Federal Aviation Administration

ANALYSIS OF THE RISK OF A BOEING 747 HAND FLOWN BALKED LANDING PENETRATING THE ICAO CODE E OFZ

Branch Study Report
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NOTICE

Executive Summary

The purpose of this study is to determine the probability of penetration of the ICAO Annex 14 Code E OFZ (Inner Transitional Surface) by a B747 during a hand-flown balked landing operation.

In the ICAO Annex 14 to the Convention of International Civil Aviation, the OFZ is specified to have a base width (Inner Approach Surface) of 120 meters for Code E aircraft and a base width of 155 meters for Code F aircraft (see Figure 1). In both cases the Inner Transitional Surface forms a plane sloping away from the base at 33.3%.

The study is intended to determine the risk of the B747, a Code F aircraft, penetrating the Code E OFZ during a hand-flown (flight director assisted) balked landing operation under typical environmental conditions.

The study applies extreme value analysis, a type of statistical analysis, to determine the penetration probability. The results of this analysis show that the probability of penetration is on the order of less than 1 in 10,000,000. Specifically, the most conservative assumptions lead to an upper bound for this probability of penetration of 1.9 in 10,000,000.

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1.0 Introduction

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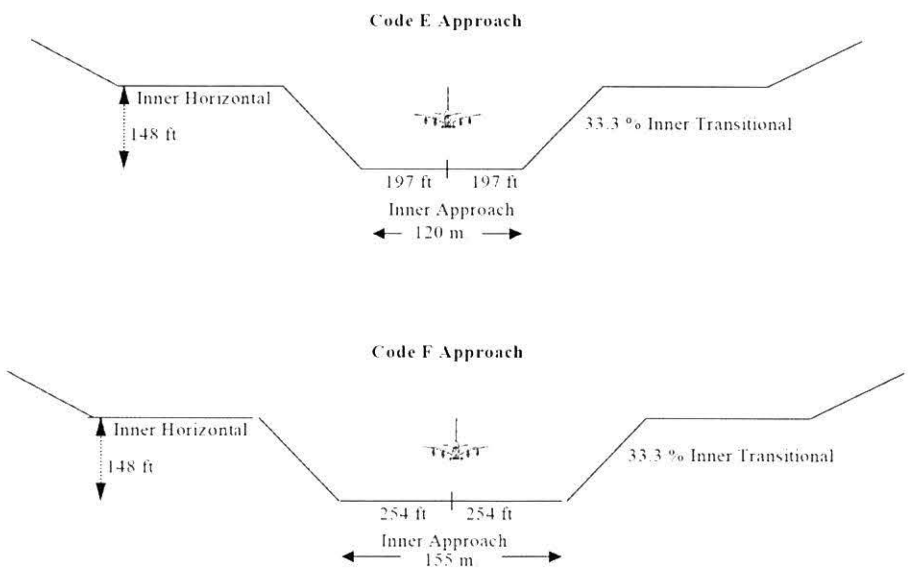
Figure 1



2.0 Test Plan

In order to determine the probability of penetration of the Code E OFZ we performed a series of tests at the NASA Ames facility during 1997 and 1998. of the balked landing operation using Boeing simulators in Toulouse and Berlin. These tests were designed to simulate the conditions of an Boeing 747 balked landing operation as closely as possible.

We performed 110 operational runs with hand flown balked landing operations.

3.0 Test Results

Since the Code E Inner Transitional Surface is a sloping surface, the relationship between the B747 wing tip and the surface varies by height even if the wing tip does not deviate laterally. For this reason, we normalized the measure of the distance from the wing tip to the OFZ surface. To do this, we defined a variable (called S) whose value is the percent lateral deviation of the wing tip between its nominal position and the Code E Inner Transitional Surface. That is, S is the actual wing tip deviation from nominal divided by the possible wing tip deviation, where *possible* means the distance from the wing tip to the surface when the aircraft is on track in the nominal position. For example, if the aircraft's lateral deviation from the nominal track is 0, the value of S is 0%. If the aircraft's left (or right) wing tip is touching the surface, the value of S is 100%. If the wing tip is exactly half way between nominal position and the surface, the value of S is 50%.

We calculated values for S for each data point along the aircraft's track starting with the initiation of the balked landing (taken to be when the throttle angle first exceeds 50°) and ending when the aircraft's lower wing tip has exceeded the 45 meter height of the sloping Inner Transitional Surface (where the surface becomes horizontal) on its balked landing ascent. We then determined the maximum S value for each of the 110 balked landing runs.

For analysis purposes the variables of interest from the test data for each run are then: the maximum S value for the run, the crosswind speed, and the planned height at which the balked landing was initiated.

4.0 Analysis

Risk is the combination of

- the consequence (or severity) of a Hazard Event and the
- probability of its occurring within the Scenario of interest.

The purpose of the present study is to determine the probability component of the risk of the Hazard Event: an B747 wing tip penetrates the ICAO Code E OFZ at least once during a Scenario operation.

Probability of OFZ Penetration

To calculate the probability that a B747 wingtip penetrates the Code E OFZ (Inner Transitional Surface) we use a three step methodology.

- First, we establish the Scenario of Interest. This is the scenario to which the probability applies. And it includes attribute assumptions such as crosswind distribution, initiation height distribution, and type of landing.
- Second, we use the data to develop a distribution of maximum S values for the Scenario of Interest.
- And third, we use this distribution to estimate probability that S > 100%, that is, that a wing tip penetrates the Code E OFZ surface under the Scenario of Interest.

1. Establish Scenario

In this scenario we assume the actual crosswind and initiation height distributions are the same as those used in the 110 test runs. We must emphasize that this is an artificial assumption based on the relationship between the actual crosswind speeds and those used in the test and the relationship between the (less well understood) apparent actual initiation height distribution and those used in the test.

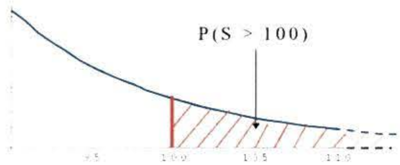
Since (a) the proportion of both higher crosswind speeds and lower initiation heights in the test is much higher than in actual conditions and (b) the relationship between those two variables and the variable S is such that higher crosswind speeds and lower initiation heights are directly related to higher values of S, then we would expect this scenario to lead to a higher probability of OFZ penetration than one using actual conditions.

Assumptions:
- A hand-flown balked landing has occurred, as in the test.
- Crosswind speeds are those of the test (not actual distributions)
- Balked landing initiation heights are those of the test (not actual distributions)

2. Develop a Distribution for Maximum S for Scenario

Next, we use classical Extreme Value Theory to develop a distribution for the maximum S values. This theory provides the two things. First, it provides a family of distributions (called GEV, or General Extreme Value distributions) that model block maximums such as those of the variable S. Second, it provides the justification for using a GEV distribution to extrapolate beyond the range of the maximum S values found in the test data.

Figure 3



5.0 Conclusion

Based on the scenario analyzed, we can calculate a reasonable upper bound on the probability of ICAO Code E OFZ penetration. To calculate a reliable upper bound on the OFZ penetration probability, we make these further assumptions:

1. Use the scenario probability (0.0).
2. Use the balked landing rate upper bound of 1.9 balked landings per 1000 landing attempts.
3. Focus only on OFZ penetrations due to balked landings, assuming that normal landing produce effectively no penetrations.

The probability of hand-flown B747 ICAO OFZ penetration during a balked landing (OFZP) is given by:

$$P(OFZP) = P(Balk) \bullet P(OFZP \mid Balk) + P(no\ Balk) \bullet P(OFZP \mid no\ Balk).$$

Which reduces to: $P(OFZP) = P(Balk) \bullet P(OFZP \mid Balk)$, since $P(OFZP \mid no\ Balk)$ is effectively zero. That is, no Balk (i.e., normal landings) produce effectively zero penetrations by assumption 3 above.

Since, $P(OFZP \mid Balk) = 0.0$, by assumption 1 above.
And, $P(Balk) < 1.9$ E-03, by assumption 2 above.
Then, $P(OFZP) = 0.0$.

That is, an estimate of an upper bound for the probability of an B747 ICAO Code E OFZ penetration during a hand-flown balked landing is determined to be 0.0. Incorporating the standard error estimate, a 95% confidence interval for the penetration probability is determined to be 0.0 ± (9.8 E-05)(1.9 E-03) or 0.0 ± 1.9 E-07.

Note that we developed this estimate using several assumptions, each of which would tend to produce a higher value rather than a lower one. So we may conclude that this estimate is a reliable upper bound on the actual probability.