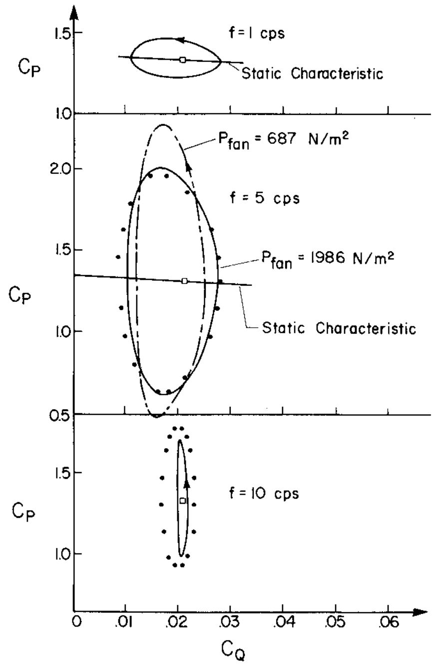

Fig. 2 Dynamic fan characteristics. Duct length = 7.62 m.

surprising. As is discussed at some length in Ref. 6 the system is behaving something like a Helmholtz resonator,[9] with the slug of air in the volute and duct oscillating back and forth on the spring associated with the plenum air capacitance.

Some results for a case in which the duct length has been increased to 7.62 m and the static fan characteristic is replaced by a constant pressure source are given in Fig. 2. The use of a constant pressure source facilitates the demonstration of a scale effect to be discussed later. All results in Fig. 2, except for the chain-dotted line marked "$P_{\text{fan}} = 687$ N/m^2," correspond to a nominal equilibrium operating fan pressure of 1986 N/m^2. The latter fan pressure is representative of that obtained on the prototype vehicle at full load. For the latter fan pressure, the continuous lines give the results of the one-dimensional unsteady analysis, and the dots are the result given by the lumped inertance model. The slight negative slope of the static characteristic is caused by friction losses in the duct. The peak in pressure fluctuations at about $f = 5$ cps is believed to be a Helmholtz resonator effect because for this geometry the Helmholtz resonator frequency is $f_h = 5.2$ cps.[9] A minimum in flow fluctuations, which occurs at about $f = 10$ cps, is believed to be a wave propagation effect because the natural frequency of the ducting f_d based on its wave propagation time is $f_d = 11.3$ cps.[3] Thus, it appears that for this case both Helmholtz resonator and wave effects are important. For frequencies greater than 10 cps, the direction of the loop often reverses, but the amplitude of both pressure and flow fluctuations remain small. As expected, the agreement between lumped inertance and full unsteady results becomes increasingly poorer as f increases.

The chain-dotted line for the results at 5 cps in Fig. 2 illustrates that, as might be expected, these effects do not scale according to the basic steady fan laws. It corresponds to a reduction of vehicle weight by a factor of about 2.90, but with the vehicle geometry unchanged and the equilibrium volume flow adjusted so that the same mean hover-gap, namely 0.64 cm is obtained. In the analysis the effective fan speed N was reduced to keep C_p the same as for the earlier results. It follows from the definitions of C_Q and the one-dimensional Bernoulli law for the air escaping from the cushion that, if the hover-gap is the same for both cases, then C_Q is also the same.

Using unsteady airfoil and cascade theory, Ohashi[4] has analysed the unsteady aerodynamic problem for the flow past the fan blades. He defines a critical frequency which characterized the frequencies required for significant unsteady blade aerodynamics to occur. It was found that for the present system this critical frequency is well above the typical frequencies expected to be encountered, so that unsteady blade aerodynamic effects are not significant.

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A Correlation of Spray Height Data for Jets Impinging on Water

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EXPERIMENTS done with small-scale jet nozzles at NASA Langley and observations of the X-13† suggest that operation of a vertical attitude takeoff and landing (VATOL) vehicle over water may produce considerable spray. The effects of this spray on visibility, corrosion, and thrust loss (due to water ingestion) could be considerable. Although a few experiments have been conducted with scale-model jets to determine spray height as a function of various flow parameters, none has resulted in a parametric formula for spray height that satisfactorily predicts full-scale results.[1,2] This Note presents the results of an analysis to find a parameter which correlates the available jet nozzle data, so that the spray height for VATOL aircraft may be estimated.

Considering the physics of this problem, spray height H_S is assumed to be a function of the nozzle exit dynamic pressure Q_N, the height of the nozzle above the water's surface H_N, the nozzle diameter D, the density of the water ρ_w, and the acceleration due to gravity g.

Thus,

$$H_S = F(Q_N, H_N, D, \rho_w, g) \tag{1}$$

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†The X-13 is an Air Force research VATOL aircraft powered by a Rolls Royce Avon turbojet engine. It first flew in 1955 and was demonstrated at the Pentagon in 1957. It has flown successfully in all flight regimes including: takeoff, hover, transition, and cruise.

Table 1 Tabulation of experimental data

D, ft	Q_N, psf	H_N, ft	H_S, ft
0.333[a]	28.3	0.667	2.667
	18.3		1.667
	8.3		1.17
	3.3	↓	0.333
	28.3	1.33	1.867
	18.3		1.333
	8.3	↓	0.587
	71.7	2.00	4.00
	31.7		2.00
	5.0	↓	0.50
	100.0	2.667	3.733
↓	71.7		3.117
0.333	26.7	↓	0.667
1.67[b]	1294.0	56.78	32.36
1.67[b]	1294.0	73.0	20.0

[a] Data from small-scale tests at NASA Langley. [b] X-13 data points.

Writing H_S as a power series,

$$H_S = \sum_{\alpha=-\infty}^{\infty} \sum_{\beta=-\infty}^{\infty} \sum_{\gamma=-\infty}^{\infty} \sum_{\epsilon=-\infty}^{\infty} \sum_{\lambda=-\infty}^{\infty} C_{\alpha\beta\gamma\epsilon\lambda} Q_N^{\alpha} H_N^{\beta} D^{\gamma} \rho_w^{\epsilon} g^{\lambda} \tag{2}$$

in which $C_{\alpha\beta\gamma\epsilon\lambda}$ are constants.

Dimensional analysis shows that, $\lambda = -\alpha$, $\epsilon = -\alpha$, $\gamma = 1 - \alpha - \beta$, so that

$$\frac{H_S}{H_N} = \sum_{\alpha=-\infty}^{\infty} \sum_{\beta=-\infty}^{\infty} C_{\alpha\beta} \left(\frac{Q_N}{\rho_w g H_N}\right)^{\alpha} \left(\frac{H_N}{D}\right)^{\alpha+\beta-1} \tag{3}$$

Data on the spray height produced by small-scale jet nozzles, expressed in the form of the parameters used in this analysis (Q_N, H_N, D), were obtained from R. Kuhn of NASA Langley, and are summarized in Table 1. These data are used to determine α, β, and C. To determine α; H_N and D are held constant. This gives the relation

$$H_S = \sum K_{\alpha} Q_N^{\alpha} \tag{4}$$

in which K_{α} is a constant.

H_S vs Q_N is seen plotted on log-log scale in Fig. 1 for a number of values of H_N/D. It is observed that the data for each H_N/D lie reasonably well on a straight line. The slopes of these lines were determined using a linear regression curve-fitting procedure. The value of α is determined from the average of the slopes of these lines. Thus,

$$\langle\alpha\rangle = \frac{0.92 + 0.95 + 0.78 + 1.36}{4} = 1.00 \tag{5}$$

This gives

$$\frac{H_S}{H_N} = \sum_{\beta=-\infty}^{\infty} C_{\beta} \left(\frac{Q_N}{\rho_w g H_N}\right) \left(\frac{H_N}{D}\right)^{\beta} \tag{6}$$

Note that this dimensionless equation contains the group $(Q_N/\rho_w g H_N)$ which is a Froude number for this problem. The Froude number is an important scaling parameter for systems involving the free surface behavior of water.[3]

The value of β is determined in a similar manner. The data have been plotted on log-log scale in Fig. 2. A linear regression curve-fitting procedure was used to determine a line through these points. The resulting equation is

$$\log\left(\frac{H_S}{Q_N}\right) = -0.539 \ \log\left(\frac{H_N}{D}\right) + \log(0.1407) \tag{7}$$

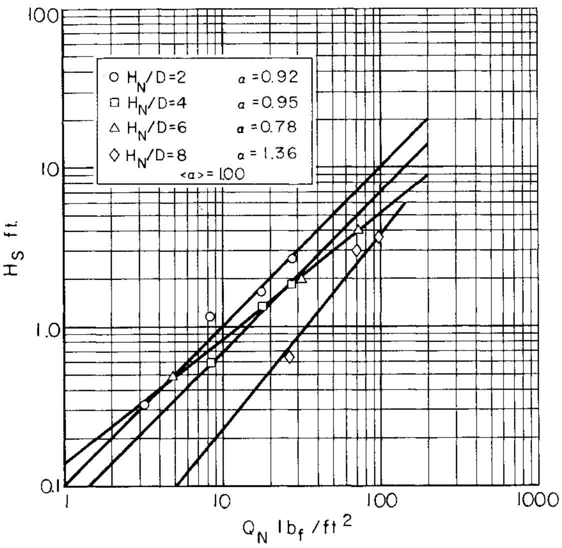

Fig. 1 Variation of spray height with nozzle dynamic pressure.

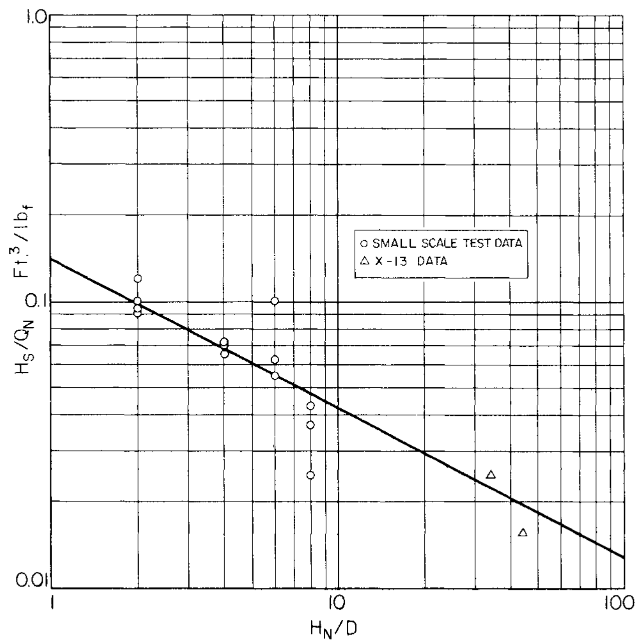

Fig. 2 Correlation of spray height data.

indicating that

$$\beta = -0.539$$

and

$$C = 0.1407 \rho_w g = 282$$

We finally arrive at the following equation for estimating spray height in terms of nondimensional quantities:

$$\left(\frac{H_S}{H_N}\right) = 282 \left(\frac{Q_N}{H_N \rho_w g}\right) \left(\frac{H_N}{D}\right)^{-0.539} \tag{8}$$

The data are plotted in Fig. 3, as a function of the calculated value of H_S/H_N. Although there is a great deal of scatter, the results appear to be randomly spread about the predicted values. Note that the full-scale X-13 point lies very close to the predicted value. Also note that essentially all of the data lie within 20% of the predicted values. For an analysis of this sort, 20% error is most reasonable.

Clearly, more test data on this problem, particularly for large nozzle diameters (1-2 ft) and high nozzle dynamic

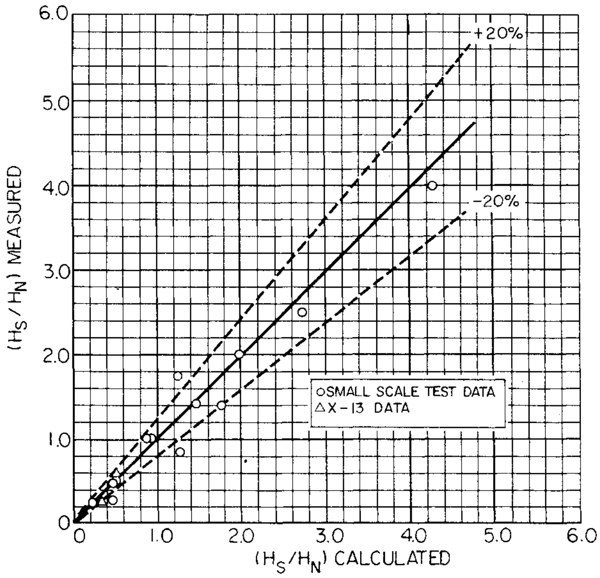

Fig. 3 Comparison of predicted and observed spray heights.

pressures (1000-3000 psf) are needed before an accurate prediction of spray height can be made. The effects of temperature, in so far as steam may be produced, have been ignored and should be investigated in future tests. In spite of this, a rough estimate of spray height can be made using the empirical equation derived here. This spray will clearly affect the operating environment of VATOL aircraft during takeoff and landing over water. This problem must be considered carefully in the design.

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Interference Effect of Catamaran Planing Hulls

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Introduction

By assuming that the effective width of a catamaran planing surface is the total width of the two surfaces or the width of the individual surface, Wang et al.[1] obtained two sets of equations for lift and center of pressure of such a surface. Comparing the experimental data with the calculated results, it was found that the drag-lift ratio of the experimental data was larger than those calculated by assuming that the effective width is the total width of the two surfaces. The deviation may be due mainly to the neglect of the interaction effect of the two surfaces. Savitsky and Dingee[2] studied the interference effects between two flat surfaces planing parallel to each other. They found that the lift generated by an individual surface when the two surfaces were placed close together was always larger than when the surfaces were widely separated. The difference may be attributed, essentially, to the interference phenomena. The merits of Savitsky's equation[3] also could be applied to the catamaran planing surface, provided that an interference factor is introduced. This Note gives a preliminary analysis of this factor. The exact value of this factor depends, essentially, on the speed coefficient and the hull configuration. Its range lies between 1.0 and $\sqrt{2}$.

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Analysis

The equations developed by Savitsky[3] have been used widely to predict the resistance and running trim of a V-shaped planing surface. For a catamaran planing surface as shown in Fig. 1, the hull is composed of one flat surface in the middle and two half V-shaped surfaces at the two sides. The width of the hull is b, and the total width of the two half V-shaped surfaces is b_l; the separation ratio is defined as

$$r = b_l / b \tag{1}$$

The limiting case is that when $r=1$, the hull becomes a single V-shaped surface. By assuming that b_l is the effective width of the planing surface, Savitsky's[3] equations for the lift C_{L0} and center of pressure C_p for flat planing surface can be written as

$$C_{L0} = \Delta / \tfrac{1}{2}\rho V^2 b^2 = (0.0012\lambda^{1/2} + 0.0055\lambda^{5/2}/C_v^2 r) r^{3/2}\tau^{1.1} \tag{2}$$

$$C_p = 0.75 - \frac{1}{2.39 + 5.21(c_v^2/\lambda^2) r} \tag{3}$$

where

λ = mean wetted length-beam ratio Lm/b
C_v = speed coefficient $V/\sqrt{gb}$
τ = trim angle

The total wetted surface S includes the wetted parts of the two inner surfaces and the bottom surfaces. It can be expressed as

$$S = b^2 [(r/\cos B) + 2\lambda \tan\tau]$$

Thus the drag-lift ratio can be written simply as

$$\frac{D}{\Delta} = \tan\tau + \frac{(V_m/V)^2 C_f}{C_L \cos\tau}\left(\frac{r}{\cos B} + 2\lambda\tan\tau\right)\lambda \tag{4}$$

where

V = speed of the surface
V_m = average bottom relative velocity
B = deadrise angle
C_f = skin-friction coefficient

The preceding analysis corresponds to the full interference condition, because it is imagined that there is no space between the two surfaces. On the other hand, if there is no interference effect, $b_l/2$ should be used as the effective width. By applying a similar analysis, the lift and center-of-pressure equations for this case are modified as

$$C_{L0} = [0.012\lambda^{1/2}/\sqrt{2} + (0.0055\sqrt{2}\lambda^{5/2}/C_v^2 r)] r^{3/2}\tau^{1.1} \tag{5}$$