



AEROSPACE INFORMATION REPORT

AIR5924™

REV. B

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Superseding AIR5924A

(R) Guidelines for the Integration of Electronic Engine Control Systems for
Transport Category (Part 25) and General Aviation (Part 23) Aircraft

RATIONALE

As part of the Five-Year Review process, this revision updates information on the integration of FADEC systems based on the most recent practices in the industry and interactions with certification authorities. This revision also adds information related to integration with turboprop aircraft.

INTRODUCTION

Modern digital electronic engine controls are capable of a much higher level of functional integration with aircraft systems than was possible with their primarily hydromechanical predecessors, and system designers have taken advantage of this increased capability. Electronic systems also result in a greater degree of physical integration with the aircraft, with increased dependence on aircraft wiring, remote (from the engine) mounted sensors and transducers, and even control units located within the aircraft.

This report captures many years of hands-on experience in solving problems arising from powerplant control integration and provides a valuable source of lessons learned from those endeavors.

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TABLE OF CONTENTS

1.	SCOPE.....	5
1.1	Purpose.....	5
1.2	Summary of Revision B.....	5
1.3	Field of Application.....	5
2.	REFERENCES.....	8
2.1	Applicable Documents.....	8
2.1.1	SAE Publications.....	8
2.1.2	ASTM Publications.....	8
2.1.3	EASA Publications.....	8
2.1.4	FAA Publications.....	9
2.1.5	RTCA Publications.....	10
2.1.6	Transport Canada Publications.....	10
2.1.7	Other Publications.....	10
2.2	Related Publications.....	10
2.2.1	SAE Publications.....	10
2.2.2	ASTM Publications.....	10
2.2.3	EASA Publications.....	11
2.2.4	FAA Publications.....	11
2.2.5	RTCA Publications.....	11
2.2.6	Transport Canada Publications.....	11
2.2.7	Other Publications.....	12
2.3	Acronyms and Symbols.....	12
2.4	Definitions.....	14
3.	APPLICABILITY.....	14
4.	THRUST AND POWER CONTROL.....	14
4.1	Control Modes.....	14
4.1.1	Primary (or Rating) Mode - Steady State Control Functions.....	14
4.1.2	Backup, Alternate, or Reversionary Mode - Steady State Control Functions.....	16
4.1.3	Controller Operation during Engine Transients.....	17
4.1.4	Use of a Soft Reversionary Mode.....	18
4.1.5	Primary or Backup Mode Activation and Switching Between Modes.....	19
4.1.6	Initiation of the Primary/Backup Mode after Engine Start.....	21
4.1.7	Control Modes on Turboprop Engines.....	22
4.2	Thrust Scheduling Logic.....	23
4.2.1	Primary Mode.....	23
4.2.2	Engine Ratings and Thrust Lapse Rates in the Backup Mode.....	45
5.	POWERPLANT FUNCTIONS.....	46
5.1	Aircraft Protection Functions.....	47
5.1.1	Reverser not Stowed (Response Mode).....	47
5.1.2	Uncontrollable High Thrust.....	48
5.1.3	Propeller Autofeather Function.....	48
5.2	Engine Protection Functions.....	49
5.3	Turboprop Functions.....	49
5.3.1	Propeller Feathering.....	49
5.3.2	Flight Idle Pitch Stop.....	49
5.3.3	Propeller Brake.....	49
5.4	Engine-to-Engine Communication.....	49
5.4.1	Protection Functions Cross-Inhibition.....	49
5.4.2	Software Version Cross-Check.....	50
6.	USE OF SENSORS, AIRCRAFT SIGNALS, AND DATA.....	50
6.1	Engine Control System Signals and the Use of Aircraft Signals.....	51
6.1.1	Thrust Lever Signals and Thrust Reverser Position Signals.....	51
6.1.2	Aircraft Air Data Output Signals.....	52

6.1.3	Aircraft Bleed Signals/Sources	53
6.1.4	Air/Ground Signals	54
6.1.5	Propeller Control Signals	54
6.1.6	A Potential Difficulty with Aircraft Discrete Data Words	54
6.1.7	Considerations for Aircraft Signals Common to Multiple Engines	55
6.2	Environmental Air Data Sensor Considerations	55
6.2.1	Aircraft Probes and Sensors	55
6.2.2	Engine Sensor and Probe Configurations (for Determining Aircraft Air Data).....	59
6.3	FADEC System Air Data Selection Logic	64
6.3.1	Ambient Pressure Selection Logic	65
6.3.2	Total Temperature Selection Logic	68
6.3.3	Total Pressure Selection Logic	69
6.3.4	Airspeed and Mach Number Selection Logic.....	70
6.4	Thrust Management Computer (TMC) Selection of TAT	70
7.	INSTRUMENTATION AND CREW INTERFACES.....	71
7.1	Aircraft Located Engine Displays and Crew Interfaces.....	71
7.1.1	Thrust Indication.....	72
7.1.2	Secondary Engine Parameters Indication.....	75
7.1.3	Full-Time versus Part-Time Display of Information.....	75
7.1.4	Digital-Only Indications	76
7.2	Display of Information Concerning FADEC System Faults and Dispatch	76
8.	MAINTENANCE CONSIDERATIONS	80
8.1	Approaches for Implementing Dispatch of FADEC Systems in Non-Full-Up Configurations	80
8.2	The Use of a CMC and Display of Information Concerning FADEC System Dispatchability	81
9.	HARDWARE AND ENVIRONMENTAL ISSUES	83
9.1	Signals Dedicated to a Given Engine Control.....	83
9.1.1	Thrust Lever Position Transducer.....	83
9.1.2	Channel Reset Signals.....	84
9.2	Signals and Wiring from a Common or Potentially Common Source	87
9.2.1	Wiring in General	87
9.2.2	Common Wiring	87
9.2.3	Common Signals.....	87
9.3	FADEC System Power Supply Considerations	88
9.3.1	Come-Alive Speed	88
9.3.2	Power Source Management	89
9.3.3	Interrupt Support	89
9.4	Backup Power Considerations.....	89
9.4.1	The Use of Aircraft Power as a Backup Electrical Power Source.....	89
9.4.2	Threshold for FADEC System Operation on its Dedicated Power Source	90
9.5	HIRF and Lightning Considerations	91
9.5.1	HIRF Protection.....	91
9.5.2	Lightning Protection	91
9.5.3	Continued Airworthiness of the FADEC System Regarding HIRF/Lightning/EMI	92
10.	CERTIFICATION.....	92
11.	NOTES	93
11.1	Revision Indicator.....	93
APPENDIX A	DISCUSSION PAPER - ENGINE PROTECTION SYSTEMS AND AIRCRAFT INTEGRATION.....	94
APPENDIX B	DISCUSSION PAPER - PROPULSION MONITORING, INDICATION, AND ALERTING OVERVIEW.....	97
Figure 1	Station definitions for 3-shaft turbofan engine	6
Figure 2	Station definitions for 3-shaft turboprop engine	6
Figure 3	Station definitions for 2-shaft turboprop engine	7
Figure 4	Typical FADEC system	7
Figure 5	Example of thrust versus thrust lever angle.....	15

Figure 6	Normal mode thrust schedule as compared with typical backup mode schedule for forward thrust.....	19
Figure 7	Logic for mode selection	20
Figure 8	Typical altitude dependent fan speed versus thrust lever angle (dashed lines show flat regions for the cruise, climb, and TO/MCT power setting detents).....	25
Figure 9	Typical altitude dependent thrust schedules versus thrust lever position.....	26
Figure 10	Example of multiplier schedule	27
Figure 11	A detented, or fixed position, thrust lever quadrant	28
Figure 12	Cross-section of a detented, or fixed position, thrust lever quadrant	29
Figure 13	Thrust versus thrust lever angle without detents	30
Figure 14	Thrust rating/mode selection panel.....	31
Figure 15	Typical thrust rating selection display on-ground, pre-flight.....	32
Figure 16	Typical thrust rating selection display in-flight	32
Figure 17	Example of power and propeller speed scheduling	33
Figure 18	Ambient temperature lapse from above ground level (AGL)	36
Figure 19	Thrust as a function of ambient temperature and altitude increase at constant Mach number.....	36
Figure 20	Thrust limiting function at low airspeed.....	39
Figure 21	Moving thrust lever autothrust system	40
Figure 22	Non-moving thrust lever autothrust system	41
Figure 23	All engines operating; available thrust schedules (cannot set maximum continuous thrust)	44
Figure 24	Aspirated total air temperature probe (Courtesy of Rosemount Aerospace Inc. The external shape of the TAT probe in the figure is a registered trademark of Rosemount Aerospace Inc.)	57
Figure 25	Typical cross-manifolded body static pressure sensing configuration.....	58
Figure 26	Typical body or nacelle static pressure sensing port	58
Figure 27	Non-aspirated TAT probe (Courtesy of Rosemount Aerospace Inc. The external shape of the TAT probe in the figure is a registered trademark of Rosemount Aerospace Inc.)	60
Figure 28	Engine inlet mounted P2/T2 probe (Courtesy of Rosemount Aerospace Inc. The external shape of the P2/T2 probe in the figure is a registered trademark of Rosemount Aerospace Inc.)	62
Figure 29	Typical FADEC system selection logic for static pressure, total temperature, and total pressure information	66
Figure 30	Typical presentation of powerplant data	71
Figure 31	Typical FADEC system engine thrust display	72
Figure 32	Typical EICAS with multi-function display	82
Table 1	List of acronyms and symbols.....	12
Table 2	List of definitions	14

1. SCOPE

This SAE Aerospace Information Report (AIR) provides methodologies and approaches that have been used to install and integrate full-authority-digital-engine-control (FADEC) systems on transport category aircraft. Although most of the information provided is based on turbofan/turboprop engines installed on large commercial transports, many of the issues raised are equally applicable to corporate, general aviation, regional, and commuter aircraft, and to military installations, particularly when commercial aircraft are employed by military users. The word “engine” is used to designate the aircraft propulsion system. The engine station designations used in this report are shown in Figures 1 to 3.

Most of the material concerns an electronic engine control (EEC) with its associated software and its functional integration with the aircraft. However, the report also addresses the physical environment associated with the EEC and its associated wiring and sensors.

Since most current transport category engines use dual-channel FADEC systems, this is the configuration addressed by this report. A typical FADEC system configuration is shown in Figure 4.

1.1 Purpose

This report provides guidance to engine/control designers and aircraft system designers for issues associated with the installation and integration of engine control systems with aircraft systems. Future technologies employed may be different from those addressed in this report, but the basic concepts are the same. The readers must judge the importance of the concepts being addressed to the technology that they are employing in a new application. The examples used have satisfied the requirements in existence at the time of design/certification; they are not considered requirements.

1.2 Summary of Revision B

This revision provides updated information on the integration of FADEC systems based on the most recent practices in the industry and interactions with certification authorities. The main topics that were updated on this revision are: backup mode for steady state control operation, automatic power reserve (APR) or automatic takeoff thrust control system (ATTCS), uncontrollable high thrust (UHT) accommodation, powerplant functions not related to engine control, use of aircraft signals, flight crew interface, and EEC channel reset and transfer. This revision also adds information on the FADEC system integration with turboprop aircraft.

1.3 Field of Application

The field of application is aerospace, primarily for FADEC-equipped engines targeted for commercial transport and general aviation aircraft installations.

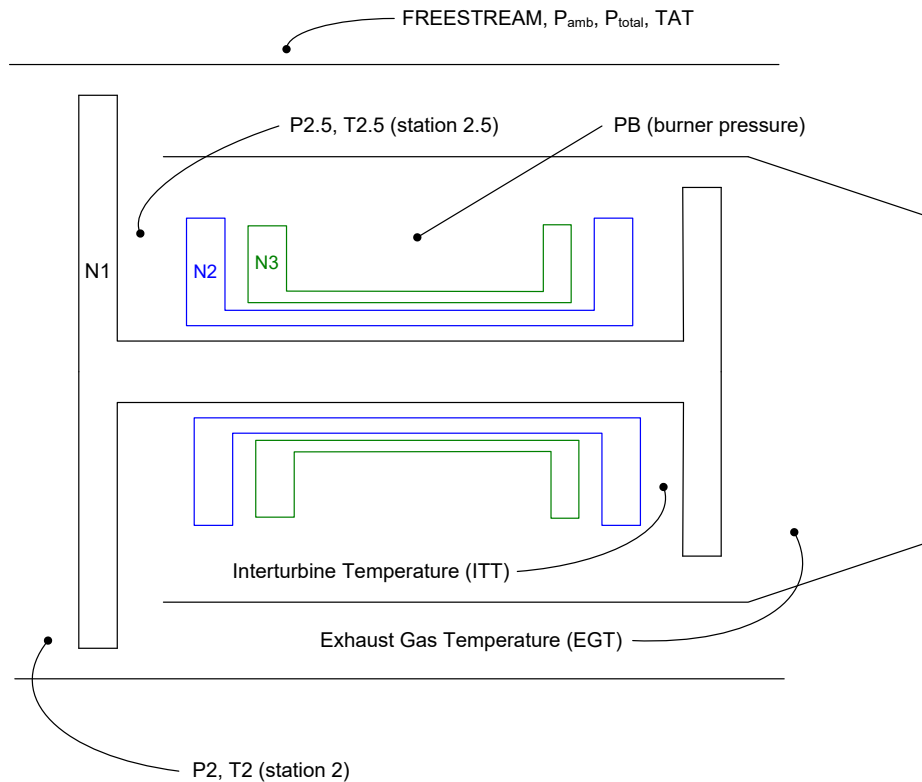


Figure 1 - Station definitions for 3-shaft turbofan engine

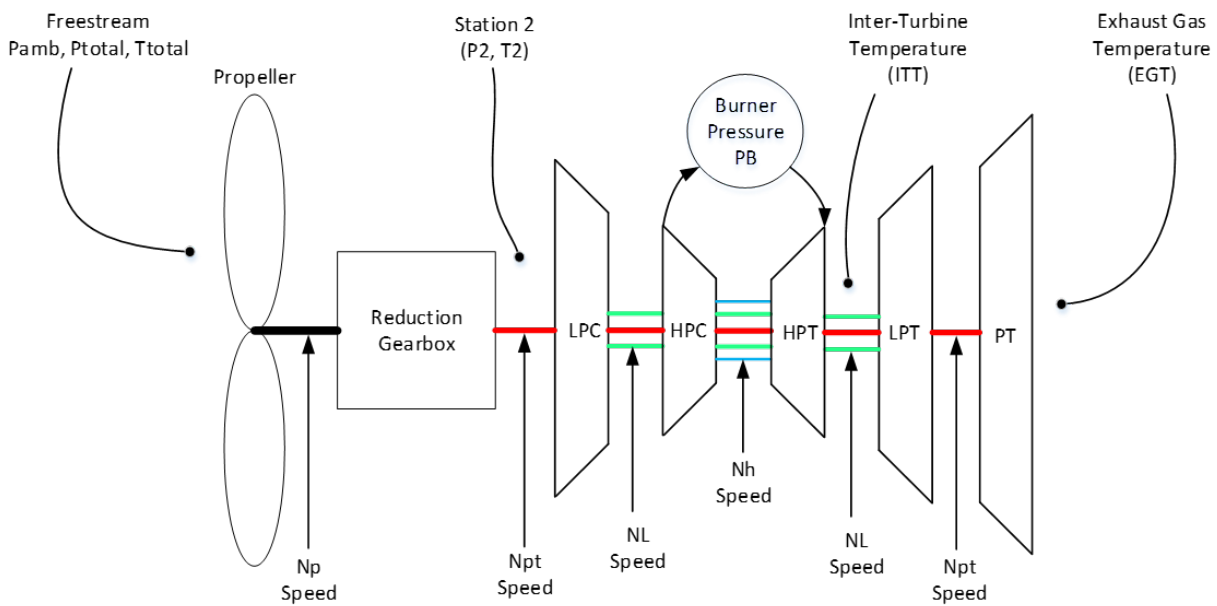


Figure 2 - Station definitions for 3-shaft turboprop engine

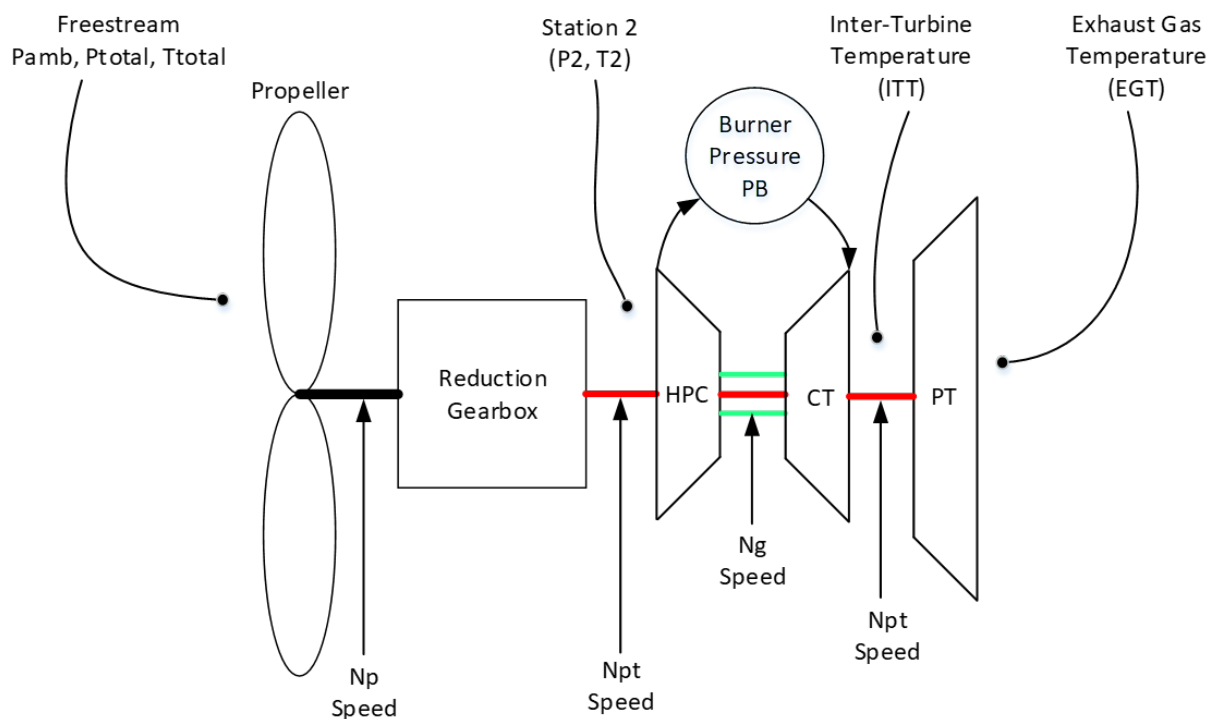


Figure 3 - Station definitions for 2-shaft turboprop engine

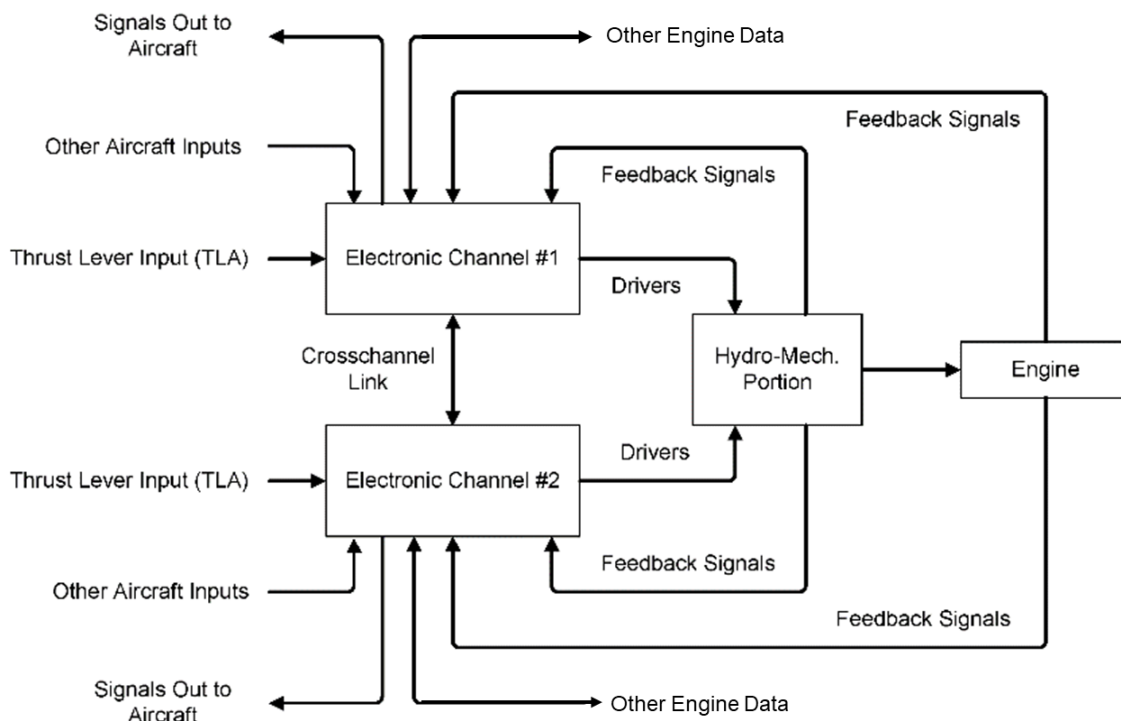


Figure 4 - Typical FADEC system

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR6181	Electronic Propulsion Control System/Aircraft Interface Control Documents
ARP4754	Guidelines for Development of Civil Aircraft and Systems
ARP4761	Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment
ARP5107	Guidelines for Time-Limited-Dispatch (TLD) Analysis for Electronic Engine Control Systems
ARP5150	Safety Assessment of Transport Airplanes in Commercial Service
ARP5416	Aircraft Lightning Test Methods
ARP5583	Guide to Certification of Aircraft in a High-Intensity Radiated Field (HIRF) Environment
AS5562	Ice and Rain Minimum Qualification Standards for Pitot and Pitot-static Probes

2.1.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM F3338 Standard Specification for Design of Electric Engines for General Aviation Aircraft

2.1.3 EASA Publications

Available from European Union Aviation Safety Agency, Konrad-Adenauer-Ufer 3, D-50668 Cologne, Germany, Tel: +49 221 8999 000, www.easa.europa.eu.

Certification Specifications:

CS-23	Certification Specifications for Normal-Category Aeroplanes
CS-25	Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes
CS-27	Certification Specifications and Acceptable Means of Compliance for Small Rotorcraft
CS-29	Certification Specifications and Acceptable Means of Compliance for Large Rotorcraft
CS-E	Certification Specifications and Acceptable Means of Compliance for Engines
CS-P	Certification Specifications for Propellers

Guidance Material:

AMC 20-3	Certification of Engines Equipped with Electronic Engine Control Systems
AMC 25-13	Reduced And Derated Take-Off Thrust (Power) Procedures
AMC 25.1309	System design and analysis
AMC E 50	Engine Control System
AMC E 780	Icing Conditions

2.1.4 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

Airworthiness Standards:

14 CFR Part 23	Airworthiness Standards: Normal Category Airplanes
14 CFR Part 25	Airworthiness Standards: Transport Category Airplanes
14 CFR Part 27	Airworthiness Standards: Normal Category Rotorcraft
14 CFR Part 29	Airworthiness Standards: Transport Category Rotorcraft
14 CFR Part 33	Airworthiness Standards: Aircraft Engines
14 CFR Part 35	Airworthiness Standards: Propellers

Advisory Circulars:

AC 20-88A	Guidelines on the Marking of Aircraft Powerplant Instruments (Displays), issued September 30, 1985
AC 20-136B	Aircraft Electrical and Electronic Systems Lightning Protection, issued September 7, 2011
AC 20-147A	Turbojet, Turboprop, Turboshift, and Turbofan Engine Induction System Icing and Ice Ingestion
AC 20-158A	The Certification of Aircraft Electrical and Electronic Systems for Operation in the High-Intensity Radiated Fields (HIRF) Environment, issued May 30, 2014
AC 23.1311-1C	Installation of Electronic Display in Part 23 Airplanes, issued November 17, 2011
AC 25-11B	Electronic Flight Deck Displays, issued October 07, 2014
AC 25-13	Reduced and Derated Takeoff Thrust (Power) Procedures, issued May 4, 1988
AC 25.1322-1	Flightcrew Alerting, issued December 13, 2010
AC 33.28-3	Guidance Material for 14 CFR § 33.28, Engine Control Systems, issued May 23, 2014

Policy Letters and Statements:

ANE-1993-33.28TLD-R1	Policy for Time Limited Dispatch (TLD) of Engines Fitted with Full Authority Digital Engine Controls (FADEC) Systems, issued June 29, 2001
PS-AIR-33.27-02	Turbine, Compressor, Fan, and Turbosupercharger Rotor Overspeed Engine Control Systems 14 CFR § 33.27(c) and (e)

TAD 95-001 PS-ANM100-1995-00104: The Role of Maintenance Computers in Exposure Time Assumptions for Quantitative Safety Analyses, issued February 22, 1995

TAD 00-113-1028 PS-ANM100-2000-00112: Availability of All-Engine Maximum Continuous Thrust (MCT), issued July 31, 2000

TSO:

C16b ELECTRICALLY HEATED PITOT AND PITOT-STATIC TUBES

2.1.5 RTCA Publications

Available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA DO-178C Software Considerations in Airborne Systems and Equipment Certifications

2.1.6 Transport Canada Publications

Available from Transport Canada, Tower C, Place de Ville, 330 Sparks Street Ottawa, Ontario K1A 0N5, Tel: 1-800-305-2059, www.tc.gc.ca.

Advisory Circulars:

AC 525-005 Operation of Thrust Reversing Systems

2.1.7 Other Publications

AIA/AECMA Project Report on Propulsion System Malfunction Plus Inappropriate Crew Response (PSM + ICR), November 1, 1998.

AIA Engine Icing Working Group Subcommittee on Engine Probe Icing: A Process for Evaluating the Performance of Temperature Probes, Combined Temperature and Pressure Probes, and Static Pressure Probes in Icing Conditions, October 6, 2017.

FAA/AIA Propulsion Committee: Third Technical Report On Propulsion System and Auxiliary Power Unit (APU) Related Aircraft Safety Hazards ("Third CAAM Report"), March 30, 2017.

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AS755 Aircraft Propulsion System Performance Station Designation

2.2.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM F3264 Standard Specification for Normal Category Aeroplanes Certification

ASTM F3064/F3064M Standard Specification for Aircraft Powerplant Control, Operation, and Indication

ASTM F3065/F3065M Standard Specification for Aircraft Propeller System Installation



Documents

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ASTM F3066/F3066M	Standard Specification for Aircraft Powerplant Installation Hazard Mitigation
ASTM F3117/F3117M	Standard Specification for Crew Interface in Aircraft
ASTM F3432	Standard Practice for Powerplant Instruments

2.2.3 EASA Publications

Available from European Union Aviation Safety Agency, Konrad-Adenauer-Ufer 3, D-50668 Cologne, Germany, Tel: +492218999000, www.easa.europa.eu.

Guidance Material:

AMC 20-1	Certification of Aircraft Propulsion Systems Equipped with Electronic Control Systems
AMC P 230	Propeller Control System

2.2.4 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

Advisory Circulars:

AC 21-16G	RTCA Document DO-160 D, E, F, and G, Environmental Conditions and Test Procedures for Airborne Equipment, issued June 22, 2011
AC 25.1309-1A	System Design and Analysis, issued June 21, 1988
AC 33.75-1A	Guidance Material for 14 CFR § 33.75, Safety Analysis (With Change 1), issued September 26, 2007
AC 35-1A	Certification of Propellers
AC 35.23-1	Guidance Material for 14 CFR § 35.23, Propeller Control System

2.2.5 RTCA Publications

Available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA DO-254	Design Assurance Guidance for Airborne Electronic Hardware
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2.2.6 Transport Canada Publications

Available from Transport Canada, Tower C, Place de Ville, 330 Sparks Street Ottawa, Ontario K1A 0N5, Tel: 1-800-305-2059, www.tc.gc.ca.

Canadian Aviation Regulations:

Chapter 523	Normal Category Aeroplanes
Chapter 525	Transport Category Aeroplanes
Chapter 527	Normal Category Rotorcraft
Chapter 529	Transport Category Rotorcraft
Chapter 533	Aircraft Engines
Chapter 535	Propellers

2.2.7 Other Publications

Goodrich Total Temperature Sensor Technical Report 5755, Rev. B, dated 1990.

2.3 Acronyms and Symbols

Table 1 - List of acronyms and symbols

Acronym	Meaning	Comments
ADC	air-data computer	
AECMA	European Association of Aerospace Industries	
AFM	aircraft flight manual	
AGL	above ground level	
AIA	Aerospace Industry Association	
AMC	acceptable means of compliance	
APR	automatic power reserve	
ATM	assumed temperature method	
ATTCS	automatic takeoff thrust control system	Also known as APR or automatic thrust reserve (ATR)
AWG	American wiring gauge	
BIT	built-in test	
CAI	cowl anti-ice	
CMC	central maintenance computer	
DAL	design assurance level	
EASA	European Union Aviation Safety Agency	
ECS	environmental control system	
EEC	electronic engine control	This term may be used to describe just the basic electronic engine control unit.
EICAS	engine indication and crew alerting system	System for displaying engine parameters and warnings to the flight crew. Also known as (electronic centralized aircraft monitoring (ECAM).
EIWG	Engine Icing Working Group	
EGT	exhaust gas temperature	In this document, the term EGT will be used, but for the purpose of this report, the term ITT could be used interchangeably with EGT.
EMI	electromagnetic interference	
EPR	engine pressure ratio	
FAA	Federal Aviation Administration	
FADEC	full-authority digital engine control	This term is generally used to represent the whole engine control system, including wire harnesses, fuel metering unit, etc.
FMEA	failure modes and effects analysis	
FOD	foreign object damage	
GA	go-around	
GMT	Greenwich mean time	
GW	gross weight	
h/w	hardware	
HIRF	high intensity radiated field	
HPC	high-pressure compressor	
HPT	high-pressure turbine	
ICR	inappropriate crew response	
IFSD	In-flight shutdown	
ITT	interturbine temperature	In this document, the term EGT will be used, but for the purpose of this report, the term ITT could be used interchangeably with EGT.
LADC	left (side) ADC	
LOPC	loss of power control	
LOTC	loss of thrust control	
LPC	low-pressure compressor	

Acronym	Meaning	Comments
LPT	low-pressure turbine	
LVDT	linear variable differential transducer	
MCT	maximum continuous thrust	
MEL	minimum equipment list	
MMEL	master minimum equipment list	
N1	engine low-pressure shaft speed	Usually also fan speed
N2	engine high-pressure shaft speed	Intermediate shaft speed in 3-shaft turbofan engines
N3	engine high-pressure shaft speed	3-shaft turbofan engines
Ng	engine gas generator shaft speed	2-shaft turboprop engines
Nh	engine high-pressure shaft speed	3-shaft turboprop engines
NL	engine low-pressure shaft speed	3-shaft turboprop engines
NP	engine propeller speed	Turboprop engines
Npt	engine power turbine shaft speed	Turboprop engines
OAT	outside air temperature	
OEI	one engine inoperative	
Pamb	ambient (static) air pressure	Indication of altitude
Pb	burner pressure	
Ps	static air pressure	
P	total air pressure	
P2	engine intake (or inlet) total pressure	
P3	HPC discharge pressure	
PSMRR	propulsion system malfunction recognition and response	
Q	dynamic pressure	P minus Ps
RADC	right (side) ADC	
RVDT	rotary variable differential transducer	
s/w	software	
TAT	total air temperature	
Theta	T2/Tstd.	
TLA	thrust lever angle	
TLD	time limited dispatch	
TMC	thrust management computer	
TPR	turbofan power ratio	
Tstd	standard day temperature	
T2	engine intake (or inlet) total temperature	
V1	takeoff decision speed	
V2	second segment climb-out speed	
Vmca	minimum control speed in-the-air	
Vmcg	minimum control speed on-the-ground	
VR	rotation speed	
Wf	fuel flow	
Wf/Pb	fuel flow - burner pressure ratio	
WOW	weight-on-wheels	

2.4 Definitions

Table 2 - List of definitions

AIRCRAFT-SUPPLIED DATA	Data that is supplied by or via aircraft systems and is used by the engine control system.
BACKUP MODE	Engine control system operation mode where the operating characteristics or capabilities of the engine control are sufficiently different from the primary mode so that the operating characteristics or capabilities of the aircraft, crew workload, or what constitutes appropriate crew procedures may be significantly impacted or changed.
FULL-UP CONFIGURATION	EEC system that has no known faults or failures present.
PRIMARY MODE	The mode that is intended to be used for controlling the engine under normal operation.

3. APPLICABILITY

This information is primarily intended for FADEC-equipped engines certifying to the applicable engine regulations and for the installation of those engines on aircraft certifying to transport and general aviation aircraft regulations. In addition, many of the issues discussed herein apply to military installations, as military derivatives of civil aircraft are more frequently being pursued by military users. The information contained herein may also be useful for engine integration into rotorcraft.

4. THRUST AND POWER CONTROL

Electronic engine controls provide thrust or power management function. The aim of this function is to simplify the management of the thrust or power during aircraft operation. It was introduced largely in transport category airplanes. The thrust or power management function computes and provides easy selection of thrust or power ratings for specific flight phases such as takeoff and climb.

25.1305(d)(1) requires a direct measurement of thrust or parameters directly related to thrust. The industry and regulatory agencies have accepted the use of fan speed (N1), engine pressure ratio (EPR), and turbofan power ratio (TPR) as compliant to this requirement. Most turbofan engines recently certified have the thrust or power management based on N1 due to the high bypass ratio of engines and a majority of the thrust coming from the fan versus the core. Power management based on N1 has a non-linear relationship with thrust at lower thrust settings. EPR provides a more direct measurement of thrust for engines having a lower bypass ratio. EPR has a linear relationship with thrust throughout the thrust setting range. A few high bypass turbofan engines utilized a turbofan power ratio (a function of P2, P3, T2, and EGT) as the thrust measurement. TPR also has a linear relationship with thrust throughout the thrust setting range and has been used in high bypass ratio engines.

For turboprop aircraft, the equivalent parameter for thrust indication is torque as required by 25.1305(e)(1). An alternative indication for torque is engine power, which is the product of the torque and propeller speed. If alternative means for torque indication is proposed, an equivalency in level of safety should be discussed with certification authorities.

4.1 Control Modes

Sections 4.1.1 to 4.1.6 provide information related to thrust or power control modes for turbofan engines, which has the thrust or power management based on N1 or EPR. Power management on turboprop engines is based on power or torque transmitted to the propeller, and a description of the control modes for this type of engine is presented in 4.1.7.

4.1.1 Primary (or Rating) Mode - Steady State Control Functions

The engine control generally has several operating modes. During steady state operation, normal control is generally governed by either closed loop control on an idle control parameter or on the engine power setting parameter when above idle. The control may operate on a limiter at high power, but operation on a limiter is usually the result of engine deterioration or an engine or control system malfunction. The thrust setting parameter in most fan engines is either N1, EPR, or in some cases TPR. Systems based on EPR and TPR share very similar strategies for engine control system design. In this document, we will use the term EPR, but all the information related to a system based on EPR can also be applied to a system based on TPR.

In most FADEC systems, the normal mode of operation is generally a rating mode that implements a control that adjusts engine thrust automatically as a function of atmospheric flight conditions. When operating in this mode, engine thrust goes from idle to maximum rated power, which is usually a function of altitude, airspeed, and ambient or total air temperature, as the thrust lever is advanced from the idle stop to the full forward stop. Figure 5 shows a typical thrust versus thrust lever position schedule. (See 4.2.1.3 and 4.2.2.2 for a more detailed discussion of programmed thrust versus thrust lever position.) Certification requirements 14 CFR § 33.28(b)(1)(iii) and CS-E 50(a)(3) require the engine control system to allow engine power or thrust modulation with adequate sensitivity and accuracy over the declared range of engine operating conditions. Operation in the forward thrust regime generally requires consideration of what is referred to as good thrust setting sensitivity or capability. This is simply the slope of the thrust parameter (and thrust) as a function of thrust lever angle. Reasonable slopes need to be provided so that the flight crew can modulate thrust as necessary for aircraft handling and set a particular value of the thrust setting parameter accurately during various phases of flight. For example, high bypass ratio engines using N1 as the thrust setting parameter may require N1 to be set within 0.1% of a physical fan speed target when conducting a takeoff, and engines using EPR as the thrust setting parameter may require EPR to be set within 0.002 of the target during a takeoff.

Setting reverse thrust in the primary (or backup) mode does not generally require any significant reverse thrust modulation capability. Figure 5 shows that there is usually a reverse idle detent and full reverse thrust lever position. In the reverse idle detent, the engine remains at idle thrust with the reverser fully deployed; in the full reverse thrust, the engine operates at maximum rated reverse thrust. The slope of the line from reverse idle to maximum reverse thrust can be quite steep, as the flight crew operating procedure is either to leave it at reverse idle or pull the thrust levers completely back to the maximum reverse stop.

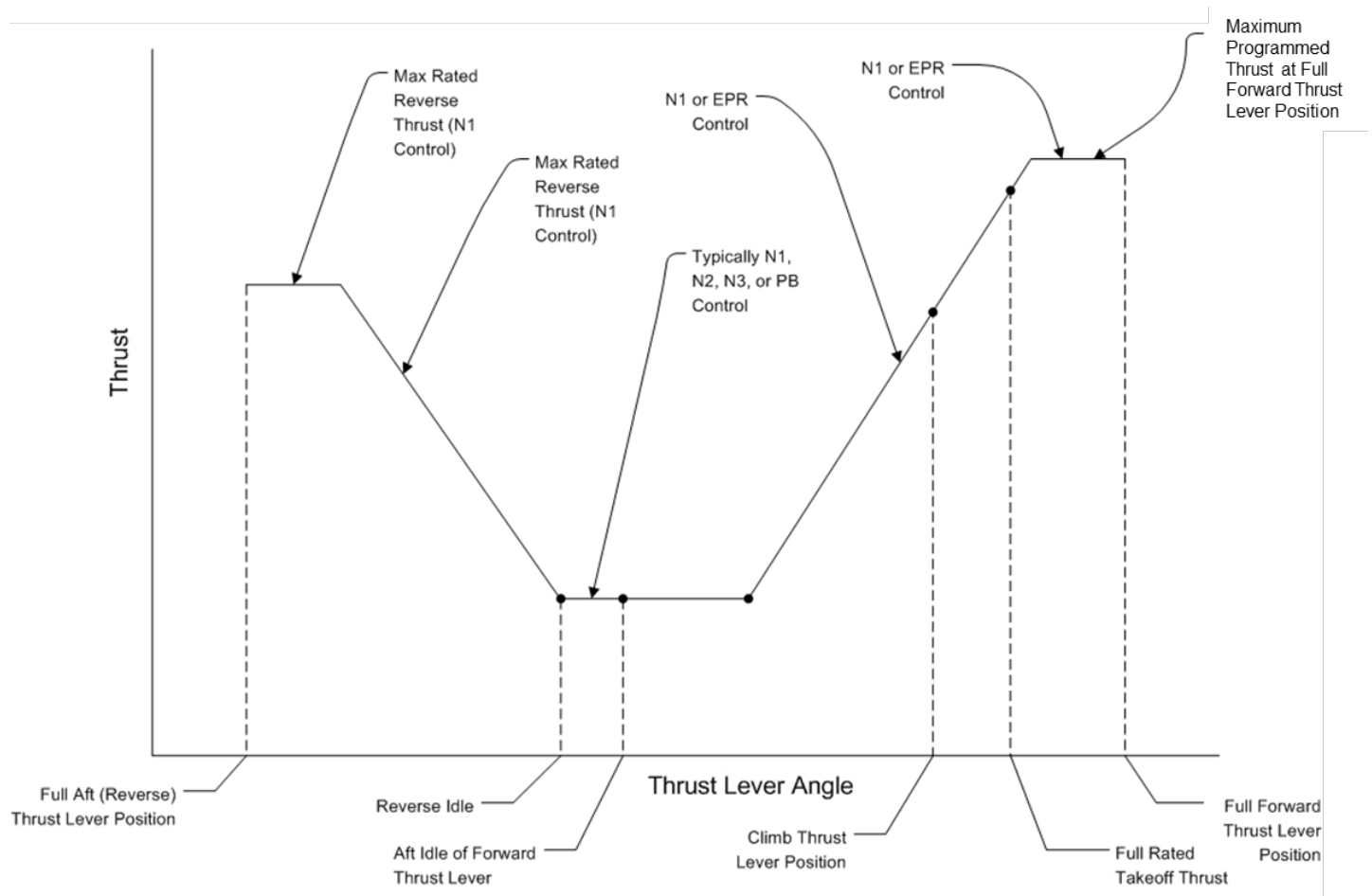


Figure 5 - Example of thrust versus thrust lever angle

4.1.2 Backup, Alternate, or Reversionary Mode - Steady State Control Functions

This section describes the main backup, degraded, alternate, or reversionary mode for steady state engine operation. For simplicity, this mode will be referred to as just backup mode in this document. This backup mode for thrust and power control is activated when the FADEC system loses the capability to control the engine based on the main thrust or power setting parameter or the capability to calculate the primary rated thrust. This backup mode is used to increase engine dispatchability or increase level of safety by providing a get-home mode. The backup modes must assure that there will be no hazardous engine effect and no unacceptable change in thrust, operating, and starting characteristics. Transition to a backup mode must be in accordance with 14 CFR § 33.28(c) and CS-E 50(b). They must be documented, tested, and approved by authorities and airframer. The AMC 20-3 gives indications, guidance, and acceptable means of compliance for backup mode implementation in case of loss or corruption of aircraft-supplied data.

Some applications, such as general aviation applications, may choose to not incorporate a backup mode due to acceptable dispatch reliability without the added complexity of incorporating additional modes. Another possibility to avoid this complexity is to implement an adequate level of redundancy for the main signals to eliminate the need to develop a backup mode, which is being used in some applications.

Some FADEC systems have a backup operating mode that is usually a non-rated mode (e.g., systems with EPR as the primary thrust control parameter). As the thrust lever is advanced from idle to the full forward position in this mode, thrust goes from idle to some high level of thrust, which in many environmental conditions may be well above the engine maximum rated thrust. The control may enter the non-rated mode as a result of a failure in the control that made the primary mode unusable or simply because the flight crew commanded the mode via a cockpit-located mode selection switch. If this non-rated mode results in inability to modulate thrust or power between idle and 90% of maximum rated power, this condition should be considered as a loss of thrust control (LOTIC)/loss of power control (LOPC) event and is probably not dispatchable.

There are applications in which the backup mode is a rating mode like the normal (or primary) mode. In these designs, rated thrust in the backup mode may or may not be equal to rated thrust in the primary mode. If takeoff rated thrust in this mode is different than the primary mode, a gross weight (GW) penalty would be applied to aircraft performance when dispatching in this mode. A typical example for this type of architecture is an engine control system that uses EPR as the primary mode and N1 as the backup mode, where a rated thrust can be defined for both modes.

In some applications, the aircraft is fully dispatchable with the engine controls operating in the backup mode. Usually, all engines are required by approved operating procedure to be placed in the same mode at dispatch. This maintains thrust lever alignment as well as similar performance on all engines. These backup modes can be dispatchable if they comply with CS-E 1030 Time Limited Dispatch and CS-MMEL requirements.

For single failures or multiple failures that result in LOTIC/LOPC, FADEC systems can provide backup modes that minimize the impact of the failures but with no guarantee on the engine performance. They are considered as get-home modes and they give an extra capability for the engines to keep producing thrust/power. These modes are used to keep the engine running after the control has suffered one or more significant component faults or failures. This report does not address these get-home modes in any detail. This report discusses the backup mode for thrust and power management because it affects the integration of the control system into the aircraft. In addition, it is usually desirable to gain approval for dispatching the aircraft with all engines operating in the backup mode - even though there may be an associated GW penalty or operational restriction for these dispatches.

For engines that use EPR as the thrust setting parameter in the primary mode, the backup mode is usually an N1 governing control. For engines that use N1 as the engine power setting parameter, N1 is usually still used as the thrust setting parameter in the backup mode. If N1 is used in both the primary and backup modes as the power setting parameter, the backup mode is usually a simplified N1 scheduled function, such as a function in which the engine goes from idle to N1 redline, or a chosen maximum N1 value as the forward thrust lever is advanced from idle to the full forward stop, such as in the case where the EEC loses air data information. (See 4.2.2 for a discussion of thrust scheduling logic in the backup mode.)

Typically, a backup mode can be implemented for engines that rely on aircraft sensors for air data, particularly the total pressure that is used to compute the Mach number, which is a key parameter for thrust ratings calculation. Loss of the FADEC system capability to calculate an airspeed signal, loss of or inability to use the air-data computer (ADC) airspeed or Mach number signals, or loss of the capability to compute EPR for an EPR-rated engine are the predominant reasons for transitioning out of the primary mode and into the backup mode. For systems that do not have adequate level of redundancy for airspeed or Mach number signals, it is good design practice to have the backup mode(s) independent of aircraft airspeed and Mach number information.

On engines using N1 as the primary power setting parameter, with systems that have multiple sources of airspeed or Mach number signals with no common mode failure, a voting logic can be implemented to select between aircraft and engine sensors, and a backup mode independent of these signals can be considered not necessary. This is typically the case of engines that have dedicated dual P2 and Pamb sensors, which makes the system not required to rely on the aircraft supplied P2 (or Mach number computation) and Pamb data. With dedicated sensors for P2 and Pamb, the engine is generally robust enough to a single failure to avoid the use of a backup mode. The classic architecture consists of using two dedicated engine sensors for P2/T2, which are generally located at the engine inlet, and two ambient pressure sensors directly located on the EEC unit. To complete this architecture, the FADEC also receives air data signals from the aircraft via a digital data link. This configuration allows the FADEC systems to detect and isolate a drift on one of the redundant signals by comparing it to the other sources of the same information. Another possible architecture to provide redundant information is through the transmission of air data information from other engines through a direct communication link between engines. In this case, the P2, Pamb, ambient temperature, and T2 are exchanged between engines to ensure adequate redundancy and the ability to isolate drift faults in a single signal. Special care must be taken to comply with certification requirement 25.903(b) Engine Isolation to prevent a failure condition where all engines use the same failed air data signal(s).

On engines that do not have their own P2 probe, the calculation of the N1 set point is based (among other things) on the total pressure parameter sent by the aircraft via an aircraft-supplied data link. In some applications, the existence of a common mode on the data link provided by the aircraft and the absence of a dedicated communication link between the engines will prevent the engine from using aircraft total pressure in the event of data link failure. To cover this case, these systems have to set up an alternate mode consisting initially of a soft revisionary mode, which freezes the calculation of the Mach number just after the loss of the total pressure signal. A hard alternate mode is triggered to replace the soft alternate mode at a second stage if the change in altitude is significant or if the thrust control is significantly changed. The hard alternate mode is generally a calculation of the simplified N1 setpoint, which ensures the thrust modulation capacity and generally provides more thrust at the maximum thrust lever position than in normal mode.

For turboprop engines with dual-channel FADEC systems, backup or get-home control modes are similar to the turbofan engine applications. On single-channel EEC systems, the backup mode can be provided by a mechanical speed governor system.

4.1.3 Controller Operation during Engine Transients

Control functions governing transient engine operation may be the same in both the primary and backup modes of controller operation. Fuel flow adjustments usually result from the difference between the command and actual values of the thrust or power setting parameter, controlling the rate of change of engine core speed or on a maximum (or minimum) allowed fuel flow schedule during the transient. Engine startup and acceleration to idle may also be the same in both the primary and backup modes, as are the auto-start and auto-relight functions (if provided). Avoid significant differences in engine operability when operating in the backup mode, as these differences can adversely affect flight crew workload.

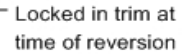
4.1.4 Use of a Soft Reversionary Mode

As engine thrust (or power) as a function of thrust lever position is usually significantly different in the primary and backup modes, a significant thrust or power change on the engine would occur if the control were to transition suddenly from one mode to the other at a high-power engine operating condition. Control mode transition must comply with certification requirements 14 CFR § 33.28(c) and CS-E 50(b). Control mode transition from primary to backup mode is supposed to be sufficiently smooth to not generate unacceptable thrust change. Generally, adequate alerts should inform the flight crew, especially if the crew is required to react to the control mode transition. Because significant thrust changes are undesirable, many system implementations use a soft reversionary mode to facilitate the transition from the primary mode to the backup mode. The soft reversionary mode provides a path by which the control can leave the primary mode without implementing a significant power change on the engine. The soft reversionary mode is a holding mode. That is, when a detected fault occurs that causes the control to not be able to maintain the primary mode, the control automatically enters the soft reversionary mode and remains there until flight crew action initiates full backup mode operation. Full thrust modulation (via thrust lever movement) should still be available in this soft reversionary mode. The soft reversionary mode is not intended to be a fixed thrust mode.

A soft reversionary mode is reasonably simple to implement. When the control has determined that it has a fault condition that cannot maintain the primary mode, it calculates the value of the backup parameter (e.g., N1 or N2) that the backup mode would command on the engine at the given thrust lever position and computes the difference between that calculated value and the actual N1 engine operating value at the time of the transfer. The control then locks this difference into the command schedule of N1 that the control would implement in the backup mode. Figure 6 illustrates this scenario. The backup mode with the locked-in trim is called the soft reversionary mode. It allows the engine to leave the primary mode with essentially no thrust change. The control then stays in this mode until the flight crew, through a distinct command signal to the control, commands the control to enter the complete backup mode. On receipt of this signal, the control sets the locked-in trim signal to zero. The flight crew should be trained to place the engine at an intermediate power condition before activating the backup control mode command. This will prevent the control from commanding what could be a large overboost power condition when the backup mode is commanded by the crew.

A question is often asked as to how well this transition works if it occurs during an engine transient. This has not proven any kind of significant difficulty. If the engine is at steady state during the transition, essentially no thrust change occurs; if the engine is in a transient, the flight crew is in the process of changing thrust due to a flight crew command, and if the locked-in value of trim is not the correct steady state one, this causes no significant difficulty, as the flight crew is expecting a power change.

Some implementations wash out the locked-in trim value of N1 as the thrust lever is moved from its position at the point of transfer. These implementations are slightly more complex, and since the flight crew should be trained to activate the backup mode when operating in the soft reversionary mode, this extra complexity may be unnecessary.



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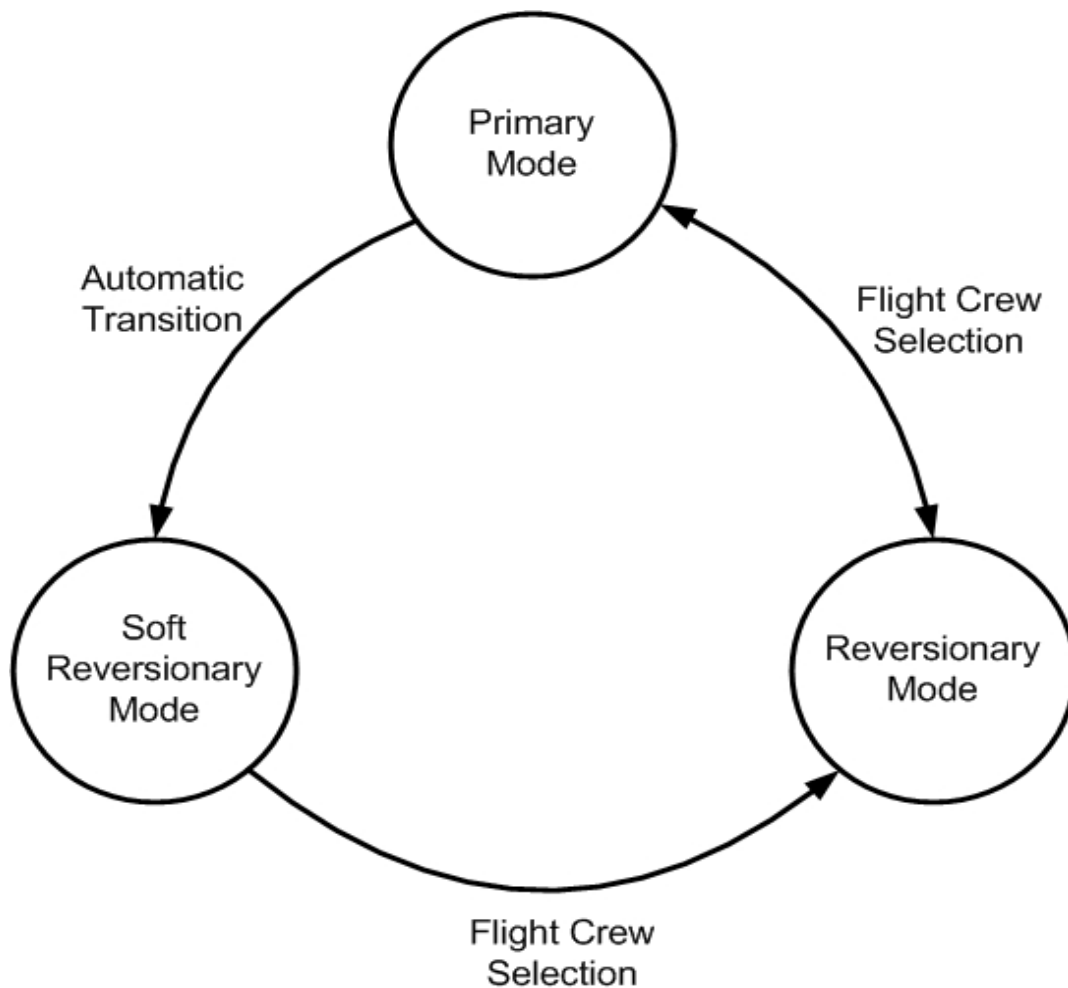


Figure 7 - Logic for mode selection

In case the control does not have the necessary signals for the primary mode, reversion to the primary mode should be locked, and the control should provide an indication of primary mode failure (see 7.1.1.3).

The reversion to primary mode is generally possible when primary mode is confirmed to be operational. If the flight crew activates a transfer from the backup mode to the primary rating mode at a forward thrust lever position, engine thrust may significantly decrease. If this were to happen in the takeoff mode to multiple engines, the aircraft might experience a significant thrust loss. If this reversion to primary mode is considered undesirable due to engine/aircraft operation condition, the control can prevent the transfer when a transfer command to primary mode is received and the engine is at high power and airspeed is low (for example, less than Mach 0.35 or Mach 0.4). If control logic is incorporated to do this, the control should not implement an automatic mode transfer to the primary mode when power is reduced or airspeed increases to a value above the decision threshold, because this would result in an unexpected thrust change. It is recommended that the control contain the logic to require the mode command signal to go through a reset, so that the mode command signal returns to the original state and is then reissued before the control accepts the signal. Each engine FADEC system should have a separate, independent mode command signal, and the flight deck indication of backup mode operation should remain until the command is reissued.

Many FADEC systems will switch between primary and backup mode automatically. This is typically done based upon system health reporting or the quality of the data from sensors used to calculate thrust. In this case, unexpected thrust change should be avoided during mode transitions. Depending on the application, the FADEC may require a power cycle or maintenance action to return the control to primary thrust mode.

4.1.6 Initiation of the Primary/Backup Mode after Engine Start

4.1.6.1 Engines Using EPR as the Primary Power Setting Parameter

Establishing a valid P2 signal is essential for engines using EPR as the primary power setting parameter. After a successful engine start, the engine control needs to determine whether to operate in the primary, backup, or soft reversionary mode. This can be complex because it depends on the operational state of the aircraft electrical power system at the time of engine start. The aircraft may be completely de-powered - except for aircraft battery power - when the first engine is started, or the aircraft may be powered by a ground power source at engine start. When the aircraft is not powered by an electrical power generator, non-essential loads are normally kept de-energized to avoid depleting battery, which may result in some aircraft signals not available for the FADEC system.

Control systems for engines using EPR as the primary thrust (or power) setting parameter will probably have their own control system dedicated total pressure probe. It is assumed that this is the case and that the control system dedicated total pressure probe, P2, is mounted inside the engine inlet and uses aircraft-provided electrical power to heat the probe and prevent probe icing. Assuming that the aircraft generators are not disengaged, and that the aircraft is not on ground power during the first engine start, the aircraft electrical system will power up when the first main generator comes online at approximately 5% below engine idle speed. Following this first engine start, aircraft power should be available for the engine control system dedicated P2 probe. The aircraft may (1) switch probe heat on automatically, (2) supply power to the control system and let the FADEC system switch it on (this is the preferred system), or (3) have the flight crew activate engine probe heat via a cockpit-located probe heat switch (the least preferred configuration). If the aircraft is configured to power the probe automatically or supply power to the engine control system (so that the FADEC system can turn on probe heat), the sequence may take several seconds. So, the FADEC system should wait an appropriate time period after reaching idle to ensure that the electrical power transfer to the engine-driven generator has been completed, before determining whether probe heat has been activated. It is desirable that the control system has its own dedicated current sensor for establishing probe heat on/off status. If not configured this way, the FADEC system will have to receive an aircraft discrete for this function. Assume that probe heat will be confirmed within the wait period, and do not have the FADEC system send any abnormal indications during this wait period. It is normal to be sending a valid EPR signal during engine ground starts, even though probe heat may not be on during starting. If confirmation of probe heat on is not received within the wait period (after reaching idle), invalidate the EPR signal and have the FADEC system begin sending the primary mode fail flag and the backup mode active signal and initiate control operation in the backup mode.

If the control is in the backup mode and the P2 probe heat on discrete is received from the aircraft (or probe heat current is sensed by the FADEC system), the FADEC system should stay in the backup mode, continue to send out the backup mode active signal, and stop sending the primary mode fail signal. Considerations should also be given to how fast an iced probe can be de-iced after probe heat is recovered before inhibiting/removing the primary mode fail signal (see 6.2.2.5).

4.1.6.2 Engines Using N1 as the Primary Power Setting Parameter

4.1.6.2.1 FADEC Systems with a Dedicated P2 Probe (and also a Pamb Sensor)

For those FADEC systems using N1 as the power setting parameter, and in which a dedicated P2 probe is provided, the activation of the backup mode following the engine start can be essentially the same as given in the above discussion for EPR-rated engines. For systems that the P2 probe is heated all the time, after a successful engine start, the FADEC system needs to receive that the P2 probe heater has been activated within the wait period. Prior to this time, the FADEC system can assume that P2 signals are valid since they are not relevant during ground start. After the wait period, if the P2 probe heater has not been activated, P2 signals can be declared invalid and proper accommodation strategy should be used.

In some applications, the P2 probe is heated only when engine ice protection is commanded or at low ambient temperatures. In such systems, the P2 signals with heater failed can still be used if ice accretion on the P2 probe is not expected.

For N1-driven engines, the P2 probe is not used during starting or idle and is mainly used for N1-rated thrust computation. So, validity of de-icing of the probe during engine start is not critical.

4.1.6.2.2 FADEC Systems without a Dedicated P2 Probe (but with a Pamb Sensor)

For those FADEC systems that do not have a dedicated P2 probe, the logic is similar to those with a probe. The FADEC system needs to receive valid total pressure signals from both ADCs, with at least one having probe heat on. The ADC total pressure signals should agree within approximately 2 to 3% of point. However, during ground operation at low forward speeds, the aircraft total pressure signals from the ADCs can vary significantly due to side-wind conditions, so the FADEC system should contain logic to accept a fairly large difference (such as 10% of point), for a reasonably long time (such as 15 seconds), before declaring a disagree between the aircraft total pressure signals. Because of cross-wind effects, many current systems are configured to not implement a cross-comparison of aircraft total pressure signals at low airspeeds.

If valid ADC total pressure signals are not received within an appropriate wait time after the engine reaches idle, with an indication that at least one of the ADC-dedicated total pressure probes has probe heat on, the FADEC system should revert to the backup mode and transmit the primary mode fail and backup mode active signals. The wait time interval is normally selected to allow for electrical power system transfers during engine starting. Again, after initiating the backup mode of operation, the control should not change modes without receiving a flight crew command to do so. If an indication that probe heat is on is received after that backup mode has been initiated, the FADEC system should remain in the backup mode, but it can indicate that the primary mode is available (assuming that it has the other needed resources for primary mode operation) by ceasing the transmission of the primary mode fail signal.

4.1.7 Control Modes on Turboprop Engines

Turboprop transport and large general aviation aircraft typically adopt the constant speed propeller concept, since it provides a better performance over a wider range of flight conditions. On this concept, the engine is governed on selected power by varying fuel flow, while the propeller is governed on selected propeller speed or blade angle, as described below:

- Forward thrust: The propeller is governed on selected propeller speed by varying propeller pitch.
- Reverse thrust: The propeller is governed on reverse propeller speed by varying propeller pitch angle. An alternate reverse control method is to use a blade angle schedule in reverse with an under-speed limiter function.
- Transition between forward and reverse thrust modes: The propeller control is based on propeller blade angle scheduling.

The operation below the flight low pitch limit is known as beta mode. In this mode, the propeller control is based on propeller blade angle position. The beta mode is used at low aircraft speed and at low power demand. In this mode, the propeller speed is controlled through the engine fuel flow.

4.2 Thrust Scheduling Logic

4.2.1 Primary Mode

4.2.1.1 Engine Idle Control

Transport category aircraft usually use several engine idle control functions. Examples of these are as follows:

- An idle schedule established to allow operation on a minimum physical or corrected core speed. There may be different schedules for ground and in-flight operation.
- Minimum core speed or bleed air pressure schedules that allow the engine to deliver given levels of engine air bleed or maintain minimum acceptable bleed pressures and temperatures. These schedules are generally at higher levels of core speed than the minimum allowed physical or corrected speed schedule, and there may be different schedules for normal bleed and the higher bleed airflows required when cowl and/or wing anti-ice are selected on. (When anti-ice bleed is on, the schedule may be established by an engine requirement to maintain a given level of core speed, above that required for engine bleed during icing conditions.) The ability to govern the engine to maintain a minimum bleed pressure at idle can result in high idle thrust conditions that affect descent and glide slope capture capability. These conditions are generally caused when the bleed demand of the aircraft requires higher engine bleed pressures at idle, thus requiring higher idle thrust. The result is a negative impact on descent profile. Logic can be and has been incorporated to cancel this higher idle speed and return to the normal, lower flight idle speed when the aircraft is in the approach configuration. This should eliminate the negative impact on landing speeds and distances that could result from a higher idle thrust.
- Minimum core speed for the accessory gearbox - The aircraft manufacturer may request a minimum core speed to allow the proper functioning and minimum performance of the accessories, such as electrical generator and hydraulic pump, that are driven by the engine accessory gearbox connected to the engine core rotor.
- A still higher idle speed schedule (sometimes called approach idle) established to allow the engine to achieve a given level of thrust within a specified number of seconds following a snap accel command. This idle speed is established by the aircraft go-around thrust requirements. Approach idle in transport category aircraft is usually activated when the aircraft is configured for approach and landing. The approach and landing configuration has a higher associated drag, and thus the descent profile is still maintained with the higher idle thrust.
- Flight idle schedule(s) (normally core speed governing) intended to provide a controlled low level of thrust during descent or approach.
- Ground idle schedule(s) (normally core speed governing) optimized for ground operations. Sometimes a higher (elevated) reverse idle is established when the thrust reverser is initially commanded to deploy. This allows the engine to start to spin up so that when the thrust reverser is deployed, and maximum reverse thrust is commanded the engine is already accelerating and reverse thrust can be achieved quicker.
- Turboprop applications may include additional idle control functions associated to functions or accessories driven by the propeller gearbox. For example, an electrical generator driven by the propeller gearbox may require a minimum speed in order to maintain a minimum electrical frequency output for the aircraft system. The propeller system may also require a minimum propeller speed control (under-speed governing) in order to maintain proper thrust management characteristics of the propeller system at low aircraft speeds. On certain turboprop engines, controlling the speed of the propeller with the pitch angle can be difficult at low power, especially on the ground at low airplane speed, because of the aerodynamic characteristics of the propeller at low power. In this case, some applications have a specific propeller speed control mode called beta mode. In beta mode, the propeller pitch is scheduled in open loop according to the thrust lever position and the airplane speed, and the propeller speed is controlled in closed loop by modulation of the flow rate of fuel.

4.2.1.2 Thrust Ratings

Power management functions provide thrust ratings that establish rated thrust for specific flight phases. Thrust ratings are elaborated in order to comply with airframer thrust requirements. These requirements generally vary according to atmospheric conditions (altitude, Mach, and ambient temperature) and aircraft needs for bleed and mechanical power extraction. The thrust setting parameter in most fan engines is N1, EPR, or TPR. On turboprop applications, the thrust setting parameter is generally the power or torque, and the rating defines also the applicable propeller set point speed. The control of the thrust is carried out by a closed loop control on the defined thrust setting parameter.

Takeoff, climb, and maximum continuous thrust are generally established to achieve good engine life (from the engine manufacturer viewpoint) and good aircraft performance (from the aircraft manufacturer viewpoint). Those two viewpoints are, by their very nature, conflicting. For fixed-wing transports, maximum continuous thrust is generally less than takeoff thrust and normally is intended for use only during one engine inoperative (OEI) conditions. However, according to FAA Policy Letter TAD 00-113-1028, it must always be available, and nothing should prevent its use during all-engines operating conditions. The use of maximum continuous thrust usually has a significant effect on engine life, so its use may be operationally limited to preserve engine life. With the high levels of engine reliability being achieved with turbine engines, the need to use maximum continuous thrust due to an OEI condition is reasonably rare.

Takeoff, climb, maximum continuous, and maximum cruise thrust ratings are generally functions of a combination of altitude, total air temperature, and airspeed (or Mach number) information. Per certification requirements 14 CFR § 33.7 and CS-E 40, the only certified thrust ratings that must be established are the takeoff and maximum continuous ratings. Climb and cruise rating are agreed thrust ratings between the aircraft and engine manufacturers.

Aircraft bleed air extraction from the engine compressor is another important parameter to be considered in the engine power management. The airframers must provide the bleed extraction demands to aircraft anti-ice and environmental control systems, and these bleed extraction levels must be considered in the thrust ratings elaboration. When the aircraft increases the bleed extraction level, a bleed decrement must be applied to the power setting parameter (N1, EPR, TPR, torque, or power) so that the EGT margin is preserved. Note that typically this bleed decrement is not applied for the reverse thrust, since the reverse thrust selection has short duration and normally the aircraft anti-ice system is commanded off during landing and rejected takeoffs.

On turbofan engines, the computed thrust ratings guarantee the thrust according to aircraft manufacturer needs. The minimum thrust is guaranteed including power extraction and sensors accuracy in all engine control system dispatchable configurations.

When operating with the thrust reverser deployed, a separate reverse thrust rating is used to schedule thrust. This is typically implemented as a fixed corrected fan speed (N1C), even for EPR and TPR rated engines.

4.2.1.3 Various Thrust (or Power) Scheduling as a Function of Thrust Lever Position

Sections 4.2.1.3.1 to 4.2.1.3.5 provide information about thrust or power scheduling as a function of thrust lever position. Particularities for turboprop applications, which also require means to control propeller speed, are described in 4.2.1.3.6.

4.2.1.3.1 TLA Selection of Thrust

It is recognized that at any given, fixed thrust lever position, thrust can change with changes in altitude, temperature, and airspeed. However, in this system implementation, the setting of a given value of the thrust setting parameter, either EPR or N1, must be achieved by moving the thrust lever. The descriptions given in the 4.2.1.3.2 and 4.2.1.3.3 are for aircraft that use a thrust versus thrust lever position schedule in which idle thrust, cruise thrust, climb thrust, takeoff thrust, and maximum programmed thrust are obtained at specific thrust lever positions as the thrust lever is advanced from the idle stop to the full forward stop. Figure 8 shows a typical fan speed versus thrust lever position schedule for such a system. The thrust lever position for full takeoff power is usually the same as that for maximum continuous power when outside the takeoff envelope.

Maximum continuous thrust is less than takeoff thrust and generally higher than climb thrust. When operating in the takeoff envelope, maximum continuous thrust is achieved at a thrust lever position between climb and takeoff. When outside of the takeoff envelope, maximum continuous becomes the maximum power setting. At high altitudes, maximum continuous is usually just a little higher than or equal to the climb power setting. Figures 8 and 9 show typical fan speed and thrust settings as a function of thrust lever angle at different operating altitudes.

In some aircraft, the thrust lever can be set to a given position, and when in that position, the FADEC system receives a command from some other aircraft avionics box as to the value of EPR or N1 to be implemented by the control. This is an autothrust system with non-moving thrust lever, and it is discussed in 4.2.1.6.2.

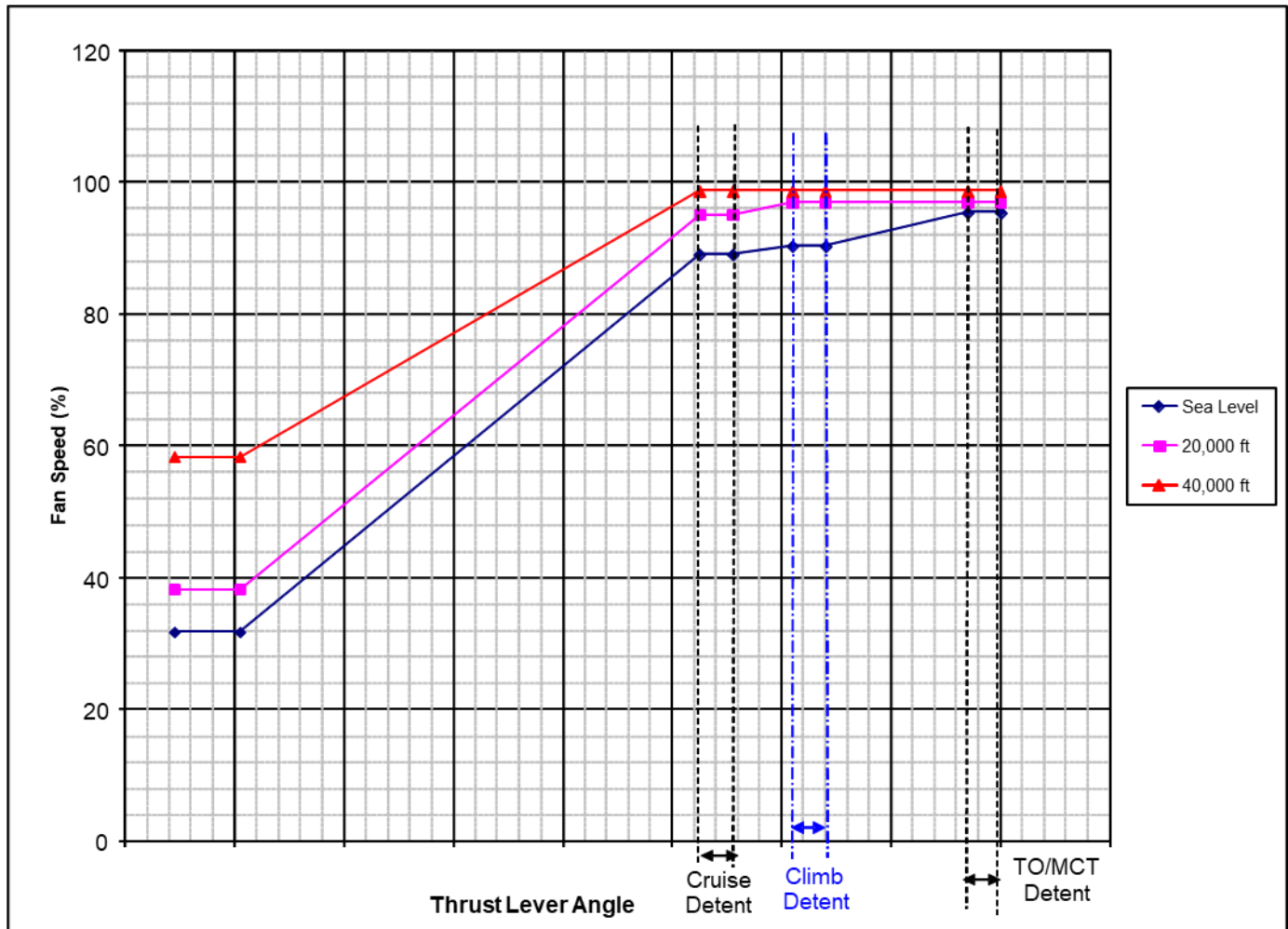


**Figure 8 - Typical altitude dependent fan speed versus thrust lever angle
(dashed lines show flat regions for the cruise, climb, and TO/MCT power setting detents)**

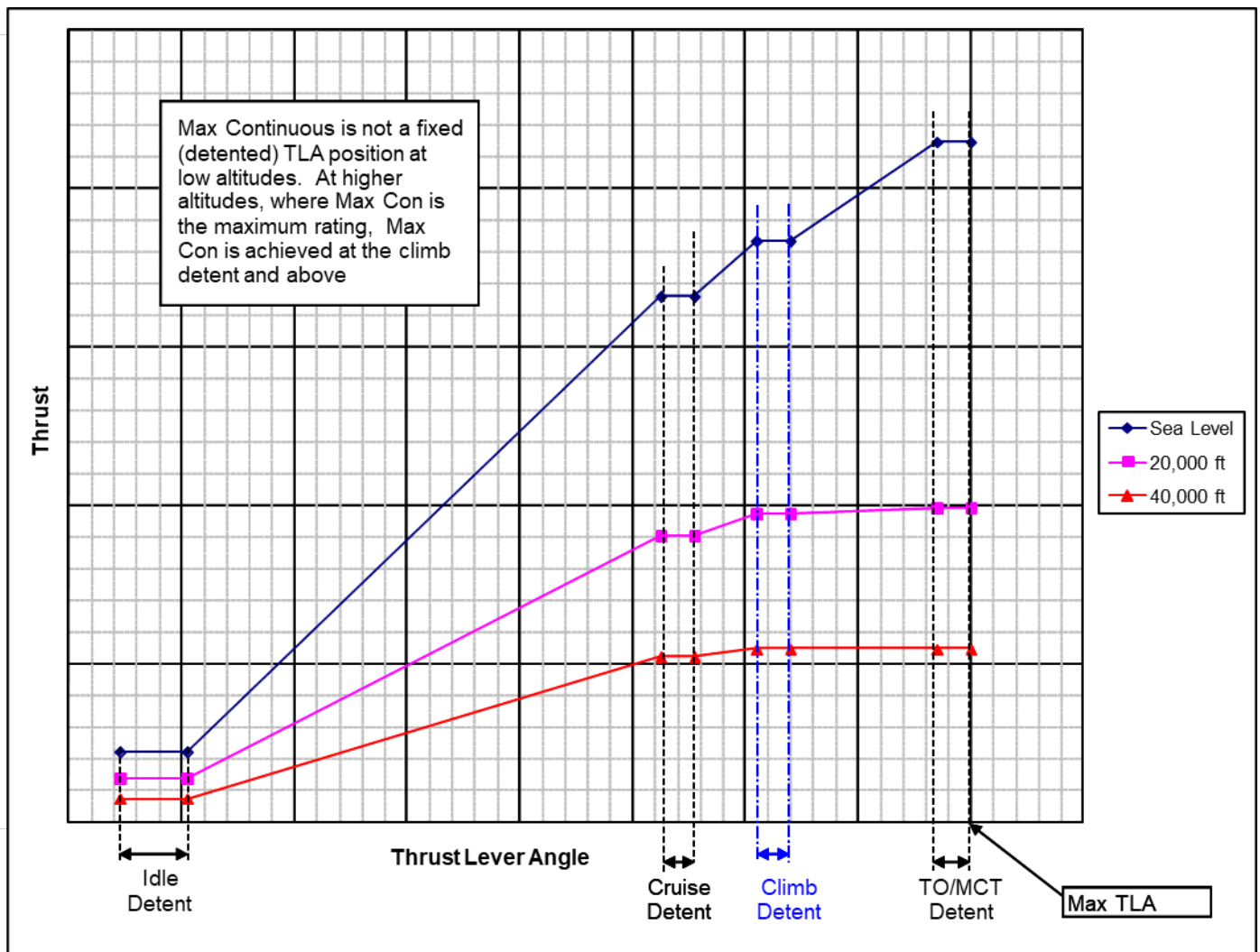


Figure 9 - Typical altitude dependent thrust schedules versus thrust lever position

The thrust commanded by the control at the full forward thrust lever stop (that is, about 2 to 3 degrees before the maximum physical stop) is referred to as the maximum scheduled thrust. This thrust level may be above the engine certificated takeoff or maximum continuous thrust. The difference between this maximum scheduled thrust and the engine maximum certified thrust is generally called headroom. Some applications may use headroom to ensure that with the worst-case stack of system sensor errors (that is, the errors associated with operation on engine sensors only), the control can always achieve the certified thrust rating for the condition. The purpose of headroom is to ensure that each and every installed engine is capable of delivering its maximum rated thrust at the full forward thrust lever position. Typical values for headroom are 0.5 to 1.5% thrust above the maximum rating. Thrust from this thrust lever position to the stop can be flat (that is, no increase as the thrust lever moves forward from that position). The 2 to 3 degrees thrust lever travel allows for inaccuracy in the rigging of the thrust lever position transducer and the associated errors in thrust lever position measurement. The design intent is that the engine will always be able to achieve its maximum certificated thrust and will not be limited due to normal tolerances in the thrust lever system. There are no certification requirements in this area as long as the flight crews are not trained to advance the thrust levers to the stop to achieve maximum rated thrust. Therefore, it is recommended that the flight crews be trained to set power to the target during normal operations, and only advance thrust levers to the full forward stop during extreme situations, such as those resulting from wind shear. Typically, general aviation aircraft do not provide headroom at the full forward thrust lever position.

There are two ways to determine the value of the power setting parameter (to which the engine will be controlled) as the thrust lever moves from the climb power position toward idle:

- Set up a low value of the same parameter as the climb power setting parameter at a forward idle thrust lever position and interpolate between this value of the climb power setting value for thrust lever positions between climb and idle.
- Multiply the climb power setting parameter value by a number less than unity and decrease the number as the thrust lever moves toward the idle stop (see Figure 10). Establish minimum lower limit operating values for the various other engine parameters, such as N2, N3, burner pressure (Pb), and fuel flow divided by burner pressure (Wf/Pb), and if the engine would want to operate below one of those values as the thrust lever is retarded to idle, switch over to that other engine parameter at idle to protect that parameter from dropping below its lower limit.

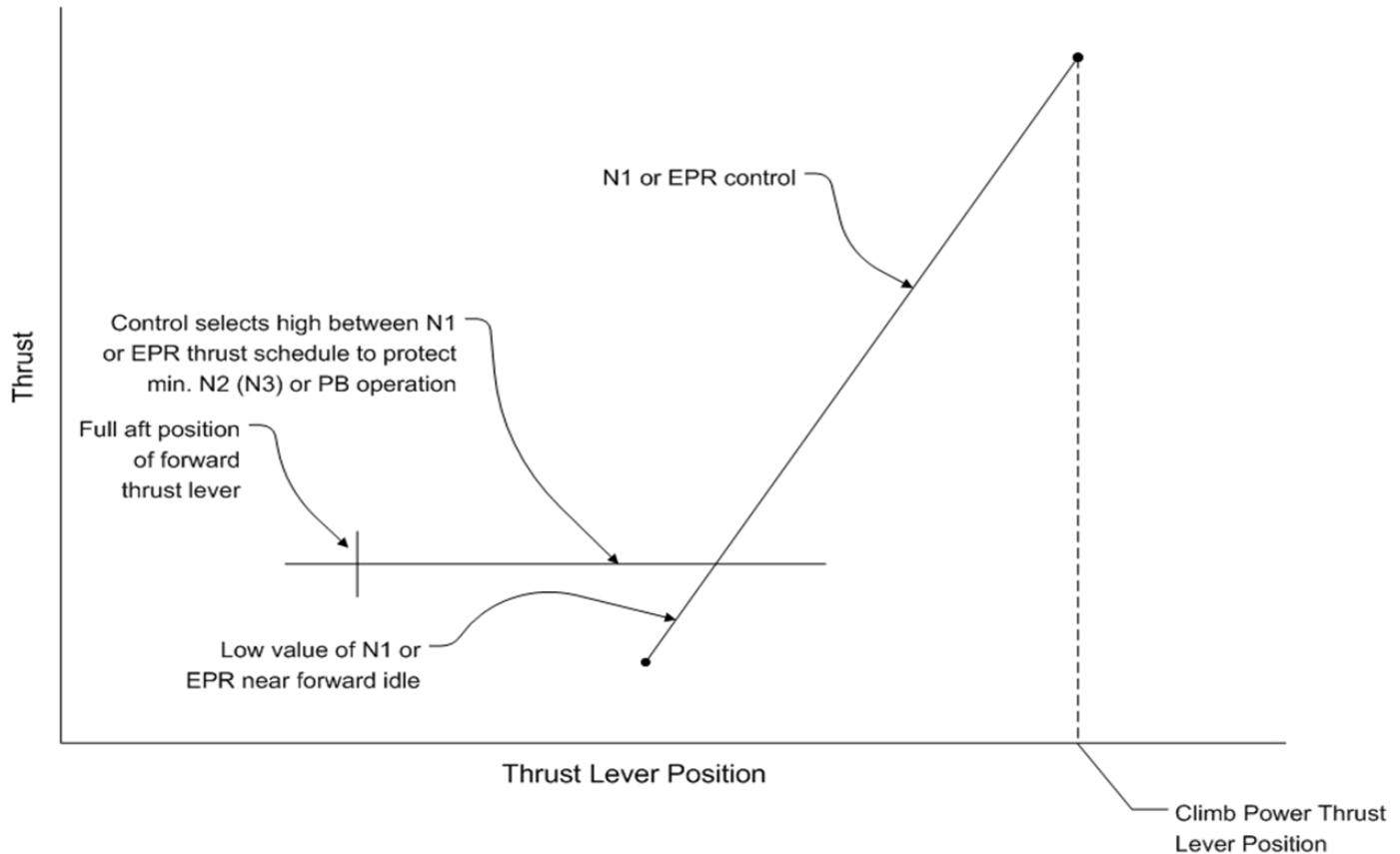


Figure 10 - Example of multiplier schedule

In many FADEC systems, the parameter being controlled when the engine is operating above idle is different than the parameter being controlled at idle. For example, engine N2 (or N3) or burner pressure may be the parameter being controlled at idle, and above idle the control parameter may be N1 or EPR. In these cases, the control transfers over to the idle control function if the controlled parameter when above idle, such as of N1 or EPR, would result in a value of the idle control parameter that is less than the idle function would allow. Either of the two approaches above can be constructed to provide a smooth transition between control parameters.

It is desirable to have the crossover from the normal EPR or N1 control to idle control occur at least 2 to 3 degrees above the thrust lever idle stop to ensure that the engine can achieve idle thrust. Flight crews typically squawk non-agreement between engine rotor speeds and other parameters during engine-idle descent conditions. Therefore, it is highly desirable that during normal flight descent conditions, all engines are operating on the same idle control when the thrust or power lever is at the idle position. Care needs to be taken to ensure the crossover point from idle to EPR or N1 control does not occur near typical approach power settings to avoid larger than expected thrust changes with small TLA movements typical on approach.

The thrust lever positions for the climb and takeoff power settings are usually determined so that thrust from idle to the maximum programmed power setting increases approximately linearly with thrust lever position.

When the thrust reversers are deployed, reverse thrust is not typically set to a target (not modulated) but rather by the flight crew pulling the thrust lever to a hard stop in the reverse direction. The FADEC may use a lever position setpoint a few degrees before the physical stop to command maximum reverse thrust, and there is typically no headroom adder in reverse thrust. Reverse idle to maximum reverse thrust typically increases linearly with thrust lever position.

4.2.1.3.2 Installations Using Thrust Lever Detents

With the advent of FADEC systems, the various thrust settings, such as maximum takeoff, maximum climb, and maximum cruise thrust, can be programmed to occur at fixed thrust lever positions. Figure 11 shows a typical fixed position thrust lever quadrant, where the fixed positions are for cruise, climb, and TO/MCT thrust. Figure 12 shows the cross-section of such a quadrant. Figure 9 provides a typical example of how thrust would be programmed as a function of thrust lever position at various altitudes. In Figure 9, the detented flats for the cruise, climb, and TO/MCT positions only have to be wide enough to take care of the thrust lever position transducer signal variations at those detented thrust lever positions.

During cruise flight phase, normally the engines are set to a thrust level required to maintain cruise speed, which normally is below the maximum cruise thrust. Because of that, some may choose to not implement a cruise detent. On the other hand, if there is a concern that the pilot may exceed the maximum cruise thrust during cruise phase, the cruise detent can aid the pilot on this task, avoiding problems related to engine life and accelerated deterioration.

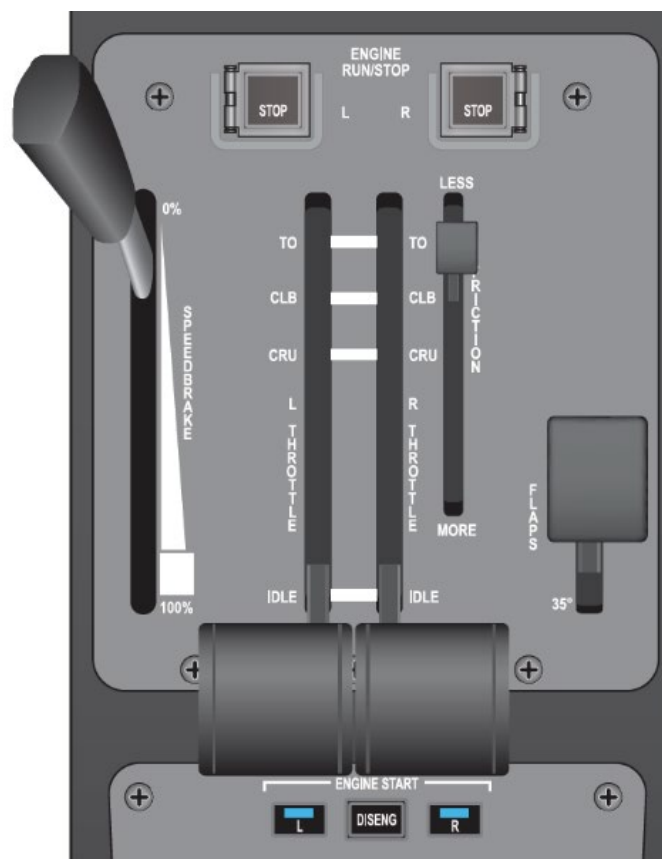


Figure 11 - A detented, or fixed position, thrust lever quadrant

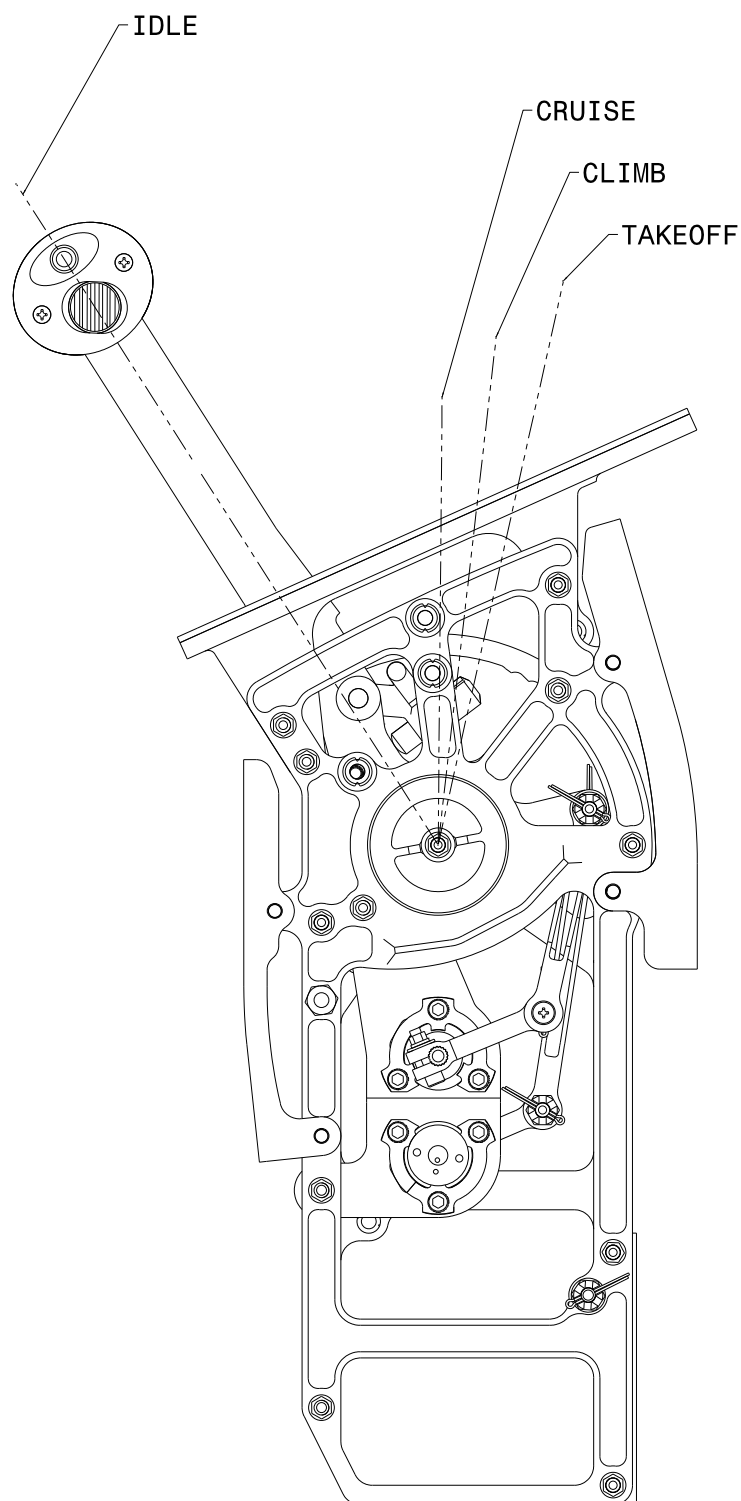


Figure 12 - Cross-section of a detented, or fixed position, thrust lever quadrant

4.2.1.3.3 Installations without Thrust Lever Detents (Using Autothrottle Systems)

Figure 13 shows how thrust might be scheduled with thrust lever angle for systems that do not use thrust lever detents. In this case, there are no flats at the maximum cruise, maximum climb, and other thrust lever positions. These systems often have autothrottle systems with thrust lever servos that move the levers to a position that achieves the requested thrust setting. Most transport aircraft have autothrottle systems that have separate servos for each thrust lever. In this case, each engine can be individually driven to the location that satisfies the desired thrust setting, but a single servo that drives all thrust levers can be used as well. In either of these configurations, it is best if there is a control law that keeps the thrust levers reasonably well aligned, so that if one lever does not move or hangs up for some reason, the other lever(s) do not continue to move and create a significant thrust asymmetry. Whether one servo for all thrust levers or separate servos are used for each lever, there will be a bit of lever stagger due to thrust level position transducer differences versus the position of each lever. However, the thrust lever stagger is usually small and acceptable when less than one-quarter of a knob. Note that autothrottles are not typically used in reverse thrust.

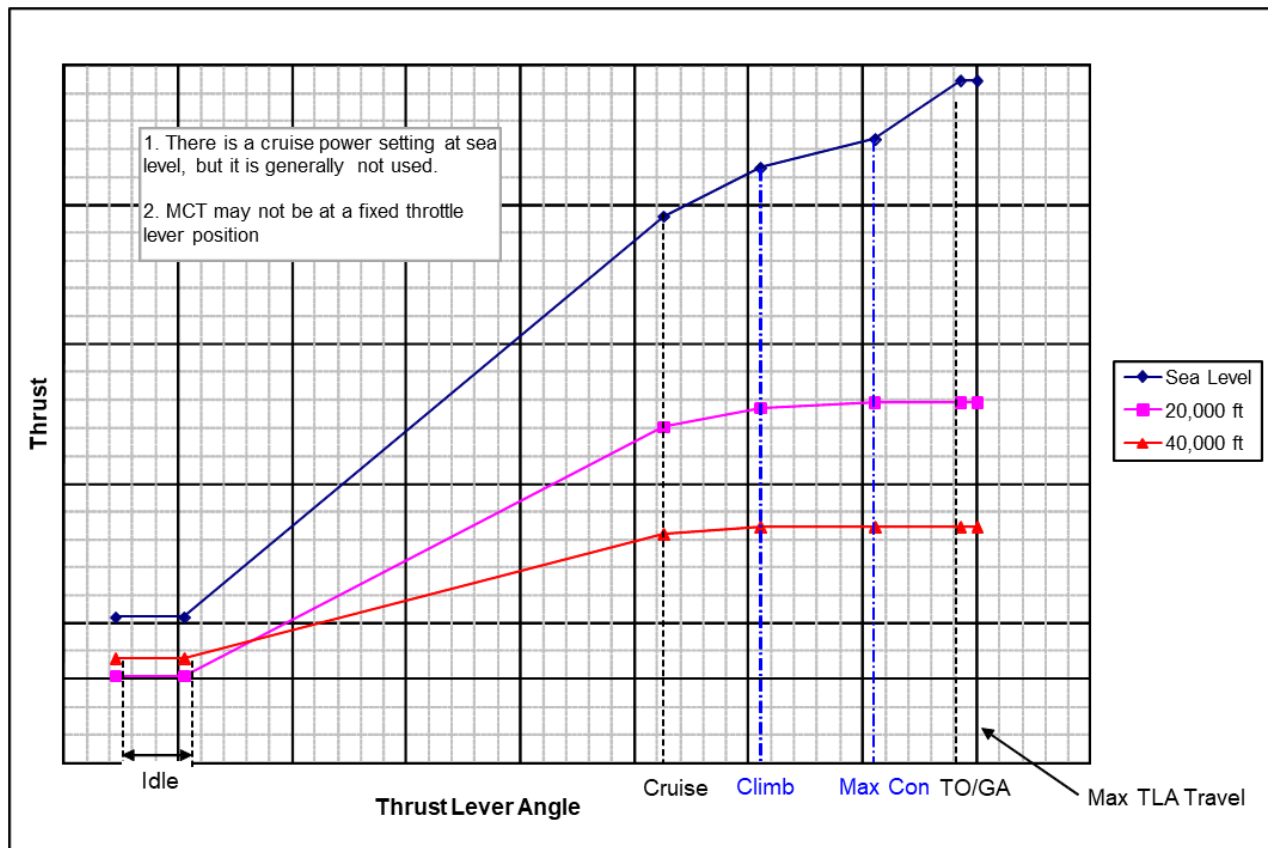


Figure 13 - Thrust versus thrust lever angle without detents

4.2.1.3.4 Thrust Mode Selection Panels

Figure 14 shows a typical thrust mode select panel. This type of panel is used to establish the selected mode thrust setting target on the thrust parameter display. The thrust setting versus thrust lever position layout may be as shown in Figures 9 or 13. When thrust lever detents are used, the value of the thrust setting parameter should match the value of the target shown on the display when the thrust lever is in the appropriate detent. When an autothrottle system is included in the design, the thrust versus thrust lever position characteristic may be programmed as that shown in Figure 13, where fixed thrust lever positions may or may not be used for the various thrust settings. In this system configuration, the autothrottle would continually move the thrust levers to achieve the cruise, climb, or maximum continuous thrust setting as environmental conditions change. Hence, when autothrottle systems are employed, the various thrust settings do not have to be at fixed thrust lever positions. The takeoff thrust position is normally at the full forward thrust lever position when operating in the primary mode.

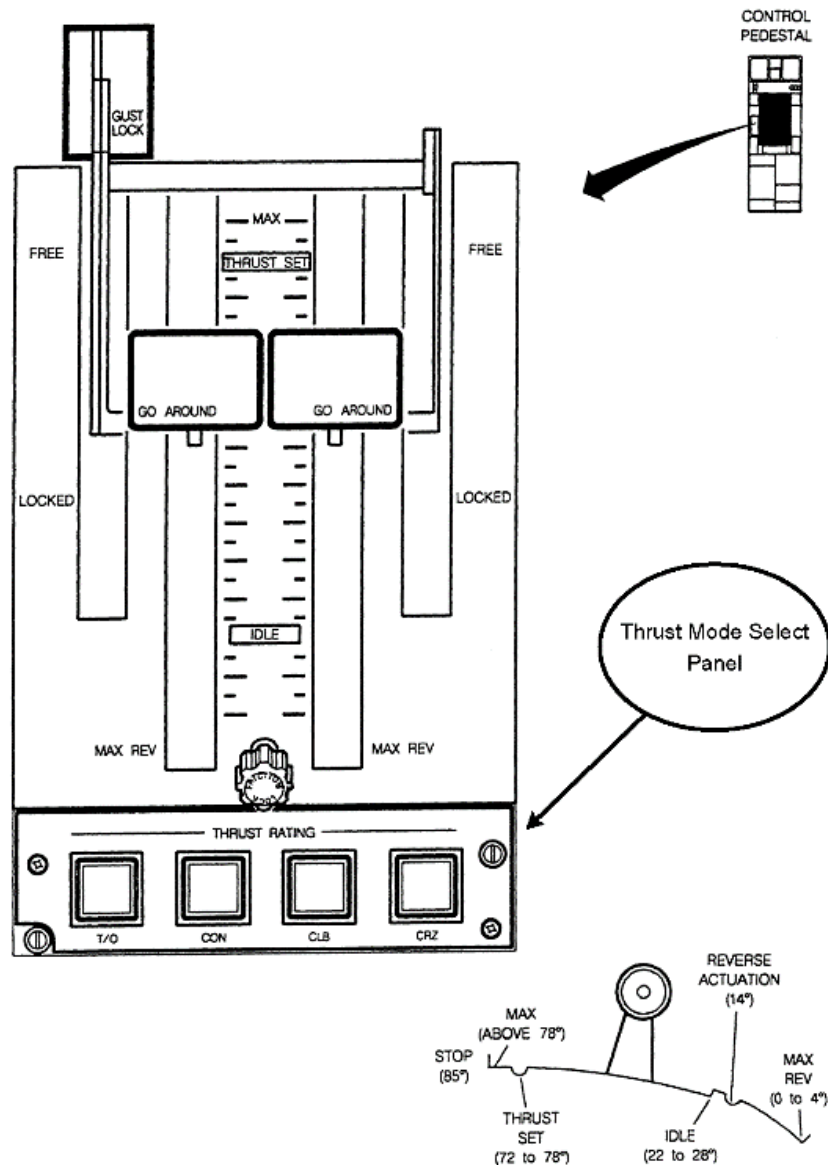


Figure 14 - Thrust rating/mode selection panel

4.2.1.3.5 Thrust Mode Selection Page

Modern aircraft do not have a thrust mode select panel as shown in Figure 14. Instead, some aircraft that incorporate thrust mode selection functionality have a thrust setting selection page (see Figures 15 and 16), which can be called up using the flight management computer (FMC) or a computer of similar name. There are generally two different pages that are available. The first is an on-ground, prior to flight page. This page allows the flight crew to select either the full-takeoff or a less than 100%, fixed percentage of takeoff thrust (i.e., a derated thrust) for the takeoff and climb portions of the flight. The percentage of derated thrust can be whatever the OEM chooses to have available. Some transport aircraft have as many as five derated thrust selections available. There is a full flight manual for these derated ratings, as described in 4.2.1.4. After having selected the takeoff rating, the flight crew can then select an additional thrust reduction by inputting an assumed temperature that is hotter than corner point day for the takeoff altitude. The flight crew then selects the climb rating, which is either the full climb rating or a derated climb rating, which is appropriately customized to ensure the climb thrust is less than the derated takeoff ratings. The derated climb thrust can be operator customized to wash out between a specified lower altitude and a specified higher altitude. For example, an operator may want the selected derated climb thrust to linearly increase to maximum climb thrust between the altitudes of 10000 feet and 20000 feet.

When in-flight, the engine thrust rating page looks a bit different (see Figure 16). The flight crew can select a full or derated climb rating, the maximum cruise rating, the maximum continuous power rating, or the go-around (shown in Figure 16 as the GA rating) thrust rating. Derated thrust settings are generally not available for these last three power settings. These selections show the thrust setting target on each engine thrust setting display when that flight mode is initiated.

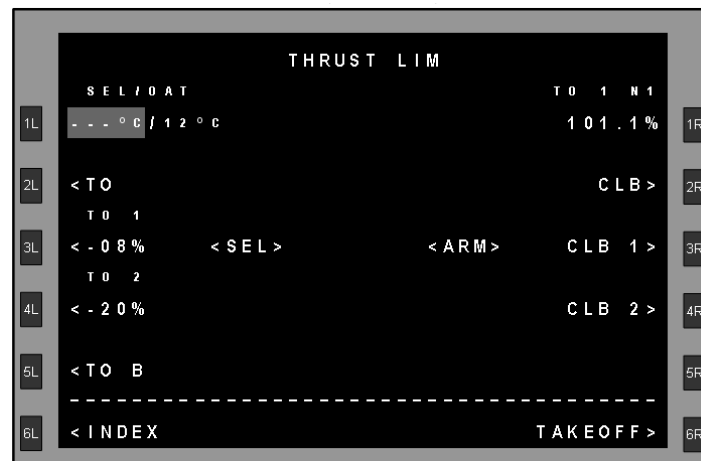


Figure 15 - Typical thrust rating selection display on-ground, pre-flight

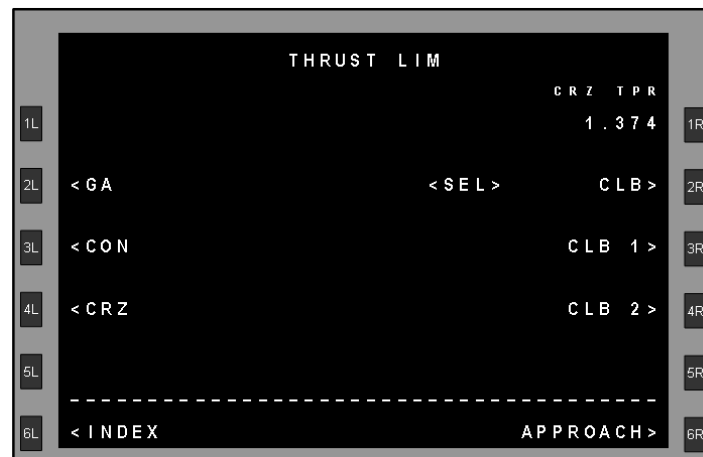


Figure 16 - Typical thrust rating selection display in-flight

4.2.1.3.6 Power Scheduling in Turboprop Aircraft

The method to control thrust on older legacy turboprop aircraft has typically been through two sets of levers: the power levers and the propeller condition levers. The power levers are used to set the engine power and, when below flight idle, to set the propeller operation in beta mode. The propeller condition lever is used to set the propeller governing speed and to feather and unfeather the propeller blades. In a typical flight, the propeller condition lever is used to set the propeller speed to values established for each flight phase (e.g., takeoff, maximum continuous, climb, cruise), then the power lever is adjusted to increase or decrease power and consequently thrust. In the same way that the power or thrust control needs to comply with 25.1143, the propeller condition control needs to comply with 25.1149, allowing separate and simultaneous control of all propellers.

Alternatively, in some applications the propeller condition lever function to set propeller speed based on flight phase was implemented through cockpit switches with each selection corresponding to propeller speed regime.

On some modern turboprop aircraft, single lever approach has been used to set both engine power and propeller condition. In forward thrust mode, power demand is linearly interpolated as a function of thrust lever position while the propeller speed is constant over the different operating ranges. For example, the propeller speed is constant from idle to maximum climb and then changes from maximum climb to takeoff, as shown in Figure 17. Besides the thrust lever, other cockpit interfaces may be required to provide specific functions, such as specific rating modes selection (e.g., low noise mode, derated mode, ice shedding mode) that can provide a specific propeller speed setting. Specific propeller speed control and power scheduling are dependent upon the aircraft, engine, and propeller functional needs.

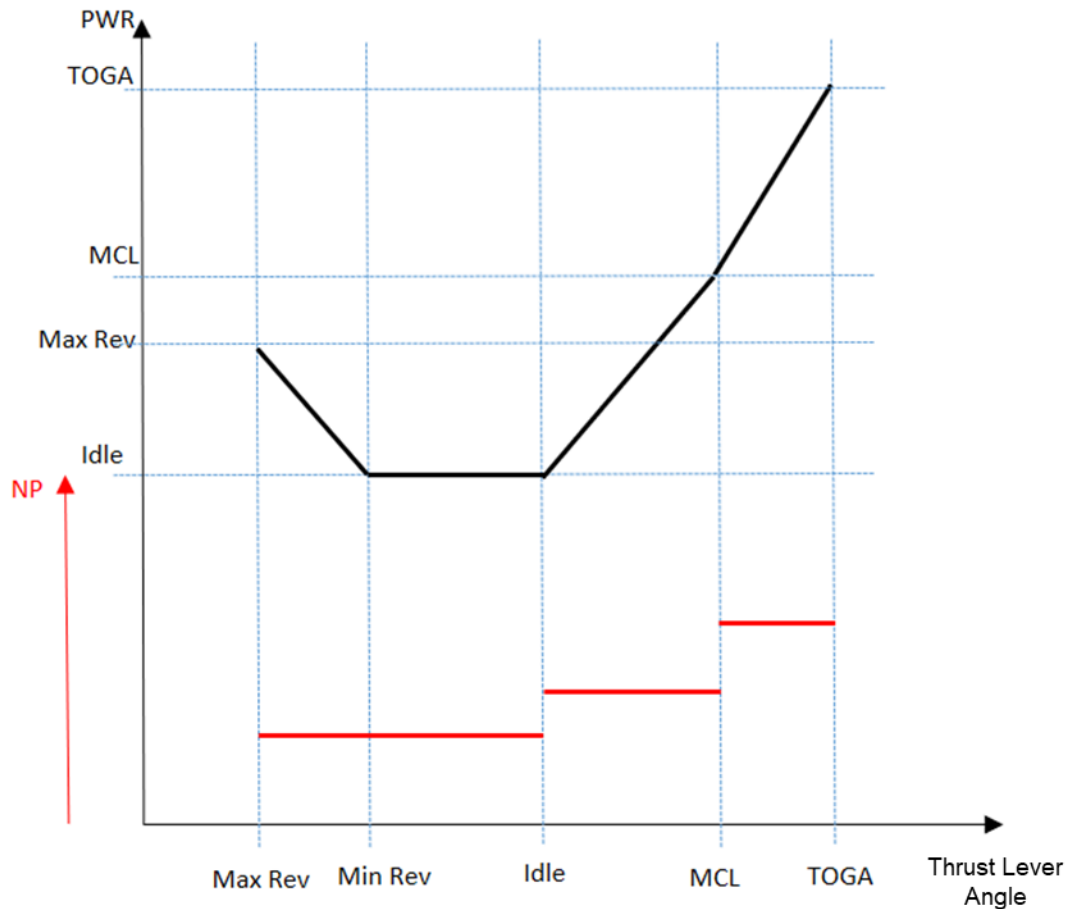


Figure 17 - Example of power and propeller speed scheduling

4.2.1.4 Derated and Reduced Takeoff Thrust Operation

When not operating at the maximum permissible gross weight for the prevailing ambient temperature and altitude conditions, using a lower takeoff thrust provides significant savings in engine life. Two basic methods implement a lower thrust setting for takeoff operation. These methods are defined in FAA Advisory Circular 25-13 and EASA AMC 25-13. One method is called derated thrust operation, and the other is called reduced thrust operation. The reduced thrust method is also known as the FLEX takeoff or assumed temperature method (ATM) of operation. The complexity and potential issues related to incorporating either derated or reduced thrust takeoffs into smaller general aviation aircraft (Part 23, Class I, II, and III) may outweigh the potential benefits to the aircraft. Derated and reduced thrust takeoff power settings are used frequently on transport aircraft because of the significant engine life savings associated with lower power settings. The characteristics of the methods are discussed below.