EGG-M-89487

CONF-900520--1

SIMULTANEOUS MEASUREMENT OF NI-AL PARTICLE SIZE, VELOCITY, AND TEMPERATURE IN ATMOSPHERIC THERMAL PLASMAS

J. R. Fincke, W. D. Swank
Idaho National Engineering Laboratory
EG&G Idaho, Inc.
Idaho Falls, ID 83415-2211

EGG-M--89487

DE91 001935

ABSTRACT

A technique for simultaneously measuring particle size, velocity, and temperature has been applied to the in-flight characterization of a Ni-Al particles sprayed in a 28 kW plasma torch. The radial distribution of particle size, velocity, temperature and particle concentration were obtained at stand off distances between 63.5 and 88.9 mm. These measurements and their relationship to the characteristics of the resulting coating are discussed. Injection geometry dependent particle sizing and an apparent fracturing of the original particles into smaller particles was observed. A significant fraction of the largest particles observed did not appear to be molten. Particle behavior was found to be relatively insensitive to gas mixture and flow rate.

INTRODUCTION

The behavior of a particle and the interactions between a particle and the plasma surrounding it are important in the understanding, development and optimization of plasma spray coating processes that involve the physical transformation of fine powders. To fully characterize the particle flow field, it is necessary to measure the particle size, velocity, temperature and number density. In many cases, it is useful to measure simultaneously parameters that are coupled, such as particle size and temperature, or size and velocity. Measurements of this type provide the link between torch parameters and particle behavior in the spray field. This data, when coupled with a detailed characterization of the coatings produced, will ultimately lead to a better understanding of the relative improtance of various parameters in the spray coating process. In this paper we will describe a measurement technique for simultaneously obtaining particle size, velocity, temperature and local number density in high temperature flow fields. Results obtained on the Ni-Al spray system are presented and their relationship to the characteristics of the deposited coating discussed.

MEASUREMENT TECHNIQUE

The measurement system developed for the simultaneous measurement of particle size, velocity and temperature integrates a laser Doppler velocimeter (LDV) system with a scattered light particle size measurement and a high speed two-color pyrometer. Since the measurement system has been described in detail elsewhere [1], only a brief description will appear here. All optics and the laser are rigidly mounted on a precision translatable table. The movement of the table results in a precise movement of the measurement volume relative to the plasma device. The particle size is determined from the absolute magnitude of scattered laser light, particle velocity is determined by a dual crossed-beam LDV, and temperature is determined from a measurement of light emitted by the individual incandescent particles at two wavelengths. A multi-line 6 W Ar ion laser is used as the light source for velocity and sizing. The LDV measurement volume, consisting of the intersection of two 514 nm beams, is situated in the center of a larger diameter 488 nm laser beam. The intersection of the LDV measurement volume and the second beam constitutes the particle size measurement volume. Simultaneously, the light emitted by the hot, incandescent particles passing through this same region is measured. The particle temperature is derived from the ratio of the signals at each of the two wavelengths observed, gray body behavior is assumed. The spatial resolution of <1 mm^3 is such that the distribution of particle size, velocity and temperature can be mapped over typical flow fields. The estimated measurement uncertainties are 125 K at 2500 K for particle temperature, 4.9μm for particle size and better than 5 m/s for particle velocity.

RESULTS

In this section measured particle spray field parameters are presented and the implications to the characteristics of the resulting coatings are examined. The commercial plasma torch used in this study has a nozzle exit diameter of 8 mm. Particles are injected into the flow, on the

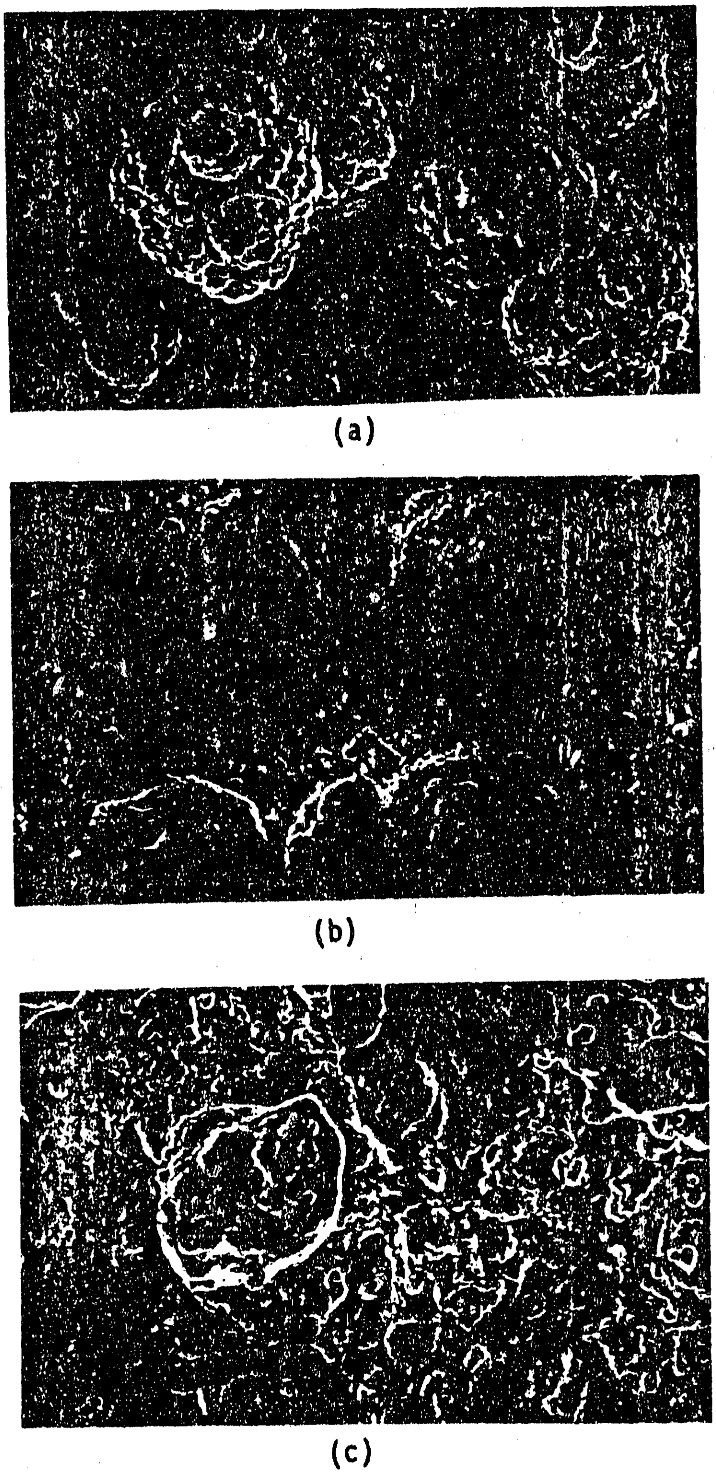


Fig. 2. (a) Unsprayed. (b) Plasma sprayed, cooled before impact. (c) Impacted on substrate.

of the larger particles appear to be only partially melted or relatively unaffected and that many smaller particles have appeared. A typical in-flight particle size histogram along with the initial particle size distribution obtained by sieving the as received particles appears in Figure 3. Only the particles which gave simultaneously valid nozzle diameter, at a single axial location, 18mm upstream of the torch exit. Typical torch operating conditions are 800 A at 35 V, for a total power input of 28 kW. Particle spray field characteristics were investigated at three gas mixes, 3.20/1.33, 3.91/1.33, and 2.49/1.33 SCMH Ar/He respectively, including the powder carrier gas flow rate of 0.37 SCMH. The torch efficiency is approximately 68%, independent of the gas mix. The measured average particle velocity at injection is 15 m/s with a standard deviation of 2.35 m/s. The injection geometry results in particle trajectories that are significantly skewed with respect to the center line of the plasma. The maximum particle density in each radial curve, Figure 1, moves further out radially as one advances axially. Therefore the majority of the particles travel from an outer radial postion inside the torch through the center of the plasma and exit the plume on the opposite side.

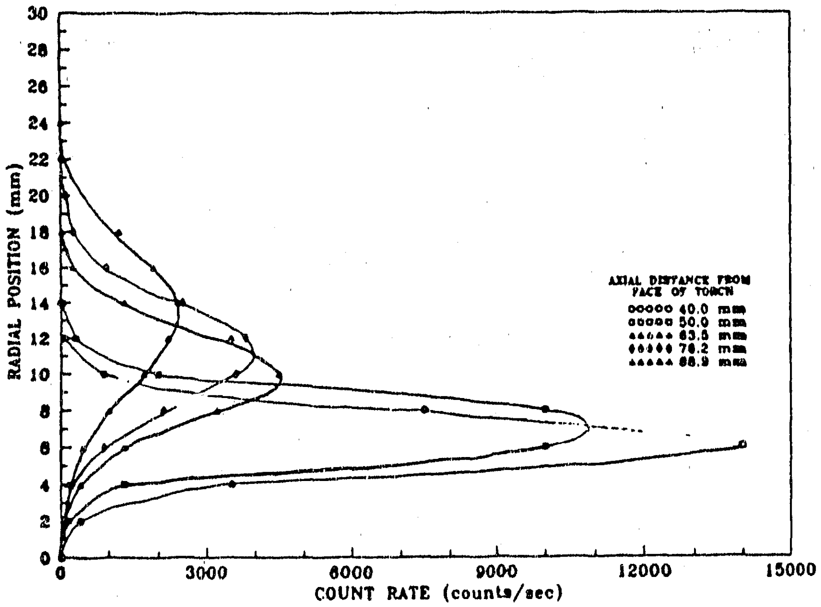


Fig. 1. Relative particle number density in the horizontal plane with horizontal injection.

The Ni-Al spray system proved to be interesting in that significant flow-induced particle sizing and an apparent fracturing or stripping of molten material to form smaller particles occurred. Figure 2a illustrates the particles as received from the manufacturer which consist of a Ni core coated with a high nickel content Ni-Al alloy. Figure 2b shows the particles after spraying and cooled in flight without impact. Note that many

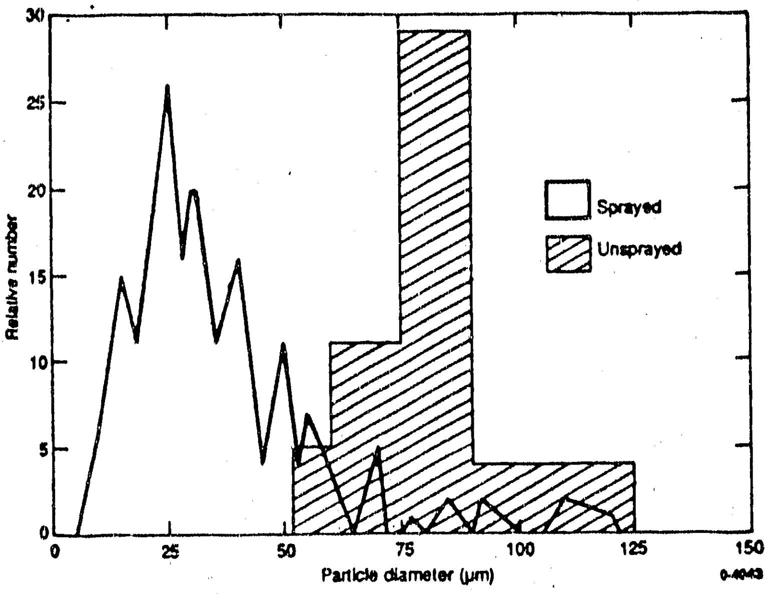


Fig. 3. Ni-Al particle size histogram (a) Unsprayed particles (b) Sprayed particles.

temperature and size data are represented. The absence of significant numbers of large particles on this plot is because the largest particles were not hot enough to give valid temperature data. This suggests that most of the larger particles are not molten on impact. In examining the coated substrate, Figure 2c, this behavior is confirmed.

Figure 4 shows the average size of particles measured at different radial positions and indicates a significant flow/injection induced particle sizing. The observed spatial distribution of size is consistent with intuition in that the larger, heavier particles have more momentum and therefore appear farthest from the injection location. Varying the gas mixture and flow

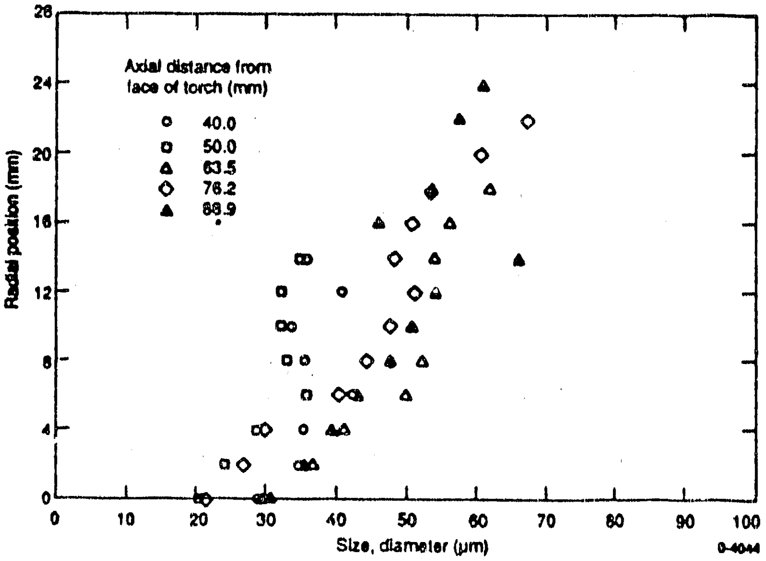


Fig. 4. Radial Ni-Al average particle size distribution.

rate resulted in no significant change in measured particle size. The average measured particle temperatures, Figure 5, are in excess of the 1900 K melting point of high nickel content Ni-Al alloys. The particle temperature data on the edges of the spray field are approximately 200 K cooler then those at the center. The measured differences in particle temperature due to changes in the gas flow rate and mixture were less than the estimated measurement uncertainty.

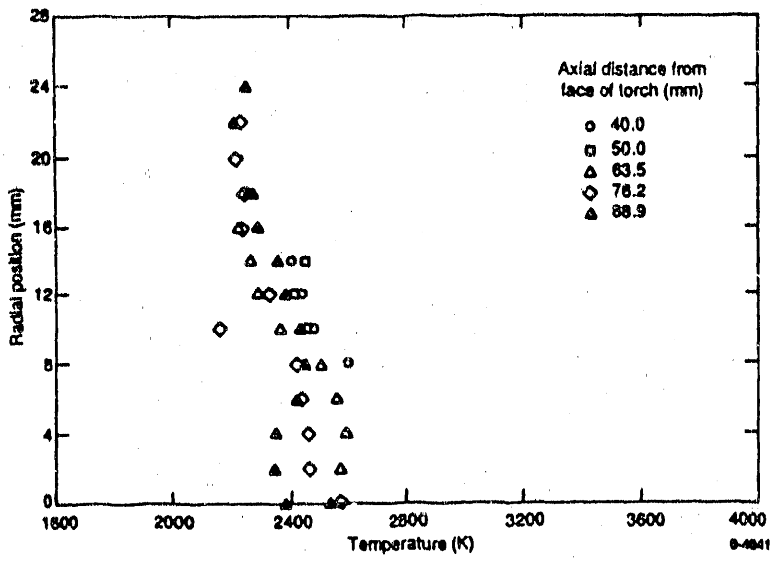


Fig. 5. Radial average temperature distributions for Ni-Al particles.

The trend shown in Figure 6, of the average particle velocity measured at different radial positions. The particles furthest from the center of the plume have the lowest velocities. This behavior is consistent with both their large size and limited residence time in the plasma. No change in particle velocity was detected as a function of gas mix or flow rate. Since the gas flow rate was varied over a narrow range,

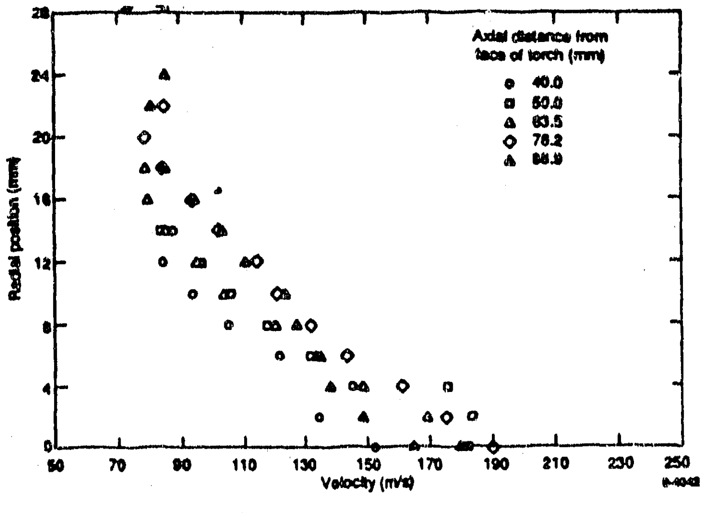


Fig. 6. Radial average velocity

4.16 SCMH to 4.60 SCMH, and the resulting gas velocity increase is on the order of 10%, this behavior is expected. N

Two-dimensional histograms of particle size and velocity and particle size and temperature appear in Fig. 7. The axial location is the nominal standoff distance of 76 mm. Two radial locations are shown, the torch center line (Fig. 7a,b) and 16 mm (Fig. 7c,d) near the edge of the particle spray field. The skewed nature of the particle flow field is readily observed in the histograms. It is interesting to note that near the torch center line the particle size distribution is significantly narrower than near the edge of the spray field. Conversely, the velocity and temperature distributions at the edge are somewhat

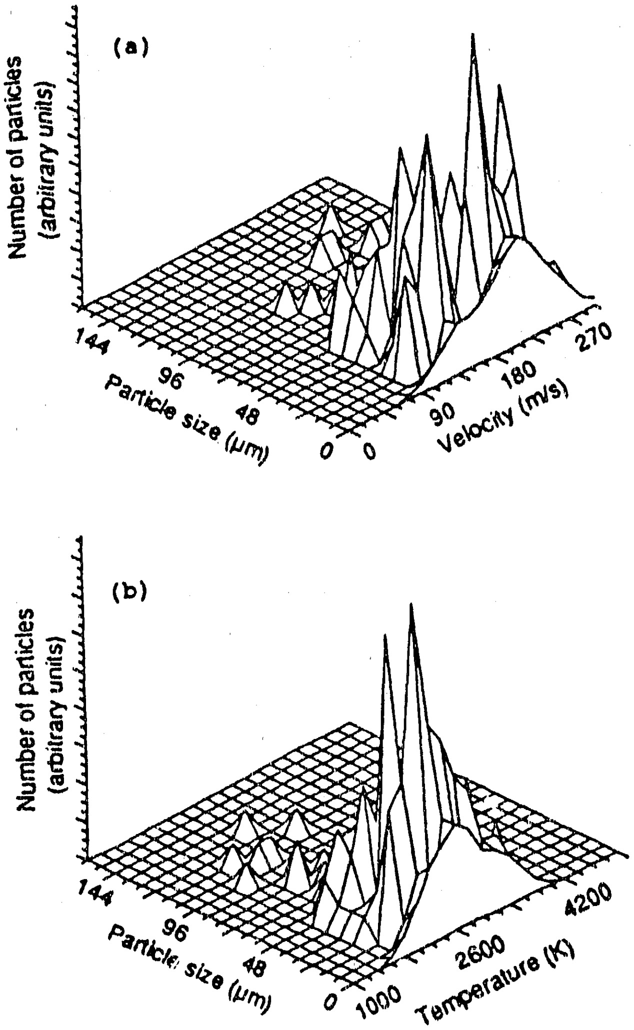


Fig. 7a,b. Two-dimensional size and velocity (a), and size and temperature (b) histograms for axial location of 76 mm, centerline.

narrower than at the center. The same effect is observed in the contour plots of particle temperature versus velocity, Fig. 8, at the same locations. The particle temperatures are closely coupled to the residence time in the plasma, which is determined, to a large extent, by the velocities of the particles. A possible explanation for the observed behavior is that the smaller particles near the center line of the torch are strongly affected by the large scale velocity fluctuations in the plasma flow field while at the edge, the larger, less responsive particles, show a smaller effect.

The implications for the spraying process are that, for a raster scan deposition , the size and temperature of the particles deposited will preferentially occur at different depths in the deposit. Depending

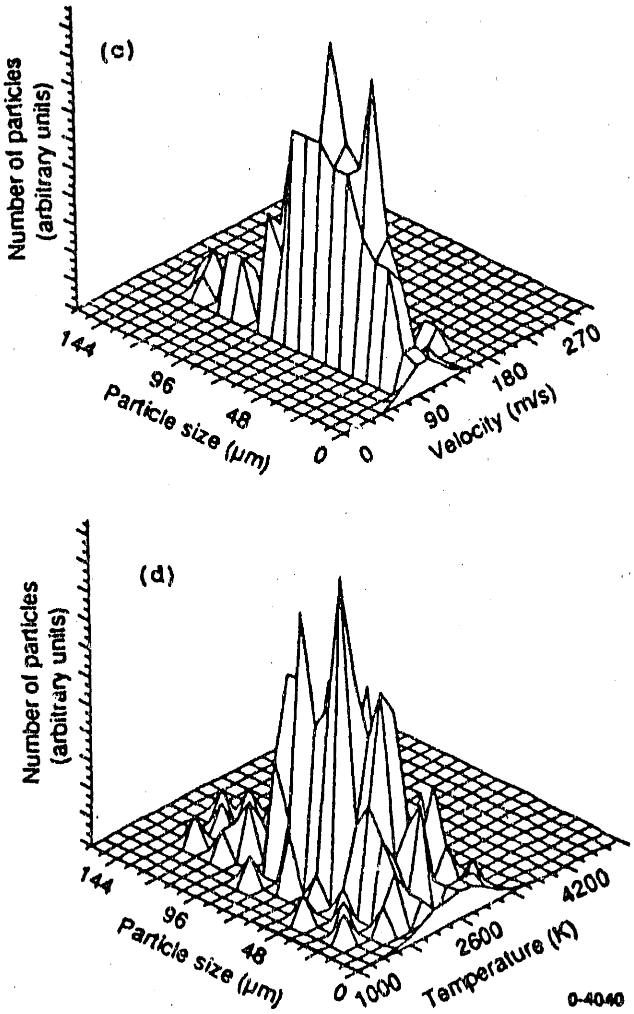
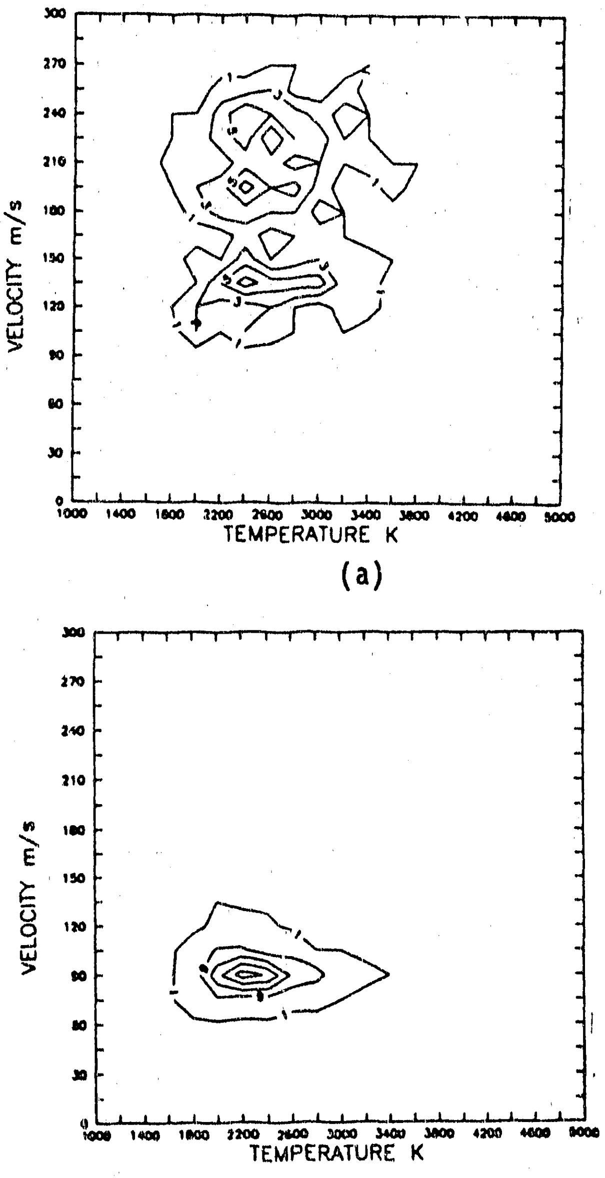


Fig. 7c,d. Two-dimensional size and velocity (c), and size and temperature (d) histograms for axial location of 76 mm, radial location 16 mm.

on the direction of the scan, the smaller hotter particles will be preferentially deposited either nearer the surface of the substrate or nearer the surface of the coating. In addition the larger particles, including the largest which may not be fully molten, will also be preferentially deposited. The phenomena observed here have the potential, upon detailed examination of coatings and assessment of coating quality, to lead to a better understanding of the relationship between spray torch and injection parameters and coating integrity.



(a)

(b)

Fig. 8. Contour plots of temperature versus velocity at an axial location of 76 mm. (a) Centerline data, (b) Radial location of 16 mm.

CONCLUSIONS

In-flight particle parameter data (particle size, velocity, temperature, and number density) provides the necessary link between the spray process parameters and the coating characteristics. Data of this type will eventually lead to more detailed and physically accurate models describing the spray coating process. The result will be greater insight into the important parameters in the process and, ultimately, better coatings. The particle injection geometry and particle velocity and mass significantly affect the spatial distribution of particle size in the plasma plume and thus can significantly alter the characteristics of the deposited coating. This may be particularly significant in cases where unmelted particles are present. Additionally the size distribution of particles may be significantly altered during heating by fracturing and/or aerodynamic stripping of a molten surface. Even though aerodynamic and injection dependent sizing effects exist and the resulting particle trajectories in the plasma can be significantly different, the resulting spatial distribution of particle temperatures is only slightly affected (100-200 K). The measured differences in particle spray field parameters were found to be insensitive to gas flow rate and mix over the range examined.

ACKNOWLEDGMENT

This work was supported by the U. S. Department of Energy, Office of Energy Research, Office of Basic Energy Sciences, U.S. Department of Energy under Contract No. DE-AC07-76ID01570.

REFERENCES

1. J. R. Fincke and C. L. Jeffery, "Simultaneous Measurement of Particle Size, Velocity and Temperature," Proceedings of the National Thermal Spray Conference, Cincinnati, Ohio, pp.55-60, October 1988.

- END -

DATE FILMED

11 / 28 / 90