primary design problems for canard configurations is finding a suitable means of longitudinal trim control that alleviates the canard stall problem while maintaining the high angle-of-attack benefits associated with close-coupled canard wing configurations.

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Parameter Variation—An Insight to V/STOL Design

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Dimensional stability derivatives gathered from a simulator during the development of the XV-4B aircraft have been varied one and two at a time in a computer program for extracting the roots of the lateral-directional characteristic equation. These roots have been used to provide complex plane plots indicating the effect of derivative variation on the dynamic characteristics of the vehicle. Secondary plots have been used to show the breakdown of the elements making up each derivative. The sources for these elements and factors affecting their prediction have been examined, along with changes required to modify the vehicle's dynamic characteristics. Some comparisons are made with other vehicles.

Nomenclature

C-rpm	= cruise engines (2) % rev/min (diverted downward for lift)
CG%mac	= center of gravity % wing mean chord
g	= acceleration due to gravity, ft/sec^2
I_x,I_z	= moment of inertia about the x and z stability axes
I_{xz}	= product of inertia about stability axes
L	= rolling moment, ft-lb, positive right wing down
L-rpm	= lift engines (4) % rev/min
L_p,L_r,L_v	= stability derivatives, rate of change of rolling moment divided by I_x with variable indicated by subscript
m	= mass of aircraft (w/g) slugs
N	= yawing moment, ft-lb, positive nose right
N_p,N_r,N_v	= stability derivatives, rate of change of yawing moment divided by I_z with variable indicated by subscript
w	= weight of aircraft lb
y	= side force, lb, positive out right wing
Y_p,Y_r,Y_v	= stability derivatives, rate of change of side force divided by mass with variable indicated by subscript
α	= angle of attack, trim value equal to zero
γ_v	= nozzle deflection (average of 6 engines) measured from a 10° aft position
δ_e	= elevator position, positive trailing edge down
δ_f	= flap deflection
θ	= pitch attitude, positive nose up, trim value equal to zero
σ	= real part of characteristic root,/sec
$j\omega$	= imaginary part of characteristic root,/sec

Subscripts

p	= perturbation rolling velocity, stability axes, positive for right wing down aircraft motion, rad/sec
r	= perturbation yawing velocity, stability axes, positive for aircraft nose right motion rad/sec
v	= perturbation side velocity, stability axes, positive for aircraft motion to the right

I. Introduction

MANY tunnel tests are run and elaborate calculations made to predict aircraft stability characteristics, particularly in the development of V/STOL aircraft. However, there is always a question as to the accuracy of these predicted characteristics.

In recent years there has been an attempt to correlate various wind tunnel, calculated and flight test data to achieve a better understanding of what is required for more accurate predictions.[3,5–7] This work has been partially successful but more is needed. Here attention has been directed to examining the effect of varying values of stability derivatives to determine their effects on vehicle dynamic characteristics.

II. Approach

Five of what are considered the more important lateral-directional derivatives are examined relative to the dynamics of the XV-4B (Fig. 1).[2,4] These derivatives listed in the order of their effect on the dutch roll mode of the aircraft are L_v, N_v, L_p, Y_v, and N_r. All the nominal lateral-directional stability axis derivatives and trim conditions used for this paper are listed in Table 1.

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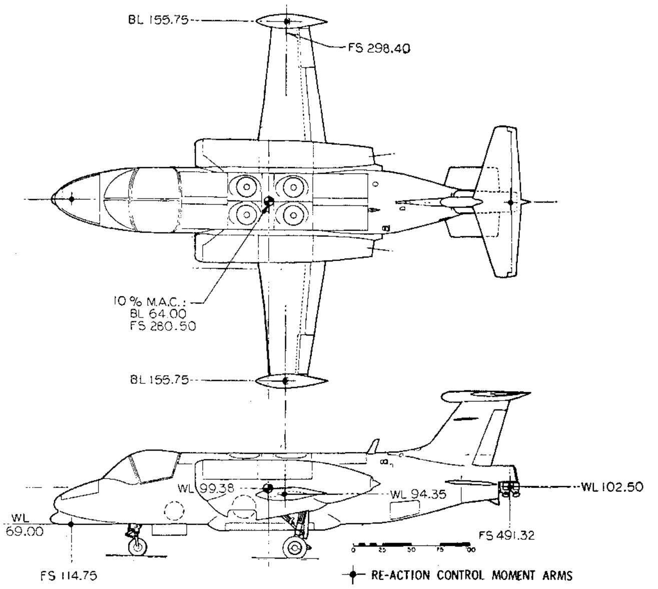

Fig. 1 XV-4B general arrangement.

The spiral and roll substance first order aircraft roots, although not shown in this paper, were on the average neutral to stable with very little changes produced by the ±100% variations of the derivatives. L_v was an exception to this near its zero value.

The basic dimensional stability derivatives used in this paper were obtained from a Flight Dynamic Laboratory's simulator program on the XV-4B,[1] extrapolating or calculating to the lower speeds where machine noise obscured the data. Data for the simulator program had been extracted from the best available sources; wind-tunnel test results supplemented by calculations.

The derivative variations shown in the root locus plots are based on a ± percentage of their absolute values. For example, the −100% value of the derivative is zero and the +100% is double the absolute value be it negative or positive.

III. L_v Rolling Moment due to Side Velocity

The static derivative $-L_v$ produced the biggest change in the characteristic roots as its value was varied. As can be seen in the complex plane map of Fig. 2a, increasing the absolute value of the negative L_v only increased the natural frequency with constant damping ratio at the hover condition. As the speed was increased the same percentage increase also produced an increase in negative damping ratio. Decreasing the absolute value of the derivative toward zero eventually produced a dynamically stable vehicle with low positive damping at most of the speeds covered.

Figure 2b provides an insight into the factors contributing to the nominal L_v derivative. The largest factor, the interference term is a function of asymmetric pressure on the upper and low surfaces of the body, wing, and vertical tail due to the flow into the inlets and outflow of the jet exhaust. About 90% of the effect is due to the vertical jet exits. The pressures on the wing are probably the predominant sources of this "dihedral effect." Therefore, in considering ways of modifying the interference term for more favorable dynamic characteristics, the location of the wing relative to the thrust exhaust would have to be considered.

The second strongest term of the rolling moment derivative is the momentum term. This effect is produced by the lateral change in direction of the airflow entering the top inlets. These inlets produced a moment away from the direction of the slip. To reduce this effect the inlet location must be located closer to the vertical center of gravity to obtain smaller a moment arm.

The third term considered is the basic aerodynamic dihedral effect stemming from the wing geometric dihedral, wing location on the fuselage and vertical tail aerodynamic center location. Reduction of this dihedral effect could be achieved by lowering the wing, lowering the vertical tail center of pressure, changing the basic dihedral effect or several other small effect changes.

IV. N_v Yawing Moment due to Side Velocity

The static derivative N_v, which is positive for most of the speed range examined, produced less variation of the roots (Fig. 3a) at low speeds than $-L_v$, the biggest change taking place at 100 knots. The 0.5 negative damping ratio and 1.0 rad/sec natural frequency at hover were not affected by variation of the derivative. Both the positive variations of the derivative and increased speed reduced the negative damping. At the −100% variation or zero value of the derivative the natural frequency and negative damping were both reduced by increased speed.

Figure 3b provides a breakdown of the static directional derivative, N_v, for the zero variation case. The momentum

Table 1 XV-4B phase I derivatives, 11,000 lb-1000 ft

Vel, knots	1 fps	10.0	20.0	40.0	60.0	70.0	100.0
γ_v, deg	−9.45	−7.85	−6.7	−4.67	−2.06	−1.0	+6.1
δ_e, deg	−6.5	−4.84	−2.8	−0.26	+2.85	+4.3	+8.9
C-rpm, %	93.3	93.3	93.3	93.5	93.8	93.5	91.25
L-rpm, %	92.8	93.2	93.3	93.5	92.56	92.0	91.25
θ, deg	0.0	0.0	0.0	0.0	0.0	0.0	0.0
α, deg	0.0	0.0	0.0	0.0	0.0	0.0	0.0
δ_f, deg	40.0	40.0	40.0	40.0	40.0	40.0	40.0
I_x, slug-ft^2	3050	3050	3050	3050	3050	3050	3050
I_z, slug-ft^2	12,900	12,900	12,900	12,900	12,900	12,900	12,900
I_{xz}, slug-ft^2	627	627	627	627	627	627	627
CG, %mac	10	10	10	10	10	10	10
N_v	−0.002	−0.000436	+0.00262	+0.00415	+0.00495	+0.00535	+0.00655
L_v	−0.032	−0.0334	−0.0345	−0.0375	−0.04	−0.041	−0.045
Y_v	−0.021	−0.125	−0.175	−0.255	−0.240	−0.240	−0.255
N_r	−0.01	−0.026	−0.034	−0.090	−0.124	−0.15	−0.230
L_r	0	+0.012	+0.060	+0.230	+0.344	+0.425	+0.640
Y_r	0	+0.055	+0.11	+0.22	+0.33	+0.385	+0.55
Y_p	0	−0.025	−0.05	−0.095	−0.14	−0.165	−0.235
L_p	−0.02	−0.100	−0.220	−0.320	−0.50	−0.80	−0.86
N_p	0	+0.004	+0.008	+0.017	+0.0255	+0.0298	+0.042

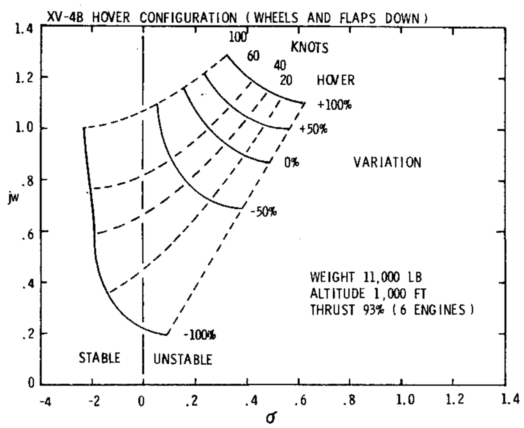

Fig. 2a Dutch roll roots as affected by L_v—moment due to side velocity.

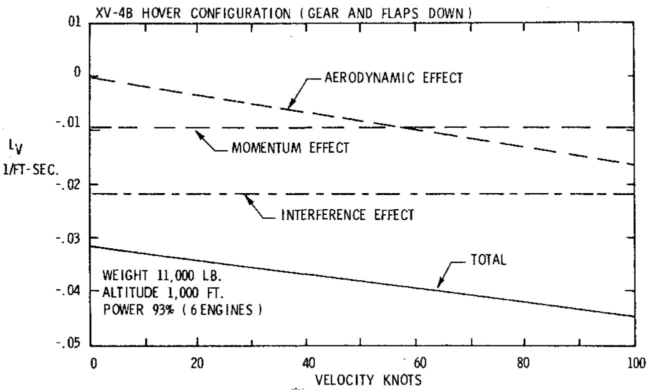

Fig. 2b Contributions to L_v—rolling moment due to side velocity.

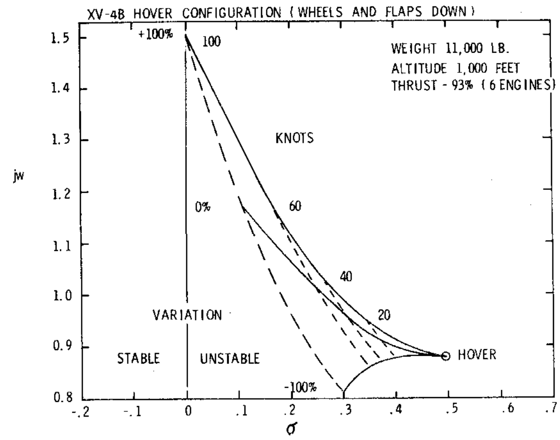

Fig. 3a Dutch roll roots as affected by N_v—yawing moment due to side velocity.

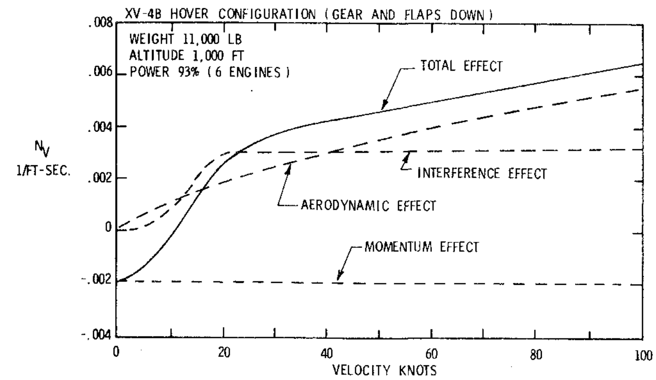

Fig. 3b Contributions to N_v—yawing moment due to side velocity.

term resulting from the side engine inlets had the largest effect at low speeds causing a static destabilizing effect. Dynamically this term increases the negative damping making the vehicle more unstable. To favorably modify the yawing moment produced by this term at hover would require a relocation or modification of the side inlets.

The second term which becomes stronger as the aircraft transitions is the interference term. It derives its effect from the same change in sidewash on the vertical tail that affected L_v, being induced by engine thrust. Third is the basic power-off aerodynamic term being produced by the vertical tail with some wing-body effects. The best way to modify this term favorably for low speed is through a larger vertical tail or a longer moment arm for the tail.

V. L_p Rolling Moment due to Roll

Figure 4a indicates that increasing the absolute value of this negative derivative had the expected effect of decreasing the negative damping and the natural frequency. Neutral dynamic stability (zero damping) was achieved at 100 knots by doubling the value of the derivative.

The derivatives used were calculated values based on pure aerodynamic factors as indicated in Fig. 4b. This derivative is primarily a function of differential lift on the wings and basically could only be changed by increasing the wing area and/or span.

VI. Y_v Side Force due to Side Velocity

Increasing the absolute value of this negative derivative as shown in Fig. 5a reduced the negative damping in a manner similar to that shown in the L_p variation of Fig. 4a. Here

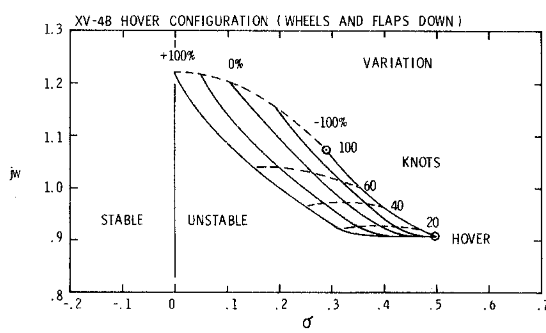

Fig. 4a Dutch roll roots as affected by L_p—rolling moment due to roll rate.

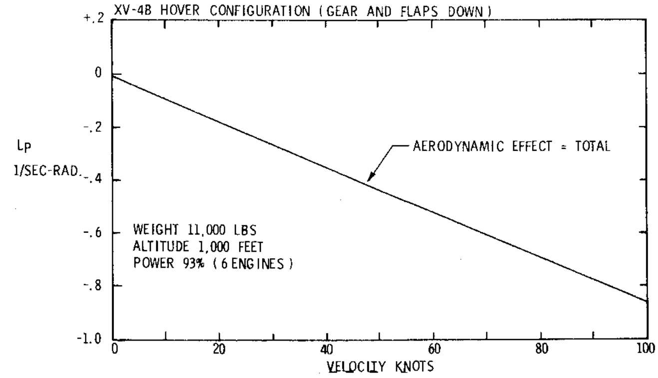

Fig. 4b L_p rolling moment due to roll rate.

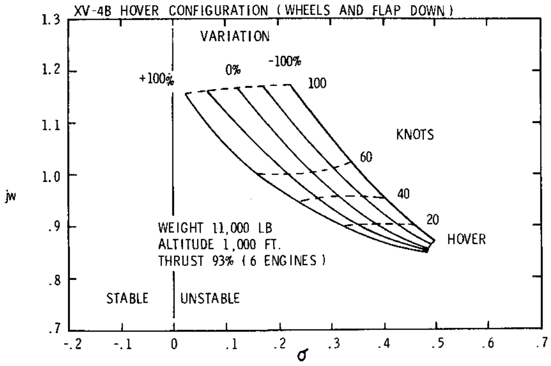

Fig. 5a Dutch roll roots as affected by Y_v—side force due to side velocity.

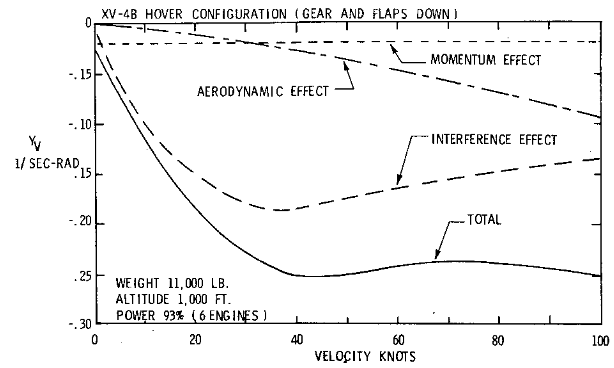

Fig. 5b Contributions to Y_v—side force due to side velocity.

again doubling the value of the derivative at 100 knots produced near zero damping.

Figure 5b provides an indication of the separate parts constituting this derivative. The interference effect is by far the strongest, again developing from the same source as the L_v derivative: differential pressures on the wing/fuselage combination as a result of thrust. The aerodynamic term is the side component of force when the aircraft is yawed, and can only be varied by changing the side area. In general, increasing the side area would reduce the negative damping. The momentum term which is small compared to the other terms in this derivative is, however, the predominant one at hover. It is produced by side forces on all engine inlets in a cross wind.

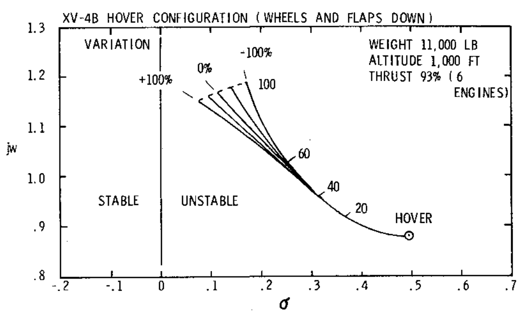

Fig. 6a Dutch roll roots as affected by N_r—yawing moment due to yaw rate.

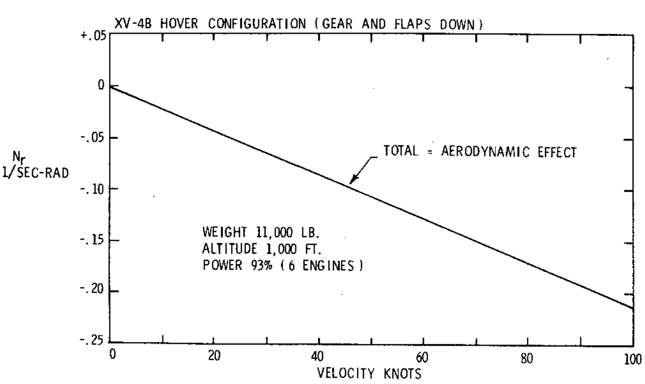

Fig. 6b N_r—yawing moment due to yaw rate.

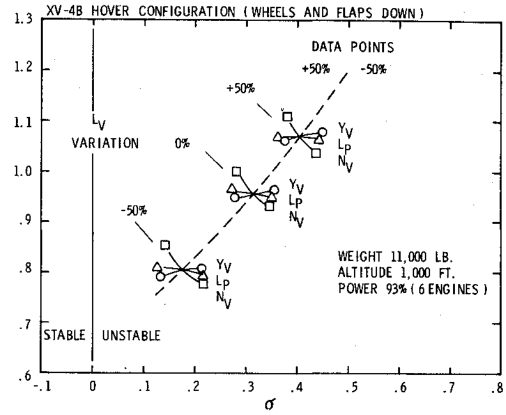

Fig. 7 Dutch roll roots for 40 knots double variation.

VII. N_r Yawing Moment due to Yaw Rate

Figure 6a indicates almost no change in the characteristic root based on the ±100% change of this negative derivative up to 60 knots. Velocity itself had the biggest effect. At 100 knots doubling the value of the derivative still had a very small effect.

Figure 6b indicates that the total derivative was based on aerodynamic effects, stemming primarily from the vertical tail.

VIII. Forty Knot Double Variation

Figure 7 is based on varying two derivatives at a time. Since the L_v variation produced the largest change, all other derivatives were varied in conjunction with it. As can be seen, the general trends of the other derivatives are the same at the ±50% L_v variation as at the zero L_v variation location. This would indicate that any design change that would make Y_v or L_p more negative, L_v less negative and N_v more positive would move the roots toward a more nearly stable condition. It should be noted, however, that the derivative signs do not always agree with the plus and minus signs used to indicate variations.

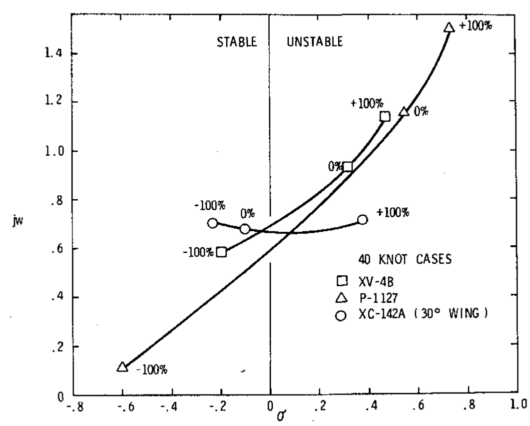

Fig. 8 Comparison of L_v variations.

IX. Comparisons of L_v Variations

Since the variation of the XV-4B derivatives indicated L_v to have the strongest effect on its dutch roll roots, a root comparison was made in Fig. 8 with two other aircraft. From this comparison it can be seen that sufficient reduction of dihedral effect, no matter how it is done or on what aircraft, will result in a dynamically stable vehicle in the lateral mode down to very low speeds.

X. Conclusions

I have, in this paper, briefly described the results of a digital computer parameter variation study in which the effects on vehicle dynamics were evaluated while modifying the "best available dimensional derivatives" for the XV-4B aircraft.

From the results of this program it has been shown that L_v is the most important lateral-directional derivative influencing the dutch roll characteristics of V/STOL aircraft at low speeds. To dynamically stabilize a V/STOL in the lateral mode it is necessary to reduce the dihedral effect. On a jet lift aircraft low-speed dynamics can be improved by proper location of jet inlets and also by placing as much distance as possible between the lift jet exit and the wing.

Other derivatives such as Y_v, L_p, and N_v can be modified by physically changing the vehicle but their effects on the dynamics are not as strong as L_v. The proper changing of the derivatives in combination can, however, produce more favorable stability characteristics.

The use of parameter variation can provide understanding of V/STOL stability and control characteristics and establish the factors that are important in the vehicle's dynamic behavior.

Thus, for V/STOL aircraft design, the stability and control considerations of the design should be put on equal status with considerations of performance requirements, because configuration variables can have gross effects on flying qualities.

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Prediction of Interference Loading on Aircraft Stores at Supersonic Speeds

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A method for theoretically predicting forces and moments on aircraft stores in supersonic flow is investigated. Linear theory is used to predict the flowfield due to a jet fighter-bomber type aircraft, representing aircraft wing, nose, pylons, and inlets. The interference loading is integrated over the store length by considering crossflow effects and buoyancy effects. The method is computerized. Theoretical pitching and yawing moment calculations for a store under an F-4C aircraft at Mach 1.2 are compared with wind-tunnel data. The results show reasonably good agreement, with the exception that finite shock effects shift the experimental data axially forward of the linear theory prediction.

Introduction

A USEFUL method for obtaining aircraft store separation characteristics is that of wind-tunnel "traverse testing," coupled with digital computer trajectory simulation. The purpose of the traverse test is to obtain interference forces and moments on the store as a function of position under the aircraft. The computer simulation uses this loading information in table form, together with the store physical characteristics and free air characteristics, to predict the store behavior at separation.

If the store interference loading is a function of store angle of attack as well as position under the aircraft, the matrix table of loading information can become prohibitively large. Fortunately the store angle of attack effect on the interference loading can usually be neglected with small error if pitch angles are small. If so, traverse testing is performed at zero store angle of attack to obtain interference coefficients, which are added linearly to free air data to obtain store loading at angle of attack. This linear superposition assumption is generally used.[1]

The purpose of the present work is to develop a theoretical method for predicting store interference loadings at zero store angle of attack as would be obtained by wind-tunnel traverse testing. The intent is to supplement wind-tunnel methods and thereby reduce the cost of separation analysis. To

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