to density and must take into account the state of the thermosphere (i.e., the atmosphere above 100-km altitude). The thermosphere is strongly affected by the solar radio and geomagnetic activity, and has strong diurnal and semiannual variations. Empirical models of the thermosphere and exosphere are given by L. G. Jacchia.[16] Beside place and time of flight, these models require daily and averaged values of 1) solar flux at 10.7 cm, and 2) the geomagnetic planetary index. These are given in the *Solar-Geophysical Data Prompt and Comprehensive Reports*, available through the National Geophysical and Solar-Terrestrial Data Center, National Oceanic and Atmospheric Administration, U.S. Dept. of Commerce, Boulder, Colo.

When the exospheric temperature has been estimated, the vertical altitude scales for three different exospheric temperatures, on the upper right side of Fig. 2, can be used to make a best estimate of the atmospheric density at the missile altitude by first interpolating an altitude for the calculated exospheric temperature. Note that the 1962 U.S. standard atmosphere[17] exospheric temperature is $\sim 1500°K$. This interpolated altitude is then read horizontally across to the exterior density scale markings on the left side of the figure. This line also gives the ambient mean freepath on the appropriately labeled exterior scale markings on the right side. Notice that the state of the thermosphere, as determined by solar activity, has a first-order effect on the ambient density and thus on the plume dimensions above 300-km altitude.

The missile thrust is entered from the scale outside the upper horizontal line of Fig. 2. This thrust is read diagonally down toward the left until it intersects the horizontal line just drawn. This is the first intersection. A vertical line is dropped from the first intersection into the lower box of the figure, where it intersects a horizontal line labeled on the left side with the given missile speed. This is the second intersection. The missile hypersonic plume scale is given by the scale exterior to the lower horizontal line of the figure. The magnitude of the missile plume scale is identified by the diagonal lines nearest the second intersection. The division of the ambient mean freepath by the hypersonic plume scale yields the plume Knudsen number.

To estimate the plume outline, the Jarvinen-Hill plume proportions for $D/T \sim 0.2$ are shown in Fig. 2 in the inset. They have been changed slightly to show better agreement with the electron-beam data when the "contact surface" is reinterpreted as described above for the viscous plume.

The procedure just described can be used to generate a series of points in the lower box, the loci of which show the history of the plume development. Notice that for full-scale missile calculations, the exterior scale markings are used as just described. For the wind-tunnel experiment design, different ranges of the variables are used, but the calculation procedure is the same, except that the interior scale markings are used.

References

[1] Thomson, A. and Harshbarger, F., "Some Comments on the Fluid Dynamics of Missile Trails," (U) *Project Firefly 1960, Vol. III, Missile Trail Mechanisms*, AFCRL 256 (III), Air Force Cambridge Research Lab., Cambridge, Mass., 1961, pp. 7141–7153.

[2] Hill, J. A. F. and Habert, R. H., "Gasdynamics of High-Altitude Missile Trails," MC-61-18-R1, Jan. 1963, MITHRAS, Inc., Cambridge, Mass.

[3] Alden, H. L. and Habert, R. H., "Gasdynamics of High-Altitude Rocket Plumes," MC-63-80-R1, July 1964, MITHRAS, Inc., Cambridge, Mass.

[4] Albini, F. A., "Approximate Computation of Underexpanded Jet Structure," *AIAA Journal*, Vol. 3, No. 8, Aug. 1965, pp. 1535–1537.

[5] Thomson, J. A. L., Barthel, J. R., Brainerd, J. J., Janda, R. S., and Schoonover, M. R., "High-Altitude Rocket Plume Structure," GD/C-DBE65-023, Sept. 1965, General Dynamics Corp., San Diego, Calif.

[6] Hubbard, E. W., "Approximate Calculation of Highly Underexpanded Jets," *AIAA Journal*, Vol. 4, No. 10, Oct. 1966, pp. 1877–1879.

[7] Moran, J. P., "Similarity in High-Altitude Jets," *AIAA Journal*, Vol. 5, No. 7, July 1967, pp. 1343–1345.

[8] Boynton, F. P., "Highly Underexpanded Jet Structure: Exact and Approximate Calculations," *AIAA Journal*, Vol. 5, No. 9, Sept. 1967, pp. 1703–1704.

[9] Boynton, F. P., "High-Altitude Rocket-Plume Structure: Experiment and Calculations," Scientific Rept. 1, June 1972, Physical Dynamics, Inc., Berkeley, Calif.

[10] Tannehill, J. C. and Anderson, E. W., "Intermediate Altitude Rocket Exhaust Plumes," *Journal of Spacecraft and Rockets*, Vol. 8, No. 10, Oct. 1971, pp. 1052–1057.

[11] Jarvinen, P. O. and Hill, J. A. F., "Universal Model for Underexpanded Rocket Plumes in Hypersonic Flow," *Proceedings of the 12th JANAF Liquid Propulsion Meeting*, Las Vegas, Nev., Nov. 17–19, 1970.

[12] Draper, J. S. and Moran, J. P., "A Study of Wind Tunnel Simulation of High-Altitude Rocket Plumes," AFRPL-TR-72-111, RR-12, Feb. 1973, Aerodyne Research, Inc., Burlington, Mass.

[13] Norman, W., Kinslow, M., and Lewis, J. W., "Experimental Study of Simulated High-Altitude Rocket Exhaust Plumes," AEDC-TR-71-25, July 1971, von Kármán Gas Dynamics Facility, Arnold Engineering Development Center, Air Force Systems Command, Arnold Air Force Station, Tenn.

[14] Smithson, H. K., Price, L. L., and Whitefield, D. L., "Wind Tunnel Testing of Interactions of High-Altitude Rocket Plumes with the Free Stream," AEDC-TR-71-118, July 1971, von Kármán Gas Dynamics Facility, Arnold Engineering Development Center, Air Force Systems Command, Arnold Air Force Station, Tenn.

[15] Plotkin, K. J. and Draper, J. S., "Detachment of the Outer Shock from Underexpanded Rocket Plumes," *AIAA Journal*, Vol. 10, No. 12, Dec. 1972, pp. 1707–1709.

[16] Jacchia, L. G., "Revised Static Models of the Thermosphere and Exosphere with Empirical Temperature Profiles," Special Rept. 332, May 5, 1971, Smithsonian Astrophysical Observatory, Cambridge, Mass.

[17] *U.S. Standard Atmosphere, 1962*, U.S. Government Printing Office, Washington, D.C.

[18] *U.S. Standard Atmosphere Supplements, 1966*, U.S. Government Printing Office, Washington, D.C.

Laser Activated, Model Surface Recession Compensator System for Testing Ablative Materials

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Introduction

THE purpose of this Note was to develop an automatic surface recession compensator system to keep an ablating model in the uniform flow region of a high-pressure hyperthermal arc heater environment. Prior to the development of this system the front surface of an ablating model receded out of the region of constant pressure into the nonuniform

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environment which was difficult to define. A laser system was incorporated into the control circuitry of the model axial drive system in the McDonnell Douglas Research Labs. (MDRL) High Impact Pressure (HIP) arc heater facility. As model recession occurs during tests, the drive system automatically compensates for the axial displacement to maintain the front surface of the model at a virtually fixed position relative to the arc heater nozzle exit. The system can control up to seven successive models per test run. A maximum model front surface movement of ± 0.005 in. with respect to the fixed reference occurs at an axial drive speed of 0.43 in./sec. This laser system has been used for testing over 600 models in the HIP facility at impact pressures up to 170 atm. The tedious procedure of measuring nose tip positions from individual high-speed movie frames to obtain recession rate can now be eliminated with resultant improvements in accuracy and efficiency.

Contents

The High Impact Pressure (HIP) 12 Mw, continuous-flow arc heater test facility[1,2] was developed in 1968. The facility has been used for numerous test programs in the development of thermal protection systems for high-performance missiles. Prior to Sept. 1970 these test programs were accomplished by inserting the models into the jet stream at a fixed axial position near the nozzle exit. In addition, recession rates could be determined only by a tedious frame-by-frame analysis of high-speed film. To improve both the accuracy and the efficiency of test data acquisition, a system[3] (Fig. 1) was designed to maintain the model front surface at a set location by automatically controlling the axial drive unit of the model actuator. The system includes a 6328 Å helium-neon laser having a nominal output of 1 mw, and a ± 10 Å bandpass filter followed by a selenium photocell having a light sensitive area of approximately 0.3 in^2. The detector mounting provides both axial and rotational adjustments for aligning the complete system in accordance with any test requirement. The output of the detector is amplified to drive a relay coil which controls the Gilman slide mount of the model actuator. The Gilman slide is axially driven by a d.c. motor through a clutch-brake unit and a 5:1 gear reducer. The displacement of the axial drive unit is continuously recorded during a test and yields an accurate measurement of the model recession rate.

The time response of the entire axial drive system is a function of the detector, control relay, clutch-brake unit, and the drive speed. Measurements have been made on the complete system to determine the delay associated with both starting and stopping of the drive system. Based on these time delay measurements (23 msec) and a simple mathematical model, one can predict the cycle time as a function of axial drive speed for various values of recession rates. As shown by Fig. 2, the optimum arrangement is for the drive speed to

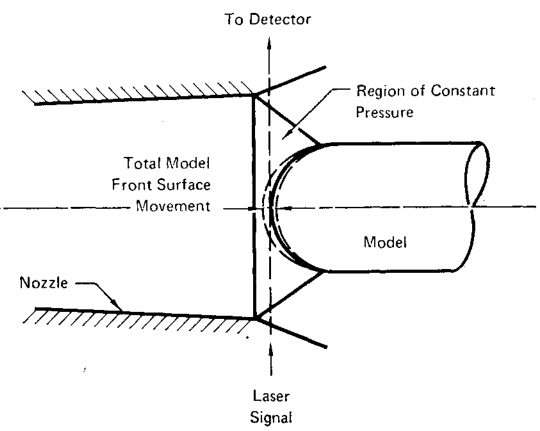

Fig. 1 Laser recession compensator configuration.

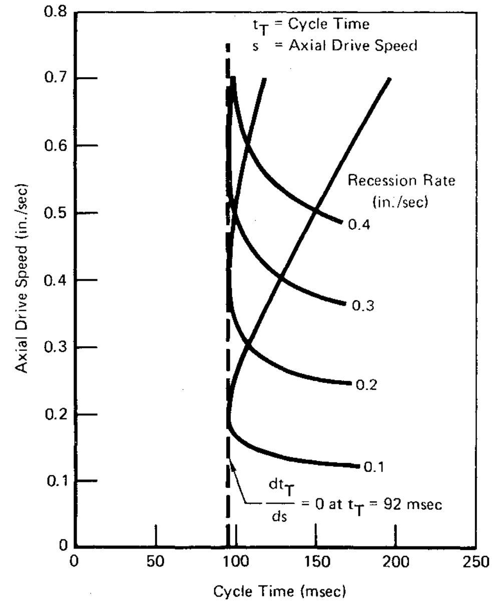

Fig. 2 Model recession compensator cycle time.

be set at twice the recession rate, which then gives a minimum start-stop cycle of 92 msec. Experimental data were also obtained on the complete system to determine its basic sensitivity. To determine the value of this model displacement sensitivity, measurements were made of the detector output. As shown in Fig. 3, the movement of the model front surface which results from the deadband in the cycling of the relay is held to approximately ± 0.001 in. and is independent of drive speed.

Included in the over 600 tested models[4,5] are several which have been routinely exposed to model impact pressures of over 170 atm, resulting from arc heater chamber pressures in excess of 200 atm using a Mach 1.7 contoured nozzle. Model surface temperatures up to 8000°F have been measured

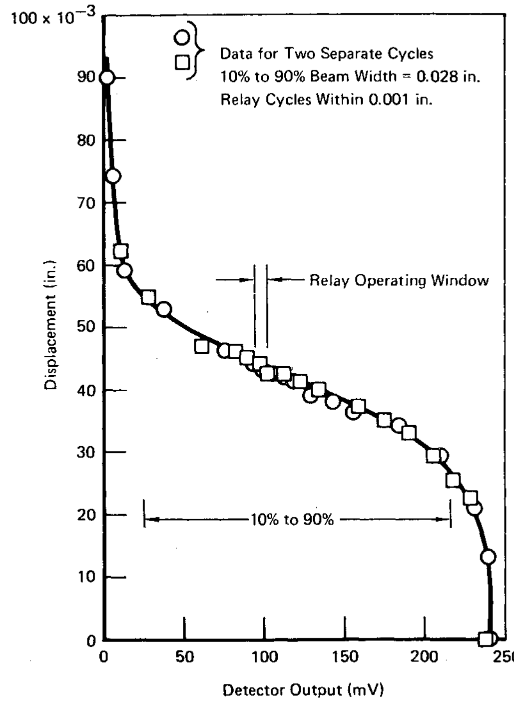

Fig. 3 Laser detector output as a function of transverse beam attenuation.

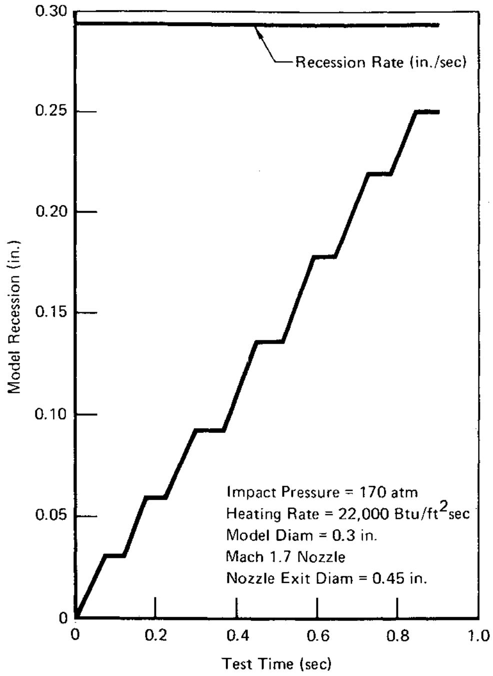

Fig. 4 Recession of experimental graphite at 170 atm.

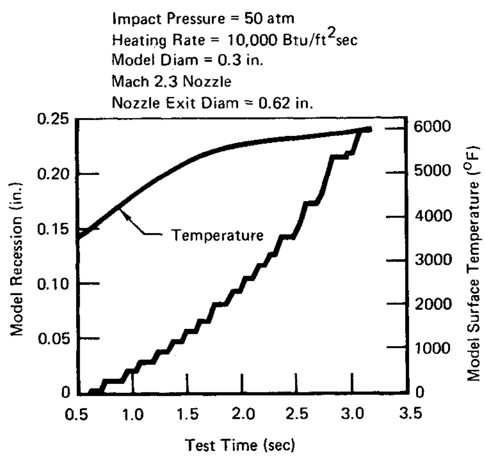

Fig. 5 Recession and temperature histories of experimental graphite.

by radiation pyrometers. A typical recession history for a 0.3-in.-diam. hemisphere-cylinder graphite composite model tested at 170 atm is shown in Fig. 4. Using an analytical expression for the curve fit to these data and differentiating the function with respect to time yields the model recession rate history also presented in Fig. 4. Additional recession data and a surface temperature history for a similar model tested at a lower pressure (50 atm) but higher Mach number (2.3) are shown in Fig. 5.

References

[1] Rinehart, W. A., Painter, J. H., Williams, R. R., and Williamson, R. A., "High Impact Pressure (HIP) Arc Heater Facility," 17th Annual IES Technical Meeting, Los Angeles, Calif., April 1971.

[2] Painter, J. H. and Ehmsen, R. J., "A 12 Mw, 200 atm Arc Heater for Re-Entry Testing," *AIAA Journal*, Vol. 9, No. 12, Dec. 1971, pp. 2307–2308.

[3] Williamson, R. A., Rinehart, W. A., and Williams, R. R., "Laser Activated, Model Surface Recession Compensator System for Testing Ablative Materials," AIAA Paper 73-380, Williamsburg, Va., 1973.

[4] Rinehart, W. A., Williams, R. R., and Williamson, R. A., "High Pressure Plasma Jet Tests," Rept. SC-Cr-71 5084, June 1971, Sandia Labs., Albuquerque, N. Mex.

[5] Kratsch, K. M., Dirling, R. B., Jr., Johnson, G. P., and Swain, C. E., "Erosion Mechanisms and Improvement of Graphite Materials," Vol. II, AFML-TR-70-307, June 1972, Air Force Materials Lab., Wright-Patterson Air Force Base, Ohio.

Round Trip Mars Missions Using Looping Trajectories in the 1980-2000 Time Period

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ORBITAL transfers which make more than one revolution have been known for some time.[1,2] However, when the transfer is interplanetary, the long trip times involved have dissuaded mission analysts from considering trajectories of more than one revolution. For example, standard Earth to Mars trajectories (Types I and II—Fig. 1a) have trip times ranging from 0.5 to 1.5 yr whereas looping trajectories (Types III and IV—Fig. 1b) have trip times ranging from 2 to 3 yr. Since the energy requirements for looping trajectories are sometimes significantly less than for standard transfers, it would be advantageous to use looping trajectories if the trip time problem can be alleviated.

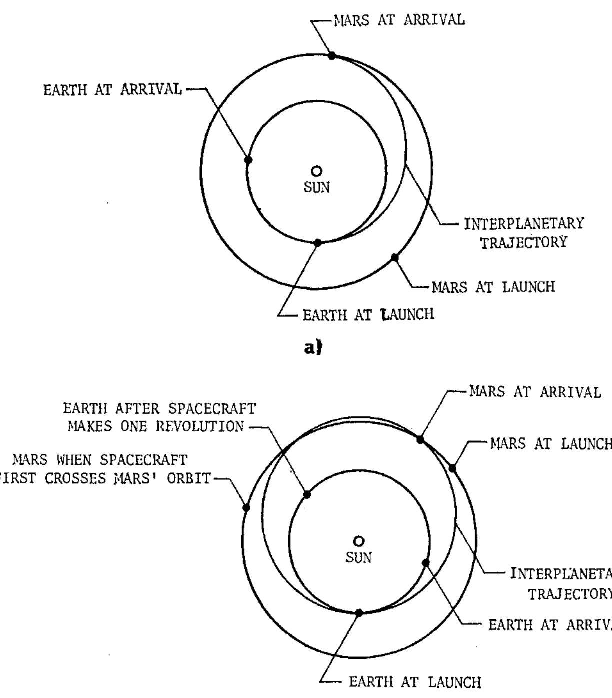

Fig. 1 Two types of Earth to Mars trajectories: a) standard (less than one revolution about the sun); b) looping (more than one revolution about the sun).

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