78-835

New Rotation-Balance Apparatus for Measuring Airplane Spin Aerodynamics in the Wind Tunnel

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An advanced rotation-balance apparatus has been developed for the Ames 12-ft Pressure Wind Tunnel to study the effects of spin rate, angles of attack and sideslip, and, particularly, Reynolds number on the aerodynamics of fighter and general aviation aircraft in a steady spin. Angles of attack to 100 deg and angles of sideslip to 30 deg are possible with spin rates to 42 rad/s (400 rpm) and Reynolds numbers to 30×10^6/m on fighter models with wing spans that are typically 0.7 m. A complete description of the new rotation-balance apparatus, the sting/balance/model assembly, and the operational capabilities is given.

Nomenclature

A	= body reference area, $\pi d^2/4$
b	= wing span (0.457 m for Figs. 3-6)
C_y	= body side force/qA
d	= diameter of centerbody (0.0762 m for Figs. 3-6)
M	= freestream Mach number
q	= freestream dynamic pressure
R_d	= Reynolds number based on d
V	= freestream velocity
α_S	= sting angle (Figs. 11 and 12)
α	= angle of attack
β	= angle of sideslip
σ	= angle between freestream velocity vector and body longitudinal axis
$\phi_{1,2,3}$	= rotational position axes (Figs. 8 and 9)
ψ	= body roll axis
ω	= angular velocity of rotary apparatus
Ω	= reduced spin parameter, $\omega b/2V$

Introduction

FOR many years the National Aeronautics and Space Administration has conducted research on the stall/spin characteristics of aircraft, primarily highly maneuverable military aircraft, but more recently including general aviation configurations. In the past, most of the stall/spin aerodynamics research was conducted at NASA's Langley Research Center using a variety of techniques.[1,2] However, in recent years NASA-Ames Research Center has begun a basic experimental research program to assess and understand the aerodynamic behavior of airplane configurations at high angles of attack,[3] with one area of emphasis being the determination of the Reynolds number effects on the aerodynamics of aircraft in a spin motion. This effort has been initiated at Ames primarily because of the five-atmosphere total pressure capability of Ames 12-ft Pressure Wind Tunnel resulting in Reynolds numbers ranging to 30×10^6/m. Exploratory experiments[4,5] were conducted on a simple research airplane-type model utilizing a modified rotary-balance apparatus originally designed for testing bodies of revolution in a coning motion.[6] One interesting case investigated in those experiments, reviewed as an illustration of the highly dependent nature of the aerodynamic forces on Reynolds number, provides a brief background on the question of the need for an advanced apparatus. The primary subject of this paper, however, is the new advanced rotary-balance apparatus itself.

Exploratory Experiments

Exploratory experiments[4,5] were conducted at $M=0.25$ with the basic airplane-like model shown in Figs. 1 and 2. Multiple six-component force/moment balances were used in the first exploratory test[4] to evaluate separately the effects of nose, tail, and the complete configuration including the wing during a steady spin motion. Subsequent tests,[5] using specially designed force balances in the nose and tail sections and eliminating the wing section and the sting balance, concentrated principally on the nose effects. Some of the prospin flow mechanisms of interest are shown in Fig. 1, including asymmetric vortices on tangent ogive noses, asymmetric flow on square-type cross sections, and vortex flow about a simple tail configuration. With rotation rates to 63 rad/s (600 rpm), manual angle-of-attack settings at $\sigma = 45$, 60, 75 and 90 deg, and roll angles of up to 10 deg for the nose, tail, and wing sections about the longitudinal axis of the model, it was possible to evaluate effects pertinent to flat spins (75 deg$<\sigma<$90 deg) and steep spins (45 deg$<\sigma<$75 deg).

An example of the aerodynamic characteristics in a flat spin motion (Fig. 3) clearly illustrates the strong dependence of the nose side-force coefficient C_y on Reynolds number and rotation or spin rate ($\Omega = \omega b/2V$). One interesting feature of

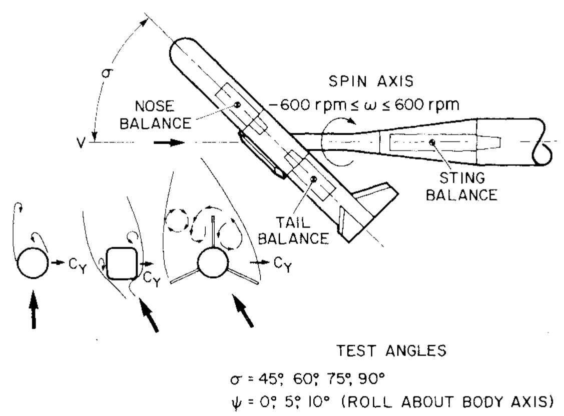

Fig. 1 Model and balance combinations and some prospin flow mechanisms.

Presented as Paper 78-835 at the AIAA 10th Aerodynamic Testing Conference, San Diego, Calif., April 19-21, 1978; submitted July 12, 1978; revision received Oct. 10, 1978. This paper is declared a work of the U.S. Government and therefore is in the public domain.

Index categories: Aerodynamics; Testing, Flight and Ground.

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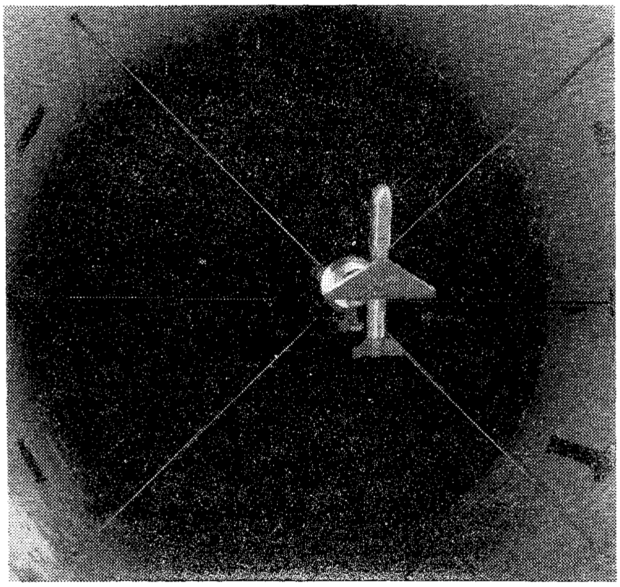


Fig. 2 Photograph of model and rotary apparatus installation in the wind tunnel.

this "flat spin case" is the observed hysteresis loop with rotation rate that occurs in the middle Reynolds number range. This phenomenon occurs as a result of the flow separation characteristics on the nose section as the rotational speed is increased and then decreased and is explained in detail in Ref. 5. Figures 4 – 6 show the Reynolds number effects on the nose side-force coefficient at $\sigma = 75$, 60, and 45 deg, respectively. No hysteresis effects were observed below $\sigma = 90$ deg. For the $\sigma = 60$ and 45 deg cases, the flow behavior and resulting side force are quite different from $\sigma = 90$ and 75 deg. The lowest Reynolds number conditions show antispin contributions rather than prospin, as for $\sigma = 90$ and 75 deg. In fact, at $\sigma = 45$ deg no condition produced a prospin contribution. The behavior of the flow is not as well understood for angles of attack less than 90 deg as it is for the two-dimensional flow of $\sigma = 90$ deg. However, static pressure measurements along with surface oil flow and sublimation tests have been made on a nonrotating model of the nose configuration and are reported in Ref. 7.

Advanced Rotary-Balance Apparatus

While the modified rotary-balance apparatus has been very useful in performing exploratory investigations on simple airplane-like configurations, the need has long been recognized for an improved apparatus for efficient test operation and for providing the load capability required for large models at high Reynolds numbers. An effort has been underway at Ames for some time to design and construct a large-scale rotary apparatus for use in the Ames 12-ft Pressure Wind Tunnel and the 11×11-ft Transonic Wind Tunnel. The rotary apparatus was designed to simulate full-scale, steady-spin motions by use of the proper combination of rotation speed and model size. Figure 7, a plot of reduced spin rate vs freestream velocity, indicates the region for most full-scale airplane spins of the military fighter class. A rotary apparatus with a rotational speed capability of 42 rad/s (400 rpm), along with the load capability for a model with a wing span of 61 cm (2 ft), provides a test envelope that encompasses most full-scale spin cases.

Avoiding unnecessary start-ups and shut-downs for model attitude changes is essential for efficient operation of a pressure tunnel. To accomplish this, the angle of attack and sideslip are capable of being changed remotely from outside the tunnel. The rotary apparatus was also designed to accommodate models of a practical size chosen to maximize the model Reynolds number but to minimize blockage effects or interference with the model. Experiments were run in the 12-ft tunnel with a nonrotating model representing the blockage of the actual apparatus, but no significant effects in the airflow in the vicinity of the model were measured. The effects of rotating the large apparatus structure behind the model are as yet unknown. Figures 8 and 9 are sketches and Fig. 10 is a photograph of the new apparatus. The angle of incidence of the model on a straight base-mounted sting with respect to the flow can be varied up to 30 deg. With the use of bent stings and top-mounted models, the angles of attack and sideslip can be varied to meet the required envelope of α from -30 to $+100$ deg with β ranging between ± 30 deg.

The angle of attack and sideslip variation is accomplished through rotation about two axes (ϕ_1 and ϕ_2 shown in Figs. 8 and 9) which intersect the spin axis at the designated longitudinal location on the model representing the center of gravity of a full-scale, free-spinning vehicle. Changes in model orientation, made remotely with small electric motors mounted in the apparatus, are done before spinning the whole assembly in the tunnel. The counterweight assembly is driven to a predetermined position that statically balances the mass distribution of the system about the spin axis. No attempt is made to balance the system dynamically. The entire apparatus is then rotated in the wind-tunnel airstream using a servo controlled hydraulic drive system that can be varied in speed between 0 and 42 rad/s (400 rpm) in either a clockwise or counterclockwise direction.

Figure 11 shows the attitude envelope obtainable with the stings selected for the first series of tests, including a base-mounted straight sting ($\alpha_S = 0$ deg) and two top-mounted bent stings ($\alpha_S = 45$ and 70 deg). Figure 12 shows a 0.05 scale F-15 fighter, the first model to be tested, mounted on each of the stings. Figure 13 is an assembly sketch of the model, balance, and the 45 deg top-mounted sting. A special, solid, six-component strain-gage balance was built for this model to optimize the load capability and to avoid modifying the top of the borrowed model to accommodate a standard balance.

The model is presently capable of manually set control deflections in the horizontal tails only. It is planned also to include the capability for setting aileron and rudder control deflections in the near future. To avoid the risk of damaging the model should something fail in the initial rotating tests (since all the components of the system are new, including the stings and balance), a dummy model was built. It is a simple dumbbell shape with a center cylinder large enough in diameter to accommodate the balance and larger diameter cylinders at each end. The total weight and the longitudinal and axial moments of inertia are identical to the actual airplane model.

Electrical power leads to the positioning drive systems and the power and signal paths from the balance are provided by a slip-ring assembly mounted in the circular housing near the strut mount. This is a low-level signal slip-ring unit containing 84 channels that provides adequate signal paths to run two six-component, strain-gage balances simultaneously, in addition to providing for remote changes in model control deflections. An angle encoder to determine accurately position information about the spin axis, if needed, is mounted on the rear of the slip-ring unit. A tachometer to determine spin rate is mounted on the hydraulic drive motor shaft. Most experiments will be conducted with the spin axis parallel to the wind stream, which will result in a steady force output from the balance at any given rotational speed. The possibility exists, however, that by inclining the rotational axis to the wind stream, say 3 or 4 deg, one can produce oscillatory force variations that, if measured and interpreted properly, might provide information on damping derivatives. This method of obtaining damping data in lieu of a forced oscillation apparatus will be investigated in the future.

Efforts are progressing to check out the operation of the entire system on a special test stand. To minimize wind-tunnel occupancy time, most of the measurements of rotating

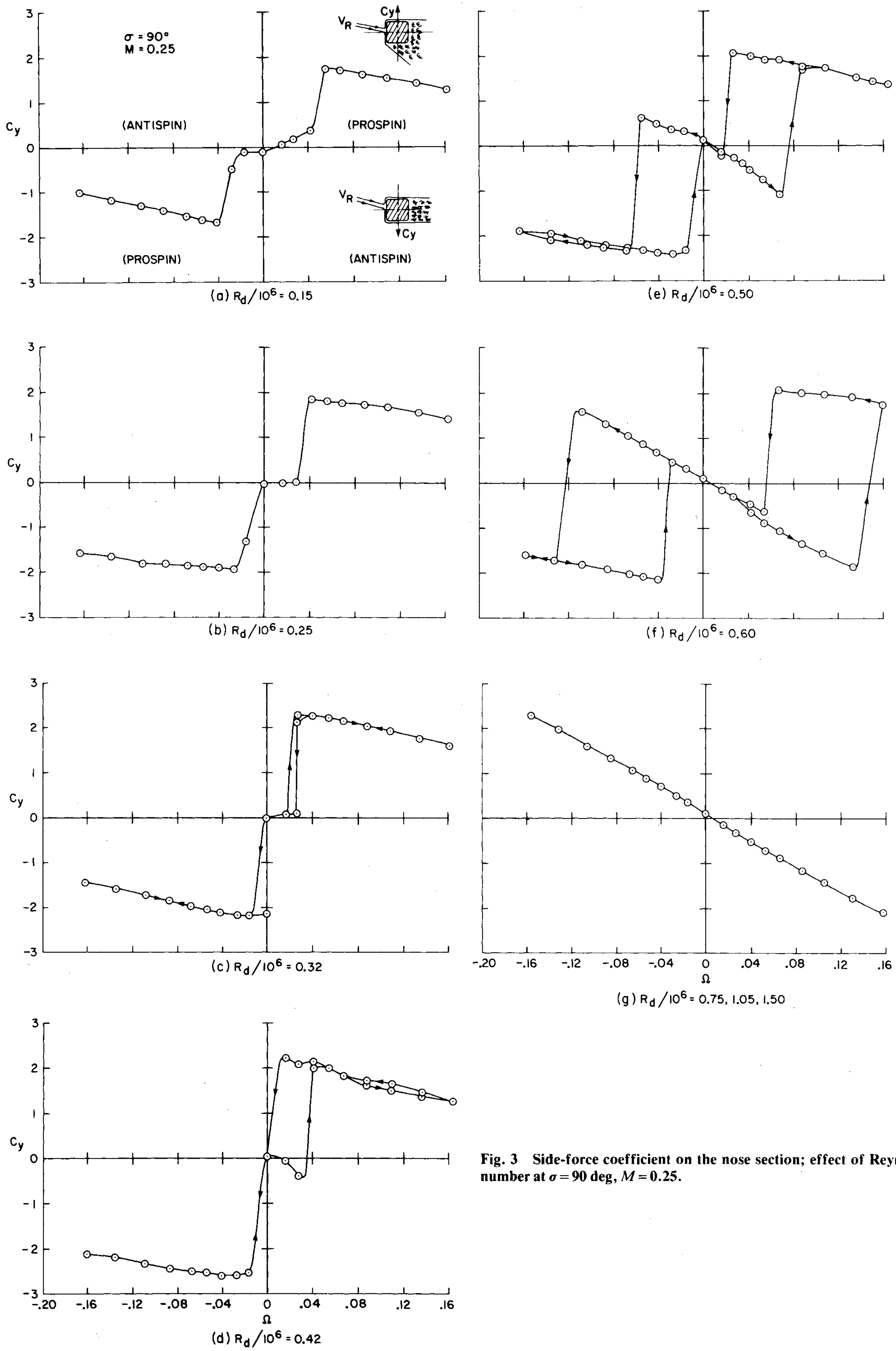


Fig. 3 Side-force coefficient on the nose section; effect of Reynolds number at $\sigma = 90$ deg, $M = 0.25$.

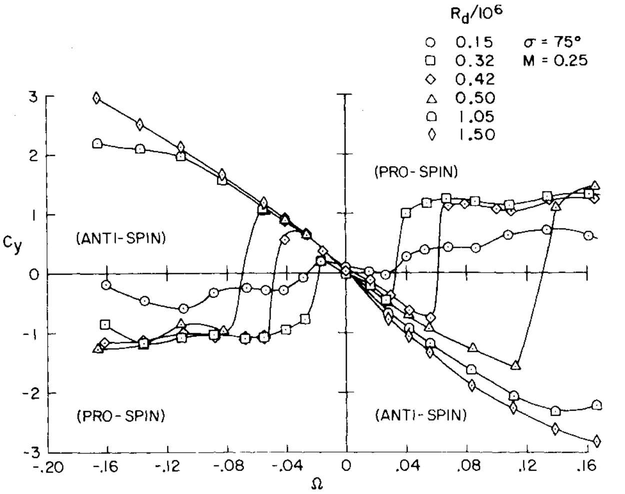


Fig. 4 Side-force coefficient on the nose section; effect of Reynolds number at $\sigma = 75$ deg, $M = 0.25$.

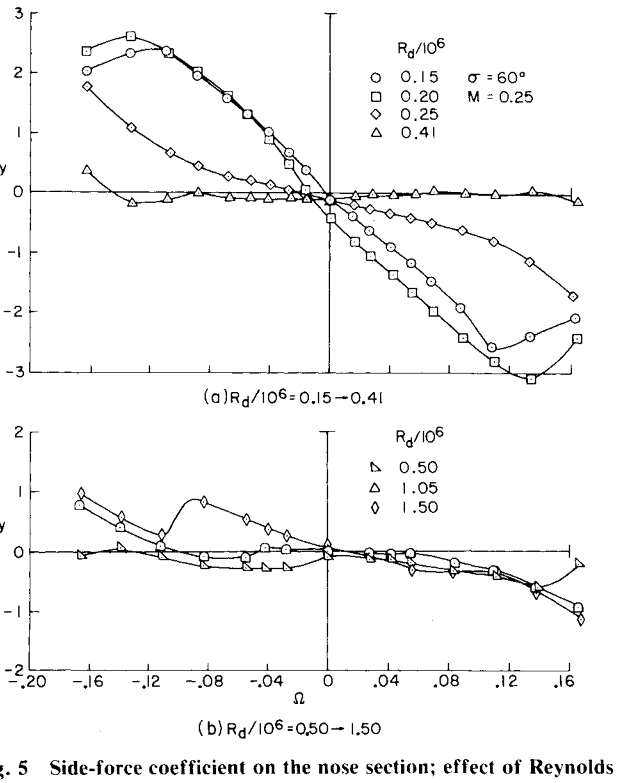


Fig. 5 Side-force coefficient on the nose section; effect of Reynolds number at $\sigma = 60$ deg, $M = 0.25$.

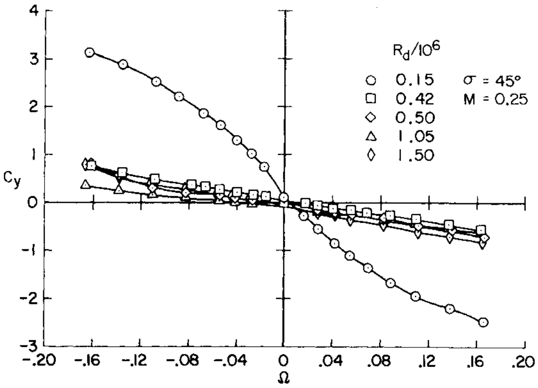


Fig. 6 Side-force coefficient on the nose section; effect of Reynolds number at $\sigma = 45$ deg, $M = 0.25$.

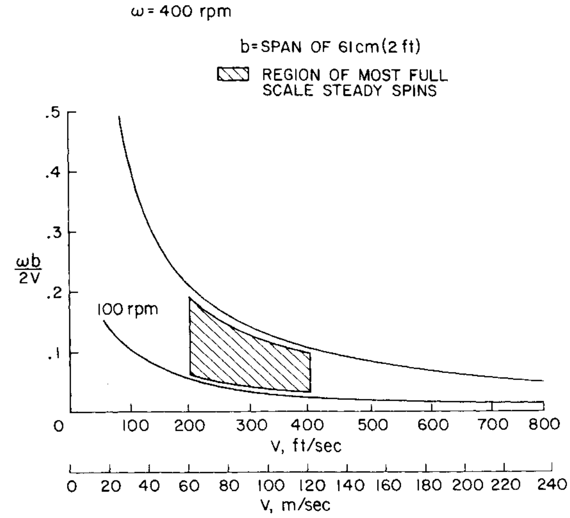


Fig. 7 Reduced spin parameter vs freestream velocity for simulating steady airplane spins.

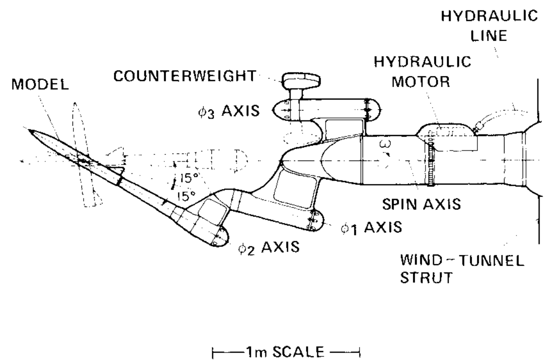


Fig. 8 Planview of new NASA Ames rotary-balance apparatus.

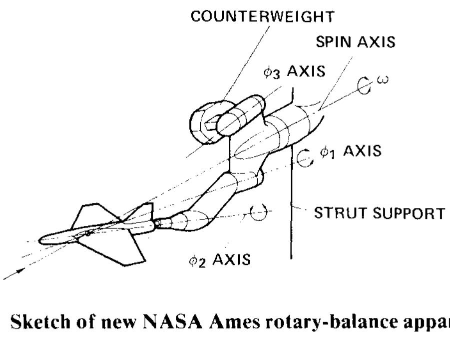


Fig. 9 Sketch of new NASA Ames rotary-balance apparatus.

inertial tares will be conducted outside the tunnel on the test stand, and only isolated checks will be made on the tares once the model and apparatus are installed in the tunnel. The first test using the new rotary-balance apparatus in the Ames 12-ft pressure tunnel should be complete by mid-1979.

Concluding Remarks

Previous exploratory tests on a rotary-balance apparatus in the Ames 12-ft Pressure Wind Tunnel have revealed that aerodynamics of simple airplane shapes are highly dependent on Reynolds number and are nonlinear with spin rate and angle of attack. A new, more advanced, rotary apparatus providing remotely controllable attitude settings has been

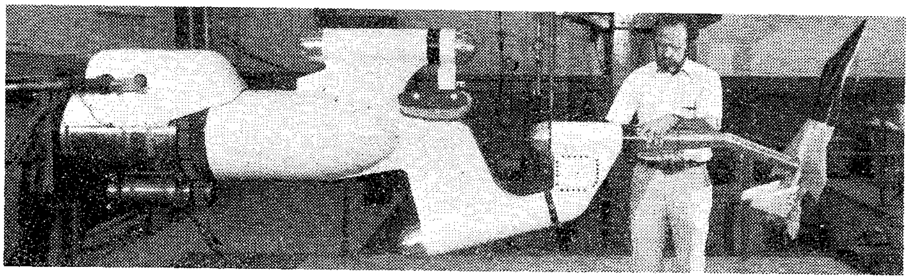


Fig. 10 Photograph of new NASA Ames rotary-balance apparatus.

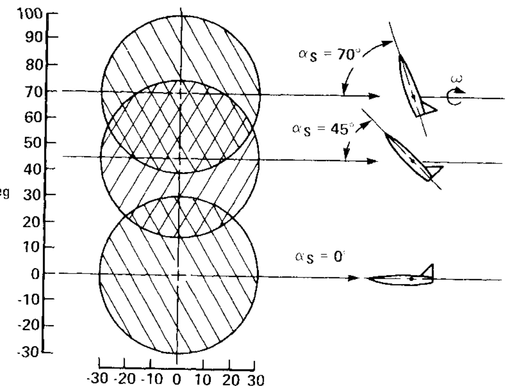
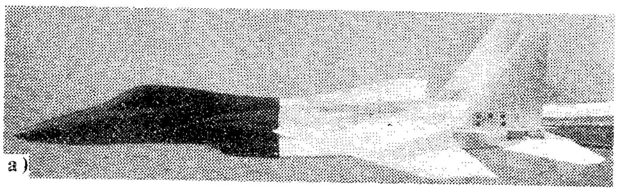
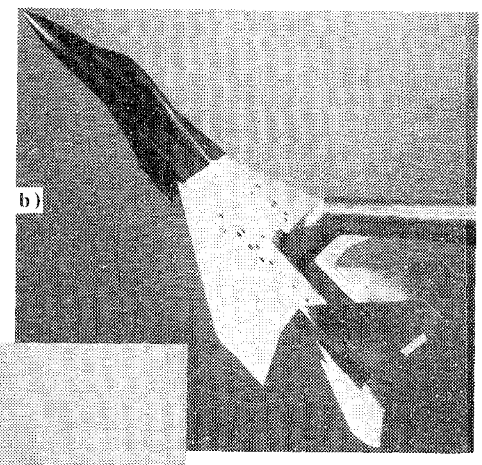


Fig. 11 Angle of attack and sideslip envelope for various sting-model angles.





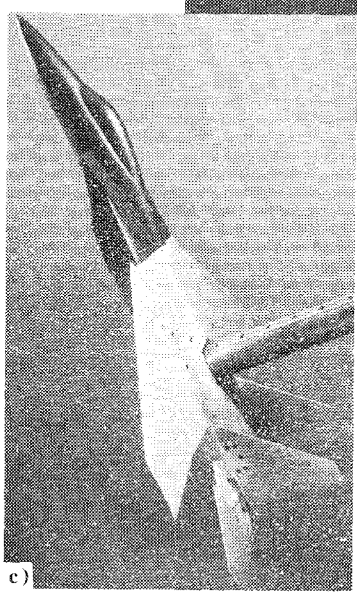


Fig. 12 Photographs of F-15 model mounted on various stings: a) $\alpha_S = 0$ deg; b) $\alpha_S = 45$ deg; c) $\alpha_S = 70$ deg.

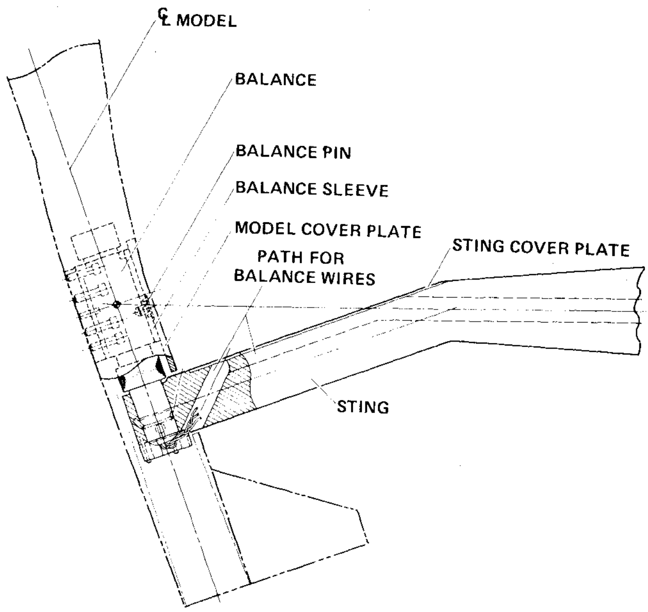


Fig. 13 Assembly of model, balance, and top-mounted sting.

developed and will provide rotary test capabilities for most airplane configurations at Reynolds numbers previously unobtainable. This new apparatus should also provide a reduced spin rate that duplicates that of most full-scale aircraft spins.

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