Thermophysics

2003 has been a particularly active year, especially in the areas of planetary exploration, computational sciences, nanotechnology, and fluid dynamics.

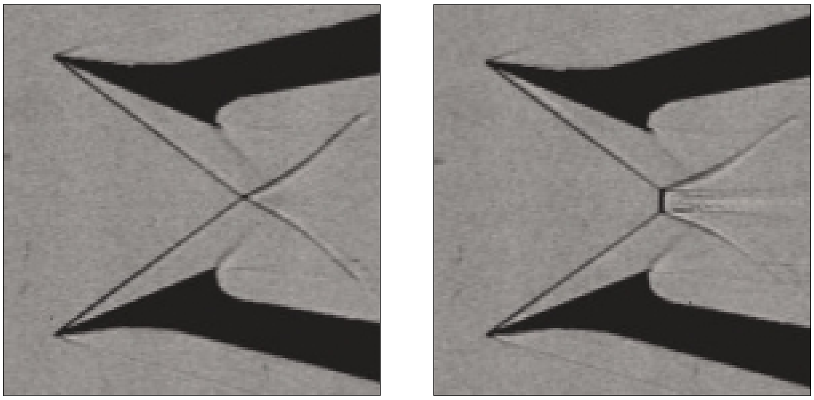
Planetary exploration

This was a watershed year for Mars missions. Thermophysics personnel from JPL participated in the thermal vacuum tests for the Mars Environmental Rover twin spacecraft and rovers, wherein the thermal design was validated. The rovers are scheduled to land in January 2004, after which their thermal health will be continually monitored for several months. The Mars Climate Sounder instrument on the Mars Reconnaissance Orbiter ended its design phase and was moved into assembly, test, launch, and operations.

Following a successful launch, the Galaxy Explorer (an Earth-orbiting deep space telescope) is obtaining information on the evolution of distant stars. Thermal engineers played an important role in designing the telescope and instrumentation. Cassini, a mission to Saturn, continues to be monitored by operational personnel including thermal engineers. Saturn orbit injection is expected to occur on July 1, 2004.

NASA-Langley led a one-year systems analysis study of an aerocapture mission to the Saturn moon Titan. Participants also included researchers from JPL, NASA-Ames, Johnson, and Marshall. Thermochemical nonequilibrium Navier-Stokes CFD codes and shock-layer radiation solvers were used to predict the aeroheating environment during aerocapture. Results showed that the radiative heating to the vehicle was three to five times greater than the convective heating. In contrast to the nonequilibrium results shown, equilibrium calculations of the flow field predicted no significant radiation, demonstrating the importance of using high-fidelity analysis tools early in the design process.

Regular (left) and Mach (right) shock wave reflections were produced in experiments conducted at Mach 4.



These results have implications for the selection and sizing of the thermal protection system (TPS), because of both the large amount of predicted radiative heating and the potential of short-wavelength radiation to heat a low-density TPS material in depth.

The high-enthalpy shock layer associated with the superorbital reentry of the planetary exploration probe from deep space has been investigated experimentally by means of the free-piston double shock tube at Japan's Institute of Space and Astronautical Science. The associated shock speed is as high as 12 km/sec in nitrogen gas or air at a pressure of about 40 Pa. Although significant nonequilibrium behavior of the rotational-vibrational temperature against the numerically predicted translational temperature was already revealed, the measurement of the translational temperature remained to be done because of experimental difficulty.

Application of the absorption spectroscopic measurement technique to the shock tube experiment was attempted for the first time and succeeded in revealing the behavior of the translational temperature associated with such a strong shock wave. Application of this measurement to such a transient phenomenon is unique because, using a standard method, it is not possible to carry out a necessary scanning of a laser oscillation frequency over the absorption frequency within the short time scale.

Computational sciences

The Air Force Research Laboratory's Center of Excellence for Computational Sciences quantified the extent of vibrational population depletion and enhancement based on state-to-state kinetics, caused by dissociation and recombination in high-temperature, highly nonequilibrium hypersonic flows considering vibration-translation and vibration-vibration energy exchange processes. The solution of the generalized depletion equations achieved for the first time is useful in evaluating an effective nonequilibrium dissociation and recombination rate in today's hypersonic computational fluid dynamic codes.

The newly developed vibration-dissociation coupling model, with no adjustable parameters, provides a basic understanding of the nonequilibrium process and enhances the predictability of heat transfer on aerospace vehicles and thrust in propulsive nozzles.

A general-purpose computational fluid flow software was developed at NASA-Marshall for predicting complex flows in rocket engine turbopump and propulsion feed systems. The Generalized Fluid System Simulation Program (GFSSP) is a robust tool that can be used across numerous industrial systems requiring complex flow analysis. GFSSP (Version 3.0) won the NASA Software of the Year award in 2001. The newly released Version 4.0 has the additional ability to handle fluid-transient, conjugate heat transfer and postprocessing. Utilizing a point-and-click graphical user interface, the program simulates cryogenic fluids with change of phase, compressible flows, fluid transients, mixture thermodynamics, conjugate heat transfer, and rotating flows in turbomachinery.

Nanotechnology

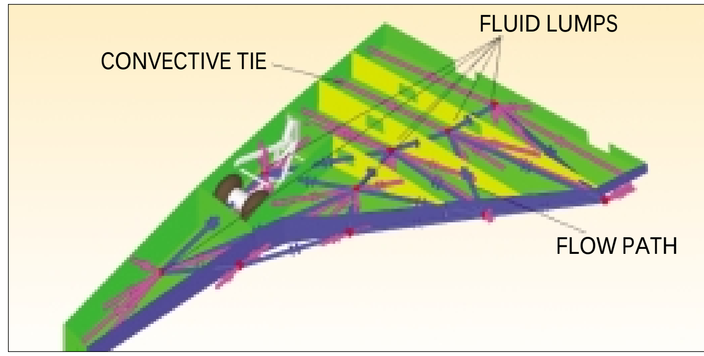
The NASA-Ames Center for Nanotechnology (NACNT) reported a robust process to integrate carbon nanotubes (CNTs) as interconnects in silicon integrated circuit manufacturing. CNTs are robust even at current densities of 109 A/cm^2, whereas copper, the material of choice today, suffers from electromigration at 106 A/cm^2.

Researchers have also reported a novel interdigitated CNT sensor for detecting small molecules such as NO_2, NH_3, and O_2, as well as larger organic molecules. The advantages of CNT sensors appear to be sensitivity, small size, and low energy consumption. In modeling aspects, a collaboration of NACNT with the Computational Plasma Dynamics Lab of Kettering University developed a finite-element-based efficient hydrodynamic algorithm that was able to benchmark the first hydrodynamic prediction in the transition regime in the flow of nitrogen, argon, and oxygen gas through anodisc membrane and CNTs.

NASA-Johnson researchers produced single-wall carbon nanotubes (SWNTs) using the laser ablation process. They also use SWNTs produced at Rice University by using the high-pressure carbon monoxide, or HiPCO, process. NASA-Johnson is developing applications of SWNTs for human spaceflight, including electrostatic discharge materials, fuel cell membranes, thermal protection materials, thermally conductive polymers, and CO_2 scrubbers. Other activities include kinetics and computational modeling of SWNT production, in collaboration with the University of Texas at Tyler and the Université Paris 13. NASA-Johnson is exploring ways of improving production measurements of laser process parameters, including the use of spectroscopic and optical diagnostics.

Fluid dynamics

In the area of fluid dynamics, experiments performed at the Institute of Theoretical and Applied Mechanics (ITAM) in Novosibirsk, Russia, confirmed the existence of a hysteresis loop in transition between steady regular and Mach reflections of strong shock waves in a supersonic flow. This phenomenon, hypothesized by Hans Hornung as early as 1979, was first observed in numerical simulations performed in 1995, but until now it had not been entirely reproduced in wind tunnels.



STS-107 Columbia conjugate venting/thermal model of a port wing aided the Columbia Accident Investigation Board (remainder of vent model not shown).

The main difficulty was the influence of the wind tunnel "noise," free-stream disturbances that promoted earlier transition to Mach reflection in the range of flow parameters, where both types of reflection were possible (the dual solution domain). Researchers at ITAM used a special low-noise wind tunnel with a low level of free-stream disturbances to perform experiments in conditions close to free flight.

In these experiments, both regular and Mach reflections were observed throughout the dual solution domain. The existence of two steady shock wave reflections at the same flow parameters has apparent practical meanings in designing hypersonic inlets, and in other aerospace applications.

CAIB support

As part of the aerothermodynamics team supporting the Columbia Accident Investigation Board (CAIB), NASA-Marshall created a venting model of the full orbiter with coupled heat transfer to the port wing structure. The air properties were based on chemical equilibrium air chemistry. The scope was to develop a tool capable of determining approximate internal bulk flow in the port wing for various breach locations and sizes (as theorized by the CAIB to have caused the reentry failure). The reason for the conjugate modeling (as opposed to venting only) was to account for the effects of the high enthalpy of the ingested flow.

Modeling was performed using SINDA/FLUINT with Thermal Desktop/FloCAD and was used to give a transient assessment of various breach scenarios. The results served to eliminate unrealistic breach scenarios and to provide flow rates and pressures as boundary conditions to the more time-consuming computational fluid dynamics analyses.

by the
AIAA Thermophysics
Technical Committee