T-45 Stability Augmented Steering System

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BACKGROUND

The ground handling characteristics of the T-45 Goshawk (a U.S. trainer variant of the Hawk aircraft) were identified as problematic since the early days of flight testing. deficiency report SA-162 addressed the "overly sensitive directional control characteristics" of the T-45 during landing rollout. This Part IK deficiency was not corrected during initial developmental testing and has presented itself in over 12 runway departures or loss of controls within the last two years. The runway departures typically occur when students who are not familiar with the landing characteristics, make large corrective inputs for aircraft heading during the landing rollout. The lowest region of directional stability has been observed in the 60-85 kt range.

A variety of potential solutions were attempted to remedy the deficiency over the years. Initially, full time nose wheel steering (NWS) was added to the aircraft. Although some improvement was noted, directional control during landing rollout remained an issue. Following the incorporation of full time NWS, several iterations of pulse width modulation NWS and active yaw damping during landing rollout were evaluated. None of these solutions provided sufficient improvement for fleet incorporation. Following these unsuccessful attempts to finding a ground handling solution, NAVAIR and Boeing initiated a ground handling study. This study resulted in a proposal to provide yaw rate feedback to the NWS to improve ground handling during landing rollout. This system became the Stability Augmented Steering System (SASS).

An engineering company that primarily investigates the handling qualities of racecars, Systems Technology, Inc., completed the study. Study results determined the geometry of the landing gear on the small airframe, combined with the material composition of the tires, created the unstable ground handling characteristics of the aircraft. Unable to practically redesign the geometry of the landing gear and the lack of suitable tire material to remake the tires, it was necessary to design a new system that could limit the departure characteristics by trying to limit the yaw that may be experienced during the landing rollout. This system had to operate in both the T-45A and the T-45C aircraft, and therefore designed as an independent system requiring limited information from the aircraft.

SASS

SASS provides yaw rate feedback to a full time nose wheel steering system. The nose wheel steering system incorporates a pilot selectable "high gain" capability for slow-speed taxi which greatly reduces turning radius by increasing turning angle and disabling the SASS. SASS contains its own internal yaw rate gyro and relies on the aircraft for airspeed and pedal inputs only. This allows SASS to be installed in

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both the T-45A and T-45C, which have different navigation systems and no aircraft model-specific modifications. The SASS receives an airspeed signal along with voltages from the Linear Variable Displacement Transducers (LVDTs) that are inline with the rudder pedals. Prior to the installation of SASS, the LVDTs sent voltages directly to the Steering Control Electronic Set (SCES), which in turn drove the nose wheel to the commanded angle. SASS is installed between the LVDTs and the SCES. SASS compares what the pilot is asking for (LVDT Voltages) and what the aircraft is actually doing (Yaw Rate). The SASS then sends a modified signal to the SCES to drive the nose wheel steering such that it negates any excessive yaw rates that may have been building while attempting to give the pilot the desired amount of turn. There were two SASS gain schedules used for initial testing. For both schedules the authority of the SASS increased with increasing airspeed in the 50 kts to 120 kts band. The first schedule, named SASS-1, applied a smaller correction factor; while the second schedule, named SASS-2, applied a higher correction factor.

While SASS was the primary solution to emerge from the STI study, an interim solution was also discovered and tested to improve ground handling until SASS could be incorporated into the Fleet. The study showed that by inflating the nose tires to 350 psi, the same pressure used whenever the aircraft is conducting operations on an aircraft carrier, some improvement in ground handling could be attained. This solution was flight tested in late 2003 and demonstrated a slight improvement in both crosswind and wet runway landings. However, due to limited improvement and concerns about accelerated hub wear in this configuration, 350 psi will only be used until SASS is installed.

Flight Test Planning

The test planning process had two major goals. The first was to develop tests to ensure the expected gain had been implemented in the software and there were no detectible problems with the software. The second was to develop test points that captured the maneuvers typically flown by students while at the same time being repeatable. Historically, students encountered problems when overcorrecting for improper aircraft lineup or heading during landing rollout. Test points were developed that attempted to simulate a student who had landed off centerline and was correcting back to centerline. Additionally, lessons learned from previous testing, as well as previous aircraft incidents, were incorporated early in the planning process.

Two test maneuvers were selected for the majority of SASS testing. The first maneuver was the Runway Offset Capture and Hold (ROCH). This maneuver was designed to set the aircraft off center and then make a student-representative correction back to centerline. For test purposes, the intercept angles were controlled within a 2 degree window for test point repeatability. ROCHs were initiated from 50, 75, and 100 kts using a build-up approach. Cooper-Harper Flying Quality Ratings (HQRs) and Pilot Induced Oscillation Ratings (PIOs) were assigned after the completion of each test point. The second maneuver was the Runway Offset Capture and Hold with moderate braking (ROCHB). This maneuver was designed to introduce student representative braking in addition to the correction back to centerline. ROCHBs were initiated at 100 kts and terminated at 50 kts. As with ROCHs, a HQR and PIO rating was assigned following each test point. The ROCHB was thought at the time of planning to be the most student-representative maneuver, though this turned out not to be the case. All of these maneuvers were completed with both gain sets and with the baseline NWS to demonstrate the improvement as well as assist in selecting a gain set for the production system.

Flight Test

Initial feasibility testing on the SASS was completed in 2002. Flight testing was completed using a build up approach. The ROCH and ROCHB maneuvers were evaluated after rudder sweeps, aircraft taxi, touch and go landings, and roll and go landings were performed and analyzed. Test results indicated that the SASS-2 was better at higher speeds, reducing the need for oscillatory inputs; however, the higher gain limited the ability to turn during taxi in low gain NWS. SASS-1 required continuous small oscillatory inputs to maintain a straight track down the runway at higher speeds but did not degrade the low speed taxi performance. For follow-on testing a hybrid gain schedule was developed which combined the improvements of SASS-2 at higher speeds with SASS-1 at lower speeds. This allowed for increased stability while limiting the degradation to slow speed taxi performance. The new gain schedule was named SASS-3.

SASS-3 was fully tested using the same process as SASS-1 and 2. Follow-on testing with SASS-3 was completed in crosswinds and on wet runways in order to ensure that the system would not affect the currently established crosswind and wet runway envelope. Testing on dry runways in crosswinds was completed with offset corrections and variations in braking in order to investigate as many student representative maneuvers as possible. Wet runway testing was only completed during straight landing roll-outs to full stops to prevent hydroplaning the aircraft off the runway. In order to ensure that student-representative maneuvers had been covered and the test community had not made incorrect assumptions, the test team allowed instructor pilots to fly in the test aircraft and perform maneuvers from the aft cockpit inside the current NATOPS envelope.

Overall, results of the testing were extremely positive. SASS-3 delivered the best qualities of SASS-1 and SASS-2 and was chosen as the production gain. SASS proved itself to be a significant improvement over the baseline T-45 and was deemed acceptable as a permanent solution to the T-45's ground handling problems.

Lessons Learned

The test team knew of some issues while planning the flight tests. The first concern that was addressed was the potential for the aircraft to leave the runway during testing. The concern was more for running off the side of the runway than the end. Validating this concern was an incident that occurred at Phoenix Sky Harbor International Airport during T-45 initial testing. The incident occurred while ferrying the aircraft from NAS Patuxent River to Edwards AFB. During a landing rollout in Phoenix, the T-45 in question suffered a locked brake on the left main tire. The initial landing attempt resulted in a blown tire and FODed that runway. This resulted in all traffic, both in flight and on the ground, being rerouted to the other runway. The T-45 executed a go-around following the first landing attempt and was also rerouted to the other runway for subsequent landing attempts. The next landing attempt resulted in a large swerve to the left following touchdown, bringing the aircraft close to airline traffic on the parallel taxiway before once again getting airborne. Though this incident was the result of a locked brake and not necessarily an inherent ground handling problem, it highlighted the danger of having personnel and equipment near the runway while high risk testing is being conducted. To mitigate this risk, the test team coordinated with the airfield control tower to ensure no aircraft were waiting near the active runway and no equipment or personnel were within 200 ft of the runway while testing was underway. Additionally, several runway surveys were completed to document hazards near the runway and develop predetermined ejection points in the event the aircraft was departing the runway.

The next lesson learned was how to conduct the build-up. The lower end of the 60-85 kt speed band exhibited the lowest stability. The question was, "should the build-up be performed using increasing or decreasing airspeed?" The test team determined that the limited amount of time required at the slow speeds to get out of the instability was safer than having to decelerate through the risk region if something failed at a high speed test point. Therefore build-up was completed in increasing airspeed.

The third lesson learned was to employ additional aircrew in the aft aircrew station during testing as an observer. It was determined by the test team, based on previous ground handling testing, that an aircrew (not necessarily T-45) would be in the aft crew station for all testing in order to assist with "Knock It Off" and traffic calls and to aid in communication with the tower and pattern traffic as necessary.

The fourth lesson learned concerned "Knock It Off" calls. "Knock It Off" criteria were established early on by the test team by calculating the necessary distance required for a rejected takeoff (RTO) at rotation speed of the heaviest aircraft. This calculation included the distance required to accelerate from a 50 kt test point (the slowest test point) to rotation speeds and still perform the RTO. These calculations were done for all runway lengths and tire configurations used throughout testing.

In addition to the lessons learned that were incorporated in the planning process, there were a couple of lessons learned from the testing itself. As mentioned earlier, the ROCHB was considered at the time of test planning to be the most student-representative maneuver. Once testing commenced, however, this was proven not to be the case. The ROCHB targeted a deceleration of 0.15 g's throughout the maneuver. As flight testing progressed, it quickly became apparent that the aircraft decelerated at 0.15 g's with no brake applied. To achieve the desired deceleration while using brakes, the aircrew had to set approximately 70% N2 on the engine and use moderate braking. Obviously this is not very representative, but due to the repeatability and the ability to remain in the desired groundspeed band longer using this procedure, it was kept with no alterations.

Lastly, the test team encountered an issue with the current T-45 rudder pedal rigging procedures. This problem, at least in part, was the result of putting a new piece of equipment in an older airplane. Late in flight test, it was discovered that a full-pedal turn commanded from the aft cockpit would result in SASS disengagement. The problem was traced to the procedures used to rig the rudder pedals. The current procedures describe in detail how to rig the system, however they do not specify any particular type of voltmeter for checking the output from the LVDTs. Prior to SASS, this had little to no effect as the voltages did not have to be exact for the NWS to work properly. However with SASS, the voltages are critical. The test team found that using different voltmeters, different voltages were read coming from the LVDTs. This, combined with the fact that the aft cockpit rudder pedals had a slightly larger range of motion, led to overvoltages during full-pedal turns from the aft cockpit, causing the SASS to disengage. While not a big concern during taxi operations, the potential existed for a student or instructor to use full pedal during a landing rollout and cause the SASS to disengage at high speed. From this came a recommendation to use a specific voltmeter for all rudder pedal riggings as well as the realization that the rigging must be checked from the aft cockpit as well.

Other Potential Benefits

From its inception, the T-45 has been quite unforgiving with a blown main tire. Over six mishaps have occurred following a blown tire. A blown main tire usually results in the aircraft departing the runway during landing rollout, so arrested landings are required if possible. However, most blown tires have occurred during landing rollout at speeds where a go-around is impractical. Though SASS was not designed to improve the blown tire handling characteristics of the T-45, simulations have shown promising results. Due to the nature of the yaw rate feedback, SASS reduces the severity of the initial swerve and almost eliminates the dynamics of the rollout, requiring the pilot to only feed in an increasing amount of rudder (NWS) to counter the increased drag on the blown tire side as the aircraft slows. Prior to SASS, the pilot was constantly adjusting rudder pedal inputs to prevent the skid angles from building up too much in one direction or the other. Though this has only been demonstrated in the simulator and not flight testing, the belief is that SASS will provide some increased stability in the event of a blown main tire. Despite this expected improvement, simulations have also demonstrated SASS does not sufficiently reduce the initial swerve due to a blown tire on touchdown enough to be safely recovered aboard an aircraft carrier. Additionally, simulations with SASS show that the aircraft is not completely controllable at slower speeds during landing rollout with both main tires blown, crosswinds from the blown tire side with a single blown main tire, or on wet runways.

At the end of the testing it was determined by the entire test team and fleet participants that installation of the system will reduce future runway departures. However, SASS will not mask a poor student aviator. If a student drives towards the edge of the runway without correcting back to centerline, the student will drive off the runway. It will also not mask a student who has the tendency to always put in oscillatory inputs since those inputs will be observed by the instructor pilot as roll felt from the aft crew station. In short, SASS will still allow instructors to identify students having problems with the landing phase of flight, but it will help prevent those same students from getting themselves into a situation from which it is impossible to recover. Installation of the system into fleet aircraft began in December 2004 and student aviators should be training with the benefits of SASS by April 2005.