



AEROSPACE RECOMMENDED PRACTICE

ARP5107™

REV. C

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Superseding ARP5107B

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

RATIONALE

This standard has been revised to harmonize its content with EASA CM-MMEL-001 and reflect new methodologies in the field.

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1. SCOPE

This SAE Aerospace Recommended Practice (ARP) provides methodologies and approaches which have been used for conducting and documenting the analyses associated with the application of Time Limited Dispatch (TLD) to the thrust control reliability of Full Authority Digital Engine Control (FADEC) systems. The TLD concept is one wherein a fault-tolerant system is allowed to operate for a predetermined length of time with faults present in the redundant elements of the system, before repairs are required. This document includes the background of the development of TLD, the structure of TLD that was developed and implemented on present generation commercial transports, and the analysis methods used to validate the application of TLD on present day FADEC equipped aircraft. Although this document is specific to TLD analyses (for FADEC systems) of the loss of thrust control, the techniques and processes discussed in this document are considered applicable to other FADEC system failure effects or other systems, such as: thrust reverser, and propeller control systems, and overspeed protection systems.

1.1 Purpose

The purpose of this document is to provide guidance on achieving approval of time-limited-dispatch (TLD) for full authority digital engine control (FADEC) systems. TLD addresses continued operational safety with faults already detected (by fault detection function, crew, or maintenance activity) and not yet repaired. In this regard, the usage of the term "TLD" refers to the concept that FADEC engine control systems shall be allowed to operate with faults for a specified period of time, after which appropriate repairs shall be made to bring the system back to a "full up" configuration. For the purposes of this document, the term "full up" is used to indicate that the FADEC system is free of faults which affect its loss of thrust control (LOTC) failure rate, as defined in Section 5. Hence, "required repairs" for this application of TLD are limited to only those faults that affect the LOTC rate, and faults that do not affect the LOTC rate, such as faults in sensors used for engine condition monitoring, are not addressed in these guidelines. Sensors that could affect the LOTC rate, such as oil pressure, oil temperature, and exhaust gas temperature (EGT) should be included in the analysis if those sensors are part of the engine's FADEC system.

This document is primarily concerned with LOTC events which are caused by failures and/or faults in the engine's control system. Engine failures from any other causes are not the subject of these guidelines, but failures that may affect MMEL activities outside of the engine should be identified. In addition, this document is not intended to establish specific requirements for FADEC system certification or design. Specific requirements pertaining to certification should be coordinated with the appropriate certifying agency.

1.2 Summary of Revisions

1.2.1 Summary of Revision A

A significant improvement in determining the fractional coefficients of the time-weighted-average (TWA) equation, which is the first approach described herein for estimating the average LOTC rate of the system, has been made and is described in 7.1. The new coefficients allow the TWA method to yield a more balanced solution - one which is closer to the Markov model solution and somewhat simpler to use.

Much has changed in the description of the Markov modeling (MM) analysis approach described in this revision. Since the original release in June, 1997, the authors of this ARP have a better understanding of the MM approach as it applies to FADEC as well as other systems. Unique to this document is the description of MM as either an Open Loop or Closed Loop model. The nomenclature of Open Loop and Closed Loop Markov models is unique to this document. The authors have not seen this terminology used elsewhere, and there is no intention herein to set any type of standard in the using of this terminology. The development of the Closed Loop MM approach has led to not having to solve a set of differential equations to obtain the steady state solution for the overall average failure rate of a system, but rather, simply solving a set of algebraic equations to obtain the solution. This was implied in the original release, because the MMs in that release were solved by integrating the differential equations until a steady state solution was obtained, where all the time derivatives were essentially zero. However, it was not specifically called out that the derivatives should be set to zero at the onset, and the resulting set of algebraic equations solved to obtain the values of the state probabilities.

In addition, it was not recognized that the values obtained for the state probabilities, which are dependent on the value of the feedback rate from the fully-failed, loss-of-thrust-control (LOTC) state to the full-up state, do not affect the failure rate of the system. Hence, although the original release provides some rationale for setting the feedback or repair rate from the fully failed LOTC state to the full-up state to unity (i.e., 1.0), the value of this feedback rate doesn't matter and the rationale for setting the feedback rate to unity can be misleading. As the new material shows, the solution is independent of all state probabilities and the value of the fully failed to full-up feedback rate. The solution is only dependent on the failure rates between the various states of the model and the repair rates used for the short time (ST), long time (LT) states, and if modeled, any no-dispatch (ND) fault states.

Experience has also shown that simulating states representing two or more failures has little influence on the overall LOTC rate of FADEC systems when the repair rates for the various fault states are much more frequent than the failure rates into and out of those fault states. When this is the case, constructing a "single state model" is usually adequate. In single state models, described in 7.2.2.3, only single fault states are modeled, and only those additional single failures that would cause the control system to go from those single fault states to the LOTC state are modeled. Adding additional multiple failure states only affects the answer by small amount, i.e., less than 5%. This is discussed in more detail in Appendix G.

Similar to the above, the use of the terminology "single state model" is unique to this document, and there is no intention to set any terminology standard with the use of this descriptive term. Some who have reviewed this document have commented that the use of the terminology single state model is misleading because a single state model actually models all dual failures that lead to the LOTC state. This is correct. However, the selection of the terminology was made because the model explicitly shows only the single failure states. All dual failures that lead to LOTC events are included in the LOTC failure state, and no dual failures that do NOT result in an LOTC event are modeled.

Revision A of this document aligned with the R1 revision to PS-ANE100-2001-1993-33.28TLD-R1, Policy for Time Limited Dispatch (TLD) of Engines Fitted with Full Authority Digital Engine Controls (FADEC) Systems.

A discussion of the elements that are considered part of the engine control system and should be represented in the LOTC analysis (see 6.5).

1.2.2 Summary of Revision B

Section 6.4, on Recommendations on Items Considered Part of the FADEC System, has been significantly expanded to provide more guidance on that subject. Section 6.6, on Recommendations on In-Service LOTC Reporting, has been added.

The functions of the system, the elements selected for use in the system, and the design implementation all depend on the overall system architecture. In addition, integration between the engine and the aircraft control systems is constantly changing. All of these factors impact the selection of the elements to include as part of the FADEC system. Therefore, the information included in this section does not provide an absolute answer, but is intended to provide a methodology to use in selecting which elements of the aircraft/engine control system should be included in the analysis.

The added Table 1 in that section illustrates how to consider all elements of the thrust or power control system, the functions and failure modes associated with the element, and then evaluate whether it is or is not part of the TLD restriction envelope depicted in Figure 3B. The table also shows the most likely result of a failure of the element by identifying the applicable area of Figure 3B.

1.2.3 Summary of Revision C

Due to the increased complexity of Engine Control integration into airframe systems, and a tendency of aircraft and engine functions to be interdependent, Engine Control TLD analyses have evolved to address functions that are not purely a function of engine controls.

Following the introduction of new EASA Part-21 requirements on Operational Suitability Data (OSD), EASA has published CM-MMEL-001 to clarify how compliance to the OSD certification basis for MMEL should be conducted by the aircraft applicant on MMEL items already subject to a TLD analysis. The referenced CM addresses EASA's concern of including airframe systems in the Engine Control TLD analysis. The intent of this inclusion is to address dispatch capability of the aircraft in a similar manner as the engine controls related items (e.g., same FADEC Short Term alert message in the cockpit). An alignment activity has been conducted between the SAE E-36 Electronic Engine Controls Committee and EASA for this version of ARP5107. Section 6.2 has been added to provide guidance on clarifying which functions are solely engine related, and which are part of other airframes systems in the TLD analysis.

1.3 Field of Application

This document applies to fault-tolerant (or redundant) FADEC control systems for aircraft engines on multi-engine aircraft. TLD addresses the level of degraded resource that is allowable - while still meeting the necessary airworthiness requirements - for FADEC controlled aircraft engines used on multi-engine aircraft. (It is noted that the submittal of a TLD analysis is not a requirement for certification of an engine incorporating a FADEC system. The analysis is a means to substantiate and obtain approval for dispatching and operating a FADEC system - for limited time periods - with faults present in the system.) Although this document specifically applies to FADEC systems on multi-engine aircraft, the methodologies presented herein with regard to achieving an overall average system failure rate can also be applied to other systems.

2. REFERENCES

2.1 Applicable Documents

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

2.1.1 FAA Publications

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

- (Original) ANE Policy Letter, dated October 28, 1993, Time-Limited-Dispatch of Engines Fitted with FADEC Systems
- Policy Memorandum, PS-ANE100-2001-1993-33.28TLD-R1, Policy for Time Limited Dispatch (TLD) of Engines Fitted with Full Authority Digital Engine Controls (FADEC) Systems, June 29, 2001
- Advisory Circular, AC 33.28-3, "Compliance Criteria for 14 CFR §33.28, Aircraft Engines, Electrical and Electronic Engine Control Systems", issued May 23rd., 2014

2.1.2 EASA Publications

Available from European Aviation Safety Agency, Ottoplatz, 1, D-50679 Cologne, Germany, Tel: +49 221 8999 000, www.easa.europa.eu

AMC 20-3 Certification of Engines Equipped with Electronical Engine Control Systems

CM-MMEL-001 Issue 1 Engine Time Limited Dispatch and Master Minimum Equipment List (MMEL)

CS-E 50 (c) Engine Control System Failures

CS-E 1030 Time Limited Dispatch (Issue 1)

2.2 Acronyms and Symbols

AFM Airplane Flight Manual

ARP Aerospace Recommended Practice

CAA Civil Aviation Authority (FAA of United Kingdom)

CFR Code of Federal Regulations (a.k.a. FARs)

CPU Central Processor Unit

CMR	Certification Maintenance Requirement
CS	Certification Specification (EASA nomenclature)
DDG	Dispatch Deviation Guide
EASA	European Aviation Safety Authority
EEC	Electronic Engine Control
EPR	Engine Pressure Ratio
FAA	Federal Aviation Administration (or Authority)
FL	Flight Length (in hours)
FADEC	Full Authority Digital Engine Control
FAR	Federal Aviation Requirement
HM (or HMC or HMU)	Hydromechanical (control or unit)
IFSD (or IFSDs)	In-Flight Shut Down(s)
IM	Installation Manual
JAA	Joint Airworthiness Authorities (of Europe) (replaced by EASA)
JAR	Joint Airworthiness Requirement (replaced by EASA CS publications)
LOTC	Loss of Thrust Control
LOPC	Loss of Power Control
LT	Long Time Fault/Fault State/Repair Interval
MEL	Minimum Equipment List (operator constructed, based on the MMEL)
MM (or MMs)	Markov Model(s)
MMEL	Master Minimum Equipment List (provided by aircraft manufacturer)
MPD	Maintenance Planning Document
MRB	Maintenance Review Board
ND	Non-Dispatchable Fault/Condition
OEM	Original Equipment Manufacturer
OSD	Operational Suitability Data
ST	Short Time Fault/Fault State/Repair Interval
TLA	Thrust Lever Angle
TLD	Time Limited Dispatch
TWA	Time Weighted Average (see Section 7)

λ	failure rate (failures per million hours)
μ	repair rate, given on a per hour basis
=	equals
$\approx$	approximately equal to
$\equiv$	defined as
$\geq$	greater than or equal to
$\leq$	less than or equal to
P	probability
T	time
t	time

3. APPLICABILITY

The applicability of these guidelines is primarily intended for FADEC-equipped engines certifying to 14 CFR Part 33, CS-E regulations, and the application of those engines to aircraft certifying under 14 CFR Part 23, 25, 27, and 29 regulations. For the purposes of this document, a reference to Part 25 should also be read as a reference to Part 23/Part 27/Part 29, for the TLD analysis. The approaches contained herein have been accepted in previous FADEC system approvals for engines installed on aircraft certified under 14 CFR Part 25 regulations. The continued acceptability of these approaches should be coordinated with the appropriate certification agency during any new certification effort. In addition, changes have been made to extend the applicability of the techniques across both the engine and aircraft certification authorities, to include CM-MMEL-001 Issue 1 Engine Time Limited Dispatch and Master Minimum Equipment List (MMEL).

This approach may also be applied to systems which are not FADEC systems.

4. HISTORICAL PERSPECTIVE

The concept of time limited dispatch (TLD) originated during the development and certification of FADEC systems used on the turbine (jet) engines of the Boeing 767 airplane. A brief discussion of some of the early applications of electronics to turbine engine controls is given in Appendix A.

5. INTEGRITY GUIDELINES

Improved dispatchability for the FADEC engine control systems was a major objective during the design and development of the Boeing 767 airplane. The approach pursued was to have the engine manufacturers conduct an analysis of all control system faults, which would include all electrical/electronic and hydromechanical/mechanical faults, to determine their influence on control system integrity. This analysis would determine the length of time a fault (or faults) could be allowed to exist - after which repair would be required - to achieve a given level of integrity. Early discussions with Seattle's Northwest Mountain (ANM) Region FAA office, which certified the 767 aircraft; New England's (ANE) FAA office, which certifies the Pratt & Whitney and General Electric engines; Britain's Civil Aviation Authority (CAA) office, which certifies Rolls-Royce engines; and all engine manufacturers ensued. Representatives from the FAA field operations office (Part 121) attended the above meetings also. Although not directly involved in certification matters, the FAA Part 121 group approves airline maintenance and operations policies and procedures, and their concurrence with the proposed approach was needed. For the purposes of this document, a reference to LOTC should be read as a reference to LOTC/LOPC for the TLD analysis. The discussions defined an LOTC event and established some significant integrity requirements for FADEC systems. The integrity requirements are contained in the recently issued revision to FAA Engine and Propeller Directorate policy letter on Time Limited Dispatch. For engines intended for Part 25 applications, the LOTC definition and the integrity requirements are as follows:

An LOTC/LOPC is defined in AC33.28-3, AMC 20-3A, and CS E-1030.

For applicants complying with CS E1030, it provides criteria in addition to LOTC criterion, among which:

- Failures leading to an inability to relight in flight shall be classified No Dispatch
- Failures leading to be one failure away from an Engine Hazardous Event shall be classified No Dispatch

When complying with CS-E 1030 and FAA policy, additional criteria may be considered in TLD analysis.

1. The average integrity of the control system has to be better than or equal to 100000 hours for faults that result in an LOTC event. In other words, the Fleet Average LOTC rate of the FADEC system has to be less than or equal to 10×10^{-6} failures per hour. This fleet average is to include all modes of control system operation, and, by definition, is the average of all dispatches, including full-up system dispatches. It should be noted that the LOTC rate objective may be different from 10×10^{-6} /EFH; CS-E 50 (c) (1) specifies that it has to be consistent with the safety objective associated with the intended aircraft application.
2. The engine control system is considered to be NOT dispatchable if the instantaneous LOTC rate is greater than 100×10^{-6} failures per hour. The instantaneous LOTC rate is defined as the calculated LOTC rate of a specific combination of failures at dispatch.
3. The control system should have a more restricted (i.e., short time) dispatch period if it has suffered a significant loss in redundancy or its instantaneous LOTC rate is between 75×10^{-6} and 100×10^{-6} failures per hour. The engine manufacturer may choose to place other dispatchable failures, which have an associated instantaneous LOTC rate less than 75×10^{-6} events per hour, in this short time dispatch category as well, as that would be conservative. (Dispatches in these configurations are generally handled via the aircraft's Master Minimum Equipment List (MMEL.) See Appendix D.)
4. A longer, but still restricted, dispatch interval is allowable when the instantaneous LOTC rate is less than 75×10^{-6} , but greater than the 10×10^{-6} , failures per hour overall target.

It has been generally accepted that if (1) the FADEC installations have been shown to comply with FAR 25.903(b) in the system configurations approved for TLD, and (2) approved TLD methods are used to monitor and govern maintenance of each engine's FADEC system, then the engines may be considered independent of each other when determining dispatch in service. Thus, the airplane could be dispatched with faults present in more than one engine's FADEC system. Since this last item involves application of TLD to the aircraft, the acceptability of this item is at the discretion of the aircraft certification authority.

The initial 10 per million hour LOTC rate integrity requirement for engines intended for Part 25 applications is documented in the revised advisory circular (AC) for FAR 33.28, AC 33.28 (or equivalent EASA AMC 20-3). An analysis to show that the control system is designed to meet this integrity requirement is usually submitted as part of engine certification. This is normally required - even when the applicant is not applying for TLD operations.

A remaining integrity requirement for aircraft certification is to show compliance with FAR(CS) 25.1309. This FAR relates to Systems and Equipment, and the requirement is that the probability of having a catastrophic multi-engine thrust loss event due to independent control system causes must be less than 10^{-9} failures on a "per hour of flight basis." In previous certifications, the FAA, EASA, and other certification authorities have agreed that the use of a fleet-wide average, control system caused LOTC rate, is acceptable when showing compliance with this requirement. Using a fleet wide LOTC rate for engine certification of 10×10^{-6} per hour results in compliance with the FAR/CS 25.1309 requirement for multi-engine aircraft. This is discussed in more detail for a twin-engine aircraft in 8.1. Thus, the integrity requirements for engine certification are consistent with those that come from aircraft certification with regard to the application of FAR 25.1309. (Note that single engine aircraft used in commercial service do not certify under Part 25 regulations; thus, FAR 25.1309 requirements do not apply to single engine aircraft.) For a twin engine aircraft, the specific risks for dual engine LOTC events, caused by loss of both engines' control systems due to faults, is given in 8.2 for the various dispatch configurations currently allowed in service. The acceptability of all dispatch configurations needs approval from the aircraft certifying authority as well. Hence, any new aircraft certification application requires coordination with the appropriate aircraft certifying authority to establish the aircraft level allowable dispatch configurations and the acceptability of the associated specific risks for limited time periods requested.

There was no intent to circumvent or establish a more severe requirement for FADEC system integrity during engine certification under 14 CFR Part 33 than would come from the aircraft certification under 14 CFR Part 25, FAR 25.1309, when the integrity requirements for FADEC systems were being established. The intent was merely to require that FADEC system integrity be equivalent to the established reliability of the then current hydromechanical engine control systems. For aircraft certifying under 14 CFR Part 25, FAR 25.901(b)(2) requires the engine control to be reliable between "normal inspections and overhauls." The above engine control system integrity requirements were considered to meet this requirement as well as the fail-safe requirements of FAR 25.901(c) and 25.1309(b). For Part 25 applications, TLD is a useful tool for assuring that appropriate instructions for continued airworthiness are provided, as required by FAR 25.1529.

It is interesting to note that since the issue of the original ARP5107 in June, 1997, there have been significant changes in engine-run reliability as a result of Extended-range Twin-engined Operations (ETOPS). In the newly coordinated activity on ETOPS requirements, the overall engine - including those IFSDs caused by aircraft systems, have to show an IFSD rate of 0.02 per 1000 hours to be allowed ETOPS operations with diversions of 3 hours or less, and an IFSD rate of less than 0.01 per 1000 hours for ETOPS operations with diversions of more than 247 minutes. Because of this, the allowance (by the engine manufacturer) for engine control system caused IFSDs has continued to be dramatically reduced. This reduction has not been the result of more restrictive FAA regulations with respect to engine control system caused IFSDs, but rather, the "pressure of ETOPS" IFSD events. Hence, the average overall FAA LOTC rate for transport aircraft engines continues to be limited to 10 events per 10^6 flight hours, although the engine manufacturer would not allow such a high rate (for just the control system) in ETOPS operations. Such an allowance would have too high an impact on the IFSD rate.

6. GENERAL ANALYSIS APPROACH

The general approach is to construct a model of the FADEC system which allows the integrity of the system to be analyzed in its full-up as well as the various fault configurations considered allowable for dispatch, and to "time average" those various states of operation to achieve the required average integrity. The integrity requirements defined by PS-ANE100-2001-1993-33.28TLD-R1, Policy for Time Limited Dispatch (TLD) of Engines Fitted with Full Authority Digital Engine Controls (FADEC) Systems, are listed in Section 5.

In general, the analysis used to determine compliance with the requirements can be completed using any analysis tool(s), provided that the tools and methods used are acceptable to the certifying authority. Hence, it is important to have discussions with the appropriate certifying office concerning the capabilities and limitations of the analysis tools before commencing the actual analysis. Examples of previous tools used include standard fault tree computer programs and Markov models.

The general rule for faults relating to a TLD analysis is this: if they affect the LOTC rate, include them in the analysis; if they do not affect the LOTC rate, leave them out. Obviously, a fault does not have to have an immediate effect on the operation of the engine to be included in the analysis. It is sufficient that the "instantaneous LOTC rate" of the control be influenced for the fault to be included in the analysis. A more detailed discussion of some typical FADEC system faults, and whether they should be included in the LOTC analysis, is given in Appendix C.

This document addresses the two types of TLD maintenance approaches as discussed in Section 14 of FAA policy PS-ANE100-2001-1993-33.28TLD-R1; the MMEL and Periodic Inspection/Repair Maintenance Approach. The MMEL maintenance approach is generally termed "on condition" or "time since fault," where the time at which the fault occurs is known, and the fault is repaired within a defined time limit of its occurrence. The Periodic Inspection/Repair approach involves a "scheduled inspection and repair" of the faults. The time of occurrence of the fault is not known, but rather, a periodic inspection for faults is made, and should a fault be found, it must be repaired at that time or within a defined time limit of the inspection.

6.1 FADEC System Configuration

The FADEC System is a hardware/software system which controls, monitors, and reports on the operation of the power plant. The FADEC System consists of the Electronic Engine Control (EEC), its associated software, all hardware with which the EEC communicates (including, but not limited to: fuel metering unit, actuators, actively controlled valves, sensors, ignition excitors, throttle, thrust reversers, health monitoring), and the communication channels utilized by the EEC (e.g., wire harnesses, pressure sense lines).

A typical (simplified) FADEC system configuration is shown in Figure 1. For simplification purposes, it is assumed throughout this report that all electrical/electronic elements of the control have redundant elements, that the redundant elements are identical, and that the control alternates between use of the redundant elements on each engine start. This last item minimizes the exposure time for the existence of latent faults in the electrical/electronic elements. The above assumptions need not be the case for the use of these guidelines, but essentially all the equations used herein would need modification to account for dissimilar redundancy and not alternating electronic element/channel operation.

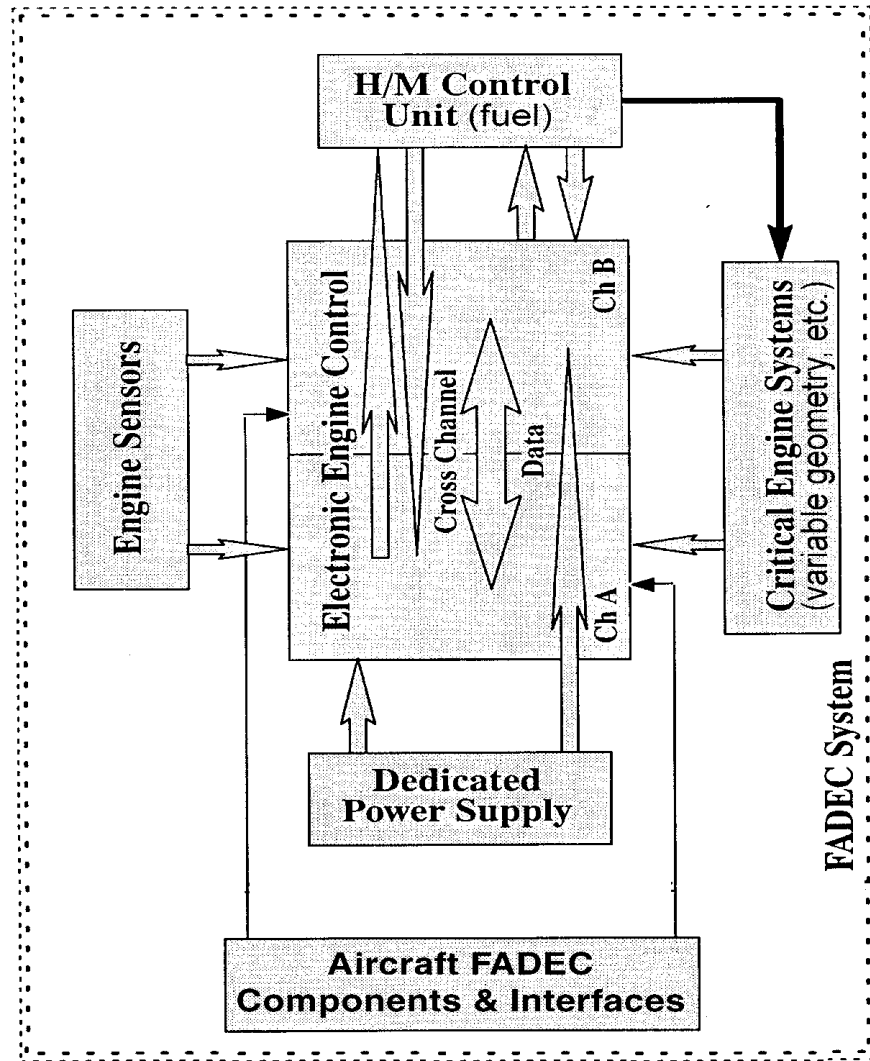


Figure 1 - Simplified FADEC system

6.2 Clarification and Management of Aircraft and Engine Control Faults Categories

Modern engine controls are increasingly reliant on airframe systems for critical inputs that may affect thrust control and dispatchability. Additionally, the control system may be providing data or functions that are utilized by airframe systems. These other systems (other than engine controls) may be a part of an MMEL for dispatch. When preparing a TLD report, in addition to identifying faults as Full Up Dispatch, Long Time Faults, Short Time Faults, and No Dispatch Faults, the applicant needs to clearly identify which faults are a function of the Engine or Engine Control and which faults are a function of another aircraft system. The faults that affect aircraft systems should be clearly identified in the engine TLD report. These faults could be included in or affect the aircraft level MMEL and be addressed by the airframer.

The original function of Full Authority Digital Engine Control (FADEC) system was to primarily manage the turbo machinery. Many of the functions are now incorporated in modern FADECs support aircraft functions. Section 6.5 provides elements to help the user to define the scope of the TLD analysis.

It is recommended that applicants clearly identify any functions that are not part of the Engine Control System in the TLD report. If these functions are to be included in the MMEL, they must be identified by the installer. This could be done as an appendix or addendum to the TLD report for clarity and ease of revision. The installation manual must include assumed airframe data reliability for the engine installation. Airframe data reliability should be considered while determining engine LOTC rate as described in 6.5.

6.3 Repair Categories: Immediate, Short, and Long Time

FADEC system faults can be grouped into one of three repair categories:

- Immediate or "no dispatch category" - As the name implies, faults in this category require repair prior to dispatch.
- Short time repair (or short time dispatch) - These faults are usually 500 hours or less, and dispatch decisions with these faults are typically handled via the aircraft Master Minimum Equipment List (MMEL). See Appendix D for further discussion of this item.
- Long repair interval (or long time dispatch) - These faults are typically 500 hours or more, and are typically handled via the operator's maintenance program.

The specific allocation of faults to the short or long time category is determined as part of "the conducting" of a TLD analysis. This determination can be influenced by an operator's maintenance policy.

The "Policy Letter from ANE FAA Regarding Time Limited Dispatch (TLD) for FADEC Controlled Engines," for TLD time limit restrictions applicable to "entry level" systems.

As indicated earlier, when complying with 14 CFR 2X.903 and showing that engine-to-engine isolation is maintained in all TLD approved dispatch configurations, it is not necessary to consider combinations of faults involving multiple engines when determining aircraft dispatch. If both the airplane and engine manufacturer wish to place limitations on TLD operations, the more restrictive of the two, on an item by item basis, should be used. For example, if the engine manufacturer indicates in the Instructions for Continued Airworthiness (ICA) for the engine that short time faults must be limited to 150 flight hours and long time faults should be limited to 500 hours, and the aircraft manufacturer places the limitation on the aircraft that short time faults should be limited to 100 flight hours and long time fault limited to 750 flight hours, the limitation should be 100 flight hours for short time faults and 500 hours for long time faults, as this is the more restrictive for each of the categories.

It is important to note that these repair categories are applicable to single faults as well as combinations of faults. For example, a mechanical/hydraulic fault that may not have caused an LOTC event on the last flight might be a stability bleed valve failure, where the bleed valve failed open, but did not cause EGT to increase to a level which would cause the flight crew to have to reduce thrust. Although the condition did not cause an LOTC event on the last flight, this is a single fault that requires immediate repair. (This assumes that the flight crew notes the effects of the failure condition and maintenance investigates and discovers the faulty condition.)

An example of a dual electronic fault that would normally require immediate repair is the loss of both channels' (free stream) total temperature sensors. This condition may not have resulted in a LOTC event on the last flight either, because the control may have been configured to accommodate such a fault. But it may be considered a non-dispatchable configuration for the control; hence, immediate repair may be required. Immediate repair is required for all combinations of faults that leave the FADEC system in a configuration where the instantaneous LOTC rate is greater than 100×10^{-06} failures per hour and/or all combinations of faults that leave the FADEC system within one fault away from LOTC.

A similar situation exists for the short and long time repair categories. A single fault, such as loss of the central processor in one channel, is a fault that is generally placed in the short time (i.e., less than 500 hours) repair category because the system suffers a significant loss of redundancy when such a fault occurs. The short time repair category might also be used to repair a condition caused by a combination of faults. For example, assume that the control experiences two independent faults, one in either channel, which by themselves might be placed in the long time (i.e., greater than 500 hours) repair category. The FADEC system could be configured so that when the two faults exist together, the repair requirement is "elevated" to the short time repair interval. This is required if the combination of faults results in a FADEC configuration where the instantaneous LOTC rate is greater than 75×10^{-06} failures per hour, but less than 100×10^{-06} failures per hour no-dispatch rate.

If two or more faults do not result in a condition of significance or concern, and by themselves, each would only require long term repair, then their combination may be left in the long time repair category as well.

Hence, in summary, the immediate (i.e., no dispatch), short time and long time repair categories can be used for single as well as combinations or multiple faults. The selection of the category is dependent on the condition of the control when operating with the fault(s).

As always, discussions between the appropriate authorities and aircraft OEMs should be held to confirm the acceptability of the various dispatch configurations and their respective operating intervals.

6.4 Classification of FADEC Fault Types

The approach used herein is to take all FADEC system faults, one by one, and determine which repair category is suitable for that fault, assuming that it is the only fault in the system, and that ultimately the fleet average LOTC rate of 10×10^{-6} failures per hour is achieved with the defined categorization. If the fleet average is not achieved, it will be necessary to place more restrictive dispatch limits on some of the faults to achieve the required rate.

6.4.1 No Dispatch (ND) Type Faults

Single faults that require immediate repair are termed no-dispatch (ND) type faults. (This should not be confused with combinations of faults that result in a no-dispatch condition.) The assumed FADEC system configuration (Figure 1) consists of redundant elements for all electronic/electrical portions of the system. Because of this assumed redundancy, the configuration has no known single electronic/electrical elements (from a functional perspective) which if failed, would require immediate repair to achieve a dispatchable configuration.

Note, however, that all single faults have to be assessed against the requirement that the instantaneous LOTC rate cannot be greater than 100×10^{-6} failures per hour when dispatching with the fault. If a single fault leaves the control in a configuration where the instantaneous LOTC rate is greater than this upper bound, the fault should be placed in the no-dispatch category. Exposure to these faults over a single flight are generally not included in the reliability analysis because the repair interval is so frequent, there is essentially no effect on the estimated LOTC rate.

Since the hydromechanical/mechanical elements of the system are assumed to be non-redundant, all ND type faults in the FADEC system discussed herein (Figure 1) are in the hydromechanical/mechanical elements. Only those ND faults which would lead to an LOTC event should be included in the analysis. If some fault redundancy is provided within the mechanical/hydromechanical elements, these can be treated as additional ST or LT faults provided the detectability and residual system reliability are adequate. The engine manufacturer(s) may elect to place single element items in the ND category that do not lead to an LOTC event. Examples of this might be an air-oil-cooler valve, which if failed open might result in the inability to maintain adequate fire extinguishing capability. Failure of such a valve would not generally lead to an in-flight LOTC event; therefore, these type ND faults should not be included in the TLD analysis.

6.4.2 Short Time (ST) Type Faults

Faults placed in the short time repair category (e.g., less than 500 hours) are termed ST type faults. From the requirements of Section 5, single faults which leave the control in an acceptable dispatch configuration, but one where the instantaneous LOTC rate is between 75×10^{-6} failures per hour and 100×10^{-6} failures per hour should be placed in this category. In addition, FAA approved TLD operations to date have all single faults which leave the control in essentially single channel operation, such as loss of one channel's CPU or power supply, placed in the ST category - even though the LOTC rate of the remaining channel may be less than 75×10^{-6} . Again, it is assumed that there are no single electrical/electronic faults which leave the control in a configuration where the instantaneous LOTC rate is greater than 100×10^{-6} failures per hour. If this were the case, those faults would have to be placed in the ND category. There are many applications where faults that could be placed in the long time category (discussed below) are placed in the Short Time category. Obviously, this is always acceptable.

6.4.3 Long Time (LT) Type Faults

Single faults placed in the long time (e.g., longer than 500 hours) repair category are termed LT type faults. Based on the requirements given in Section 5, LT faults must not leave the FADEC system in a configuration where the instantaneous LOTC rate is greater than 75×10^{-06} failures per hour. Examples of these faults might be loss of a sensor or any other input or feedback signal for which there is redundancy (or adequate fault accommodation in the case where redundancy is not provided for all electronic elements) - and a suitably low LOTC rate is maintained.

6.4.4 “Applicant Defined Dispatch” or “Engine Manufacturer/Airframer Convenience”

AMC E 1030 and FAA TLD policy memo, introduce a category for failure out of LOTC criteria.

This Engine Control System failures are classified in dispatch category “Applicant Defined Dispatch” (AMC E 1030) or “Engine Manufacturer/Airframer Convenience” (FAA TLD policy memo). These failures have to be assessed for TLD with engineering judgment or with Aircraft MMEL policy when these ones are included in HAZ or CAT Failure conditions as per CS 25.1309.

As prescribed by EASA CM MMEL 001 issued January 21, 2015, the dispatch on these failures must be in a separate section of TLD analysis and are not in TLD approval.

6.4.5 Combinations of Faults and Undetected (UC) Faults

Figure 2 shows a very simplified FADEC system fault configuration diagram which is used for the LOTC analysis. Figure 3A shows Figure 2 expanded into a flow diagram leading to the LOTC state. “Undetected faults” have been added to these diagrams. Undetected faults are faults in the electronic portions of each control channel for which no means of detection or accommodation has been provided. Since these faults are unaccommodated, it is assumed that they would lead to LOTC events. Typical undetected fault rates are between 0% and 5% of the total of both channels (electronic) failure rates. The analysis should provide substantiation for the value used. (It is noted that undetected faults which result in an LOTC event do not remain “undetected” for long. Some prefer classifying these as simply “uncovered” faults.)

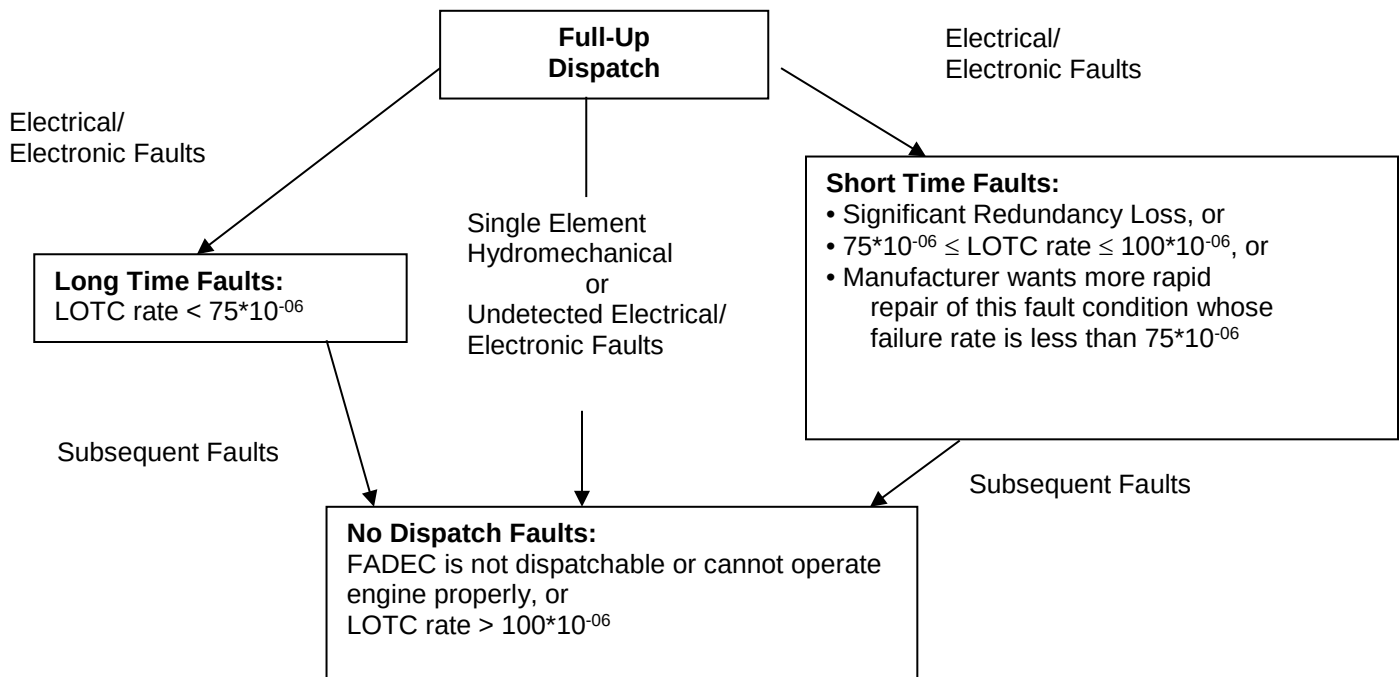


Figure 2 - Simplified FADEC system fault diagram

Figure 3A is not intending to imply that all combinations of ST and LT faults in both channels lead to LOTC events. The analysis has to look at each combination and determine whether they are truly independent and together would lead to an LOTC event. This is the cornerstone of any reliability analysis. The usage of the TLD approach is dependent upon the knowledge that the system has been thoroughly and accurately analyzed for operation with single and combinations of faults - at least to the second fault level. The third fault level does not have to be analyzed if the applicant elects to take the conservative position that all third faults lead to an LOTC event. The analysis will yield the conservative result that the repair intervals will be sooner than those that would have been obtained had third faults been analyzed. Analyzing the combinations of faults is the difficult and tedious part of the analysis, and this is where much of the work is. It should be noted if the analysis is only completed to the second fault level, there will be occasions in service when the FADEC systems are actually dispatched and operated with more than two faults present. However, the likelihood of three or more independent faults occurring within the short or long term repair interval - and still having the control function with no discernible effect - is quite small; therefore, the impact on the fleet average is expected to be negligible. A TLD analysis should include some analysis and documentation to substantiate this assertion.

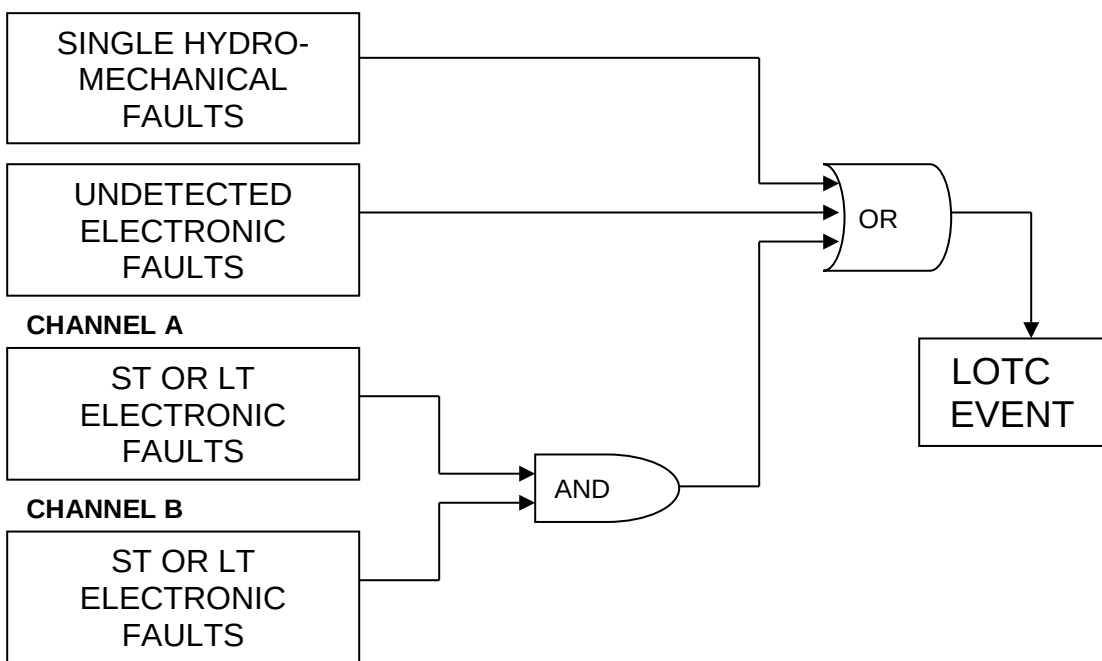


Figure 3A - Simplified flow diagram for FADEC system faults leading to LOTC

6.4.6 Aircraft Related Information

A discussion of the aircraft's MMEL, operator's MEL, dispatch deviation guide (DDG), and maintenance review board (MRB) report; how ND-, ST-, and LT-type faults relate to those documents; how LT faults became a certification maintenance requirement (CMR); and some options for handling LT faults to remove them from the CMR classification is presented in Appendix D.

6.5 Recommendations on Items Considered Part of the FADEC System

The question "What elements of the system are to be included?" is frequently raised relative to LOTC analysis and Time Limited Dispatch. This section addresses that question. The functions of the system, the elements selected for use in the system, and the design implementation all depend on the overall system architecture. In addition, integration between the engine and the aircraft control systems is constantly changing. All of these factors impact the selection of the elements to include as part of the FADEC system. Therefore, the information included in this section does not provide an absolute answer, but is intended to provide a methodology to use in selecting which elements of the aircraft/engine control system should be included in the analysis.

In general, the analysis used to predict the frequency of an LOTC should include all elements in the thrust or power control system that can contribute to an LOTC event. It is the overall LOTC rate for a given engine and aircraft that is relevant to obtaining and maintaining TLD in service.

Since TLD is a benefit to engine manufacturer customers, the engine manufacturer has a vested interest in obtaining TLD for the installed engine control system. Including the required aircraft elements in the analysis allows the engine certification authority visibility of total LOTC rates. Therefore, the engine manufacturers must include the relevant aircraft supplied control elements as part of the engine control system when seeking approval of TLD operations. The engine manufacturer may provide the airframe information by obtaining it from the airframer or by using data from the engine manufacturer's applicable prior history. The overall installed engine LOTC rates will also be reviewed and used by the aircraft certification agency in approving TLD operations for the aircraft.

Note that the LOTC analysis and reporting does not include the details, analysis, and corrective actions associated with basic engine events. And the engine manufacturer is not expected to (1) substantiate any airframer predictions, (2) explain the details of aircraft element failures which contribute to LOTC events, or (3) monitor and manage any resulting changes to the aircraft systems. Hence, the engine manufacturer may not be in a position to provide detailed information on any aircraft element failures which could lead/contribute to LOTC events, even though those aircraft elements are considered part of the engine control system. It is anticipated that when LOTC events occur, the engine manufacturer will be made aware of them. If those events are caused by aircraft elements which are part of the engine control system, the engine manufacturer is expected to coordinate with the aircraft manufacturer to determine whether corrective actions are needed - so that the engine control system can continue to meet its Continued Airworthiness requirements.

In general, the following guidelines apply when selecting the elements to include in the LOTC analysis:

- The LOTC event is related to an engine control failure or malfunction. The engine control system failure may involve aircraft supplied element failures or malfunctions. In some cases, the failure may result in flight crew action to reduce power or thrust, or initiate an engine shutdown.
- All In-Flight Shut Downs (IFSDs) are a subset of LOTC events (see Figure 3B), and all engine control system caused or induced IFSDs and fail fixed rotor speed, thrust or fixed fuel flow conditions are forms of LOTC.
- If a component is part of the control system and its failure or malfunction can contribute to an LOTC event, it should be included in the LOTC analysis.
- If a component is not directly part of the engine control system but has an electrical interface with the EEC, it is a candidate for contributing to an LOTC event and should be considered for inclusion in the analysis.
- If a component is part of the basic engine mechanical system, but not part of the mechanical portion of the engine control system, it is usually not a candidate for an engine control system related LOTC event, and therefore, not included in the engine control system LOTC analysis.
- The FAA TLD policy allows exclusion of the fuel pump from being included as part of the engine control.
- Components to be included are not limited to the redundant electrical parts of the control system.
- If a component can cause an erroneous value to be displayed in the cockpit, and the Installation and Operational Manuals published by the engine manufacturer either direct or advise the crew to shut down the engine or reduce thrust or power, the component should be included in the LOTC analysis.
- LOTC events which directly result from a failure to follow instructions in the manuals published by the Engine Manufacturer are not included in the analysis.
- LOTC events which do not occur during normal operation (operations outside conditions defined in the engine IM or AFM) are not included in the TLD analysis.

Figure 3B attempts to illustrate the concept of selecting the events and causes of the events, and hence, the elements to be included in the TLD analysis.

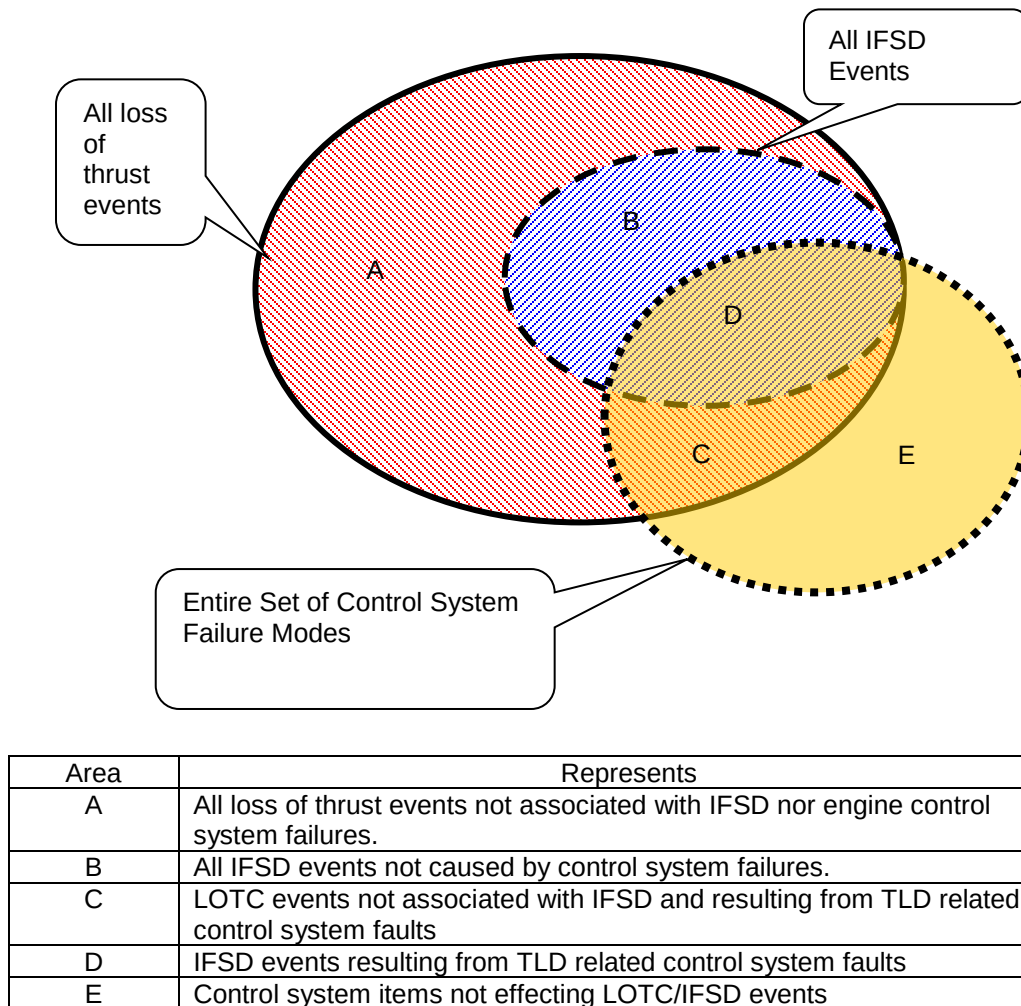


Figure 3B - Illustrations of all LOTIC events, all IFSD events, and engine control system elements involved in a TLD analysis

Figure 3

Figure 3B is intended to provide visibility on what power plant faults have to be taken into account in the TLD analysis. Specifically, LOTIC is a term referring to loss of thrust control events caused only by the Engine Control System.

The envelope shown as “Entire Set of Control System Failure Modes” includes some, but not all, LOTIC events and some, but not all, IFSD events. The subset of those events applicable to TLD that overlap the TLD considerations envelope are shown as areas “C” and “D.” Those LOTIC and IFSD events not applicable to TLD are shown as areas “A” and “B.”

As discussed in 6.3, there are many functions in an EEC system that have no effect on the LOTIC rate of the control. These items have to be given consideration as candidates when completing the task of “considering what items should be in the TLD analysis” to document the fact that they have no impact on the control system’s LOTIC rate. These items are represented by area “E” in Figure 3B. These EEC system functions faults that do not affect LOTIC rate should be clearly identified in the Engine TLD report. These faults could be included in or affect the aircraft level MMEL and be addressed by the airframer.

Table 1 illustrates how to consider all elements of the thrust or power control system, the functions and failure modes associated with the element, and then evaluate if it is or is not part of the TLD restriction envelope depicted in Figure 3B. The table also shows the most likely result of a failure of the element by identifying the applicable area of Figure 3B.

Table 1 - Typical categorization of FADEC system elements

Engine Electrical Control System			
<i>Item</i>	<i>To Be Included</i>	<i>Figure 3B Failure Area</i>	<i>Included Yes/No/If</i>
EEC	Primary engine control providing power setting, fuel flow setting and splitting, engine operability control, and engine limit protection functions.	C or D	Yes
	Auto or continuous ignition may need to be included.	C, D, or E	If
Engine Condition/Health Monitoring	Yes, if impact on LOTC rate.	C, D, or E	If
	No, if no impact on LOTC rate (inspection is presumed to provide adequate analysis).		
Other electronic boxes	Yes, if it has impact on LOTC rate. (If not, area "E.")	C, D, or E	If
	Yes, if it includes processing of signals listed elsewhere that affect LOTC rate. (Area "E" if no effect on LOTC rate.)	C, D, or E	
	Yes, if it includes processing of fault detection and reporting data related to TLD.	C or D	
Ambient temperature and pressure sensors	Yes, for FADEC dedicated sensors. (Unless the system is configured to use the aircraft sensors as primary or only.)	C (possible D)	Yes
Engine operating parameter sensors (pressure, temperature, speed)	Yes, sensors that may contribute to LOTC.	C	If
	No, sensors used only for monitoring; e.g., engine performance monitoring or secondary systems.	E	
Electrical cables, including airframe cables (as appropriate)	Yes, but only for cables that carry a signal applicable to LOTC/IFSD.	C	If
Igniters, ignition exciter, and associated cables	No.	N/A	No
Dedicated EEC alternator	Yes, includes the electrical generation portion of the alternator and any drive shafts/couplings/bearings within the alternator.	C or D	Yes
Alternator Drive Assembly (but not part of alternator)	No.	A or B	No
Cockpit throttle position elements	Yes, for electrical throttle position sensor and aircraft electrical cables connecting the sensor to the EEC.	C or D	Yes
	No, for mechanical parts of throttle system.	A or B	
Aircraft data bus inputs to EEC	Yes, if it can contribute to engine control system caused LOTC.	C	If
Rating, configuration, and thrust trim definition (connectors/boxes)	Yes, if it can contribute to LOTC rate.	C	Yes



Engine Electrical Control System			
<i>Item</i>	<i>To Be Included</i>	<i>Figure 3B Failure Area</i>	<i>Included Yes/No/If</i>
Engine fault detection sensors, conditioners, and computers (e.g., overspeed limiters)	Yes, if effect on LOTC rate and control system operation/maintenance. (Area "E" if no effect on LOTC rate.)	C, D, or E	If
Engine transient performance	Yes, if caused by failure within the control system. No, if caused by engine damage or deterioration preventing it from operating with correctly implemented control limits.	C A	If
Engine transient due to lightning strike	No, if events caused by engine damage due to direct effects or engine surges due to pressure/thermal inlet effects. Yes, if control system upsets caused by EMI, HIRF, or the indirect effects of lightning. This is true during all dispatchable configurations. Control related events must be reported.	A or B	If
Inappropriate pilot commanded shutdown	No	B	No
Aircraft auto throttle or auto thrust system	No	A	No

Fuel System			
<i>Item</i>	<i>Comments</i>	<i>Figure 3B Failure Zone</i>	<i>Included Yes/No/If</i>
Mechanical fuel pump	No, excluded per FAA policy. Considered part of basic engine.	A or B	No
Accessory gearbox elements associated with fuel pump or Metering Unit Drive	No, engine mechanical systems are not considered to be part of the control system.	A or B	No
Fuel Filter Condition sensors	Yes, if fault results in restriction on power setting or time at power.	C	If
Flow meter	Yes, if active part of fuel control.	C or D	If
Fuel metering unit	Yes.	C or D	Yes
Active fuel flow divider valves	Yes, assumes fault results in restriction on power setting or time at power. Active refers to any valves that are controlled by the FADEC to divide or stage flow to the burner.	C or D	Yes
Combustor flow control	Yes, assumes fault results in restriction on power setting or time at power.	C or D	Yes
Other fuel actuated control units	Yes, if unit associated with the control of any function listed elsewhere as applicable.	C or D	If
Fuel nozzles and fuel lines	No, considered part of basic engine.	A or B	No
Fuel temperature or pressure sensors	Yes, if the fault results in restriction on power setting or time at power.	C	If
Fuel lines, manifolds, etc.	No, considered part of basic engine. Fixed position flow distribution or pressure modification devices within the manifolds are included in the same category as fuel lines and manifolds.	A or B	No



Variable Geometry and Bleed Systems			
Item	Comments	Figure 3B Failure Zone	Included Yes/No/If
Compressor Variable Stator Vane Actuators and position sensors	Yes, assumes fault can impact engine performance to cause a LOTC. Actuator means the device that receives the air or fuel muscle to position the loop.	C or D	Yes
Variable (Bleed) actuators and position sensors	Yes, assumes fault can impact engine performance to cause a LOTC. Actuator means the device that receives the air or fuel muscle to position the loop.	C or D	Yes
Variable Stator Vane and Bleed Actuation System Unison Rings, links, clevis, vane bearings, etc.	No, defined as all mechanism(s) connecting the control actuator mechanical output to the variable position air flow device.	A or B	No
Air bleed valves (transient or start)	Yes, assumes fault results in reduction in power or a restriction on power setting or time at power.	C	Yes
Pneumatic and hydraulic servo lines used to provide force to position valves, actuators, etc.	Yes, tubes and hoses which provide pneumatic or hydraulic pressure used to position valves and actuators, assuming that mis-positioning of these valves or actuators could result in an LOTC.	C	Yes

Engine Oil/Lubrication System			
Item	Comments	Figure 3B Failure Zone	Included Yes/No/If
Oil tanks and lines	No.	B	No
Mechanical Oil Pumps	No.	B	No
Electronic Debris sensors and conditioners	No, assumes there is no control-initiated input to power setting.	N/A or E	No
Filter condition sensors	No, assumes there is no control-initiated input to power setting.	A, B, or E	No
Temperature and pressure sensors	Yes, if there is control-initiated input to power setting or if a control system fault leads to erroneous indication which the Engine Operating Instructions would require the pilot to reduce power.	C or D	If

Aircraft Interfaces			
Item	Comments	Figure 3B Failure Zone)	Included Yes/No/If
Vibrations sensors and conditioners	No, assumes there is no control-initiated input to power setting. Yes, if a control system fault leads to erroneous indication which the Engine Operating Instructions would require the pilot to reduce power.	A C or D	No If
Engine performance/ health monitoring sensors wired direct to cockpit	No.	A	No
Aircraft Power	Yes, if the failure of aircraft power can affect LOTC rate.	C or D	If



Propulsion System and Installation			
<i>Item</i>	<i>Comments</i>	<i>Figure 3B Failure Zone</i>	<i>Included Yes/No/If</i>
Basic engine turbo-machinery	No.	A or B	No
Engine Operability or Performance	No, includes thrust loss due to engine deterioration, surge, and reduction of power required to stay within limits. Yes, if a surge results in engine power fluctuations and that surge would have been prevented by a properly functioning control system, or was caused by an improperly functioning control system.	A or B	If
Thrust reverser position sensors	Yes, if a failure of a thrust reverser position sensor can result in a change in thrust setting (e.g., selection of idle thrust).	C	If
Thrust reverser actuation and control systems	No, if fault results in inability to deploy or stow the reverser but does not restrict engine power setting. Yes, if the engine does not provide commanded thrust.	N/A C	No Yes
Engine anti-icing sensors, controllers, and control valves	Yes, if these elements are used within the engine control system for automatic engine internal anti-icing.	C	If

Propulsion System & Installation			
<i>Item</i>	<i>Comments</i>	<i>Figure 3B Failure Zone</i>	<i>Included Yes/No/If</i>
Sensors, cables, or signal processing elements for aircraft electric or hydraulic power	No	A	No
Cockpit display signals	Yes, if erroneous display can lead to flight crew initiated thrust reduction or IFSD; e.g., incorrect rotor speed or EGT displayed. No, if only informational (e.g., fuel flow).	C or D E	If
Cockpit Display Systems	No, cockpit display systems are not considered part of the engine control system.	A or B	No
Aircraft Bleed Extraction	No.	A	No

Engine Configuration			
<i>Item</i>	<i>Comments</i>	<i>Figure 3B Failure Zone</i>	<i>Included Yes/No/If</i>
Brackets/clamps mounting bolts, seals, etc. associated with elements listed as applicable	No.	N/A	No
Thermal shields and insulation blankets	No.	A or B	No



Engine Configuration			
<i>Item</i>	<i>Comments</i>	<i>Figure 3B Failure Zone</i>	<i>Included Yes/No/If</i>
Pneumatic lines to sensors	Yes, if fault detection and accommodations can result in an LOTC.	C or D	Yes
Powerplant sensors which communicate directly with the aircraft and do not communicate with the EEC	No.	B	No

Items Unique to General Aviation Applications or Rotorcraft			
<i>Item</i>	<i>Comments</i>	<i>Figure 3B Failure Zone</i>	<i>Included Yes/No/If</i>
Collective Compensation Input	Yes, for electrical compensation sensor and associated electrical cables.	C	Yes
	No, for mechanical parts of the compensation system.	N/A	No
FADEC back up battery	Yes.	C or D	Yes
Torque Sensor	Yes, if the system has torque control or limiting.	C	If
Turbine temperature sensing system	Yes, if system has temperature limiting or OEI limiting, or pilot reduces power due to false (high) indication.	C	If

6.6 Recommendations on In-Service LOTC Reporting

After TLD approval is obtained and field experience is achieved, the FAA policy requires reporting of the field experience to provide continuing validation of the TLD analysis, identification of emerging trends that require field action, component redesign, etc. As part of this reporting process, the engine manufacturer should collect the data for all LOTCs that occur on an installation, including any that are caused by aircraft systems.

Only actual LOTC events shall be counted for reporting relative to the allowable event numbers provided in the FAA policy. Some failures occur without an LOTC that are identified by system fault detection. Corrective action is taken before an LOTC event has occurred. If those same failures had occurred at a different engine operating condition, an LOTC may have occurred. Since there was no LOTC, none is reported against the allowable number of events criteria. However, the TLD analysis related to these failures should be reviewed to determine if appropriate failure rates for the failures was used in the analysis. Even though it may not have caused an LOTC event, if the failure rate for the in-service faults and their effect on the LOTC rate is considerably greater than the one used in the TLD analysis, corrective action should be considered. Corrective actions may involve a greater restriction on the time allowed for operating with faults that contribute to the failure mode of concern, or redesign and replacement of the parts involved to achieve the desired design reliability for those components.

7. CALCULATION APPROACHES - SINGLE ENGINE ANALYSIS

7.1 A Simple Time-Averaging Approach

Note that the terminology "fleet average" is used synonymously with "time-weighted average." This is appropriate because any given engine may have more or less ST and/or LT faults than the expected number, but these guidelines are intended for use in a large fleet of engines where all possible single faults will occur at or close to their expected rates, and if all faults are allowed to remain in the system for the maximum approved number of hours before repair is accomplished, the LOTC rate of the control will approach the expected value. It is recognized that in practice, many faults are repaired sooner than the maximum allowed time; therefore, the fleet averaged LOTC rate may be quite a bit lower than the expected value.

A simple "time-weighted-averaged (TWA) LOTC rate" is one wherein the LOTC rate is determined as the sum of (1) the hydromechanical/mechanical failures, (2) the undetected faults, and (3) a time-weighted-average value of the FADEC system's dual channel, electrical/electronic failures. The failures and failure rates leading to an LOTC event are shown graphically in Figure 4.

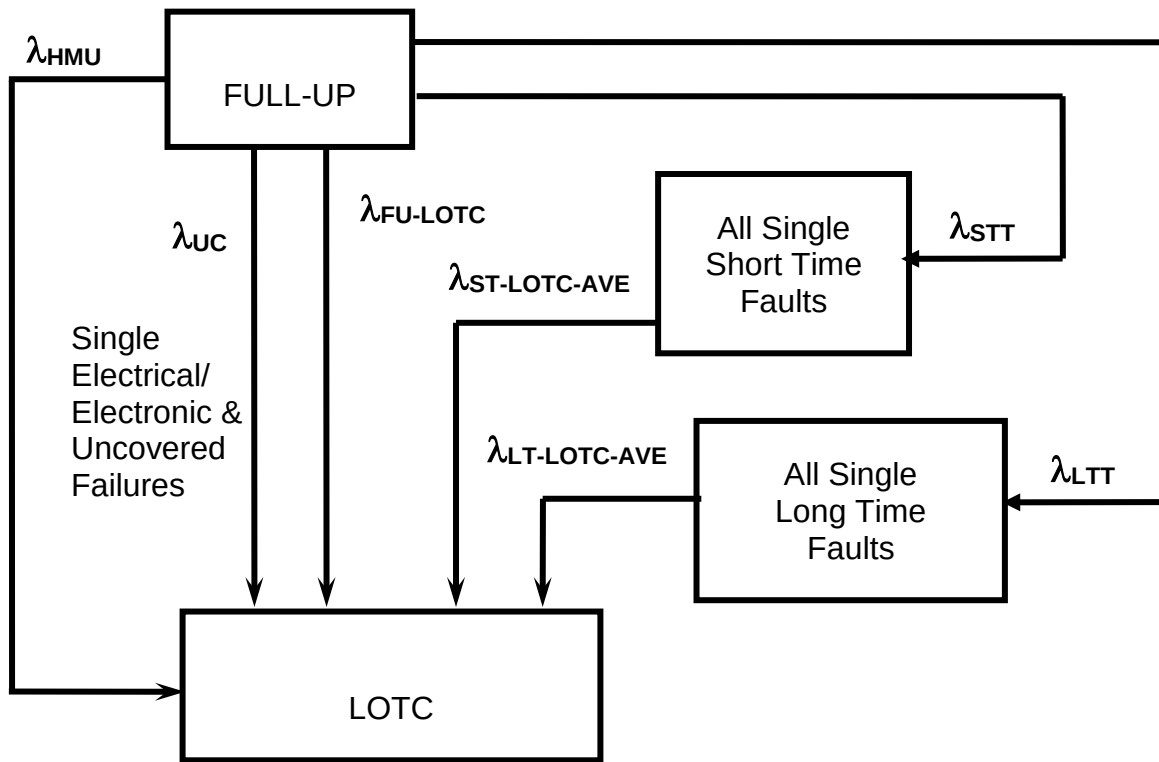


Figure 4 - A graphical representations of the failure paths of a simple FADEC system that lead to LOTC

The TWA failure rate for the dual channel electronic failures is determined as the sum of single hydromechanical and undetected electrical/electronic failures that lead directly to an LOTC event plus the percentages of time spent in a given operating configuration multiplied by the average LOTC rate of that configuration. Hence, the fleet TWA LOTC rate for a simple FADEC system is given as:

$$\lambda_{\text{LOTC-AVE}} = \lambda_{\text{HM+UC}} + \lambda_{\text{FU-LOTC}} * \text{Fract}(\text{FU}) + \lambda_{\text{ST-LOTC-AVE}} * \text{Fract}(\text{ST}) + \lambda_{\text{LT-LOTC-AVE}} * \text{Fract}(\text{LT}) \quad (\text{Eq. 1})$$

where: $\lambda_{\text{HM+UC}} = \lambda_{\text{HMC}} + \lambda_{\text{UC}}$

λ_{HMC} represents the sum of the rates of all single mechanical/hydromechanical faults which lead to LOTC events.

λ_{UC} represents the sum of the rates of all undetected/uncovered electrical/electronic faults assumed to lead to LOTC events.

$\lambda_{\text{FU-LOTC}}$ is the (average) failure rate from the full-up configuration to the LOTC state caused by failures in the redundant portions of the electronic control system, in one flight. (Single electrical/electronic failures that lead to an LOTC event are contained in λ_{UC} , which is described below.)

$\lambda_{\text{ST-LOTC-AVE}}$ is the average failure rate of the system due to a second electrical/electronic fault when operating in an ST fault dispatch configuration.

$\lambda_{\text{LT-LOTC-AVE}}$ is the average failure rate of the system due to a second electrical/electronic fault when operating in an LT fault dispatch configuration.