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SPIN-TUNNEL INVESTIGATION OF A 1/40-SCALE MODEL OF THE F-111A AIRPLANE WITH STORE LOADINGS AND WITH SUPPLEMENTARY SPIN-RECOVERY DEVICES

COORD NO. AF-AM-440

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Hampton, Va. 23665

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SUMMARY

An investigation has been made in the Langley spin tunnel to determine the spin and spin-recovery characteristics of the F-111A airplane in the symmetric and asymmetric stores loading conditions. Tests were also made with the model in the clean condition to determine whether the spin-recovery characteristics could be improved by the use of supplementary devices.

The test results indicated that when the F-111A airplane is in the stores loading condition, it is prone to spin at all wing-sweep configurations which is similar to the results obtained with no stores. Two general spin modes are possible on the airplane. A fast rotating, flat spin mode is readily obtained at the 50° wing-sweep configuration and is indicated as possible when the wing sweep is 26° or 72.5°. An oscillatory spin mode is indicated at all wing-sweep configurations. The test results obtained for asymmetric loading conditions indicated that as the asymmetric moment of the stores is increased, the airplane will spin flatter and faster in the direction of the lighter wing.

The recovery characteristics of the airplane in the stores loading condition are unsatisfactory even with the use of the recommended (optimum) recovery technique (simultaneous movements of the rudder to full against the spin, the ailerons to full with the spin, and the elevators to full up).

Three supplementary devices provided significant improvement in the spin-recovery characteristics. These devices included (1) increased differential horizontal-tail deflection, (2) deployment of a large canard (fuselage access door) on the inboard side (right side in a right spin) of the nose, and (3) deployment of a large wing-tip parachute on the outboard wing (left wing in the right spin).

INTRODUCTION

At the request of the U.S. Air Force, an investigation of a 1/40-scale model of the General Dynamics F-111A airplane has been made in the Langley spin tunnel. Spin and recovery characteristics were determined with symmetrical and asymmetrical store loadings at three wing-sweep conditions. Tests were also made with the model in the clean condition to determine whether the spin and recovery characteristics could be improved by use of various supplementary recovery devices such as wing-tip parachutes, opening electronic bay doors on the nose, increased deflection of controls, nose strakes, ejecting nose radome section, and so forth. Results of previous tests of the model in the clean condition are reported in reference 1.

SYMBOLS

Values are given in both SI and U.S. Customary Units. The measurements and calculations were made in the U.S. Customary Units.

b wing span, m (ft)

$\bar{c}$ mean aerodynamic chord, m (ft)

I_X, I_Y, I_Z moment of inertia about X, Y, and Z body axis, respectively, kg-m^2 (slug-ft^2)

$\frac{I_X - I_Y}{mb^2}$ inertia yawing-moment parameter

$\frac{I_Y - I_Z}{mb^2}$ inertia rolling-moment parameter

$\frac{I_Z - I_X}{mb^2}$ inertia pitching-moment parameter

m mass of airplane, kg (slugs)

S wing area, m^2 (ft^2)

V full-scale true rate of descent, m/sec (ft/sec or fps)

x distance of center of gravity rearward of leading edge of mean aerodynamic chord, m (ft)

z distance between center of gravity and fuselage reference line (positive when center of gravity is below line), m (ft)

α angle between fuselage reference line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), deg

μ relative density of airplane, $\frac{m}{\rho Sb}$

ρ air density, kg/m^3 (slugs/ft^3)

ϕ angle between span axis and horizontal, deg

Ω full-scale angular velocity about spin axis, rev/sec

MODEL AND TEST CONDITIONS

A 1/40-scale model of the airplane was built and prepared for testing by the Langley Research Center of the National Aeronautics and Space Administration. The model, as tested, represents the superweight-improvement-program (SWIP) version of the airplane. A three-view drawing of the model showing the 16°, 26°, 50°, and 72.5° wing-sweep configurations is shown in figure 1. The weights and locations of the stores are given in figure 2. Figures 3 to 5 are drawings of supplementary spin-recovery devices with figure 3 showing asymmetric strakes, figure 4 showing a fuselage nose door and the nose radome section, and figure 5 showing a wing-tip parachute. Photographs showing the model illustrating the configurations tested with external stores installed in the 26°, 50°, and 72.5° wing-sweep configurations are shown in figures 6(a), 6(b), and 6(c), respectively. The dimensional characteristics of the airplane are presented in table I and the mass characteristics of the airplane and the model are presented in table II. Table III indicates the stores loading conditions tested at the three wing-sweep angles. The asymmetric stores loading conditions tested for the 26°, 50°, and 72.5° wing-sweep configurations are presented in table IV(a), IV(b), and IV(c), respectively. Table V gives the test conditions covered in the tests of supplementary spin and recovery devices. The results of an extensive test program on the airplane in the clean condition have been reported in reference 1, and an analysis of these results together with those of reference 2 was used to define the area of investigation that was needed and the supplementary spin-recovery devices.

The tests were conducted in the Langley spin tunnel. The characteristics of the tunnel and the test techniques used are described in reference 2. The test technique is also described briefly in the appendix of the present paper for the convenience of the reader. The appendix also indicates the precision of measuring the spin characteristics.

Because it is impractical to ballast models exactly and because of inadvertent damage to models during tests, the weight and mass distribution of the model shown in table II varied within the following limits:

Weight, percent	0.1 low to 0.6 high
Center of gravity, percent $\bar{c}$	0.3 forward to 0 rearward
Moments of inertia:	
I_X, percent	2.1 low to 0.4 high
I_Y, percent	1.8 low to 1.34 high
I_Z, percent	1.8 low to 1.0 high

A remote-control mechanism was installed in the model to actuate the controls for the recovery attempts. Sufficient torque was exerted on the controls to move them fully and rapidly for the recovery attempts. The controls used on the airplane include spoilers, rudder, and all-movable horizontal tail. The horizontal-tail planes move together for pitch control and differentially for roll control. This control will be referred to hereafter as the elevator and aileron, respectively, for simplicity. Wing upper surface spoilers are used for additional roll control of the airplane at the forward wing-sweep angles. Past experience has indicated that spoilers on the upper surface of the wing have no influence on the spin and spin recovery; therefore, the spoilers were not used on the spin-tunnel model for this investigation. The controls were set within an accuracy of $\pm 1^\circ$.

The normal maximum control deflections (measured perpendicular to the hinge lines) used on the model for this investigation were as follows:

Rudder deflection, deg	7.5 right, 7.5 left
Elevator:	
Trailing edge up, deg	25
Trailing edge down, deg	10
Ailerons, deg	8 up, 8 down
Horizontal-tail maximum control surface movement:	
Trailing edge up, deg	30
Trailing edge down, deg	15

Greater deflections of the horizontal tail were used in tests to determine the effects of such extended deflections, and these cases are specifically pointed out in the tables and in the discussion of results.

RESULTS AND DISCUSSION

Specific results of spin-tunnel model tests cannot always be applied directly to corresponding full-scale conditions. It is necessary to evaluate the spin-tunnel data with a background knowledge of previous spin programs where spin-tunnel and full-scale results have been correlated. Experience has shown that by applying such an evaluation to the spin-tunnel data, meaningful and valid spin and recovery characteristics can be predicted for the full-scale airplane. The results of an extensive test program made on the model in the clean condition and reported in reference 1 were used in planning this test program as well as in evaluating these results.

The model test results are presented in table III for the symmetrical stores loading conditions. The results of asymmetrical stores loadings are presented in table IV and the results of the supplementary spin and recovery devices are presented in table V. In the table, the column labeled "spin block" gives a symbol of a spin chart to show, at a glance, the positions of the elevators and ailerons for the spin for a given run. The dot on the symbolic spin chart indicates the control position; the arrow indicates where the elevator and ailerons are moved for recovery.

All the model test results, in the tables and text, have been converted to full-scale values and the discussion of the results is presented in terms of predicted full-scale spin and recovery characteristics. All center-of-gravity positions are presented with reference to the mean aerodynamic chord of the 16° wing-sweep configuration.

The investigation included tests to determine the aerodynamic effects, if any, of external stores. At the beginning of the test program, the external stores were replaced by equivalent lead weights; thus, the aerodynamic shape was eliminated, but the mass remained constant. These results (data not presented) showed that the aerodynamic characteristics of the stores had no significant effect on the spin and recovery characteristics of the airplane; therefore, most of the tests were conducted with lead weights to represent the weight of the stores and to reduce the time loss due to damage to the stores.

Symmetrical Stores Loading Condition

Spin and recovery characteristics for erect spins for the stores loading condition are presented in table III. Spins were readily obtained for all stores loading conditions. Three sensitive pro-spin control configurations, determined from reference 1, were investigated and indicated that the airplane would have two general spin modes. A fast rotating, flat spin mode was readily obtained with the 50° wing-sweep configuration and was indicated as being very possible at the 26° and 72.5° wing-sweep positions. An oscillatory spin mode was indicated for all wing-sweep positions.

The fast, flat spin and the oscillatory spin are very similar to the ones encountered in the clean condition and reported in reference 1. The only appreciable difference is the higher rate of descent which is attributable to the difference in the gross weight. The flat spin is fairly steady with variations in pitch and roll of less than $\pm 5^{\circ}$. The mean angle of attack is about 81° and the mean bank angle is near 0°. The spin rate is about 3 sec/turn and the rate of descent is approximately 107 m/sec (350 ft/sec).

The oscillatory spin is characterized by large oscillations in pitch and roll. The mean angle of attack varies from 60° to 80° with oscillation about this mean of approximately $\pm 10^{\circ}$ to $\pm 30^{\circ}$. The mean bank angle was near 0° with oscillations as much as $\pm 35^{\circ}$. The rate of descent varied from 125 to 137 m/sec (410 to 450 ft/sec) and the spin rate from 4 to 6 sec/turn.

The recovery characteristics of the model in the stores loading configuration are unsatisfactory from all spin modes. The recommended recovery technique of the airplane, established in reference 1, is simultaneous movements of the rudder to full against the spin, the ailerons to full with the spin, and the elevators to full up. Even though this recovery technique is the optimum, it is not adequate to provide satisfactory recoveries from the fully developed spin.

Asymmetric Stores Loading Conditions

Erect spin and recovery characteristics for asymmetric stores loading conditions were investigated at the 26°, 50°, and 72.5° wing-sweep configurations and the results are presented in table IV(a), IV(b), and IV(c), respectively. The results were similar for each wing sweep configuration. As the asymmetric moment was gradually increased, the model progressively spun flatter and faster in the direction of the lighter wing. Asymmetric loadings degraded the recovery characteristics and the airplane is not expected to be recoverable from the developed spin with asymmetric loadings.

Supplementary Spin-Recovery Devices

Various supplementary devices were tested on the model at 26° and 50° wing-sweep configurations in an effort to improve the spin-recovery characteristics. The devices were of two different types – fixed and deployable. The fixed devices were used in an attempt to change the spin mode so that satisfactory spin recoveries could be obtained.

The deployable devices (mounted in the nondeployed position so as not to interfere with the normal developed-spin characteristics) were deployed, either alone or in conjunction with application of the recommended recovery control, to determine whether their use would influence the recovery characteristic.

The results of these tests are presented in table V. The developed-spin characteristics for the normal clean configuration with recovery attempts by using normal recovery controls are presented in tests numbered 1 and 5 (flat, fast rotating spin mode of the 50° wing-sweep configuration); 18 (flat, fast rotating spin mode of the 26° wing-sweep configuration); and 22 (oscillatory spin mode of the 26° wing-sweep configuration) and are presented for comparison purposes to determine the effectiveness of the supplementary devices.

Increased control deflection.- Increasing the aileron deflection for recovery (tests 2, 3, 4, 6, 7, and 24 of table V) made a marked improvement in the spin-recovery characteristics. As indicated in the results of reference 1, the recoveries were faster when the elevator was moved to the full up position rather than to neutral, in conjunction with the increased aileron deflection. As can be seen from test 7 of table V, increasing the movement of the ailerons to ±20° provided positive and satisfactory recoveries from the fast rotating, flat spin mode. (Compare the results with those for test 1.)

Test 19 shows that increasing the elevator deflection to 45° up in conjunction with normal aileron and rudder movements was not favorable for recovery. (Compare the results with those for test 18.)

Nose strakes.- The use of symmetrical strakes fixed on each side of the nose (data not shown) was not effective in aiding recovery. Asymmetrical fixed strakes of various configurations were mounted on the antispin side of the nose (right side in a right spin) and the results are presented in tests 8 to 13 of table V. As can be seen, the presence of an asymmetrical strake on the nose changed the spin mode and made a marked improvement in the recovery characteristics; since an asymmetric strake would probably not be deployed prior to the spin, these tests were probably not realistic. In order to evaluate the effect of deploying an asymmetrical strake after the spin had developed, tests were run in which a large strake was deployed in conjunction with the recommended recovery technique. These results (data not presented) showed only a small improvement in the recovery characteristics, and indicated that the change in spin mode was the reason for the improved recoveries shown in tests with fixed asymmetric strakes.

Fuselage access doors.- Tests 14 and 15 of table V show the effects of opening the fuselage access doors to an angle of 90° in conjunction with the application of the recommended recovery technique. In test 14, opening doors on both sides of the nose proved to be ineffective. However, in using the doors asymmetrically, only the door on the inboard side (right side in a right spin) of the nose was opened and all recovery attempts provided satisfactory results (test 15). Other possible access door configurations of smaller sizes were tested, but they did not provide satisfactory recoveries and the results are not presented.

Wing-tip parachutes.- Tests 16 and 17 of table V show the results of deploying wing-tip parachutes on the outboard wing (left wing in a right spin) while maintaining pro-spin controls. The smallest parachute considered to be adequate to stop the spin rotation had a laid-out-flat diameter of 7 m (23 ft) when based on a drag coefficient of 0.50 and the distance from the canopy to the attachment point was 27 m (90 ft). The post-recovery motion was very wild at times and for this reason such a wing-tip parachute would probably be considered undesirable for use on the full-scale airplane.

Leading-edge flaps.- Tests were made by deflecting leading-edge flaps in conjunction with the recommended recovery technique. The angle of deflection was 25° down and the hinge line was at 10 percent wing chord. As test 20 shows, the flaps did not appreciably improve the recovery characteristics.

Nose radome.- Approximately 3.048 m (10 ft) of the nose was jettisoned in conjunction with application of the optimum recovery technique in order to evaluate the effect of the radome on the spin-recovery characteristics of the airplane. The separation line of the nose radome section was at the forward edge of the electronic access door as shown in figure 4. As can be seen in test 21, jettisoning this part of the nose in addition to use of the recommended recovery technique did not appreciably affect the spin or recovery characteristics. Tests were also made with the nose radome section rotated 90° to the left and 90° to the right with no appreciable effect; therefore the results are not presented.

Landing drag parachute.- Although the F-111 airplane does not have a landing drag parachute, a landing-type drag parachute was deployed in conjunction with application of the recommended recovery technique. The parachute had a laid-out-flat diameter of 7 m (23 ft) based on a drag coefficient of 0.50 and the distance from the canopy of the parachute to the airplane attachment point was 27 m (90 ft). As can be seen in tests 24, 25, and 26, this procedure did not prove to be a satisfactory recovery technique.

Asymmetrically extended wing tip.- The outboard wing tip (left wing tip in a right spin) was extended approximately 102 cm (40 in.) in conjunction with application of the recommended recovery technique in an effort to improve the spin-recovery characteristics (by producing an antispin rolling moment). The use of this technique did not appreciably improve the recovery characteristics and the results are not presented.

CONCLUSIONS

Based on the results of this investigation, the erect spin and recovery characteristics of the F-111A airplane at 9144 m (30 000 ft) are given for the configurations indicated. Test results of store loading configurations lead to the following conclusions:

1. The airplane is prone to spin at all wing-sweep configurations (a result which is similar to the airplane spin characteristics without stores) and has unsatisfactory spin-recovery characteristics.

2. Both fast-flat and oscillatory spin modes are possible on the airplane and may be described as follows:

(a) The fast, flat spin was fairly steady with variations in pitch and roll of less than $\pm 10^{\circ}$. The mean angle of attack was about 81° and the mean bank angle was near 0°. The spin rate was about 3 sec/turn and the rate of descent was approximately 107 m/sec (350 ft/sec).

(b) The oscillatory spin is characterized by large oscillations in pitch and roll. The mean angle of attack varies from 60° to 80° with oscillations about this mean of $\pm 10^{\circ}$ to $\pm 30^{\circ}$. The mean bank angle was near 0° with oscillation as much as $\pm 35^{\circ}$. The rate of descent varied from 125 to 137 m/sec (410 to 450 ft/sec) and the spin rate from 4 to 6 sec/turn.

3. The recommended control technique for recovery from erect spins for all wing-sweep configurations is simultaneous deflections of the rudder to full against the spin, the ailerons to full with the spin (stick right in a right spin), and the elevators full up. Even though this technique is the optimum, it is not adequate to provide satisfactory recoveries on the airplane.

4. Asymmetric stores loadings cause the airplane to spin faster and flatter in the direction of the light wing.

Test results of supplementary devices to improve the spin and recovery characteristics lead to the following conclusions:

1. A significant improvement in the recovery characteristics was obtained by (a) increasing the differential horizontal-tail deflection to $\pm 20^{\circ}$, or (b) by deploying a large canard (fuselage access door) on the inboard side of the nose (right side in a right spin).

2. Either the use of fixed symmetrical nose strakes, or deployment of an asymmetrical nose strake on the inboard side of the nose (right side in a right spin), offers some small favorable effect on the spin and spin-recovery characteristics, but the improvement is not expected to be sufficient to provide satisfactory recoveries.

3. Deployment of a wing-tip parachute on the outboard wing (left wing in a right spin) will terminate the spin but is undesirable because of the wild post-recovery motions that are often produced.

4. Other supplementary recovery devices, such as jettisoning the nose radome section, rotating the nose radome section about the body axis $\pm 90^{\circ}$, asymmetrically extending

a wing tip, deflecting the leading-edge flaps, deploying a landing-type drag parachute, or increasing the elevator deflection, were investigated but were found to offer no appreciable aid to spin recovery.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., January 31, 1974.

APPENDIX

TEST METHODS AND PRECISION

General descriptions of model testing techniques, methods of interpreting test results, and correlation between model and airplane results are presented in reference 2.

Spin-tunnel tests are usually performed to determine the spin and recovery characteristics of a model for all control configurations for the airplane. Recovery is generally attempted by rapid full reversal of the rudder, by rapid full reversal of both rudder and elevators, or by rapid full reversal of the rudder simultaneously with the movement of the ailerons to full with the spin. Tests are conducted for the various possible loading conditions of the airplane because the control manipulation required for recovery is generally dependent on the mass and dimensional characteristics of the model. (See ref. 2.)

Turns for recovery are measured from the time the controls are moved to the time the spin rotation ceases. Recovery characteristics of a model are generally considered to be satisfactory if recovery is accomplished with 2 or 3 turns, depending on the spinning condition of the model. This value has been selected on the basis of full-scale-airplane spin-recovery data that are available for comparison with corresponding model test results.

For spins in which a model has a rate of descent in excess of that which can readily be obtained in the tunnel, the rate of descent is recorded as greater than the velocity at the time the model hit the safety net, for example, >91.44 m/sec (>300 ft/sec), full scale. In such tests, the recoveries are attemped before the model reaches its final steeper attitude and while it is still descending in the tunnel. Such results are considered to be conservative; that is, recoveries are generally not as fast as when the model is in the final steeper attitude. For recovery attempts in which a model strikes the safety net while it is still in a spin, the recovery is recorded as greater than the number of turns from the time the controls were moved to the time the model struck the net, for example, >3. A recovery in >3 turns, however, does not necessarily indicate an improvement over a recovery in >7 turns. A recovery in 10 or more turns is indicated by ∞. When a model recovers without control movement (rudder held with the spin), the results are recorded as "no spin."

Results determined in free-spinning tunnel tests are believed to be true values given by models within the following limits:

α, deg	±1
ϕ, deg	±1
V, percent	±5
Ω, percent	±2
Turns for recovery obtained from motion-picture records	±1/4
Turns for recovery obtained visually	±1/2

The preceding limits may be exceeded for certain spins in which the model is difficult to control in the tunnel because of the high rate of descent or because of the wandering or oscillatory nature of the spin.

The accuracy of measuring the weight and mass distribution of models is believed to be within the following limits:

Weight, percent	±1
Center-of-gravity location, percent $\bar{c}$	±1
Moments of inertia, percent	±5

Controls are set within an accuracy of $\pm 1^{\circ}$.

REFERENCES

1. Bowman, James S., Jr.; and Lee, Henry A.: Spin-Tunnel Investigation of a 1/40-Scale Model of the F-111A Airplane. NASA TM SX-1672, U.S. Air Force, 1968.
2. Neihouse, Anshal I.; Klinar, Walter J.; and Scher, Stanley H.: Status of Spin Research for Recent Airplane Designs. NASA TR R-57, 1960. (Supersedes NACA RM L57F12.)

TABLE I.- DIMENSIONAL CHARACTERISTICS OF THE F-111A AIRPLANE

[All dimensions are based on 16° wing sweep unless otherwise indicated]

Overall length	2240.6 cm (882.12 in.)
Wing:	
Span	19.2 m (63 ft)
Area	48.8 m^2 (525 ft^2)
Root chord (at airplane center line)	383.2 cm (150.883 in.)
Tip chord	124.5 cm (49 in.)
Mean aerodynamic chord, $\bar{c}$	275.6 cm (108.5 in.)
Leading edge of $\bar{c}$, distance rearward of leading edge of root chord	114.3 cm (45 in.)
Aspect ratio	7.56
Taper ratio	3.08
Dihedral, deg	1
Incidence, deg	1
Airfoil section –	
Root (modified)	NASA 64A210.68
Tip	NASA 64A209.8
Horizontal tail:	
Total area	37.8 m^2 (407.3 ft^2)
Span	8.94 m (29.33 ft)
Aspect ratio	2.11
Taper ratio	6.897
Sweepback of leading edge	57°30"
Dihedral, deg	-1
Root chord (at airplane center line)	683.26 cm (269 in.)
Tip chord (theoretical)	99.06 cm (39 in.)
Airfoil section	Biconvex
Vertical tail:	
Area	10.4 m^2 (111.7 ft^2)
Span	2.7 m (8.9 ft)
Taper ratio	2.435
Root chord	542.2 cm (213.47 in.)
Tip chord	222.7 cm (87.67 in.)
Sweepback of leading edge, deg	55
Airfoil section	Biconvex
Rudder area	2.72 m^2 (29.3 ft^2)

Dimensions for all wing-sweep angles:

Wing-sweep angle, deg	16	26	50	72.5
Span, m (ft)	19.2 (63)	18.1 (59.5)	14.7 (48.3)	9.7 (31.95)
Mean aerodynamic chord, $\bar{c}$, cm (in.)	275.6 (108.5)	278.9 (109.8)	364.7 (143.6)	704.8 (277.5)
Fuselage station at leading edge of $\bar{c}$, cm (in.)	1214.1 (478.0)	1242.1 (489.0)	1243.6 (489.6)	966.7 (380.6)

TABLE II.- MASS AND INERTIA CHARACTERISTICS OF THE F-111A AIRPLANE FOR TYPICAL LOADINGS USED FOR THE 1/40-SCALE-MODEL TESTS

[Values given are full scale; moments of inertia are given about center of gravity]

Loading	Weight, N (lb)	Wing sweep, deg	Wing span, m (ft)	$\bar{c}$, cm (in.)	Leading-edge $\bar{c}$, fuselage station, cm (in.)	Center-of-gravity location: Fuselage station, cm (in.)	Center-of-gravity location: $x/\bar{c}$ based on – 16° sweep	Center-of-gravity location: $x/\bar{c}$ based on – Actual sweep	Center-of-gravity location: z, waterline, cm (in.)	Relative density, μ, at – Sea level	Relative density, μ, at – 9 144 m (30 000 ft)	Moments of inertia, kg-m² (slug-ft²): I_X	I_Y	I_Z	Mass parameters: $\frac{I_X - I_Y}{mb^2}$	$\frac{I_Y - I_Z}{mb^2}$	$\frac{I_Z - I_X}{mb^2}$
									Airplane								
1	385 170 (86 590)	26	18.14 (59.5)	278.9 (109.8)	1242.1 (489.0)	1313.4 (517.1)	0.360	0.256	455.9 (179.5)	36.20	96.62	502 858 (370 894)	405 354 (298 978)	889 509 (656 077)	76×10^{-4}	-375×10^{-4}	300×10^{-4}
2	331 649 (74 558)	50	14.72 (48.3)	364.7 (143.6)	1243.6 (489.6)	1353.1 (532.7)	.504	.300	457.2 (180.0)	38.39	102.46	181 500 (133 689)	413 297 (304 836)	577 180 (425 712)	-317	-224	540
3	331 649 (74 558)	72.5	9.72 (31.9)	704.9 (277.5)	966.7 (380.6)	1369.8 (539.3)	.565	.572	456.7 (179.8)	58.05	154.85	120 265 (88 704)	427 621 (315 401)	530 247 (391 095)	-962	-321	1283
4	320 270 (72 000)	26	18.14 (59.5)	278.9 (109.8)	1242.1 (489.0)	1305.3 (513.9)	.331	.237	469.4 (184.8)	30.10	80.37	133 380 (91 000)	542 320 (400 000)	630 450 (465 000)	-390	-82	472
5	222 410 (50 000)	50	14.72 (48.3)	364.7 (143.6)	1243.6 (489.6)	1336.0 (526.0)	.442	.253	464.8 (183.0)	25.83	68.75	71 180 (52 500)	406 740 (300 000)	461 650 (340 500)	-683	-112	795
									Model								
6	385 041 (86 561)	26	18.14 (59.5)	278.9 (109.8)	1242.1 (489.0)	1322.6 (520.7)	0.394	0.289	456.6 (183.3)	36.19	96.59	504 541 (372 135)	405 973 (299 434)	874 095 (644 708)	76×10^{-4}	-363×10^{-4}	286×10^{-4}
7	331 969 (74 630)	50	14.72 (48.3)	364.7 (143.6)	1243.6 (489.6)	1334.8 (525.5)	.434	.250	463.3 (182.4)	38.44	102.59	179 668 (132 518)	418 838 (308 923)	572 999 (422 628)	-326	-210	536
8	333 499 (74 974)	72.5	9.72 (31.9)	704.9 (277.5)	966.7 (380.6)	1343.4 (528.9)	.470	.531	459.0 (180.7)	58.38	155.72	117 717 (86 825)	435 242 (321 022)	535 121 (394 690)	-986	-310	1295
9	317 730 (71 429)	26	18.14 (59.5)	278.9 (109.8)	1242.1 (489.0)	1321.8 (520.4)	.390	.286	440.7 (173.1)	29.86	76.70	125 436 (92 518)	541 886 (399 580)	639 478 (471 661)	-391	-92	483
10	220 835 (49 646)	50	14.72 (48.3)	364.7 (143.6)	1243.6 (489.6)	1325.1 (521.7)	.403	.224	445.8 (175.5)	25.57	68.24	70 784 (52 208)	404 811 (298 577)	444 964 (328 193)	-685	-82	767

TABLE III.- SPIN AND RECOVERY CHARACTERISTICS OF THE F-111A AIRPLANE FOR THE STORES LOADING CONDITION AT THREE WING-SWEEP ANGLES

[Right erect spins; model values converted to full scale; U, inner wing up; D, inner wing down; A, against; W, with. (Recoveries are attempted as indicated.)]

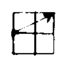
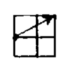
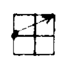
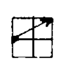
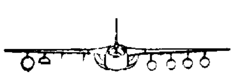
Spin block	Test	Loading	Control setting for spin			Spin characteristics					Control movement for recovery			Turns for recovery
			Rudder, deg	Aileron, deg	Elevator, deg	α, deg	φ, deg	V, m/sec	V, ft/sec	Ω, rev/sec	Rudder, deg	Aileron, deg	Elevator, deg	
26° wing sweep														
	[a]1	6	7.5W	8A	25 up	[b]42 120	22U 22D	127	417	0.28	7.5A	8W	----	∞
						[b]52 101	12U 12D	≈137	≈450	0.32				∞
	2	6	7.5W	0	25 up	[b]40 110	20U 20D	127	417	0.26	7.5A	8W	----	>3, >5
	[a]3	6	7.5W	8A	0	[b]70 90	5U 12D	≈140	≈459	0.27	7.5A	8W	25 up	∞
						[b]37 117	16U 28D	≈125	≈409	0.33				∞
50° wing sweep														
	4	7	7.5W	8A	25 up	[b]35 128	55U 50D	≈122	≈401	≈0.27	7.5A	8W	----	∞
	5	7	7.5W	0	25 up	[b]27 92	28U 37D	≈127	≈417	≈0.17	7.5A	8W	----	2½, 3, >5
	[a]6	7	7.5W	8A	0	81	1U	107	350	0.36	7.5A	8W	----	4½, ∞
						[b]45 115	55U 56D	119	392	0.40				∞
	7	7	7.5W	8W	25 up	(c)	No spin							
	8	7	7.5W	0	0	(d)	No spin							
	9	7	7.5W	8W	0	(d)	No spin							
72.5° wing sweep														
	[a]10	8	7.5W	8A	25 up	[b]30 120	65U 60D	≈140	≈459	0.23	7.5A	8W	----	∞
						(d)	No spin							
	[a]11	8	7.5W	0	25 up	[b]52 113	42U 63D	≈140	≈459	0.32	7.5A	8W	----	3, 3½
						(d)	No spin							
	[a]12	8	7.5W	8A	0	[b]47 108	67U 77D	≈140	≈459	0.36	7.5A	8W	25 U	6, 8
						(d)	No spin							

[a]Two conditions possible.
[b]Oscillatory spin. Range or average of values given.
[c]Rotational rate decreases until model enters a glide.
[d]Oscillates in pitch and roll, then rolls or pitches into an erect or inverted dive.

TABLE IV.- SPIN AND RECOVERY TEST RESULTS OF ASYMMETRIC LOADING CONDITIONS OF THE 1/40-SCALE MODEL OF THE F-111A AIRPLANE

[Right erect spins
Control settings for spin: rudder full with, elevator neutral, and ailerons full against
Control settings for recovery attempt: rudder full against, elevator full up, and ailerons full with
Model values converted to corresponding full-scale values
Values for ϕ given as U (inner wing up) and D (inner wing down)]

(a) 26° wing sweep

Loading condition		Spin block	Asymmetric moment, m-N (ft-lb)	Developed spin characteristics				Turns for recovery
				α, deg	ϕ, deg	V, m/sec (ft/sec)	Ω, rev/sec	
	All stores on		0	[a]70 90	5U 7D	≈140 (459)	0.27	∞
				[a]37 117	16U 28D	≈125 (409)	0.33	∞
	3661 N (823 lb) off inboard wing		17 036 (12 565)	[a]69 87	6U 5D	122 (401)	0.38	∞
				[a]47 110	25U 24D	≈137 (450)	0.38	∞
	7322 N (1646 lb) off inboard wing		27 679 (20 415)	81	0	122 (401)	0.37	∞
				[a]54 115	19U 21D	132 (433)	0.40	∞
	10 983 N (2469 lb) off inboard wing		55 295 (40 784)	77	1U	118 (386)	0.38	∞
				[a]45 115	28U 25D	≈129 (424)	0.38	∞
	14 643 N (3292 lb) off inboard wing		77 656 (57 277)	78	1U	115 (376)	0.39	∞
				[a]39 123	29U 25D	≈160 (524)	0.39	∞
	18 304 N (4115 lb) off inboard wing		105 272 (77 646)	77	3U	112 (363)	0.41	∞

[a]Oscillatory spin. Range or average of values given.

TABLE IV.- SPIN AND RECOVERY TEST RESULTS OF ASYMMETRIC LOADING CONDITIONS OF THE 1/40-SCALE MODEL OF THE F-111A AIRPLANE – Concluded

[Right erect spins
Control settings for spin: rudder full with, elevator neutral, and ailerons full against
Control settings for recovery attempt: rudder full against, elevator full up, and ailerons full with
Model values converted to corresponding full-scale values
Values for ϕ given as U (inner wing up) and D (inner wing down)]

(b) 50° wing sweep

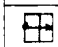
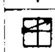
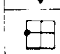
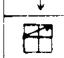
Loading condition	Spin block	Asymmetric moment, m-N (ft-lb)	Spin characteristics				Turns for recovery
			α, deg	ϕ, deg	V, m/sec (ft/sec)	Ω, rev/sec	
All stores on		0	80	1D	107 (350)	0.36	$4\frac{1}{2}$, ∞
3661 N (823 lb) off inboard wing		9 411 (6 941)	81	1D	105 (345)	0.36	3, ∞
7322 N (1646 lb) off inboard wing		18 820 (13 881)	80	3U	105 (345)	0.40	∞
10 983 N (2469 lb) off inboard wing		28 312 (20 882)	85	2U	105 (345)	0.48	∞
18 304 N (4115 lb) off inboard wing		57 186 (42 179)	86	5U	102 (355)	0.52	∞

(c) 72.5° wing sweep

Loading condition	Spin block	Asymmetric moment, m-N (ft-lb)	Spin characteristics				Turns for recovery
			α, deg	ϕ, deg	V, m/sec (ft/sec)	Ω, rev/sec	
All stores on		0	47 108	67U 77D	≈140 (459)	0.36	6, 8
10 983 N (2469 lb) off inboard wing		29 429 (21 706)	61 110	48U 42D	≈140 (459)	0.33	4, 5, 6
21 965 N (4938 lb) off inboard wing		58 858 (43 412)	85	16U 20D	107 (350)	0.40	4, 6, $7\frac{1}{2}$
29 287 N (6584 lb) off inboard wing		80 505 (59 378)	85	7U 9D	104 (340)	0.51	7, ∞

TABLE V.- EFFECTS OF SUPPLEMENTARY DEVICES ON THE SPIN AND SPIN-RECOVERY CHARACTERISTICS OF THE 1/40-SCALE MODEL

[Values given as: A (against), W (with), U (inner wing up), and D (inner wing down). (Recoveries are attempted as indicated.)]

Spin block	Test	Loading	Wing-sweep angle, deg	Supplementary fixed device	Control positions for spin			Spin characteristics					Control movements for recovery			Supplementary deployable device	Turns for recovery
					Rudder, deg	Aileron, deg	Elevator, deg	α, deg	φ, deg	V, m/sec	V, ft/sec	Ω, rev/sec	Rudder, deg	Aileron, deg	Elevator, deg		
	1	10	50		7.5W	8A	0	85	3U	105	345	0.35	7.5A	8W	0		∞
	2	10	50		7.5W	8A	0	85	3U	105	345	0.35	7.5A	16W	0	Aileron travel increased to ±16°	4, 4½, 4¾, 5
	3	10	50		7.5W	8A	0	85	3U	105	345	0.35	7.5A	20W	0	Aileron travel increased to ±20°	1¾, 2¼, 2½, 3, 3
	4	10	50		7.5W	8A	0	85	3U	105	345	0.35	7.5A	24W	0	Aileron travel increased to ±24°	2, 2¼, 3, 3½
	5	10	50		7.5W	8A	0	84	3U	105	345	0.38	7.5A	8W	25 up		3¼, 3½, 4, ∞
	6	10	50		7.5W	8A	0	84	3U	105	345	0.38	7.5A	16W	25 up	Aileron travel increased to ±16°	2½, 2¾, 3, 3¼
	7	10	50		7.5W	8A	0	84	3U	105	345	0.35	7.5A	20W	25 up	Aileron travel increased to ±20°	2, 2½, 2½
	8	10	50	Strake A (see fig. 3)	7.5W	8A	0	81	3U	90	295	0.36	7.5A	8W	25 up		1, 1½, 1½, 1¾
	9	10	50	Strake B (see fig. 3)	7.5W	8A	0	81	3U	88	290	0.35	7.5A	8W	25 up		1½, 1¾, 1¾, 2
	10	10	50	Strake C (see fig. 3)	7.5W	8A	0	81	3U	88	290	0.36	7.5A	8W	25 up		2, 2¼, 2½, 2½
	11	10	50	Strake D (see fig. 3)	7.5W	8A	0	82	2U	88	290	0.37	7.5A	8W	25 up		2, 2¼, 2½, 2½
	12	10	50	Strake E (see fig. 3)	7.5W	8A	0	82	2U	88	290	0.36	7.5A	8W	25 up		1¾, 2¼, 2½
	13	10	50	Strake F (see fig. 3)	7.5W	8A	0	82	2U	88	290	0.34	7.5A	8W	25 up		1¾, 1¾, 2, 2, 2¼
	14	10	50		7.5W	8A	0	80	2U	88	290	0.36	7.5A	8W	25 up	Canard (see fig. 4) on both sides of nose	4¼, 5¼
	15	10	50		7.5W	8A	0	80	2U	88	290	0.36	7.5A	8W	25 up	Canard (see fig. 4) on antispin side of nose	2, 2, 2, 2, 2
	16	10	50		7.5W	8A	0	83	0	88	290	0.37	----	---	----	7.01-m (23-ft) wing-tip parachute (see fig. 5)	1¼, 2
	17	10	50		7.5W	8A	0	83	0	88	290	0.37	----	---	----	5.79-m (19-ft) wing-tip parachute (see fig. 5)	2, 2¾, 4¼
	18	9	26		7.5W	8A	0	78	2U	98	322	0.32	7.5A	8W	25 up		2¼, 2¾, 3, >3¼
	19	9	26		7.5W	8A	0	78	2U	98	322	0.32	7.5A	8W	45 up	Elevator travel increased to 45° up	7, 7¾
	20	9	26		7.5W	8A	0	78	2U	98	322	0.32	7.5A	8W	25 up	Leading-edge flaps deflected 25° down (hinge line at 10% chord)	7
	21	9	26		7.5W	8A	0	78	2U	98	322	0.32	7.5A	8W	25 up	3.048-m (10-ft) nose radome section jettisoned	>4, >5
	a22	9	26		5W	3A	17 up	67 85	30U 30D	95	311	0.20	5A	5W	17 up		∞
	a23	9	26		5W	3A	17 up	67 85	30U 30D	95	311	0.20	5A	16W	17 up	Aileron travel increased to ±16°	1, 1¼, 2, 2, 2
	a24	9	26		5W	3A	17 up	67 85	30U 30D	95	311	0.20	5A	5W	17 up	Landing drag parachute	1½, 3, ∞
	a25	9	26		5W	3A	17 up	67 85	30U 30D	95	311	0.20	5A	16W	17 up	Landing drag parachute and aileron travel increased to ±16°	1½, >4½
	a26	9	26		5W	3A	17 up	67 85	30U 30D	95	311	0.20	5A	25W	17 up	Landing drag parachute and aileron travel increased to ±25°	1, >3½, 6

aOscillatory spin. Range or average of values given.

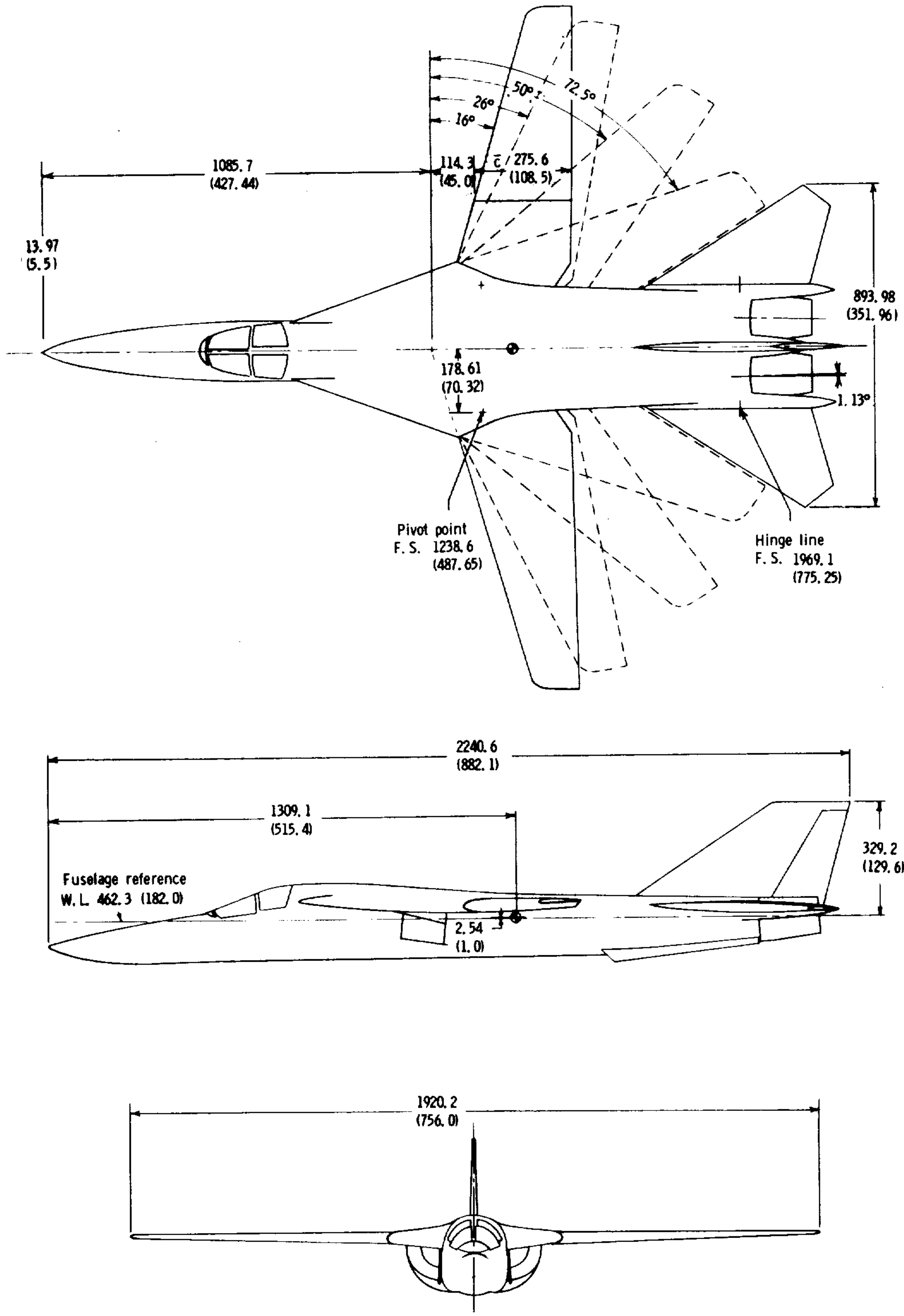
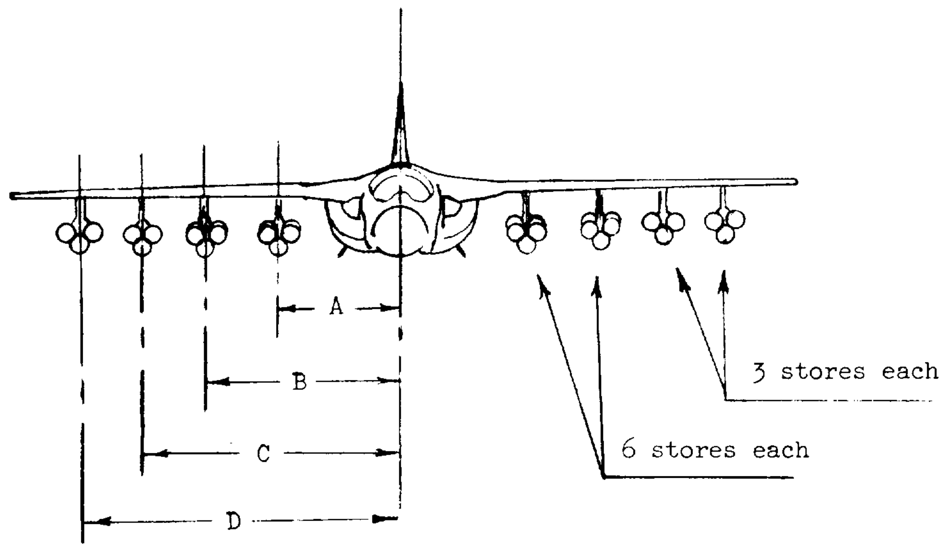


Figure 1.- Three-view drawing of F-111A airplane showing wing-sweep angles used in investigation. Center of gravity shown is for 39.5 percent mean aerodynamic chord. Dimensions are in centimeters (inches). F.S. denotes fuselage station; W.L., water line.



Wing sweep deg	A cm (in.)	B cm (in.)	C cm (in.)	D cm (in.)
26	291.08 (114.6)	465.33 (183.2)	610.87 (240.5)	754.38 (297.0)
50	257.05 (101.2)	395.48 (155.7)		
72.5	212.6 (83.7)	295.66 (116.4)		

Figure 2.- Front-view drawing showing positions of stores. Each store is 3661 N (823 lb).

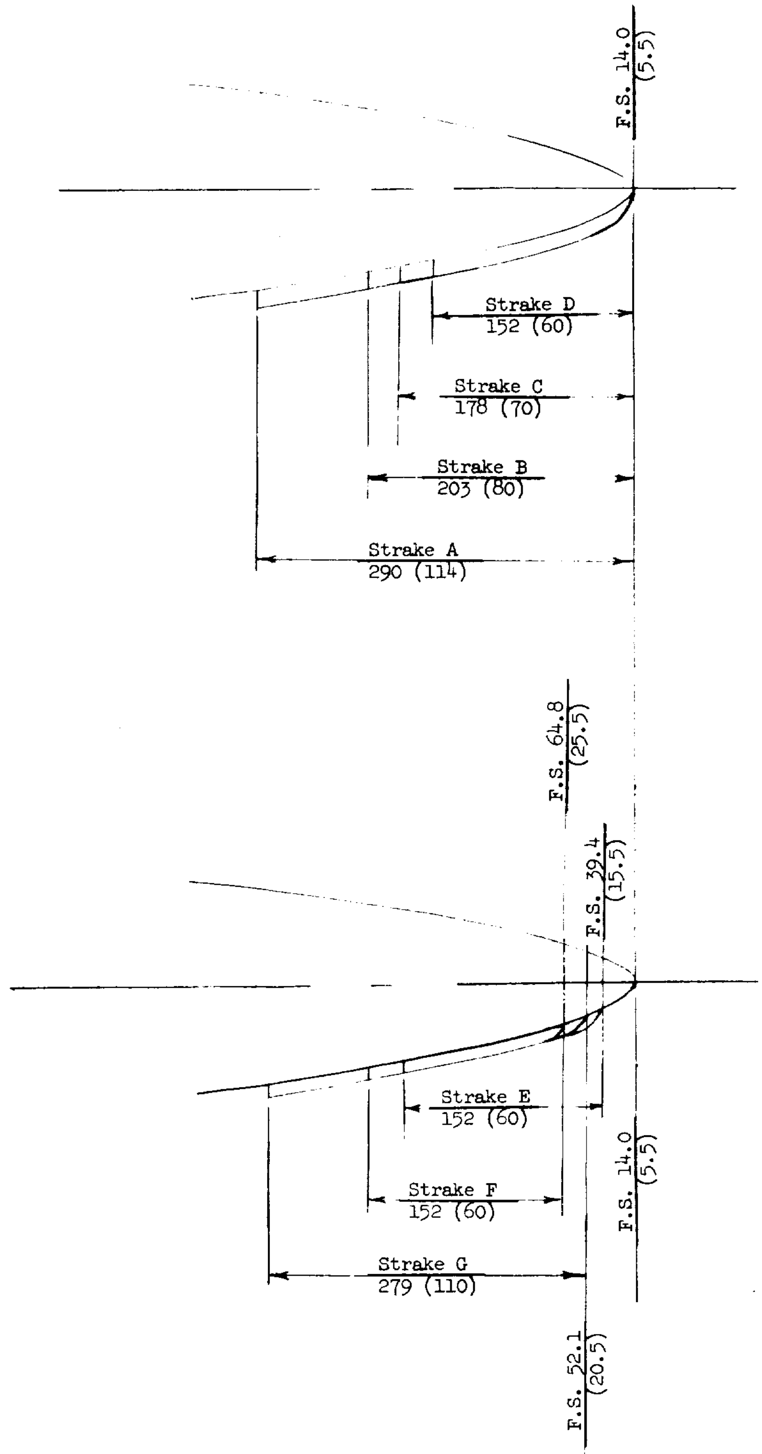


Figure 3.- Top-view drawing of nose of F-111A airplane showing asymmetric strake configurations used in investigation. Strakes are 12.7 cm (5.0 in.) wide and 1.27 cm (0.50 in.) thick. Dimensions are in centimeters (inches).

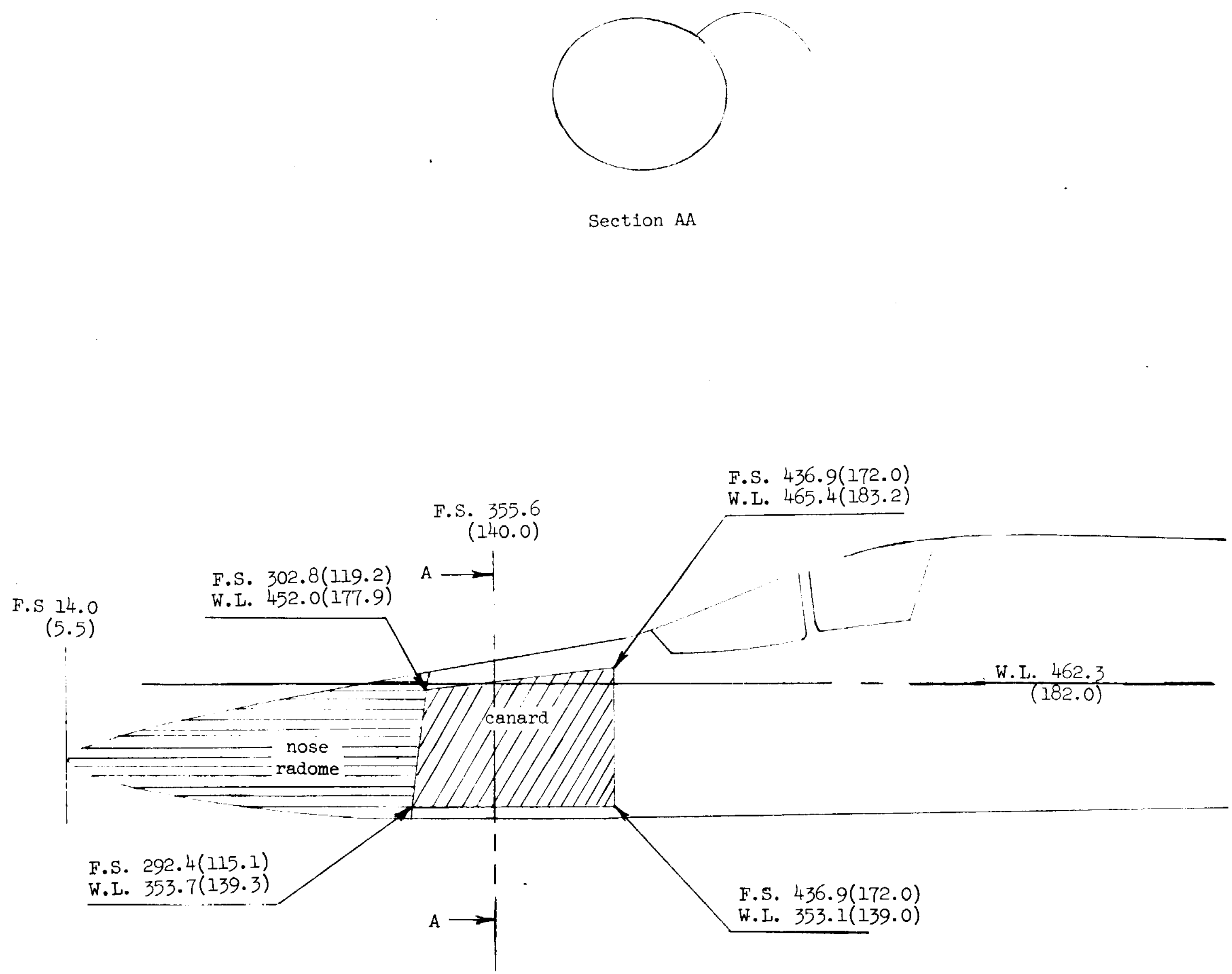


Figure 4.- Side-view drawing of the nose of the F-111A airplane showing the locations of the nose radome and the canard (electronic bay door), and a cross-sectional view of the nose showing the opened canard. Dimensions are in centimeters (inches). F.S. denotes fuslage station; W.L., water line.

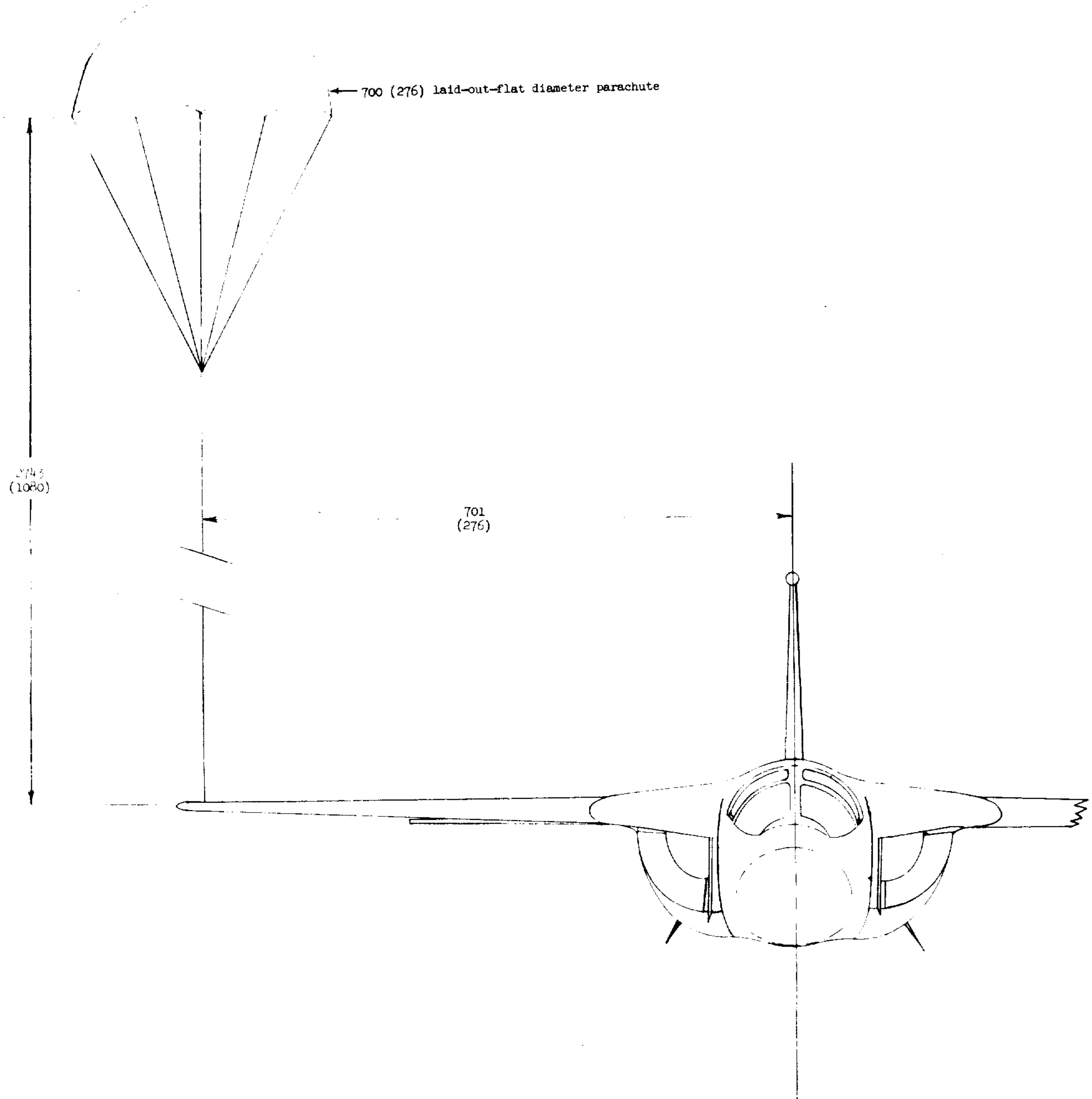
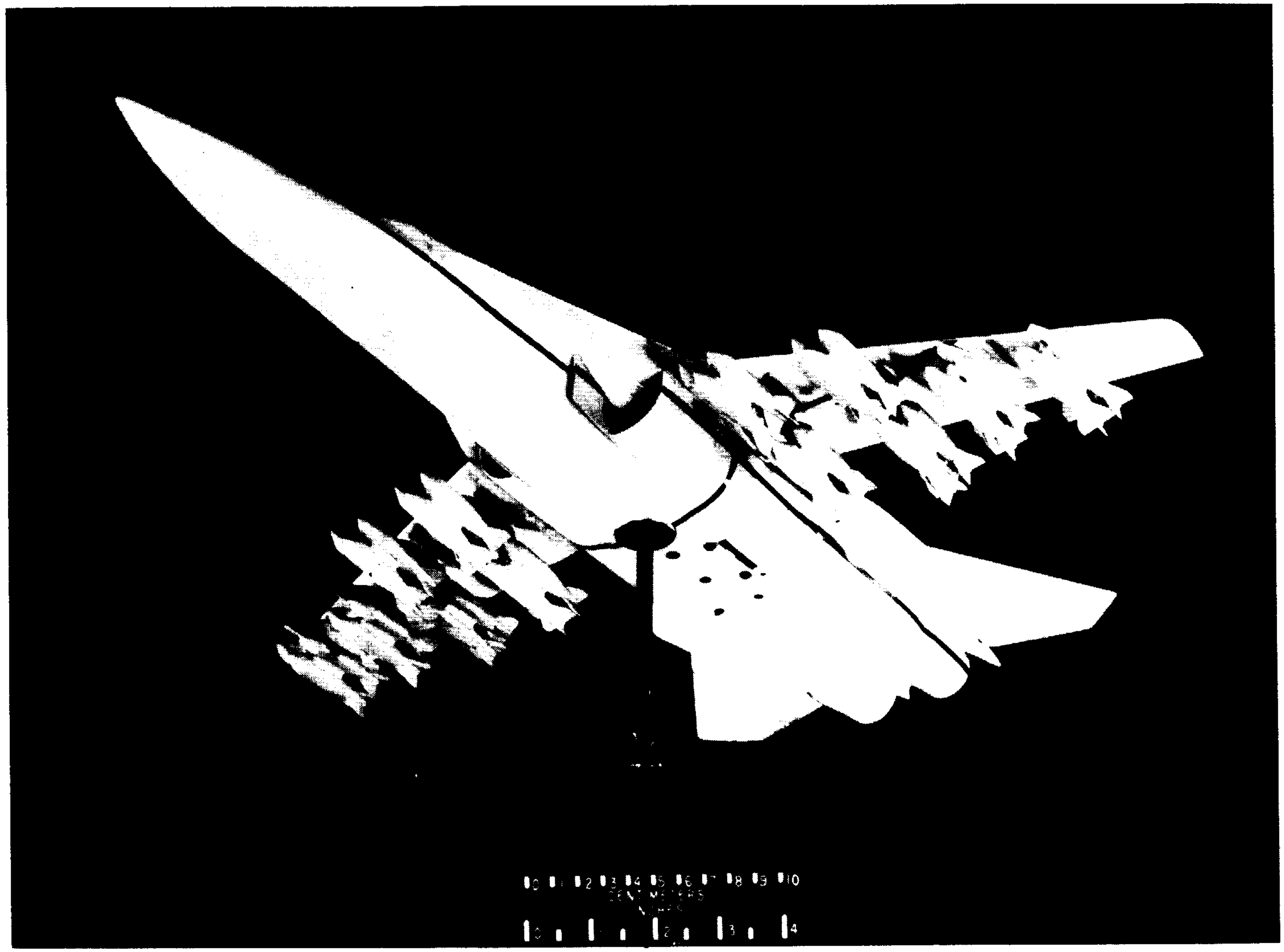


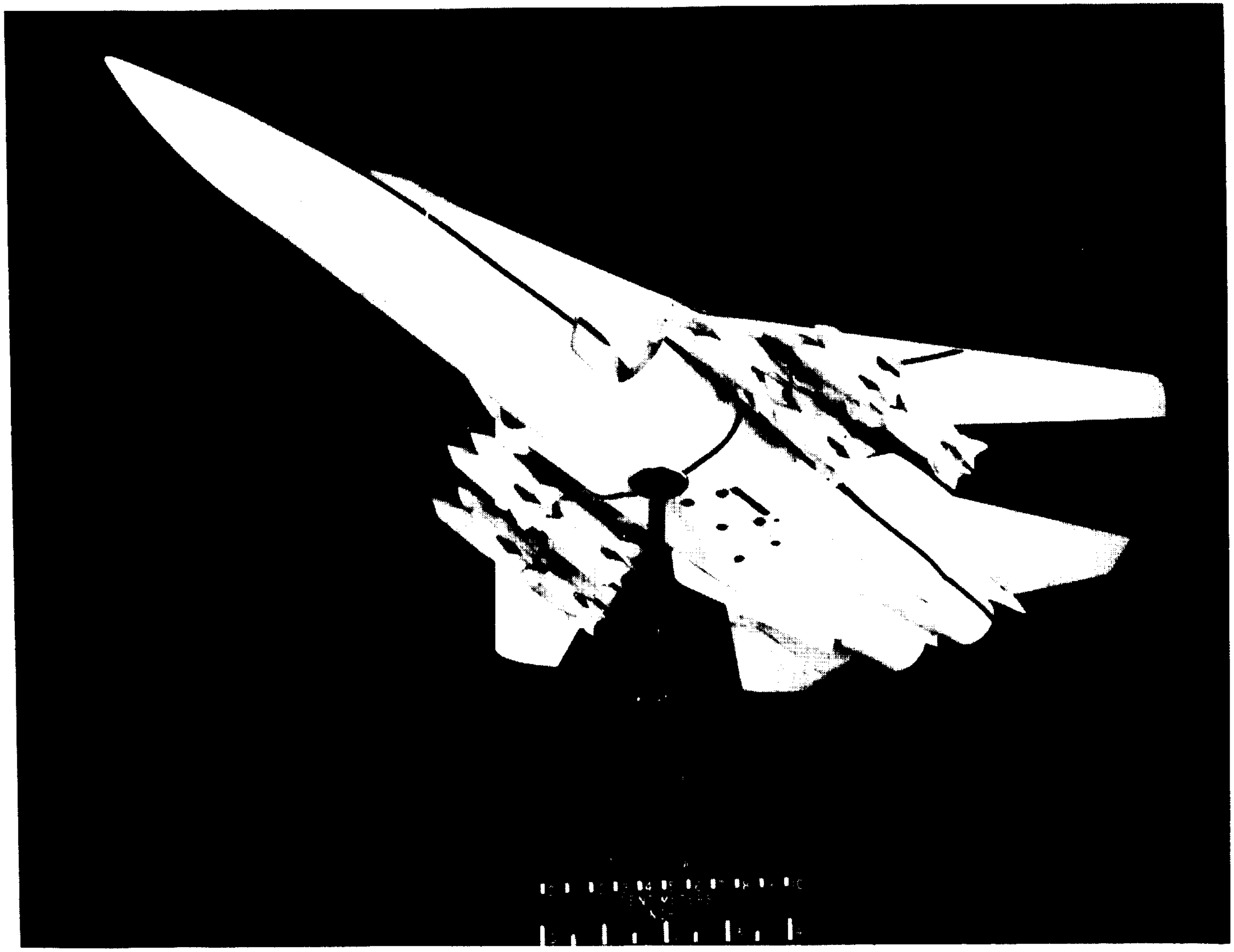
Figure 5.- Front-view drawing of the F-111A airplane in the 50° wing-sweep configuration showing the wing-tip parachute. Dimensions are in centimeters (inches).



L-69-1839

(a) 26° wing sweep.

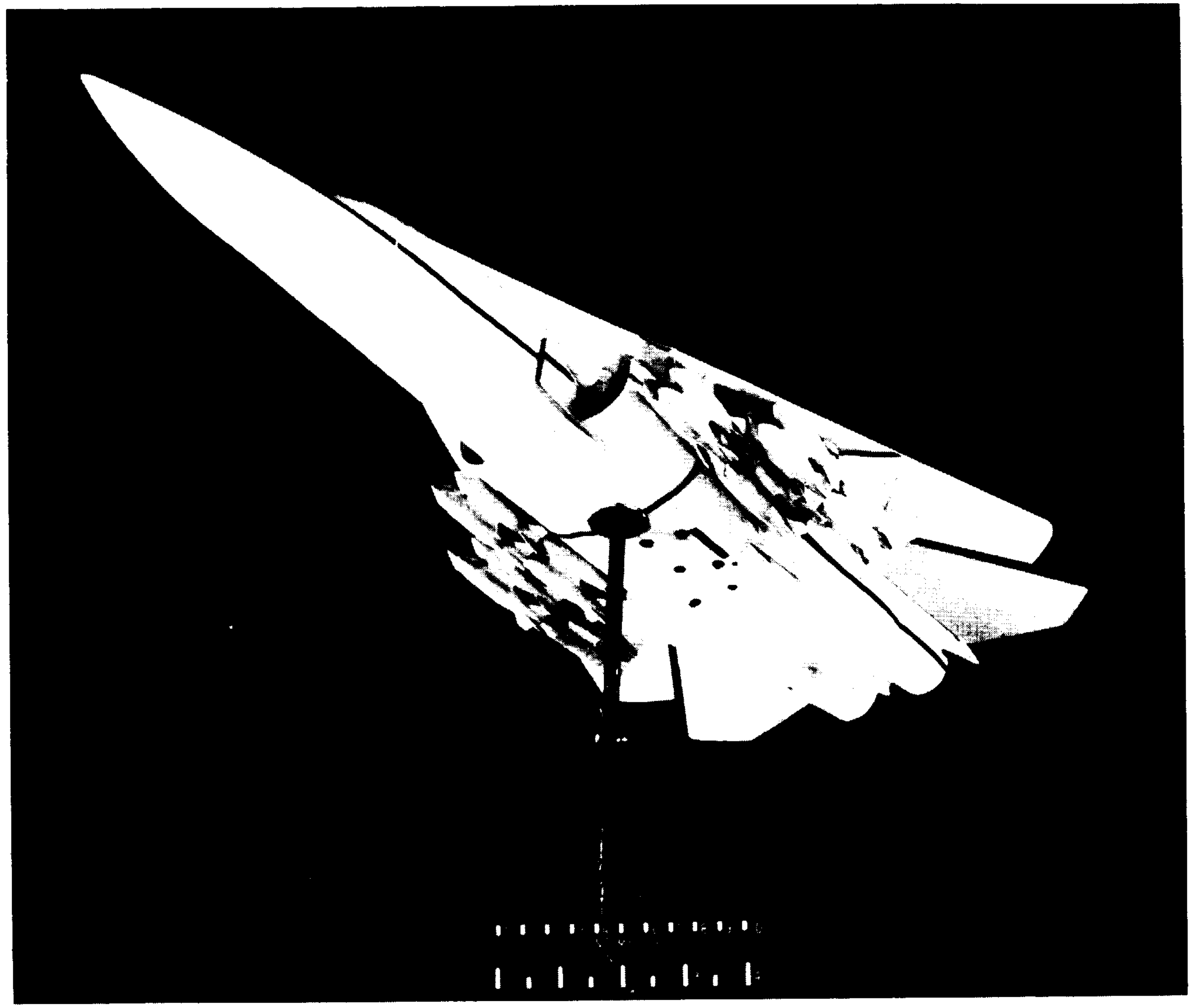
Figure 6.- Photograph of model of F-111A airplane showing stores configuration at various sweep angles.



L-69-1835

(b) 50° wing sweep.

Figure 6.- Continued.



L-69-1833

(c) 72.5° wing sweep.

Figure 6.- Concluded.