Technical Comments

Comment on "Sonic Booms Attributed to Subsonic Flight"

E. J. KANE*
The Boeing Company, Seattle, Wash.

IN Ref. 1 the author developed relationships based on the method of geometric acoustics for atmospheric conditions which could result in the formation of sonic booms by subsonic airplanes. In checking the results it was found that the inequality (4) is in error by a factor of 2. The error stems from the failure to substitute the expression for $\cos\gamma$, which is a function of z, in the expression for $[d(\Delta x)/dz]$ before performing the integration with respect to z. The correct result is

$$-hz/a > 1 - M$$

A more general form of the conditions (4) and (8) can be obtained from Ref. 2 for arbitrary variations of atmospheric conditions with z. This relationship is

$$M > [(a + u) - u_a]/a_a$$

where M = airplane Mach number; a = sound speed at distance z from airplane; u = wind speed at distance z (positive in (+) x direction); a_a = sound speed at airplane; and u_a = wind speed in x direction at airplane.

The qualifications mentioned by the author[1] in his discussion should be re-emphasized, especially those concerning the spreading of the energy associated with the elementary subsonic disturbances and their formation into shock waves. The rapid dissipation of this energy with distance from the airplane in subsonic flow would probably preclude coalescence into a shock wave, even in the presence of high wind shear.

References

[1] Barger, R. L., "Sonic Booms Attributed to Subsonic Flight," *AIAA Journal*, Vol. 5, No. 5, 1967, pp. 1042–1043.
[2] Kane, E. J. and Palmer, T. Y., "Meteorological Aspects of Sonic Boom," Rept. RD 64-160, Sept. 1964, Federal Aviation Agency SRDS.

Received June 8, 1967.
* Aerodynamics Engineer, Supersonic Transport Branch. Member AIAA.

Reply to Comment by E. J. Kane

R. L. BARGER*
NASA Langley Research Center, Hampton, Va.

INEQUALITY (4) is in error as a result of the failure of the analysis to account for the refractive effect of the wind. However, Kane's suggested correction to the analysis would still yield an incorrect expression for the wave fronts. [It would not satisfy the partial differential equation (11) of Ref. 1.] With regard to the general inequality stated by Kane it should be noted that: 1) the equation for the wave fronts was not required in the derivation; 2) the inequality was obtained from consideration of the rays associated with the wave envelope formed at supersonic speeds; and 3) its applicability as a criterion for formation of an envelope of elementary disturbances at subsonic Mach numbers was apparently not discussed in Ref. 2. Another mechanism for generating subsonic booms (suggested by some recent experiences) is the tail wave which may extend a considerable distance below an airplane flying at a Mach number very close to one.

Received August 9, 1967.
* Aerospace Engineer.

References

[1] Milne, E. A., "Sound Waves in the Atmosphere," *The Philosophical Magazine*, Ser. 6, Vol. 42, 1921, pp. 96–114.
[2] Kane, E. J. and Palmer, T. Y., "Meteorological Aspects of Sonic Boom," Rept. RD 64-160, Sept. 1964, Federal Aviation Agency SRDS.

Comment on "Thermal Radiation from Solid Rocket Plumes at High Altitude"

A. J. LADERMAN* AND D. J. CARLSON†
Aeronutronic Applied Research Laboratories, Philco-Ford Corporation, Newport Beach, Calif.

IN a recent paper Fontenot[1] described a method for estimating base heating rates due to radiation from aluminized solid propellant exhaust plumes for conditions where the particle temperatures are controlled by radiation rather than by convection. In this analysis gas radiation was neglected and the particles were assumed to be of a unique size with uniform distribution and temperature at each cross section of the plume. Similar to Morizumi and Carpenter,[2] Fontenot reduced the problem to that of an equivalent radiating surface. This then required determination of the local temperature of the plume and its apparent emissivity. The purpose of this note is to show that the energy balance used to calculate the plume temperature is in error and, more significantly, to point out that the data used to describe the spectral emissivity of the plume are not valid for aluminum oxide.

To determine the variation of temperature with axial distance, Fontenot assumed a conical shape of the plume and considered a control volume comprised of the conic section between two closely spaced circular cross-sectional planes located normal to the axis. The change in internal energy of particles passing through the control volume was equated to energy radiated from the lateral conic surface. This is an un-

Received June 9, 1967.
* Supervisor, Experimental Fluid Mechanics Section. Member AIAA.
† Principal Engineer, Fluid Mechanics Department. Member AIAA.

warranted oversimplification, however, since in the case of an optically thin plume, all particles within the control volume can "see" the surroundings, and energy is emitted from each particle in all directions without subsequent attenuation. When the plume is optically thick, radiation from particles in the interior of the plume is absorbed by the surrounding particles. In this case, only those particles located within a layer one "optical depth" from the boundary of the plume radiate to the surroundings. However, since this layer is essentially optically thin, radiation is again in all directions rather than only through the lateral surface of the control volume. In both cases, then, the energy balance is incorrect. When the plume is optically thin, the radiation term in the energy balance should be expressed as the summation of contributions from all particles within the control volume using, of course, the emissivity appropriate to the individual particles. In the radiation controlled, optically thick case, a solution to the equation of radiative transfer is required which accounts for the radial temperature gradient that is established by cooling of the outer layer of the plume.

To determine the plume emissivity, Fontenot assumed that, within the temperature and wavelength intervals of interest the absorption coefficient α_λ of an aluminum oxide particle cloud could be expressed as $\alpha_\lambda = 0.57/\lambda$,[3,4] where λ is the wavelength in microns. (Refs. 3 and 4 were originally Refs. 5 and 6 in Fontenot's paper.) Although the functional relationship is valid, examination of Refs. 3 and 4 (as well as of the text of Ref. 1) revealed that the coefficient 0.57 was obtained from observations of soot-laden flames. Since solid carbon is a much more efficient emitter than aluminum oxide, the aforementioned expression cannot be applied to plumes comprised of alumina particles. The optical properties of alumina particles, however, can be found from Mie theory[5] using the refractive index data obtained by several investigators.[6–8] On the basis of the individual particle properties, Bartky and Bauer[9] have determined the emittance of homogeneous alumina containing plumes and discussed application of their results to inhomogenous media.

In spite of repeated statements by Fontenot that his assumptions are justified by the agreement between his theoretical results and experimental data, the information presented here clearly demonstrates that the assumptions are not realistic. Several methods for calculating radiation from optically thick plumes which correctly take into account the appropriate spectral optical properties of the alumina particles have been developed.[10–12]

References

[1] Fontenot, J. E., "Thermal Radiation from Solid Rocket Plumes at High Altitude," *AIAA Journal*, Vol. 3, No. 5, May 1965, pp. 970–972.

[2] Morizumi, S. J. and Carpenter, H. J., "Thermal Radiation from the Exhaust Plume of an Aluminized Composite Propellant Rocket," *Journal of Spacecraft and Rockets*, Vol. 1, No. 5, Sept.-Oct. 1964, pp. 501–507.

[3] Schach, A., "Strahlung von Leuchtenden Flammen," *Z. Tech. Physik*, Vol. 6, 1925, 530–540.

[4] Sato, T. and Matsumoto, R., "Radiant Heat Transfer from Luminous Flame," *International Developments in Heat Transfer*, Pt. IV, The American Society of Mechanical Engineers, New York, 1961, pp. 804–811.

[5] van de Hulst, H. L., *Light Scattering by Small Particles*, Wiley, New York, 1957.

[6] Gryvnak, D. A. and Burch, D. C., "Optical and Infrared Properties of Al_2O_3 at Elevated Temperatures," *Journal of the Optical Society of America*, Vol. 55, 1965, pp. 625–629.

[7] Carlson, D. J., "Emittance of Condensed Oxides in Solid Propellant Combustion Products," *Tenth Symposium (International) on Combustion*, 1965, The Combustion Institute, Pittsburgh, Pa., pp. 1413–1424.

[8] Adams, J. J. and Colucci, S. E., "The Spectroscopic Measurement of Gas and Particle Temperature in Metallized Propellant Combustion," *ICRPG/AIAA Solid Propulsion Conference*, Paper S66-175, Chemical Propulsion Information Agency, Washington, D. C., July 1966.

[9] Bartky, C. D. and Bauer, E., "Predicting the Emittance of a Homogeneous Plume Containing Alumina Particles," *Journal of Spacecraft and Rockets*, Vol. 3, No. 10, Oct. 1966, pp. 1523–1527.

[10] Bobco, R. P. and Edwards, R. H., "Radiation from an Absorbing Scattering Conical Dispersion with Non-Uniform Density," Rept. 21, SSD60571R, Dec. 1966, Hughes Aircraft Co., Space Systems Div., Culver City, Calif.

[11] Laderman, A. J. et al., "Study of Thermal Radiation, Particle Impingement Heating, and Flow Field Analysis of Solid Propellant Rocket Exhausts," U-4045, April 1967, Aeronutronic Publication.

[12] Carlson, D. J. and Laderman, A. J., "Method of Calculation of Solid Propellant Plume Radiation," presented at "Two-phase Flow Symposium," Edwards Air Force Base, March 1967.

Comment on "Effect of Simulated Micrometeoroid Exposure on Performance of *N/P* Silicon Solar Cells"

R. A. Breuch*
Lockheed Palo Alto Research Laboratory, Palo Alto, Calif.

In a paper[1] examining the effects of simulated micrometeoroid exposure on shielded and unshielded *N/P* silicon solar cells, the authors arrived at the conclusion that an unprotected *N/P* silicon solar cell will degrade to 50% of its initial short-circuit current in about 34 space days. This result was based on the flux model of Ref. 2, from which the authors arrived at a value of 0.225 joule/year incident on a 1- × 2-cm surface in space. An even larger change was arrived at (50% in 4 space days), using the data from Ref. 3 (4.95 joule/year). Because the degree of damage incurred for relative short periods in space was so extensive, the authors suggest that integral covers, or very thin coatings that protect against radiation (elementary charged particle), may not be adequate to protect the cell against micrometeoroids.

The micrometeoroid flux models that the authors used are inconsistent with recently published data.[4–6] Specifically, it can be determined from Ref. 4 that only 0.0029 joule/year will be incident on a 1- × 2-cm surface in space. It is therefore appropriate that the authors re-evaluate their studies and present the updated damage predictions. It is expected that both the problem area that they alluded to in Ref. 1 and the previously published problems on the effects of simulated micrometeoroid exposure of thermal control surfaces[7] will be significantly affected.

References

[1] Mirtich, M. J. and Bowman, R. L., "Effect of Simulated Micrometeoroid Exposure on Performance of *N/P* Silicon Solar Cells," *AIAA Journal*, Vol. 5, No. 7, July 1967, pp. 1364–1366.

[2] Loeffler, I. J., Clough, N., and Lieblein, S., "Recent Developments in Space Power System Meteoroid Protection," Paper 64-759, Sept. 1964, AIAA; also "Recent Developments in Meteoroid Protection for Space Power Systems," *AIAA Progress in Astronautics and Aeronautics: Space Power Systems Engineering*, edited by G. C. Szego and J. E. Taylor, Vol. 16, Academic Press, New York, 1966, pp. 503–523.

[3] Alexander, W. M. et al., "Review of Direct Measurements of Interplanetary Dust from Satellites and Probes," TN D-1669, May 1963, NASA, p. 39.

Received August 11, 1967.

* Scientist. Associate Member AIAA.