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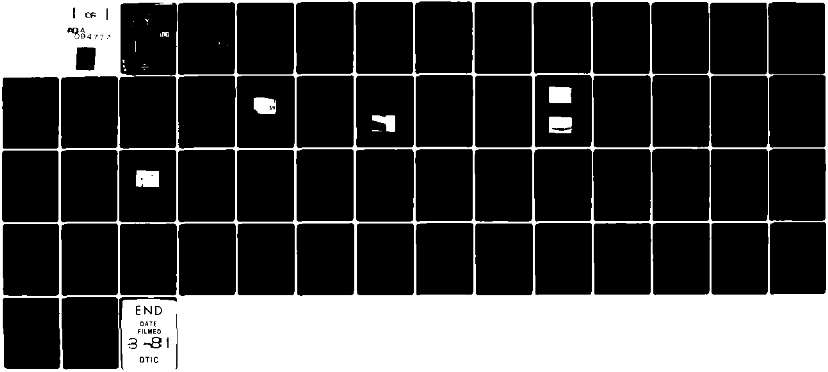

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LEVEL II

SCHOOL OF ENGINEERING

WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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VALIDATION OF THE WRIGHT-PATTERSON VERTICAL WIND TUNNEL.

THESIS

AFIT/GAE/AA/80D-10

James W. Hickman
Major USAF

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AFIT/GAE/AA/80D-10

VALIDATION OF THE WRIGHT-PATTERSON VERTICAL WIND TUNNEL

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

by
James W. Hickman, B.S.
Major USAF
December 1980

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AFIT/GAE/AA/80D-10

Preface

This study represents my attempt to duplicate spin results obtained at the NASA-Langley vertical wind tunnel by using one of their models in the Wright-Patterson vertical wind tunnel. The tests consisted of evaluating the model in the same configurations that were originally accomplished by the NASA. The results were then compared to the original results obtained at the Langley tunnel.

I extend my thanks to my thesis advisor Dr. Robert A. Calico of the Air Force Institute of Technology faculty for his direction in organizing the objectives of this study. Also, I wish to thank Capt. Jim Silverthron and Capt. Roie Black for their support as thesis committee members.

My special thanks also goes to the Air Force Flight Dynamics Lab and to Mr. William Bennett and Mr. Donald Sine at the Wright-Patterson vertical wind tunnel for their untiring help during the test period.

Most of all, I extend a loving thank you to my wife, Patsy, who did more to keep me on the right track during this period than words can express.

James W. Hickman

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List of Symbols

a	speed of sound
F_m	force acting on model
F_p	force acting on prototype
Fr	Froude number
g	acceleration of gravity
l	length
M	Mach number
Re	Reynolds number
V	velocity
α	angle of attack
ϕ	angle between Y axis of airplane and horizontal (roll angle)
ρ	density
μ	viscosity

Abstract

A spin capability evaluation of the Wright-Patterson vertical wind tunnel was completed using a model of the Bell X-5. The X-5 model was previously spin tested in the NASA vertical wind tunnel at Langley AFB, Va. The study compared results obtained at the NASA-Langley vertical wind tunnel with the test results obtained at the Wright-Patterson vertical wind tunnel. The Langley results were used as the basis for this evaluation. Information was available on spin characteristics of the model with respect to various control surface configurations and recovery attempts using control deflections. The spin tests revealed a stable equilibrium spin and recovery, where applicable, could be established and observed for each corresponding stable equilibrium spin and recovery that was observed at Langley.

VALIDATION OF VERTICAL WIND TUNNEL
FOR SPIN TESTING

I. Introduction

Purpose

The spin maneuver has plagued both military and civil avaiation with numerous loss of aircraft and lives since the birth of powered flight. Spins usually result when the aircraft is flown at a high angle of attack approaching a stalled condition or at a high angle of attack in turning flight. This condition may be inadvertently entered during the various phases of flight from the traffic pattern to the complicated maneuvers encountered during combat by modern jet fighters. The characteristics of a spin are the angle of attack exceeding the stall accompanied by a high yaw rate. Autorotation and sideslip are combined with the downward motion in a spin. If a steady spin is established, the actual path is a vertical spiral. The axis of this spiral is termed the axis of spin. The axis of rotation is fixed to the aircraft and moves about the axis of spin at some fixed distance. (Fig. 1) Since lift is perpendicular to the relative wind it is horizontal and balances the centrifugal force. Drag is vertically upward and opposes the effect of weight. (Ref. 1) Since a spinning motion can cause and often results in the sudden disorientation of the pilot and delays the initiation of recovery procedures, it

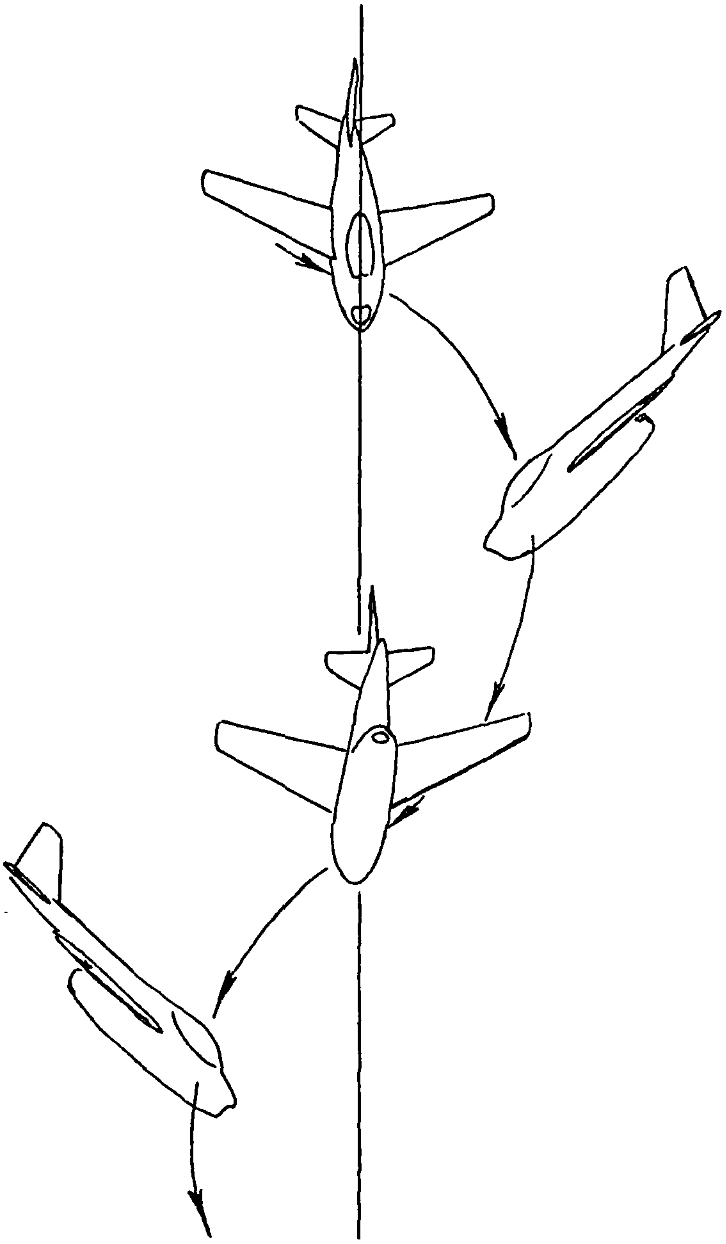

Fig. 1 Spin Profile Representation

becomes more important that we understand and develop methods to return the aircraft to a normal flight condition. This is especially important for the modern jet fighter which inherently has a high rate of descent during a spin. The purpose of this study is not to evaluate the spin characteristics of a particular aircraft but rather to provide a valid tool that is readily available and may be used to evaluate the spin characteristics of state-of-the-art aircraft designs. Therefore, the purpose for the study was to evaluate, validate and operate the Flight Dynamics Lab vertical wind tunnel for spin testing of aircraft.

Test results obtained from a vertical wind tunnel provide valuable information concerning spin susceptibility of aircraft and recovery techniques from the special kind of flight motion known as the spin phenomenon. It is interesting to note, as Melvin N. Gough points out in the AGARD Report 27, February 1956, that the spin tunnel had never missed in predicting the optimum control technique for recovery up to that time. The spin phenomenon occurs where the angle of attack becomes greater than that for maximum lift and flow separation begins. If, at the stalling speed, there is a rolling instability where one wing drops and a form of auto-rotation takes place, the aircraft enters a spin. This spin is in the downward direction and may involve a steep or flat spiral accompanied with violent rotations. The angle of attack ranges between 30 and 40 degrees for a steep spin and in the neighborhood of 60 degrees for a flat spin. The equations used for longitudinal equilibrium do not reveal a reason for this motion except when one considers the gyroscopic effect caused by the moments of inertia of the aircraft about the longitudinal and normal axis. Therefore, these moments of inertia are quite important with respect to the spin phenomenon. The fact that the spin is considered to be significant is primarily because it is a motion which can be entered inadvertently. Also, both fighter and trainer aircraft must demonstrate the ability to satisfactorily terminate a developed spin. It has been found that in certain cases the control surfaces may be quite adequate for normal flight conditions, but fall short of the effectiveness required for recovery from a spin.

Background

Currently, the Wright-Patterson vertical tunnel had not been used to observe and evaluate the spin characteristics of aircraft for several years. The primary reason for this lack of use for spin evaluations has been due to the fact that the greater amount of spin testing has been concentrated at Langley. This left the testing at the Wright-Patterson facility to become less directed at study of the spin phenomenon and more diversified in other areas where a vertical flow field is required. The tunnel has been well maintained and improvements incorporated to keep the facility as up to date as possible.

In recent years there have been many advancements in the design of forward swept wing aircraft. At the present time, the forward swept wing fighter is undergoing study at Wright-Patterson. The availability of the vertical wind tunnel should not be overlooked in the evaluation of this new generation of fighter aircraft since we have very little information available on the spin characteristics of forward swept wing aircraft.

II. Facility

The U.S. Air Force Flight Dynamics Lab 12 Foot Vertical Wind Tunnel is an atmospheric pressure, open jet tunnel without provisions for varying pressure, temperature, density, or viscosity of the air. Construction was begun in 1943 and the tunnel was put into full operation in 1945. It is driven by one 16 foot diameter, 4 bladed, controllable pitch fan with laminated maple blades. The fan is powered by a 1000 horsepower DC motor and has a maximum speed of 875 RPM. The test section shape is a 16 sided polygon which gives a test section dimension of an inscribed circle of 12 feet in diameter. The height of the test section is fifteen feet. Details of the Wright-Patterson vertical wind tunnel are shown in Appendix A.

It is possible to vary the velocity in the test section from approximately 0 fps to 150 fps. Parachute performance tests, model spinning and spin recovery tests, tests of free falling bodies, and rotary wing model tests are some of the tests accomplished in the vertical tunnel. Data is recorded by the use of 16mm motion picture cameras. The tunnel is equipped to give the operator a velocity read-out in feet per second, miles per hour and inches of water. There are two counters shown in (Fig. 2) mounted on the wall of the tunnel, one opposite the operator and one for the recording camera, that gives the run number

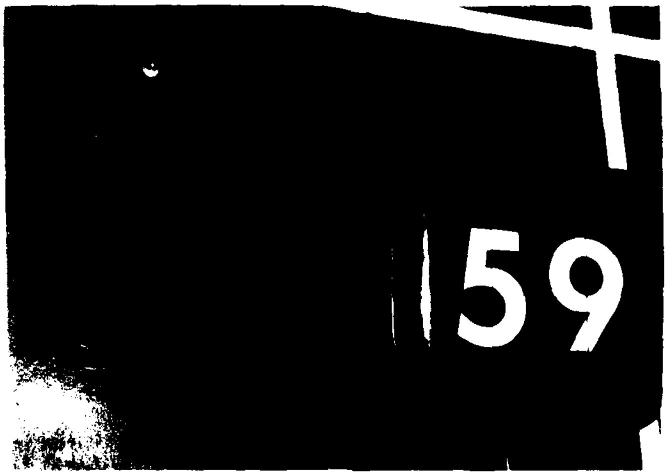

Fig. 2 Run Number Counter

that is being accomplished. A vertical net surrounds the test section to prevent model damage during test runs. The net is constructed of nylon and is dyed black to reduce any glare that would interfere with filming. There are three "windows", located approximately 120° apart, that provide access to the test section. At the base of the net there are 16 hinged boards (flapper boards) which are used to deflect the flow in the test section and thereby control the position of the model (Fig. 3 shows each of these components). The flapper boards are plywood panels that are mounted on hinges and attached on the perimeter of the test section at floor level. The boards are manually operated and may be used one at a time or in any combination that is required. Surrounding the entire test section is safety railing for the protection of observers that may be near the net during operation. One section of the railing was removed to provide easy access for the person making the launch. Normally three people are required to accomplish a spin test. This includes one for speed adjustment, one for photography, and one to launch the model. It is helpful if one or two additional people are available to assist in operation of the flapper boards.

A Gauss belt, made of 1/2 inch cooper tubing consisting of 12 turns, surrounds the test section. (Fig. 4 shows a close-up of Gauss belt). When energized, it sets up a strong magnetic field inside the test section. The magnetic field thus created is used to change the control setting of the model.

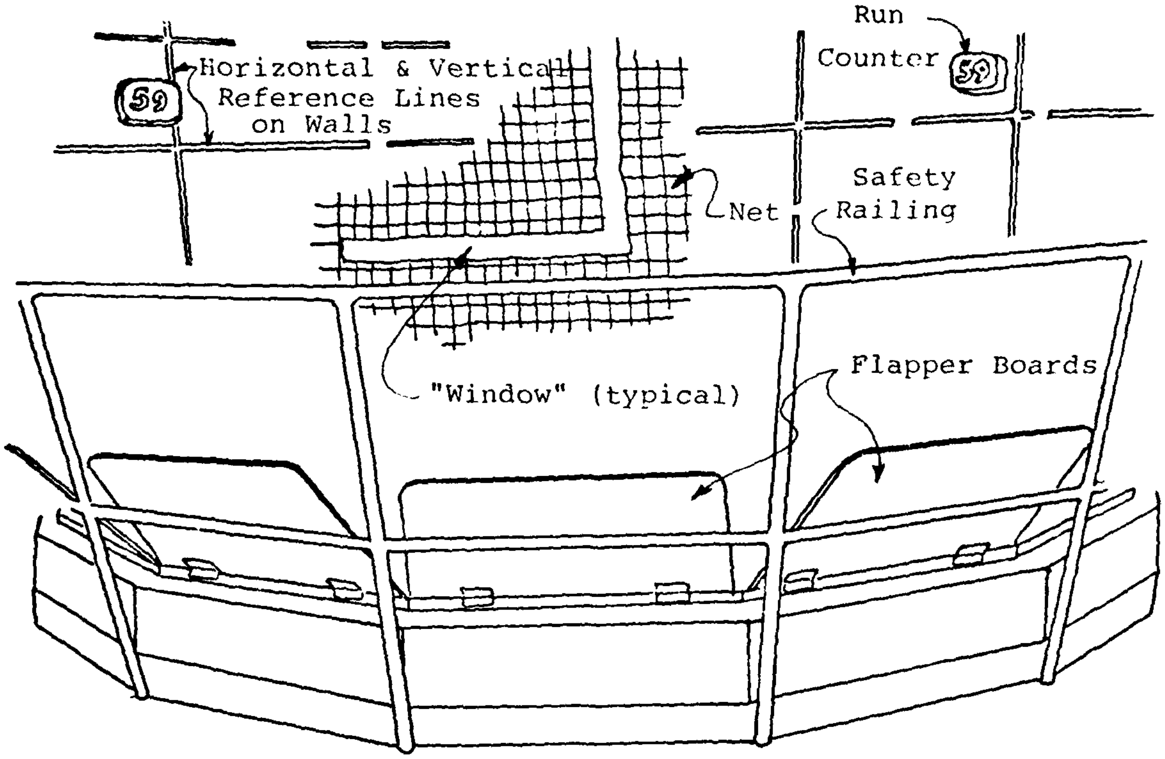

Fig. 3 View of Test Section

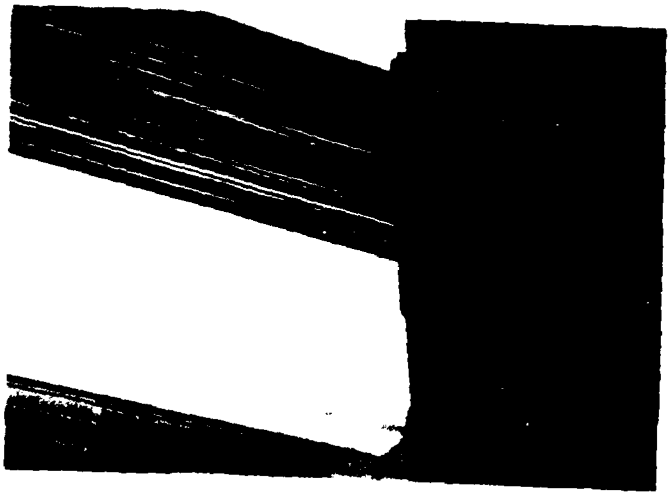

Fig. 4 Close-up View of Gauss Belt

III. Evaluating the Tunnel

Evaluation of the tunnel began with the examination of the flow in the test section. This was accomplished with a rake consisting of 24 pitot tubes spaced 6 inches apart to cover the overall width of the test section. The rake and probe positions and their coverage are shown in Appendix E. The data was recorded on tape and is on file at the Flight Dynamics Laboratory. A profile of the initial flow is shown in Fig. 5. It was decided alter the flow profile by adding a flow restricting screen on top of the flow straightening section located below the test section. This screen acts to slow down the flow in the center of the test section out to approximately 18 inches from the edge. Fig. 6 shows a typical flow profile after the installation of the screen and the dish that is created to keep the model in the center of the test section. The screen installation is shown in Fig. 7. Spin tunnels have a saucer-shaped velocity gradient in the test section where the centerline velocity is approximately 5 to 10 per cent lower than at the edge which tends to center the spinning model. (Ref. 2) In order to prevent the model from inadvertantly leaving the test section, a net was installed to surround the test section from floor level to the top of the test section. The net also provides protection to observers that may be standing near the test area since the model direction is unpredictable when it is not in a stable spin. The net proved to be a worthy investment

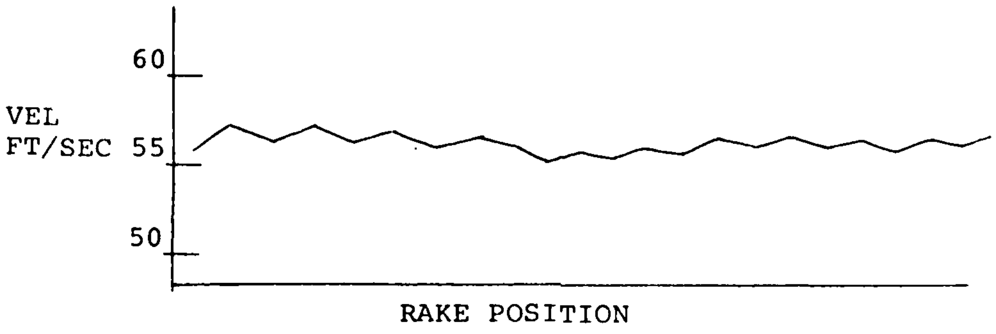

Fig. 5 Profile of Initial Flow (Typical)

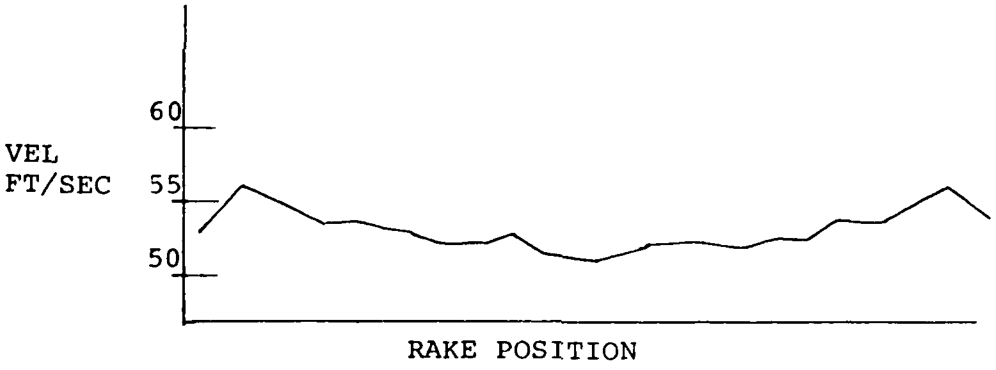

Fig. 6 Flow Profile after Screen Installation (Typical)

Fig. 7 Screen Installation

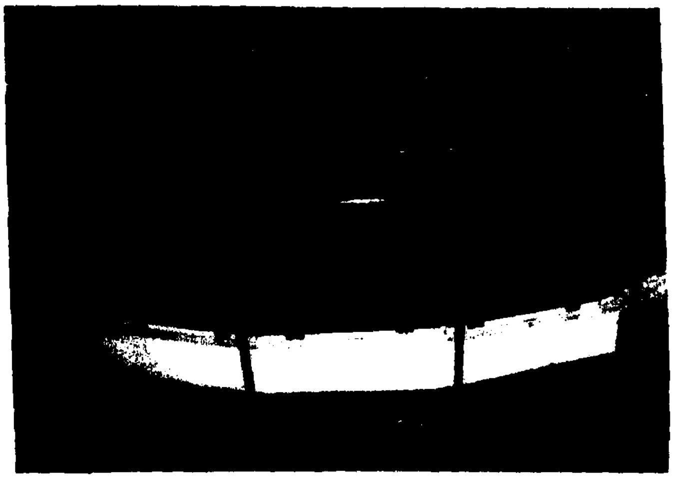

Fig. 8 Net Surrounding Test Section

during the test runs. Fig. 8 shows the position of the net.

A secondary method to position the model in the flow was the installation of flapper boards around the perimeter of the section at floor level. These boards are normally positioned like the petals of a flower (opened from the center of the test area) and are used to reposition the model while it is in spinning flight. If the model drifts toward the net, a board or combination of boards may be deflected toward thus creating a jet of air that, in effect, pushes the model away from the net and back into the center of the test section. The boards are very effective when the model is at eye level or below. When the model is above eye level, the model becomes very sensitive to the deflection of the boards and their movement must be gentle. If the movement of the boards is too rapid when the model is above eye level, the induced turbulence will tend to "dump" the model from the spinning condition and it must be relaunched.

IV. Modeling Laws

In order to establish dynamic similarity of a model and its full scale counterpart, the dimensionless quantities Reynolds number, $\rho \frac{Vl}{\mu}$, Froude number, $\frac{V}{\sqrt{gl}}$, and Mach number, $\frac{V}{a}$, must be the same in the model test and full scale flight. If a model test is to be performed using the same fluid at the same conditions (temperature, density, viscosity) as full scale, it is only possible to make one of the three numbers equal to the full scale value for the model test. It sometimes is in the model than is the prototype. If more than two importance parameters (Re,M, Fr) are involved, the construction of a proper model is not usually feasible. (Ref. 3)

For an aircraft that is in a spin condition, the predominant forces that it experiences are the inertia and gravity forces. Since the basic requirement for dynamic similarity is that the force which act on corresponding masses in the model and prototype be in the same ratio ($\frac{Fm}{Fp}$ = constant) throughout the entire flow field. The forces acting on the fluid elements will thus control the motion of these elements, and it follows that dynamic similarity will yield similarity of flow patterns. Consequently, the flow patterns will be the same in the model as in the prototype if geometric similarity is satisfied and if the relative forces acting on the fluid are the same in the model as in the prototype. Thus, the Froude number in the model must be equal to the Froude number in the prototype. (Ref. 4) Since the wing is in a stalled condition during spinning flight, the Reynolds number becomes relatively unimportant. Also, we should note that since the velocities involved are small, the Mach number becomes insignificant and can be neglected. By making the test Froude number equal to the full scale flight Froude number, the ratio of the inertia forces to gravity forces for the model test and full scale flight will be equal. The models needed for spin testing must be similar to the full scale aircraft both dynamically as well as geometrically. Therefore the dimensions, mass and moments of inertia must be correctly reproduced. (Ref. 5)

V. Evaluation of Model

Description

The model made available for the tunnel evaluation was the Bell X-5. Although the X-5 was a variable sweep aircraft, the model used had the wings fixed at a sweep angle of 45^{0} (This was one of the many X-5 models used during the original spin tunnel testing of the X-5). The model has a wing span of 15 inches and a length of 19 3/4 inches. This is a suggested size for future models to be used for spin evaluation in the Wright-Patterson vertical tunnel. The spin model span should be less than one-fifth that of the test section. (Ref. 2) Therefore, the tunnel should support a model with a wing span of up to 2.4 feet. If the spin model size is 1/n full scale, the other scaling should be as follows for the condition of equal Froude number. (Ref. 2)

Parameter	Dimension	Model/Full Scale
Length	L	1/n
Mass	M	$1/n^3$
Time	T	$1/\sqrt{n}$
Linear velocity	L/T	$1/\sqrt{n}$
Angular velocity	1/T	$\sqrt{n}$
Moment of Inertia	L^2	$1/n^5$

A sample computation for the F-4 would be the following:

Given: $Ix_m = 25001$ slug-ft^2

$Iy = 122186$ slug-ft^2 Full Scale

$Iz = 139759$ slug-ft^2

If the model scale is 1/29, then $1/n^5 = 1/20511149$. Use this to multiply each of the moments of inertia which gives the following for the model:

$$Ix_m = 4.29528 \times 10^{-4} \text{ slug ft}^2 = .061852 \text{ slug-in}^2$$

$$Iy_m = 2.0992 \times 10^{-3} \text{ slug ft}^2 = .3022848 \text{ slug-in}^2$$

$$Iz_m = 2.40112 \times 10^{-3} \text{ slug ft}^2 = .3457612 \text{ slug-in}^2$$

Construction of the X-5 model consisted of balsa-filled fiberglass wings and tail surfaces with a fiberglass shell for the fuselage. A fine cut was made around the canopy, including a small area of the fuselage, to provide access to the actuator that deflects the control surfaces. Each control surface is held in place by a single piece of cord that is attached to the actuator. When the actuator is released small rubber bands, attached to each control surface, deflect the surface to the opposite setting. When the control surface is released by the actuator, a small flag on a short (4 to 6 inches) piece of string is released into the slipstream. This provides the means by which timing for the spin recovery attempt is recorded on film or video tape. (The canopy is simply held in place by the use of celephane tape on either side. The tape provides easy access to the actuator in order that it may be reset for subsequent runs.) The actuator consists of a permament bar magnet that trips a hair spring when exposed to the strong magnetic field of the Gauss belt. The magnet was pivoted in the center and when the external field was energized it (the magnet) would become aligned with the field and

and trip the spring.

Launch Technique

Launching of the model is a coordinated effort on the part of the tunnel operator and the person making the launch. The tunnel operator sets an approximate speed that will support the spinning model and signals the launcher that he is clear to attempt a launch. The launcher may indicate to the operator that the speed is too high or low as the case may be. It was found that the easiest launch method was to hold the model by the underside of the fuselage and induce the spin motion by a slight turn of the wrist as shown in Fig. 9. In order to enter the model into a left spin it was easier to make the launch with the left hand. This technique differs from that used by NASA at the Langley tunnel. Their method is to hold the model by the nose and toss it into the airstream. This method would not work during the test and was probably because of the difference in the sizes of the test section. (The Langley tunnel is approximately eight feet larger in diameter).

Model Recovery

Once the equilibrium spin has been established and the data recorded, the model may be recovered by reducing the velocity of the airstream and allowing it to settle into the net below the test chamber. It may then be picked up

Fig. 9 Launch Technique

by using a pole that has a hook on one end. The hook should be designed to fit around a certain part of the model. There is no requirement for special equipment to catch or pick up the model.

Data Recording

Data from the spin test may be recorded by the use of high speed movie cameras or on video tape. The use of the video tape system gives an immediate look at a test and rough measurements may be obtained without waiting for processing. High speed movie film provides a very clear picture of the spin configuration and can be used to accurately measure angle of attack, roll angle, and rate of spin. The angle of attack and roll angle are obtained by projecting the movie on a screen that is marked off in degrees and stopping the film on specific frames to measure the desired angles. The camera can be equipped with a data door that prints elapsed time on the side of the film. With a slight modification it will also be possible to record the airspeed and/or other data on the film in addition to time. The filming is easily coordinated between the operator and the photographer.

VI. Results

Spin Evaluation

The study was completed to determine if it was possible to match spin results obtained at the Wright-Patterson vertical wind tunnel with corresponding spin results previously obtained at the Langley vertical facility. Table I lists an average angle of attack (α) and an average roll angle (φ) for each of the configurations examined. Each numerical average is derived from a minimum of 10 measurements taken from the movie film of each recorded test. Each equilibrium spin was allowed to become well established before the film data was recorded. This permitted any oscillations induced during the launch to become minimized. The observations made during the test runs for each configuration closely resembled the data available in the Langley report. The data furnished by Langley did not indicate the existance of multiple equilibrium spins for any individual control setting. Therefore no attempt was made to determine if other equilibrium spins existed for a given configuration.

Comparison of the velocities for each case revealed a maximum difference of ± 2 feet per second. This was consistant throughout the evaluation.

Spin Recovery

The steady spins were reproduced in every case that had been observed at Langley. These were for all cases where the ailerons were in a neutral position or where the ailerons were held against the spin. In the case where the ailerons were held with the spin, an equilibrium spin could not be established and the model would dive for recovery following the launch. This effect of the ailerons is reflected in Table I. In each case where a recovery was predicted by use of ailerons, in the Langley results, a very satisfactory recovery was obtained. For this particular model the expected recovery results were immediately evident.

TABLE 1

Wright-Patterson Test Configuration and Results

Spin Direction	Spin Configuration				α (deg)	ϕ (deg)	Ω (rpm)	Recovery Method (Remarks)
	#	Elevator (deg)	Aileron (deg)	Rudder (deg)				
Left	1	0	0	35 L	43.5	4.6	102	rudder reversal only, 1 thru 18 (steady spin)
	2	25 U	0		43.7	4.6	98	
	3	25 U	15 A		58.6	4.6	105	
	4	0	15 A		60.1	3.5	106	
	5	20 D	15 A		60.3	3.1	106	
	6	20 D	0		58.6	2.6	103	
	7	20 D	15 W					(no steady spin)
	8	0	15 W					
	9	25 U	15 W					
Right	10	25 U	15 A	35 R	59.2	-3.5	102	(steady spin)
	11	0	15 A		60.2	-2.4	105	
	12	20 D	15 A		61.4	-2.3	104	
	13	20 D	0		41.0	-3.3	105	
	14	0	0		44.0	-2.4	103	
	15	25 U	0		41.1	-3.6	99	
	16	25 U	15 W					(no steady spin)
	17	0	15 W					
	18	20 D	15 W					
Left	19	20 D	15 A	35 L	62.0	3.5	109	rudder and aileron reversal, 19 thru 24 (steady spin until control reversal, then model dives out of spin) (#21 also exhibited an equilibrium spin at a=47.2 and ϕ=7.3)
	20	0	15 A		60.9	3.1	110	
	21	25 U	15 A		59.8	3.8	105	
Right	22	25 U	15 A	35 R	61.8	-2.9	104	
	23	0	15 A		62.0	-2.4	111	
	24	20 D	15 A		63.6	-1.8	110	

U = up, D = down, A = against spin, W = with spin, L = Left, R = Right

VII. Discussion

Baseline Evaluation

The characteristics of the spin information provided by the NASA at Langley are shown in Table II. Table I shows the characteristics obtained in the Wright-Patterson facility for each of the configurations and includes remarks on the recovery techniques used for each control setting. In the first set of spins, (i.e. left spin, rudder with spin) configurations 1 and 2 reflect a notable difference in the angles of attack when compared to the corresponding angles of attack contained in the Langley data. Angles of attack in configurations 3 thru 9 matched the Langley data very well. The values obtained for ϕ were very close to the values obtained at Langley.

In the second set (right spin, rudder with spin) the values obtained also compared very favorably with what was furnished by Langley except for the angle of attack results for configuration number 12.

At this point it is important to note the similarity of the runs made in the left spin direction and those made in the right spin direction. For each spin in the left direction, there is a mirror image spin in the right direction. The mirror image spins are listed in Table III. This brings up the question of the possibility of multiple equilibrium spin modes for any given configuration. A comparison of each left spin with the mirror image right

TABLE II

Langley Test Configurations and Results

Spin Direction	Spin Configuration #	Elevator (deg)	Aileron (deg)	Rudder (deg)	α (deg)	ϕ (deg)	Ω (rpm)	Recovery Method
Left ↓	158	0	0	35 L ↓	56.7	4.5	109	(rudder reversal)
	155	25 U	0		55.7	4.8	102	
	154	25 U	15 A		61.0	4.6	107	
	159	0	15 A		59.0	3.9	112	
	160	20 D	15 A		58.1	3.5	113	
	161	20 D	0		56.8	5.0	110	
	162	20 D	15 W					
	157	0	15 W					
	156	25 U	15 W					
Right ↓	142	25 U	15 A	35 R ↓	58.4	-2.0	102	
	147	0	15 A		57.0	-4.3	111	
	148	20 D	15 A		56.4	-2.0	112	
	149	20 D	0		43.6	-4.2	109	
	146	0	0		48.3	-3.0	104	
	143	25 U	0		43.1	-5.0	96	
	144	25 U	15 W					
	145	0	15 W					
	150	20 D	15 W					
Left ↓	251	20 D	15 A	35 L ↓	58.3	5.5	111	(rudder and aileron reversal)
	250	0	15 A		58.3	5.2	111	
	249	25 U	15 A		57.4	6.1	106	
Right ↓	259	25 U	15 A	↓	58.6	-3.7	105	
	257	0	15 A		58.0	-3.9	112	
	258	20 D	15 A		59.7	-2.1	112	

U = up, D = down, A = against spin, W = with spin, L = Left, R = Right spin for each control setting yields some significant information. There is very good comparison of the data with the exception of control configurations 6 and 13. This exception reflects a difference that is very close to the difference found between the Langley and Wright-Patterson results for configurations 1 and 2 as shown before. No information was received from Langley that indicated that more than one spin mode could be obtained. It was during the examination of the film of configuration 21 that two different angles of attack had been recorded for identical control settings. One spin exhibited an α of 59.8 degrees and the second an α of 47.2 degrees. The difference being 12.6 degrees which compares to the difference between the Wright-Patterson results and the Langley information for configurations 1 and 2 (13.2 and 12.0 degrees respectively). Reexamination of the Langley data shows that mirror image configuration numbers 161 and 149 (see Tables II and III) reflect an angle of attack difference of 13.2 degrees.

Validity of Results

From the documented testing that had been done in the Langley facility, it can be concluded that two (at least) equilibrium spins exist for each given control configuration of the X-5 model. The difference in angle of attack that at first appears to be in error is not easily understood until each spin result is compared with the mirror image spin.

TABLE III

Mirror Image Spins

Left Spin	Right Spin
1 (158)	14 (146)
2 (155)	15 (143)
3 (154)	10 (142)
4 (159)	11 (147)
5 (160)	12 (148)
6 (161)	13 (149)
7 (162)	18 (150)
8 (157)	17 (145)
9 (156)	16 (144)
21 (249)	22 (259)
20 (250)	23 (257)
19 (251)	24 (258)

Example: Run #3 has a mirror image in run #10, etc.

Note: the Langley run numbers are shown in paraenthesis

The Langley information confirms the existance of the multiple spin modes in configurations 158/146, 155/143, and 161/149.

VIII. Conclusions and Recommendations

Conclusions

Comparison of the results obtained at the Wright-Patterson vertical wind tunnel with the information received from Langley led to the conclusion that the Wright-Patterson facility does provide accurate spin date. This conclusion is based on having been able to duplicate the results obtained by Langley. Also significant, was the discovery of two equilibrium spin modes which differed by approximately 8 to 14 degrees depending on the control surface settings. The possibility of the existence of two equilibrium spins was not a factor that was being considered nor had any information directly indicating this been received from Langley. The discovery came from careful examination of the spin test films made at Wright-Patterson followed by reexamination of the Langley results.

Models are normally launched by hand into the test section with an initial rotation. Thus, several more spins are repeated in the tunnel then in actual flight. Therefore, it is possible to produce a spin that could not be easily gotten into with the full scale aircraft. It is important to note that given enough time, some pilot will manage to experience such a spin. It is when a pilot gets into a spin that the information obtained in the spin tunnel becomes of value. For instance, it is not immediately evident to some pilots that the ailerons should be positioned with the direction of the spin. This is the type of information that spin testing is ultimately aimed at and possibly the best argument for making use of the Wright-Patterson vertical wind tunnel.

Recommendations

The vertical wind tunnel is a facility which is inexpensive to operate and capable of yielding important information in the area of spin susceptibility and recovery techniques of modern aircraft. The tunnel is in excellent operating condition and should be used to the fullest to make spin evaluations of aircraft being studied at Wright-Patterson.

The Gauss belt was used to reverse the control surfaces during this test. This method is not only time consuming but has been outdated by the availability of modern radio control devices. By using radio controls to actuate the control surfaces, the effectiveness of the tunnel can be greatly enhanced. This can be illustrated by considering the number of times the control surfaces could be changed during a single run. With the Gauss belt the number would be limited to one, whereas radio control permits any number of control surface deflections in addition to being able to examine intermediate positions. Radio controls are readily available and are relatively inexpensive. Radio controlled models are currently being used at the Langley tunnel.

Instrumentation for determining the moments of inertia of any models tested in the tunnel will be a necessity for spin evaluation. At the present time this is the only component that is not readily available in order to accomplish a spin test. Selection of the instrument could be made with advisement from the NASA at Langley.

Although design studies and spin tunnel tests play an important roll in design corrections, considerable judgement backed by experience must also be employed in making the determination as to whether or not the proposed design will or will not have adequate control. That desired experience and judgement can only be gained through continued use of the vertical wind tunnel as a tool for the spin analysis of aircraft.

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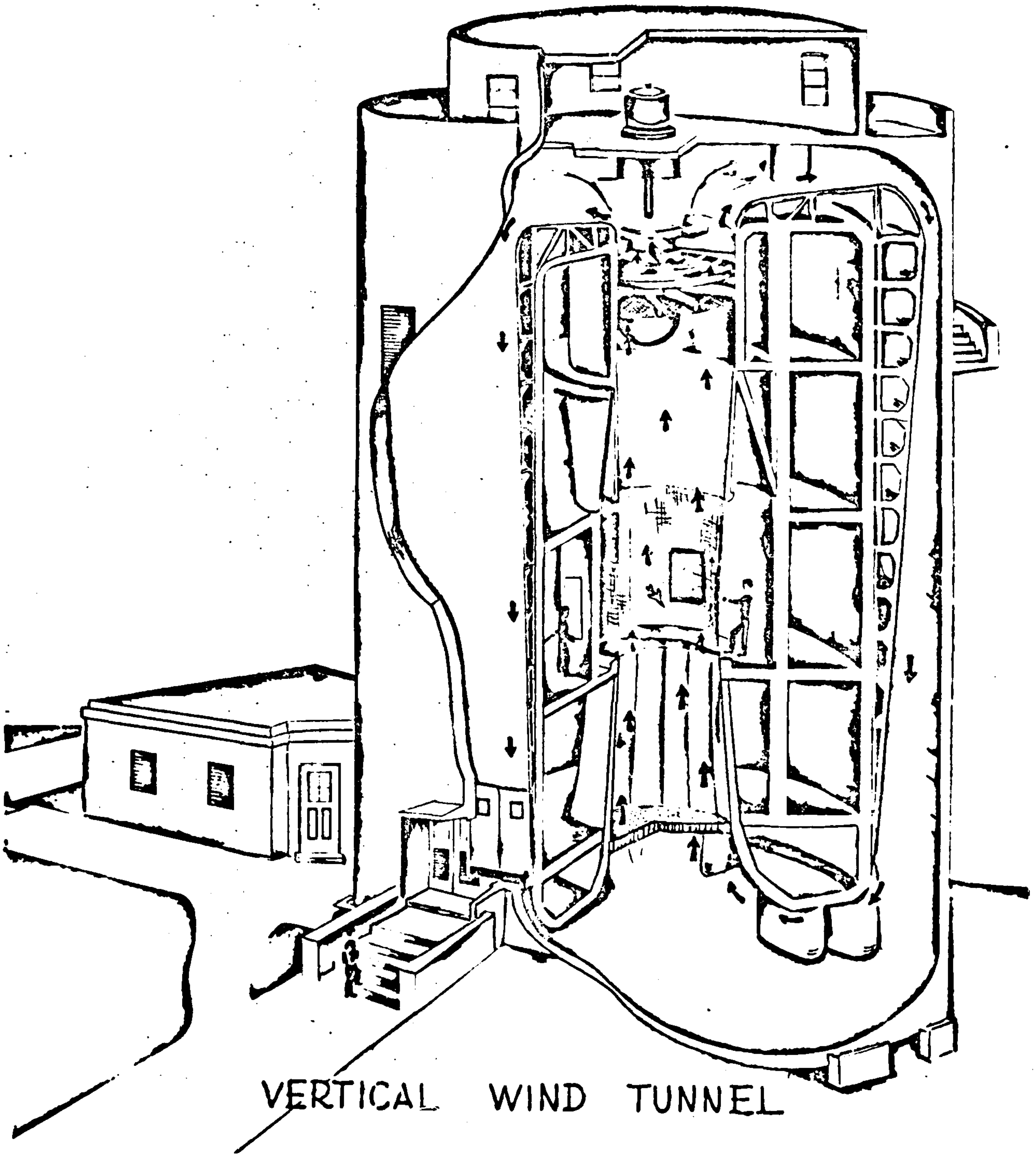
Appendix A

Type	Closed Annular Return
Overall Size	86' high, 56' 8" diameter
Centerline Circuit	
Test Section Type	Open Throat
Test Section Shape	16 Side Polygon
Test Section Dimension	12' Across Inscribed Circle
Test Section Length	15' High
Contraction Ratio	9.9 to 1
Maximum Velocity	102 mph
Maximum Mach Number	0.14 mph
Maximum Dynamic Pressure	25 psf
Power	1000hp DC Motor, Ward Leonard Speed Control System
Energy Ratio	0.65
Temperature Control	None
Stagnation Temp. Range	Approx. Atmospheric
Operating Pressure Range at Fan Section	Approx. Atmospheric
Air Drive	One 16' Dia. 4-Bladed, Controllable Pitch Fan With Laminated Maple Blades
Drive Shaft	10' Long, 6" Dia., Solid Steel Shafts
Maximum Fan RPM	875
Model Support System	Horizontal Parachute Test Strut
Auxiliary Equipment	Position-airspeed-time, data recording 16 mm motion picture cameras Electronic data recording equipment available on limited basis
Type of Tests	Parachute Performance Tests Model Spinning and Spin Recovery Tests Tests of Free Falling Bodies Rotary Wing Model Tests
Estimated Cost	$750,000
Construction Begun	March 1943
Tunnel Put in Operation	May 1944 (Limited) August 1945 (Full)
Reimbursable Rates (DoD User)	$400 per day (Civilian Labor) Plus Photographic Materials and Processing for Specific Test Requirements

Appendix B



VERTICAL WIND TUNNEL

Appendix C

Bell X-5 Model Description

Dimensions

Wing Span	15 inches
Length	19 3/4 inches
Horizontal Stabilizer (span)	5 3/4 inches
Vertical Stabilizer (height)	4 inches

Control Surface Settings

rudder	$\pm 35^\circ$
elevator	$+20^\circ$ to -25°
aileron	$\pm 15^\circ$

APPENDIX D

AFDAL VERTICAL WIND TUNNEL
OPERATIONS CHECK LIST
WIND TUNNEL START-UP

	FUNCTION	ACTION	REACTION	REMARKS
1.	Request Electrical Power for 1000 H.P. Vertical Wind Tunnel Motor	Telephone Central Ext. 56902	Electrical Power Available at Power Panel in M.G. (Motor Generator) Room	Note: If entrance to fan section should be required - shut off fan and shut off M.G. set. Obtain keys to lock for fan section access door from tunnel operator. Tunnel Operator can not start M.G. set until keys have been returned to the operator and inserted in interlock system.
2.	IN M.G. ROOM: Connect A.C. Power to Control Circuits	Switch Circuit Breaker No. 6 (On Power Panel to ON Position)	A.C. Power connected Thyristor Power Supply Transformer, basic regulator, and 110V A.C. Control Circuits	
3.	IN M.G. ROOM: Connect Generator Field to Power Supply	Switch Circuit Breaker No. 5 (on Power Panel) to ON Position	Connects Generator Field to Thyristor Power Supply. Reset Circuit is closed	
4.	IN M.G. ROOM: Energize RESET Circuitry	Push RESET Button (located on upper control cabinet panel, bottom left corner)	RESET Relay energized OVERLOAD Relay is reset. GREEN Light (adjacent to RESET Button) lights up, indicating Ready Condition	
4a.	Lock outside test facility door			
4b.	Turn on intercom			

FUNCTION	ACTION	REACTION	REMARKS
5. Get ready for M.G. Start and Tunnel Blower Run-up	Move to First Floor Test Station OUTSIDE CONTROL CONSOLE: Console should be GREEN (Disregard Gauss Ring Lamps)		
6. AT TEST STATION: Energize Cooling Blower	OUTSIDE CONTROL CONSOLE: Move CBF Handle to CLOSE position	Cooling Blower Fan running indicator Light (CBF)	
7. AT TEST STATION:	OUTSIDE CONTROL CONSOLE: Move OCB Handle to CLOSE position	M.G. Set starting. Indicator light YELLOW; after 1-2 Sec. RED M.G. Set operating	If M.G. Set Fails to start, contact FDMT, Bldg 25C (Mr. Leo Conner, Ext 52137) ascertaining that Power Circuit Breaker for VWT is closed.
8. AT TEST STATION: Check SPEED CONTROL Rheostat	Turn SPEED CONTROL Rheostat to indicate 000 on both the INSIDE and OUTSIDE control panels		
9. AT TEST STATION: Select Control Station from which Speed Control is to be exercised	Move INSIDE/OUTSIDE Selector Switch on INSIDE Control Panel to desired position	Switches Speed Control to desired Control Station	Secure Test Area. Close Doors to Test Section. Check and Calibrate Test Instrumentation, if required

WIND TUNNEL BLOWER IS NOW READY FOR RUN-UP

NOTE - Five (5) to Ten (10) Minutes should be allowed between Function 2 and Function 10 to insure sufficient stabilization of Control Modules

	FUNCTION	ACTION	REACTION	REMARKS
10.	AT TEST STATION Turn Interlock key ON	OUTSIDE CONTROL PANEL Remove Interlock key from hook and insert in Interlock	Power becomes available for Wind Tunnel Blower	
11.	AT TEST STATION: Energize Wind Tunnel Blower Motor	AT SELECTED CONTROL PANEL: Push START button	Indicator lights located on OUTSIDE Control Panel (below PHOTO LIGHTS Switch Handle) switch from GREEN to RED. Tunnel Fan Blades are idling.	INSIDE/OUTSIDE Switch Setting (transfer of control) may still be made at this function.
12.	AT TEST STATION: Adjust Airflow Speed in Test Section	AT SELECTED CONTROL PANEL: Turn SPEED CONTROL Rheostat to desired Setting	Velocity of the Airflow increases or decreases to desired values	If INSIDE/OUTSIDE Switch Setting is changed, W.T. Blower will decelerate rapidly and go to idling. To restart return to Function 8.

CONTROL EXPERIMENTAL TESTING

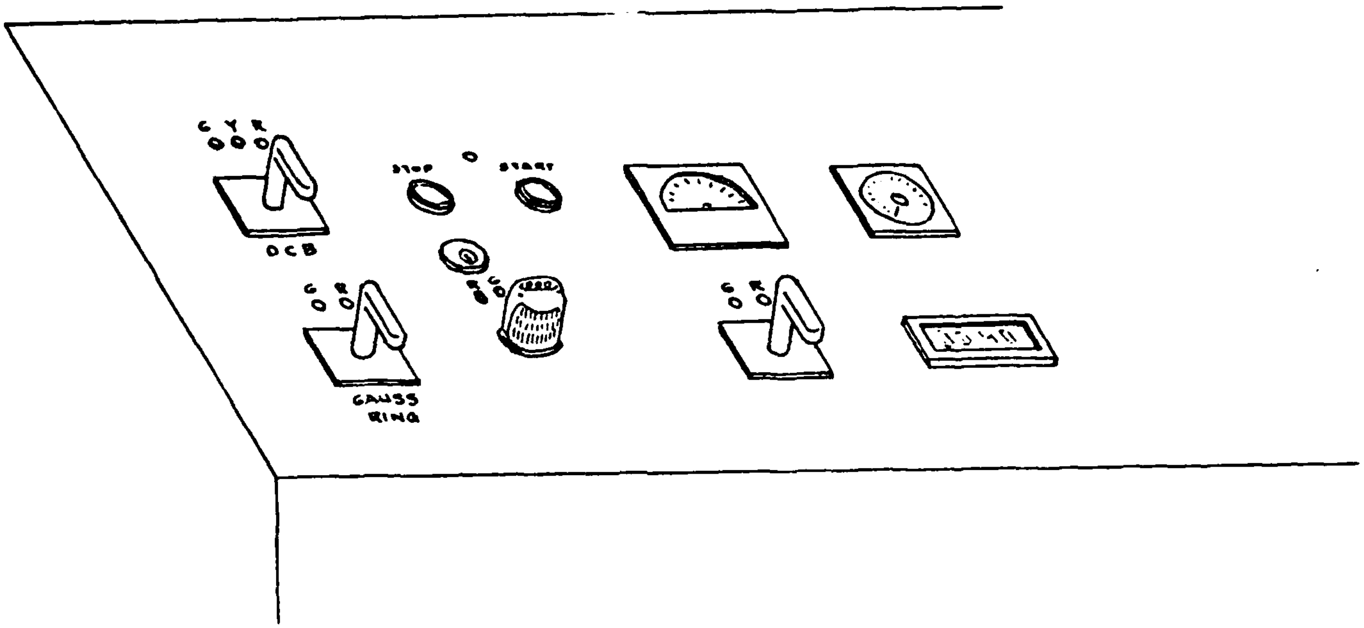
PROCEDURE FOR EMERGENCY SHUT-DOWN OF WIND TUNNEL BLOWER

AT TEST STATION: Emergency Stop of W.T. Blower	Push STOP Button on either INSIDE or OUTSIDE Control Panel	Regenerative (Very Rapid) Braking of W.T. Blower Motor idle. Indicator lights located on OUTSIDE Control Panel (below PHOTO LIGHTS Switch Handle) switch from RED to GREEN (at idling)	To start W.T. Blower again, return to Function 8.

WIND TUNNEL SHUT-DOWN

	FUNCTION	ACTION	REACTION	REMARKS
1.	AT TEST STATION: Return Airflow Speed in Test Section to Zero	AT SELECTED CONTROL PANEL: Turn SPEED CONTROL Rheostat to indicate 000	W.T. Blower decreases Idle Speed	
2.	AT TEST STATION: De-energize Wind Tunnel Blower Motor	Push STEP Button on either INSIDE or OUTSIDE Control Panel	W.T. Blower Motor Stops Indicator Lights on OUTSIDE Control Panel (below PHOTO LIGHTS Switch Handle) switch from RED to GREEN	
3.	AT TEST STATION: Turn Interlock Key OFF	OUTSIDE CONTROL PANEL: Remove key from Interlock and replace on hook	Power no longer available for wind tunnel blower	
4.	AT TEST STATION: De-energize Cooling Blower	OUTSIDE CONTROL CONSOLE: Move CBF Handle to OFF Position	Cooling Fan Motor Stops. Indicator Lights (CBF) switch from RED to GRREN	
5.	AT TEST STATION: De-energize M.G. Set	OUTSIDE CONTROL CONSOLE: Move OCB Handle to OFF Position	M.G. Set Stops. Indicator Lights switch from RED to GREEN	
6.	AT TEST STATION: Inform Central Dispatch of Tunnel Shut-Down	Telephone Central Dispatch Ext. 52257		
7.	IN M.G. ROOM: Remove Generator Field from Power Supply	Switch Circuit Breaker No. 5 (on Power Panel) to OFF Position	Power removed from Generator Field. RESET Relay de-energized. GREEN Light (adjacent to RESET Button) extinguished	

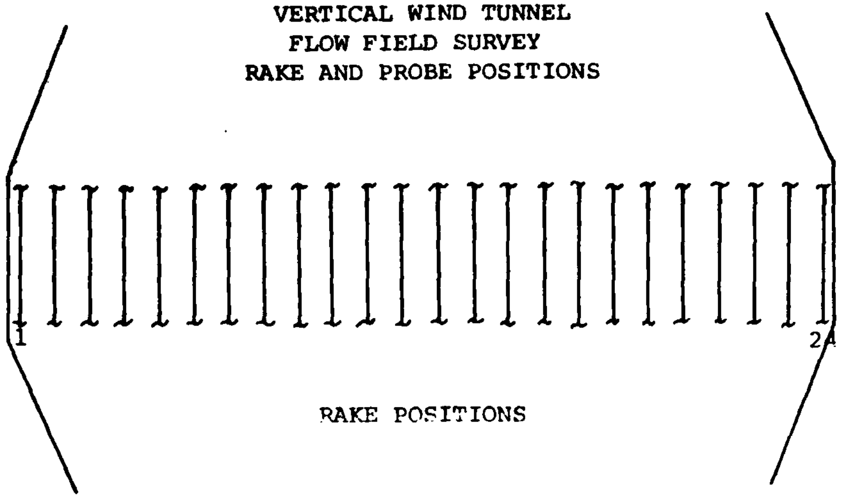
	FUNCTION	ACTION	REACTION	REMARKS
8.	IN M.G. ROOM: Remove A.C. Power from Control Circuits	Switch Circuit Breaker No. 6 (on Power Panel) to OFF Position	A.C. Power removed from Thyristor Power Supply Transformer, basic Regulator, and 110V A.C. Control Circuits	



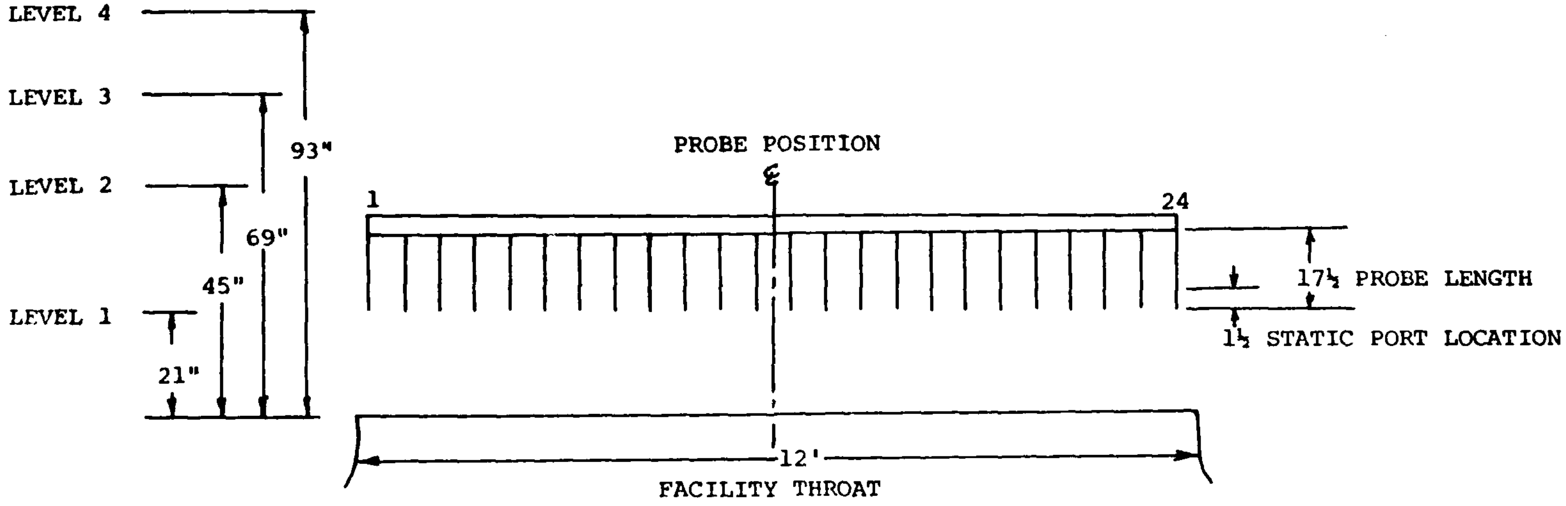
OPERATOR CONTROL PANEL

APPENDIX E

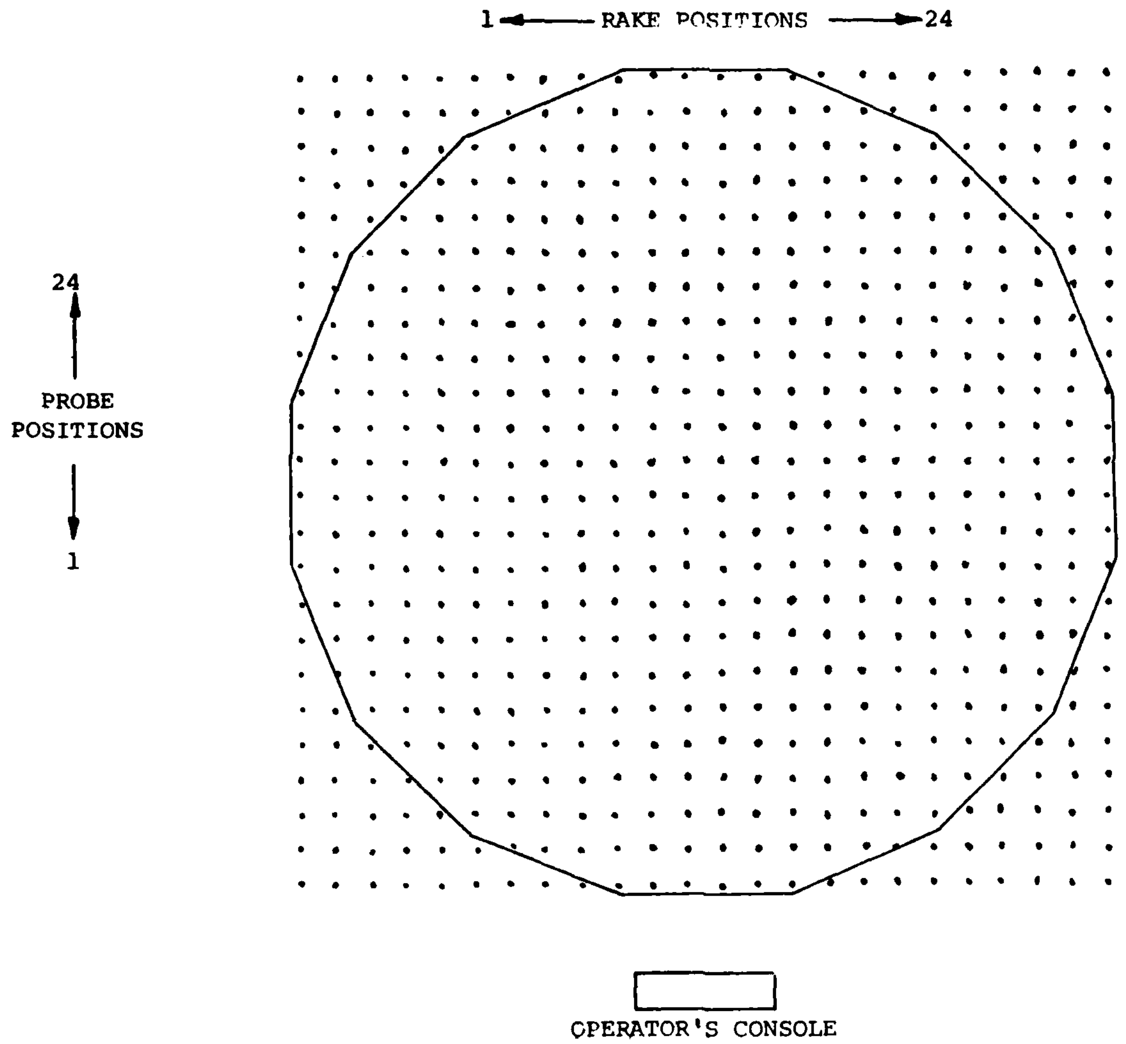
VERTICAL WIND TUNNEL
FLOW FIELD SURVEY
RAKE AND PROBE POSITIONS



RAKE POSITIONS



VERTICAL WIND TUNNEL
FLOW FIELD SURVEY
RAKE AND PROBE POSITIONS



Vita

James W. Hickman was born 9 November 1940 in Fairmont, West Virginia. He graduated from Farmington High School, Farmington, West Virginia in 1958 and attended Fairmont State Teachers College until entering the Air Force through the Aviation Cadet Navigator/commissioning program in November 1961. He was graduated and received his commission in October 1962 after which he was assigned to Dover AFB, Delaware, as an instructor navigator in the C-124. His assignment involved a world-wide flying mission and it was in this capacity that he functioned until he left active duty in January 1967. In June 1967, he returned to school at Wichita State University, Wichita, Kansas and received the degree of Bachelor of Science in Aeronautical Engineering in June 1969. Upon graduation, he was employed as an engineer with Cessna Aircraft Company, Wichita, Kansas until he was recalled to active duty in June 1971. On return to active duty, he was assigned as navigator on KC-135's and was stationed at McConnell AFB, Kansas, and K.I. Sawyer AFB, Michigan. He served as instructor navigator and as a Standardization/Evaluation navigator until February 1978 at which time he became Wing Navigator. He functioned in this position until reporting to the Air Force Institute of Technology in May 1979 where he was enrolled in Graduate Aeronautical Engineering.

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A spin capability evaluation of the Wright-Patterson vertical wind tunnel was completed using a model of the Bell X-5. The X-5 model was previously spin tested in the NASA vertical wind tunnel at Langley AFB, Va. The study compared results obtained at the NASA-Langley vertical wind tunnel with the test results obtained at the Wright-Patterson vertical wind tunnel. The Langley results were used as the basis for this evaluation. Information was available on spin characteristics of the model with respect to

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20. various control surface configurations and recovery attempts using control deflections. The spin tests revealed a stable equilibrium spin and recovery, where applicable, could be established and observed for each corresponding stable equilibrium spin and recovery that was observed at Langley.

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