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Debris Environment and Effects Program Alpha Version 1.0 User's Guide

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This report has been approved for publication.

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Determining the current debris population is the first step toward quantifying the hazard posed by natural and man-made debris. Ground-based sensors currently track and maintain orbits of the largest objects in this population. Statistical estimates of the population of smaller objects have also recently been made. The second step toward quantifying the hazard is to use models to estimate future debris populations and the effects they could have on future space operations. The United States Air Force Research Laboratory (AFRL) has developed and is improving such a model as part of its space debris research program. The model is called the Debris Environment and Effects Program (DEEP). DEEP was developed to: 1) estimate a range of possible future debris environments based on a variety of parameters, 2) determine the collision hazard for specific vehicles operating in these environments, 3) determine the effects of potential collisions on vehicle mission performance, and 4) evaluate the effects of implementing various options for mitigating man-made debris.

The software development was halted in 1996 due to lack of funding, and the work to date is documented in this DEEP Software User's Guide.

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TABLE OF CONTENTS

LIST OF FIGURES

EXECUTIVE SUMMARY

Determining the current debris population is the first step toward quantifying the hazard posed by natural and man-made debris. Ground-based sensors currently track and maintain orbits of the largest objects in this population. Statistical estimates of the population of smaller objects have also recently been made. The second step toward quantifying the hazard is to use models to estimate future debris populations and the effects they could have on future space operations. The United States Air Force Research Laboratory (AFRL) has developed and is improving such a model as part of its space debris research program. The model is called the Debris Environment and Effects Program (DEEP). DEEP was developed to: 1) estimate a range of possible future debris environments based on a variety of parameters, 2) determine the collision hazard for specific vehicles operating in these environments, 3) determine the effects of potential collisions on vehicle mission performance, and 4) evaluate the effects of implementing various options for mitigating man-made debris.

The software development was halted in 1996 due to lack of funding, and the work to date is documented in this DEEP Software User's Guide.

INTRODUCTION

DEEP Introduction

This user's guide is for the Debris Environment and Effects Program (DEEP) Alpha Version 1.0 (DEEPA1). DEEP is a FORTRAN (much of it FORTRAN 90) program to model the orbital debris environment and its effects on orbiting assets. This program was developed through efforts of the Air Force Space Debris Program Office by ORION International Technologies.

DEEP had its genesis in work performed by ORION International Technologies in support of the U.S. Air Force (AF) Space Debris Research Program. In the early 1990s, ORION worked with and modified the National Aeronautics and Space Administration (NASA) EVOLVE model. One of the key additions to this model was the inclusion of the IMPACT breakup model (IMPACT was developed by The Aerospace Corp. for the Air Force). As the model changed it was renamed the EVOLVE-D program. Eventually, it was realized that continued modifications to the original EVOLVE program may not produce the desired results for the Department of Defense (DoD).

In 1994 and 1995, DEEP was conceived and the framework for this program was completed. This program still uses many of the functional modules and models of the EVOLVE and IMPACT models, but now they are contained in a new FORTRAN 90 framework. Additionally, in 1995, a DOS-based menu/plotting/graphics ability was added to the program.

At the same time the DEEP code was being developed, the AF Space Debris Research Program completed the initial release of the Debris Analysis Workstation (DAW). DAW is "a collection of debris analysis tools hosted on a SUN platform to perform studies of debris generating events such as ballistic missile intercepts, on-orbit explosions or collisions." DAW is currently being used by several organizations within the DOD to support debris analysis.

One of the original intentions of the AF Space Debris Research Program was to incorporate DEEP into DAW to provide further on-orbit debris analysis capability. This users guide is one step towards making DEEP a useful debris analysis tool.

Organization of the User's Guide

- Introduction: some quick notes to get started
- Background: provide a road map for program features to the user
- Space debris overview/background: provide some basic knowledge on space debris
- DEEP overview: quick overview of Alpha Version 1.0 methodology
- DEEP user interface: show the interface and explain what options are available so the user can make intelligent input
- DEEP example: provide an example of the default-input files for a sample run of DEEP
- References
- Bibliography

System Requirements

This version of the program must be running on an IBM compatible computer using a DOS interface. It is recommended that one have at least 32 MB of memory, though it will run with less. The minimum set of files takes approximately 5 MB of hard disk space. Depending on some of the options, the data files can take up more than 10 MB of additional disk space after a run.

Installation

DEEP is installed by copying the DEEP directory from the ZIP drive to the hard drive. It should be placed at the top of the directory tree. This can be achieved by "dragging" the DEEP file to the main directory of the desired hard drive.

It is very important that the following files be in the directory from which you are running the program:

- deep.def
- mes.def
- plot.def

PLEASE READ the **README.TXT** file in the DEEP directory.

Bug/Enhancement Reporting

There exist a number of known bugs in this version. Please e-mail information on the bug or a request for feature enhancement to:

Dr. Ron Madler
madler@pr.erau.edu

BACKGROUND

Methodology

DEEP follows a standard methodology for orbital debris models as will be described in the following sections. This procedure is outlined below and discussed in more detail in References 1 and 2.

- Use known breakup rates and launch rates to populate the present orbital debris environment.
- Use traffic models to predict the future space traffic and launch patterns.
- Estimate future explosions based on past breakup rates, or based on launch patterns.
- Calculate the expected collision rates at every step in the integration.
- From the expected collision rates, estimate future collisions. This can be done either in a deterministic manner or by running a Monte-Carlo simulation and averaging the data over many trials.
- At each time step, examine the effect of the environment on spacecraft of interest.
- Report on the data, and examine figures.

Implementation

Program DEEP is still in its development phase and is not yet ready for release. The basic framework for the overall program is in place, but not all of the models/modules have been completed. However, since this project has been canceled, and it is unlikely that the program will be revived, the progress to date is being documented in a final report to close out the effort.

Limitations

As one would expect, an Alpha version of a program has many limitations. The major limitations of the program have to do with the DOS-based graphical interface, the incomplete modules, lack of verification of the results, and also that the only data saved is for the plot files. The results in this version do not correspond to the known environment and should not be used.

Future Version Plan

Future versions of the program will address the above limitations to:

- de-couple the user interface and plot processor from the functional elements of the program so it can run on any platform
- verify individual models
- encapsulate functional modules to improve reliability, portability, and extensibility
- finish individual models
- incorporate effects models

1. SPACE DEBRIS OVERVIEW/BACKGROUND

It has been recognized since 1946 that space debris could create a hazard for spacecraft, though when Whipple[3] first noted this threat he had not considered the risk of artificial space debris. Not until the early 1980s was there a recognition that human-generated debris could pose a threat to spacecraft. The DEEP model is meant to examine the artificial debris environment and the effects of both natural and artificial debris on spacecraft.

A tool such as DEEP is needed because meteoroids and orbital debris will strongly affect future spacecraft design and operations. Space debris, human-generated and natural debris, is a potential hazard because of its high expected impact velocities. Meteoroids will average about 20 km/s, while orbital debris averages 10 km/s for LEO and 0.5 km/s for GEO. These are the average expected encounter velocities; the actual range depends on the orbits and encounter geometry. At these velocities even very small particles have high kinetic energies and can thus cause significant damage.

Space debris damage can range from surface erosion and degradation to damage of mission-critical systems or even breakup of the spacecraft. Several research organizations have shown that, if our present space practices continue, serious or catastrophic on-orbit collisions with orbital debris could occur within the next century. Even now, meteoroids and orbital debris are affecting spacecraft design. For example, due to concerns about meteoroids and orbital debris, the RADARSAT program added 17 kg of shielding to its spacecraft.

The high closing velocity between orbiting objects is one reason to be concerned about debris. Another is that we cannot detect, much less track and maintain an orbit on, most of the objects in space. While rocket bodies and payloads contain almost all the mass in orbit, the majority of the objects in orbit are operational debris or fragmentation debris. Approximately 150 on-orbit satellite fragmentations have occurred, producing much debris. Many events produced few trackable objects or produced quickly decaying objects. Others have produced numerous fragments above the region of significant atmospheric drag. These fragments may pose a collision risk to spacecraft for many years to come. The GEO region is of special concern because it has no natural mechanism that removes debris.

Already more than half of the approximately 9000 objects tracked by the United States Space Command (USSPACECOM) are fragmentation or operational debris. Although 9000 objects may not seriously hinder space operations, it is known that a significantly larger number of **untrackable** objects smaller than 10 cm exist in low-Earth orbit. Because these objects can't be tracked, they can't be avoided by maneuvering. This is not surprising because the United States' national assets being used to track and catalog debris were never intended for that purpose. However, NASA and DOD have been collecting statistical data on untrackable, yet detectable, objects so we can better model the LEO debris environment and the sources of debris.

In order to understand the hazard of debris and how to minimize or shield spacecraft from debris damage, we must understand the distribution of objects in space, their sources and sinks, and how the environment is measured and modeled. First one recognizes that all the orbital material in space has come from launches of spacecraft, so the orbital debris issue is really about how that mass is distributed (i.e., the number of objects and their orbits). Figure 1-1 (adapted from reference 4) shows the estimated flux of space debris as a function of size. It can be seen from the figure that the artificial debris dominates the hazard at the larger sizes. Figure 1-2 estimates the spatial density in LEO as a function of altitude for tracked objects and fragmentation debris. Note that this density is averaged over all latitudes and that it varies with latitude because space objects have various inclinations. Over time, the spatial densities and flux rates will change due to natural decay, new launches, and fragmentations.

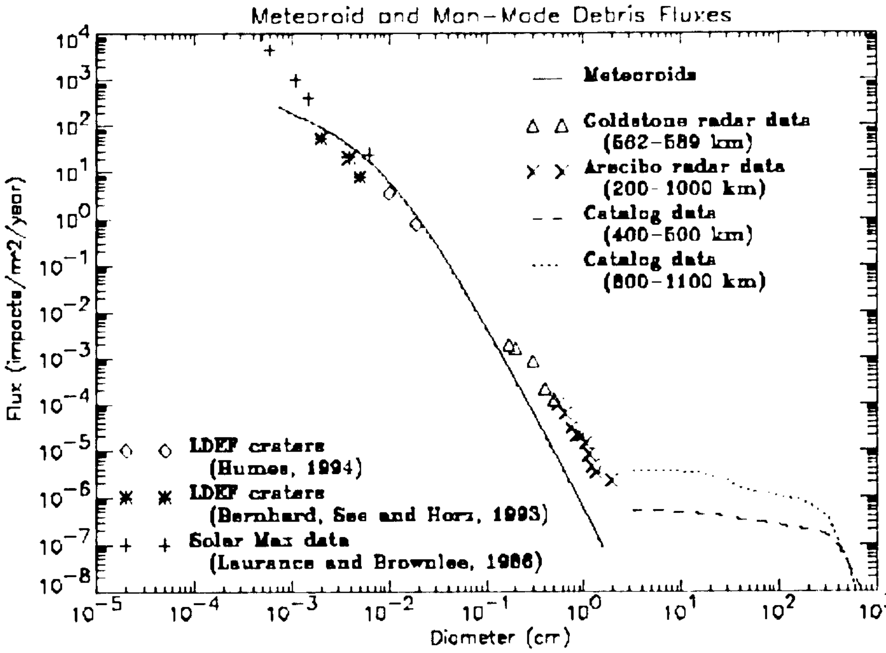

Figure 1-1: Meteoroid and Orbital Debris Fluxes for Low Altitude Orbits

This figure shows that human-generated orbital debris has much higher impact rates than meteoroids for large and small debris diameters.

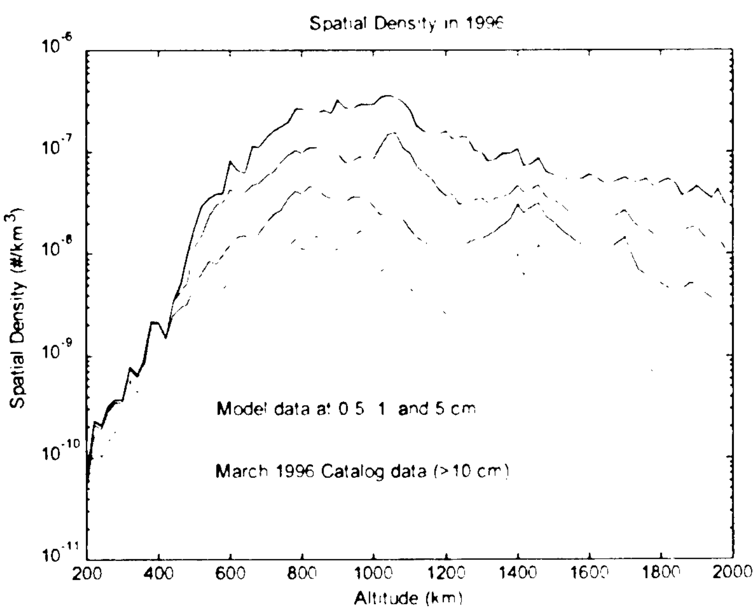

Figure 1-2: March 1996 Catalog Data (Objects > 10 cm)

Figure 1-2 compares the March 1996 catalog data with model data at smaller sizes. The lines, going from bottom to top, represent objects in the catalog, those greater than 5 cm, 1 cm, and 0.5 cm in diameter, respectively. As expected, the distributions are similar and there are many more small objects produced by the fragmentations. The model data represents known on-orbit objects and debris from fragmentations.

Understanding Sources and Sinks

For the spacecraft designer or operator, debris is any external object that could interfere with the satellite. Each launch may accumulate one or more payloads, rocket bodies, and operational debris in orbit. Operational debris can include: large trackable objects, such as fairings and interstage adapters; small trackable objects, such as Ed White's glove from Gemini 4; and small debris not detectable from the Earth, such as explosive bolts and lens caps[5]. The **tracked** objects in orbit, as of May 1996, can be categorized as either active payloads (6%); inactive payloads (24%); rocket bodies (18%); operational debris (11%); anomalous event debris (2%); or fragmentation debris (39%)[6]. Besides these obvious sources there is also evidence for a number of other sources such as paint flecks from surface degradation, solid rocket motor slag and particulates, and liquid NaK coolant from reactors. Figure 1-3 illustrates how sources and sinks interact with the space environment. Only by understanding all of the sources and sinks can we accurately model the orbital debris environment and its hazard to spacecraft.

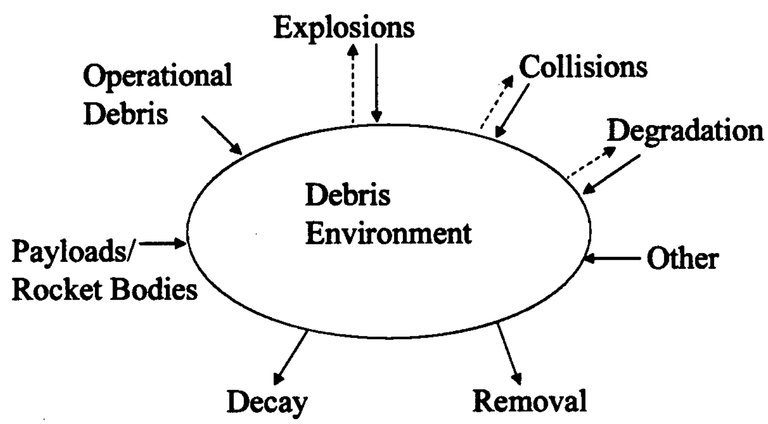

Figure 1-3: Sources and Sinks of Orbital Debris

Presently the only sink for objects in LEO is natural decay, with the exception of shuttle removal. In the future, end-of-life burns may be a common sink for controllable objects in orbit. The NASA Safety Standard recommends end-of-life maneuvers that result in reentry within 25 years or objects being "reorbited" out of the high traffic orbital regimes, including LEO, GEO, and semi-synchronous orbit[7].

Modeling the Debris Environment

Considerable work has gone into developing models for the debris environment. DEEP is one of these models. Debris environment evolution models keep track of each object launched into space and its tracked operational debris, simulate known fragmentations, estimate the future launch and explosion rates, simulate future collision events, and incorporate any other sources of debris to understand the present and future debris environment. These physics based models take considerable time to run due to their complex nature.

Though only a few fragmentation events occur each year, we should know how to deal with a fragmentation event near highly valuable assets. An event will produce many fragments in a slowly expanding "debris cloud," with some regions of high density. A spacecraft passing through these regions is more likely to collide with a particle than otherwise. In the future, it may be necessary to maneuver to avoid these high-density regions just after a breakup, when we can predict their location. Presently, however, there is no efficient procedure to warn spacecraft operators when a fragmentation event has occurred in any region of space. Figure 1-4 illustrates the phases of debris cloud evolution. The time to reach the even background state depends on the energy of the breakup and its orbit characteristics but can be on the order of years.

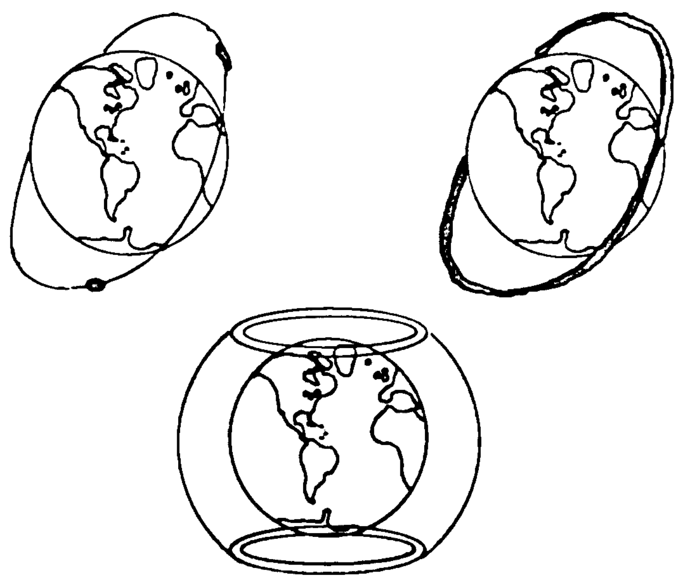

Figure 1-4: Phases of Debris Cloud Evolution

The phases of debris cloud evolution are shown in Figure 1-4. The initial relative velocity causes the fragments to separate. The different objects experience different periods and perturbations, causing the orbits to spread into a torus and eventually an even band of debris.

2. DEEP OVERVIEW

The Debris Environment and Effects Program (DEEP) Alpha Version 1.0 (DEEPA1) is a model for the orbital debris environment. This version has been developed in FORTRAN 90 for the IBM PC-compatible computer running MS-DOS. The program data input and operation is performed through a menu-driven interface, as will be shown in the next section.

Being a model for the orbital debris environment, it has several key components. The basic overview of the program flow is shown in Figure 2-1. Each of the boxes in this figure represents a functional module within DEEP. The user is assumed to be familiar with the terms and concepts presented in the background section. The two DEEP papers in the references provide details on the DEEP model.

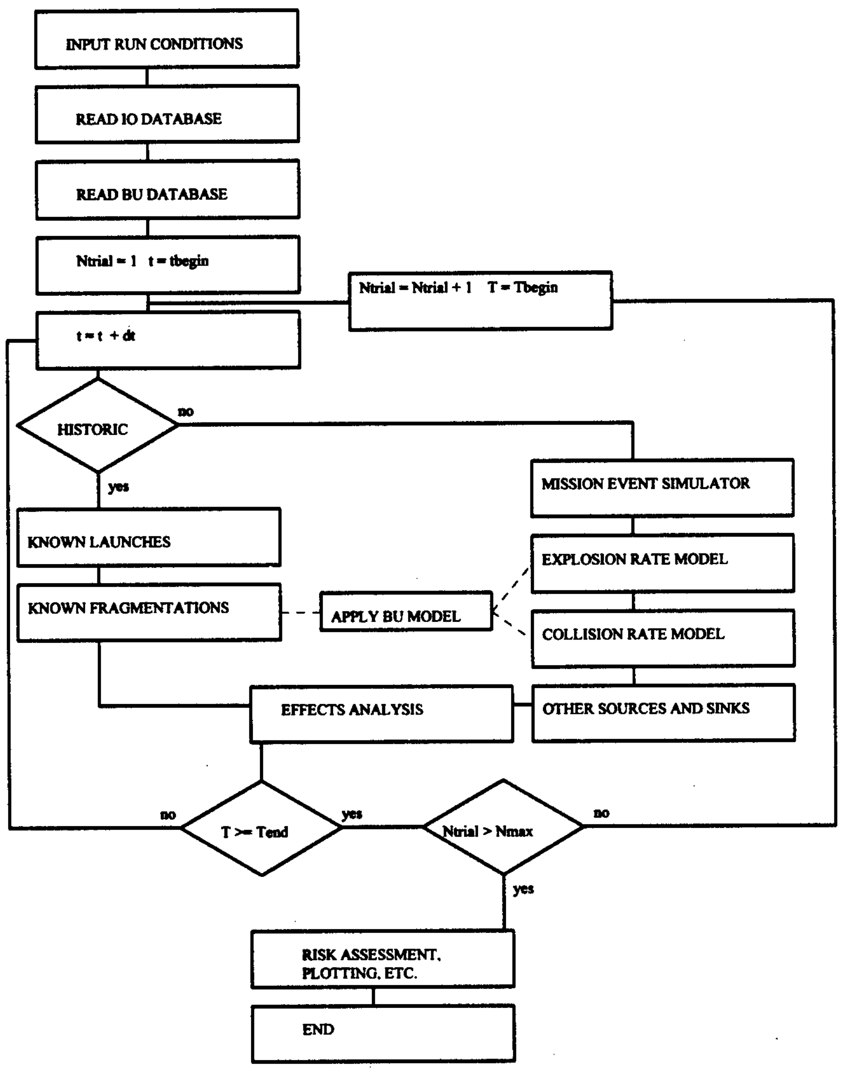

Figure 2-1: Approximate DEEP Flow Diagram

3. DEEP USER INTERFACE

The DEEP interface was developed for an IBM PC-compatible computer running MS-DOS. Therefore it must be run in a DOS window and will not have any type of windowing interface. The following paragraphs show and briefly explain the interface for DEEP.

DEEP Main Menu

The first interface one sees is the DEEP input menu, as shown in Figure 3-1. This comes up with the default values as provided in the default file: deep.def. The user now has the option of changing any of the input parameters. After the user is finished with this menu, the output is written to the file deep.inp, so that the input parameters can be viewed or used as input at a future time. These parameters are necessary to define the timeline and scope for the analysis run.

```
                              DEEP Main Menu
                              Run Conditions                 Files... MES...

  Maximum Number of IO   :  9000   Maximum Number of Debris Clouds :    150
  Breakup Model          : EVOLVE  Monte Carlo Future Projections  :     No
  Num. Frgmts./Subcloud  :   100   Number of Monte Carlo Trials    :    N/A
                                   Random Number Generator Seed    : -12456
 ------------------------- Time Specifications ---------------------------

         Historical/Future Cutoff Time (cal. years) : 1994.00
         Time Range Start  (cal. years)             : 1957.00
         Time Range End    (cal. years)             : 1994.00
         Propagation Time Step (years)              :    1.00
         Number of Time Steps                       :      38
 ------------------ LEO Control Volume Specifications --------------------

      Altitude Bins            Latitude Bins            Right Ascension Bins
 Number of Bins    :      19 Number of Bins  :     1  Number of Bins  :     1
 Bin Width (km)    :  100.00 Bin Width (deg) :180.00  Bin Width (deg) :360.00
 Min Altitude (km) :  200.00
 Max Altitude (km) : 2000.00
              Estimated Program Image Size (Mb) : 12.22
```

Figure 3-1: DEEP Main Menu

MES Mission Edit Menu

This menu is not functional in this version of DEEP because this module has not been fully implemented.

```
                         MES Mission Edit Menu
Select mission type (1-1): MES Mission : SCIENCE           Origin :   USA
Perigee alt. (mean)      [km]:  800.00  Deorbit at end of life?      :   Yes
Perigee alt. (variance) [km]:    50.00  Explosion type               :  None
Apogee alt.  (mean)      [km]: 1200.00  Use collision avoidance?     :    No
Eccentricity (mean)          :    0.05  Minimum coll. av. size   [m]:     0
Eccentricity (variance)      :    0.01  Num. of objects w/ same orb.:     1
Inclination (mean)      [deg]:    1.10  Object removal flag          :     1
Inclination (variance) [deg]:     0.02  Object type                  :  PAYL
Right asc. (mean)       [deg]:   33.00  Upper stage (US) removal     :     0
Right asc. (variance)  [deg]:    12.00  US explosion type            :  None
Arg. of perigee (mean) [deg]:    70.00  Time to deorbit US [cal. yr]: 1990.00
Arg. of per. (var.)     [deg]:   50.00  US perigee altitude     [km]:  200.00
Cross-sect. area (mean) [m²]:     2.00  US apogee altitude      [km]:  400.00
Cross-sect. area (var.) [m²]:     0.20  US inclination         [deg]:   28.50
Mass (mean)              [kg]: 1000.00  US mass                 [kg]: 1000.00
Mass (variance)          [kg]:  100.00  US cross.-sect. area    [m²]:    3.00
Stationkeeping duration [yr]:     4.00  Produce operational debris? :    Yes
Launch time       [cal. yr]: 1995.00    OD mass                 [kg]:    0.01
Launch time stop  [cal. yr]: 2010.00    OD cross.-sect. area    [m²]:    0.00
Initial launch rate   [#/yr]:     2.00  OD production rate    [#/yr]:    4.00
Launch time var.  [cal. yr]:     1.00   OD production duration  [yr]:    1.00
Launch rt. growth rt [#/yr²]:     0.00  Stop time/OD production [yr]: 1990.00
```

Figure 3-2: MES Mission Edit Menu

This menu illustrates some of the necessary information to accurately predict the on-orbit impact of each launch. The basic parameters for the spacecraft, the upper stage, and any operational debris are input with this menu. The default values are represented in MES.DEF. The updated values are to be printed to the file MES.INP.

Plot Selection Menu

```
                          Plot Selection Menu
Plot Number :   1                     Write File?       Filename :
Plot Type                    :
Plot Dimension               :
Dependent Variable           :
Independent Variable(s)      :
Mass/Size Representation :                  Mass Value Type :

                              Fixed Parameters
      Fragment Mass (kg)      :         Range : 0.10E-05 - 10000.00 kg
      Latitude (deg)          :         Range :   -90.00 -     90.00 deg
      Right Ascension (deg):            Range :     0.00 -    360.00 deg

<CR> Accept Field/Invoke Menu  <F10> Next Plot <ESC> Exit  <↑,↓,Tab> Move/Select
                   Select Two Independent Variables
                  √   Time (calendar year)
                      Mean Debris Diameter (cm)
                      Mean Debris Mass (kg)
                      [illegible]
                      Latitude (deg)
                      Right Ascension (deg)
              <Spacebar>-Mark  <CR>-Accept  <ESC>-Exit
```

Figure 3-3: Plot Selection Menu

The menu in Figure 3-3 allows one to select a number of plots. It is quite important to understand the plot menu since the only data saved is that used to generate these plots. When a plot is prepared, the user either exits with an <ESC> or goes to the next plot with an <F10>.

The user can select two major plot types: 2 dimensional with one independent variable, or 3 dimensional with 2 independent variables. The menu above illustrates a 3-D plot, which requires two independent variables, shown in the menu extension. An example of a 3-D plot is shown in Figure 3-4.

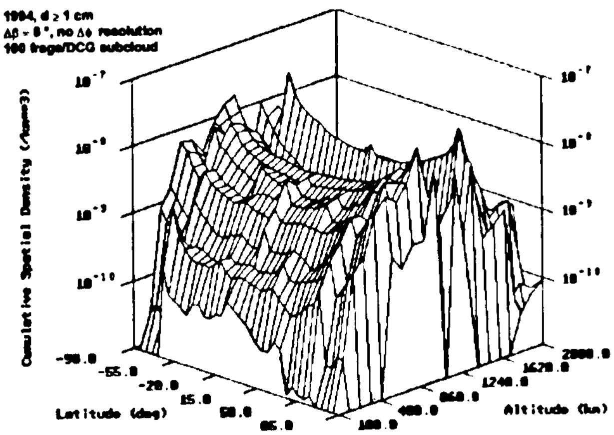

Figure 3-4: Sample of 3-D plot of spatial density versus altitude and latitude

Status Menu

After all the input selections have been made, the program initializes the storage arrays and begins to process this run. Then the status menu shows the progress of the program as it integrates over time and processes the Monte-Carlo simulations.

Plot Viewing Menu

When the program has completed all the calculations and saved the data for the plots indicated above, the plot-viewing menu appears. This menu allows the user to view whichever plots were selected before the calculations. When done viewing the plots, the program exits.

If the user wishes to see some plot other than those selected at the beginning, the program must be run again from the beginning. In this case the DEEP.INP, PLOT.INP, and MES.INP files can be copied as the default (*.def) files and used as input to match the previous results.

4. DEEP EXAMPLE

This section contains the default files for a simple example. The default files are found in the main DEEP directory and also in the example directory. While the results from this example are not correct, they illustrate the flow of the program.

Notes on file: DEEP.DEF

⇒ The default files must have the structure shown below. The first line is a comment line; the next 20 lines are either integers or real numbers. Then there are 4 lines of characters – the comments on these lines must be after the 51st column so as not to be read into the path or file names.

⇒ It is important to be sure that the paths and files specified in the DEEP.DEF file actually exist.

⇒ It is strongly recommended that one NOT read from or write to the restart files. These files basically save all the data from the program and can take up very large amounts of disk space.

FILE: DEEP.DEF

```
---this is file DEEP.DEF -- the defaults for DEEP -- see comments at EOF
9000        !NORB -> Maximum number of IO
150         !NBUMX -> Maximum number of breakups
31          !NSIZE -> Max. number of mass/size bins
0           !IBUMOD -> Breakup model flag (0 = EVOLVE BUM, 1 = IMPACT BUM)
100         !NPCS -> Maximum number or "trace" frags./subcloud allowed
19          !NALT -> Max. number of altitude bins
200.0       !ALTMIN -> Minimum altitude bin value
2000.0      !ALTMAX -> Maximum altitude bin value
150.        !RMIN -> min altitude before auto decay (km)
1           !NLAT -> Max. number of latitude bins
1           !NRA -> Max. number of rt. asc. bins
0           !MCFLAG -> Monte Carlo process flag (0 = No, 1 = Yes)
-12456      !ISEED -> random number gen. seed
1           !NTRIALMX -> Max. number of MC trials
40          !NTSMAX -> Max. number of time steps
1957.0      !YRSTRT -> Fractional calendar year time range start (e.g. 1993.7)
1994.0      !YREND -> Fractional calendar year time range end (e.g. 2004.12)
1994.0      !FUTSTRT -> Cutoff calendar year time designating future beginning
1.0         !DTIME -> Propagation time step (years)
2.1         !CD -> coefficient of drag (2.0-2.2)
\deep\histdat\                                      !path to Launch files (50)
\deep\histdat\                                      !path to BU files (50 chars)
histbu.dat                                          !BU data filename (50 chars)
\deep\bumodel\                                      !path to IM3 files (50)
0           !which historic BU file to use (0=evolve method,1=new)
                        41          !unit number for restart files
0         !read restart file flag (0=no,1=yes)(after each trial)
\deep\restart\                                      !path to restart files
rest94.dat                                          !name of restart file
0         !write restart file flag (0=no,1=yes)(after each trial)
\deep\restart\                                      !path to restart files
rest94.dat                                          !name of restart file
\deep\data\                                         !path to output plot files
3         !numsc - followed by scha(i),schp(i),sci(i),scap(i),scra(i),scxa(i)
700.0,400.0,62.0,114.0,326.0,10.0                    ! sc to study effects on
750.0,400.0,62.0,114.0,326.0,10.0                    ! sc to study effects on
800.0,400.0,62.0,114.0,326.0,10.0                    ! sc to study effects on



----------- not used below this line -- use for comments and such ----
```

Notes on file: MES.DEF

⇒ This file must be present but is not used at this time because the Mission Event Simulation (MES) module has not been completed.

⇒ The contents of this file tell the MES how to add future launches and associated debris according to the contents of this file.

```
-- MES.DEF -- contains the default MES variables -
          0                    !Method to do future launches(0=MES,1=file)
\deep\launch\                  !Path to alternate MES file
futla.dat                      !File for future launches
          0                    !Method to do future breakups(0=MES,1=file)
\deep\launch\                  !Path to alternate MES file
futbu.dat                      !File for future breakups
          1                    !Number of MES type orbits (real)
 --------------- Separator -------------
USA                            !Launching organization (char*4)
science                        !Mission type (char*20)
    800.000                    !Perigee altitude [km] (real)
    50.0000                    !Apogee variance (real)
    1200.00                    !Apogee altitude [km] (real)
   -1.00000                    !Eccentricity (real)
   -1.00000                    !Eccentricity variance (real)
    63.3000                    !Inclination [rad] (real)
    1.00000                    !Inclination [rad] (real)
   -1.00000                    !Right asc. of the asc. node [rad] (real)
   -1.00000                    !RAAN variance [rad] (real)
   -1.00000                    !Argument of perigee [rad] (real)
   -1.00000                    !Argument of perigee [rad] (real)
    2.00000                    !Cross-sectional area [m**2] (real)
   0.200000                    !Cross-sectional area [m**2] (real)
    1000.00                    !Mass [kg] (real)
    100.000                    !Mass [kg] (real)
    4.00000                    !Stationkeeping duration [years] (real)
    1995.00                    !Launch time [cal. years] (real)
    2010.00                    !Cal. year to stop launches (real)
       2.00000                    !Initial launch rate at latime [#/yr] (real)
    1.00000                    !Launch rate variance [cal. yrs] (real)
   0.000000                  !Lin launch rate growth rate [#/yr/yr] (real)
          1                    !Deorbit at end of life (0=No, 1=Yes) (int)
          0                    !Exp. flag [0=none,1,2=LIE, 3,4=HIE] (int)
          0                    !Collision avoidance flag (int)
          0                    !Min. size for coll. avoidance [mm] (int)
          1                    !Num. of objs. sharing identical orbit (int)
          1                    !Obj. removal flag (1=keep, 0=remove) (int)
test                           !Object type (character*4)
 --------------- Upper Stages -------------
          0                    !In orbit flag (1=in orb,0=remove)(int)
          0                    !US exp flag (0=none,as above)(int)
    1990.00                    !Year to begin deorbiting R/Bs(real)
    200.000                    !US perigee height [km](real)
    400.000                    !US apogee height [km](real)
    28.5000                    !US inclination [deg]->[rad](real)
    1000.00                    !US mass [kg](real)
    3.00000                    !US area [m^2](real)
 --------------- Op Debris -------------
          0                    !(0=none,1=OD produced) (int)
   0.100000E-01                !Operational debris mass [kg] (real)
   0.100000E-03                !OP DEB area [m^2] (real)
    4.00000                    !number of op deb/year (real)
    1.00000                    !How long objects are created [year] (real)
```

Notes on file: PLOT.DEF

⇒ This file contains the input to create a 2-D figure of spatial density versus time.

⇒ The plot will be a cumulative spatial density for objects > 10 cm at an altitude of 500 km.

```
-- PLOT.DEF -- contains the default plotting variables -- comments at end
1957.0       ! timfix                 !Fixed time value
10.0         ! sizfix                 !Fixed size value
1.0          ! masfix                 !Fixed mass value
500.0        ! altfix                 !Fixed altitude value
0.0          ! latfix                 !Fixed latitude value
0.0          ! rafix                  !Fixed right ascension value
1            ! plt(plotnum)%plottype  !Plot Type (0=Ln,1=Ln w/pts,2=Sc,3=His)
2            ! plt(plotnum)%plotdim   !Plot dimension flag (2=2-D,3=3-D)
0            ! plt(plotnum)%dpvartyp  !Dep. var.type (0=Spat. Dens.,1=Flux)
1            ! plt(plotnum)%invartyp  !Indep. variable type (see PLOT.INC)
1            ! plt(plotnum)%sizemass  !Mass/size rep. flag (0=Size,1=Mass)
1            ! plt(plotnum)%cumdiff   !Cum./diff. flag (0=Diff.,1=Cum.)
0.0          ! yaw !Yaw angle (deg)
70.0         ! pitch !Pitch angle (deg)
135.0        ! roll !Roll angle (deg)
3.0          ! axlen !Axis length (in)
8.5          ! xorg !Origin X-coordinate (in)
5.6666666    ! yorg !Origin Y-coordinate (in)
5.0          ! scale
1            ! icoor !Draw coordinate axes (0 = No, 1 = Yes)
1            ! ieplan !Draw equatorial plane flag (0 = No, 1 = Yes)
1            ! ioplan !Draw orbital plane flag (0 = No, 1 = Yes)
0            ! itartyp !Target type flag (0 = Single Sat, 1 = Constellation)

---------- not used below this line -- use for comments and such ----
kens old input stuff
1957.0,10.0,1.0,500.0,0.0,0.0
1,3,0,1,37,1,1
0.0,70.0,135.0,3.0,8.5,5.6666666,5.0,1,1,1,0
timefix,sizefix,massfix,altfix,latfix,lonfix
ipltyp,ipltdim,idepvar,invar2d,invar3d,imassiz,icumdiff
yaw,pitch,roll,axlen,xorg,yorg,scale,icoor,ieplan,ioplan,itartyp
```

REFERENCES

1. "Space Debris Environment and Effects Modeling," by K.W. Yates, S.R. Maethner, and D.B. Spencer; AIAA Paper 95-0663, Presented at the 33rd Aerospace Sciences Meeting, Jan. 9-12, 1995, Reno, NV.
2. "Program DEEP: A Modeling Approach for Estimating the Space Debris Environment and its Effects," by D. Spencer, S. Maethner, K. Yates, and R. Madler; IAA Paper 95-IAA.6.4.04, Presented at the 46th International Astronautical Congress, Oct. 2-6, 1995, Oslo, Norway.
3. "Possible Hazards to Satellite Vehicles from Meteorites", by F.L. Whipple, Douglas Aircraft Company, Project Rand, Supplement to Report No. SM-11827, September 1, 1946,, pp. 61-68.
4. National Research Council Committee on Space Debris. *Orbital Debris: A Technical Assessment.* Washington, D.C.: National Academy of Sciences, 1995.
5. Johnson, N.L., and McKnight, D.S. *Artificial Space Debris.* Malabar, FL: Krieger Publishing, 1987.
6. Grissom, W., and Myers, G., "History of On-Orbit Satellite Fragmentations." Tenth Edition, Teledyne Brown Engineering, July 1996.
7. NASA Office of Safety and Mission Assurance (Code Q). "Guidelines and Assessment Procedures for Limiting Orbital Debris." NASA Safety Standard (NSS) 1740.14, August 1995.

BIBLIOGRAPHY

1. Madler, R.A., and Culp, R.D. "Calculating Collision Rates, Intersection Angles and Relative Velocities Between Intersecting Orbits." AIAA 94-3740, Presented at the AIAA/AAS Astrodynamics Conference, Scottsdale, Arizona, August 1-4, 1994.
2. "Policy For Limiting Orbital Debris Generation." NASA Management Instruction (NMI) 1700.8, April 5, 1993.
3. Reynolds, R.C., Loftus, J.P., Weinstock, R.W., and Frazier, W.R. "Handbook to Support NASA Policy Limiting Orbital Debris Generation." in *Space Environmental, Legal, and Safety Issues*, T.D. Maclay, Editor, Proc. SPIE Vol. 2483, pp. 132-143, 1995.
4. Spencer, D., S. Maethner, K. Yates, and R. Madler. "Program DEEP: A Modeling Approach for Estimating the Space Debris Environment and its Effects." IAA Paper 95-IAA.6.4.04, Presented at the 46th International Astronautical Congress, Oct. 2-6, 1995, Oslo, Norway.
5. Stansbery, E.G., Stanley, J.F., Kessler, D.J., Tracy, T., Matney, M., Hock, L., and McIntyre, K. "Orbital Debris Environment Characteristics Obtained by Means of the Haystack Radar." in *Proceedings of the First European Conference on Space Debris, Darmstadt, Germany, April 5-7, 1993*, W. Flury, Editor, ESA SD-01, pp. 323-327, July 1993.

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