NMP/EO-1 TECHNOLOGY DESCRIPTION

1.0 INTRODUCTION

1.1 Title of the Advanced Technology: Carbon-Carbon (C-C) Radiator

1.2 ADT Lead:

Dr. Steve Benner/724.4
Phone: 301/286-4364
Fax: 301/286-1704
e-mail: Steve.m.benner@gsfc.nasa.gov

1.3 Sponsoring IPTD: MAMS

1.4 Category of proposed use: Category II (Thermal)

1.5 1.5 Supplying organization:

CSRP - Carbon-Carbon Spacecraft Radiator Partnership - a partnership that includes DOD, NASA and Industry (6 government and 4 industry partners), to promote the use of C-C technology for spacecraft applications and foster its development. The partnership is led by Elizabeth Shinn of Wright Patterson AFB with Dr. Howard Maahs of NASA Langley as the deputy lead.

1.6 Primary technology candidate contact:

Ms. Elizabeth Shinn, Wright Patterson AFB
Phone: 513/255-9062
Fax: 513/476-4706
e-mail: shinnet@ml.wpafb.af.mil

1.7 Useful secondary contacts:

Dr. Howard Maahs, NASA Langley
Phone: 757/864-3498
Fax: 757/864-7730
e-mail: h.g.maahs@larc.nasa.gov

2.0 BACKGROUND:

2.1 Characterize the candidate technology: (what is it; how does it work; where does it go, etc.)

Carbon-Carbon is a special class of composite materials in which both the reinforcing fibers and the matrix material is pure carbon. The use of high conductivity fibers in C-C fabrication (such as K1100 or K321) yields a material that has both high strength and high thermal conductivity. Since its density is much lower than aluminum, significant weight savings can be realized with the replacement of aluminum panels and radiators with C-C. Another advantage offered by C-C over high conductivity composites, such as K110/M55J because it's thermal conductivity though the thickness of the material is much higher.

The current baseline EO-1 employs the use of radiators consisting of honeycombed aluminum panels. These are baselined as passive radiators with no heat pipes. The technology plan is to replace one of the of the S/C honeycomb radiator panels with a C-C panel. The aluminum panel that will be replaced measures approximately 22" by 27." The panel will be used in an area where a high thermal conductivity is needed to meet the thermal requirements. This should be a good demonstration of the potential use of the potential use of C-C technology for S/C radiators.

2.2 How will the utilization of this technology enhance science in the 21st Century?

The trend to future satellites is towards higher power density along with a reduction in size and weight. C-C composite materials have markedly higher thermal efficiency than aluminum and therefore offer improved performance for lower volume mass. C-C composites will enable more compact packaging of electronic devices because of their ability to effectively dissipate heat from high power density sources. Studies has shown that the entire pipe panels can be replaced by high conductivity C-C for some applications, thus reduction system complexity and integration and testing costs. Furthermore, since C-C is a structural material, it can serve dual purposes as both a structural and thermal management material, and eventually eliminate the need for thermal doubler plates, which add substantial mass to a S/C. In addition being a composite, the structural and thermal properties are tailorable, thus adding capability and flexibility to S/C designs.

2.3 Why is this considered a revolutionary technology development?

The use of composite materials for S/C applications dovetails nicely with the trend towards smaller, lighter weight S/C. They offer significant weight reductions and a much lower coefficient of thermal expansion, compared to traditional aluminum construction. The use of C-C composites adds the benefits of high thermal conductivity in all directions, not just in-plane. C-C is therefore ideal for heat dissipation in high power density electronics and radiator applications. First generation S/C are already emerging that employ composite technology in the structure and panels. Later generation S/C will be all composite in that the subsystems such as electronic boxes and instruments will be made of nontraditional materials as well. This is leading to a revolution in the design and manufacturing processes in the aerospace industry and will be an enabling technology for the future smaller and lighter S/C.

2.4 Why is space flight necessary to validate this technology?

The use of C-C materials represent a departure from accepted practice for S/C radiator design. Because of this, C-C is viewed as unproven technology. Also, a flight will require that the C-C panels are subjected to the flight qualification process including vibration and thermal vacuum tests. Space flight will prove C-

C performance in space environment and provide the flight heritage needed to gain acceptance in the S/C design community.

3.0 PROPOSED INTEGRATION & VALIDATION APPROACH:

3.1 Describe your proposed approach to incorporating this candidate technology into the NMP/EO-1 flight and justify your categorization:

C-C will be incorporated as a Category 2 technology as a replacement for an aluminum radiator panel on the S/C. The proposed application is a straightforward replacement of the existing honeycomb panel, with the same size and shape C-C panel. If the C-C panel is not available for flight, substitution of an aluminum honeycomb could be easily accomplished.

3.2 Describe the approach presently in budget:

The present approach is to use an aluminum structure for the spacecraft. The final design will be based on S/C thermal and structural analysis. Honeycombed aluminum panels are used as radiator panels on the exterior of the S/C.

3.3 Describe how you proposed approach effects the baseline approach:

The proposed approach does not adversely affect the baseline approach. It will provide a benefit in weight reduction and improved radiator performance resulting in additional heat transport capability.

3.4 Describe the interface with the spacecraft or the Advanced Land Imager (ALI)

The C-C honeycomb panel will be built to the design drawings as a direct replacement of the baseline aluminum panel. The honeycomb panel will be exposed to the external environment and will require a thermal control coating This is not a problem for C-C as both Silver Teflon and white paint coatings have been successfully applied to C-C in the past.

3.5 Describe the impacts on the spacecraft or the ALI:

The ALI is sensitive to particulate contamination. The C-C panels will be coated with a flight approved encapsulant such as epoxy to preclude any particulate generation.

A secondary impact on the S/C deals with the validation of the technology. It will be useful to attach thermistors to the radiator panel to validate its performance in space and to assess any degradation that may occur with time. This would have to be correlated with any expected degradation on the thermal control coating the impact on the S/C is the request for up to six additional thermistor channels above the baseline. Spacecraft. accelerometer data would also provide useful information on launch loads.

3.6 Describe you proposed approach to the integration and test of the candidate technology:

C-C technology is already quite mature and is used in areas as the Space Shuttle wing leading edges and brake pads. Engineering Test Units (ETU's) of C-C doublers have already been delivered to GSFC for evaluation and test. Thermal Vacuum testing has been done to verify the thermal conductivity of the material and confirmed the overall performance of C-C. The testing was performed at GSFC, and monitored by Swales and GSFC personnel.

The C-C flight units (one flight and one spare) will be subjected to extensive testing prior to integration on the S/C. Vibration tests and structural analysis will be performed as necessary to verify the mechanical properties of the material and thermal vacuum tests will be used to verify the thermal properties. Once the panel is integrated on the S/C, they should perform as well or better than the baseline aluminum panels. Performance will be confirmed during the S/C testing as well.

3.7 Describe your approach to operations in general and to validation in particular for the candidate technology:

The C-C application should have very little impact on S/C operations and will generally be a one for one replacement of baseline S/C hardware. Validation will be accomplished with the use of flight thermistor data to verify that the S/C components are maintained at expected temperature levels and correlation with the S/C thermal model will be performed. Thermistors will be placed on the honeycomb panel to monitor the thermal gradient. The thermal conductivity and thermal efficiency of the C-C can then be determinated from these readings along with correlation to the thermal model. Any degradation over time will also be examined with regard to a long-term reliability of the C-C material.

3.8 Describe the specific impacts on spacecraft resources:

Mass: A direct replacement of the aluminum panel with a C-C panel results in a mass savings, since C-C has a density that is 65% of that for aluminum, and a thermal conductivity that is good or better, depending on the fiber material used for the C-C make up. The thermal conductivity of C-C can be enhanced with high conductivity fibers, but this also increases the cost of the panel. Cost tradeoffs and final fiber selection will occur as the S/C design matures. The potential mass savings to future mission are substantial if the material is utilized for additional S/C applications, such as battery sleeves and electronics box construction. Once the technology is proven on the EO-1, use of C-C materials on other future S/C will be more easily accomplished.

Powder: Negligible, low power required if additional thermistor channels are used.

Volume: No impact to the EO-1. However future missions could take advantage of the C-C weight savings since the structural loads would be reduced.

Thermal: Additional heat rejection capability is offered with C-C, which can offer improved thermal performance. Additional heat rejection is not desired, the heat rejection of the C-C radiators can be easily reduced by the use of appropriate thermal control coatings, without resorting to replacement of the panels with lower conductivity materials.

Propellant: No impact on the EO-1, S/C weight reduction reduces prop requirements for future missions.

C & DH: The incorporation of additional thermistors for technology validation could impact the avionics and data storage and handling systems.

Comm: No Impact.

ACS/pointing: No impact on the EO-1, weight reduction will reduce ACS requirement on future missions.

Flight S/W: Minor impact - modifications to accumulate the additional thermistors.

Environmental: The C-C material can generate particulate contamination. A coating will be used to preclude this; coatings have been successfully used on C-C in the past.

3.9 Describe how would contractually acquire the advanced technology and identify the deliverables:

The C-C panels will be provided by the C-C partnership at "no cost" to the EO-1 program. This will include any thermal or contamination control coatings that are required and could include the installation of flight instrumentation if desired by the project. The deliverables would include two identical honeycomb panels (one flight with one spare). Also copies any documentation such as materials, certification, fabrication logs, and supporting analysis and test will be provided.

A Memorandum of Agreement (MOA) or similar document between the CSRP and the EO-1 project would be an appropriate contractual mechanism, since the CSRP is run by government personnel.

3.10 Describe any facilities issues or special GSE or FSE:

GSFC facilities will be required for the vibration and thermal vacuum test of the C-C panels. These facilities are ready available upon request (and funding).

4.0 AVAILABILITY:

4.1 Identify the earliest date when an Engineering Test Units (ETU) or comparable demonstration hardware (and/or software) would be deliverable to the project:

ETU of the C-C have already been delivered and the thermal vacuum test program has been completed to test these panels at GSFC. No other ETU requirements have been identify by the project.

4.2 Identify the earliest date when the flight hardware (and/or software) would be deliverable to the project:

The honeycomb flight panels will be fabricated after the spacecraft design is finalized, (TBD) Approximately 8 months will be required for fabrication, coating, test and evaluation of the panels prior to delivery to the project. This will still allow ample time for S/C integration and test, the S/C need date has been identified as TBD

5.0 RISK:

5.1 Characterize the technical risk associated with this candidate technology. Identify specific risk mitigation approaches to the technical risk that would recommend.

The risk associated with the use of the C-C is relatively low due to the maturity of the technology and its present use in other are such as the shuttle wing leading edge. Its use in Spacecraft applications is new, although other types of composite material have already been flown. The primary risk is reliability of the material itself: Will it hold up under the vibration forces of launch? Will it maintain a high thermal conductivity after numerous thermal cycles and exposure to space environment? These risks will be mitigated through analysis and ground tests. Vibration test and thermal vacuum tests will subject the flight panel to the expected environmental conditions. When the panels complete these tests, they will be delivered to the project for S/C I&T. The risk of degradation of the material itself is low, C-C material has held up well under tests in the past, and has already seen use on the Space Shuttle in the very severe thermal environment of the wing leading edge, so material degradation problems are not expected.

5.2 Similarly characterize the schedule risk associate with this candidate technology.

Identify specific risk mitigation approaches to the schedule risk that you would recommend. Identify any schedule "trigger points" that represent decisions to shift to alternative development paths.

The schedule risk is the delivery of the flight panels to the project on time, or the failure of one of the panels during flight qualification testing. This is easily mitigated by maintaining the fallback option to implement aluminum honeycomb panel if the C-C panels are not available. This option could be implemented at any time during the S/C development at a relatively low cost. Also the inclusion of flight spares precludes risks associated with accidental damage to the flight panel. The current fabrication lead time is approximately 12-15 weeks for C-C, so fabrication of additional panels could seriously impact schedule. That is why the spares program is included.

5.3 Lastly, characterized the budgetary risk associated with this candidate technology. Identify specific risk mitigation approaches to the budgetary risk that would recommend. Identify the total budgetary reserve you wold recommend to make the aggregate risk incorporating this candidate technology acceptable.

The budgetary risk involves additional costs if difficulties arise with the flight panels. However the majority of the risk is assumed by CSRP and no t the EO-1 project since they are delivering the C-C panels at "no cost". The to the EO-1 is substantially reduced by maintaining the fallback position for the aluminum panel. This requires the fabrication of an extra aluminum panel, however, it is similar toe the other five aluminum panels already needed for the S/C, so the fabrication cost of this "backup" panel is relatively low.

Recommended Reserves:

$26 K, which is 20% of the Swales/GSFC costs listed below. The reserves would cover any extra testing or integration difficulties that may arise.

6.0 BUDGET

Determine the cost to incorporate and validate the advanced technology by using a spread sheet comparison between the budget distribution for the current approach pursued by Swales/Litton and that of the advanced technology. Identify any cost sharing with the supplier. Identify funding for the fiscal years 1996 through 2000 and subdivide the entries into Development Integration & Test and Operations, which includes the validation of the technology. Be sure to include and highlight the cost of the risk mitigation approaches you recommended under Risk.

Although this is a category II technology, the budget impact to the flight project is relatively minor, since the design process is essentially the same for the radiators, whether the material used is aluminum composite or C-C. There are some additional costs to the project related to trade studies, system level coordination between the project and the CSRP, and flight qualification and validation of the technology, with an estimate of these listed below. There is a significant contribution by the CSRP supplier in that the panels will be provided at no cost to the NMP. This contribution is estimated at approximately $220 K for the flight panels plus approximately 1.2 man-years of civil service effort ($400 K total if cost at $150 K/man-year). With a 20% reserve of $80 K, the total contribution by the CSRP is $480 K.

7.0 RECOMMENDED DISPOTITION:

Justify the incorporation of this candidate technology on the NMP-EO-1 flight. Weight the benefits described in the introduction against the accommodation impacts associated with budget, schedule and overall risk. Is the NMP/EO-1 flight a suitable cost effective testbed for this candidate technology? How well does this candidate technology contribute to the most robust technology mission we can afford?

Carbon-Carbon technology us highly recommended for incorporation on the EO-1 flight. While the benefits to the EO-1 are not "revolutionary," the potential mass savings are real, and this will be a pathfinder mission for more widespread uses of the C-C technology in future missions. The relative cost of the project is low, especially due to the "no cost" contribution of the flight panels by the C-C partnership. A viable fallback position has been identified if the C-C panels are not available for flight and the impact to the spacecraft design is minimal. NMP/EO-1 is an ideal testbed for this technology and the logical first step for the application of C-C technology to the spacecraft community.