INTRODUCTION OF THE VENUS INSTRUMENTATION FOR THERMOPHYSICS & AEROSCIENCES (VISTA) PROJECT FOR THE NASA DAVINCI MISSION TO VENUS

Edward R. Martinez[1], Jose A.B. Santos[2], Ruth A. Miller[3], Christopher O. Johnston[4], Eli R. Hiss[5]

[1,2,3]NASA Ames Research Center, Moffett Field CA 94035, USA
[4]NASA Langley Research Center, Hampton VA 23681, USA
[5]Jacobs Inc., Moffett Field CA 94035, USA

ABSTRACT

The NASA Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI) mission is scheduled to launch in 2031 and explore Venus via two flybys, and a probe descent in 2033. A new supporting project has been created to provide engineering sensors for the DAVINCI probe aeroshell named Venus Instrumentation for Thermophysics and Aerosciences (VISTA). The VISTA project's main objectives are to instrument the heatshield with thermocouples, and the backshell with a Schmidt-Boelter heat flux sensor. This paper will describe the overall VISTA effort to design, deliver, and support the safe integration of the sensors into the DAVINCI spacecraft.

[1]Senior Engineer, Thermal Protection Materials Branch
[2]Senior Aerospace Engineer, Thermal Protection Materials Branch
[3]Aerospace Engineer, Entry Systems Vehicle Development Branch
[4]Senior Research Scientist, Aerothermodynamics Branch.
[5]Aerospace Engineer, Thermal Protection Materials Branch

1. INTRODUCTION

NASA has developed a requirement of developing an option for Engineering Science Investigation (ESI) for missions that have an Entry Descent and Landing (EDL) component. The ESI would deliver sensors for integration into the spacecrafts aeroshell to make measurements during hypersonic, and slower, atmospheric entry. The goal of the ESI is to obtain diagnostic and technical data about vehicle performance and entry environments, with minimal impact to mission implementation. The strategic goal for NASA is to be able to use these data to improve the designs of all future missions that involve EDL at Solar System bodies with atmospheres. In the past, ESI has been delivered for Mars Science Laboratory in 2012, called Mars Entry, Descent and Landing Instrument (MEDLI) [1]. The ESI has also been delivered for Mars 2020, called MEDLI2, [2]. The VISTA project is a further example of ESI being developed for entry into Venus, that will leverage these prior mission experiences and technologies. VISTA uses thermal plugs on the heatshield of the aeroshell to measure in-depth and near-surface temperatures, similar to those used by MEDLI and MEDLI2 projects. The backshell uses a Commercial-Off-the-Shelf (COTS) TRL9 heat flux sensor (flown on the Mars 2020 backshell as part of the MEDLI2 sensor suite). VISTA will be the first EDL aeroshell measurements recorded at Venus since NASA's Pioneer Venus Program in 1978 [3]. The beneficiaries of VISTA data are the mission architects of future robotic and human missions, particularly missions involving EDL. Although the specific data set involves atmospheric entry and descent into a carbon dioxide dominated atmosphere, many aerothermodynamic and thermal protection conclusions will be applicable for extreme environment forebody heatshield design. Specific goals and objectives are listed in the table 1 below.

Technology Goal	
Goal #1	Obtain measurements about the atmospheric entry as the DAVINCI probe enters Venus during Entry and Descent, using a suite of thermocouples on the forebody and a heat flux sensor on the backshell.
Goal #2	Analyze the flight measurements taken during atmospheric entry to reconstruct the aerothermodynamic environment and TPS material response, validate NASA's design tools, and evaluate TPS sizing margins.
Project Objectives	
Objective #1	Conduct flight environmental testing and performance characterization of the instrument suite.
Objective #2	Deliver the flight hardware and support integration onto the DAVINCI spacecraft.
Objective #3	Support flight operations (cruise checkout activities, entry and descent), perform post-flight data analyses, and publish results.
Objective #4	Measure near-surface Thermal Protection System (TPS) temperatures as a function of time at 5 locations on the forebody.
Objective #5	Measure in-depth TPS temperatures as a function of time at 5 locations.
Objective #6	Measure total heat flux as a function of time at 1 location on the aftbody.
Objective #7	Measure radiative heat flux as a function of time on the aftbody.

Table 1. Technology Goals and Project Objectives for VISTA

The VISTA project is sponsored by NASA's Science Technology Mission Directorate (STMD), and, managed by Ames Research Center (ARC).

2. VISTA SENSORS

VISTA consists of two sensor suites.

2.1. Thermocouple sensors

"Similar to the Pioneer Venus Large Probe, the Probe Flight System (PFS) flies ballistically, without need of attitude control or propulsion, due to the inherent aerodynamic stability of its 45° forebody cone and CG location. The 2.24-meter diameter heatshield (HS) uses Carbon-Carbon (CC) TPS that was developed by Lockheed Martin Space Co. (LMSC) and successfully flown on the Genesis sample return capsule." [4]. The first sensor suite is the heatshield temperature instrumentation, which consists of 5 thermocouple (TC) plugs embedded in the forebody heatshield. The sensor placement is based upon aerothermal environments calculated for the DAVINCI mission, and, NASA predictions. Figure 1 shows preliminary locations of both sensor suites on the entry system aeroshell.

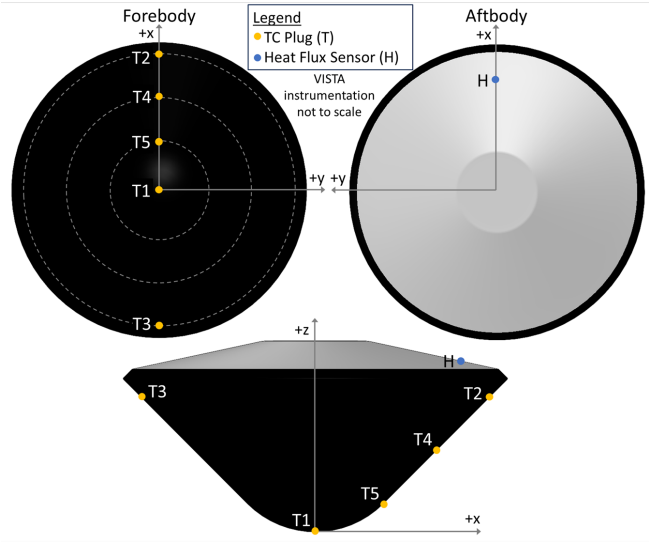


Fig 1. Preliminary VISTA Sensor Layout on the DAVINCI Heatshield and Backshell.

The near-shoulder location on the forebody, 2, is shown because it encounters the peak flank heating. Other points on the conical region of the forebody could also be chosen, with analysis presented in this section being equally relevant. The defining aerothermal characteristics of this near-shoulder region of the vehicle is that turbulence has a large impact on the heating. Figure 2 presents the large increase in the near-shoulder convective heating when going from laminar to turbulent, where a slight increase due to roughness augmentation is also shown [5]. The contribution from radiative heating, however, is seen to be small.

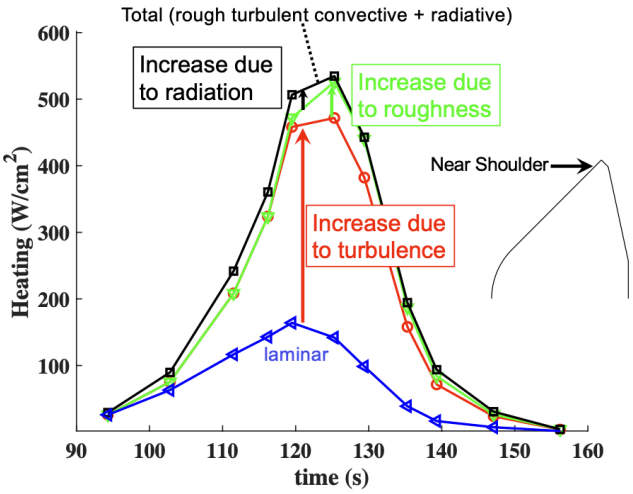


Fig. 2 Contributions of turbulence, roughness, and radiation on the non-ablating near-shoulder heating. [5]

Thermocouple (TC) plugs will be embedded in the FiberForm, the insulating material of the forebody heatshield. Installed from the Inner Mold Line (IML) side of the TPS material stack-up [6]. Multiple TCs will be positioned at various depths within the plug based on in-depth predictions. The TC plugs are planned for five locations in the heatshield. Thermocouple fabrication leverages NASA ARC in-house processes based on experience from prior flight missions.

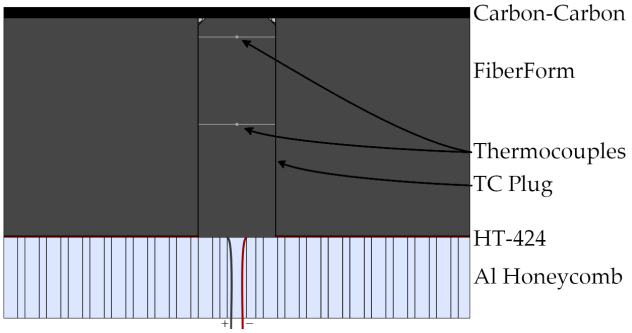


Fig 3. Schematic of a Thermal Plug in the heatshield

A Thermal Plug Pathfinder effort has been planned to evaluate several criteria for designing the plugs, and their installation technique. Prior missions with thermal plugs using PICA for Mars entry, and Orion with Avcoat HS TPS, have used an epoxy around the cylindrical surface to bond the plug in place. The preference for the VISTA plugs is to be installed dry, without epoxy, to minimize the number of materials that must be modeled to analyze the post-flight data. The Pathfinder effort will examine various tolerances of hole and plug diameters to determine an acceptable dry press fit method.

Also planned, are a series of ground tests for the thermal plugs that will include shock, vibration, and thermal vacuum testing from launch vehicle loads and cruise thermal temperatures. Arc jet testing at margined heat shield peak heating during entry at Venus will also be conducted. It is required to demonstrate that the inclusion of VISTA will not affect the DAVINCI aeroshell in any consequential way.

2.2. Heat Flux Sensor

The second sensor suite is the backshell heat flux sensor, which measures total heat flux. The sensor is based on a design named the Schmidt-Boelter gage. These transducers measure the convective and absorbed radiative heating during atmospheric entry. Again, these transducers were qualified and previously flown as part of MEDLI, MEDLI2, and the MPCV Orion Developmental Flight Instrumentation (DFI) Project for the Artemis Program.

'The baseline convective and radiative heating for the backshell cone and base locations are presented in Fig. 4. These are the result of non-ablating axisymmetric simulations assuming laminar backshell flow (while the forebody is fully-turbulent) and homogeneous recombination.'[5].

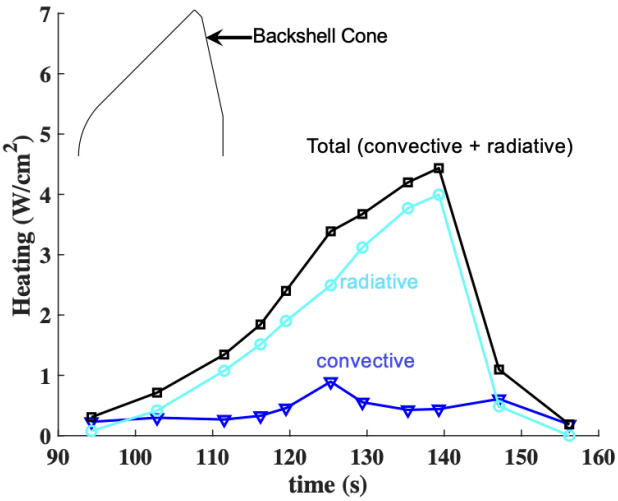


Fig. 4 Summary of the backshell heating resulting from laminar, non-ablating, axisymmetric simulations. [5]

The total radiative sensor currently planned for VISTA is a Schmidt-Boelter gage that was previously flown on MEDLI2. It is manufactured in the USA by the Medtherm Corp. Model 22171-01KS, shown in the Fig 5 below. The total heat flux sensors have a measurement range of 0–15 W/cm2 and include a surface type K thermocouple embedded in the epoxy surrounding the Schmidt–Boelter gauge [7].

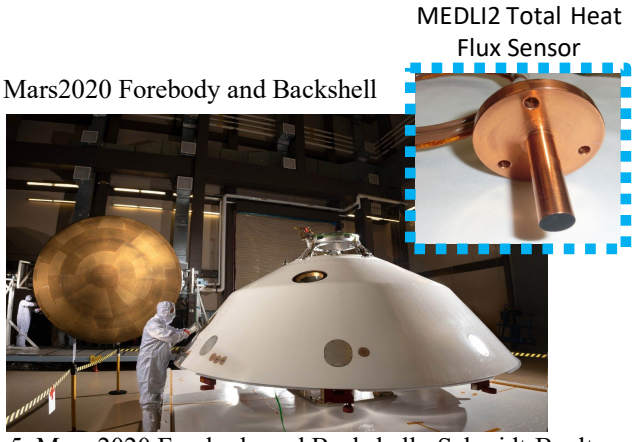


Fig 5. Mars 2020 Forebody and Backshell: Schmidt-Boelter total heat flux sensor [7].

A schematic of how the heat flux sensor is attached to the backshell for MEDLI2 is shown in Fig 6. The flight proven approach is to bolt the sensor to the honeycomb structure, while using shims and RTV-560 epoxy as gap fillers where necessary. This approach provides a rigid attachment that will survive launch and entry loads.

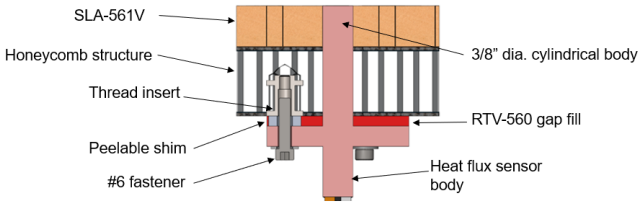


Fig 6 MEDLI2 Critical Design Review heat flux gage installation schematic

The DAVINCI provided DAS requires power supplied from the entry probe to function. The DAS is powered off until a specified time prior to entry interface (EI), nominally T_{EI} – 1.5 hrs. (The DAS is powered on periodically during cruise to Venus for check outs.). VISTA data will be collected by the Entry and Descent System (EDS) avionics at 4 Hz and then transferred to the Descent Sphere (DS) in 1 Hz packets. The data is time-tagged to the DS clock at receipt of packet. The data collection stops prior to heatshield ejection, and all data from the DAS is transferred to the DAVINCI avionics for uplink to the DAVINCI Orbiter. Sometime after the DAVINCI Orbiter receives the VISTA data, it will be telemetered back to Earth.

3. SCHEDULE

The overall schedule is now described. The first significant effort is the Plug Pathfinder laboratory exploration described above. This will take place in 2025-2026. Results of this effort will lead to plug design, and installation method for flight. The next major milestones will be to complete ground testing of thermal plugs and acceptance testing of the heat flux sensor in 2028. Flight fabrication of instumented plugs will take place in 2029 as well as delivery for installation into the flight heat shield. The latest planned schedule is for DAVINCI launch in 2031, with EDL and Probe descent into the Venus atmosphere in 2034. Post flight analysis of the VISTA data would begin in 2034 and last a year.

4. CONCLUSION

The VISTA project will deliver aeroshell instrumentation to measure TPS performance during Venus hypersonic atmospheric entry for the NASA DAVINCI mission. The addition of this data set could prove exceedingly valuable for the evaluation, design, and, certification of future missions using a Carbon-Carbon heatshield at extreme environments for planetary Entry Descent and Landing.

5. REFERENCES

[1] Gazarik, M. J., et al., "Overview of the MEDLI Project," *2008 IEEE Aerospace Conference*, Big Sky, MT, USA, 2008, pp. 1-12, doi: 10.1109/AERO.2008.4526285.

[2] White, T.R., et al., "Mars Entry Instrumentation Flight Data and Mars 2020 Entry Environments", AIAA 2022-001, https://arc.aiaa.org/doi/10.2514/6.2022-0011

[3] Pitts, W.C., Wakefield, R.M., "Performance of entry heat shields on Pioneer Venus probes", Journal of Geophysical Research Volume: 85, Dec 1980.

[4] M. Sekerak et al., "The Deep Atmosphere Venus Investigation of Noble gases, Chemistry and Imaging (DAVINCI) Mission: Flight System Design Technical Overview," *2022 IEEE Aerospace Conference (AERO)*, Big Sky, MT, USA, 2022, pp. 1-11, doi: 10.1109/AERO53065.2022.9843454.

[5] Johnston C., et al., "Aerothermal Analysis of the DAVINCI Probe for the VISTA Project", NASA Langley Research Center, Hampton, VA 23681, Version 1, January 2025

[6] Stackpoole M., et al., "Thermal Protection System Technology Maturation and Sustainment in Support of In situ Science Missions: HEET and PICA", 11th Ablation Workshop University of Minnesota, Minneapolis, MN USA, September 16-17, 2019

[7] Miller R.A., et al., "Aftbody Heat Flux Measurements During Mars 2020 Entry", Journal of Spacecraft and Rockets, Vol. 61, No. 2, March-April 2024.