When the mass transfer number B equals 20 for the data in Ref. 1, this expression equals approximately 0.11. In addition, the kink observed in the velocity profiles displayed as Fig. 2 of Ref. 1 for $B = 20$ suggests the presence of separation.

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Comments on "Ion-Neutral Propulsion in Atmospheric Media"

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In a recent paper, Christenson and Moller[1] have derived some performance parameters for an electrostatic "fan" in which the negative ions are produced by multiple point corona discharges. Their experimental findings qualitatively agreed with theory and showed a peak flow power efficiency

$$\eta = \tfrac{1}{2}\rho u^3/jV_0$$

to be 0.9%. Approximately 90% of the input electrical power jV_0 was found to be transferred into heat. Such low efficiency levels obviously do not make an attractive propulsion device. This negative finding is in agreement with that reached by the writer in an earlier analytical investigation[2] of electrostatic propulsion. In Ref. 2, the equations governing the one-dimensional electrostatic propulsion channel were solved numerically, permitting a reduction in simplifying assumptions.

The writing of the present Comments has been prompted primarily by Christenson and Moller's discussion of possible increased efficiency through reductions in ion mobility. Their indicated effort here is to effect this reduction by the utilization of pulsed high voltages, estimating that a reduction of the ion mobility in air by two orders of magnitude would result in a power efficiency of approximately 30%. However, it appears doubtful that such reductions of mobility will be accomplished by a pulsating applied field alone. Even if this indeed could be accomplished, serious inherent shortcomings of the device would still be retained, as can be demonstrated by the following considerations. Using the nomenclature of Ref. 1, the momentum added to the flow, i.e., the thrust produced per unit cross-sectional area is $\rho u^2 = (\epsilon/2)E_L{}^2$.

Now the collector field E_L cannot exceed the breakdown field E_b at the prevailing atmospheric conditions. In fact, engineering experience has shown that E_L would have to be appreciably below E_b if serious operating difficulties are to be avoided. Setting $E_L = E_b$ therefore represents an optimistic upper limit. Using $E_b = 3 \times 10^6$ v/m the maximum thrust produced is computed to be 0.832 psf.†. This upper limit on thrust is independent of the ion mobilities. It is apparent that very large areas of corona arrays would be required to produce thrust levels of any practical interest. Since the storage of large quantities of electrical energy is impractical aboard vehicles flying in the atmosphere, additional weight penalties would be incurred due to the power conversion and high-voltage conditioning equipment. Large corona array areas would also be detrimental to the over-all drag. It is in the light of these practical considerations that the possibility of a 30% power efficiency (neglecting internal drag losses) becomes more remote.

The writer is aware of the fact that the breakdown electric field can be exceeded in high frequency corona discharges. However, the work of Early and Martin[3] on pulsating field coronas (5–12 kc/sec) has shown that most of the added electrical energy in this operating mode goes into heating, ionization, and other energy states but not into directed momentum increase, which would augment thrust. Also not to be ignored is the fact that field pulsations will be detrimental to thrust by lowering the average value of E_L, all other conditions being held constant.

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† This is the sea-level thrust; with altitude, thrust would diminish because of the decrease in E_b.

Reply by Author to A. Maciulaitis

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We agree with Maciulaitis that the low efficiency level does not indicate immediate construction of a useful aerodynamic propulsion unit of the type investigated. This, however, was not the intent of our study.[1] The purpose of the investigation was to obtain explicit theoretical performance relationships that could be validated by experimental results. One advantage in obtaining such closed-form expressions is that the gross physical behavior of the mechanism in question and the dependence of performance on certain physical parameters can more readily be determined. For example, we feel that the dependence of velocity, thrust, and power efficiency on the parameter ϕ is immediately made clear by the explicit relations in spite of the necessary assumptions.

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We certainly concur that the power efficiency is at present not indicative of a self-contained vehicle, a problem to be considered subsequent to efficiency improvements on the "corona-wind" process.

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Structures, Structural Dynamics, and Holography

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THE purpose of this Comment is to inform AIAA members of the existence of a new and potentially powerful experimental technique for determining static and dynamic deformation characteristics of structures. It is based on the electro-optical technique known as holography,[1] which has become one of the most active, publicized, and fascinating technical developments of this decade.

Holography involves the illumination of a two-dimensional photographic plate, called a hologram, with a coherent light source, such as a laser, to produce a three-dimensional image of the object recorded on the hologram. The image has all the appearances of the actual object, including parallax relations between near and far points on the object. Holography is truly lensless, three-dimensional photography.

The hologram is made by illuminating the object with laser light. The light or wavefront reflected from the object is recorded on the photographic plate and contains both amplitude and phase information of the light waves.

The experimental technique with which experimentalists in structures and structural dynamics should become familiar is called holographic interferometry.[2] It also has exciting possibilities in experimental fluid mechanics, such as three-dimensional flow visualization of shock waves; one such application produced a holographic interferogram of the shock waves generated by a 22-caliber bullet.[2] The technique involves double or multiple exposures of the photographic plate. One exposure constitutes the comparison beam of a conventional interferometer. The second exposure is the test scene. Interference fringes due to changes in optical path length between the exposures are then visible on the image produced by illuminating the hologram. These fringes are directly related to the deformation history of the object between exposures.

Thus, in the case of double exposures, static structural deformations due to applied load can be determined.[3] By making a hologram before loading, then applying load and re-exposing the plate, the image formed from the doubly exposed hologram will contain interference fringes from which the three-dimensional structural deflections can be determined with accuracy on the order of a fraction of a wavelength of light; that is, fractions of a micron. The number of fringes between any two points together with the focal position of the fringes determine the deflections.

By using a continuum of multiple exposures, vibration characteristics of structures can be determined as the result of time-averaged holographic interferometry.[4,5] The photographic plate is exposed with the object at rest. Then the object is set in sinusoidal vibration and the plate continuously exposed during the vibration. When the resulting hologram is viewed, the interference fringes observed represent contours of constant amplitude. They display not only the over-all three-dimensional modal and nodal patterns but also allow the amplitude at each point to be determined accurately to within a fraction of the wavelength of light. These results are obtained without the need for placing any measuring device on the vibrating structure or otherwise disturbing it.

Holographic interferometry produces three-dimensional virtual images of the original scene, superimposed upon which is the complete record of the interference phenomena. These three-dimensional interferograms constitute an accurate record of optical path-length changes over a broad range of directions. The interference fringes can be examined from different directions and with different focal positions in order to measure path-length differences along various viewing paths and thus determine three-dimensional structural deformation characteristics under static and dynamic loads. The significance of this new tool to experimentalists in structures and structural dynamics is of revolutionary importance, in the opinion of this writer.

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Errata: "Boundary-Layer Flows with Large Injection and Heat Transfer"

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THE following errors have been discovered in the aforementioned article:

1) Equation (26a) should read

$$(d^2Z_1/df^2) + f(dZ_1/df) + 2\beta(G_1 - Z_1) = 0$$

2) Equation (27) should read

$$Z_1(f) - G_1(f) = [\exp(-f^2/4)][\ldots$$

where it is to be noted that $G_1(f) \to 0$ exponentially as $f \to +\infty$.

3) Equation (41) should read

$$Z^{-1/2} \simeq \tilde{Z}_0^{-1/2} + Z_0^{1/2} - \ldots$$

4) Equation (47) should read

$$\delta_0 = c^{-1}\int_{-c}^{0} (\tilde{Z}_0^{-1/2} - 1)df = \ldots$$

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