Cir 317
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Effects of PANS-OPS Noise Abatement Departure Procedures on Noise and Gaseous Emissions

Approved by the Secretary General
and published under his authority

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GLOSSARY

DEFINITIONS

Adjusted top of climb. The common mission point after top of climb beyond which the remaining part of the flight is common for a set of compared procedures and a given aircraft.

A-weighted sound level. Basic sound/noise level scale used for measuring environmental noise including that from aircraft.

Brake release. The point on the runway from which a departing aircraft commences its take-off.

Carbon dioxide. A component of gaseous emissions comprised of one carbon and two oxygen atoms.

Close-in zone. The zone underneath the flight path, typically extending from the point of initiation of the noise abatement departure procedure up to the crossover point.

Crossover point. The point underneath the flight path at which the sign of the difference between the noise profiles for two compared departure procedures changes.

Cutback. The reduction of engine power from take-off thrust to a lower thrust setting, usually climb thrust.

Distant zone. The zone underneath the flight path, typically extending from the crossover point.

Nitrogen oxide. A component of gaseous emissions comprised of a mixture of nitrogen monoxide and nitrogen dioxide.

Noise. Unwanted sound. Metrics used in this document, such as A-weighted sound level, convert a sound level into a noise level.

Noise level. A decibel measure of sound on a scale which indicates its loudness or noisiness.

Noise profile. The profile obtained by computing noise levels at regular intervals along the flight track from start of initial climb-out until the point where the aircraft has reached a given altitude.

ABBREVIATIONS AND ACRONYMS

AGL	Above ground level
CO_2	Carbon dioxide
dBA	Decibel A-weighted sound level
ft	Feet
ICAO	International Civil Aviation Organization
ISA	International Standard Atmosphere
KIAS	Knots indicated airspeed
L_A	A-weighted sound level
L_{Amax}	Maximum A-weighted sound level
lb	Pound

MCLT	Maximum climb thrust (engine setting usually selected for climb-out phase)
MTOW	Maximum take-off weight
NADP	Noise abatement departure procedure
NM	Nautical mile
NO_x	Nitrogen oxide
PANS-OPS	Procedures for Air Navigation Services — Operations
Point X	Adjusted top of climb
SAE	Society of Automotive Engineers
SL	Sea level
STD	Standard
TOGA	Take-off go-around (maximum take-off thrust setting)
TOW	Take-off weight
V_2	Take-off safety speed

Chapter 1

INTRODUCTION

1.1 PURPOSE AND SCOPE

1.1.1 The purpose of this document is to provide information to aircraft and aerodrome operators with regard to the selection and development of noise abatement departure procedures designed according to the guidance in PANS-OPS, Volume I, Part I, Section 7, Chapter 3. Quantitative information regarding the effects of noise abatement departure procedures on noise and gaseous emissions are provided for a limited number of today's commercial transport jet aircraft.

1.1.2 The scope of this document is limited to noise abatement departure procedures that can be operated with aircraft currently in service.

1.1.3 Data are provided for a range of business, regional, narrow-body and wide-body aircraft (see Chapter 5, Table 5-1) based on common assumptions concerning operational parameters (e.g. take-off weight, thrust settings, atmospheric conditions) for the different aircraft categories.

1.1.4 This material is intended to provide only a general insight into the effects of departure procedures on noise and emissions. The selection of appropriate departure procedures for a given airport and/or fleet mix requires further dedicated study, taking into account particularities such as geographical location and atmospheric conditions.

1.1.5 The quantitative results and conclusions presented are valid only for the aircraft and conditions included in this study and should not be generalized or extrapolated.

1.1.6 In applying this guidance, users should seek advice from noise and emissions experts.

1.2 DOCUMENT OUTLINE

1.2.1 Chapter 2 summarizes the PANS-OPS noise abatement departure procedures that can be selected by the operator. It also highlights the main parameters relevant to the selection of such procedures with regard to environmental criteria due to their supposed influence on noise and gaseous emissions.

1.2.2 Chapter 3 describes the effects of departure procedures on noise and emissions and the methods and metrics used to quantify those effects. It also explains the graphical representation of that data in the appendices to this circular.

1.2.3 Chapter 4 describes the four variants of noise abatement departure procedures evaluated in this circular, provides the basis for comparison of those procedures, and common assumptions regarding operational flight parameters.

1.2.4 Chapter 5 provides a synthesis of the NADP noise and emissions data contained in the appendices. Comparisons are made of the various departure procedures, and the results are summarized in a series of tables showing the noise and emissions differences per compared procedure. The results per aircraft type are shown in the appendices.

1.2.5 Chapter 6 summarizes the conclusions that are valid concerning the analysis, in Chapters 2 to 5, of the effects of four variants of departure procedures on noise and emissions for eight commercial aircraft.

Chapter 2

NOISE ABATEMENT DEPARTURE PROCEDURES

2.1 PANS-OPS GUIDANCE

2.1.1 PANS-OPS, Volume I, Part I, Section 7, Chapter 3, provides guidance with respect to noise abatement departure procedures. It includes recommendations regarding the conditions in which such procedures can be safely used and the envelope within which the main flight parameters defining the procedure can be safely adapted for airport noise mitigation.

2.1.2 PANS-OPS also provides two examples of NADP procedures: one to mitigate noise at relatively shorter distances and one to mitigate noise at relatively greater distances from the brake release point (see 2.2).

2.1.3 Furthermore, PANS-OPS states that the number of departure procedures developed and used by the operator for a given aircraft should be limited to two, one identified as the normal procedure and the other to be used for noise abatement. Within these constraints, the operator must determine which procedure to select.

2.2 PANS-OPS EXAMPLES OF NOISE ABATEMENT PROCEDURES

2.2.1 Figures 2-1 and 2-2 (extracted from PANS-OPS, Volume I, Part I, Section 7, Chapter 3) provide a schematic description of NADP 1 and 2 procedures and the zones where these procedures are expected to provide noise abatement (close-in and distant relative to the brake release point, respectively).

2.2.2 As shown in Figures 2-1 and 2-2, the procedures take place between a minimum of 800 ft and a maximum of 3 000 ft AGL, allowing operators to develop specific procedures to suit their local situations. The term used previously in PANS-OPS, ICAO Procedure A, constituted a specific procedure within the NADP 1 family; similarly ICAO Procedure B constituted a specific procedure within the NADP 2 family. The flexibility currently provided in the PANS-OPS guidance remains limited to two procedures.

2.3 PROCEDURE DEVELOPMENT AND APPRAISAL OF ENVIRONMENTAL EFFECTS

2.3.1 The PANS-OPS guidance, the main goal of which is to provide recommendations for safe aircraft operations, does not provide quantitative information regarding the zones where the aforementioned procedures provide noise abatement, or the size of the noise differences in those zones.

2.3.2 The selection of an appropriate procedure with regard to airport-specific environmental constraints requires the quantification and analysis of the available operational solutions in terms of noise and/or gaseous emissions. The effects of the procedures on the environment depend on the type of aircraft and the operating conditions. Assessment of the effects on noise as part of procedure development should therefore be based on actual information regarding the airport fleet mix and geographical position of the airport and its runway(s) with regard to noise-sensitive areas.

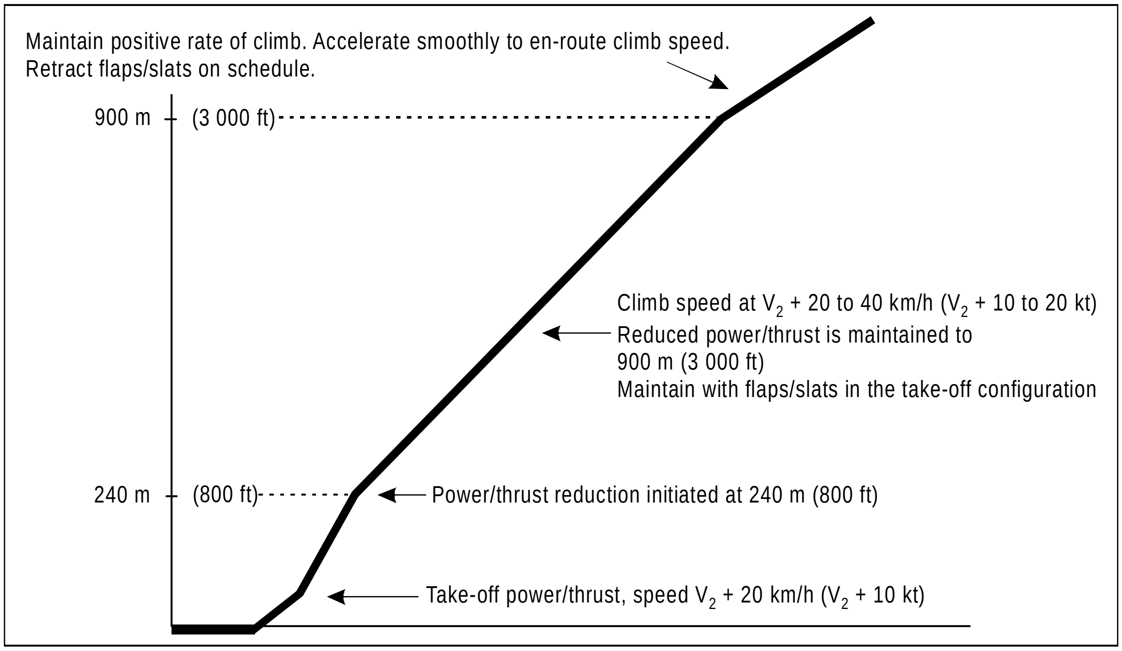


Figure 2-1. Noise abatement take-off climb — Example of a procedure alleviating noise close to the aerodrome (NADP 1)

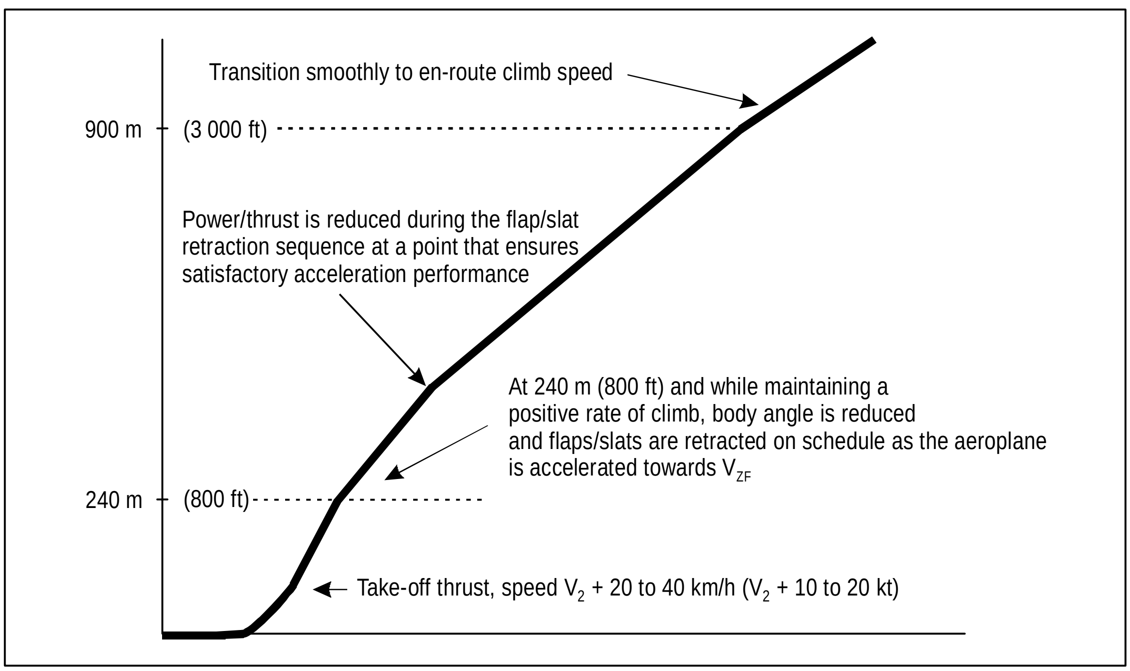


Figure 2-2. Noise abatement take-off climb — Example of a procedure alleviating noise distant from the aerodrome (NADP 2)

Chapter 3

QUANTIFICATION OF THE EFFECTS OF NOISE ABATEMENT DEPARTURE PROCEDURES ON NOISE AND GASEOUS EMISSIONS

3.1 NOISE

3.1.1 For departure operations the main noise source is aircraft engines. For a given aircraft and a given atmospheric condition, the noise perceived by an observer positioned on the ground depends mainly on the thrust setting, the height of the aircraft and its speed. The speed of the aircraft affects the duration of the noise event.

3.1.2 The noise perceived on the ground for a single event can be expressed in terms of maximum-level metrics and in terms of total noise exposure metrics. The maximum-level metrics consider only the peak noise level registered during a noise event. Exposure metrics quantify the total amount of noise during the relevant part of the noise event. Whereas the maximum level corresponds to a certain time and the position of the aircraft, the exposure level corresponds to noise emitted during a part of the aircraft's departure.

3.1.3 The noise underneath the flight path is critical for the assessment of noise produced by the different departure procedures. For this study, noise levels were computed at regular intervals along the track from start of initial climb-out until the point where the aircraft reached 10 000 ft AGL, resulting in so-called "noise profiles".

3.1.4 Establishing a relationship between the development of maximum noise levels below the flight path and events along the flight path (e.g. thrust cutback or transition from climb to acceleration) is relatively straightforward. For exposure-based metrics, this is more difficult due to the integration of noise over a time interval during which several changes in aircraft state and climb performance can occur. For analysis of the procedures in this document, the maximum A-weighted noise level is considered.

3.1.5 Flight profiles were computed using aeroplane manufacturer in-house performance engineering software. Noise levels were computed for these profiles using in-house noise calculation tools, compliant with SAE AIR-1845.

3.2 EMISSIONS

3.2.1 For the departure operations considered in this study, the emissions source is the aircraft main engines. For a given aircraft the operational emissions depend on the aeroplane and engine types, engine thrust setting and operating time to "study evaluation" altitudes of 1 000 ft and 3 000 ft, and adjusted top of climb.

3.2.2 The total NO_x emissions produced for each take-off procedure are presented at 1 000 feet, the typical limiting altitude for NO_2 concerns, and 3 000 feet AGL, the typical boundary layer mixing altitude and the ICAO landing/take-off altitude limit. The total CO_2 emissions produced for each take-off procedure are presented at a common mission point after top of climb (adjusted top of climb, see Chapter 4, 4.1.3).

3.2.3 Emissions were calculated by individual aeroplane manufacturer propriety aeroplane performance methods (see 3.1.5) that provided aeroplane flight path and fuel burn. CO_2 production was calculated directly from fuel burn. NO_x production was determined via fuel flow methods and certified engine emissions data.

3.3 GRAPHICAL REPRESENTATION OF THE NOISE AND EMISSIONS DATA

3.3.1 Figure 3-1 illustrates the graphical representation of the noise and emissions data in the appendices. The graphs show the effects on noise and emissions per aircraft and per pair of NADP procedures. In Figure 3-1 the procedures are named Procedure Y and Procedure Z. The title of each graph specifies the aircraft type and the assumed take-off weight.

3.3.2 Noise levels are demonstrated per procedure by means of noise profiles, showing noise underneath the flight path as a function of distance from brake release. These profiles provide insight on the decrease in noise levels with increased distance from brake release. The applied noise metric is the maximum A-weighted noise level (L_{Amax}). A relative scale is used for these profiles.

3.3.3 A third profile provides the difference between the noise levels of the two procedures, which allows rapid assessment of the amount and the sign of the difference as a function of distance from brake release. The third profile has three distinct characteristics, all of which are important in the selection of noise abatement departure procedures:

a) a "close-in" noise difference zone, typically extending from the point of initiation of the procedure up to the crossover point;

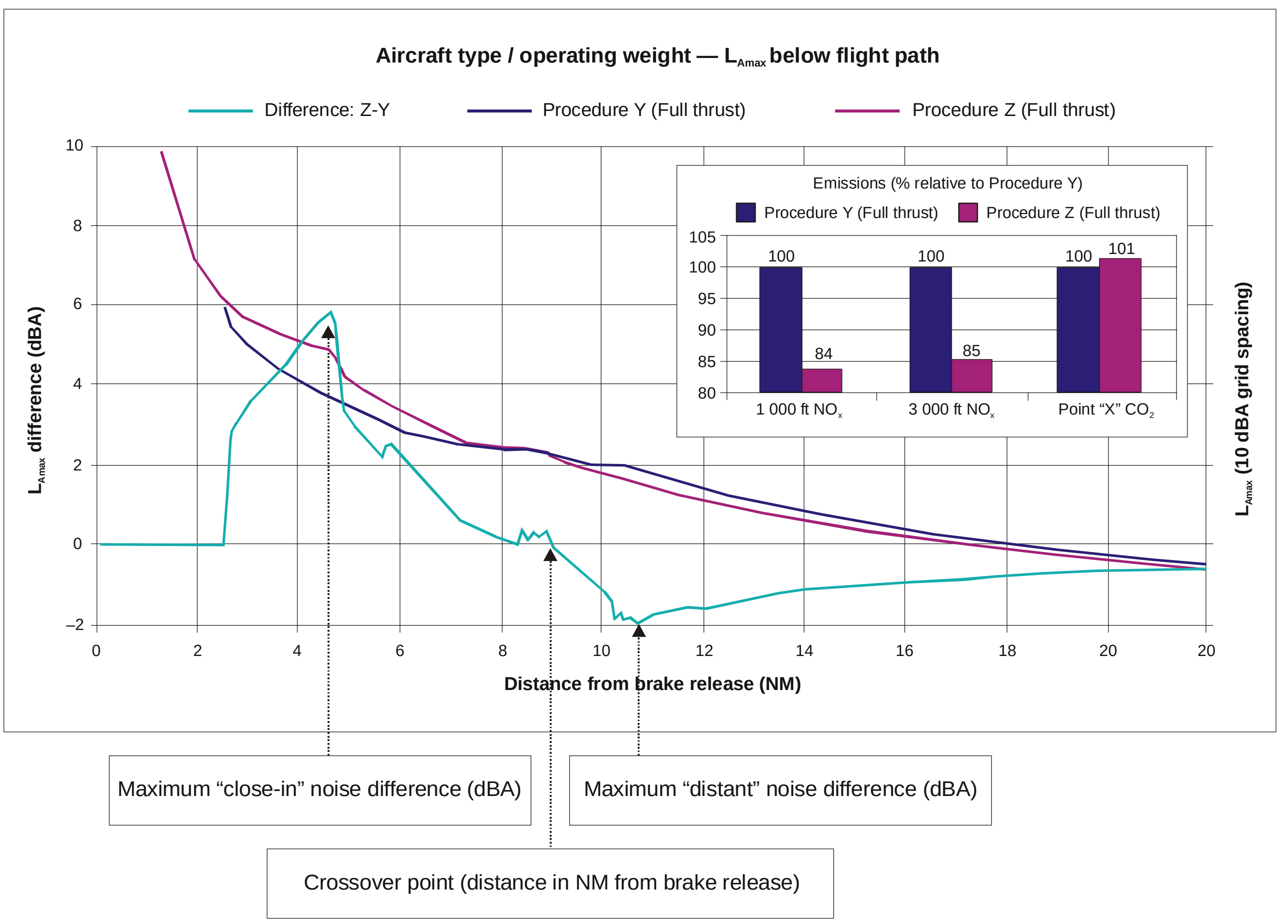


Figure 3-1. Graphical representation of the effects on noise and emissions for two procedures

b) a “crossover point”, which is generally the point at which the sign of the difference changes; and

c) a “distant” noise difference zone, extending from the crossover point.

3.3.4 The maximum close-in noise difference and the maximum distant noise difference designated in Figure 3-1 are included as indicators in the procedure comparisons in Chapter 5.

3.3.5 Emissions levels are represented by means of bar charts. The charts provide the total amount of NO_x emitted between brake release and altitudes of 1 000 ft or 3 000 ft AGL, respectively “1 000 ft NO_x” and “3 000 ft NO_x” in Figure 3-1. A third quantity provided in the bar chart is the total amount of CO_2 emitted between brake release and the adjusted start of cruise, referred to as “Point ‘X’ CO_2” in the bar chart. All results are given as a percentage relative to the first of the two procedures in the chart and are printed above the bar charts to facilitate appraisal of the differences.

3.3.6 The appendices also provide a second graph showing the flight path.

Chapter 4

DEPARTURE PROCEDURES ANALYSED

4.1 PROCEDURE DESCRIPTIONS

4.1.1 Table 4-1 shows the four variants of departure procedures designed in accordance with PANS-OPS that are evaluated in this circular. This includes two NADP 1 variants (Procedures 1 and 2) and two NADP 2 variants (Procedures 3 and 4). The table also includes the take-off and departure climb up to 10 000 ft AGL, relevant to the noise assessment. A schematic description of the succeeding climb-out to adjusted top of climb is provided in Figure 4-1.

4.1.2 Procedures 1 and 2 illustrate the effect of cutback height. Procedures 3 and 4 illustrate the effect of thrust cutback at the beginning and end of the acceleration and flap retraction phase. The selected procedures also allow comparison between NADP 1 and NADP 2, which is described in more detail in 4.2.

Table 4-1. Variants of departure procedures

Procedure 1	Procedure 2	Procedure 3	Procedure 4
Take-off thrust, lowest flap setting[1]	Take-off thrust, lowest flap setting[1]	Take-off thrust, lowest flap setting[1]	Take-off thrust, lowest flap setting[1]
Climb at V_2 + 15 KIAS[2] to 800 ft AGL	Climb at V_2 + 15 KIAS[2] to 1 500 ft AGL	Climb at V_2 + 15 KIAS[2] to 800 ft AGL	Climb at V_2 + 15 KIAS[2] to 800 ft AGL
Cut back to MCLT	Cut back to MCLT	Accelerate and retract flaps[3]	Cut back to MCLT[4]
		At zero flap cut back to MCLT	Accelerate and retract flaps[3]
Constant speed climb to 3 000 ft AGL	Constant speed climb to 3 000 ft AGL	Constant speed climb to 3 000 ft AGL	Constant speed climb to 3 000 ft AGL
Accelerate to 250 KIAS while retracting flaps[3]	Accelerate to 250 KIAS while retracting flaps[3]	Accelerate to 250 KIAS[3]	Accelerate to 250 KIAS[3]
Climb at constant speed to 10 000 ft AGL	Climb at constant speed to 10 000 ft AGL	Climb at constant speed to 10 000 ft AGL	Climb at constant speed to 10 000 ft AGL
End profile at 10 000 ft[5]	End profile at 10 000 ft[5]	End profile at 10 000 ft[5]	End profile at 10 000 ft[5]

1. Flap/slat setting according to the most commonly used flap/slat setting for a given aircraft type.
2. V_2 + 15 kt is considered to be the default, unless the aircraft operations manual recommends another take-off speed.
3. During the acceleration phases, the energy share between acceleration and climb performance is as applied by the manufacturer for the given aircraft.
4. The moment at which the cutback made is compatible with the performance of a specific aircraft in the study and in line with manufacturer's standard operating procedures.
5. For noise predictions the profile end is assumed at 10 000 ft. For the CO_2 analysis the profile continues until the adapted start-of-cruise point.

4.1.3 Figure 4-1 provides a schematic representation of the vertical procedures from brake release until the adjusted top of climb ("Point X"). Take-off to the adjusted top of climb represents the portion of the flight profile that is dependent on the choice of departure procedure. Flight profiles after the adjusted top of climb are assumed to be common for each aeroplane type and therefore are not modelled in this study.

4.2 COMPARISONS

4.2.1 The procedures described in 4.1 are evaluated in pairs. For each aircraft type, four comparisons are made in order to demonstrate the effects of the type of procedure and the influence of the timing and altitude at which the thrust cutback occurs.

4.2.2 The comparisons and their objectives are as follows:

a) Procedure 1 versus Procedure 2: demonstrates the influence of cutback height for NADP 1.

b) Procedure 1 versus Procedure 3: compares NADP 1 to NADP 2 (NADP 2 features a late cutback).

c) Procedure 1 versus Procedure 4: compares NADP 1 to NADP 2 (NADP 2 features an early cutback).

d) Procedure 3 versus Procedure 4: demonstrates the influence of the timing of the cutback for NADP 2.

4.2.3 Comparison of Procedures 1 and 2 assesses the influence of cutback height on noise for a close-in noise abatement departure procedure. Cutback height varies from 800 ft AGL, the minimum height according to the guidance, to 1 500 ft AGL, the maximum cutback height observed in most of the currently applied departure procedures.

4.2.4 Comparison of Procedure 1 to Procedures 3 and 4 demonstrates the difference between NADP 1 and NADP 2 procedures. Two variants of NADP 2 procedures are used because these procedures are believed to be quite sensitive to the timing of thrust cutback.

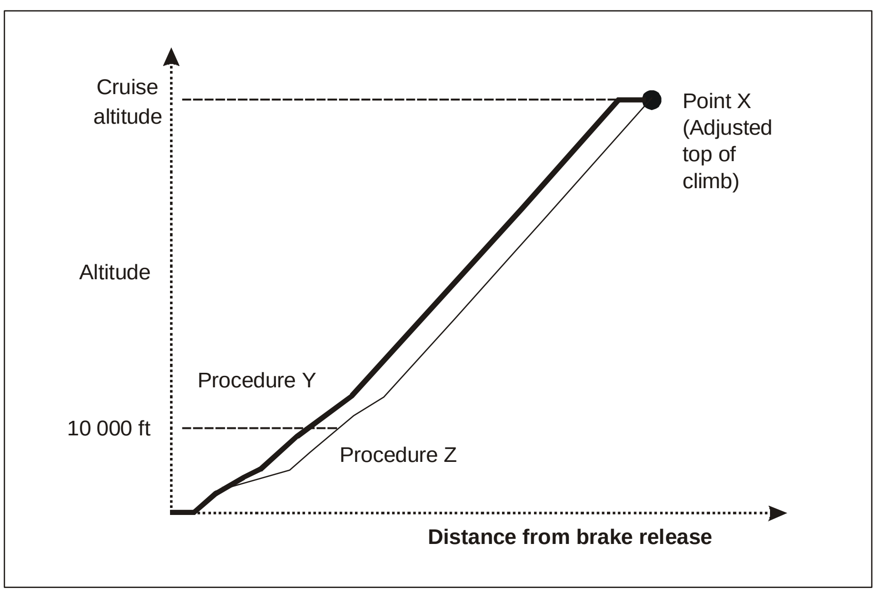


Figure 4-1. Adjusted top of climb (Point X)

4.2.5 Comparison of Procedures 3 and 4 demonstrates the impact on noise and emissions of the timing of thrust cutback in an NADP 2 procedure.

4.3 TAKE-OFF THRUST SETTINGS

4.3.1 In order to simulate real operational conditions, this study is performed in parallel for two cases, using different assumptions for the take-off thrust setting and the take-off weight.

4.3.2 The first case assumes a full take-off thrust setting and a maximum take-off weight. The second case assumes a reduced take-off thrust setting and a performance (climb) limited take-off weight. For this case, the thrust used must correspond to a level between full take-off thrust and the maximum thrust reduction allowed. In this analysis, the percentage of thrust reduction is assumed to correspond to either 10 per cent or 12 per cent, and the actual level chosen is believed to be close to the average thrust setting used in daily practice. This portion of the study is restricted to those aircraft for which maximum climb thrust is less than 90 per cent of full take-off thrust.

4.3.3 Because they are at different take-off weights, comparison of the two cases is not valid. In practice, take-off weight is a constraint and take-off thrust setting is adjusted by the pilot to meet departure performance safety limits in compliance with operator policy.

Chapter 5

SYNTHESIS OF THE NADP NOISE AND EMISSIONS DATA

5.1 INTRODUCTION

5.1.1 This chapter provides a synthesis of the NADP noise and emissions data presented in the appendices to this circular.

5.1.2 The aircraft/engine combinations used in this noise and emissions study are presented in Table 5-1. The data set includes a range of narrow-body, wide-body, regional and business jet aircraft.

5.1.3 In sections 5.2 to 5.4, the results of the study are summarized per pair of compared procedures. The quantitative results are summarized in Tables 5-2 to 5-4, which contain indicators of characteristic noise and emissions differences, as explained in Chapter 4. A qualitative interpretation is given as well.

5.2 PROCEDURE 1 VERSUS PROCEDURE 2

5.2.1 Comparison of Procedures 1 and 2 allows the effect of a change in cutback height (respectively 800 and 1 500 ft AGL) for two NADP 1 type procedures to be determined. The height profiles in the appendices show the steeper climb profiles for Procedure 2 for all cases, due to the delayed cutback.

5.2.2 Table 5-2 provides the noise and emissions differences per aircraft type for both full and reduced take-off thrust. For the Falcon 2000EX only full take-off thrust data are available.

Table 5-1. Aircraft types included in this study

Aircraft category	Aircraft	Engine	MTOW (pounds/tonnes)	Related appendix
Narrow body	Airbus A320-214	CFM56-5B4/P	169 800/77	A
	Boeing 737-700	CFM56-7B24	154 500/70	B
Wide body	Airbus A330-223	PW4168A	513 700/233	A
	Airbus A340-642	TRENT 556	811 300/368	A
	Boeing 767-400	CF6-80C2B8F	450 000/204	B
	Boeing 777-300	TRENT 892	660 000/300	B
Regional jet	Bombardier CRJ900ER	CF34-8C5	82 500/37	C
Business jet	Dassault FALCON 2000EX	PW308C	42 200/19	D

Table 5-2. Noise and emissions differences between Procedures 1 and 2

Comparison	Aircraft	Take-off thrust	Maximum close-in* noise difference (dBA)	Crossover* point (NM)	Maximum distant* noise difference (dBA)	NO_X difference 1 000 ft (per cent)	NO_X difference 3 000 ft (per cent)	CO_2 difference Point X (per cent)
Procedure 2-1	A320-200	FULL	+5.0	2.5	–1.8	+1.4	+1.4	–0.2
Procedure 2-1	A330-200	FULL	+5.3	3.0	–2.0	+1.8	+3.2	–0.2
Procedure 2-1	A340-600	FULL	+2.4	3.6	–2.0	+1.5	+2.1	–0.3
Procedure 2-1	B737-700	FULL	+0.8	2.6	–0.2	–0.1	+0.5	0.0
Procedure 2-1	B767-400	FULL	+5.0	3.5	–1.8	+1.2	+3.2	–0.1
Procedure 2-1	B777-300	FULL	+3.5	3.9	–2.0	+0.7	+2.8	–0.1
Procedure 2-1	CRJ900ER	FULL	+1.5	2.6	–1.1	+0.3	+0.7	0.0
Procedure 2-1	F2000EX	FULL	+2.0	1.9	–0.9	–0.7	–0.3	–0.3
Procedure 2-1	A320-200	REDUCED	+2.6	2.4	–1.6	+1.2	+0.7	–0.1
Procedure 2-1	A330-200	REDUCED	+4.0	2.6	–1.4	+1.1	+1.8	–0.2
Procedure 2-1	A340-600	REDUCED	+1.5	3.7	–1.2	+0.2	+0.7	–0.2
Procedure 2-1	B737-700	REDUCED	+1.2	3.0	–0.6	+0.3	+1.2	0.0
Procedure 2-1	B767-400	REDUCED	+4.0	3.8	–1.8	+0.9	+1.9	–0.1
Procedure 2-1	B777-300	REDUCED	+2.8	4.1	–2.0	0.0	+1.0	–0.2
Procedure 2-1	CRJ900ER	REDUCED	+0.6	2.3	–0.5	+0.1	+0.2	–0.1

* Explained in Chapter 3.

5.2.3 The results in Table 5-2 indicate similar trends for the different aircraft types. The results indicate that performing the cutback at 800 ft AGL rather than at 1 500 ft AGL leads to a noise reduction close-in, which can be attributed to the reduction in engine source noise. The magnitude of this noise reduction varies for the aircraft in this data set from 0.6 dBA to 5.3 dBA.

5.2.4 For distant zones, the 800 ft AGL cutback leads to more noise than the 1 500 ft cutback, due to the steeper climb-out of the latter. The "distant" noise differences are considerably smaller than the "close-in" differences. After peak differences ranging from –0.2 dBA to –2.0 dBA, the noise differences gradually reduce throughout the remainder of the climb-out phase.

5.2.5 The crossover point between the noise profiles varies roughly with aircraft size, ranging from 1.9 NM for business aircraft to 4.1 NM for large twin-jet aircraft at reduced thrust.

5.2.6 The emissions data in Table 5-2 show that, compared to Procedure 1, Procedure 2 produces differences in NO_x of –0.7 to +1.8 per cent through 1 000 ft and –0.3 to 3.2 per cent through 3 000 ft AGL. Procedure 2 reduces CO_2 by as much as 0.3 per cent through the adjusted top of climb.

5.3 PROCEDURE 1 VERSUS PROCEDURE 3

5.3.1 With the comparison of Procedures 1 and 3, the difference between an NADP 1 and an NADP 2 procedure can be determined in terms of their effects on noise and emissions. Procedure 3 features a cutback at the end of the acceleration and flap retraction phase. The height profiles in the appendices indicate better climb performance for Procedure 1 up to about 3 000 ft AGL, but better overall climb performance up to 10 000 ft for Procedure 3.

5.3.2 The results in Table 5-3 indicate the “close-in” noise reduction obtained with Procedure 1 compared to Procedure 3. The peak values of noise difference in the “close-in” area before the crossover point vary from 3.5 to 8.1 dBA.

5.3.3 In the “distant” area beyond the crossover point, noise differences are smaller, with peak differences between –0.2 and –3.7 dBA, and are spread out over a larger area.

5.3.4 The crossover point ranges from 5.5 to 8.1 NM from brake release for all except the business aircraft, which has its crossover point at 3.3 NM.

5.3.5 The emissions data in Table 5-3 show that Procedure 3 produces up to 17.2 per cent more NO_x through 1 000 ft and up to 19.8 per cent more NO_x through 3 000 ft AGL. Procedure 3 however leads to a reduction of CO_2 of as much as 2.7 per cent through the adjusted top of climb.

5.4 PROCEDURE 1 VERSUS PROCEDURE 4

5.4.1 As with the preceding comparison, the comparison of Procedures 1 and 4 enables the noise and emissions differences between an NADP 1 and an NADP 2 procedure to be determined. NADP 2 Procedure 4 features a cutback at the beginning of the acceleration and flap retraction phase. Although climbing out less steeply than Procedure 1 in the initial phase, Procedure 4 provides a steeper overall profile up to 10 000 ft AGL.

5.4.2 The noise results summarized in Table 5-4 indicate similar trends as in the preceding comparison. Compared to Procedure 4, Procedure 1 provides noise reduction in the “close-in” area, with peak differences ranging from 3.0 to 7.0 dBA.

Table 5-3. Noise and emissions differences between Procedures 1 and 3

Comparison	Aircraft	Take-off thrust	Maximum close-in noise difference (dBA)	Crossover point (NM)	Maximum distant noise difference (dBA)	NO_X difference 1 000 ft (per cent)	NO_X difference 3 000 ft (per cent)	CO_2 difference Point X (per cent)
Procedure 3-1	A320-200	FULL	+7.7	7.2	–2.7	+16.6	+13.3	–2.3
Procedure 3-1	A330-200	FULL	+8.1	6.5	–3.0	+16.9	+8.0	–2.2
Procedure 3-1	A340-600	FULL	+5.6	7.7	–3.7	+14.6	+10.2	–2.6
Procedure 3-1	B737-700	FULL	+3.5	7.6	–0.3	+11.2	+7.2	–1.7
Procedure 3-1	B767-400	FULL	+7.0	5.8	–2.0	+9.5	+19.8	–1.8
Procedure 3-1	B777-300	FULL	+4.8	6.5	–2.0	+10.5	+11.7	–1.5
Procedure 3-1	CRJ900ER	FULL	+3.7	7.3	–0.5	+13.5	+0.8	–1.1
Procedure 3-1	F2000EX	FULL	+6.0	3.3	–2.9	+14.8	+4.2	–2.4
Procedure 3-1	A320-200	REDUCED	+6.2	7.0	–2.1	+16.9	+11.2	–2.2
Procedure 3-1	A330-200	REDUCED	+7.2	6.2	–2.2	+17.2	+6.0	–2.5
Procedure 3-1	A340-600	REDUCED	+5.5	7.9	–2.8	+13.9	+8.9	–2.7
Procedure 3-1	B737-700	REDUCED	+3.6	8.1	–0.5	+10.7	+7.7	–1.9
Procedure 3-1	B767-400	REDUCED	+5.0	5.5	–2.0	+9.1	+14.4	–2.0
Procedure 3-1	B777-300	REDUCED	+3.9	8.0	–2.0	+9.9	+8.7	–1.7
Procedure 3-1	CRJ900ER	REDUCED	+3.6	6.5	–0.2	+14.6	+0.3	–1.2

5.4.3 In the “distant” area, overall Procedure 4 produces less noise, with peak noise differences reaching –2.6 dBA. For several aircraft, distant noise reduction is marginal and less well developed compared to the case of Procedure 1 versus Procedure 3. In the case of the regional jet, with reduced thrust full crossover was not obtained; however, this particular result is valid only for this example and no general conclusion can be drawn. Hence, in this instance a crossover point was chosen by comparing the noise difference plot to that of full thrust, and the Procedure 1 versus Procedure 3 comparison with both thrust settings. These plots all show strong similarity and the resulting crossover points show similar trends.

5.4.4 The crossover point ranges from 7.8 to 11.0 NM for wide-body aircraft, is slightly smaller for regional aircraft and occurs around 3.3 NM for business aircraft. Overall the crossover occurs later than for the comparison between Procedures 3 and 1.

5.4.5 The emissions data in Table 5-4 show that Procedure 4 produces up to 15.5 per cent more NO_x through 1 000 ft and up to 9.9 per cent more NO_x through 3 000 ft AGL. Procedure 4 however leads to a reduction of CO_2 of as much as 2.4 per cent through the adjusted top of climb.

Table 5-4. Noise and emissions differences between Procedures 1 and 4

Comparison	Aircraft	Take-off thrust	Maximum close-in noise difference (dBA)	Crossover point (NM)	Maximum distant noise difference (dBA)	NO_X difference 1 000 ft (per cent)	NO_X difference 3 000 ft (per cent)	CO_2 difference Point X (per cent)
Procedure 4-1	A320-200	FULL	+7.0	8.1	–1.6	+14.6	+9.9	–2.0
Procedure 4-1	A330-200	FULL	+4.3	9.7	–1.7	+12.3	+2.1	–2.0
Procedure 4-1	A340-600	FULL	+5.9	9.2	–2.2	+11.0	+4.3	–2.3
Procedure 4-1	B737-700	FULL	+3.1	8.0	–0.1	+10.2	+5.7	–1.7
Procedure 4-1	B767-400	FULL	+4.0	9.5	–0.5	+6.0	+8.5	–1.7
Procedure 4-1	B777-300	FULL	+4.0	9.0	–0.8	+6.1	+5.7	–1.3
Procedure 4-1	CRJ900ER	FULL	+3.0	7.7	–0.2	+9.6	+0.5	–0.6
Procedure 4-1	F2000EX	FULL	+3.5	3.3	–2.6	+8.1	+1.9	–1.8
Procedure 4-1	A320-200	REDUCED	+6.6	7.8	–1.3	+15.5	+9.7	–2.0
Procedure 4-1	A330-200	REDUCED	+6.0	8.3	–1.4	+14.4	+2.8	–2.3
Procedure 4-1	A340-600	REDUCED	+6.1	9.1	–2.0	+12.5	+6.3	–2.4
Procedure 4-1	B737-700	REDUCED	+3.0	9.0	–0.2	+9.7	+5.3	–1.9
Procedure 4-1	B767-400	REDUCED	+4.0	10.0	–0.5	+6.7	+7.8	–1.8
Procedure 4-1	B777-300	REDUCED	+4.0	11.0	–0.8	+7.0	+5.7	–1.5
Procedure 4-1	CRJ900ER	REDUCED	+3.3	6.6	0.0	+12.8	–0.1	–0.8

5.5 PROCEDURE 3 VERSUS PROCEDURE 4

5.5.1 Comparison of Procedures 3 and 4 enables the effect of the timing of cutback during the acceleration and flap retraction phase for an NADP 2 procedure to be determined. Procedure 3 features a cutback to climb thrust at the end of the acceleration and flap retraction phase whereas Procedure 4 has a cutback at the beginning. This results overall in a steeper climb-out profile for Procedure 3.

5.5.2 The results in Table 5-5 show that performing the cutback to climb thrust at the beginning of the acceleration phase is always better for close-in noise reduction but always worse for distant noise reduction. The noise reduction obtained “close-in” with Procedure 4 ranges from –0.8 to –5.5 dBA and can be attributed to a reduced engine noise level.

5.5.3 The maximum noise differences in the “distant” zone vary between 0.4 and 4.2 dBA and can be attributed to differences in height profile. Unlike the trade-off in close-in and distant noise reductions when comparing Procedure 1 to Procedures 2, 3 or 4, here the magnitude of peak close-in and distant noise differences are very similar.

5.5.4 The crossover point ranges from 2.4 to 5.5 NM and is in fact located close to the point where cutback for Procedure 3 takes place.

5.5.5 The emissions data in Table 5-5 show that Procedure 4 produces up to 5.8 per cent less NO_x through 1 000 ft and up to 9.5 per cent less NO_x through 3 000 ft AGL. Procedure 4 however leads to an increase of CO_2 of as much as 0.7 per cent through the adjusted top of climb.

Table 5-5. Noise and emissions differences between Procedures 3 and 4

Comparison	Aircraft	Take-off thrust	Maximum close-in noise difference (dBA)	Crossover point (NM)	Maximum distant noise difference (dBA)	NO_X difference 1 000 ft (per cent)	NO_X difference 3 000 ft (per cent)	CO_2 difference Point X (per cent)
Procedure 4-3	A320-200	FULL	–5.4	3.7	+4.2	–1.7	–2.9	+0.3
Procedure 4-3	A330-200	FULL	–5.5	3.6	+4.1	–4.0	–5.4	+0.2
Procedure 4-3	A340-600	FULL	–2.5	4.9	+4.2	–3.1	–5.3	+0.3
Procedure 4-3	B737-700	FULL	–0.8	3.5	+0.6	–0.9	–1.4.	0.0
Procedure 4-3	B767-400	FULL	–4.8	5.5	+3.8	–3.3	–9.5	+0.1
Procedure 4-3	B777-300	FULL	–3.8	5.0	+3.5	–3.9	–5.4	+0.2
Procedure 4-3	CRJ900ER	FULL	–1.6	2.7	+1.2	–3.4	–0.3	+0.5
Procedure 4-3	F2000EX	FULL	–4.4	2.4	+0.6	–5.8	–2.2	+0.7
Procedure 4-3	A320-200	REDUCED	–2.9	3.5	+2.6	–1.2	–1.3	+0.2
Procedure 4-3	A330-200	REDUCED	–3.9	3.1	+2.8	–2.4	–3.0	+0.2
Procedure 4-3	A340-600	REDUCED	–1.3	5.4	+2.7	–1.2	–2.4	+0.2
Procedure 4-3	B737-700	REDUCED	–1.3	3.6	+1.3	–0.9	–2.3	0.0
Procedure 4-3	B767-400	REDUCED	–4.0	5.5	+3.5	–2.1	–5.8	+0.2
Procedure 4-3	B777-300	REDUCED	–3.0	5.0	+3.8	–2.6	–2.8	+0.3
Procedure 4-3	CRJ900ER	REDUCED	–0.6	2.5	+0.4	–1.6	–0.4	+0.4

Chapter 6

CONCLUSIONS

6.1 The effects of noise abatement departure procedures, designed according to PANS-OPS guidance, on noise and emissions have been analysed for eight commercial jet aircraft. The conclusions outlined in 6.2 to 6.10 are valid for these eight aircraft.

6.2 The procedures evaluated include two NADP 1 and two NADP 2 variants. The analysis confirms that NADP 1 minimizes noise in a zone relatively close to the brake release point, whereas NADP 2 minimizes noise in the zone further away from brake release.

6.3 Close-in noise differences between NADP 1 and NADP 2 are generally bigger than distant noise differences.

6.4 The point where the noise difference changes sign is called the crossover point and is shown to occur between 5.5 to 11 NM distance from brake release for regional and wide-body aircraft.

6.5 The cutback height has a significant influence on noise for both NADP 1 and NADP 2. It determines both the location of noise reduction areas and the amount of noise reduction in those areas.

6.6 The magnitude of the noise differences for procedures using full thrust are larger than those with reduced thrust. However, the use of full thrust and maximum take-off weight will not be encountered frequently in operation.

6.7 NADP 2 tends to produce less CO_2 and more NO_x compared to NADP 1.

6.8 In terms of accumulated NO_x up to 3 000 ft above ground level, NADP 2 appears to produce between 5 to 20 per cent more NO_X than NADP 1 for wide-body aircraft. For regional and business aircraft, the differences are smaller.

6.9 In terms of accumulated CO_2 up to adjusted top of climb, NADP 2 variants appear to produce 0.6 to 2.7 per cent less CO_2 than NADP 1.

6.10 The results indicate that, of the procedures included in this study, no single departure procedure minimizes overall noise and emissions simultaneously. Depending on local airport requirements, trade-offs must be made between close-in versus distant noise, NO_x versus CO_2 emissions and, finally, noise versus gaseous emissions.

Appendix A

RESULTS — AIRBUS

AIRCRAFT STUDIED

A320-214, CFM56-5B4/P

- Take-off in CONF 2
- Climb at V_2 + 10 kt IAS
- Take-off thrust/weight cases:
  - — Full thrust (TOGA)/MTOW = 77 t
  - — 12 per cent reduced thrust/TOW = 71 t

A330-223, PW4168A

- Take-off in CONF 2
- Climb at V_2 + 15 kt IAS
- Take-off thrust/weight cases:
  - — Full thrust (TOGA)/MTOW = 233 t
  - — 12 per cent reduced thrust/TOW = 200 t

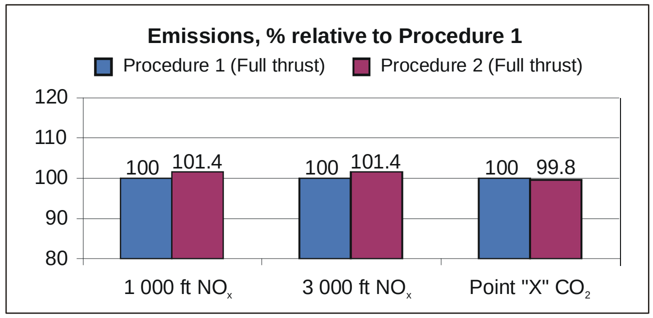
A340-642, RR Trent 556

- Take-off in CONF 3
- Climb at V_2 + 10 kt IAS
- Take-off thrust/weight cases:
  - — Full thrust (TOGA)/MTOW = 368 t
  - — 12 per cent reduced thrust/TOW = 348 t

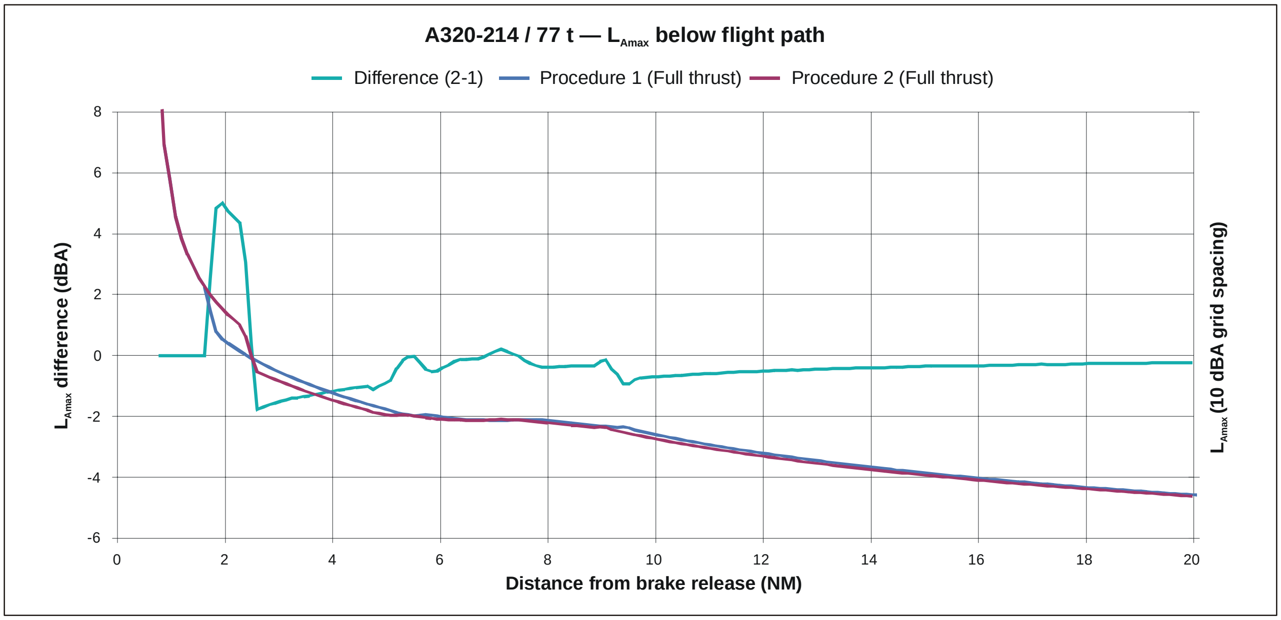
ATMOSPHERIC CONDITIONS

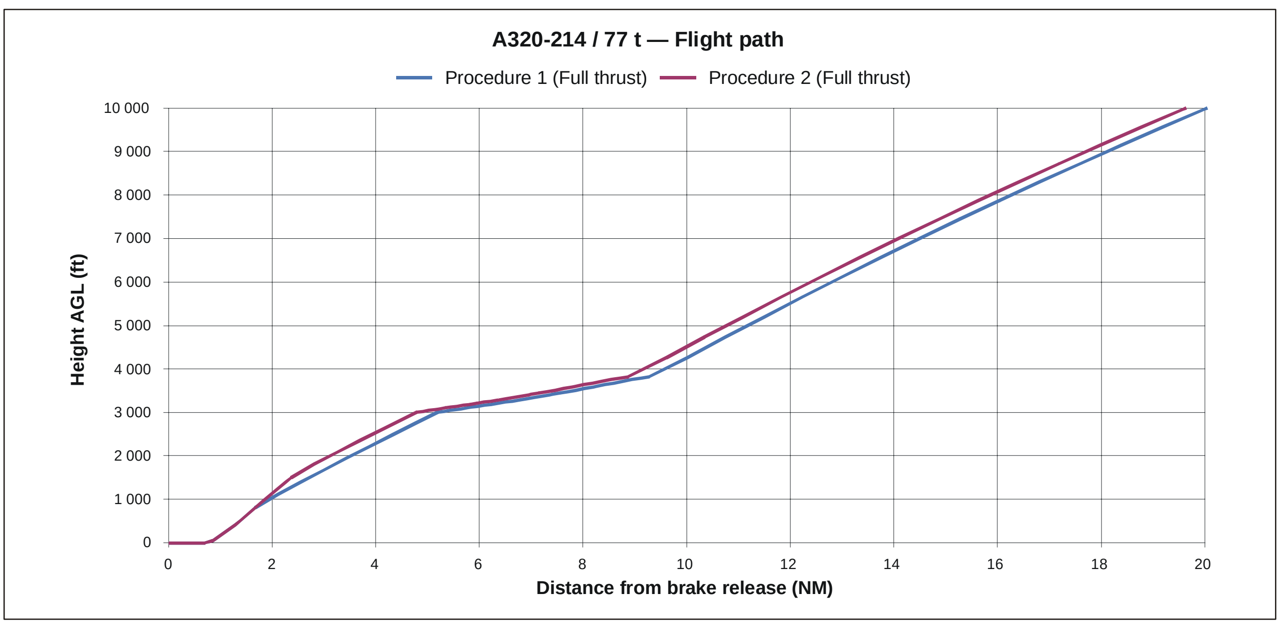
Temperature:	ISA
Relative humidity:	70 per cent
Wind:	No wind
Runway elevation:	Sea level

A320-214, CFM56-5B4/P
- **Full thrust (TOGA)**
- **MTOW = 169 800 lb**



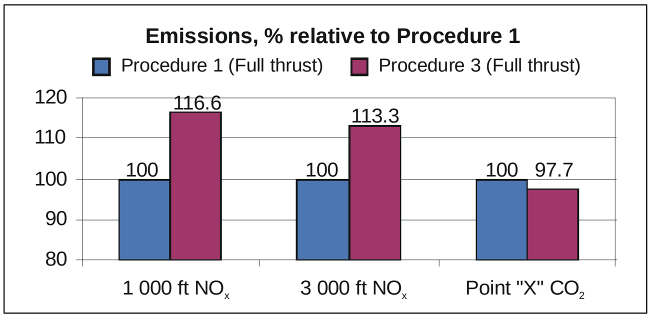
Comparison of Procedures 1 and 2





A320-214, CFM56-5B4/P

- **Full thrust (TOGA)**
- **MTOW = 169 800 lb**



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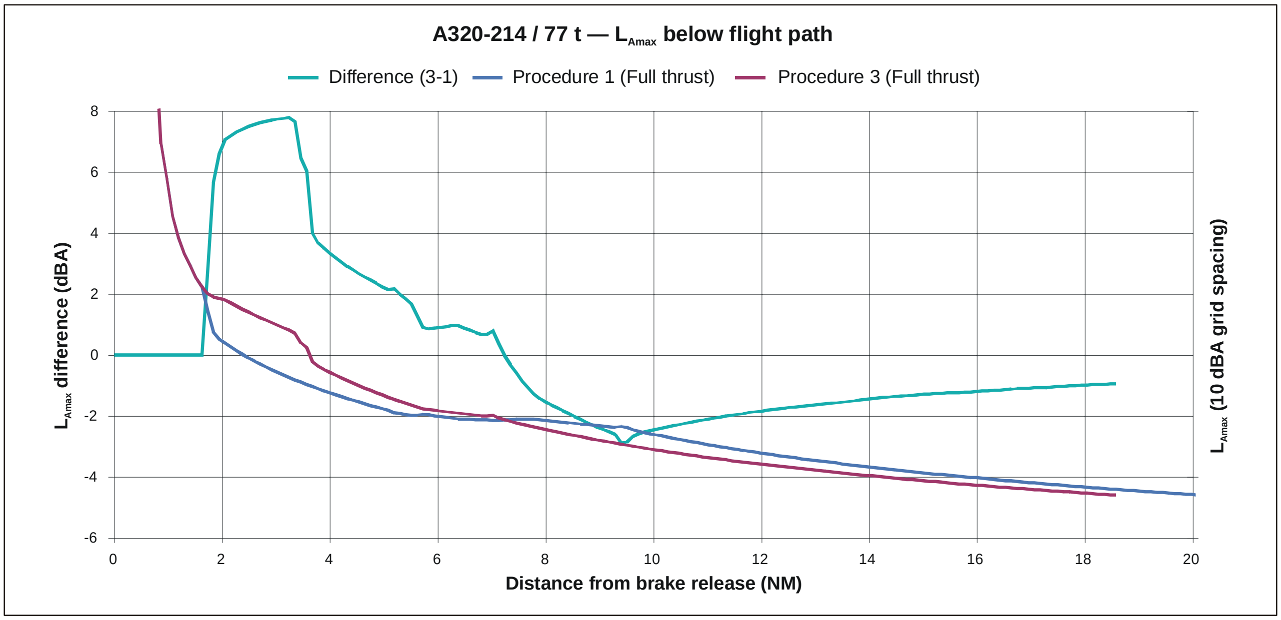
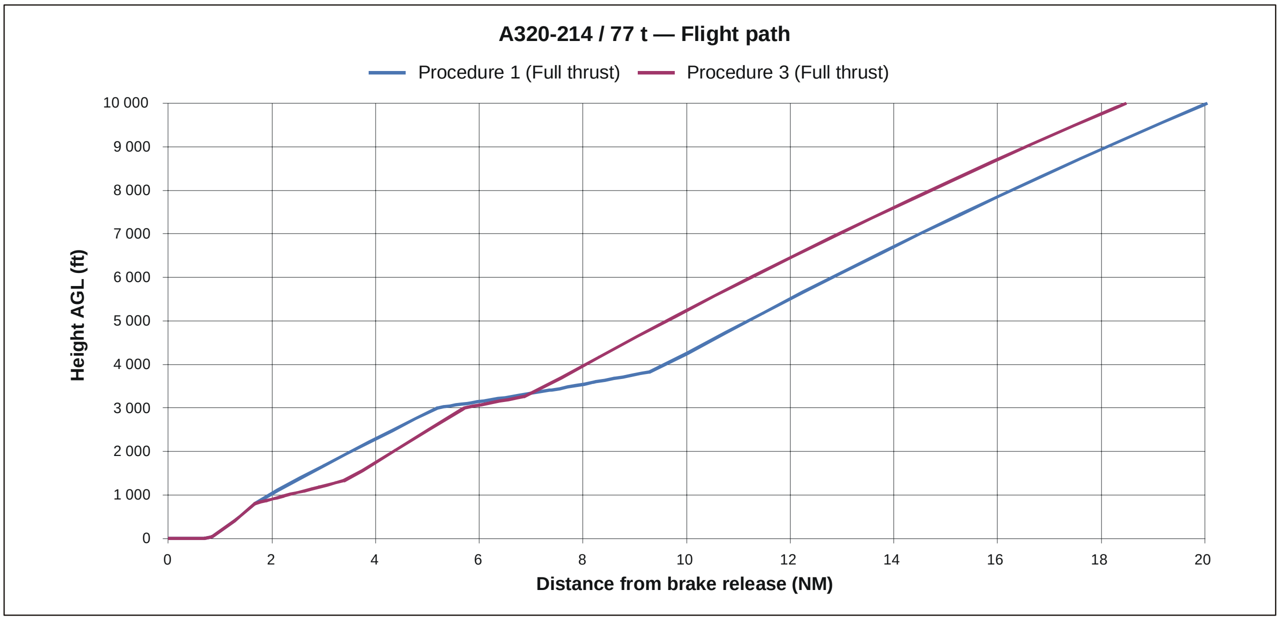
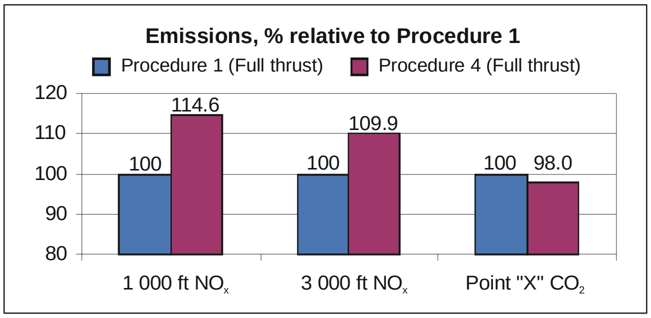


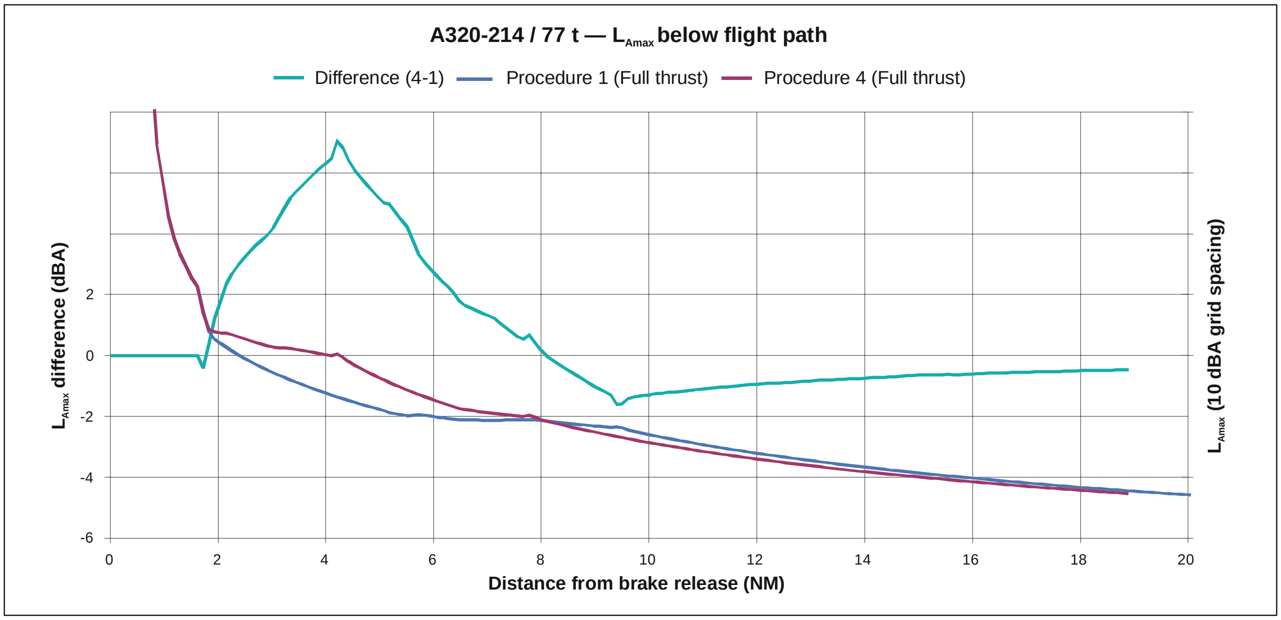


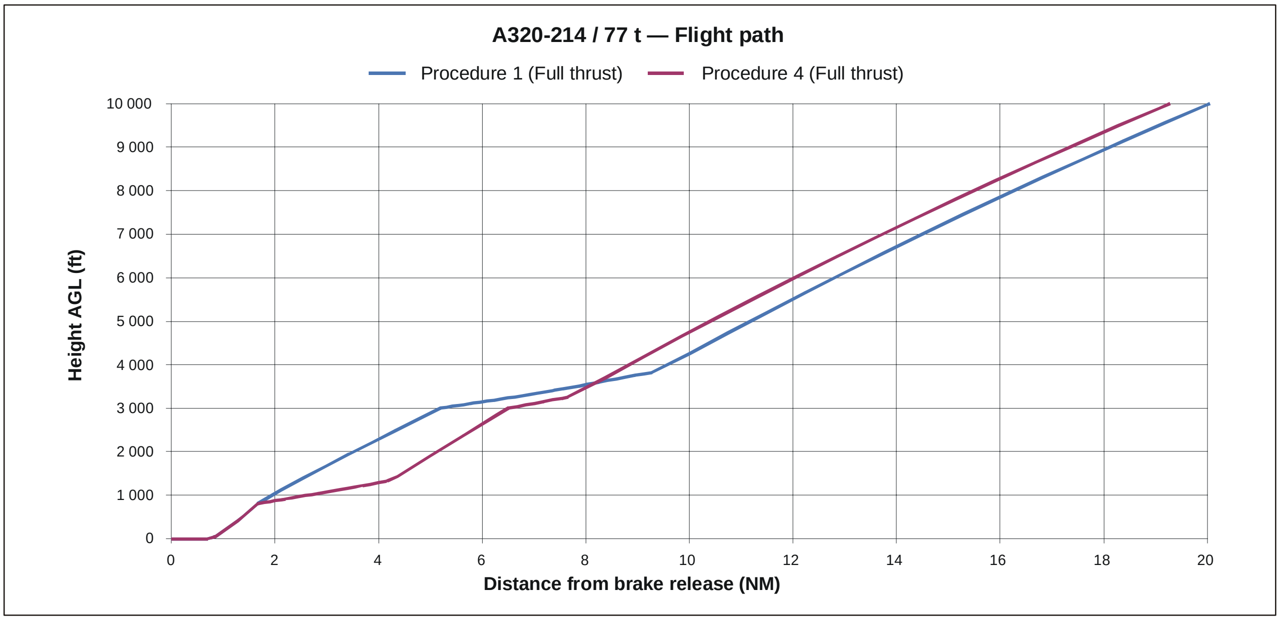
A320-214, CFM56-5B4/P

- **Full thrust (TOGA)**
- **MTOW = 169 800 lb**

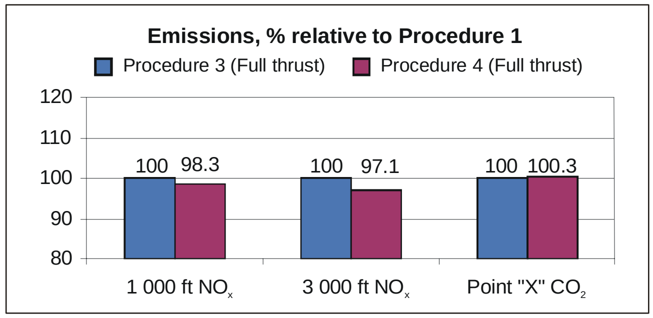


Comparison of Procedures 1 and 4

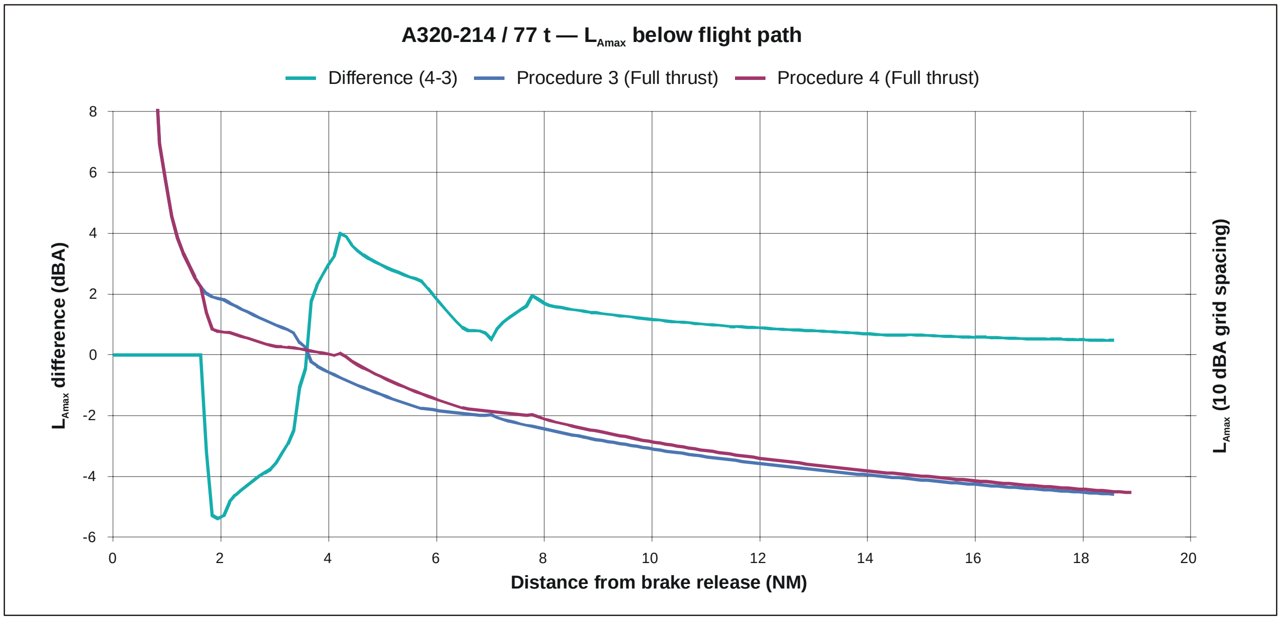


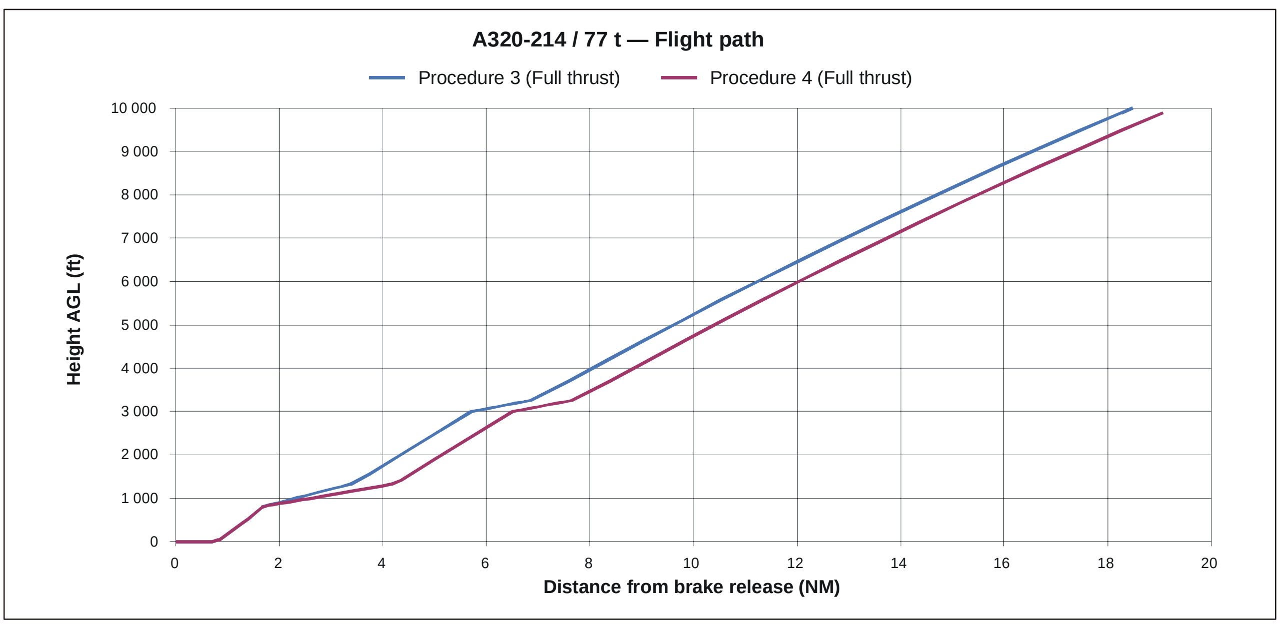


A320-214, CFM56-5B4/P
- **Full thrust (TOGA)**
- **MTOW = 169 800 lb**



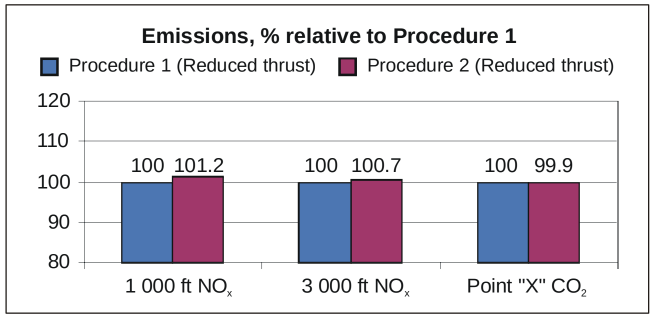
Comparison of Procedures 3 and 4



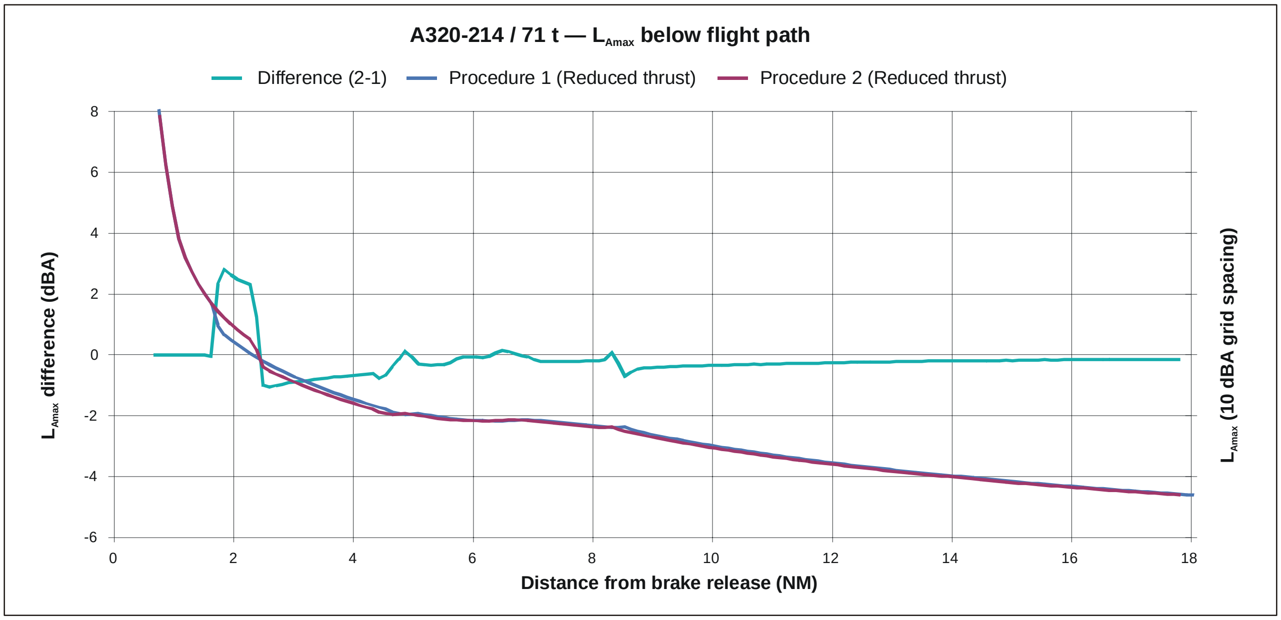


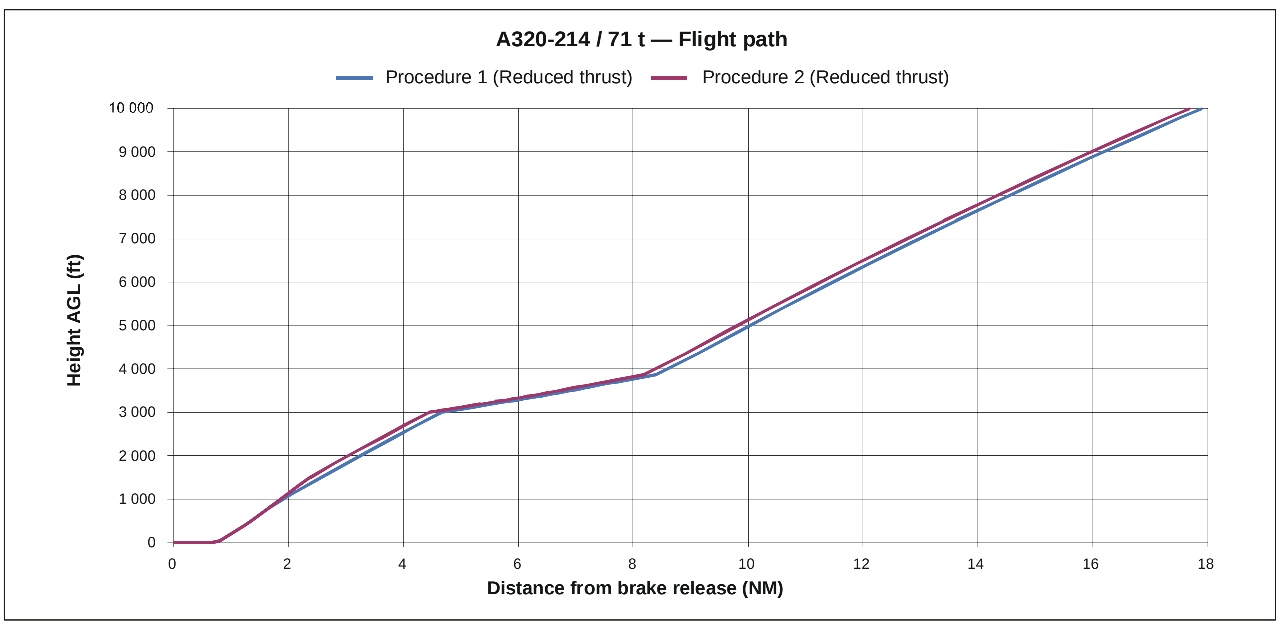
A320-214, CFM56-5B4/P

- **12 per cent reduced thrust**
- **TOW = 156 600 lb**



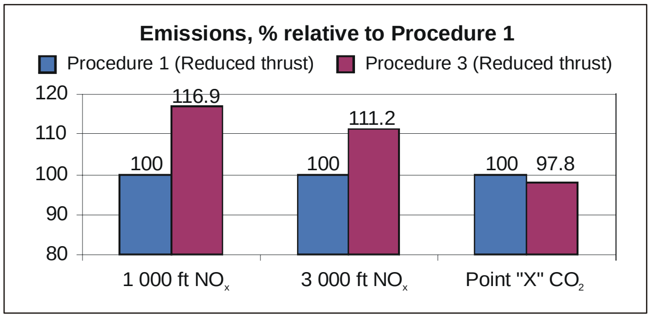
Comparison of Procedures 1 and 2





A320-214, CFM56-5B4/P

- **12 per cent reduced thrust**
- **TOW = 156 600 lb**



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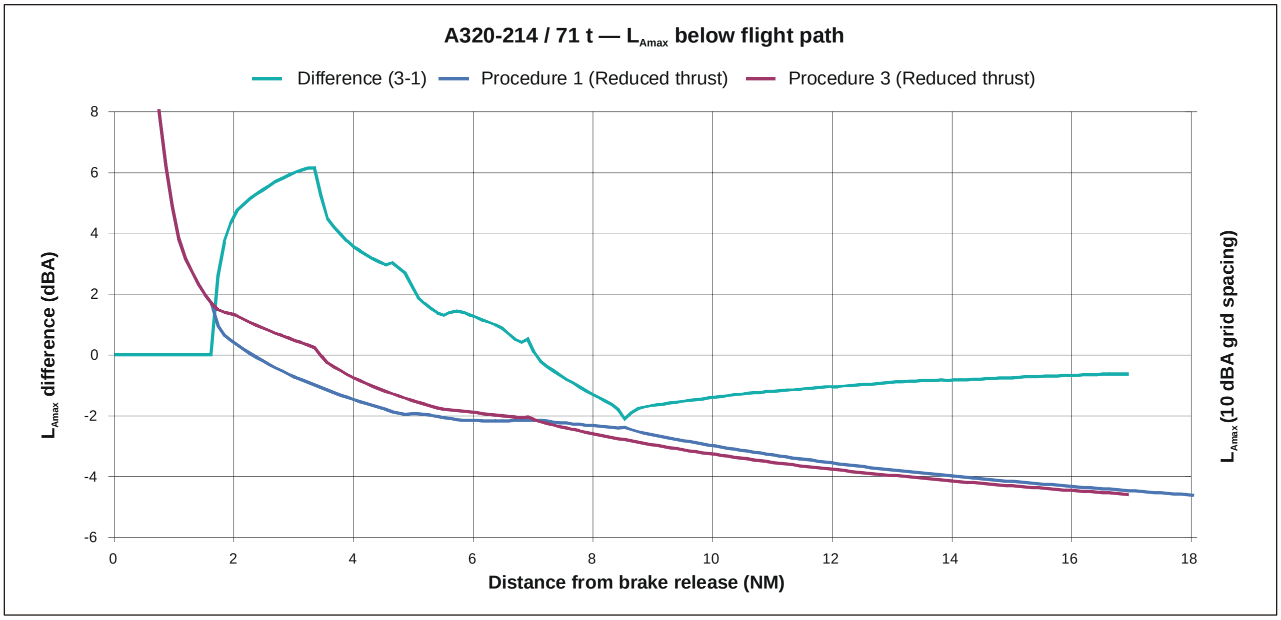
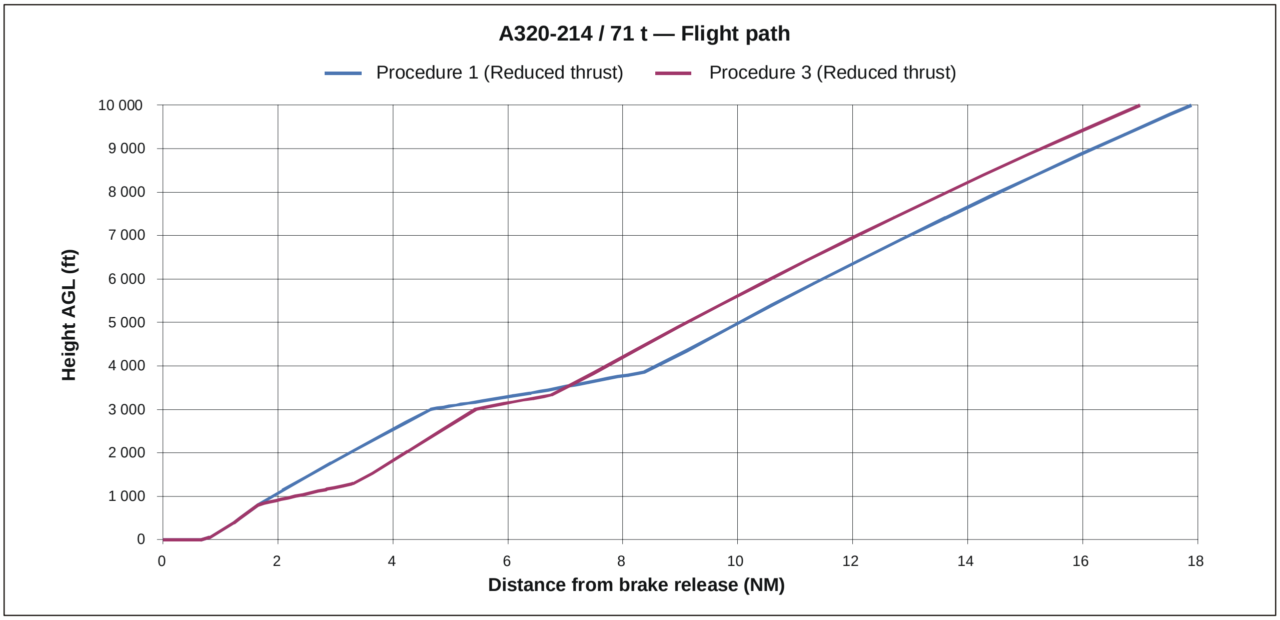
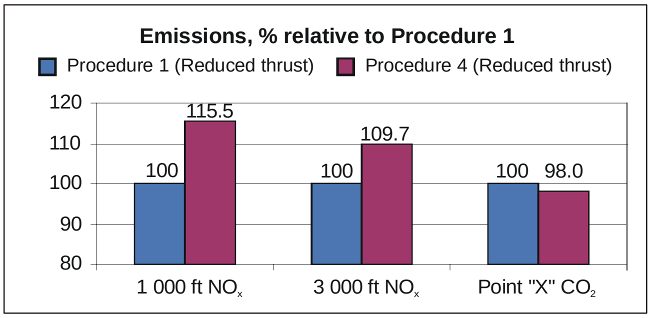




A320-214, CFM56-5B4/P
- **12 per cent reduced thrust**
- **TOW = 156 600 lb**



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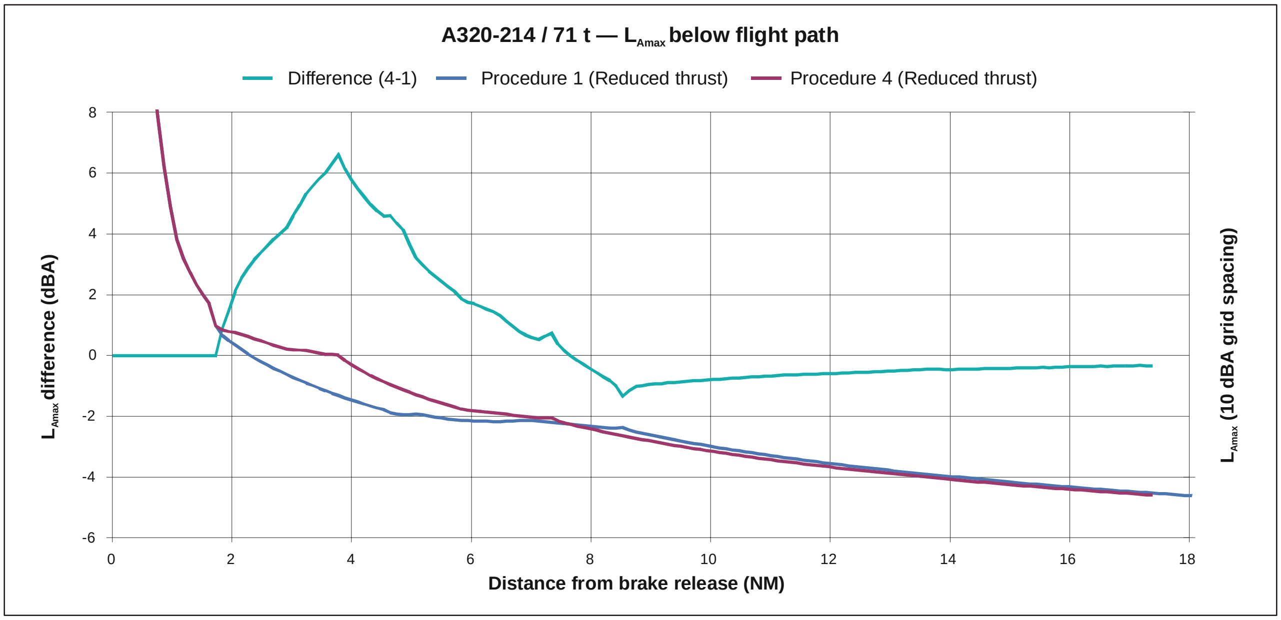
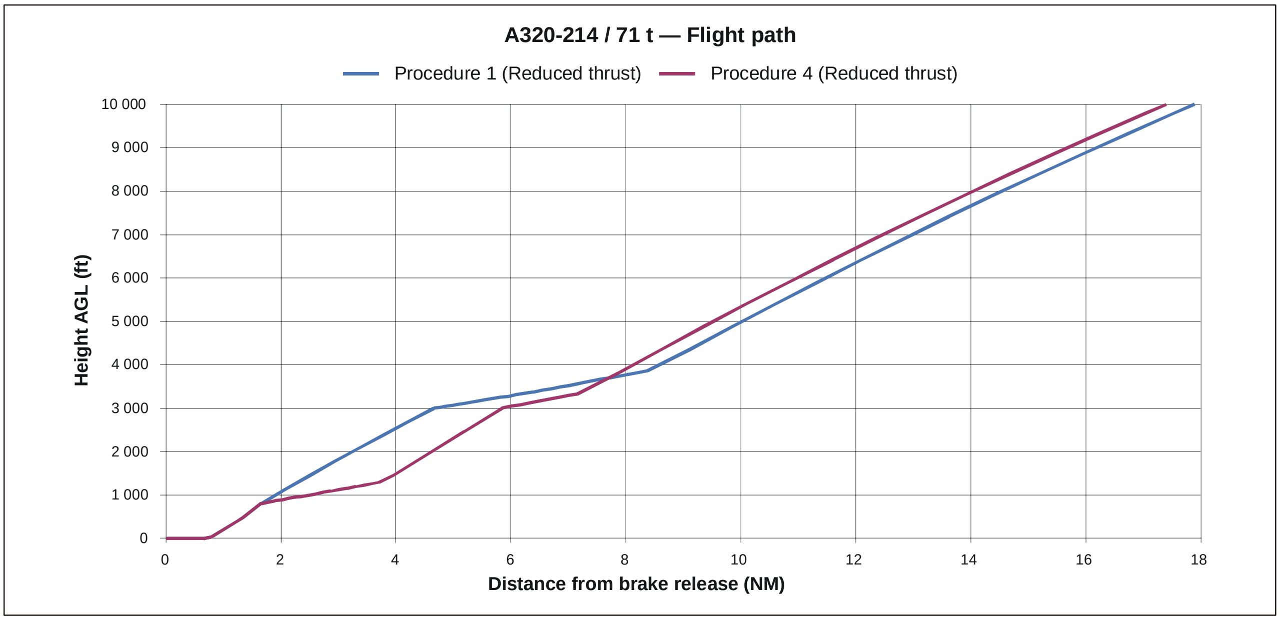
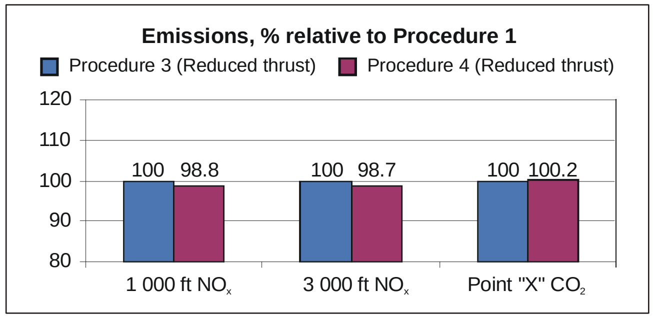


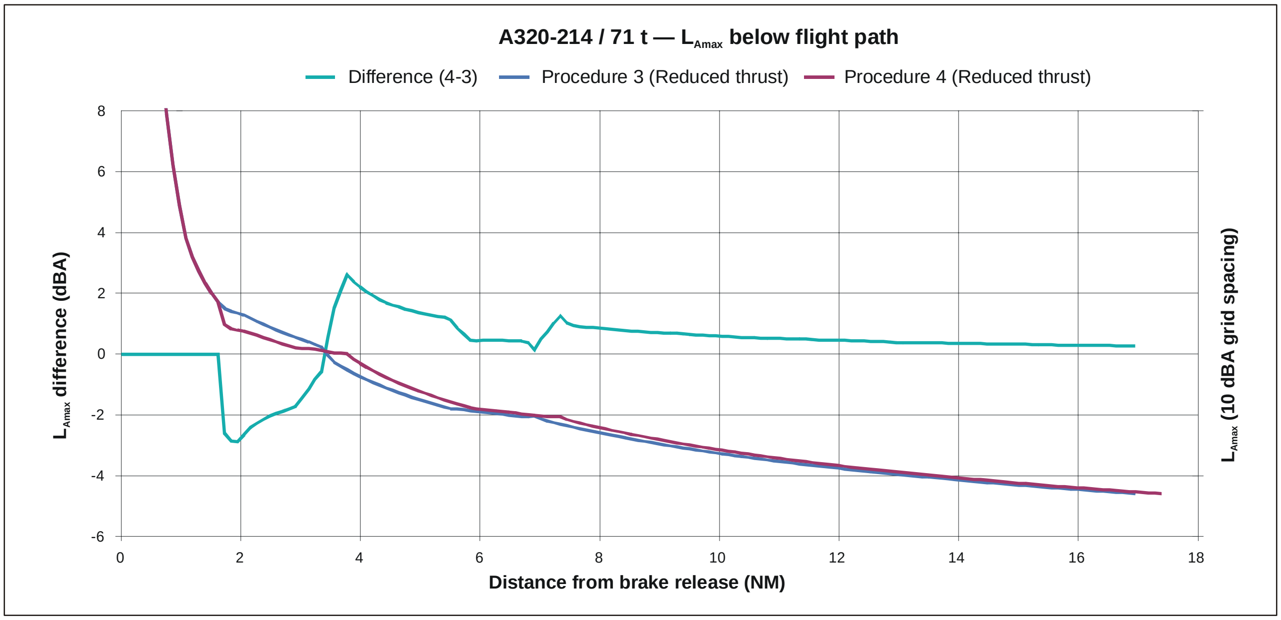


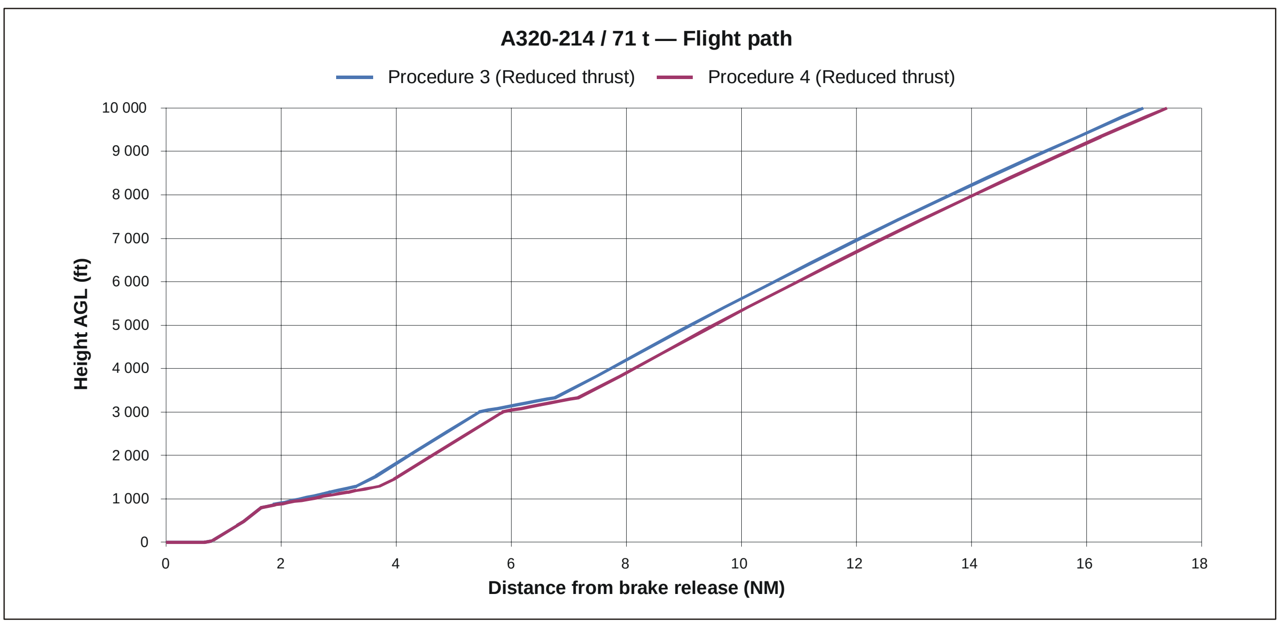
A320-214, CFM56-5B4/P

- **12 per cent reduced thrust**
- **TOW = 156 600 lb**

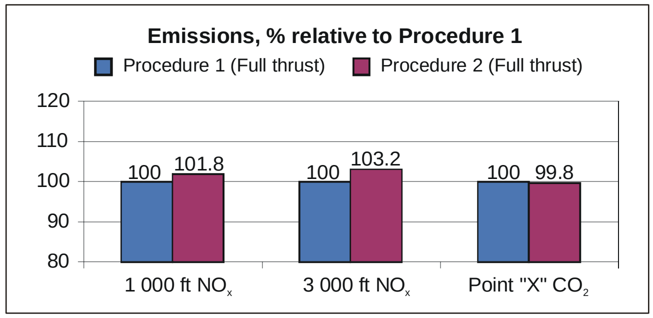


Comparison of Procedures 3 and 4

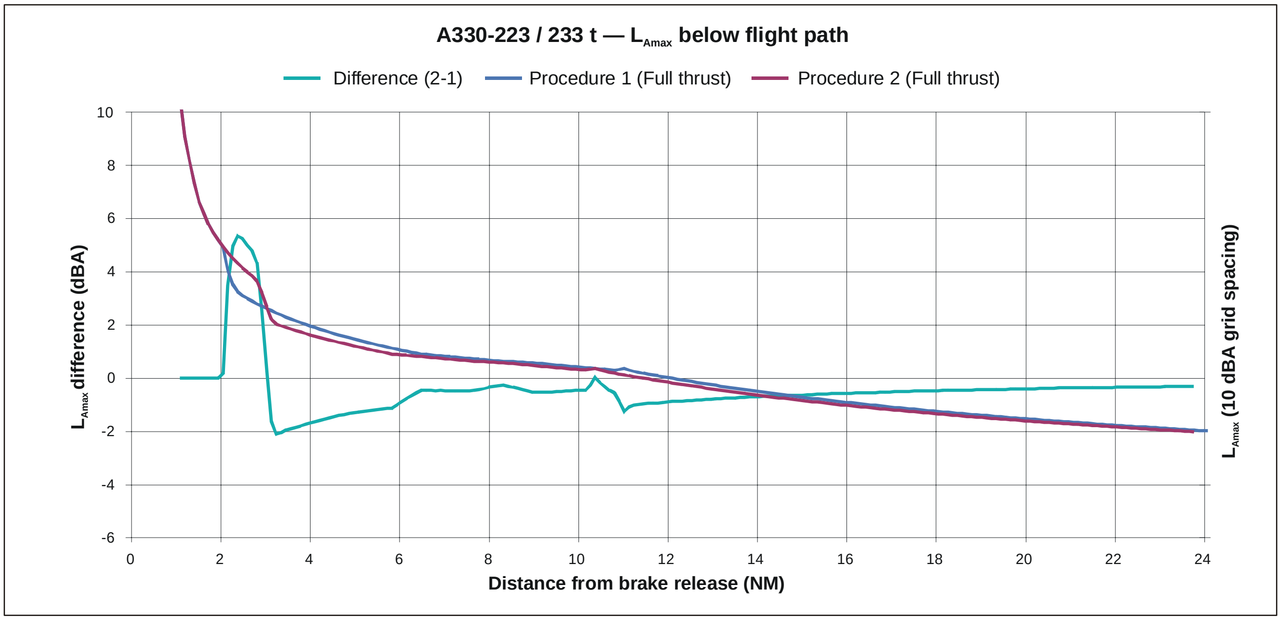


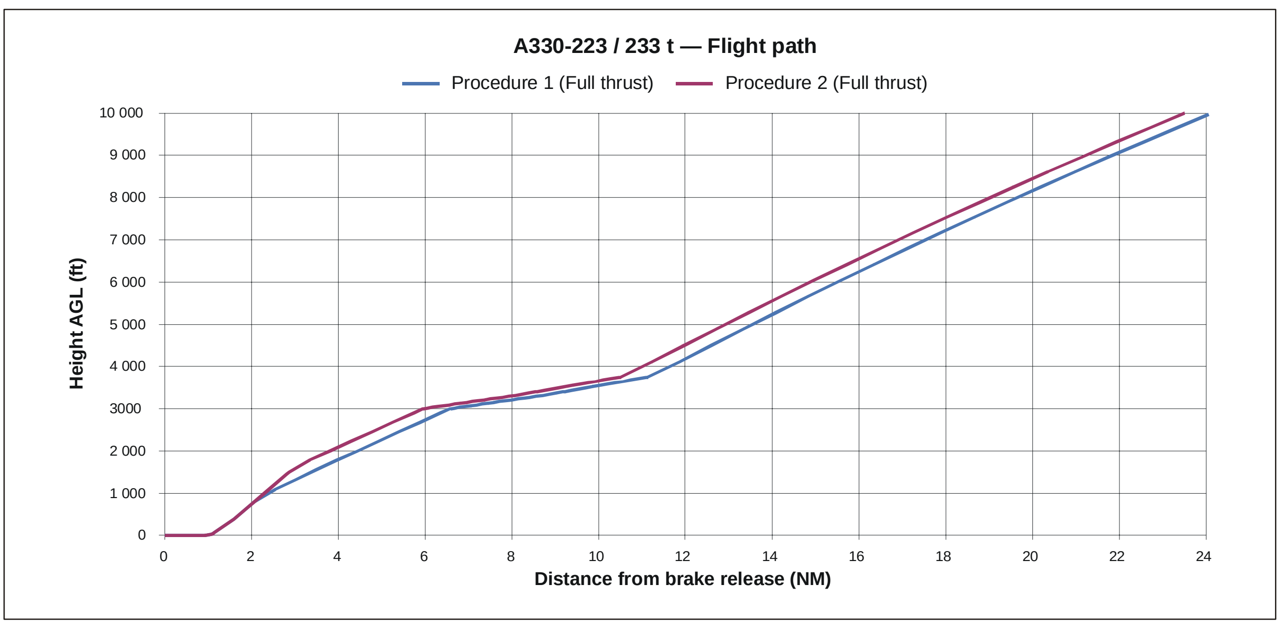


A330-223, PW4168A
- **Full thrust (TOGA)**
- **MTOW = 513 700 lb**



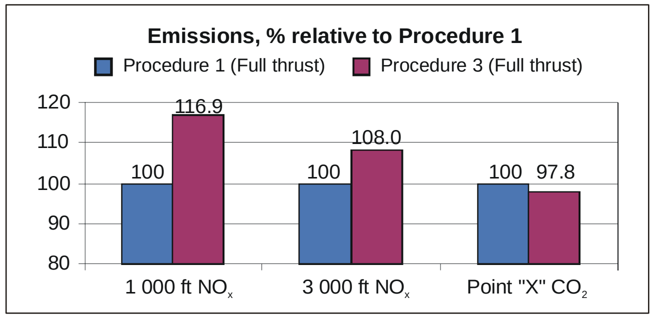
Comparison of Procedures 1 and 2



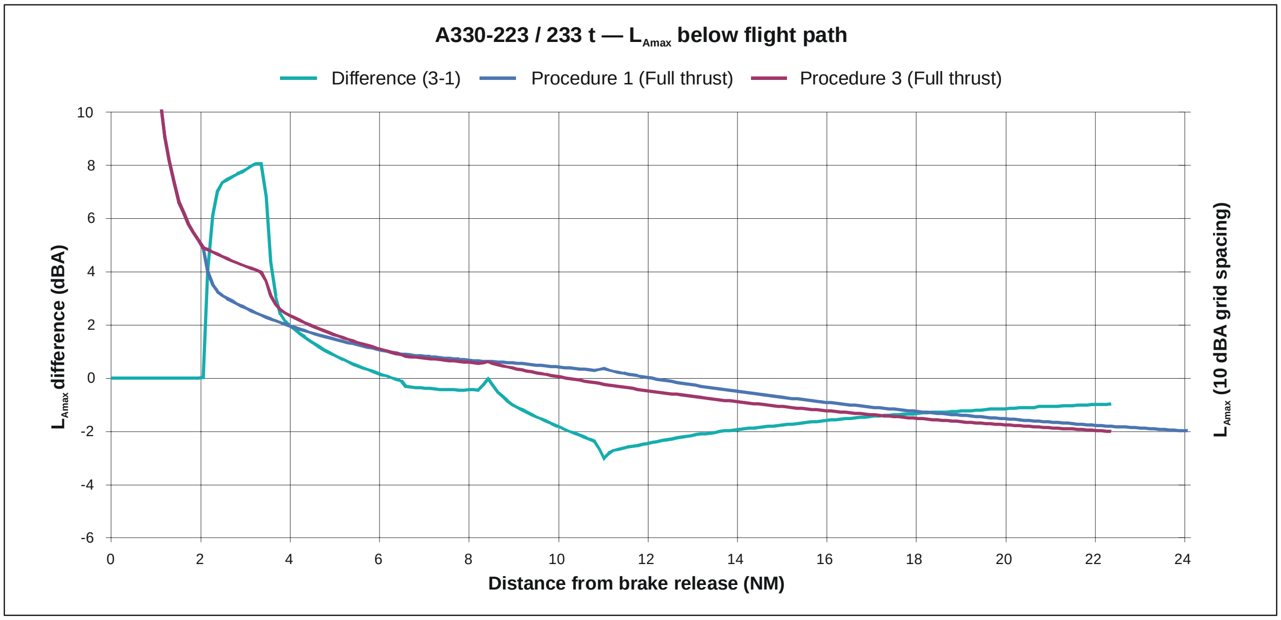


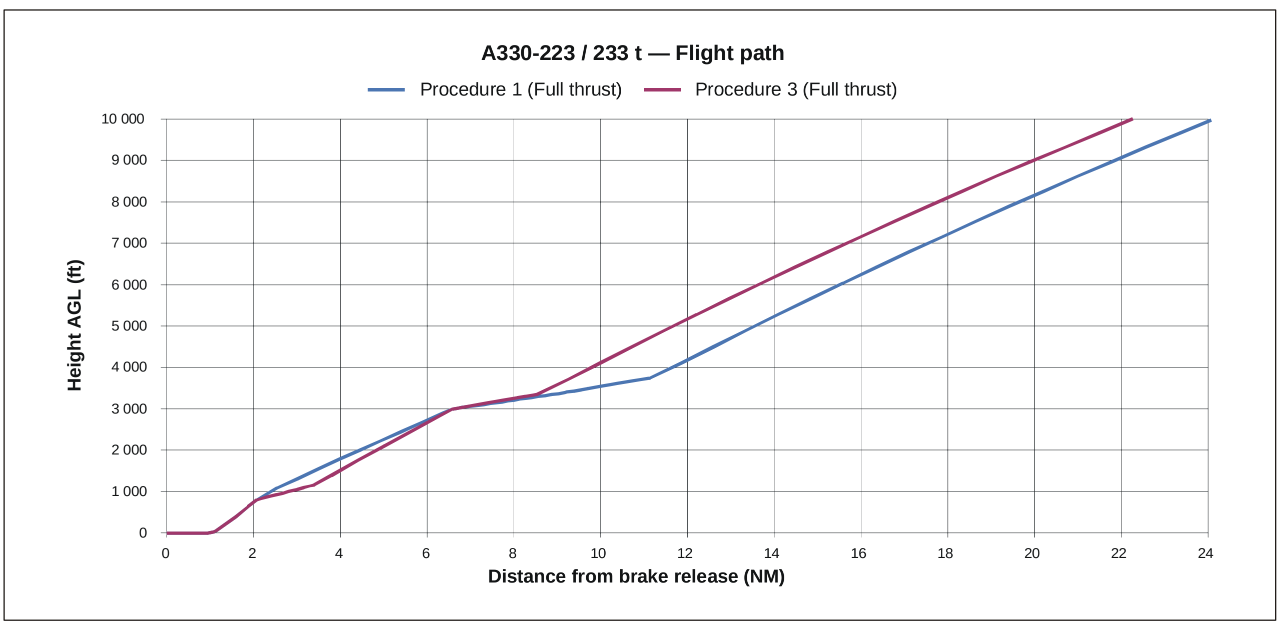
A330-223, PW4168A

- **Full thrust (TOGA)**
- **MTOW = 513 700 lb**



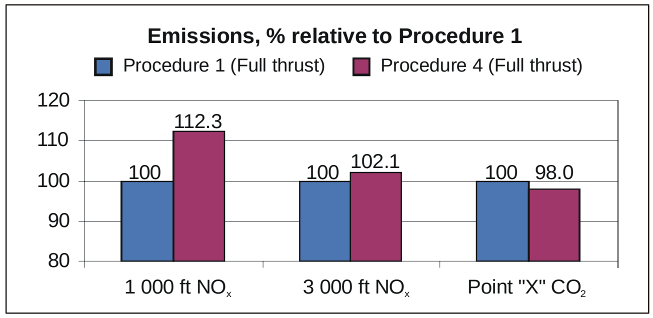
Comparison of Procedures 1 and 3



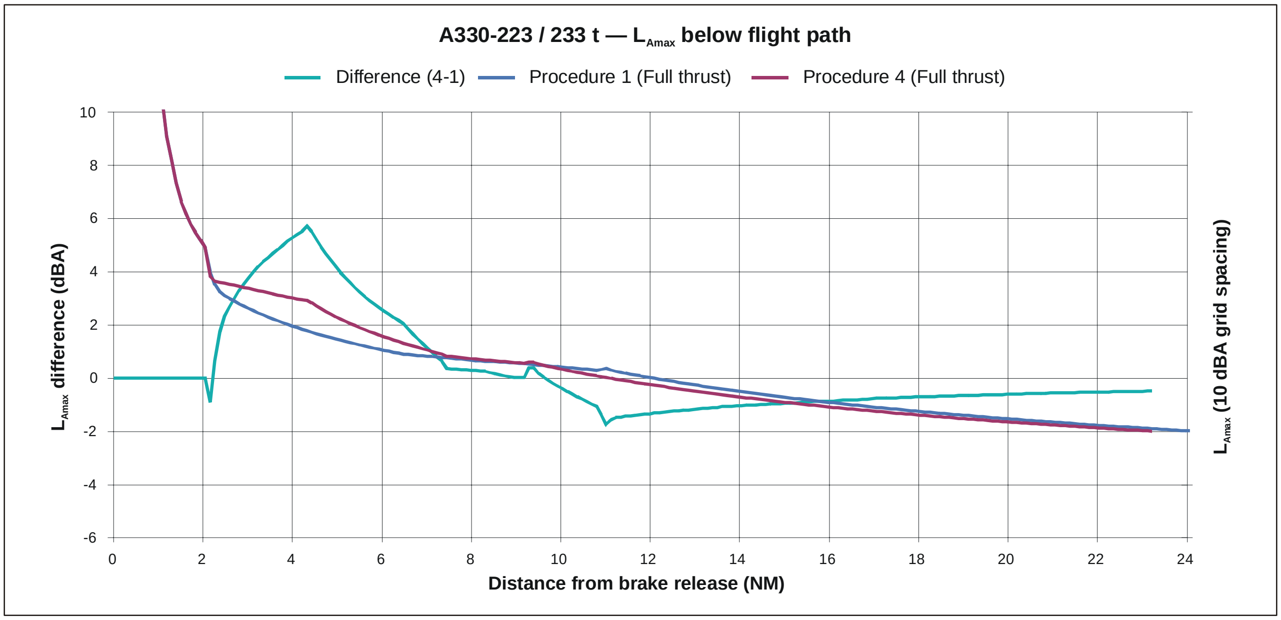


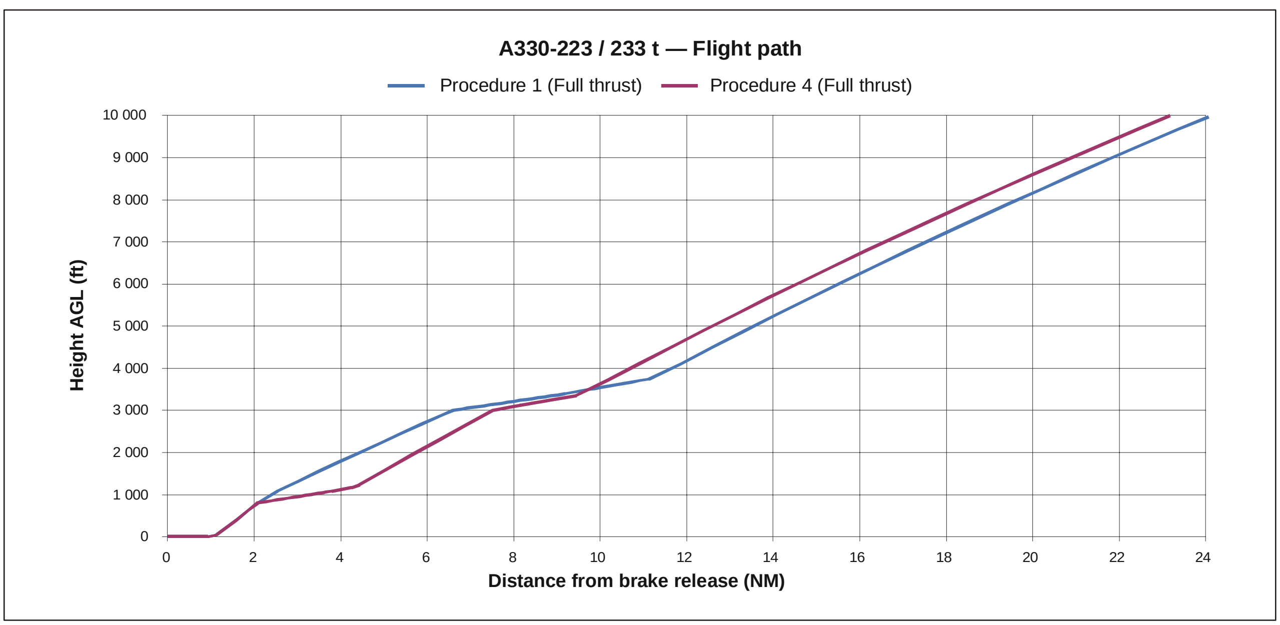
A330-223, PW4168A

- **Full thrust (TOGA)**
- **MTOW = 513 700 lb**



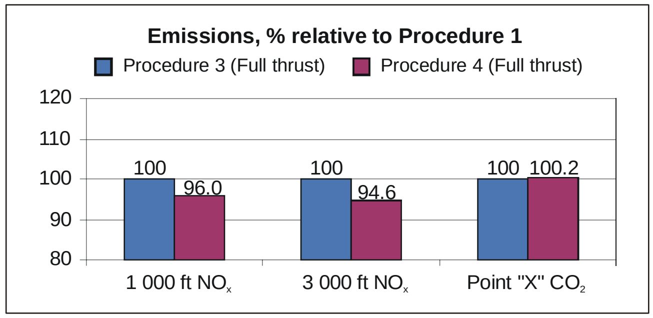
Comparison of Procedures 1 and 4



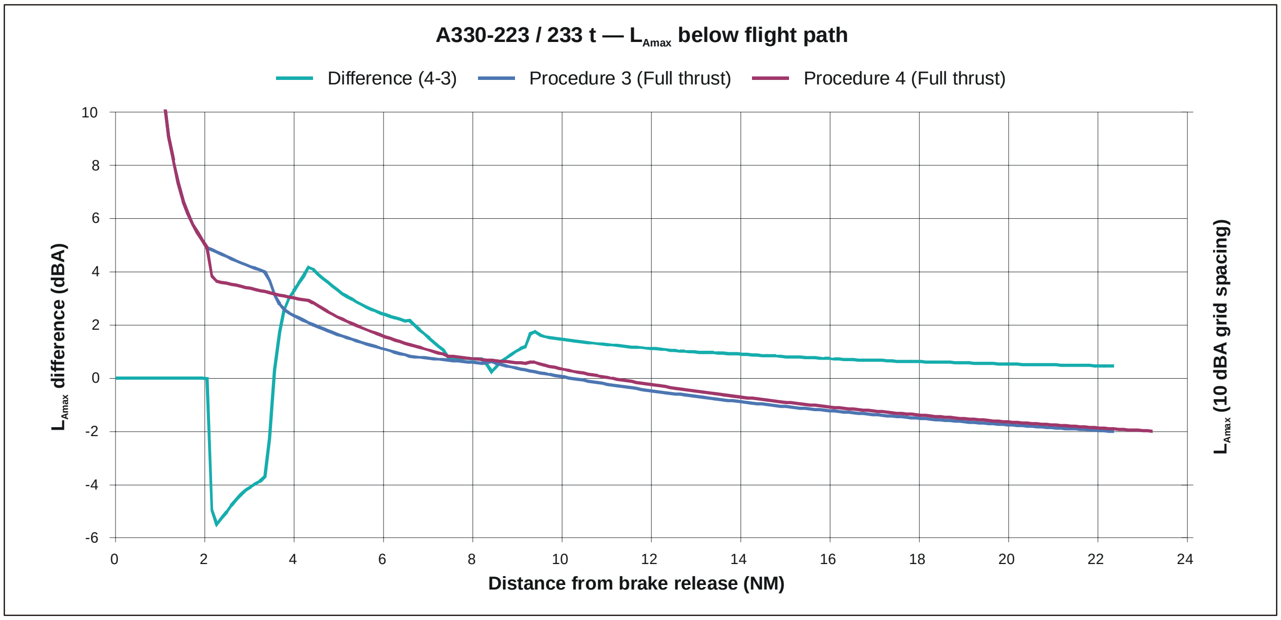


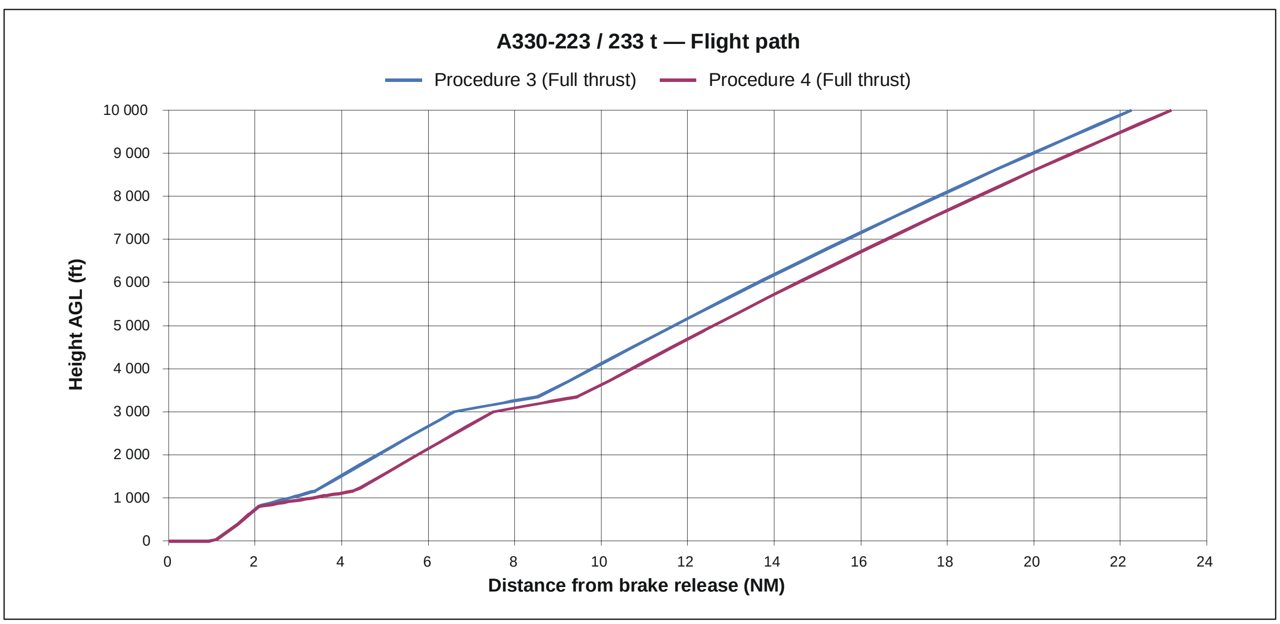
A330-223, PW4168A

- **Full thrust (TOGA)**
- **MTOW = 513 700 lb**



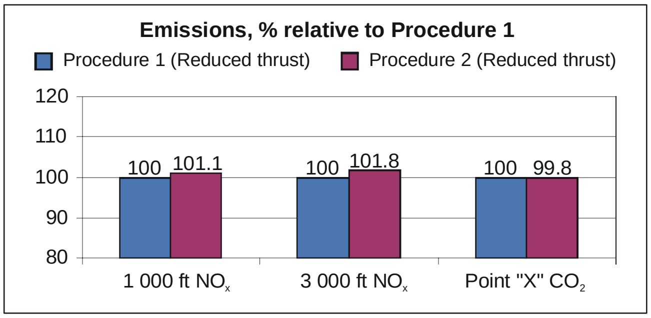
Comparison of Procedures 3 and 4



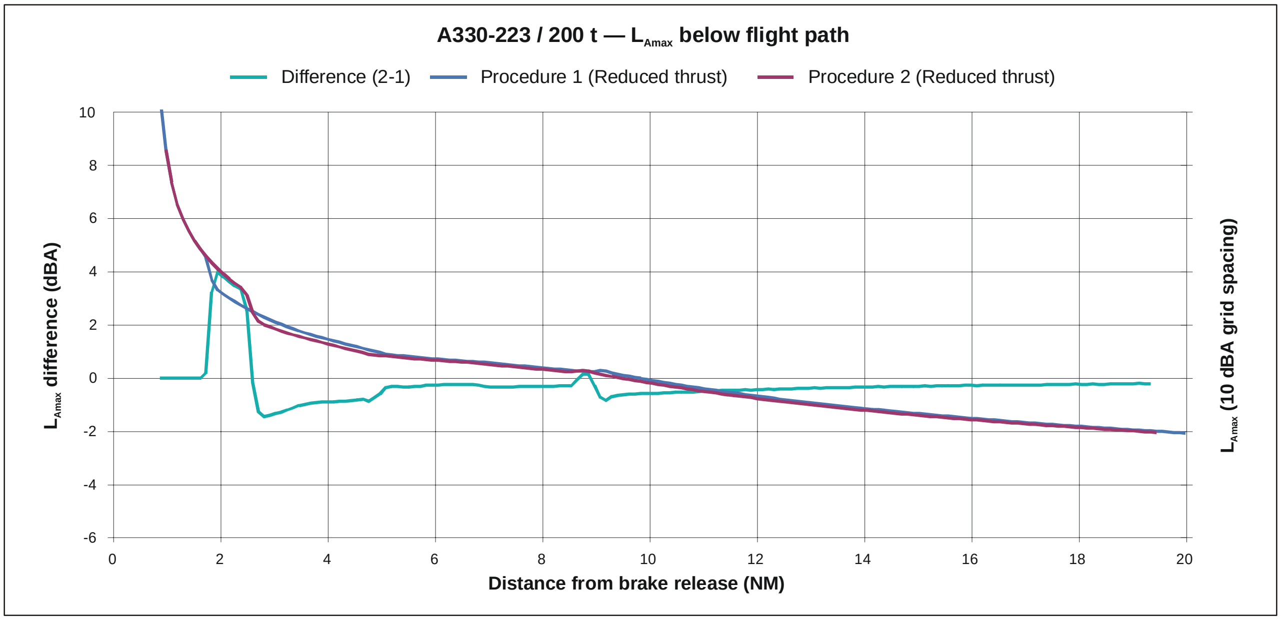


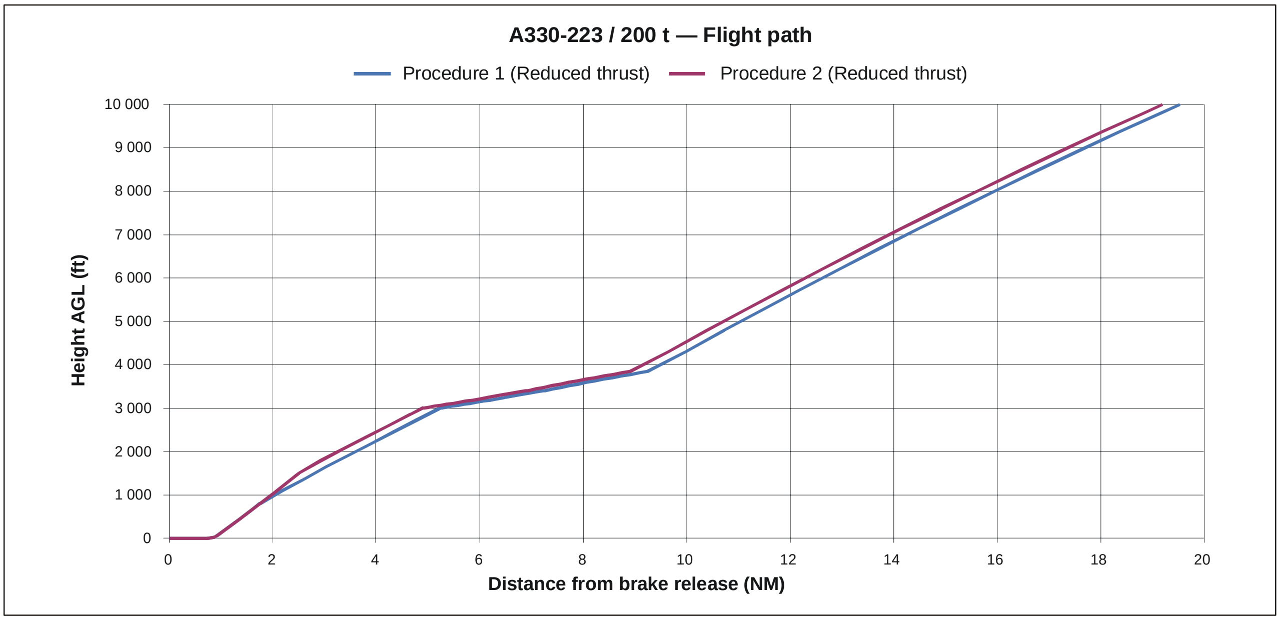
A330-223, PW4168A

- **12 per cent reduced thrust**
- **TOW = 441 000 lb**



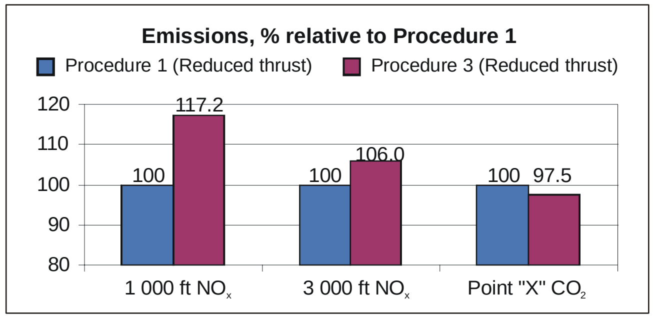
Comparison of Procedures 1 and 2



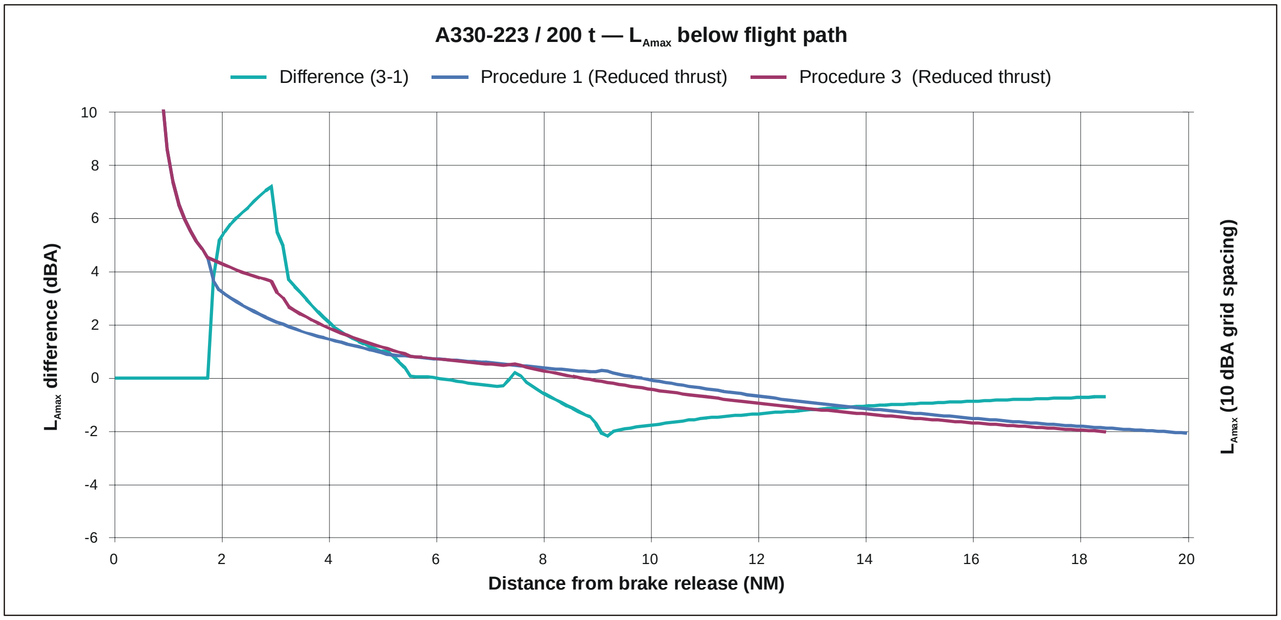


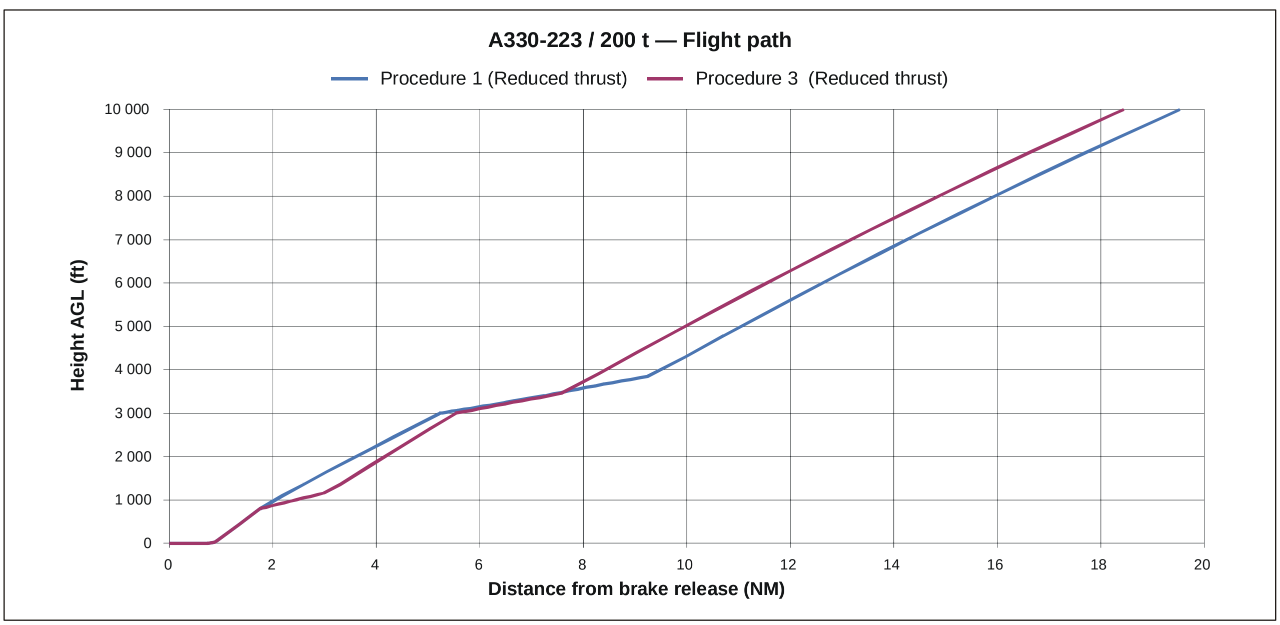
A330-223, PW4168A

- **12 per cent reduced thrust**
- **TOW = 441 000 lb**



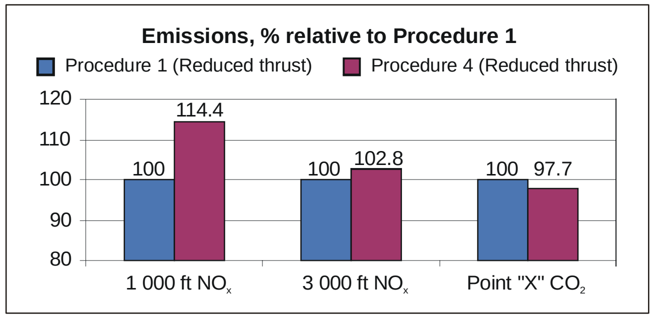
Comparison of Procedures 1 and 3



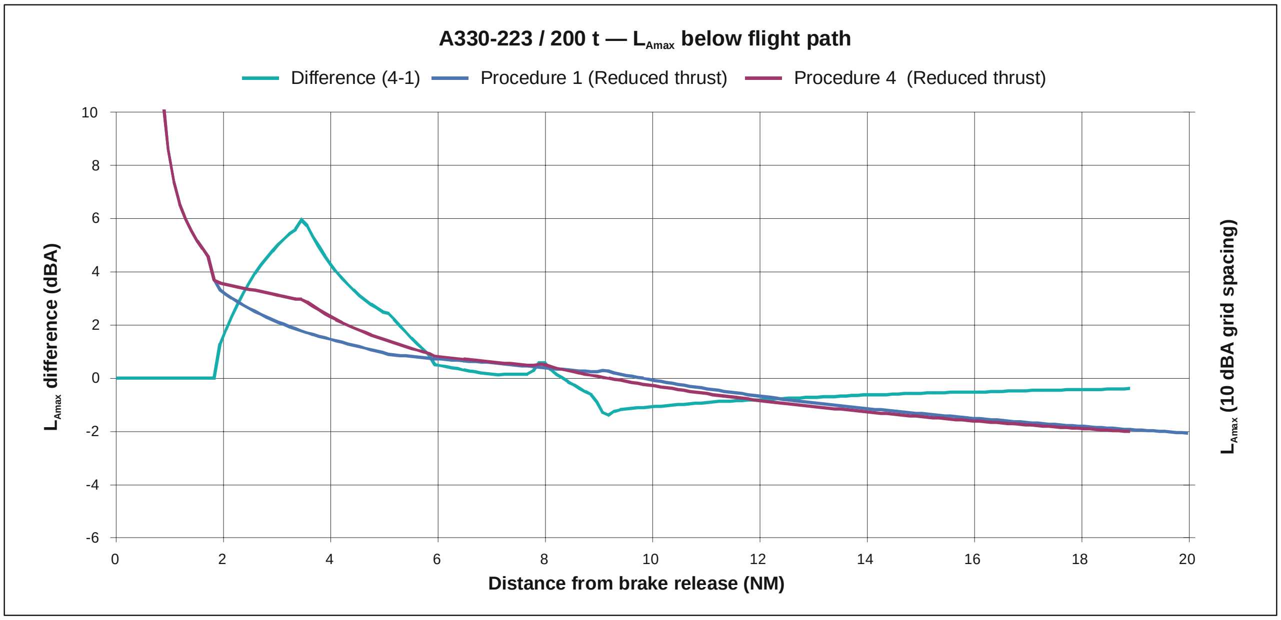


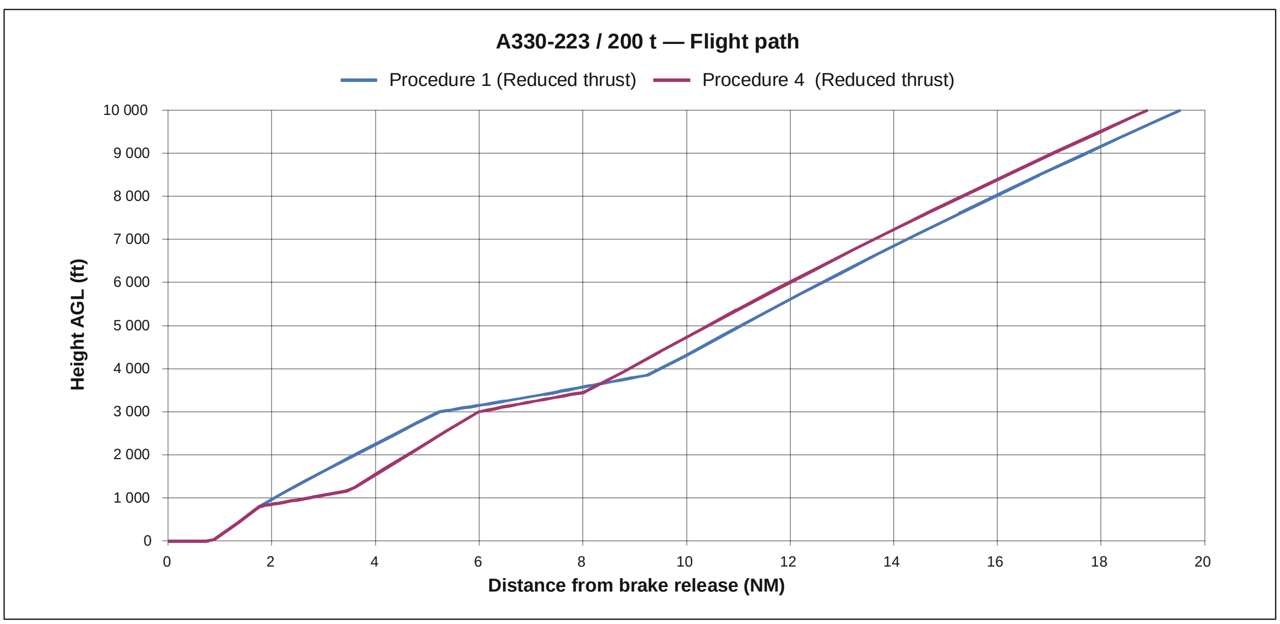
A330-223, PW4168A

- **12 per cent reduced thrust**
- **TOW = 441 000 lb**



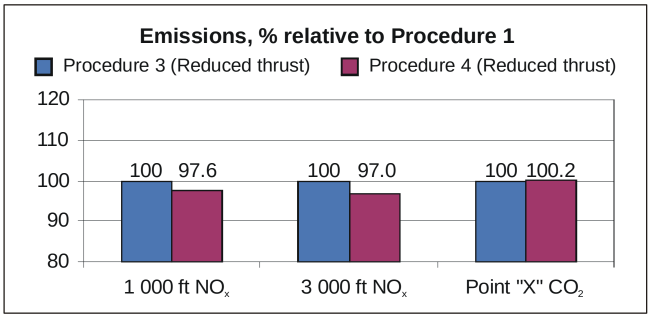
Comparison of Procedures 1 and 4



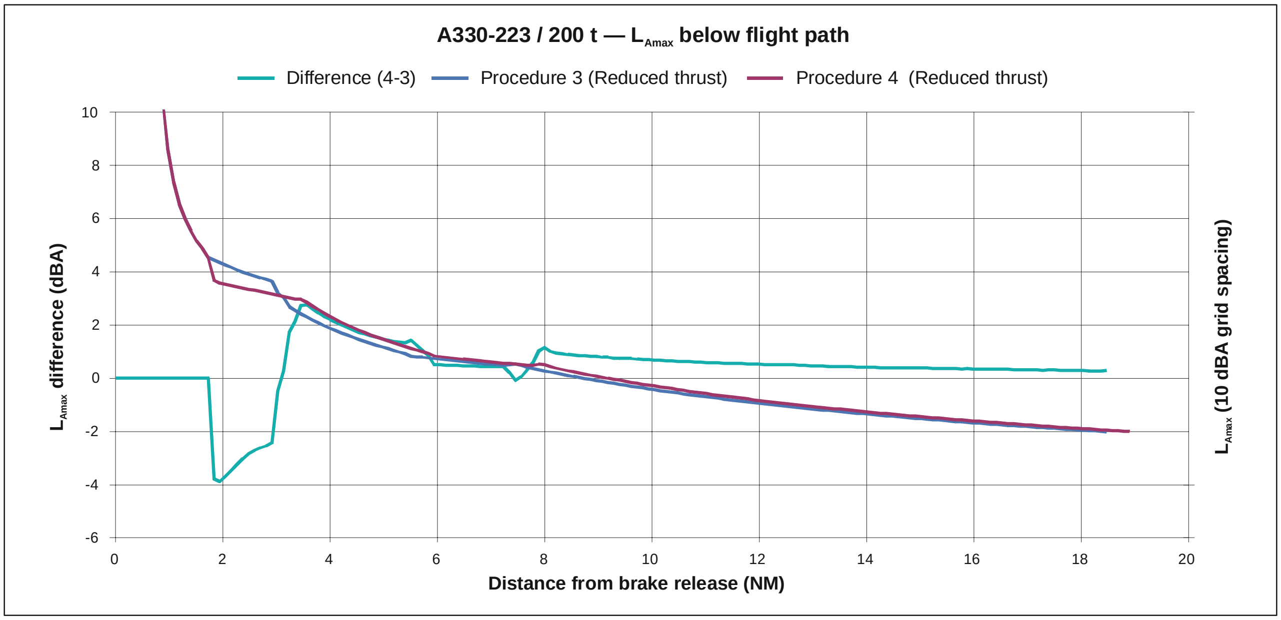


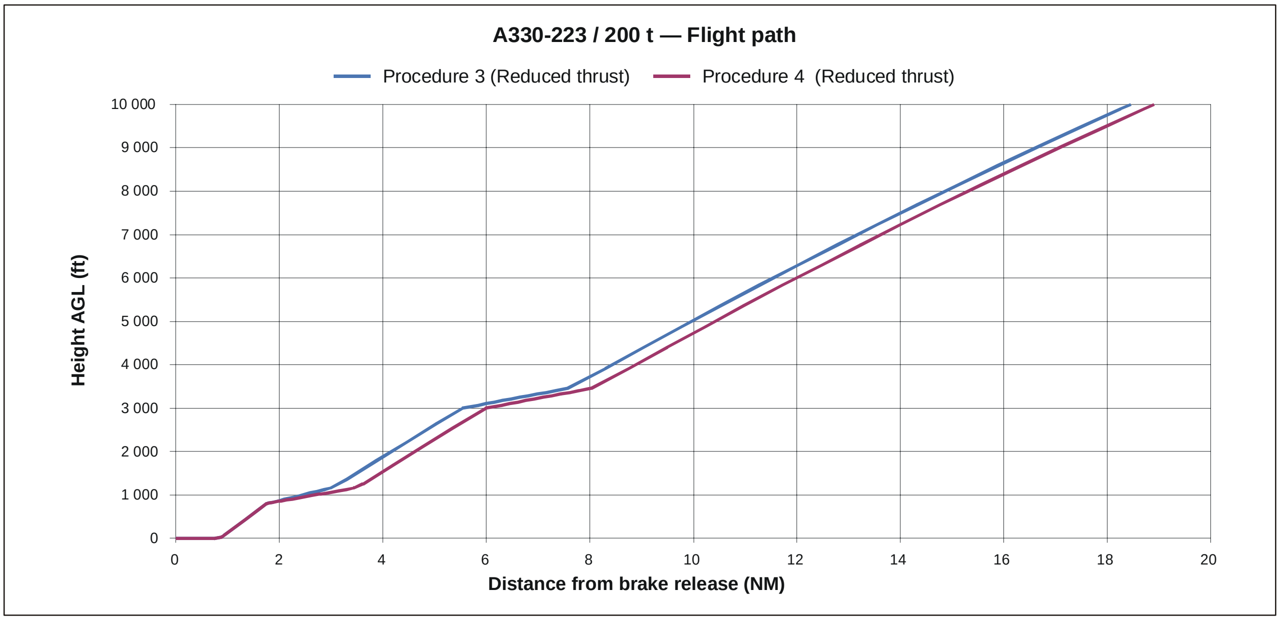
A330-223, PW4168A

- **12 per cent reduced thrust**
- **TOW = 441 000 lb**

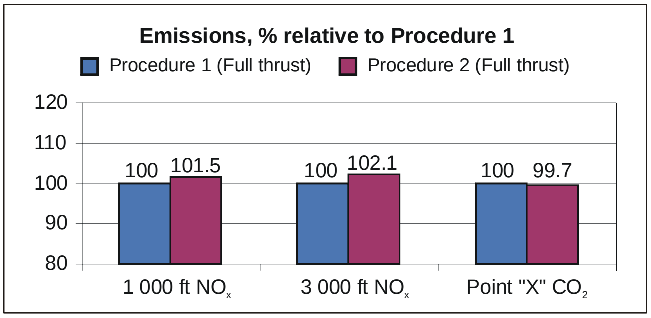


Comparison of Procedures 3 and 4

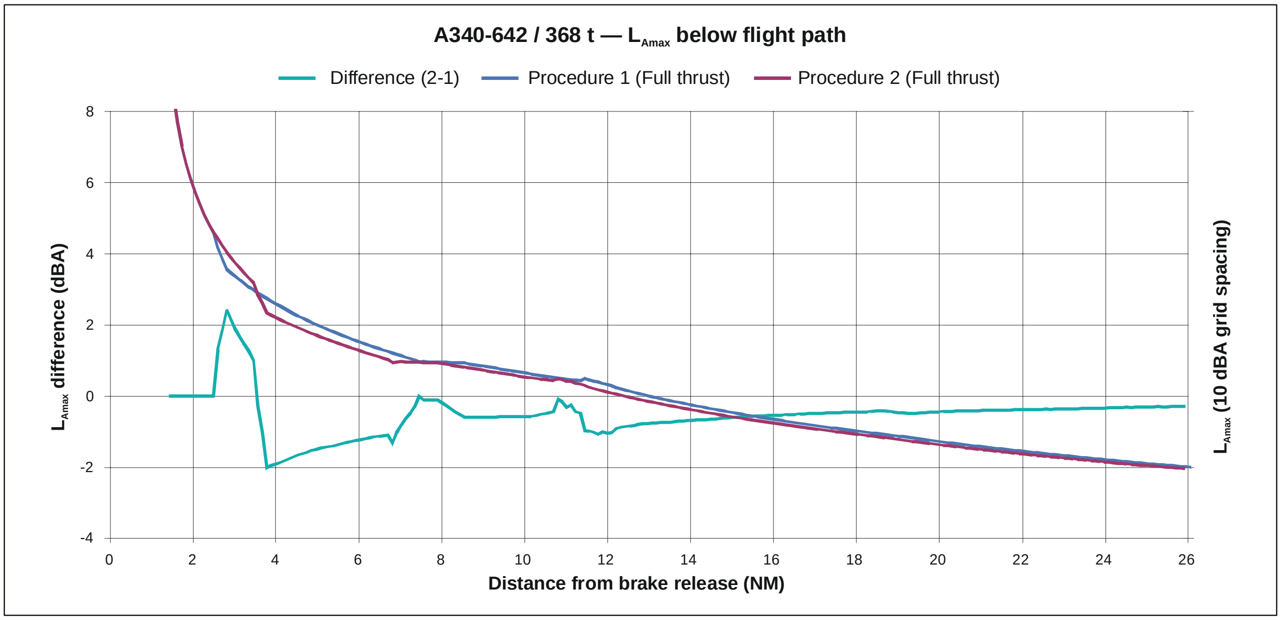


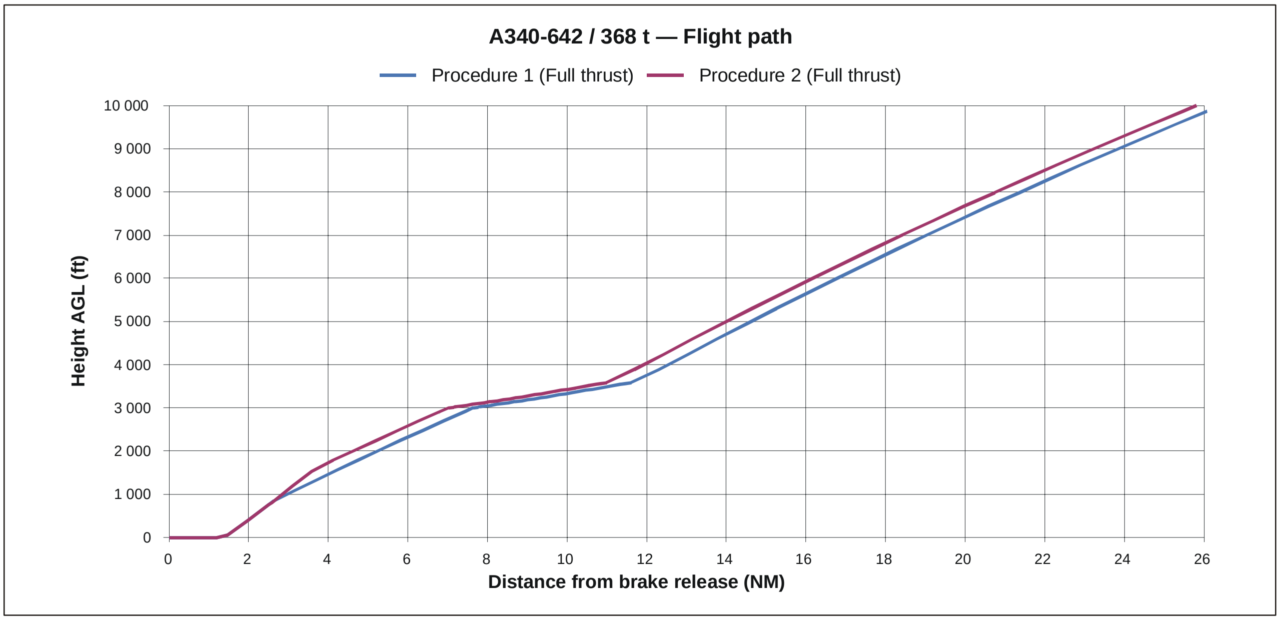


A340-642, RR Trent 556
- **Full thrust (TOGA)**
- **MTOW = 811 300 lb**



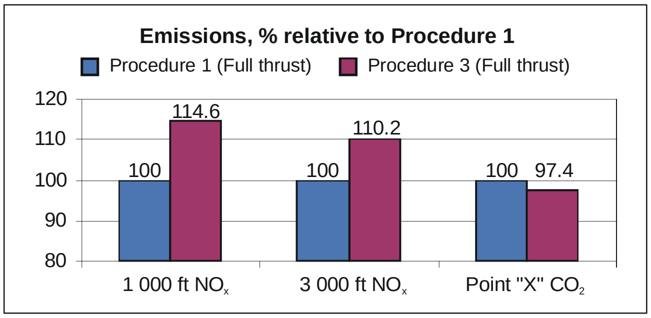
Comparison of Procedures 1 and 2



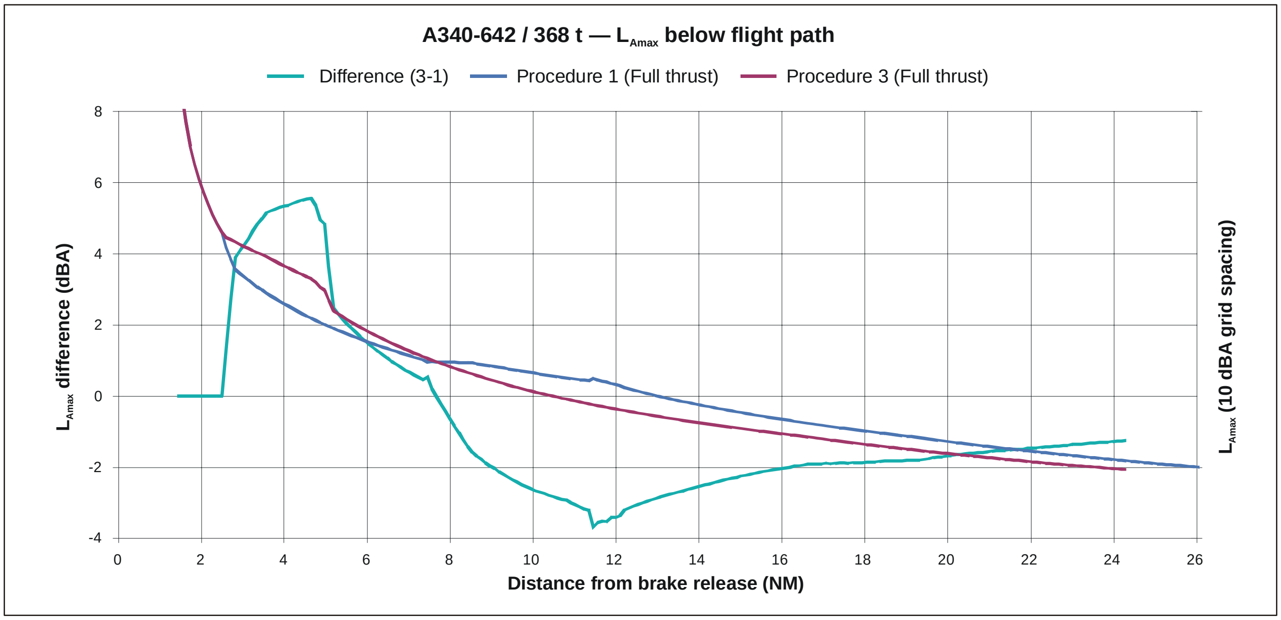


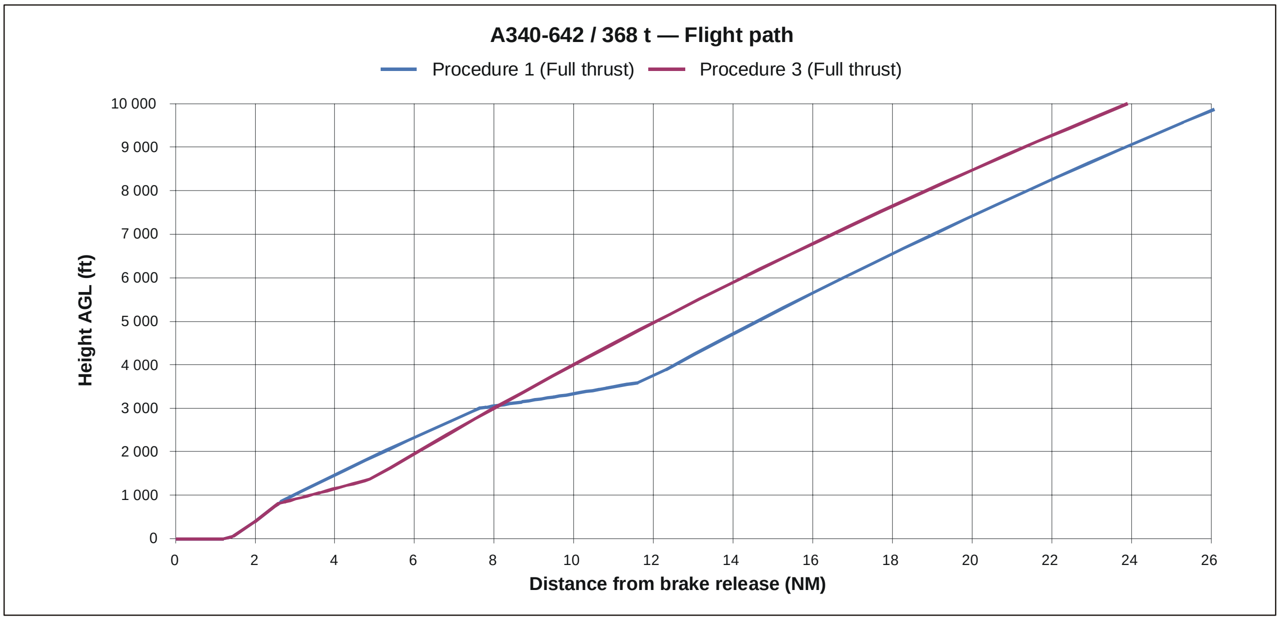
A340-642, RR Trent 556

- **Full thrust (TOGA)**
- **MTOW = 811 300 lb**

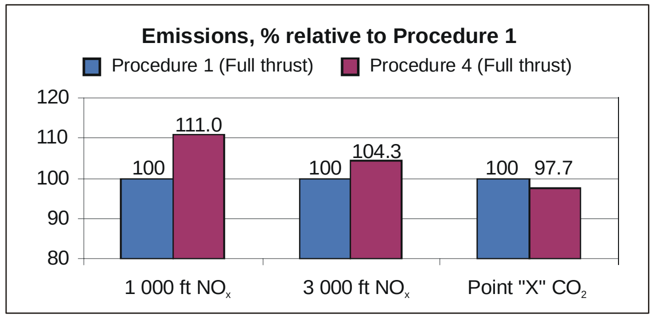


Comparison of Procedures 1 and 3

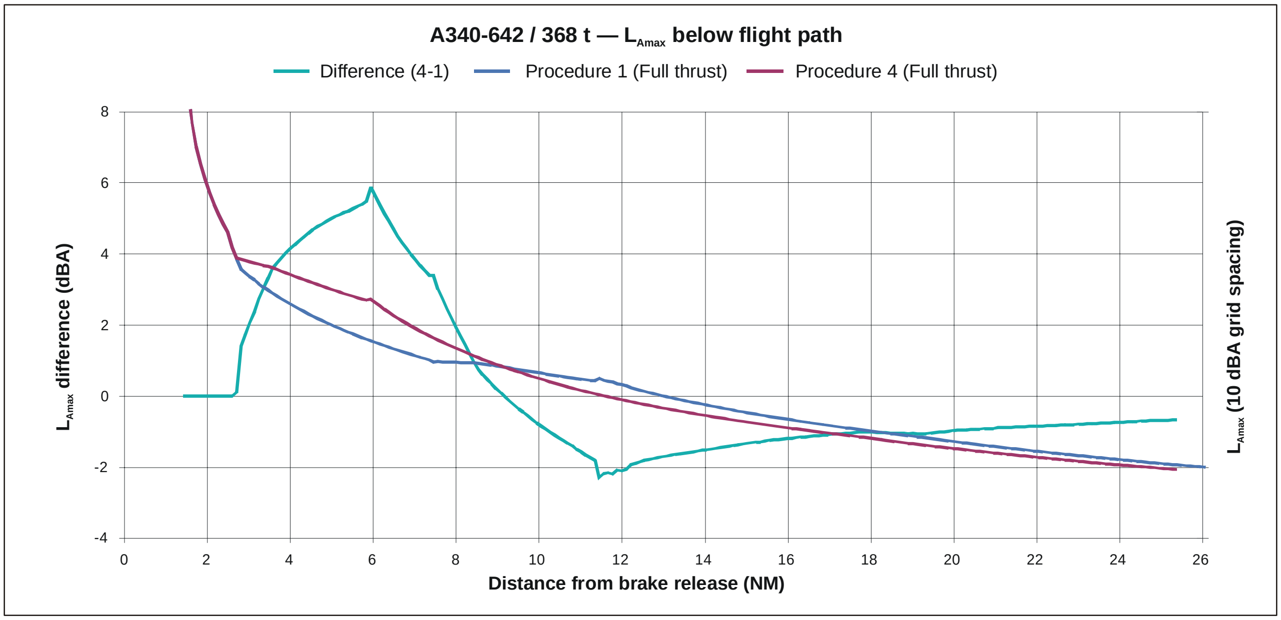


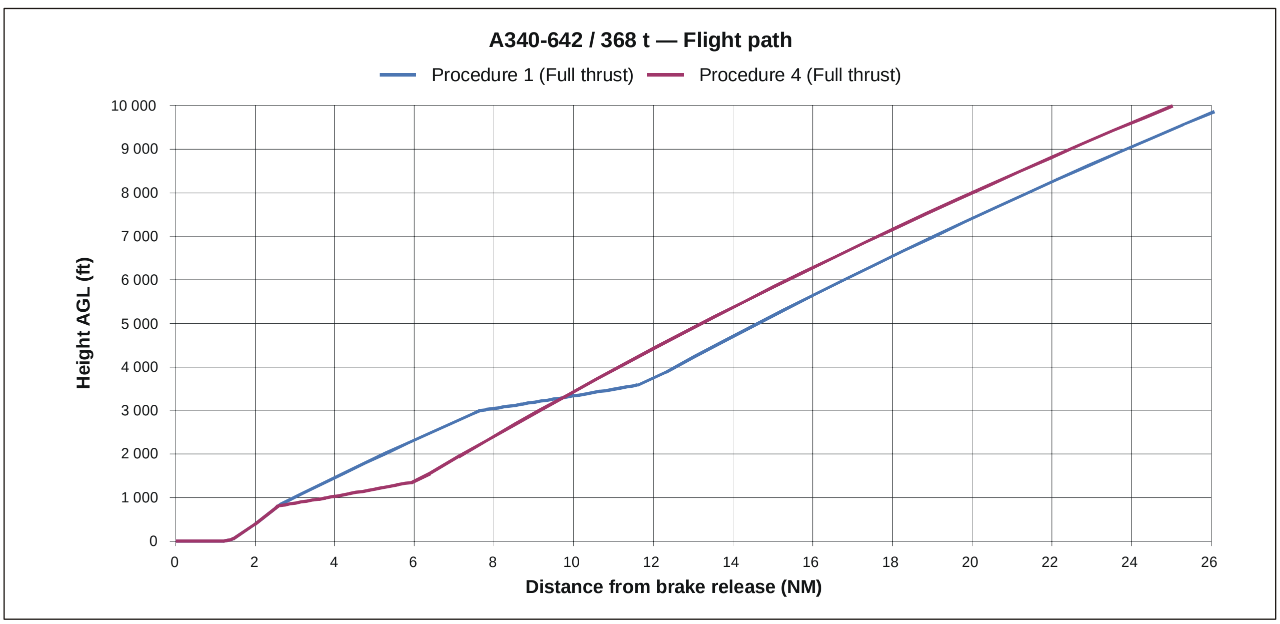


A340-642, RR Trent 556
- **Full thrust (TOGA)**
- **MTOW = 811 300 lb**



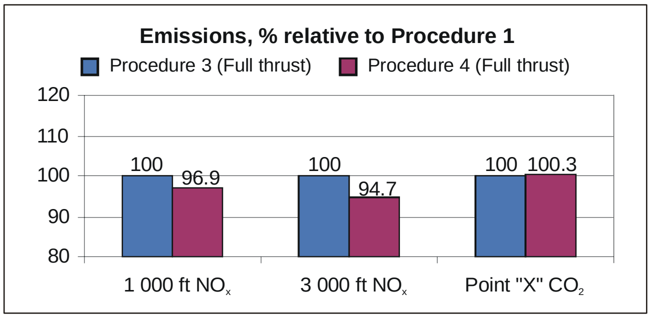
Comparison of Procedures 1 and 4



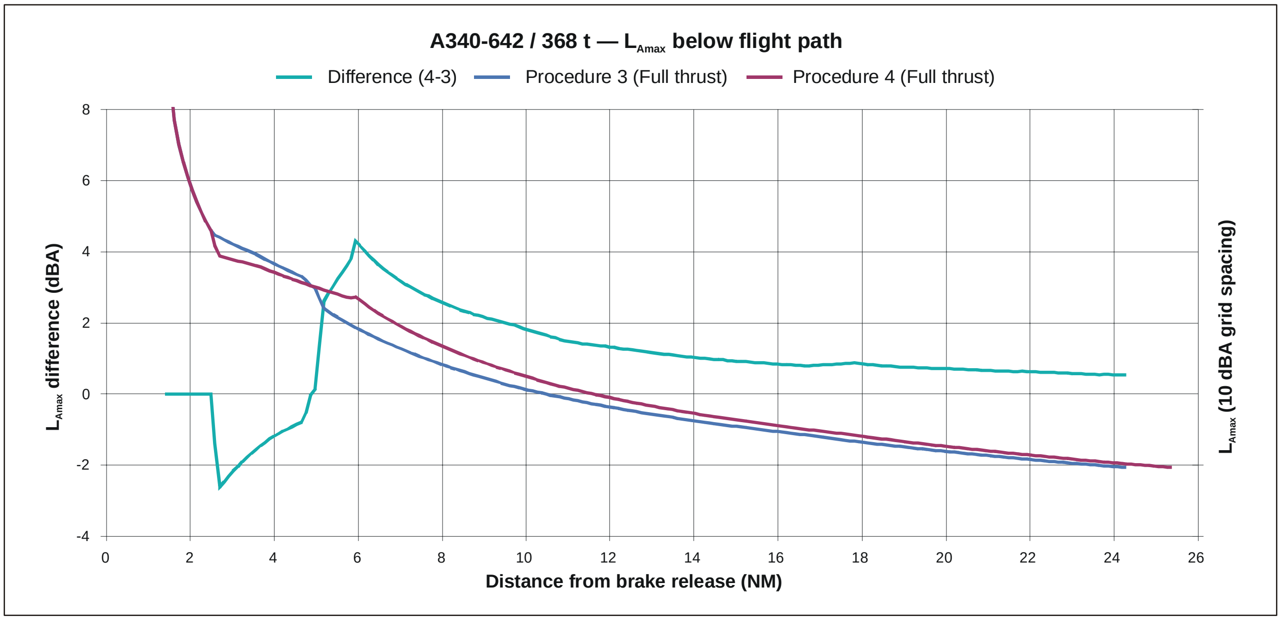


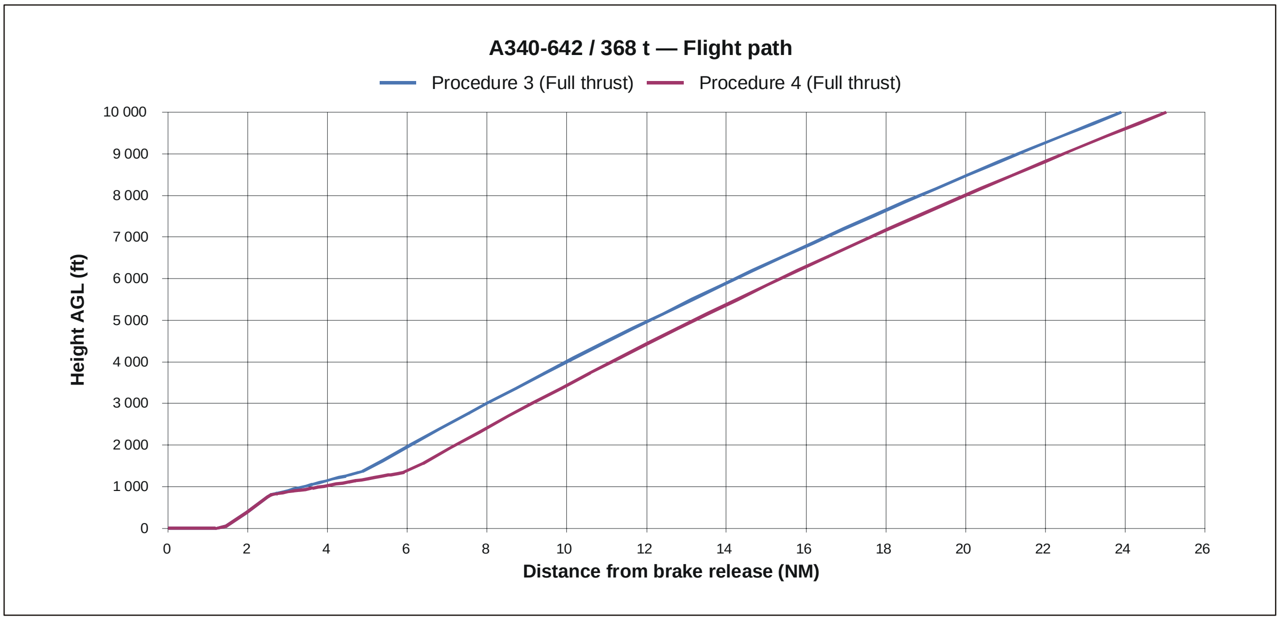
A340-642, RR Trent 556

- **Full thrust (TOGA)**
- **MTOW = 811 300 lb**



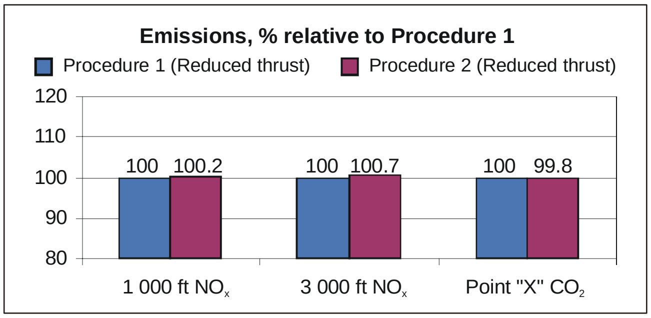
Comparison of Procedures 3 and 4



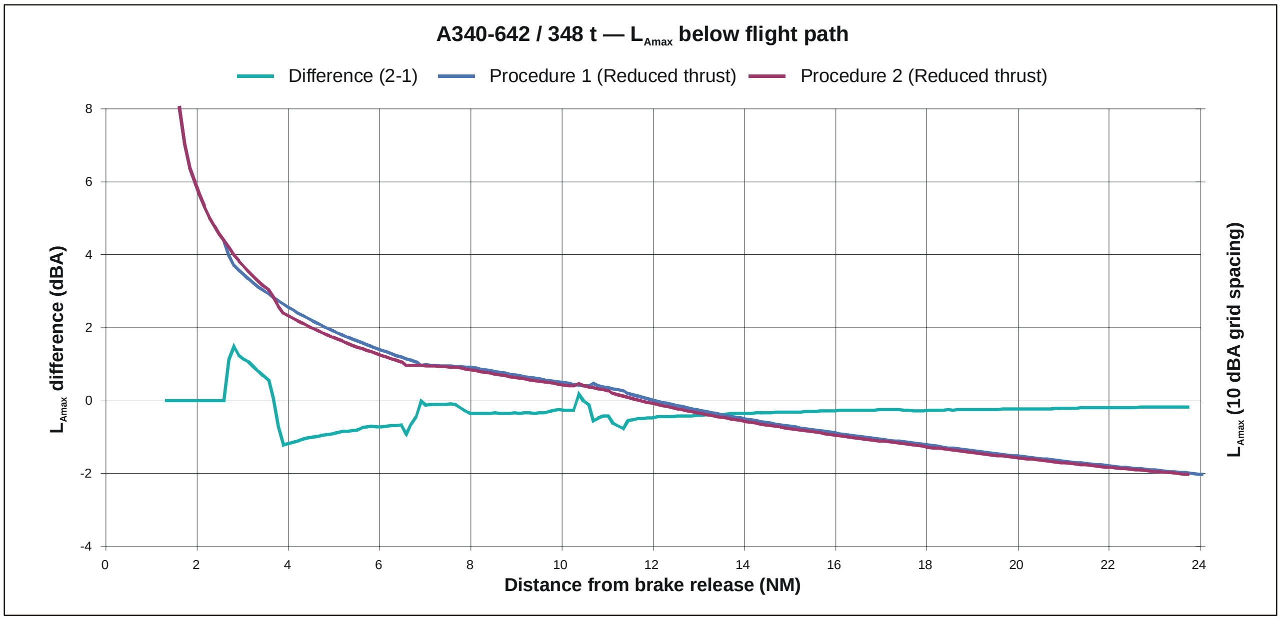


A340-642, RR Trent 556

- **12 per cent reduced thrust**
- **TOW = 769 500 lb**

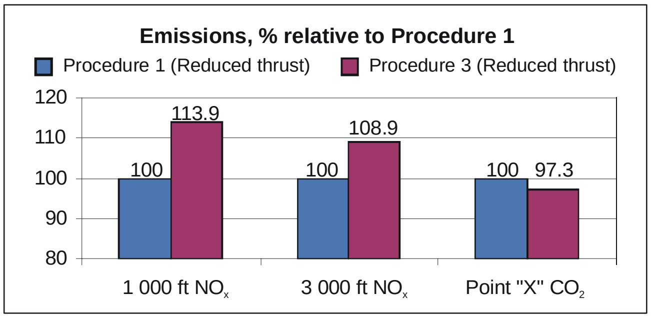


Comparison of Procedures 1 and 2

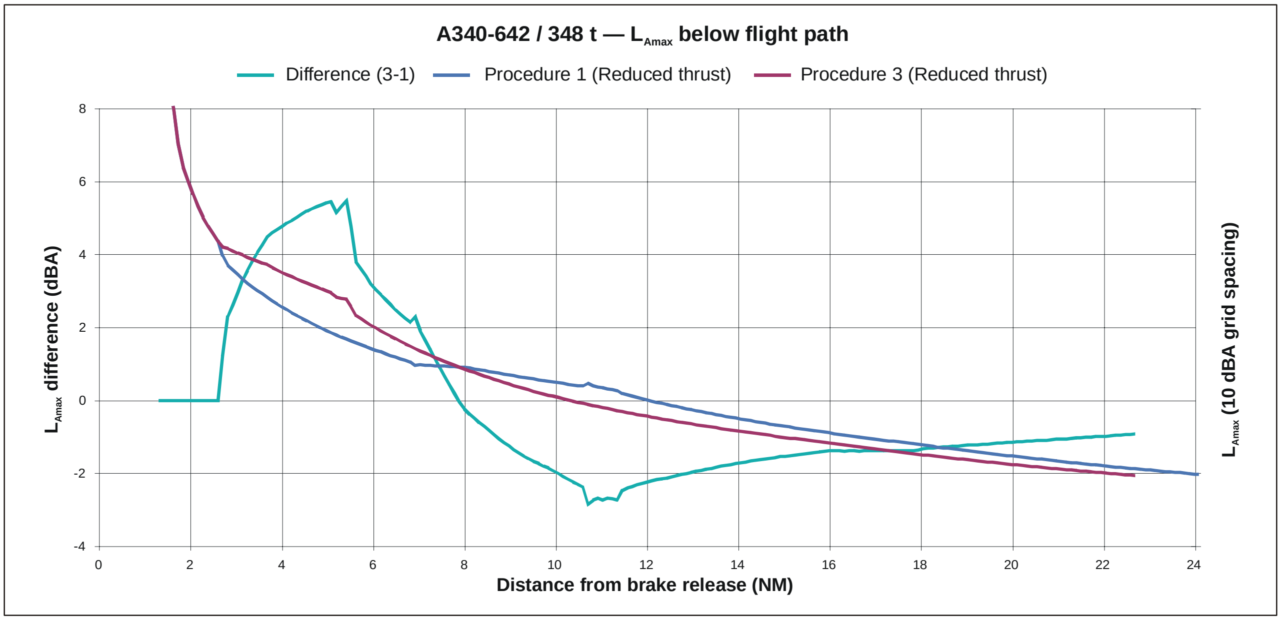


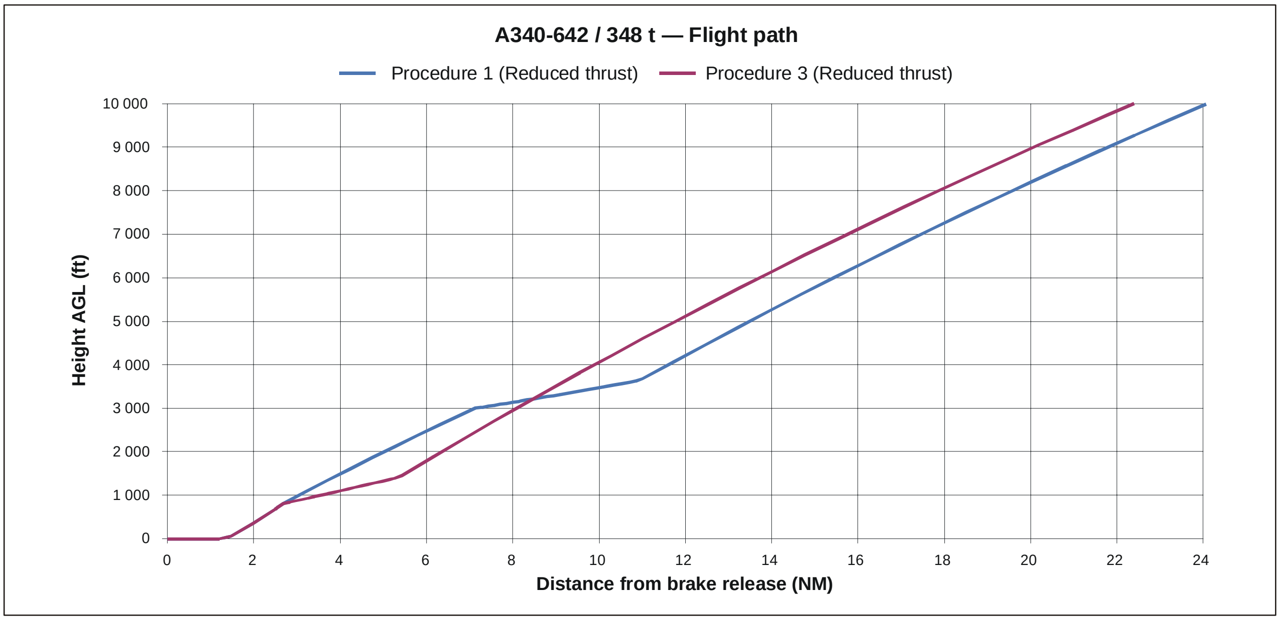
A340-642, RR Trent 556

- **12 per cent reduced thrust**
- **TOW = 769 500 lb**



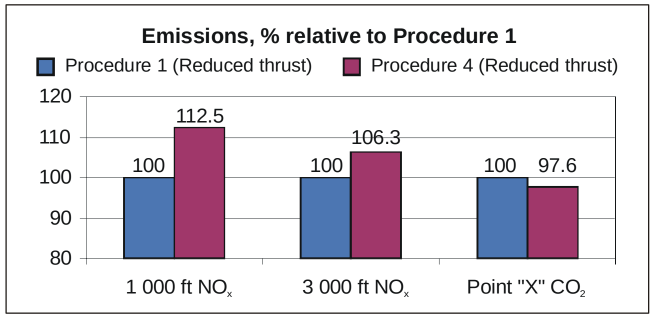
Comparison of Procedures 1 and 3



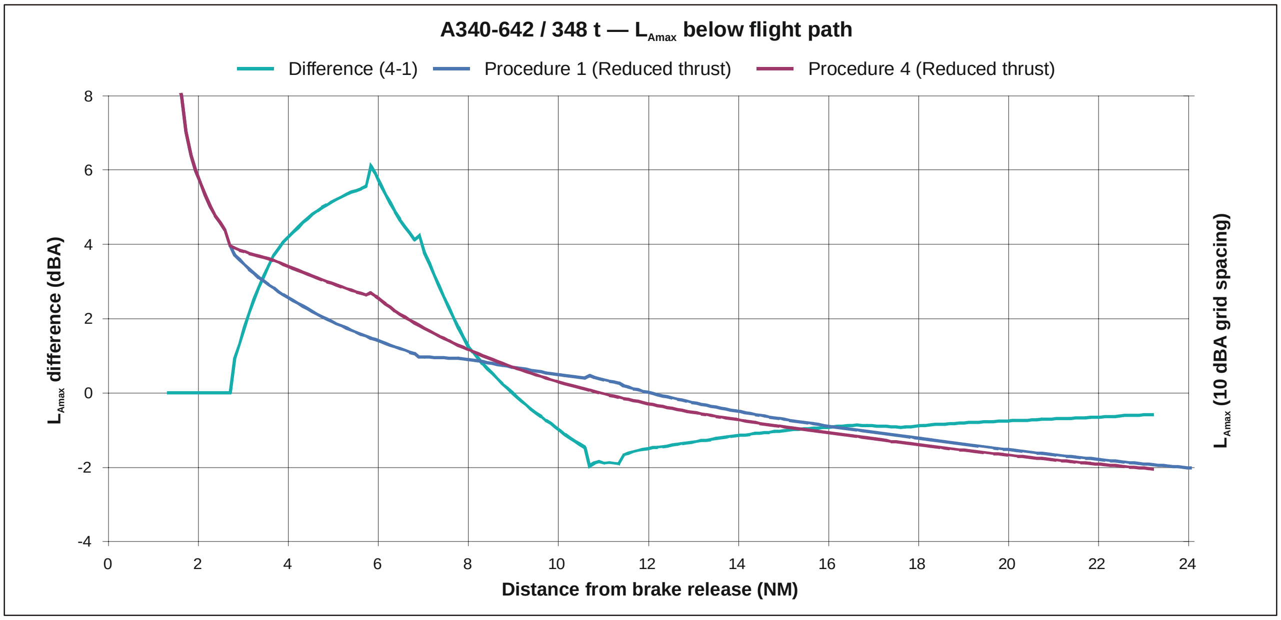


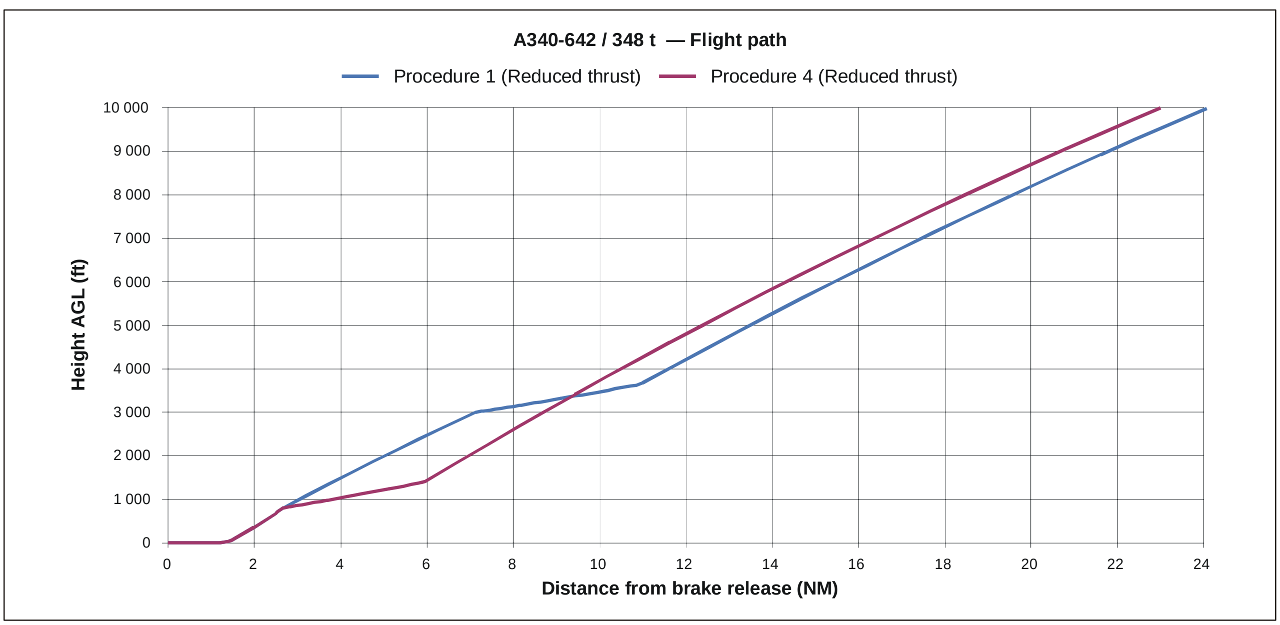
A340-642, RR Trent 556

- **12 per cent reduced thrust**
- **TOW = 769 500 lb**



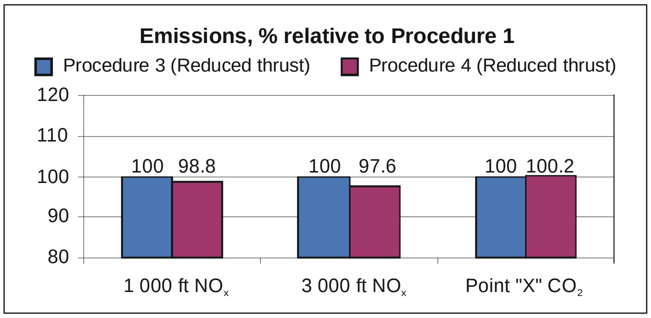
Comparison of Procedures 1 and 4



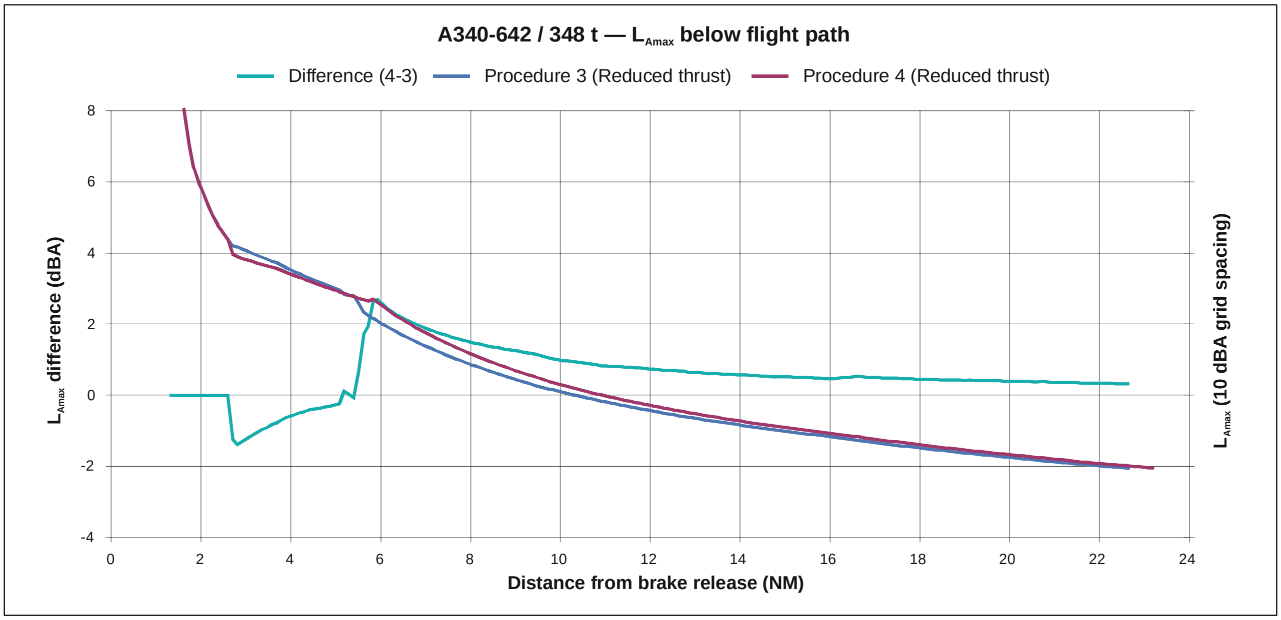


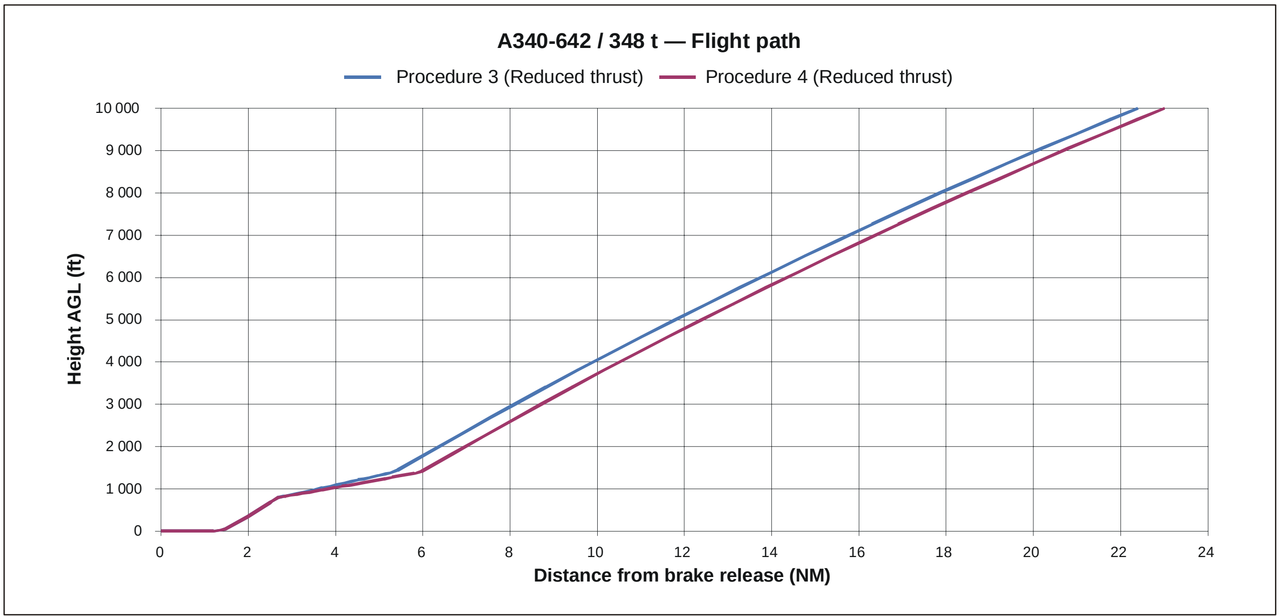
A340-642, RR Trent 556

- **12 per cent reduced thrust**
- **TOW = 769 500 lb**



Comparison of Procedures 3 and 4





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Appendix B

RESULTS — BOEING

AIRCRAFT STUDIED

737-700/CFM56-7B24

- Climb limit weight with flap 5, SL/STD day
- Maximum take-off rating = 154 500 lb
- 10 per cent reduced thrust = 152 100 lb

767-400ER/CF6-80C2B8F

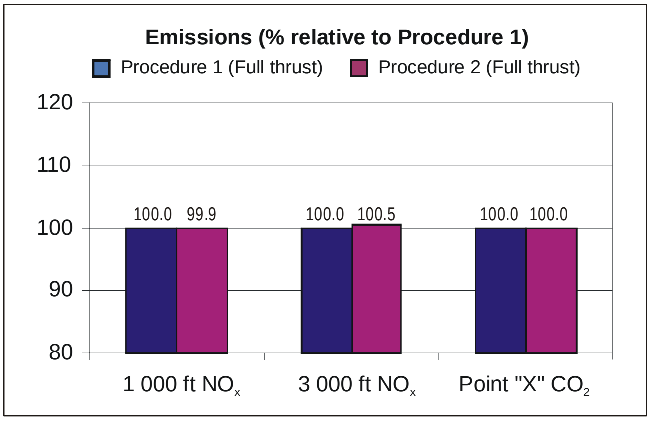
- Climb limit weight with flap 5, SL/STD day
- Maximum take-off thrust = 450 000 lb
- 10 per cent reduced thrust = 440 000 lb

777-300/Trent892

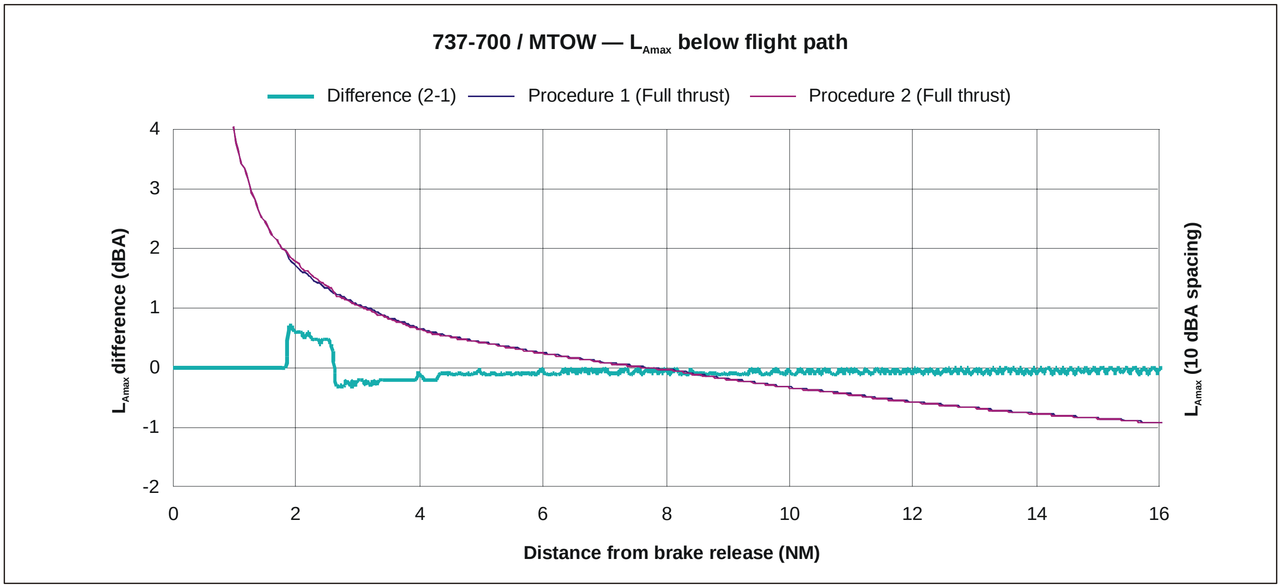
- Climb limit weight with flap 5, SL/STD day
- Maximum take-off thrust = 660 000 lb
- 10 per cent reduced thrust = 629 100 lb

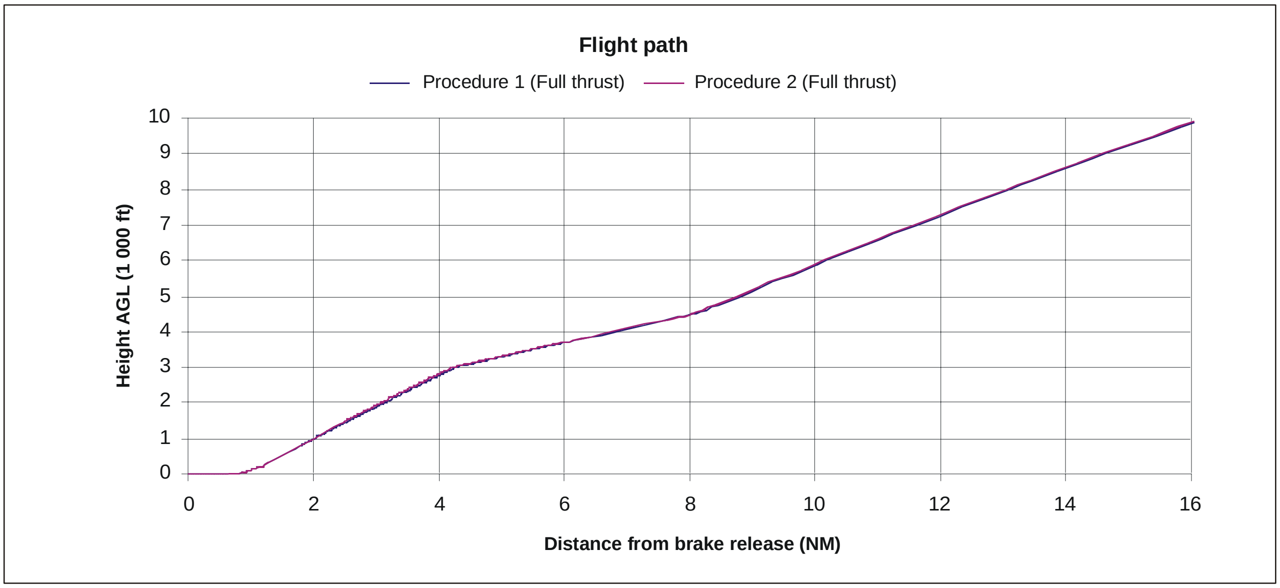
737-700/CFM56-7B24

- **Full power thrust**
- **MTOW = 154 500 lb**



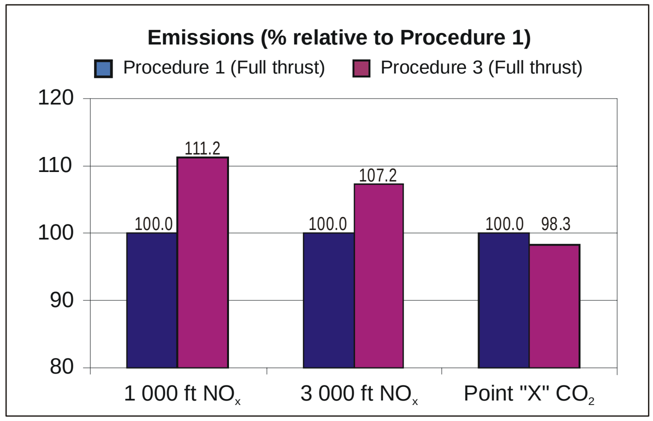
Comparison of Procedures 1 and 2



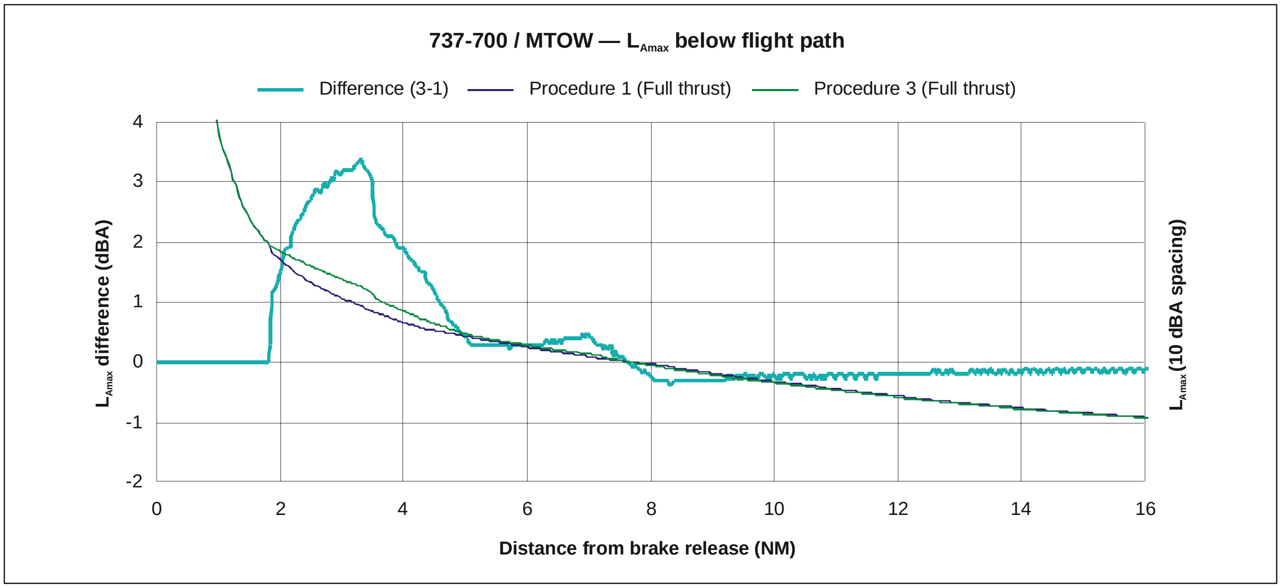


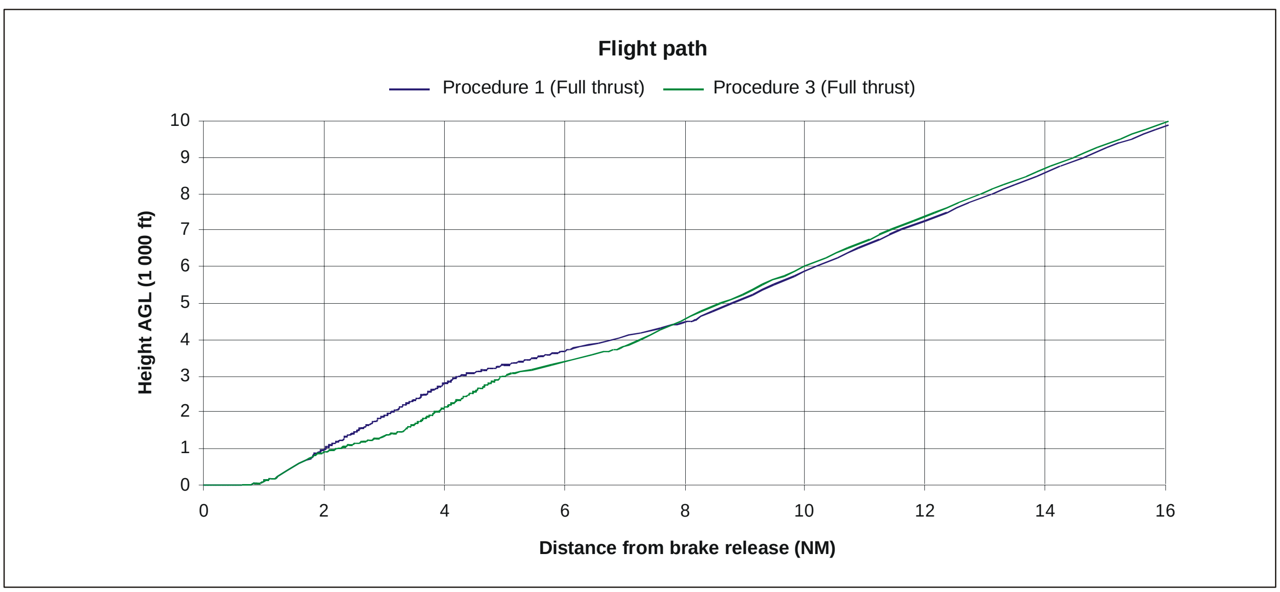
737-700/CFM56-7B24

- **Full power thrust**
- **MTOW = 154 500 lb**



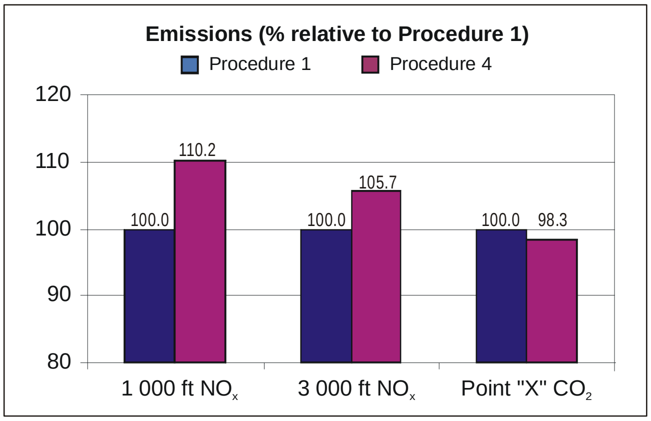
Comparison of Procedures 1 and 3



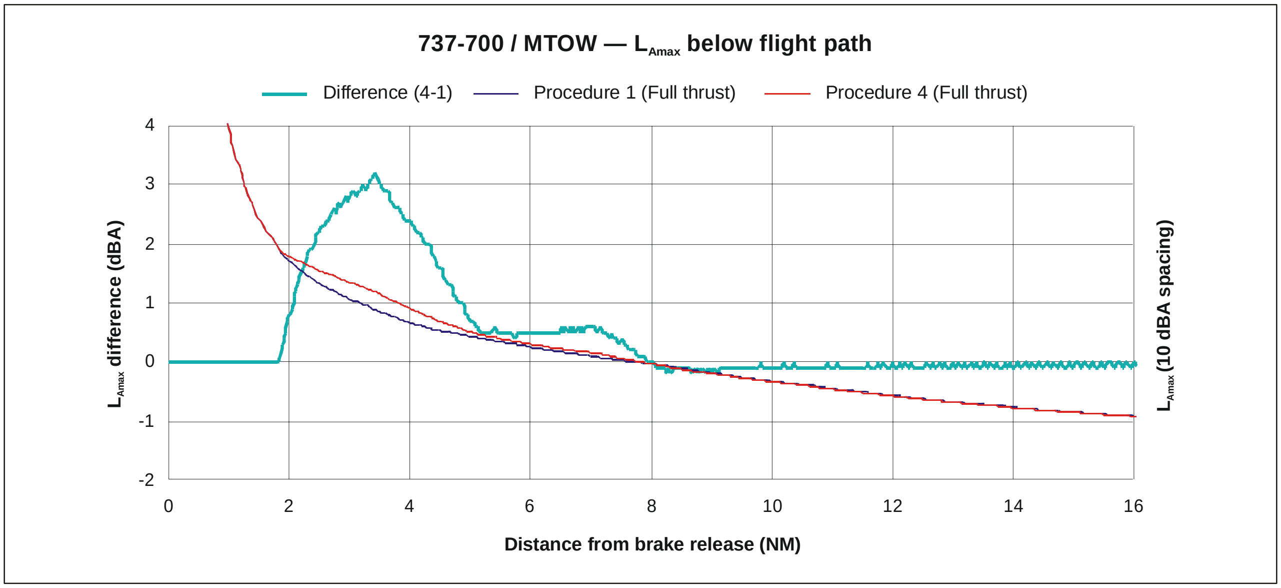


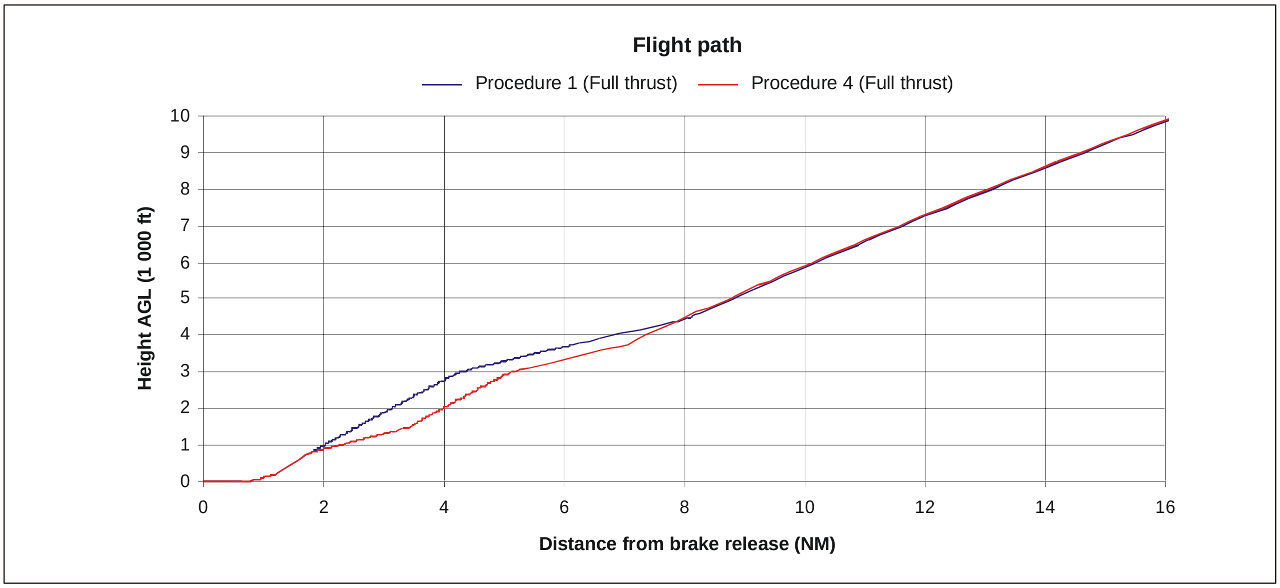
737-700/CFM56-7B24

- **Full power thrust**
- **MTOW = 154 500 lb**



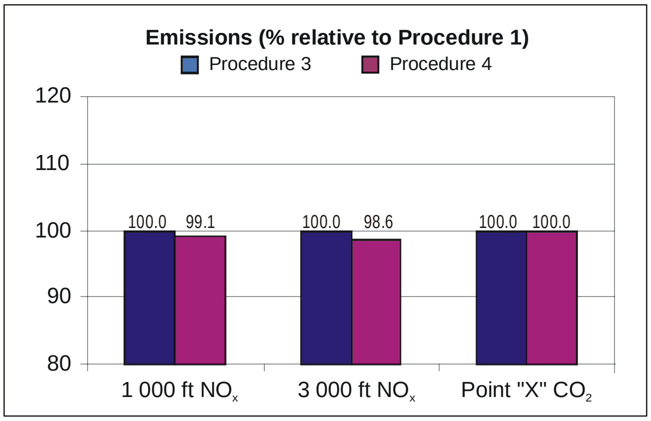
Comparison of Procedures 1 and 4



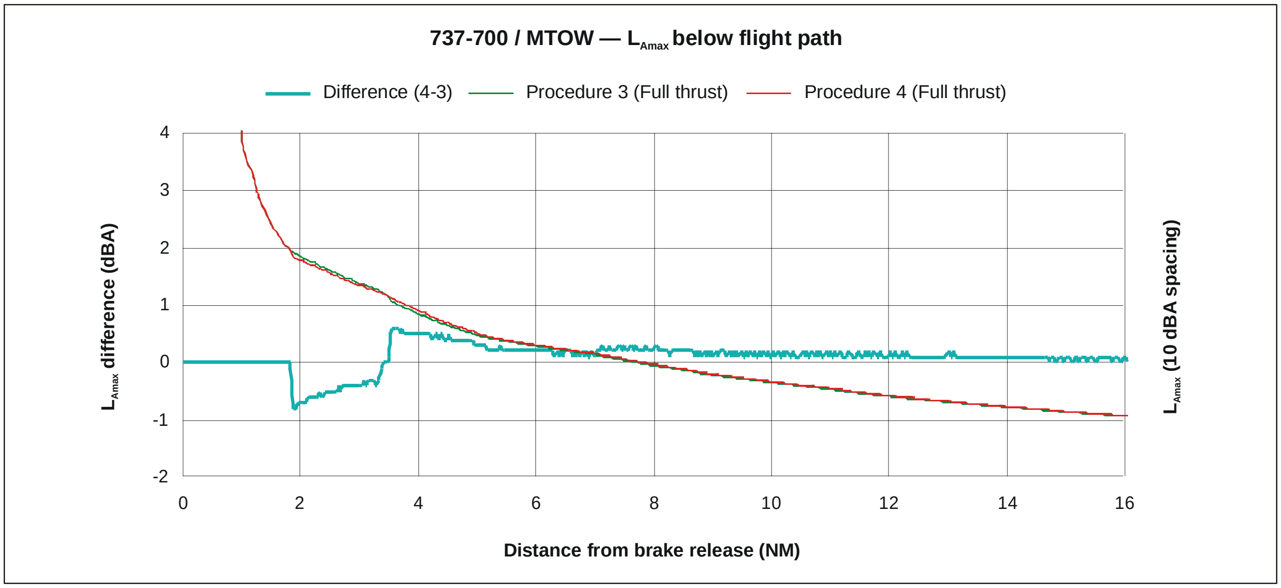


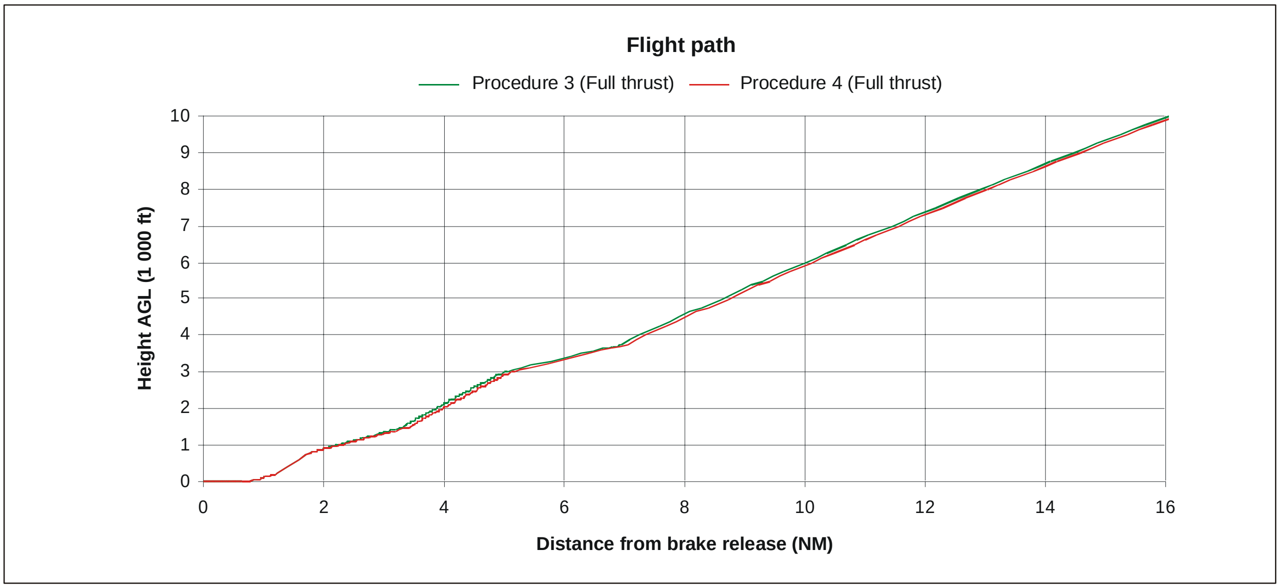
737-700/CFM56-7B24

- **Full power thrust**
- **MTOW = 154 500 lb**



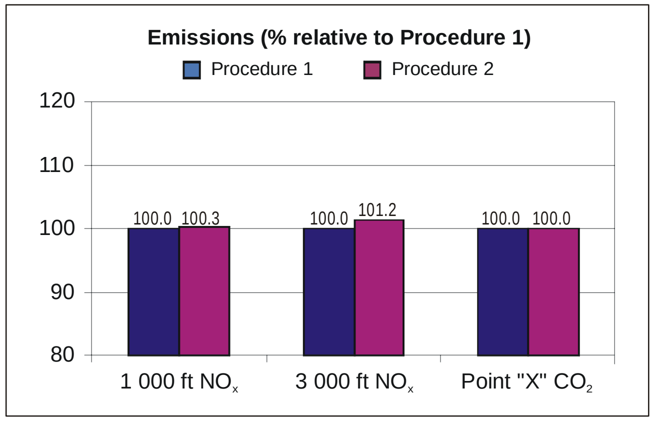
Comparison of Procedures 3 and 4



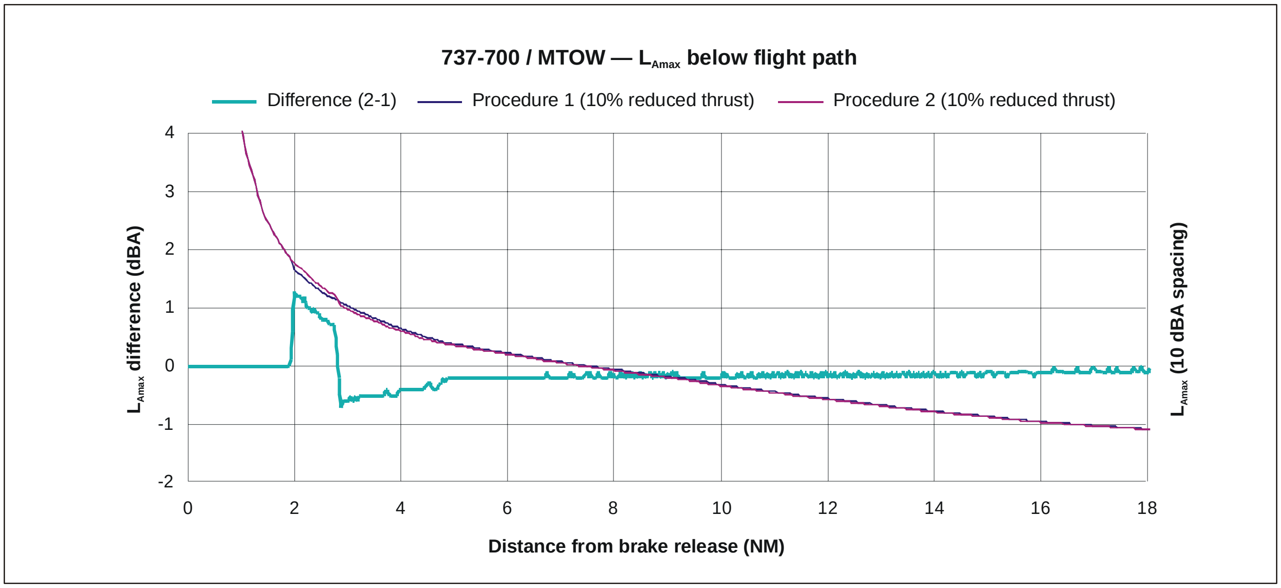


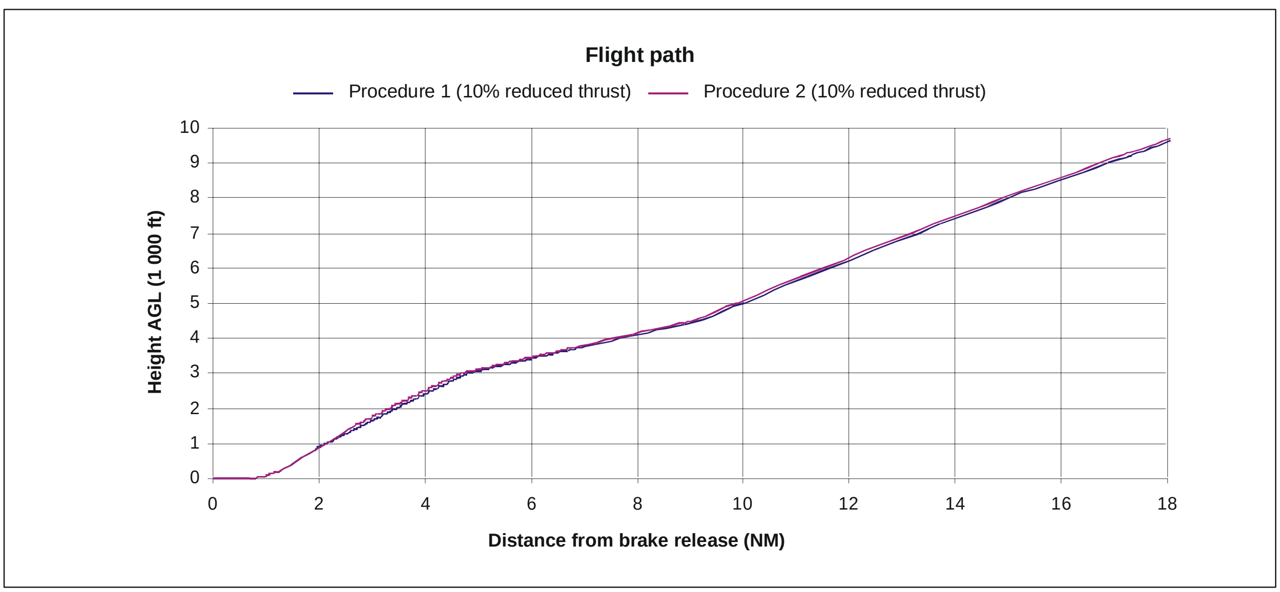
737-700/CFM56-7B24

- **10 per cent reduced thrust**
- **MTOW = 152 100 lb**



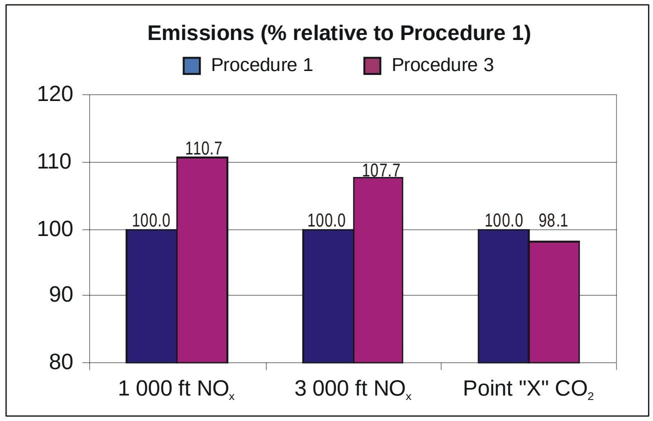
Comparison of Procedures 1 and 2



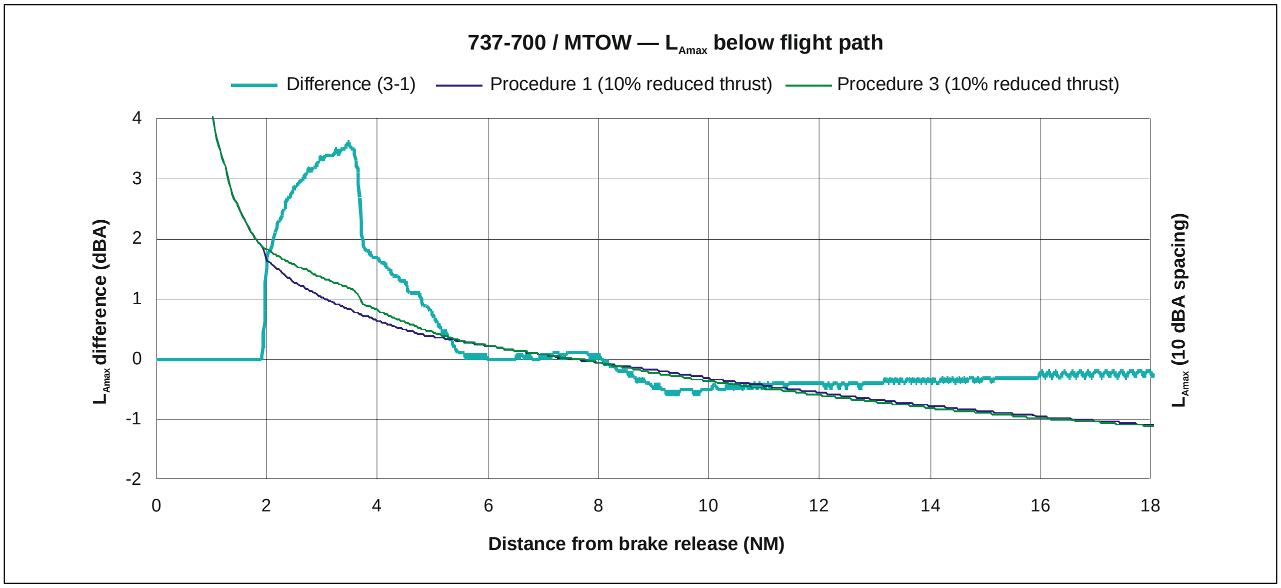


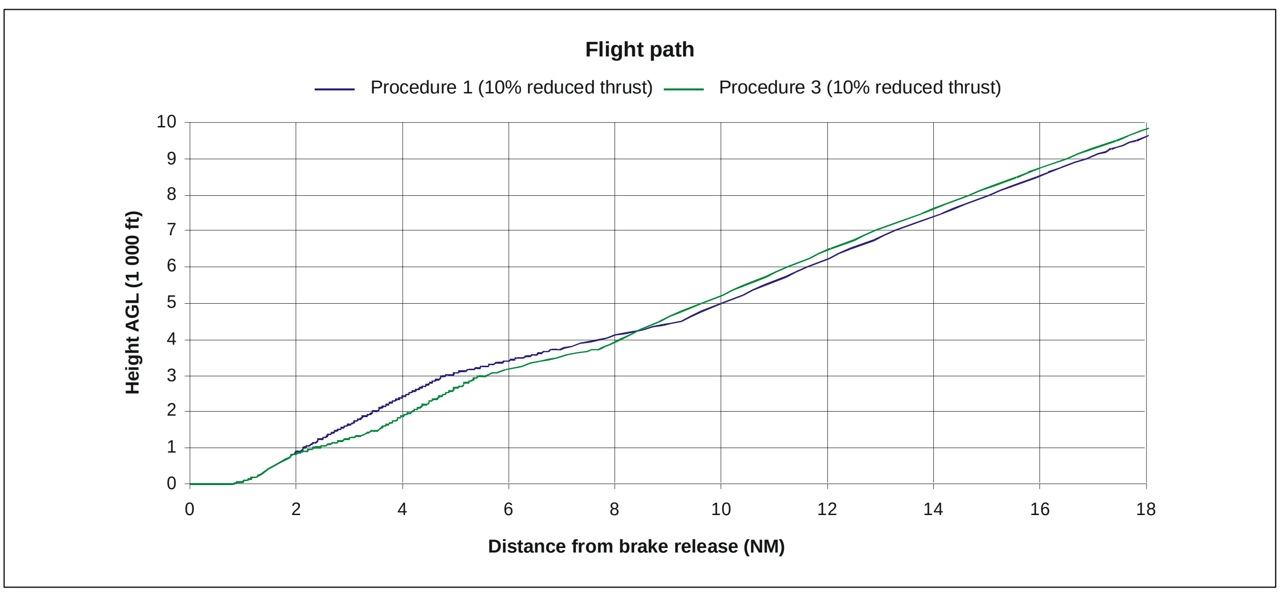
737-700/CFM56-7B24

- **10 per cent reduced thrust**
- **MTOW = 152 100 lb**



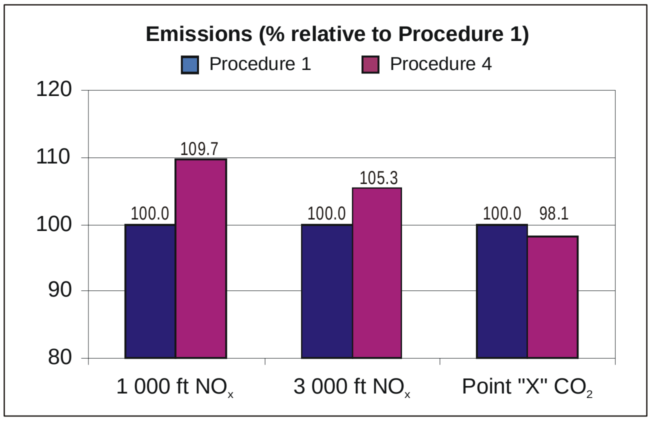
Comparison of Procedures 1 and 3



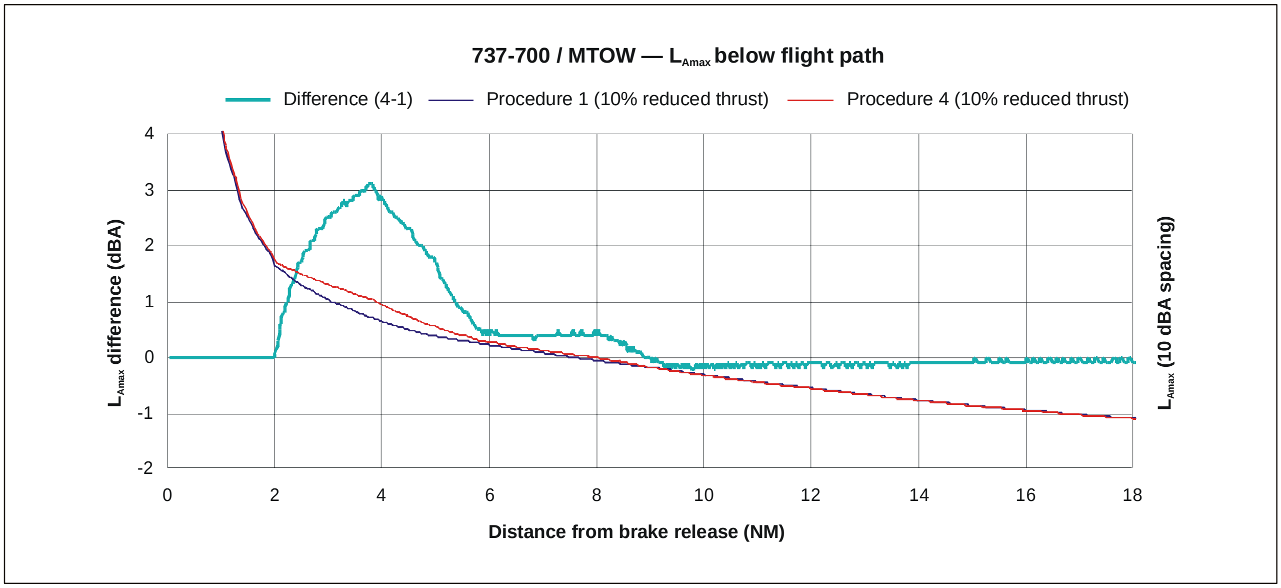


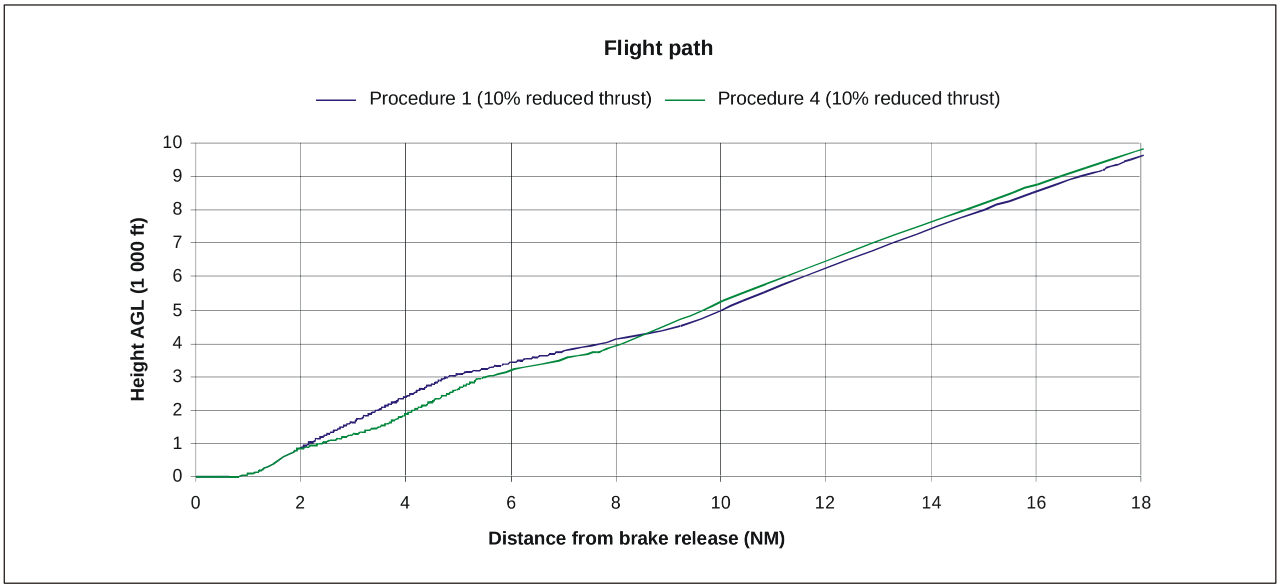
737-700/CFM56-7B24

- **10 per cent reduced thrust**
- **MTOW = 152 100 lb**



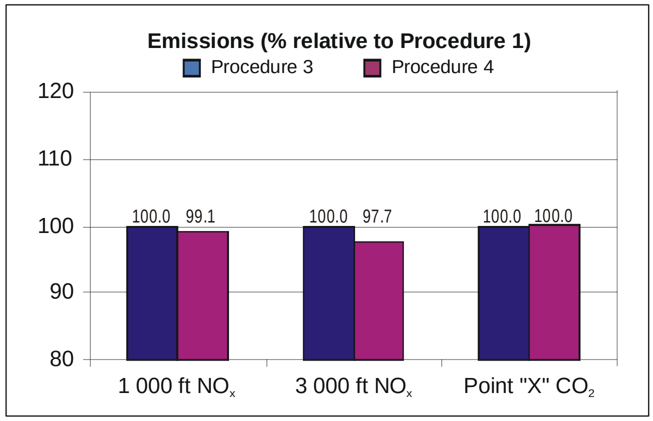
Comparison of Procedures 1 and 4





737-700/CFM56-7B24

- **10 per cent reduced thrust**
- **MTOW = 152 100 lb**



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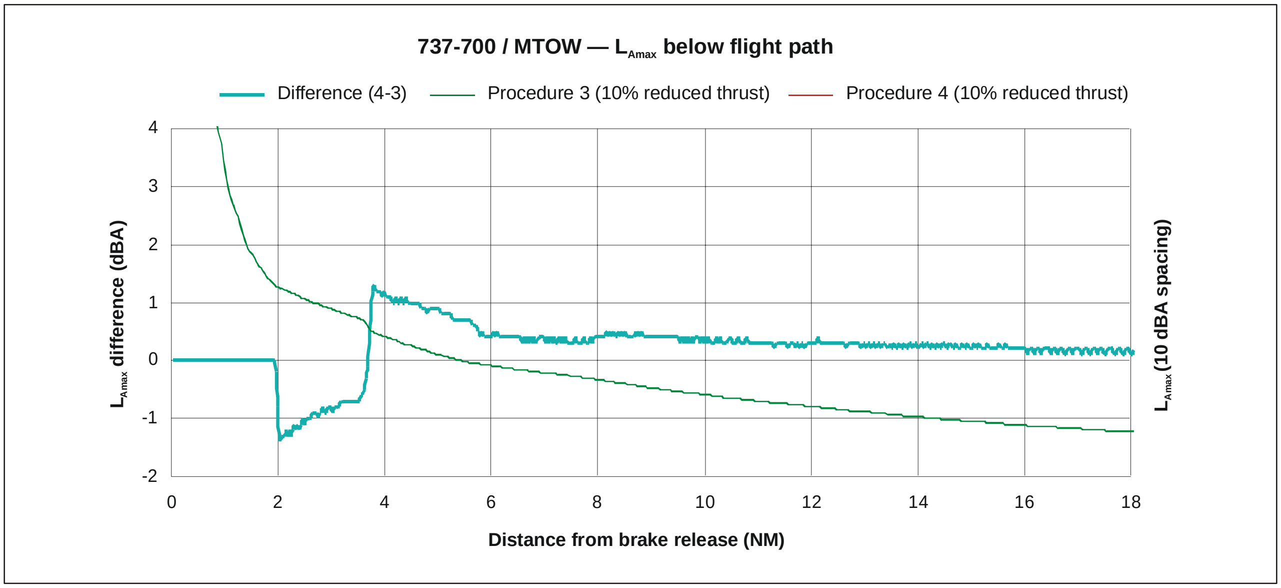
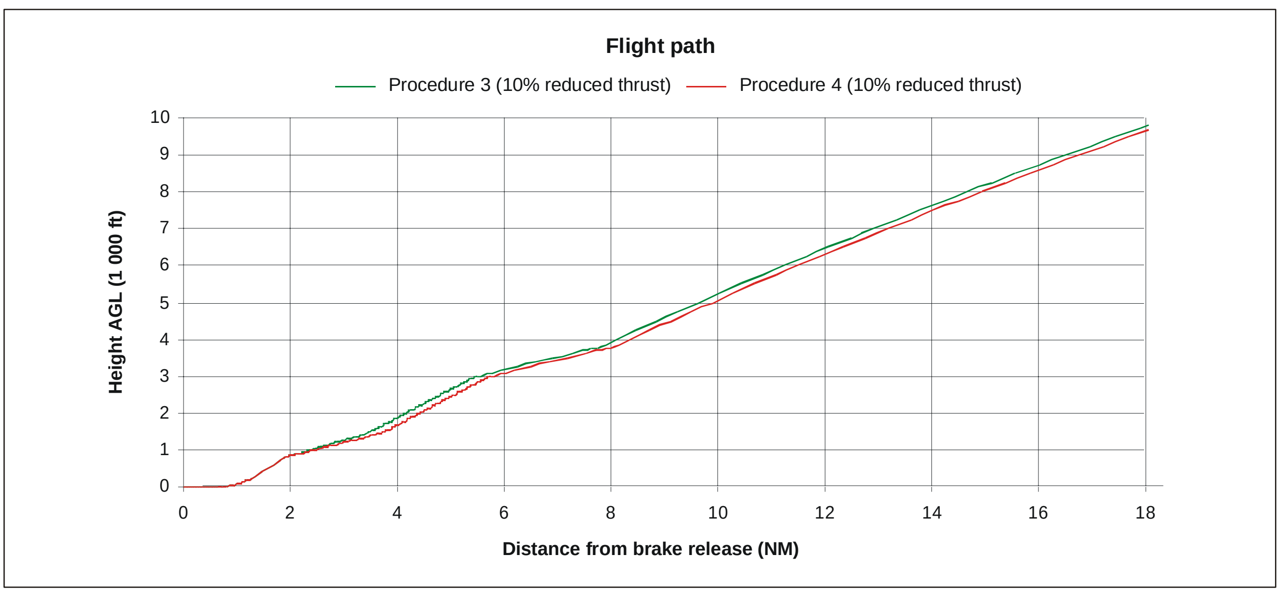
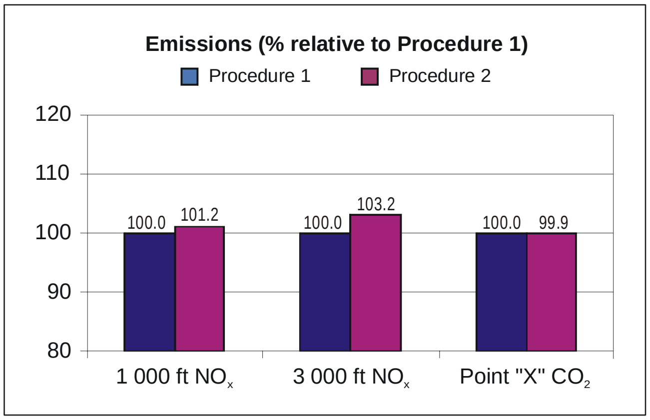


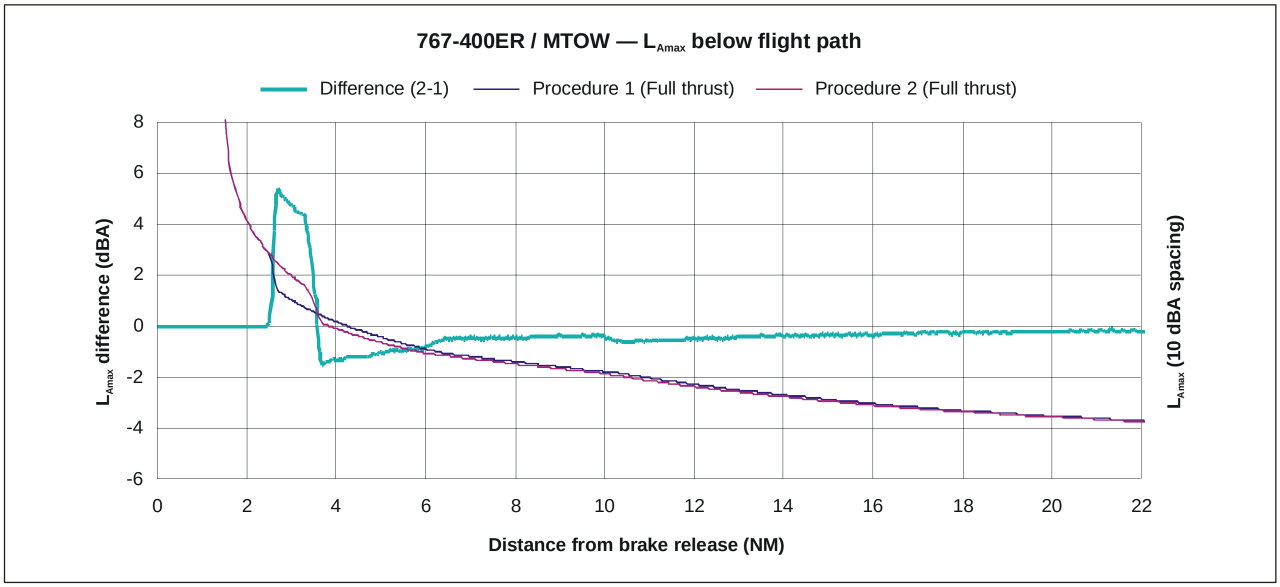


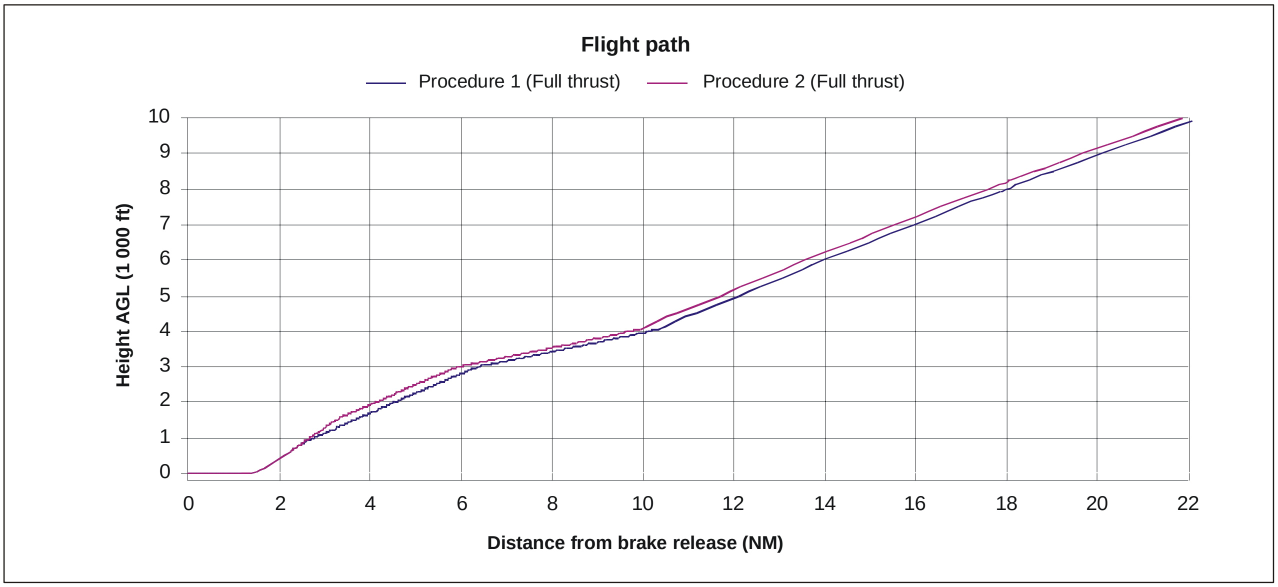
767-400ER/CF6-80C2B8F

- **Full power thrust**
- **MTOW = 450 000 lb**



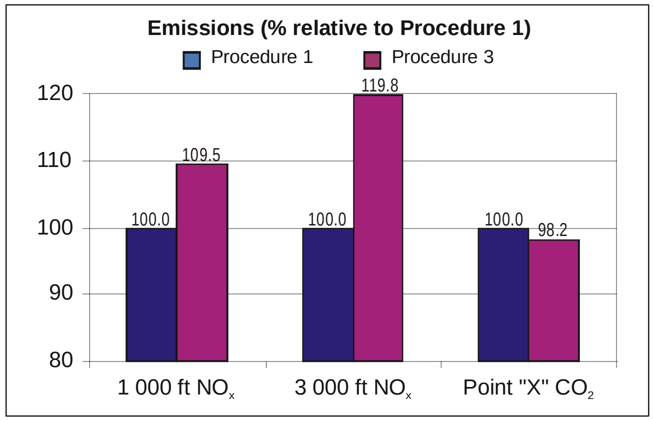
Comparison of Procedures 1 and 2



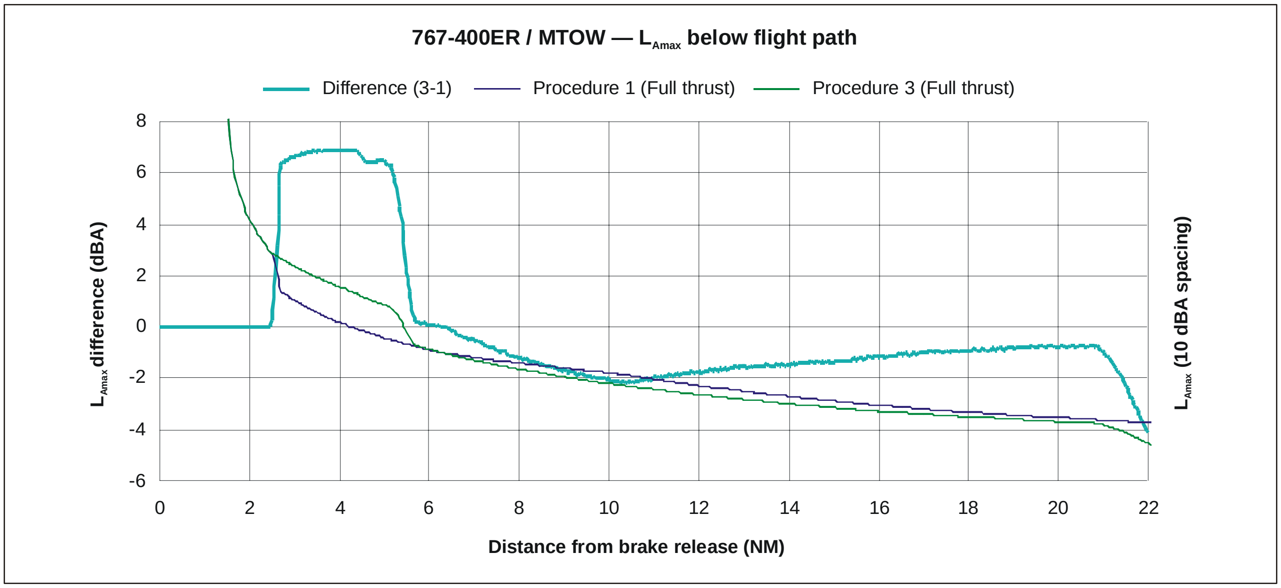


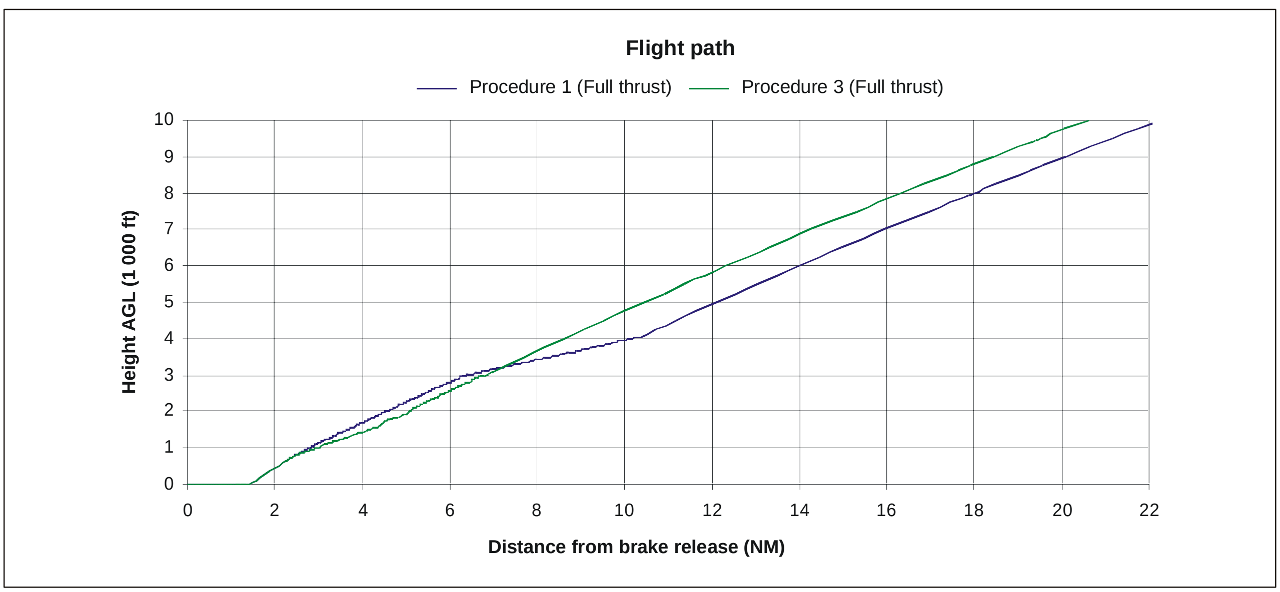
767-400ER/CF6-80C2B8F

- **Full power thrust**
- **MTOW = 450 000 lb**



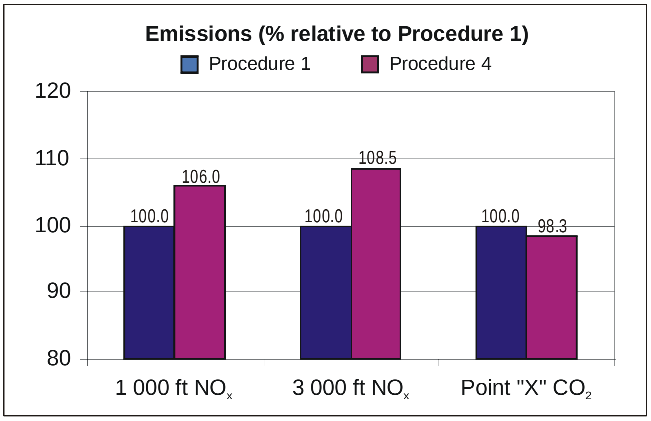
Comparison of Procedures 1 and 3





767-400ER/CF6-80C2B8F

- **Full power thrust**
- **MTOW = 450 000 lb**



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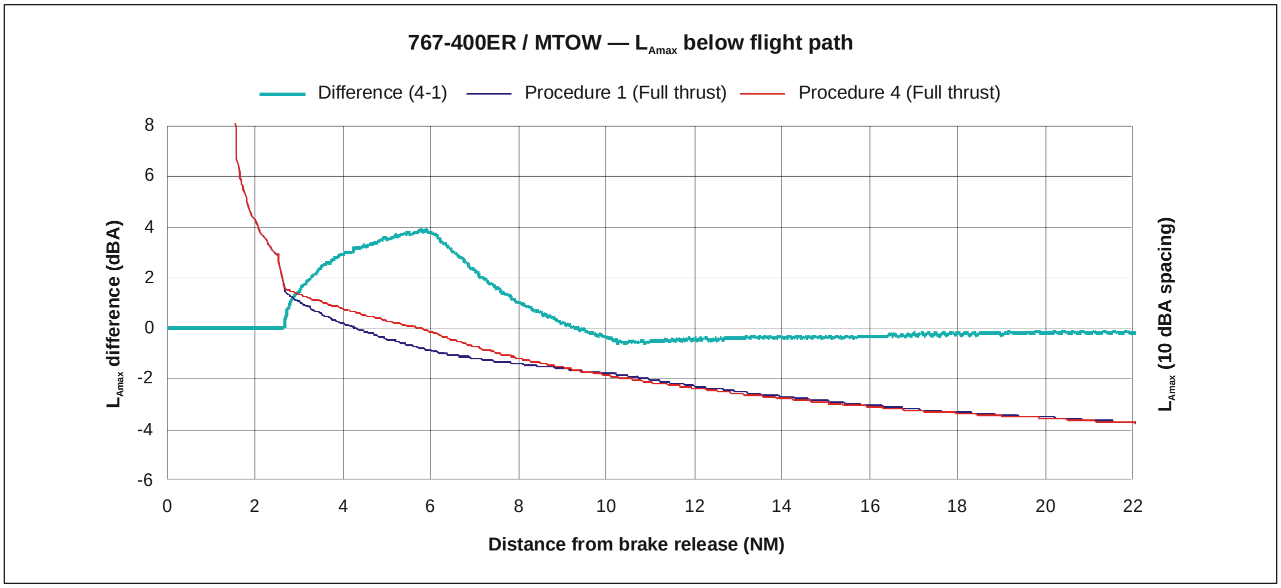
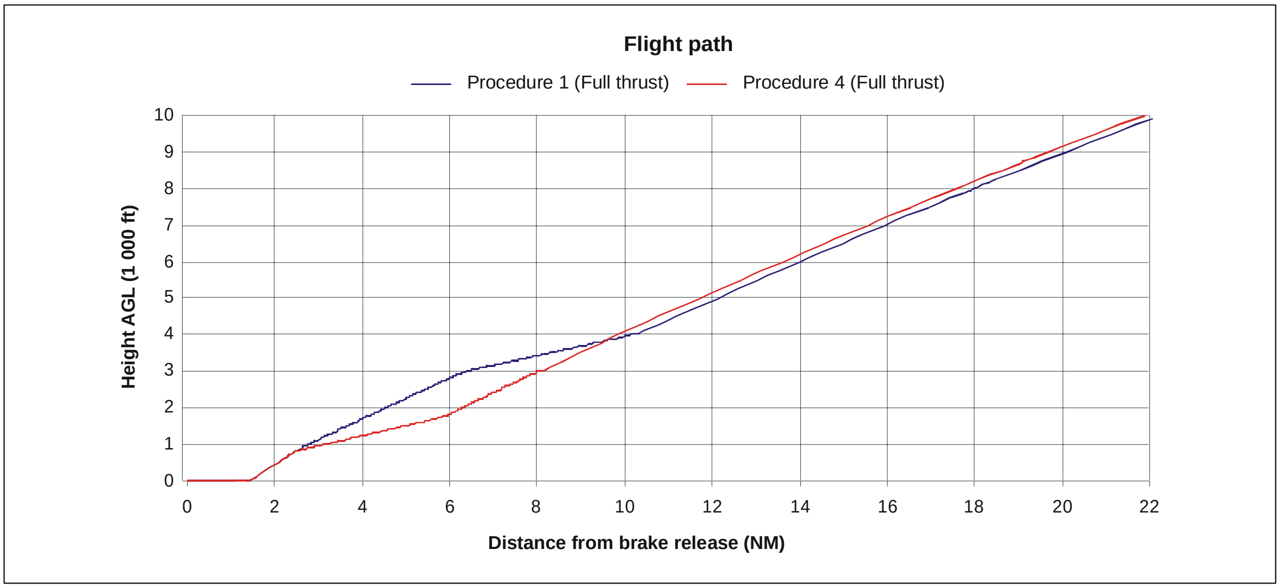
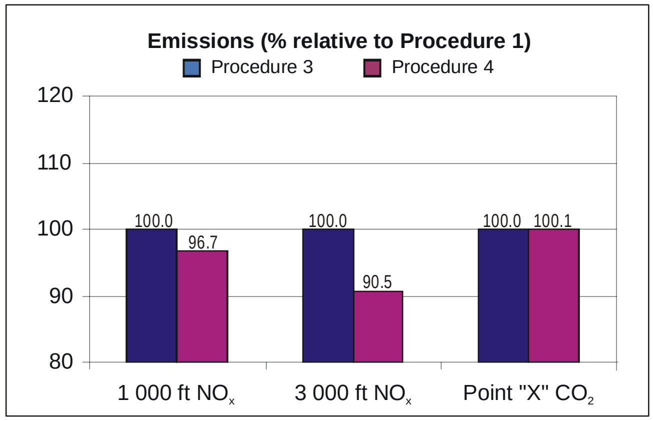


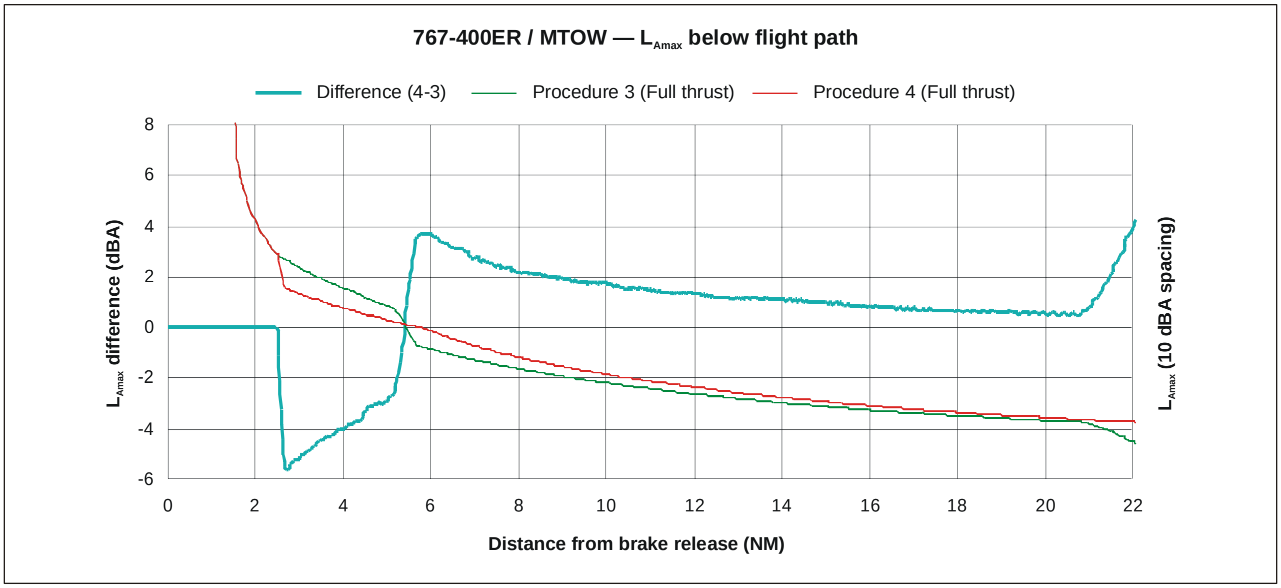


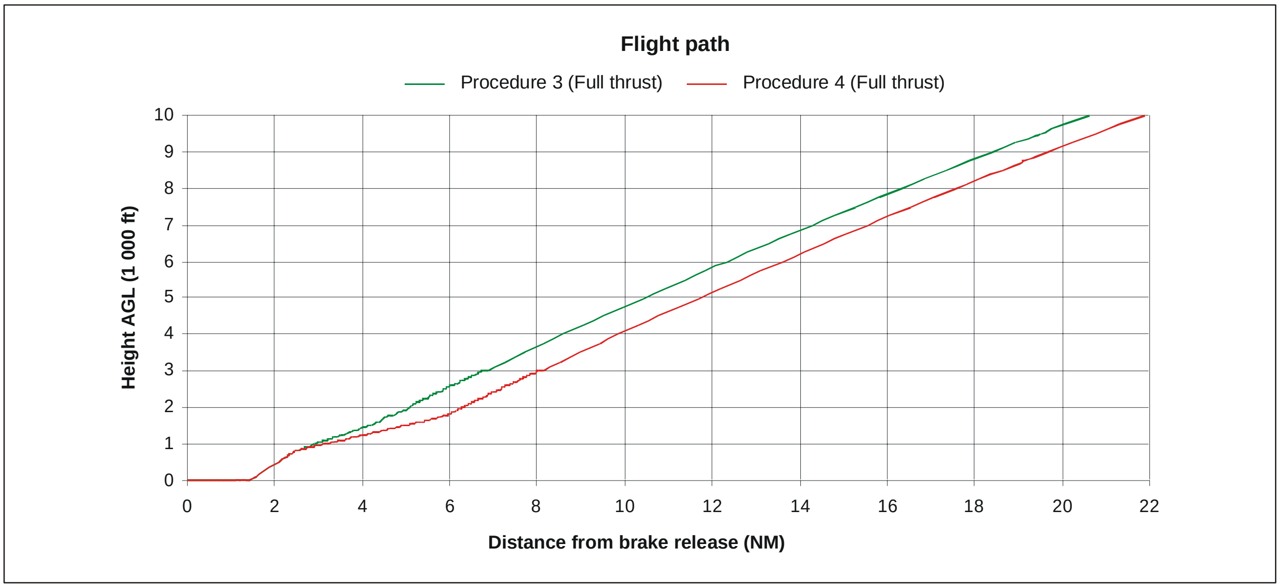
767-400ER/CF6-80C2B8F

- **Full power thrust**
- **MTOW = 450 000 lb**



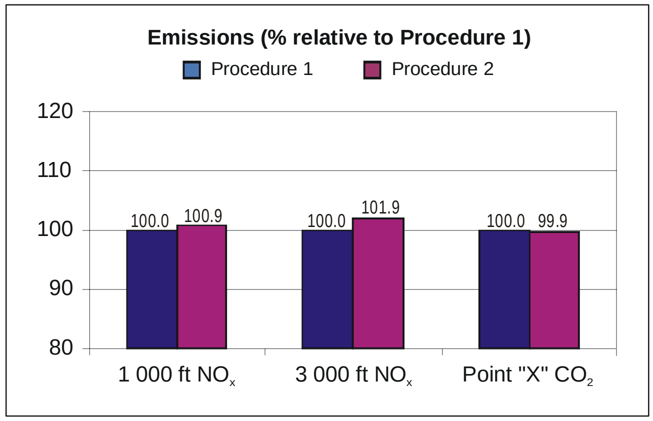
Comparison of Procedures 3 and 4



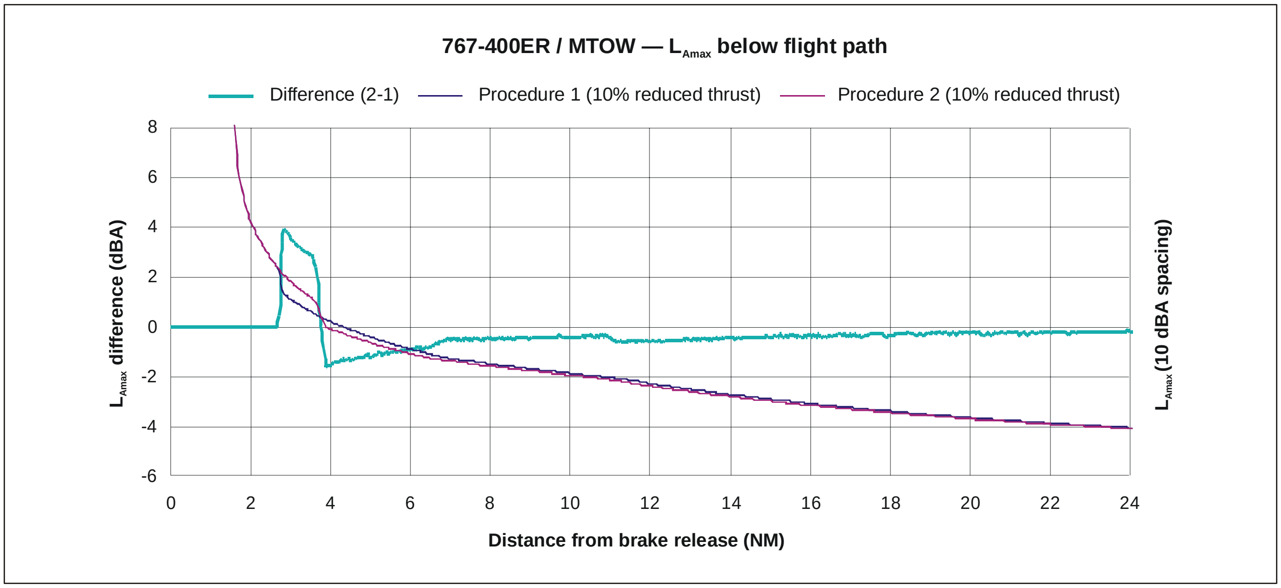


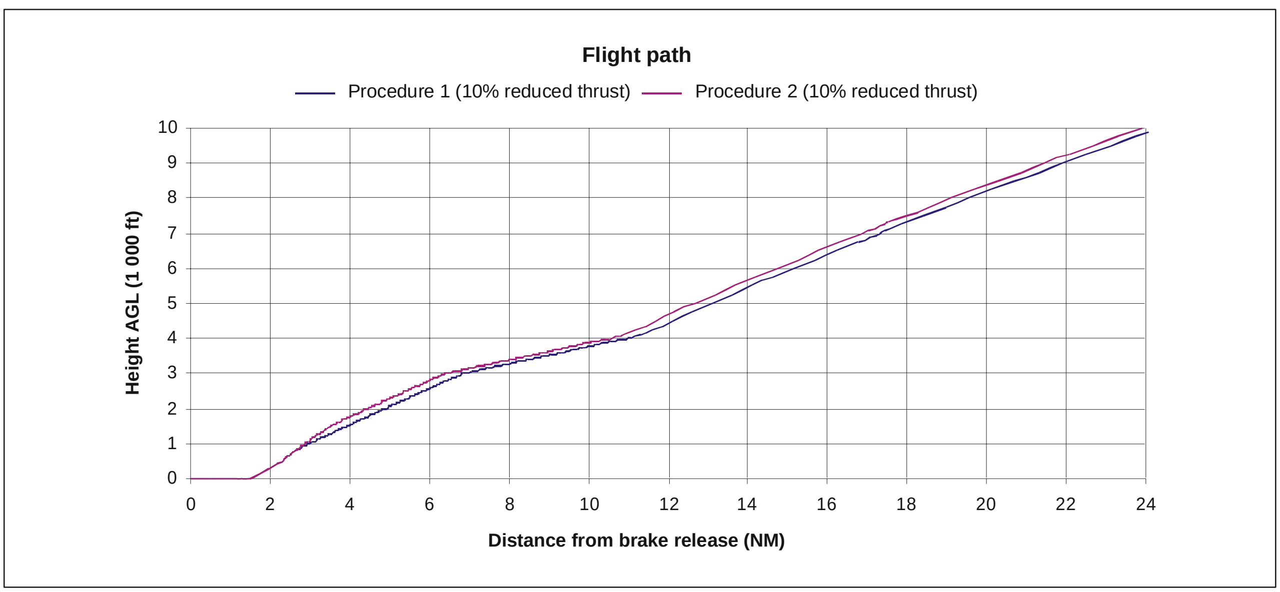
767-400ER/CF6-80C2B8F

- **10 per cent reduced thrust**
- **MTOW = 440 000 lb**



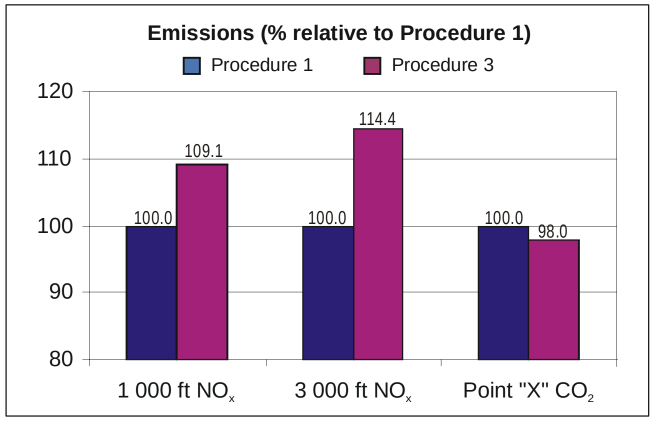
Comparison of Procedures 1 and 2





767-400ER/CF6-80C2B8F

- **10 per cent reduced thrust**
- **MTOW = 440 000 lb**



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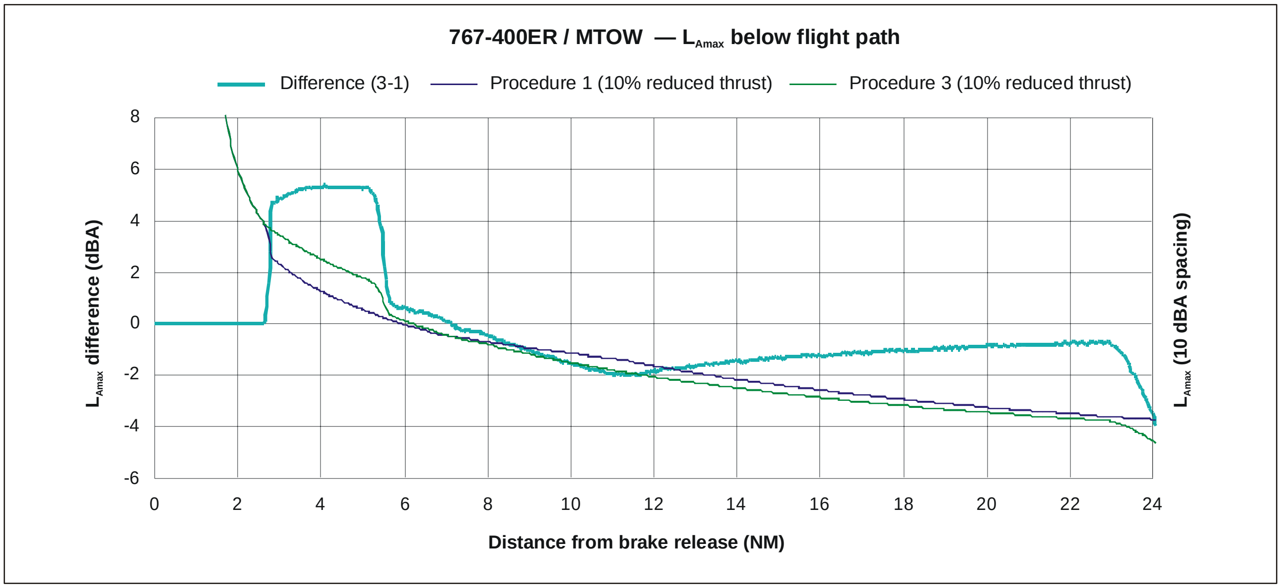
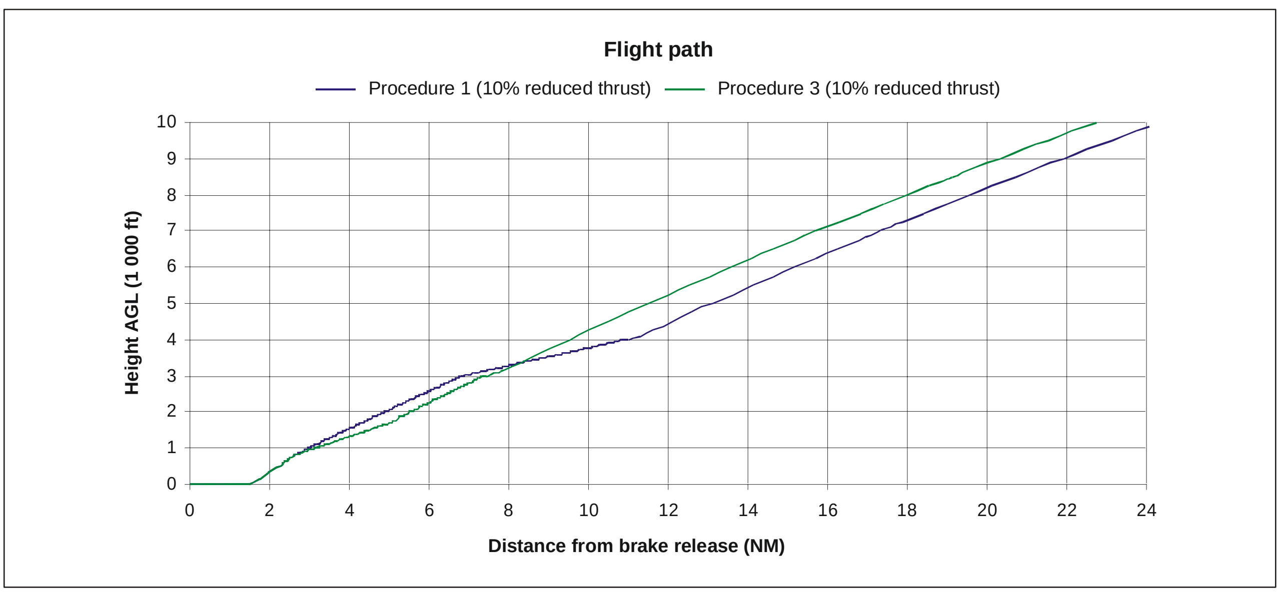
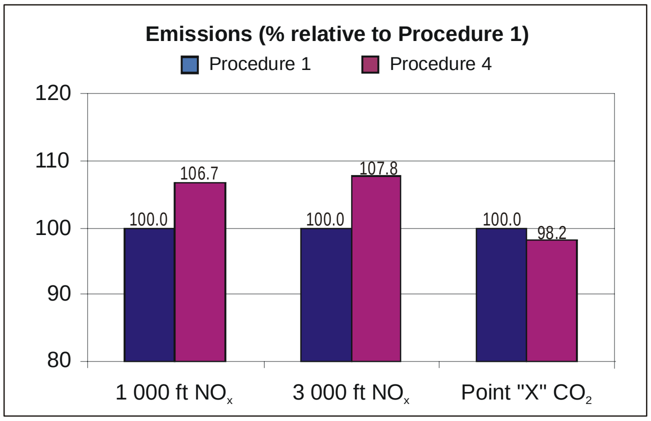


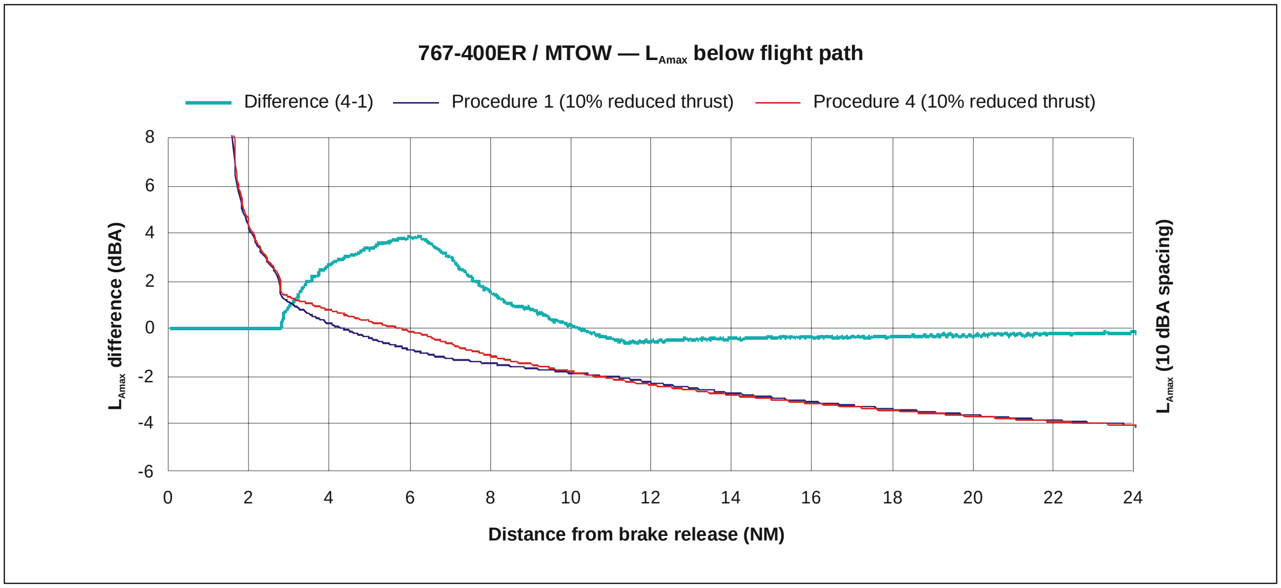


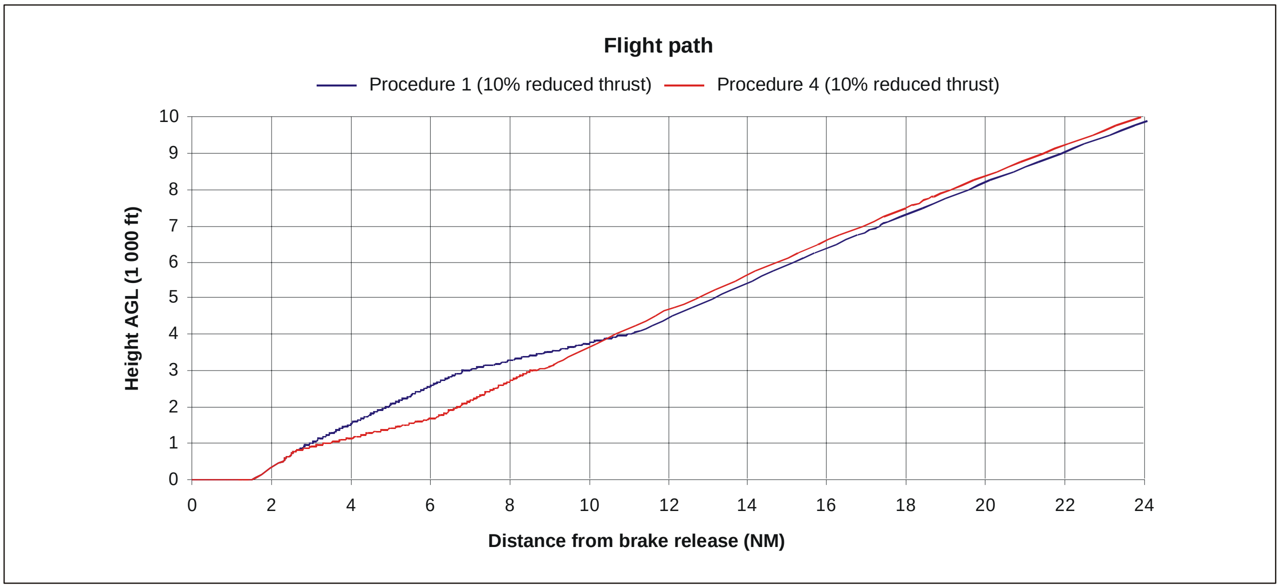
767-400ER/CF6-80C2B8F

- **10 per cent reduced thrust**
- **MTOW = 440 000 lb**



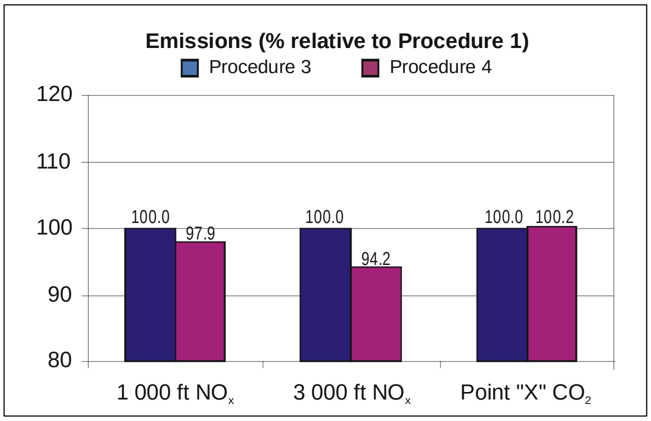
Comparison of Procedures 1 and 4



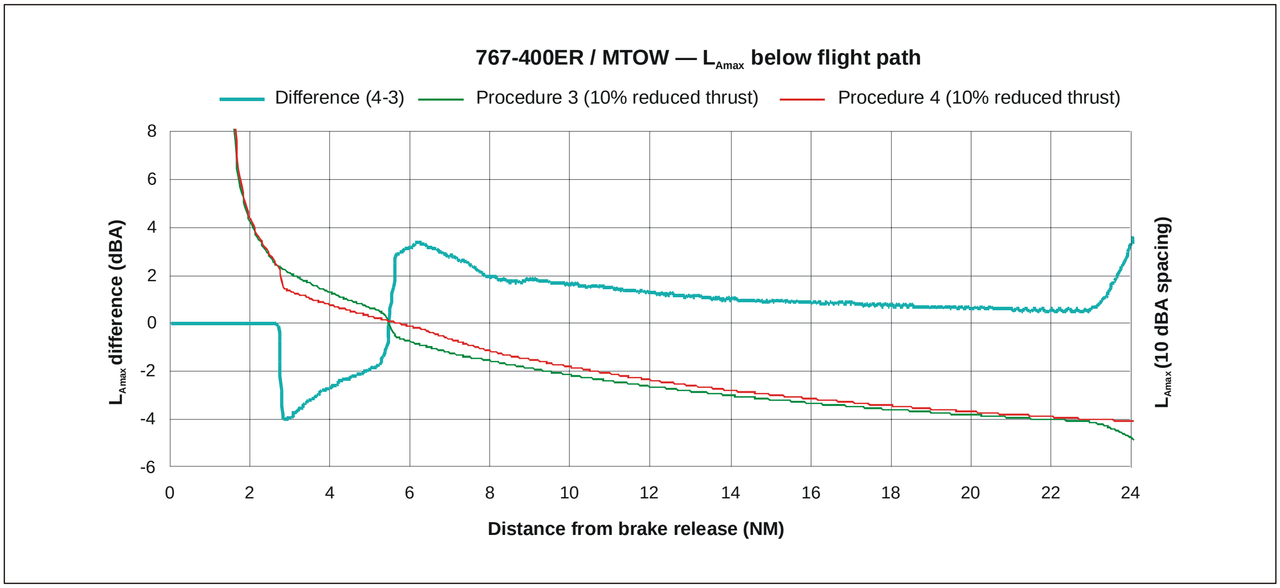


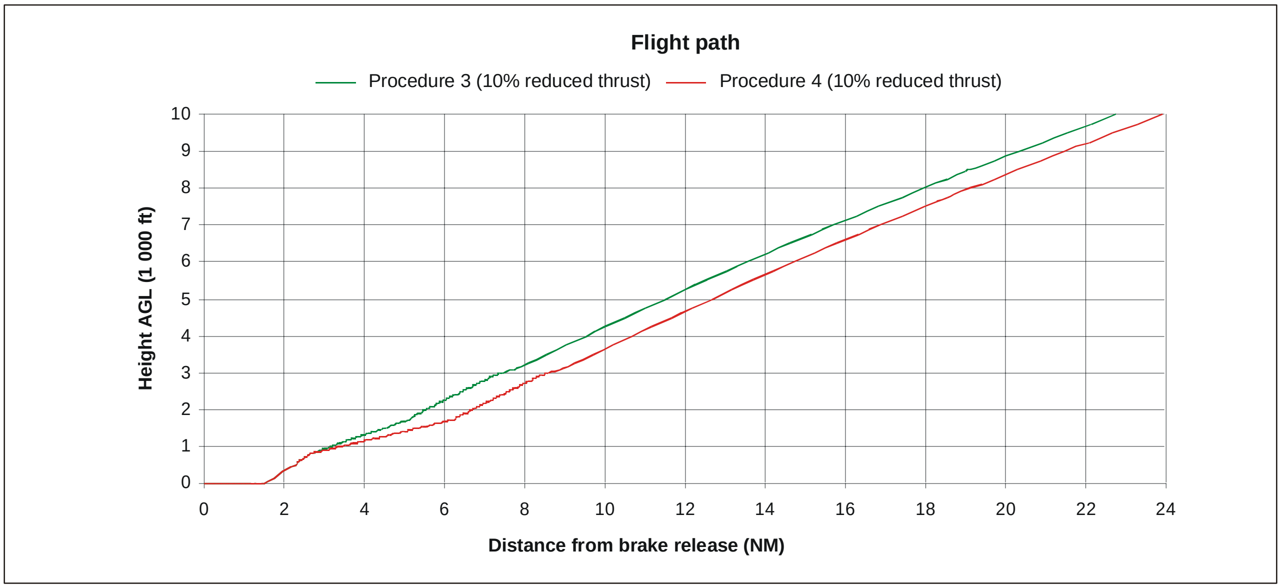
767-400ER/CF6-80C2B8F

- **10 per cent reduced thrust**
- **MTOW = 440 000 lb**

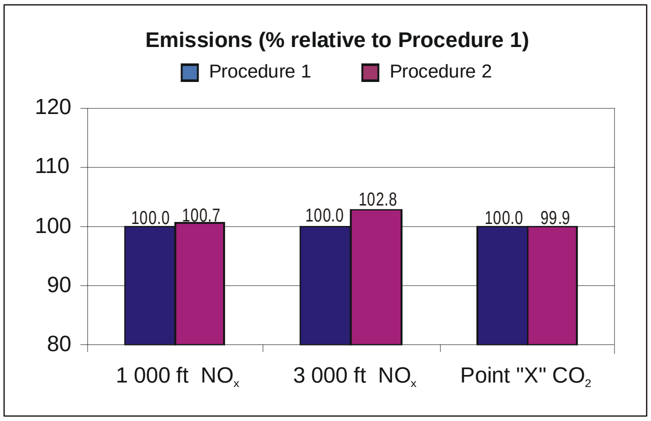


Comparison of Procedures 3 and 4

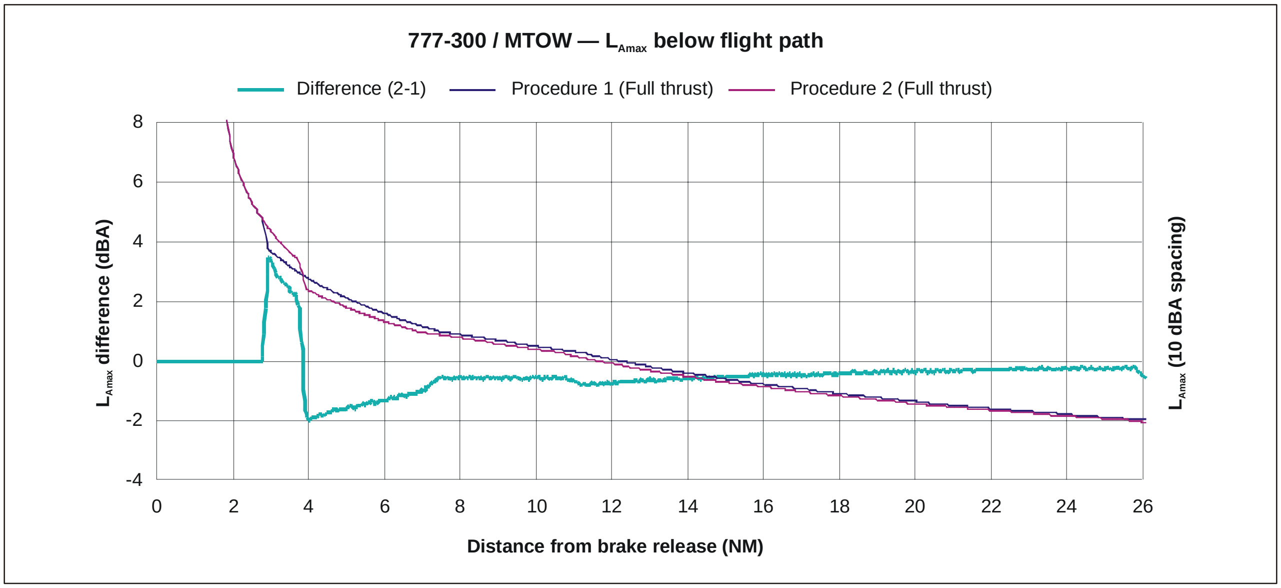


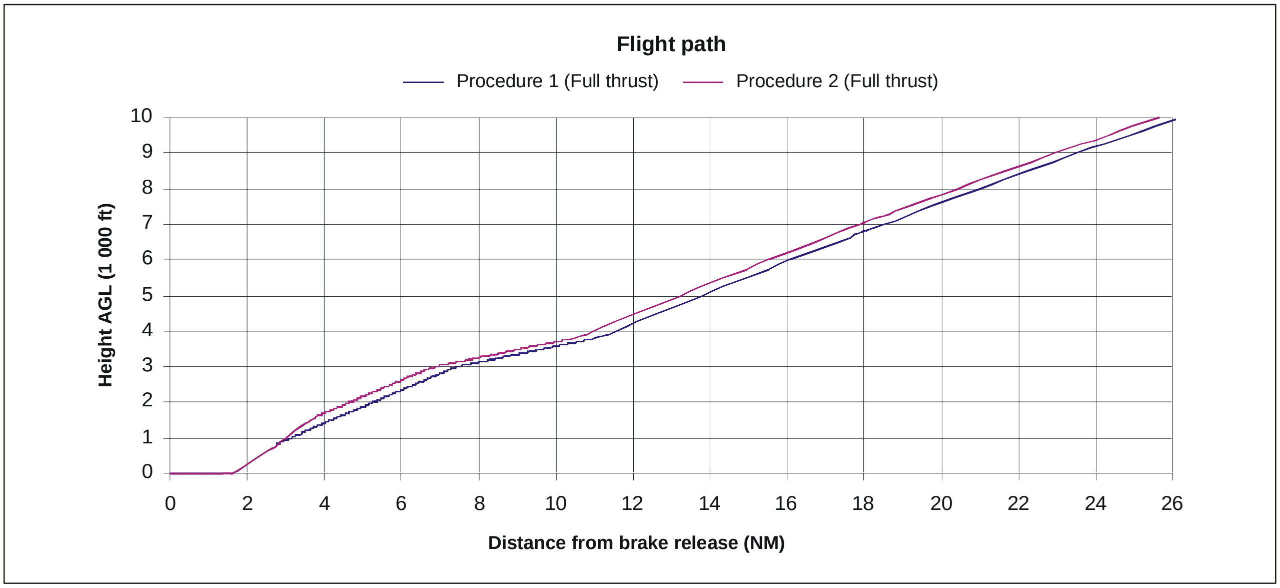


777-300/Trent 892
- **Full power thrust**
- **MTOW = 660 000 lb**



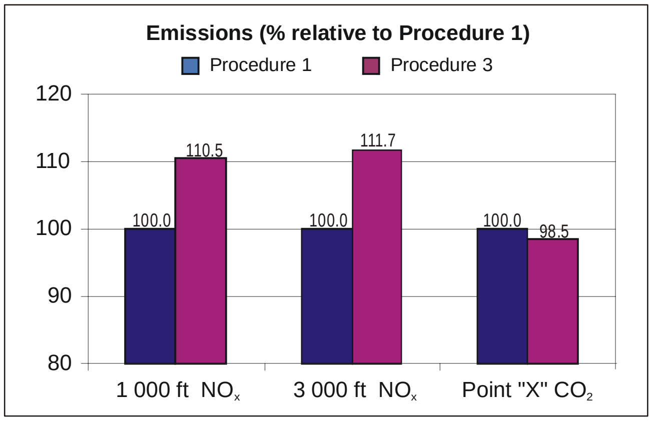
Comparison of Procedures 1 and 2



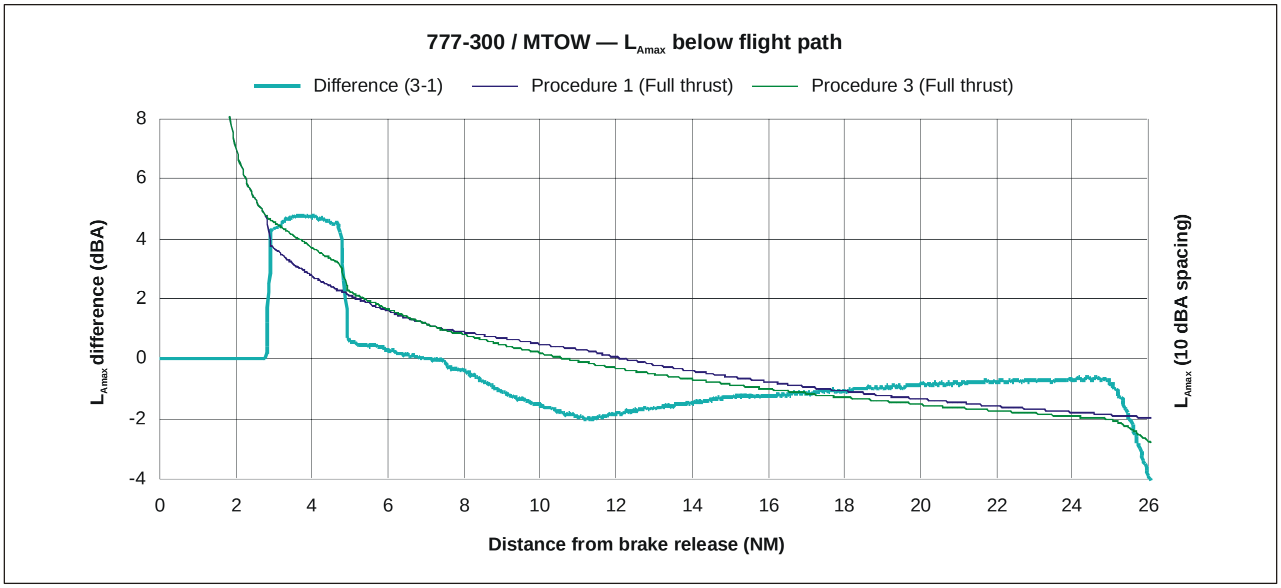


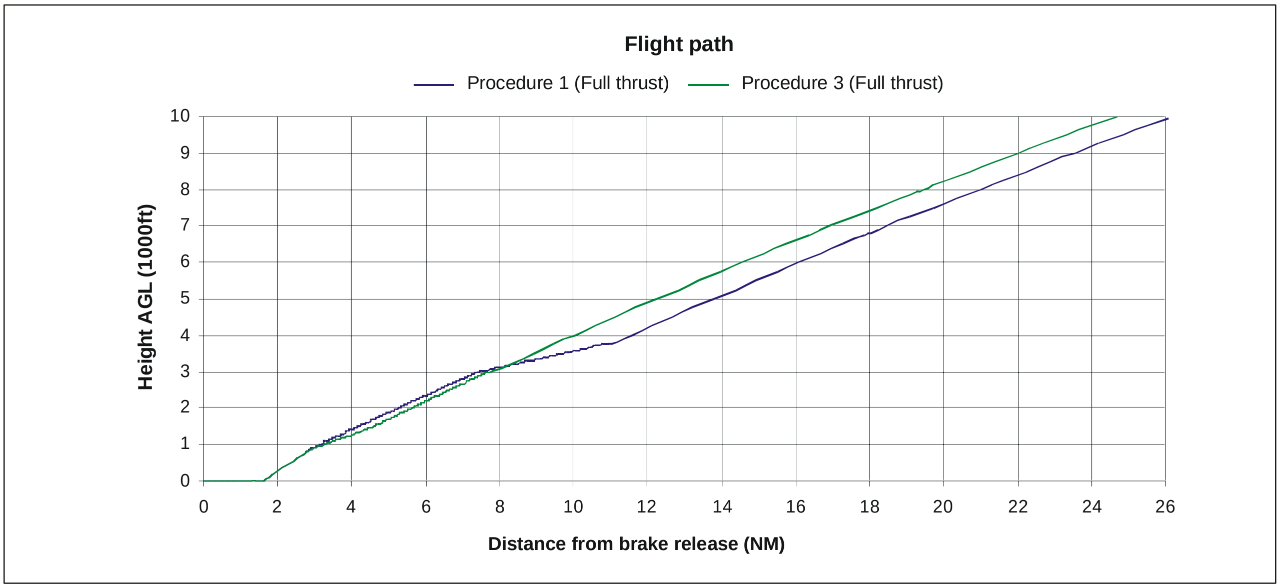
777-300/Trent 892

- **Full power thrust**
- **MTOW = 660 000 lb**



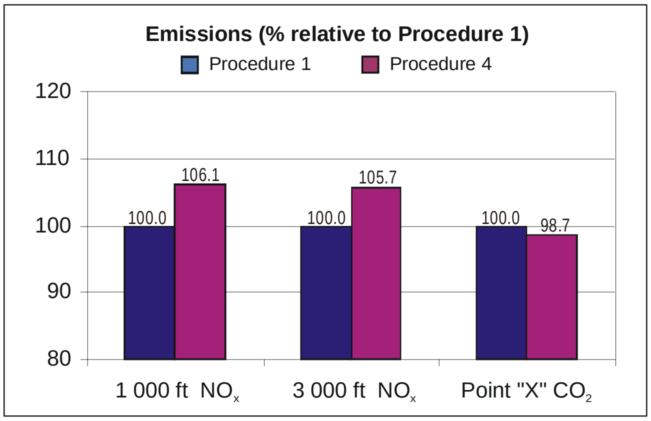
Comparison of Procedures 1 and 3



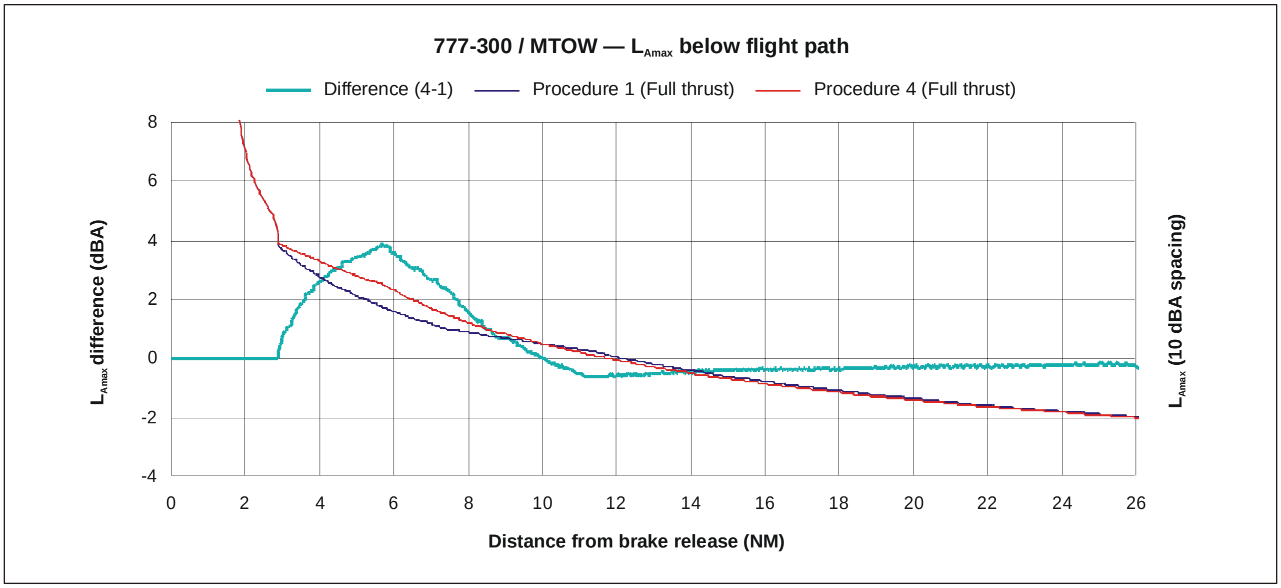


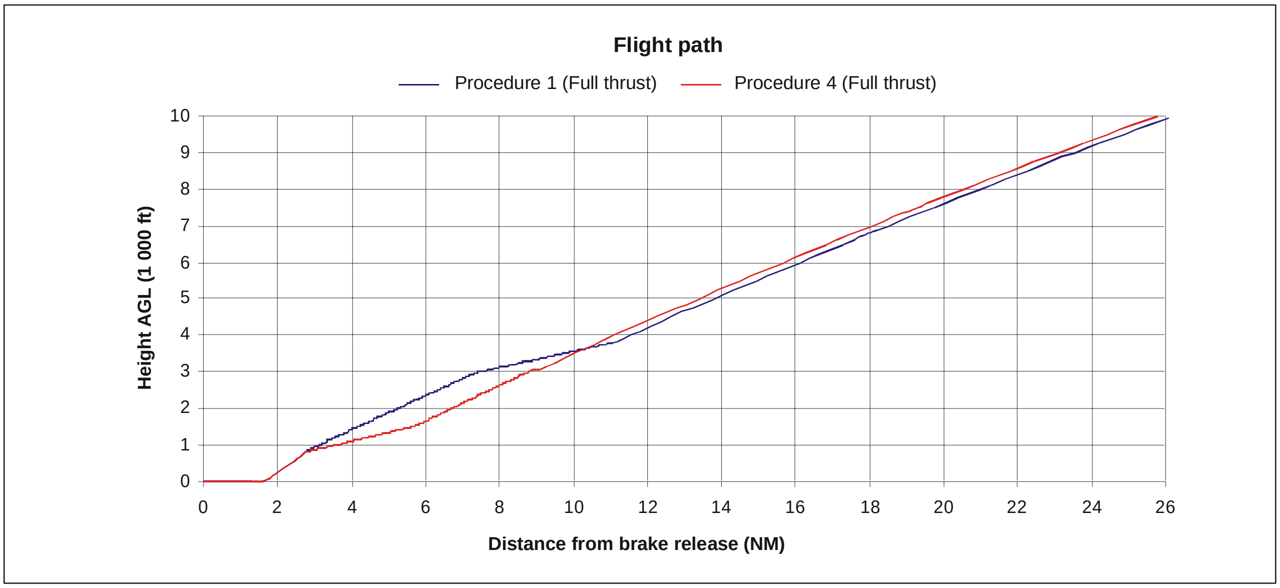
777-300/Trent 892

- **Full power thrust**
- **MTOW = 660 000 lb**

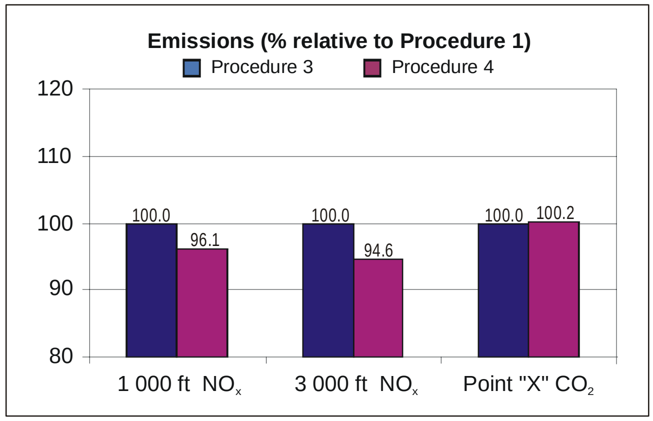


Comparison of Procedures 1 and 4

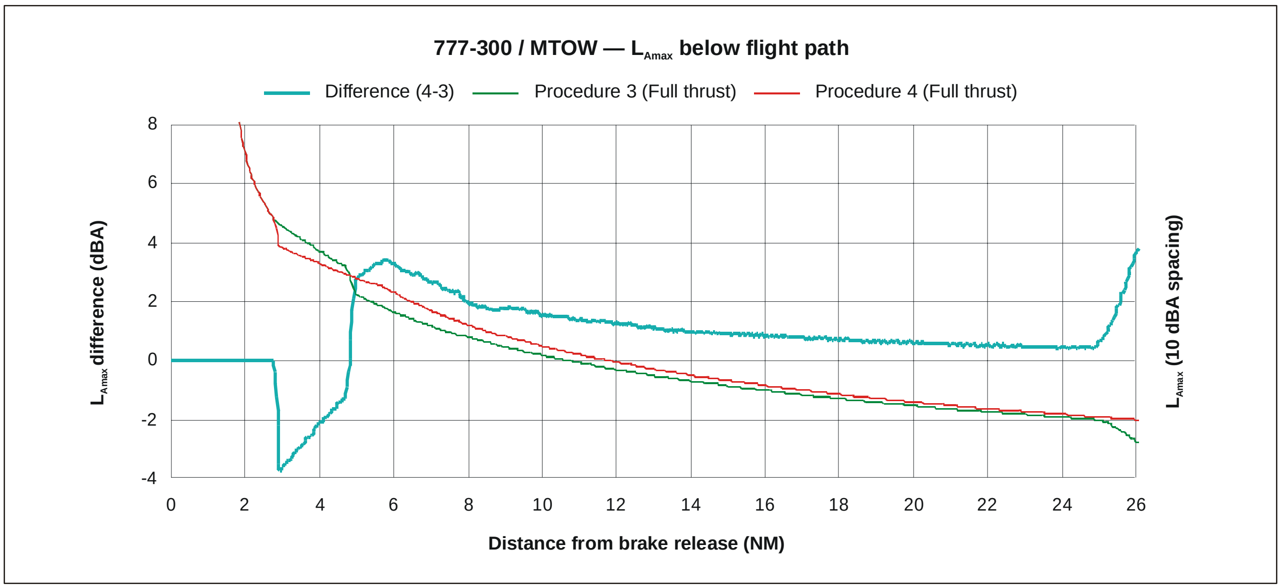


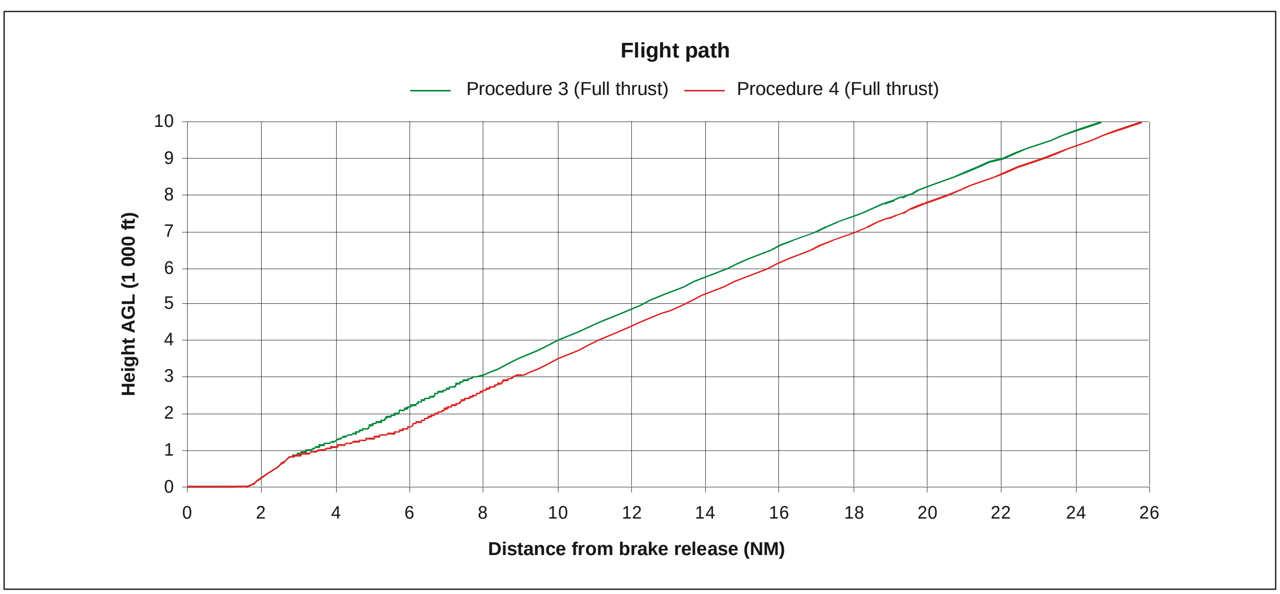


777-300/Trent 892
- **Full power thrust**
- **MTOW = 660 000 lb**



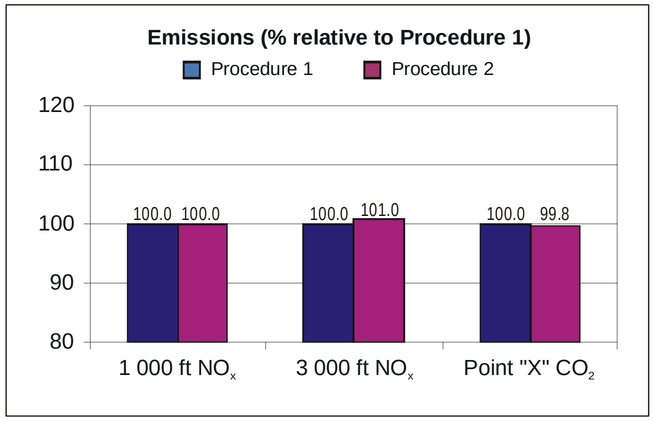
Comparison of Procedures 3 and 4



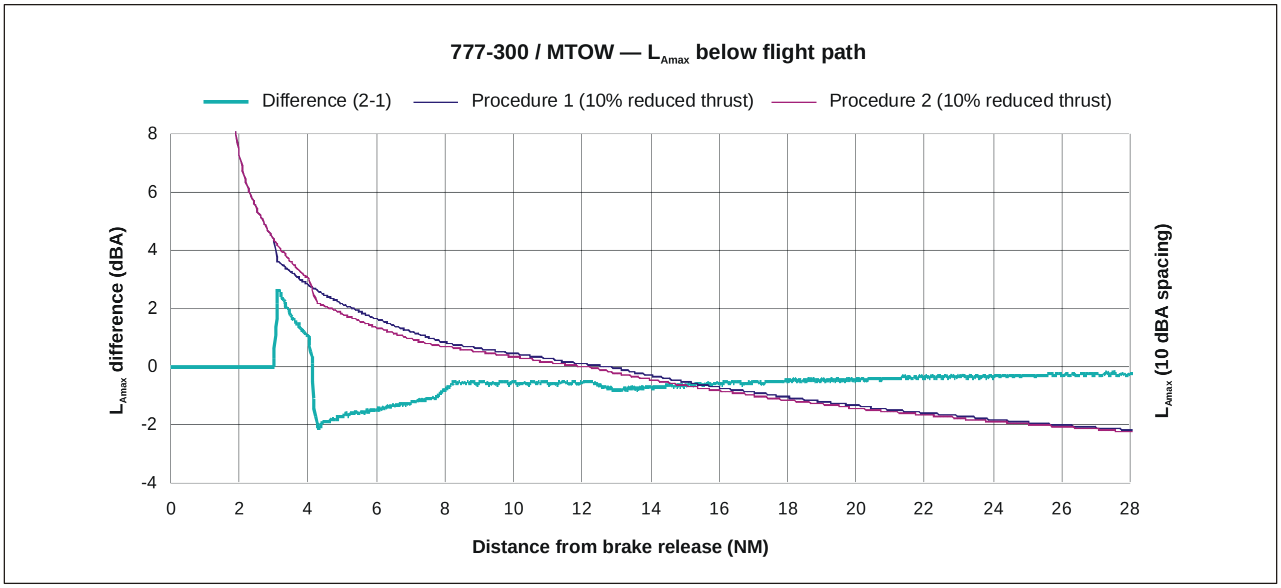


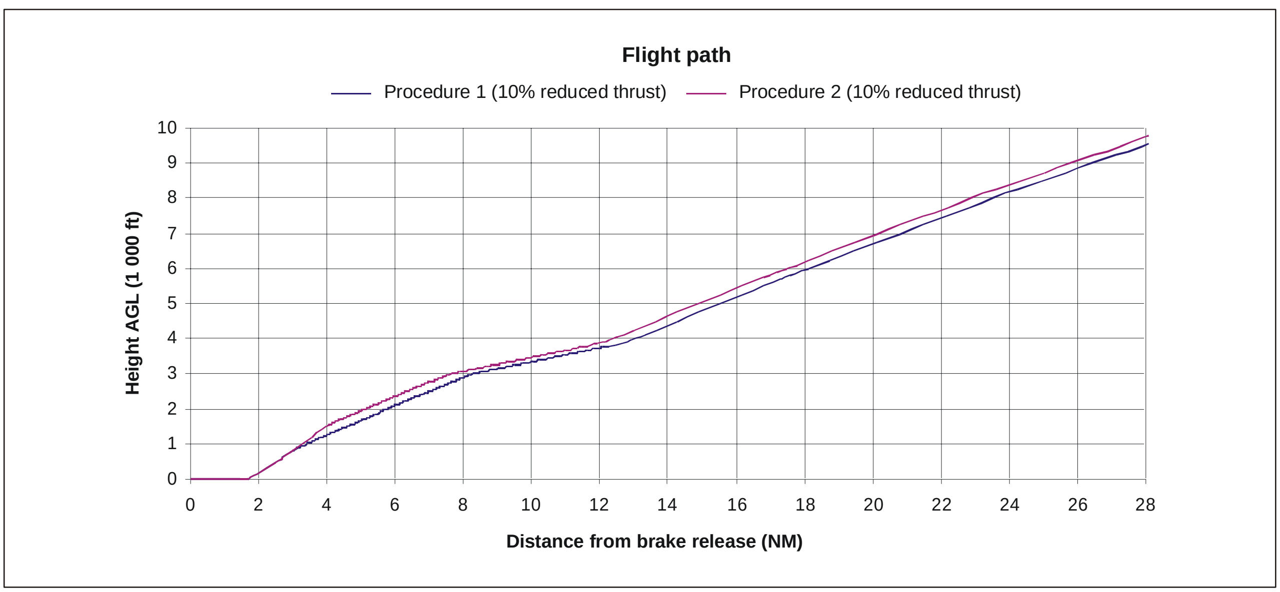
777-300/Trent 892

- **10 per cent reduced thrust**
- **MTOW = 629 100 lb**



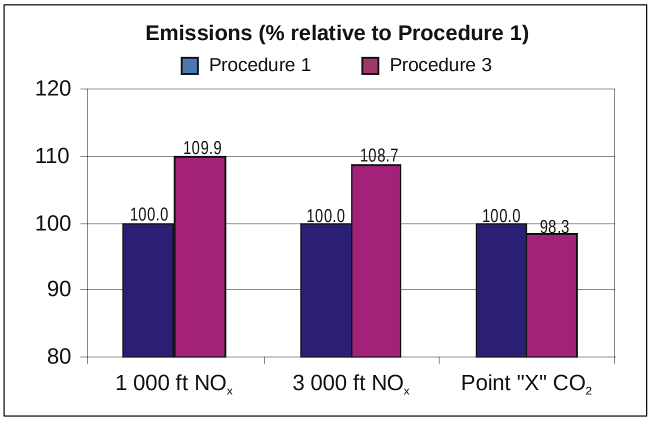
Comparison of Procedures 1 and 2



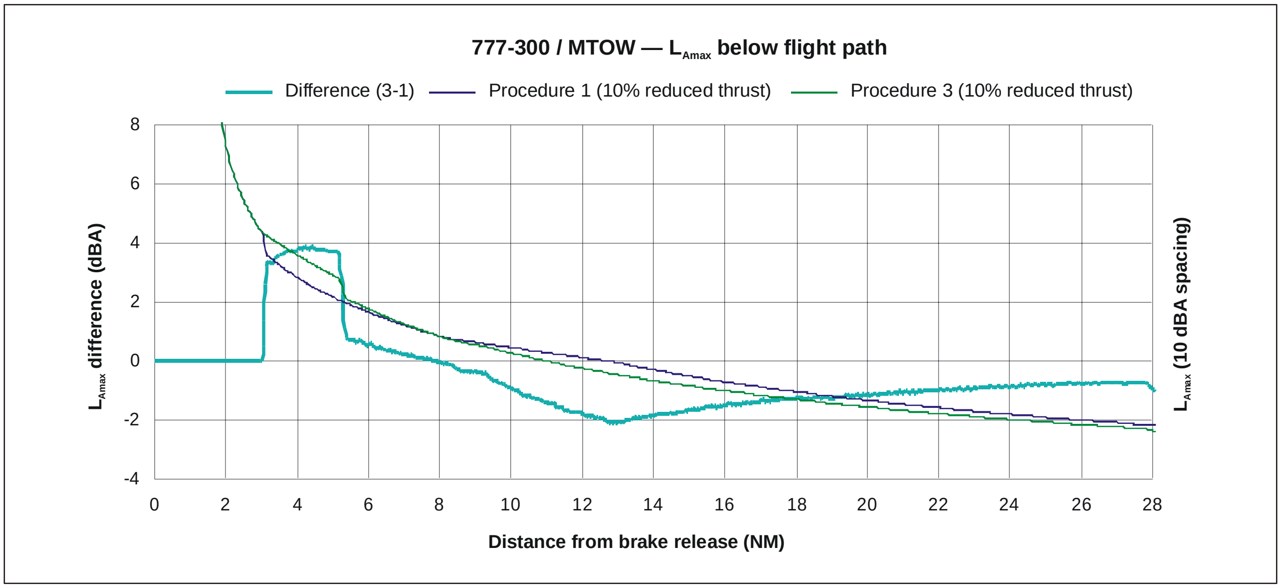


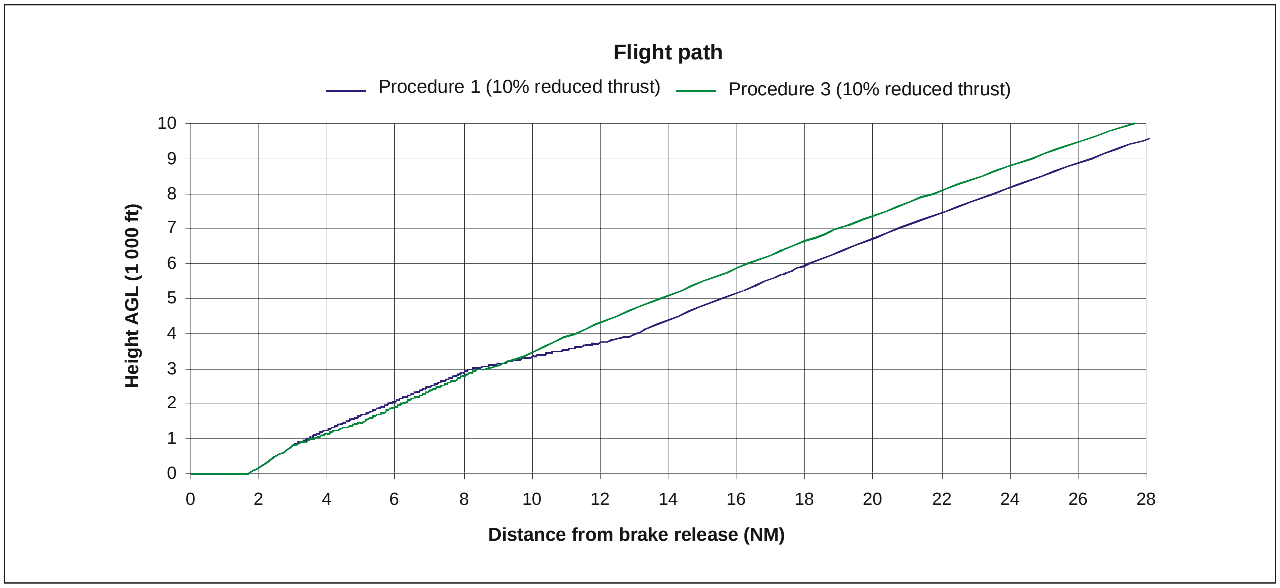
777-300/Trent 892

- **10 per cent reduced thrust**
- **MTOW = 629 100 lb**



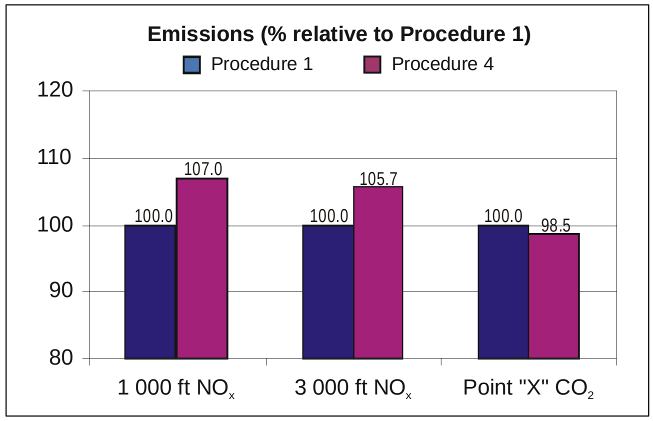
Comparison of Procedures 1 and 3



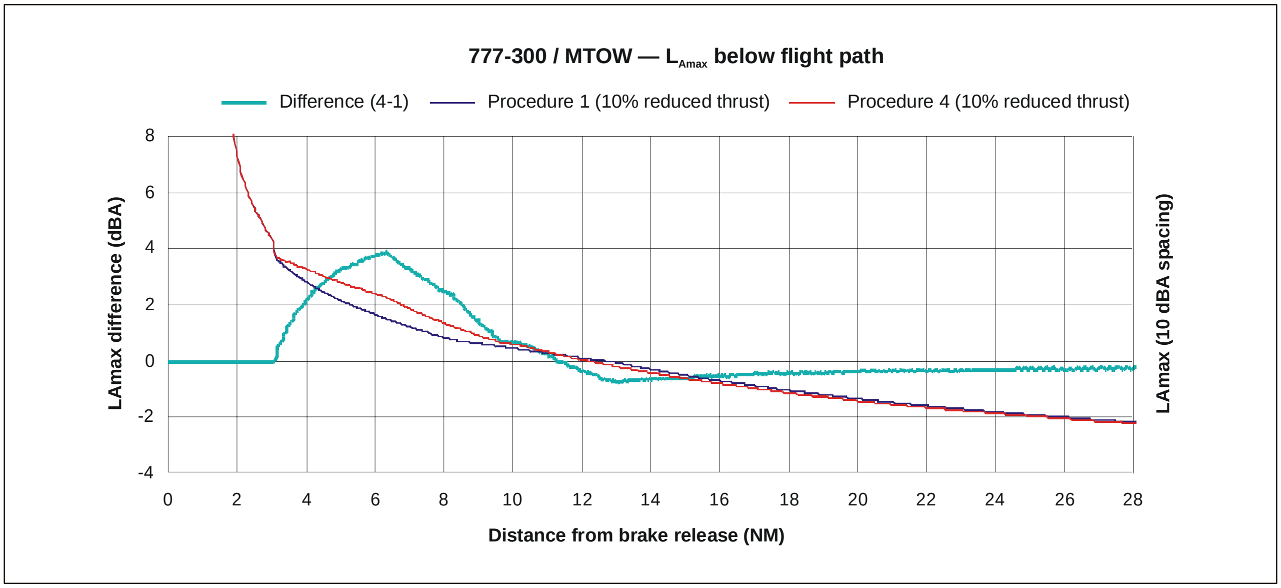


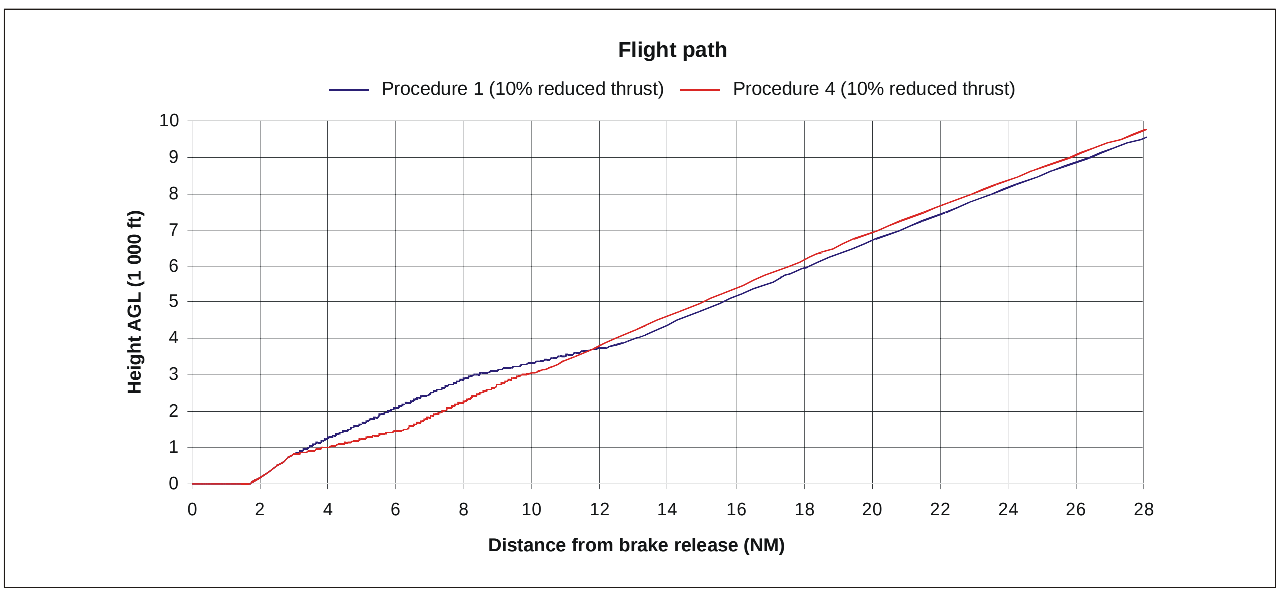
777-300/Trent 892

- **10 per cent reduced thrust**
- **MTOW = 629 100 lb**

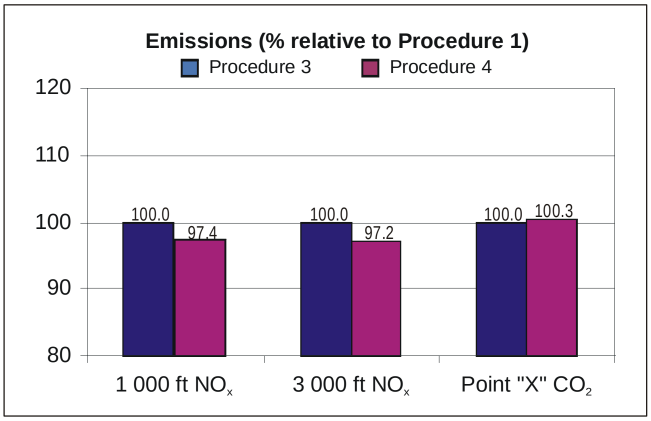


Comparison of Procedures 1 and 4

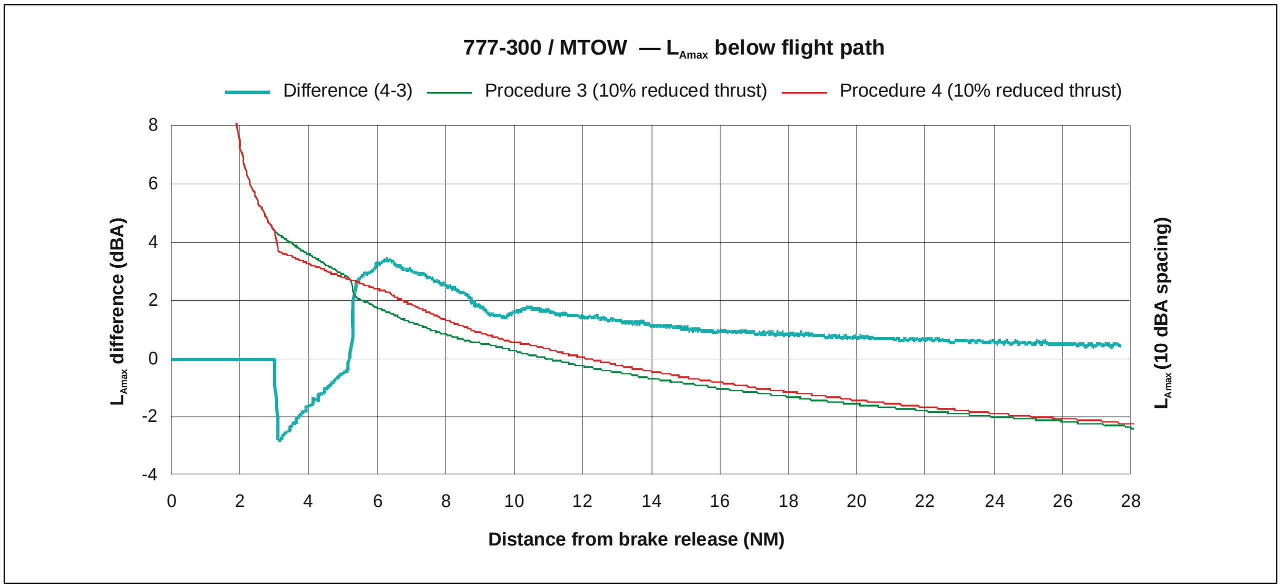


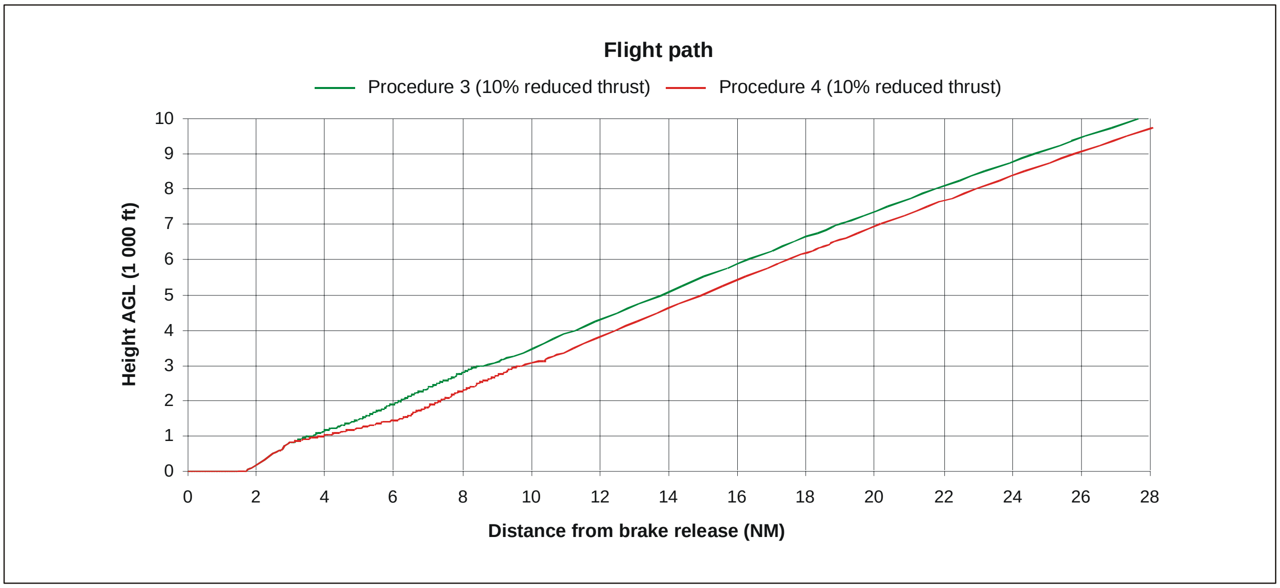


777-300/Trent 892
- **10 per cent reduced thrust**
- **MTOW = 629 100 lb**



Comparison of Procedures 3 and 4





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Appendix C

RESULTS — BOMBARDIER

AIRCRAFT STUDIED

CRJ900ER, CF34-8C5

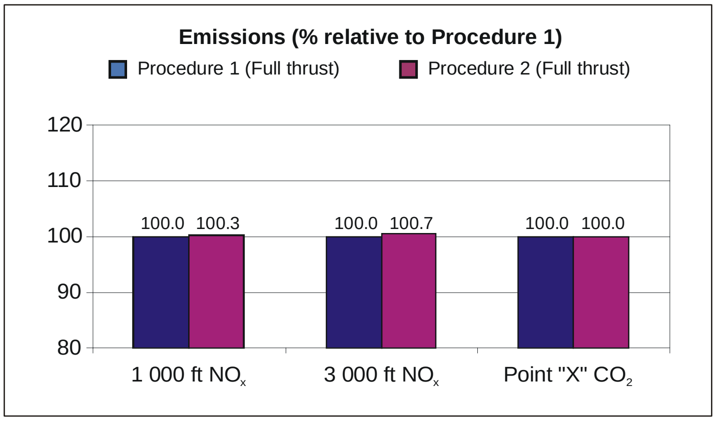
- Take-off in flaps 8 configuration
- Initial climb at V_2 + 10 KIAS
- Common climb schedule from 10 000 ft AGL to adjusted top of climb
- Adjusted top of climb: 35 000 ft AGL cruise altitude
- Thrust/weight cases:

  Full thrust:
  — TOGA
  — MTOW = 82 500 lb
  Reduced thrust:
  — 10 per cent reduced thrust
  — TOW = 74 034 lb

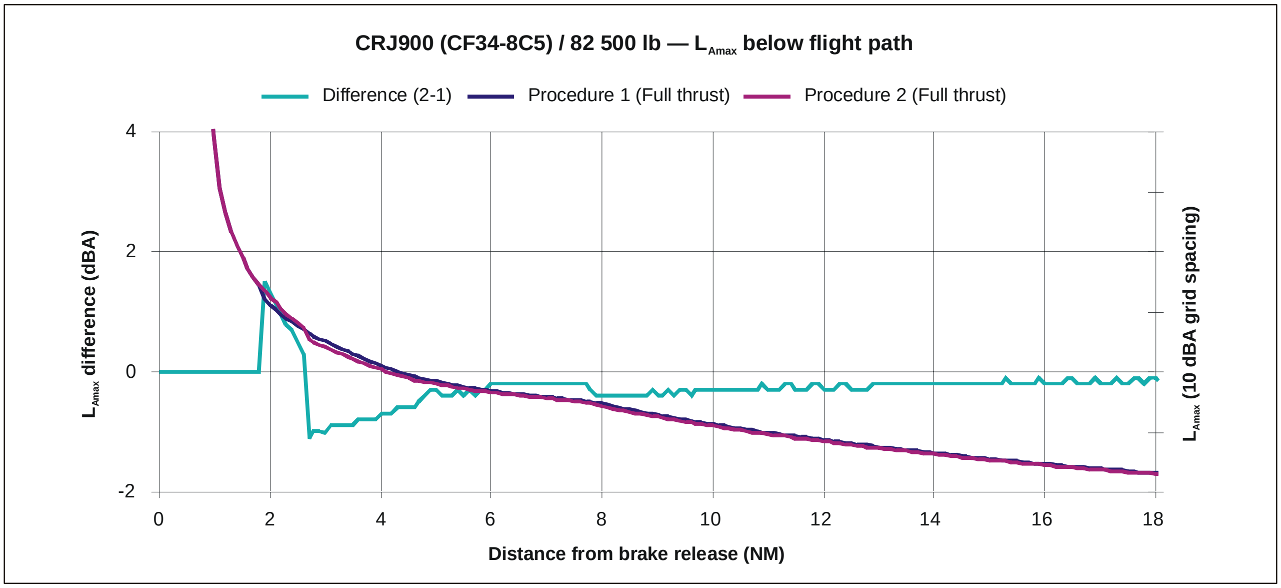
ATMOSPHERIC CONDITIONS

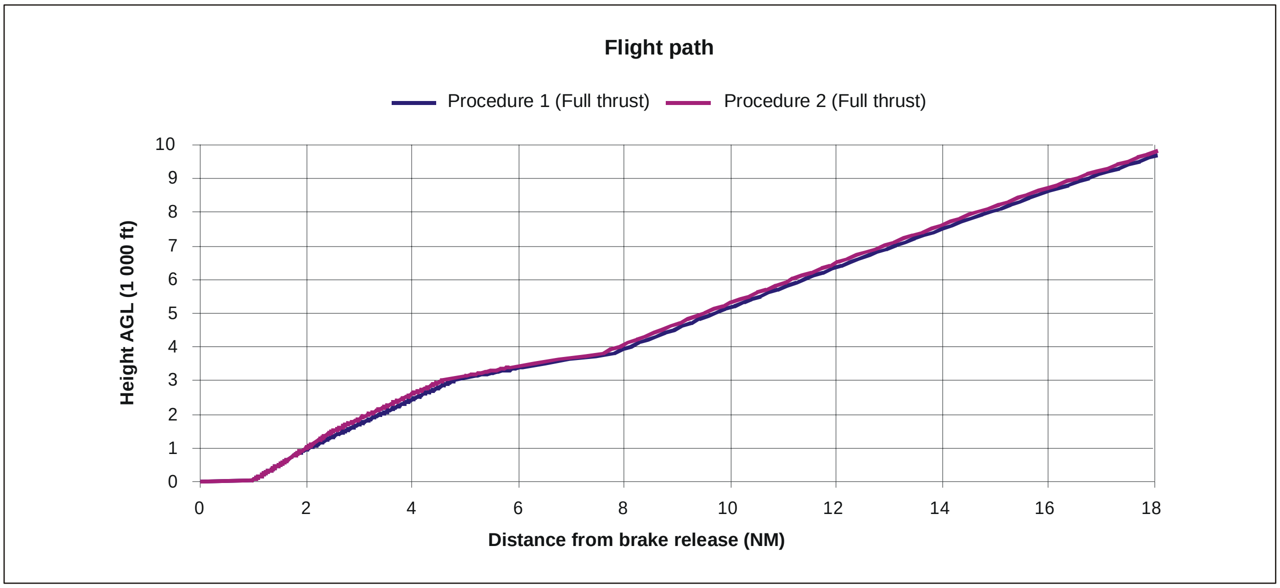
Temperature:	ISA
Relative humidity:	70 per cent
Wind:	Zero
Elevation:	Sea level

CRJ900ER, CF34-8C5
- **Full thrust**
  - **— TOGA**
  - **— MTOW = 82 500 lb**



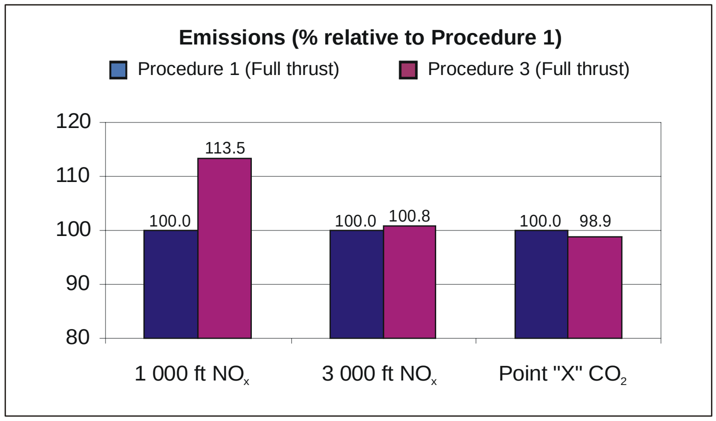
Comparison of Procedures 1 and 2



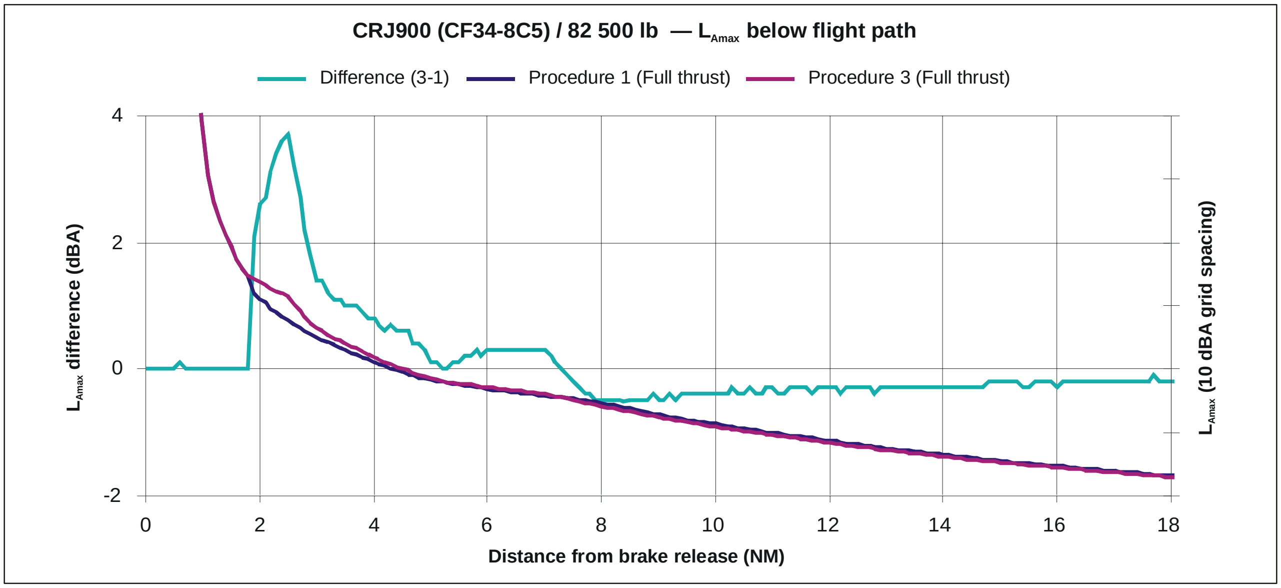


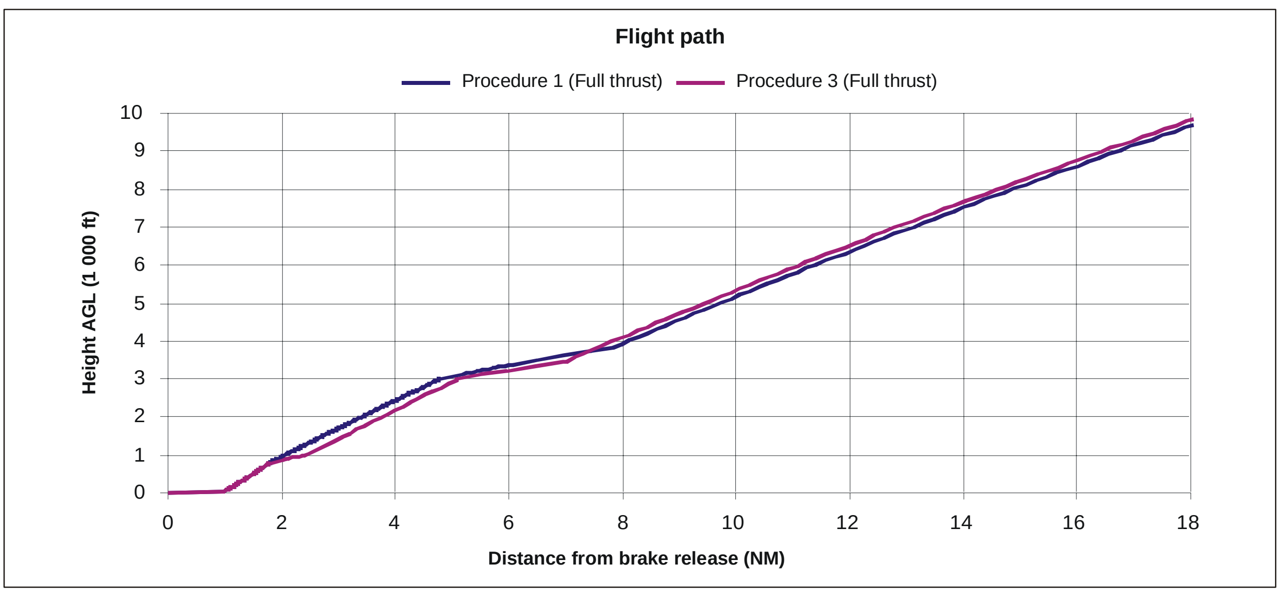
CRJ900ER, CF34-8C5

- **Full thrust**
  - **— TOGA**
  - **— MTOW = 82 500 lb**



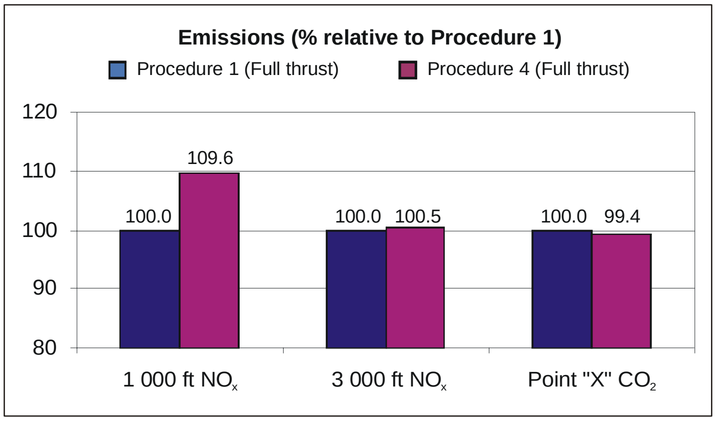
Comparison of Procedures 1 and 3



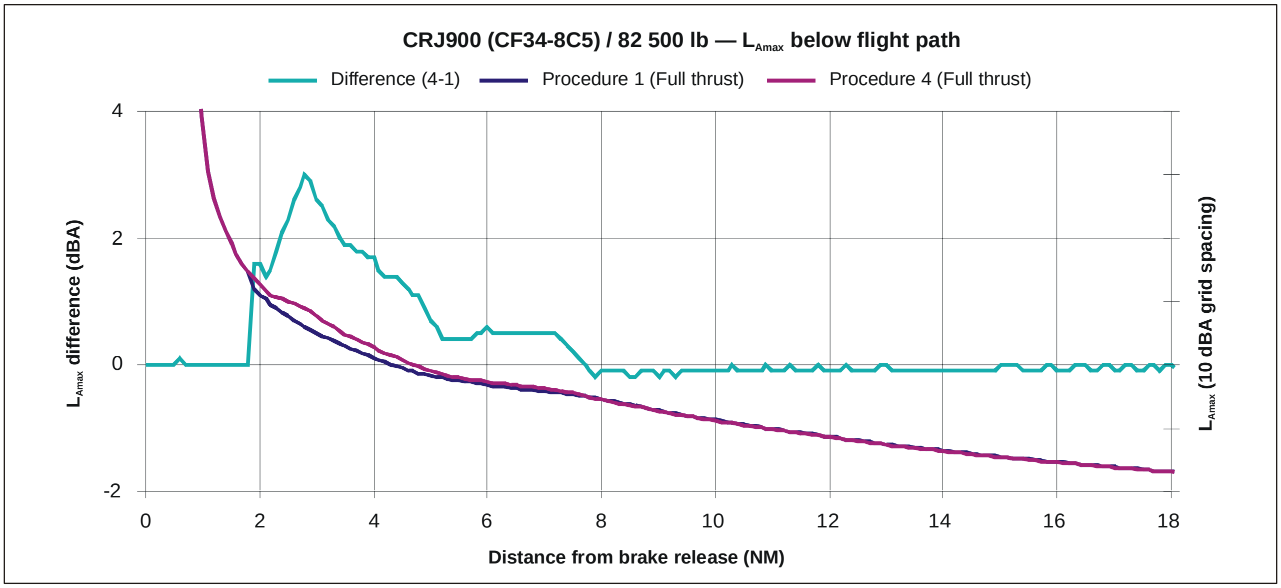


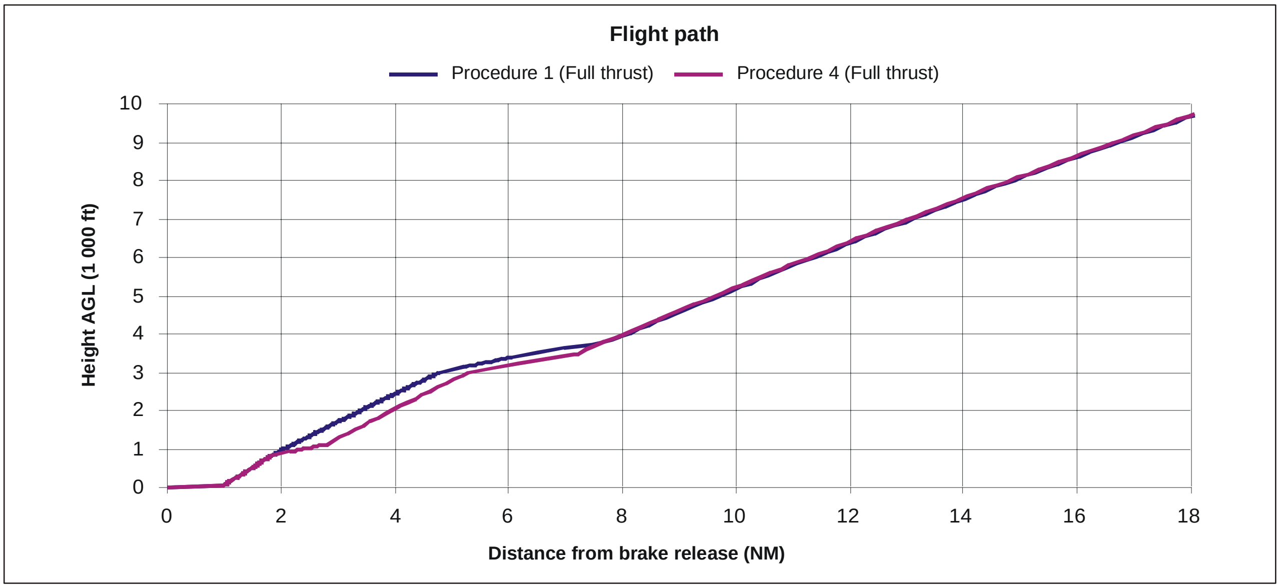
CRJ900ER, CF34-8C5

- **Full thrust**
  - — **TOGA**
  - — **MTOW = 82 500 lb**



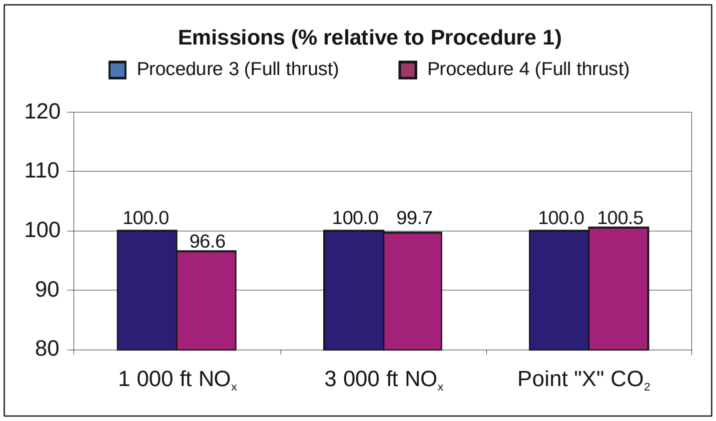
Comparison of Procedures 1 and 4



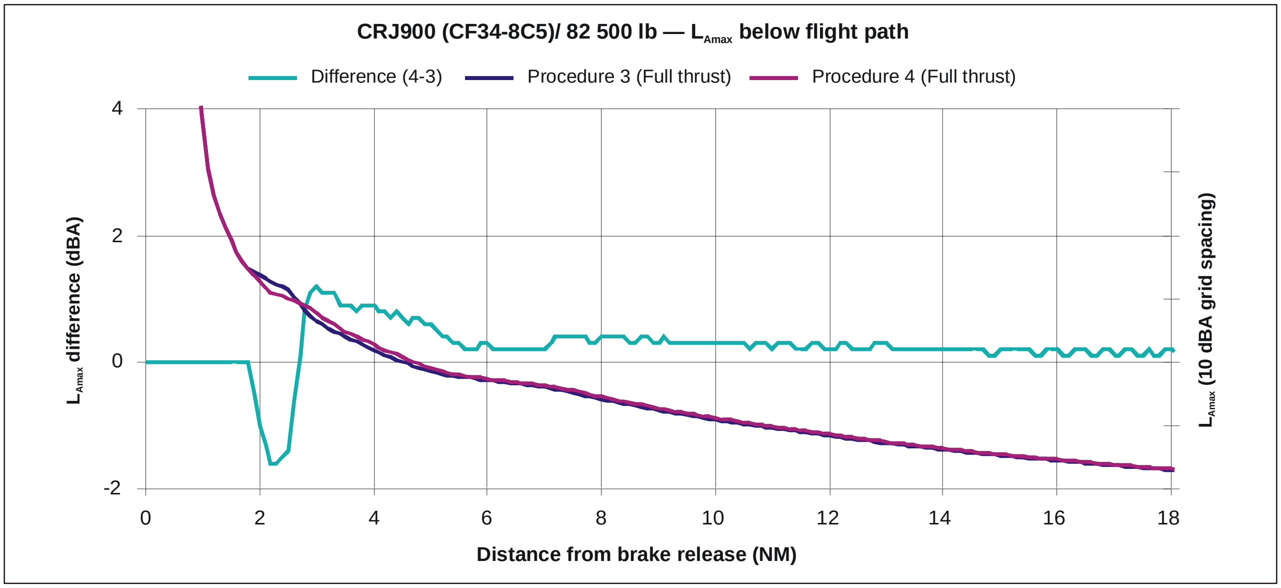


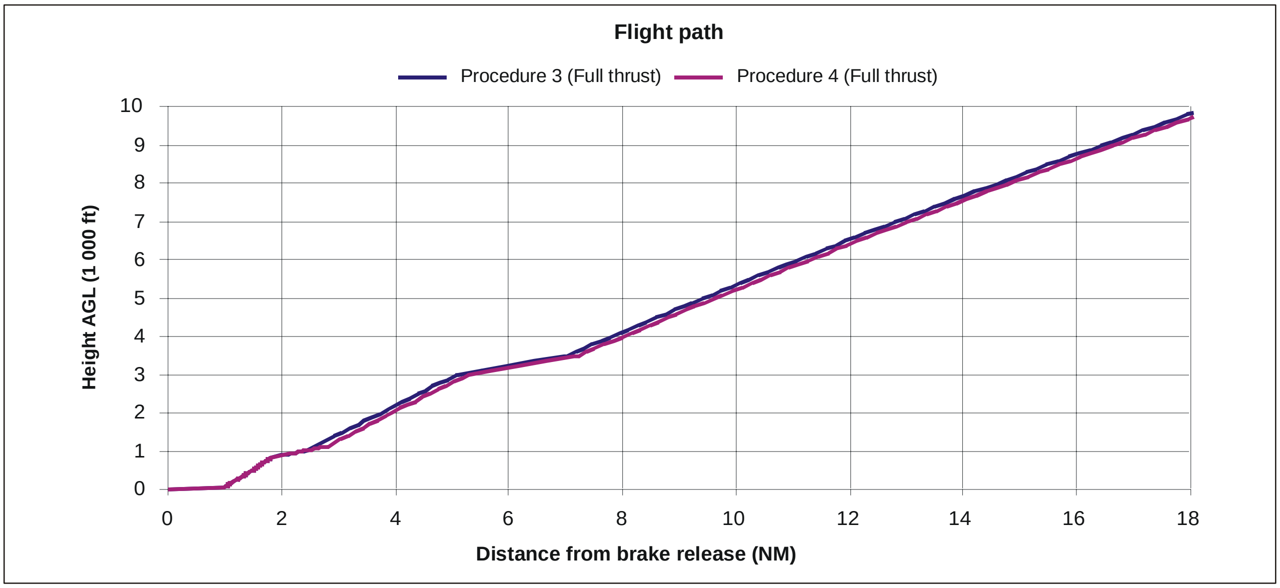
CRJ900ER, CF34-8C5

- **Full thrust**
  - — **TOGA**
  - — **MTOW = 82 500 lb**



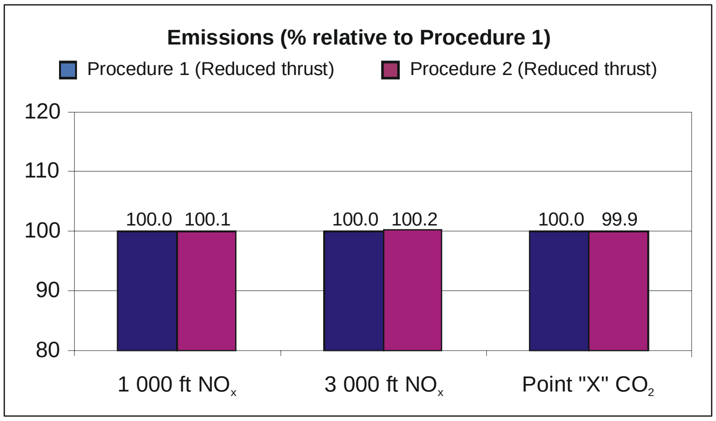
Comparison of Procedures 3 and 4



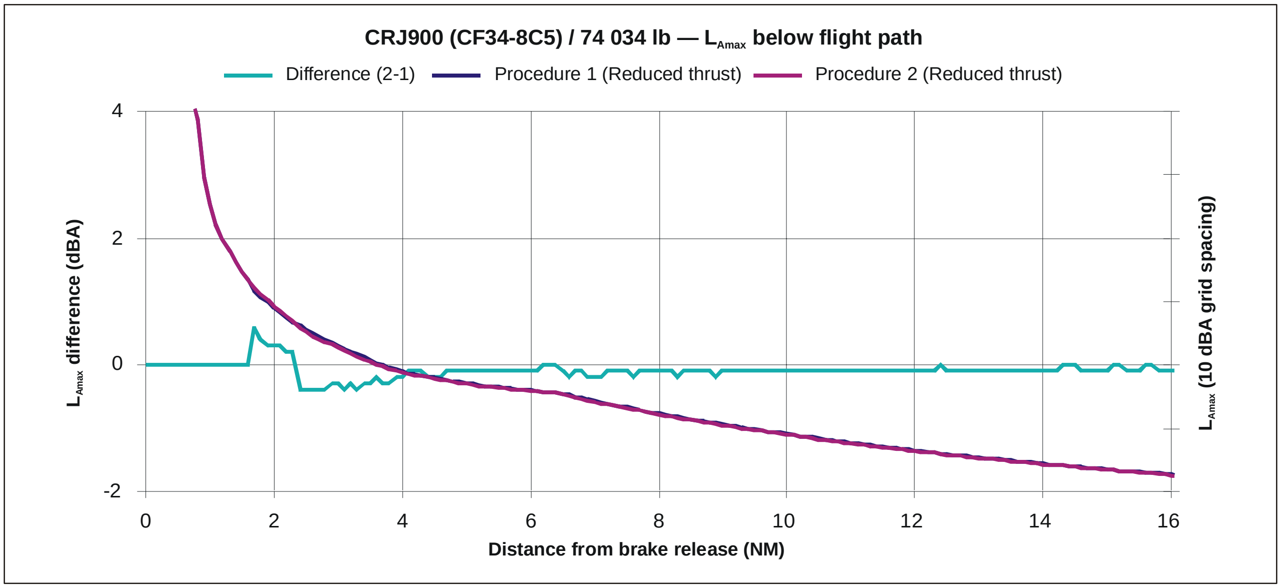


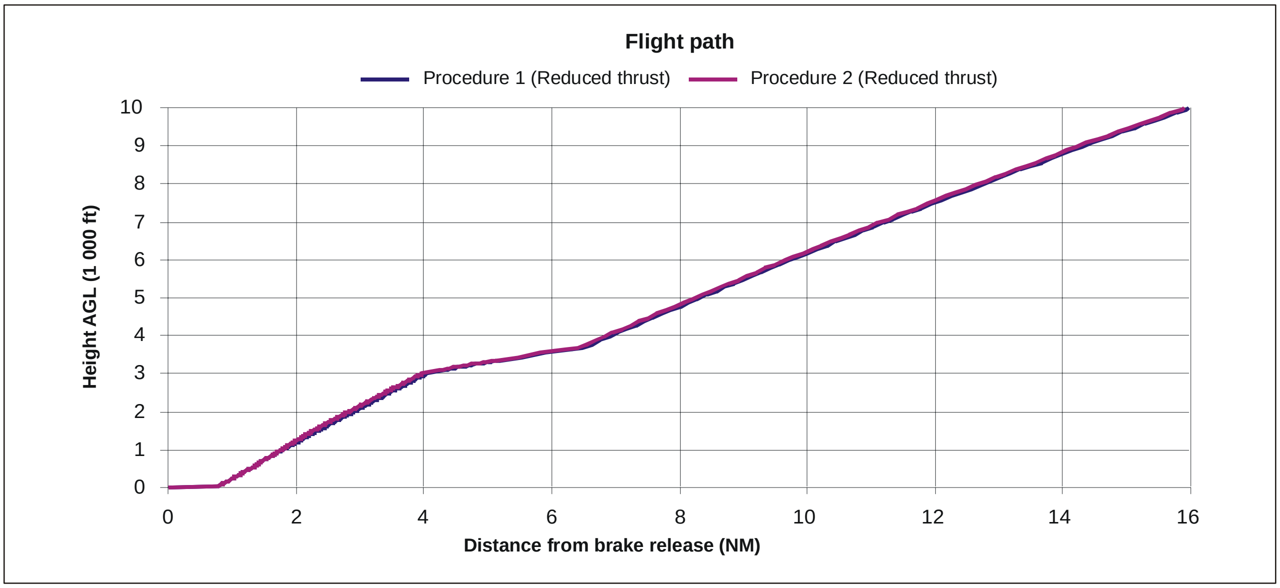
CRJ900ER, CF34-8C5

- **Reduced thrust**
  - — **10 per cent reduced thrust**
  - — **TOW = 74 034 lb**



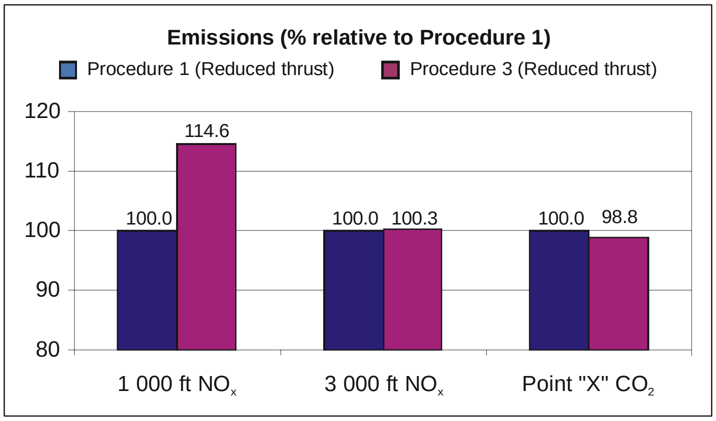
Comparison of Procedures 1 and 2



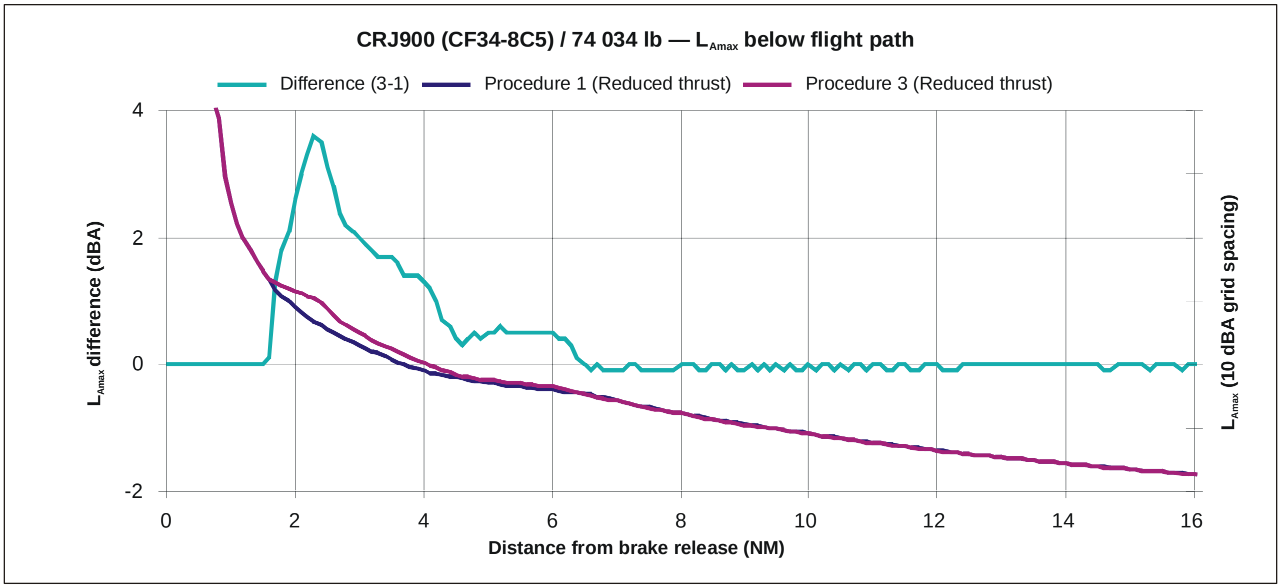


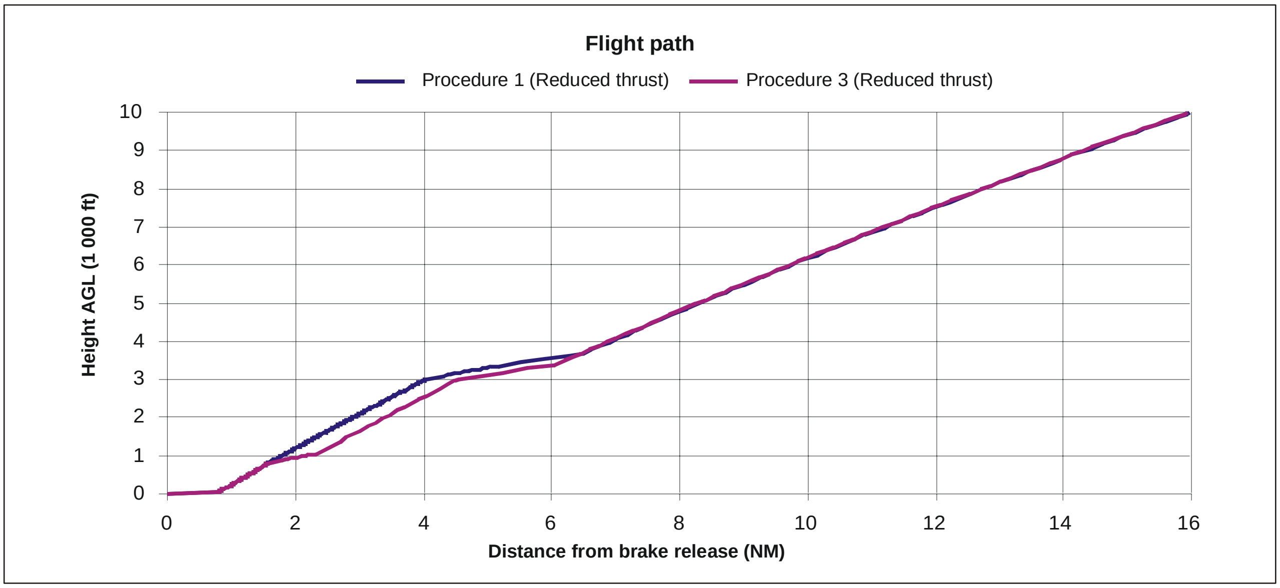
CRJ900ER, CF34-8C5

- **Reduced thrust**
  - — **10 per cent reduced thrust**
  - — **TOW = 74 034 lb**



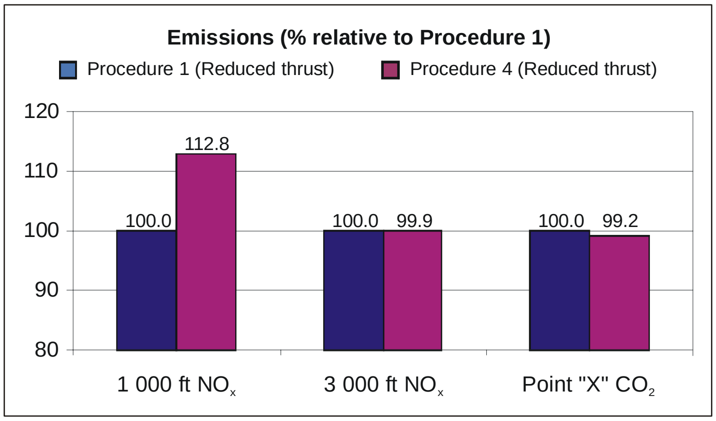
Comparison of Procedures 1 and 3



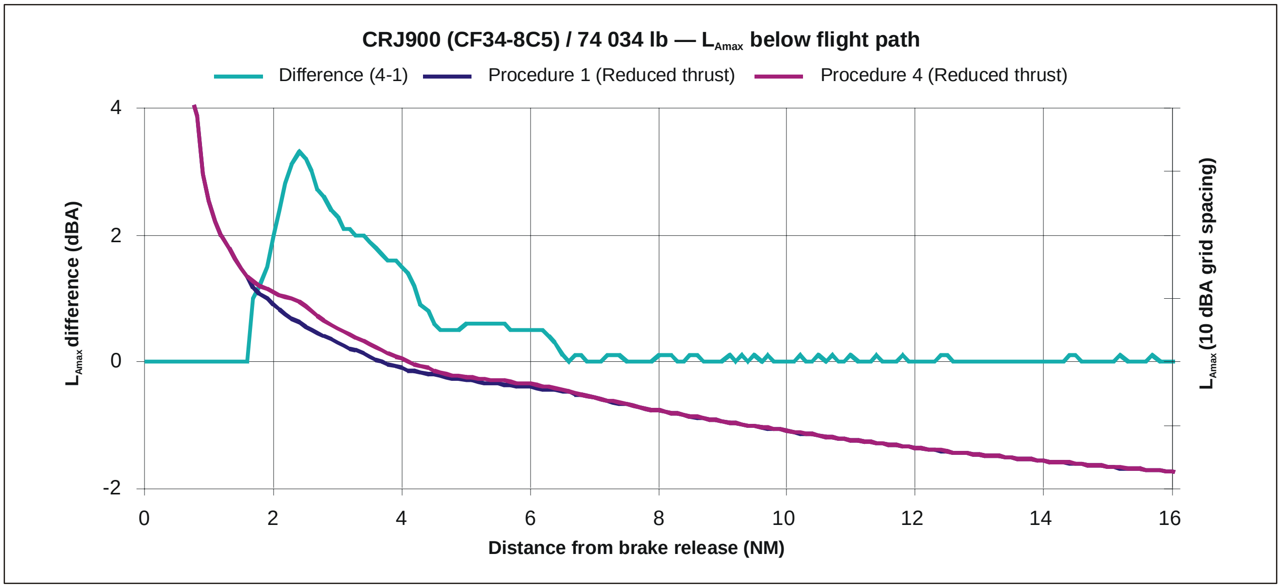


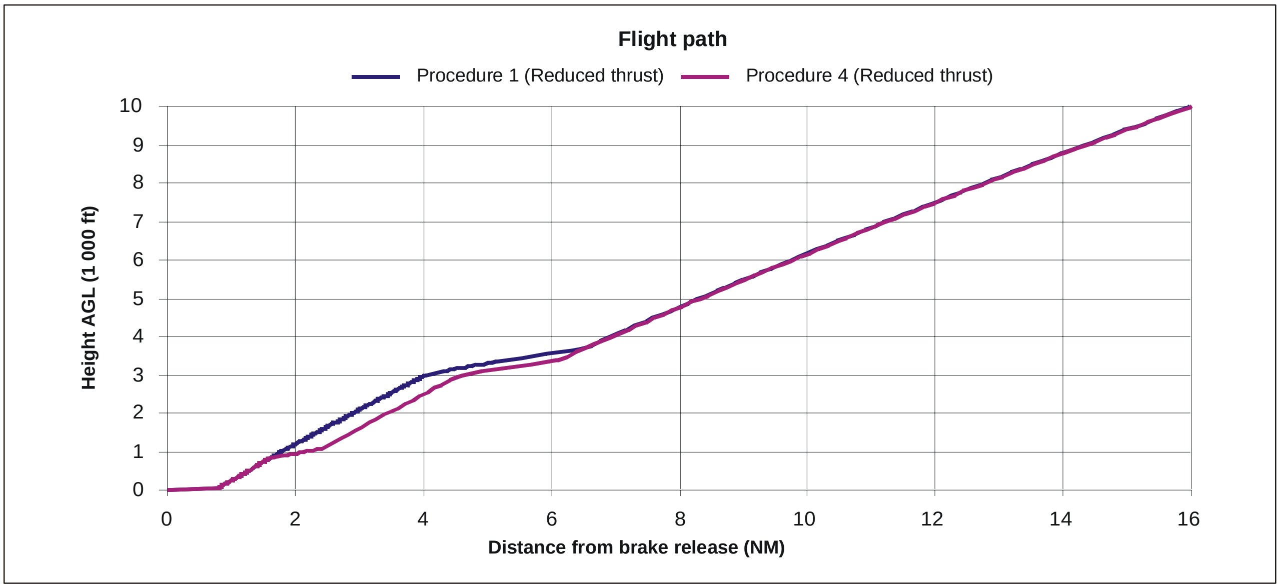
CRJ900ER, CF34-8C5

- **Reduced thrust**
  - **— 10 per cent reduced thrust**
  - **— TOW = 74 034 lb**



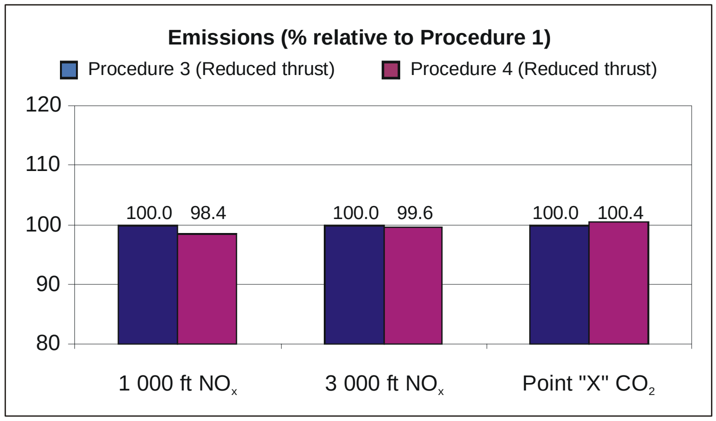
Comparison of Procedures 1 and 4



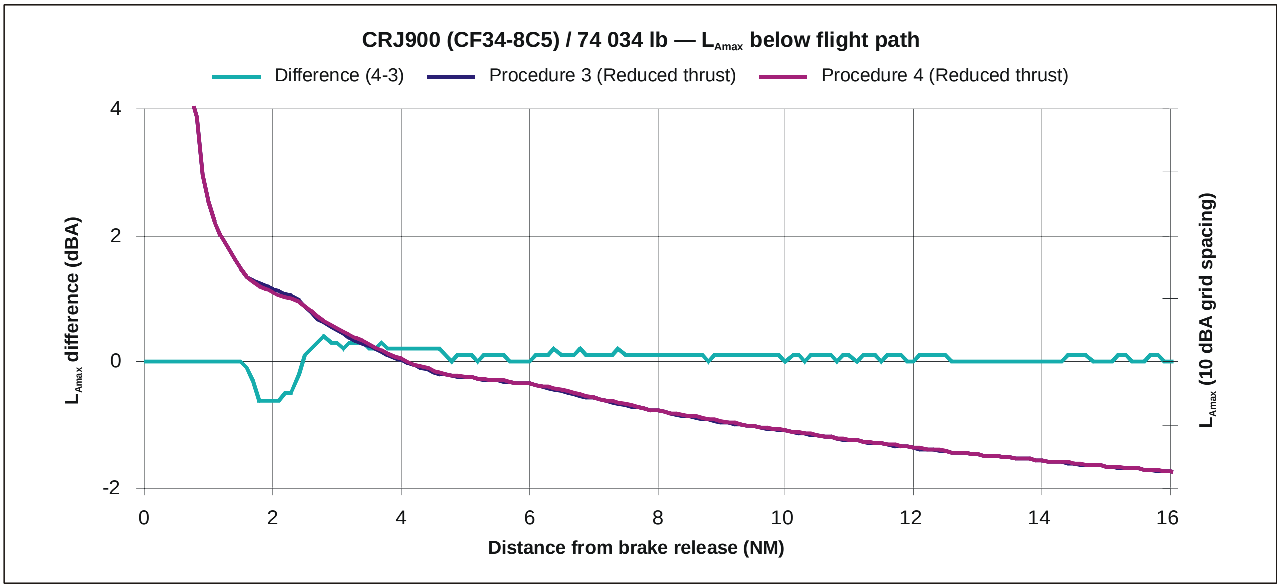


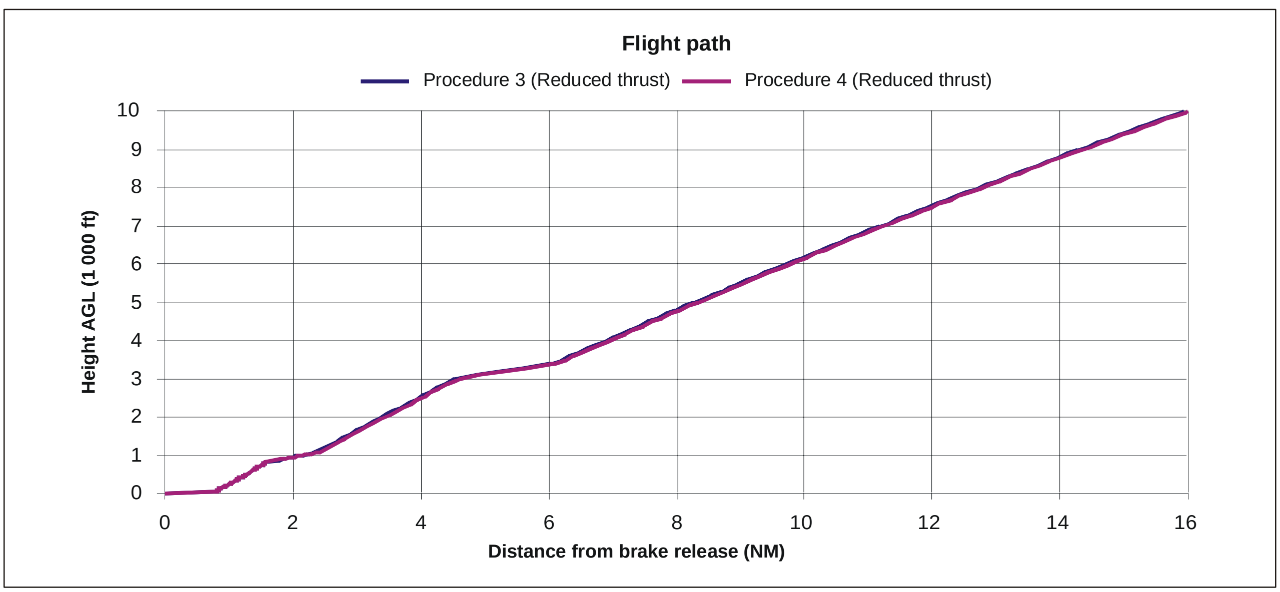
CRJ900ER, CF34-8C5

- **Reduced thrust**
  - **— 10 per cent reduced thrust**
  - **— TOW = 74 034 lb**



Comparison of Procedures 3 and 4





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Appendix D

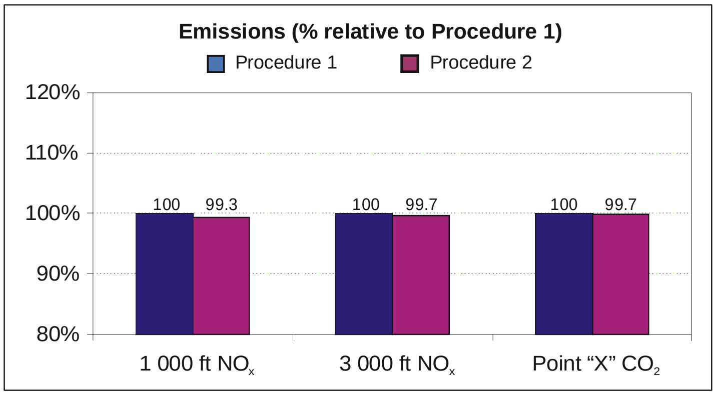
RESULTS — DASSAULT

AIRCRAFT STUDIED

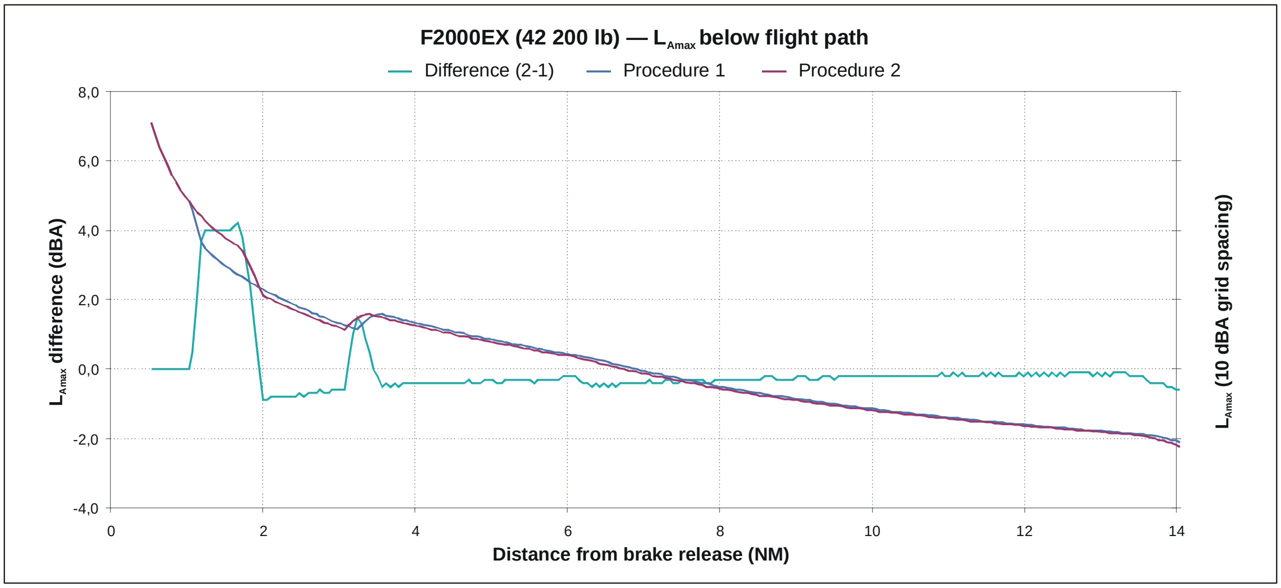
FALCON 2000EX, PW308C

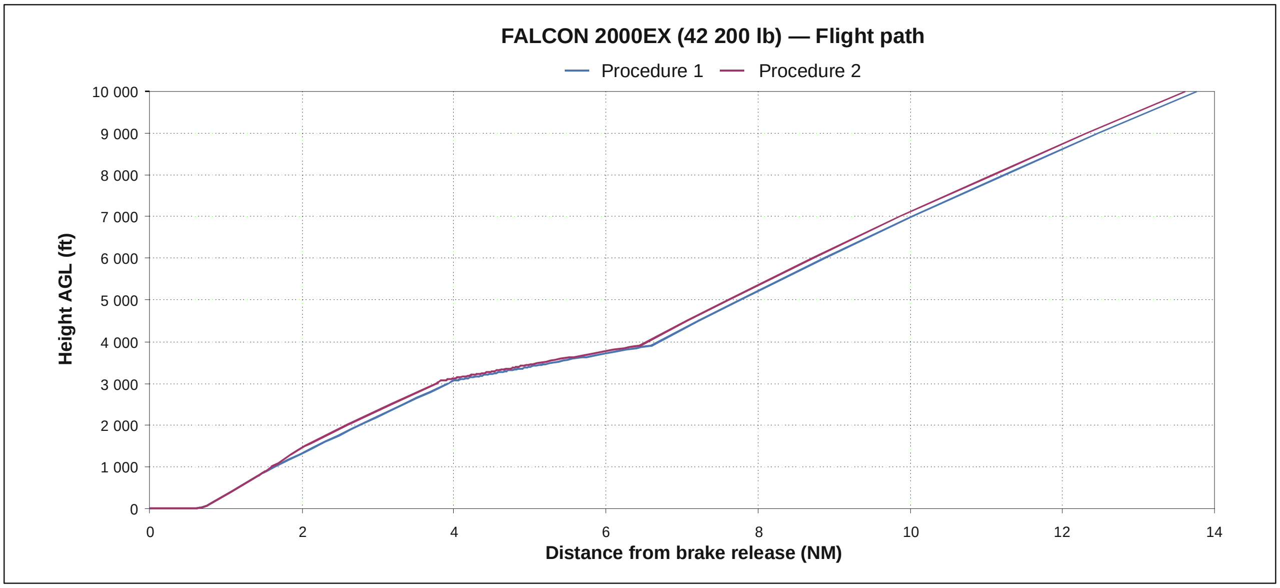
- Take-off in SF2
- Climb at V_2 + 15 kt IAS
- Full thrust (MTO)
- MTOW (42 200 lb)
- Cutback to MTO — 13 per cent

FALCON 2000EX, PW308C
- **Full thrust (MTO)**
  - **— TOW = 42 200 lb**



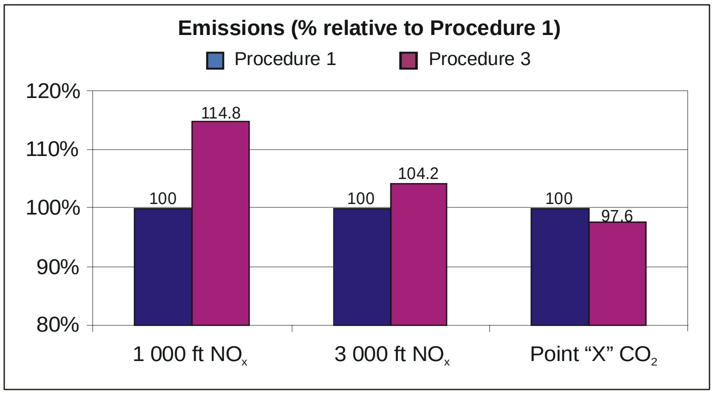
Comparison of Procedures 1 and 2



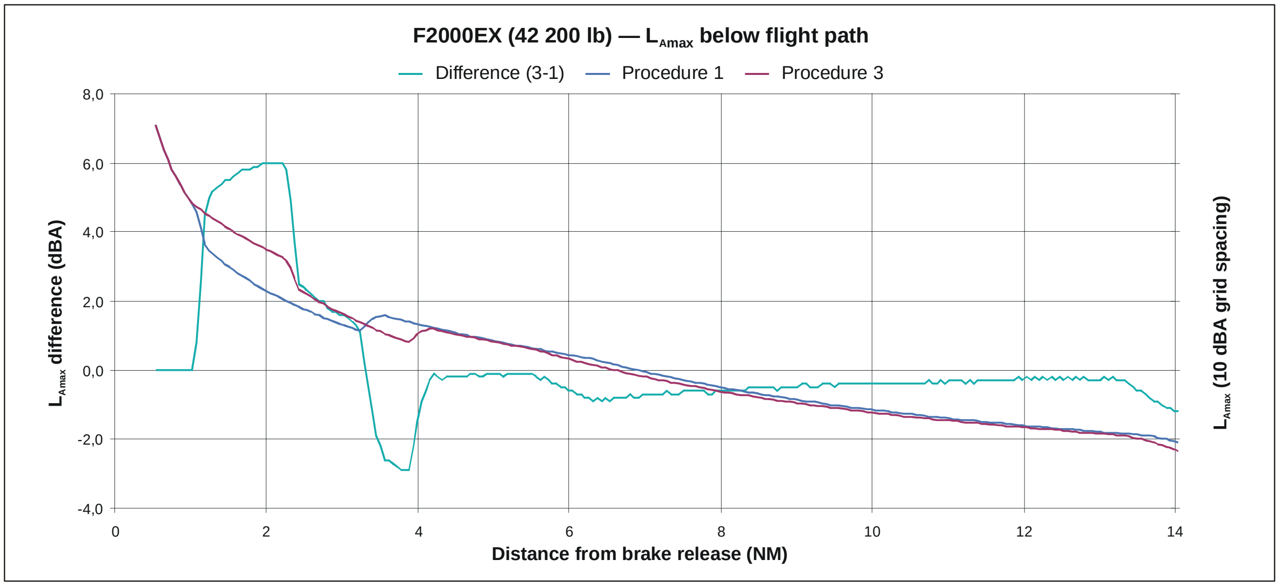


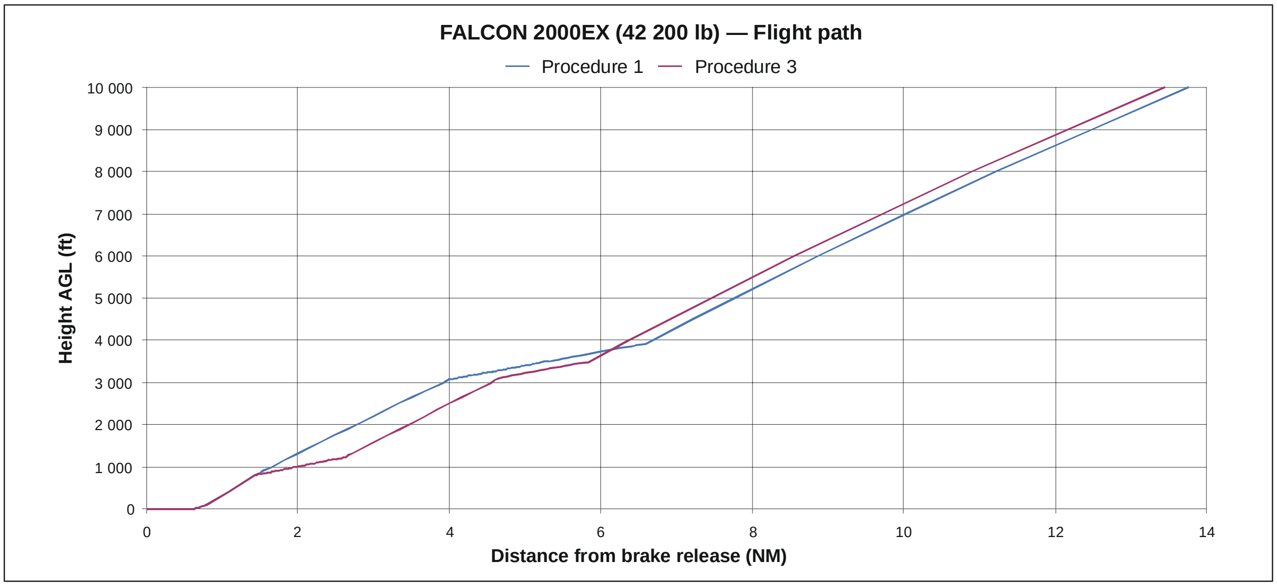
FALCON 2000EX, PW308C

- **Full thrust (MTO)**
  - **— TOW = 42 200 lb**



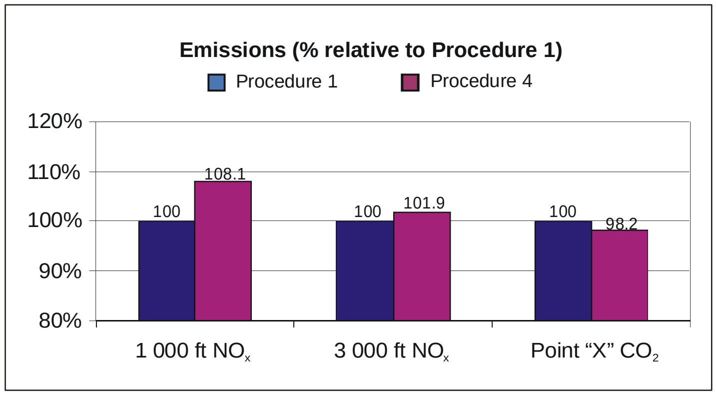
Comparison of Procedures 1 and 3



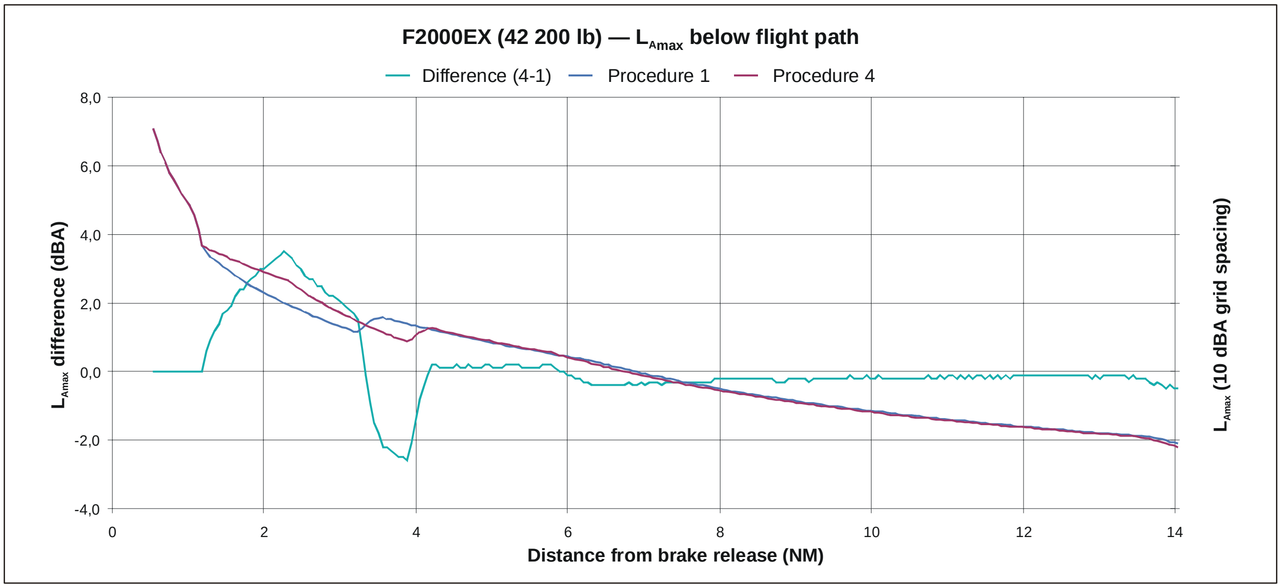


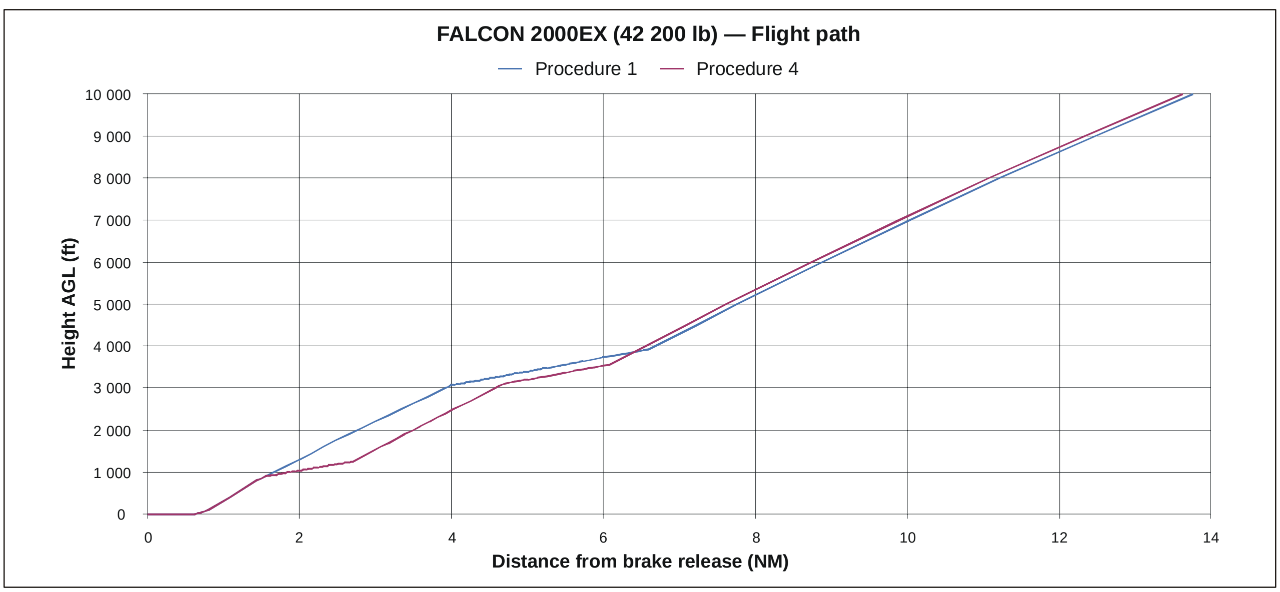
FALCON 2000EX, PW308C

- **Full thrust (MTO)**
  - **— TOW = 42 200 lb**



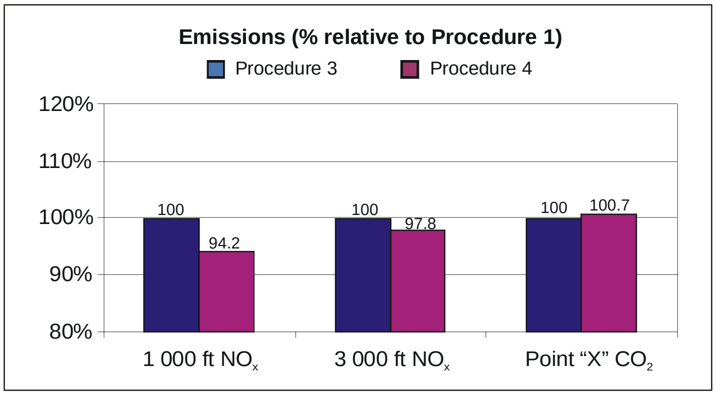
Comparison of Procedures 1 and 4



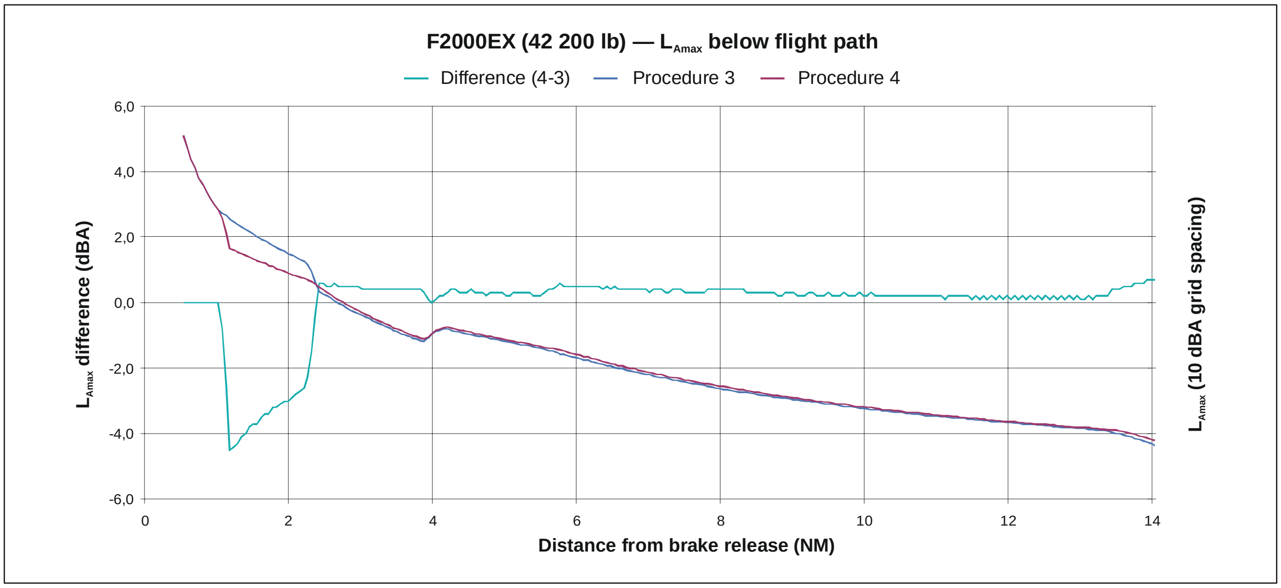


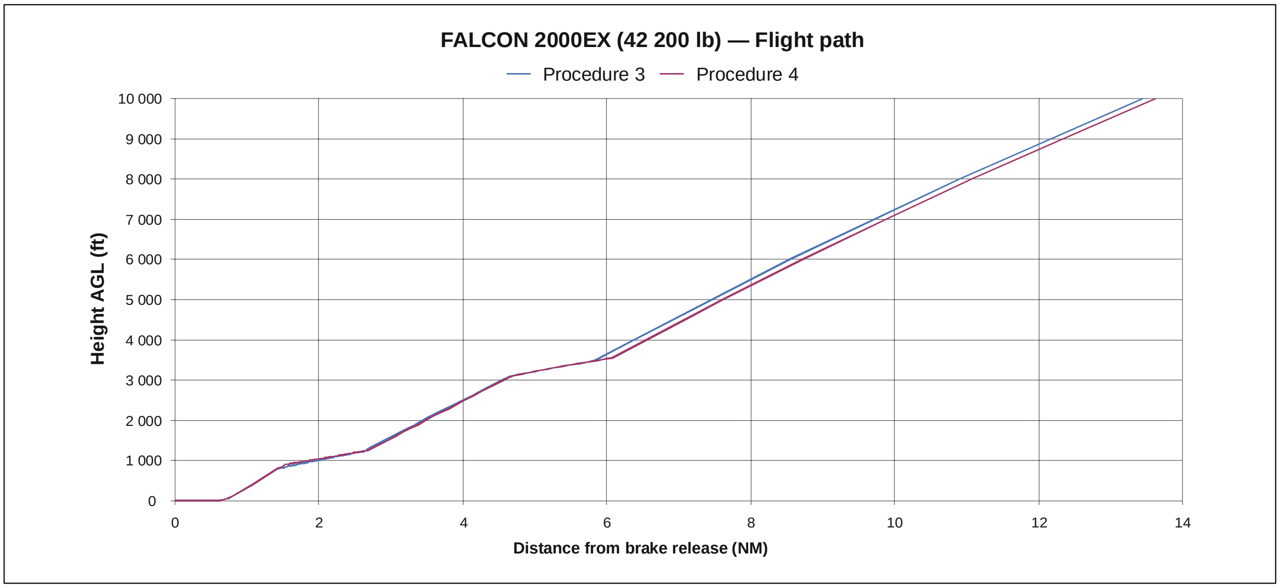
FALCON 2000EX, PW308C

- **Full thrust (MTO)**
  - **— TOW = 42 200 lb**



Comparison of Procedures 3 and 4





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