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KEEP EAGLE F-15E High Angle-of-Attack Flight Test Program

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The KEEP EAGLE flight test program was conducted from August 1994 until August 1995 at Edwards Air Force Base by a combined government/contractor test team to evaluate improvements to F-15E high angle-of-attack and spin recovery characteristics. This paper traces the program from its inception in 1992 until its conclusion in 1995, with emphasis on the test approach and flight test techniques employed for this high-risk program. Specifically, the test approach included novel assessments of spin recovery control power early in the flight test program using controlled buildups in yaw rate. The program also used simulation effectively to improve test efficiency and maintain test team proficiency with normal and emergency procedures. These techniques allowed a relatively aggressive flight test program without compromising safety. A total of 18 different aircraft configurations were successfully tested, with 146 developed spins completed throughout the course of 81 program flights.

Nomenclature

Ix = moment of inertia, aircraft x axis
Iy = moment of inertia, aircraft y axis
Nx = normal acceleration, aircraft x axis
R = yaw rate, deg/s
R' = yaw acceleration, deg/s^2
α = angle of attack, deg
β = angle of sideslip, deg

Introduction

THE F-15 Eagle first entered operational service with the U.S. Air Force in single-seat A and two-seat B models in the mid-1970s. The developmental flight test program produced excellent high angle-of-attack (AOA) flight characteristics, and included numerous departures and 114 developed spins using a test aircraft equipped with a spin recovery parachute system. An upgrade program concluded in the early 1980s produced single-seat C and two-seat D models that included the capability to carry new conformal fuel tanks (CFTs) mounted on each side of the fuselage under the wing roots. High AOA flight testing of an F-15C model with CFTs confirmed the excellent high AOA characteristics of the airframe and CFT combination. However, although no intentional spins were attempted and a spin recovery chute was not installed, an unanticipated spin was encountered. This spin, which recovered promptly with full recovery controls, was later attributed to the adverse vortex effects produced by the flight test noseboom.

Initial development of the two-seat F-15E model to fulfill both air-to-air and air-to-ground attack roles also began in the early 1980s. Airframe changes for the F-15E included a maximum gross weight increase to 81,000 lb, up nearly 20% from the F-15C and 45% over the original F-15A, with associated moment of inertia changes. The CFTs were also upgraded to an air-to-ground configuration with external stub pylons, and the airframe modified to carry Low Altitude Navigation and Targeting Infrared for Night (LANTIRN) pods, as shown in Fig. 1. Flight control changes for the F-15E included incorporation of a triplex digital system to augment the existing mechanical system, replacing the dual analog system used in earlier F-15 models.

Despite these changes, departure and spin flight testing of the F-15E was not considered necessary during the F-15E full-scale development flight test program conducted from 1986 to 1988. The good history of earlier F-15 models at high AOA, combined with simulator predictions of continued good high AOA characteristics with the F-15E, contributed to this decision. However, after the F-15E became operational in 1989 field pilots began to report differences in F-15E high AOA characteristics, including an increased tendency for roll reversals and departures. Limited high AOA flight testing confirmed these characteristics. Finally, two spin mishaps in September 1991 and August 1992 resulted in the loss of two operational aircraft and two crew members. These events led to a 20-deg α limit for the F-15E configured with CFTs, which significantly restricted the aircraft's air-to-air capability.

The KEEP EAGLE program was initiated in October 1992 by the U.S. Air Force F-15 Systems Program Office and Air Combat Command (ACC) to address these F-15E high AOA issues. Specifically, the dual objectives of the KEEP EAGLE program were to improve the existing F-15 aerodynamic database, and develop and verify high AOA and spin recovery enhancements using a spin chute equipped test aircraft.

Initial Program Activities

Wind-Tunnel Studies

Initial KEEP EAGLE program activity was directed at improving the F-15 high AOA aerodynamic database to provide the most accurate analytical model for flight control design enhancements and test plan development. Free spin, forced oscillation, rotary balance, and fixed wind tunnels were all used to supplement and refine the existing database, and in fact identified that the CFTs reduced roll damping. Wind-tunnel studies also indicated that full recovery controls were required to recover the CFT equipped F-15E above ~60 deg/s yaw rate, and that increased differential stabilator deflection would be an effective spin recovery control effector. Detailed reports documenting the free spin and rotary balance studies are identified in Refs. 1 and 2.

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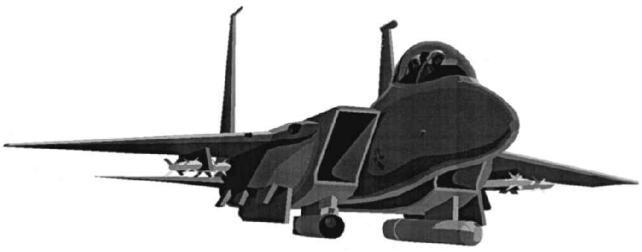

Fig. 1 F-15E external configuration.

Approximately 50% of the test points later collected during the flight test program would be used to verify the aerodynamic database through parameter identification (PID) methods. The time and effort expended early in the KEEP EAGLE program to analytically improve the aerodynamic database significantly improved test safety and efficiency later during conduct of the flight test program.

Flight Control Software Development

Changes to the original F-15E digital flight control system were limited to terrain following and autopilot functions to minimize design and testing requirements. However, with the mandate to improve high AOA capability, the flight control designers were able to fully utilize the potential of the new digital system. The flight control computer (FCC) operational flight program (OFP) developed to improve the F-15E's high AOA characteristics was Version 7.

The F-15E flight control system consists of a limited authority digital triplex control augmentation system (CAS) for the stabilators and rudders, and a high-authority mechanical system for the stabilators, rudders, and ailerons. Prior to the software changes incorporated in Version 7, the CAS contributed very little to lateral–directional flying qualities at high AOA. In fact, the CAS was designed to disengage at yaw rates above 42 deg/s to avoid the possibility of commanding prospin inputs. The mechanical control system was also limited in that it used longitudinal stick position as an estimator of AOA, which allowed pilots to rather easily defeat the lateral control washout features of the flight control system at high AOA. Additionally, the mass property changes in the F-15E airframe and aerodynamic characteristics of the CFTs made the stick position estimator technique less accurate. A significant benefit of the F-15E's digital system was the ability to schedule the control laws with actual AOA, instead of stick position.

The Version 7 designers approached the problem of improving F-15E high AOA flying qualities by implementing new control system feedbacks and control paths. Three new CAS feedbacks to the stabilator were incorporated. These feedbacks were fully active only above 20-deg $\boldsymbol{\alpha}$ to minimize the design, ground, and flight test requirements for the new OFP. The first two feedbacks, sideslip and sideslip rate feedback, were added to the differential stabilator to increase apparent lateral–directional stability and dutch roll damping. The net effects of these two feedbacks were improved departure resistance, reduced wing rock, and improved roll performance above 20-deg α. The third feedback was an inertial pitch coupling term to the collective stabilator. This was added to improve AOA control during rolling maneuvers above 20-deg α, and was needed because of the increased roll and yaw rates available with Version 7.

Version 7 also increased roll control power by adding a command path between the rudder pedals and differential stabilator. Rudder pedal inputs would now command the differential stabilators to move in the direction opposite the commanded roll at high AOA. This created proverse sideslip, which in turn rolled the aircraft in the desired direction.

Finally, Version 7 increased spin recovery control power with a feature called direct electric link (DEL). DEL retained limited CAS control of the differential stabilators after the standard CAS disengaged above 42 deg/s yaw rate. This nearly tripled the differential stabilator available for spin recovery, from 12 to 32 deg, providing a significant boost to the spin recovery control power available with the existing mechanical spin recovery aid, which only allowed full mechanical lateral control authority.

In addition to the FCC OFP changes developed for KEEP EAGLE, an improved departure warning system (IDWS) was also incorporated to provide accurate departure warnings to the aircrew. The IDWS used both aircraft response (α, R, and R') and pilot control inputs (aileron and rudder pedal) to anticipate an impending departure and issue an audible warning to the aircrew.

Test Plan Development

Test Approach

The classic buildup approach to high AOA departure/spin flight testing as identified in U.S. Air Force Military Specification MIL-F-83691B (Ref. 3) provided the basis for KEEP EAGLE test planning. This approach essentially consisted of a buildup in test maneuvers from stalls (phase A), stalls with brief aggravated control inputs (phase B), stalls with 3-s aggravated inputs (phase C), to 15-s aggravated inputs and spins (phase D). However, several important refinements to the military specification approach were made for KEEP EAGLE flight testing, with full government and contractor concurrence.

The aggravated maneuver blocks for phase C and D testing consisted of crossed (opposing) and coordinated (same direction) lateral stick and rudder inputs at AOAs from 10 deg to full aft stick (~40 deg). Recovery criteria for these aggravated maneuver blocks were CAS disengagement as a result of yaw rate, 360 deg of roll, or 15 s of control input. A refinement to the approach described in the specification was achieved by combining the 3 s of sustained aggravated inputs for phase C with the 15 s of sustained aggravated inputs in phase D. Simulator predictions were showing generally benign response with aggravated inputs, and with CAS disengagement as the recovery criteria for either control input duration, test efficiency was improved by combining the maneuvers.

But perhaps the most significant objective of the KEEP EAGLE flight test program was an assessment of the effectiveness of spin recovery control power with DEL, because of the discontinuity between analytical results that had indicated satisfactory spin recovery characteristics, and the two operational F-15E spin losses. The unanticipated spin during F-15C high AOA testing in the early 1980s had also shown that spins were possible despite analytical predictions to the contrary and recovery criteria intended to avoid them. In addition, the test team felt strongly that it was critical from a safety standpoint to identify spin recovery control power and characteristics in a controlled, buildup manner, before attempting other potential departure maneuvers that could inadvertently develop into a spin. The approach developed to ensure that spin recovery control power was evaluated at the appropriate point in test maneuver progression is shown in Fig. 2. A standard phase A through D test sequence would have completed all 1 g and accelerated aggravated maneuvers prior to any intentional spin attempts.

The assessment of spin recovery control power required the use of a yaw rate buildup technique to bridge the gap between the sustained aggravated inputs and developed spins of phase D. This yaw rate buildup approach was achieved by wiring the mechanical spin recovery aid to a special pilot selectable switch in the cockpit. This manual spin switch provided full aileron and mechanical differential stabilator regardless of AOA (or longitudinal stick position), allowing the mechanical spin recovery aid to be used as a spin entry aid. This approach was essentially similar to using a flutter exciter control unit or variable gain flight control feature to generate optimized inputs for other specialized types of flight testing.

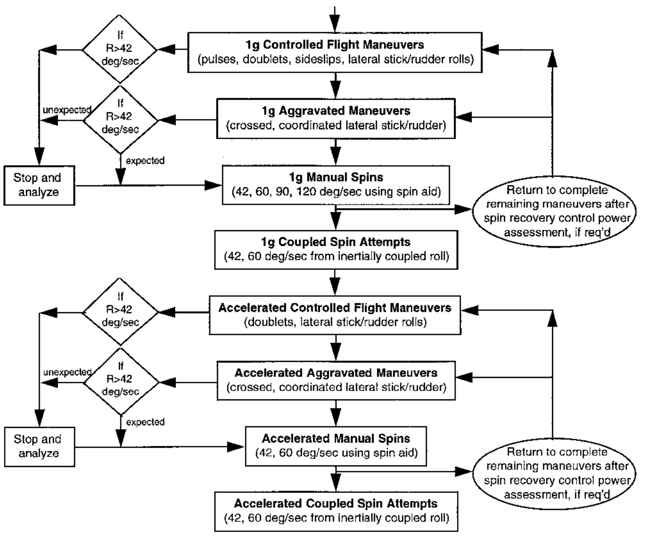

Fig. 2 Departure/spin test approach.

With the manual spin aid activated, rudder was used to generate initial yaw and roll from a 1 g full aft stick stall, then opposite lateral stick (a pro-spin input) was added to generate and control additional adverse yaw into the desired spin direction. Manual spins using the manual spin switch during piloted simulator evaluations (using the latest updated database) indicated controllable spin entries were possible because of the aerodynamic characteristics of the fuselage-loaded ($Iy > Ix$) airframe of the F-15. That is, full aileron and differential stabilator deflections at high AOA were very effective producers of adverse yaw, as opposed to use of the rudder, which is typically the most powerful directional control on a wing-loaded aircraft ($Ix > Iy$). Spin yaw rate targets of CAS disengage (42 deg/s), 60, 90, and 120 deg/s were used. Sustained inverted spins with the F-15 had not been experienced operationally and were not attempted during this test program.

In addition to the obvious interest in spin recovery control power and departure characteristics, standard open-loop flying qualities maneuver blocks were also developed for collection of PID data. These maneuver blocks consisted of longitudinal, lateral, and rudder pulses and doublets; steady heading sideslips; and lateral stick and rudder rolls.

Configuration Buildup

Since the CFTs were not a permanent aircraft installation, it was possible to fly with wing pylons only as the first flight test configuration. This provided a good buildup configuration because of the aerodynamic similarity of the clean F-15E to the F-15A and its excellent high AOA characteristics. CFTs were then added as the next flight test configuration, which represented a typical air-to-air training configuration for field air crews. This was also the configuration in which the two operational F-15Es were lost to departures/spins.

Subsequent flight test configurations added various combinations of air-to-air missiles, lateral weight asymmetries, LANTIRN pods, and external fuel tanks. Configurations were sequenced based on lateral–directional stability considerations and ACC operational priorities.

Test Aircraft Preparations

The test aircraft used for KEEP EAGLE flight testing was the first F-15E built, F-15E no. 1. The spin chute design installed on E-1 was based on the chute system successfully used during the F-15A spin program. This design used a 33.5-ft ringslot canopy on a riser that positioned it 100 ft aft of the aircraft. Deployment was through a tractor rocket that pulled the chute canister aft of the aircraft, with the chute deploying from the canister. The design was strengthened because of the heavier weight of the F-15E model and to account for higher pull-off angles associated with higher anticipated yaw rates.

No backups for standard aircraft hydraulic or electrical systems were considered necessary for KEEP EAGLE testing because of the excellent history of the F-15s F100 engines at high AOA and the redundancy provided by two engines. Inflight starts of both the jet fuel starter and engines were performed to verify that these systems met the airstart minimums defined in the flight manual. A special digital electronic engine control (DEEC) software load was also installed in the right engine, whereas the left engine retained the production DEEC load to obtain production representative results. The special DEEC software load had previously been developed for high AOA testing on the F-16 and increased the stall margin of the engine to lessen the chance of compressor stall under the inlet distortion conditions anticipated for high AOA maneuvering.

The flight control surfaces were rigged per technical order procedures and checked periodically throughout the program to ensure they remained within operational limits. Special attention was also paid to the gun bay, since previous high AOA evaluations had indicated that the gun bay configuration and exhaust vent near the right wing leading edge had an effect on high AOA symmetry. The production gun and ammo feed system could not be installed in the test aircraft because of instrumentation installations, but the gun exhaust louvers were left open and the gun muzzle port was plugged to resemble the production configuration as closely as possible.

Because of adverse and nonproduction forebody vortex effects seen during F-15C high AOA testing (including the unintentional spin), a noseboom was not installed during this testing. AOA and sideslip measurements were obtained from the aircraft's inertial navigation system, with a secondary source of sideslip obtained from a sideslip chin vane installed on the lower surface of the forward fuselage in place of the radar altimeter antenna. Finally, an additional chest restraint was added to both ejection seats to provide additional aircrew restraint during high yaw rate or other violent high AOA maneuvers.

Flight Test Results

General

After verification testing of the spin recovery parachute and other aircraft systems including regression testing of the new Version 7 FCC OFP, KEEP EAGLE high AOA flight testing began in August 1994 and spanned 12 months, 81 flights, and 170 flight hours. Overall, F-15E high AOA flying qualities with the Version 7 enhancements were excellent, with significant improvement in controllability and reductions in wing rock, roll hesitations, and roll reversals. Also, with 5000 ft-lb or less of lateral weight asymmetry and without a centerline fuel tank, the aircraft was extremely resistant to departures and spins. With 10,000 ft-lb of lateral asymmetry and in configurations with a centerline tank, departure resistance degraded somewhat, but the aircraft was still considered resistant to departure. Testing also indicated that the aircraft could still depart in the lower AOA range between 5–20-deg α, where the Version 7 control laws were not active. In particular, the aircraft would reliably depart and spin in any configuration with sustained misapplication of lateral stick in an inertially coupled roll entered near 15-deg α. However, departures and spins could only be developed by ignoring the IDWS tone for several seconds or more.

Spin recovery was excellent in all configurations and from all entries. A total of 146 developed spins were completed throughout testing, with the manual spin technique used very effectively to generate controlled yaw rate buildups. The highest yaw rate obtained during testing was 133 deg/s during a 8.5 turn-right spin, with three of those turns used for recovery. All spins consistently recovered in less than three turns and 5000 ft and the spin recovery parachute was never required.

The aircraft did exhibit a strong right bias during both controlled maneuvers and departures, with noticeably higher roll and yaw rates to the right. This characteristic was considered production representative and was principally attributed to the pressure differential from the gun exhaust vent located near the leading edge of the right wing root. Left spins above 60 deg/s yaw rate could not be achieved, despite efforts to increase yaw acceleration in the spin through inertial coupling by forward stick movement. Left spins were also much more oscillatory, which prevented yaw rate stabilization. The following aircrew comments summarize the spin characteristics for right and left spins:

> (Right) spin entries were typified by a relatively slow yaw rate build-up through CAS disengage. After CAS disengage the yaw rate acceleration increased slightly until approximately 60 deg/sec. Above 60 deg/sec the yaw rate took off aggressively to around 90–100 deg/sec where it stabilized with ±5 deg/sec oscillations. Spin recovery controls were very effective with a steady decrease in yaw rate occurring immediately with lateral stick input. The yaw rate would steadily decrease until around 60 deg/sec where the yaw rate would rapidly decrease and the aircraft would pitch out of the spin . . .
>
> Left spins were much more violent than right spins . . . Yaw rates were very slow to build-up, typically taking a full 360° of rotation to even get the IDWS tone to come on. Passing approximately 30 deg/sec the yaw rate would aggressively oscillate approximately ±20 deg/sec with very noticeable lateral accelerations. Upon reaching CAS disengage, the spins were accelerated by slowly moving the longitudinal stick forward a couple of inches while maintaining full pro-spin controls. This would accelerate the yaw rate . . . but the yaw rate oscillations would eventually build-up and pitch the aircraft out of the spin. The aircraft does not like to spin to the left . . .

The following comments also convey the cockpit forces experienced during aggravated departures and high rate spins, where eyeballs out Nx reached 3.5 g at the forward pilot's station:

> The airplane abruptly snap rolled . . . had it not been for the extra chest restraint and locked inertia reel, my head would've been banged against the canopy . . .
>
> Eyeballs out g's at 130 deg/sec became uncomfortable, and visual focus began to suffer . . . An operational pilot might find himself flung over the stick unless the shoulder harness inertia reel locked . . .

A typical time history of a high rate spin to the right is given in Fig. 3. This spin shows the typical yaw rate hang-up near 90 deg/s and subsequent yaw rate acceleration caused by inertial coupling as forward stick is applied. The rapid reduction in yaw rate when full spin recovery differential tail is applied through DEL is also apparent.

A summary of the qualitative effects of lateral weight asymmetries and significant external aerodynamic configuration changes on the high AOA and departure/spin characteristics of the F-15E are presented in the following sections. Additional quantitative aerodynamic results of KEEP EAGLE flight testing are documented in the McDonnell Douglas Aerospace and U.S. Air Force final project reports.[4,5]

Lateral Asymmetry Effects

With an F-15 at high AOA, a lateral asymmetry actually results in departure away from the heavy wing. This is because of the relationship between wing dihedral effect and the vertical tail contribution to directional stability. For this test program, lateral asymmetries of 5000 and 10,000 ft-lb were investigated as individual effects and then combined with various external aircraft configurations. Initially, missiles were carried on one side of the aircraft with all fins removed. The fins were removed to reduce any aerodynamic effect they might have on the high AOA characteristics of the test aircraft.

However, even with 10,000 ft-lb of asymmetry the aircraft behavior did not closely match simulator predictions, exhibiting characteristics closer to a symmetrically loaded aircraft. To better understand the effects of lateral asymmetry, a pure mass asymmetry was then flight tested in the form of trapped fuel in the CFTs. Either 900 or 1800 lb of JP-8 fuel were trapped in either CFT, with the opposite CFT remaining empty. This resulted in the desired 5000 or 10,000 ft-lb of lateral asymmetry without an external aerodynamic asymmetry.

With pure mass asymmetries the predicted results of the asymmetry were seen. At 5000 ft-lb left wing heavy, the effects of the asymmetry were noticeable, but not objectionable to the aircrews. Maximum roll rates to the right were generally higher than they had been with symmetric loadings, but biases away from the heavy wing could still be countered with rudder. Spin recovery was generally not affected by this asymmetry.

As expected, the 10,000 ft-lb pure mass left wing heavy lateral asymmetry resulted in stronger biases away from the heavy wing. Above 30-deg α, rolls to the left were often not possible and rolls to the right were rapid and hard to counter. Spins to the right achieved target yaw rates more rapidly than symmetric configurations. Spin recovery performance was not affected by this asymmetry, with the exception of the dive pull-up after spin recovery. These pull-ups were limited to a maximum of 20-deg α to reduce the chance of a secondary departure/spin.

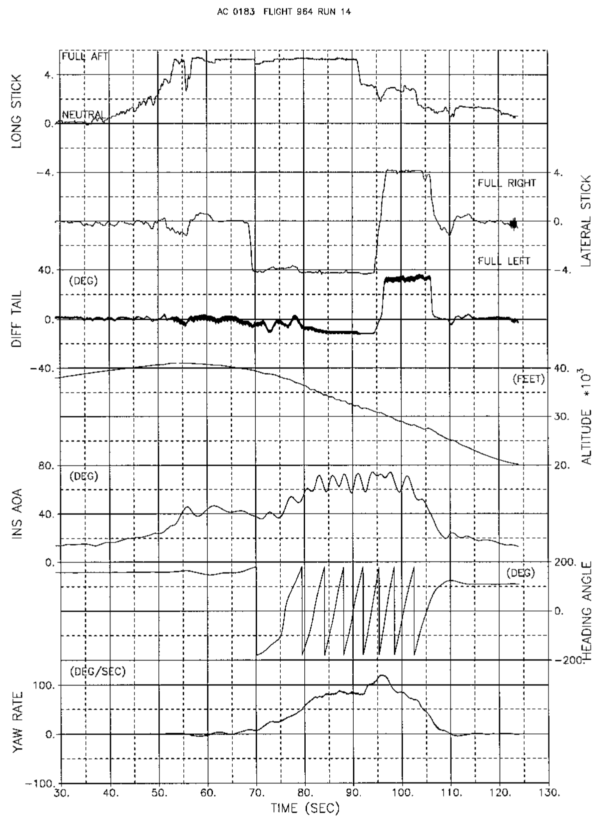

Fig. 3 Typical spin time history.

Configuration Effects

The effects of external aircraft configurations were assessed throughout the test program. Of particular interest was the CFT configuration, since ACC had placed a 20-deg α restriction on this configuration following the loss of the second F-15E. With Version 7, flying qualities in this configuration were excellent.

Wing rock was substantially reduced as compared to earlier FCC versions, and was even less than in the clean configuration since Version 7 was optimized for CFTs. Flying qualities at full aft stick were better in the CFT configuration than clean, primarily because full aft stick gave a higher AOA with CFTs, moving the aircraft out of a region of reduced stability. Maximum yaw rates attained during spins in the CFT configuration were slightly higher than clean, but recovery remained rapid with antispin controls. Once above 60 deg/s yaw rate, the aircraft would generally not recover with neutral controls. As a result of the successful testing in this configuration, the test team recommended removal of the 20-deg $\boldsymbol{\alpha}$ restriction.

Another configuration of interest was CFTs with LANTIRN pods. The F-15E had always been limited to 20-deg α in this configuration, mainly because analytical and flight test data had not been available to allow the envelope to be opened up above 20-deg α. Flight test results showed that flying qualities and spin characteristics were essentially unchanged from the CFT configuration and fully supported removal of the pre-existing 20-deg α limit. Another operationally significant configuration that always had a 20-deg α limit was CFTs with wing tanks. Flight testing revealed no significant deficiencies, although pitch sensitivity was increased. Again the recommendation was made to remove the 20-deg α limit.

The CFT and centerline tank configuration was of interest since analytical studies and previous flight testing indicated that the centerline tank had a noticeable effect on high AOA flying qualities. High AOA flying qualities and 1-g spin characteristics were similar to other configurations; however, coupled maneuvers showed less departure resistance. The test team recommended a 20-deg α limit for any configuration with a centerline tank and over 5000 ft-lb lateral asymmetry, a limit that was not previously in the Flight Manual. When LANTIRN pods were added, flying qualities degraded somewhat more, but were still considered better than the F-15A-D models.

Other operationally representative CFT-based configurations were evaluated based on ACC priorities. These included four AIM-120s and four AIM-7s; LANTIRN pods, wing tanks, and four AIM-120s; single LANTIRN navigation pod; and single LANTIRN targeting pod. No significant degradation was noted, although coupled maneuvers with the single LANTIRN pods were somewhat more oscillatory.

Engine Performance

Overall engine performance was excellent, with only one nonrecoverable engine stall during the entire program. During spins, the engines were affected by airflow disturbances created by the large changes in AOA and sideslip. This was most apparent during oscillatory spins with corresponding oscillations in engine burner pressure at approximately the same frequency as the actual spin oscillations. The engine oscillations were always more pronounced on the engine opposite the direction of the spin because of a fuselage forebody shielding effect. The engine fluctuations did not indicate impending engine stalls, but rather the recovery of pressure in the engine as the shielding effect was reduced.

The one nonrecoverable stall occurred during the dynamic recovery from a right accelerated manual spin maneuver. The maneuver was entered from a split-*s* and thus had a higher energy state than many of the previously attempted spins. The stall occurred in the high-pressure compressor on the engine away from the spin (left), most likely as a result of high distortion induced by the severe 32-deg α, 34-deg $\boldsymbol{\beta}$, and 209-kn airspeed combination. After maneuver recovery the engine was shutdown and restarted to clear the stall. No engine damage resulted.

Asymmetric thrust for spin recovery was tested on a limited basis during the program. Because of safety considerations, testing was accomplished only at relatively high altitudes. However, asymmetric thrust was expected to have the greatest effect on spin recovery at lower altitudes where differential thrust yawing moment would be more pronounced because of the higher thrust levels available. As expected, engine thrust asymmetry effects were masked by other spin recovery factors at the altitude conditions tested during KEEP EAGLE flight testing.

Continuing Use of Simulator

Simulation was effectively used during testing to supplement flight test results by allowing the test team to continuously assess and prioritize the requirement for test plan maneuvers. In several instances low-value test points were able to be combined or deferred. For example, originally separate internal fuel only and CFT fuel test conditions were combined, half-input buildup maneuvers that were not providing true buildup because of the characteristics of the flight control system were deleted, and planned maneuver repeats at medium altitude were deleted after early flight test results had adequately quantified altitude effects. By closely tracking predicted simulation results with actual flight test results, all test team members were able to fully concur with the elimination of over 33% of the originally planned test points, without affecting safety or the technical objectives of the program. These deletions were only possible because the original test plan had been developed with a healthy level of distrust of the simulator model.

However, it should be noted that test points were only eliminated or combined after flight test results had validated the simulator model in a particular configuration. In fact, in some instances buildup maneuvers were added where flight test results had not closely matched predicted results. For example, flight test evaluation of the 5000 and 10,000 ft-lb pure mass asymmetries had not been originally planned, and was only conducted because of the unanticipated flight test results obtained with the external aerodynamic asymmetries.

Preflying upcoming configurations in a cockpit and control room mockup throughout the flight test program also provided the opportunity to practice test maneuver techniques and remain familiar with expected aircraft response. This significantly improved aircrew and control room efficiency during actual flight test operations, and minimized in-flight repeats of test maneuvers. Finally, frequent simulator sessions provided the opportunity to remain proficient with emergency procedures and assess secondary flight safety factors such as the potential for aircraft over-*g* or under-*g* at planned test conditions.

Conclusions

The KEEP EAGLE high AOA flight test program successfully restored the air-to-air capabilities originally anticipated and expected for the F-15E, and in fact substantially expanded them by lifting pre-existing AOA restrictions for LANTIRN pod and external wing tank configurations. Conversely, an AOA restriction was recommended for the centerline tank configuration where none had existed previously, based on KEEP EAGLE flight test results. F-15E high AOA characteristics were significantly enhanced with the flight control changes incorporated in Version 7 software, with substantial improvement in responsiveness and controllability at high AOA, and dramatic improvement in spin recovery control power.

The KEEP EAGLE flight test team also achieved a breakthrough in the approach to departure/spin flight testing, with an appreciation for the early and controlled assessment of spin recovery control power, and its benefits to subsequent test safety and efficiency. This approach was developed by analyzing previous F-15 high AOA experience, simulator/database predictions, and the more general aerodynamic characteristics of the fuselage-loaded F-15 airframe.

Finally, simulation was used very effectively throughout the flight test program in several areas. First, the simulator was an indispensable tool in developing the test approach, test techniques, and both normal and emergency procedures. Simulation was also effectively used to supplement flight test results by continuously assessing upcoming maneuvers and conditions, and providing a technical basis for deleting or adding maneuvers. Finally, preflying selected maneuvers for each configuration in the simulator provided insight and proficiency with expected aircraft response, highlighted potential loads concerns, and provided frequent opportunities to practice emergency procedures.

Acknowledgments

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