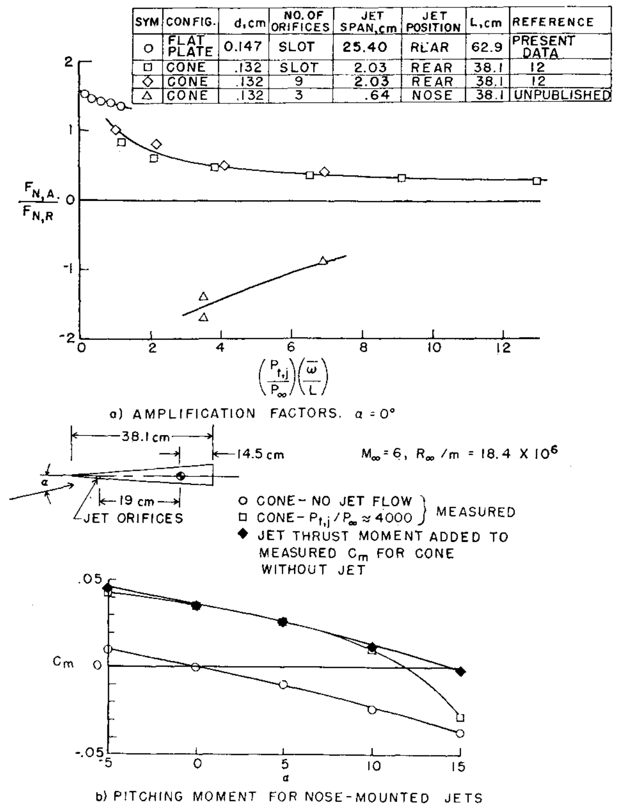

Fig. 3 Effect of jet location and body geometry on jet interaction.

increased outflow and circumferential spreading of the separation about the cone; furthermore, increasing the jet pressure increases the separation distance and increases the amount of outflow and separation spreading.

The movement of the secondary jets (orifices) from an aft location on the upper surface to a position near the nose on the lower surface of the cone model influences the magnitude of the jet interaction forces and relocates the resultant center of pressure. Unpublished data obtained in the study of Ref. 12 show the effect of jet location on the jet interaction forces (Fig. 3a) and the pitching moment (Fig. 3b). With the jets located near the nose of the cone, the amplification factors become negative, and the resultant jet interaction normal force ($F_{N,A}$) is situated longitudinally such that it adds only slightly to the over-all pitching moment (C_m) near zero angle of attack. At the higher angle of attack, this negative resultant $F_{N,A}$ is situated such that it almost nullifies the contribution of the jet reaction force $F_{N,R}$ to the over-all pitching moment. This result suggests that the shuttle orbiter utilizing forward mounted control jets could encounter severe control problems since the vehicle maintains a large angle of attack during entry. The negative amplification factors and the loss in efficiency in C_m at the higher angle of attack are a result of disturbances which include low-separation pressures and circumferential cross flows propagating downstream of the jets.[13] These cross flows may produce aerodynamic coupling between lateral-directional forces and moments.

In summary, outflow and jet location significantly influence the magnitude and behavior of the secondary jet interaction forces. Continued refinements in jet interaction analyses which do not account for outflow are of limited usefulness in the design of control systems for supersonic and hypersonic vehicles. Furthermore, the jet total back pressure ratio increases with either jet pressure ratio or freestream Mach number and analyses which assume a constant back pressure are subject to error when used to extrapolate jet interaction forces.

References

[1] Werle, M. J., "A Critical Review of Analytical Methods for Estimating Control Forces Produced by Secondary Injection," NOLTR 68-5, Jan. 4, 1968, sponsored by the Naval Ordnance Lab., Internal Development Fund, Task No. MAT-03L-000/F009-98 12 Problem 011, White Oak, Md.

[2] Spaid, F. W. and Zukoski, E. E., "A Study of the Interaction of Gaseous Jets from Transverse Slots with Supersonic External Flows," *AIAA Journal*, Vol. 6, No. 2, Feb. 1968, pp. 205–212.

[3] Sterrett, J. R., Barber, J. B., Alston, D.W., and Romeo, D. J., "Experimental Investigation of Secondary Jets from Two-Dimensional Nozzles with Various Exit Mach Numbers for Hypersonic Control Application," TN D-3795, Jan. 1967, NASA.

[4] Morrisette, E. L., Stone, D. R., and Whitehead, A. H., Jr., "Boundary Layer Tripping with Emphasis on Hypersonic Flow," *Viscous Drag, Proceedings of the Symposium on Viscous Drag Reduction*, Plenum Press, New York, 1969, pp. 33–51.

[5] Cassel, L. A., Durando, N. A., Bullard, C. W., and Kelso, J. M., "Jet Interaction Control Effectiveness for Subsonic and Supersonic Flight," Rept. RD-TR-69-21, Sept. 1969, U.S. Army Missile Command, Redstone Arsenal, Ala.

[6] Barnes, J. W., Davis, J. G., and Tang, H. H., "Control Effectiveness of Transverse Jets Interacting with a High-Speed Free Stream," Vol. 1, Design Charts, Theoretical and Experimental Results, AFFDL-TR-67-90, Sept. 1967, Air Force Flight Dynamics Lab., Wright-Patterson Air Force Base, Ohio.

[7] Strike, W. T., Jr., "Analysis of the Aerodynamic Disturbances Generated on a Flat Plate Containing Lateral Jet Nozzles Located in a Hypersonic Stream," AEDC-TR-67-158, Jan. 1968, Arnold Engineering and Development Center, Arnold Air Force Station, Tenn.

[8] Sterrett, J. R. and Barber, J. B., "A Theoretical and Experimental Investigation of Secondary Jets in a Mach 6 Free Stream with Emphasis on the Structure of the Jet and Separation ahead of the Jet," *Separated Flows, Pt. 2, AGARD Conference Proceedings No. 4*, May 1966, pp. 675–700.

[9] Werle, J. J., Driftmyer, R. T., and Shaffer, D. G., "Jet Interaction-Induced Separation: The Two-Dimensional Problem," *AIAA Journal*, Vol. 10, No. 2, Feb. 1972, pp. 188–193.

[10] Whitehead, A. H., Jr., Sterrett, J. R., and Emery, J. C., "Effects of Transverse Outflow from a Hypersonic Separated Region," *AIAA Journal*, Vol. 10, No. 4, April 1972, pp. 553–555.

[11] Thayer, W. J., III and Corlett, R. C., "Gas Dynamic and Transport Phenomena in the Two-Dimensional Jet Interaction Flowfield," *AIAA Journal*, Vol. 10, No. 4, April 1972, pp. 488–493.

[12] Barber, J. B. and Staylor, W. F., "Investigation of Secondary Jets on a Cone at a Mach Number of 6," *Journal of Spacecraft and Rockets*, Vol. 3, No. 10, Oct. 1966, pp. 1554–1555.

[13] Amick, J. L. and Hays, P. B., "Interaction Effects of Side Jets Issuing from Flat Plates and Cylinders Alined with a Supersonic Stream," WADD TR 60-329, June 1960.

The Optical Temperature of the Apollo 15 Exhaust Plume

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Introduction

DURING the launch of Apollo 15, an optical pyrometer was used to estimate the peak plume temperature of the Saturn V first stage exhaust. The purpose of this experiment was to obtain a temperature in the visible region of the spectrum which, when combined with other measurements in the infrared,[1–3] would provide data for a theoretical model of the exhaust plume conductivity[4,5] during a launch.

Measurement

A disappearing filament optical pyrometer, Leeds and Northrup Model 8622C, was used at 0.65μ. The instrument was calibrated on a 1050°C blackbody source at the Kitt Peak National Observatory. The plume was viewed through the Leeds and Northrup telescope from a location about 5060 m west of the launch pad. At the time of launch the air temperature was 28.4°C, the relative humidity 70%, and the visibility greater than 16 km. When viewed through the pyrometer, the plume appeared to have two bright regions of approximately the same peak temperature, a narrow bright band immediately behind the exhaust nozzles, a dark region, and then a longer hot region. With the filament adjusted to match the peak plume intensity, the pyrometer indicated a temperature of 2170°C with an observational error estimated to be ±25°C.

Discussion

Since the total atmospheric attenuation coefficient at 0.65μ was about 0.14 km^{-1}, (see Ref. 6) the measured optical temperature of 2170°C corresponds to a true plume temperature of 2370°C, assuming the plume radiated like a perfect blackbody. Infrared studies of the Saturn V plume during launch, all based on the assumption of a blackbody source, agree reasonably well with the above value. Morgan and Baldwin[1] measured a peak plume temperature of 2290 ± 250°C during the Apollo 14 launch with a two-channel infrared radiometer operating at 1.26 and 1.68μ. Kuhn[2,3] reports peak plume temperatures of 1900 ± 250°C for Apollo 14, and about 2100°C for Apollo 15 based on infrared radiometers and a thermal scanner operating in the $8.5–12\mu$ region. Heckscher and Pagliarulo[7] attempted a direct measurement of the Apollo 15 plume temperature on the launch umbilical tower; however, their equipment did not sample the hot, luminous portion of the plume, and a peak value of only 352°C was obtained.

References

[1] Morgan, C. A. and Baldwin, R. C., "Radiometric Temperature Measurement of Apollo 14/Saturn V Exhaust," LEC/HASD 649D.21.053, March 1971, Lockheed Electronics Co., Houston, Texas.

[2] Kuhn, P. M., "Apollo 14 (AS-509) Experiments," NOAA Final Rept. to NASA-KSC for Contract CC88026, March 31, 1971, NOAA, Boulder, Colo.

[3] Kuhn, P. M., "Results of Observations Made at KSC During AS-510 Launch," NOAA Final Rept. to NASA-KSC for Contracts CC-88026 and CC-59753, Nov. 1971, NOAA, Boulder, Colo.

[4] Uman, M. A., "Electical Breakdown in the Apollo 12/Saturn V First Stage Exhaust," Research Rept. 70-9C8-H1VOL-R1, May 4, 1970, Westinghouse Research Labs., Pittsburgh, Pa.

[5] Roidt, R. M., "Quasi-Steady Velocities and Temperatures in the Saturn V First Stage Exhaust," Research Rept. 70-1E9-TAHDQ-R1, Nov. 12, 1970, Westinghouse Research Labs., Pittsburgh, Pa.

[6] McClatchey, R. A., Fenn, R. W., Selby, J. E. A., Garing, J. S., and Volz, F. E., "Optical Properties of the Atmosphere," AFCRL Rept. 70-0527, Sept. 22, 1970, Air Force Cambridge Research Labs., Bedford, Mass.

[7] Heckscher, J. L. and Pagliarulo, R. P., "Saturn V/Apollo 15 Exhaust Plume Electrical Conductivity Measurements," AFCRL Rept. to NASA-KSC, Oct. 22, 1971, Air Force Cambridge Research Labs., Bedford, Mass.