Production of Axially Focused Colloid Beams

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THE application of colloid sources to microthrust rockets has been extensively discussed in the literature.[1,2] These colloid sources, which have usually been operated at voltages of 5 kV to 9 kV, have exhibited two problems. Firstly, the colloid beams produced, when analyzed by time of flight (TOF) techniques, have been shown to contain a broad distribution of charge to mass ratios. As a result, the beam thrust efficiency, defined as $\eta = \langle u \rangle^2 / \langle u^2 \rangle$, where u is beam particle velocity and $\langle\ \rangle$ denotes average over particles in the beam,[3,4] has been found to be as low as 0.7.[5] Secondly, the spatial distribution of these colloid beams has usually been divergent and asymmmetric, leading to asymmetrically distributed mass flow rate, charge to mass ratio and thrust.[6] These effects, which were found by point to point TOF measurements, degrade rocket performance by giving side thrust components. They also introduce uncertainties into the calculation of axial thrust from simple TOF measurements.[7] Clearly, better microthrust rocket performance could be obtained by finding means for producing axially focused colloid beams with narrow distributions of charge to mass ratio.

This note describes the results of a series of experiments using a conventional colloid source operating with a relatively lowly doped NaI—glycerol fluid. It is indicated that, with capillary voltages greater than about 13 kV, axially focused beams can be reliably produced, with average charge to mass ratios variable between 10 coul/kg and 100 coul/kg. The beams exhibit a narrow distribution of charge to mass ratios, with thrust efficiencies exceeding 0.90 in general. The work formed part of a study of means for providing high specific impulse beams by post-acceleration of beams with low charge to mass ratios.

The source used sprays NaI doped glycerol from a single capillary tube positioned flush with the outer surface of a flat extractor plate. The extractor hole diameter was 4.75 mm. Capillary tube sizes ranged from 0.10 mm i.d. by 0.20 mm o.d. to 0.25 mm i.d. by 0.45 mm o.d. In each case the capillary tip had a funnel shaped internal bevel with a total included angle of 120°. Both stainless steel and Pt—Ir capillaries were used. Fluid doping levels of between 2.5 g and 7.5 g NaI/100 ml glycerol were used. Fluid pressures during source operation ranged from 2 cm to 20 cm Hg, while capillary voltages ranged from 3 kV to 20 kV. Spatial distributions of the beams were observed using a phosphor screen and a segmented electrical detector. The phosphor screen, which has been described elsewhere,[8] gives an instantaneous visual display of the beam that may be photographed. The segmented electrical detector, in conjunction with a thyratron switching circuit to control the capillary voltage was used for TOF measurements. This detector has five concentric rings, electrically insulated from each other, whose outer perimeters subtend angles of 5°, 15°, 25°, 35°, and 45° at the capillary tip.

Initial attempts to produce an axially focused beam were unsuccessful. Operation of the source at voltages between 5 kV and 9 kV produced beams which were off axis and asymmetric and which contained a broad range of charge to mass ratios. These observations are similar to results reported by Geis.[6] It was then discovered that operation of the same source at voltages between 13 kV and 20 kV produced well focused beams with a narrow distribution of charge to mass ratio.

The behavior of the source as observed in the present experiments is given by the following *typical* sequence as the capillary voltage was raised from 3 kV to 20 kV: at 3 kV, the beam consisted of a series of stable, periodic particle bursts, at 5 kV, the beam changed to a stable, constant dc level. For both cases the beam consisted of discrete jets distributed part way around the arc of a hollow cone. At 9 kV, the stable dc current level and the charge to mass ratio had increased, the range of charge to mass ratios present in the beam had broadened, and the beam had become better focused insofar as it now consisted of a complete hollow cone of discrete jets. From 9 kV to 13 kV the beam suffered instabilities in current level and spatial distribution. *At 13 kV, a sudden transition to a new, lower, stable dc level occurred. Simultaneously, the spatial distribution became an axially focused cluster of discrete jets, and the charge to mass ratio exhibited a very narrow distribution of values with thrust efficiency of the order of 0.90.* From 13 kV to 20 kV, the foregoing mode of operation continued, with trends towards higher currents, higher charge to mass ratios and more highly focused beams. The thrust efficiency gradually decreased to about 0.9 at 20 kV. It is noteworthy that over this range of voltage no ions were detected in the beam. In this regard the operation is in contrast with the behavior below 10 kV where ions were often present along with the charged glycerol droplets. Above 20 kV instabilities again appeared.

Figure 1 shows typical results of a parametric analysis of a source with a 0.18 mm i.d. by 0.33 mm o.d. stainless steel capillary tube for a fluid doping level of 2.5 g NaI/100 ml glycerol. Charge to mass ratios produced by the source are

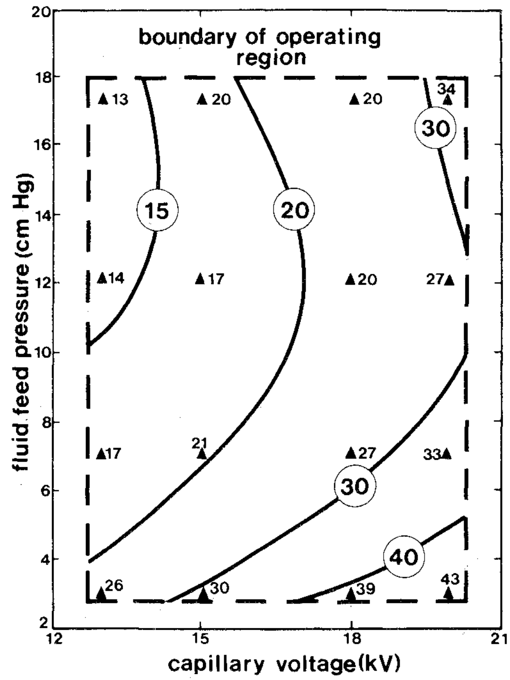

Fig. 1 Charge to mass ratio contours (coul/kg) as a function of fluid feed pressure and capillary voltage for a source with a 0.18 mm i.d. by 0.33 mm o.d. stainless steel capillary and a fluid doping level of 2.5 g NaI/100 ml glycerol. The numbers shown adjacent to the solid triangles represent average values of the charge to mass ratios obtained, at the indicated pressures and voltages, from a number of experiments with this source. Beams formed at any operating point within the dashed lines were axially focused with a narrow distribution in charge to mass ratio.

Received August 1, 1974.
Index category: Electric and Advanced Space Propulsion.
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shown as a function of fluid feed pressure and capillary voltage. The dashed lines enclose the region for which stable, well focused, axial beams were obtained. Within this region, pressure and voltage could be varied to give a continuous range of charge to mass ratios. At each of the operating points indicated in the figure, several TOF measurements were made at different times, with the source being brought to the desired pressure and voltage from a variety of different initial values. While there was a degree of nonreproducibility the average values of the charge to mass ratio over the various measurements were quite consistent and were useful as indicators of the probable value to be achieved at a given operating point. It appeared that the use of Pt—Ir capillaries led to more reproducible results than could be obtained with stainless steel capillaries. The average values are shown beside each of the operating points in Fig. 1. By interpolation between points, contours of constant charge to mass ratio have been estimated.

Stable and consistent source operation, similar to that indicated in Fig. 1 has been observed over the complete range of capillary sizes and fluid doping levels previously mentioned. For each different source a stable and axially focused beam was produced between about 13 kV and 20 kV for fluid feed pressures between 2 cm Hg and 18 cm Hg. The associated charge to mass ratios of the beams, which depends on the capillary size, on the operating pressure and voltage and on the amount of doping, varied between about 10 coul/kg and 100 coul/kg. High pressure and low voltage gave the lowest charge to mass ratios while low pressure and high voltage gave the highest values. Smaller capillary tubes and higher doping levels tended to yield consistently higher charge to mass ratios.

Figures 2a and 2b show the spatial distribution of a typical beam in the axially focused region. The beam was produced at a capillary voltage of 20 kV using a 0.18 mm i.d. by 0.41 mm o.d. Pt—Ir capillary tube, 5 g NaI/10 ml glycerol fluid, and a fluid feed pressure of 7.8 cm Hg. Figure 2a is a photograph of the beam incident on the phosphor detector. Figure 2b shows the corresponding current measured at each segment of the concentric ring detector. Both detectors were at the same distance from the source. About 65% of the beam current lies within a cone that makes a half angle of 5° with the detector axis. Negligible current was detected beyond 15°.

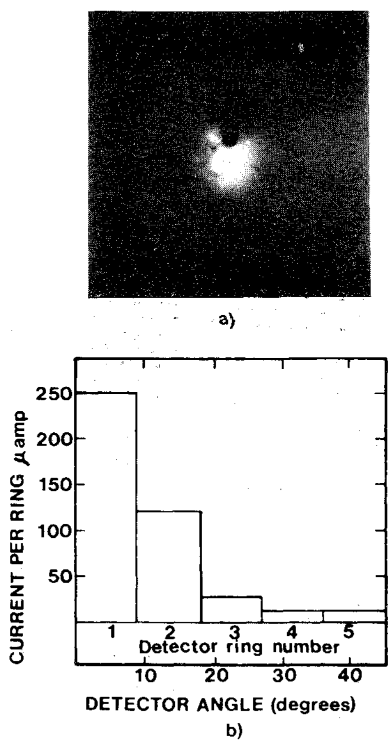

Fig. 2 a) Phosphor screen detector display of a beam produced at a capillary voltage of 20 kV using a 0.18 mm i.d. by 0.41 mm o.d. Pt—Ir capillary tube, a 5 g NaI/100 ml glycerol fluid and a feed pressure of 7.8 cm Hg. b) Current distribution of the above beam as measured on the concentric ring TOF detector.

These results indicate that a colloid source of conventional design can produce well focused axial beams with narrow distributions of charge to mass ratio by using relatively large capillary voltages and lowly doped working fluids. In this way it is possible to produce high quality colloid beams for use in reliable and efficient microthrust rockets. Such beams are also of interest in micrometeoroid simulation,[9,10] and in microparticle-surface interactions which may hold potential for producing plasma and fusion phenomena.[11]

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Measured Three-Dimensional Effects in Transonic Airfoil Testing

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During a series of tests conducted to examine the flowfield of a supercritical airfoil, the issue of deviation from two-dimensionality was examined. Earlier surface flow visualization data[1] had provided an indication of the difficulty in attaining spanwise uniform flow.

Received August 7, 1974. This research was conducted under the McDonnell Douglas Independent Research and Development Program in cooperation with the NASA Ames Research Center.

Index category: Research Facilities and Instrumentation.

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