# 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 5-year review process, this revision adds information on the integration of FADEC systems in general aviation (GA) aircraft. It also adds additional information on FADEC control system integration in Transport category 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. While this is a major impetus for the publication of this report, the report also addresses many issues that apply to hydromechanical controls.

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.





**TO PLACE A DOCUMENT ORDER:** **Tel: 877-606-7323 (inside USA and Canada)**
**Tel: +1 724-776-4970 (outside USA)**
**Fax: 724-776-0790**
**Email: CustomerService@sae.org**
**SAE WEB ADDRESS: http://www.sae.org**

**SAE values your input. To provide feedback on this Technical Report, please visit http://www.sae.org/technical/standards/AIR5924A**

TABLE OF CONTENTS

# 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 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 Figure 1.

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 of today’s transport category engines use dual-channel full-authority digital engine control (FADEC) systems, this is the configuration which is addressed. A typical FADEC system configuration is shown in Figure 2.

## 1.1 Purpose

This report provides guidance to engine/control designers and aircraft system designers on the 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 A

This revision provides information on the integration of FADEC systems in general aviation (GA) aircraft and adds additional information on FADEC control system integration in Transport aircraft.

## 1.3 Field of Application

The field of application is aerospace, primarily for FADEC equipped engines targeted for commercial Transport and GA aircraft installations. The information contained herein may also be useful for engine integration into rotorcraft and those military aircraft which are derivatives of civil aircraft.

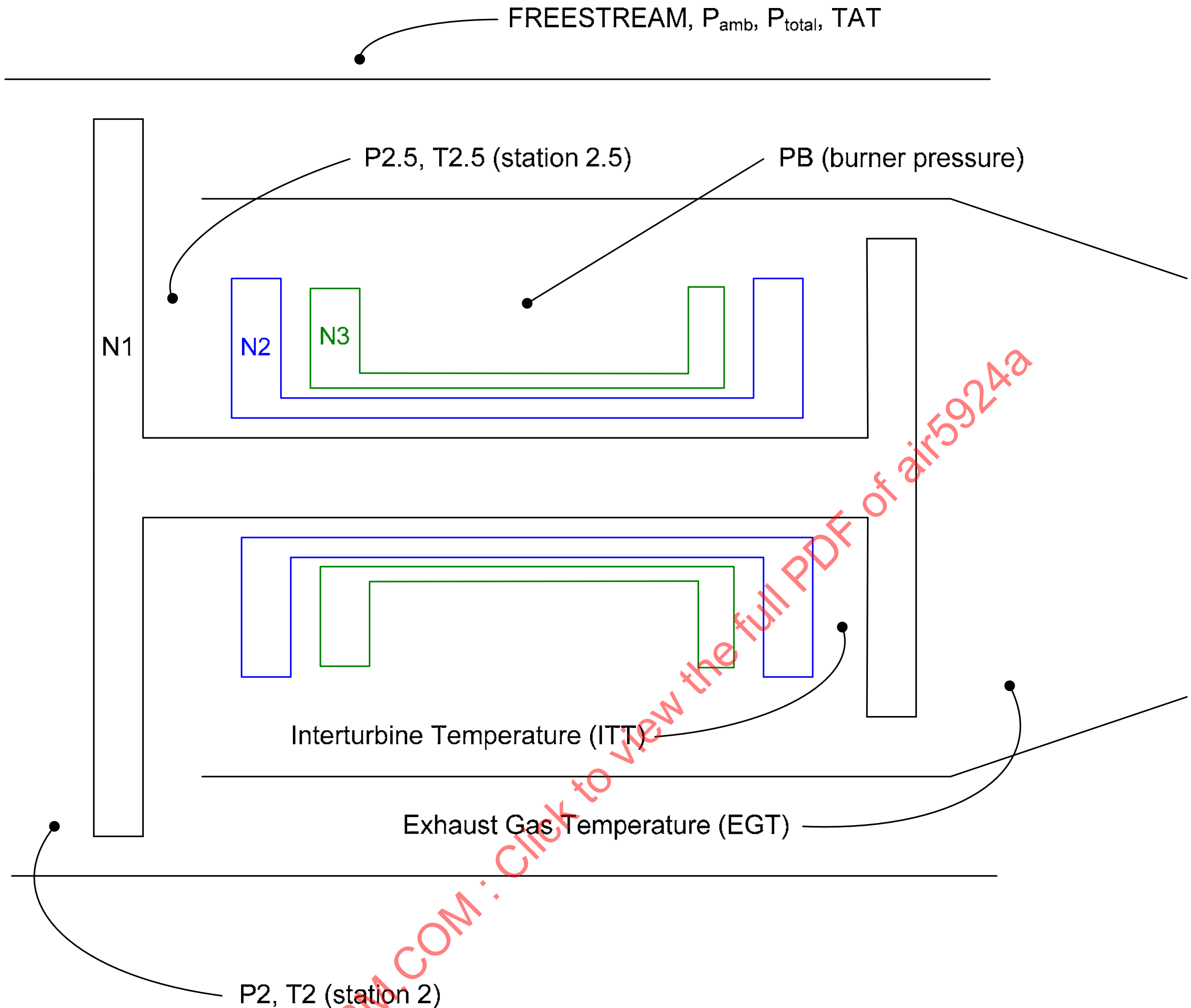




FIGURE 1 - STATION DEFINITIONS USED HEREIN

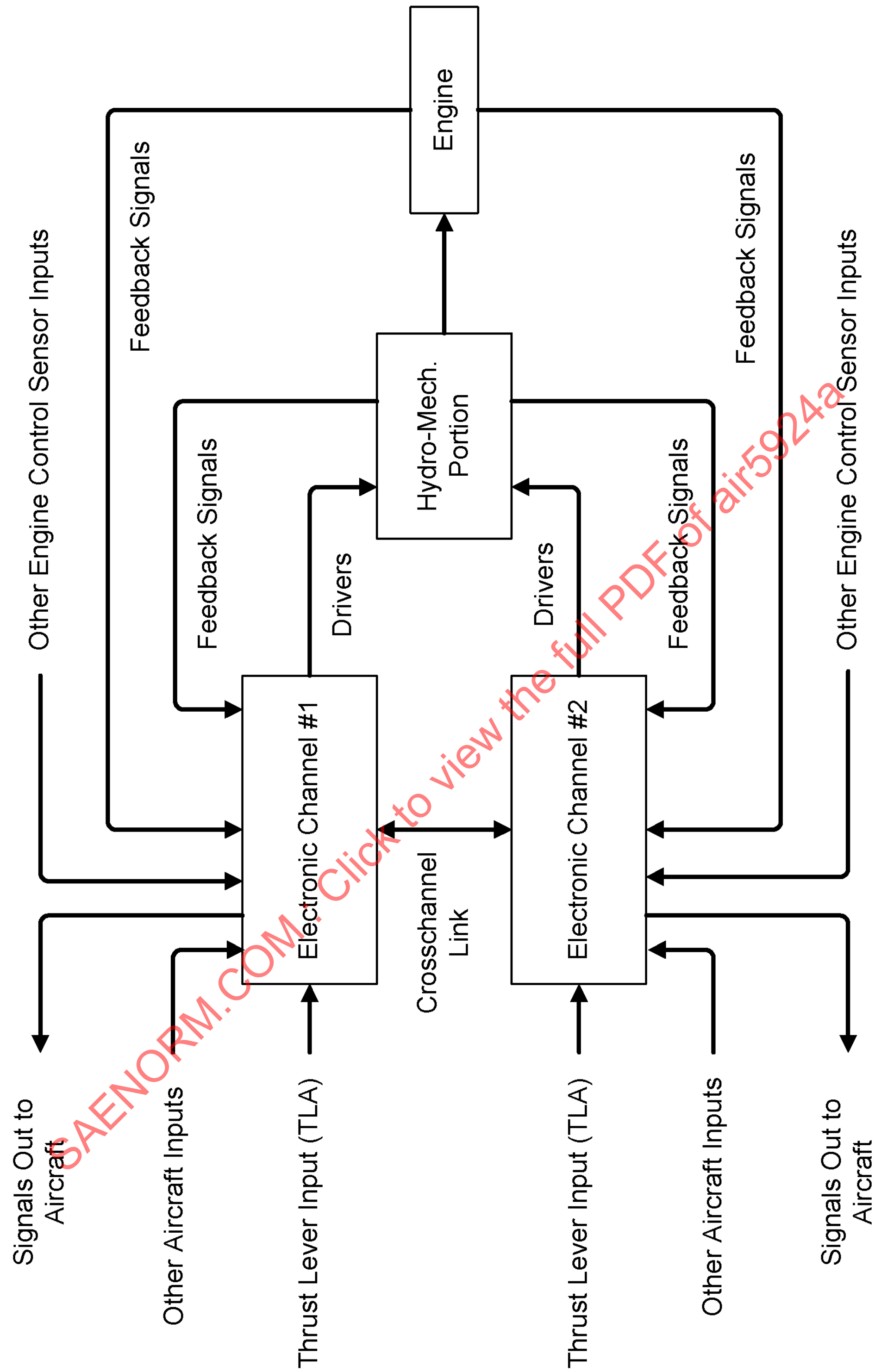


FIGURE 2 - TYPICAL FADEC SYSTEM

## 2. REFERENCES

### 2.1 Applicable Documents

The following publications form a part of this report to the extent specified herein. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

#### 2.1.1 Federal Aviation Administration (FAA) Publications

14 CFR Parts 23, 25, 27, 29, 33 and Advisory Circulars (ACs) available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591. A few of the ACs are:

- AC 20-53B, Protection of Aircraft Fuel Systems Against Fuel Vapor Ignition Caused by Lightning, issued June 2006.
- AC 20-88A, Guidelines on the Marking of Aircraft Powerplant Instruments (Displays), issued September 30, 1985.
- AC 25-11A, Electronic Flight Deck Displays, issued June 21, 2007.
- AC 20-136B, Aircraft Electrical and Electronic Systems Lightning Protection, issued September 2011.
- AC 20-158, The Certification of Aircraft Electrical and Electronic Systems for Operation in the High-Intensity Radiated Fields (HIRF) Environment, issued July 2007.
- AC 21-16G, RTCA Document DO-160 D, E, F, G, Environmental Conditions and Test Procedures for Airborne Equipment.
- AC23-1311-1B, Installation of Electronic Display in Part 23 Airplanes [with change 1 incorporated], issued February 17, 2009.
- AC 25-13, Reduced and Derated Takeoff Thrust (Power) Procedures, issued May 4, 1988.
- AC 33.28-1, Compliance Criteria for 14 CFR §33.28, Aircraft Engines, Electrical and Electronic Control Systems, issued June 29, 2001.

Transport Aircraft Directorate Policy Letters:

- Policy Letter TAD 95-001, The Role of Maintenance Computers in Exposure Time Assumptions for Quantitative Safety Analyses, issued February 22, 1995.
- Policy Letter TAD 00-113-1028, Availability of All-Engine Maximum Continuous Thrust (MCT), issued July 31, 2000.

Engine and Propeller Directorate Policy Letter:

- Policy Letter: 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.

Small Aircraft Directorate Memos:

- Full Authority Digital Engine Control (FADEC) Installation Compliance Review, issued 28 January 2009.

2.1.2 European Aviation Safety Agency

Certification Specification (CS) 23/25/27/29/E

2.1.3 Other Documents

AS755 Aircraft Propulsion System Performance Station Designation and Nomenclature

ARP5107 Guidelines for Time-Limited-Dispatch (TLD) Analysis for Electronic Engine Control Systems

AIR6181 Electronic Propulsion Control System/Aircraft Interface Control Documents

RTCA DO-178C Software Considerations in Airborne Systems and Equipment Certifications (issued December 1992, and ERRATA sheet issued December 2011)

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

2.2 Acronyms and Symbols

TABLE 1 - LIST OF ACRONYMS AND SYMBOLS

| | Meaning | Comments |
|---|---|---|
| ADC | Air-data Computer | |
| AGL | Above Ground Level | |
| AFM | Aircraft Flight Manual | |
| ATM | Assumed Temperature Method | |
| ATTCS | Automatic Take-off Thrust Control System | Also known as APR or ATR (Automatic Power or Thrust Reserve) |
| CMC | Central Maintenance Computer | |
| CMR | Certification Maintenance Requirement | |
| 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 Cockpit Advisory System | System for displaying engine parameters and warnings to the flight crew. Also known as ECAM (Electronic Centralized Aircraft Monitoring) |
| EPR | Engine Pressure Ratio | |
| FADEC | Full-authority Digital Engine Control | This term is generally used to represent to whole engine control system, including wire harnesses, fuel metering unit, etc. |
| FOD | Foreign Object Damage | |
| GA | General Aviation | |
| GW | Gross Weight | |
| LADC | Left (side) ADC | |
| LOTC | Loss of Thrust Control | |
| 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 engines |
| N3 | Engine high-pressure shaft speed | 3-shaft 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 total pressure | |
| Q | Dynamic Pressure | P minus Ps |
| RADC | Right (side) ADC | |
| TAT | Total Air Temperature | |
| Theta | T2/Tstd. | |
| TLA | Thrust Lever Angle | |
| TLD | Time Limited Dispatch | |
| TMC | Thrust Management Computer | |
| Tstd | Standard Day Temperature | |
| T2 | Engine intake 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 | |



## 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 GA 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

### 4.1 Control Modes

#### 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's 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 large fan engines is either fan speed (N1) or engine pressure ratio (EPR).

In most modern 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 3 shows a typical thrust versus thrust lever position schedule. (See 4.2.1.3 thru 4.2.2.2 for a more detailed discussion of programmed thrust versus thrust lever position.) 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) modes does not generally require any significant reverse thrust modulation capability. Figure 3 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 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.

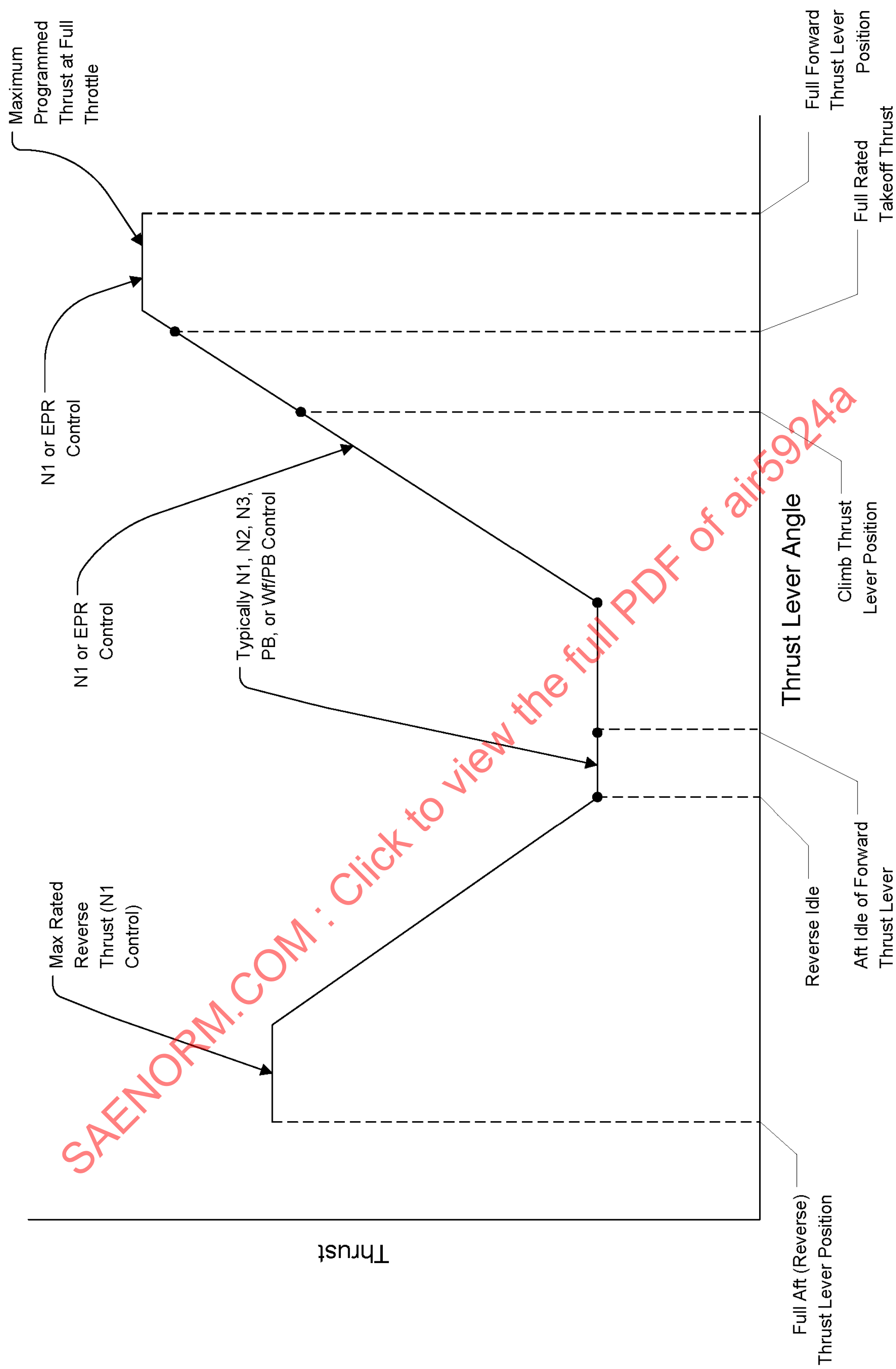




FIGURE 3 - EXAMPLE OF THRUST VERSUS THRUST LEVER ANGLE

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

This section describes the main backup mode. Some applications such as general aviation applications may opt to not incorporate a backup, alternate, or reversionary mode due to acceptable dispatch reliability without the added complexity of incorporating additional modes.

Most modern large transport FADEC systems have a backup, alternate, or reversionary operating mode that is usually a non-rated mode. 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's 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. There are applications in which the backup or alternate 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 less than that of the primary mode, a gross weight (GW) penalty would be applied to aircraft performance when dispatching in this mode.

In most large transport 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.

Modern FADEC systems have several "get-home" modes. 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 main backup mode because it is one of the more important items in understanding 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 or alternate mode is usually a fan speed (N1) governing control. For engines that use N1 as the engine's 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 as the forward thrust lever is advanced from idle to the full forward stop. (See 4.2.2 for a discussion of lapse rates in the primary and backup modes.) It is good design practice to have the backup or alternate mode(s) independent of aircraft airspeed and Mach number information. Loss of the FADEC system's capability to calculate an airspeed signal, loss of or inability to use the 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.

### 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 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. 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 or alternate 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 4 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.

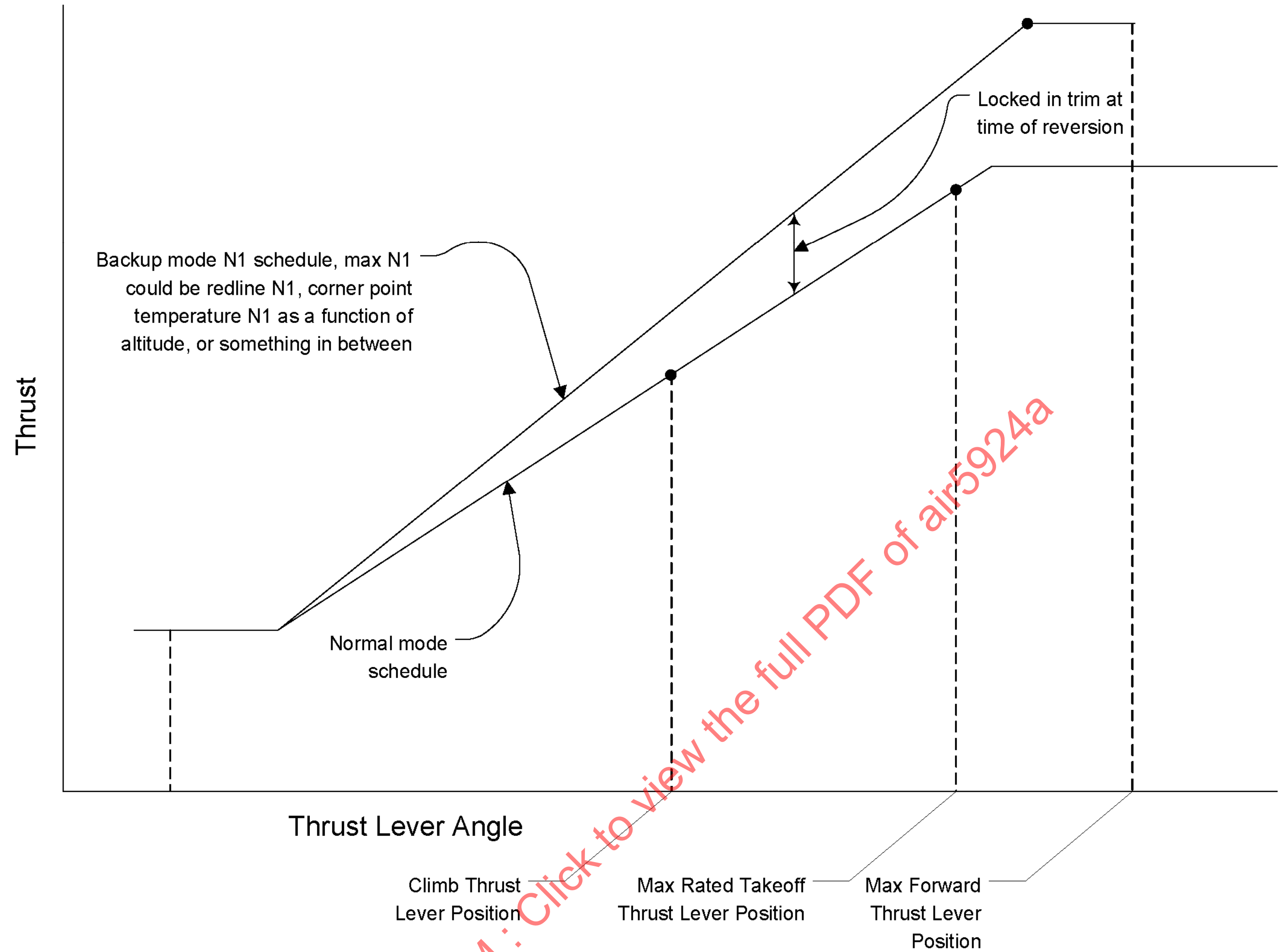


FIGURE 4 - NORMAL MODE THRUST SCHEDULE AS COMPARED WITH TYPICAL ALTERNATE (OR BACKUP) MODE SCHEDULE FOR FORWARD THRUST



### 4.1.5 Primary or Backup Mode Activation and Switching Between Modes

Figure 5 shows suggested mode selection logic. In general, whatever the thrust lever position, the control should go directly to the backup mode when it receives the flight crew command to change modes. If the thrust lever is at the maximum forward position, a significant overboost may result. However, even though there may be a significant thrust increase, the control should prevent the engine from exceeding any rotational speed limitations. There has occasionally been considerable discussion of trying to incorporate some logic in the FADEC system to avoid this situation, but generally the instructors and flight test pilots have indicated that flight crews should know what they are doing when they activate cockpit switches, and that they should exercise the proper procedure of retarding power before initiating a mode change.

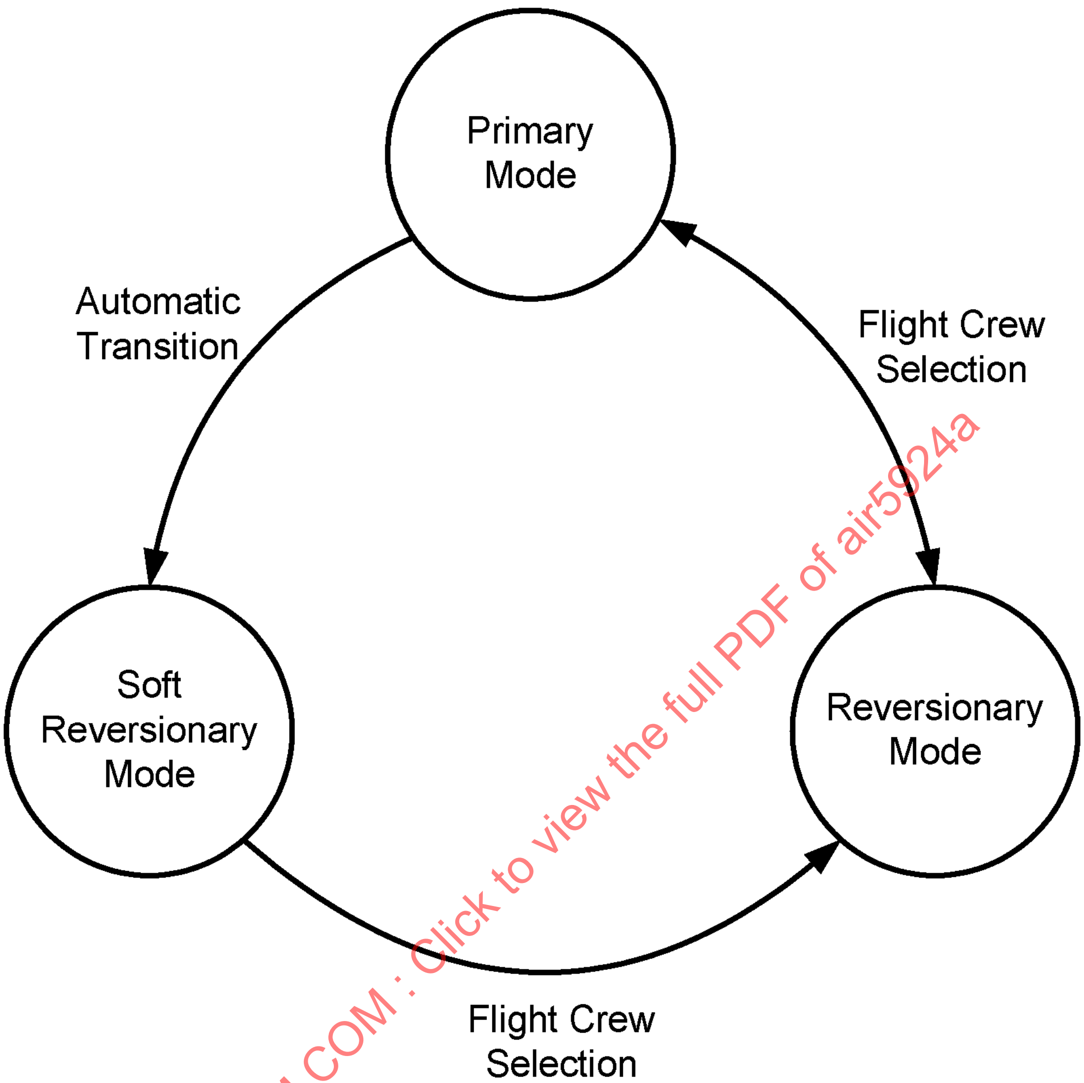




FIGURE 5 - LOGIC FOR MODE SELECTION

NOTE: 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 it applies, address this in the following manner:

In the case in which the control does not have the necessary signals for the primary mode, the control should already be providing an indication of primary mode failure (see 6.1.3), and it will stay in the backup mode. Therefore, there will be no thrust change. If, however, the control has the signals available to enter the primary mode, it could do so. If this is considered too undesirable, the control can be configured to contain logic that would prevent the transfer. For example, the control can be configured to look at such signals as airspeed and engine power setting when a transfer command to primary mode is received, and if the engine is at high power and airspeed is low (that is, less than Mach 0.35 or 0.4), the control logic can be configured through software logic to reject the mode change command. 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 re-issued 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.

4.1.6 Initiation of the Primary/Backup Mode at 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's electrical power system at the time of engine start. The aircraft may be completely de-powered - with the exception of aircraft battery power - when the first engine is started, or the aircraft may be powered by a ground power source at engine start.

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's 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 on-line at approximately 5% below engine idle speed. Following this first engine start, aircraft power should be available for the engine control system's 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 (typically 12 s), 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 have 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 5.4.2.4).



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 primary, soft reversionary, or backup mode following the engine start is essentially the same as given in the above discussion for EPR-rated engines.

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 s), before declaring a disagree between the aircraft's total pressure signals. Because of cross-wind effects, many of today's 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. The initialization times for the sources of ADC total pressure probe heat and the FADEC controller receiving an ADC total pressure signal with an indication that probe heat is on can be as long as 10 to 12 s. So have the control wait that long before declaring the ADC total pressure signals invalid and initiating the backup mode. 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.

## 4.2 Thrust Scheduling Logic

### 4.2.1 Primary Mode



Engine Idle Control, Thrust Ratings, and Thrust Lapse Rates as a Function of Altitude, Air-speed and Temperature:

#### 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. 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's 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.

- 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's 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.

#### 4.2.1.2 Engine Ratings

Takeoff, Climb, and Maximum Continuous Thrust (or Power) Ratings: For transport category aircraft, takeoff, climb, and maximum continuous thrust are generally established to achieve (1) good engine life (from the engine manufacturer's viewpoint), and (2) good aircraft performance (from the aircraft manufacturer's viewpoint). Those two viewpoints are, by their very nature, conflicting. For fixed-wing transports, maximum continuous thrust is generally less than takeoff thrust and is really only intended for use during one engine inoperative (OEI) conditions. However, 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. With the high levels of engine reliability being achieved with modern turbine engines, the need to use maximum continuous thrust is reasonably rare.

For large transport aircraft, the takeoff and climb selected thrust settings (see 4.2.1.4) are often less than the maximum takeoff and climb ratings. This is done to save engine life. For G/A aircraft the takeoff and climb thrust settings are generally equal to the maximum ratings. For transports, 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. The only certified thrust ratings for transports are the Takeoff and Maximum Continuous ratings. Climb and cruise rating are “agreed” thrust ratings between the aircraft and engine manufacturers.

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

##### 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. In other words, the system is not one in which the thrust lever is 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. That type of system is discussed in 4.2.1.3.2.

The descriptions given below are for transports 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 6 shows a typical thrust 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 throttle 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 6 and 7 show typical fan speed and thrust settings as a function of throttle lever angle at different operating altitudes.

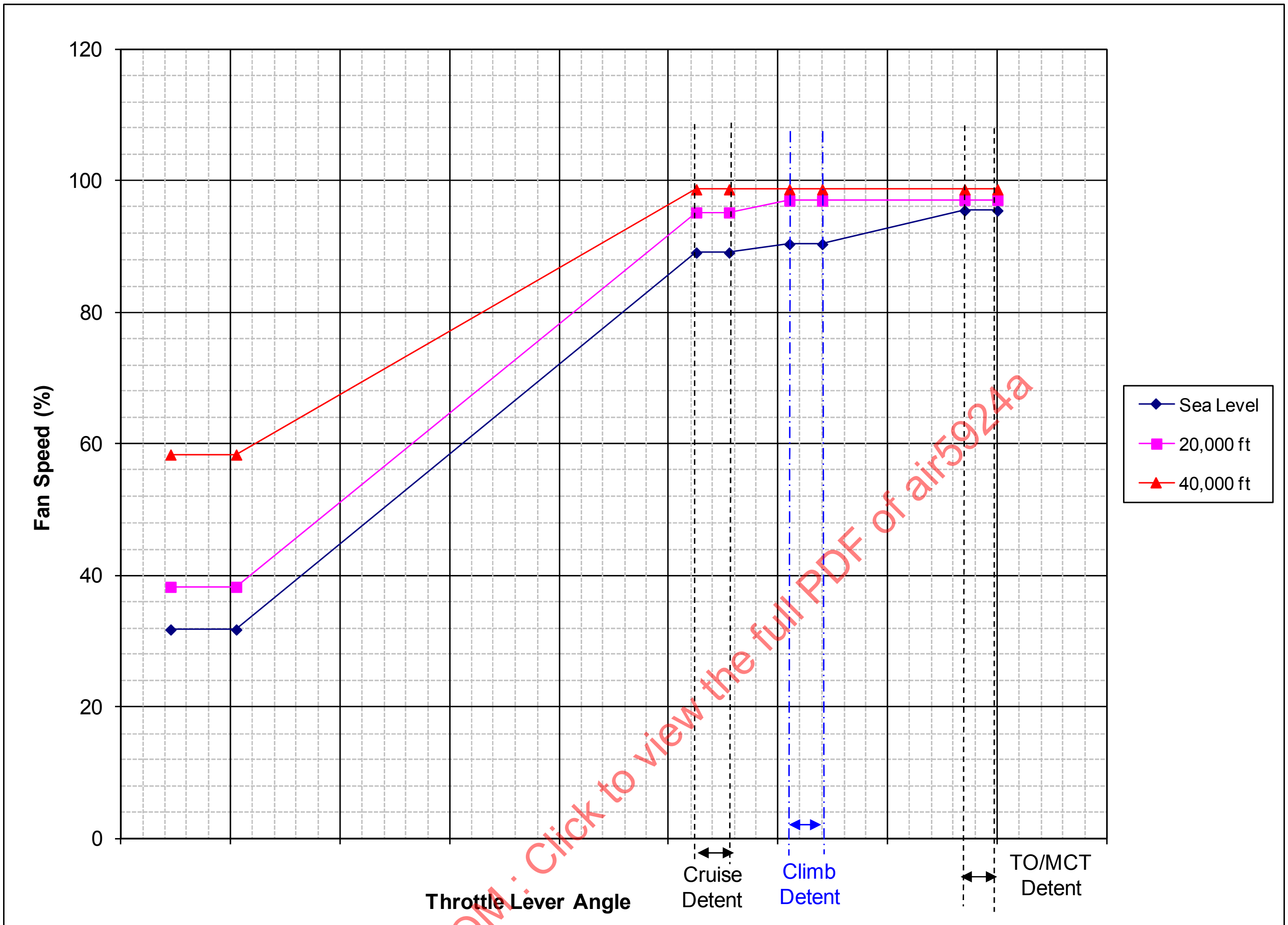


FIGURE 6 - TYPICAL ALTITUDE DEPENDENT FAN SPEED VERSUS THROTTLE LEVER ANGLE
(NEED TO SHOW THE DOTTED LINES FOR THE CRUISE,
CLIMB AND T.O./MCT POWER SETTING DETENTS (FLATS)

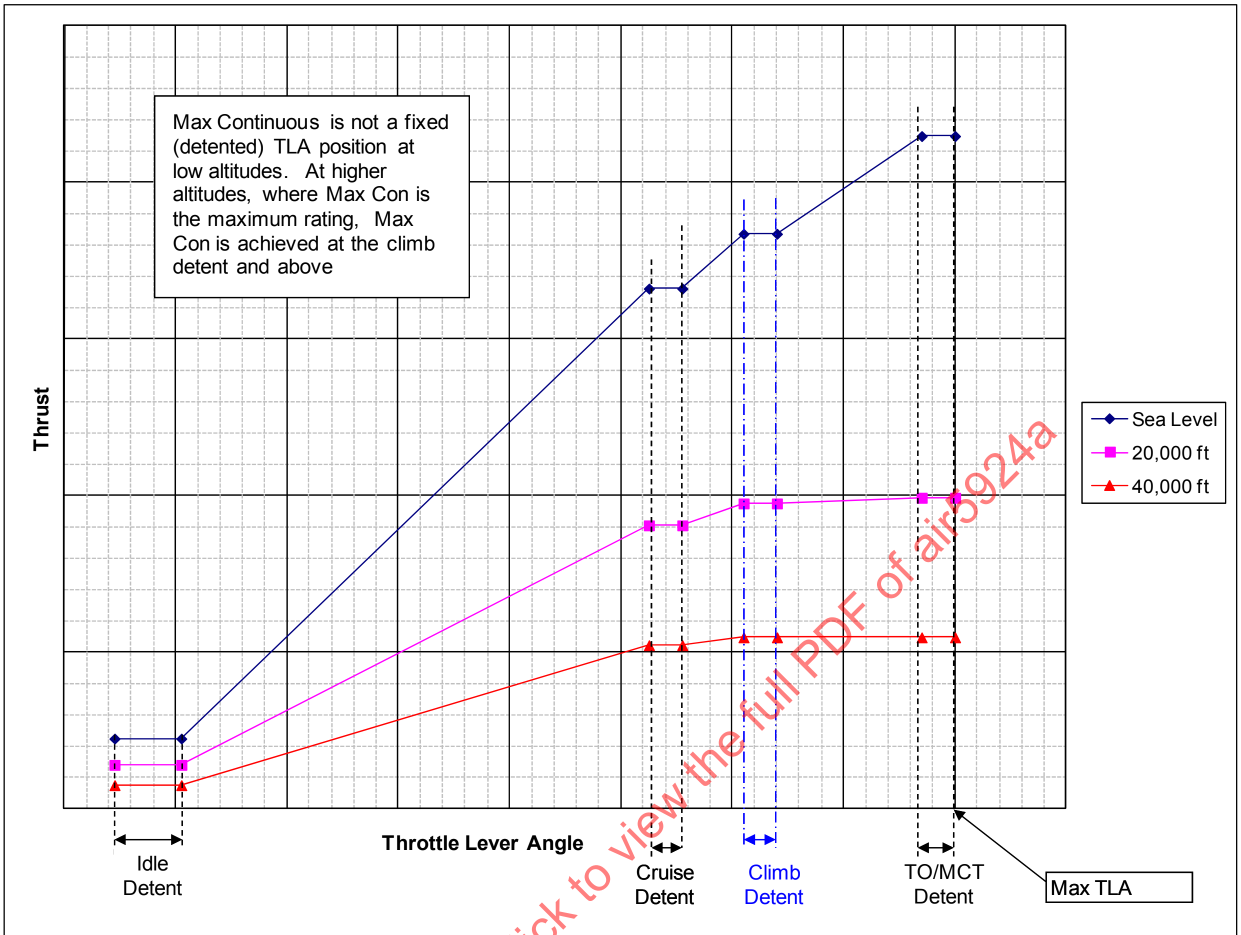




FIGURE 7 - TYPICAL ALTITUDE DEPENDENT THRUST SCHEDULES VERSUS THRUST LEVER POSITION

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's certificated takeoff or maximum continuous thrust. The difference between this maximum scheduled thrust and the engine's 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 full throttle the engines during extreme situations, such as those resulting from wind shear. Typically, general aviation aircraft do not provide "headroom" at the full throttle 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:

A - 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.

B - 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 8). 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.

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.

4.2.1.3.2 Installations Using Thrust Lever Detents

With the advent of FADEC systems, the various thrust settings, such as max takeoff, max climb and max cruise thrust can be programmed to occur at fixed throttle positions. Figure 9 shows a typical fixed position throttle quadrant, where the fixed positions are for cruise, climb, and TO/MCT thrust. Figure 10 shows the cross-section of such a quadrant. Figure 7 provides a typical example of how thrust would be programmed as a function of throttle position - at various altitudes. In the figure, the detented “flats” for the cruise, climb and TO/MCT positions only have to be wide enough to take care of the throttle position transducer signal variations at those detented throttle positions.

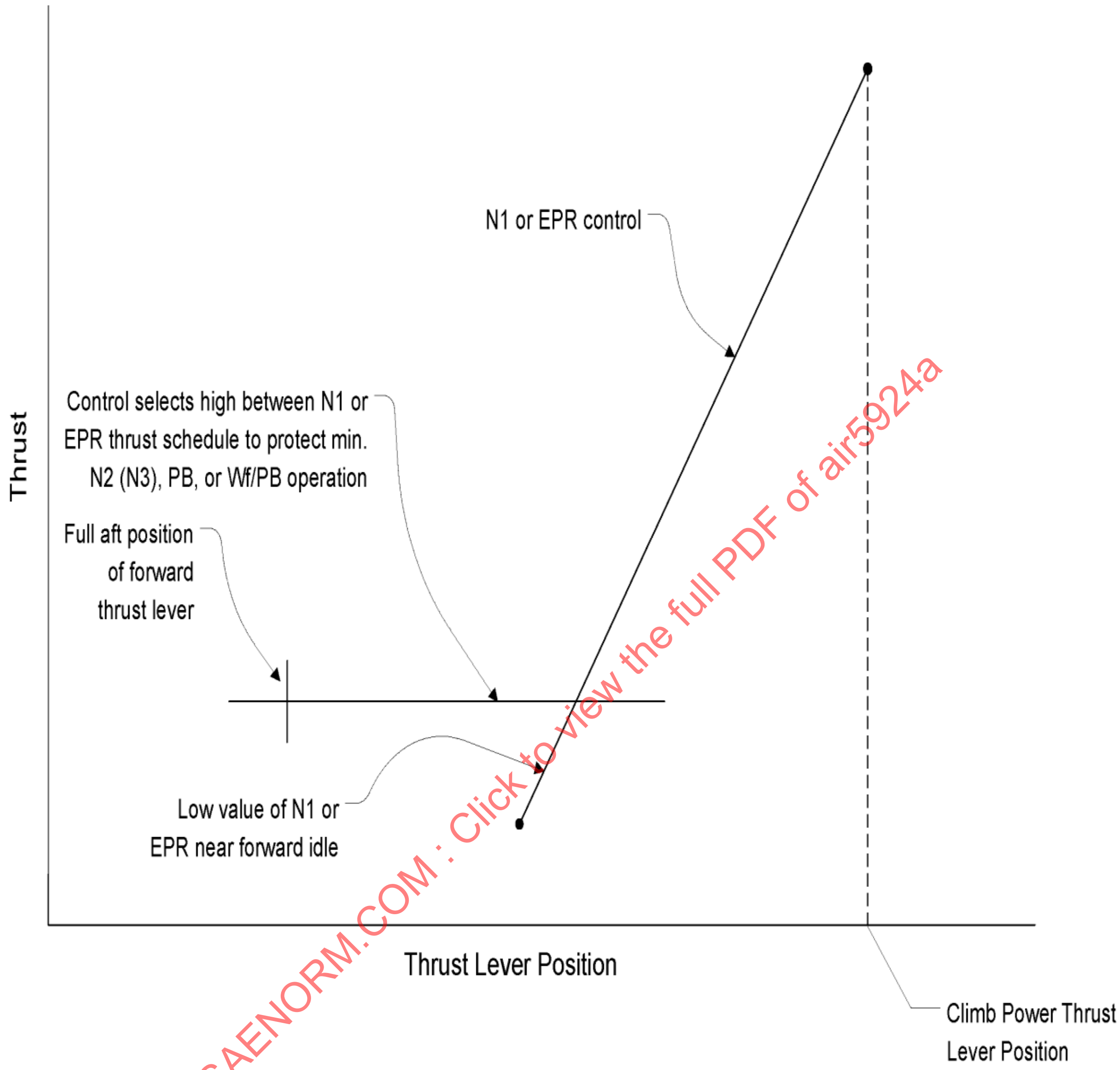




FIGURE 8 - EXAMPLE OF MULTIPLIER SCHEDULE

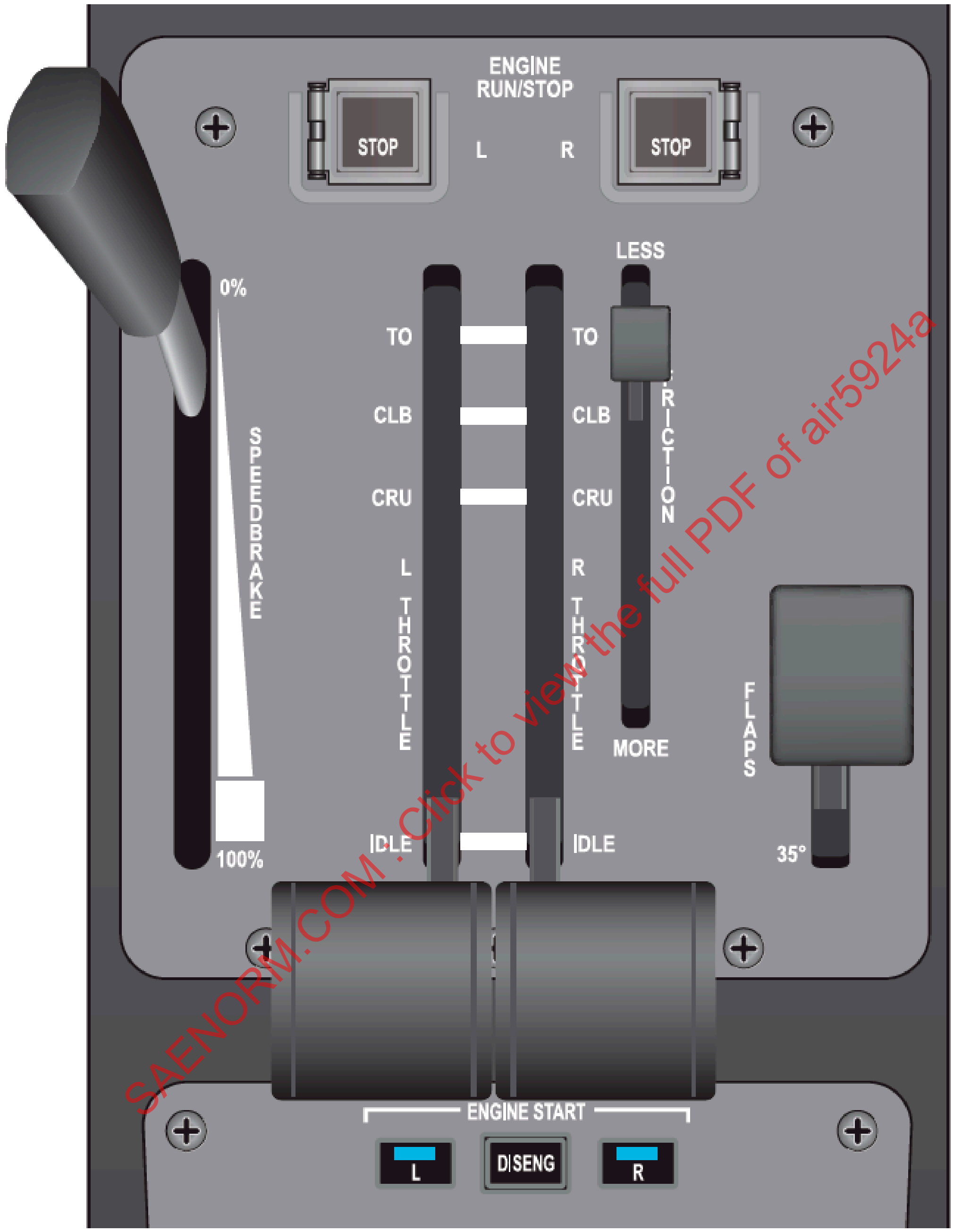




FIGURE 9 - A DETENTED OR “FIXED POSITION” THROTTLE QUADRANT

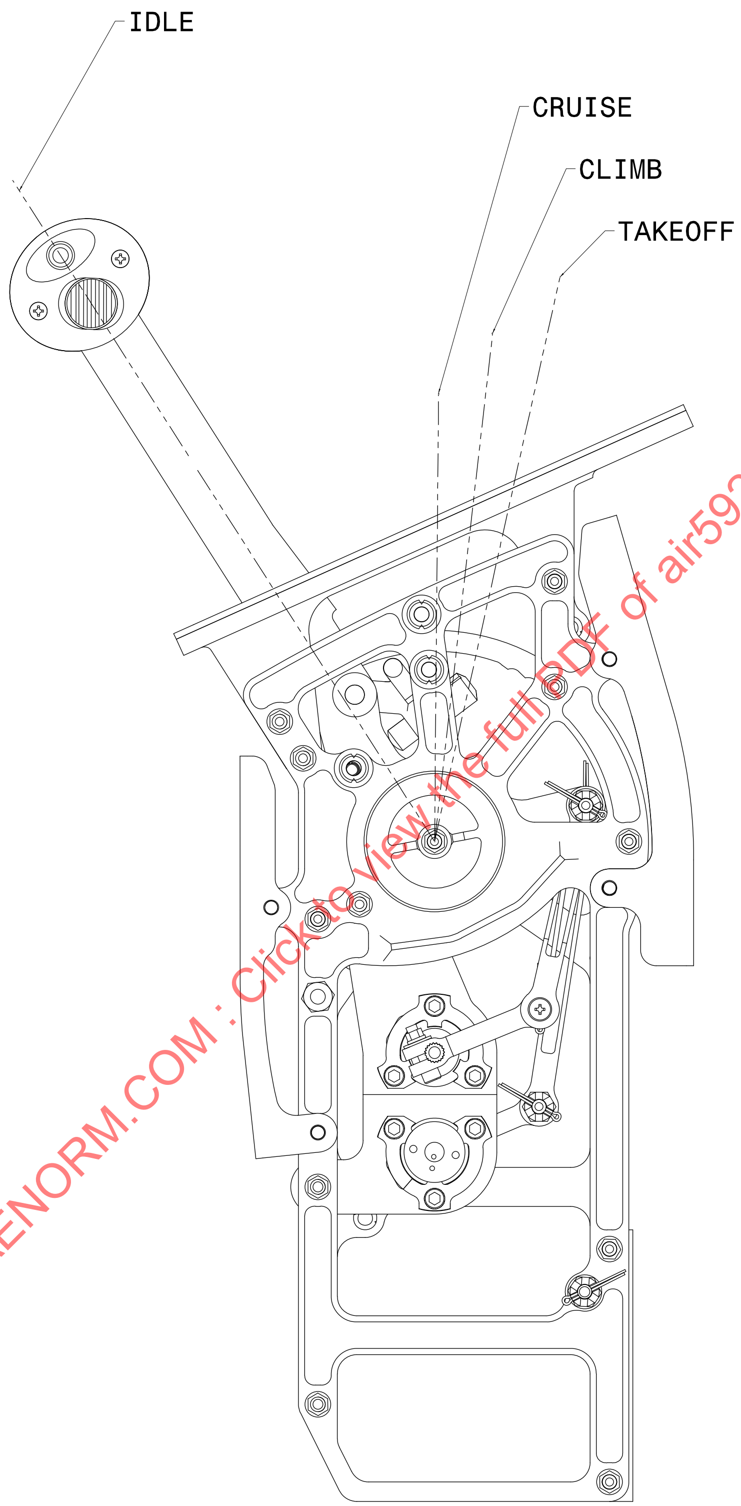




FIGURE 10 - CROSS-SECTION OF A DETENTED OR “FIXED POSITION” THROTTLE QUADRANT

4.2.1.3.3 Installations without Thrust Lever Detents (using autothrottle systems)

Figure 11 shows how thrust might be scheduled with throttle lever angle for systems that do not use throttle level detents. In this case there are no “flats” at the max cruise, max climb and other throttle positions. These systems often have autothrottle systems with throttle servos that move the throttles to a position that achieves the requested thrust setting. Most modern transport aircraft have autothrottle systems that have separate servos for each throttle. In this case each engine can be individually driven to the location that satisfies the desired thrust setting, but a single servo which drives all throttles can be used as well. In either of these configurations, it is best if there is a control law that keeps the throttles reasonably well aligned, so that if one throttle does not move or “hangs up” for some reason, the other throttle(s) do not continue to move and create a significant thrust asymmetry. Whether one servo for all throttles or separate servos are used for each throttle, there will be a bit of throttle stagger due to thrust level position transducer differences versus the position of each throttle. However, the throttle stagger is usually small and acceptable when less than one-quarter of a knob.

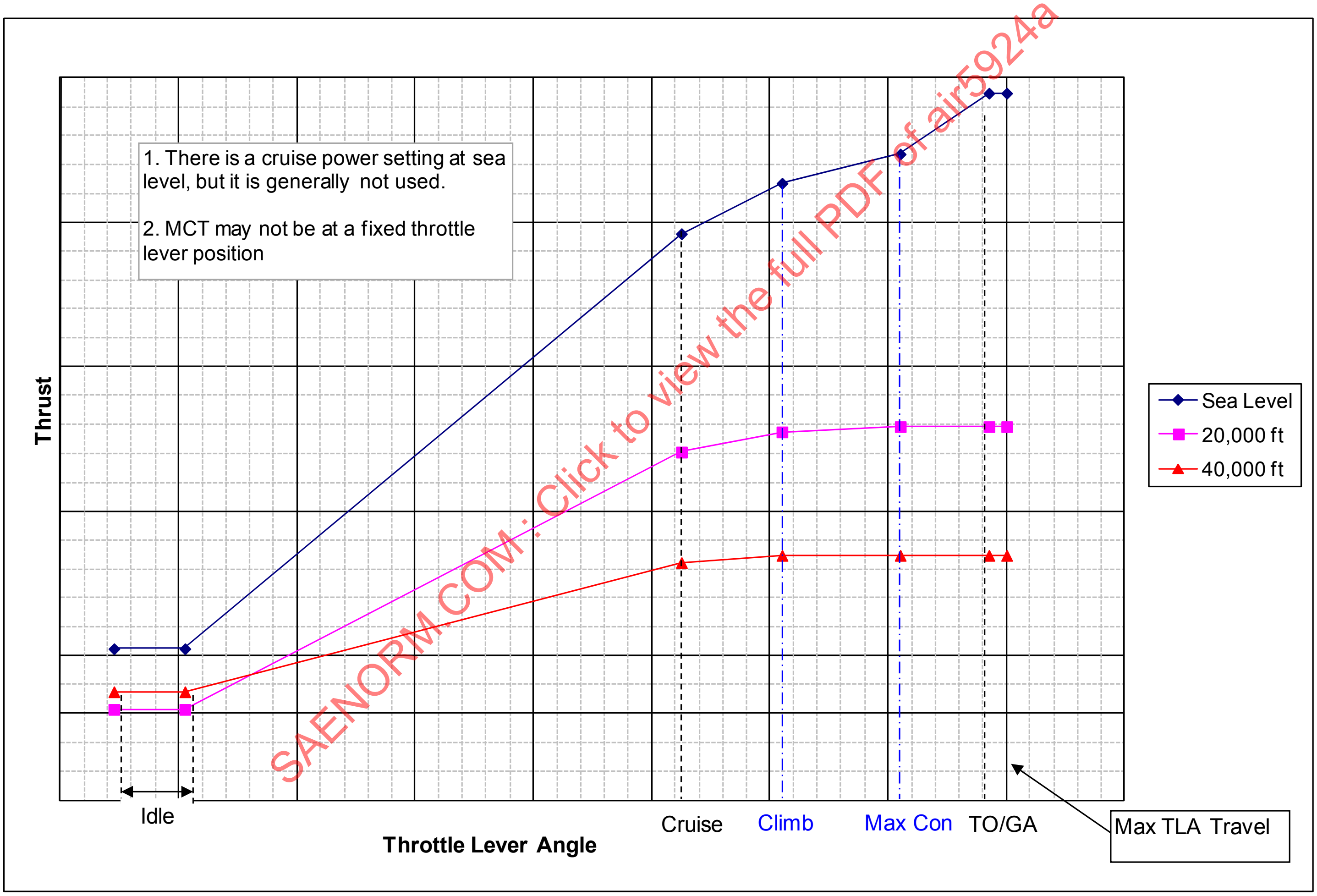




FIGURE 11 - THRUST VERSUS THROTTLE LEVER ANGLE WITHOUT DETENTS

4.2.1.3.4 Thrust Mode Selection Panels

Figure 12 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 throttle position layout may be as shown in Figures 7 or 9. When throttle detents are used, the value of the thrust setting parameter should match the value of the target shown on the display when the throttle is in the appropriate detent. When an autothrottle system is included in the design, the thrust versus throttle position characteristic may be programmed as that shown in Figure 11, where fixed throttle positions may or may not be used for the various thrust settings. In this system configuration, the autothrottle would continually move the throttles to achieve the cruise, climb or max continuous thrust setting as environmental conditions change. Hence, when autothrottle systems are employed, the various thrust setting do not have to be at fixed throttle positions. The takeoff thrust position is normally at the full forward throttle position - when operating in the primary mode.

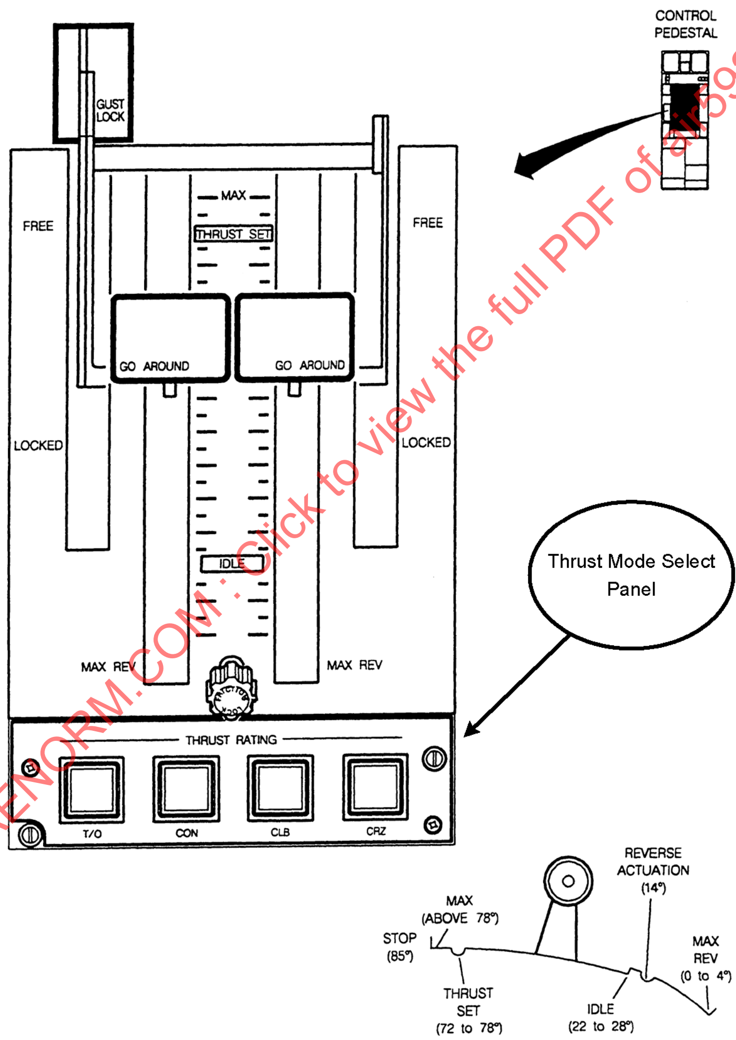




FIGURE 12 - THRUST RATING/MODE SELECTION PANEL

4.2.1.3.5 Thrust Mode Selection Page

Modern transport aircraft do not have a thrust mode select panel as shown in the figure above. Instead, modern transports which incorporate thrust mode selection functionality have a thrust setting selection page (see Figure 13), 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. In transports, 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 max climb thrust between the altitudes of 10 000 and 20 000 ft.

When in-flight, the engine thrust rating page looks a bit different (see Figure 14). The flight crew can select a full or derated climb rating, the max cruise rating, the maximum continuous power rating or the go-around (shown in Figure 14 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’s thrust setting display - when that flight mode is initiated.

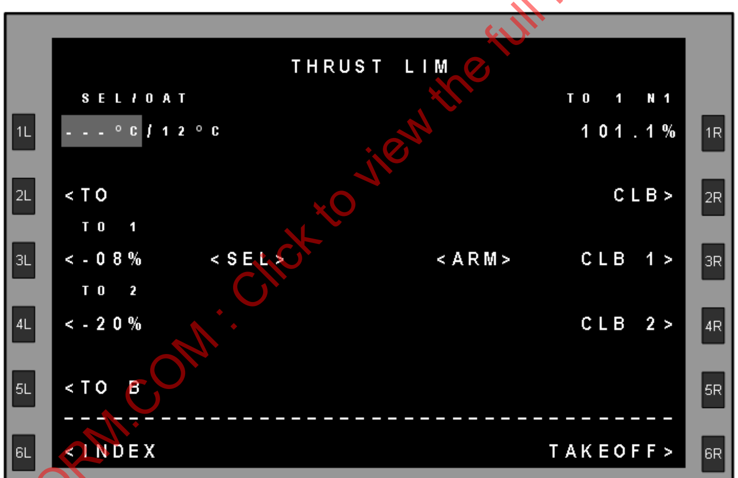


FIGURE 13 - TYPICAL THRUST RATING SELECTION DISPLAY ON-GROUND, PRE-FLIGHT

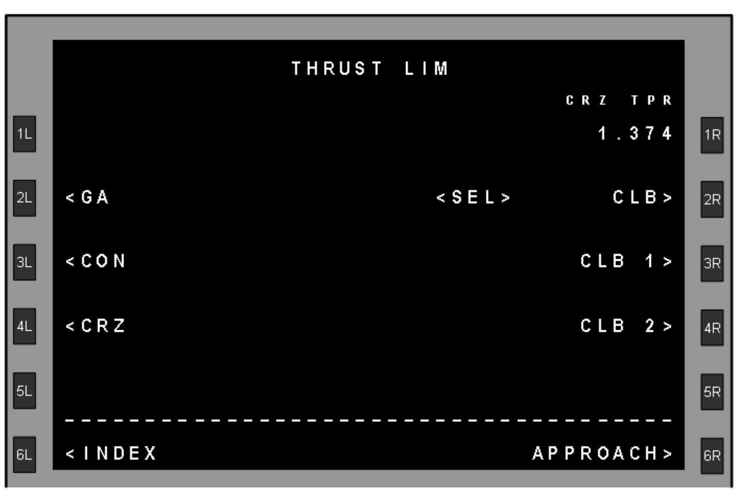


FIGURE 14 - TYPICAL THRUST RATING SELECTION DISPLAY IN-FLIGHT

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 a 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. 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 GA 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.

4.2.1.4.1 Derated Thrust Operation

Derate takeoffs have historically been performed throughout the jet transport era. Before the extensive use of onboard computers, a takeoff derate could be easily defined at dispatch, and a takeoff performed at less than full rating has well-defined performance limits. The inclusion of capable onboard performance computers has allowed the installation of pre-programmed derate values (usually identified as Derate 1, Derate 2, etc.) and allows onboard computation of the derate power settings, but the determination and use of derate thrust has, in concept, changed little over the years.

Similar to a full takeoff rating, a Derated Thrust Rating is an officially recognized lower engine thrust rating. This means that when this rating is used on an aircraft, there is a set of aircraft performance data in the aircraft's flight manual (AFM) for that rating, as if lower thrust engines were installed on the aircraft. This data would include the power setting data (that is, values of the thrust setting parameter) as a function of altitude and temperature and all the aircraft performance data that specifies the maximum gross weights for that thrust setting as a function of takeoff flap setting, and runway length. This data also includes V-speeds, such as the minimum control speed on the ground (Vmcg), decision speed (V1), rotation speed (VR), the second segment climb-out speed (V2), and the minimum control speed in the air (Vmca). It is important to note that these V-speeds (V1, VR, V2) will be lower than the full takeoff thrust V speeds because of the reduced asymmetric thrust associated with an engine failure at V1. The associated minimum control speeds (Vmcg and Vmca) will be lower as well. If the aircraft is loaded to the maximum gross weight allowed for the derated thrust setting, the aircraft would be performing a performance-limited takeoff. This means that if the aircraft suffers an engine failure during the takeoff roll, the performance of the aircraft will just meet either the field length limits or the minimum engine-out climb gradients required by the regulations (depending on which parameter is limiting for a given takeoff situation). Regular use of derated thrust settings would result in a higher percentage of performance-limited takeoffs than full time use of the max rated takeoff setting.

When using derated takeoff thrust settings, the full-throttle thrust setting may or may not be limited to that derated thrust setting. The reason for this is that if the full throttle position selects the full engine thrust rating, and the flight crew were to select the full throttle position after an engine failure slightly above V1, the aircraft would be at a lower speed, where rudder authority would not be sufficient to compensate for the larger thrust asymmetry. This could cause the aircraft to laterally depart the runway. With the exception of automatic takeoff thrust control system (ATTCS) operation (discussed in 4.2.1.7), the flight crew is trained to not change the thrust setting following an engine loss in the takeoff mode. Full engine thrust rating may be provided for emergency conditions, like wind shear, or after aircraft has achieved higher airspeeds, when rudder authority is sufficient to compensate the larger thrust asymmetry.

There are many transport aircraft that do not limit full-throttle thrust to the selected derated thrust. In these cases, if the thrust level is advanced to the full-forward position, the engine FADEC system will set maximum rated thrust for the flight condition, not the selected derate(d) thrust.

4.2.1.4.2 Reduced Thrust Operation

This method for using a lower takeoff power setting has existed nearly as long as the concept of derated thrust, but requires a somewhat more complex process to determine the allowable thrust setting for any given takeoff. The method has gained increased acceptance for transport aircraft with the advent of onboard performance computers, which allow more precise definition of the ambient parameters required for any given takeoff in which use of reduced thrust is desired. This method only requires one rating, the full takeoff rating, to be stored in flight computers, and this one rating can be used to obtain a lower value of the power setting when the aircraft is operating at a lower-than-the-maximum-allowed-gross-weight at the prevailing ambient temperature and altitude conditions.

When discussing reduced thrust operations, one may often say that, “We’re providing assumed-temperature-method (ATM) derated thrust capability on the aircraft.” Although everyone usually knows what the speaker means, we should not use the word “derate” in that phraseology, but rather refer to it as “reduced thrust” capability to avoid confusing the two methods.

Reduced thrust operations are slightly different than derated thrust operation in that there are no new performance charts in the AFM for this type of operation; the same full takeoff performance charts are used. In reduced thrust operations, if the GW of the aircraft is less than the maximum GW allowed for the current outside air temperature (along with the other variables of flap position, runway length, etc.) then one enters the performance charts backwards, with the aircraft’s GW and determines from the charts the appropriate value of the thrust setting parameter. The parameter that is usually determined is the maximum outside-air-temperature (OAT) at which the aircraft could perform a takeoff at this GW. That hot day temperature is then inserted into the airplane performance computer and the thrust setting for that temperature is then determined and displayed as the target on the thrust setting parameter display.

For reduced thrust takeoff operations, the V-speeds that must be used for that takeoff are the same as the V-speeds associated with those for the full takeoff power setting at the same temperature. Therefore, the V-speeds for the same thrust setting using a reduced thrust procedure will be higher than those used for a derated thrust takeoff. Takeoff distances and takeoff profile (climb performance) ) will be nearly the same as the derated thrust case, because although V1 will be higher in the reduced thrust case, the VR and V2 speeds will be the same - as they are based on aircraft GW.

Another item that provides slightly more performance capability when performing a reduced thrust takeoff at the same power setting as the derated takeoff is the slight engine thrust differences due to the air density difference effects on engine thrust. In both cases the same power setting value is set at the beginning of the takeoff. However, in the reduced thrust takeoff, the day is actually colder than the day temperature for the limiting takeoff case, and therefore the air is slightly denser than it would be at the higher temperature, and the engine will make slightly more thrust with the denser air. This slightly higher thrust (at the same thrust setting) will give the reduced thrust operating aircraft a higher thrust-to-weight ratio, and therefore, slightly better performance.

When the practice of using reduced thrust settings was established, the process/procedure was not allowed on contaminated runways. The reasons for this are not clear. It was probability just conservatism, but this limitation still exists. Because of this, transports always provide derated thrust setting capabilities as well as reduced thrust capability.

4.2.1.4.3 Combinations of Derate and Reduced Thrust Operations

It is acceptable to combine both the derated and reduced thrust operating methods. When doing this, select the derated thrust level first. If the derated thrust level chosen allows a maximum GW that is greater than the GW to which the aircraft is loaded, an additional thrust reduction using an approved method, such as ATM as applied to the derated performance calculations, is allowed.

#### 4.2.1.5 Engine Thrust Lapse Rates from the Basic Ratings Computations

In the following discussion, takeoff thrust set or setting applies to the value of the thrust setting parameter that is set during a takeoff. In a typical turbofan powered transport aircraft, this is the value of the thrust setting parameter that is set by the flight crew (or automatically by the Autothrottle or flight management system), when the aircraft is between 60 and 80 knots during the takeoff-roll. Although not normally done, the takeoff thrust setting could be done statically. All transport aircraft typically use a call-out of thrust set by the non-flying pilot at or around 80 knots. There is no rule requiring this; it is just a typical operating procedure recommended by the transport aircraft manufacturers and used by virtually all operators.

The profile that the engine thrust follows after takeoff thrust set is usually referred to as the engine's takeoff thrust lapse rate. This lapse rate is important because it is used to compute the aircraft's takeoff performance. This lapse rate is how thrust changes with altitude, temperature, and airspeed. When completing aircraft performance calculations, it is assumed that static or ambient air temperature follows the standard atmospheric profile and decreases 2 °C per thousand feet of altitude increase; therefore, by definition, the lapse rate is only a function of airspeed and altitude and the on-ground temperature. Note: The engine’s actual thrust lapse rate may be a function of total air temperature (TAT) because the control may be using an actual real time selection of temperature to determine the thrust rating. (See 4.2.1.6.2 for more discussion on this subject.) Figure 15 illustrates this, showing the change in ambient temperature expected to occur during standard day operation, along with the temperature lapse that may occur when climbing out into a cold or hot (i.e., temperature inversion) atmosphere. During the cold or hot day conditions, thrust will not be the same as the standard day climb out thrust if the engine control is using actual, real time sensed temperature. This is illustrated in Figure 16. Section 4.2.1.5.2 discusses the impact of this.

As the engine control is scheduling thrust by controlling EPR or N1, the data in the control that determines how EPR or N1 varies with altitude and airspeed determines the takeoff thrust lapse rate.

##### 4.2.1.5.1 Full and Reduced Takeoff Thrust Lapse Rates without Lock and Lapse Logic

In most modern FADEC systems used today, the ratings for takeoff and climb are continuously calculated as a function of the FADEC system's selected values for the environmental parameters (that is, total temperature, altitude or barometric pressure, and Mach number or airspeed), and the control simply governs the engine to the value(s) computed. If the thrust lever is in the full takeoff position, the control varies the thrust setting parameter (for example, N1 or EPR) by modulating fuel flow and other variables as needed to follow the calculated value of takeoff thrust. If the thrust lever is in the climb position, the control governs the engine to the climb power setting calculation. If the thrust lever is between the takeoff and climb power positions, the control interpolates between those two power setting calculations. If the thrust lever is less than the climb power setting, which is common with reduced thrust takeoffs, the control simply governs the engine to some fraction of the climb power setting calculation.

When operating at lower than maximum gross weights and performing takeoffs at thrust settings below the full takeoff thrust setting, the lapse rate that thrust follows after power set is still called the takeoff thrust lapse rate even though the engine is not operating at full takeoff power. This lower thrust setting lapse rate is just as important as the full takeoff thrust lapse rate because aircraft performance will be based on this lapse rate for the lower thrust takeoffs. Therefore, takeoff thrust lapse rates must be established for all full and lower takeoff thrust power settings. This is particularly important when performing reduced thrust takeoffs using the ATM method as described in 4.2.1.4.2. After thrust set, the control will be governing and lapsing thrust from a set point that is less than the full takeoff thrust setting value, but it is the same thrust setting value that would be set for full takeoff thrust on a hotter temperature day. Therefore, the difference in the thrust lapse rates when setting the same value of engine power during hot and cold day operating conditions must be understood to properly account for aircraft performance during reduced thrust takeoffs.

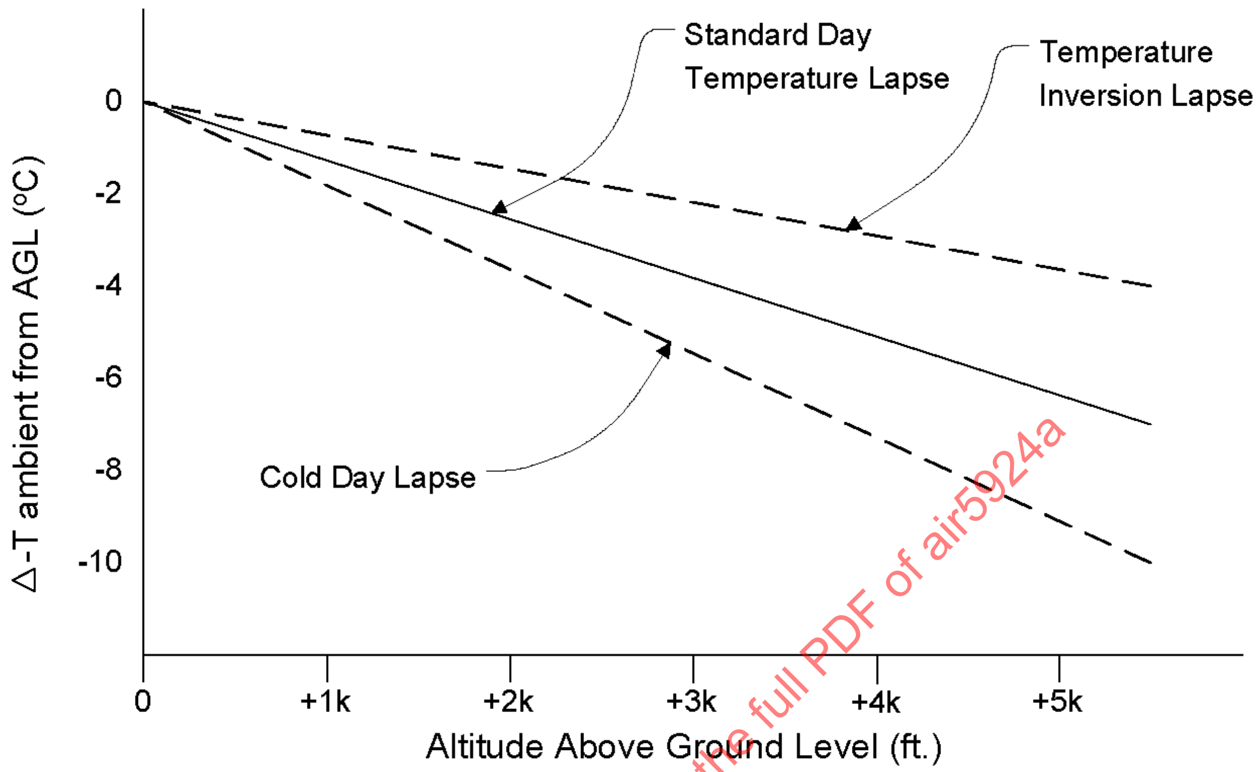


FIGURE 15 - AMBIENT TEMPERATURE LAPSE FROM AGL

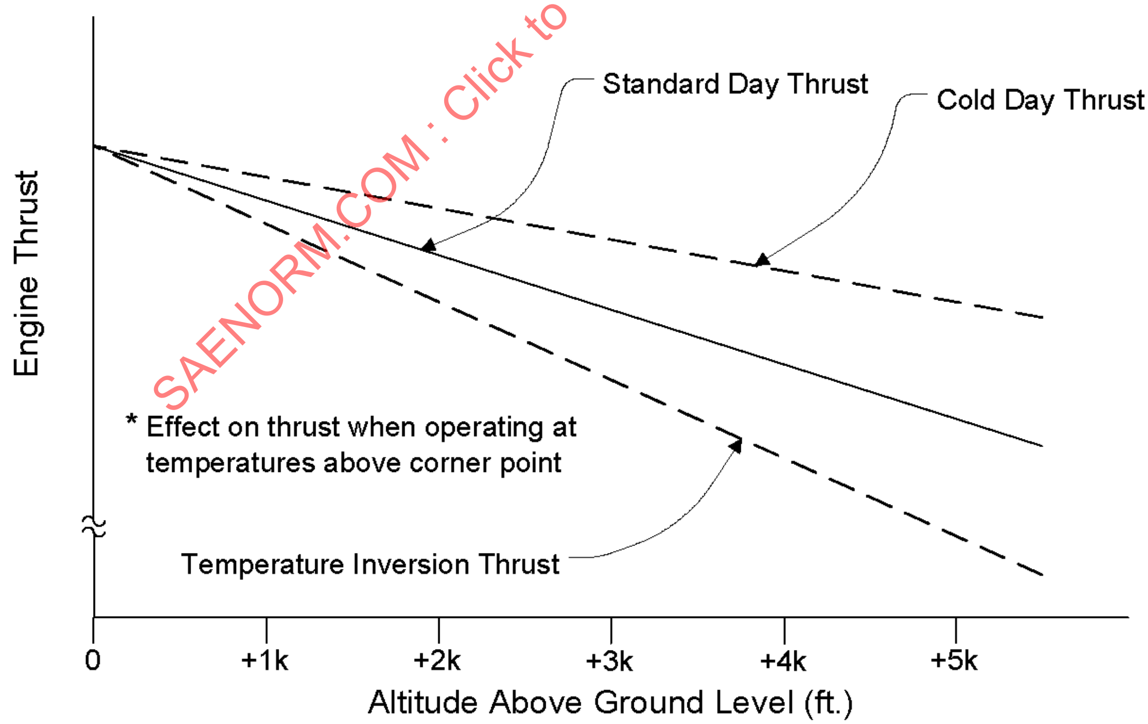


FIGURE 16 - THRUST AS A FUNCTION OF AMBIENT TEMPERATURE AND ALTITUDE INCREASE AT CONSTANT MACH NUMBER

4.2.1.5.2 Takeoff Lapse Rates Using Lock and Lapse Logic

Due to the complexities involved with different takeoff thrust lapse rates at the same value of the power setting parameter on hot and cold days, it is beneficial to both engine life and aircraft performance calculations to define a specific engine lapse rate characteristic and construct that characteristic into the control system. The control logic that contains and implements this characteristic has been termed lock and lapse logic. Several engine manufacturers use lock and lapse logic for controlling the engine's thrust lapse during the takeoff. In this implementation, the control system locks in the pressure altitude and temperature information at approximately 60 knots and programs a given lapse rate as a function of the change in altitude, and change in Mach number or CAS, and, in some implementations, the 60 knots set value of the thrust setting parameter, EPR, or corrected fan speed (that is, $N1/(Theta)^{0.5}$). These types of implementations are recommended because the lapse rate in thrust is always the same for a given altitude and a given initial value of thrust setting. This type of implementation does not require an extensive analysis to show that assumed temperature derated takeoffs have the same lapse rates.

The change in temperature can be either the change in static temperature or the change in total temperature. Since the control knows Mach number (and airspeed), the change in static temperature is easily computed. Using the change in freestream temperature allows the control to program a takeoff thrust schedule that maintains an approximately constant exhaust gas temperature (EGT) throughout the takeoff. However, when performing takeoffs into temperature inversions, the implementation that adjusts engine thrust during inversion conditions results in LESS thrust than the aircraft flight manual assumes. Airplane performance computations assume that outside air temperature (OAT) decreases 2 °C per 1000 ft of increase in elevation. If the actual static OAT does not do this (that is, if it decreases less than expected with increasing altitude), then the engine may be holding constant EGT, but the aircraft is getting less thrust than planned. If this is the case, many engine FADEC systems implement a lock and lapse logic that locks in the OAT at 65 knots and programs an assumed temperature lapse rate with altitude in which the static air temperature decreases at 2 C per 1000 ft of altitude and disregards the actual static air temperature change with altitude. The engines could go over EGT redline if the engines are close to redline at power set and the aircraft encounters a temperature inversion during climb-out, but the aircraft will be getting the planned thrust. If an engine fails during takeoff, getting the planned takeoff thrust from the remaining engines is more important than engine over-temperature concerns. In addition, when all engines are working properly, most takeoff conditions end around 400 ft AGL. The engines are then reduced to climb power, and the lock and lapse logic is disabled when the thrust lever is moved from the takeoff to the climb position or other logic, such as exceeding a given Mach number (like Mn 0.45), so, the exposure to over-temperature conditions occurring during normal operations is small.

This latter approach of locking the altitude and OAT at approximately 60 knots and programming engine thrust using an assumed 2 C static OAT decrease per 1000 ft of altitude is the recommended approach to implementing takeoff thrust lapse rates, because this is the thrust used for aircraft performance calculations.

An approach used in Part 23 aircraft is to lock the temperature and pressure used to determine the power setting at the beginning of the takeoff roll and hold these values for a set time after rotation or the pilot retards the throttle(s) from the takeoff position. The “set time” used is based on the time it takes the aircraft to clear ground obstacles. A reasonable height to consider for a ground obstacle clearance is 1000 ft. After the timer expires the control reverts to normal sensor operation.

4.2.1.5.3 Lapse Rates for Fan Speed Controlled Engines without a Dedicated P2 Probe

As discussed above, engine controls systems that use fan speed as the power setting parameter may have a thrust rating definition in which the ratings are not significantly affected by Mach number or airspeed during low speed operating conditions. In this situation, it has been considered acceptable for the engine control not to incorporate a dedicated P2 probe and sensor into the FADEC system. If this is the approach pursued, the sole sources for Mach number (or airspeed) information will be the aircraft's ADCs. For obvious reasons, it is important that ADC failures do not cause the thrust of all engines to be significantly affected in the critical modes of operation. While all modes of operation are important, it is generally recognized that two of the critical modes are the takeoff and the engine out, maximum continuous thrust operating conditions.

For systems without a dedicated P2 probe and sensor, it is recommended that the engine control system have essentially no Mach number influence on the scheduled thrust rating when operating in the takeoff mode. One way to achieve this is to use lock and lapse logic for the takeoff. At 65 knots, the takeoff altitude and static air temperature are frozen. (At least one of the ADCs needs to be alive and transmitting data to implement this. If both are available, the one that indicates the higher airspeed should be used. If the two ADCs disagree, selecting the higher of the two airspeed signals may cause the control to lock-up sooner than it should, but this is generally conservative.) The lapse rate is programmed as a function of only two variables; the change in altitude and, if desired, the 65 knots set value of corrected fan speed. At constant altitude, this logic results in a given value of physical fan speed set at 65 knots and maintained at constant altitude, but as airspeed increases, total temperature increases and thus, corrected fan speed decreases with increasing airspeed. This decreasing corrected fan speed with increasing airspeed will tend to keep EGT constant, which is desirable. When using this logic, physical fan speed is usually programmed to change as altitude increases. The programmed change is normally implemented by adding a delta N1 as a function of delta altitude. This logic will essentially allow the takeoff thrust rating to be independent of any ADC airspeed errors or failures in the takeoff mode. If, after a suitable time period, no air data information is available from either air data computer to the engine control, the above lock and lapse logic cannot be implemented. In this case the control should indicate a primary mode fail condition and should enter the soft reversionary or backup mode, depending on thrust position and (possibly) air/ground information.

For all other modes, the average of the ADC Mach numbers can be used as long as the Mach numbers agree within 0.05 Mach (see 5.5.4).

4.2.1.5.4 Limiting Thrust at Low Calibrated Air Speeds (CAS) during Ground Operations

A recent control system trust limiting characteristic has been added for large transport engines. This is a characteristic where the engine FADEC system limits thrust at low forward airspeeds to prevent large fan blade stresses from occurring and shortening blade life. A sample limiting characteristic is shown in Figure 17.



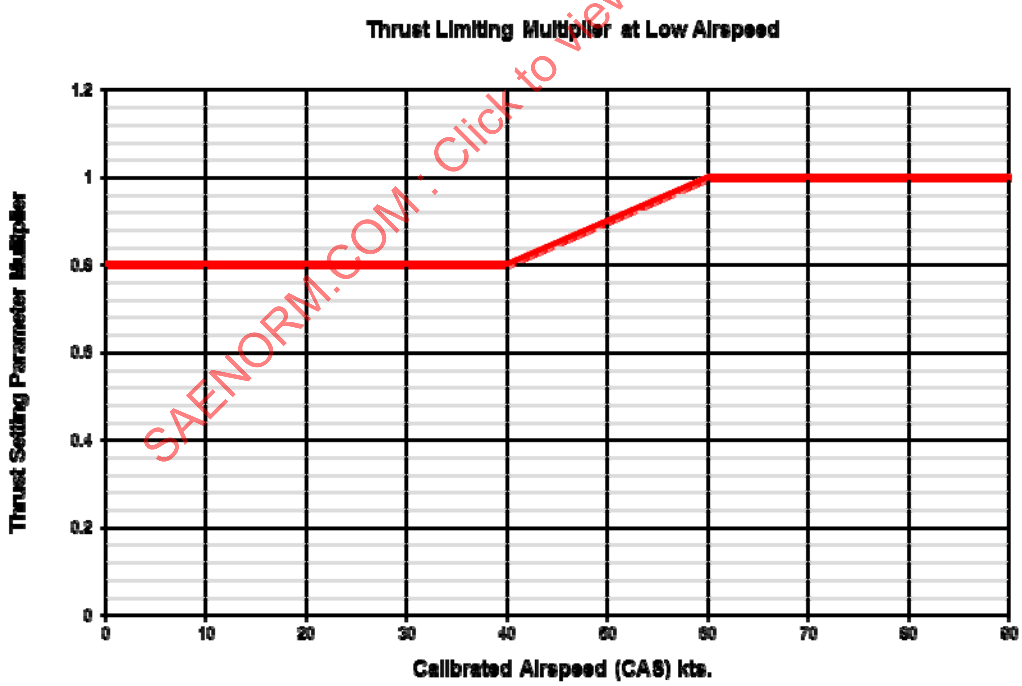


FIGURE 17 - THRUST LIMITING FUNCTION AT LOW AIRSPEED

In this example, thrust is limited to 80% of the maximum rated thrust when calibrated air speed (CAS) is below 40 knots and is linearly ramped up to 100% of rated thrust as airspeed increases from 40 to 60 knots. These functions have been found to be acceptable. The impact of such a characteristic on aircraft performance (e.g., takeoff runway lengths) has to be taken into account. In general CAS may not be available from the aircraft's air data computer (ADC) until 20 or 30 knots. This should not be a problem, as the multiplier can be a constant number below 30 knots. If this is a concern, logic can be employed to use wheel speed until airspeed is available. Wheel speed will generally be less than CAS. If the two CAS signals differ a bit, use the higher one, as the important thing is to get thrust set by the "call out" airspeed/thrust check point. In Transports this check is usually around 80 to 85 knots. In Part 23 business jets it can be a lower value, like 65 knots. The pilot acceptability of this function can be established during flight test.

4.2.1.6 Autothrottle/Autothrust Systems - Engine Control in Primary Mode

4.2.1.6.1 Moving Thrust Lever, Autothrottle Systems

For transports that use an autothrottle servo to move the thrust levers as the primary means of commanding a thrust change, the engine power ratings as a function of thrust lever position are usually implemented as discussed above. The autothrottle system may use a single servo to drive all thrust levers or separate servos for each thrust lever. Figure 18 depicts a simple autothrottle system schematic. In modern systems, the feedback from the thrust lever servo positioning system is generally used for servo limit protection and rate control, and the feedback from the FADEC system units are usually the EPRs or N1s that the FADEC systems are commanding of the engines. In a typical implementation, when the highest FADEC system EPR or N1 command achieves the value desired by the autothrottle computer, the autothrottle servo system stops driving the throttles. In those systems using a single servo motor to drive all thrust levers, the computer used to drive the thrust levers, which is herein referred to as the thrust management computer (TMC) or flight management computer (FMC), may provide digital trim signals to the EECs to align the power setting parameters, to compensate for the rigging errors and slight thrust lever position differences, which would otherwise result in differences in the power settings between engines. In these systems, it is recommended that the servo system go to a "hold mode" at approximately 65 knots. This hold mode should be designed into the system to prevent an autothrottle servo system error from moving the thrust levers and commanding thrust changes on all engines after takeoff power set. The FADEC systems should latch any trim signals received from the TMC system prior to the speed at which the AFM instructs the flight crew to verify takeoff setting. For larger transport aircraft this is at approximately 65 knots and the flight crew must confirm the engines are operating at the target power setting at approximately 80 knots. For smaller aircraft, the flight crew/pilot may confirm the Takeoff power setting at a lower speed, like 65 knots. By having the autothrottle servo system go to the hold mode and the EECs latch any trim inputs at the appropriate speed, the flight crew has time to adjust the power setting as necessary. Eighty knots (60 for smaller aircraft) is typically used as the point above which the flight crew should have power set and not make further adjustments.

Systems using a separate autothrottle servo for each thrust lever should be designed to work in the same way as single servo systems. Multiple servo systems may or may not employ trim signals for each engine's FADEC system; this would depend on the accuracy of the servo system. Systems with a single servo for all throttles or separate servos for each throttle generally incorporate an automatic disconnect feature which disables the system if reasonable throttle alignment is not maintained.

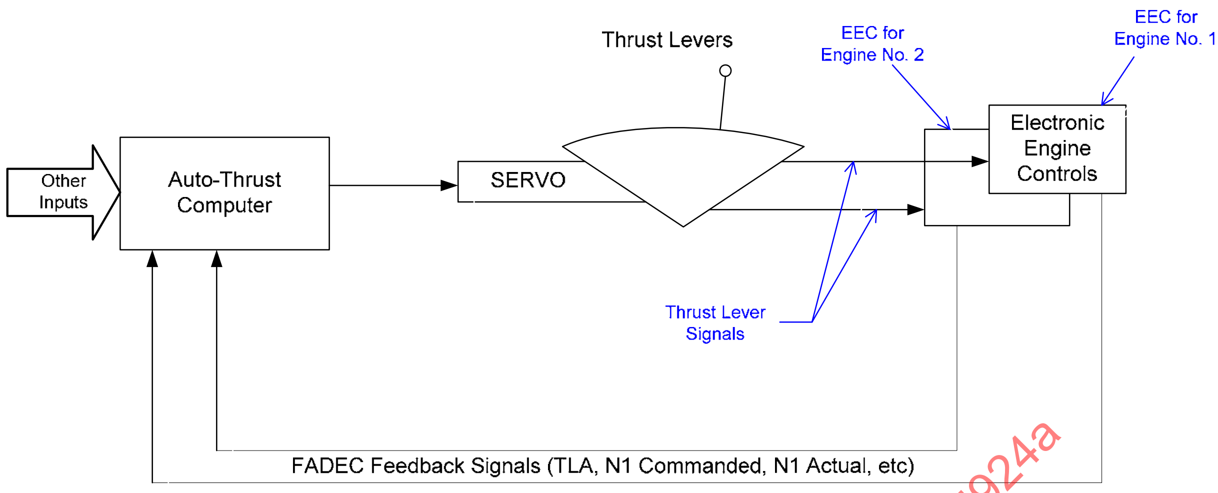


FIGURE 18 - MOVING THRUST LEVER AUTO-THRUST SYSTEM

4.2.1.6.2 Non-Moving Thrust Lever, Autothrust Systems

Some autothrottle systems are configured not to use a servo to drive the thrust levers, but instead to use an electrical/electronic thrust management system input to the FADEC system(s) to modulate thrust. In these systems, the thrust levers are manually advanced by the flight crew to the appropriate detent position, such as the cruise or climb position, and when the autothrust system is armed and active, the FADEC system accepts thrust commands from the thrust management computer. Figure 19 illustrates such a system. In these systems, it is recommended that the EECs lock the thrust command signal at 65 knots in the takeoff mode, and not accept any thrust command changes from the TMC until at least 400 ft AGL is reached.

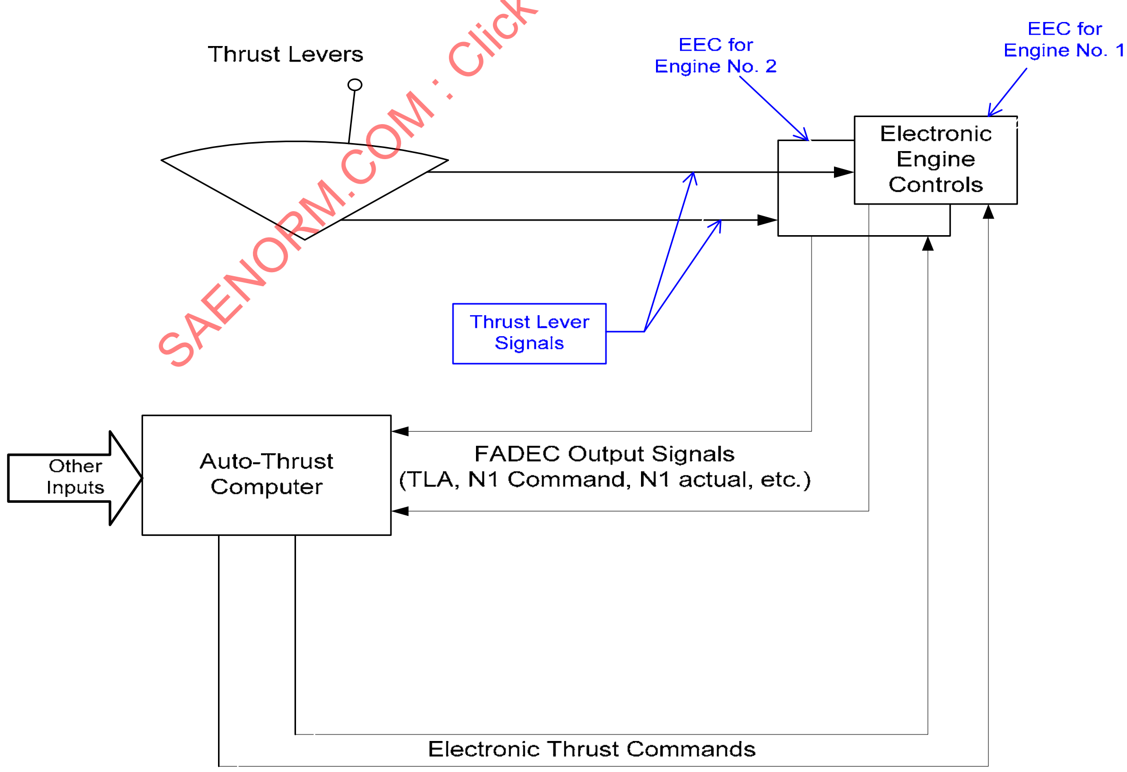


FIGURE 19 - NON-MOVING THRUST LEVER AUTO-THRUST SYSTEM

In the non-moving throttle/autothrust systems in current transport aircraft, the autothrust system cannot command a higher thrust than that associated with the throttle position. Hence, it cannot up-trim the engine; it can only down-trim it. So, if the flight crew needs or wants a higher thrust setting from the autothrust system, the flight crew has to advance the throttles to a higher position. To disengage the autothrust system, the pilot retards the throttle to a position where the thrust at that throttle position aligns with the thrust being commanded by the autothrust system and then disengages the autothrust system. This allows a disengagement with essentially no - or a small - thrust change.

4.2.1.6.3 Takeoff, Climb, Cruise and GA Autothrottle/Autopilot Operations

The intent here is to provide a very brief discussion of autothrottle/autopilot operations.

The Takeoff autothrottle/autothrust operation is simple. The throttle are placed either via servos or manual throttle movement to the takeoff position or moved to achieve the takeoff target power setting target, and thrust is achieved by the FADEC controllers in governing the engine(s) to the takeoff power setting target. There is no autopilot function. The throttle servos go to a “hold condition” by having servo power removed between 60 and 80 knots so that autothrottle system malfunctions above 80 knots do not affect engine thrust.

In some of the early autothrottle/autopilot designs, the climb mode function was to have the autothrottle control airspeed by controlling thrust and the autopilot was set on controlling rate of climb via the elevator. In these early designs, if a high rate of climb was requested, the autopilot had the authority to pitch up the airplane to a condition where forward speed could not be maintained (because thrust is limited to the maximum climb thrust selected) and the aircraft could actually stall. This is more likely under high gross weight conditions.

One of the newer autopilot/auto control modes during climb conditions is to set climb power and hold forward speed using the elevator. The forward speed will be a commanded CAS until the desired Mn is captured, and then climb at constant Mn to the commanded altitude. During these conditions the rate of climb will simply “fall out” depending on the climb thrust and the aircraft gross weight. If the airplane GW is light, the elevator could pitch the airplane up to an uncomfortable angle (i.e., attitude). Airplanes are not normally this lightly loaded, but when this occurs, a reduced climb power rating can be selected, or the flight crew can simply reduce power manually. This will cause the elevator to pitch the airplane down (reducing attitude) to maintain forward speed. This can also be achieved by having the autopilot control thrust to achieve a commanded climb rate. In heavy GW conditions, if too high a climb rate is requested, the thrust will simply be limited to the maximum climb thrust selected and the climb rate will simply “fall out” at the thrust setting, but these control functions, the aircraft will always be able to achieve its commanded airspeed.

At cruise conditions, the airplane will be on altitude and Mach hold conditions during autopilot/autothrottle operation. In this condition the elevator is normally used to control altitude and thrust used to control airspeed/mach number. If the airplane can maintain the airspeed/mach conditions at a power setting below max cruise, it will do so. If it cannot, the airplane will slow down.

Similarly, during GA or maximum continuous operating conditions, the airplane may be in a flight-level-change mode where the airplane conditions of speed and altitude rate of change can be satisfied without the need for max GA or Max Con thrust. If this is the case, then the engine will operate at a lower power than those maximum ratings.

Most all of the newer airplane autopilot designs incorporate envelope protection, where if thrust is limited and airplane speed is decreasing toward a minimum allowed airspeed - for a given altitude and flap setting condition - the autopilot will use the elevator to reduce airplane pitch and protect that minimum airspeed.

4.2.1.7 Automatic Power Reserve (APR) or ATTCS Systems

Many of today's small and medium-sized transport aircraft employ APR systems, which are also known as ATTCS. These are systems that are designed to sense an engine failure when operating in the takeoff or go-around modes of flight and command a thrust increase on the remaining engines. The current FAA rule applying to such systems is given in Appendix H of 14CFR Part 23 and Appendix I of 14 CFR Part 25. A revised rule, which is a harmonized effort toward achieving commonality between FAA, EASA, and Transport Canada requirements for these types of systems, has been drafted and will be available for public comment in the future. The revised rule would allow new APR systems to implement thrust increases greater than 11%, but would limit credit in takeoff and go-around performance to be not greater than 11%. For example, assume that an APR (or ATTCS) takeoff is being performed at a reduced thrust (from maximum APR thrust) of 25%. If an engine fails, the remaining engines may increase to the maximum APR thrust, but the credit to aircraft performance will be limited to that associated with an 11% thrust increase. The airplane performance credit refers to the aircraft GW for engine out performance, which in this case would be limited to that associated with only an 11% thrust increase on the remaining engines.

The original discussions and regulation material on APR systems refer to full APR takeoff thrust as 100% thrust, and normal takeoff thrust was limited to being not less than 90% of that full thrust value during APR operation. This is a thrust decrease of 10% from maximum thrust. The newly harmonized material uses the wording of an 11% increase from the normal takeoff thrust setting. The 11% increase in the new wording and the 10% decrease in the original wording refer to the same increment.

The limiting of aircraft performance credit to that associated with an 11% thrust increase, in both the past and newly proposed regulatory material, was established by the FAA so that, "the all-engine performance is not significantly degraded and that a minimum level of performance is available if an engine and ATTCS failure occur simultaneously."

The introduction of FADEC systems allowed APR functionality to be completely contained in the FADEC system. Aircraft interfaces are generally limited to an APR on/off selection switch and displays of APR functionality. The new designs incorporate multiple data paths between the engine control systems. Engine information in these data paths is used by each engine control to determine whether another engine has failed. If it has, then the control system(s) on the non-failed engine(s) calls for a thrust increase. The probability of having a failed engine, in combination with the probability that the remaining engine(s) will not increase in thrust due to a control system malfunction, has to be extremely improbable (that is, the failure rate for this combination of failures has to be less than $10^{-9}$ events/flight hour).

An additional certification requirement when implementing APR systems concerns the engine displays. The requirement is for the flight crew(s) to be able to determine that the engine is capable of achieving the APR thrust setting without exceeding any engine limits when they set the lower takeoff thrust. (This requirement is not clearly specified in the current Part 25, Appendix I, requirements; the newly harmonized, proposed revision to the rule contains this requirement.) In general, past applicants have met this requirement by providing two redlines on the appropriate engine displays. The lower redline is not really a redline, it is a reference value. This indicates to the flight crews that if normal (that is, reduced) takeoff or go-around thrust can be set with the engine operating below the reference redline, then full APR thrust can be achieved without the engine exceeding its real redline. Some new aircraft/FADEC system designs are not using the dual redline approach. In these systems, an aircraft avionics unit or the FADEC system incorporates a suitable alert to notify the crew if the engine does not have adequate margin(s) to get to APR thrust without exceeding an engine operating limit. In addition, many of today's aircraft have some sort of engine health monitoring, which is performed on engine data recorded during the takeoff and analyzed on-ground, to determine if the engine can get to full takeoff thrust (i.e., full ATTCS thrust) without exceeding limits. If the analysis indicates that the engine cannot achieve full takeoff thrust without exceeding limits, the engine is scheduled for removal and refurbishment.

4.2.1.8 Two Basic Thrust versus Thrust Lever Position System (FAA) Requirements

There are two basic thrust versus thrust lever position system requirements that, although well known, have caused difficulty in some installations.

4.2.1.8.1 Requirement for Increasing Thrust with Forward Thrust Lever Position

The first is the requirement that thrust must monotonically increase with forward thrust lever motion. Flats (that is, thrust remaining unchanged with thrust lever movement) are acceptable. This requirement has been overlooked in some cases, when large reduced takeoff thrust operations are employed. This omission has occurred when the thrust lever system uses a fixed position for climb rated power as well as takeoff power. In these systems, the thrust lever is placed in the takeoff position for all takeoffs, including all derated and reduced thrust takeoff operations. It is easy to implement a derate and/or reduced thrust condition when power being used for that takeoff is less than normal climb power. Therefore, climb power must be lowered on those takeoffs as well, because otherwise thrust can actually increase when the thrust lever is retarded from the takeoff position to the climb position. This would not meet FAA regulatory requirements. Most designers recognize this requirement, but there have been cases in which this has been overlooked. The simplest solution is to have the control do a select low between the computed takeoff thrust setting value and the climb thrust setting value when computing the climb power setting.

4.2.1.8.2 Requirement for Maximum Continuous Thrust Setting Capability with All Engines Operating

An FAA requirement, expressed in the Transport Aircraft Directorate Policy Letter 00-113-1028, dated July 31, 2000, is that the capability must exist for setting maximum continuous power on all engines at all flight conditions (see 4.2.1.2). Some designers believe that the capability for setting maximum continuous power is only required during engine inoperative conditions. This has been a problem in past thrust control systems in which ATTCS is used full time. Figure 20 illustrates how thrust scheduling has been implemented in some past aircraft. The particular thrust schedule being used by the flight crew is selected by a mode control panel in the cockpit. The schedules are available for selection during all-engine operative conditions, and the system automatically switches to a Max Continuous Thrust schedule when an engine inoperative condition is sensed from engine data. In these systems, the normal takeoff thrust setting is usually 10% below full takeoff (APR) thrust and in many instances is below the maximum continuous thrust setting.

Note that the flight crew cannot set maximum continuous thrust on the engines during an all-engine-operative condition if the system is designed as shown in Figure 20, because the maximum continuous power setting is on the step from normal takeoff power to full APR power. It is not possible to set maximum continuous thrust in such a configuration.

A simple solution is to provide a ramp up from the normal takeoff rating to the maximum takeoff rating and make the slope acceptable for setting power at a point along the slope.

Another approach would be to have a cockpit-located, maximum continuous selection switch that changes the selectable thrust schedules from Normal to Max Continuous when the switch is activated. This allows the flight crew to select Max Continuous Thrust schedules and set maximum continuous power on all engines whenever that thrust setting is desired.

4.2.1.9 Fan or Core Speed Synchronization Function

Engine synchronization is a function which can be integrated as part of the electronic control system. The synchronization function is primarily used on aircraft with body mounted engines, but may be used in wing mounted configurations as well. The purpose of engine synchronization is to match speeds between multiple engines to eliminate the beat frequency and resulting noise in the aircraft cabin that occurs with engines running at different mechanical speeds. The control system can be set to accept a synchronization command from a synchronization select switch in the cockpit, or to automatically synchronize engine speeds when certain conditions, such as throttle lever angles matching within a specified tolerance, are met. Synchronization can be configured to synchronize fan speeds (N1) or core speeds (N2) depending on the installation and the susceptibility of the airframe to noise. While cabin noise is generally more critical at higher power settings, it is typical for engine synchronization to be available at all power settings from idle to max continuous.

Two options exist for synchronizing the engines, either a master/slave arrangement or an averaging arrangement. In the master/slave arrangement, one engine is the master and the other engine(s) have their power settings adjusted to match the master engine. In an averaging arrangement, the engines speeds, either N1 or N2 depending on the syncronization mode, are averaged and then all engines are run at the average power setting to match. Regardless of the arrangement, the engine isolation requirements of 23.903(c) and 25.903(b) must be met (i.e., failure of one engine must not affect the remaining engine(s) while synchronization is active). This is achieved by limiting the authority of the synchronization function.

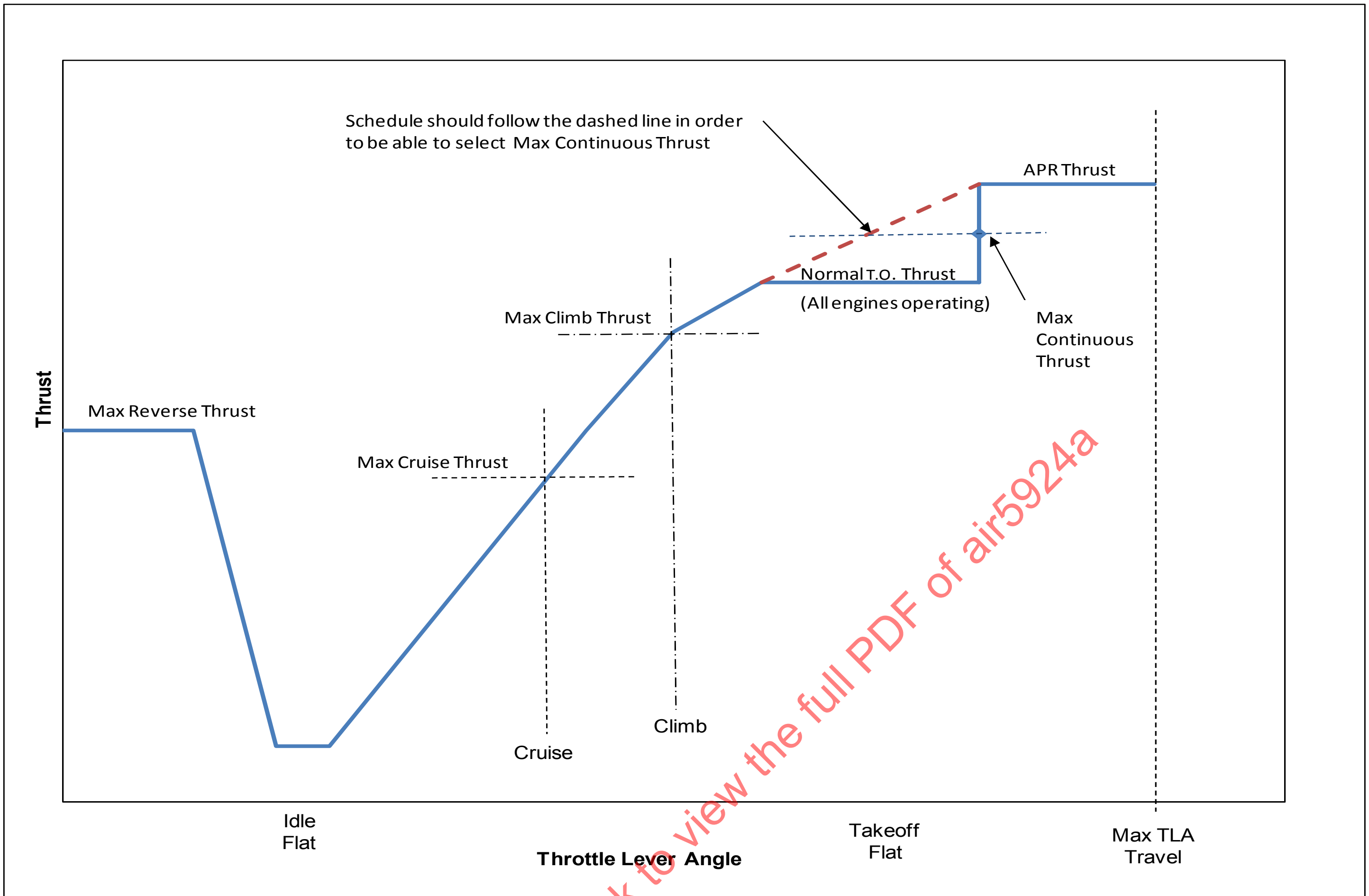




FIGURE 20 - ALL ENGINES OPERATING; AVAILABLE THRUST SCHEDULES (CANNOT SET MAXIMUM CONTINUOUS THRUST)

### 4.2.2 Engine Ratings and Thrust Lapse Rates in the Backup (or Alternate) Mode

#### 4.2.2.1 Idle Control

Idle control is generally the same in both the primary and backup modes; the functions that might typically be incorporated into idle control are discussed in 4.2.1.1. These functions can be the same because their implementation generally only involves the use of altitude and total temperature information, and the control system normally has this information available in all dispatchable modes. If this is the case, the control is usually considered non-dispatchable if its own sensors supplying this information are inoperative.

#### 4.2.2.2 Thrust versus Thrust Lever Position - Non-Rating Modes

For turbofan engines that use EPR as the primary thrust setting parameter, control in the backup mode is normally that of governing fan speed. Therefore, thrust in the backup mode is determined by the programmed schedule of N1 as a function of thrust lever position. Air speed or Mach number information may not be available to the control. Indeed, this may be the reason that the control is in the backup mode. In this mode, the control is usually programmed to schedule fan speed from some fraction of the full thrust value of N1, up to the full thrust value of N1, as the thrust lever is advanced from idle to the full forward stop. The full thrust value of N1 can be a function of altitude and, if desired, total temperature. As in the case of control in the primary mode, the multiplier fraction used when the thrust lever is at idle needs to be small enough that the control will select the idle function as the thrust is reduced to idle.

4.2.2.3 Backup Mode Lapse Rates - A Simple Approach

As the backup mode does not usually implement a rating type of control function, there is no need to lock-up aircraft discretes, such as those associated with customer bleed, at 65 knots. Changes in these discretes generally have no effect on the controller's N1 setting, and without airspeed, the controller cannot use a lock and lapse logic routine to implement a given lapse rate. Therefore, the lapse rate is quite simple. If the scheduled value of N1 is only a function of thrust lever position and altitude, the control will hold a constant fan speed at constant altitude. (Increasing airspeed (at constant altitude) while holding physical fan speed constant causes corrected fan speed to decrease. This tends to hold EGT constant during the takeoff.) The lapse rate of thrust with airspeed and altitude is readily calculable and must be compared with that of the full up rating mode. If the lapse rate is not equal to or better than the full-up mode, a gross weight penalty will probably be necessary for takeoffs in this mode. If the ATM reduced thrust takeoffs (see 4.2.1.4.1) are allowed in the backup mode, the lapse rates for these types of takeoff also must be compared with those of the full-up mode.

The full thrust scheduled value of N1 may be a function of total temperature as well as altitude. This makes the calculations of the lapse rates much more complex because it adds another variable, but the principal remains the same. The lapse rates in the backup mode, at all altitudes and temperatures, must be compared with those of the primary, or full-up mode, and the appropriate aircraft performance adjustments must be made. Any performance adjustments must be contained in the aircraft's master minimum equipment list (MMEL), because the MMEL will be the reference used to allow dispatch in the backup or alternate mode.

4.2.2.4 Backup Mode Lapse Rates - Autothrottle/Autothrust Operation

If the autothrottle moves the thrust levers to achieve a target thrust (for example, N1), the operation of the autothrottle is essentially the same in the backup mode as the primary mode. Again, the autothrust or autothrottle computer should go to a hold mode at 65 knots to ensure that a fault in that system does not inadvertently move the thrust lever(s) after power set.

The non-moving autothrottle system or autothrust system is not so simple. The FADEC system still knows what thrust position allows the autothrust function to be activated, but since the EECs cannot lock at 65 knots (because they might not have airspeed), it is recommended that the fixed thrust lever, autothrust system not be used when performing takeoffs with the EECs in the alternate mode. The difference between this and the moving autothrottle system is that in the case of the moving thrust system, the flight crew can see inadvertent thrust movement after thrust set. In the non-moving thrust autothrust system, the flight crew would have to diagnose an inadvertent thrust change from the engine displays. This could be difficult to do in a timely manner. If it is agreed that this is the case, the engine control can be programmed to ignore autothrust inputs during ground operation in the backup mode. If this approach is taken, a time delay on the air/ground transitions should be used to inhibit autothrust operation until an adequate altitude is achieved. This will prevent an erroneous autothrust command from affecting all engines at lift-off.



4.2.3 Automatic Shutdown or Low Thrust/Power Modes

This report does not intend to fully address all control, thrust, or power modes; however, there are two modes that usually receive considerable discussion because these modes implement a significant thrust or power deduction on the engine.

4.2.3.1 Reverser not Stowed (Response Mode)

As thrust in the opposite direction of that commanded by the thrust lever can be extremely detrimental to aircraft performance, many FADEC systems are programmed to rapidly go to idle thrust or power if a confirmed not-stowed or deployed thrust reverser position signal is sensed or received by the control and the aircraft is in-flight. Most FADEC systems have their own, dedicated reverser position signals. There usually is not much discussion as to how quickly fuel flow should be reduced to idle. In many engine control systems, decelerations to idle can be quite slow at altitude. The required response time should be established by coordination with the installer/aircraft manufacturer. A rapid decel may be required, and although the engine may experience a decel surge and/or flameout in such a situation, the rapid engine response may be necessary to maintain aircraft safety. At least one airplane, the DC-8, was certified to allow in-flight thrust reverser operation on the inboard engines to improve descent capability.

#### 4.2.3.2 Thrust Higher than Commanded and Not Decreasing

Recent emphasis has been placed on failure conditions in engine control systems in which thrust or power can be higher than commanded and not decreasing. Such conditions can lead to a hazardous or potentially catastrophic failure condition at the aircraft level. Such a situation occurred on a twin engine, wing-mounted aircraft during ground operation. In this case, an engine control system failure caused thrust to go above takeoff thrust during the takeoff roll. The control did not respond to a throttle command to reduce thrust (on both engines), and the aircraft departed the side of the runway. Although there were no fatalities, an ensuing fire resulted in a complete hull loss.

Although the failure mode could be addressed at the aircraft level through an aircraft system that shuts down the non-responding engine, the installers/aircraft manufacturers will probably want/require the engine manufacturers to provide protection for the engine control system single failures that could lead to such a condition. If the condition is a result of multiple failures, the combination of those multiple failures will have to be shown to be suitably small.

### 4.3 Auxiliary Functions

The FADEC installation may have a number of auxiliary functions. Examples are: pitch control, synchronization, load sharing, and engine condition monitoring. The implementation and integrity of these functions should be consistent with the safety and hazard analyses for the engine and aircraft.



## 5. USE OF SENSORS, AIRCRAFT SIGNALS, AND DATA

There is detailed discussion in this section of the use of aircraft signals. Section 5.5 presents a detailed discussion of the EEC's selection of aircraft Air Data Computer information, but in general, the discussion on the use of aircraft signals is from a functional point-of-view. There is not much discussion, by choice, of the hardware (h/w) and software (s/w) details of the EEC's interfaces with other aircraft computers or other aircraft elements, such as hard wired switches.

It is important to establish a list of the aircraft's interfacing computers and switch devices and the definition of the signals sent to the EEC from those devices, as well as the signals sent out from the EEC. To this end, it is recommended that an interface control document (ICD), as described in AIR6181, be developed between the engine and aircraft manufacturer (or installer), to describe the details of these signals. The ICD may also contain information concerning the key operational details of the aircraft avionics/elements (i.e., electrical bus on which they operate) as well as characteristics, such as the "boot up" times for the EEC on-ground and in-flight. Suggestions of what might be documented in an ICD are contained in AIR6181. This information is quite helpful in creating adequate fault accommodation logic within the EEC and the aircraft systems.

### 5.1 Engine Control System Signals and the Use of Aircraft Signals

The functional requirements for the use of aircraft signals by FADEC systems are quite different if the signals are dedicated to one engine only or are common to more than one engine. For those signals dedicated to an individual engine, such as the engine's thrust lever input signal, it is acceptable to allow a failure in the signal(s) to cause a significant (for example, greater than 10%) engine power loss. The regulatory requirements for the control system operation with regard to power losses are provided in 14 CFR § 33.28, CS-E, and the associated advisory material. If aircraft signals used by the control can affect more than one engine, the allowable power or thrust change may be much more restricted.

### 5.2 Signals Dedicated to an Individual Engine

Signals dedicated to an individual engine include analog (continuous variable), discrete (on/off), or digital (numerical) signals.

### 5.2.1 Thrust Lever Signals and Thrust Reverser Position Signals

Many current FADECs use dedicated analog-type signals from the aircraft for some of the FADEC system interface functions. Traditionally, two such signals have been the thrust lever position signal and the thrust reverser position signal. If these signals are changed to digital-type signals in the future - assuming that a digital-type position sensor is used - is not particularly important here. The primary intent of this paragraph is to indicate that these signals are dedicated to a specific engine and that a failure of these signals cannot directly affect the operation of any other engine(s). Therefore, these signals are allowed to have a relatively large effect on engine thrust when they fail. Currently, the engine control is not required to take a specific action when these signals are lost. Some engine controls are programmed to maintain the engine's current thrust setting, and some engine controls are programmed to run the engine to flight idle or a fixed value of thrust when the signals are lost. Refer to 4.2.3.2.

There is a special situation. In many installations, the transducer used for the thrust lever angle or position may be set up to operate between certain limits. If a signal outside of those limits is received by the control, the control may be programmed to assume that the sensor is failed. In the case of the thrust lever position transducer, consideration of the following condition is recommended:

Many FADEC systems are programmed to command maximum (or a defined amount greater than 100%) rated thrust on the engine if the thrust lever is placed in the full forward position. When the full thrust signal is programmed to request a thrust greater than normal, maximum takeoff thrust, the full thrust position will not be used during the normal takeoff conditions. If the engine control is programmed to implement an idle thrust command when the thrust lever position signal is lost or out-of-range, consider the possibility that the thrust lever position transducer may have been mis-rigged during maintenance activities so that it may rotate to an out-of-range signal condition when the thrust lever is positioned full forward. This condition may not be noted by the flight crew during everyday operations, as most takeoffs are at less than maximum takeoff thrust conditions. Such a situation could cause an engine to go to idle when the flight crew is asking for maximum thrust. There are at least two approaches to addressing this issue. The first is to design the thrust lever rigging mechanism to have limited authority, so that the thrust lever transducer cannot be rigged to give an out-of-range condition. In a derivative application, it may not be possible to limit the rigging authority. In these cases, a second approach may be used with a redundant channel FADEC system implementation. Assuming a dual channel system, as an example, if the two signals from a single thrust lever are valid and agree; and if both indicate that the thrust lever signal is out of range, the last in-range value can be held to prevent the engine from going idle. The first approach is the preferred approach. Whatever fault accommodation is used, it must not look at other engine(s) TLA, and any failures leading to an out-of-range signal on one engine should not affect other engine(s). The best way to guarantee you do not have out of range signals is to ensure that the throttle has an appropriate stop at the maximum throttle position to prevent the resolver or RVDT from going to an out range position. This margin can also be accomplished in software by opening up the tolerance between the max achievable throttle stop position signal and the out-of-range limit. In the case where both transducers on one engine's throttle position indicate an out-of-range condition and the "last good value is held", it is recommended that the FADEC accept the throttle signal(s) as valid when they come back-into-range and both transducer signals on that throttle are in reasonable agreement.



### 5.2.2 Engine Sensors and Probes for A/C Environmental Data (see 5.4.2)

### 5.2.3 Cowl and Wing Anti-Ice Signals/Sources

In many installations, wing anti-ice bleed may be selected during the pre-flight procedures, but the wing anti-ice valves do not actually open until liftoff or a specified time thereafter. This is because the aircraft will have been sprayed with de-icing fluid, and the fluid should have time to dissipate before anti-icing heat is applied. Normally, cowl anti-ice can be selected on after engine start, and the CAI valve will open immediately. In general, crew operating procedures will instruct that CAI not be selected on if TAT is above 10 °C. It is recommended that the signal of those bleeds come directly from the cockpit switch and not the valve controlling the bleed. This will allow the correct thrust setting to be set by the flight crew prior to the takeoff roll; and although EGT will increase when the valve opens after liftoff and bleed air is extracted from the engine, the correct engine thrust setting will be maintained.

Several modern aircraft now employ automatic ice detection systems that activate the engine's anti-ice bleed air system if ice buildup is detected. In these systems, the cockpit switch for cowl and wing anti-ice may have an AUTO position, and the switch may be selected to that position. If this is the case, the FADEC system will be dependent on the icing detection system for the CAI and WAI on/off status.

5.2.4 Air/Ground Signals

The air/ground transition signal can come from several sources. It may come from nose wheel compression or squat switches, main gear compression or squat switches (these are sometimes called weight-on-wheels discretes), main gear tilt switches, or other suitable sensors. In general, the transition to the air mode should not cause any significant thrust change on the engine. Knowledge of the air/ground transition is used in several functions. These include air data selection logic, thrust reverser logic, and several other logic functions. It should also be noted that air/ground transition discretes have not proven to be very reliable in some applications, so care should be exercised when using this discrete. For critical functions it is important to ensure that this signal is logically combined with other independent indicators to establish a signal of the required integrity.

5.2.5 Other Dedicated Signals

Dedicated discrete signals may be used for functions such as engine air bleed on/off signals, air bleed high/low selection signals, high idle/low idle enable signals, and others. These signals generally have a limited power or thrust impact on the engine. For these signals it is recommended that the loss of the signal result in the control implementing a fail-safe condition. The fail-safe condition may be dependent on a specific aircraft system and/or configuration. For example, loss or lack of the air/ground signal may cause the control to limit idle thrust on the engine to a high idle setting. (This is generally considered fail-safe because go-around performance for the aircraft is usually based on engine acceleration capabilities, which are usually performed from the high idle setting. Thus, failing to high idle protects in-flight aircraft performance. This condition may not be evident to the flight crew in flight, but it would be during ground operation. If dispatch with the engine(s) operating at the high idle setting is permitted, the condition and appropriate performance penalties should be contained in the aircraft's master minimum equipment list (MMEL), because stopping distance would be impacted during a rejected take-off (RTO) event.)

The discrete signals are usually dedicated to a specific engine with dedicated switches, sensors, and wiring so that no single or common failure could cause an incorrect signal to be sent to more than one engine's FADEC system.

These same aircraft signals could be received by the FADEC system in digital form. These signals would function like the dedicated signals. For these signals to be dedicated and independent for each engine, different computers would have to receive input signals from independent sensors and send the information to a specific FADEC system. The question always arises as to whether this separation of engine signals can be achieved in a configuration in which an aircraft computer interfaces with all engines through the same digital data bus, but a data bus in which there are separately identified words for each engine. This is considered acceptable. A question for this situation is the software and hardware integrity of the computer sending out those independent engine signals and the authority level given those signals. If those levels are acceptable, these signals can be considered engine-dedicated signals as well. See 5.3.2 for additional discussion of this subject.



5.2.6 A Potential Difficulty with Aircraft Discrete Data Words

FADEC system designers should be aware of a potential difficulty when using aircraft avionics (ARINC 429) discrete data words. This problem can and has occurred in several installations in which the aircraft discrete data words contain aircraft status information that originates from multiple sub-systems (for example, bleed management computers, brake control units, etc.). Most aircraft have central systems or concentrator units that receive the data from these subsystems, then repackage some or all of the data that comes in on numerous labels into a few bit packed ARINC 429 discrete words.

The problem is how to indicate the validity of data from multiple line replaceable units (LRU) in the two bit ARINC Sign Status Matrix (SSM=Fail/Warn or Normal) of the ARINC word being sent to the FADEC. In some implementations, the SSM for the discrete words being sent to the FADECs is not set to Fail/Warn when some of the data being sent from the subsystem to the aircraft concentrator unit is set to Fail/Warn. Thus, the FADEC would believe that the data received from the aircraft concentrator unit is valid (i.e., good data) when some of the subsystem data sent to the integrating unit is actually invalid. This could lead to the FADEC using default or erroneous aircraft data. Depending on the overall engine/aircraft ARINC architecture, this could be a common mode problem. The FADEC designers should be aware of this potential difficulty and work with the installer to get a detailed understanding of aircraft data sent to the electronic engine controller. In future systems this type of difficulty should be considered during the development of the protocol for the data bus and electronic data/word transmissions.

Another area of consideration should be the Source Designation Indicator (SDI) bits. Typically SDIs are used as either the source or destination indictor in an ARINC 429 data word. This needs to be decided early and maintained throughout all systems in the bussing architecture (to include FADEC, avionics and other electronic systems). It is very important to maintain coordination between the Aircraft, Engine, and Avionics manufacturers throughout the design cycle. An effective way to achieve this is by using a shared document detailing ARINC Data word definitions for buses common to the FADEC and Avionics systems.

## 5.3 Aircraft Signals Common to Multiple Engines

### 5.3.1 Aircraft Air Data Output Signals

For transport category aircraft, two operating, independent air data computers (ADCs) are required for dispatch. Many transports have a third ADC, which can be used as a spare. One commonly called the left ADC, generally supplies information to the captain's display, and the other, the right ADC, supplies information to the co-pilot's displays. This is the configuration used for the air data selection logic discussed in this section. When two air data computers are used, the left ADC output bus is normally connected to channel A of all engine FADEC systems, and the right ADC is normally connected to channel B of all systems. Channel A and B of each FADEC system cross-talk the data, so each FADEC system channel has both sets of information.

Most FADEC controllers receive aircraft ADC information and use it in the computation of engine ratings, such as one engine inoperative, takeoff, maximum continuous, climb, and go-around ratings. Engine ratings are a function of pressure altitude, freestream static or total air temperature, and Mach number or airspeed, but air data is also used in other logic functions as well. The use of ADC information by all EECs allows the engine controls to compute the same values for the engine ratings, and therefore, the thrust lever alignment across the engines is usually very good (at the same power setting). The concern is that use of the same data by multiple engines could affect multiple engines if the data is faulty. To address this concern, independent engine sensors may be used to validate ADC information; if the engine sensors differ significantly from aircraft ADC information, the engine control normally reverts to its own sensors' values.

Air data may also be used in other logic functions, such as detecting faults in engine mounted sensors. The concern is the same as with the rating calculations in that the improper use of the aircraft air data information could invalidate the same sensor on multiple engines. This is an important consideration because the aircraft air data sensors may be affected differently than the equivalent sensors on the engine. As an example, aircraft mounted ADC sensors can be affected by angle-of-attack changes, while the engine inlet tends to straighten the airflow and reduces this effect.

Another important consideration for the use of air data by the engines is to ensure that the ratings computed by the engines and other aircraft LRU agree when all systems are normal. Due to the differences in tolerances and in the location of the sensors measuring the local air data information, the engines and the rating computer on the aircraft will calculate slightly different ratings. In the days of analog displays this was not much of an issue, as the individual systems calculated values that were close to each other, and the differences were smaller than the analog display resolution. With the advent of digital cockpit displays, in which ratings are shown to the resolution of two or three digits past the decimal, small differences become more obvious. It is possible that if the engines and thrust rating computer all used their own sensors, the individual sources would calculate rating values in which the differences would be greater than the thrust setting accuracy requirements. This raises the issue of which displayed numeric value is correct. The use of common validated air data results in all the calculations being equal, thus eliminating this issue.

5.3.2 Other Aircraft Signals

In multi-engined aircraft, many of the signals sent to the FADEC system are signals that are common to more than one engine. If properly handled, this is acceptable, whether they are analog, discrete, or digital signals.

Many configurations in a digital system have digital signals that are dedicated to a FADEC system in a given engine location by virtue of location information in the digital word. The initial consideration may be that dedicated digital signals can be handled in the same manner as dedicated analog signals. However, in many (probably most) cases, the dedicated digital signals come from a common source. This might be a common computer and/or a common sensor. Examples of dedicated digital signals are power or thrust trim signals or engine air bleed demand signals that are sent by a thrust management computer to all engine control systems on a common digital data bus. Although these signals may be on the same data bus, the signals are dedicated to particular engine locations by virtue of an engine position code or some other means that may be embedded within the signal or the particular engine location. Thus, each FADEC system is intended to read its own signals and ignore the others. The engine FADEC systems generally know their locations based on discrete signal inputs in the aircraft wiring to the engines

Signals of this type may be dedicated to each engine; however, failure modes in the sending computer could alter all signals, thereby affecting the control of more than one engine. Because of this, it is recommended that for fixed wing, multi-engined aircraft, the engine control allow only a limited authority for these signals. The recommended limit is approximately ±5% thrust in the takeoff mode, and larger values when outside the takeoff mode. Like the latching logic discussed in 4.2.1.5.2 and 4.2.1.6, all of the dedicated digital signals that come from a common source or computer, as well as those that affect thrust, should be latched at approximately 65 knots in the takeoff mode.

5.4 Environmental Air Data Sensor Considerations

The following discussion provides information on some typical aircraft air data sensor configurations.

5.4.1 Aircraft Probes and Sensors

5.4.1.1 Total Temperature Probes and Sensors

Total air temperature (TAT) is used in several aircraft functions. TAT or static air temperature, calculated from TAT and Mach number (Mn), is one of the environmental parameters used to determine the engine thrust/power setting, which is needed for the autothrottle/autothrust function. TAT may also be used in the other functions, systems, and calculations such as:

- Determination of True Airspeed
- Flight Management System/Function Fuel Predictions
- Wind calculations
- Terminal Collision Avoidance System (TCAS) resolution advisories
- Wing Ice Detection system
- Windshear detection/protection system

Many aircraft have a single total temperature probe. In this case, the probe generally has two independent resistive elements, which are used to sense the total temperature and to supply the two air data computers with electrically independent signals. Since the signals come from a single probe, the two sensors are subject to common probe failures. Any foreign-object-damage (FOD) or probe contamination could cause both resistive elements in a single sensor to agree, but be incorrect. Some aircraft use separate probes for the two independent aircraft TAT signals. This is a preferred situation when it comes to selecting a total temperature signal because it eliminates any immediate concern about common probe failures or malfunctions.

Other aircraft may use engine inlet temperature (T2) probes supplied with the engines and mounted in the nacelle inlets. When this is the case on multi-engine aircraft, the engine temperature signals may be averaged to minimize thrust or power level splits. Fault accommodation should be employed to maintain engine isolation.

Temperature from the engine probes may also be used to display temperature in the cockpit and calculate the engine thrust ratings in-flight, but engine temperature signals are usually not available or valid until after engine start. If a TAT or outside air temperature (OAT) is needed prior to engine start for display of the takeoff power setting and gross weight calculations, the data has to be available from an aspirated airframe supplied TAT probe, or control tower temperature or the OAT from the automatic-terminal-information-service (ATIS) report, which is available at many airports, can be manually input to the aircraft avionics for calculation of the engine power/thrust setting. For small airports that have no ATIS or control tower available, the nearest Flight Service station can be contacted for airport conditions.

The procedure of manually inputting OAT into the aircraft thrust management function for takeoff works quite satisfactorily on many aircraft. There are many that believe the procedure of manually inputting an OAT for the takeoff mode offers a path for flight crew/pilot error that could lead to an incorrect thrust setting, but there is little indication that this has been a problem. Some transport aircraft do not have an aspirated aircraft TAT probe, and therefore, on these aircraft the flight crew inputs an OAT into the flight management system to obtain the takeoff thrust setting target.

After engine start, the engine inlet T2 values can be used to validate the aircraft TAT that is being used to determine the engine thrust rating.

There are generally two types of aircraft body mounted TAT probes. Those that are aspirated, as shown in Figure 21, in which airflow from the aircraft's internal environmental control system (ECS) is discharged from the aft end of the probe, causing freestream air to pass through the probe during static conditions, and those probes that are not aspirated. Aspirated probes, if not clogged from FOD, yield a reasonably accurate total temperature signal during static conditions. Probes that are not aspirated can be (depending on their location) significantly affected by solar radiation and should not be used during ground operation as the source of OAT when establishing/calculating the takeoff power setting. These probes generally look the same as the probes shown in Figure 21, but there is no aspiration (i.e., bleed air-in) connection to the probe.

Whether aspirated or not, total temperature probes are typically **not** heated on the ground. The application of probe heat would cause a significant error in the sensed temperature. For aspirated probes, the aspiration is not strong enough to compensate for the errors caused by heater power at static conditions. Total temperature probe heat is usually applied when the aircraft transitions to the air mode or exceeds a given ground speed, like 60 knots. Most air data computers will output a TAT signal that contains an indication of probe heat status: on or off.

However, probe reliability and cost (due to size) has resulted in an operational difference between GA aircraft and transport aircraft. On transport aircraft the probe heat is turned on after engine start, regardless of outside TAT, whereas GA aircraft probe heat is typically activated by the pilot based upon current conditions (i.e., heat turned on in icing conditions only).

Temperature and pressure probe heaters are typically designed to keep the probes free from ice in supercooled liquid water icing conditions defined by Appendix C to 14CFR Part 25. The amount of heat required to melt and evaporate ice crystals is considerably more than that required to evaporate supercooled liquid water. Therefore, even with probe heat on, there have been reports of total temperature probe(s) icing-up temporarily in flight when operating in an ice crystal environment. Ice crystal environments are typically associated with the area around highly convective thunderstorms. The certification conditions for operation in ice crystal environments are defined in Appendix D to 14 CFR Part 33. When probes become blocked with ice, the signal tends to drift toward 0 °C, because the aft exit of the “hood of the probe” becomes restricted and an ice/water mixture tends to accumulate around the sensor(s). As the signal drifts toward 0 °C, the thrust setting of the engine changes. Simply applying more probe heat has not proven successful in keeping the probes free of ice in these ice crystal conditions. Increasing the probe heat further presents problems as too much heat affects signal accuracy during high altitude (low air density) and low speed conditions. Considerations need to be given to address this potential effect of probe icing when operating in heavy ice crystal conditions.

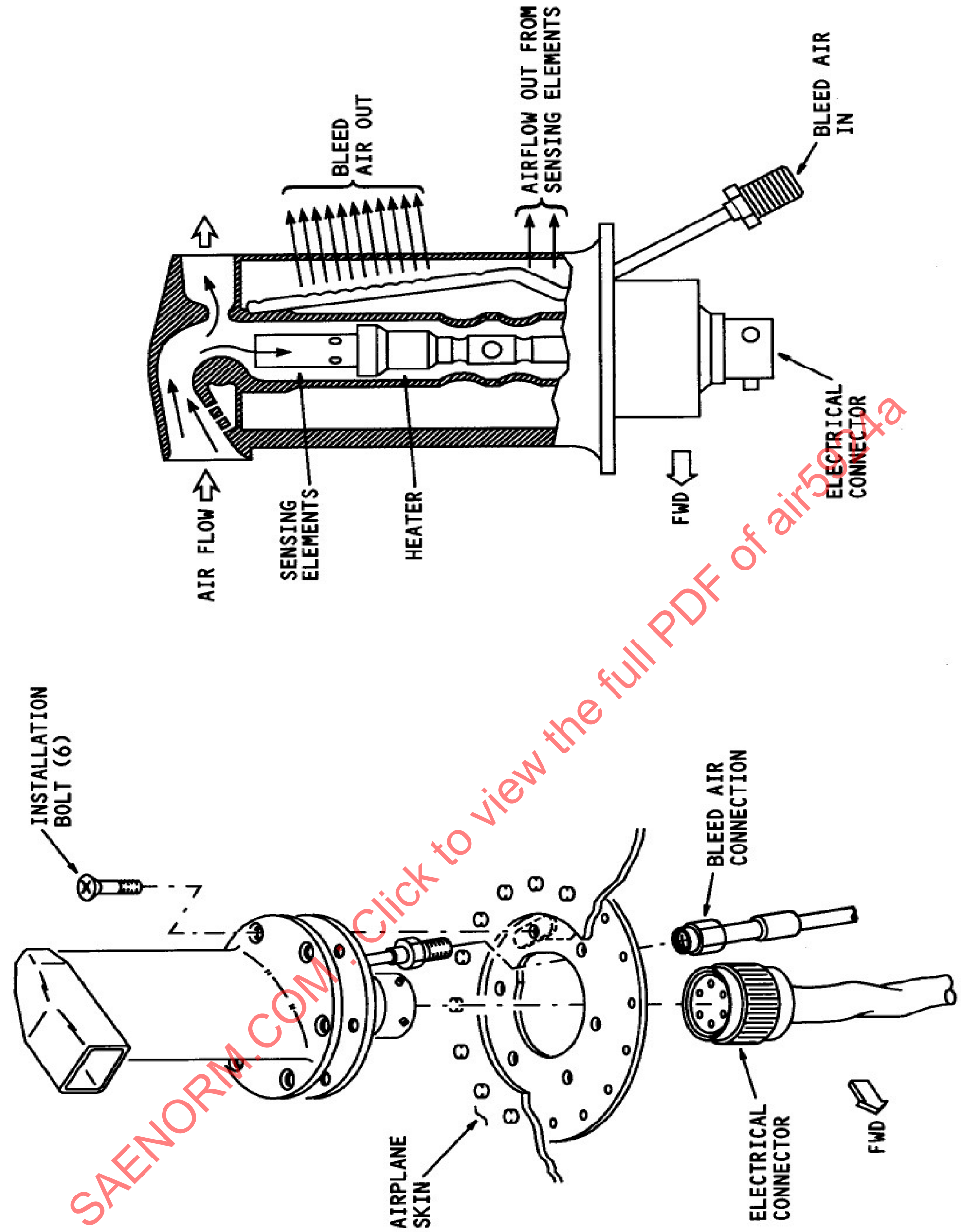


FIGURE 21 - ASPIRATED TOTAL AIR TEMPERATURE PROBE
(COURTESY OF ROSEMOUNT AEROSPACE INC. THE EXTERNAL
SHAPE OF THE TAT PROBE IN THE FIGURE IS A REGISTERED
TRADEMARK OF ROSEMOUNT AEROSPACE INC.)

There are two methodologies that may be utilized to determine the engine inlet sensor temperature and the resultant engine operational and cockpit interface effects due to Appendix D conditions. The first method is to define the desired operational flight conditions (the aircraft may not be capable of the full envelope depicted in Appendix D) and test the entire engine and control system package in the appropriate conditions. The testing should assess both the engine operability and cockpit interface warnings and notification for assurance that no unsafe conditions exist. Testing should include both anti-ice and de-ice conditions. At the current time, testing to the full or aircraft operational portion of the Appendix D environment is largely unfeasible due to facility limitations. As an alternative, for the control systems effects only, the following methodology may be employed.

- Using the conditions specified in Appendix D, work with the installer (or specify the intended altitude/airspeed conditions that will be detailed in the engine installation manual) to determine the applicable aircraft conditions.

- These aircraft conditions need to be translated to engine inlet conditions and can vary due to inlet “capture effects” and significantly different airspeed due to the inlet efficiency and engine power setting.

- These conditions may be further adjusted based on T2 sensor test facility capabilities mostly due to Mach Numbers (i.e., if the test facility has lower Mach capability, the liquid-water-content (LWC) may need to be increased to provide the equivalent accretion and sensor load.)

- The T2 sensor output should be tested in anti-ice (anticipated environment) mode and de-ice (unanticipated) mode for sensor performance.

- Evaluate the engine operability effects for the temperature offsets at the flight conditions (i.e., thrust change, surge margin, blowout margin, etc.).

- Evaluate the aircraft cockpit indications and identify the effects (i.e., EICAS indication, faults indications, engine operating parameters, etc.).

- If possible, obtain the aircraft effects of the engine and indication system responses and evaluate with the aircraft System Safety Assessment.

Operation in all conditions with anti-ice on shall meet the same operability requirements as those associated with the EMI/HIRF effects listed in AC33.28, latest version. De-ice operation shall target not exceeding a 10% power reduction for a limited period and not lead to an unsafe condition. The ultimate acceptability shall be the responsibility of the airframer. The engine sensor capability and engine operability for both the anti-ice and de-ice operation should be documented in the engine installation manual and any aircraft operational considerations in the Aircraft Flight Manual.

#### 5.4.1.2 Ambient Pressure Probe and Probe Heat Configurations

Barometric altitude, as determined from the sensed value of ambient static pressure, is an important parameter to aircraft/engine performance and operations. The sensors used in most aircraft air data systems are quite accurate (0.25% of full scale or better). The normal static pressure inputs to the air data computers are from manifolded static ports on either side of the aircraft. A typical configuration is shown in Figure 22. The manifolding is done to minimize the effects of aircraft yaw and angle-of-attack. The static ports may be heated, but typically, they are not. A typical static port pickup is shown in Figure 23. The static ports may also be located on the side of the aircraft’s total pressure (pitot) probes. In these configurations the, there are usually two static pickup locations on each total pressure probe and there are at least two total pressure probes, one on each side of the aircraft. The static pickups from one pitot probe are cross-manifolded with the static pickups from the pitot probe on the other side of the aircraft - in a manner similar to that shown in Figure 22 - and the two manifolded pressure signals interfaced with the two air data computers. Some aircraft may provide a third source of ambient pressure. It may be only one port with the pneumatic signal feeding directly to a standby display. This display may provide an electrical signal output available to other users. If it does, it is an excellent source for an independent pressure altitude signal.

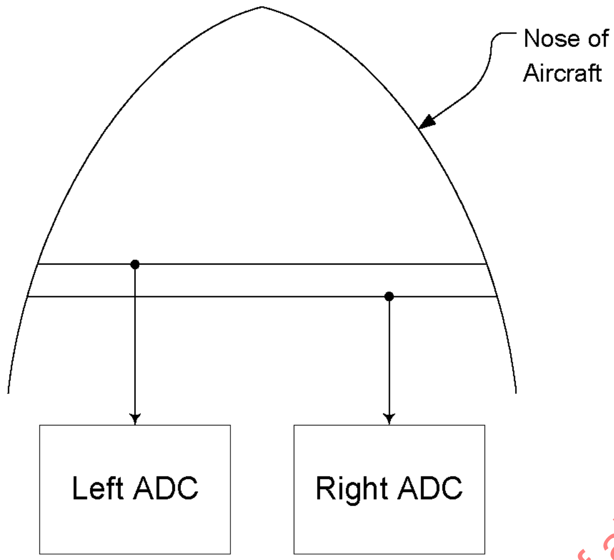


FIGURE 22 - TYPICAL CROSS-MANIFOLDED BODY STATIC PRESSURE SENSING CONFIGURATION

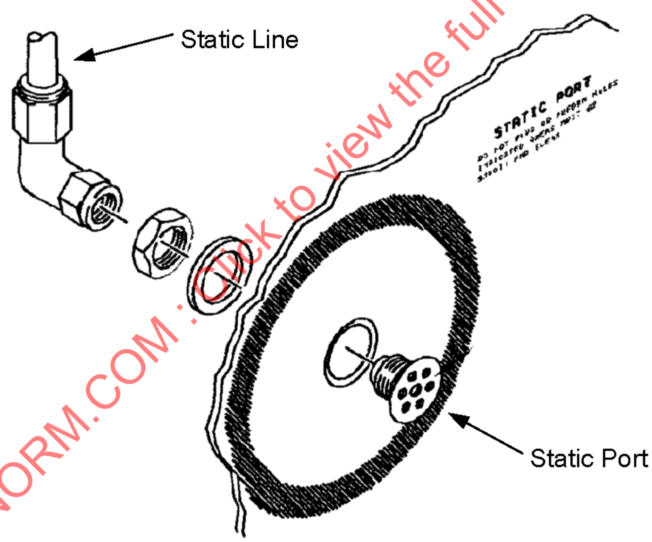


FIGURE 23 - TYPICAL BODY OR NACELLE STATIC PRESSURE SENSING PORT



The static pressure ports are sometimes heated; not from a concern that the ports will ice-up in-flight, but to address the concern of condensation, which could cause water to flow down the body of the aircraft during overnight (static) conditions, accumulate in the pickup port(s) and freeze. In these situations, heat is used to de-ice the static port(s) after aircraft power up. If the static pressure pickup port locations are on the sides of the aircraft's total pressure probes, it is important to check that probe heat is on before using the static pressure value. In these cases if probe heat is not on, the front of the total pressure probe may ice-up, and the airflow around the static pressure ports may be disturbed. This could result in an error in the sensed static pressure measurement.

5.4.1.3 Total Pressure Signals

The aircraft's total pressure sensor signal, in combination with the aircraft's static pressure signal, is used to compute the aircraft's calibrated airspeed and Mach number. The total pressure signals are obtained from two separate total pressure probes. The two probes feed independent pressure signals to the two separate air data computers. Modern aircraft total pressure probes are usually de-iced electrically. A low heat wattage is generally used during ground operation, and the probes transition to a high heat setting in-flight. Low heat is used during ground operation to achieve improved probe heater life. The total pressure signal transmitted from the ADCs usually includes a heat on indication. That signal may or may not indicate low or high heat operation. If the total pressure signal has two heat settings, and if the signal is to be used by the engine control to determine calibrated airspeed and/or Mach number, it is important to ascertain if the probe is on high heat in-flight. A probe on low heat can ice-up in ice or moisture conditions in-flight. Since many aircraft may not have probe heat activated on the aircraft's total pressure probes when operating on external ground power, or the aircraft may not even be electrically powered when the first engine is started, a suitable waiting period should be used before the FADEC system attempts to validate and use the aircraft’s total pressure signal. The waiting period can be similar to that used for validating engine P2, as discussed below.

In some applications, aircraft total pressure probe heat is turned on by the flight crew after engine start. In this type of system there has been a tendency to delay turning on the probe heat until the aircraft takes the active runway as a means to extend heater life. To prevent nuisance indications, consider delaying the heat check until engine power is set above levels required for taxi. Yet do not make the delay so long that detection of probe heat off occurs during the take-off roll, which could cause a potential for a RTO.

Some ADCs may not put total pressure on the ADC’s digital output bus. These systems may provide dynamic pressure, Q, which is (P - Ps). During ground operating conditions, the measured total pressure may be less than the measured static pressure Ps during cross- and tail-wind conditions. Since Q is not allowed to be negative, Q may be broadcast as zero or as an invalid signal during these conditions. Assuming probe heat is present, a fairly long period, such as 30 s to several minutes, should elapse before air data Q is declared to be unavailable, to allow transient environmental conditions to subside (assuming that Q is set to invalid during these conditions). If the FADEC system does not receive a valid Q signal after this time, air data Q should be declared to be unavailable. If the FADEC system receives a good Q signal during this countdown period, the timer should be reset. If the engine control does not have its own P2 probe, the engine manufacturer should request the installer to have total pressure output as a separate, individual signal on the ADC's output bus. This, or having Q be a valid signal of zero when measured P is less than measured Ps, will improve the robustness of the FADEC system's primary mode. Also, all modern transports have ground speed (GS) available from the inertial reference units (IRUs). If this is made available to the FADEC units, the FADECs can have additional logic to disregard an invalid Q until GS is greater than approximately 30 to 40 knots. This will avoid having the FADEC declaring Q invalid during ground operation in tail wind conditions.

5.4.1.4 Airspeed and Mn Calculations/Signals

Aircraft airspeed is very important to aircraft operations, but it doesn’t have as large an impact on thrust setting as do altitude (pressure altitude) and temperature, whether it be static or total temperature. Airspeed, either calibrated airspeed or Mn, is calculated from Pamb and Ptotal pressures. Calibrated airspeed is generally available at speeds above 30 knots. Mach number usually does not become active until it exceeds approximately 0.10 to 0.12. Even though airspeed (Mn) does not have a large effect on the thrust rating, it is important from thrust lapse rate considerations as discussed in 4.2.1.5.

5.4.2 Engine Sensor and Probe Configurations (For Determining Aircraft Air Data)

Turbine engine thrust ratings are a function of the environmental operating conditions. The parameters involved are barometric altitude (Pamb), total air temperature (TAT), and airspeed, generally listed as Mach number (Mn). The thrust rating parameter can be some form of engine pressure ratio (EPR) or fan speed (N1). The “look-up” tables for the rating parameter value for a given operating condition can be quite different for different engines. For example, the tables could be: a function of pressure altitude or Ptotal, Tstatic or TAT, and with or without a bias for Calibrated Air Speed or Mach Number.

These are all acceptable, and they can all be determined from Pamb, TAT, and Mn. So, the purpose of the discussion below is how to measure these parameters, and this report makes no recommendation as to how the rating parameter for the engine - as a function of the operating condition - should be stored in an aircraft computer or presented in the aircraft flight manual (AFM).

5.4.2.1 Engine Total Temperature Probes and Signals

As discussed earlier, total or static freestream air temperature is also important to determining the engine power or thrust rating, and it is recommended that the engine control have its own dedicated total temperature sensor. (Static temperature is not measurable.) The probe, which usually contains two sensors when two FADEC system channels are provided, is normally located in the engine intake. Typically, two types of probes have been used. The first type is a hooded probe, much like the aircraft's total temperature probe. If desired, this type of probe can be combined with a total pressure probe, so that one probe serves both purposes. The hooded type of TAT probe, whether combined with a total pressure probe or not, needs to be de-iced. In modern FADEC systems, this is usually done with aircraft supplied electrical power.

If the total temperature probe does not incorporate the combined function of sensing total pressure, a vane type total temperature probe may be used. This type of probe does not incorporate a hood. It has a turning vane that directs the airflow against a resistive temperature element, like the probe shown in Figure 24. These types of probes will build and shed ice during icing conditions.

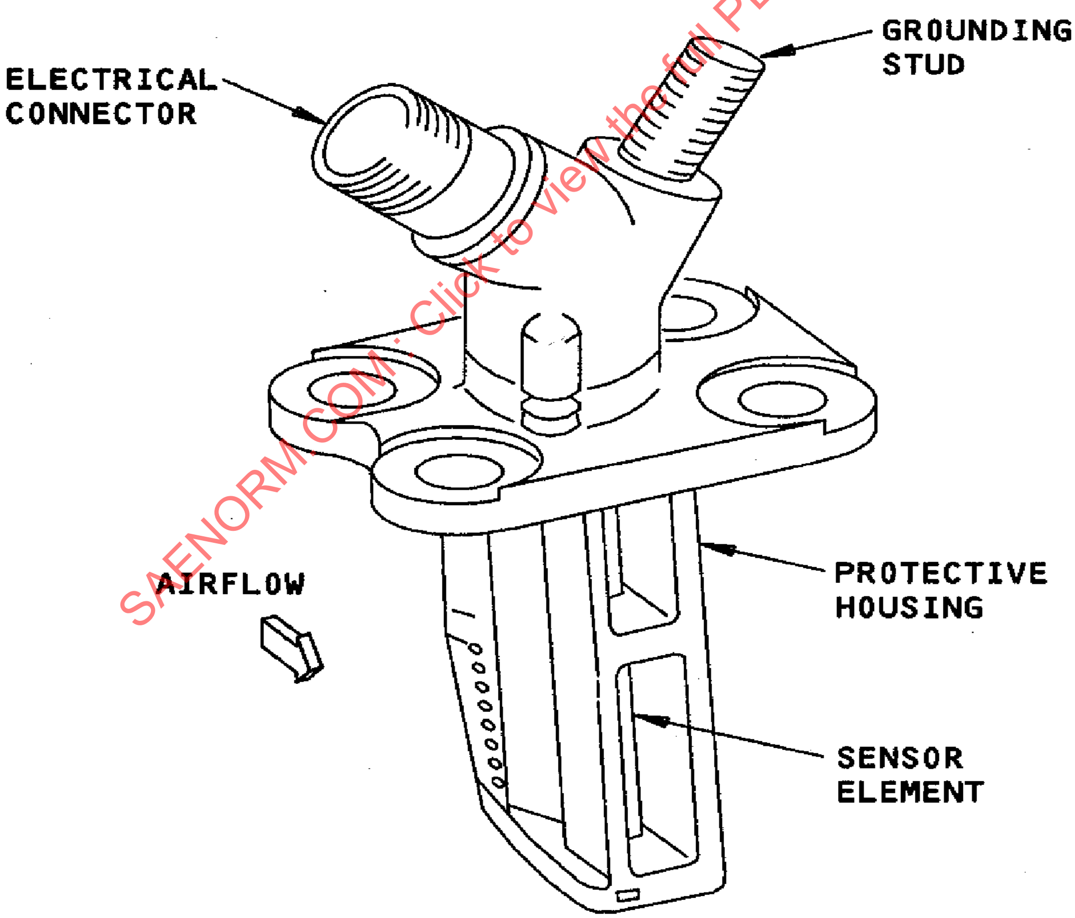


FIGURE 24 - NON-ASPIRATED TAT PROBE
(COURTESY OF ROSEMOUNT AEROSPACE INC. THE EXTERNAL SHAPE OF THE TAT PROBE IN THE FIGURE IS A REGISTERED TRADEMARK OF ROSEMOUNT AEROSPACE INC.)

Locating a TAT sensor aft of the fan is not recommended. There have been attempts to locate a total temperature sensor there because of the concern for a condition where a sensor ahead of the fan breaks off and damages the fan, or ice shedding off of the probe could damage the fan. When a sensor has been located behind the fan, a temperature rise correction term as a function of fan speed has been used to attempt to correct the sensor reading to freestream conditions. This is always difficult. Trying to compensate the fan temperature rise during engine transients and heavy moisture conditions has generally not been very successful.

5.4.2.2 Static Pressure Measurement Considerations

5.4.2.2.1 Internal Fan Case Pressure Measurements

Since ambient pressure can have a reasonably strong influence on the engine's thrust or power rating, the engine control may have its own dedicated ambient pressure signal. Most FADEC systems for larger engines are fan case mounted. Smaller engines may have the FADECs mounted off engine, for example, in the aircraft aft electronics bay. If the fan case has a solid aft bulkhead or adequate ventilation to prevent pressure build up, so that the fan case pressures are isolated or adequately relieved from any increased pressures coming from the fan exit system and the thrust reverser system, then a simple opening on the side of the FADEC system feeding an inner cowl pressure signal to an internal FADEC system pressure sensor has proven adequate. This pressure may be sufficiently accurate to use without correction, or a correction factor as a function of airspeed and altitude may be needed. Internal fan cowl pressures - in a fan case with a solid aft bulkhead - have not needed a correction for engine power setting, but it is always a possibility that should not be overlooked. A fan case located duct burst will obviously affect the FADEC system sensed static pressure.



5.4.2.2.2 External Engine Cowl Pressure Pickups

When a cascade-type reverser design is used and the fan case does not have a solid aft bulkhead, but uses seals to isolate the fan case compartment from the thrust reverser and fan exit nozzle system, it is recommended that the engine ambient pressure pickups for wing-mounted engines are located on the engine fan cowls in a manner similar to the way static ports are placed on the aircraft (that is, ports on either side of the nacelle). A picture of cowl-mounted static pressure pickups is shown in Figure 23. For aircraft aft fuselage-mounted engines, the static pickups may be located on the aircraft body. Useful locations may be determined from wind-tunnel testing and validated during flight testing. These static pressure locations may require a correction factor, which is usually defined as a $\Delta P/P_{(sensed)}$, in which $\Delta P$ is $P_{(true\ ambient)} - P_{(sensed)}$. $\Delta P/P_{(sensed)}$ is usually defined as a function of Mach number. A correction with aircraft angle-of-attack may also be necessary, but this should be avoided, if possible, because aircraft angle-of-attack information is not always available. Small adjustments of the static port locations around the cowl will generally yield locations that are reasonably insensitive to angle-of-attack. The sensed pressure will probably be slightly sensitive to the pressure increase that occurs under the aircraft surfaces as the aircraft rotates and lifts off, but this increase has not been found to present significant difficulty.

5.4.2.3 Engine Total Pressure Probes

Engines using engine-pressure-ratio (EPR) as their thrust setting parameter should have their own total pressure (P2) probe. EPR is generally some function of Pexhaust/P2, where Pexhaust is the total pressure in the exhaust nozzle. In these cases, the inlet total pressure (P2) measurement is usually combined with the total temperature probe and mounted in the engine inlet. A combined P2/T2 probe is shown in Figure 25. The location chosen for the probe is important. If the inlet's airflow separates at high airflow or high angle of attack conditions, the sensed value of P2 will be lower than it should be. (This can be controlled somewhat by not allowing P2 to be less than Ps, the static pressure. Note: P2 should not be invalidated when this happens, unless P2 is out-of-range low. It can be set equal to Ps during these conditions.) Thus, the selected location for the P2 probe should be investigated to determine the recovery of the sensed P2. A P2 probe may yield a low pressure value due to inlet separation effects. For a given value of EPR, a lower than actual P2 measurement will result in a lower than desired thrust being set. This can happen at high inlet airflows during low airspeed conditions. Therefore, the sensed value of P2 may need a correction at such conditions. If a correction is needed, it is usually a function of aircraft Mach number and engine power setting. The inlet should be reasonably clean from 60 knots and up and should not experience any significant airflow separation with aircraft angle-of-attack (within the aircraft's operating envelope). This should be verified for each individual installation to ensure it is true. The effects of yaw and sideslip should also be considered.

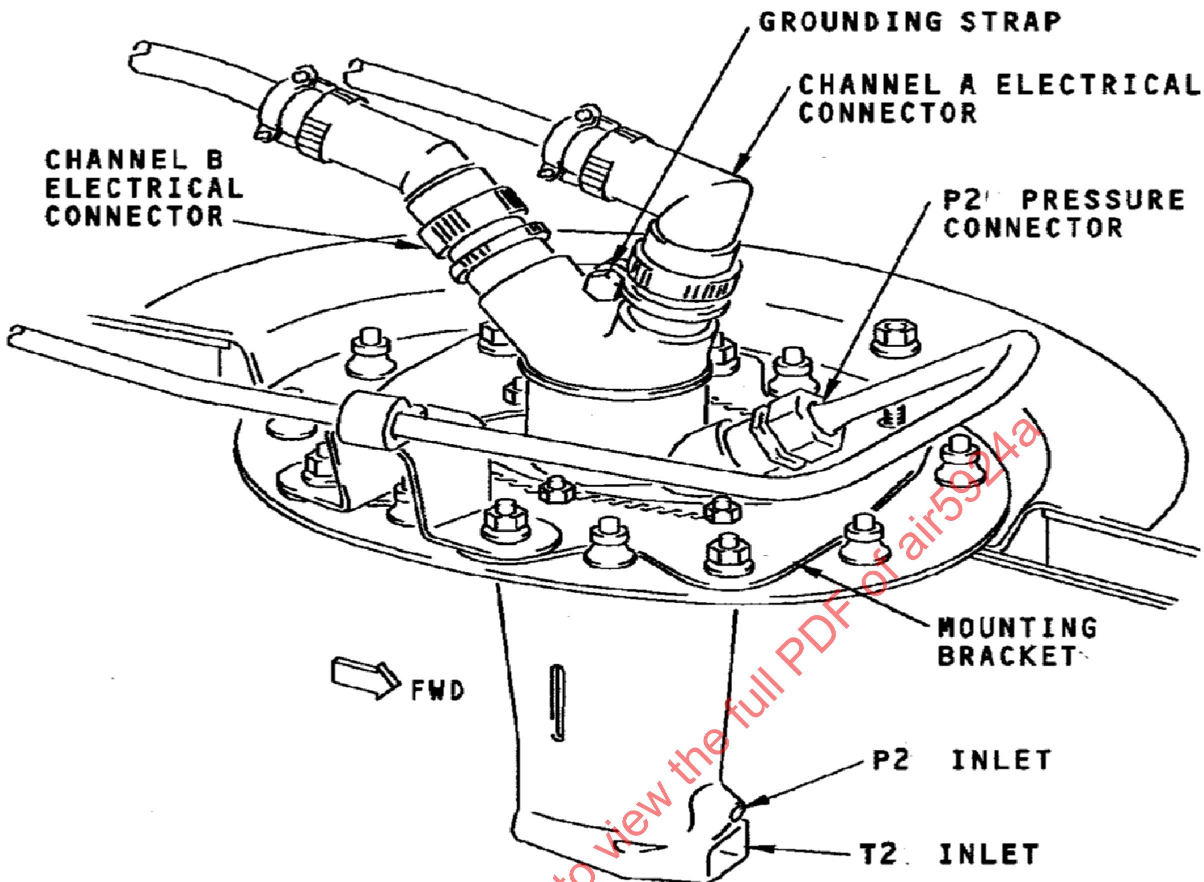


FIGURE 25 - ENGINE INLET MOUNTED P2/T2 PROBE
(COURTESY OF ROSEMOUNT AEROSPACE INC. THE EXTERNAL SHAPE OF THE P2/T2 PROBE IN THE FIGURE IS A REGISTERED TRADEMARK OF ROSEMOUNT AEROSPACE INC.)



#### 5.4.2.4 Total Pressure or Static Pressure Measurement, or Both

Engines using N1 as the thrust setting parameter may have both a total and static pressure measurement, or may simply use one of the two. This usually depends on how the engine's power setting parameter (N1) is scheduled as a function of the environmental parameters. For example, some small turbine engines have N1 power setting charts that are only a function of total pressure and total temperature. There is no Mn or airspeed effect on the ratings. Hence the engine control system only uses a combined P2/T2 for environmental data.

Large high bypass ratio engines, which use N1 as the power/thrust setting parameter, have the rating as a function of pressure altitude (Pamb), static temperature and Mn. Since static temperature must be calculated from total temperature, the aircraft Mn is needed. The control may have both static and total pressure probes/sensors, so it is able to compute Mn directly, or it may sense just ambient pressure (for altitude) and use A/C air data Mn to compute static temperature from its sensed total temperature. These systems need to incorporate an alternate mode of operation when aircraft Mn is not available, as discussed in 4.1.2 and 4.1.6.2.2.

5.4.2.5 Probe Heat Considerations: P2, Combined T2/P2, and Simple T2 Probes

Since probe heat usually requires considerable power (for example, 300 W or more), probe heat is generally supplied by aircraft power. Combined P2/T2 probes (see Figure 25) generally require more anti-icing heat than P2 probes due to their increased surface area. It is recommended that heater power be turned on and off by the FADEC system during engine starting, at 2 or 3% N2 (or N3) below the engine's lowest idle speed or as a function of N1. On smaller non-EPR rated engines used on GA aircraft, the application of probe heat may be applied only when engine anti-ice is selected on, due to temperature correction accuracy. The decrease in temperature accuracy can be critical for min-max thrust power setting on non-EPR controlled engines. For all turbine engines, both those for transports and those for GA aircraft, an accurate total temperature value is needed for accurate engine thrust setting. Where the thrust rating is scheduled as a function of static air temperature, an accurate total air temperature along with an accurate air speed or Mach number is needed, so that the static temperature can be calculated. Static air temperature, by itself, cannot be accurately measured.

The engine-mounted aircraft electrical generators may or may not be on-line by the time idle N2 (or N3) is reached. A current sensor should be used to confirm heater power. This sensor could be aircraft-supplied, in which case a discrete signal indicating heater operation should be supplied to the FADEC system, or the sensor could be contained in the FADEC system's electronics unit itself. In either case, wait an appropriate period before performing the check on probe heat. This is similar to the discussion of validation engine P2 that is given in 4.1.6.1. If heater power is not confirmed after an appropriate wait period, it is recommended that for those engines using EPR as a thrust setting parameter, EPR be set to invalid and the control revert to an alternate mode. If heater power comes back after an extended outage period, it is acceptable to re-set EPR to valid if it is known that the probe will de-ice when power is reapplied; however, if the probe is iced, it may take a significant period of time for the probe to de-ice and start working properly, and this delay should be taken into account. The control should NOT automatically revert back to the EPR mode (see 4.1.6.1).

Concerning the T2 portion of combined P2/T2 probes and simple T2 probes: If the electrical heater circuit fails, the probe will most likely sense the correct total temperature, but the time constant of the probe becomes considerably longer in icing conditions. Therefore, if the heater circuit fails and the sensed total temperature is below 10 C, the engine control temperature selection logic must account for the significant increase in time delay that the sensor may have. (The FADEC system will not know if the probe is operating in icing conditions, or just cold clear air conditions when TAT is below 10 C.) If probe heat returns after being inoperative for a significant period of time (and a long time constant is being used because T2 has been below 10 °C for some time), approximately 2 to 5 min should elapse before changing from the use of a long time constant to a short time constant, or other special logic that may be used to account for probe icing, so that the probe has a chance to de-ice. After loss of heat during icing conditions, the re-application of heat while still in icing conditions can be problematic. It must be proven that the probe will de-ice when heat is restored in icing conditions. Then the transient effects of re-establishment of heat must be accommodated. Depending on the probe design and the nature of the ice build-up, it is possible that the air trapped in the probe around the sense element will initially heat up and yield an erroneous temperature. The logic used to allow re-use of the T2 signal when heat is re-applied needs to properly account for these types of transient responses. The use of a cowl anti-ice signal to imply that T2 probe heat is on has caused some difficulties. It is better to have a FADEC dedicated signal or current sensor to indicate probe heat being on.



5.5 FADEC System Air Data Selection Logic

The air data selection logic should comply with the requirements of 14 CFR §33.28, as detailed in AC 33.28-1. In general, the regulation states that errors or faults in aircraft signals used by the EECs should not result in a thrust change - due to undetected faults - of greater than 3% when operating in the takeoff envelope. Outside the takeoff envelope, greater undetected thrust changes have been accepted.

The following logic is an approach to meeting the requirements of §33.28, but it is not the only method or logic that can be used. However, it has been shown to meet the requirements in previous applications. This section also provides guidance on an approach that can be used to evaluate selection logic even though a specific manufacturer's implementation might differ in detail. The objective here is to use air data signals - when they are correct - to determine the engine thrust ratings, so that all the thrust levers align throughout the operating envelope. The objective is NOT to replace engine information with air data information. It is also not acceptable to have a failure or malfunction in aircraft air data signals cause an unacceptable (see AC 33.28-1) change in power or thrust on any or all engines.

5.5.1 Ambient Pressure Selection Logic

Since the aircraft's pressure altitude signals from the left (L) and right (R) ADCs of transport aircraft are independent, the FADEC system selection of pressure altitude is generally straightforward.

Today's FADEC systems are configured with either one or two dedicated Pamb signals. Those FADEC systems with two sensors generally use either the one closest to the average of the ADC signals or an average of the two engine dedicated signals (if they are in reasonable agreement) to complete the logic described below. It is acceptable to select the aircraft's ambient pressure (or pressure altitude) signal if the signal agrees with the engine's ambient pressure signal(s) - after the engine signal(s) have been corrected for position error. A detail to be considered is the system response when the tolerance between the ADC signals and the engine sensor is exceeded. The simplest approach is to make a step change to the engine sensor value as the difference between the ADC value and the engine sensor value exceeds the acceptable tolerance band. This approach results in a step change in thrust. As a response to a failure this is a generally acceptable response. However, if the step change is a result of aircraft maneuvers causing transient exceedances of the tolerance band, then the step change may not be acceptable.

The following describes a way of implementing a smooth transition between ADC data and engine data. This smooth transition logic is used in the discussion of the total temperature and total pressure selection logic, as well.

The design intent is to use ADC information whenever it agrees with engine sensor information. Therefore, the control is allowed to use ADC Pamb(s) if they are within a given ΔP of the engine control system's ambient pressure signal. ΔP should be chosen so that a faulty aircraft Pamb signal will not cause a thrust change of more than 3% on all engines when operating in the takeoff envelope. (The ±3% thrust change requirements usually results in a ΔP of approximately 0.3 psid.) The selection priority of which air data ambient pressure signal to use (left ADC or right ADC) is usually given to the one that is closest to the engine's Pamb signal, but if the left ADC Pamb is within the ΔP criterion, give this ADC value preference so that all engines will compute maximum rated thrust using the same parameter(s). (If the left ADC Pamb is not within ΔP of the engine's but the right ADC is, use the right ADC's Pamb.) Once the aircraft's closest Pamb signal becomes farther than the chosen ΔP away from the engine's signal, the engine needs to begin moving over to its own signal. To avoid a step change, this can be accomplished with a linear interpolation between the aircraft signal and the engine signal over an interval from ΔP to 2*ΔP, so that the engine is operating on its own signal when the difference between the aircraft and engine signals is double the chosen ΔP starting value. At this point, stay on the engine signal unless the difference becomes less than the double ΔP threshold. If the difference becomes less than the double ΔP threshold, start interpolating again. If the signal difference becomes less than ΔP, select the ADC's Pamb signal. This logic is referred to as smooth transition or fairing logic and is illustrated in Figure 26. This same logic can be used for total temperature selection and total pressure selection as well.

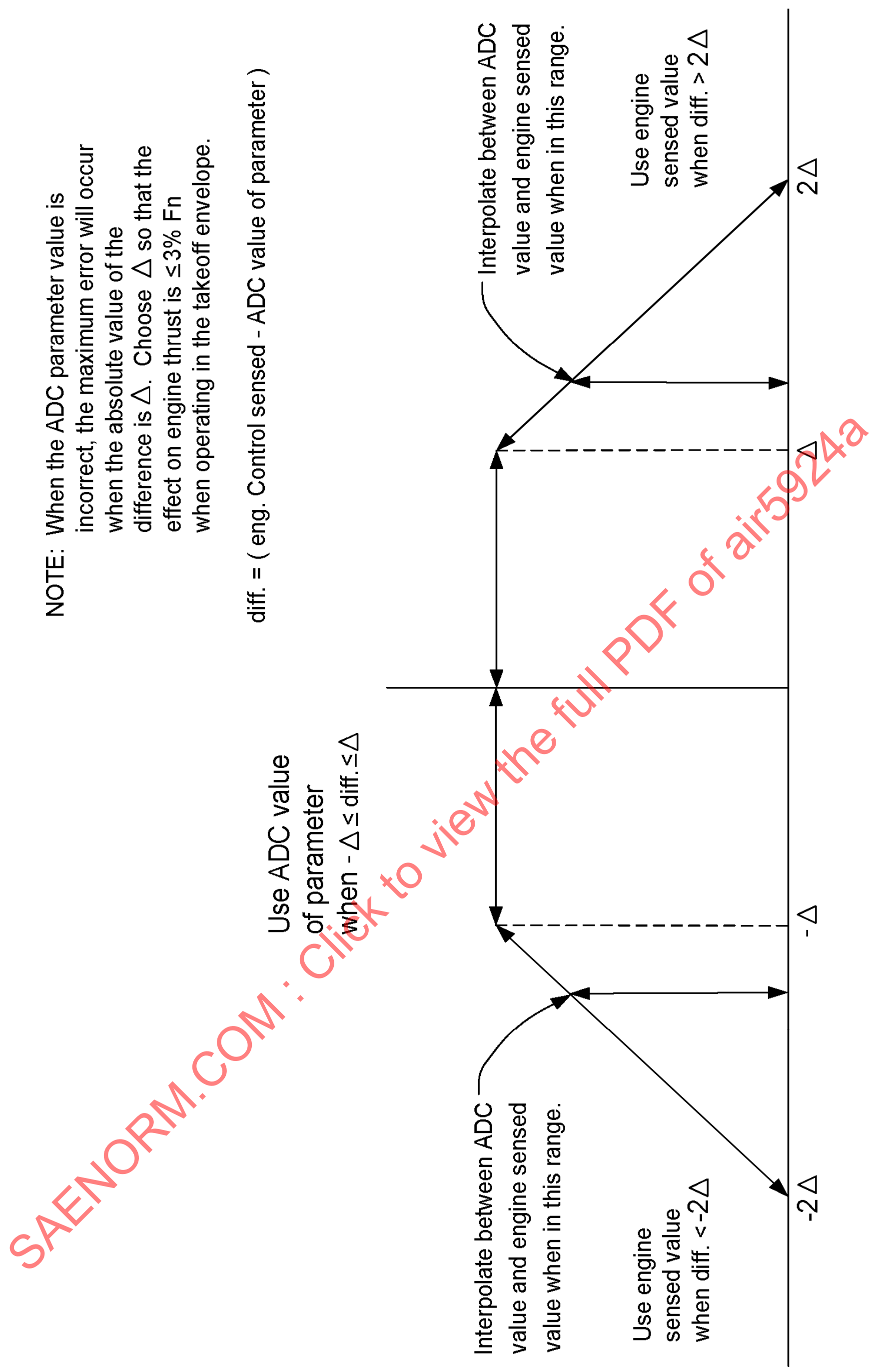


FIGURE 26 - TYPICAL FADEC SELECTION LOGIC FOR STATIC PRESSURE, TOTAL TEMPERATURE, AND TOTAL PRESSURE INFORMATION

If the engine's ambient pressure signal suddenly goes out of range and the aircraft's ambient pressure signal is available and valid, use it for get home purposes. A valid FADEC system dedicated pressure signal is usually required for dispatch.

The following selection logic can be used to assess the health of the engine’s remaining (that is, remaining if it started with two sensors and one has failed, or if the FADEC system only has one sensor) Pamb signal:

If the FADEC system has access to two aircraft ADC ambient pressure signals and

a. If the two aircraft ADC signals agree within approximately 0.1 psia, or so, and if necessary, at least one of their probe heats is on; and

b. If the engine's remaining Pamb signal differs from both of the ADC signals by more than 2*$\Delta$P psid or greater, then:

c. Declare the engine's Pamb signal failed for the remainder of the flight and use the aircraft's ADC ambient pressure signal to get home. Latch an engine Pamb fail message. Declare the control to be in a non-dispatchable configuration, and after having locked out the engine's Pamb signal, don't use it again in that flight.

If the two aircraft ADC Pamb$_s$ do not agree within $\Delta$P psia, various schemes may be used to determine what Pamb signal the engine control should use. Some examples are:

a. If the engine control has two dedicated Pamb sensors and those sensor values agree, use the average of the two engine sensor Pamb values as the selected Pamb.

b. If only one engine Pamb sensor value is available and it agrees with one of the ADC’s Pamb$_s$ within $\Delta$P, use that ADC Pamb as the selected signal.

c. If only one engine Pamb sensor value is available, and that signal and the two ADC signals all differ by more 2*$\Delta$P, then either select the engine Pamb signal or go to a default value.

The above logic works well for determining engine Pamb sensor soft shifts and other malfunctions when the two ADC Pamb values agree and are correct, but there have been situations in which this logic may not work so well. These situations occur when the two aircraft ADC values agree and are wrong. Such situations have occurred during maintenance when the static ports were taped over, and the tape was not removed before returning the aircraft to service. If the above logic is used during such a situation, it is possible for all engines to end up operating on incorrect ADC values of Pamb.

A solution to this might be to have the other engine(s) Pamb signal(s) available to all engine controls. This would appear to offer a significant benefit for fault isolation, detection and accommodation. If this were the case, the engine control system could revert to their own Pamb signals if the other engine Pamb$_{(s)}$ agree and differ from the ADC Pamb$_s$. It is possible in this situation to have improper maintenance done to all engines at essentially the same time, which results in the engine Pamb$_s$ agreeing, but being incorrect. The only mitigating factor in this scenario may be that to prevent common engine maintenance problems from occurring, the operators are continually encouraged to work on only one engine at a time between revenue flights.

There is one configuration logic that is often used to obtain engine-to-engine separation, and it has not appeared to offer any significant advantage to FADEC system or aircraft operation. This logic has been used on twin engine aircraft and is as follows: When the left and right Pamb$_s$ disagree by a certain amount, have the left engine FADEC system only compare itself with the left ADC Pamb, and the right engine FADEC system only compare itself with the right ADC Pamb. While this achieves engine-to-engine separation, it immediately results in a configuration in which one engine FADEC system is selecting and using ADC information (because the engine and aircraft Pamb agree), but the other engine reverts to its own sensor values (because it disagrees with the aircraft Pamb). Sometimes this results in thrust stagger and an associated flight crew squawk. Therefore, when the two ADC values disagree with each other, have the engine control use the one that’s closest to its own value. This will keep both (all) engines operating on the correct ADC Pamb throughout the flight, and since the pilot’s and co-pilot’s altitude information will not agree in that flight, the ADC system will receive the required maintenance before the next flight.

Finally, when the engine control is not configured to receive information from the other engine(s) $Pamb_{(s)}$, and all three $Pamb_s$ for one engine control system - the two ADC $Pamb_s$ and the remaining engine Pamb - differ considerably and the engine's signal is in range, use the engine signal. This will maintain engine-to-engine separation.

A single FADEC system Pamb sensor has been considered acceptable because of the redundancy of independent aircraft altitude sensors. Due to this, some engine manufacturers have requested that the engine be allowed to operate full time on the aircraft's sensors and that any need for an engine static pressure sensor be deleted. However, even with aircraft designs in which electrical power is considered critical, conditions of total power loss for significant periods of time are expected to occur. That is why many fly-by-wire aircraft have dedicated power sources - engine located - to maintain power to those critical flight control functions. Therefore, it is considered inappropriate - at this time - to let a signal of such importance as pressure altitude be supplied by the aircraft systems for all engines. If it could be shown that the engine operates satisfactorily and meets all of its FAA Part 33 requirements without pressure altitude information, it would, of course, be a different matter. Obviously, if other sensors internal to the engine could supply the needed information, that would also be considered acceptable.

The above discussion does not apply to those engine controls using an N1 power setting parameter, which is scheduled as a function of total pressure and total temperature, as these engines would not even have or need an ambient pressure sensor.

NOTE: It is recommended that the engine Pamb signal be frozen following touch-down on the landing. The Pamb signal can become quite erratic during thrust reverser operation, and the selection logic will not work well.

5.5.2 Total Temperature Selection Logic

The total temperature selection logic is quite similar to the ambient pressure selection logic, but there are differences in the fault detection logic when only one TAT aircraft probe with two temperature sensors is used.

For aircraft systems with two separate aircraft mounted probes, the selection logic is essentially the same: Use ADC TAT if it agrees with engine T2 within approximately ΔT °C (see Figure 26). The ΔT that meets the ±3% thrust change requirement in the takeoff envelope is generally around 2 to 3 C. Again, as with Pamb, the LADC should be given preference, but the RADC TAT should be used if it is the only signal meeting the ΔT criterion. If neither ADC is within ΔT of engine T2, use the one that is closest to the engine and begin fairing to the engine sensor's value of T2 over an interval from ΔT to 2*ΔT, so that the engine is selecting its own T2 value when the difference between the closest ADC TAT and the engine's T2 is equal to or greater than 2*ΔT. This fairing logic is similar to that used for the Pamb selection, as discussed above.

When there are two separate aircraft probes, the failure detection logic is essentially the same as the Pamb failure logic given above; however, for the total temperature signal, the use of the selection logic is dependent on knowing when the aircraft's TAT signals can be used. During static or taxi conditions with the engines running, the engine's T2 signals may have a higher degree of accuracy than the aircraft's TAT signals. When mounted inside the engine inlet, the probe benefits greatly from inlet airflow, and even if the aircraft TAT probe is aspirated during ground operation, it can have heating errors from solar radiation. Therefore, in most applications, the following total temperature logic is only used in flight. Since the engine probe is generally equal to or better than the aircraft TAT probes, the malfunctioning condition that the logic is attempting to detect is a partially plugged engine T2 probe.

The logic is as follows:

If the FADEC system has access to two independent aircraft ADC TAT signals, and the aircraft is operating in a regime in which it is known that the aircraft TAT signals should be good, and

a. If the two aircraft signals agree within approximately ΔT C, and at least one of their probe heats is on, and

b. If the engine's T2 signal(s) differ from both of the ADCs by more than 2*ΔT, for a significant period of time, then

c. Declare the engine's T2 signals failed for the remainder of the flight and use the aircraft's ADC TAT signals to get home. Latch an engine T2 message. Declare the control to be in a non-dispatchable configuration, and after having locked out the engine's T2 signal, don't use it again in that flight.

d. If the airframe does not have independent TAT probes and there is an engine temperature split between engines, then each engine should use its own engine sensor even though this may result in a thrust split.

If the two aircraft ADC TAT signals do not agree within ΔT C, various schemes can be used to determine what total temperature signal the engine control should use. Some examples are:

a. If the engine control has two separate, dedicated T2 probes and sensors and those sensor values agree, use the average of the engine sensor T2s as the selected TAT value.

b. If only one engine T2 probe with two sensors is used, and the two engine sensor values agree, but those values and both of the ADC TAT values all disagree by more than 2*ΔT, then either select the engine T2 signal or go to a default value.

When a single aircraft probe with two separate sensors for the two ADCs is used, aircraft TAT should probably not be used unless the engine's T2 sensors (there are usually two in the same engine probe) are both confirmed as failed. In single aircraft TAT probe configurations, the aircraft TAT signals are **NOT** independent. It is just as likely for the aircraft's TAT probe to be partially plugged as the engine's T2 probe. If both engine sensors are definitely confirmed as failed, use the average of the aircraft TAT if both are valid. Use the valid one if one is invalid, or use a default values as appropriate. This is another configuration in which having each engine's T2 signals be available to all engines would appear to offer a significant benefit for fault isolation, detection and accommodation. The benefit is that of being able to construct a more robust detection logic for determining faulty engine T2 signals.

Some GA aircraft utilize the engine T2 as the aircraft's sole temperature (TAT) source (i.e., no airframe TAT probe available as a voter should the engines' T2 signals disagree). In these circumstances the airframer needs to utilize a robust fault management to ensure both engines are not operating on bad temperature data. In the event of a T2 mismatch between the engines, often the method incorporated is to separate the engines and have them operate on their own T2 signals. This can result in a thrust mismatch, but provides engine isolation to common mode failures.

Concerning default values: Use the corner point day temperature as a function of altitude for the ratings or transition to an alternate non-rating mode. Use a conservative T2 default with altitude that tends to close down the stator vanes, or place other variable geometry in a position that favors improved engine stability - even if the engine cannot make full thrust because it would hit an N2 or N3 redline limiter - with the altered geometry in place. If involved, use a conservative value of T2 for the engine's accel and decel fuel flow limits.

If the control uses T2 for rating determination only, and other internal engine sensor information is used to set the variable geometry and fuel limiting schedules (and any other important items), the control could be considered dispatchable with the engine's T2 sensors failed. If this is the case, it is assumed that the control would go to a non-rating mode when both T2 signals are considered failed, and the control does not have to send a no dispatch message to the aircraft. There should be a provision to put all other engines in the same mode so that the thrust levers align during power settings, even if the aircraft is equipped with separate autothrottle servos for each thrust lever.

Many inlet located temperature sensors indicate erroneous TAT when the engine is in reverse thrust during ground operations. One solution that could be considered is to freeze the engine's TAT value when reverse thrust is commanded on the ground.

5.5.3 Total Pressure Selection Logic

For an EPR controlled engine, it should be acceptable to use the selected total pressure signal, whether it is the engine control's dedicated signal or the air data total pressure signal, in the calculation, display, and control of EPR.

If the FADEC system has a total pressure probe - with one or two pressure sensors located within the FADEC system - the selection logic for the FADEC system total pressure signal is quite similar to that for ambient pressure and total temperature. Again, the agreement between the aircraft's total pressure signals and engine's P2 signal should be established so that the effect on all engines from faulty aircraft total pressure signals meets the ±3% criterion in the takeoff envelope.

In setting up FADEC system logic to detect engine P2 system faults, experience has shown that any tolerance test between air data total pressure and engine P2 should NOT be done when operating below a Mach number of approximately 0.2. The aircraft's signal can be quite erratic during ground operations and cross-wind conditions, and in previous FADEC system applications that have used tolerance checks between ADC total pressures and engine P2s to validate the FADEC system's signal, there have been numerous reports of false engine P2 fail messages latched by the FADEC system during ground operations. In flight, ADC total pressure is normally quite accurate. However, caution should be used before declaring the engine's P2 failed if it falls out of tolerance with aircraft P2. Several incidents have occurred in which the aircraft has been dispatched with the aircraft's total pressure probes inadvertently left capped by maintenance or with probe heat not selected on by the flight crew. In these cases, had the engine controls been set-up to select ADC total pressure when the two ADC total pressures agree and the engine's P2 differs, all engines would have reverted to the use of aircraft total pressure. This would have aggravated the situation. Therefore, it is important to make sure that probe heat is on the aircraft probes, and even if the two aircraft ADC total pressure signals agree, and they differ significantly from the engine's P2 signal, it is recommended that the engine control either: (1) follow its own P2 signal; or (2) set a fault flag on its own signal and transition to the soft reversionary mode. If the engine control's P2 signal is faulty, the flight crew will note it in the first of these options via different values (between the engines) in the other engine parameters. In the second option, the flight crew will note the mode transition and place the control on the hard reversionary mode. This mode is generally independent of freestream total pressure. As with the engine's Pamb and T2 signals, it would appear to be beneficial to all FADEC systems to have each engine's P2 signals be available to all other engines for fault isolation, detection, and accommodation. This would allow a more robust detection of faulty or malfunctioning engine P2 signals to be constructed.



5.5.4 Airspeed and Mach Number Selection Logic

Airspeed (or Mach number) generally has a small impact on engine ratings in the takeoff envelope. It can be significant at higher speed conditions, such as at Mach 0.6 and above, but these are generally considered to be higher altitude conditions. For engines that incorporate a P2 probe, the calculation of airspeed from the FADEC system's selected static and total pressure signals is straightforward.

For engines that do not have a P2 probe, compare the two ADC Mach number signals and, if they agree within 0.05 Mach, use the average. When in flight, make sure that at least one of the aircraft total pressure probes has high heat on and allow sufficient time after the ground/air transition of the aircraft's weight-on-wheels (WOW) or air/ground transition detection system to apply high power to the aircraft's total pressure probes before checking for the high heat signal. If high heat does not come on, it is suggested that the control default to a conservative Mach number schedule as a function of altitude. For large turbine engine aircraft, a suggested schedule is Mach 0.2 from 2000 ft altitude to 1500 ft above the highest altitude certified for takeoff. This protects go-around performance. From 1500 ft above the highest certified takeoff altitude, the default Mach number schedule should reflect the engine-out, max-continuous-power, drift-down-speed-schedule for the intended aircraft. Obviously, this ensures that the engines will deliver maximum continuous thrust or power during engine out conditions. This portion of the schedule only has to go to the highest obstacle clearance altitude along the intended flight path. For aircraft flying over mountainous regions, this can be as high as 21 000 ft. From that altitude, the schedule can fair over to the normal Mach number cruise schedule as a function of altitude. If the Mach numbers differ by more than 0.05 for several seconds, for example 10 s or more, hold the last good average value while the clock is running, and then transition to the default schedule. The control should latch that condition and not shift back to using ADC Mach number, even if the ADC Mach numbers were to then agree within 0.05. Doing this could cause the thrust of all engines to abruptly go up or down during the transition. In general practice, the Mach number values from the two ADC should never differ by more than 0.05 during normal operation.

5.6 Thrust Management Computer (TMC) Selection of TAT

As many aircraft have a common TAT probe with two elements, both elements will agree, but be incorrect if the probe becomes blocked due to icing or FOD. Indeed, many TMCs do not even cross-compare the two TAT values from the left and right ADCs to see if they disagree. They simply use the left ADC TAT and, if it becomes invalid, which may be based on a gross failure such as the signal going out of range, they switch to using the right ADC TAT. As a result, there have been several reported incidents of incorrect TAT signals causing incorrect engine rating information to be displayed to the flight crew. Based on this experience, it is recommended that the aircraft's TMC compare multiple sources of TAT before selecting a valid TAT for use in the calculation of engine ratings.

If the two ADC TAT signals agree within ΔT of each other (for example, approximately 3 °C), but they differ significantly from the engine T2 signals and the engine T2s agree with each other, the aircraft TAT probe is probably partially plugged. This is a situation that can occur more frequently on an aircraft that is configured to use one probe. If the single aircraft probe is partially plugged, the two TAT signals will probably be higher than true TAT, but they may not be out-of-range. If the aircraft computer computing thrust uses this signal, the calculated thrust rating will probably be lower than it should be.

Aircraft that are not equipped with an aspirated TAT probe are not usually set up to have the TMC use the engine's T2 probe for TAT information to determine the takeoff power setting. In these aircraft, the flight crew has to either look up the rating in a power setting chart based on altitude, tower OAT, gross weight, runway length, and flap setting, or manually input a TAT to the TMC, so the TMC can look up the rating. Because of these situations and other conditions, it is recommended to program the EECs to be able to achieve at least 0.5 to 1.5% more than the full takeoff rated thrust at the full forward thrust position (see 4.2.1.3). During manual operations, the flight crew (during pre-flight) may input a reported tower TAT that is correct at the time, but because of the time lag involved, it is colder than actual runway conditions when the actual takeoff commences. If the engine cannot achieve the target set by the flight crew, the crew may elect to abort the takeoff. A little headroom provided by the FADEC system addresses this concern. Aborted takeoffs caused by small temperature differences during hot day operating conditions should be avoided.

Aircraft thrust management systems may use the FADEC system to compute the ratings. This eliminates some of the differences in the computation of a rating that can occur when using different computers with different environmental data. However, as some of those calculations may have to be completed before engine start, the aircraft systems will probably have to send TAT information to the control to obtain the calculated information (because the engine's T2 signal is probably not valid when the engine is not running). Therefore, the same situation as that described in the paragraph above could occur. In addition, the ratings computed from multiple engine FADECs may differ from one another depending on if the airplane air data signals, or engine signals are selected and used. In order to display one common thrust setting target on the aircraft thrust management systems, another fault isolation scheme will have to be implemented to determine which FADEC provides the most accurate ratings.

# 6. INSTRUMENTATION AND FLIGHT-CREW INTERFACES

## 6.1 Aircraft Located Engine Displays and Switches

It is not the intent of this report to describe all of the propulsion displays provided or used in an aircraft. The general display requirements are given in the appropriate sections of the CFR, such as §§23.1305 and 25.1305 as well as the appropriate foreign authority regulations. The intent is to mention a few displays in which standardization would be helpful and some indicators that are needed and not specified in §§23.1305 and 25.1305. Also, see AC 20-88A and AC 25-11A for additional guidance on displays. In general, the engine displayed parameters of rotor speeds, EGT and all other displayed parameters that are needed to support a flight crew procedure, such as on-ground and in-flight engine operations have to be available throughout the approved flight envelope. This does not apply to those cases where one or more displayed parameters are allowed to be inoperative for a specified period of time (i.e., via the MMEL/MEL).

Figure 27 illustrates a typical propulsion system flight deck display.

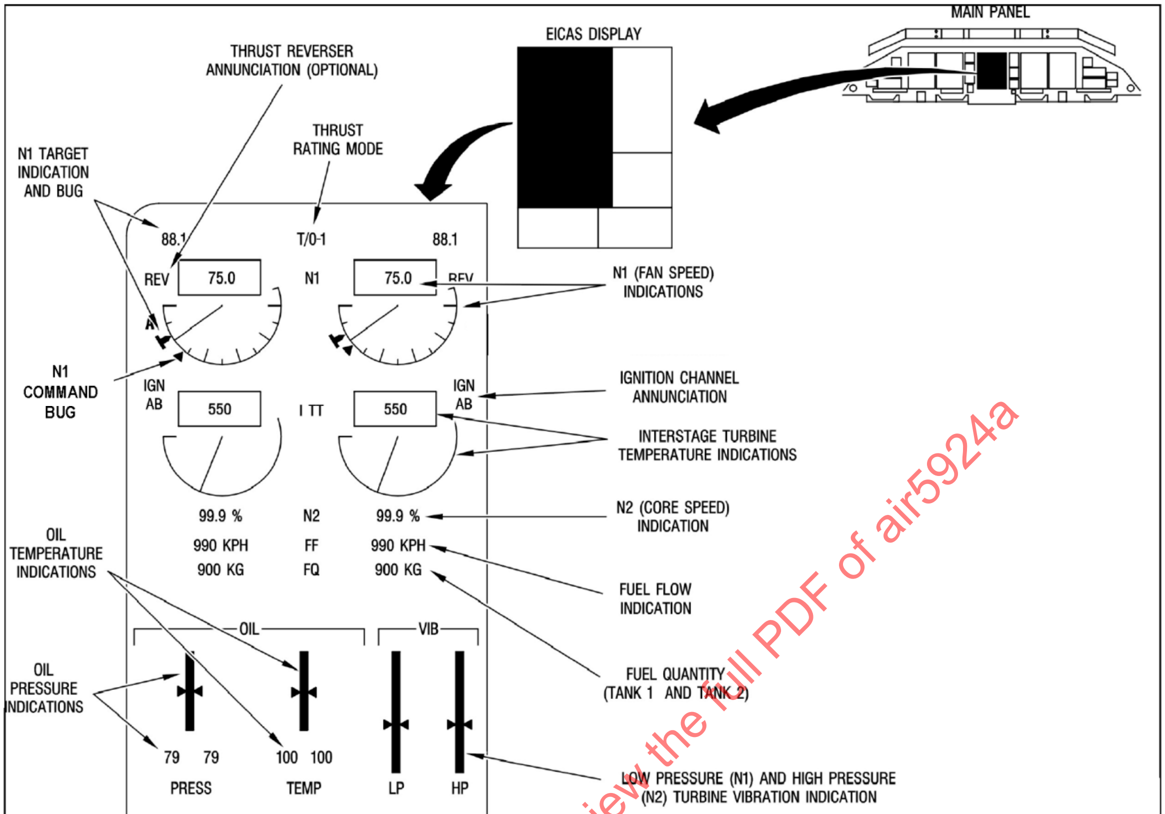


FIGURE 27 - TYPICAL PRESENTATION OF POWERPLANT DATA



6.1.1 Thrust Setting Parameter Display - Primary Mode of Operation

There are several different configurations for the display of thrust setting parameter. Whether the display is a circular or a vertical tape type of display, it is desirable for the display to show the following information:

a. The actual value of the parameter;

b. The control system (instantaneous) commanded value of the parameter;

c. The value that the FADEC system would command if the thrust or power lever were advanced to the maximum forward position;

d. The target value for the parameter as determined by a thrust, flight management computer, or FADEC system; and

e. Any redline or maximum certified limit that is required to be observed by the flight crew, such as a rotor speed redline.

Figure 28 depicts a typical thrust setting display showing this information. The control system commanded value of the parameter is quite helpful to the flight crews because it moves with thrust lever position and shows the value being commanded of the engine when it reaches steady state operation. The maximum value to which the engine would operate, shown in Figure 28 as the max bar at the top of the display, is also informative. If, due to some malfunction, the max bar is the target bug, which is provided by the thrust or flight management computer, the flight crew would know that something is wrong, because the display is indicating that the engine control is not capable of achieving the target value at the full forward thrust lever position. The flight crew would not initiate a takeoff under such conditions. Note that the max bar does not represent the parameter value for maximum rated engine thrust at that flight condition. It merely represents the parameter value commanded at full thrust lever position. This should always be greater than the maximum rated thrust value. (See 4.2.1.3 for more discussion on thrust versus thrust or power lever position.)

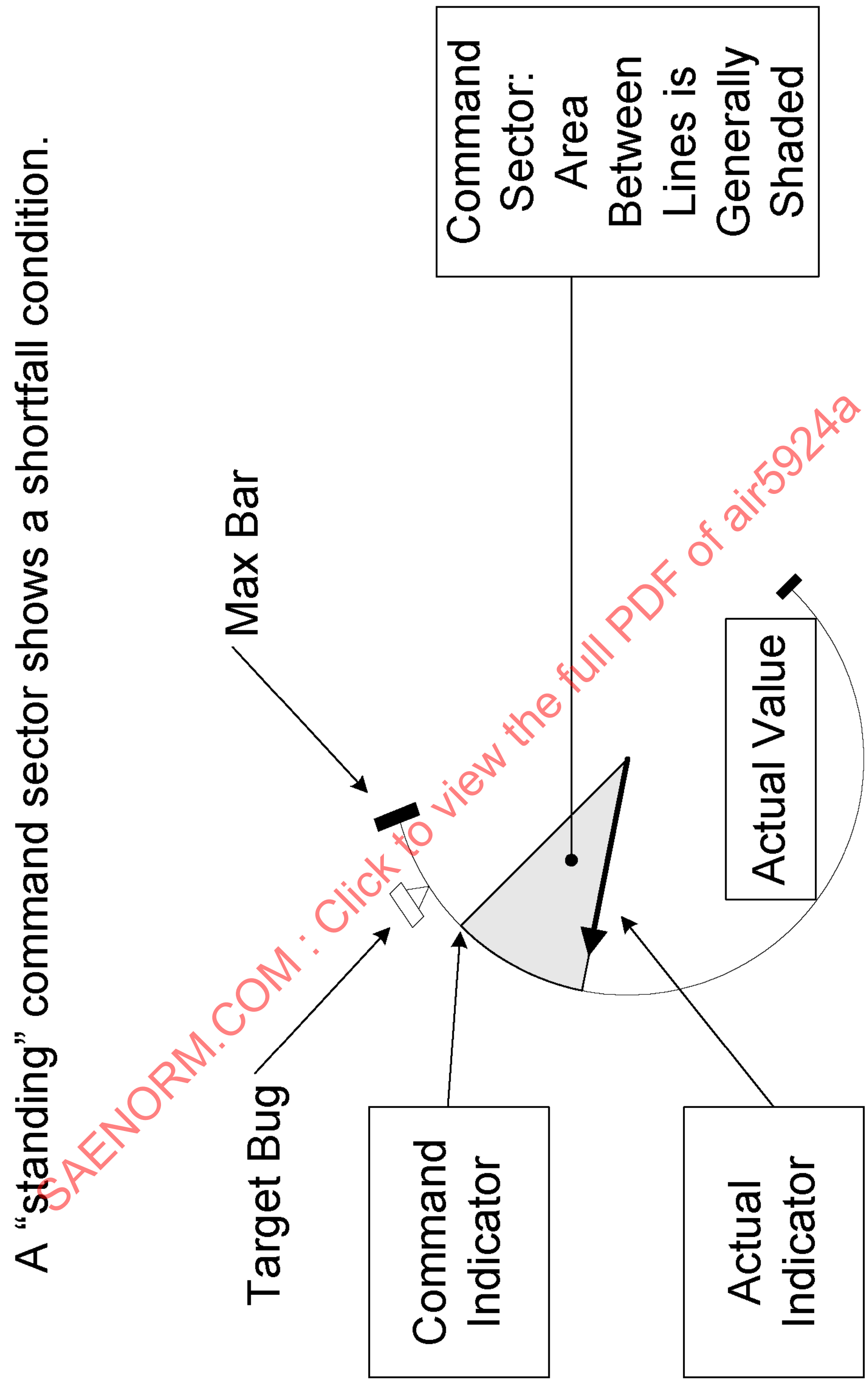


FIGURE 28 - TYPICAL FADEC ENGINE THRUST DISPLAY

At steady state conditions, the commanded value of the thrust setting parameter should be equal to the actual value. A standing difference between the two would indicate abnormal control system or engine operation. For example, as the fuel pump deteriorates, the pump may not be able to deliver the fuel flow needed to achieve the commanded value of the thrust setting parameter. Such a situation would be squawked by the flight crew and investigated and corrected by maintenance.

If it is considered that the maximum rated value of thrust is more important than the value to which the engine would run at full thrust, let the max bar be driven by the TMC and let the circular arc showing the outline of the display stop at the maximum value the engine control would command at full thrust. This is shown in Figure 28. This display format is acceptable, but it becomes a bit more difficult to determine if the engine is capable of achieving the target thrust at full thrust lever position, because the ending of the circular arc is not as apparent as the max bar.

Since the control is generally designed not to govern the engine to EPR at idle, logic is usually added to the displayed EPR (or N1) command signal to eliminate the disagreement between the command and actual values of EPR (or N1) at idle condition. Simple logic, such as the following, has proven to be adequate.

IF (EPRcmd.GT.1.15)EPRcmd-display = EPRcmd
IF[(EPRcmd.LE.1.15).and.(EPRactual.GT.1.15)]EPRcmd-display = 1.15
IF[(EPRcmd.LE.1.15).and.(EPRactual.LE.1.15)]EPRcmd-display = EPRactual

The above logic assumes that the engine is capable of being close loop EPR controlled at EPRs above 1.15 at all flight conditions. If not, use a threshold value that is. The threshold value can be a function of altitude and Mach number if desired.

For an N1 rated and controlled engine, which operates on N2 or some other parameter, such as a minimum bleed delivery pressure at idle, the logic for the display might be:

IF (N1cmd.GT.40%)N1cmd-display = N1cmd
IF[(N1cmd.LE.40%).and.(N1actual.GT.40%)]N1cmd-display = 40%
IF[(N1cmd.LE.40%).and.(N1actual.LE.40%)]N1cmd-display = N1actual

The above, of course, assumes that the engine will always be in N1 control at N1 rotor speeds above 40% physical speed. If not, the logic needs to contain a number at which the engine is under N1 control.

6.1.2 Thrust Setting Parameter Display - Backup Mode of Operation

The thrust setting display in the backup mode can be very similar in function to that shown in the primary mode. If the primary mode uses EPR as the power setting parameter, the backup mode will probably be fan speed, N1. In past applications, the EPR display for the primary mode of control had a max bar at the full scale position of the display that represented the FADEC system full thrust commanded value for EPR. When the control reverts to the soft reversion mode, or the pilot selects the backup mode, the EPR display blanks and shows no information, and the N1 display becomes the power setting display. This display has the same indicators on it as the primary display, but in this case, the display also shows the redline value of N1. Also, it was felt that using the max bar to show the maximum value to which the engine would be controlled at full thrust would not be especially useful, because generally, this value was too far above the maximum rating to be of much value. Therefore, although the max bar on the EPR display in the primary mode represents the full thrust value of FADEC system commanded EPR, in the backup mode, the max bar on the N1 display is driven by the aircraft's TMC and shows the N1 for the maximum rated value of thrust at that flight condition.

Changing the meaning of the max bar from one mode of engine control to another is not considered to be good practice, even though the display parameter changes from EPR to N1 when the control reverts to the backup mode. For N1 controlled engines, the thrust setting display would be N1 for both modes. If it is desired to have the max bar represent the maximum certified thrust value (at that flight condition) in the backup mode, it is recommended that max bar have this same meaning in the primary mode, and that the end of the circular arc represent the maximum value of N1 commanded by the FADEC system at full thrust lever position.