94-4000

Memorandum

RECEIVED
JUL 1 - 1994
ANM-180S
FAA SACO

U.S. Department of Transportation
Federal Aviation Administration

Subject: INFORMATION: Transmittal of Revised Document Transport Airplane Thrust Reverser System Review Criteria

Date: JUN 30 1994

From: Manager, Transport Airplane Directorate Aircraft Certification Office, ANM-100

Reply to Attn. of:

To: Manager, Small Airplane Directorate, ACE-100
Manager, Aircraft Engineering Division, AIR-100
Manager, Engine & Propeller Directorate, ANE-100
Manager, Rotocraft Directorate, ASW-100

The purpose of this memorandum is to transmit a copy of the revised document, "Criteria for Assessing Transport Turbojet Fleet Thrust Reverser System Safety," dated April 15, 1991, Revision A, dated June 1, 1994. The revised guidelines provided within this document were developed by the industry/FAA thrust reverser steering committee based on updated information gathered during review of airplanes during the fleet review activity. The revisions primarily concern the safety analysis criteria presented in Appendix C. The information contained within the revised document has been discussed with industry and is currently being used for the completion of ongoing fleet assessments. If questions arise concerning this subject the person in my staff most familiar with this issue is Mike Dostert, Airframe and Propulsion Branch, ANM-112, (206) 227-2132).

Darrell M Pederson
for Ron Wojnar

Enclosure

cc:
ANM-100L, ANM-100S, ANE-150, ANE-170, ACE-115A, ACE-115C, ACE-115W, ASW-150

ROUTE	NOTE	ACTION
ANM-100S		
ANM-101S		
ANM-103S		
ANM-120S		
ANM-130S		
ANM-140S		
ANM-150S		
ANM-190S		
FILE		

April 15, 1992
Revision A
June 1, 1994

Criteria for Assessing
Transport Turbojet Fleet
Thrust Reverser System Safety

1. Purpose:

This document provides guidelines for an evaluation of the thrust reversing systems on subsonic turbojet transport category airplanes that are operating in the current fleet. This evaluation is being performed under the authority of Section 609 of the Federal Aviation Act to determine if an unsafe condition exists requiring FAA Type Certificate action.

2. Scope:

This re-evaluation of Transport Airplane thrust reverser systems is being accomplished at the direction of the Manager of the Transport Airplane Directorate, Mr. Ron Wojnar. It is being conducted under the auspices of an AIA Steering Committee chaired by Mr. Ted Ralston of the Douglas Aircraft Company, with major airframe, engine, thrust reverser manufacturer and ATA representatives along with representatives from various regulatory authorities. Although the criteria set forth in this document appear to parallel Part 25 airworthiness standards, the fleet evaluation is a separate exercise to identify and correct any unsafe thrust reverser designs and the criteria herein differ from the airworthiness standards of Part 25.

The criteria adopted for the fleet evaluation are based on the premise that no failures of the thrust reverser system components anticipated to occur in service should prevent continued safe flight and landing. For the purpose of this evaluation, the thrust reverser system will be acceptable if either of the following criteria can be satisfied:

1) The airplane type is shown to be controllable in the event of an inadvertent deployment under the provisions of Appendix B of this document, or,

2) The catastrophic inadvertent deployment event is shown to be extremely improbable under the provisions of Appendix C of this document.

The parameters and criteria presented herein are meant to be used for this fleet assessment program and are not intended to be applicable to new type certificate compliance demonstrations.

3. Background:

During previous certification programs the FAA may not have fully considered the effects of in-flight thrust reverser deployment on aircraft controllability. Some thrust reverser systems have not been considered as critical systems and have not been designed as critical systems. Service history shows approximately 200 in-flight thrust reverser deployment incidents have occurred on transport category airplanes. Four accidents are believed to have been related to inadvertent inflight thrust reverser deployment. Two of these are believed to have been caused by erroneous pilot action. One was due to improper dispatch of the airplane with indication that the thrust reversers were unlocked. A recent in-flight thrust reverser deployment at relatively high airspeed and engine power is thought to be a major contributor to an air carrier accident.

Investigation of this last accident has resulted in a new awareness of the potential aerodynamic effects of a thrust reverser deployment on airplane controllability. This fleet safety assessment is being imposed to ensure that airplanes can either be shown to provide continued safe operation following an inadvertent deployment of a thrust reverser or are designed to preclude such a deployment.

Airplane designs differ in the number, size and location of engines (wing, fuselage or tail-mounted), use of automatic thrust reduction systems, engine rating and deceleration schedules, design and location of critical aerodynamic surfaces with respect to the engine, and the efflux patterns of thrust reverser airflow. These parameters typically determine the system criticality with respect to airplane controllability after a malfunction.

This fleet safety assessment is being imposed based on new awareness of the potential effects of a thrust reverser deployment on airplane controllability. Airplanes that do not provide continued safe operation following an inadvertent deployment of a thrust reverser must be designed to assure that the thrust reverser system meets the criteria of Appendix C of this document.

4. Definitions:

For the purposes of this document, the following definitions apply:

(a) Thrust Reverser System: Those components which spoil or redirect the engine exhaust flow to decelerate the airplane. The components include the engine mounted hardware, the reverser control system, indication and actuation systems and any other airplane systems that have an effect on the thrust reverser operation.

(b) Deployment: A movement of all or part of the thrust reverser from the stowed position to a position which spoils or redirects the engine airflow.

5. Re-evaluation Criteria:

The following airplane models are to be re-evaluated to assess the safety aspects of the thrust reverser system:

BOEING	DOUGLAS	AIRBUS	LOCKHEED	OTHERS
B707/720	DC8	A300	L1011	G-II,III,IV
B727	DC10	A310	Jetstar	Learjet
B737	MD11	A320	Sabreliner	Beech 400
B747	DC9			Cessna Citation
B757	MD80			BAC 1-11
B767				IAI Astra/Westwind
				Falcon
				Hawker Siddeley 125
				Canadair Challenger
				Fokker 100

Note: Modifications to the above aircraft certificated by Supplemental Type Certificate are also to be included in the current evaluation.

The following process should be used in evaluating each airplane model:

Step 1 -

(a) A listing of all previous in-flight thrust reverser deployment incidents (all causes including pilot error) and related in-service problems with the system is to be provided by the manufacturer to the FAA. Fleetwide data is shown in Appendix A for reference.

(b) An appropriate **qualitative** safety analysis is to be prepared to show that no single failure in the thrust reverser system can result in a hazardous reverser deployment. Review of the incident data will provide an understanding of the types of factors that should be considered when reviewing the assumptions used by the manufacturer.

(c) Each thrust reverser system will then be evaluated to assure that the cause of previous reverser incidents has been addressed and appropriate actions have been taken to preclude future deployments. This evaluation should include a review of all relevant Service Bulletins (including fleet incorporation status). These data are to be used in evaluating controllability, reliability, maintainability and other operational aspects of the reverser system.

Step 2 - The airplane manufacturer will propose one of the following categorizations and perform the related evaluation for each model airplane:

Category I: Airplanes for which controllability is not or cannot be demonstrated per Appendix

B shall be considered Category I. For aircraft in this category the following shall apply:

(a) Safety analyses to determine the adequacy of the system safeguards , indications, flight crew and maintenance procedures, must be performed per Appendix C.

Category II: Airplanes for which controllability can be demonstrated per Appendix B shall be considered Category II. For aircraft in this category the following shall apply:

(a) Documented in service deployment data may be used to establish controllability. Extrapolation of in-service data will be assessed on an individual basis. However, many airplane configurations do not have sufficient in-service thrust reverser deployment data to establish controllability.

(b) Safety analyses to determine the adequacy of the system safeguards , indications, flight crew and maintenance procedures, must be performed per Appendix C.

Step 3 - The applicant will review the results of Steps 1 and 2 with the FAA and the FAA will determine the need for subsequent action.

APPENDIX A

UNWANTED THRUST REVERSER DEPLOYMENT INCIDENT HISTORY

A The purpose of this appendix is to provide a listing of previous in flight thrust reverser deployment incidents.

A.1 Each thrust reverser system should be evaluated to assure that the cause of previous reverser incidents has been addressed and appropriate actions have been taken to preclude future deployments. This evaluation should include a review the all relevant Service Bulletins (including fleet incorporation status). A listing of previous thrust reverser deployments incidents which occurred on various airplane models is required. Review of these incidents will provide an understanding of the types of factors that should be considered when reviewing the assumptions used by the manufacturer in preparing the FMEA. One should note that maintenance errors play a significant roll in many of the deployment incidents.

A.2 SUMMARY CHART OF UNWANTED INFLIGHT THRUST REVERSER DEPLOYMENT CAUSES, TRANSPORT AIRPLANES, ALL MODELS, THRU APRIL 15, 1992.

CAUSE	ACCIDENTS	DEPLOYMENTS	Percent of Total
Pilot Error	2	9	7
(Improper dispatch)	1		
Maintenance Error		28	20
Component Failure	1	75	55
Unknown		25	18
TOTAL	4	137	100

Note: 1) This summary does not include the DC-10 and B747 turbine reverser deployments.
2) There were 138 reverser deployments, some with multiple causes, which resulted in the total of 142 shown above.

A.2 Individaul Airplane Model Service History
(Page 1 of 2)

THRUST REVERSER INFLIGHT DEPLOYMENT INCIDENT HISTORY
(SUMMARY DATA)
THROUGH SEPTEMBER 30, 1991

A/C MFG	A/C TYPE	NO. ENG.	NO. BUILT	FLT HOURS	NO. DEPLOY.*	CAUSE				NO. ACCDNT
						COMM'D	MAINT	FAILURE	UNKWN	
Airbus	A300/A310	2	518	9,110,702	0	0	0	0	0	0
	A320	2	209	511,552	0	0	0	0	0	0
Boeing	707/720	4	1006	41,800,000	29	0	4	20	5	0
	727	3	1832	79,400,000	26	2	2	12	10	0
	737-100,-200	2	1144	45,800,000	5	1	2	0	2	0
	737-300,-400,-500	2	981	12,200,000	1	1	0	0	0	0
	747 (Fan)	4	875	33,100,000	25	0	11	10	4	0
	(Turbine)	4			80	0	8	44	28	0
	757	2	392	3,100,000	0	0	0	0	0	0
	767	2	392	4,200,000	2	0	1	1	0	1
Douglas	DC8-20,-30,-40,-50,-6	4	446	27,200,000	8	1	0	7	0	1
	DC8-70	4	110	1,860,000	2	0	1	1	1	0
	DC9	2	976	44,000,000	18	2	2	13	1	1
	MD80	2	943	11,000,000	0	0	0	0	0	0
	DC-10/KC-10	3	446	19,000,000	7	1	2	4	0	0
	MD-11	3	24	32,000	0	0	0	0	0	0
Lockheed	Jetstar I, II, 731	4	202	1,458,000	4	0	1	1	2	0
	L-1011-1, -3	3	249	9,340,000	1	0	1	1	0	0

* The number of deployments may be less than the total number of causes due to multiple cause events.

A.2 Individual Airplane Model Service History
(Page 2 of 2)

THRUST REVERSER INFLIGHT DEPLOYMENT INCIDENT HISTORY
(SUMMARY DATA)
THROUGH SEPTEMBER 30, 1991

A/C MFG	A/C TYPE	NO. ENG.	NO. BUILT	FLT HOURS	NO. DEPLOY.*	CAUSE COMM'D	MAINT	FAILURE	UNKWN	NO. ACCDNT
British Aerospace (BAe)	125-700	2	32	109,000	1	0	1	0	0	0
	125-800	2	55	186,000	0	0	0	0	0	0
	BAC1-11	2	243	7,802,820	1	0	1	0	0	0
Dassault	FJF (Fanjet Falcon)	2	476	3,700,000	4	1	0	2	1	0
	F10 (Falcon)	2	226	1,050,000	1	0	0	1	0	0
Fokker	F-100	2	140	250,000	0	0	0	0	0	0
Gulfstream	GII, IIB	2	256	1,948,649	1	1	0	1	0	0
	GIII	2	202	689,898	0	0	0	0	0	0
	GIV	2	152	159,193	0	0	0	0	0	0
Canadair	CL-600	2	81	258,238	1	0	0	1	0	0
	CL-601	2	151	259,898	0	0	0	0	0	0
Cessna	Citation	2		6,300,000	1	0	1	1	0	1
Lear	Learjet 24-36	2	426	1,861,500	0	0	0	0	0	0
	Learjet 55	2	126	371,700	0	0	0	0	0	0

* The number of deployments may be less than the total number of causes due to multiple cause events.

APPENDIX B

DEMONSTRATION OF SAFE AIRPLANE FLIGHT WITH AN INADVERTENT REVERSER DEPLOYMENT

B1. Evaluation Methods:

The basis for evaluation of airplane handling qualities during and after an in-flight thrust reverser deployment will be proposed by the manufacturer. A task oriented pilot rating approach, based on the FAA Handling Qualities Rating Method (HQRM), and/or methods based on the Cooper-Harper and MIL-STD rating levels is suggested. This task oriented methodology has been applied in various special condition forms to the Airbus A320 and McDonnell-Douglas MD-11, and is similarly part of the certification basis for the Airbus A330/A340 and Boeing 777. (Advisory material on the HQRM is available from the FAA.)

Pilot conclusions would be expressed in the descriptive categories of SATISFACTORY (SAT), ADEQUATE (ADQ), AND CONTROLLABLE (CON) (Ref Figure 3A). For reference the Cooper-Harper rating scale is provided in Figure 1. The acceptable range from SAT to ADQ recognizes the range of situations which an airplane fleet will experience over its operational life, and, to a large extent, addresses variability in pilot opinion regarding airplane controllability for specific flight conditions. For inadvertent reverser deployment cases, ratings for steady-state and/or long term flight conditions must be at least ADQ, while transient conditions resulting from deployment may be rated as CON.

Consideration must also be given to the performance degradation associated with continued flight with a reverser deployed. The aircraft must be shown to have sufficient *climb* performance following a deployment at some point during the takeoff path to be able to safely return for a landing. This determination involves consideration of the reliability up to this point and the climb capability with the reverser deployed. For example, if a rigorous safety analysis shows an inflight deployment up to approximately 1500 feet AGL is extremely improbable, then no further *climb* performance substantiation is required. Lacking this analysis, a performance analysis addressing height of deployment, resulting climb capability and effect on the net flight path is required. *Furthermore, if inflight reverser deployment anywhere along the Operational Flight Profile would be limiting on the critical fuel scenario or other route restrictions, this must be taken into account to assure continued safe flight and landing at a suitable airport.*

For the purposes of this fleet assessment, tasks will be assessed: (1) along an Operational Flight Profile defined uniquely for each airplane evaluated for the deployment transient maneuver, and (2) for continued safe flight and landing per the manufacturer's recommended procedures contained in the AFM. The Operational Flight Profile is illustrated in Figure 5, and described in Appendix B-I.

Substantiation of controllability and performance necessary for continued safe flight and landing on older airplanes may be based on a combination of inspection of available safety analyses, climb capability with reverser deployed, in-service data, comparison to similar configuration aircraft, in-flight restow capability and other pertinent data.

B2. Flight Envelopes:

The concept of flight envelopes aid in (1) establishing bounds and probability for tasks and (2) establishing variability of HQ expectations. Three envelopes are appropriate to be used in the controllability verification. They are:

* Normal Flight Envelope (NFE): Generally associated with practical, routine operation and/or prescribed conditions, whether all-engine or engine inoperative.

* Operational Flight Envelope (OFE): Generally associated with warning onset (i.e. Stall Warning, Overspeed Warning, etc.); outside the NFE.

* Limit Flight Envelope (LFE): Generally associated with airplane design limits or Electronic Flight Control System limits.

  NOTE: The manufacturer's recommended procedures may be bounded by an envelope smaller that Normal Flight Envelope (NFE).

B3. Tasks:

Piloting tasks to be evaluated consist of:

(1) Transient Maneuver:

* Recovery from the inadvertent deployment transient,

(2) Continued Safe Flight and Landing:

* Maneuvering Appropriate to the Recommended Procedure, (including trim and unattended operation).

* Precision Tracking (e.g., ILS glide slope tracking, and speed/altitude tracking).

B3.1. Task (1) - **Transient Maneuver:**

The critical task for most airplanes will be demonstrating the ability to recover from the upset caused by an inadvertent thrust reverser deployment, and the resulting large changes in attitude and flight path. Reaction times will be the same as allowed for autopilot hardovers, that is, one second (after recognition) for the initial climb and landing cases, and three seconds (after recognition) in other cases where it may reasonably be expected that the autopilot would be engaged and the crew be at a lower state of vigilance. For cases immediately after takeoff, or immediately prior to landing, where the pilot is expected to be at a high state of vigilance, and actively controlling the flight path, it will be acceptable to react immediately after recognition of the failure. For cases where time delays are applied, the time will be based on the first recognition of the abnormality, for example, an annunciation in the cockpit, or unexpected aircraft motion.

Pilot assessment of airplane characteristics during, and following an inadvertent deployment should result in ratings of not less than CONTROLLABLE during the deployment transient. In interpreting the acceptability of the CONTROLLABLE finding, a supplementary Cooper-Harper evaluation with no rating worse than 9 for the task of controlling the transient.

B3.2 Task (2) - Continued Safe Flight and Landing:

This task may be considered to have *three* subparts:

(a) verifying that the manufacturer's recommended procedure is acceptable, and

(b) verifying that the airplane's handling qualities are rated ADEQUATE for the recommended procedure. Consistent with certification practice, small excursions from the recommended procedure should be made to ensure a safety margin exists.

(c) verifying that any route limitations such as critical fuel reserves and level flight altitude capability are identified and accommodated.

This task is envisioned to be essentially the same as has been done on past certification programs with more emphasis paid to extended flight duration, and flight in the higher altitude cruise regime.

B4. Failure Conditions:

Failures or system losses to be considered are only those *anticipated to be present during a* thrust reverser *inflight deployment incident*, but the most critical engine location should be established and examined. *Any* related MEL dispatch deviations *must* be considered.

B5. Compliance Methods:

Compliance may be shown by analysis, test, simulation, or a combination there of. Simulator validity must be established. Known aspects of simulation fidelity include critical model assumptions, general faithfulness, simulator processing time limits, motion cues, non-linearities, buffet areas, projection of reverser disturbance into lateral-directional axes, etc. The manufacturer should document a systematic program of analyses, and modeling methods (such as parameter identification techniques) which also utilize flight test and wind tunnel test results and any other information necessary to build a suitable analytic tool. Each manufacturer must submit a validation compliance report.

B6. Flight Test:

Flight testing of the transient maneuver and continued safe flight and landing, if required to validate the simulation or analysis, may be conducted at nominal values of gross weight, c.g., thrust, etc. The critical values of these parameters should be considered in the simulator testing or analyses when extrapolating the flight tested condition to the limits of the Normal Flight Envelope. Large extrapolations may not be allowed. It is acceptable that this extrapolated event exceed structural loads in excess of the design limit when the typical 150% safety factor to ultimate load has been used in the design. For continued safe flight and landing, it may be assumed that thrust is not greater than idle. Shutting down the affected engine is an acceptable part of the procedure.

Operational Flight Profile:

The initial flight phase consists of an all-engine takeoff climb profile, flown at takeoff power, and ranging from sea level to the maximum certificated takeoff altitude.

The second phase is an acceleration and "clean-up" (i.e.; retraction of high lift devices), with thrust reduction from takeoff power to climb power occurring during this phase. Included in this phase may be a point of flight control transition, where some surfaces may be limited to lesser travel or authority, or completely locked out.

The third phase is an acceleration to enroute climb speed. This is a combination acceleration and climb, at climb power.

The fourth phase is a climb at the enroute climb speed(s), at climb power. The climb speed schedule is usually narrowly defined for most types.

The fifth phase is a continuation of the climb, but in the Mach regime, and continuing to the initial cruise altitude.

The sixth phase is a Mach regime cruise. This phase is limited by the maximum certificated altitude, and ranges from the Mach number providing the minimum allowed maneuver margin to buffet onset, to the maximum recommended cruise Mach number. This phase is also characterized by a decreasing cruise speed range as altitude increases. The industry "standard" with respect to maneuver margin is 1.3g, however, the applicant should also demonstrate an altitude/speed/power combination that equates to a lesser margin (e.g. 1.2g), if current operational practice for the model in question allows operation at the reduced margin. The power setting in this phase should be thrust for level flight at the recommended cruise Mach number, but need not exceed maximum continuous thrust. However, this phase may be considered to have a wide range of speed/power/altitude combinations which can include cruise at M_{MO}.

The seventh phase is a descent from cruise, and consists of power reduction, acquisition of the recommended descent Mach number, and descent at that Mach number into the airspeed regime. This phase can also consist of a wide range of speeds and power settings, and should include flight at V_{MO}. If the subject airplane includes overspeed protection which prevents flight at V_{MO}, then the maximum attainable speed should be demonstrated.

The eighth phase is an area and terminal arrival phase which is characterized by deceleration, descent, configuration changes, and associated low to level-flight power settings.

The ninth phase is final approach. This is characterized by the recommended landing flap configuration, speed in the V_{REF} regime, and thrust as required to maintain a stabilized approach flight path.

The last phase to be considered is a "go-around", which is characterized by takeoff power on all engines, flap retraction to an intermediate setting, and attainment of a target climb speed.

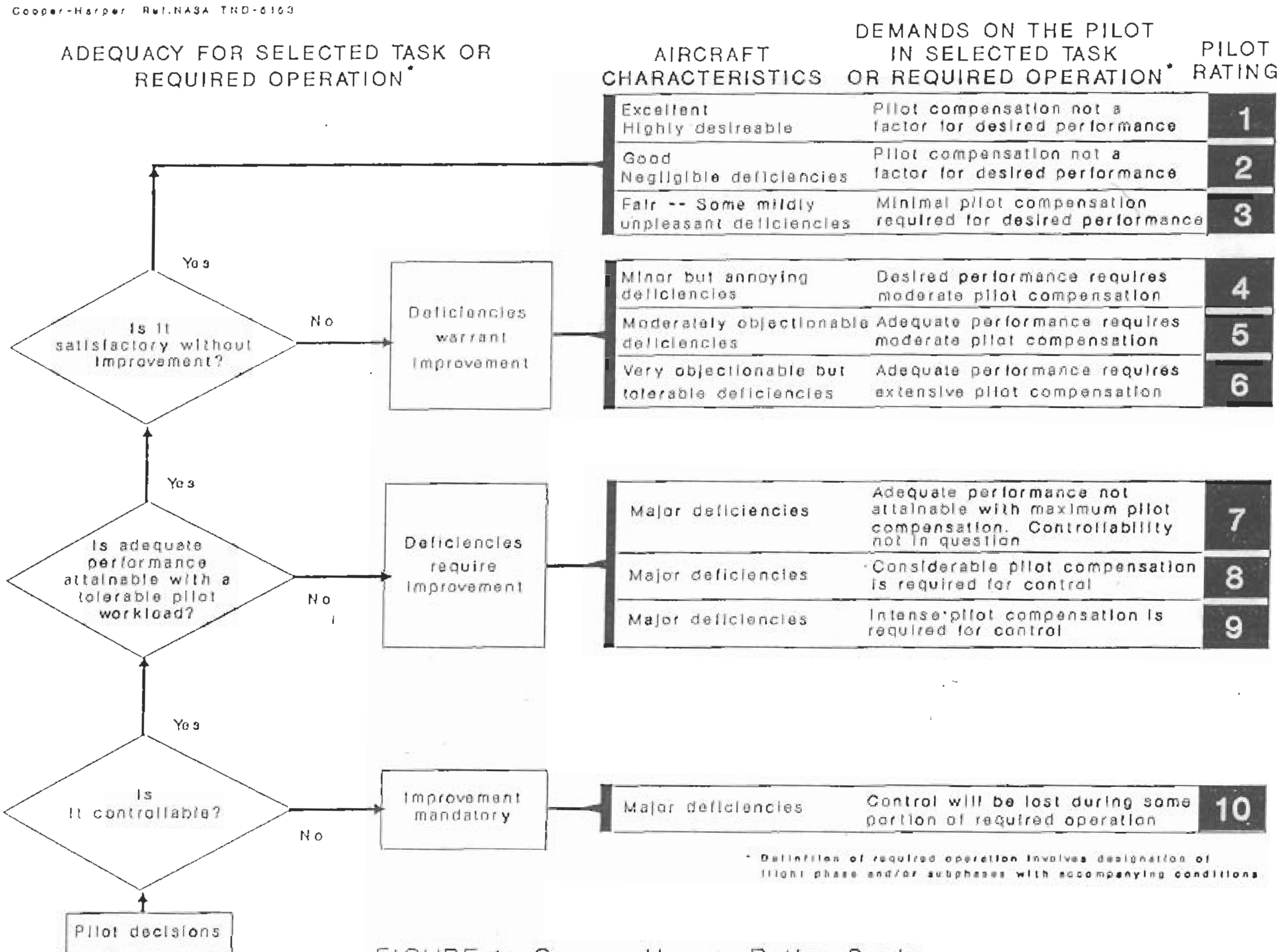


FIGURE 1: Cooper-Harper Rating Scale

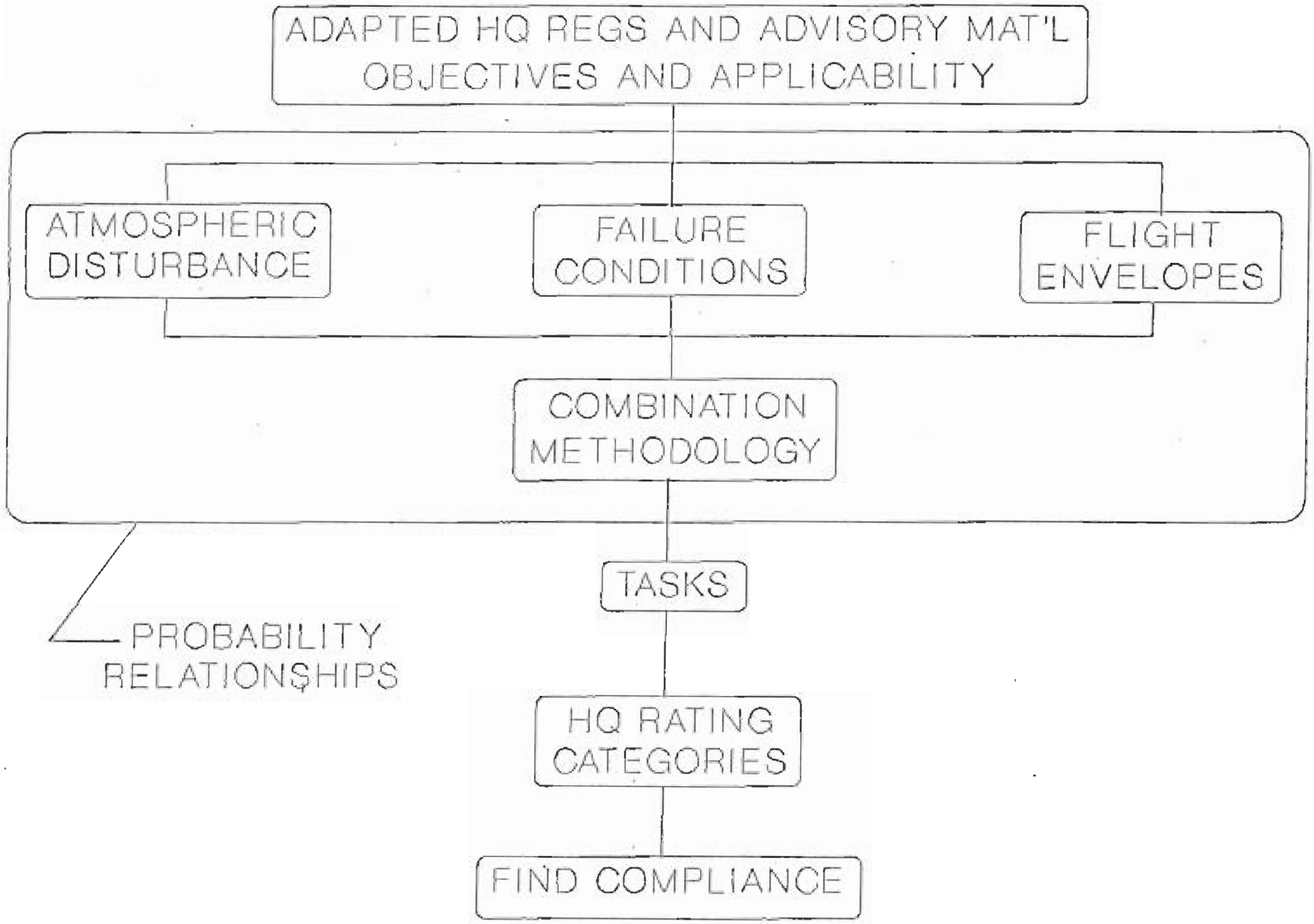


Figure 2: Major Elements of Task-Oriented Handling Qualities Rating Method

FAA HQ RATING	FAA DEFINITION	COMPARISON		
		CH	MIL STANDARD	
			LEVEL	QUAL
SAT	Full performance criteria met with routine pilot effort and attention.	1 - 3.5	1	SAT
ADQ	Adequate for continued safe flight and landing; full or specified reduced performance met, but with heightened pilot effort and attention	3.5 - 6.5	2	ACCEPT
CON	Inadequate for continued safe flight and landing, but controllable for return to safe flight condition, a safe flight envelope and/or reconfiguration so that HQ are at least adequate	6.5 - 9	3	CON

FIGURE 3A: Pilot Ratings

FLIGHT CONDITION	ATMOSPHERIC DISTURBANCE								
	LIGHT			MODERATE			SEVERE		
	FLIGHT ENVELOPE								
	NFE	OFE	LFE	NFE	OFE	LFE	NFE	OFE	LFE
PROBABLE CONDITION	S	S	A	A	C	C	C	C	C
IMPROBABLE CONDITION	A	A	C	C	C		C		

S = SATISFACTORY A = ADEQUATE C = CONTROLLABLE

FIGURE 3B: Minimum HQ Requirements

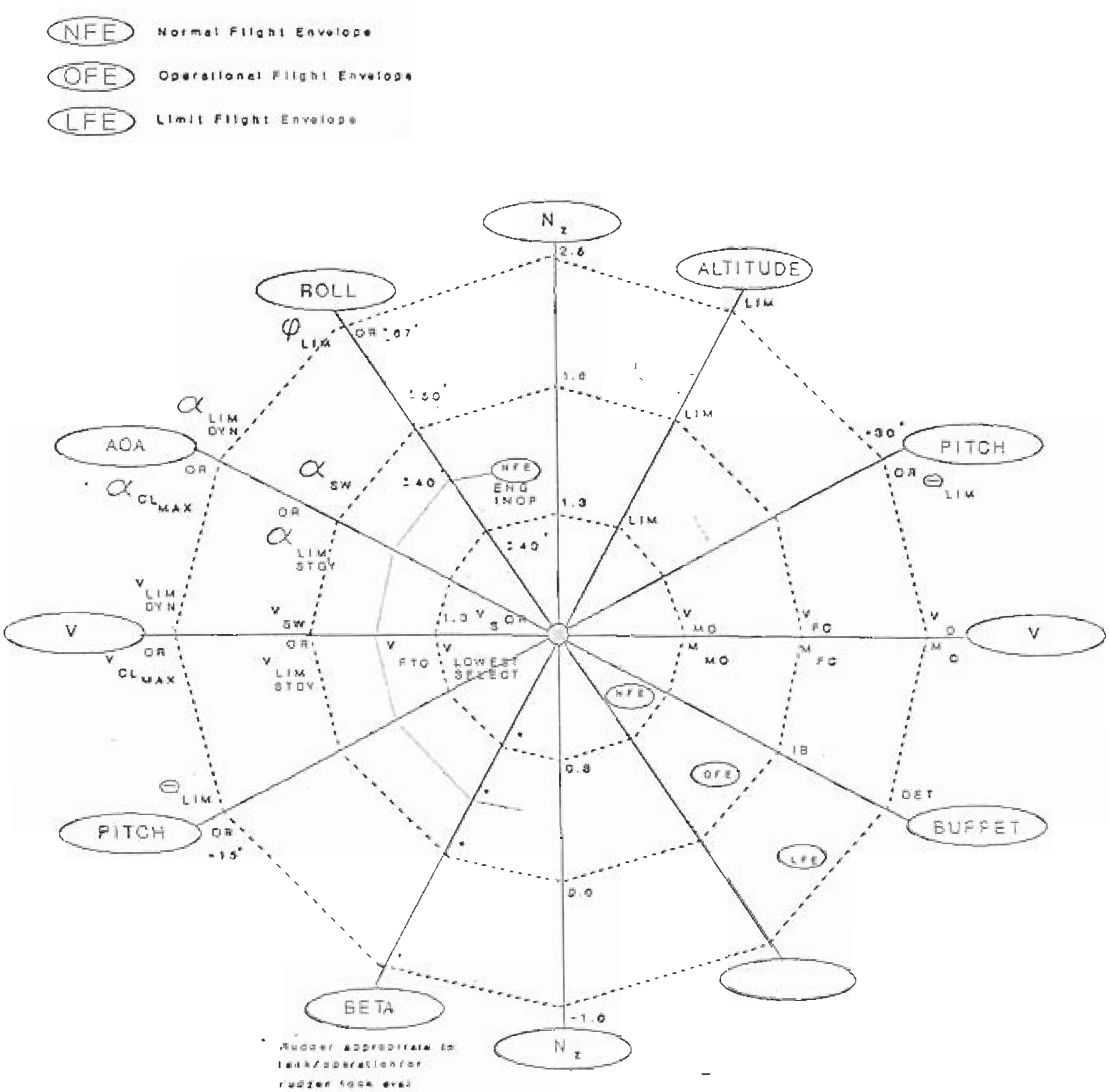


Figure 4A: Flaps UP Flight Envelopes

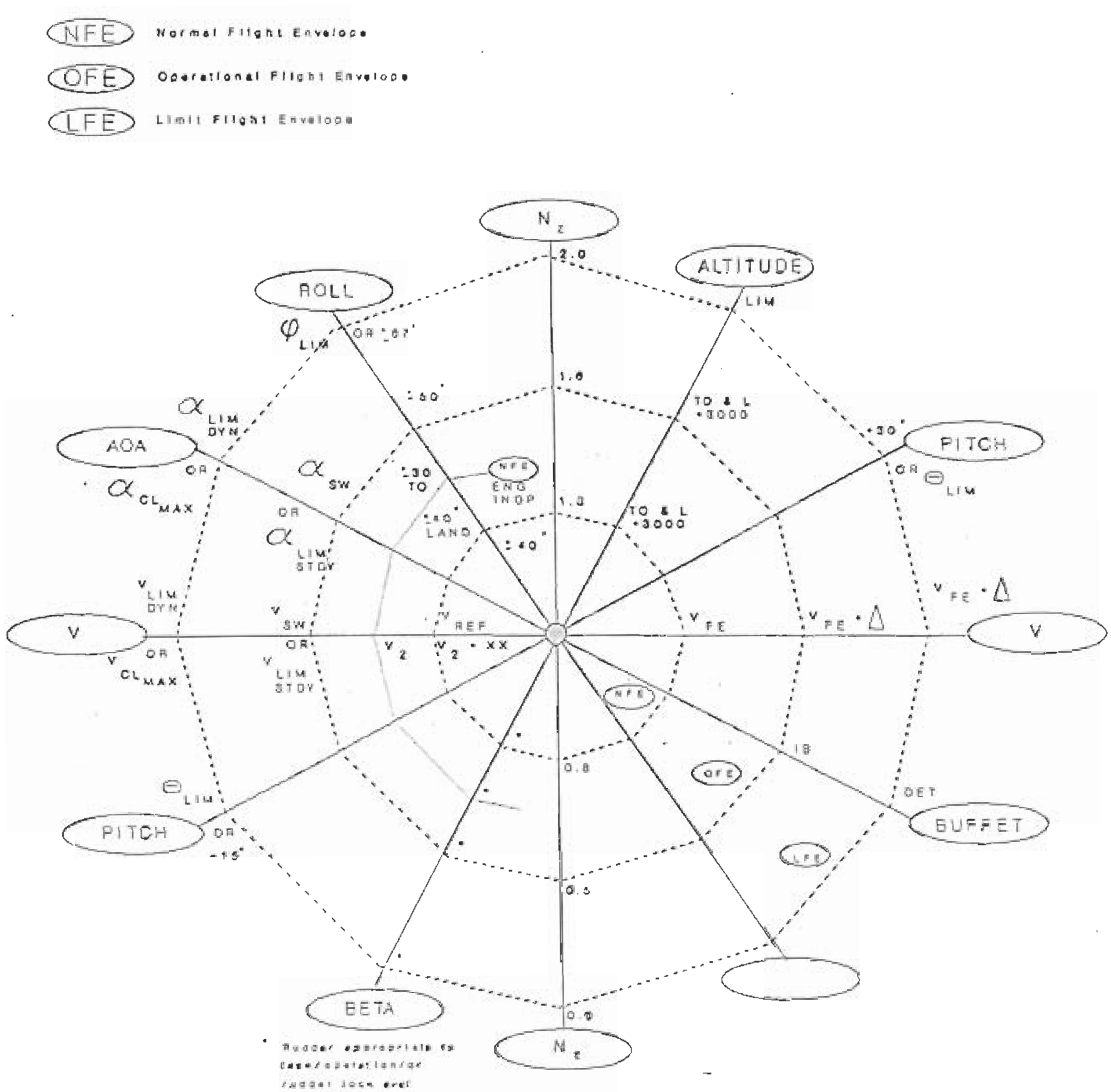
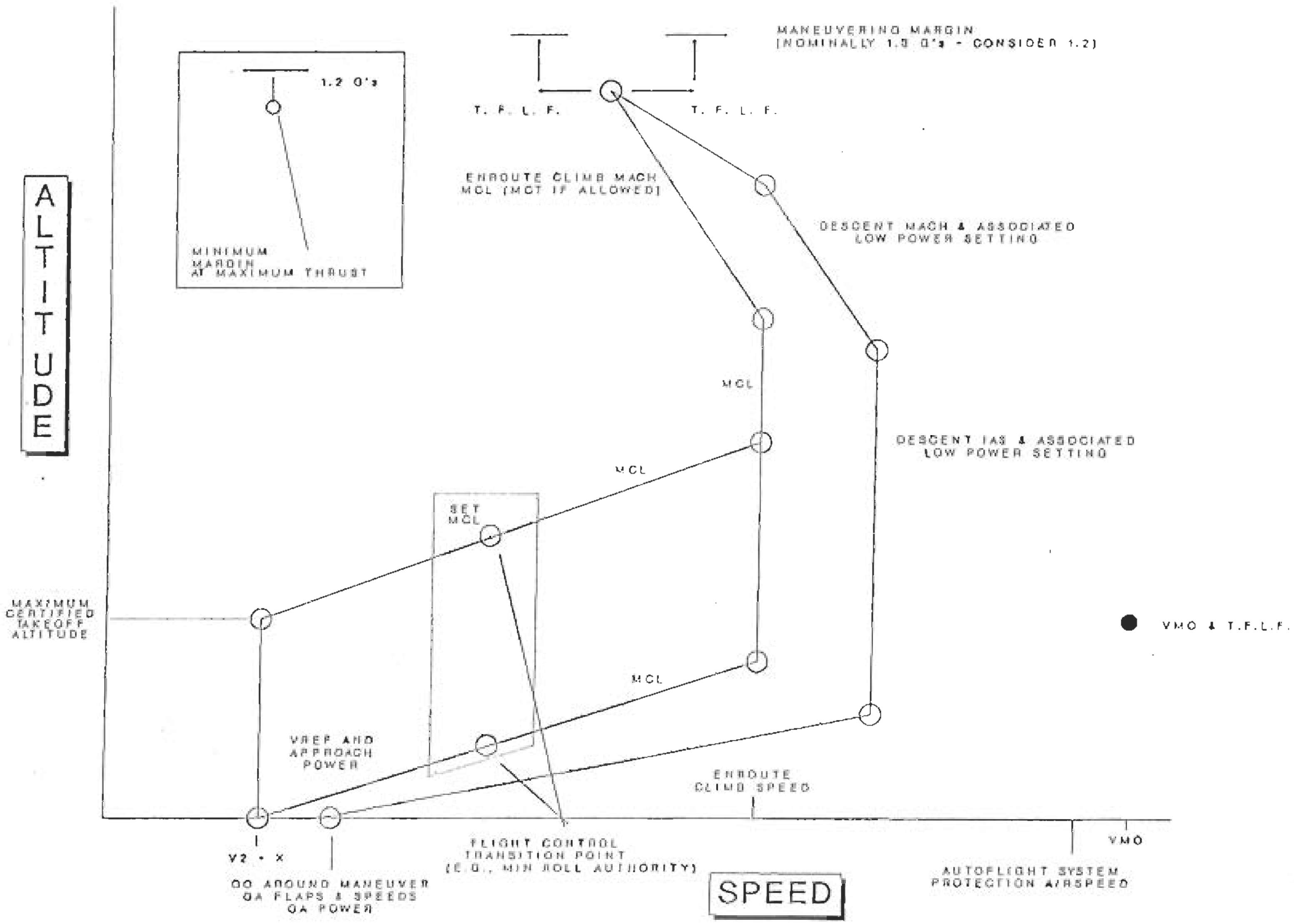


Figure 4B: Flaps DOWN Flight Envelopes

Figure 5: OPERATIONAL FLIGHT PROFILE



APPENDIX C

THRUST REVERSER SYSTEM SAFETY ANALYSIS

C1. Purpose

This appendix applies exclusively to the analyses required for this fleet assessment. It defines an acceptable means, but not the only means, of performing these analyses. Paragraph 5 of this bulletin defines Category I and II aircraft based on whether or not controllability has been establish per Appendix B. A safety analysis is required for both categories of aircraft. However, the type and objectives of these analyses differ as follows:

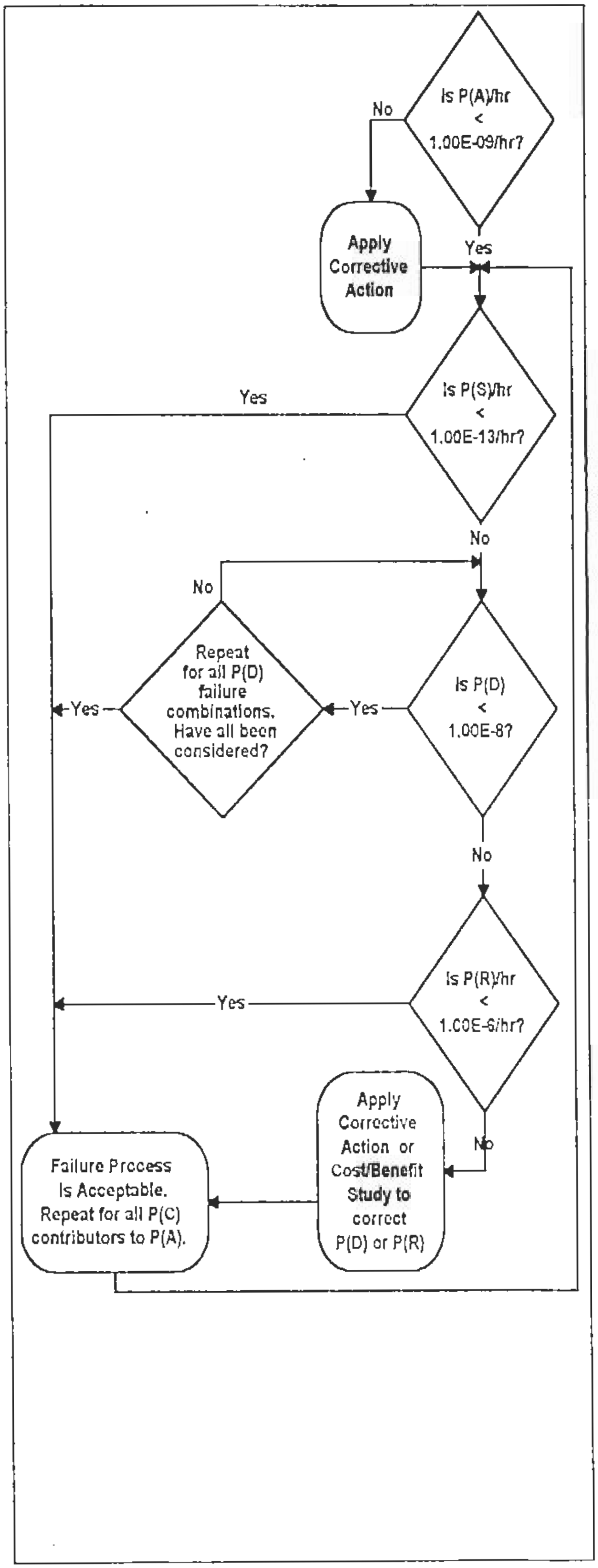
(1) A rigorous qualitative safety analysis must be performed on both Category I and II aircraft to show that no single failure, malfunction or anticipated pilot action will cause an inadvertent inflight deployment which would jeopardize continued safe flight and landing of the aircraft. In addition to the traditional Failure Modes and Effects Analysis (FMEA), a top down analysis, at least to the assembly level, and a "Common Cause Analysis" should be performed to assure that any relevant single failure modes are identified.

(2) A formally validated quantitative safety analysis must be performed on Category I aircraft to show that, considering all combinations of failures, the probability of a catastrophic inflight thrust reverser deployment is extremely improbable (i.e.$<1\times10^{-9}$/flt.hr.).

(3) A safety analysis, either qualitative or quantitative as is appropriate for the complexity of the design, must be performed on Category II aircraft to show that a thrust reverser deployment, while the aircraft is airborne and below the minimum altitude for a "controlled recovery" as defined in Appendix B, is extremely improbable and that inadvertent inflight thrust reverser deployment is extremely remote (i.e.$<1\times10^{-7}$/flt.hr.) in other parts of the flight envelope.

(4) A "specific risk analysis" must be performed on Category I and II aircraft if the design can have faults present for more than one flight which contribute to a catastrophic scenario more probable than 1×10^{-13}/flt.hr. While the safety analysis requirements of (2) and (3) establish an acceptable "average risk" for the fleet, it is recognized that this does not assure an acceptable maximum "specific risk" on any one flight. The presence of relevant pre-existing faults, both latent and those permitted by MMEL, will temporarily raise the "specific risk" above the allowable "average risk". Therefore, this analysis must show that, for any single or specific combination of pre-existing faults which are anticipated to occur in the fleet life of the airplane type and not precluded from dispatch by the MMEL, the probability of catastrophic inflight thrust reverser deployment never exceeds 1×10^{-6}/flt.hr.. For the purpose of this analysis, specific failure conditions whose probability of occurrence is greater than 1×10^{-8}/flt.hr. must be assumed to occur in the fleet life of the airplane type unless a lower total fleet exposure time can be justified. See Figure 1.

FIGURE 1
AIA CATEGORY 1 AIRCRAFT RISK ASSESSMENT CRITERIA



P(A) = **"Average"** system probability of thrust reverser inadvertant deployment inflight (TRIDIF). See the 25.1309-1A Advisory Circular. The maximum average risk limit is 1.00E^{-9} per flight hour. P(A) is the overall average risk of TRIDIF and includes all specific contributing failure processes.

P(S) = **"Specific"** probability of any TRIDIF failure process involving exposure times in excess of one flight duration.

- There can be many P(S) contributors to P(A) and all contributors must be evaluated.
- P(S)/hr = P(D) x P(R)/hr
- P(S) is constant for a given failure process, but can be made up of various combinations of P(D) & P(R).
- If P(S)/hr < 1E-13/hr, accept.
- If not, check all possibe contributing P(D) failure combinations.

P(D) = "Dispatch" probability of a particular failure combination.

- P(D) is the joint probability of the combined failures.
- P(D) decreases as failures are added to the failure combination.
- All possible failure combinations must be evaluated.
- Exposure time is the total maintenance interval.
- If P(D) is < 1E-8/hr for the particular failure combination, accept.
- If not, check corresponding P(R).

P(R) = "Residual" probability of TRIDIF, given a P(D) failure state.

- P(R) is the joint probability of the one or more defenses still remaining.
- P(R) increases as defenses fail and are "moved" to the P(D) side.
- At least one defense is detectable, so exposure time for this defense is equal to one flight duration.
- If P(R)/hr is <1E-6/hr, accept.
- If not apply corrective action.

C2. Introduction

Service history indicates that numerous unwanted inflight deployments have occurred on thrust reverser systems designed to preclude such deployments. The majority of these deployments have resulted from improper maintenance, flight crew errors, and unanticipated system failures. In most instances these systems were designed such that two independent failures were believed to be required to cause an inadvertent deployment. Assumptions used in some failure analyses did not accurately reflect the actual failure modes, effects, or rates. Also the interdependence of system failures, existence of intermittent faults, and operational aspect such as human factors and maintenance practices were often not properly accounted for. Therefore, a disciplined analysis process (see para C3) and the lessons learned from service experience (see para.C4) must be applied to minimize the uncertainty in the analyses performed under this appendix.

C3. General Analysis Guidance

The terms, criteria, and techniques delineated in FAA Advisory Circular (AC) No. 25-1309-1A [hereafter referred to as: "the AC"], as augmented by the additional guidance provided in this appendix, shall constitute an acceptable means of performing the required failure analyses.

Traditional transport airplane safety philosophy establishes that no single conceivable failure shall be allowed to be catastrophic regardless of it's probability (see paragraph 7(g) of the AC). Beyond this single failure criteria, engineers will often need to augment their judgment on how much and how many of the "fail-safe design" principles listed in the AC such as conservative design margins, redundancy, design directed "fail-safe" failure modes, and reliability are necessary to achieve the safety levels the traveling public expects. To help make these kinds of decisions, the AC establishes "standards" for what constitutes an acceptable inverse relationship between the probability and the severity of hazardous events.

Any safety analysis is only as accurate as the assumptions, data, and analytical techniques utilized. Therefore, the validity of each of these factors must be formally justified for every failure analysis performed under this appendix.

As a minimum the analysis documentation should address:

(1) the rationale for failure modes considered (i.e. reference to applicable standards such as ROME, Mil-Spec, or documented company standards; reference to applicable service experience; or reference to a failure mode analysis where possible causal influences and their effects are evaluated). This should also include the rationale for how modes induced by outside influences were established.

Note: the failure of "structural elements" must be considered and identified in the analyses.

(2) failure effects determination and verification methods;

(3) methods used to assure completeness of any "top down" analysis;

(4) rationale for failure rate data source applicability;

(5) methods by which each failure will be detected, isolated and eliminated within the assumed exposure times; and

(6) verification of any fault independence assumptions. This should include a comprehensive "Common Cause Assessment".

When providing these justifications, the effects of other systems which have physical, zonal or functional interfaces with the reverser must be taken into account.

Any "outside" influences which could render the safety analysis invalid should be identified and acceptable means for mitigating these influences defined .

Explicitly validating the accuracy of all aspects of an analysis is usually impractical. Therefore any uncertainty in the validation must be identified and evaluated to demonstrate that the analysis results are insensitive to that uncertainty.

If any system modifications are required to meet this inflight deployment criteria, the effect on ground deployment reliability should be assessed in a manner consistent with the AC.

C4. Lessons Learned from Service Experience

Each analysis should address all applicable lessons learned from the collective fleet experience such as:

- Protection from inadvertent crew actuation should be provided.
- Any assumption that aerodynamic means (differential pressure) will keep an unrestrained reverser stowed will need to be validated considering anticipated variations in manufacture, service deterioration, and flight conditions.
- Maintainability, both in the design and procedures (i.e. MMEL, Airplane Maintenance Manual, etc.) must be verified. This should include at least verification that the system and procedures support the safety analysis assumptions, are tolerant to anticipated human errors, and that any critical procedures are highlighted for consideration as required inspection items. (See §121.369 (b) for considerations of a "required inspection item")
- The impact of latent failures should be minimized. This should include latency due to faults which are "made latent" either due to loss of the detection means or due to the fault being

intermittent.

- o System contamination tolerance must be assessed.
- o The impact of operation under the MMEL should be minimized.
- o Any system separation/isolation assumptions must be validated.
- o The accuracy and effectiveness of flight deck design and crew procedures as they relate to reverser operation and failure modes should be verified.
- o Protection from common cause failure sources such as environmental conditions, engine uncontained rotor failure, and engine fire should be provided.
- o Protection from the effects of engine imbalance, especially on any locking or restraining devices, should be provided.

APPENDIX D

MAINTAINING THRUST REVERSER SYSTEMS
DESIGN CONSIDERATIONS AND DOCUMENT DEVELOPMENT

Design Objectives:

System Design should consider maintainability of product as a primary design objective. Since troubleshooting reverser system problems is not an exact science, it can result in intensive labor usage with no assurance that the actual problem has been addressed. When designing thrust reverser systems to satisfy system failure analysis (Appendix C), the design should not compromise on maintainability of product. A design which merely increases the number of redundant systems to satisfy Appendix C criteria should be discouraged. As systems are added, extra maintenance training is required to detect latent failures that could occur in those systems. System design should also consider and incorporate improved troubleshooting procedures.

Part 1: Design Parameters that Provide for Maintainability of Product

1. Positive deactivation of the reverser actuator power supply shall be easily applied for protection of personnel during maintenance. It should be possible to deploy the Reverser for ground testing/troubleshooting without the engine operating.

2. The reverser shall be capable of midstroke reversal of direction during maintenance without damage to actuators or structure. Also, actuator failures should not result in structural damage.

3. Lockout procedures (deactivation for flight) of the thrust reverser system should be simple, clearly described in the maintenance manual, and possibly placarded somewhere on the nacelle.

4. Thrust reverser un-stowed and unlocked indication shall be easily discernible during walk-around inspection.

5. The number of relays used in the indication system should be kept to a minimum. Poor system reliability can often be attributed to the large number of relays in the system.

6. If the airplane has onboard maintenance monitoring and recording systems, the system should have provisions for storing all fault indications. This would be of significant help to maintenance personnel in locating the source of intermittent faults.

7. Provisions should be made in system design to allow easy access to the components for both fault isolation and replacement. Jackscrew design will include provisions for lubricating the bearings on-wing without major disassembly of the reverser. Rub surfaces, pivot bearings, and track liners should be designed with easily replaceable wear strips or bearings. They should be made of best available wear surface materials and the design should provide for maximum wear resistance.

8. Provisions shall be provided for easy adjustment of deploy and stow switches. Pedestal switches are very difficult to rig. Cowl tension latches should have a tension adjustment feature that can be adjusted without opening the cowling. The latches should be designed so that they can easily be checked for proper latching in the locked position.

9. Documentation shall be provided that describes a rigging check is accomplished after adjustment of any thrust reverser actuator drive system component.

10. Documentation shall be provided that describes cycling of the system under power whenever maintenance is performed. This shall also apply to any manual drive opening/closing of the reverser.

11. If locks are installed as security against reverser deployment in flight, a means shall be provided for maintenance personnel to determine if locks are operating correctly.

Part 2: Considerations When Developing Maintenance Documentation

The following operators comments provide a critique of existing documentation for thrust reverser systems and offer suggestions on manual improvements.

1. The reasons and the significance of accomplishing critical tasks should be included in the AMM. This would eliminate a lot of second guessing as to whether or not a particular task really needs to be done a certain way.

2. Additionally, the AMM should include instructions or references as to what to do if the results of a check or operational test do not agree with those given in the AMM. The manual should recommend some corrective action if a system fails a test or check. This would ensure the critical components are not overlooked in the troubleshooting process.

3. Each manufacturer should convene regular conferences with the operators to discuss Fault Isolation Manuals/Troubleshooting Manuals. The purpose of the conference would be to identify inefficiencies and errors that exist in the manuals.

4. The Maintenance Manuals often are not updated to account for all the problems and fixes being experienced by the operators. There are unique troubleshooting procedures and service tips which the airlines have developed over the years which should be incorporated into the Maintenance Manual. This information should be shared to benefit all operators.

5. Maintenance Manual fault isolation troubleshooting materials (FIFI/TAFI/FIM) that are complex and time consuming to read are often ineffective. When documentation is difficult to understand, troubleshooting ends up being the "shot-gun" approach where many components are unnecessarily replaced. This practice not only delays a permanent fix to the problem but results in the removal and consequent shop expense of confirming that components were improperly removed from service.

6. The Maintenance Manual inspection items and intervals do not always keep pace with the problems and maintenance needs unique to high time aircraft.

7. Better coordination is needed between the thrust reverser system manufacturers and engine and airframe manufacturers in the development of fault isolation/troubleshooting sections of the Aircraft Maintenance Manuals.

8. It is desirable that airframe manufacturers validate/verify maintenance documentation on actual airplanes prior to in-service operation.

FILE: f:\home\med\reverser\AIAcrita.doc