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TA-4J Spin Training Through Simulation

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A methodology to provide spin training for the TA-4J pilots was formulated and implemented on the TA-4J Operational Flight Trainer (Device 2F90). User experience indicates the simulation provides worthwhile training in erect spin recognition and recovery procedures. This paper presents details of the formulation of simulation requirements, development of spin simulation, acceptance test methodology and user experience.

Nomenclature

t = time, s
α = angle of attack, deg
δ_a = right aileron deflection, trailing edge down positive, deg
δ_e = elevator deflection, trailing edge down positive, deg
δ_r = rudder deflection, trailing edge left positive, deg
θ = pitch attitude, nose up positive, deg
ϕ = roll attitude, right wing down positive, deg
ψ = yaw attitude, nose to the right positive, deg

Introduction

PILOT training in out-of-control flight enhances the flying skills of the pilot, enabling him to exploit the full capability of the airplane with increased confidence and safety. However, actual practice of departures from controlled flight in some U.S. Navy tactical aircraft can lead to dangerous situations which must be tempered by flight restrictions to avoid loss of the aircraft. Such restrictions apply to the TA-4J airplane with respect to intentional spins. The TA-4J is utilized by the U.S. Naval Air Training Command as an advanced jet trainer where a part of the syllabus includes aerobatics and air combat maneuvering. Intentional spinning is not permitted in this airplane but occasionally spins do develop from pilot error during out-of-control flight situations. In fact, loss of TA-4J aircraft in stall/spin incidents occurs on a continued basis during maneuvering flight training. In an effort to reduce these losses, the Chief Naval Air Training (CNATRA) searched for a means to augment the existing pilot training aids for TA-4J spin characteristics, namely, the narrative discussion contained in the NATOPS Flight Manual[1] and a training film[2] developed from spin flight tests. Attention was directed toward the TA-4J flight simulator, known as Device 2F90 Operational Flight Trainer (OFT), to provide hands-on pilot training in spins, but tests demonstrated that the existing data base did not accurately simulate TA-4J spin characteristics. Therefore CNATRA established the requirement to add a spin training capability to the OFT, and the U.S. Naval Training Equipment Center (NAVTRAEQUIPCEN) and Goodyear Aerospace Corporation undertook the development of the required modification. This was a unique effort in that prior to this, a Navy flight simulator has not been specifically modified to provide spin training. This paper presents details of the formulation of simulation requirements through analysis of the flight test data available; the development of the spin simulation to meet the simulation requirements; and finally acceptance test methodology and user experience.

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Description of the TA-4J Airplane

The TA-4J airplane (Fig. 1) is a two-place (tandem) trainer version of the A-4 series attack airplane designed and manufactured by the McDonnell-Douglas Corporation for carrier and land based operations. Its identifying features include a low wing with modified delta planform, swept-back empennage, and a large canopy area. The spin characteristics of the TA-4J airplane have been tested in a series of flight test programs conducted by the airframe contractor and the U.S. Naval Air Test Center (NAVAIRTESTCEN). Test results are documented in Refs. 3 and 4.

The Ref. 3 effort placed primary emphasis on evaluating the suitability of the TA-4J (then designated TA-4F) airplane as a spin trainer. Erect and inverted spins were evaluated with various wing store loadings and from a variety of entry conditions. Within the scope of these tests, the TA-4J was spin resistant and exhibited no tendency to spin inadvertently. Erect spin modes were either the highly oscillatory diving spiral mode or the classic erect spin mode, depending on external wing store loading. Inverted spins were attainable in all loadings tested. The erect spin modes were not disorienting and caused no pilot confusion, but inverted spins were usually violently oscillatory, disorienting, and could be structurally damaging due to negative *g* overstresses.

Reference 3 recommended that intentional erect spins be permitted in the TA-4J airplane since they were sufficiently predictable. Intentional inverted spins were not recommended because of structural and recovery problems. However, it was decided not to permit any intentional spins primarily because incorrect pilot technique with lateral control could result in a rapid transition from an erect to an inverted spin.

Description of the TA-4J OFT

The TA-4J OFT (Device 2F90) (Fig. 2), built by Goodyear Aerospace Corporation, is a three-degree-of-freedom moving base simulator. Each unit or deck consists of a set of four cockpits and instructor consoles all operated by a pair of Xerox Sigma 5 digital computers and a common hydraulic power supply system. Each cockpit interior is identical to the forward cockpit of the TA-4J airplane with respect to internal measurements, cockpit instruments and controls. Each instructor console consists of instruments and controls for monitoring and modifying flight conditions to simulate various emergencies and malfunctions. The motion base provides limited motion in pitch (± 15 deg), roll (± 15 deg), and heave (± 6 in.) and is capable of simulating buffet and turbulence.

A visual system is attached to one cockpit at each of three training sites. This visual system, built by General Electric Corporation, provides low-resolution, color, computer generated images (CGI) displayed on three large screens placed in front of the cockpit. These screens provide a field of view consisting of ± 105 deg horizontally and ± 30 deg vertically.

The simulation of the TA-4J flight characteristics provided by the OFT are considered quantitatively and qualitatively representative for pilot training in normal instrument, aerobatic, and emergency procedures tasks. The simulation of high-angle-of-attack (AOA) characteristics had been validated only for stalls entered from erect (as opposed to inverted) flight. While the simulation did exhibit poststall gyrations when spin entries were attempted, these gyrations were not considered representative of the TA-4J airplane characteristics.

Spin Simulation Problem

The airplane spin phenomenon, as defined in Ref. 5, is an uncontrolled, large angle, six-degree-of-freedom motion experienced by an airplane operating in the stalled aerodynamic region. The spin is a highly complex motion influenced by a host of nonlinear variables including the aerodynamic aspects of the airflame, aircraft mass distribution, and maneuver entry flight conditions such as airspeed, normal acceleration, and flight control deflections. The complexity of the spin motion is indicated by the variety of descriptors required to characterize each spin mode, such as erect or inverted; steep or flat; oscillatory or steady; and low or high rates of spin rotation or angular velocity.

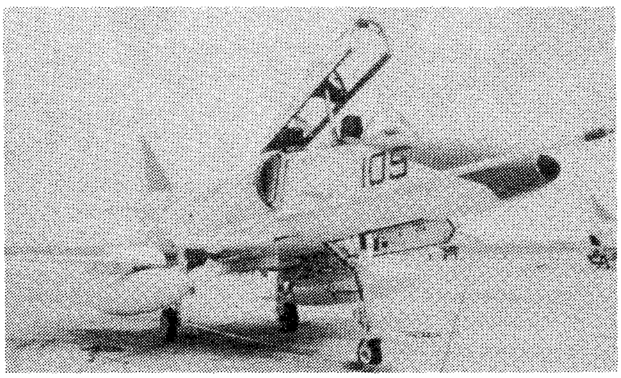


Fig. 1 TA-4J aircraft.

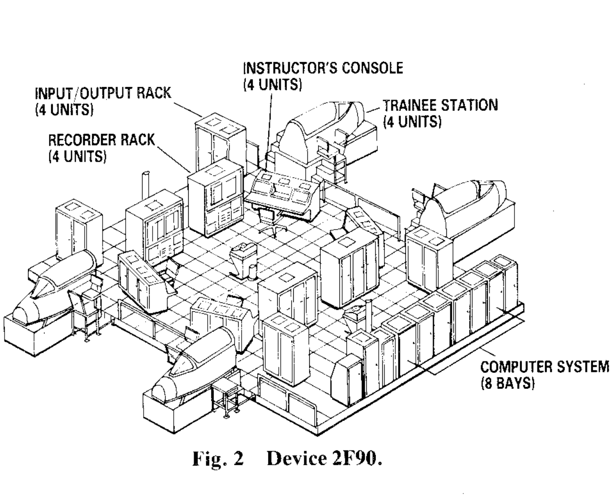


Fig. 2 Device 2F90.

From a simulation viewpoint, the airframe aerodynamic parameters above stall AOA are the most difficult variables to define. In addition, it is rare that a comprehensive set of actual test data exists for use as a criteria source for thorough validation of a spin simulated model. Thus the designer of a spin simulation is faced with some large gaps in terms of input data (aerodynamic coefficients at high AOA) and output data (time histories of airplane response during various spin modes and with various control deflection combinations).

It is obvious that some amount of output data must be obtained before any simulation can proceed. These data help define mass distribution and entry conditions, but the simulation designer still must often develop his own aerodynamic coefficients for input data. A common approach is to apply multiplication factors to the classical aerodynamic derivatives. An iterative approach is then utilized to adjust each factor until, hopefully, all the output time history characteristics have been matched. However, since the effect of each term on spin characteristics is not clearly understood and the spin motion is very complex, such an iterative method is very inefficient without an extensive set of time histories and the services of test pilots and aerodynamicists knowledgeable in the particular aircraft's spin characteristics. Excellent simulations of departure characteristics have been developed in this manner in flight simulators for the A-7E and F-14A airplanes in Devices 2F111 and 2F95, respectively. However, without data and expert guidance, the iteration process may only produce a match of gross characteristics such as turn rate and altitude loss at the expense of other important characteristics such as attitude, oscillation phasing, and response to incorrect control inputs.

Another approach to aerodynamic modeling is the application of parameter identification techniques.[6] These techniques have been gaining popularity in recent years as viable means of determining aerodynamic characteristics from flight data although they have not been extensively applied toward improving simulation fidelity. In order to be successful, these methods require a large amount of high-quality flight test time histories as well as wind-tunnel data. Lack of such a data base precluded the application of parameter identification techniques to this spin simulation.

A third concept for modeling spin aerodynamic derivatives involves consideration of rotary balance effects, as discussed in Ref. 7. These rotary balance effects arise from the fact that airflow impinges on opposite sides of the airframe simultaneously when the airplane is rotating about a vertical axis near the center of gravity. In Ref. 7, rotary balance coefficients were shown to be effective in modeling spin characteristics and they could be determined directly in special wind-tunnel tests. However, no rotary balance coefficient data were available for the TA-4J airplane.

The TA – 4J spin simulation had to be accomplished with very limited flight test data and test pilot expertise. The only TA-4J data readily available were a limited set of time histories published in Ref. 3; the narrative in the same report and in the NATOPS Flight Manual[1]; and the TA-4J spin training film.[2] Other film test data existed in unpublished form from follow-on programs, but these data provided no amplification over information already at hand. A further problem was that there were no Navy test pilots available with current spin experience in the TA-4J airplane since the last set of official spin tests had been concluded several years ago. Test pilots with relevant spin experience in other aircraft types were available, but they were considered useful for final acceptance testing only, since they did not have sufficient experience to assist in development. Therefore this spin simulation had to be developed from a very limited data base, and then validated by engineers and pilots who had no first-hand experience with TA-4J spins. This meant that the design and test requirements had to be as explicit as possible to ensure efficient development and validation of the simulation

Requirements Formulation

The original request from fleet instructor pilots for spin simulation in the TA-4J OFT expressed a need for training capability in both the erect and inverted spin modes. These pilots envisioned a capability in the simulator for reenacting stall/spin accidents that occurred inadvertently owing to pilot error in maneuvering flight. However, the NAVTRAEQUIPCEN team felt that there were too little data available to achieve this capability. In addition, it was felt that training for a very dynamic situation such as spins should be structured as much as possible to insure that the student pilot could clearly identify cause and effect relationships due to both proper and improper cockpit control actions. Therefore the spin simulation requirement had to describe a complex phenomenon in straightforward terminology in order to insure that training objectives could be met.

The spin simulation objectives were developed through discussions between CNATRA and NAVTRAEQUIPCEN. The primary objective was to provide training in proper cue recognition and psychomotor responses to enable safe recovery from out-of-control flight. This objective had to be balanced against several limiting factors, the most significant of which were limited availability of criteria data and test pilot expertise, limited computer memory capacity in the OFT (only 2500 words available for spin simulation), and a relatively modest funding level. It was decided to model the training capability of the OFT after the recommendations of Ref. 3, which were developed for spin training in the actual airplane. Since intentional inverted spins were not recommended in Ref. 3, the decision was made to simulate the erect spin modes only, and to exclude simulation of the inverted spin characteristics. The decision to eliminate the complex inverted spin modes alleviated concern over achieving some measure of success within the constraints mentioned above.

Once the scope of the spin simulation had been confined to the erect modes, the training objectives were further refined to include the effects of any combination of cockpit control inputs and to insure that spin characteristics were accurately displayed on the cockpit instruments, especially those of primary importance to the pilot in a spin situation, namely, angle of attack, turn needle, attitude indicator, and airspeed indicator. The effects of peripheral cues derived in the simulation from the motion and visual systems were considered secondary owing to the limited capabilities of these systems, and these cues were to be included in the model only to the extent that they did not induce negative aspects to the training. In summary, the objectives of the spin simulation were to provide proper response characteristics for the erect spin modes of the TA-4J airplane as seen on the cockpit instruments. All combinations of cockpit control deflections were to be considered in order to demonstrate the effects of both proper and improper pilot control actions.

The desired spin characteristics were described in a tabular format as described in the Appendix which also includes an explanation of the test techniques and nomenclature. Table A2 of the Appendix outlines the erect spin mode tests and Table A3 of the Appendix outlines the diving spiral mode tests. The contents of the Appendix were developed at the NAVTRAEQUIPCEN by careful analysis of the airplane spin documentation. It was fortunate that both the NAVAIRTESTCEN flight test report[3] and the spin training film[2] contained thorough narrative discussions of significant spin characteristics upon which to base the expected response during the entry, steady-state, and recovery phases. In addition, Ref. 3 contained detailed discussions of the effects of misapplied controls and other effects (such as speed brake and power settings) which were used to formulate these expected response requirements. The referenced narratives were thorough enough so that reliance on the relatively crude time history traces in Ref. 3 for detailed analysis was minimized. In addition, commonality of the simulation with existing fleet spin training aids for the TA-4J airplane was ensured by utilizing the same narrative material.

Simulation Method

The simulation technique employed here has several advantages. It is general in nature and can be easily adapted to other flight simulators. The computer requirements are minimal—the TA-4J erect spin simulation uses only 1550 words of computer memory. It is an effective method to train the pilots in the basic procedures of out-of-control flight without an extensive aerodynamic data base or the services of experienced pilots and aerodynamicists.

The underlying philosophy is to provide the necessary cues to the pilot for successful spin training using simple equations that directly drive the instruments and motion and visual systems and replicate the basic spin characteristics outlined in Tables A2 and A3 without satisfying the mathematical constraints of the equations of motion. The TA-4J exhibits consistent tendencies in all phases of spin, departure through recovery, even though the actual values of variables such as angle of attack may differ considerably from one flight to another. The simulation method takes advantage of this consistency.

The erect spin methodology is discussed below and the diving spiral simulation is similar. The aircraft has three definitive phases, namely, entry/incipient spin, fully developed spin, and recovery, details of which have been given in the Appendix. Recovery is effected by any of the right combination of control inputs and the recovery rate depends on the applied control input. Premature removal of recovery control will result in the aircraft reverting to spin. Based on the flight condition, the phase that is presently simulated, and the control inputs applied, switching is done from one phase to another while maintaining a smooth transition. An example is given below for the roll angle and other variables are modeled in a similar fashion. To avoid repetitiveness, wherever possible, the magnitude of variables such as recovery attitude, time period of oscillation, etc., are chosen randomly for each simulation. Once the turn rate goes to zero, the simulation is switched back to the aerodynamic model and the pilot flies out of the dive with the aerodynamic simulation.

A. Roll Angle, ϕ, During Incipient Erect Spin

a) $t_0 < t < t^*$:

$$\phi_{i+1} = \phi_i + \dot{\phi}\Delta t \qquad (1)$$

$$\dot{\phi} = (360\,k\text{sign} - \phi_0)/(t^* - t_0) \qquad (2)$$

where t_0 is the time at which departure occurs, t^* is the time at which one roll is completed, ϕ_i and ϕ_{i+1} are current and next values of ϕ, respectively, ϕ_0 is initial roll attitude in degrees, and Δt is computer frame time. $k$sign is ± 1 and is equal to sign$(-\delta_{r_0})$ to ensure roll in the applied direction of the rudder. δ_{r_0} is the rudder deflection at t_0.

b) $t > t^*$:

$$\phi_{i+1} = \phi_{a_{i+1}} \left[\sin \frac{2\pi(t_{i+1} - t^*)}{T_\phi}\right] k\text{sign} \qquad (3)$$

$$\phi_{a_{i+1}} = \phi_{a_i} + (\phi_{a_c} - \phi_{a_i})\Delta t / T_\phi \qquad (4)$$

where T_ϕ is the period of oscillation for roll angle and ϕ_{a_c} is the desired amplitude of oscillation. The variable ϕ_{a_i} is initialized at t^* to the value of roll angle at t^*.

Equation (4) allows the magnitude of oscillation to reach the desired value in an exponential fashion.

B. Roll Angle During Steady Erect Spin

$$\phi_{i+1} = \phi_{a_{i+1}} \left[\sin \frac{2\pi (t_{i+1} - t^*)}{T_\phi} \right] k\text{sign} \tag{5}$$

$$\phi_{a_{i+1}} = \phi_{a_i} + (\phi_{a_c} - \phi_{a_i}) \Delta t / T_\phi \tag{6}$$

$$\begin{aligned} \phi'_{a_c} &= 3\,|\delta_a|, & |\delta_a| &> \delta_{a_{\max}}/3 \\ &= 20, & |\delta_a| &< \delta_{a_{\max}}/3 \\ \phi''_{a_c} &= \Delta\phi, & \delta_e &> a_1 \\ &= 0, & \delta_e &< a_1 \\ \phi_{a_c} &= \phi'_{a_c} + \phi''_{a_c} \end{aligned}$$

where $\delta_{a_{\max}}$ is the maximum aileron deflection, $\Delta\phi$ is increase in roll due to forward elevator, and a_1 is a constant (all in degrees); other variables are as defined earlier. Note that the above formulation permits a smooth change in the roll angle oscillation under all conditions.

C. Roll Angle During Recovery from Erect Spin

The number of turns to recovery depends on the recovery control as shown in Table A2. The flight test data indicated that the attenuation of spin is gradual in the beginning but the turn rate rapidly goes to zero in the last one-quarter turn (when turn rate reaches about 40 deg/s). Hence the recovery simulation has been divided into two phases to reflect this. The equations for ϕ are given below.

a) Turn rate >40 deg/s:

$$\phi_{a_{i+1}} = \phi_{a_i} - \frac{\phi_{a_i} \Delta t'}{T_r + T_f} \tag{7}$$

$$\phi_{i+1} = \phi_{a_{i+1}} \left[\sin \frac{2\pi (t_{i+1} - t^*)}{T_\phi} \right] k\text{sign} \tag{8}$$

where

$$\Delta t' = \Delta t \, N_{\text{opt}} / N$$

In the above equations, the decay rate of ϕ is adjusted through $\Delta t'$ to reflect the type of recovery control. N_{opt} and N are the number of turns for optimum recovery control and the actual recovery control applied, respectively. T_r is the time required to reach a turn rate of 40 deg/s had optimum recovery been applied during the existing flight conditions, and T_f is the time it will take the spin to completely stop from a turn rate of 40 deg/s. T_r and T_f are calculated as part of the simulation.

b) Turn rate <40 deg/s:

$$\phi_{i+1} = \phi_{a_{i+1}} \left[\sin \frac{2\pi (t_{i+1} - t^*)}{T_\phi} \right] k\text{sign} \tag{9}$$

where

$$\phi_{a_{i+1}} = \phi_{a_i} - \frac{\phi_{a_i} \Delta t}{T_f - t + t'} \tag{10}$$

In the above equation t' is the time at which the turn rate reaches a magnitude of 40 deg/s. $T_f - t + t'$ goes to zero only when the turn rate becomes zero when the spin simulation is no longer required.

Figure 3a shows a classic erect spin time history recorded in flight. Figure 3b shows a similar case flown in the simulator. It may be noted that the recovery with optimum controls occurs within 1½ to 3 turns in both cases and the trends on bank angle and heading are similar. The angle of attack for the simulator run is the cockpit instrument reading and hence is pegged at 30 units, as per Table A2, whereas the nose boom angle-of-attack reading was recorded in flight tests.

Testing the Simulation

The acceptance tests for the spin simulation at Naval Air Station (NAS), Meridian, Miss., consisted of pilot evaluation by local instructor pilots and a spin experienced test pilot from NAVAIRTESTCEN, and formal engineering test procedures based on the tests in the Appendix, which included time history recordings of significant spin parameters. At the conclusion of these tests, the simulation was considered sufficiently representative of TA-4J spin characteristics for use in training student Naval aviators.

The pilot evaluation portion of this program was somewhat unusual in that none of the pilots had actually experienced spins in the TA-4J aircraft. However, the test pilot from NAVAIRTESTCEN was serving as the staff spin instructor pilot for the U.S. Naval Test Pilot School and he was very knowledgeable in typical spin characteristics. He had regularly demonstrated spin characteristics to student test pilots and fleet fighter pilots using the T-2C airplane in programs such as described in Ref. 8 and his spin experience included several types of jet aircraft, some of which were very similar to the TA-4J. This pilot evaluated the simulated spin characteristics using the test techniques of the Appendix and other entry and recovery methods. Several minor deficiencies were identified which were subsequently corrected in the

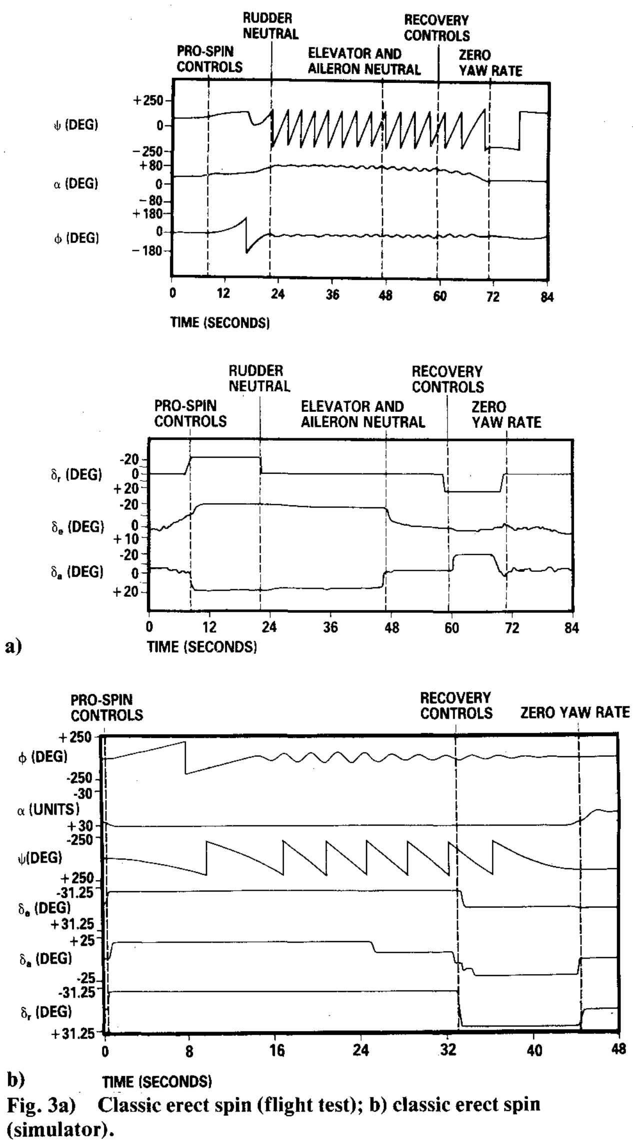


Fig. 3a) Classic erect spin (flight test); b) classic erect spin (simulator).

software, but, in general, the test pilots considered the simulation representative of this type of aircraft except for certain limitations imposed by design, i.e., maneuver predictability and minimal visual cues. Maneuver predictability concerned the fact that while the airplane steady-state spin characteristics were predictable, the stall and poststall gyration preceding spin entry was very dependent upon entry conditions, particularly airspeed and normal acceleration. The simulation is inherently predictable in these areas and it was recommended that the student Naval aviator not enter a spin in the simulator in other than 1*g*, wings level flight. The visual cues available in the OFT cockpits so equipped are minimal during spins due to the limited field of view. It was recommended that student Naval aviators rely primarily on

Table A1 Initial conditions[a]: altitude, 30,000 ft; internal fuel, 3000 lb; airspeed, 150 KIAS; landing gear and flaps, up; speedbrake, in; power, idle

Spin mode	Loading	External fuel quantity
Diving spiral	No stores or two 300-gal drop tanks	None
Classic erect spin	Two 300-gal drop tanks	More than 2000 lb

[a] Initial altitude, airspeed, internal fuel, power setting, or speedbrake position is not critical for obtaining either spin mode; the values presented are just suggested conditions based on airplane test results. The landing gear and flaps must be up to obtain either spin mode. If external fuel quantity is between zero and 2000 lb, then either spin may occur.

Table A2 Erect spin mode tests

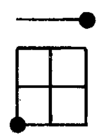
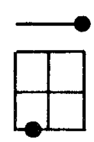
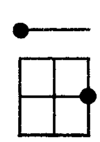
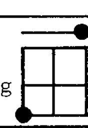
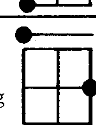
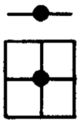
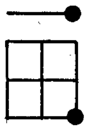
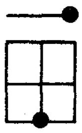
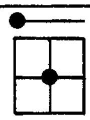
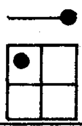
Test item	Maneuver phase	Control input	Expected response
1. Typical incipient spin (to the right)	Entry and incipient spin (controls applied at 20 to 21 units AOA)	 TRIM: greater than 2 deg	Roll and yaw in direction of applied rudder. Pitch up to about 20 deg, followed by pitch down to nearly -90 deg after 180 deg of roll, thereafter pitch attitude oscillates slightly about -30 deg. Lateral oscillations of ±60 deg with 2 to 3 sec period developing after first rolling turn Total maneuver consists of a roll and two turns with a time span of 18 sec and altitude loss of 2500 ft
2. Classic erect spin (to the right)	Fully developed steady state (preceded by Item 1)	 TRIM: same as Item 1	Pitch attitude: Oscillate between -25 deg and -35 deg with 2 to 3 sec period Roll attitude: With 1/3 left lateral input oscillations of less than ±20 deg with 2 to 3 sec period. Amplitude increase when left lateral control input increased Yaw rate: Steady, 3-1/2 to 4 sec per turn Angle of attack: Cockpit indicator pegged at 30 units (actual angle of attack varies between 75 and 85 deg) Airspeed: Fluctuates from 50 to 150 KIAS, may sometimes reach 185 KIAS Altitude loss: 1100 to 1500 ft per turn Turn needle: Pegged in spin direction
3. Optimum recovery technique	Recovery to level flight (from right spin, Item 2)	 TRIM: 4 deg	Yaw rate: Goes to zero within 1-1/2 turns Pitch attitude: -70 deg Lateral control to neutral after turn stops Altitude loss: 4000 to 5000 ft with airspeed at 220 to 250 KIAS and normal acceleration at 2 to 2-1/2 g Buffet: Occurs during dive recovery, depending on angle of attack/Mach number conditions
4. Effect of longitudinal trim on entry	Entry	TRIM: -1 deg 	Post stall gyrations, no spin
5. Effect of longitudinal trim on recovery	Recovery to level flight (from right spin, Item 2)	TRIM: 10 deg 	All parameters same as Item 3 except that a push force of approximately 10 lb required to attain neutral longitudinal stick position and to maintain dive recovery parameters

Table A2 Erect spin mode tests (continued)

Test item		Maneuver phase	Control input	Expected response
6. Effect of neutralizing all controls		Recovery to level flight [from spin to right (Item 2) or left]	 TRIM: 4 deg	Yaw rate: Goes to zero within 3 to 5 turns Other parameters: Same as Item 3
7. Effect of aileron	A. Toward spin direction	Initial recovery (from right spin, Item 2)	 TRIM: any	Yaw rate: Goes to zero in 2 to 3 turns
	B. Neutral		 TRIM: any	Yaw rate: Goes to zero in 4 to 6 turns
8. Effect of rudder		Initial recovery (from right spin, Item 2)	 TRIM: any	Yaw rate: More than 2 turns required before reaching zero
9. Effect of elevator		Steady state spin (during right spin, Item 2)	TRIM: any 	Yaw rate: Increase by approximately 20 deg/sec Roll attitude: Oscillation amplitude increases slightly

Note: The left erect spin, including control effects, is symmetric to the right erect spin.

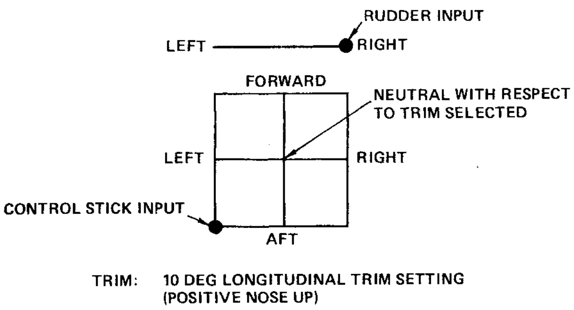


Fig. A1 Cockpit control position symbology.

cockpit instruments in the simulator to determine spin characteristics and proper recovery controls. This recommendation coincided with the original simulation design intent to teach recognition of spin characteristics based on cockpit instruments since it was well known that pilots could be misled and become disoriented when trying to reference the outside horizon during spins in the airplane.

The fleet instructor pilots were asked to conduct each of the test maneuvers in the Appendix to become familiar with the simulation capabilities. They were then asked to note any anomalies with respect to flight training requirements, their flying experience, and their knowledge of published information on the TA-4J spin characteristics.[1,3] In addition, the instructor pilots observed the tests conducted by the NAVAIRTESTCEN test pilot. The primary complaints expressed by these pilots were the lack of inverted spin capability and the restriction of spin entry to wings level, unaccelerated flight but they agreed to introduce the spin simulation into the OFT syllabus and to observe its effectiveness before recommending further development or corrective action.

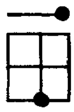
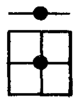
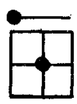
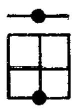
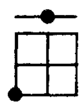
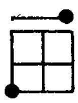
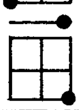
User Experience

The spin simulation was initially implemented in the syllabus at NAS, Meridian as part of the last visual-equipped simulator "flight" for the student Naval aviator prior to flying the TA-4J airplane. After several months of utilization, the instructor pilots now feel that the spin simulation provides worthwhile training in the procedures required to recognize and recover from erect spins. The repeatability aspect of the simulation is considered an asset because it enhances the instructor's credibility in taking a student pilot through the spin demonstration. The simulation has also been educational for the instructor pilots themselves because they did not always apply the right controls for recovery in their first simulator practice sessions. Training value is considered somewhat limited because the violent disorienting motion cues that are characteristic of spins could not be provided owing to OFT motion system limitations. The lack of inverted spin characteristics in the simulation remains a serious concern.

Conclusion

A successful simulation of the erect spin characteristics of the TA-4J airplane was developed and implemented to provide training for student Naval aviators. This effort is significant because of constraints imposed by limited availability of aircraft data and test pilot expertise, and by limited computer memory space available in the OFT. Certain limitations were imposed on the simulation by design to ensure meaningful instruction capability within program constraints. The most significant design limitations were the

Table A3 Diving spiral mode tests

Test item	Maneuver phase	Control input	Expected response
1. Typical diving spiral (to the right)	Entry and steady-state (controls applied at 20 to 21 units AOA)	 TRIM: any	Initial response Roll and yaw in direction of applied rudder Steady-state response Angle of attack: Varying between 20 and 30 units (up to 70 deg). Pitch attitude: Approximately -50 deg (varying between -30 deg and -90 deg). Roll attitude: Oscillatory (amplitude = ±45 deg, period = 2 sec). Oscillation amplitude increases to maximum of ±70 deg as airspeed increases Yaw rate: Hesitant and never greater than 40 deg/sec Indicated airspeed: Fluctuating and increasing to 220 KIAS
2. Optimum recovery	Recovery (from Item 1)	 TRIM: any	Recovery within 3 to 4 sec (yaw rate and wing rock go to zero) followed by normal dive recovery to level flight.
3. Effect of rudder (applied opposite to turn direction)	Recovery (from Item 1)	 TRIM: any	Recovery within 3 to 4 sec (yaw rate and wing rock go to zero) followed by normal dive recovery to level flight.
4. Effect of elevator	Recovery (from Item 1)	 TRIM: any	No change, diving spiral should continue
5. Effect of aileron	Entry (Controls applied at 20 - 21 units AOA)	 TRIM: any	Initial response: Slow roll in direction of applied aileron Steady-state response: Typical diving spiral in direction of applied aileron after two initial rolls
6. Effect of aileron and rudder combination (Controls applied at 20 to 21 units AOA) A.	Entry and steady state	TRIM: any 	Enter typical diving spiral to right with occasional transition to erect spin for 1 to 3 turns
B.	Entry and steady state	TRIM: any 	Enter diving spiral to right with violent roll oscillations (roll rates up to 200 deg/sec)

Note: Left diving spiral, including control effects, is symmetric to right diving spiral.

exclusion of the inverted spin modes and restriction of erect spin entry to wings level, unaccelerated flight conditions. The technique formulated for this spin simulation was general in nature and could be easily expanded or applied to other flight simulators. The spin simulation underwent testing conducted by engineers, by a spin experienced test pilot from NAVAIRTESTCEN, and by fleet instructor pilots and it was considered representative of the TA-4J airplane erect spin characteristics. User experience indicates the simulation provides worthwhile training in erect spin recognition and recovery procedures. The lack of an inverted spin simulation remains a serious user concern but the instructors consider the inherent predictability of the model as an asset in demonstrating spin characteristics to the student Naval aviator.

Appendix: TA-4J OFT Erect Spin Test Method and Test Conditions

1) Erect spin characteristics consist of two modes: classic erect spin mode and diving spiral mode. Entry into each mode is a function of external fuel quantity and cockpit control position. Typical initial conditions are presented in Table A1. The pilot technique for entering either spin mode is as follows: set longitudinal trim as required by test procedures while remaining stabilized at approximately 150 KIAS; decelerate at approximately 2-5 knots/s by applying aft stick; when AOA reaches 20 to 21 units, smoothly apply full rudder input in the direction of the spin and slowly place the stick full aft followed by the desired lateral stick input.

2) The simulation will exhibit the appropriate poststall gyration followed by the steady-state mode, as outlined in Tables A2 and A3. Once the poststall gyration has commenced, any combination of control inputs can be attempted to observe the effect on spin characteristics (see Tables A2 and A3). The symbology utilized to denote cockpit control positions in the spin test tables is shown in Fig. A1.

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