.1 mm to 1 cm will be important

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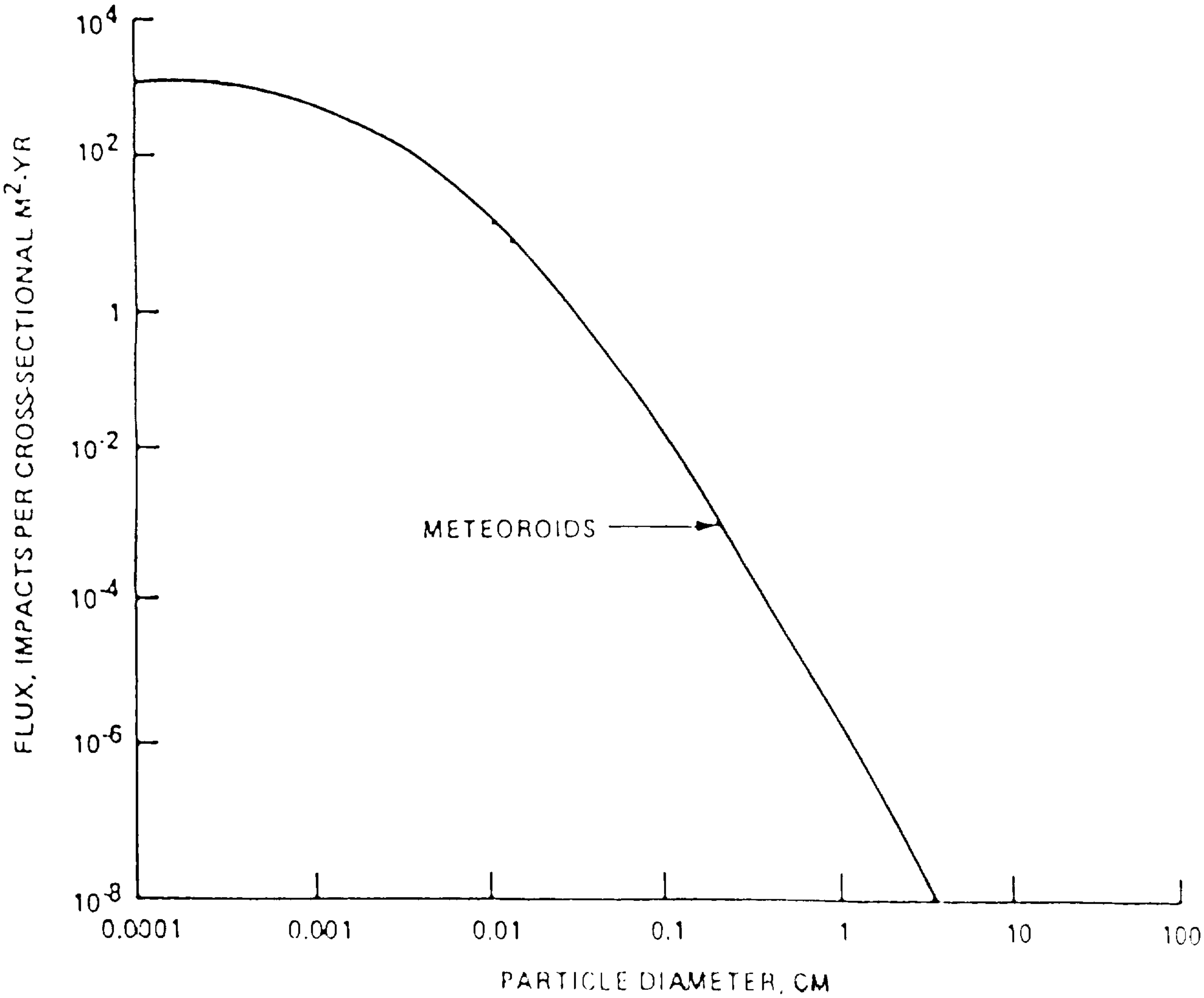
METEOROID FLUX

As a result of measurements by Pegasus and Explorer satellites and photographic and radar meteors, the meteoroid flux has been defined at 1 AU for about 20 years. When used for Earth orbit, both an Earth shielding factor and a gravity concentration factor must be applied to give the flux shown here, published in Planetary and Space Sciences, July, 1970, Vol. 18, No. 7, pp. 953-964.



ORBITAL DEBRIS POPULATION

Within 2000 km of the Earth's surface, there is also an estimated 3,000,000 kgm of man-made orbiting objects. These objects are in mostly high inclination orbits, and sweep past one another at an average speed of 10 km/sec. Most of this mass is concentrated in about 3000 spent rocket stages, inactive payloads, and a few active payloads. A smaller amount of mass, about 40,000 kgm, is in the remaining 4000 objects currently being tracked by US Space Command radars. Most of these objects are the result of over 90 on-orbit satellite fragmentations. Consequently, from these considerations alone, it is likely that smaller satellite fragments exist in low Earth orbit in sufficient quantities to exceed the meteoroid flux.

- Over 6000 objects catalogued by NORAD* and "permanently" in Earth orbital space (over 16,000 injected into orbit to date)

- Approximately 4,000,000 lbs at altitudes below 2000 km (most approximately 3 meters in diameter)

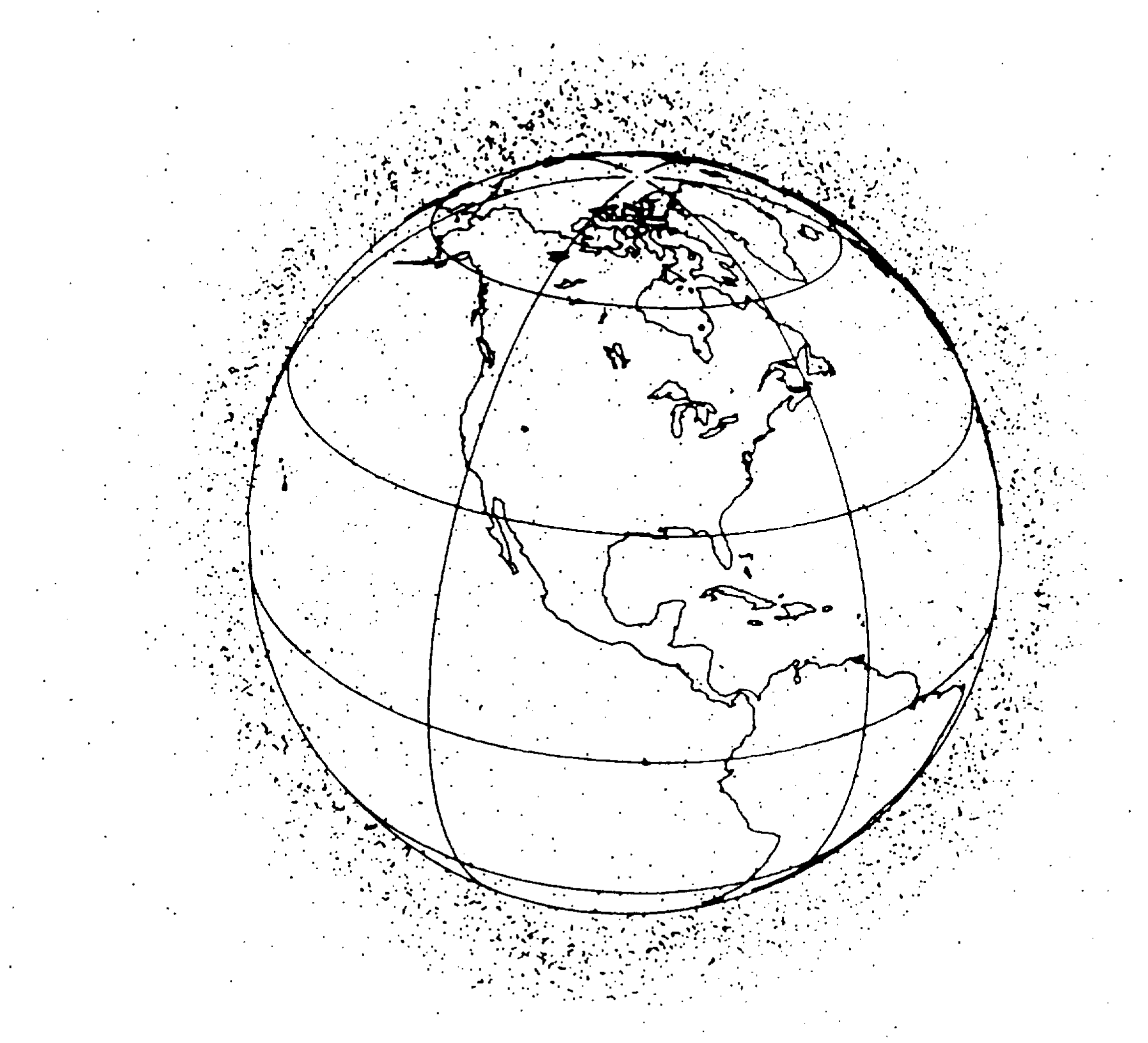
- High intersection angles produce high collision velocities

- If only a small fraction (0.01%) of the mass were in a smaller size range, the resulting environment would exceed the meteoroid environment in that size range. Possible sources of smaller objects are:
  - explosions
  - hypervelocity collisions
  - degradation of spacecraft surfaces
  - solid rocket motors firing in space

* North American Air Defense Command

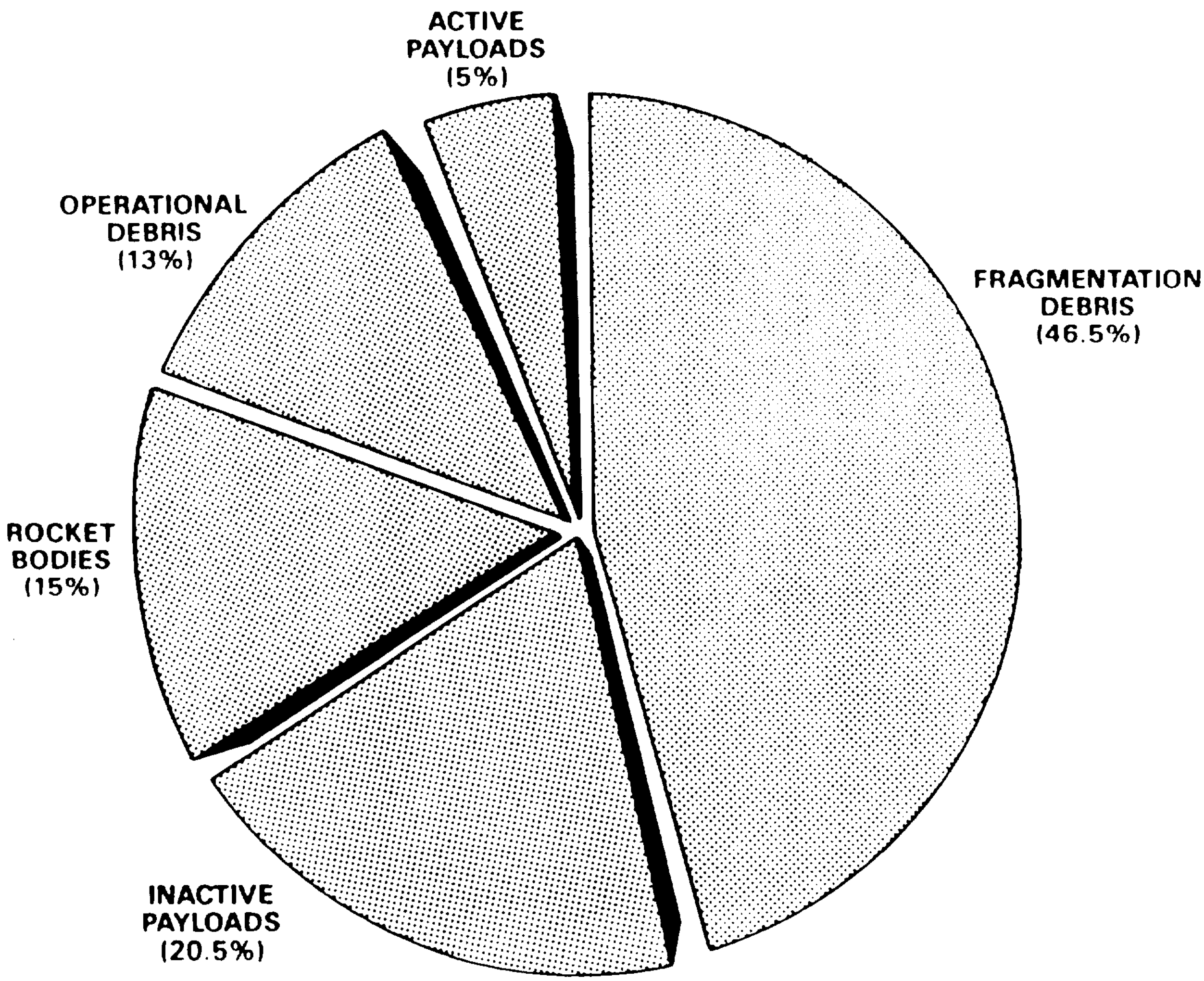
THE MAY 30, 1987 CATALOGUE AS OBSERVED FROM A POINT IN SPACE

The position of about 7000 objects cataloged by US Space Command is shown. Most objects are at altitudes less than 2000 km, and are nearly randomly distributed over the surface of the Earth. Consequently, collision probabilities are nearly independent of a spacecraft's orbital inclination, and collision velocities are high, averaging about 10 km/sec. The dots representing orbiting objects are not to the same scale as the size of the Earth; consequently, collision probabilities with the catalogued population are low, unless the spacecraft is larger than about 100 meters in diameter.



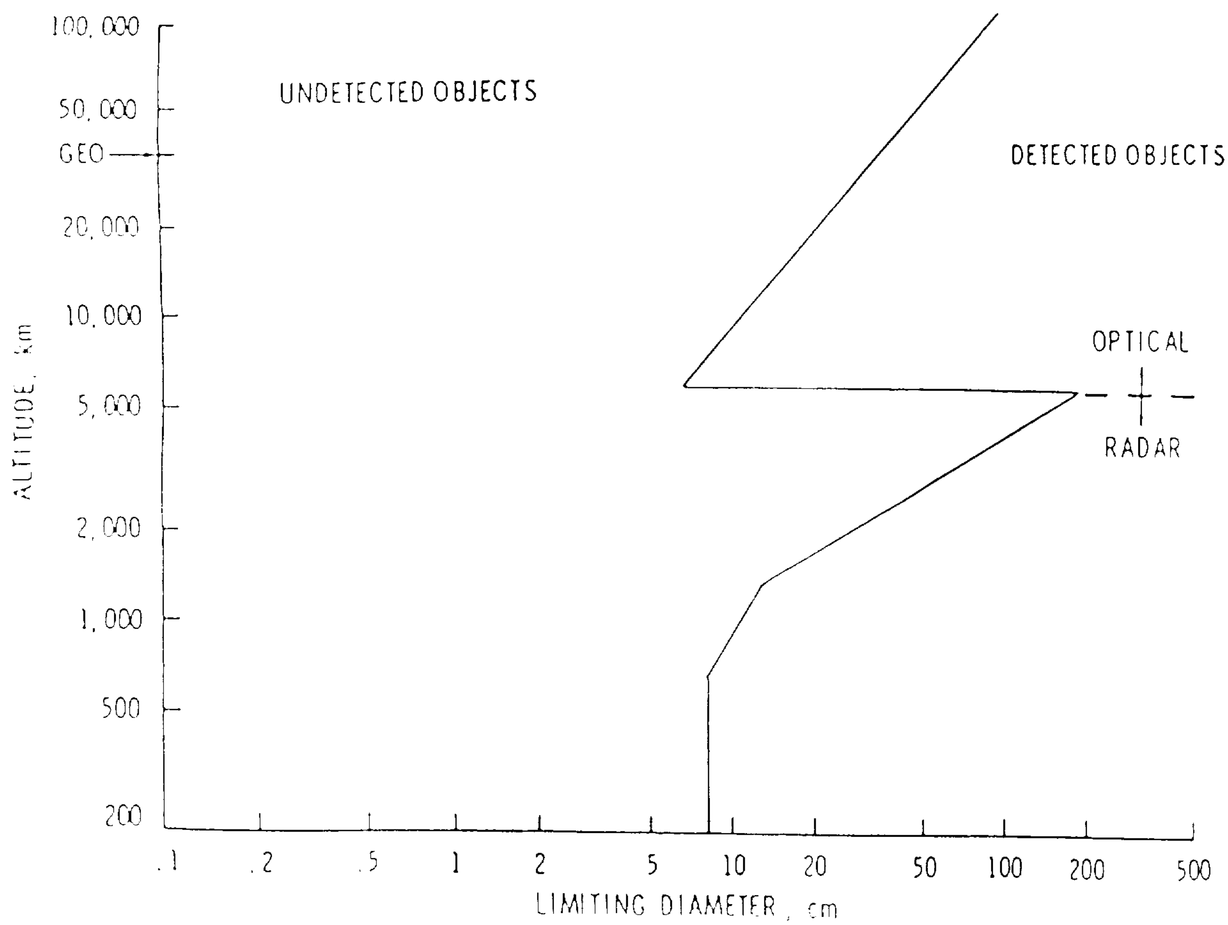
CATALOGUED EARTH SATELLITE POPULATION, 1 JANUARY 1987

Only about 5% of the catalogued population is active payloads. The remaining is orbital debris, with the largest percentage coming from on-orbit fragmentation events. Of the more than 90 events, only about 25 events contribute to more than 90% of the fragments. Because of new operations procedures, since 1981, only 1 US event has made any contribution to the accumulation of fragments in orbit; the USSR has been the major contributor in recent years.



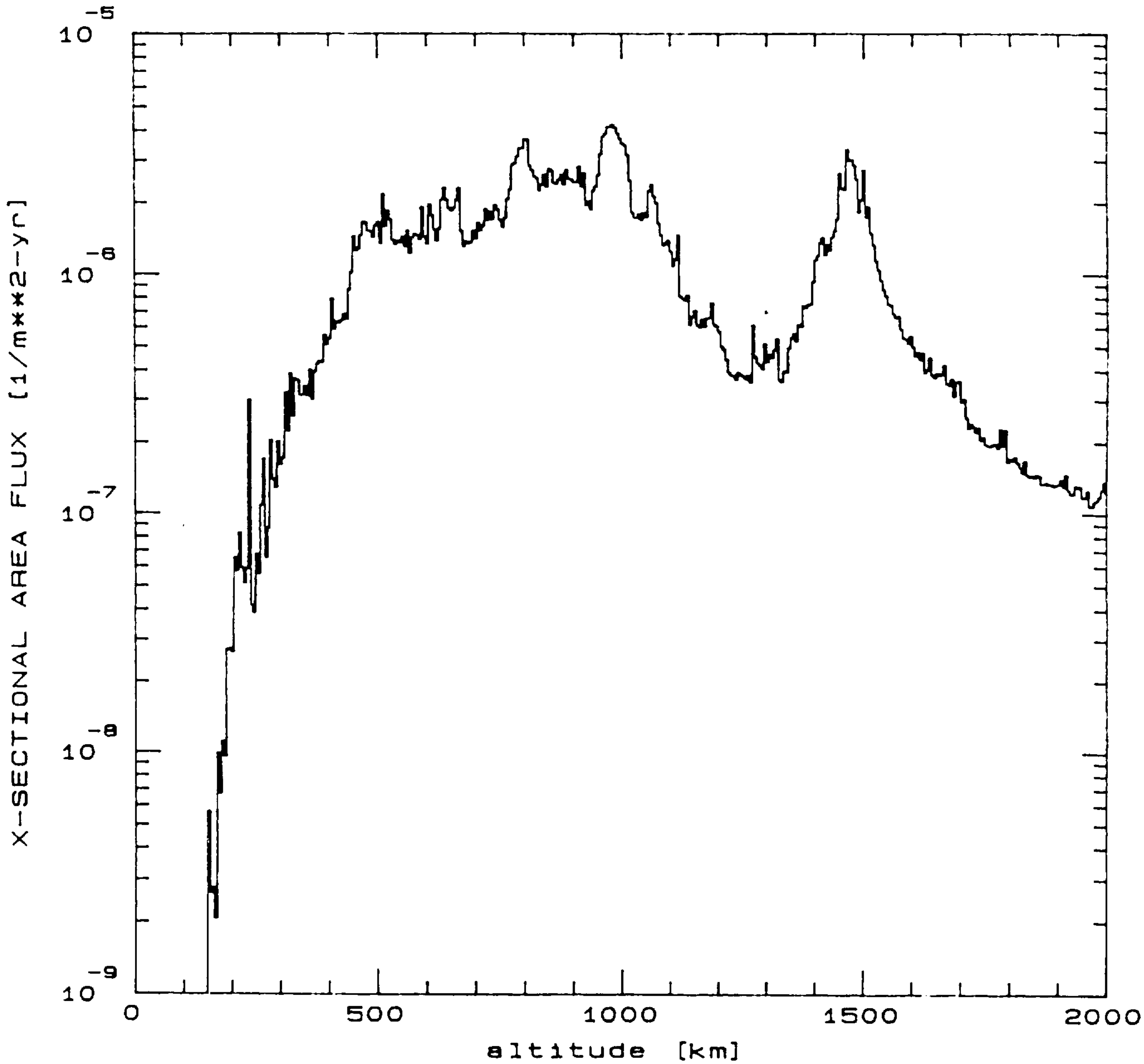
US SPACE COMMAND OPERATIONAL CAPABILITY TO DETECT SATELLITES

Because the US Space Command radars use a radar wavelength that is about 70 cm, their ability to detect and catalogue objects smaller than about 10 cm is very limited, even at low altitudes. At higher altitudes, they use optical techniques to catalogue objects. Note that an extrapolation of the optical technique to low altitudes would allow the detection (but not cataloguing) of 1 cm objects at 500 km. This technique has been experimentally used by MIT's Lincoln Labs.



US SPACE COMMAND CATALOGUED OBJECTS-JANUARY 1987

In January, 1987, the US Space Command was tracking about 6300 catalogued objects. The flux of the objects was calculated by the technique described in the publication Icarus, Vol. 48, 1981, pp. 39-48. To calculate the collision probability with a spacecraft, multiply the flux by the cross-sectional area of the spacecraft. For example, a very large spacecraft, 100 meters in diameter, at 500 km would have about a .015 probability per year of collision with a catalogued object. However, typically several hundred additional objects are awaiting catalogue, and these objects usually significantly increase the collision probabilities at altitudes below 500 km.



1987 SATELLITE BREAKUPS

During the year of 1987, a large number of breakups occurred. Most of these breakups occurred at altitudes below 500 km. At these lower altitudes, it is very difficult to maintain an accurate catalogue because the orbits are changing rapidly and because the objects do not pass over radar sites as frequently. Typically, more than a year is required to catalogue most of the fragments following a major breakup.

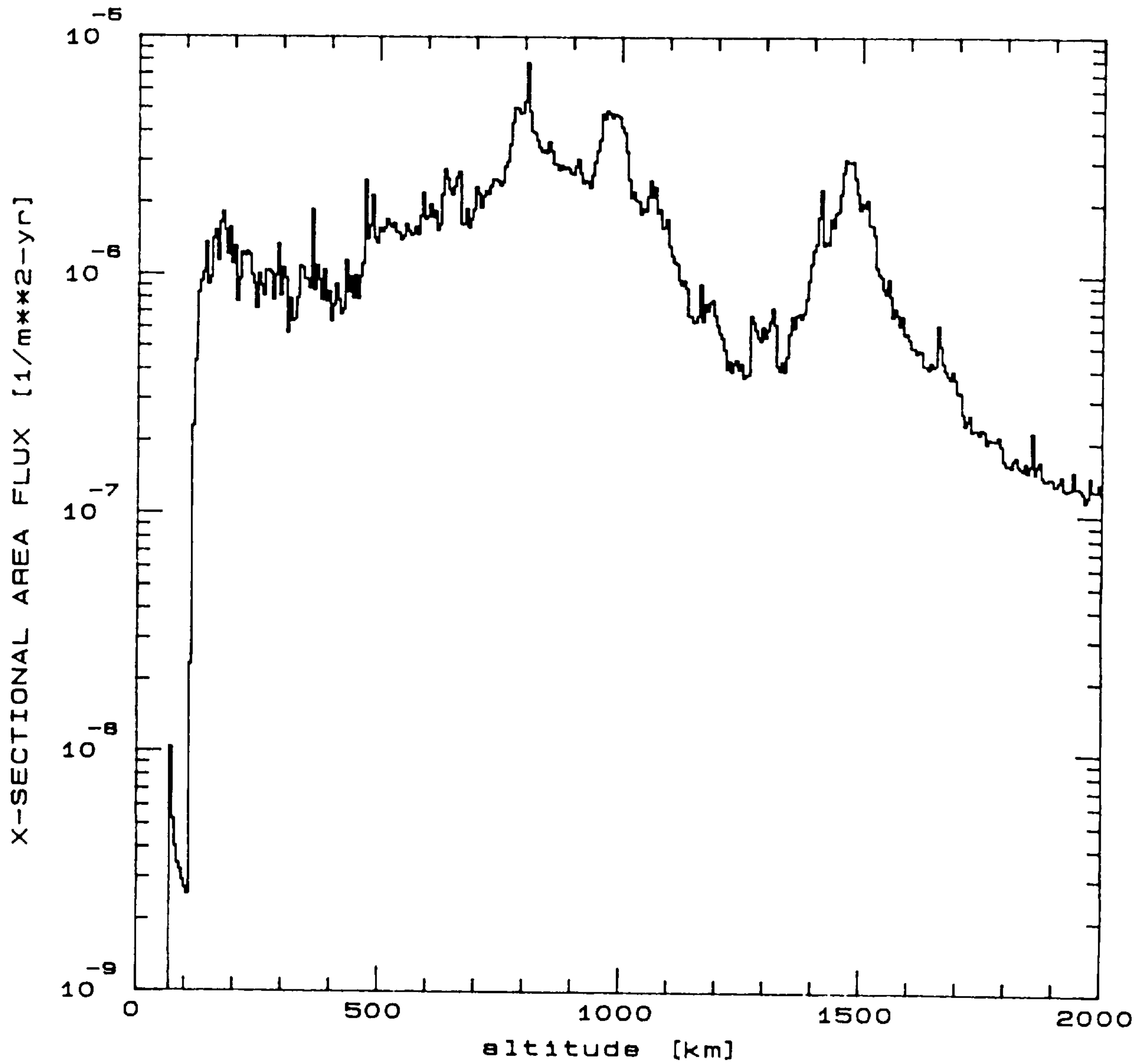
Cataloged fragments as of January 10, 1988

Breakup Date	Satellite Name	Breakup Altitude (km)	Orbital Perigee (km)	Orbital Apogee (km)	Orbital Inclin. (deg.)	Trackable Fragments Estimated	Trackable Fragments Catalogued
1-28-87	COS1813	390	359	417	73	1000	190
7-26-87	COS1866	243	167	361	67	1000	9
9-18-87	ARIANE	?	246	36523	7	>15	1
9-21-87	COS1769	333	310	444	65	150	4
11-20-87	COS1646	406	401	434	65	150	25
12-17-87	COS1823	1485	1477	1523	74	>60	43

The estimated number of fragments was determined from radar data from individual radar sites.

US SPACE COMMAND CATALOGUED OBJECTS-JANUARY 1988

Although most of the fragments from the 1987 breakups were not catalogued, there was still a very large increase in the flux at altitudes below 500 km due to these breakups. At these lower altitudes, most of the fragments will reenter soon, and the flux should return to near its 1987 values within a year, assuming new breakups do not occur. However, the large increase at 800 km, which was due to the belated cataloguing of a breakup that occurred in November, 1986, will remain for 50 to 100 years.



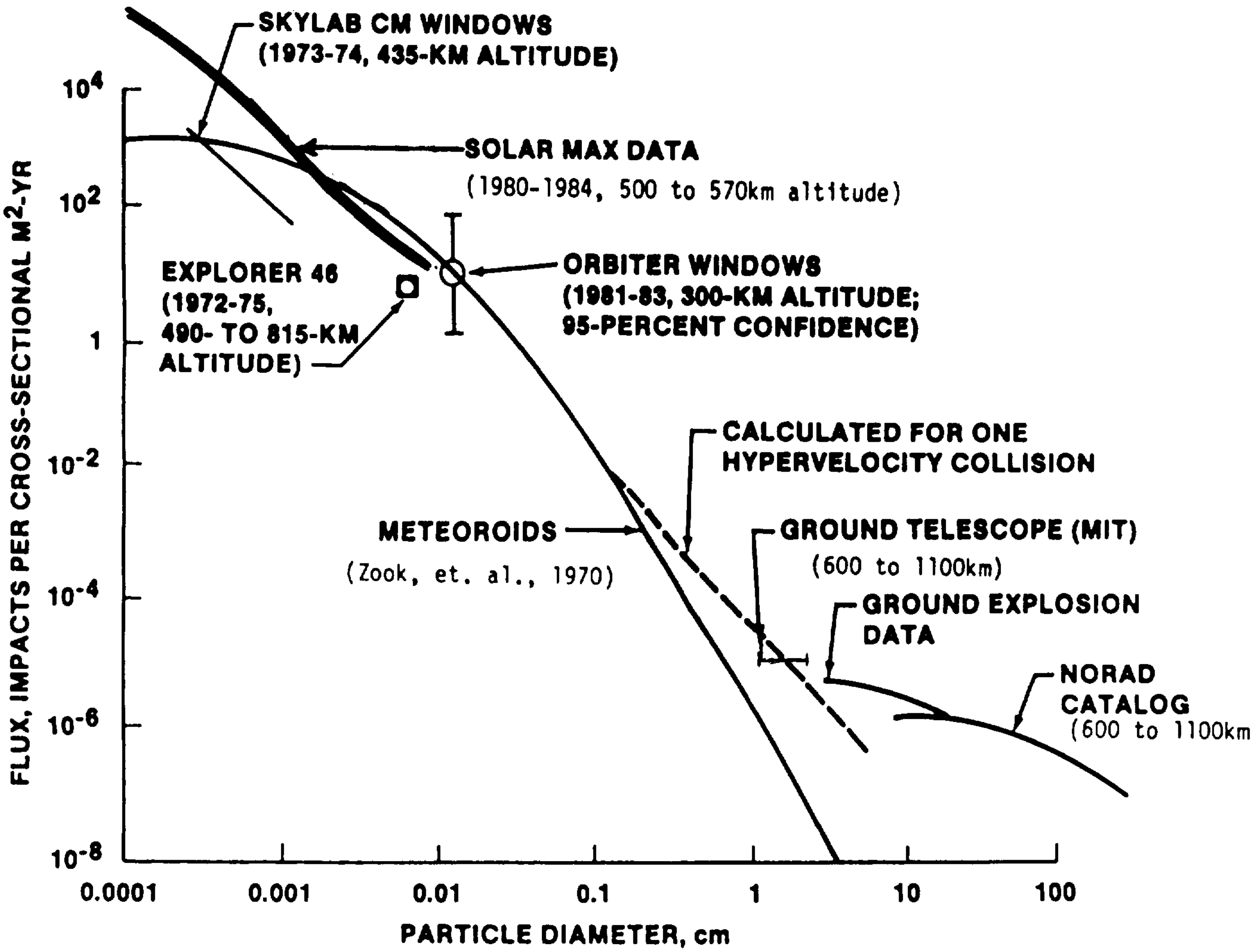
NASA'S ACTIVITIES TO DEFINE ENVIRONMENT

Because of the likelihood that a large number of objects with diameters less than 10 cm are in orbit, JSC has had a program for the last 10 years to better determine this environment. US Space Command ground radar data has been used to better understand the nature of each satellite fragmentation so that better predictions could be made concerning the total number of fragments generated. Ground telescopes have been used to detect 16th visual magnitude orbital debris and has found about 5 times the catalogued number of objects. IR measurements of satellite fragments have determined that these fragments are dark, having an albedo of about 0.1. Spacecraft surfaces, such as orbiter windows and returned Solar-Max satellite surfaces have been examined for hypervelocity impacts. A model has also been developed which predicts future orbital debris growth as a result of random collisions between satellites.

- Analysis of NORAD/ground radar data
- Acquire and analyze ground telescope data
- Acquire, analyze, and curate for research purposes returned spacecraft surfaces
- Model NASA, DoD, other traffic models
  - collision fragmentation
  - predict consequences of various activities in space

EXISTING ORBITAL DEBRIS MEASUREMENTS COMPARED TO METEOROID FLUX

All orbital debris measurements to date show an orbital debris flux that is either nearly as large as, or greater than, the meteoroid flux. The chemical composition of material found in hypervelocity pits on the Apollo/Skylab windows, the orbiter windows, and Solar-Max surfaces was used to distinguish orbital debris from meteoroids. Directionality was used to make this distinction on Explorer 46. The MIT telescopes were likely detecting 2 cm objects. Modeling hypervelocity collisions and ground explosions predict the distributions shown. However, no measurements have been made in the critical 1 mm to 1 cm size range. Modeling predicts that the amount of debris in this size range will increase significantly as the result of random collisions.



MODELING

Modeling consists of using various space traffic models, using past and predicted satellite fragmentation events to predict the future orbital debris environment. Such modeling consistently predicts that even if small debris did not already exist, it will soon exist in large quantities due to random collisions between larger orbiting objects. The most probable type of collision would be between an old rocket body, or inactive payload, and a large satellite fragment.

INPUTS

- DOD, NASA, ESTIMATED USSR TRAFFIC MODEL
- SATELLITE BREAKUP MODELS

OUTPUTS

- FLUX AS FUNCTION SIZE, ALTITUDE, TIME
- VELOCITY, DIRECTION DISTRIBUTIONS

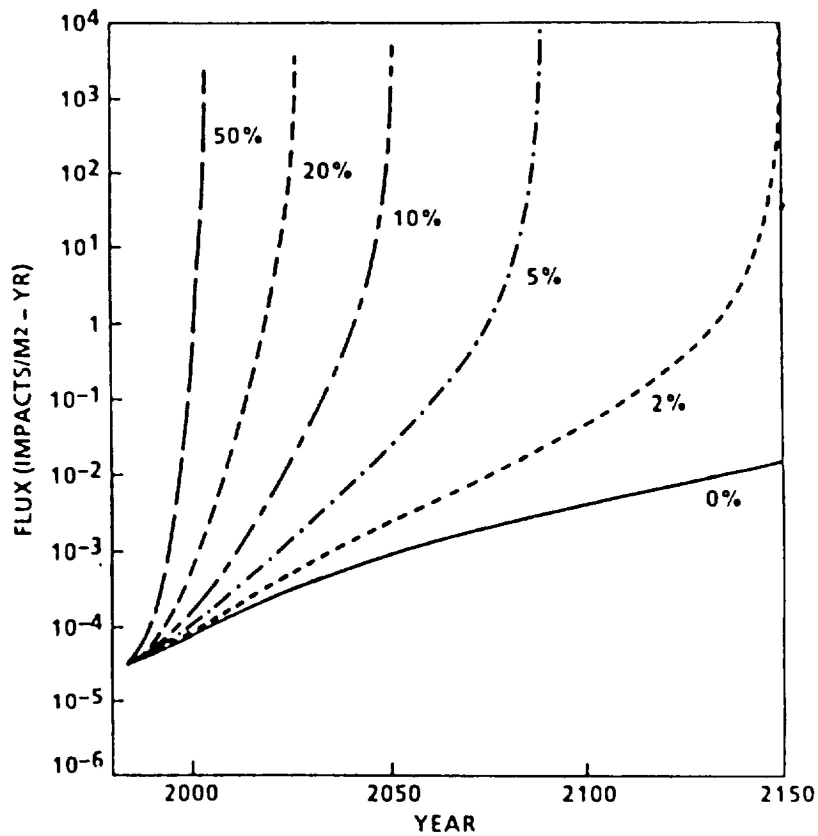
CONCLUSIONS

CASCADING EFFECT OF SATELLITE COLLISION FRAGMENTATION COULD PRODUCE AN EXPONENTIAL GROWTH IN THE 1 MM TO 1 CM POPULATION WITHIN THE NEXT 20 YEARS, DEPENDING ON

- TRAFFIC MODELS
- SATELLITE BREAKUP MODELS

DEBRIS FLUXES FROM OBJECTS 4 MM ,OR LARGER, AT 1000 KM ALTITUDE

By assuming a yearly percentage increase in the current launch rate, and that future small debris originates only from random collisions between orbiting objects (i.e., no future accidental or intentional explosions), a prediction of the future environment is made. As a result of cascading collisions, the small debris increases at a much faster rate than the launch rate alone would predict. Eventually, a critical density of larger objects would be reached, causing a very rapid increase in the rate of satellite collisions, generating small debris at a rate that would be independent of the launch rate. A 5% per year increase in the current launch rate could cause this critical density to be reached by the year 2060, while a 10% per year increase in the launch rate could cause the critical density to be reach by 2030. See the publication Advances in Space Research, Vol. 6, No. 7, 1986, pp. 109-117.



Debris fluxes from objects with diameter 4 mm or larger at 1000 km altitude with different increase rates of yearly traffic input.

TECHNIQUES TO OBTAIN DATA ON DEBRIS--1 CM AND LARGER

Various studies and experiments have shown that techniques to statistically sample the orbital debris environment at sizes smaller than catalogued by US Space Command can be conducted from either space based or ground based experiments. In both cases, remote sensing techniques must be used in order to provide a large effective collecting area. The cost of constructing a space based instrument is larger than a ground based instrument, and does not include the cost of launch, or the spacecraft; consequently, ground based measurements are more cost effective. Although ground telescopes have provided excellent data, they are limited by lighting constraints...for example, most sun synchronous orbits cannot be observed from latitudes closer to the equator than 45 degrees. However, a single X-band radar near the equator could sample all orbits. NASA plans to have such a radar operational by 1991.

TECHNIQUE	COST*	TECHNOLOGY RISK	DATA RETURN	COMMENTS
SPACE BASED				ALTITUDE LIMITED TO SPACECRAFT ALTITUDE
RADAR[1]	HIGH	LOW	LOW	RADAR NOT OPTIMIZED FOR PERFORMANCE
LIDAR[1]	HIGH	HIGH	LOW	
OPTICAL[1]	MED	LOW	HIGH	
IR[2]	HIGH	LOW	HIGH	
GROUND BASED				ALTITUDE LIMITED TO LESS THAN 500KM
⇒ RADAR[3]	LOW	LOW	HIGH	X BAND RADAR
OPTICAL[4]	LOW	LOW	LOW	TWO 30 INCH TELESCOPES, ASSUMING HIGH ALBEDO
				LIGHTING CONSTRAINTS LIMITS DATA RETURN

1. G.E. STUDY, 1982; BATTELLE STUDY, 1983; JPL 1987
2. IRAS EXPERIENCE
3. BATTELLE, TELEDYNE BROWN ENG., JPL, JSC STUDIES, 1987
4. MIT DATA; INHOUSE EXPERIENCE

*COST

LOW LESS $20M

MED $20M TO $50M

HIGH GREATER $50M

TECHNIQUES TO OBTAIN DATA ON DEBRIS--1 MM AND LARGER

The cost of building a ground based system which could sample the 1 mm environment is considerably higher than the system to sample the 1 cm environment. In addition, the technology risk is higher for the required K-band radar. Consequently, the most cost effective technique of obtaining this data is a space based optical detector. JPL proposed earlier this year a configuration, called "Quicksat", which would orbit a pair of 25 cm telescopes, each with sensors consisting of 8X16 CCD "macropixels". The spacecraft and instrument would cost $100M-- more than NASA can currently afford.

TECHNIQUE	COST*	TECHNOLOGY RISK	DATA RETURN	COMMENTS
SPACE BASED				ALTITUDE LIMITED TO SPACECRAFT ALTITUDE
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IR[2]	HIGH	LOW	HIGH	
GROUND BASED				ALTITUDE LIMITED TO LESS THAN 500 KM
RADAR[3]	HIGH	HIGH	HIGH	K BAND RADAR
OPTICAL[4]	HIGH	LOW	LOW	TWO 300 INCH TELESCOPES, ASSUMING HIGH ALBEDO; LIGHTING CONSTRAINTS LIMITS DATA RETURN

1. G.E. STUDY, 1982; BATTELLE STUDY 1983; JPL 1987
2. IRAS EXPERIENCE
3. JPL, 1987; JSC, 1987
4. UNIV. TEXAS PROPOSAL, 1985

*COST
LOW LESS $20M
MED $20M TO $50M
HIGH GREATER $50M

TECHNIQUES TO OBTAIN DATA ON DEBRIS--1 MM AND SMALLER

Meteoroids smaller than 1 mm have been measured using satellite "impact" sensors since the 1960's. However, only recently has consideration been given to determining the trajectory of the impacting meteoroid. Being able to discriminate between orbital debris and meteoroids is essential to any type of sensor. By obtaining trajectory information, one can determine which objects are in Earth orbit. If the surface is planned to be returned for analysis, then chemical composition of material found associated with the impact can be use to determine if the object is natural or man-made. Both techniques can be used on a single experiment; that is, the trajectory could be measured, and the impact surface later returned for analysis. Such experiments may be used on the Space Station Cosmic Dust Facility.

SPACE BASED SENSORS

Techniques	Technology Risks	Debris, Meteoroid Discriminator	Flight Experience
Telemeter Data		Trajectory	No trajectory configurations:
Intrinsic Charge Sensing	HIGH		Lab experiment only
Impact Plasma Sensing	LOW		Pioneer 8, 9, Helios, Heos, Giotto
Capacitive Sensing	LOW		Vega, Pegasus
Returned for Analysis		Chemical Composition	
capture cell	LOW		Solar Max, LDEF
Low density Foam	LOW		Flights scheduled

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CONCLUSIONS

Orbital debris is already a major design consideration for Space Station Freedom and is becoming important to the design of unmanned spacecraft. Mathematical models predict the environment will increase with time. The amount it increases is dependent on future operations in space, and how these operations are conducted. Therefore, it is important to understand the sources of debris and which operations will minimize debris generation. This requires that debris be monitored. Currently, NASA plans to have an operational capability to monitor 1 cm debris at 500 km by 1991. However, there are currently no plans to monitor the environment of smaller debris which will be important to future spacecraft design.

- **Existing measurements indicate the current Orbital Debris Environment in Low Earth Orbit is more important to spacecraft design than meteoroid environment.**

- **Mathematical Models predicts significant increases in the orbital debris environment within the near future.**

- **Need to monitor environment of 1 cm and smaller orbital debris**