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Development of a Spacecraft Materials Selector Expert System

G. Pippin
The Boeing Company, Seattle, Washington

Prepared for Marshall Space Flight Center
Under Contract NAS8–98213
and sponsored by
The Space Environments and Effects Program
managed at the Marshall Space Flight Center

June 2002

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1 Introduction

Section 1 of this report is an introduction.

Section 2 contains a description of the knowledge base tool and examples of its use. A downloadable version of the Spacecraft Materials Selector (SMS) knowledge base is available through the NASA Space Environments & Effects program. For instructions as to how to acquire this knowledge base, go to the SEE web-site (http://see.msfc.nasa.gov) and look in the model/database section.

Section 3 contains a short description of the content of each individual module within the SMS expert system.

Section 4 is a summary of topics covered at a training session conducted at NASA MSFC to introduce people to the Spacecraft Materials Selector tool and its capabilities.

Section 5 is a discussion of how information is weighted as to significance and accuracy. The weighting system uses a technique of assigning numerical values, called "Certainty Factors," to individual pieces of information.

Section 6 is a summary of the contract activities.

The "Spacecraft Materials Selector" knowledge base is part of an electronic expert system. The expert system consists of an inference engine that contains the "decision-making" code and the knowledge base that contains the selected body of information. The inference engine is a software package previously developed at Boeing, called the Boeing Expert System Toolkit (BEST).

The goal of the contract was to produce an expert system that included an electronic knowledge base containing information about on-orbit materials performance. A second goal was to provide the electronic package in a configuration suitable for distribution to appropriate organizations. This artificial intelligence tool was developed to assist in the storage, rapid retrieval, and interpretation of two sets of information. The knowledge base can identify the likely environments encountered by a selected spacecraft during a specific mission, as well as the performance of selected materials exposed to those same environments. The information within the knowledge base is primarily obtained from published literature describing flight experiments and/or results from operational spacecraft. There is some information from unpublished flight experiment results, and a small amount of information from ground test results.

The initial operating capability of the Spacecraft Materials Selector (SMS) knowledge base is described within this report. The SMS tool contains significant information about metallized Teflons, Kapton, and MLI insulation and is summarized below:

- A small amount of qualitative information is available concerning selected paints and metals

- Results predicted for eccentric orbits are generally less well defined than results from circular orbits
- The assessments of micrometeoroid and debris and thermal cycling environmental factors are very qualitative and limited in scope
- The atomic oxygen and electron and proton particulate fluences are extracted from rather detailed models
- Solar UV exposure level estimations are embedded within the rules
- Precise answers are given for certain well-defined sets of conditions
- For not-so-well-defined conditions, the estimation is only good to a rough order-of-magnitude
- The geometric definitions of the radiation belts altitude ranges are very qualitative.

2 Spacecraft Materials Selector (SMS) Expert System

The next several sections of this report describe the capabilities, structure, content of SMS, and several examples demonstrating the use of this knowledge base.
The knowledge base asks a user to define an application and a space flight profile: when is the hardware to be launched?, how high will it be?, how long will it remain operational?, and some details about the orientation of the spacecraft. The knowledge base then defines environments and/or performance of selected materials or hardware under the specified environments.

2.1 Knowledge base subject area

There are essentially two capabilities contained within this knowledge base:

- A description of the environment factors for a selected spacecraft mission profile.
- An estimation of the expected performance of a specific material or piece of hardware, chosen from a selected group of materials or hardware (MLI is the only current hardware example in the knowledge base) for which data is available.

Most of the information content in the SMS concerns Earth orbits from LEO to GEO conditions. The materials information is for thin films- Kapton and metallized Teflons, a variety of paints and coatings- A276 polyurethane, Z93 ZnO-based pigments in silicate binders, several silicones and other white thermal control coatings, metals-aluminum, gold, silver and a modest amount of information concerning other metals, and MLI assemblies and individual MLI-parts material sections.

2.2 Source of data

Periodic searches of the unclassified, open literature were conducted during this contract. The initial search was to locate as much published data on materials performance in space as possible. Two annual updates to this search were made in early 2000 and 2001. A subsequent search specifically for MLI results was carried out in late 2001. Information ultimately captured within the SMS has been obtained from the Long Duration Exposure Facility, the Passive Optical Sample Assembly I & II experiments, results from several Space Transportation System (STS) flights, including the EOIM I, II, and III experiments, Hubble Space Telescope repair missions, the Solar Maximum Repair Mission, Orbiting Solar Observatory, a Lockheed Low Earth orbit flight experiment, Skylab, SCATHA, ML-101 coatings experiment, NTS-2, IMP-H, coatings experiments on GPS, and several commercial and government spacecraft operating at Geosynchronous locations. References to the original sources of data are provided within certain responses made by the knowledge base.

2.3 SMS expert system content

The SMS expert system contains estimates of optical properties values and/or mechanical properties performance data for specific materials under generally specified ranges of exposure conditions. Thickness changes under atomic oxygen exposure, influence of contamination under certain conditions, and observations concerning the visual appearance for selected materials may be obtained.

The Spacecraft Environments Assistant (SEA) module contains rules to determine the significance of up to 27 environmental factors for a given flight.

Subsequent sections describe the content of each specific materials knowledge base in greater detail.

2.4 SMS expert system structure

The overall Spacecraft Materials Selector tool is actually a connected set of knowledge bases. The primary knowledge base is also called the SMS and contains detailed definitions of each and every parameter used by the other knowledge bases that are part of this expert system. The SMS expert system is organized in this modular fashion so that new information about a specific material may be added to an existing knowledge base, or a completely new materials knowledge base may be created, without requiring changes to every other knowledge base in the set.

2.5 Mechanics of a consultation

To use this tool, a person "runs a consultation." To consult with the knowledge base, SMS is opened, the run button is "clicked," and the user is asked a question by SMS. The user then "clicks" one of the available answers. If the question requires a numerical answer, the value must be input manually.

Essentially, the knowledge base has a set of defined parameters. Determining the "value" of certain of these parameters is the goal of the knowledge base. Exactly what parameters the knowledge base tries to determine during a given consultation depends on answers being provided by the user. Depending on the specific response to a given question, the knowledge base will respond with a variety of additional questions. When the knowledge base has asked all the questions it "knows" relative to the mission profile being considered, the results predicted by the SMS expert system are displayed.

2.6 Help Function

During a consultation, if the intent of a question is not clear, the help function may be used to clarify the purpose of the question and the kinds of answers expected. An example is the parameter "init-launch-day." The parameter definition below includes the name of the parameter, its legal values (in this case integers from 1 through 31), the

question that may be posed to the user, and the response that will be given if the user queries the help function when the question is asked.

parameter init-launch-day,
trans' mission launch day',
legal int{1,31},
prompt'What day of the month will the spacecraft be launched?\n\n',
help'Init-launch-day is the day of the month when the mission of interest was, or will be, launched. For long missions (greater than about 10 months), if the launch day is not known, the program will assume the 15th of the month is the launch day.';

In this case , the help function essentially tells the user that the knowledge base wants to know the day the spacecraft was, or will be, launched. The help function also indicates that the program will make an assumption for longer missions, even if the specific day of the launch is not really known.

Another example, where the intent of the question may be subject to more interpretation, is the question "What is the estimated level of the molecular contamination?" The allowed values of the parameter contamination are subject to interpretation. The complete "definition" of the parameter is listed below.

parameter contamination,
trans'molecular contamination',
legal text{negligible,minimal,low,moderate,heavy,severe},
prompt'What is the estimated level of the molecular contamination?\n\n',
help'This is a qualitative assessment of the extent of molecular contamination present. Negligible or minimal contamination implies that contamination can be essentially ignored in the assessment of materials properties. Low contamination means contamination is present but at levels that cause at most slight changes in the substrate. Moderate contamination induces significant measurable changes in the properties of the hardware. Heavy implies very thick or visible deposits that cause the measured surface properties of the hardware to be significantly influenced by the properties of the contaminant layer rather than the substrate. Severe implies that the surface properties are dominated by the properties of the contamination.';

In this case, the help function gives a description of each possible value of this parameter to give the user a physical picture of the amount of contamination on the surface.

2.7 Example consultations and interpretation

Five example consultations and the outputs from those consultations are presented below. The examples are chosen to demonstrate the type of information that can be extracted from the SMS.

Comments concerning selected features of a consultation are provided in bold italics to distinguish them from the actual text of the consultation.

These examples are meant to be illustrative, not comprehensive. The answers provided to the questions are in **bold type.** For certain questions, no answer will be shown. In such instances, the answer to the question chosen was "unknown." The use of the help function is also demonstrated in two instances.

2.7.1 Case 1: Environments for the ML-101 flight.

The contents of a file called ml-101.doc are listed below. This list is essentially the mission parameters for the ML-101 satellite as reported in "ML-101 Thermal Control Coatings: Five Year Space Exposure," R.A. Winn, AFML-TR-78-99.

purpose	environments-exposure-estimate
launch-date	yes
init-launch-year	1972
launch-month	october
init-launch-day	unknown
time	years
orbit-type	yes
inclination	98
craft-motion	spinning
comparison	no
year-num	0.25
altitude	740
spin-axis	sun-earth-axis
mission-profile	ml-101

The following consultation uses the ML-101 mission parameters as answers to the questions asked by the expert system.

When a consultation is started, the knowledge base makes a few initial comments.

This system allows a user to obtain materials recommendations and
end-of-mission materials properties predictions for selected spacecraft applications.

The user is asked to define an engineering application and then identify a material from a selected list. The knowledge base will ask for information concerning the spacecraft mission, materials properties essential for the application, and the conditions under which the material is to be used.

The goal of the knowledge base is to determine the expected performance of the material and to assess if the specific material will work for the indicated application. When an environmental assessment is sufficient, the scope of the goal is reduced to predicting the environments experienced during a particular mission.

Following the comments, the knowledge base asks the first question; essentially, "what is the purpose of the consultation?". After certain questions, the knowledge base may make comments before proceeding automatically to the next question.

1 :Is this consultation for a materials performance assessment or to make an environmental exposure estimate?
environments-exposure-estimate

The application must be identified to be able to assist you with a materials recommendation.
Calling the mission profile definition kb to obtain a determination of environmental exposure conditions for a given flight.

2 :Is the mission launch date known (even approximately)? (For short missions, year, month, and day are needed. For longer missions, year and month are enough.)
yes

3 : Would you characterize the mission as lasting days, weeks, months, or years)?
years

4 :Is the orbit shape approximately circular?
yes

5 :What is the orbital inclination(0o east, 90o at poles,
and 180o west)?
98

6 :How would you describe the general motion of the spacecraft?
spinning

7 : Material performance data is available from a number of operational satellite and flight experiments. Selected flights have been grouped into several general exposure categories. Do you wish to review previous mission profiles for one or more mission exposure categories?
no

8 :What calendar year will the spacecraft be launched?
1972

9 :During what month will the spacecraft be launched?
october

10 :What day of the month will the spacecraft be launched?

In question 10, the answer is blank, because this detail was not known. The knowledge base treats a "blank" response as an "I do not know".

11 :How many years will(did) the spacecraft fly?
0.25

12 :What is the approximate initial altitude of the spacecraft in km?
740

13 :What is the orientation of the axis of rotation?
sun-earth-axis

14 :Indicate which one or more of the following spacecraft or satellites(ldef, sts, posa, solar-max, scatha, skylab, MIR, ml-101, impl, ots2, lockheed leo experiment) has a mission profile similar to the flight being considered. If no previous flights approximate the current flight, select none.
ml-101

At this point, the knowledge base provides a series of statements, numerical values for selected variables, a list of factors present at significant levels in the ambient environment around the spacecraft, and a list of factors that might be significant for the defined conditions.

Particles (electrons and protons) ejected from the sun during solar flare activity will reach spacecraft flying in orbits between ~45 and 135 degrees inclination, at any altitude, and could lead to significant radiation dose, depending on the intensity of solar particle event, level of shielding and altitude.

The approximate fluence of atomic oxygen is 9.19828e+017 atoms/cm2

The approximate fluence of solar ultraviolet radiation is about 399.968 Equivalent Sun Hours.

Taking into account the self-shielding of the spacecraft structure, the effective dose is reduced by a factor of 2 from the numerical value of the surface dose predicted here.

Atomic oxygen exposure levels present
minimal-ao
Solar exposure environment factors present
solar-protons
soft-x-rays
solar-electrons
high-energy-protons

Solar uv radiation level present:
moderate-solar-uv
earth-albedo

Additional environments present:
micrometeoroids
thermal-cycling
trapped-cosmic-rays
cosmic-rays
debris

The approximate fluence of electrons from all sources, based on a look-up table built using the AE8 models, is 3.38592e+012 electrons/cm2

The approximate dose level of electrons from all sources, based on a look-up table built using the AE8 models, is 315230 rads

The approximate fluence of protons from all sources, based on a look-up table built using the AP8 models, is 2.69354e+009 protons/cm2

The approximate dose level of protons from all sources, based on a look-up table built using the AP8 models, is 3814.75 rads

Solar exposure environment factors potentially present
hard-x-rays

Solar flare induced environments potentially present
rf-bursts

Additional environment factors that may be present:
trapped-electrons and protons

The value selected for "year-num" in the above example is 0.25. This choice selected for the parameter "year-num" caused the knowledge base to assess materials performance after a 3-month on-orbit exposure. The ML-101 satellite provided 5 years of data on the performance of selected materials. To determine the "end-of-mission" performance, the change command must be used. For example, if the question "How many years did the spacecraft fly?" is the 11th question asked by the knowledge base, then typing the command: "change 11" would cause the question "How many years did the spacecraft fly?" to be repeated. At this point the user could respond 5. The knowledge base would then re-ask any other questions that might have different answers depending on the time period of interest. At the completion of this process, a revised set of conclusions would be stated.

2.7.2 Case 2: Multi-Layer Insulation performance in low Earth orbit

This consultation is to evaluate the performance of a multi-layer insulation blanket for a hypothetical flight in a very low orbit. The first ten questions define the mission parameters. The remaining questions are directed toward the MLI performance. Comments have been included relative to the significance of certain questions and responses.

1 :Is this consultation for a materials performance assessment, a hardware evaluation, or to make an environmental exposure estimate?
hardware-evaluation

The application must be identified to assist with a materials recommendation.

2 :Is the mission launch date known (even approximately)? (For short missions, year, month, and day are needed. For longer missions, year and month are enough.)
yes

3 : Would you characterize the mission as lasting days, weeks, months, or years)?
weeks

4 :Is the orbit shape approximately circular?
yes

5 :What is the orbital inclination(0o east, 90o at poles,
and 180o west)?
17

6 :How would you describe the general motion of the spacecraft?
fixed

7 :Material performance data is available from a number of operational satellite and flight experiments. Selected flights have been grouped into several general exposure categories. Do you wish to review previous mission profiles for one or more mission exposure categories?
no

8 :What calendar year will the spacecraft be launched?
2005

9 :During what month will the spacecraft be launched?
november

10 :What day of the month will the spacecraft be launched?
26

11 :Is the engineering application being considered thermal control, shielding, or insulation?
thermal-control

At the initial operating capacity of the knowledge base, the value of the application parameter really causes no variation in the subsequent questioning. It is a placeholder, built-in for completeness. Should the knowledge base be expanded, this parameter will become more significant.

Calling the mission profile definition kb to support a hardware performance evaluation.

12 :Is the material being used on a radiator, a reflector, or MLI?
MLI

13 :How many weeks will(did) the spacecraft fly?
13.0

14 :What is the approximate initial altitude of the spacecraft in km?
285

15 :Is the surface ram facing?
yes

16 :Indicate which one or more of the following spacecraft or satellites(ldef, sts, posa, solar-max, scatha, skylab, MIR, ml-101, impl, ots2, lockheed leo experiment) has a mission profile similar to the flight being considered. If no previous flights approximate the current flight, select none.
none

The approximate fluence of atomic oxygen is 2.70009e+021 atoms/cm2

The approximate fluence of solar ultraviolet radiation is about 413.902 Equivalent Sun Hours

Taking into account the self-shielding of the spacecraft structure, the effective dose is reduced by a factor of 2 from the numerical value of the surface dose predicted here.

17 :Would you describe the outer layer of the insulation material as a metallized film or a beta-cloth?
metallized-thin-film

18 :What part of the assembly and integration sequence is being considered?
assembly

19 :What is the performance issue being addressed?
heat-conduction

20 :What MLI component material(s) is(are) of interest?
aluminized-Kapton

21 :What section(s) of the MLI is(are) being considered?
all

Because the indication is that all components of an MLI blanket are of interest, several observations have been made.

Properties of several outer cover layer materials are included in NASA/TP-1999-209263. Materials include Beta cloth, Aluminized Beta cloth, Reinforced Tedlar, Coated and Backed Kapton, Backed Teflon, Coated and Backed Teflon.

Properties of aluminized Kapton, goldized Kapton, aluminized Mylar, polyester, and Teflon reflector layers are reported in NASA/TP-1999-209263.

Heat loss through an MLI blanket near the seams is a major contributor to increased overall effective emittance. Seam losses may be minimized by avoiding seams that extend through all layers of the MLI. Test results presented in AIAA 95-2015 show a decrease in effective emittance by a factor of 2.6 when MLI is fabricated using staggered seams, in comparison with identical MLI using through seams.

22 :Is the stitching exposed to the environment or nonexposed?
exposed

Atomic oxygen exposure levels present
high-ao
Solar uv radiation level present:
moderate-solar-uv
earth-albedo

Additional environments present:
cosmic-rays
thermal-cycling

The approximate fluence of electrons from all sources, based on a look-up table built using the AE8 models, is 6.91356e+010 electrons/cm2

The approximate dose level of electrons from all sources, based on a look-up table built using the AE8 models, is 6659.47rads

The approximate fluence of protons from all sources, based on a look-up table built using the AP8 models, is 1.02515e+008 protons/cm2

The approximate dose level of protons from all sources, based on a look-up table built using the AP8 models, is 26.791 rads

23 :Is contamination likely to be a factor?
no

Solar exposure environment factors potentially present
soft-x-rays
hard-x-rays
high-energy-protons

Additional environment factors which may be present:
debris
micrometeoroids

Solar exposure environment factors not present
at levels sufficient to effect materials performance
solar-protons
solar-electrons

Additional possible environment factors not present
under these conditions
trapped-electrons
trapped-protons

2.7.3 Case 3: Long Term Kapton performance at geosynchronous altitude

The following example predicts the performance of Kapton flown at geosynchronous conditions, such as on the "Spacecraft Charging at High Altitude" experiment.

1 :Is this consultation for a materials performance assessment or to make an environmental exposure estimate?
materials-performance-assessment

2 :Is the mission launch date known (even approximately)? (For short missions, year, month, and day are needed. For longer missions, year and month are enough.)
yes

3 : Would you characterize the mission as lasting days, weeks, months, or years)?
years

4 : Is the orbit shape approximately circular?
yes

5 :What is the orbital inclination(0o east, 90o at poles,
and 180o west)?
7.9

6 :How would you describe the general motion of the spacecraft?
solar-tracking

7 :Material performance data is available from a number of operational satellite and flight experiments. Selected flights have been grouped into several general exposure categories. Do you wish to review previous mission profiles for one or more mission exposure categories?
no

8 :What calender year will the spacecraft be launched?
1979

9 :During what month will the spacecraft be launched?
february

10 :What day of the month will the spacecraft be launched?
2

11 :Is the engineering application being considered thermal control, shielding, or insulation?
thermal-control

Calling the mission profile definition kb to support a materials performance determination.

12 :Is the material being used on a radiator, a reflector, or MLI?
radiator

13 :How many years will(did) the spacecraft fly?
10

14 :What is the approximate initial altitude of the spacecraft in km?
33000

Atomic oxygen is not a consideration for altitudes above ~1000 km.

For non-low Earth orbit conditions, atomic oxygen will not
be present in quantities sufficient to change materials properties.

15 : What is(are) the surface exposure(s)?
sun

16 :Indicate which one or more of the following spacecraft or satellites(ldef, sts, posa, solar-max, scatha, skylab, MIR, ml-101, impl, ots2, lockheed leo experiment) has a mission profile similar to the flight being considered. If no previous flights approximate the current flight, select none.
scatha

17 : What is the angle (degrees) between the surface normal and the Sun?
0

The approximate fluence of solar ultraviolet radiation is about 79750.9 Equivalent Sun Hours

Taking into account the self-shielding of the spacecraft structure, the effective dose is reduced by a factor of 2 from the numerical value of the surface dose predicted here.

18 :Are you examining a specific material?
yes

19 :What is the material of interest?
Kapton

Calling the Kapton knowledge base.

20 :Does the polymeric film have a metallized mirror surface? Answer y/n.
yes

21 :What is the metal used for the mirrored surface? aluminum, silver or gold?
aluminum

22 : Does the material have a coating applied?
no

23 :What is the initial film thickness (in mils)?
Typical commercially available thicknesses include 0.3, 0.5, 1, 2, 3, 5, 7.5 and 10 mils.
3

24 :Is the mirror a first surface mirror (FSM) or a second surface mirror (SSM)?
SSM

Solar absorptance and thermal emittance are estimated using curve fits to Sheldahl, Inc. data for aluminum-backed Kapton materials of different thicknesses.
Estimated end of mission optical properties of Kapton are taken from a curve fit of SCATHA data, AIAA-91-1325.

25 :Is contamination likely to be a factor?
no

The reflectance of Kapton will be specular. The appearance of the Kapton will be moderately-darkened.

Solar exposure environment factors present
solar-protons
solar-electrons
high-energy-protons
soft-x-rays
hard-x-rays

Solar flare induced environments present
rf-bursts

Solar uv radiation level present
extreme-solar-uv

Additional environments present:
micrometeoroids
debris
thermal-cycling
trapped-electrons
cosmic-rays

The approximate fluence of electrons from all sources, based on a look-up table built using the AE8 models, is 8.10084e+015 electrons/cm2

The approximate dose level of electrons from all sources, based on a look-up table built using the AE8 models, is 7.42193e+008 rads

The approximate fluence of protons from all sources, based on a look-up table built using the AP8 models, is 2.03152e+013 protons/cm2

The approximate dose level of protons from all sources, based on a look-up table built using the AE8 models, is 1.58778e+007 rads

Solar UV radiation levels potentially present:
earth-albedo

This prediction is an example of the limits of the knowledge base. In fact, at geosynchronous altitudes Earth albedo is not generally a consideration, although the output of the knowledge base suggests that it might be. A detailed examination of this prediction actually showed that the prediction of the knowledge base is that the Earth albedo is probably not a significant factor at geosynchronous altitudes.

Absorptance change for 1 mil aluminum-backed Kapton specimens exposed to ~11000 ESH (and no atomic oxygen) on LDEF was 0.02-0.04; emissivity decreases on these specimens were all -0.01 or smaller.

Absorptance changes were 0.03-0.035 for Kapton blankets in-service on the Solar Max satellite exposed to 7000-8000 ESH. A Kapton specimen flown under geosynchronous (GEO) conditions on SCATHA received ~11000 ESH in
just 4 years and had an absorptance change of ~0.15. The difference in these results is due to the higher particulate radiation exposures at GEO with respect to LEO.

The initial properties of the Kapton are as follows:
The initial thickness is 3 mil(s).
The initial thermal emittance is 0.759816.
The initial solar absorptance is 0.459028.

The end-of-mission thermal emittance will be : 0.759816
The end-of-mission solar absorptance will be : 0.671567

2.7.4 Case 4: Flight planned for a high proton radiation environment

This consultation is for a hypothetical mission flying in an elliptical orbit between an altitude reachable by the Space Shuttle and an altitude within the trapped proton belt.

1 :Is this consultation for a materials performance assessment or to make an environmental exposure estimate?
materials-performance-assessment

2 :Is the mission launch date known (even approximately)? (For short missions, year, month, and day are needed. For longer missions, year and month are enough.)
yes

3 : Would you characterize the mission as lasting days, weeks, months, or years)?
months

4 :Is the orbit shape approximately circular?
no

5 :What is the orbital inclination(0o east, 90o at poles,
and 180o west)?
57

6 :How would you describe the general motion of the spacecraft?
fixed

7 :Material performance data is available from a number of operational satellite and flight experiments. Selected flights have been grouped into several general exposure categories. Do you wish to review previous mission profiles for one or more mission exposure categories?
no

8 :What calender year will the spacecraft be launched?
2004

9 :During what month will the spacecraft be launched?
july

10 :What day of the month will the spacecraft be launched?
24

11 :Is the engineering application being considered thermal control, shielding, or insulation?

thermal-control

Calling the mission profile definition kb to support a materials performance determination.

12 :Is the material being used on a radiator, a reflector, or MLI?
radiator

13 :How many months will(did) the spacecraft fly?
24

14 :What is the approximate initial perigee in km?
(the minimum altitude of the orbit)
450

15 :What is the approximate initial apogee in km?
(the maximum altitude of the orbit)
2500

16 :Is the surface ram facing?
yes

Calculated eccentricity is 0.130523

17 :Indicate which one or more of the following spacecraft or satellites(ldef, sts, posa, solar-max, scatha, skylab, MIR, ml-101, impl, ots2, lockheed leo experiment) has a mission profile similar to the flight being considered. If no previous flights approximate the current flight, select none.
none

Particles (electrons and protons) ejected from the sun during solar flare activity will reach spacecraft flying in orbits between ~45 and 135 degrees inclination, at any altitude, and could lead to significant radiation dose, depending on the intensity of solar particle event, level of shielding and altitude.

The approximate fluence of atomic oxygen is 2.5236e+020 atoms/cm2

The approximate fluence of solar ultraviolet radiation is about 2429.5 Equivalent Sun Hours

18 :Are you examining a specific material?
yes

19 :What is the material of interest?
agfep

Calling the teflon knowledge base.

20 : Does the material have a coating applied?
no

Both FEP and PTFE Teflon will be attacked by atomic oxygen, with the PTFE being attacked at a slower rate under the same conditions. Indium tin oxide (ITO) coating may be put on silverized or aluminized FEP for electrical charge bleed-off. Such coatings are generally thin and optically transparent.
3.4e-025 cm3/atom is the long term Ag/FEP recession rate under atomic oxygen exposure as determined from multiple specimens on the LDEF.

21 :What is the initial film thickness (in mils)?
Typical commercially available thicknesses include 0.3, 0.5, 1, 2, 3, 5, 7.5 and 10 mils.
5.0

Absorptance of Ag/FEP is a representative value estimated from multiple sources.

Thermal emittance value is determined from a curve fit of data for emittance of different thicknesses of Ag/FEP published by Sheldahl, Inc.

22 :Is contamination likely to be a factor?
no

The end of mission solar absorptance estimated from curve fits of published SCATHA, NavStar, NTS-2, ml-101, and SOLRAD 11 data is 0.114013.

Mechanical shock to the silver layer will distrub the granular structure and cause the AgFEP to be visually discolored. Impacts on LDEF and Solar Max left "frozen shock wave" imprints from the pressure wave associated with the impact. Damaged areas appear to be smaller for free-standing flims than for areas in intimate contact with underlying support structure.

The reflectance of agfep will be specular.
The appearance of the agfep will be slightly-changed.

The initial material properties of the agfep are as follows:
The initial thickness is 5 mil(s).
The initial thermal emittance is 0.741197.
The initial solar absorptance is 0.07.

Atomic oxygen exposure levels present
significant-ao

Solar exposure environment factors present
solar-protons
soft-x-rays
solar-electrons
high-energy-protons

Solar uv radiation level present:
significant-solar-uv
earth-albedo

Additional environments present:
micrometeoroids
thermal-cycling
trapped-cosmic-rays
cosmic-rays

The approximate fluence of electrons from all sources, based on a look-up table built using the AE8 models, is 4.18478e+014 electrons/cm2

The approximate dose level of electrons from all sources, based on a look-up table built using the AE8 models, is 3.55888e+007 rads

The approximate fluence of protons from all sources, based on a look-up table built using the AP8 models, is 4.93253e+011 protons/cm2

The approximate dose level of protons from all sources, based on a look-up table built using the AP8 models, is 647034 rads

Solar exposure environment factors potentially present
hard-x-rays

Solar flare induced environments potentially present
rf-bursts

Additional environment factors which may be present:
trapped-protons
debris

Additional possible environment factors not present
under these conditions
trapped-electrons
For a mission experiencing a total atomic-oxygen-fluence of 2.5236e+020 atoms O/cm2, the following end-of-mission properties are expected:

The thickness loss of the metallized Teflon film will be 0.0337805 mil(s).
The end-of-mission metallized Teflon thickness will be 4.96622 mil(s).

The end-of-mission thermal emittance will be : 0.740194
The end-of-mission solar absorptance will be : 0.114013

2.7.5 Case 5: Conceptual Mission Senario

This consultation is for a not-so-well-defined mission. A two to three year mission is being considered for a spacecraft that will fly in an elliptical "geo-transfer" type orbit that reaches close to geosnchronous altitudes. Details such as an expected launch date, or orbital inclination, have not been established. In this case, the knowledge base is led to ask rather more general questions as it attempts to define the environments as well as possible given the conceptual idea of a mission, rather than a detailed, specific mission plan.

1 :Is this consultation for a materials performance assessment, a hardware evaluation, or to make an environmental exposure estimate?
environment-exposure-estimate

The application must be identified to assist with a materials recommendation.
The application must be identified to support a hardware evaluation.
Calling the mission profile definition kb to obtain a determination of environmental exposure conditions for a given flight.

2 :Is the mission launch date known (even approximately)? (For short missions, year, month, and day are needed. For longer missions, year and month are enough.)
no

3 : Would you characterize the mission as lasting days, weeks, months, or years)?
months

4 :Is the orbit shape approximately circular?
no

5 :What is the orbital inclination(0o east, 90o at poles,

and 180o west)?

6 :How would you describe the general motion of the spacecraft?
fixed

7 :Material performance data is available from a number of operational satellite and flight experiments. Selected flights have been grouped into several general exposure categories. Do you wish to review previous mission profiles for one or more mission exposure categories?
no

8 :How many months will(did) the spacecraft fly?
30

9 :What is the approximate initial perigee in km?
(the minimum altitude of the orbit)

10 :What is the approximate initial apogee in km?
(the maximum altitude of the orbit)
33000

Here, a guess is made, as the satellite is expected to reach near-geosynchronous altitudes.

11 :What is the eccentricity of the orbit?

This fact is not really known, so no response is given. At this point the knowledge base asks a more specific question about elliptical orbits. A request is made to the help function to understand what the program is trying to learn. The knowledge base makes additional comments to try to clarify the question and then repeats the question.

12 :Is the orbit shape circular, elliptical,
highly-elliptical(with eccentricities greater than 0.6), or unbounded?
help
A circular orbit is one which maintains an approximately constant altitude above the surface of the Earth. An elliptical orbit (as used here) is one which has an eccentricity of less than 0.6; or, equivalently, the ratio of the furthest distance from the center of the Earth to the nearest distance from the center of the Earth is less than 4. A highly-elliptical orbit (as used here) is one which has an eccentricity of 0.6 or more; or, equivalently, the ratio of the furthest distance from the center of the Earth to the nearest distance from the center of the Earth is 4 or greater. An unbounded orbit is one which does not repeat its motion periodically

12 :Is the orbit shape circular, elliptical,
highly-elliptical(with eccentricities greater than 0.6), or unbounded?
elliptical

13 :Is the spacecraft in earth-orbit, translunar,
lunar-orbit, or interplanetary orbit?
earth-orbit

14 :Is the surface ram facing?

15 :What is the surface orientation with respect to
the direction of motion?

16 : What is(are) the surface exposure(s)?
sun-facing

17 :Indicate which one or more of the following spacecraft or satellites(ldef, sts, posa, solar-max, scatha, skylab, MIR, ml-101, impl, ots2, lockheed leo experiment) has a mission profile similar to the flight being considered. If no previous flights approximate the current flight, select none.
none

The next question seeks a qualitative answer relating to the environmental conditions expected on a mission of the type being considered. A request for help is made to understand the nature or the expected response.

18 :How would you describe the exposure conditions?
help
Spacecraft exposure conditions are generally indicated by altitude ranges, type of orbit(leo,meo,geo,lunar), presence of radiation belts, and/or similarity to the range of exposure conditions experienced by previous spacecraft. Leo, meo, and geo refer to low Earth orbit, mid Earth orbit, and geosynchronous orbits, respectively. Van-Allen refers to exposure to both inner and outer radiation belts.

19 :How would you describe the exposure conditions?
meo

20 :Does the spacecraft travel in an eastward, westward, polar, or
sun-synchronous orbit?
east

The estimated fluence of solar ultraviolet radiation should be less than 5245.22 Equivalent Sun Hours

Solar exposure environment factors present
solar-protons
solar-electrons

Solar uv radiation level present:
high-solar-uv

Additional environments present:
micrometeoroids
trapped-protons
cosmic-rays
thermal-cycling

The NIL response appears when the knowledge base tries to provide answers that it really does not have for the specific parameters. Such cases point to changes needed in the construction of the knowledge base.

The approximate fluence of electrons from all sources, based on a look-up table built using the AE8 models, is NIL electrons/cm2

The approximate dose level of electrons from all sources, based on a look-up table built using the AE8 models, is NILrads

The approximate fluence of protons from all sources, based on a look-up table built using the AP8 models, is NIL protons/cm2

The approximate dose level of protons from all sources, based on a look-up table built using the AP8 models, is NILrads

Solar exposure environment factors potentially present
soft-x-rays

Solar UV radiation levels potentially present:
earth-albedo

Additional environment factors which may be present:
debris
trapped-electrons

3 Content of individual knowledge base modules

The overall Spacecraft Materials Selector knowledge base is separated into several individual modules (each module is, in fact, a knowledge base), each connected to the primary knowledge base. This organization allows changes to rules or parameters, and addition or removal of rules or parameters, to be made quickly and easily. This also minimizes the editing and testing time as a change is introduced to the system.

3.1 SMS (Spacecraft Materials Selector)– main knowledge base

The SMS module contains all the parameters used by each knowledge base within this expert system. This was done for convenience in making changes to the knowledge base. This module establishes the purpose of the current consultation and determines those parameters that are not relevant to the current consultation. This module calls other modules needed for the consultation.

3.2 SEA (Space Environments Advisor)

This module evaluates each possible environmental factor to determine if the specific factor contributes significantly to the environment around the spacecraft. For those environmental factors determined to be present, given sufficiently detailed inputs, a quantitative value may be determined. The knowledge base also indicates those factors that may be present, but cannot be conclusively established. Essential factors not present are also identified.

3.3 Specific Materials

This module calls the particular knowledge base for the material of interest for the current consultation. Depending on the material selected, this knowledge base may also restrict the parameters that are being evaluated. For example, if Z93, a white, inorganic paint performance is being determined, the knowledge base will not need to consider parameters such as polymeric-film-thickness, mirror, or mirror-metal. These parameters are simply not meaningful when considering such a paint.

3.4 Material Selector

This is a dummy module set up to allow a possible future comparison between candidate materials for a given application. At present this module is not specifically used by SMS.

3.5 Kapton

This module assesses the effects of atomic oxygen on Kapton based on a series of low Earth orbit (LEO) experiments. Measurements range from space shuttle exposures to results from the Long Duration Exposure Facility (LDEF). A recession rate of 3.0 x 10-24 cm3/atom, determined from multiple flight experiments, is used to determine mass and thickness loss. Mechanical data has been obtained from hardware returned from

certain LEO lights. Long term (multiple-year exposures) optical property data is available from a number of experiments at both LEO and geosynchronous orbits. Thermal emittance of Kapton (and other thin film polymer materials) is a function of thickness. Flight results for Kapton coated with various materials is also included, as are a few results from carbon-filled "black-Kapton." Coatings have included mirror materials (gold, aluminum), electrically-conductive materials such as indium-tin-oxide, and silicate-based atomic-oxygen-resistant coatings to maintain thermal properties.

3.6 Ag/FEP

This module contains significant data on the optical and mechanical performance of metallized FEP (Fluorinated Ethylene-Propylene) from over 20 different experiments on at least a dozen different spacecraft. The atomic oxygen recession rate of FEP changes as a function of solar ultraviolet radiation exposure. Measurements range from <0.05 E-24cm3/atom (STS experiments) to ~0.34 E-24cm3/atom (LDEF thermal control blanket examination). Variation of emissivity as a function of thickness is captured. A function predicting changes in solar absorptance as a function of particulate (electrons) radiation dose has been determined using measurements from ten different spacecraft. Mechanical properties of FEP as a function of solar exposure have been measured for selected hardware.

This module also contains selected information concerning the properties of Tetra-fluoro-ethylene (TFE).

Some qualitative information about the influence of contamination, micrometeoroid and debris impacts, and mechanical constraints on the properties of metallized FEP, is contained in this module.

3.7 Paints

This module contains a small quantity of information about a few selected "inorganic" paints. Data is presented for zinc-ortho-titanate and YB-71 paints in geosynchronous applications. The information in this module is the most limited in scope of all the material modules.

3.8 Silicones

A variety of paint systems use a silicone binder with different pigments. The ML-101 experiment included several such paints. Over an extended period of time, IITRI has developed a silicone-based paint system that has been used on many space vehicles. Results from specific uses of "S13"-type paints are captured in this module.

3.9 A276

Results from LDEF and STS flight experiments are captured for this paint system that consists of a polyurethane binder with a TiO2 pigment.

3.10 Z93

This paint system is essentially ZnO pigment in a potassium silicate binder. Results from Space Shuttle experiments, LDEF, and certain geosynchronous satellites are included in this module. Results are primarily solar absorptance as a function of exposure.

3.11 Metals

Oxidative stability of gold, silver, platinum, osmium, copper, tungsten, nickel, and aluminum is documented with results primarily from STS and LDEF experiments. All results captured in this module are for LEO exposures.

3.12 MLI (Multi-Layer Insulation)

Information in this module is primarily based on NASA/TP-1999-209263, Multilayer Insulation Material Guidelines, April 1999, M.M. Finckenor and D. Dooling, Satellite Thermal Control Handbook, David G. Gilmore, ed., 1994, augmented by results of operational experience from Solar Maximum Satellite, LDEF, the Hubble Space Telescope, and selected flight experiments.

4 Training Course

Boeing organized and conducted a small training session for selected NASA personnel to show how to plan, make, test and maintain a knowledge base, and use an artificial intelligence tool to capture, store, and retrieve information about a particular subject. The following paragraphs summarize a few key points from the training session.

Examples of knowledge base applications, types of knowledge bases, such as forward-chaining and backward chaining systems, picking the subject and assessing its suitability for capture in a knowledge base, how to set the strategic goals, and planning for initial operating capability were discussed. An example using a small "Contamination" knowledge base was developed. The participants then constructed a simple knowledge base of their own.

4.1 Background

A distinction needs to be made between two types of knowledge.

First, there is algorithmic knowledge. This knowledge comes from a structured sequence of steps that leads to a problem solution. Mathematical models used to determine numerical values for are an example. This approach is to reach a precise, detailed specific answer.

Second, there is heuristic knowledge. Heuristic knowledge is "experience-based" knowledge using previous observations, "rules-of-thumb," and strategies that improve the methods of finding solutions to complex problems. This approach is rapid, using limited time and resources, and includes a risk because the knowledge presented is integrated into a conclusion based partly on subjective interpretations.

An Expert System amplifies available information. Electronic systems provide the vehicle for rapid distribution, and allow regulation. The knowledge base can be hosted at a specific web site. Access may be controlled to allow use-only by most people, and modification allowed by only a few selected people. Configuration control needs to be maintained with these systems.

An Expert System assists a person in making decisions about a very specific topic, to check, verify, or challenge a decision. An electronic system can make scarce information available when the expert cannot be present. Using a knowledge base, an organization may capture, store, and then retrieve such information even after the knowledgeable person (expert) has left the organization.

Backward-chaining systems, such as the SMS, are suitable for applications that may require a relatively large number of inputs and reach relatively few conclusions. A frequently cited example is diagnostic systems, particularly associated with medical applications.

Inference nets, often used in backward-chaining systems, are more efficient, but less flexible and less powerful than pattern-matching systems.

4.2 Attributes of Knowledge Bases

There are several distinct advantages to an electronic knowledge base:

- Such a system provides a relatively easy widespread distribution of scarce knowledge The modular structure allows ease of modification
- Consistency of answers is provided
- The system is perpetually accessible
- These systems provide preservation of expertise and ease of growth
- These systems allow solution of problems involving incomplete data
- These systems also provide an explanation of the solution, although this feature is typically weak in expert systems

There are several potential disadvantages to knowledge bases that must be recognized. The answers may not always be correct. The knowledge is limited to the domain of expertise, and the coverage of the problem domain is not always complete. This is certainly the case for evaluation of materials performance on spacecraft. Data only exists for certain orbits with specific exposure conditions. Rule-base systems may exhibit a "lack of common sense." These systems can only ask the questions that have been built into them. Addition of contradictory knowledge is a possibility, especially for domains where the information is relatively sparce. Modifications to an existing rule may require changes in other rules. As the number of rules in a knowledge base increases, the knowledge base may develop "opacity," meaning that it is hard to see the effect of an individual rule. This is one of the reasons the SMS is being constructed in modular, independent sections.

4.3 Selection of Knowledge Base Application

To determine if a knowledge base is the appropriate tool to solve a problem, one must consider both the "suitability of application" and the "availability of resources." The example questions listed below were essentially taken from The Engineering of Knowledge-Based Systems, by A.J. Gonzalez and D.D. Dankel, Prentice-Hall, 1993.

To determine "suitability of application," the following kinds of questions should be considered.

- Does a problem really exist?
- Is a knowledge base suited to provide an answer?
- Is human problem-solving being replicated?
- Is the knowledge heuristic?
- Does the knowledge change periodically?
- Is the knowledge well-understood and accepted by
- human experts?

- Are inputs always complete and correct?
- Can the problem be solved through other means?
- Does the problem pass the "telephone" test?-can all the data needed by the expert be provided over the phone?
- Is a knowledge base approach really justified?

To determine the "availability of resources," the following kinds of questions should be considered.

- Does management support the effort?
- Is time available?
- Is an expert available?
- Does the expert support the effort?
- Is the expert competent and articulate?
- Is the expert in close physical proximity?

The more of the questions from both the above lists that have a "yes" answer, the greater the likelihood of success.

4.4 Subject Selection

The domain of knowledge that is being captured with the expert system should be specific. This criterion suggested that the definition of the environment around a spacecraft is a good domain to be addressed by a knowledge base. There are a finite number of attributes and their values are determined by a (relatively) small set of underlying conditions.

One should consider if the topic of interest lends itself to being captured within a knowledge base. Not all problems need a knowledge base to solve the problem. The task should be considered in terms of time and complexity. A question that may take just a few minutes to answer does not need a knowledge base. A project that may take several weeks to months of analysis and computation may not be suitable for a knowledge base. Similar projects that may be repeated from time to time, such as preliminary design studies, or materials trade studies, activities that may take a few hours to days to provide an answer, may be suitable applications for knowledge base development. Such considerations lead to the initial development of the SEA system that was the precursor and basis for the overall SMS expert system.

There are already a few existing knowledge base tools for space applications. Work carried out at The Aerospace Corporation and at Lockheed-Martin are described in several papers, including SAE Technical Paper Series 901410, "An Expert System for Atomic Oxygen Effect Analysis," A.L. Lee, 20th Intersociety Conference on Environmental Systems, Williamsburg, Virgina, July 9-12, 1990, "Vehicles Knowledge-Based Design Environment," April Gillam, J. Of Spacecraft and Rockets, Vol. 30, #3, May-June 1993, and "Spacecraft Environmental Anomalies Expert System," H.C. Koons and D.L. Gorney, J. of Spacecraft and Rockets, Vol. 31, #2, March-April 1994.

4.5 Strategic goal

The type of end result needed must be considered carefully and selected before beginning detailed development of a knowledge base. A backward-chaining knowledge base is essentially an electronic storage system.

Consider the Spacecraft Environments Assistant (SEA) and Spacecraft Materials Selector (SMS) development. This expert system went through several iterations before the appropriate organizational principles listed below became clear.

- Define mission profile → SEA predicts environments, or
- Define mission profile → SMS assesses materials performance.

If the goals change during development, the organization of the knowledge base may no longer be appropriate, leading to "drift"-subtle changes over time. Parameter names should be selected with care. An essential question is: "Would someone new to the project be able to understand the meaning of each parameter?"

4.6 Development of Knowledge Base capabilities

Before starting to build a knowledge base the strategic goals established should include a long-term goal and a goal for the initial operation. Premature release of a knowledge base under development can defeat your purpose if it is not perceived as helpful to people trying to use it.

A practical approach is plan for specific initial operating capabilities. Expert systems can be useful before they are "complete." They can also improve in capability as new information becomes available and is added. The initial operating capability should be a specific set of rules that provide results for a limited set of conditions that is a sub-set of the domain of interest.

The initial capability will be increased over time as additional rules are added, new topics added (for example new materials and/or new materials properties being added to SMS).

4.7 Calls to external programs or functions within the inference engine

The knowledge bases contained within SMS occasionally call other programs or functions, obtain a value for a parameter from outside the knowledge base, return and continue with the consultation using the new information. Certain functions are built into the inference engine and used directly by the knowledge base. During a consultation, SMS has the ability to call a function to calculate the fluence of atomic oxygen for a given set of conditions. SMS also has a set of "look-up tables" for proton and electron dose levels embedded within the expert system. These tables were constructed with data generated using the NASA AP8 and AE8 particulate radiation models.

5 Certainty Factors

Certainty Factors (CFs) are one method of representing uncertainty in the conclusions of a knowledge base. CFs are the tool used by SMS.

The Certainty Factor values selected to represent the degree of confidence in specific conclusions result from subjective judgments on the part of the individual constructing the knowledge base. CFs are the essential feature of a knowledge base that makes it different from algorithmic determinations. The values placed on certainty factors for specific values of parameters under differing conditions are based on the experience of the person making the assignments. This is the essential method through which the experience and judgment of the person constructing the data base is inserted into this electronic tool. Selection of the value for a CF also introduces risk into the knowledge base.

5.1 Assignment of Certainty Factors

There are both certain advantages, and certain risks, involved with using Certainty Factors.

- Certainty Factors are a simple computational model that allows an estimate of confidence in the conclusions being drawn.
- Certainty Factors permit expression of belief or disbelief in each hypothesis – express the effect of multiple sources of evidence.
- Certainty Factors allow a quantifiable uncertainty about knowledge being captured in a knowledge base.
- Certainty Factors are not statistically based. They are "easily" provided. One does not need a large data set as with other formalisms

Problems with Certainty Factors include how to handle non-independent evidence (must all be in one rule), and the fact that new knowledge may require changes in assigned CF values.

5.2 What Certainty Factors Represent

A Certainty Factor reflects the belief that a particular parameter value is or is not true. They also are the vehicle used to change the degree of certainty about a particular "fact." CFs are assigned to the specific value of each parameter used in a rule. The value of a CF may range from +1.0 to –1.0 and may change during consultation based upon conclusions made by the knowledge base. A CF of 1.0 means the value is absolutely certain (you believe the result to be true, period). A value 0f –1.0 means the result is absolutely false. Each parameter value starts out with a CF of 0.0 (no information to say if result is true or false). When a rule is "fired", the CFs of the concluded values are determined in several steps: First, the CFs of the premise are combined. Second, the CFs of the premise and the conclusion are multiplied to give the new "concluded" CF associated with the particular parameter value. The concluded CF from the rule being

"fired" is then combined with any previously concluded CF for that particular parameter value. There are several specific ways the CFs are combined depending on the specific values of the "previous" and ""current" CFs.
A CF value greater than 0.2 means a value is known to be true. A CF value of 0.1 is an indication that a "fact" might be true, but the information available is not conclusive.

5.3 Calculation of Certainty Factors within the program

The determination of CFs in BEST essentially uses the algorithm developed for the medical diagnostic knowledge base called EMYCIN. An electronic-based discussion, published in the book, "Rule-Based Expert Systems," by Bruce Buchanan and Edward Shortliffe, Addison-Wesley Publishing Company, 1984, concerning the development of CFs, highlights some of the issues with assignment of CFs to specific parameter values.

Under certain conditions, information from several rules, no one of which provides a definite answer, may lead to a prediction that the knowledge base asserts is a fact. This can lead to some logical fallacies. A robust knowledge base will also need some cases that indicate when assertions may not be true. There should be a practical limit on the number of rules making conclusions about a given parameter. This issue has been discussed in published papers concerning backward-chaining rule-based systems. ("A Framework for Comparing Alternative Formalisms for Plausible Reasoning," E.J. Horvitz, D.E. Heckerman, and C.P. Langlotz, AAAI-86, vol I, Pp.210-214)

5.4 Methodology for assigning Certainty Factor parameter values in rules

The methodology that was essentially followed for assigning CFs to parameter values in rules within the SMS is shown below. Other schemes could be devised, the essential point is to select and use only one method.

A value that has been calculated is given a Certainty Factor of 1.0.

A conclusion that may be true is assigned a Certainty Factor value of 0.15, 0.1, or 0.05. This is for a case where even if the premise is true, additional information is required to assert the conclusion is true. The specific value chosen reflects the judgment of the expert.

A value of 0.15 for a CF is for information that makes a result highly likely. A value of 0.1 for a CF is the "standard" that implies a result is probably true but needs further verification, or will be true in certain conditions that must be independently identified as being present. A value of 0.05 for a CF is for a conclusion that is possible under circumstances that need considerable further definition. Similarly, for highly unlikely results a -0.15 value is assigned. For results probably not true but needing further proof, -0.1 is used, and -0.05 is for a possible negative conclusion under circumstances that need considerable further definition.

A conclusion believed to be true is assigned a CF of 0.2. Because the program requires a CF >0.2 to consider a fact known, assigning values of 0.2 to a conclusion means the program must have some form of supporting evidence to "know" the fact is true.

CFs of 0.3, 0.4, or 0.5 on conclusions are assertions we believe such conclusions to be true and would require very strong contrary data to change our beliefs.

Adding or subtracting 0.02 CF units differentiates between two or more possible results when you believe one result might be slightly more or less likely than the others. This may be used when an engineer feels the conditions that would make the particular result true are more likely than other sets of conditions. For the current SMS application, this level of detail is probably lost in the uncertainty of the raw data on which the conclusions are based.

The Spacecraft Environments Assistant and Spacecraft Materials Selector knowledge bases use only the default CF value of 1.0 for the premise clauses. Varying the CFs for selected premises could be used to fine tune a knowledge base, but this subtlety is probably not required during early stages of knowledge base development.

In practice one can vary CFs by considerable amounts and still reach the same conclusions. A 1.0, 0.5, 0.2 hierarchy for CFs will probably work for applications similar to SMS.

6 Summary

An expert system has been constructed to provide information about the performance of selected materials under space flight conditions. The system is run by an inference engine, the Boeing Expert System Toolkit (BEST). The knowledge base contains information gathered primarily from the unclassified, published literature, augmented by a few unpublished results. This package should be considered to be the initial operating capability of this system.

The Kapton, AgFEP, and MLI modules contain substantially more information than the other materials modules. The Spacecraft Environments Advisor (SEA) module contains the capability to predict (given sufficient inputs) numerical values for selected environmental factors, or make qualitative comments regarding the presence, potential presence, or absence of about 27 different factors.

A glossary of terms has been included with the downloadable version of the knowledge base. This glossary contains the definition of each parameter that could potentially have its specific value selected by the user. A built-in HELP function is also embedded within the expert system. The HELP function gives a short description of the meaning of each parameter.

This tool is intended to be of use during preliminary design activities for planned satellite missions. It should also benefit materials engineers making materials recommendations for satellite projects. It is best treated as an advisor, or assistant, reminding the engineer what environments might be important for a particular project, and providing some insight into previous results and sources of information. An engineer or scientist may use this tool to confirm their judgment about a particular issue, or to rapidly assess a series of "what if?" questions. Like all "experts," there is a limit to the knowledge contained in this system. Also, this system could be wrong about certain "facts." Results, especially results that may be surprising should be confirmed by independent sources.

The tool does provide an effective means for rapid preliminary evaluations of space environments and selected material performance properties.

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13. ABSTRACT *(Maximum 200 words)*

This report contains a description of the knowledge base tool and examples of its use. A downloadable version of the Spacecraft Materials Selector (SMS) knowledge base is available through the NASA Space Environments and Effects Program. The "Spacecraft Materials Selector" knowledge base is part of an electronic expert system. The expert system consists of an inference engine that contains the "decision-making" code and the knowledge base that contains the selected body of information. The inference engine is a software package previously developed at Boeing, called the Boeing Expert System Tool (BEST) kit.

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