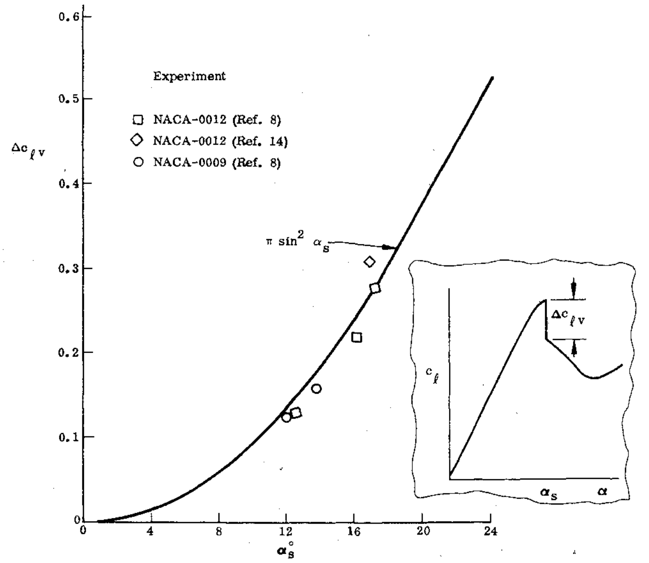

Fig. 4 Comparison between predicted and measured lift loss due to "spilled" leading-edge vortex.

Refs. 2 and 9 can, without undue complications, be extended to include the "spilled" vortex effects. These effects are always important when predicting $c_{n\,\mathrm{MAX}}$ and $-c_{m\mathrm{MAX}}$ during dynamic stall, whereas the effects on the damping in pitch become important only at rather high frequencies. At $\bar{\omega}=0.30$, for example, the α width of the vortex-induced c_m peak is very modest and does not significantly affect the enclosed area‡ (see Fig. 1). The simple means by which the "spilled" leading-edge vortex effects can be described are as follows. The initial transient phase during which the separation point overshoots its quasi-steady position can be desribed by including the moving separation point effect[2,9], and the subsequent transient phase during which the "spilled" vortec travels from the leading edge to the trailing edge can be described by a simple application of the concept of equivalence between the time-dependent two-dimensional "spilled" leading-edge vortex and the stationary three-dimensional leading-edge vortex existing on sharp-edged slender delta wings. The agreement between predictions based on this very simple "spilled" vortex concept and large-amplitude dynamic experimental data is such that the concept merits further study.

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‡This is, of course, the reason why the measured stall-induced negative aerodynamic damping[16] could be predicted by a theory[2,9] that did not include the "spilled" vortex effect.

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Captive Testing for Conducting Aircraft Motion Analysis Studies

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Introduction

WHEN an aircraft experiences an external configuration change (addition of stories, airframe modification, etc.), the aerodynamic data matrix used to describe the aircraft in analytical motion simulation is often invalidated. In the past, the aerodynamist has modified the original data matrix to account for configuration changes either empirically or by acquiring new aerodynamic data from additional wind tunnel tests. An alternate approach for investigating aircraft motion sensitivity to external configuration changes is through captive wind tunnel testing. Captive testing has been used successfully by the Royal Aircraft Establishment for investigating the lateral/directional stability characteristics of aircraft.[1] A pilot test[2] conducted in the AEDC Aerodynamic Wind Tunnel (4T) investigated captive testing as a tool for defining aircraft departure characteristics. Because of the success of these tests, the possibility of conducting aircraft motion analysis studies in the AEDC Propulsion Wind Tunnel (16T) with captive testing becomes attractive.

Description of Captive System

Captive testing is accomplished through a closed-loop system consisting of the model balance, model support system, and digital computer shown in Fig. 1. The test article is installed in the wind tunnel on a 6-component internal straingage balance. The model and balance are supported by a high pitch/roll positioning system.

The model is initially positioned at some angle of attack and sideslip depending on the nature of the maneuver to be generated. The model forces and moments are measured and fed input to an on-line digital computer. These measured aerodynamic data, along with the wind tunnel operating conditions, model mass characteristics, control deflection

Received Aug.1,1975; presented as Paper 75-983 at the AIAA 1975 Aircraft Systems and Technology Meeting, Los Angeles, Calif., Aug. 4-7, 1975; revision received Feb. 26, 1976.

Index categories: Aircraft Aerodynamics (including Component Aerodynamics); Aircraft Handling Stability, and Control; Aircraft Testing (including Component Wind Tunnel Testing).

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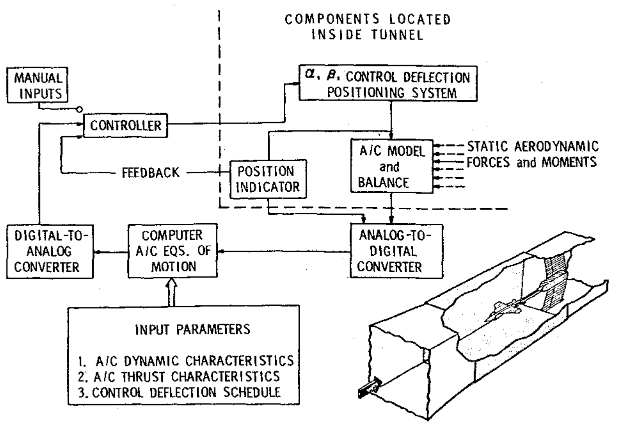

Fig. 1 Captive installation and block diagram of the computer control loop.

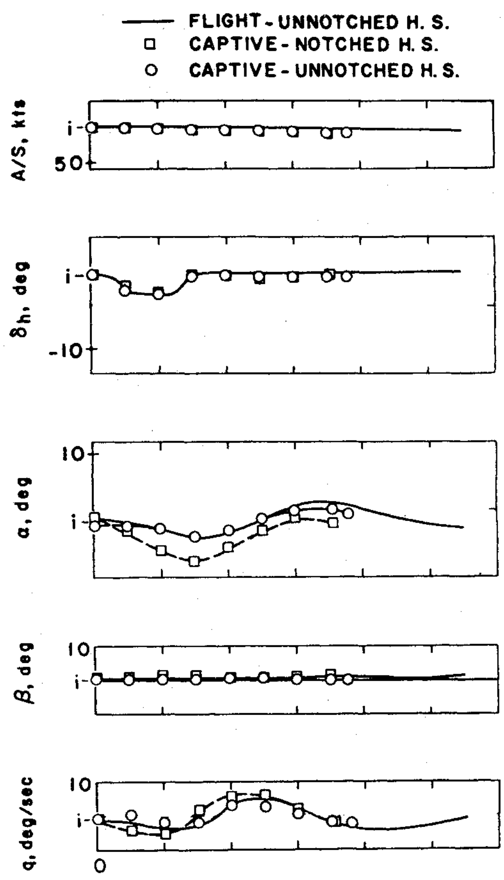

Fig. 2 Captive/flight longitudinal motion.

schedules, dynamic stability derivatives, thrust characteristics, and model angular positions are used in solving the Euler equations of motion. The computed solutions are used in controlling the orientation of the model through a point prediction technique.[3] The technique involves using the last two successive measured values of each static aerodynamic coefficient to predict the magnitude of the coefficient of the next prediction interval. The prediction interval used in the subject test was 0.08 sec. The predicted coefficients are used to calculate the new model angle of attack and sideslip by integrating the equations of motion every 0.005 sec over the prediction interval. The system is then commanded to move the model to the new angular positions, and the aerodynamic loads are measured. If the new measurements agree with the predicted values, the process is continued over another prediction interval of the same magnitude. If the measured and

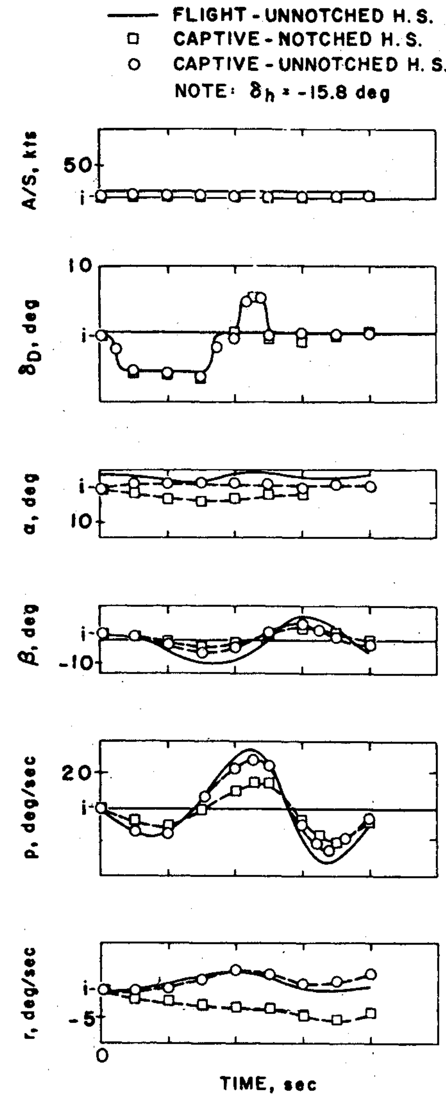

Fig. 3 Captive/flight lateral/directional motion.

predicted values do not agree within the specified precision, the calculations are repeated over a prediction interval one-half the previous value. This process is repeated until a complete maneuver has been obtained.

The aircraft Mach number is calculated at each prediction interval, and the wind tunnel Mach number is adjusted to within ±0.003 of the calculated value. Thus, the aerodynamic coefficients are measured at the correct Mach number throughout the maneuver. Also, the aircraft thrust is calculated and modified with each prediction interval by mathematic modeling of the simulated aircraft engine/inlet installed thrust as a function of Mach number, altitude, angle of attack and sideslip. The generated manuver is a function of the control surface deflection schedule. For the subject test, the deflection schedules were input as functions of flight time, t.

Captive/Flight Motion Correlation

To establish captive testing as a useful technique for conducting aircraft motion analysis studies in the AEDC 16T wind tunnel, the following experiment was conducted. Using a 1/20-scale model of the NASA RPV, simulated motion was generated in the wind tunnel for comparison with RPV flight motion.

Captive/flight data correlation for RPV longitudinal and lateral/directional motion are shown in Figs. 2 and 3, respectively. Each of these figures depicts three separate time history

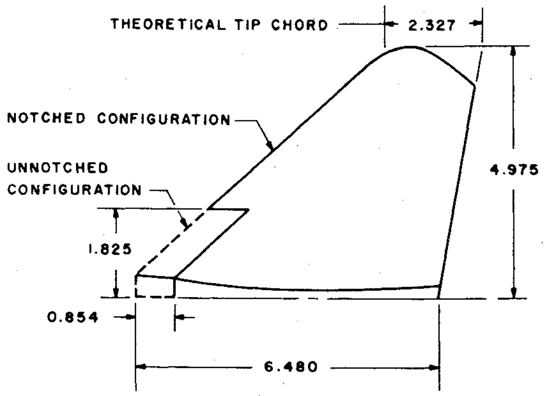

Fig. 4 Horizontal stabilizer plan form. All dimensions are in inches. Note: Unnotched stabilizer has approximately 5.4% more area.

motions: one flight and two wind tunnel generated. The longitudinal maneuver, Fig. 2, was generated from a horizontal stabilizer (δh) doublet at a trimmed flight condition. The lateral/directional maneuver, Fig. 3, represents an aileron doublet obtained by differentially deflecting the model horizontal stabilizers (δD). The differential deflections occur at about a nominal horizontal stabilizer setting (δh) of -15.8 deg. The flight data were acquired with an "unnotched" horizontal stabilizer configuration, Fig. 4. Flight test, with both "notched" and "unnotched" horizontal stabilizers, showed no measurable change in aircraft trim angle of attack (α) with either stabilizer. Because of this, the initial wind tunnel simulated motion was acquired with the 1/20-scale model utilizing an existing "notched" horizontal stabilizer. As seen in both the longitudinal and lateral/directional motion [pitch (q), yaw (r), roll (p), angle of sideslip (β)], the wind tunnel maneuvers with the "notched" stabilizer have motion frequencies near the flight data but show large deficiencies in amplitude. Also the angle of attack at which the wind tunnel model is trimmed for the lateral oscillations of Fig. 3 is approximately 4 to 6 deg lower than the RPV model for the nominal δh setting of -15.8 deg. The assumption that the "notched" stabilizer would have nearly equal the effectiveness of the "unnotched" version in the wind tunnel as seen in flight was a poor one.

An "unnotched" horizontal stabilizer was incorporated on the wind tunnel model and new longitudinal and lateral/directional maneuvers were generated, Figs. 2 and 3, respectively. The amplitude discrepancies between RPV and captive motion have decreased, and generally good data correlation exist in all motion planes.

The remaining deficiency in amplitude continued to be the result of a less effective horizontal stabilizer on the wind tunnel model. To achieve exact agreement between captive motion generated in the wind tunnel and flight motion, a better aerodynamic representation of the flight vehicle than was provided by the wind tunnel model must exist.

Conclusions

Captive testing provides a means of conducting an aircraft motion analysis study without the acquisition of static aerodynamic data matrices. An aircraft model with a full compliment of aerodynamic control surfaces is required for generating complex aircraft maneuvers although aircraft dynamic stability characteristics may be investigated without control movements.

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Potential Flow about Impulsively Started Rotors

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Nomenclature

B	= number of blades
B_i	= normal velocity components of the blade at element i
C_T	= thrust coefficient
NC,NS	= element number along chord and span
R	= rotor radius
V	= axial velocity
Γ	= circulation
$\Delta\phi_p^w$	= potential jump across wake element p
θ	= pitch angle
λ	= advance ratio, $\lambda = V/\Omega R$
σ_j	= doublet strength per unit area of element j
ψ	= azimuth angle
Ω	= rotational speed

Introduction

IN Ref. 1 a method was developed for the calculation of unsteady three-dimensional lifting potential flows and was applied to impulsive motion of wings and rotors. This work was motivated by the difficulties encountered by previous methods for predicting static thrust on propellers and rotors,[2] as well as by inadequacies in representing the complicated wake geometries observed behind highly loaded wings and in the vicinity of multi-bladed propellers or rotors with low inflow velocity. Here, some of the results for the rotor problem are illustrated.

Formulation

By using Green's theorem,[3] an exact integral solution for the inviscid incompressible flowfield due to rotor motion is obtained, wherein by a continuous distribution of doublets on each of the blades and their respective wakes. For the case of a rotor in combined rotational and axial motion, application of the exact surface tangency condition and evaluation of the resulting surface integrals by means of a discrete set of small surface elements yield the following matrix equation that is to be solved

$$[A_{i,j}]\ \{\sigma_j\} = \{B_i\} - [A^w_{i,p}]\ \{\Delta\phi^w_p\} \tag{1}$$

Here, $A_{i,j}$ is the normal induced velocity coefficient on the ith element of blade 1 due to the doublet distribution of the jth element of each blade. $A^w_{i,p}$ is similarly defined. The numerical solution is obtained in a step-by-step fashion, rotors being impulsively started from rest. Quadrilater sur-

Presented as Paper 75-126 at the AIAA 13th Aerospace Sciences Meeting, Pasadena, Calif., Jan. 20-22, 1975; submitted Feb. 24, 1975; revision received Feb. 6, 1976. This work was sponsored by the Air Force Office of Scientific Research under Contract F44620-72-C-0026.

Index categories: Rotary Wing Aerodynamics; Nonsteady Aerodynamics.

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