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Thrust Reverser Analysis for Implementation in the Aviation Environmental Design Tool (AEDT)

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1. Introduction

The United States Department of Transportation, John A. Volpe National Transportation Systems Center (Volpe Center), Environmental Measurement and Modeling Division, in support of the Federal Aviation Administration’s (FAA) Office of Environment and Energy (AEE), has conducted an analysis on thrust reverser usage and how it is to be implemented within the Aviation Environmental Design Tool (AEDT).

1.1. Background

This letter report presents an updated implementation for thrust reversers in AEDT. Currently, thrust reverser is applied to all STANDARD approach profiles in the Integrated Noise Mode (lNM) as 60% of the max rated thrust for jets and 40% for props over a distance of 90% of the total roll-out distance after touchdown. These thrust values during landing ground roll in INM were used to ensure good agreement between measured and modeled noise, but were not necessarily representative of actual thrust levels during thrust reverser deployment. The ground roll distance associated with reverse thrust in INM is also somewhat arbitrary. Since the aircraft performance model is common to noise and emissions computations in AEDT, the unrealistically high thrust assumption specifically is an issue when computing fuel flow and emissions. Therefore, there is a need to update thrust reverser assumptions in AEDT to better represent conditions in typical aircraft operations.

The FAA has committed to developing a noise module within AEDT that is compliant with European Civil Aviation Conference (ECAC) Doc 29 3rd Edition 2005 "Report on Standard Method of Computing Noise Contours Around Civil Airports" (Doc 29). This implementation of thrust reversers in ADET was undertaken in cooperation with the United Kingdom (UK) Civil Aviation Authority (CAA) as part of the effort to update ICAO Circular 205, and to advance the previous related work of ECAC DOC 29. Doc 29 specifies a more complex implementation of reverse thrust than currently exists in INM, citing a typical reverse thrust power level of 20% of static thrust coupled with an additional noise-power-distance (NPD) dB adjustment that varies according to distance traveled from touchdown. Even though this implementation is more representative of actual thrust reverser deployment, the Doc 29 development team noted that their recommendation was preliminary and that they were still investigating the issue further. This letter report presents an interim solution to better represent thrust reversers in AEDT.

2. Analysis

The net corrected thrust value during thrust reverser deployment was determined for narrowbody and widebody aircraft using data from the FAA Statistical Loads Data reports for the Airbus A320 [1], Boeing 737-400 [2], 767-200 [3], and 747-400 [4], which are comprised of data from over 100 airports in at least 30 countries. The data from these reports are based on a large sample of aircraft operations and provide a general sense of thrust reverser usage for each reported aircraft type. The findings in each FAA report were verified for consistency with independent data from the UK CAA. Table 1 lists the data sample sizes represented in each FAA report.

Table 1. Report Sample Information

Aircraft Report	# of Aircraft	# of Operations
A320	56	10,066
B737-400	17	11,721
B767-200ER	10	1,270
B747-400	N/A	11,066

Each FAA report contains the cumulative probability of %N1 while thrust reversers are deployed. By using the cumulative probability curves presented in the appendix of each report, distribution charts were created showing the %N1 used during reverser deployment. Figures 1 and 2 display an example cumulative probability curve and the associated distribution chart for the 747.

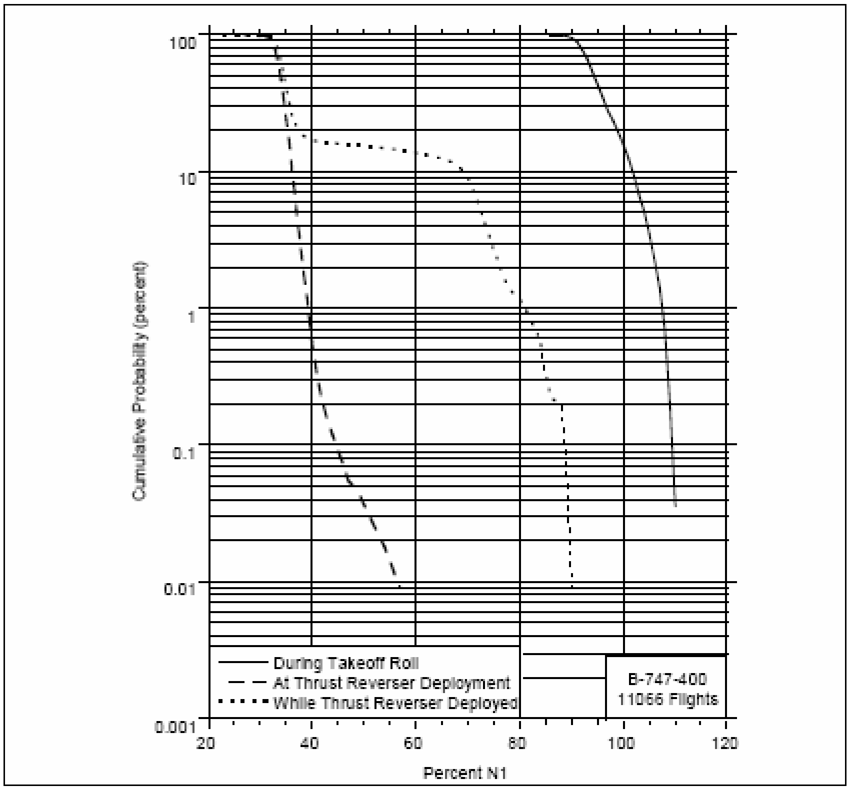

Figure 1. Cumulative Probability of %N1 for the 747

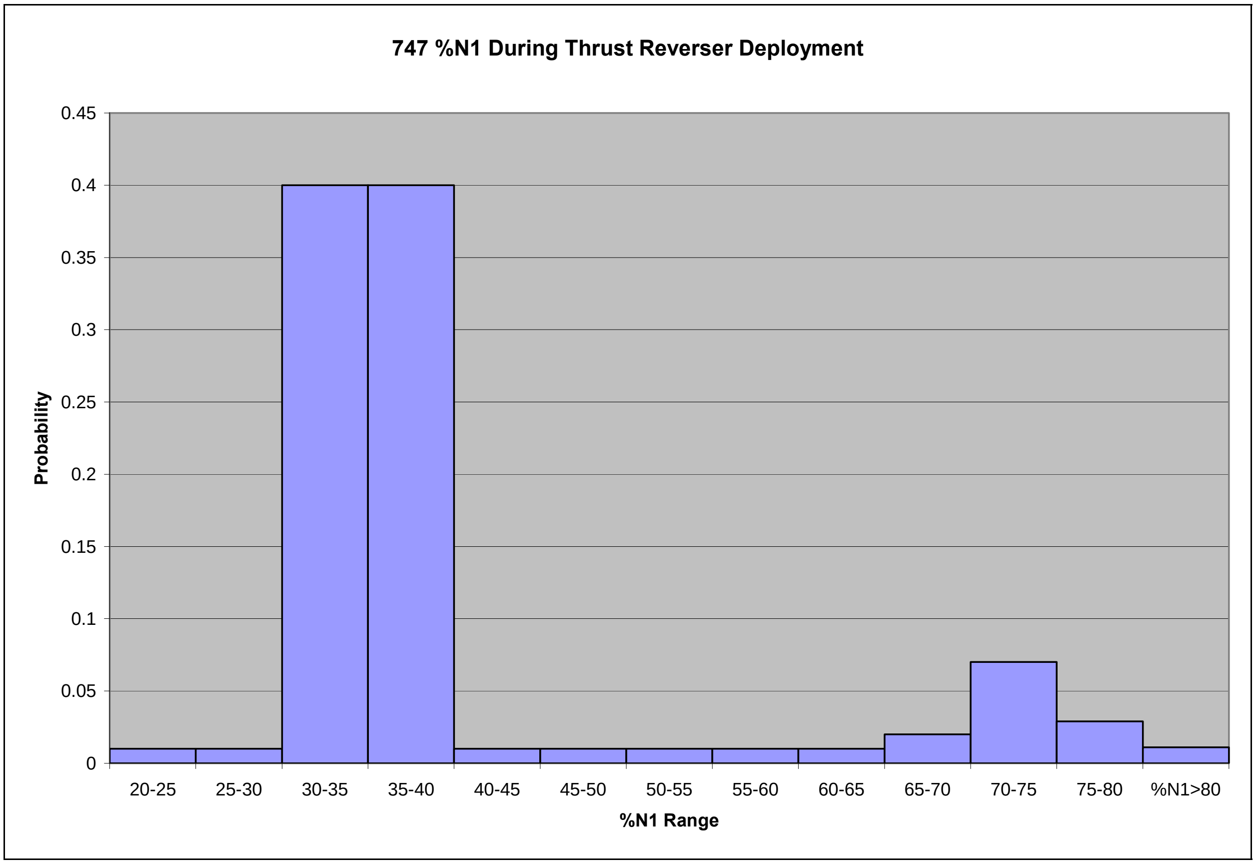

Figure 2. Distribution of Time Thrust Reversers are Deployed for the 747

For each aircraft type, %N1 during reverser deployment was determined. The average for each aircraft was calculated by multiplying the mid-point of each range, by the probability of that range occurring, to obtain a weighted value[1]. Table 2 lists the averages for each aircraft as well as the equivalent net corrected thrust and percent of max rated thrust values for each %N1 average. Net corrected thrust was determined using generalized thrust curves to convert %N1 into net corrected thrust for typical engines used for each aircraft type.

[1] For example, Figure 2's 747 distribution chart indicates that the %N1 during thrust reverser deployment was between 35 and 40 %N1 for 40% of the operations. The mid-point of that range of 37.5 %N1 was multiplied by the probability of 0.40 to obtain a weighted value of 16.875. A weighted value was calculated for each %N1 range and probability of occurrence and was then summed to obtain an average value of %N1 while the reversers were deployed.

Table 2. Average %N1 During Reverser Deployment, Net Corrected Thrust During Reverser Deployment, and Percent of Max Rated Thrust

Aircraft	%N1 During TR Deployment	Net Corrected Thrust (lbs/δam)	Percent of Max Rated Thrust (%)
A320	68.4	8,000	32.0
B737-400	73.5	9,700	41.3
B767-200ER	73.5	16,800	28.0
B747-400	40.7	3,752	6.3

Average percent of max rated thrust values during thrust reverser deployment were determined for both widebody aircraft and narrowbody aircraft using the calculated values in Table 2. The A320, 737, and 767[2] were placed into the narrowbody category and the 747 was placed in the widebody category. An average percent of max rated thrust for each category was determined by weighting each average value by the number of operations for each aircraft type in Table 1. Table 3 lists the weighted values and averages determined for the narrowbody and widebody aircraft categories.

Table 3. Weighted Values and Averages of percent of max rated thrust and duration of reverser deployment

<table>
<tr><th>Category</th><th>Aircraft</th><th># of Operations</th><th>Percent of Max Rated Thrust (%)</th><th>Weighted Thrust Value</th><th>Weighted Thrust Average (%)</th></tr>
<tr><td rowspan="3">Narrowbody</td><td>A320</td><td>10,066</td><td>32.0</td><td>14</td><td rowspan="3">36.5</td></tr>
<tr><td>B737-400</td><td>11,721</td><td>41.3</td><td>21</td></tr>
<tr><td>B767-200ER</td><td>1,270</td><td>28.0</td><td>1.5</td></tr>
<tr><td>Widebody[3]</td><td>B747-400</td><td>11,066</td><td>6.3</td><td>6.3</td><td>6.3[4]</td></tr>
</table>

[2] The 767 is typically recognized as a widebody aircraft, however 767 data supported this aircraft be grouped into the narrow body category.

[3] To be included in the widebody category with the 747 is the A340, 777, and MD-11. For the purpose of this implementation in INM, all other aircraft should be considered in the narrowbody category.

[4] It should be taken into consideration that when thrust reversers are applied to reduce speed for widebody aircraft (e.g., landing on a shorter runway), a reverse thrust level of between 30% to 40% max rated thrust may be more appropriate than 6%.

3. Conclusion

Based on the results in Table 3, the average percent of max rated thrust that widebody aircraft use during thrust reverser deployment is approximately 6%. For practical implementation purposes, a value of 10% of maximum thrust will be used to model thrust reversers on widebody aircraft in AEDT (instead of 6%). INM models the thrust level at 10% of max rated thrust at the end of ground roll, it would be unrealistic to drop thrust levels during landing ground roll to 6% and then increase the thrust level back up to 10% at the end of ground roll. For the purposes of this implementation, the widebody aircraft category in INM includes the 747, A340, 777 and the MD-11 only, whereas all other jet aircraft are included in the narrowbody category. For narrowbody aircraft, 40%[5] of max rated thrust is proposed for use during reverser deployment.

[5] The percent of max rated thrust for narrowbody aircraft is rounded up from 36.5% to 40% due to the uncertainty in converting %N1 into percent of max rated thrust for each aircraft type. The corresponding percent of max rated thrust to specific %N1 may vary a few percentage points under different flight conditions.

4. References

[1] “Statistical Loads Data for Airbus A-320 in Commercial Operations,” FAA Report DOT/FAA/AR-02/35, April 2002.

[2] “Statistical Loads Data for Boeing 737-400 in Commercial Operations,” FAA Report DOT/FAA/AR-98/28, August 1998.

[3] “Statistical Loads Data for the B-767-200ER Aircraft in Commercial Operations,” FAA Report DOT/FAA/AR-00/10, March 2000.

[4] “Statistical Loads Data for the Boeing 747-400 in Commercial Operations, “FAA Report DOT/FAA/AR-04/44, January 2005.