bore must not be so narrow that the consequent resistance to flow exceeds the capability of the well pump, and the bore must be wide enough to accommodate suspended particles. The tube must not kink or fracture at low temperatures. It should be sufficiently insulated to prevent freezing during normal operation and it should tolerate inadvertent freezing.

This work was done by Michael Hecht and Frank Carsey of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
NPO-40031

Real-Time Simulation of Aeroheating of the Hyper-X Airplane

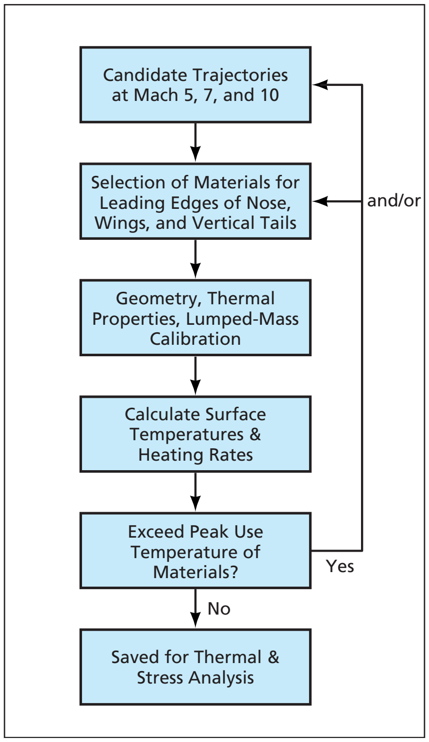
Computational simulations are expected to provide guidance for initial design choices.

Dryden Flight Research Center, Edwards, California

A capability for real-time computational simulation of aeroheating has been developed in support of the Hyper-X program, which is directed toward demonstrating the feasibility of operating an air-breathing ramjet/scramjet engine at mach 5, mach 7, and mach 10. The simulation software will serve as a valuable design tool for initial trajectory studies in which aerodynamic heating is expected to exert a major influence in the design of the Hyper-X airplane; this tool will aid in the selection of materials, sizing of structural skin thicknesses, and selection of components of a thermal-protection system (TPS) for structures that must be insulated against aeroheating.

The Hyper-X airplane will include an inlet/combustor/nozzle assembly attached to an airframe. The forebody of the inlet will consist of a leading edge and a tungsten ballast. Movable wings and vertical tail rudders will give the autonomous airplane controllability. Mounted inside the airframe will be all the active systems needed to fly and to demonstrate the ramjet/scramjet engine. The fuel-burning and flight hardware will be instrumented to collect and telemeter flight data.

Because of the short duration of flight, critical areas on the airframe TPS will be limited to the leading edges on the nose, cowl, and side walls of the inlet and the horizontal wings and vertical tails. In addition to other aeroheating effects, gap heating is expected to occur at horizontal wing roots, and at vertical rudder roots by amounts that will vary with movement of the rudders.



The **Computational Simulation of Aeroheating** is one of several real-time simulations used in initial design studies. This simulation can be used to eliminate flight trajectories that would give rise to local temperatures in excess of structural-design temperature limits.

The present capability for real-time computational simulation of aeroheating makes it possible to predict temperature as a function of time at critical heating locations on the Hyper-X airplane. Simulations of this type are used extensively to select acceptable flight trajectories by eliminating ones for which structural-design temperature limits would be exceeded (see figure). Other real-time simulations can be performed, using software modules that enable evaluation of other aspects of operation and design, including aerodynamics, reaction control system, flight guidance, and airplane structures. At speeds in excess of mach 2, aeroheating is considered important enough to affect design parameters, so that it becomes necessary to include a software module for simulation of aeroheating.

Thus far, a mathematical submodel of a nose with a solid carbon/carbon leading edge has been incorporated into the mathematical model used in the simulation of aeroheating. This submodel model includes 14 temperature nodes. Other submodels of aeroheating of the tail rudder and the leading edges of the horizontal and vertical tails were undergoing development at the time of reporting the information for this article.

This work was done by Les Gong of **Dryden Flight Research Center**. *For further information, contact the Dryden Commercial Technology Office at (661) 276-3143.*
DRC-98-76

Using Laser-Induced Incandescence To Measure Soot in Exhaust

This system incorporates several improvements over prior LII soot-measuring systems.

John H. Glenn Research Center, Cleveland, Ohio

An instrumentation system exploits laser-induced incandescence (LII) to measure the concentration of soot particles in an exhaust stream from an engine, furnace, or industrial process that burns hydrocarbon fuel. In comparison with LII soot-concentration-measuring systems that have been described in prior *NASA Tech Briefs* articles, this system is more complex and more capable.

Like the other systems, this system includes a pulsed laser and associated optics that shape and aim a laser beam through an exhaust stream. The laser beam heats entrained soot particles to incandescence. Light from the glowing soot particles is collected by two bandpass-filter-and-photodetector assemblies for measurement of the intensity of the incandescence as a function of time in two wavelength bands. On the basis of the established principle of two-color pyrometry, the instantaneous temperature of the glowing soot particles is determined from the ratio between the instantaneous intensities in the two wavelength bands.

The heating of the soot particles by absorption of laser light and the subsequent cooling of the particles through incandescence (and, when applicable, through evaporation of volatile materials from their surfaces) are complex nanoscale processes that can be represented by a computational model in which, during the decay of incandescence following the laser pulse, the time-dependent absolute intensities and the time-dependent temperature depend, further, on the volume concentration and surface area of the soot particles. In this system, the model is inverted to obtain the number density and size of the primary soot particles. The mass density of soot averaged over the probe volume can then be calculated from the volume concentration.

Calibration of the photodetectors and the optical components that precede them is necessary for determining absolute intensities. In this system, calibration is performed by use of a strip-filament lamp or other extended light source that has a known radiance traceable to that of a standard source maintained by the National Institute of Standards and Technology.

Uniform heating of all soot particles in the probe volume and in a sheath volume surrounding the probe volume is necessary to ensure accuracy. To satisfy this requirement, (1) the laser beam is expanded into a sheet of finite thickness that is perpendicular to the viewing axis of the detecting optics, and (2) the detecting optics include an iris that defines the probe volume as a cylindrical central, mid-thickness region within the beam.

In prior LII systems, the laser fluence is so great that soot particles are heated to temperatures above the sublimation temperature of carbon (about 4,000 K). This was done to produce an LII signal that was somewhat independent of laser fluence, making it unnecessary to measure the temperatures of soot particles. Unfortunately, the loss of mass through sublimation alters the very quantity (mass density of soot) that one seeks to measure. Also for prior LII systems, the laser fluence required to reach sublimation temperatures is dependent upon the initial particle temperature, and is affected by condensed species such as volatile organic compounds and water. In this self-calibrating system, the intensity measurements are used to adjust the laser fluence to keep the laser-heated soot particles below the sublimation temperature.

This work was done by William D. Bachalo and Subramanian V. Sankar of Artium Technologies, Inc. for **Glenn Research Center**.

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17479-1.