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ABSTRACT

The study of the natural space environment and its effects on spacecraft is one of the most important and least understood aspects of spacecraft design. The Space Environments and Effects (SEE) Program prepared the Meteoroids and Orbital Debris Lesson Plan, a SEE-focused high school curriculum to engage students in creative activities that will improve their math and science concept skills as well as introduce them to the natural space environment. Four main lesson objectives feature students defining vocabulary related to meteoroids and orbital debris, reviewing and summarizing articles pertaining to the orbital debris environment, interacting with a guest speaker in discussion topics about orbital debris and the hazard it poses, and proposing a method and designing a prototype for the reduction of space debris. (CCM)

NASA's Space Environments and Effects (SEE) Program

Meteoroid and Orbital Debris Lesson Plan

This information my be found at the following website under the "What's New" category:

http://see.msfc.nasa.gov

Welcome to Meteoroids and Orbital Debris Lesson Plan

It is NASA's policy to involve the educational community in our endeavors to inspire America's students, create learning opportunities, and enlighten inquisitive minds. It is one of the Marshall Space Flight Center's (MSFC) missions to research, develop, verify and transfer space environments effects technologies to its community. A key strategy applied to meet this mission is education; educating not only the managers, designers, and operators of spacecraft, but also the general public, including high school students, who will be our future managers, designers, and operators of America's spacecraft.

The study of the natural space environment and its effects on spacecraft is one of the most important and least understood aspects of spacecraft design. The Space Environments and Effects (SEE) Program, has worked with Sparkman High School in Huntsville, Alabama, to prepare a SEE focused high-school curriculum that will engage students in creative activities that will improve their math and science concepts and skills as well as introducing the students to the natural space environment.

This cooperative effort began after Sparkman submitted an unsolicited proposal to the SEE Program to develop a high-school level space environments and effects curriculum. The teachers polled the students and found that a majority of the students were interested in the meteoroid and orbital debris environment. The SEE Program recognized the enthusiasm of the Sparkman teachers and interest of the students and wanted to help establish a quality space environment curriculum that will spark a greater interest in math and science for the students to pursue.

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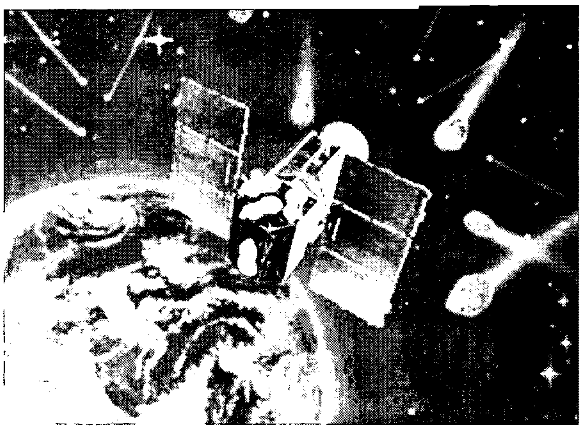
Meteoroids and Orbital Debris Lesson Plan

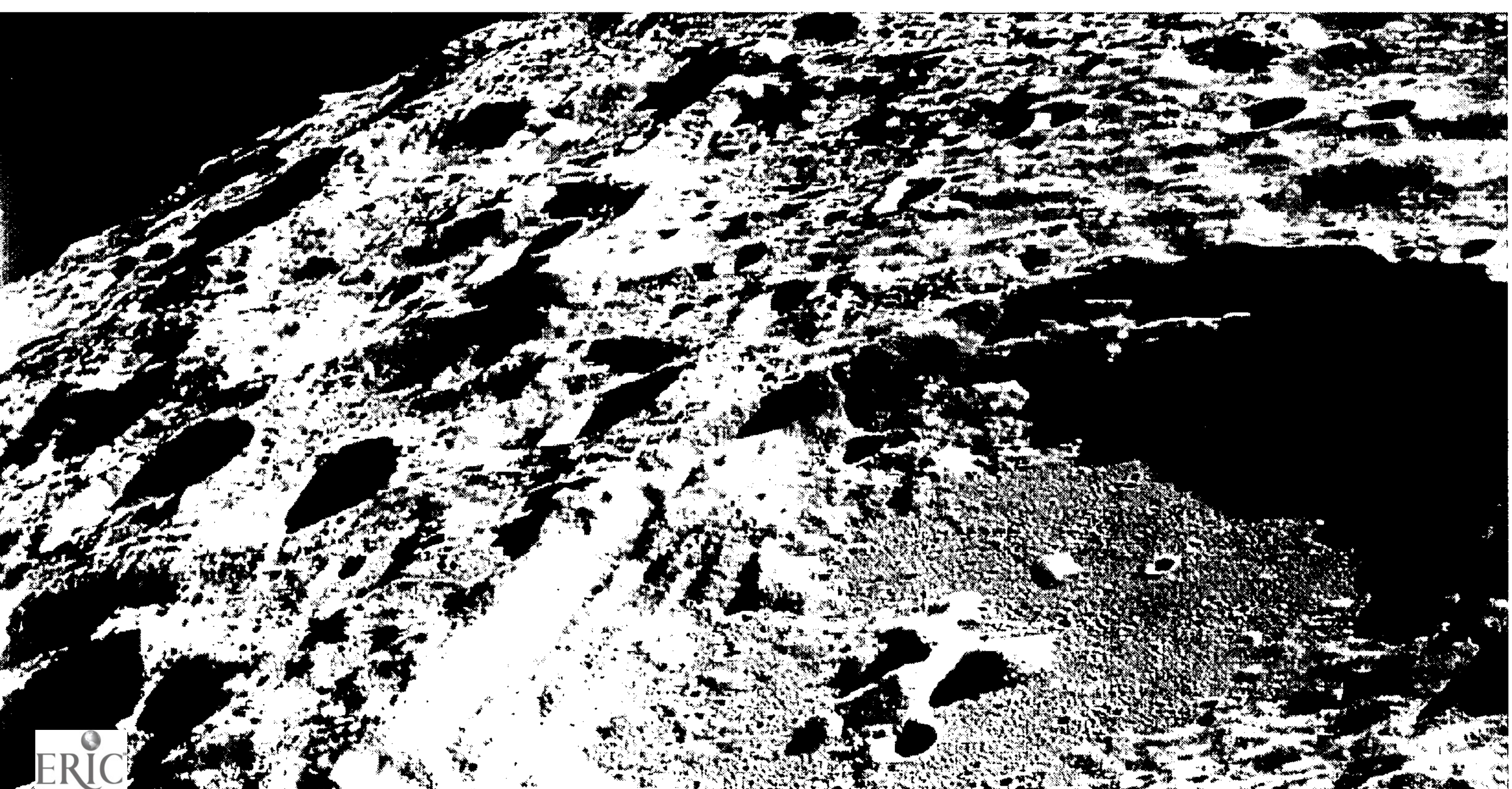
Welcome to Meteoroids and Orbital Debris

Lesson Plan



Introduction:

In recent history, space has gained a new type of inhabitant---trash! Forty years of space exploration has led to the accumulation of significant quantities of orbital debris. These objects range in size from a tiny paint chip to a giant inoperable satellite, and they travel at such incredible velocities that their presence is a point of extreme concern for scientists and astronauts. These projectiles strike with astounding force and can create shock waves in metal. Scientists are working to create materials that can best withstand these types of hypervelocity impacts.



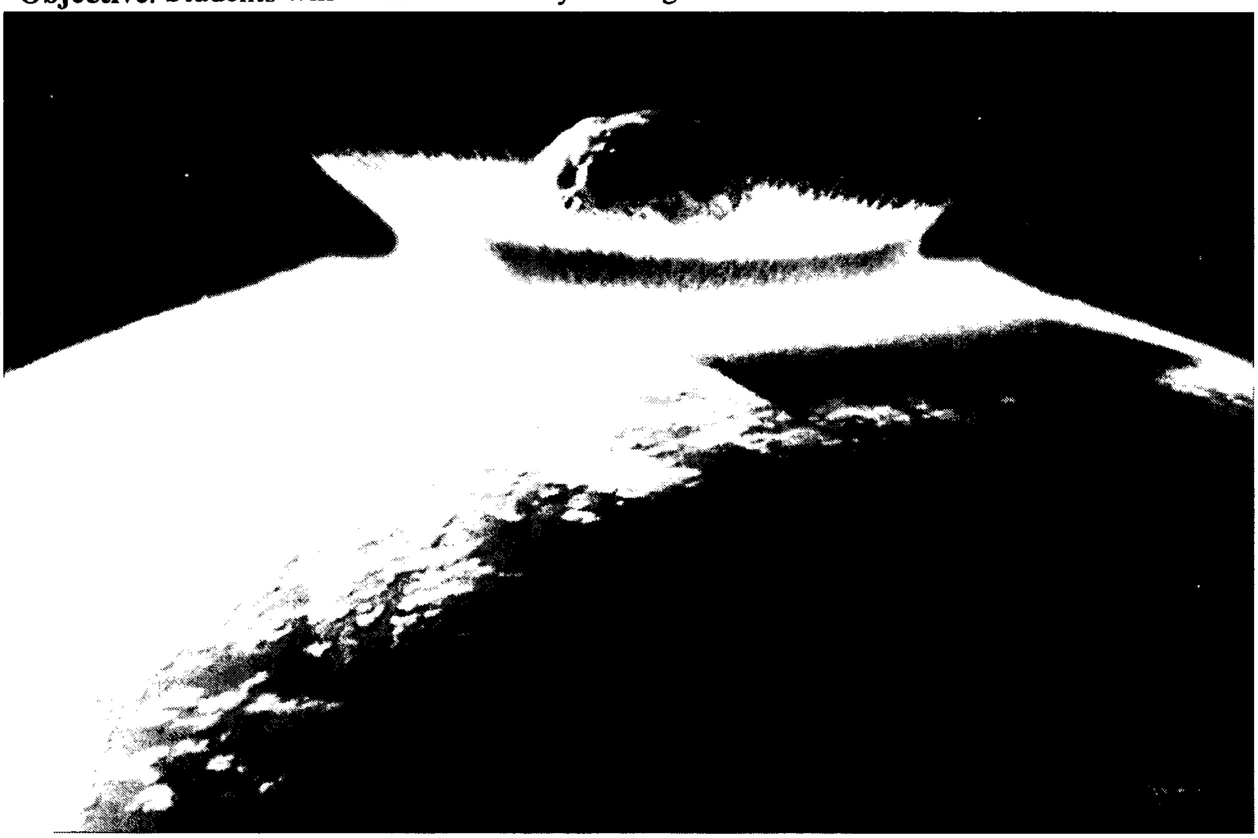
Session 1

Session 1

Introduce the students to the idea that space has environments. Many students relate the idea of environmental issues only to life sciences, so they will need to be informed of space environments and the atmospheric conditions on other planets. The runaway greenhouse effect on Venus is a good discussion point, since most students are familiar with the concept of the greenhouse effect. For the purpose of this lesson set, there is no need to enter into an in-depth discussion of the other space environments at this point.
(See the Publications section of the Contents)

Activity One:

Objective: Students will define vocabulary relating to meteoroids and orbital debris.



Introduce Vocabulary (See Appendix A for definitions; transparencies follow Appendix A to help illustrate terms)

- Difference between meteor/meteorite/meteoroid (Mention origin of meteoroids: ejecta from asteroids and comets. The Leonid meteor shower in November is a good example of what occurs when the earth passes through the path of a comet's debris. NASA is greatly concerned about the danger this debris poses to orbiting satellites. The Leonids' could even cause delays in scheduled mission launches.)
- Micrometeoroids (These are the main source of erosion on the moon.)

- Vesta meteorites
- Mini-Comets
- Fireball
- Stream
- Shower
- Crater (draw and label)
- Rays
- Orbital debris environment (ODE) Include discussion of the difference between the particles. Cometary particles are very light and ash-like. Asteroidal particles are very dense and rock-like. Vehicle particles include paint chips, bits of metallic debris left over from explosions, etc.
- Path
- Trajectory
- Velocity
- Acceleration

Activity Two:

Hands-on activity

Types of Impact Sites

Objective: The students will simulate meteorite impacts on various types of terrain and observe the effects.

Material needed:

- Gravel
- Water
- Sand
- Various sized "meteorites"(stony-rock, irons-coins, marbles,etc.)
- Flour
- Cocoa
- Pasta(lasagna, spiral, regular spaghetti)
- Aluminum pie pans
- Meter stick
- Iron filings
- Soil
- Wet sand
- Sturdy chair

Procedure:

This activity is best done outside or with drop cloths, and use safety goggles.

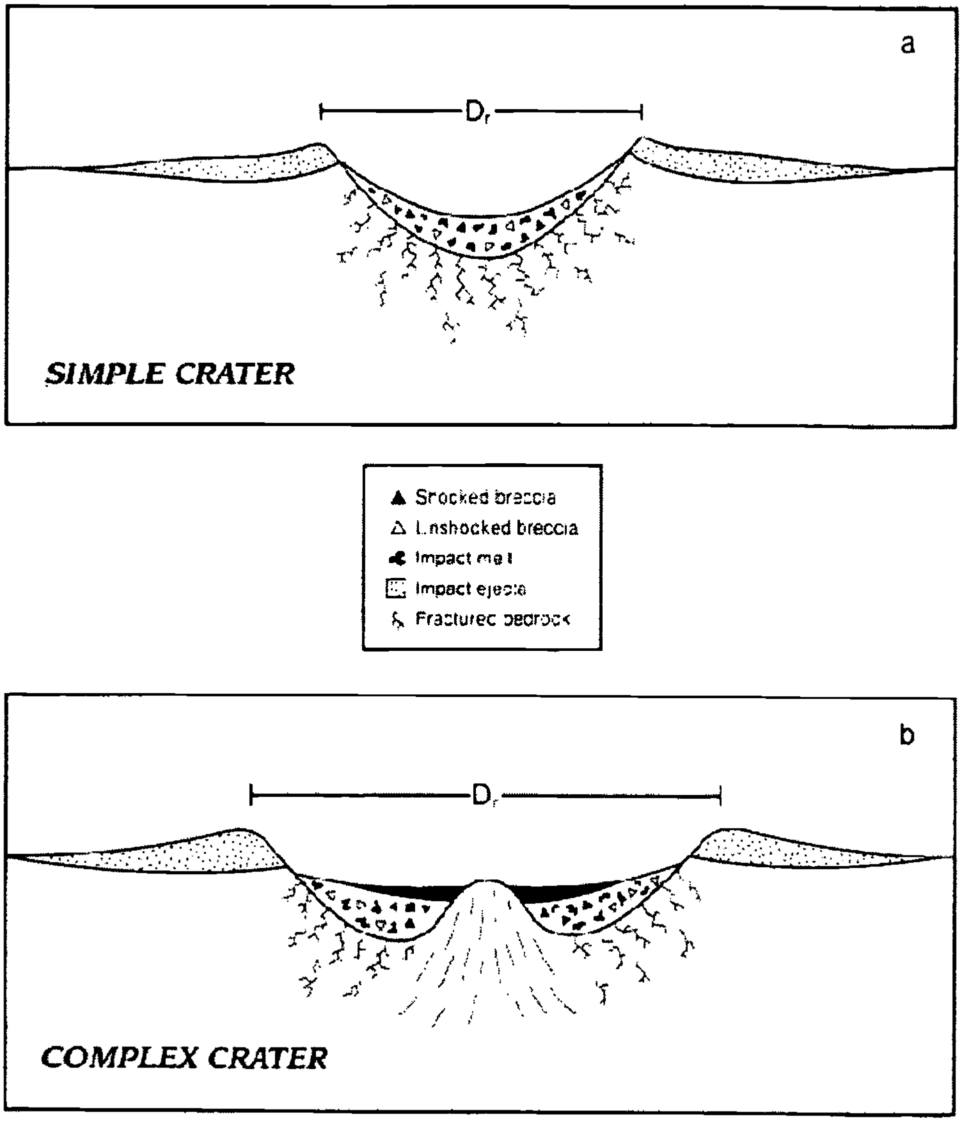
1. Place drop cloth on the floor or ground.
2. Place the pie pan in the center of the cloth. Fill the pie pan with the chosen type of terrain(i.e. water, sand, gravel, etc.)
3. Choose a meteorite.
4. Stand in the chair next to the pie pan.
5. Have one group member function as a "spotter" to help the "dropper" maintain his/her balance.
6. A third group member should hold the meter stick in a matter such that the distance the meteor falls can be measured.
7. Release the meteorite so that it will impact as close to the center of the pie pan as possible.
8. Make a notation of the distance of the fall of the meteorite.
9. Draw a sketch of the impact site and write a brief description of the site.
10. Repeat steps 2-9 for each selected terrain.
11. Standing a few feet to the side of the pie pan, project the meteorite into the pie pan at an angle.
12. Draw a sketch of what you see.

Teacher will demonstrate the following:

- Fill one pie pan 3/4 full with flour. Sprinkle a tablespoon of cocoa over the flour. Repeat steps 4-7.
- Crumble the spaghetti, spirals, and lasagna into various sizes. Fill a pie pan 3/4 full with the pasta, taking care to concentrate the majority of lasagna noodles on or near the top. This will demonstrate the appearance of regolith(lunar soil) on the moon, show the mixture to the class by using a projection apparatus.

Suggested evaluation methods.

1. Have students evaluate their hypothesis according to the data collected and write a brief conclusion.
2. How would a student vary the experiment to evaluate a separate hypothesis(create the hypothesis, then make suggestions)



Activity Three:

(Begin on session 1, end on session 2)

Reading Activity

- Select 8 to 10 articles relating to meteorites, orbital debris, etc.
- Assign each student an article, making sure that 3 to 4 students have the same article in order to be grouped together in session 2.
- Tell the students that they will write a one to two page summary of their article. Students will need to be prepared to present the summary to the class in session 2.

Evaluation

Homework

1. Study for vocabulary quiz.
2. Finish reading the article and write summary.

****** Tell students to start collecting materials for project on session 3-4. No specifics need to be given at this time. Simply ask students to bring aluminum foil, pipe cleaners, paint, construction paper, paper towel rolls, etc. If each student brings his/her materials in a shoebox, storage will be MUCH easier.**

Session 2

Session 2

Activity One:

Objective: Students will review and summarize articles pertaining to the orbital debris environment.

To review the vocabulary words briefly before the quiz, try this simple activity. On a clean transparency film, write a scrambled version of the vocabulary list. Reveal the words one at a time, and the students will orally define the word after they unscramble it. (Quiz-See Vocab Test)

Activity Two:

People who had the same articles are grouped together to discuss the articles and select a spokesperson who will deliver a summary to the class.

Option: Have each group member present one aspect of the article.

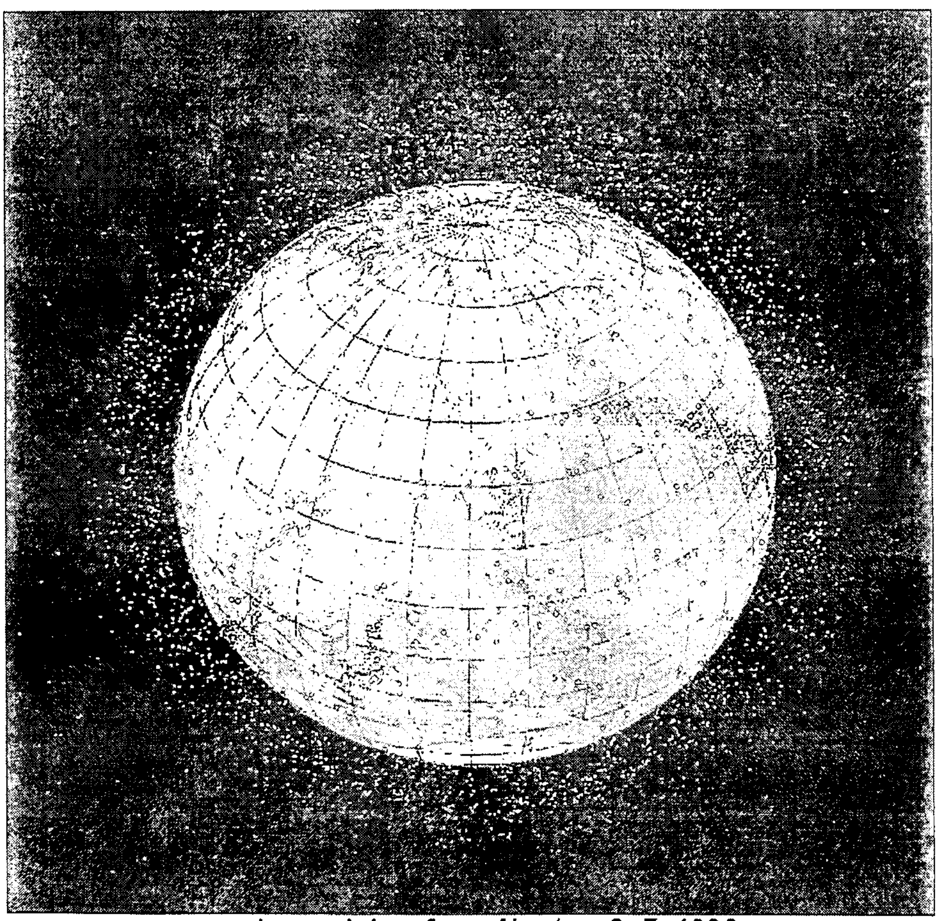


Image taken from *Newton, 2, 7, 1998.*

Activity Three:

BOMBS AWAY!

(Simulated Hypervelocity Impacts)

Objective: The student will evaluate the differences in the impact sites caused by each type of projectile.

Background Information:

In recent history, space has gained a new type of inhabitant-trash!. Forty years of space exploration has lead to the accumulation of significant quantities of orbital debris. These objects range in size from a tiny paint chip to a giant inoperable satellite, and they travel at such incredible velocities that their presence is a point of extreme concern for scientists and astronauts. These projectiles strike with such force that they create shock waves in metal, and they can even shatter and disperse in a phenomenon known as the debris cloud. Scientists are working to create materials that can best withstand these hypervelocity impacts.

Materials:

- Meter stick and/or ruler
- Spring gun from ballistic pendulum
- Round projectiles for spring gun (i.e. steel ball, aluminum ball, wooden ball, etc. these can be purchased as a set)
- Graduated cylinder
- Water
- Aluminum pie pans
- C-clamp
- 1 sheet of carbon paper
- Several sheets of white paper
- Tape
- Graph paper
- Colored pencils
- Permanent marker

Your turn...

PROCEDURES A

1. Weigh the projectile on a triple beam balance and record this weight in the data table.
2. Fill the graduated cylinder with approximately 150 ml of water.
3. Gently drop the projectile into the graduated cylinder.
4. Record the change in the water level (volume) in the data table.
5. Calculate the density of the projectile (Hint: Density = mass/volume)
6. Repeat steps Al through A5 for each projectile.

*** You may want to pour the water from the graduated cylinder into a beaker in order to easily remove the projectile from the cylinder. Dry the projectile before returning it to its case.

PROCEDURES B

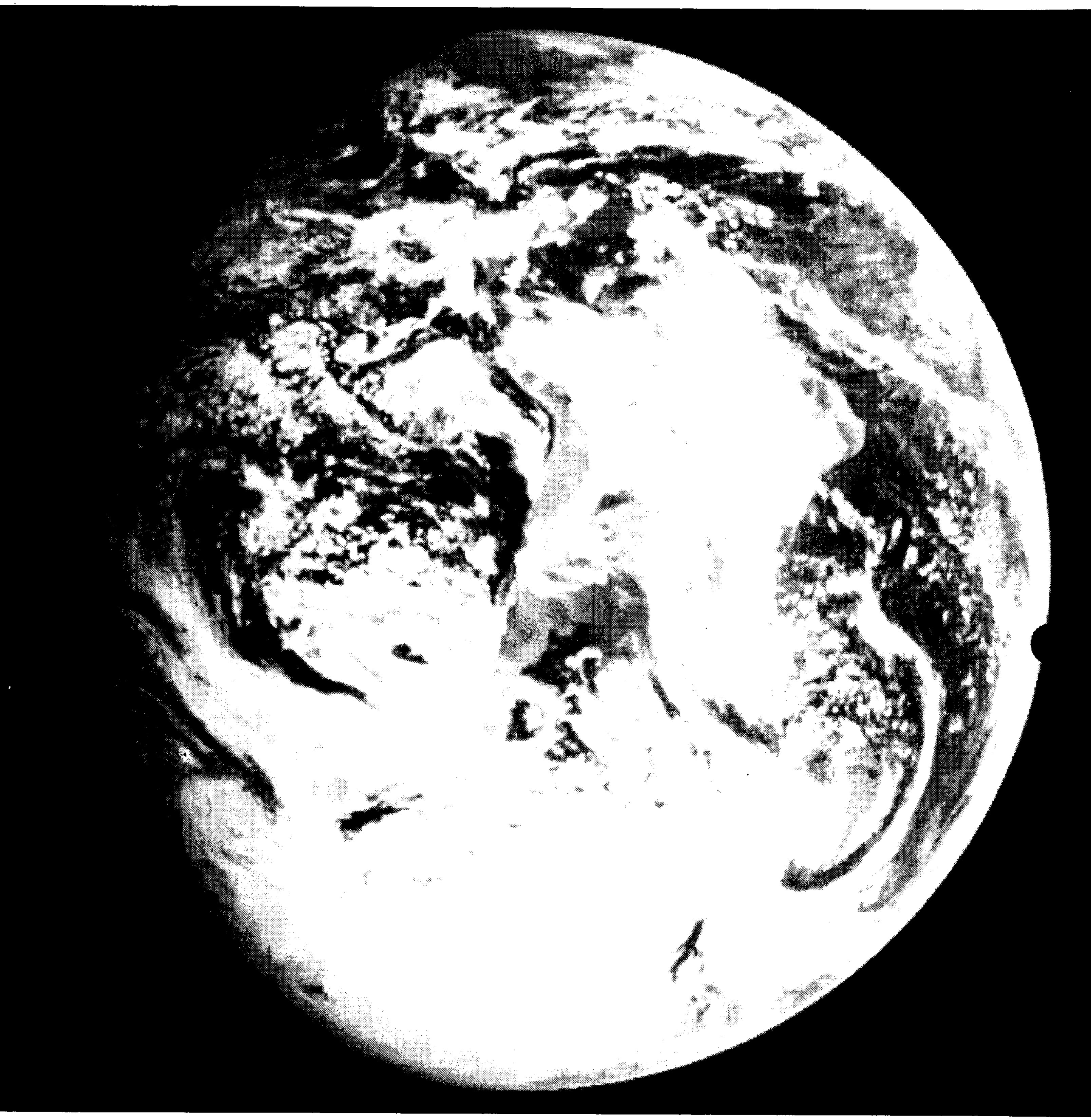
1. Your teacher will demonstrate how to attach the spring gun to the table suing the C-clamp.
2. Load a projectile into the pendulum.
3. Fire a test shot to approximate the landing site of the projectile.
4. Place a sheet of white paper, covered with a sheet of carbon paper, on the floor in the approximate areas of the impact.
5. Fire another shot onto the paper, using the same projectile.
6. Remove the carbon paper from the white paper.
7. Carefully place the center of an aluminum pie pan (upside down) on the mark created by the projectile on the white paper on the floor.
8. Using a permanent marker, label the pie pan so that you will know which projectile (steel, wood, etc.) was shot at it.
9. FIRE AWAY! Fire tree shots using the same projectile. BE CAREFUL NOT TO MOVE THE GUN EVEN SLIGHTLY OR THE PROJECTILE MAY NOT ALWAYS HIT THE PIE PAN!
10. Repeat steps 2-8 using a different projectile.

MAKE A GRAPH!

Directions: Analyze your data to list the projectiles in order of increasing density. Examine the pie pans, and rank them 1 -10 in order of increasing damage. (The least damaged pan will be labeled # 1, and the most damaged pan will be labeled # 10). Construct a bar graph, placing the density values from the projectiles along the horizontal axis. The scale for the vertical axis should be set as 1(bottom) through 10 (top). Shade in a bar that relates the damage assessment to the density of the projectile.

Conclusions:

Analyze your graph to make a decision concerning how density of a projectile relates to the damage the projectile causes. Most natural meteoroids have a density close to that of stone, while much of the man-made debris in space has metallic densities (generally higher than densities of stones). Imagine you are a researcher working in the field of meteoroids and orbital debris. Write a brief letter to a NASA engineer concerning your findings from this lab, including suggestions about which types of debris he should be most concerned with when designing spacecraft.



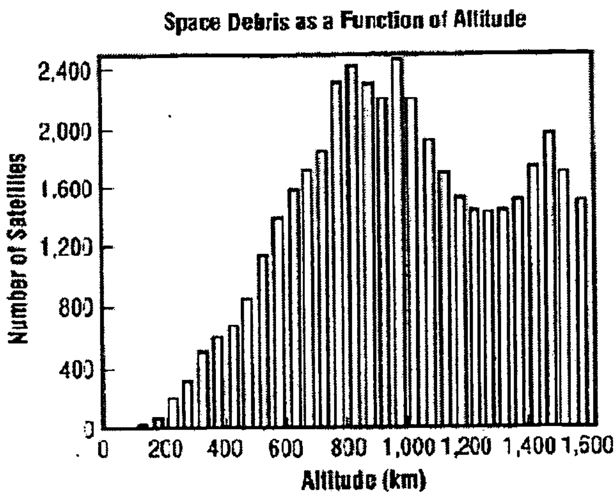
Session 3

Session 3

Activity One:

Objective: Students will interact with a guest speaker in discussion topics related to orbital debris and the hazards it poses.

** If you do not have access to guest speakers you may want to: 1) expand the calculations, 2) move on to session 4, 3) review meteor information under the Leonids (See Contents section).



Activity Two:

Objective: Solve situational problems involving velocity and acceleration. (See Velocity Problems: answer key is provided)

WORK PROBLEM #1 AND PROBLEM #9 AS EXAMPLES BEFORE ASSIGNING THE PRACTICE SET.

Session 4/5

Activity One:

Objective: Students will propose a method and design a prototype for reduction of space debris.

SDCA

We go farther to pick up trash than anyone else!

Space Debris Collection Agency Proposal (SDCA) (Cooperative Learning Project)

****** Students should have been told on day one that they would need to start collecting household material and bring them to class (i.e. cardboard, straws, rubber bands, etc.)**

Background information:

Students will need prior knowledge of terminology relating to space debris (i.e. orbital debris environment, micrometeoroids, velocity, acceleration, impact, etc.). Understanding of the scope the space debris problem on an international scale.

PROBLEM

Propose a method and design a prototype for reduction of space debris.

Introduction: Students are contractors preparing research proposals to present to the SDCA approval panel (teacher and 2 other panel members). Working in small groups, students will construct a prototype of a "debris elimination system" from basic household items and craft supplies and describe the function(s) of their systems in written proposal format (see attached from)

Research Proposal

Proposal Title:_______________________________________

Presented by_______________________

Date: ___________________

Sketch of prototype and peripherals:

Detailed project description (how will the mechanism work?):

Personnel Requirements (i.e. Is it a manned mission? How many? Remote? Etc.):

Projected outcomes (How long will the clean-up effort last? What % elimination? Etc.):

Estimated Total Cost:

Itemized price list:

SDCA

We go farther to pick up trash than anyone else!

Project Evaluation Form

Proposal Title:____

Presented by:______________________

Date:_________

I. General (worth 3 points each)

Neatness _____

Completeness _____

Creativity _____

Plausibility _____

II. Prototype (worth 4 points each)

Is the sketch appropriate? _____

All described mechanisms represented? _____

Does the prototype function as intended? _____

III. Project Description (worth 4 points each)

How will prototype be deployed? Retrieved? _____

Complete description of function _____

Explanation of personnel requirements and management techniques _____

Explanation of outcomes _____

Plausibility of cost _____

IV. Group Presentation (worth 4 points each)

5 Minute time limit ______

All members participated ______

Demonstration of prototype function ______

Discussed all aspects ______

Professionalism ______

TOTAL POINTS (60 points maximum) __________

Articles

Article 1

The Dangers of Orbital Debris
by Jeff Foust

While the NBC miniseries Asteroid dramatized the threat asteroid impacts are to the Earth, satellites in orbit around the Earth face a much more Mundane -- but equally dangerous threat: orbital debris, or space junk.

During last month's repair of the Hubble Space Telescope, astronauts found a small hole in the dish of one of the telescope's antennas. A collision with a small piece of space junk is considered the likely cause. During the repair mission the shuttle, with the Hubble docked in its payload bay, had to fire its maneuvering jets to avoid coming "dangerously" close to a fragment from a Pegasus rocket which exploded several years ago.

Not all spacecraft are as lucky. Last year ground controllers lost contact with CERISE, a small British-built satellite. Weeks later, engineers used the data from the satellite to discover that the satellite has been struck with a fragment from an Ariane rocket which had exploded several years ago. The collision broke off part of the satellite which helped maintain its stability.

Orbital debris is becoming a major concern for those planning spacecraft missions in Earth orbit, either in low Earth orbit (LEO) or in geosynhronous orbit (GEO). It is a concern that will grow as constellations of dozens and hundreds of communications satellites are launched into LEO, such as Iridium and Teledesic, and while large targets for space junk are constructed, namely, the International Space Station.

The problem with counting orbital debris is that even tiny pieces of junk can cause significant damage. At orbital velocities of over 28,000 km/h (17,500 mph). an object as small as 1 cm in diameter has enough kinetic energy to disable an average-size spacecraft. Even objects as small as I mm can damage sensitive portions of spacecraft.

A 1995 NASA Study, "Guidelines and Assessment Procedures for Limiting Orbital Debris", notes that there are about 6,000 objects in LEO being tracked by the U. S. Space Command. Of these only about 5 percent are operating spacecraft. More than half are fragments from on-orbit explosions, like the Ariane explosion which created the debris that disabled CERISE. About 40 percent are dead spacecraft and upper stages of rockets left in orbit.

However, that 6,000 is only the tip of the iceberg. It represents only those objects that can be tracked by groundbased radars. The 1995 NASA study estimates that there are 15,000 objects in LEO 10 cm or larger; one of those is enough to "catastrophically fragment" a spacecraft, adding to the debris problem.

The same study estimates that there are about 150,000 fragments 1 cm or larger, enough to disable a spacecraft, and more than a million objects I mm or larger. Finally, the study estimates that there is over a billion tiny particles as small as 0.1 mm in diameter -- mostly remnants from solid rocket motor firings -- that still have enough to wear down spacecraft surfaces.

Not all the news about orbital debris is bad. In 1996 NASA updated its models for estimating the amount of orbital debris in LEO. The new model incorporated radar observations from Haystack Observatory in Massachusetts with a refined dynamical model. The new results found that the

Population of objects 1cm or larger in orbit might be just half the number estimated by a model five years before.

Nonetheless. even if there are only 75,000 objects 1 cm or larger in LEO, it's cause for concern for spacecraft planners. Debris this size is large enough to disable a spacecraft, but too small to be tracked and avoided. The only way to deal with this debris is to add as much shielding as feasible. and hope the spacecraft is lucky through its planned mission.

The 40 percent of the trackable objects in LEO that are old spacecraft or upper stages can make the debris problem even worse by becoming sources of even more small debris. This can happen either when the object is stuck by current space debris, fragmenting the vehicle into hundreds or thousands of smaller pieces. This can also happen of the spacecraft's own accord. through such events as exploding batteries or bursting fuel tanks.

Orbital debris has become a concern for those planning even small spacecraft missions into LEO. It's become a major concern for those working on what will become the largest structure in LEO, and thus the largest target for debris: the International Space Station.

The threat of impacts by orbital debris has been a concern throughout the design of the space station. On a list of top ten hazards for the space station compiled last year by the NASA Safety Office, the threat of impacts by micrometeorites and orbital debris ranked sixth ("extremely hazardous EVAS" to repair space station solar panels was on top of the list.)

In January, a National Research Council committee released a study evaluating NASA's efforts to study the threats of orbital debris. While largely positive, the committee did find some areas of concern about plans to protect the station from debris.

"Overall efforts to protect the space station have been extensive and thorough," said committee chair George Gleghorn. a retired vice president and chief of engineering at the TRW Space and Technology Group.

"However," he noted, "the space station will be particularly vulnerable to collisions due to its size and because it will be in orbit for at least 15 years.

The committee's greatest concern was about how well Russian-built modules would be able to deal with the impact threat of space junk. The committee thought the Russian contribution to the station was not sufficiently shielded to protect the station's occupants.

The ability of a particular module to withstand an impact from orbital debris is measured using, a computer module. Given the known size and shielding of a module, and the estimated population of orbital debris, engineers calculate the "probability of no penetration" (PNP), that is, the probability that a module will not be penetrated by debris in a ten-year period.

The overall goal of the space station is a PNP of 0.81, which is a 19 percent chance that the station will be penetrated by orbital debris at least once in its first ten years. This is mandated by requiring the Russian contributions have an overall PNP of 0.90. and the American and other modules have an identical overall PNP.

While the American and other modules have had little problem reaching their goal. the Russian modules have fallen far short of their goal of a 0.9 PNP. A design review in 1994 found the Russian sections to have an abysmal PNP of 0. 12, making, it almost certain they would be penetrated at least once by orbital debris.

Since then the Russians have improved the quality of their shielding. but their PNP is still only

0.6. bringing the overall probability of no penetration for the station down to 0.55 -- far short of the goal of 0.81.

Although the new orbital debris models improved the PNP to 0.85, above the goal, the committee still expressed concern about the lack of shielding in the Russian-built Service Module. At the time of their report, plans were to add additional shielding to the module after launch in 1998. Since then, the launch of the module has been delayed, likely to no sooner than the end of 1998 and possibly later. There has been no indication if this delay will allow engineers to add additional shielding to the station before launch.

Shielding for the station generally involves a system called a "Whipple bumper." A thin outer layer of material, Usually aluminum, is placed a short distance in front of the module wall. The aluminum bumper is designed to vaporize any junk that hits it, and spreads any remaining debris out into a larger area that can be absorbed by the module wall, or "catcher" below the bumper.

The shielding is designed to absorb impacts of objects up to 1 cm in diameter. Beyond that, it can only minimize the amount of penetration the debris creates in the station module. Unfortunately, objects larger than 1 cm up to 10-20 cm cannot be tracked and avoided reliably. leaving a window of vulnerability to the station from medium-sized debris. Until shielding or tracking can be improved, there is little to do but hope that the station is lucky.

There have been a number of schemes developed to counter the problem of orbital debris. Proposals have ranged from garbage-collecting spacecraft to lasers which vaporize parts of debris, creating an impulse which pushes them into orbits that speed their demise by burning up in the Earth's atmosphere. However, none of these proposals will likely be implemented any time in the near future, for reasons of cost if nothing else.

The emphasis of NASA's plans for dealing with space junk has been prevention. The 1995 NASA study which looked at orbital debris listed several Guidelines for minimizing the problem. It suggested dying spacecraft and booster stages be Pushed Into "graveyard" orbits outside of LEO and GEO. where even if they break apart, they will contribute little to the orbital debris in the more populated orbits.

The study also suggested steps be taken to prevent the creation of debris from spacecraft and booster stage explosions by venting fuel which might burst fuel tanks and discharging batteries which might explode.

Similar sentiments were expressed by those attending a recent international forum on the problem of orbital debris, organized by the United Nations in Vienna. These was considerable interest with dealing with space junk in GEO, an increasingly-crowded orbit that has its share of defunct spacecraft and space junk.

One proposal was to require spacecraft to move 300 km (180 mi.) beyond GEO when they have reached the end of their lifetimes, to make room for new spacecraft and to limit the possibility of the defunct spacecraft contributing to the debris problem.

The Vienna meeting is part of a larger 5-year plan by the UN to put together guidelines to minimize the creation of space junk.

Until we can find the money for debris-deflecting lasers or garbage-collecting spacecraft, it appears the key to reducing orbital debris is the same lesson taught time and time again on Earth: don't litter.

Article 2

Orbital junk threatens space station
Vincent Kiernan, Washington,DC

Russia's contributions to the planned International Space Station will be so poorly shielded against impacts with orbital debris that they could jeopardize the entire project and put astronauts' lives at risk. Additional shielding should be added to these segments, says a report from the US National Academy of Sciences.

The first components of the space station will be launched next year. A series of modules will then be bolted on until construction is completed in 2002. The surface area of the finished station will total some 11,000 square metres. This will provide a huge target for orbiting space junk, including the debris of old satellites and rockets.

NASA plans to use ground-based radars to detect large chunks of debris and maneuver the station out of their way. The craft will be protected against small fragments by aluminum shielding.

But computer models of the bombardment that the station is likely to receive suggest that the Russian-built components would probably be penetrated by debris at least twice during the station's 15-year life, says the academy committee. An accident ofthis type would almost certainly render the station useless. The structure could even break apart, killing astronauts.

Russia is to provide a service module with living and working areas for the station's crew, a cargo block with docking ports. a power-generating platform, escape pods to evacuate astronauts in an emergency and three research modules. The vulnerability of this hardware is "a major problem", says the academy committee, which studied the issue at NASA's request.

The committee was chaired by George Gleghorn, formerly chief engineer for the satellite manufacturer TRW Space and Technology Group in Redondo Beach,California. He says that when the US wooed Russia as a partner in the station, it agreed to incorporate components that had already been designed for Russia's own use. But the components were not designed to NASA's standards for durability against debris. By contrast, says Gleghorn, hardware from other partners, such as Japan and the European Space Agency, was designed from scratch, and NASA was able to impose stricter standards.

Nicholas Johnson, an expert on orbital debris at NASA's Johnson Space Center in Houston, says that the Soviet and Russian space programmes never tried to shield their orbiting space stations from space junk. One reason is that orbital debris is relatively rare at the 400-kilometre altitude at which S Soviet and Russian space stations, all based on the same design, have orbited. 'They have 25 years' worth of experience with one basic tin can, and they've never had a problem,' says Johnson. '

But the International Space Station will fly at an altitude of 350 kilometres, where space junk is more abundant.

Additional shielding cannot be added to the Russian service module before its launch later this year because there is no room for it inside the rocket that will send it into orbit. Extra shielding could be installed by astronauts at a later date. But The academy committee warns that the busy station assembly schedule means that this probably will not be done for several years--leaving the station open to a catastrophe.

Article 3

Did Sally die in vain?
Mark Ward on why we must wring solemn promises from the telecomm giants

It was a great Year. Bjorn Borg won Wimbledon for the third year running, and The Deer Hunter cleaned up at the cinema and won several Oscars. But most significantly in 1978, the New Wave pop group Devo released its first album, Are We Not.Men? Side two featured a track called Space Junk. It was a sensitive story about Sally, who, was struck down dead by a chunk of space junk as she walked down an alley.

The boys from Akron, Ohio , had been inspired by the fiery return to Earth of a Soviet satellite that had spread radioactive debris across the snowy wastes of northern Canada earlier that year. No one was killed--especially anyone called Sally. Since 1978, pieces of space junk have continued to make a nuisance of themselves on a regular basis. So far, though, the only life that they have claimed is that of a Cuban cow. However, Delia Adela Guevara de Palazzo narrowly escaped becoming the first human victim when in 1991 a 1.5-kilogram fragment of the Soviet Salyut space station hurtled into her back garden in Argentina. Up in space, meanwhile, pieces of old rockets have dented shuttle windows on several occasions. And last year, a hunk of an old Ariane rocket was blamed for knocking the French satellite Cerise out of its orbit. Space scientists estimate that around 100,000 pieces of orbital debris now whiz above our heads. They travel at thousands of kilometres a second and can do serious damage to any object they smash into.

Most nations with a space programme are now looking into ways of avoiding adding to the mess. Their efforts though, are likely to come to naught because 22 space companies are determined to put three times as many satellites into orbit as were launched in the past 40 years. They plan to create networks of small satellites in low Earth orbit, at altitudes of between 700 and 3000 kilometres. The payoff will be that anyone with a mobile phone connected to one of these networks will be able to make calls to and from anywhere in the world, be it the middle of the Sahara or the centre of the Pacific. If all the companies succeed in their plans, the number of satellites in space will exceed 1000.

Yet every time a satellite is put into orbit, more debris is created. All satellites jettison a second-stage and third-stage rocket to get into orbit, which float around and add to the junk. The fairings surrounding a payload are also blown off into space. And it is reasonable to assume that some of the rockets taking the satellites into orbit will go wrong and shower even more debris into space. To make matters worse, the satellites themselves have a finite life and have to be replaced periodically.

NASA predicts that if the amount of debris exceeds 150,000 fragments of 1 centimetre or larger, space flight could become impossible. Every spacecraft would have to run the gauntlet of the orbiting junk cloud. And collision with debris could cripple a craft or render its payload useless.

It may now be too late to stop the new satellite networks being built. However, because the networks of satellites will have a global reach, their owners must negotiate the right to transmit into every country that they fly over. Governments could easily refuse permission, ruining the prospects for these networks. And another show stopper could be a lack of cash. Already many of the companies with plans for large networks are finding it difficult to raise the money to realize their plans. Only the 66-satellite Indium network and the 48-satellite system of Globalstar have raised all the money they need. Most of the others are struggling.

But perhaps the most ambitious plan of all, the Teledesic network, may succeed because if it fails to find enough money, its two inventors, Craig McCaw and Bill Gates, can afford to pay the difference out of their own pockets. The company plans to put some 300 satellites in orbit at a cost of around $9 billion. Gates alone is worth more than $13 billion and McCaw is not far behind-- in 1994, AT&T bought the cellular phone network he had setup for $11.5 billion.

McCaw and Gates hope that Teledesic will enable them to get around the biggest bottleneck on the Internet-the last hundred metres or so between the exchange and the Internet user. The prospect of high-speedaccess to the Net is something many people and companies are likely to find irresistible.

However, the new networks depend on satellites being launched in low orbits, which are notorious for creating space debris in their wake, and this is causing growing concern in the European Space Agency. Clearly, more promises are needed of the'sort that the UN has wrung from Indium and Globalstar that they will avoid dangerous intersecting orbits. Can Teledesic with its 300 strong fleet do the same?

Sadly, with the clouds of space junk spreading as a result of setting up these networks, it looks as if in the future much of human exploration will be confined to cyberspace rather than outer space.

Article 4

Russian space module "in need of more protection"

[Washington] Russian-built sections of the international space:e station will have to be fitted with extra shielding to protect against damage from orbital debris, says a report published last week by the US National Research Council(NRC).

The NRC, the operational arm of the National Academy of Sciences, says that the station may receive warnings about possible collisions with large objects more often than previously thought -- ten times a year instead of six times. But it adds that the National Aeronautics and Space Administration (NASA) and its European, Japanese and Canadian partners have a sensible plan to counter the threat from debris.

Shields on the station's outer surfaces will pulverize small objects that strike the station at high speed. But Russian components under construction - particularly a 'service module' that will house the initial crew of three - have not been shielded to the same standard as other sections of the station.

The risk is not that the pressurized module would be penetrated by debris - the walls are thick enough to prevent that - but that plumbing and other exposed hardware on the outside would be damaged, according to Nicholas Johnson of the NASA Johnson Space Center. He was originally a member of the NRC panel, but resigned earlier this year when he took a job as NASA's expert on space debris.

Even before the NRC report appeared, US and Russian engineers had a solution in mind. Spacewalking astronauts could fit the Russian components with additional shielding after the hardware is delivered to orbit.

Installing the shielding before launch is ruled out by the way the module fits on top of its booster rocket, says Johnson. But the proposed strategy has the advantage of deferring any expense associated with shielding to later in the programme.

Russian engineers have tended to play down the threat from debris, Pointing out the lack of serious problems in their decades of experience with small space stations. Johnson agrees that NASA errs on the side of caution: "We have placed high standards on the space station in terms of reliability."

Objects larger than 10 cm in diameter could cause serious damage if they hit even shielded parts of the station, so the strategy for them is different: get out of the way. US military surveillance cameras that track orbiting junk would issue a warning whenever an object was about to come too close to the station, and the entire structure would be moved.

Such wamings have been issued in the past for the US space shuttle, and recently the Americans began providing the same service to the Russian Mir space station. The shuttle has been moved out of the way to avoid a collision, but Russian space officials have so far chosen not to move Mir on the few occasions it has been warned, trusting in the very long odds against a collision.

Even if the number of warnings does increase from six to ten a year as the NRC report suggests that it might, on the basis of recent predictive models - international space station managers would also be free to ignore a warning. They might do so if some delicate, ultra-quiet microgravity experiment would be jeopardized by firing the station's manoeuvnng engines.

Article 5

Space Station May Be Exposed To Damage From Orbital Debris
Jan. 8, 1997

WASHINGTON -- Some portions of the international space station -- particularly the Russian sections -- may be more vulnerable than others to damage from collisions with meteoroids and orbital debris, says a new report* from a committee of the National Research Council. NASA should work with the Russian Space Agency to identify and resolve significant differences in the design of shielding operational procedures, and repair techniques.

In addition, although new information reveals that most debris will strike the space station at somewhat slower speeds than originally assumed, it also indicates that objects may hit the space station from a wider range of directions, the committee said. Measures that are needed to guard against collisions and minimize potential damage include designing future protective shields to withstand a broader array of potential threats and developing a better damage-control plan.

"Overall efforts to protect the space station have been extensive and thorough." said committee chair George Gleghorn, retired vice president and chief of engineering, of the TRW Space and Technology Group. "However, the space station will be particularly vulnerable to collisions because of its size and because it will be in orbit for at least 15 years. Space station managers need to take extra precautions to reduce the risk of harm to the space station and its crew. The success of these precautions will depend on continued international efforts to reduce the amount of new debris -- such as fragments from satellite or rocket body breakups -- left behind from other missions."

In-orbit assembly of the space station -- a cooperative effort between NASA and the Canadian, Russian, Japanese, and European space agencies is scheduled to begin late this year. While most space debris is tiny and probably will be stopped by the layer of shielding that will protect each module of the space station, large objects could cause severe damage. Current plans call for the space station to be moved out of the path of debris large enough to be tracked by ground-based sensors. Unless major technological advances occur, the space station will not be able to rely on onboard sensors to provide such warnings. Protective design features and procedures will be used to reduce damage from objects that may penetrate the shields.

While overall plans to protect the space station are well-developed, the committee said that Russian modules may be more vulnerable to damage from collisions because they are not as well-shielded as the U.S., European, and Japanese segments. Although efforts to shield the Russian modules have shown progress, some of them still do not meet space station program requirements. Shielding needs to be improved for these areas. In particular, improving protection for the Russian-built service module, planned to provide propulsion and to serve as living quarters for the initial crew, should be made a high priority for space station managers.

Russian emergency procedures also vary considerably from U.S. plans for protecting the crew and vehicle if an object penetrates the space station. Better coordination between the international partners is needed for designing early warning systems and establishing uniform procedures for locating all crew members in an emergency. Space station managers should explore methods such as exchanging on-site engineering representatives and holding additional technical meetings to improve coordination and hasten agreement on these issues.

NASA should start an accelerated shield-testing program to ensure effectiveness against the predicted type and amount of debris, especially as new information becomes available, the report says. The shields currently are tested to determine whether they meet specific program requirements, such as being able to stop spherical debris measuring 1 centimeter in diameter traveling up to 10 kilometers per second. However, debris resulting from explosions, breakups, or rocket firings will vary in size. shape, and density. Limited data are available on the performance of the proposed shields against ob ects with different characteristics. Computer simulation capabilities also could be upgraded to enable more thorough shield testing.

The space suits that the U.S. space station crew plans to wear also need to be reassessed to ensure that they will be resistant to punctures. New information suggests that the amount of small debris most likely to puncture a space suit may be two to three times greater than previously expected.

The space station program should intensify planning to minimize damage from objects not stopped by shields or tracked by sensors, the committee said. Plans are in the early stages of development for preventing catastrophic loss of life and equipment if collisions do occur. Contingency efforts have focused on events that would threaten the space station or crew immediately, such as if a module wall were punctured. However, other types of damage could cause problems long after the fact. For example, damage to solar cells could result in short-circuiting and other power failures.

In addition to improving coordination with the Russians, more work is needed to design escape procedures, to evaluate sensors that detect and locate damage from penetrations, and to plan for permanent repairs, the committee said. Damage-control hardware such as pressure sensors and oxygen masks should be developed. The program must take preparations now for any enhancements that will have to be made in orbit, because hardware modifications in space will be difficult. Managers need to assess the capabilities of the space station to operate safely with damaged wiring, pipes, and other systems.

Plans also call for the space station to move out of harm's way when the U.S. Department of Defense (DOD) space surveillance network detects objects that may hit the spacecraft. Space station partners should resolve issues that would prevent the spacecraft from moving promptly whenever a warning is received, the committee said. For example, existing plans require that the space station not be moved when the space shuttle is attached because of concerns about the structural stresses such movements would create.

The potential number of "false alarms" that the DOD tracking system issues should be minimized, the committee said. New predictive models indicate that false warnings may force the space station to move more often than the current goal of no more than six times a year. NASA should work closely with DOD to determine whether improvements in the tracking system are possible.

The space station management process also warrants attention, the committee said. Management is overseen by teams of representatives from NASA, the international partners, and the Boeing Corp., the prime contractor for the space station. There are two approaches used for assessing overall risks. Orbital debris does not fit easily into either of them, making it difficult to present a cohesive picture of risks posed by these objects. Managers need to make special efforts to ensure that all risks are addressed.

The study was funded by NASA. The National Research Council is the principal operating arm of the National Academy of Sciences and the National Academy of Engineering. It is a private, non-profit institution that provides independent advice on science and technology issues under a congressional charter.

Article 6

Leonard David is a space writer based in Washington DC

WHEN the space shuttle Columbia touched down at the Kennedy Space Center in Florida last November, none of the seven crew realized how close they had come to disaster. During its 16-day mission one door of the shuttle's cargo bay was hit by a projectile that left a crater almost 2 certimetres across and 6 millimetres deep. At the bottom of the crater among the microscopic debris from the impact, lay a millemetre lump of fused metals including silver, lead and elements used to make electrical solder. "We believe Columbia was hit by a piece of electronic circuit board," says Eric Christiansen, chief analyst at the Hypervelocity Impact Test Facility at the Johnson Space Center in Houston.

The fragment almost certainly came from a satellite or rocket that had exploded in orbit. Further examination of the crash site revealed that the particles were travelling at 5 kilometres per second. At that speed, it could have punched a hole through a sheet of aluminum one centimetre thick. Had the cargo doors not been partially closed, the fragment would have hit vital oxygen tanks in the shuttle hold causing untold damage.

The incident highlights the growing problem of orbital debris, but the shuttle is not the only worry. In 1998, NASA plans to launch the International Space Station which, after its four-year construction, will operate in orbit for ten years, much longer than a typical two-week shuttle mission. NASA engineers know that during this time, the station will have to survive numerous collisions with fragments like the one that hit Columbia last year. They also know that some impacts will be far worse and have developed a 'bumper" to absorb most of them. Despite this precaution the odds that one of these collisions will penetrate the station's hull are frighteningly high. At best, this would cause the station's atmosphere to leak into space. At worst, the particle could hit a crew member causing serious injury or even death. If the threat from orbiting debris weren't bad enough, in November 1999 the Earth is due to be bombarded by the heaviest shower of meteors it has seen for years. Meteors have a much higher velocity than orbiting debris. How the space station will fare is anybody's guess. But calculating the amount of debris in orbit is no easy task. "You assume a rate at which debris is created and then you assume a rate at which it re-enters the atmosphere," says Gene Stansbery, the physicist who is in charge of orbital debris models at the Johnson Space Center. Debris creation is governed by factors such as the number of launches each year, the rate at which the redundant satellites and rocket stages begin to fragment and the size of particles they form.

Rockets and satellite break up for a number of reasons. Explosions are a major cause. In February, the final stage of a Russian Proton rocket exploded on its journey into space sending at least 200 large metal fragments into orbit, each with the potential to devastate the shuttle or space station. Another cause is the erosion of spacecraft surfaces and paintwork caused by highly reactive atoms of oxygen in the upper atmosphere.

Some debris is deliberately dumped in space. For instance, lens caps that cover sensitive instruments during launch must be jettisoned once the satellite has settled into an orbit. In 1990, the space shuttle recovered a satellite that had been in orbit for six years. Analysis on the ground showed that it was speckled with urine and fecal matter. NASA concluded that it had come from previous Russian and American space missions.

Eventually most of this debris will re-enter the Earth's atmosphere, however. At low altitudes of around 300 kilometres, where the shuttle and the space station will orbit, friction with the upper atmosphere acts like a natural vacuum cleaner, slowing the particles down so they re-enter and burn. But even this factor in NASA's calculations is unreliable because the atmosphere heats up and expands during penods of high solar activity, increasing the cleaning effect.

Stansbery calibrates his models using impact analyses from shuttle flights and other missions, and radar measurements of the number of particles in orbit made from the ground. NÅSAs Haystack radar system can spot particles as small as 5 millimetres across passing overhead. By watching a section of the sky and extrapolating their results, researchers can build up a statistical picture of what's up there. "There are around 400,000 pieces of orbital debris that we can see," says Stansbery.

Larger objects are tracked by the US Space Command in Colorado Springs, which has a worldwide network of radars capable of tracking objects larger than 10 centimetres across. Space Command catalogues large fragments so that it can distinguish between the re-entry of orbital debris and incoming ballistic missiles. It has more than 8000 objects on its books. Despite all this data, NASA still gets it wrong. Columbia suffered three times as many impacts as predicted. Stansbery says the hits generally involved particles less an I millimetre across, such as flecks of paint eroded from aging rocket stages by atomic oxygen-a problem that grows as the number of tanks increases year by year. Although these particles are too small to pierce the shuttle or the space station, they can damage the heat shields on the shuttle and its windows, which are expensive to replace.

To smarten up its predictions NASA must find better ways of modeling how the space environment is likely to change over the next few decades, stresses Nicholas Johnson, principal scientist for Kaman Sciences Corporation in Colorado Springs. "We've been in this game long enough that we shouldn't be doing back-of-the-envelope kind of calculations," he says. "But that, in essence, is still what we're doing."

Such is the concern over the threat from debris that in February the White House produced a report outlining ways to combat the problem. Key options included better design for launch vehicles and spacecraft. Boosters, for example, can shed key parts such as nose cones and payload ejection devices before reaching orbital velocity. And any that do reach orbit would deliberately use up any left-over fuel and discharge any pressurized containers which can otherwise cause explosions.

The report says that even simple measures could help. Lens caps could be tethered to their instruments and old spacecraft deliberately maneuvered back into the atmosphere or sent into higher "graveyard" orbits out of harm's way. "As a result of these efforts, the growth rate of orbital debris will decline, although the overall debris population will still increase," notes the White House study.

Researchers are also working on ways of flying the space shuttle to minimize damage. For example, once in orbit the shuttle flies back-wards, engines first. This is because the engines are no longer needed once the shuttle is in space and so can be used to absorb the impact of any debris approaching the shuttle head on. This minimizes any damage to the heat shields at the front of the craft which are vital later in the mission during re-entry. Similar measures can be adopted with the space station. For instance. it can be oriented to present the smallest possible target to oncoming debris. Nevertheless, the space station's bumpers will have to cope with many hits. NASA has plumped for a design based on an idea proposed by Fred Whipple of the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts, to protect spacecraft from meteor showers. Whipple's idea is a "meteor bumper"-a sheet of metal placed a few centimetres from the ship's hull that acts as a shield. When a meteoroid strikes, the shield absorbs the shock of the impact and the resulting fragments and vapor dissipate benignly between the bumper and vehicle's skin'.

Whipple's idea has since been refined. The ideal material for the bumper must be flexible so that it can be wrapped around the station and light so that it can be lifted into orbit . But one of the most important factors is its density, says Christiansen. When something strikes the bumper, the impact sends a shockwave through the fragment causing it to explode. This shockwave is highest when the density of the bumper and the fragment are the same. "The ideal density is around 2.8 times higher than water, about the same as aluminum," he says.

Indeed, the outer layer of the station's shield will be aluminum sheeting about 2 millimetres thick. But aluminum tends to break up during an impact creating more fragments that could damage the layer below. So NASA engineers have developed a woven blanket of carbon fibres coated with ceramics that will sit in the gap between the outer shield and the hull of the space station. Although ceramics are brittle in their pure form, their density matches aluminum. "The Kevlar blanket provides strength and prevents the fragmentation that occurs with aluminum." says Christiansen.

At the Johnson Space Center's Hypervelocity Impact Test Facility, Christiansen and a senior engineer, Jeanne Lee Crews, are testing the shield using light gas guns that fire projectiles into it at 7.5 kilometres per second. To date, their Whipple shield has performed superbly, says Christiansen. Projectiles tend to fragment and spread out as they pass though each layer. "By. the time they reach the inner pressure vessel, their energy has dissipated," he explains. The greater the space between the layers the more protection the shield will give the ship. Any fragments that penetrate the aluminum layer will then spread over a wider area before hitting the carbon fibre/ceramic blanket.

The most vulnerable parts of the station, living quarters and those facing in the direction of travel, for example, will be given shielding with a space up to 30 centimetres between the outer aluminum shield and the hull. On the other hand, some less vulnerable areas will have no shielding at all.

But even the most heavily protected areas can only withstand so much. Christiansen says the gas gun tests show that the shield can withstand a direct hit from an aluminum sphere 1-3 centimetres across. "it will protect against larger particles if the impact is oblique," he adds. If these hit head on, they could cause the atmosphere inside the station to leak into space, hit vital machinery and possibly even injure or kill an astronaut inside, admits Christiansen.

Meteors will be travelling even faster than orbiting debris at around 20 kilometres per second. In November 1999, the Earth will pass through a cloud of dust will produce a shower of over 10,000 meteors-the heaviest in 33 years. "We are anticipating a very intense storm at that time," says Walter Marker, a senior researcher at the Johnson Space Center. If necessary NASA can add more shielding and angle delicate solar panels to present a small surface area to the incoming storm and then cross their fingers.

So how likely is the station to be holed? Christiansen has calculated this probability based on the relatively crude orbital debris models that are available today and by calculating the vulnerable surface area of the fully constructed space station in 2002. "The chances of penetration are one percent per year," he says. That is frighteningly high: the figures imply that during its 10-year life-time, the station has a one in ten chance of being holed by, debris. But Crews is resigned to the threat: 'There is no way to shield against everything."

Article 7

Please dispose of your spacecraft carefully
Vincent Kieman, Washington DC

Spacefaring nations should do more to prevent debris accumulating in Earth orbit, warns the US National Research Council. If they don't, important orbits could become so clogged with high-speed orbiting debris that they become a 'death zone", presenting a potentially lethal hazard to spacecraft. The risks will grow as more countries and companies send satellites into orbit.

Although natural processes-such as the expansion and contraction of Earth's atmosphere-cleanse hundreds of tonnes of debris from low orbits each year, there is nothing to Hoover up the particles from higher orbits. Junk in high orbits will remain there for thousands or even millions of years. If pieces of debris collide at high speed, they produce a shower of smaller pieces, each with the potential to penetrate a spacecraft's shield or an astronaut's space suit. Robot "cleaners' or other technologies for picking up the pieces are unlikely to materialize soon, says the council in a report published last week.

"Once we load these orbits with debris, it is very difficult to get it out,' says George Cleghorn, head of the panel that prepared the report and former chief engineer for TRW Space and Technology Group. 'The world ought to be responsible for what it's doing."

The panel, which included experts from the US, Japan, Canada, Russia and Germany, says that without such technology the best strategy is to reduce the amount of debris dumped into space.

There are currently about four dead satellites in orbit for every operating one. Dead satellites can be struck by other debris or explode spontaneously to produce a cloud of debris. The team suggests that satellites nearing the end of their lives should be moved into 'disposal orbits" reserved for dead spacecraft.

Exactly where the satellites would be shunted off to would depend on their altitude. Dying satellites in low Earth orbits could have their orbit adjusted before they finally lose power and die so that they plunge into Earth's atmospheres in twenty or thirty years' time and burn up. By contrast, communications satellites orbiting 36,000 kilometres above the Equator could be programmed to fire their rockets one last time, sending them into a special disposal orbit 300 kilometres higher, and safely out of the way of live satellites.

This proposal may meet opposition from telecommunications companies that operate satellites, admits Nicholas Johnson, an expert on space debris at Kaman Sciences in Colorado Springs, Colorado, and a member of the NRC panel. Moving a dying satellite into a disposal orbit would consume rocket fuel that could keep the satellite operating for a few more months.

The panel also calls on countries to take extra precautions to prevent dead rockets and satellites from exploding, spewing shrapnel throughout space. Spent rockets that have blown up in orbit account for 25 percent of known space debris. Most countries already drain residual fuel from the junked rocket stages to prevent spontaneous explosions.

Batteries must also be made safe. As a satellite passes through space, static builds up, and batteries can accumulate more charge than they can hold. This can cause massive electrical discharge that ruptures the battery. The panel says batteries on dying satellites should be fully discharged and then short-circuited to prevent this. "Virtually nobody does that now," says Johnson.

Another hazard for space travelers is peeling paintwork from old craft, already thought to be a major source of debris. Better spacecraft designs and materials could stem this source of debris. International law has never tackled the problem of space debris and the NRC can do no more than make suggestions. But the report could form the basis internationally agreed rules for preventing space debris, says Johnson. "We hope that most of the world space community will adopt and accept this report."

Article 8

Alleged dino killer found in New Jersey.

Flying at more than nine thousand miles per hour, hot steamy clouds of vaporized rock shot off from a giant meteor that smashed into Chicxulub, Mexico, about sixty-five million years ago. Was the impact powerful enough to do in the dinosaurs? Apparently it was a pretty big wallop. Geologists have now discovered evidence of this massive meteorite strike as far away as New Jersey. And the site is giving them their first really clear view of creatures' survival patterns before and after the crash.

The clouds of vaporized rock splashed into the ocean. Cooled quickly by the water, the droplets of hot rock solidified into glass balls called spherules. Richard K. Olsson and Kenneth G. Miller of Rutgers University and their colleagues drilled a nearly two-thousand-foot-deep borehole north of Atlantic City -- sixty-five million years ago New Jersey's gambling paradise was under three hundred feet of water. What they found was a two-inch layer of spherules. It was a real surprise. "We were really not expecting to find a layer that thick. We were expecting to hunt with a microscope," says Olsson.

Spherule layers up to three feet thick have been found in the Gulf of Mexico. They have been of little use to geologists trying to figure out exactly what got killed off when, however. Because the impact was so devastating, tidal waves and earthquakes jumbled up many of the sediments around the spherules, making it hard to see which layers -and which creatures found within those layers - were older or younger.

The New Jersey layer landed far enough away from the impact so that the spherules formed a distinct feature. "Prior to the impact, you can see quite a diversity" of plankton fossils, notes Olsson. "Above the spherule layer, diversity is much lower." More than ninety percent of plankton species disappeared right after the spherules formed. Olsson, who estimates that it took about ten minutes for the clouds to travel the 1,500 miles from Mexico, believes that such far-flung spherules underscore that there were indeed "tremendous environmental effects from a single event." Big enough, perhaps, to do in the biggest animals in the world.

Article 9

Database: Expanded Academic ASAP

Subject: space debris

Library: Univ. of Alabama-Huntsville

Source: E, March-April 1996 v7 n2 pl4(2).

Title: Garbage in orbit: debris from 40 years of space exploration presents a thorny disposal problem.

Author: Chris Hayhurst

Abstract: About half of the 4,500 spacecraft that have been launched into space since 1957 remain in orbit. They have become debris that poses navigational problems for functional spacecraft. It is necessary to find effective disposal procedures for this space debris.

Subjects: Space debris - Management, Space pollution - Prevention

Electronic Collection: A18375314, RN: A18375314

A two-ton Chinese spy satellite the size of a small car is headed for a crash landing somewhere on Earth. Although most satellites quickly burn up when they reenter Earth's atmosphere, this one is prepared for the fiery ride, and is deemed sufficiently armored to survive it. Launched from the Gobi Desert in October 1993, the spacecraft malfunctioned 10 days later. Since then it has been losing altitude, and is expected to drop from the sky in early April. Most likely it will plunge into the ocean, but other possible landing sites include many of the Earth's major cities and all of the continental United States.

Since the launch of the Soviet "Sputnik I" in 1957, over 4,500 spacecraft have been hurled from the Earth's surface, nearly half of which remain in orbit. According to the new book Orbital Debris: A Technical Assessment, only about 10 percent of these craft are still functional; the rest simply constitute space junk, very expensive garbage. But that's just the intentional debris. There are also many tons of "mission-related" garbage littering the solar system.

Among the useless junk released into space during a craft's deployment and operation are spent rocket bodies, lens caps, bolts, aluminum oxide particles from rocket motor exhausts, paint chips and fragmentary objects generated by more than 120 spacecraft and rocket body breakups.

Large debris at relatively high orbital altitudes is so stable it can perform loops around the Earth for millions of years. All told, there are trillions of projectiles, ranging from particles less than a millimeter in size to larger objects like the Chinese satellite. The U.S. Space Station in Colorado Springs keeps busy tracking and cataloging 8,000 of these objects, leaving the positions of more than a few others in doubt. The debris remains in orbit until retarding forces cause it to disintegrate in flames into the atmosphere or, as sometimes happens, it plunges back to Earth.

Astronauts have reason to worry about entering such a potentially lethal environment. A paint chip one millimeter in diameter traveling at 10 kilometers per second could easily tear a hole in a space suit. If the astronaut survives the impact, the resulting pressure loss is still very dangerous.

There's not nearly as much danger to the Earthbound. Nicholas Johnson, senior scientist at the Space Environment and Orbital Debris Resource Center at the Kaman Sciences Corporation in Colorado Springs, says, "Nearly 17, 000 objects have reentered the atmosphere. The majority are burned up, and of those that do make it, most splash harmlessly into the ocean." One famous example is the 100-ton Skylab, the first U.S. space station, which broke up and rained down on the Indian Ocean and remote parts of the Australian desert in 1979. According to Johnson, errant spacecraft have never caused a confirmed-injury and apparently no property has ever been damaged.

Joe Loftus, assistant director for engineering at the National Aeronautics and Space Administration (NASA)'s Johnson Space Center in Houston, has studied orbital debris for the last 20 years. He says, "Because space is a commerce and the people who operate in space know each other, it's in everybody's self-interest to preclude contamination of the space environment." In the past, he says, weather satellites have routinely been sent into space for up to five years, after which parts would fail or become obsolete. They fixed that sending up fresh satellites. "The difficulty is they accumulate," says Loftus. "Now there are satellites and upper stages that will continue to go round and round for a thousand years." Today, NASA designs lighter rocket bodies and sends them into lower orbits to increase atmospheric drag and accelerate orbital decay.

The garbage that already litters space continues to be a problem. In the absence of the chemical, natural and artificial recycling processes used on Earth, objects sent into orbit become fossil-projectiles. This leaves future space-faring generations to cope with dangerous technological relics.

According to the Technical Assessment, one disposal technique involves shifting space debris from current orbits into "disposal orbits," where they do not pose a threat to functional spacecraft. Another idea is to develop a. space vehicle whose sole purpose is that of a patrolling garbage man. Unfortunately, some predictions put the price of such a project at over $15 million for each piece of junk removed.

Satellites never appear as more than tiny specks in the sky, but as long as debris is dragging through the atmosphere, in line for a free fall back to Earth, there's always a chance that some space junk will come home in a rather spectacular way.

CONTACTS: Space Environment and orbital Debris Resource Center, Kaman Sciences Corporation, P.O. Box 7463, Colorado Springs, CO, 80933/(719)591-3600; National Aeronautics and Space Administration, Johnson Space Center, 2101 NASA Road 1, Houston, TX 77058/(713)483-0123.

Article 10

Database: Expanded Academic ASAP

Subject: space debris

Library: Univ. of Alabama-Huntsville

Source: Insight on the News, Nov 18, 1996 vl2 n43 p39(i).

Title: Space junk piles high. (orbital debris)

Author: Kenneth Silber

Abstract: Spacecraft could be damaged if they collide with orbital debris, made of parts of old satellites and rockets. Approximately 100,000 pieces of debris are large enough to do considerable damage to orbiting satellites. Engineers are trying to create spacecraft designs that reduce the amount of debris.

Subjects: Space debris - Accidents, Astronautics - Accidents, Artificial satellites - Accidents

magazine Collection: 86C3410

Electronic Collection: A18850079, RN: A18850079

Orbital debris - pieces of old satellites and rockets - is a growing threat to spacecraft.

Nearly four decades into the space age, garbage has become a serious problem on the final frontier. Scientists and engineers are grappling with the hazards posed by orbital debris, the remnants of old satellites and rockets still circling the Earth.

Collisions between space junk and functioning spacecraft have occurred on numerous occasions. Astronauts repairing the Hubble Space Telescope spotted a three-quarter-inch hole in one of the instrument's antennas, apparently a consequence of debris. Satellites are particularly vulnerable:

* The Long Duration Exposure Facility, a school-bus-sized satellite, recorded more than 30,000 impacts by debris or meteoroids during six years in orbit.

* Kosmos 1275, a Russian satellite, is believed to have been destroyed by a collision with space junk. In addition, some small tethered satellites launched by the United States have been lost as debris sliced through the cords connecting them to other spacecraft.

* The French military satellite Cerise was hit in late July by a briefcase-sized piece of a French Ariane rocket left over from an explosion 10 years earlier. The collision broke Cerise's 20-foot stabilization arm in half, causing the satellite to tilt while in orbit. Mission controllers are attempting to correct the problem.

During the last several years, scientists have discovered that a considerable amount of debris was left behind by nuclear-powered spy satellites operated by the Soviet Union from the late 1960s until the mid-1980s. The nuclear reactors, placed in high orbits to keep their radioactive material far from Earth, have emitted clouds of a highly corrosive liquid coolant.

Some 9,500 orbiting objects, each at least the size of a baseball, are monitored by the Space Surveillance Network, an Air Force system based in Colorado. Numerous additional objects too small to be tracked from Earth also present hazards due to the high speeds attained in orbit. (Even small flecks of paint have dented cockpit windows during space-shuttle missions.)

"There are probably 100,000 pieces large enough to do severe damage, if not catastrophic damage, to an orbiting satellite," Robert Culp, a professor of aerospace engineering at the University of Colorado at Boulder, tells Insight.

The United States and other space-faring nations have begun implementing policies to reduce the production of new debris. For example, mission controllers routinely burn or vent excess fuel at the end of a launch to lessen the danger that a used rocket will explode into numerous fragments. In addition, engineers have moved away from early spacecraft designs that allowed bolts and other parts to break off into orbit.

Such considerations will become even more pressing during the next several years as commercial satellite systems become bigger and more complex. Engineers are positioning satellites in slightly divergent orbits so that debris from one satellite failure will not interfere with others in the network.

Human space flight, of course, requires special precautions to minimize the danger of collisions. The National Aeronautics and Space Administration operates the nation's space-shuttle fleet under guidelines intended to maintain a safe distance from any large objects. Early this year, the shuttle Endeavor took evasive maneuvers to circumvent a defunct 350-pound Air Force satellite. NASA also has begun keeping cargo-bay doors partially closed during shuttle missions to protect vulnerable components from smaller pieces of debris.

The International Space Station, scheduled for assembly in orbit early in the next decade, will require additional measures to protect it against impacts, notes Nicholas L. Johnson, senior scientist for orbital debris at NASA's Johnson Space Flight Center in Houston. "The odds of that vehicle being hit really increase simply because of how long it will be up there and how big it is". The station will include shielding composed of Kevlar and other composite materials to protect its habitation module and other critical sections.

Not all of the objects that pose a threat to spacecraft are man-made, however. Every November, the Earth passes through a trail of natural debris left behind by an ancient comet, a phenomenon known as the Leonid meteor shower. And in November 1998, the Earth again will pass through a particularly dense section of the trail; some insurance companies already have declared they will not provide coverage for any resulting satellite losses.

Article 11

Database: Expanded Academic ASAP

Subject: meteoroids

Library: Univ. of Alabama-Huntsville

Source: Geographical Magazine, March 1997 @,69 -13 c2E3 (Z,

Title: The guests. (meteorites: includes related article on where they are most commonly found)

Author: Monica Grady

Abstract: Meteorites provide information about the formation of the Solar System. They are pieces of very old material that have fallen from space to the Earth. Most result from asteroid collisions in the Asteroid Belt between Mars and Jupiter, but over a dozen from the Moon and another 12 from Mars have also been identified. The three main types of meteorite are stone, iron, and stony-iron. Stony-iron meteorites are the rarest and are often quite beautiful. Antarctica is the best place to find meteorites because there the ice and aridity preserve them, sometimes for as long as a million years.

Subjects: Meteorites - Observations

Electronic Collection: A19286928, RN: A19286928

Each year approximately 40,000 tonnes of extraterrestrial material, most of it dust, bombards the earth. But where does it come from, and why does it land here?

Visitors from space arrive on the Earth with amazing frequency, not as alien monsters or little green people in flying saucers, but as meteorites, extraterrestrial material ranging from the tiniest of dust grains to enormous impact crater-forming bodies. Meteorites were formed at the birth of the Solar System, about 4,560 million years ago. We have no material on Earth this old, so it is only by studying meteorites that we can learn about the processes that shaped our Solar System and our planet.

Our Sun was born in a rotating cloud of gas and dust, called a nebula. Gradually this cloud collapsed and dust grained joined together to form bigger and bigger bodies, eventually producing the Sun and planets. The Sun is at the centre of the Solar System, and all the planets orbit around it.

The Asteroid Belt, the place from which most meteorites come, lies between Mars and Jupiter. Asteroids orbit the Sun at a distance three times that of the Earth from the Sun -- three Astronomical Units (AU) , or 450 million kilometers. There are several thousand asteroids, the largest of which is about 1,000 kilometers across (the Earth has a diameter of about 13,000 kilometers) - These rocky, metallic or carbon-rich bodies are the remaining after the planets formed; Jupiter's gravitational pull prevented them from joining together to form a single planet.

The asteroids are in stable orbits around the Sun, but occasionally, thanks to the influence of

Jupiter, the orbit of an asteroid is altered so it collides with another and breaks up. Fragments of broken asteroid fall to Earth as meteorites.

We know that meteorites came from the Asteroid Belt as fireballs created by incoming meteoroids because they have been photographed. From their direction and speed, scientists can calculate the orbits of these meteoroids, and all are seen to extend out to the Asteroid Belt.

One of the most recent meteorite falls occurred on a Friday afternoon in October 1992. at Peekskill, New York. The track of the fireball was recorded on several video cameras, mostly by members of the public attending outdoor football games. The video footage has edited together to produce a film of the fireball travelling over the northeastern U.S. The meteorite eventually landed in the boot of a car -- the video film can be viewed on the web site at http://ccf.arc.nasa.gov/sst/, using an MPEG viewer.

As well as meteorites from the Asteroid Belt, Earth has also received more than a dozen meteorites that have come from the surface of the Moon. Lunar meteorites have been compared directly with samples brought by the Apollo and Luna missions. The surface of the Moon is covered in the craters caused by impacting bodies. The force of these impacts is sometimes sufficient to throw material off its surface, and it is this that arrives on Earth. In the same way, rocks have come to us from Mars: scientist have identified 12 Martian meteorites.

The very bright fireball often associated with an incoming meteoroid is the result of frictional heating as the body travels through the atmosphere. Only the outermost surface melts; the resulting droplets of molten material are carried away by the speed of passage. Finally, as the molten surface rapidly cools to a glassy coating, or fusion crust, which helps scientist identify meteorites. The interior of a meteorite remains cool and unchanged, and meteorites are cold when they land.

The very smallest of micrometeorites do not melt as they pass through the atmosphere, whereas those that are slightly larger melt and form tiny rounded droplets. Very large meteorites fall only every million years or so. Arizona's 1.2 kilometre-diameter, Meteor Crater, was produced by the impact of an iron meteorite about 50,000 years ago. The original meteorite weighted up to 25,000 tonnes, and would have been about 35 to 40 metres across, but most of it was vaporized by the impact. A really big meteorite, probably about 10 kilometres in diameter, fell at Chicxulub on the Gulf of Mexico about 65 million years ago. As well as forming a crater 200 to 300 kilometres across, the environment changes brought about the impact are thought by many scientist to have resulted in the extinction of the dinosaurs. Several smaller meteorites weighted about a kilogram fall on the Earth every year, but only five or six are seen to fall. The last one seen to fall in England was in May 1991, at Glatton, near Peterborough. This stony meteorite weights just over half a kilogram and fell through a hedge of conifers the garden of a Mr. Pettifor, who was startled by the whining noise it made as it hurtled through the air.

Meteorites are pieces of ancient material that survive their fall to Earth from space. There are three main types of meteorite (stone, iron and stony-iron) , reflecting their main composition. Meteorites are named after a place near where they fall or are found. Most meteorites (96 percent of falls) are stony, made up of the same minerals as many terrestrial rocks, minerals containing silicon, oxygen, magnesium, iron and calcium. Stony meteorites can be sub-divided into those have formed from melts of their parent bodies (like terrestrial igneous rocks), and those which have remained unchanged since formation, or aggregation. The latter are known as chondrites, after the small rounded droplets of once-molten material (chondrules) they contain.

Iron meteorites comprise, as their name implies, mainly iron metal, and generally contain between seven to 15 percent of their weight in nickel. These meteorites have been formed during the melting of the parent bodies from which the meteorites originated.

The final main sub-division of meteorites is the stony-irons: a mix, as the name suggests, of stone and metal. These are very rare meteorites and beautiful in appearance. They are produced from the intergrowth of iron and magnesium, silicate minerals with iron metal. Like iron meteorites, they were formed during the melting of.their parents.

Different types of meteorites provide evidence about events that have occurred as the Solar System formed and evolved. Iron meteorites are the closest physical analogy we have to the material that forms the Earth's core. The stony meteorites represent material from the core/mantle boundary of their parent body.

The most primitive meteorites, the CI carbonaceous chondrites, are rich in water, sulphur and organic compounds. These might be the material remaining from comets, which are essentially a mixture of ice and dust, after all the ice has evaporated. It is material like this that brought volatiles to the newly-formed Earth, and helped established its atmosphere and oceans.

Several of the 12 Martian meteorites found on Earth contain pockets of glass formed during the shock event that ejected them from the surface of Mars. When this glass is melted in the laboratory, gas that was trapped inside the glass by the shock is released and compared with that analyzed by the Viking space probes in 1976. The compositions are similar, although Martian meteorites also contain carbonate grains, produced below the surface of Mars when water circulated through the planet. A recent report by scientists from NASA has described evidence for fossilized Martian bacteria inside these carbonate patches, showing that life might once have existed there. By studying meteorites like this, we can learn about events that have taken place in the past on our neighboring planet, a planet whose surface now appears to be dry.

FURTHER READING

Meteorites: The Key to our Existence by Robert Hutchinson and Andrew Graham (Natural History Museum HMSO, 5. 95 [pounds sterling])

RELATED ARTICLE: where are meteorites found?

Meteorites fall almost randomly over the Earth's surface, and are often lost -- either because they fall into the ocean, or among other rocks. Many are recovered from deserts (both cold and hot) , as the dry environment ensures their preservation, and the lack of vegetation enhances their chance of being found. More meteorites have been found in Antarctica that anywhere else in the world. This is not because more fall there, but because those that do are preserved in the ice, often for up to 4 million years. Constant scouring of the ice surface by wind reveals concentrations of meteorites at natural barriers to flowing ice, such as the foot of a mountain. Meteorites come in all sizes; from the very tiny- (about one thousandth of a millimeter across) to the very large (bigger than a house) . The smallest micrometeorites fall all the time; approximately 40,000 tonnes fall on the Earth each year.

Monica Grady is curator of meteorites at the Natural History Museum, London.

Appendix A
Vocabulary

Appendix A

Meteoroids and Orbital Debris Vocabulary

1. Meteor: A light phenomenon, which results from the entry into Earth's atmosphere of a solid particle from space.

2. Meteoroid: A solid object moving through interplanetary spaces, of a size considerably smaller than an asteroid, but considerably larger than an atom or molecule.

3. Meteorite: Any solid particle from outerspace that reaches the surface of the earth.

4. Fireball: A bright meteor with luminosity, which equals or exceeds that of the brightest planets.

5. Micrometeorite: A very small meteor-like particle with a diameter of less than a millimeter.

6. Trajectory: The line of motion of a meteor relative to the Earth.

7. Path: The projection of the trajectory on the celestial sphere, as seen by the observer.

8. Shower: A number of meteors with approximately the same trajectories.

9. Stream: A group of meteor-like bodies with nearly identical orbits.

10. Vesta meteorites: Originate from the asteroid Vesta: thought to be volcanic in origin.

11. Orbital Debris Environment: All of the natural and man-made (non-functioning) Earth-orbiting objects.

12. Velocity: Distance traveled per unit of time.

13. Acceleration: The change of velocity over a unit of time.

14. Crater: A depression caused by impact.

15. Ray: Bright lines of debris radiating from impact craters.

Appendix B
Vocabulary Quiz

Appendix B

METEOROIDS AND ORBITAL DEBRIS
VOCABULARY QUIZ

Name:____________________________Date:_________ Period:______

Directions: Fill in the blank with the word that correctly completes the statement.

Meteor	Meteoroid	Vesta	Fireball	Stream	Ray
Meteorite	Micrometeorite	Wake	Crater	Path	
Orbital Debris Environment		Trajectory	Velocity	Acceleration	

1. A bright meteor with a luminosity that equals or exceeds that of the brightest planets is called a __________.
2. The line of motion of the meteor relative to the Earth is known as the __________.
3. A projectile from space which has reached the surface of the Earth without being completely vaporized is called a __________.
4. The __________ is anything left along the trajectory of a meteor after the head of the meteor has passed.
5. The projection of the trajectory on the celestial sphere as seen by the observer on Earth is called the __________.
6. A __________ is a number of meteors with approximately parallel trajectories.
7. A group of meteor-like bodies with nearly identical orbits is a __________.
8. A __________ is a very small meteorite with a diameter of less than one millimeter.
9. A solid object moving in interplanetary space, of a size considerably smaller than an asteroid and considerably larger tan an atom or molecule is known as a __________.
10. The light phenomenon that results from entry into the Earth's atmosphere of a solid particle from space is known as a __________.
11. __________ is defined as distance traveled per unit of time.

12. __________ is the change in velocity over a unit of time.

13. Bright lines of debris projecting from the edges of craters are known as __________.

14. All of the natural and man-made (non-functioning) Earth-orbiting objects are collectively called the __________.

15. Any meteorite originating from the only know volcanic asteroid is called a _________ meteorite.

Answers to Vocabulary Quiz

1. Fireball
2. Trajectory
3. Meteorite
4. Wake
5. Path
6. Shower
7. Stream
8. Micrometeorite
9. Meteoroid
10. Meteor
11. Velocity
12. Acceleration
13. Rays
14. Orbital debris environment
15. Vesta

Appendix C
Velocity and Acceleration Problems

Appendix C

Meteoroids and Orbital Debris
Velocity and Acceleration Practice Problems

DIRECTIONS: Solve the following situation problems using equations for velocity and acceleration.

1. What is the speed of a rocket that travels 9000 meters in 12.12 seconds?
2. What is the speed of a jet plane that travels 528 meters in 4 seconds?
3. After an impact involving a non-functioning satellite, a paint chip leaves the surface of the satellite at a speed of 96 m/s. After 17 seconds, how far has the chip landed?
4. The space shuttle Endeavor is launched to altitude of 500 km above the surface of the earth. The shuttle travels at an average rate of 700 m/s. How long will it take for Endeavor to reach its orbit?
5. How long will your trip take (in hours) if you travel 350 km at an average speed of 80 km/hr?
6. How many seconds will it take for a satellite to travel 450 km at a rate of 120 m/s?
7. What is the speed of a walking person in m/s if the person travels 1000 m in 20 minutes?
8. How far (in meters) will you travel in 3 minutes running at a rate of 6 m/s?
9. A trip to cape Canaveral, Florida takes 10 hours. The distance is 816 km. Calculate the average speed.
10. In 0.5 seconds, a projectile goes from 0 to 300 m/s. What is the acceleration of the projectile?
11. A meteoroid changed velocity from 1.0 km/s to 1.8 km/s in 0.03 seconds. What is the acceleration of the meteoroid?
12. The space shuttle releases a space telescope into orbit around the earth. The telescope goes from being stationary to traveling at a speed of 1700 m/s in 25 seconds. What is the acceleration of the satellite?
13. A dragster in a race accelerated from stop to 60 m/s by the time it reached the finish line. The dragster moved in a straight line and traveled from the starting line to the finish line in 8.0 sec. What was the acceleration of the dragster?

Appendix C1

Velocity and Acceleration Answers

Meteoroids and Orbital Debris
Velocity and Acceleration Answer Sheet

1. d=vt (distance = velocity multiplied by time)

   d=9000 m
   t=12.12 sec.
   solving for v, v=d/t,

   v=742.57 m/sec.

2. d=vt

   d=528 m
   t=4 sec
   solving for v, v=d/t,

   v=132 m/sec.

3. d=vt

   v=96 m/sec.
   t=17 sec.

   d=1632 m

4. d=vt

   d=500,000 m
   v=700 m/sec.
   solving for t, t=d/v,

   t=714.3 sec.(11.9 min.)

5. d=vt

   d=350,000 m
   v=80,000 m/hr.
   solving for t, t=d/v

   t=4.375 hrs.

6. d=vt

d=450,000 m
v=120 m/sec
solving for t, t=d/v,

t=3750 sec.

7. d=vt

d=1000m
$t=20\text{ min.}\left(\frac{60\text{ sec.}}{\text{min}}\right)=1200\text{ sec.}$
solving for v, v=d/t,

v=0.83 m/sec.

8. d=vt

v=6 m/sec
$t=3\text{ min.}\left(\frac{60\text{ sec.}}{\text{min}}\right)=180\text{ sec.}$

d=1080 m

9. d=vt

d=816,000 m
$t=10\text{ hrs.}\left(\frac{60\text{ min.}}{\text{hrs}}\right)\left(\frac{60\text{ sec.}}{\text{min}}\right)=36{,}000\text{ sec.}$
solving for v, v=d/t,

v=22.67 m/sec. **or**

d=816,000 m
t=10 hrs.
solving for v, v=d/t,

v=81.6 km/hr.

10. a=v/t (acceleration = velocity divided by time)

t=0.5 sec.
v=300 m/sec.

a=600 m/sec.^{2}

11. a=v/t

t=0.03 sec.
v=0.8 km/sec.

a=26.7 km/sec.^{2}

12. a=v/t

t=25 sec.
v=1700 m/sec.

a=68 m/sec.^{2}

13. a=v/t

t=8 sec.
v=60 m/sec.

a=7.5 m/sec.^{2}

Final Exam

SPACE ENVIRONMENTS

Meteoroids and Orbital Debris

EXAMINATION

DIRECTIONS: Based upon your knowledge of the orbital debris space environment and the international problem of orbital debris, answer the following questions in correct short answer form. Each question is worth 20 points. Be as thorough as possible ... show what you know!

1. Define the following terms: meteor, meteoroid, and meteorite.

2. Explain how speed, velocity, and acceleration are related, and write a formula for each.

3. a) Choose one of the major points made by the guest speaker and discuss your opinion of the topic.

   b) What is the Leonids meteor shower and what are its causes?

4. Describe the orbital debris environment and the hazards it poses for space exploration.

5. Describe briefly a method for experimentally determining whether or not a certain material is acceptable for constructing Earth-orbiting spacecraft. Consider the requirement that the material should be both strong and lightweight. Relate these requirements to the hazards of orbital debris and meteoroids.

National Science Education Standards

CORRELATION BETWEEN SPARKMAN HIGH SCHOOL

ORBITAL DEBRIS ENVIRONMENT LESSON PLANS
AND
THE NATIONAL SCIENCE EDUCATION STANDARDS

In preparing and implementing the orbital debris environment lesson plans, science teachers followed the guidelines set forth in the National Science Education Standards. The following items show the correlation between objectives set forth within the lessons and the national standards.

(1) **Science and Technology** / Content Standard E / Abilities of Technological Design /Understandings About Science and Technology

> Students were instructed to identify the problems associated with the orbital debris environment; propose designs and choose between alternative solutions; and implement, evaluate and communicate a proposed solution.

(2) **Science in Personal and Social Perspectives** / Content Standard F / Environmental Quality / Natural and Human-Induced Hazards / Science and Technology in Local, National, and Global Challenges

> Students examined and discussed how natural materials and materials from human societies affect the physical environments of Earth and space. Discussion and debate integrated economics, policies, politics, and ethical dilemmas associated with the challenges that will inevitably be faced by the International Space Station due to orbital debris.

Submitted by: ***Sparkman High School, Toney, Alabama***

HOME OF THE *SENATORS*

Related Publications

Space Environments and Effects
Related NASA Publications

Meteoroids and Orbital Debris

- Cynthia Belk*, Jennnifer Robinson, Margaret Alexander, William Cooke** and Steven Pavelitz***, **Meteoroids and Orbital Debris: Effects on Spacecraft**, NASA RP-1408, Electromagnetics and Aerospace Environments Branch, Systems Analysis and Integration Laboratory, Science and Engineering Directorate, NASA Marshall Space Flight Center, AL 35812 and *Universities Space Research Association, **Computer Sciences Corporation, ***Sverdrup Technology, Inc., August 1997,
  pp. 24.

  Keywords: natural space environment; spacecraft environment; environmental effects and impacts; meteoroids and orbital debris; orbital debris source, size, lifetime, and mitigation source, size, lifetime and mitigation

  Abstract: The natural space environment is characterized by many complex and subtle phenomena hostile to spacecraft. The effects of these phenomena impact spacecraft design, development, and operations. Space systems become increasingly susceptible to the space environment as use of composite materials and smaller, faster electronics increases. This trend makes an understanding of the natural space environment essential to accomplish overall mission objectives, especially in the current climate of better/cheaper/faster. Meteroids are naturally occurring phenomena in the natural space environment. Orbital debris is manmade space litter accumulated in Earth orbit from the exploration of space. Descriptions are presented of orbital debris source, distribution, size, lifetime, and mitigation measures. This primer is one in a series of NASA Reference Publications currently being developed by the Electromagnetics and Aerospace Environments Branch, Systems Analysis and Integration
  Laboratory, Marshall Space Flight Center, National Aeronautics and Space Administration.

- **Orbital Debris Quarterly News**

- **Orbital Debris Document Repository**

- **Single Wall Penetration Equations**

- **Estimation of Meteoroid Flux for the Upcoming Leonid Storms**

- **National Research Council: Spacecraft Face Increasing risk from orbital debris**

- **MSFC Technical Papers from Structures and Dynamics Laboratory**

- **Interagency Report on Orbital Debris**

- K.B. Hayashida and and J.H. Robinson, **TSS Tether Cable Meteoroid/Orbital Debris Damage Analysis, NASA TM-108404** , Structures and Dynamics Laboratory, NASA Marshall Space Flight

Center, AL 35812, April 1993, (N93-27023).

Abstract: This report summarizes the damage analysis performed on the tether cable used for the tethered satellite system (TSS), for the damage that could be caused by meteoroid or orbital debris impacts. The TSS consists of a tethered satellite deployer and a tethered satellite. The analytical studies were performed at Marshall Space Flight Center (MSFC) with the results from the following tests: (1) hypervelocity impact tests to determine the "critical" meteoroid particle diameter, i.e., the maximum size of a meteoroid particle which can impact the tether cable without causing "failure"; (2) electrical resistance tests on the damaged and undamaged tether cable to determine if degradation of current flow occurred through the damaged tether cables; and (3) tensile load tests to verify the load carrying capability of the damaged tether cables. Finally, the HULL hydrodynamic computer code was used to simulate the hypervelocity impact of the tether cable by particles at velocities higher than can be tested, to determine the extent of the expected tether damage.

- The National Science and Technology Council Committee on Transportation Research and Development, **Interagency Report on Orbital Debris**

Abstract: Taking into consideration the results of the National Research Council orbital debris technical assessment study funded by the National Aeronautics and Space Administration, an Interagency Working Group under the direction of the Office of Science and Technology Policy and the National Security Council revised and updated the 1989 Report on Orbital Debris. This 1995 Report contains an up-to-date portrait of our measurement, modeling, and mitigation efforts and a set of recommendations outlining specific steps we should pursue, both domestically and internationally, to minimize the potential hazards posed by orbital debris.

- N. C. Elfer, **User's Manual for Space Debris Surfaces (SD_SURF)**, NASA CR-4705 , Prepared for Structures and Dynamics Laboratory, Science and Engineering Directorate, NASA Marshall Space Flight Center, AL 35812, Contract NAS8-38856, by Lockheed Martin Marietta Manned Space Systems P.O. Box 29304, New Orleans, LA 70189, February 1996, pp. 208.

Keywords: bumpers, debris shields, hypervelocity impacts, impact, meteoroids, orbital debris, probability of no penetration, space debris

Abstract: A unique collection of computer codes, Space Debris Surfaces (SD_SURF), have been developed to assist in the design and analysis of space debris protection systems. SD_SURF calculates and summarizes a vehicle's vulnerability to space debris as a function of impact velocity and obliquity. An SD_SURF analysis will show which velocities and obliquities are the most probable to cause a penetration. This determination can help the analyst select a shield design which is best suited to the predominant penetration mechanism. The analysis also indicates the most suitable parameters for development or verification testing. The SD_SURF programs offer the option of either FORTRAN programs and Microsoft EXCEL spreadsheets and macros. The FORTRAN programs work with BUMPERII version 1.2a or 1.3 (COSMIC released). The EXCEL spreadsheets and macros can be used independently or with selected output from the SD_SURF FORTRAN programs.

- N. C. Elfer, **Structural Damage Prediction and Analysis for Hypervelocity Impacts - Handbook, NASA CR-4706** , Prepared for Structures and Dynamics Laboratory, Science and Engineering Directorate, NASA Marshall Space Flight Center, AL 35812, Contract NAS8-38856, by Lockheed Martin Marietta Manned Space Systems P.O. Box 29304, New Orleans, LA 70189, February 1996, pp. 320.

Keywords: aluminum alloys, bumpers, debris shields, fracture mechanics, hypervocity impacts, impact, meteoroids, orbital debris

Abstract: This handbook reviews the analysis of structural damage on spacecraft due to hypervelocity impacts by meteoroid and space debris. These impacts can potentially cause structural damage to a Space Station module wall. This damage ranges from craters, bulges, minor penetrations, and spall to critical damage associated with a large hole, or even rupture. The analysis of damage depends on a variety of assumptions and the area of most concern is at a velocity beyond well controlled laboratory capability. In the analysis of critical damage, one of the key questions is how much momentum can actually be transfered to the pressure vessel wall. When penetration occurs without maximum bulging at high velocity and obliquities (if less momentum is deposited in the rear wall), then large tears and rupture may be avoided. In analysis of rupture effects of cylindrical geometry, biaxial loading, bending of the crack, a central hole strain rate and R-curve effects are discussed.

- A. J. Piekutowski, **Formation and Description of Debris Clouds Produced by Hypervelocity Impact, NASA CR-4707** , Prepared for Structures and Dynamics Laboratory, Science and Engineering Directorate NASA Marshall Space Flight Center, AL 35812, Contract NAS8-38856, by University of Dayton Research Institute 300 College Park Avenue, Dayton, Ohio 45469-0182, February 1996, pp. 266.

Keywords: bumper shield, debris cloud, fragmentation, fragment-size, hole size, hypervelocity impact, meteoroids, multicomponent shield

Abstract: Forty-one light gas gun tests were performed to examine the formation of debris clouds produced by the hypervelocity impact of aluminum spheres with thin aluminum sheets at normal incidence. Two tests were performed with the bumper sheet at an oblique angle. All tests provided multiple-exposure, orthogonal-pair flash radiographs of the debris clouds produced by the impacts. The failure and fragmentation of the aluminum sphere was observed to be an orderly process. Measurements taken from the flash radiographs were used to determine: (1) the velocity of a number of characteristic points in the debris clouds; (2) fragment sizes; and (3) fragment-size distributions. Sphere diameter, bumper-sheet thickness, and impact velocity were the primary test variables. The effects of bumper-thickness-to-projectile-diameter ratio, impact velocity, and material on the debris-cloud formation process were evaluated. A collection of models was developed and used to describe the formation of various debris-cloud elements. A method for estimating the state of the material in a debris cloud was developed. Features observed in the radiographs of the debris clouds indicated that the estimation procedure was reasonable. Analyses of the holes formed in the bumper sheets and damage patterns produced on witness plates behind the bumpers complemented the analyses of the flash radiographs.

Related Links

SEE Related Links-Meteoroid and Orbital Debris

Meteors and Meteoroids: http://rosy.ukc.ac.uk/~nm1/meteors.html

The EuReCa Project: http://rosy.ukc.ac.uk/space/eureca.html
Hypervelocity Impact and Studies: http://rosy.ukc.ac.uk/hvi.html

NASA-JSC Space Science Branch: http://sn-callisto.jsc.nasa.gov/

Micrometeorite Lab: Governing Equation:
http://www.oc.nps.navy.mil/~jenner/courses/mmlab.html

Long Duration Exposure Facility (LDEF): Meteoroid and Orbital Debris:
http://www-curator.jsc.nasa.gov/curator/seh/ldef/ldef.htm

Space Exposed Hardware: http://www-curator.jsc.nasa.gov/curator/seh/seh.htm

Stratospheric Dust: http://www-curator.jsc.nasa.gov/curator/dust/dust.htm

European Space Agency: Space Debris Activities:
http://www.esoc.esa.de:80/external/mso/debris.html

Long Duration Exposure Facility(LDEF): http://setas-www.larc.nasa.gov/index.html

Leonids: http://web99.arc.nasa.gov/~leonid?index.html

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