AN OVERVIEW OF THE NASA ORBITAL DEBRIS PROGRAM PLAN

George M. Levin

NASA Headquarters, Washington, D. C.

ABSTRACT

As result of the National Space Policy issued by President Reagan in January 1988, NASA has acted to develop a long term plan to measure, model, mitigate, and protect against orbital debris. The objectives of both the LEO and GEO orbital debris program within NASA are as follows:

* to minimize/reduce orbital debris accumulation consistent with mission requirements,
* to define the debris environment,
* to develop advanced shielding techniques,
* to participate in the development of policies on orbital debris, and
* to work with external organizations to safeguard assets in geostationary orbits.

The paper reviews NASA's approach to dealing with the major aspects of each area of the orbital debris problem.

1. SUMMARY OF THE PROBLEM

In January, 1988, President Reagan issued a new National Space Policy declaring:

> "All sectors will seek to minimize the creation of space debris. Design and operations of space tests, experiments and systems will strive to minimize or reduce accumulation of space debris, consistent with mission requirements and cost effectiveness."

The estimated mass of man-made orbiting objects within 5,000 KM of the earth's surface is now about 3,000,000 KG. These objects are in mostly high inclination orbits and pass one another at an average speed of 10 KM/SEC. Most of this mass is contained in about 3000 large objects which are either spent rocket bodies or active/inactive satellites.

Of the smaller debris objects, the majority consist of pieces from some 113 on-orbit fragmentations or break-ups. Recent radar and optical measurements of the orbital 'debris environment combined with the hypervelocity impact pit analysis on spacecraft surfaces returned from orbit indicate a total mass of 1000 KG for debris of 1 to 10 CM, and about 100 KG for debris 0. 1 to 1.0 CM. With 2/3 of the total mass in orbit in Low Earth Orbit (LEO), below 5,000 KM altitude, the distribution of mass and relative velocity is of serious concern to spacecraft operating in LEO.

In the case of Space Shuttle flights, statistics predict one impact pit on a window per average five day mission. Actual experience is following, on average, the statistical prediction with some Shuttle missions experiencing no impacts while others missions had multiple impacts. By the time of the STS-45 mission, in April 1992, a total of 23 Shuttle windows have been replaced due to pitting; 90% of this pitting was caused by orbital debris impacts.

The debris problem in geostationary orbit is believed to be equally serious. Because of the difficulty in observing objects in geostationary orbit, the problem is nowhere near as well defined as the LEO environment. Recently information was made public concerning two major fragmentations in geostationary orbit. With our increased knowledge about the geostationary orbital debris environment, the Satellite Communication Community has undertaken serious efforts to address limiting potential orbital debris damage to their valuable assets.

2. ORBITAL DEBRIS PROGRAM MANAGEMENT IN NASA

The Advanced Programs Division, a part of the Office of Space Systems Development (Code D), manages the coordinated NASA wide orbital debris program. The Off ice of Space Systems Development works closely with the Off ice of International Relations (Code I) to organize and focus NASA's international activities. NASA participates with other agencies such as the Department of State, the Department of Defense, the Department of Transportation, the Federal Communications Commission, etc., to develop and implement a long-term national policy for orbital debris

3. OBJECTIVES OF THE NASA ORBITAL DEBRIS PROGRAM

The objectives of both the LEO and GEO orbital debris program within NASA are as follows:

* to minimize/reduce orbital debris accumulation consistent with mission requirements

* to define the debris environment, develop models and maintain databases for U.S. and international space agencies

  -- conducting measurements (both radar and optical), and data analysis/interpretation
  -- conducting analysis of returned samples (LDEF, Solar Max Mission, Westar)

* to develop advanced shielding techniques

* to participate in the development of NASA national and international orbital debris policies

* to work with external organizations to safeguard U.S. assets in space.

4. ORBITAL DEBRIS MILESTONES, DELIVERABLES, AND PRODUCTS.

The schedules set out in Figures 1 through 4 define the major milestones and deliverables associated with the Orbital Debris Five Year Plan developed by the Office of Space Systems Development. Near term milestones and products are directed towards supporting the Space Station Freedom Program (SSF). They are providing the necessary environmental data in support of the SSF Critical Design Review in 1993. Following the completion of this milestone, the resources of the orbital debris program will be redirected towards a more balanced approach to the long-term measurement, modeling and mitigation of the LEO and GEO debris environment. The following sections provide more detailed information on the background, objectives and approach to be followed in the modeling, measurement, mitigation and protection programs.

4.1 Orbital Debris Modeling

Background
Modeling activities are generally concerned with interpreting what can be directly measured in terms of what one would like to know. Until recently, orbital debris measurements were very limited. Previous predictions based on these limited measurements had a wide range of uncertainty. Recent measurements, which provide more and more accurate data, are providing opportunities to test past predictions and to improve the fidelity of these models. These refined models will be used both to predict the future environment which will affect the operational life of spacecraft and to evaluate the impact of proposed mitigation techniques on the future environment.

Initially, no models existed and most of NASA's orbital debris funding was directed towards the development of a modeling capability. Now orbital debris models are being used routinely to support NASA's activities and programs. In the immediate future, with the acquisition of new data, additional resources will be directed at improving and enhancing NASA's orbital debris modeling capabilities.

Objectives
1. Continue to support orbital debris related activities and major NASA programs.

2. Improve the fidelity of existing models by incorporating new environmental data.

Approach
1. New definitions of the orbital debris environment ("engineering" environment models) will be provided to Space Station Freedom, as well as other manned and unmanned programs, as required. Existing models will be used to

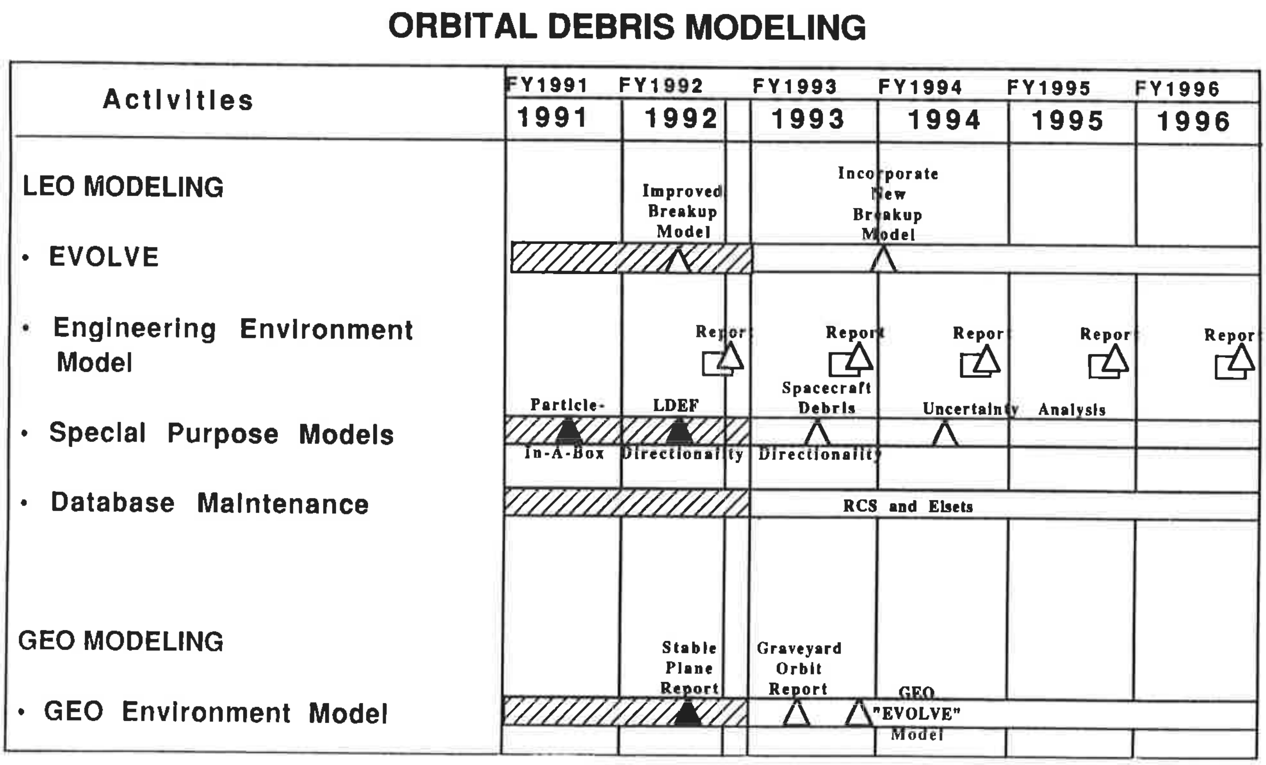

Figure 1. Orbital Debris Modeling

evaluate the consequences of proposed techniques to control the future environment. Some proposed strategies are the planned reentry of future upper stages and payloads at the end of their operational life; the imposition of operational constraints on proposed major space initiatives, such as new lunar and Mars initiatives, and constellations for civilian communications and national defense; and the use of new debris measurement techniques, such as orbiting telescopic sensors. Existing models will be used to provide data to support conferences, publications, and joint national and international meetings.

2. Improved satellite breakup models will be developed as a result of new ground tests by the Defense Nuclear Agency (DNA). New sources of orbital debris as identified by LDEF and the Haystack Orbital Debris Radar will be incorporated into the long-term Evolutionary model (EVOLVE). A long-term geosynchronous evolutionary model will be developed based on new data indicating that explosions have occurred in geosynchronous orbit, a new understanding of the long-term consequences of the lunar and solar gravity on the motion of objects at geosynchronous altitude, and expected new measurements of the geosynchronous environment.

4.2 Measurements

Background

Orbital debris measurements cover the size range from microns to meters, and the altitude range from low earth orbit to geosynchronous orbit (GEO). No single method can cover this range of sizes. The microdebris population has been measured by analysis of impact pits on material returned from space. Objects in the size range from a few millimeters up to tens of meters have been measured using radars and telescopes. The critical size regime relative to protection of large spacecraft in low earth orbit is the range from a few millimeters to about 10 centimeters. The Haystack Orbital Debris Radar is used to measure this critical size population in low earth orbit.

These measurements solved the immediate problem of defining the current environment in low earth orbit. However, the debris environment continues to change as new breakups occur. In the coming years It will be necessary to continue to monitor the debris environment to determine the effects of new breakups, and to monitor the effectiveness of debris control and mitigation techniques.

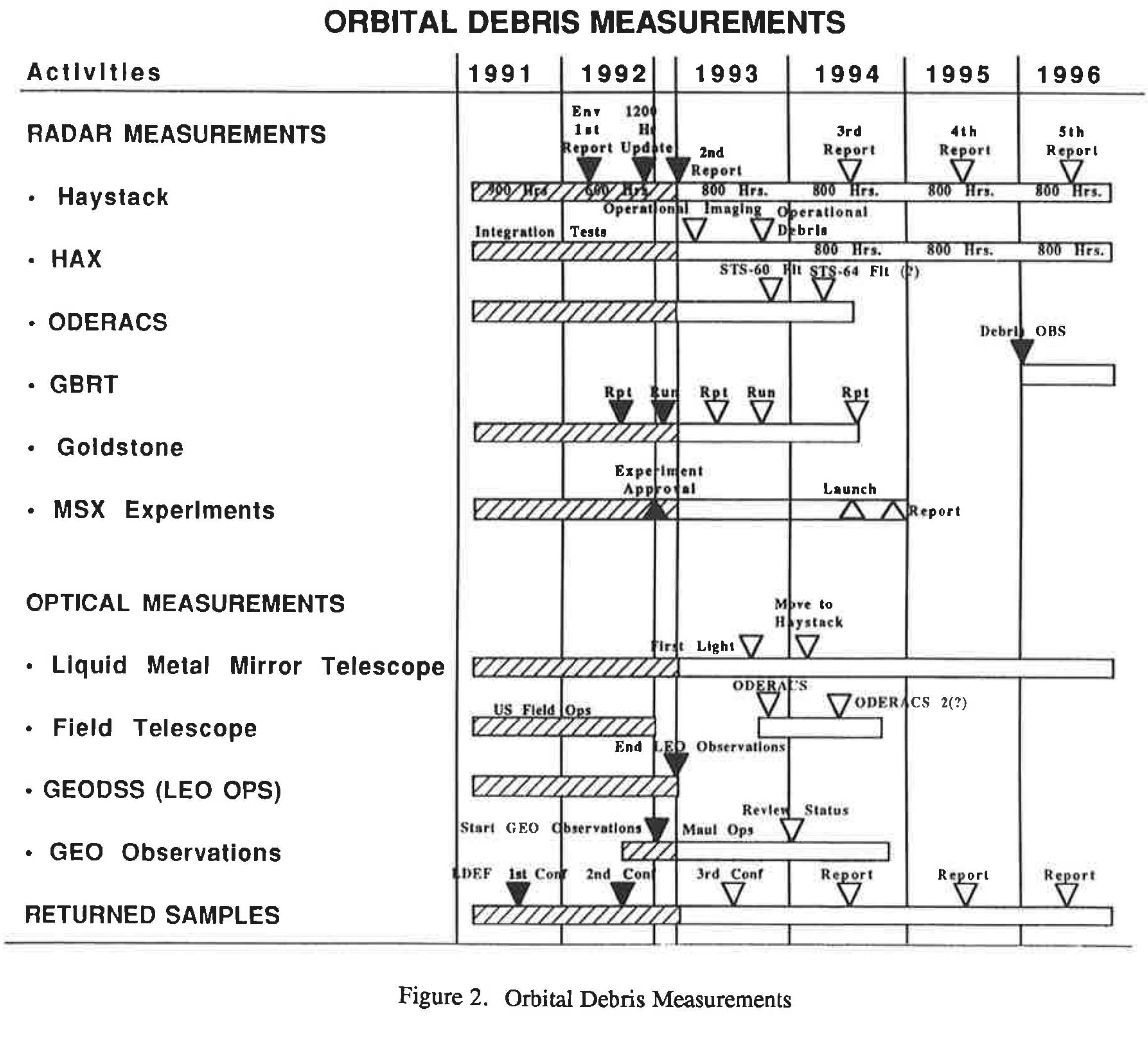

Figure 2. Orbital Debris Measurements

Two breakups have been observed in GEO. It is likely that more breakups have occurred. Because of the value of GEO as the site for communication satellites, it is essential that the debris population in GEO be measured and monitored. There is strong evidence that there is a significant population of debris in geotransfer (GTO) orbits. Since debris in these GTO orbits crosses the GEO plane, these debris objects add to the geostationary hazard. Measurements of debris in GTO are also needed to further definitize and assess the debris hazard in GEO.

Theoretical models of the debris environment predict that spontaneous generation of debris by collision has already begun at altitudes near 1000 km. On average, one collision of a 1/2 cm debris object with another object should occur each year, and smaller sizes should collide more frequently.
Experimental verification of this prediction would provide the powerful evidence needed to initiate steps to slow the growth of the debris environment.

Objectives

1. Continue to measure and monitor the debris environment in low earth orbit.

2. Measure the debris environment in GEO and GTO orbits.

3. Verify the theoretical predictions that spontaneous generation of debris by random collisions has begun.

Approach

1. The Haystack Orbital Debris Radar and the Haystack Auxiliary Radar (HAX), supplemented by optical measurements, will be used to measure debris in the size range from about 1 to 10 cm. Debris in the size range from about 0.2 cm to 1 cm will be measured using the Goldstone radar. Microdebris will be measured by analysis of impact pits on surfaces returned from space.

2. Ground-based telescope (such as the GEODSS telescopes) and radars (such as the Goldstone and Haystack radars) are used for GEO and GTO measurements. They are limited to sizes of the order of 1 meter. Even data limited to that size are welcome, because of the complete lack of data on the GEO debris population.

3. Theoretical models predict that collisions of debris should be occurring now in regions near 1000 km. Each collision will generate a pulse of gas and microdebris, which could be detected by an orbiting sensor. Efforts should be made to implement such a sensor.

4.3 Mitigation

Background
Most of the orbital debris now in orbit has resulted from explosions of spent upper stages and payloads. In order to slow down the growth of debris, methods to minimize explosions need to be implemented.

In low earth orbit (LEO), this alone will not be sufficient to prevent the growth of debris. If upper stages and payloads are allowed to accumulate in low earth orbit, collisions will eventually occur. Debris from these collisions will enter into a "chain reaction" that will cause the debris population to grow rapidly. Thus, in the future, it will be necessary to deorbit spent stages and payloads.

In geosynchronous orbit (GEO), the situation is different. It is essential to minimize explosions, as in LEO. However, prevention of collisions by deorbiting spent stages and payloads is not practical, because of the energy requirement. Alternatively, these objects can be put into supersynchronous "graveyard" orbits. Another possibility is the use of a 7.3 degree inclination orbit, where collision velocities of uncontrolled objects are much reduced.

Objectives

1. Define methods for minimizing explosions in orbit, both in LEO and GEO.

2. Demonstrate the need for deorbiting of spent stages and payloads from LEO.

3. Evaluate different strategies for deorbiting from LEO.

4. Determine the optimum locations for "graveyard" orbits in GEO.

5. Demonstrate the application of stable 7.3 degree inclination orbits to minimization of crowding and collision in GEO.

6. Foster the adoption of these methods in the space programs of all spacefaring nations.

Approach

1. Stored energy in upper stages and payloads must be removed at the end of useful life. Since procedures to accomplish this vary with the specific upper stage or satellite, these procedures must be defined and implemented by the operators for each stage or payload.

2. Develop model predictions of the effect on the orbital debris environment of removing spent upper stages and payloads from orbit. Develop drag devices and thrusters for deorbiting of spent stages and payloads. Demonstrate the performance for these devices, and define the cost impacts associated with their use.

3. The simplest way to control crowding in GEO is by boosting spent stages and payloads into supersynchronous, or "graveyard" orbits. The optimum altitude of the "graveyard" orbit must be defined and agreed upon by all users of this orbit. Another way of reducing crowding is to use the 7.3 degree inclination "stable" orbit. Perform analyses showing how this orbit can be used to minimize crowding and collisions in GEO.

4. Develop an awareness of the need for slowing the growth of orbital debris in both LEO and GEO among all users of space. This includes U.S., Japanese, Russian, European, and Chinese space agencies. Joint research projects, meetings, and various other national and international activities are pursued.

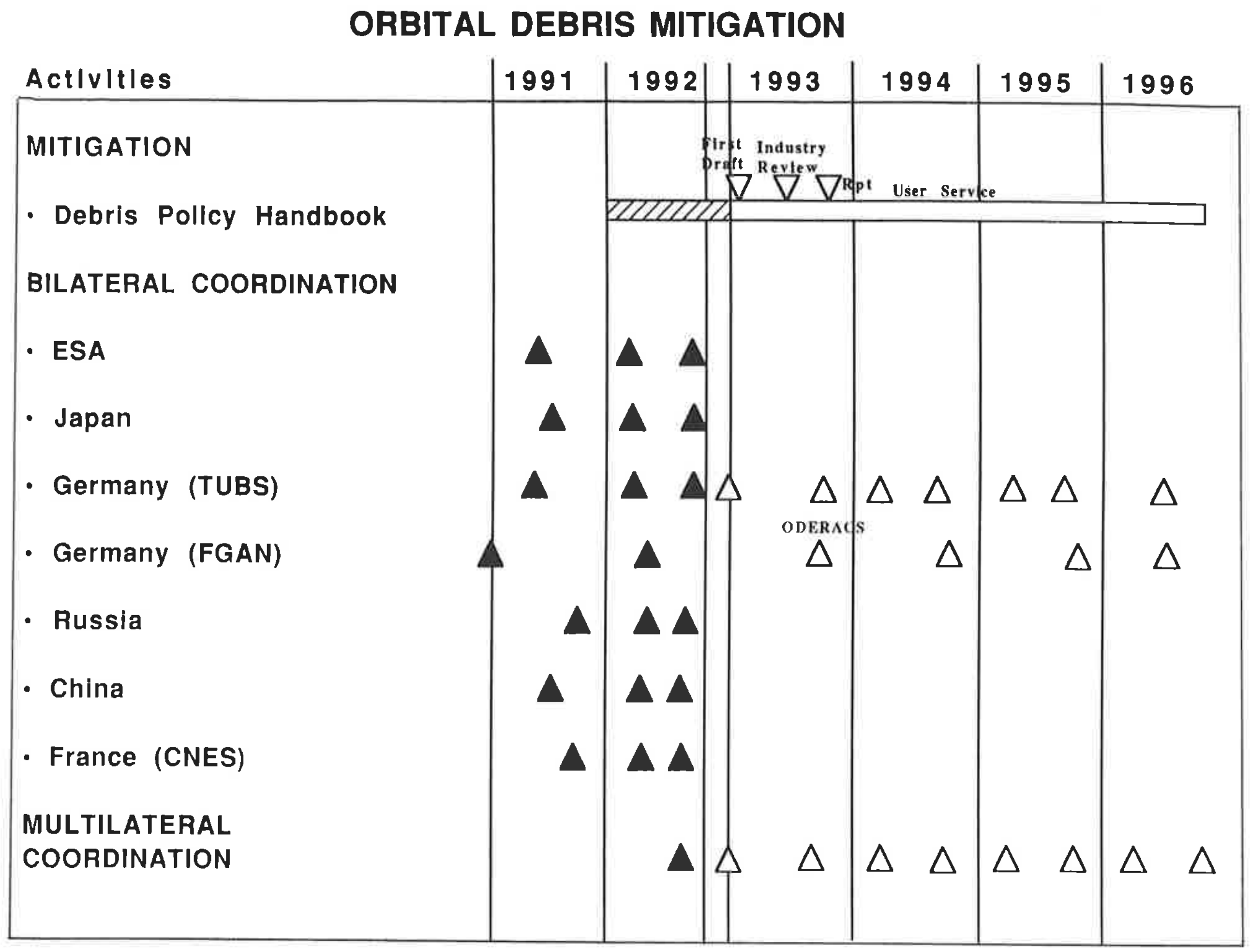

Figure 3. Orbital Debris Mitigation

4.4 Protection

Background

All long-duration spacecraft will require some degree of protection form hypervelocity impact (HVI) by meteoroids and/or orbital debris. The Long Duration Exposure Facility (LDEF) has shown that the dangers of HVI to spacecraft are not only in the form of catastrophic type failures, but in the more insidious form of a continual erosion to spacecraft surfaces and elements.

HVI shielding has been employed since the Apollo program where the concerns were for meteoroid impacts to the spacecraft on orbit and on the surface of the moon. Not until the Space Station Freedom program began has there been a concern for the added danger of HVI from orbital debris.

There has been a continuing NASA research effort to develop low-weight shielding. The results have been promising: the Multi-Shock Shield and the Mesh Double-Bumper Shield both save at least half of the weight required by the standard Whipple Shield.

The increasing need to not only protect spacecraft from damaging HVI but to provide surfaces which will not produce damaging debris lends itself to implementing some of the state-of-the-art light-weight materials as shielding material for advanced spacecraft. These new materials would produce nondamaging particles when impacted so that the secondary particles (from the shield) would not add to the orbital debris hazard.

The shielding research is dependent upon the capability to simulate the damaging effects of HVI on potential shielding materials and configurations. The present capability allows velocities up to around 8 km/sec to be attained in the laboratory with a known mass and a measurable velocity using light-gas gun capabilities. For shielding research the impacting projectile must be of a significant size to adequately represent that which is expected on orbit. Higher velocities can be attained with existing launchers when particles in the micron size range are sufficient.

Objectives

1. Develop HVI launchers capable of accelerating large size projectiles (greater than 100 microns) intact, at velocities above 8 km/sec.
2. Research new shielding materials and configurations.

3. Develop numerical codes and analytical equations for predicting HVI damage to complex shields and spacecraft systems

ORBITAL DEBRIS PROTECTION

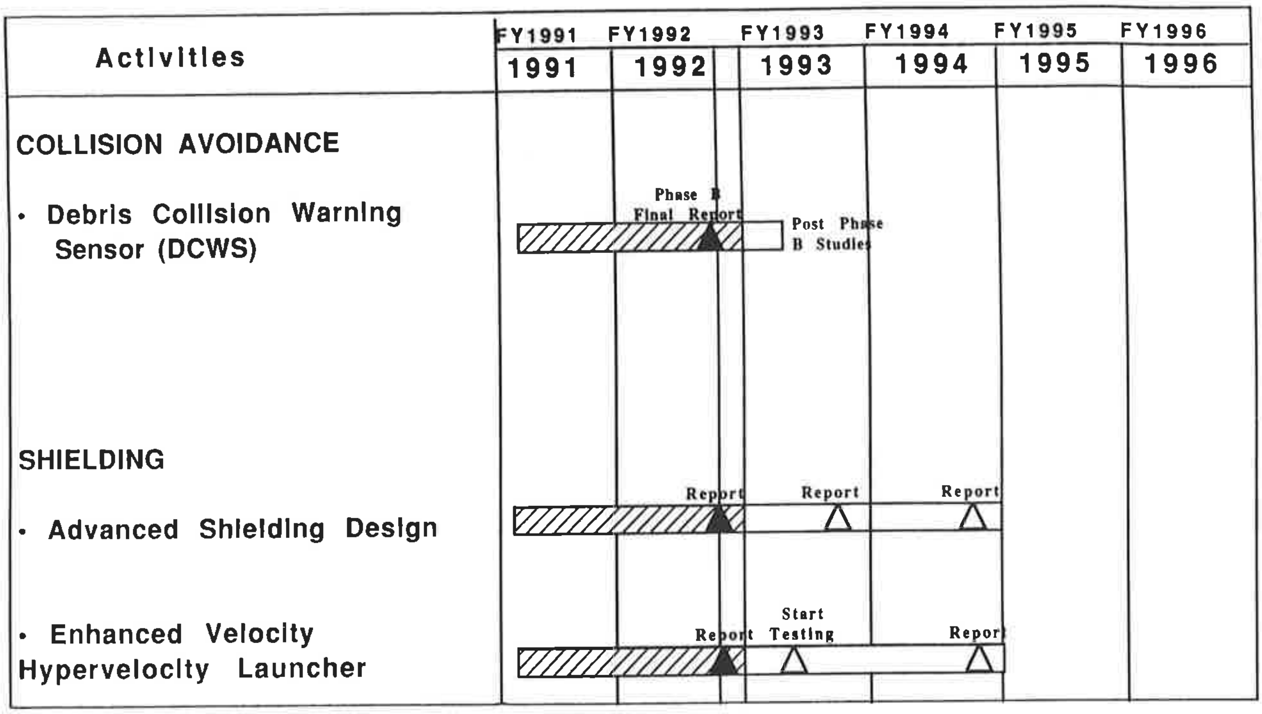

Figure 4. Orbital Debris Protection

Approach

1. There are a number of promising launcher proposals available for research and development. The DOD, DOE and DNA are also interested in developing these HVI launcher capabilities. There is presently a working group including NASA with these other agencies which is attempting to advance the HVI launcher capabilities by jointly funding the most promising of the proposed launchers. NASA will participate as one of the promoters and supporters for advancing this technology.

2. Evaluation of numerous new state-of-the-art materials and configurations will be conducted in a test program at the NASA JSC Hypervelocity Impact Test Facility (HIT-F). The program will consist of prediction (codes), test and analysis in the evaluation and development of new shielding concepts and debris mitigation techniques, including debris sweepers, non-damaging secondaries, etc.

3. The development of new HVI equations and codes to predict the performance of spacecraft meteoroid and debris protection systems will continue with interfaces with Sandia, Lawrence Livermore, and Oak Ridge National Laboratories, as well as DOD organizations (Phillips Laboratory, DNA). This effort includes new and refined equations-of-state and material failure models to accurately model the impact response of new shielding materials. HVI test data is used to verify the codes before predicting impact performance beyond test capabilities.

5. FUTURE PLANS

In 1989 the "Report on Orbital Debris" issued by the Interagency Group (Space) was published. This report represented an interagency consensus on the issues associated with orbital debris. The Report not only set out the issues, but it focused as a national "touchstone" for planning and decision making in the years following its release. The Advanced Programs Division has developed a NASA wide orbital debris program plan which has drawn on the knowledge we have accumulated from our extensive discussions DOD, other government agencies, the international community and the aerospace industry. This NASA planning has also drawn heavily on the 1989 Report.

However, it is timely to involve other key players in the technical planning of future activities. To this aim, NASA proposes to sponsor a Technical Assessment Study to put together an international consensus on the current understanding and the necessary requirements to deal with the major technical issues associated with the orbital debris problem. The details associated with the development of this proposed new technical "touchstone" are set out below.

Objective:

To Conduct a Technical Assessment Study of - the present understanding of our ability to measure and model the current and projected orbital debris environment - the current technical capabilities and limitations of means for measuring the debris population
- the areas of greatest uncertainty in our understanding of the debris environment - the methods for reducing observational limitations and uncertainties - the various

techniques for protecting spacecraft against the orbital debris environment
- the various methods for preventing, reducing and controlling the debris environment now and in the future

To create an inventory of all stored energy systems presently on orbit.

Purpose:

To develop an improved technical baseline on orbital debris, a common "touchstone", with international credibility, without political or policy influences, for use by policy makers and space agencies.

Method:

Prominent international technical and scientific personnel, expert in the various aspects of orbital debris would gather to produce a draft text of the technical report. Discussions and preparation of the final report are planned to take about three weeks. Final editing and publication of the Technical Assessment Study would take place in the months following the study.

Product:

The final product of this effort will be a report of global perspective: - defining all of the major technical considerations - delineating the state of knowledge in each area considered - discussing areas for improvement, with an attendant prioritized set of suggested actions

By inviting technical experts from around the world to participate in the conduct of the Technical Assessment Study, NASA expects that its final report would provide a new baseline for coordinating and focusing both the national and the international efforts dealing with the long term aspects of the orbital debris problem. NASA is planning to have the Technical Assessment Study completed by the end of 1994.