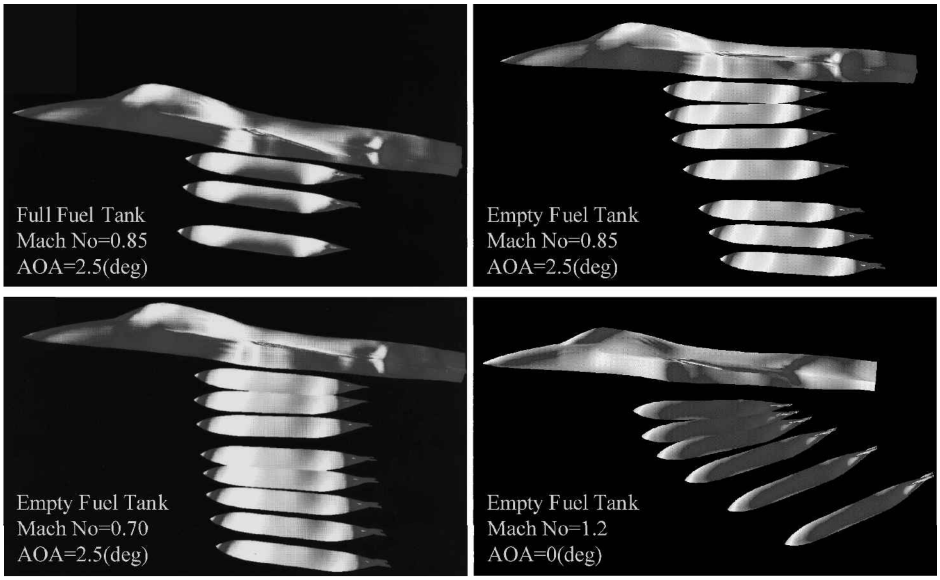

Fig. 3 Trajectory demonstrations of the full/empty 275-gal fuel tank separation at four kinds of flight condition (M_∞ = 0.7–1.2 and α = 0–2.5 deg).

flight speed increases to supersonic regime, the aerodynamic effect acted on the empty tank will hugely dominate the tank trajectory. The pressure drag produced by the oblique shock waves on the body and fin surfaces will make certain that the tank has a large movement backward from the flight direction. The overall trajectories for the preceding three cases are depicted in Fig. 3. It is apparent that the tank body pitched nose down first, followed by a nose up in the subsonic and transonic flows, while the fuel tank moved backward and pitched down rapidly as a result of the large pressure drag in the supersonic flow. As studied in the subsonic and transonic cases, the empty tank has a wave-like pattern in the pitch motion during separation process. Nevertheless, in the supersonic case the tail fins of the tank cannot produce large enough pitch-up moment to correct the pitch-down attitude. Thus, the tail tank body moves upward rapidly and can be potentially dangerous for impacting the aircraft. In addition, in the real flight the initial dropped pitch rate for the fuel tank could not be controlled accurately, and also some uncertified factors or flow disturbances could not be predicted completely in advance. This flight mission about safety should be more concerned in the supersonic store separation. Throughout this numerical analysis we suggested the fight Mach number for the empty 275-gal fuel tank separation should be limited to 0.85.

Conclusions

The application of the unsteady program, which consists of the Euler solver, the overset grid method, and time-accurate relaxation method, has shown the capabilities for unsteady motion analysis that related the external store separation problem. In this Note the predicted trajectories for the 275-gal fuel tank in the full and empty fuel conditions are analyzed. Also, the numerical data are presented for the comparison with the CTS test and free flight test. From the numerical study we can obtain a safe Mach-number limit for the external tank separation. In the present study the flight Mach number for the mission of empty 275-gal fuel tank separation is suggested to 0.85.

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Sensitivity Analysis to a Forced Landing Maneuver

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Introduction

FLIGHT simulators are becoming more sophisticated in replicating actual flying maneuvers and conditions. Despite the advancement of technology, a flight simulator cannot perfectly represent a particular aircraft in all aspects. For example, the

Received 20 February 2002; revision received 1 August 2002; accepted for publication 18 September 2002.

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mathematical model of the aircraft is never fully accurate, and the motion and visual systems have physical limitations that make the full representation of the sensation of flying always less than perfect. Regulatory authorities around the world are beginning to approve, or are considering the approval of, single engine gas turbine (SEGT) aircraft for regular public transport (RPT) operations. This will require the flight simulator industry to consider exploring the use of flight simulators for SEGT aircraft in RPT operations.

This Note investigates the effect that the tolerances prescribed in the international standards in Ref. 1 have on the performance of flight simulators used for pilot training. A simplified analytical model for the Beech Bonanza model E33A retractable aircraft was used to determine the effect of the aforementioned to tolerances on forced landings. It was found that the effect of the tolerances is highly sensitive on the nature of the maneuver flown and that, in some cases, negative transfer of training may be induced by the tolerances.

Forced Landing

The forced landing maneuver is used as a case study for investigating the sensitivity of the maneuvers to errors in modeling for human in the loop simulation. Research in the field of trajectories flown during forced landings after takeoff has been reported in the literature. Landing an aircraft that has suffered engine failure during takeoff is one of the classifications of a forced landing. The general recommendation in the aviation literature for such a situation is to land straight ahead.[2–4] For example, the Federal Aviation Authority (FAA) regulations recommend that pilots land straight ahead and should never attempt track reversals in an effort to land on the departure runway. Rogers[5] conducted an experiment and confirmed that this training procedure is ingrained in pilot behavior. He found that when pilots were given this exercise 85% of the pilots landed straight ahead after engine failure at 500-ft above ground level. This straight ahead landing procedure is recommended for failures up to about 200 ft in altitude. However, Rogers suggests that, for forced landings from a higher altitude, a turnback maneuver may be flown because higher altitude allows for more time in the air. His analysis, based on the Beech E33A Bonanza single engine aircraft, uses the brake release point as the reference point for all distances calculated. The pilot flies along the extension of the runway centerline to a height of 650 ft, where the engine fails. At this point in the forced landing maneuver, the pilot can either land straight ahead (gliding at maximum lift to drag velocity) or turn (at 5% above the stall velocity with a 45-deg angle of bank) and then glide until touchdown at the maximum lift to drag velocity. The effects of landing gear retraction/extension were not considered. The turnback maneuver produces a trajectory that resembles a teardrop shape.

Sensitivity Analysis

Flight-test data obtained from actual flight will contain unavoidable errors, and an important consideration is to investigate the effect of these errors on the ability of pilots to perform particular flight maneuvers. There is also the problem of not being able to fly maneuvers that will be required for training in flight simulators. The theoretical forced landing maneuver considered in this Note will never be found in any of the qualification documents that are used for evaluating flight simulator performance because it is a maneuver for which flight-test data would be difficult if not impossible to obtain safely. Hence, this sensitivity analysis is carried out to illustrate the potential deficiency that may arise from the existing flight simulators requirements. A sensitivity analysis is carried out from brake release to touchdown using general flight dynamics equations[6] and data based on the Beech Bonanza E33A retractable aircraft characteristics obtained from Rogers.[5] The data are shown in Table 1 for a forced landing maneuver. The data for initial takeoff ground roll and distance to clear 50 ft obstacle are obtained from Rising Up Aviation Resources.[§] The aircraft is assumed to climb at 1200 ft/min, at a constant velocity of 91 mph, and at constant heading parallel to the runway till the engine fails at an altitude of 650 ft. After engine failure, the flight maneuvers used and the assumptions made are identical to those of Rogers.[5] The turning speed is $1.05V_{\mathrm{stall(clean)}}/\sqrt{(\cos\phi)}$ banking at 45 deg, where ϕ is bank turn angle during turn, and the gliding to touchdown speed is $V_{L/D\,\max}$ (122 mph). It is assumed that the transition from turning speed to gliding speed occurs instantaneously. The sensitivity analysis consisted of varying the parameters defined in the flight simulator regulations by the tolerances specified in the regulations.[1] Table 2 shows the acceptable tolerances for the parameters involved in the track reversal maneuver. These are the tolerance parameters during the takeoff distance phase to at least 200-ft above ground level (AGL), the climbing to clear 50-ft obstacle phase, the landing phase from a minimum of 200 ft above ground level to nosewheel touchdown, and the flight and maneuver envelope protection functions. (Note that takeoff distance is the distance from brake release until the aircraft has reached a specified altitude.)

For the maneuver considered in this Note, the engine failure after takeoff, the engine failure analysis is based on engine failure at a specific altitude. The failure altitude occurred at an altitude of 650 ft with deviation of ±10% in height and ±200 ft in longitudinal distance along the runway length that are accumulated from brake release to engine failure. An airspeed variation of ±3 kn and a bank angle variation of ±10 deg during turn were also used for all of the segments of the maneuver. This accumulation in error is attributed from the normal flight segments tolerances specified by flight simulator tolerances as shown in Table 2. Hence, to determine the magnitude of the sensitivity of the forced landing maneuver to the tolerances in this analysis, flight dynamics equations used in this analysis were applied to three failure cases: the reference case, where no tolerance specifications were applied to the flight dynamics equations; the upper limit; and the lower limit that resulted from the different normal flight segments parameters tolerances

Table 1 Beech Bonanza Model 33A characteristics[5]

Parameter	Value
Gross weight, lb	3300
Wing area, ft^2	181
$L/D_{\max}$	10.56
Power, brake horsepower	285
Propeller	Constant speed three-blade
V_{cruise} at 65%, mph	190
$V_{\mathrm{stall(clean)}}$[a] power off, mph	72
$V_{\mathrm{stall(dirty)}}$ power off, mph	61
$V_{L/D\,\max}$,[b] mph	122
$V_{\gamma\,\max}$[c] at sea level, mph	91
$V_{R/C\,\max}$[d] at sea level, mph	112.5
R/C at sea level and 3300 lb, ft/min	120
Parabolic drag polar	$C_D = 0.019 + 0.0917C_L^2$

[a]Gear and flaps rextracted.
[b]$L/D_{\max}$ = maximum lift to drag ratio.
[c]Here γ = glide angle.
[d]Maximum rate of climb.

Table 2 Flight simulator tolerances from international standards[1]

Maneuver	Tolerance
Takeoff	±200-ft ground roll, ±3-kn airspeed at which the last main landing gear leaves the ground, ±20 ft in height from brake release to at least 200 ft AGL.
Climb	±3-kn airspeed at nominal climb speed and at midinitial climb altitude, rate of climb ±100 ft/min.
Landing	±3-kn airspeed from 200-ft AGL to nosewheel touchdown, ±10 ft or 10% in height from a minimum of 200-ft AGL to nosewheel touchdown.
Flight envelope protection functions	±10% bank angle during approach.

[§]Data available online at http://www.risingup.com/planespecs/info/airplane117.shtml.2000.

combinations as specified by the International Civil Aviation Organization (ICAO).

Results and Discussion

All possible combinations of ground roll, airspeed, height, and bank angle tolerances of errors from normal flight segments were considered, and it was found that the upper limit in touchdown location was given by +200 ft in ground roll, +10% in height, −3 kn in velocity, and +10% in bank angle, as specified by the ICAO standards. The combination giving the lower limit in touchdown location is −200 ft in ground roll, −10% in height, +3 kn in velocity, and −10% in bank angle, as specified by the ICAO standards. The tolerances in ground roll and in failure altitude simply transform to a translation in the longitudinal distance along the runway. In addition, it was found that the failure altitude has the most effect on the touchdown locations.

Figure 1 shows the results for the sensitivity analysis. The three curves at A represent the effect of the tolerance on the specific case for a teardrop turnback to the runway. The touchdown point varies from −210 to +570 ft. At B, the three curves represent the sensitivity if the pilot attempts a continuous 360-deg turn and touchdown on the runway. In this case, the touchdown point varies from −1639 to +1935 ft, a significantly larger range of error. At C, the three curves represent the case where the pilot glides straight ahead, the procedure recommended by the FAA. The touchdown point varies from −1650 to +1800 ft.

There are potentially significant transfer of training issues that arise from this analysis. For example, turnback procedure A produces a relatively small error. An error of 780 ft in a simulated flight from a typical runway of a length of about 4000 ft would probably not be significant. However, a pilot turning a full 360 deg, whose heading is now in the same direction as the takeoff direction and touchdown on the same runway (proceedure B) will encounter a possible variation of 3574 ft, clearly a significant possible error. In addition, if a pilot elected to land straight ahead (proceedure C), there would be a possible error of 3450 ft. An error of this magnitude could make the difference between whether a suitable field is reached or missed.

The critical point here is that the magnitude of performance errors in a flight simulator cannot be assumed to be simply proportional to the tolerances for various individual parameters, but they may be highly dependent on the task being performed. For example, in the turnback case A, the errors appear small. The errors are small because the errors tend to cancel each other out, even in the worst case. In the simple glide straight ahead and in the 360 deg turn maneuver, the errors tend to accumulate.

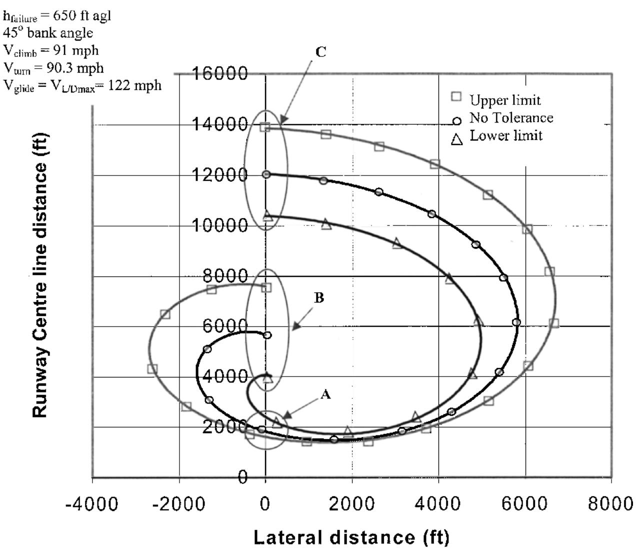

Fig. 1 Landing profile subject to international standard tolerance.

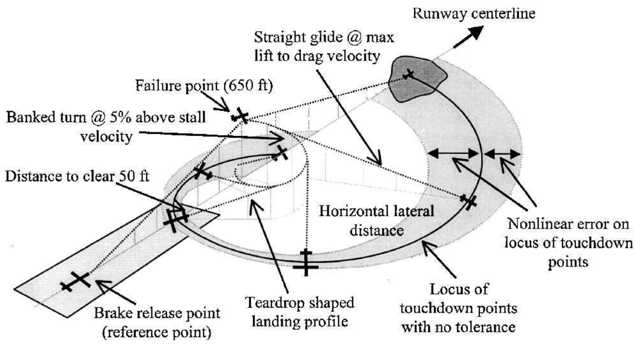

Fig. 2 Sensitivity of tolerance on locus of touchdown points.

The implications of the sensitivity analysis are shown in Fig. 2. The shaded area depicts the nonlinear error characteristics, near the case where no tolerances in error were considered in the analysis, for the locus of touchdown points. As the failure altitude increases, the error for the 360-deg turn (case B) will move toward the straight glide to touchdown landing maneuver (case C). This result suggests that the simulated performance characteristics of every maneuver that is to be flown in a simulator should be validated against data from flight tests in the actual aircraft. It cannot be assumed that just measuring the input parameters alone is sufficient to ensure the simulator will provide adequate accuracy for all training exercises.

Conclusions

This Note demonstrates the importance of analyses of simulator requirements and the consideration of such requirements within the context of particular maneuvers to be flown. The sensitivity analysis shows that a simulator may incur potentially significant errors in the task of handling an engine failure after takeoff for a single engine aircraft. This raises the question of the ability to use simulators to train pilots aptly for engine failure after takeoff using the tolerances as specified in current regulations because the resultant errors are maneuver dependent. With increasing prevalence of SEGT aircraft for RPT operations and the increasing usage of flight simulators for smaller aircraft, the problems discussed become increasingly relevant. It is not sufficient to assume that the present simulator regulations will be adequate for such operations. New applications of flight simulators will also require new types of data to be collected from flight tests. For example, the data collection methods should ensure that the tolerances achieved in the simulators are relevant for the specific training tasks performed in the simulators.

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