STRIKING A BALANCE BETWEEN CONFIRMATORY VERSUS EXPLORATORY FLIGHT TEST PHILOSOPHY

[Experiences from Out-of-Control Flight Test of IJT Prototype]

By Wing Commander Maheswar Patel (Retd)
Senior Flight Test Engineer (Fixed Wing)
HAL, Bangalore Complex

List of Abbreviations

AOA	Angle of Attack
AOS	Angle of Side Slip
ARDC	Aircraft Research and Design Centre
ASR	Air Staff Requirements
ASPS	Anti Spin Parachute System
BAE	M/s British Aerospace Engineering
BAR	M/s Bhirle Applied Research Inc
CSFO	Counter Surface Force Operation (CSFO)
HAL	Hindustan Aeronautics Limited
IJT	Intermediate Jet Trainer
IYMP	Inertia Yawing Moment Parameter
CSFO	Counter Surface Force Operation
SVXR	Shifted Vertical Extended Rudder
TPV	Tail Plane Vane
SVF	Side Ventral Fin
LHS	Left Hand Side
PDG	Post Departure Gyration
PSG	Post Stall Gyration
RHS	Right Hand Side
SAMF	Side Area Moment Factor
URMC	Unbalanced Rolling Moment Coefficient
TDPF	Tail Damping Power Factor

List of Tables

List of Figures

List of Appendix

1. **Introduction.**

1.1 The present trends and advances in science and technology suggest that sometime in the future all military aircraft will be spin and departure proof. Till then training requirements for recovery from spin or any other out of control flight event will be an integral part of military pilots' training curriculum. Thus, in the requirements specified for the Hindustan Jet Trainer (HJT-36) for fulfilling the need of Intermediate Jet Training (IJT) of the Indian Air Force, the requirements for intentionally spinning the aircraft for up to six turns to either side is one of the important decisive factors.

1.2 The advances in past decades have made flight test of prototype aircraft more of a validation or confirmatory task especially in controlled flight regimes. The aircraft behavior in terms of handling and performance is invariable predicted and in flight test, the same is validated or confirmed. Hence, Predict-Test-Validate has invariable been the philosophy of flight testing in controlled flight regimes. When, the same philosophy is adopted for out of control non linear flight regimes such as spin, Post Departure Gyration (PDG), Post Stall Gyration (PSG) after conducting necessary ground tests such as Rotary Balance, Force Oscillation and high AOA wing tunnel tests; to some extent, predictions about the aircraft behavior can be made. However, the level of confidence and fidelity of such predictions and simulations are available to a much reduced extent. When large deviations between the aircraft behavior from predicted one in the out-of-control flight or in an intentional spin is experienced, major and minor aerodynamic, inertia and control fixes are tried out. In such cases following the Predict Test Validate philosophy by looping back to prediction after repeating the Rotary Balance, forced oscillation and high AOA tests are not always feasible. Hence, a balance between confirmatory and exploratory flight test is necessary in such out of control flight test campaigns.

1.3 The aerodynamic, mass and moment of inertia configuration of HJT-36 was not principally designed with sole focus on intentional spinning. Once the design and development of the prototype was done and initial flight tests commenced, the prediction of departure, spin and recovery characteristics of the first aircraft configuration were analyzed and tested in vertical wind tunnel. As a result of flat and fast modes predicted; various spin fixes were tried to make the spin somewhat acceptable. This had been done prior to stall and departure flight evaluation. After the first violent and catastrophic out of control flight events during stall testing, the departure and spin prediction were revisited. High AOA wind tunnel tests and Rotary balance tests were undertaken to better predict the aircraft stall, departure and spin behavior with various aerodynamic and inertia fixes. After that, stall and departure testing recommenced. After another unexpected and unacceptable aircraft departure event, the aircraft configuration underwent major change with Shifted Vertical and Extended Rudder (SVXR). The high AOA wind tunnel, forced oscillation and rotary balance tests were repeated. Subsequently, the departure and spin testing started to show some promise. The subsequent paragraphs present the ongoing experiences in flight testing the HJT-36 prototype for stall, departure and spin in various configurations. Despite the six degree of freedom and pilot in loop simulation model not being perfect, the prediction was gainfully utilized to not only undertake flight testing safely and efficiently, but also some minor fixes to the aircraft could be explored successfully to make the aircraft spin behavior more acceptable.

2. **HJT-36 Stall and Spin Flight Test Experiences**. The relevant aspects of confirmatory versus exploratory flight testing of the HJT-36 aircraft in stall and post stall angle of attack regime in three different aerodynamic configurations is discussed in the succeeding paragraphs. As on date six turns spins to both the sides have been demonstrated on the HJT-36 aircraft.

2.1 IJT Aerodynamic Configuration Relevant to Stall and Spin. The HJT-36 Intermediate Jet Trainer (IJT) ac is intended to replace the Kiran Mk-I and Mk-II jet trainer as per the Air Staff Requirement (ASR) 01/99. The primary role specified is intermediate stage jet training in primary role and Counter Surface Force Operation (CSFO) in secondary role. The tandem seating arrangement, rear cockpit vision and other main performance requirements such as max speed of 0.75mach/ 750 Kmph CAS, max altitude of 9 Km, maximum external load carrying capacity of 1000kg are the main design drivers. The leading particulars of the aircraft are listed in Table 1 below. Looking at the absence of wing twist and rudder surface positioning, it can be realized that the stall and spin requirements may not have been the dictating design drivers at the preliminary stage of aircraft design. It was probably thought that after the satisfactory design of the aircraft to meet other important performance and role requirements, minor aerodynamic and configuration fixes can be put in place to achieve the desired stall and spin characteristics.

Table 1. Leading Particulars of HJT-36 Intermediate Jet Trainer

Sl No	Parameter	Value	Unit
01	AUW at NTC	4250	Kg
02	Wing Reference Area	18	m^2
03	Reference Span	10	m
04	Reference Aspect Ratio	5.556	
05	Mean Aerodynamic Chord	1.9185	m
06	Root Chord	2440	mm
07	Taper Ratio	0.3846	
08	Thickness to Chord Ratio	15 at root and 12 at Tip	%
09	LE Sweep back	15.6	deg
	Seep at 0.25 c	11.3	deg
10	Dihedral Angle	2	deg
11	Twist Angle	0	deg

2.2 IJT Stall and Spin Requirements. The requirements are specified by the Indian Air Force as per Air Staff Requirement (ASR) 01/99 as follows.

2.2.1 Stall Requirements. An unmistakable natural stall warning commencing 10% above stall speed in level flight, docile behaviour accompanied by a distinct nose drop without any excessive wing drop are the major requirements of aircraft stall characteristics as stipulated in the ASR.

2.2.2 Spin Requirements. The ASR stipulates that the aircraft should be capable of demonstrating intentional spin upto six turns to both sides with pro-spin control input and recover safely thereafter. The spin behaviour should be predictable and consistent with rates of rotation less than 120 deg per sec. Oscillation in pitch must be less than $\pm$ 10 deg and that in roll should be less than $\pm$ 20 deg. Recovery should be prompt and consistent with conventional anti spin controls. From a 2 turn spin, ac should recover within one turn. Controls free, the aircraft should recover within two turn. Total height loss in two turn spin from entry to dive pull out should be less than 1.5 Km. It should be possible to recover from inverted spin safely. The applicable standard were Mil-F-8785c, Mil-S-83691 and Mil Std 1797-A. As the development progressed these Mil standard were superseded by MIL-STD 1797-B and hence this was applied in most cases. In some cases for control stretch and control forces, the applicable Def Stan is made applicable.

2.2.3 All requirements seems fair except for the spin motion so smooth for the oscillation to be contained within $\pm$ 10 deg in pitch and $\pm$ 20 deg in roll. Such, non oscillatory spins are the hallmark of a more perfectly balanced developed spin from which the chances of recovery are less in comparison to a oscillatory spin. The true spirits of an out of control spin training are considered appropriate from a moderately oscillatory spin. Albeit, the requirement of a control free recovery remains patent even in such cases. If the spin is stabilized more and more in roll and pitch, the ability for the aircraft in general to recover control free most likely could diminish in most cases.

2.3 Aircraft Configurations. Three major aerodynamic configurations have been flight tested for stall/spin, until demonstration of six turn spin has been achieved without the use of the onboard Anti Spin Parachute System (ASPS) presently.

2.3.1 Configuration -1 [Basic]. Before stall flight testing and incorporation of stall fixes, the spin fixes installed on the aircraft were two side mounted nose strakes and two side ventral fins [Configuration – 1 [Basic]]. In addition to this, various stall fixes were tried on the aircraft without any concrete result till Apr 2011. In 28 Apr 2011 on PT-1 aircraft, during stall flight testing in approach configuration, the aircraft departed and entered into a PDG from which there was no recovery. The investigation into the crash concluded that the excessive control stretch prevented the pilot to apply intended recovery control.

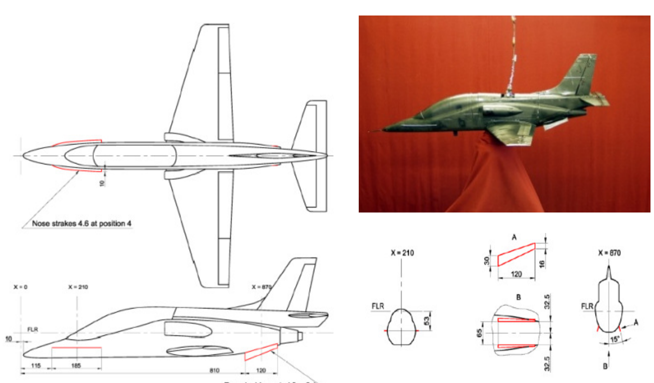


Fig 1. AC Basic Configuration Flight Tested

Albeit consultancy were sought from M/s BAE Systems to suggest aerodynamic fixes for acceptable stall and spin fixes without any large scale modification to the existing ac configuration.

2.3.2 Configuration - 2 [Post BAE Consultancy]. Subsequent to BAE consultancy, the side mounted nose stakes were removed due to its adverse effect on stall characteristics of the aircraft. As the stall progressed the stall fixes that were finalized for progressing with departure and spin testing were Extended Chord Fences (ECF) at 65 % half wing span, second set ECF at 38% half wing span, first Breaker Strip (BS) at 38% MAC butted to ECF, second BS at 24% MAC, Tail Plane Vane (TPV) and 100 kg wing tip mass on each wing [Configuration – 2]. As the aggravated stall and intentional spin flight test progressed, few departure events led to the conclusion that this configuration needed major change to achieve intentional stable spin mode with pro-spin control application. The aircraft configuration changed after consultancy from M/s Bhirle Applied Research Inc (BAR).

Fig 2. AC Configuration with Stall Fixes

2.3.3 Configuration -3 [SVXR]. In order to achieve intentional stable spin mode with pro spin controls applied, it was suggested to move the vertical tail aft by 1180 mm and extend the rudder bottom surface. Hence, the Shifted Vertical Extended Rudder (SVXR) came as a major aerodynamic configuration change. In addition to this some other minor fixes such as wing leading edge droop, V nose strake, reduced rudder deflection etc were proposed.

Fig 3. HJT-36 LSP-04 in Pre and Post SVXR Modification

2.4 Empirical Spin Predictions of IJT. The departure susceptibility of the aircraft was predicted in terms of the $C_{n\beta Dynamic}$ and Lateral Control Departure Parameter (LCDP). Additionally, predictions of the aircraft spin and spin recovery characteristics were made from the Side Area Moment Factor (SAMF), Unbalanced Rolling Moment Coefficient (URMC) and Tail Damping Power Factor (TDPF) before the present SVXR configuration change was proposed. The empirically predicted behaviour are listed in table below.

Table 2. Empirical Spin Prediction of HJT-36 Aircraft

Sl No	Configuration	SAMF	URMC	TDPF [*]	Predicted Spin Recovery Characteristics
1	Basic Config-1	0.80	0.0209 – 0.0201	594 x 10^{-6}	Oscillatory, Controls Centre & Satisfactory Recovery
2	Pre SVXR Config-2	0.78	0.0209 – 0.0198	595 x 10^{-}	Oscillatory, Controls Centre & Satisfactory Recovery
3	Post SVXR Config-3	0.65	0.2414	840 x 10^{-}	Mild Oscillatory, Controls Centre & Satisfactory Recovery

[*] Indicated Effectiveness of Anti Spin Rudder and In-spin Aileron

2.5 Ground Tests for Spin Predictions. The wind tunnel tests to predict the aircraft spin characteristics in the above mentioned three configurations are as follows.

2.5.1 Wind Tunnel Tests [Configuration – 1]. Prior to commencement of the stall flight tests, two campaign of wind tunnel test in the vertical wind tunnel tests were done at TsAGI, Zhukovsky, Russia for the basic aircraft configuration [Configuration-1]. This test was done to identify modes in erect and inverted spins, to study recovery controls, for sizing Anti Spin Parachute and effect of various configurations on spin. Steady flat and fast spin mode with intense recovery control (application of roll stick in addition to pitch stick and rudder for certainty of recovery) was predicted for the initial configuration. The side mounted nose strakes and ventral fins were installed on the aircraft as potential spin fixes. The predicted erect spin was with AOA of 62-72 deg with rotation speed of 1.11 to 1.95 rad/sec.

2.5.2 Wind Tunnel Tests [Configuration – 2]. High AOA and rotary balance test at ONERA were conducted to predict stall and spin behaviour of the aircraft with the suggested fixes. Various stall and spin fixes were tested in the wind tunnels.

2.5.3 Wind Tunnel Tests [Configuration -3]. Static, force oscillation and rotary balance tests were undertaken to predict and recommend aerodynamic fixes for achieving a satisfactory erect spin mode that could be consistently and repeatable entered into and recovered from intentionally. During the test it was analyzed that the basic ac either had no stable pro spin mode or had very low spin stability. SVXR provided additional control authority for more stable spin equilibrium. The various changes to aircraft configuration that showed promise after the wind tunnel tests are as follows

(a) Shifted Vertical and Extended Rudder. Shifting of the existing vertical tail by 1180 mm and extending the rudder at the bottom This (SVXR modification) was the most promising baseline configuration.

(b) Wing Leading Edge Droop. (Additional roll damping and roll stability)
(c) V nose Strake. (Prevention of spin mode sustenance at high AOA)

2.6 Mathematical Modeling and Computer Simulation.

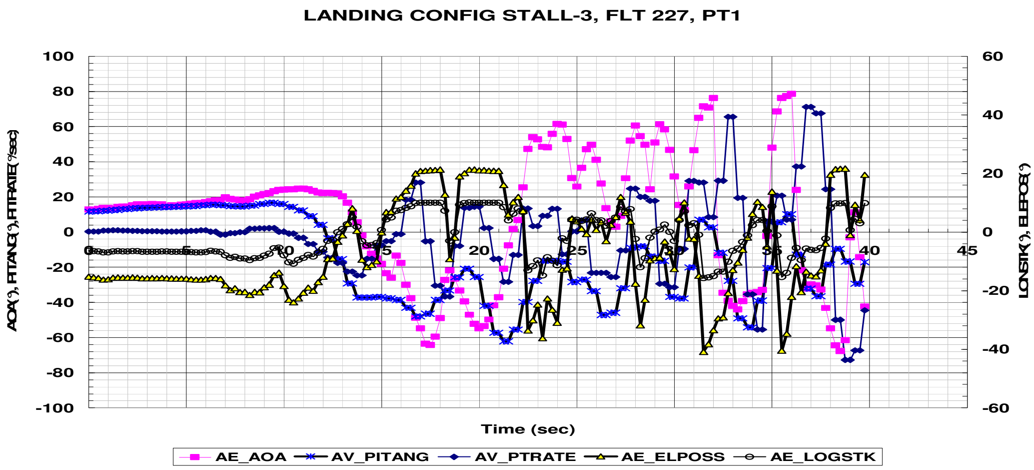
2.6.1 Modeling and Simulation [Configuration – 1]. The predicted behaviour for spin and departure were available only from the vertical wind tunnel tests and empirical predictions. No mathematical modeling and simulations for spin were available.

2.6.2 Modeling and Simulation [Configuration -2]. A mathematical model in MATLAB was made available by BAE systems to investigate the high alpha characteristics of the aircraft to a set of elevator, aileron and rudder control input. The static and rotary wind tunnel tests provided the initial set of aero-dataset for predictions of spin behaviour of the aircraft. This mathematical model was incorporated into the flight dynamics of the IJT simulator by Aircraft Research and Design Centre (ARDC), HAL. With this, the computer simulation with joystick and rudder pedal was used extensively to plan, rehearse and analyze the aircraft spin flight test. As the model supplied by BAE could not be optimized for a better flight response match, HAL made an in-house 6 Degree of Freedom (DOF) model at subsequent stages.

2.6.3 Modeling and Simulation [Configuration – 3]. Based on static, force oscillation and rotary balance tests conducted by BAR, a mathematical model of the post stall flight regime was constructed. This model response was compared against the flight data available so far (before this configuration) of various post stall flight test points. No sustained spin mode was predicted at lower angle of attack for Configuration-2. The aerodynamic coefficient (additional directional stability and yaw damping) that would have to be modified to achieve a stable spin mode at lower angle of attack were identified. In order to achieve such changes various major aerodynamic and inertia modifications were tried. In the modeling and simulation, the SVXR modification demonstrated a repeatable steep oscillatory spin with full rudder and elevator around an average AOA of 30 deg (60 deg pitch down). The recovery from this spin was achieved through centralizing the controls. Addition of the wing leading edge droop smoothened the spin with spin attitude decreasing by 5 deg (35 deg AOA). As the addition of V nose strake, made the aircraft spin motion unsustainable any time AOA exceeded beyond 40 deg, it was predicted that its addition would prevent ac spin motion beyond 40 deg AOA.

2.7 Flight Test Approach during Exploratory and Confirmatory Flight Testing.

2.7.1 Initial Phase of Stall Flight Testing [Configurtion -1], The flight tests for stall had commenced in the year 2010 on the PT-1 and PT-2 aircraft. Various minor fixes such as fences, aileron droop, vortex generator etc were tried on the prototype aircraft. The flight test campaign for stall had commenced without any emergency spin recovery devices. The flight test approach during this period was of incremental exploratory nature. The flight test used to look for pitch down and g break well past the predicted stall AOA until vicious wing drop at AOA more than 20 deg. The approach was purely a suck and see approach. On 28 Apr 2011 during a stall tests in approach configuration, the aircraft departed and never recovered and crashed. The departure and resultant loss of control during 1g level stall flight test in approach configuration was attributed to excessive control stretch [more than the stipulated 20% at maximum load]. Consultancy was recommended for suggesting minor aerodynamic fixes for achieving desired stall and spin fixes.



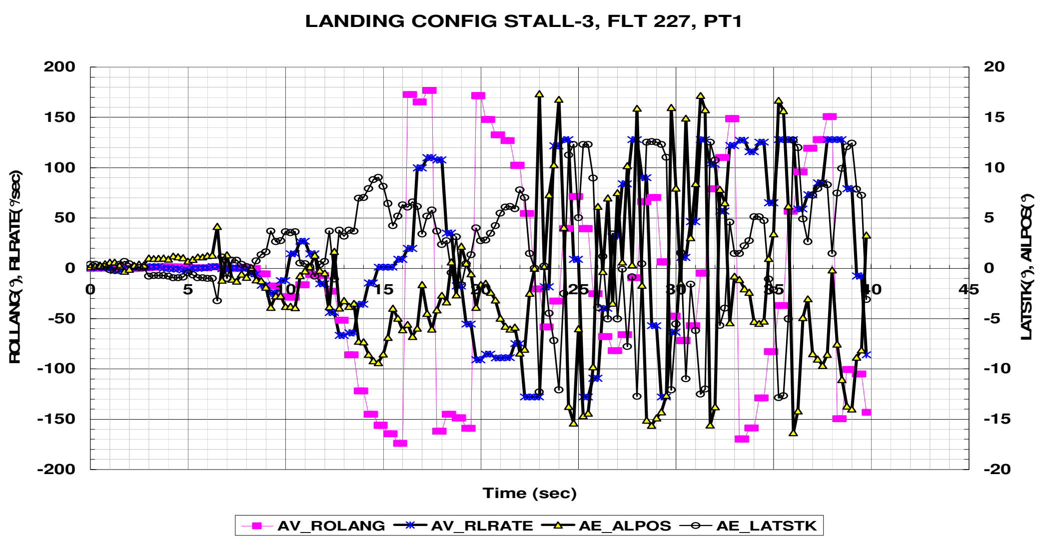


Fig 4. Time History Plot of PT-1 Flight 227

2.7.2 Flight Testing [Configuration -2]. After stiffening of control runs and clearance of ASPS through flight test, high AOA flight tests recommenced with the stall and spin fixes recommended by M/s BAE Systems. A mathematical model was available from the consultant where in the stall, aggravated stall and spin behaviour could be predicted with a given set of pilot input. The initial fixes suggested for stall did not work in flight test out as predicted by the model. Through various wind tunnel tests in HAL's wind tunnel, the position of the BS were optimized and flight tested. Major improvement in the stall characteristics were obtained when the BS was butted to the inner ECF at 38% half wing span. Subsequent stall flight tests after incorporation of two extended chord fences, two breaker strips and tail plane vanes found the 1g level stall characteristics of the aircraft acceptable for progressing with further flight tests for aggravated stall, PDG and spin. As it was intended to develop an aerodynamic configuration that can be intentionally spun, it was considered appropriate not to adopt the flight test phases sequentially as suggested in MIL-1797B for demonstration. After acceptable 1g level stall, aggravated stalls and incipient spin flight test were undertaken. More detailed discussion on this aspects are presented in paragraph 2.7.4 below.

2.7.2.1 In one of the flight, during spin entry attempt; prolonged post departure gyrative motions were experienced with large excursions in AOA, AOS and other flight parameters. During this aircraft neither showed any signs of sustained yaw motion in same direction nor was the AOA consistently above stall. It was noticed that aircraft exhibited a very strong tendency of inverted spin/PDG. Recovery could be achieved by sustained application of aft stick. Hence, it was fairly established that the aircraft in its present configuration did not have a stable erect spin mode. After this departure event, a configuration change was necessitated to achieve a stable erect spin mode. Large deviations were noticed between the aircraft and model predicted response. The time history of the event is presented in the figure below.

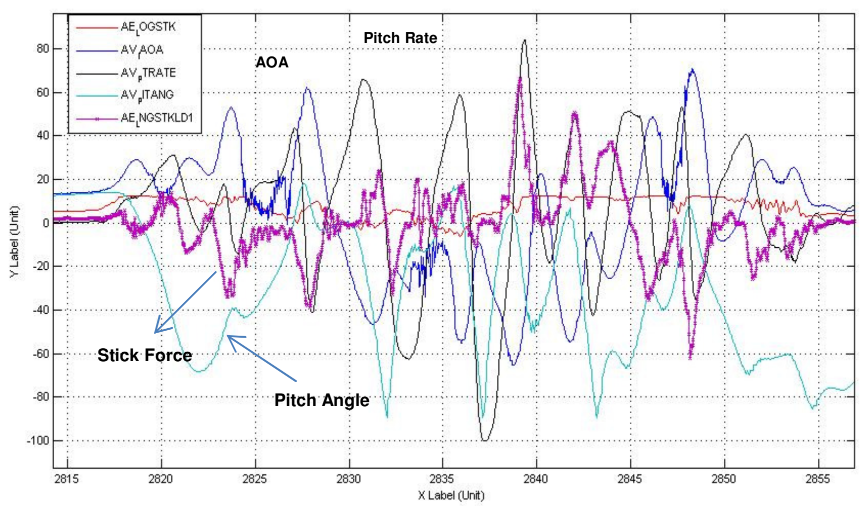


Fig 5. <u>Time History Plot of Departure Event in Pre SVXR Configuration</u>

2.7.3. <u>Flight Testing [Configuration -3]</u>. The flight test campaign re-commenced with the bare SVXR modification as shown in Fig 3 above. Since the earlier ASPS could not be adopted with the SVXR configuration, a new ASPS customized to HJT-36 ac by M/s Airborne System Ltd, was flight tested in two successful deployment in two successive flights. The aggravated stalls with briefly and grossly misapplied controls from level and turning flights were flight tested to assess the departure resistance. Subsequent to this, various entry techniques for intentional spin from level and turning flight were evaluated. Initial flight evaluation began with entry attempts to both side and from both the cockpits. As the duration and no of turns increased larger deviations between flight and model response were noticed. As a result of this; more cautious approach was adopted for further flight testing as it was a compromise between confirmatory and exploratory high AOA testing.

2.7.3.1 Contrary to the predictions, the 3 turn LHS and RHS spin on the basic SVXR configuration were highly oscillatory (especially in roll) accompanied by aircraft un-stalling more frequently during spin. Hence, the second fix suggested by M/s BAR i.e wing leading edge droop was flight tested. This fix although reduced the oscillation, it could not address the issue fully to an acceptable level. By this time; it was fairly established that the aircraft tended to exhibit more willingness to spin to the left. Also it was observed that the most consistent/efficient spin entry was from stall with elevator followed by rudder.

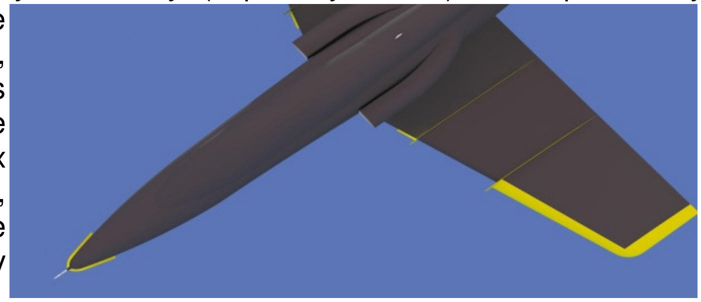


Fig 6. Wing Droop and Nose Chine on Basic SVXR Configuration

2.7.3.2 Subsequently, the pilot in loop simulation in various combinations of elevator and rudder control deflections were tried to achieve a smoother spin so that progress towards six turns spin could be made safely. As a result of these studies on the pilot in loop simulator, the elevator and ruder deflections were reduced from 30/18 to 24/14 degree respectively. As the aircraft showed more willingness to spin to the LHS, the six turn spin to left hand side were first demonstrated on the SVXR configuration with wing leading edge droop and reduced control deflection.

2.7.4 As the spin fixes suggested so far were not working to an absolute extent to reduce the oscillations, additional spins fixes such as Fuselage Nose Chine (FNC), Central Ventral Fins (CVF) and removal of existing fixes (TPV and SVF) were studied in-house by ARDC, HAL. As the dynamic and rotary balance test could not be undertaken for these configurations with minor aerodynamic fixes, the static wind tunnel tests were undertaken at HAL's static wind tunnel. The significant changes in aero dynamic and control derivatives were only plugged into the mathematical models for predicting the response (either leaving aside the dynamic derivatives as it is in some cases or altering them based on empirical calculations in few other cases). Flight tests with nose chine indicated significant improvement in aircraft spin behavior [Flight test done with model prediction with Cnb and Cma change only]. As predicted by the model, the oscillation in AOA and rotation rates reduced significantly. With this configuration, the six turn spins to both sides were demonstrated, consolidated and validated. The plots of the ac spin behavior and predictions are placed at figures below.

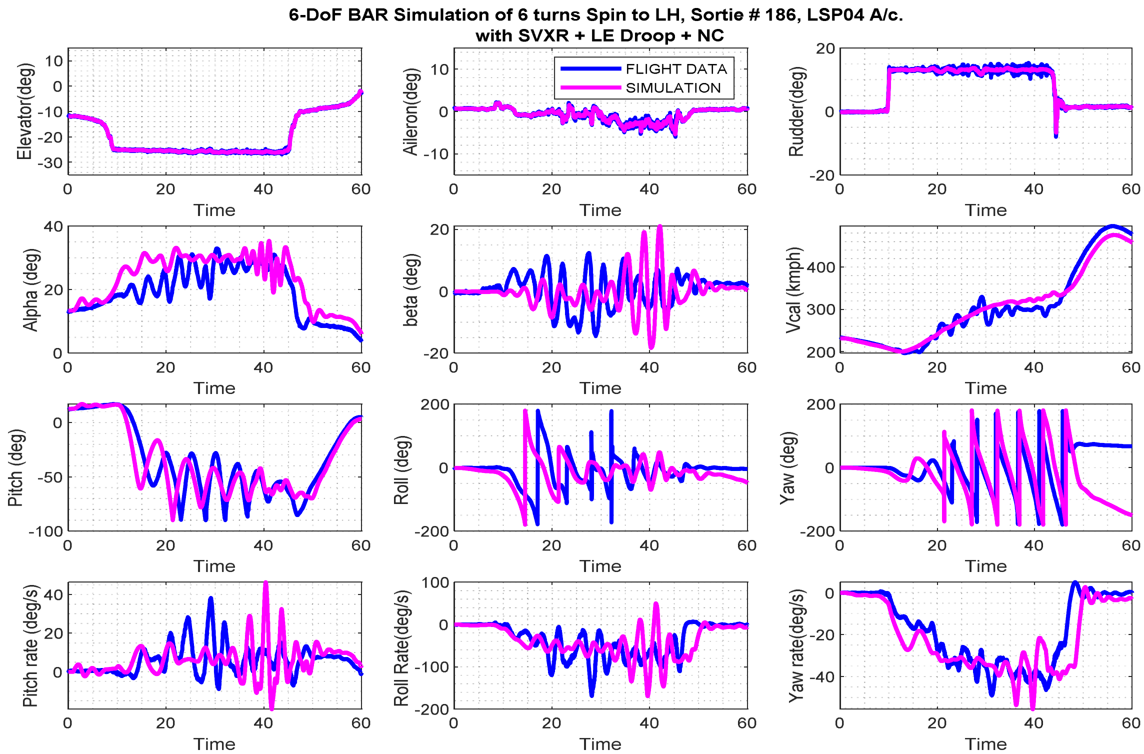


Fig 7. Simulation vs Flight Response LHS 6 Turn Spin

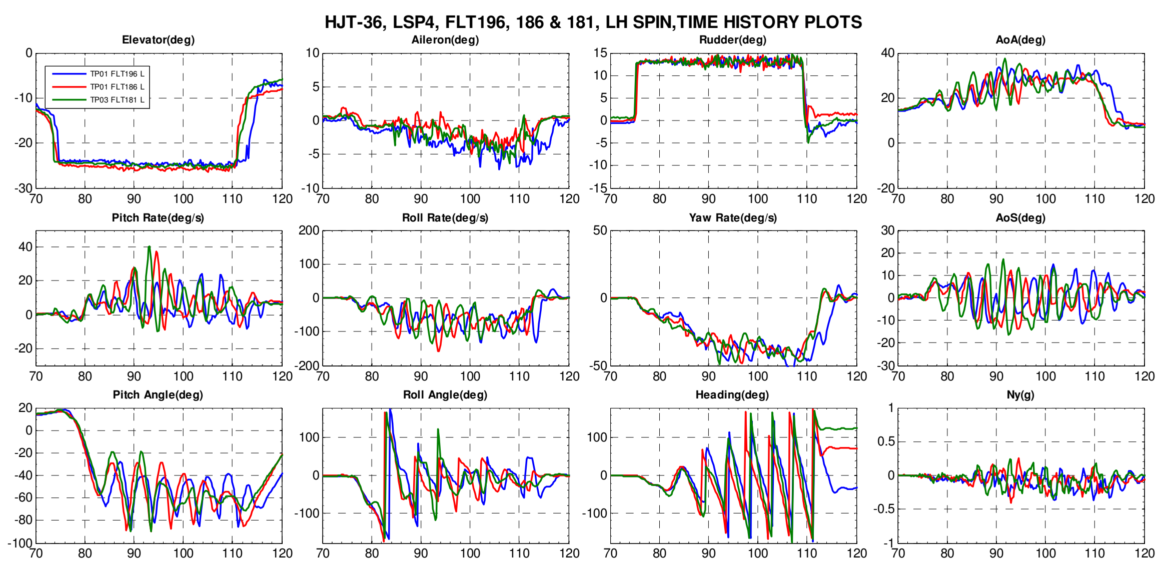


Fig 8. <u>Six Turn Spins to LHS on HJT-36 Aircraft with ASPS in Three Different Flights</u>

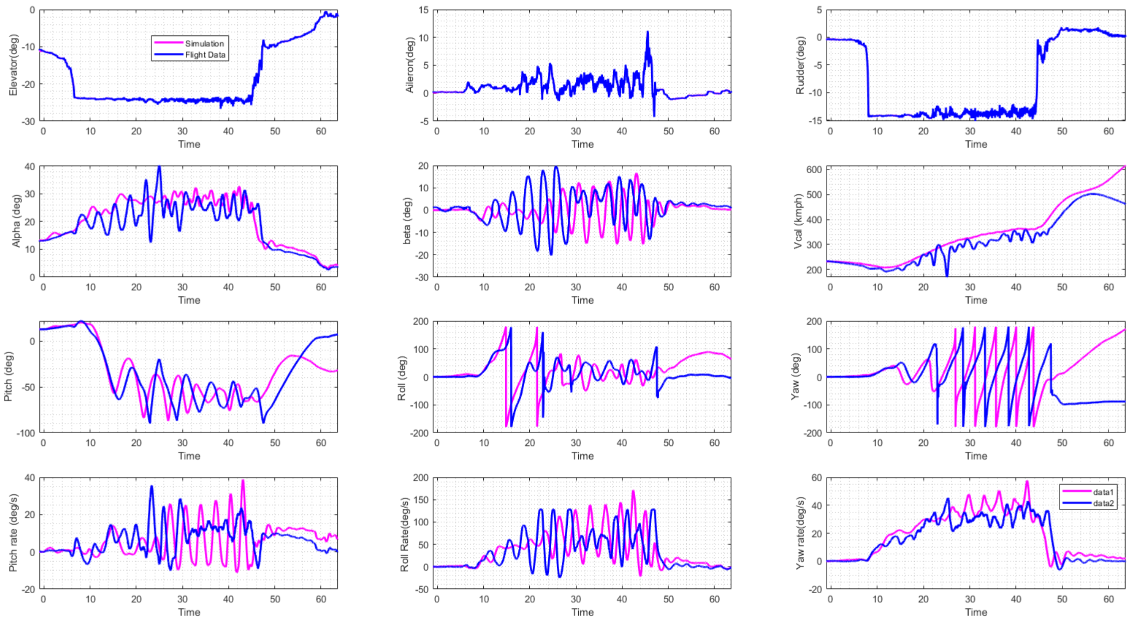


Fig 9. Simulation vs Flight Response RHS 6 Turn Spin

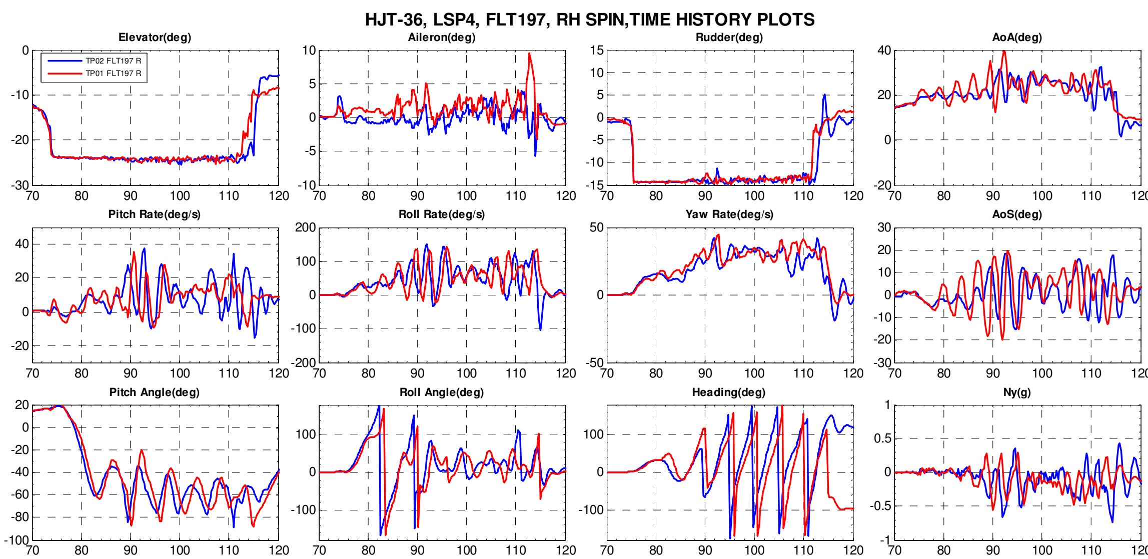


Fig 10. Six Turn Spins to RHS on HJT-36 Aircraft with ASPS

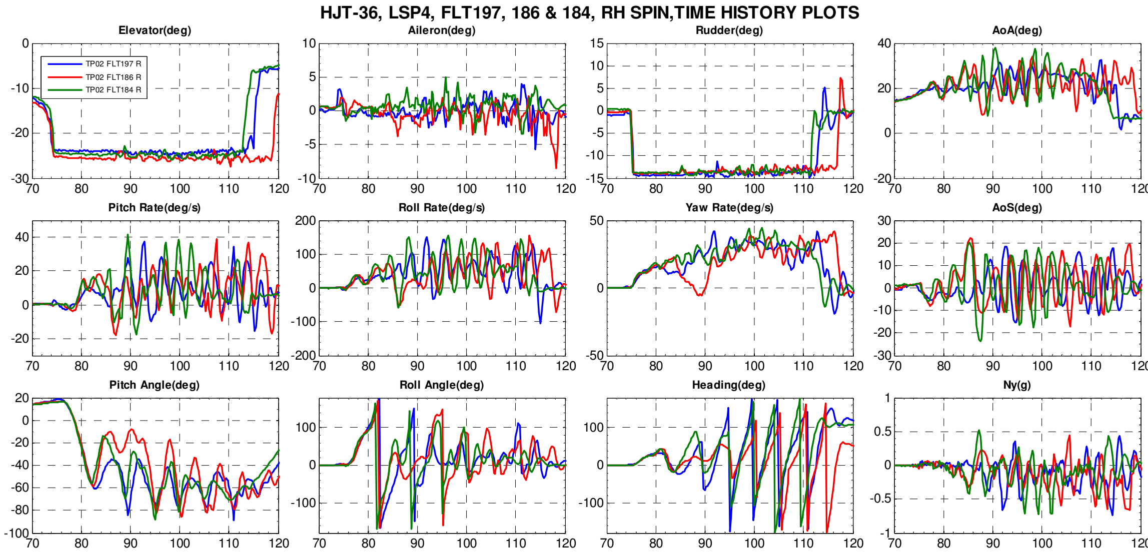


Fig 11. <u>Six Turn Spins to RHS on HJT-36 Aircraft with ASPS in 3 Flights</u>

2.7.3.4 As the TPV and SVF were legacy fixes put on the successful SVXR configuration, its presence needed to be reaffirmed. Model predictions based on static wind tunnel tests at HAL indicated that the spin could remain somewhat indifferent to their presence or absence. Hence, flight test were undertaken with a cautious approach with the TPV and SVF removed. However, it was noticed that the absence of TPV made the latter half of a six turn spin more oscillatory. With the absence of SVF, the spin AOA increased by 5 deg and oscillation increased. On the RHS, reversal in roll and yaw were experienced without the SVF. Thus, the TPV and SVF are put back on the aircraft and decision to remove the ASPS has been made. The various aircraft configurations flight tested for stall and spin after SVXR modifications are listed in Table X below.

Table 3. <u>Configurations Flight Tested for Intentional Spin Flight Tests</u>

SI No	Configuration	No of Spin Turns Tested to	Flight No	Result
0	SVXR Basic with ASPS	--	116-117	ASPS Trials
1	SVXR Basic	3T LH and RH	118-148	3T LH and RH
2	SVXR with Wing LE Droop	3T LH and RH	149-160	3T LH and RH
3	SVXR+Wing LE Droop + Reduced Elevator and Rudder Deflection	6T LHS with ASPS	161-178	Highly oscillatory 6T to LHS demonstrated first time
4	SVXR+Wing LE Droop + Reduced Elevator and Rudder Deflection + Nose Chine	6T LHS and 6T RHS with ASPS	179-186	Acceptable 6T LHS and RHS Spin with ASPS

5	SVXR+Wing LE Droop + Reduced Elevator and Rudder Deflection + Nose Chine without TPV-5	6T LHS and 6T RHS with ASPS	187-191	4T Stable Initial Spin; lateron becoming oscillatory.
6	SVXR+Wing LE Droop + Reduced Elevator and Rudder Deflection + Nose Chine without TPV-5 and SVF	6T LHS and 2T RHS with ASPS	192-195	Departure and Reversal in spin to RHS and Higher oscillation to LHS
7	SVXR+Wing LE Droop + Reduced Elevator and Rudder Deflection + Nose Chine	6T LHS and 6T RHS with ASPS	196-197	Confirmation and Validation before ASPS Removal

2.7.3.5 Different Flight Test Approach Followed for Spin Development. The flight test phases prescribed in MIL-STD-1797B 9Table 2 of Appendix A] for demonstration could not be followed in sequence for development of a satisfactory aircraft configuration for the HJT-36 ac for intentional erect spin. The flight test for the aircraft is divided into two stages namely developmental and certification. During the developmental stall and spin stage, the objective is to develop an aerodynamic configuration that is capable of intentional erect spin. Once, a satisfactory 1g stall and intentional erect spin configuration is achieved both with and without ASPS, the flight tests for the requirements of the certification stage can be taken up. Hence, the stall and departure and spin assessments from abrupt AOA rate and from tactical maneuvers are planned during certification flight tests once Phase A to D flight test during the developmental stage is completed with and without ASPS. A suggested approach with modifications to the requirements given in MIL-STD-1797B is placed at Table 1 of Appendix A.

3. Conclusions

3.1 The flight response of an aircraft to a pro spin control can be predicted and modeled to a fair degree of fidelity after static, force oscillation and rotary balance tests in the wind tunnel. Though the prediction could be gross, it is considered fair to progress with flight test in a cautious and incremental manner. As the flight test progresses, the flight test data could be utilized to increase the model match. However, in order to further improve the aircraft flight response to pro-spin control input, there was a need in the HJT-36 aircraft to alter aerodynamic configuration through minor fixes and change in maximum control deflections. As the dynamic and rotary balance test could not be undertaken for these configurations with minor aerodynamic fixes, the static wind tunnel tests were undertaken. The significant change in static aero dynamic and control derivatives were only plugged into the mathematical models for predicting the response (either leaving aside the dynamic derivatives as it is in most cases or altering them based on empirical calculations in other cases). Further, flight tests on the HJT-36 aircraft with reduced pro-spin control deflections, nose chine installation, removal of side mounted tail plane vanes and side ventral fins demonstrated that such approach of striking a balance between confirmatory and exploratory flight test philosophy was the most efficient approach for achieving a desirable intentional erect spin characteristics on the IJT aircraft.

3.2 The HJT-36 aircraft was to be intentional spun. Hence, achieving acceptable spin characteristics through aircraft configuration changes was a primary developmental task. Thus, the flight test phases outlined in Mil-std 1797B for flight demonstration could not be followed sequentially during development. The erect spin modes were first established upto a maximum six turns to the side that the ac was more willing to sustain i.e to LHS. Once, the aircraft spin mode was somewhat established safely and consistently to this side, the behavior to other side were explored more safely and efficiently. Introduction of nose chine on the HJT-36 aircraft reduced oscillation and made the difference in LHS and RHS spin lesser. The flight test phases for development of a satisfactory ac configuration for intentional spinning needed to be different than the one prescribed in military standard for demonstration. The flight test phases for developmental out of control flight test for trainer ac need consideration for presence and absence of emergency spin recovery system. A suggested approach for flight test phases for the out of control flight test of trainer class of aircraft that are to be intentionally spun is placed at Appendix A.

References

1. Modeling and Evaluation of Configuration Updates for the Hindustan Aircraft Limited HJT-36 Trainer Aircraft by John Ralstom, Bihrle Applied Research, Inc dated May 2018.

2. Review of Empirical Studies on Spin and Recovery Characteristics of HJT-36 Aircraft HAL/ARDC/HJT36/ADY/109 dated 22/05/2015

3. BAE Systems Aerodynamic Support to Hindustan Aeronautics Limited Covering the HJT-36 Intermediate Jet Trainer Studies, Analysis and Results of the Rotary Balance Test Data, Report No: BAe-BAE-RP_GEN_5331, Issue-1, Dated, 24th September 2014.

4. Development of 6 Degree of Freedom Flight Dynamic Model and its validation against BAE Model, Report No. HAL/ARDC/HJT36/FM/008, Issue: Nil, dated 09 May 2015.

5. MIL-STD-1797-B 15 February 2006 on Flying Qualities of Piloted Aircraft.

Appendix A

SUGGESTED FLIGHT TEST PHASES
FOR DEVELOPEMENTAL AND SPIN CERTIFICATION OF AN AIRCRAFT TO BE SPUN INTENTIONALLY

Table 1. Flight Test Phases for Developmental and Certification Stages

Test Phase	Control Application	Category	Maneuver Requirements
DEVELOPEMENTAL STAGE			
A Stalls	Pitch control applied to achieve the specified AOA rate. Roll. yaw. and decoupled' control inputs as normally required for the maneuver task. Recovery initiated after the pilot has a clear indication of. a) a definite g break, or b) a rapid_ uncommanded angular motion. or c) the aft stick stop has been reached and AOA is not increasing. Or d) sustained intolerable buffet For those air vehicles where clear indications of stall are not evident and where the minimum permissible speed is other than the stall speed. recovery may be initiated somewhat beyond the arbitrary limit(s).	A and B	Entry conditions:. 1) One-g stall with smooth AOA rate: 2) Accelerated. s tall with smooth AOA rate
		C	Entry conditions: 1) One-g stall with smooth AOA rate
B Stalls with aggravated control inputs	Pitch control applied to achieve the specified AOA rate. Roll. yaw. and decoupled control inputs as normally required for the maneuver task. When conditions a). b). c). or d) from above have been attained controls briefly misapplied, intentionally or in response to unscheduled air vehicle motions. before recovery Is initiated.	A and B	Entry conditions. I) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate
C Stalls with aggravated and sustained control inputs	Pitch control applied to achieve the specified AOA rate, Roll, yaw and decoupled control inputs as normally required for the maneuver task. When conditions a), b). c). or d) from above have been attained controls are misapplied. intentionally or in response to unscheduled air vehicle motions. and held for 3 sec before recovery attempt is Initiated	A and B	Entry conditions. I) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate
D Post-Stall Gyration / Post Departure Gyration / Spin	Pitch control applied to achieve the specified AOA rate. Roll, yaw and decoupled control inputs as normally required for the maneuver task. When conditions a), b). c). or d) from above have been attained.. controls applied in the most critical manner to attain each possible mode of past-stall motion and held for various lengths of time up to 15 sec or 3 fully-developed spin turns or maximum number of turn required for certification whichever occurs later. before the recovery attempt is initiated	A and B	Entry conditions 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate

CERTIFICATION STAGE			
A Stalls	Pitch control applied to achieve the specified AOA rate. Roll. yaw. and decoupled' control inputs as normally required for the maneuver task. Recovery initiated after the pilot has a clear indication of. a) a definite g break, or b) a rapid_ uncommanded angular motion. or c) the aft stick stop has been reached and AOA is not increasing. Or d) sustained intolerable buffet For those air vehicles where clear indications of stall are not evident and where the minimum permissible speed is other than the stall speed. recovery may be initiated somewhat beyond the arbitrary limit(s).	A and B	Entry conditions:. 1) One-g stall with abrupt AOA rate' of at least 8°/sec 2) Accelerated stall with abrupt AOA rate of at least 8°/sec 3) Tactical[6]
		C	Entry conditions:. 1) Accelerated stall with smooth AOA rate
B Stalls with aggravated control inputs	Pitch control applied to achieve the specified AOA rate. Roll. yaw. and decoupled control inputs as normally required for the maneuver task. When conditions a). b). c). or d) from above have been attained controls briefly misapplied, intentionally or in response to unscheduled air vehicle motions. before recovery Is initiated.	A and B	Entry conditions:. 1) One-g stall with abrupt AOA rate of at least 8°/sec 2) Accelerated stall with abrupt AOA rate of at least 8°/sec 3) Tactical
		C	Entry conditions. 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate
C Stalls with aggravated and sustained control inputs	Pitch control applied to achieve the specified AOA rate, Roll, yaw and decoupled control inputs as normally required for the maneuver task. When conditions a), b). c). or d) from above have been attained controls are misapplied. intentionally or in response to unscheduled air vehicle motions. and held for 3 sec before recovery attempt is Initiated	A and B	Entry conditions. 1) One-g stall with abrupt AOA rate of at least 8°/sec 4) 2) Accelerated stall with abrupt AOA rate of at least 8°/sec 3) Tactical
D Post-Stall Gyration / Post Departure Gyration / Spin	Pitch control applied to achieve the specified AOA rate. Roll, yaw and decoupled control inputs as normally required for the maneuver task. When conditions a), b). c). or d) from above have been attained.. controls applied in the most critical manner to attain each possible mode of past-stall motion and held for various lengths of time up to 15 sec or 3 fully-developed spin turns whichever occurs first, before the recovery attempt is initiated .	A and B	Entry conditions 1) One-g stall with abrupt AOA rate of at least 8°/sec 2) Accelerated stall with abrupt AOA rate of at least 8°/sec 3) Tactical

Table 2. Flight Test Phases for Stall, Departure and Spin Demonstration as per MIL-STD-1797B

For Class IV air vehicles which do not employ AOA limiting devices:

Test Phase	Control Application	Flight Phase Category	Maneuver Requirements
A Stalls	Pitch control applied to achieve the specified AOA rate. Roll, yaw, and decoupled[1] control inputs as normally required for the maneuver task. Recovery initiated after the pilot has a clear indication of: a) a definite g break, or b) a rapid, uncommanded angular motion, or c) the aft stick stop has been reached and AOA is not increasing, or d) sustained intolerable buffet. For those air vehicles where clear indications of stall are not evident and where the minimum permissible speed is other than the stall speed, recovery may be initiated somewhat beyond the arbitrary limit(s).	A and B	Entry conditions[2]: 1) One-g stall with smooth AOA rate[3] 2) Accelerated[4] stall with smooth AOA rate 3) One-g stall with abrupt AOA rate[5] of at least 8°/sec 4) Accelerated stall with abrupt AOA rate of at least 8°/sec 5) Tactical[6]
		C	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate
B Stalls with aggravated control inputs	Pitch control applied to achieve the specified AOA rate. Roll, yaw, and decoupled control inputs as normally required for the maneuver task. When conditions a), b), c), or d) from above have been attained, controls briefly misapplied[7], intentionally or in response to unscheduled air vehicle motions, before recovery is initiated.	A and B	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate 3) One-g stall with abrupt AOA rate of at least 8°/sec 4) Accelerated stall with abrupt AOA rate of at least 8°/sec 5) Tactical
		C	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate
C Stalls with aggravated and sustained control inputs[8]	Pitch control applied to achieve the specified AOA rate. Roll, yaw, and decoupled control inputs as normally required for the maneuver task. When conditions a), b), c), or d) from above have been attained, controls are misapplied[7,9], intentionally or in response to unscheduled air vehicle motions, and held for 3 sec[9,10] before recovery attempt is initiated.	A and B	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate 3) One-g stall with abrupt AOA rate of at least 8°/sec 4) Accelerated stall with abrupt AOA rate of at least 8°/sec 5) Tactical
D Post-Stall Gyration, Spin and Deep Stall Attempts[8] (This phase required only for training air vehicles which may be intentionally spun and for air vehicles in which sufficient departures and developed spins did not result during Test Phases A, B, and C to define characteristics of each possible out-of-control mode)	Pitch control applied to achieve the specified AOA rate. Roll, yaw, and decoupled control inputs as normally required for the maneuver task. When conditions a), b), c), or d) from above have been attained, controls applied in the most critical[11] manner to attain each possible mode of post-stall motion, and held for various lengths of time up to 15 sec or 3 fully-developed spin turns, whichever occurs first, before the recovery attempt is initiated.[9,12]	A and B	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate 3) One-g stall with abrupt AOA rate of at least 8°/sec 4) Accelerated stall with abrupt AOA rate of at least 8°/sec 5) Tactical