Flight Operations Briefing Notes

Supplementary Techniques

Handling Engine Malfunctions

I Introduction

The failure rate of aircraft engines has reached an all-time low. This means that many flight crews will never face an engine failure during their career, other than those in the flight simulator.

However, simulators are not fully representative of engine failures because accelerations (e.g. due to a failed engine), noise (e.g. caused by an engine stall), or vibrations (e.g. in the event of a blade rupture) are hard to simulate.

Consequently, flight crews are not always able to identify and understand engine malfunctions. Incorrect crew understanding of engine malfunctions can lead to unnecessary engine shutdowns, but also to incidents and accidents.

The objective of this Flight Operations Briefing Note is to:

- Provide basic guidelines to identify engine malfunctions
- Give typical operational recommendations in case of engine malfunctions.

II Statistics – Background Information

When the jet engine was introduced in civil aviation in the 1950s (de Havilland Comet, Sud-Aviation Caravelle), the available thrust was less than 10,000 lbs.

Today, high by-pass ratio engines produce up to 115,000 lbs of thrust.

During the same time, the rate of In-Flight Shut Downs (IFSD) has decreased as follows:

	IFSD (per 100,000 engine FH)
1960s	40
Today	Less than 1

(Source: AIA/AECMA Project Report on Propulsion System Malfunction + Inappropriate Crew Response, November 1998)

Figure 1

In-Flight Shut Down Rate

In other words:

- In the 1960s, in average each engine failed once a year
- Today, in average, each engine fails every 30 years.

This improvement in the rate of IFSD has allowed the introduction of ETOPS (Extended Twin Operations) in 1985. Among other criteria, to be approved for ETOPS 180, the rate of IFSD must be less than 2 per 100 000 engine flight hours.

This also means that pilots that start their career today will probably never experience an IFSD due to an engine malfunction.

However, despite the significant improvement in engine reliability, the number of accidents (per aircraft departure) due to an incorrect crew response following an engine malfunction has remained constant for many years. This prompted a study with all major industry actors involved (aircraft and engine manufacturers, authorities, accident investigation agencies, pilot organizations).

Among the results were:

- The vast majority of engine malfunctions are identified and handled correctly. However, some malfunctions are harder to identify
- Most crews have little or no experience of real (i.e. not simulated) engine malfunctions
- Simulators are not fully representative of all malfunctions
- Training does not sufficiently address the characteristics of engine malfunctions.

The following crew undue actions, caused by engine malfunctions, have been observed:

- Loss of control (trajectory not adapted to the engine failure)
- Rejected takeoff above V1

- Shutdown of the wrong engine
- Unnecessary engine shutdown
- Application of the wrong procedure / Deviation from the published procedure.

III Engine Parameters

III.1 Primary Engine Parameters

The primary engine parameters are permanently displayed on the Engine and Warning Display (EWD), or on the center panel (A300/A310). These parameters are (**Figure 2**):

- EPR (Engine Pressure Ratio) and/or N1 (Fan speed) as applicable
- N2 (and N3 for RR engines): High Pressure Compressor rotor speed
- EGT: Exhaust Gas Temperature.

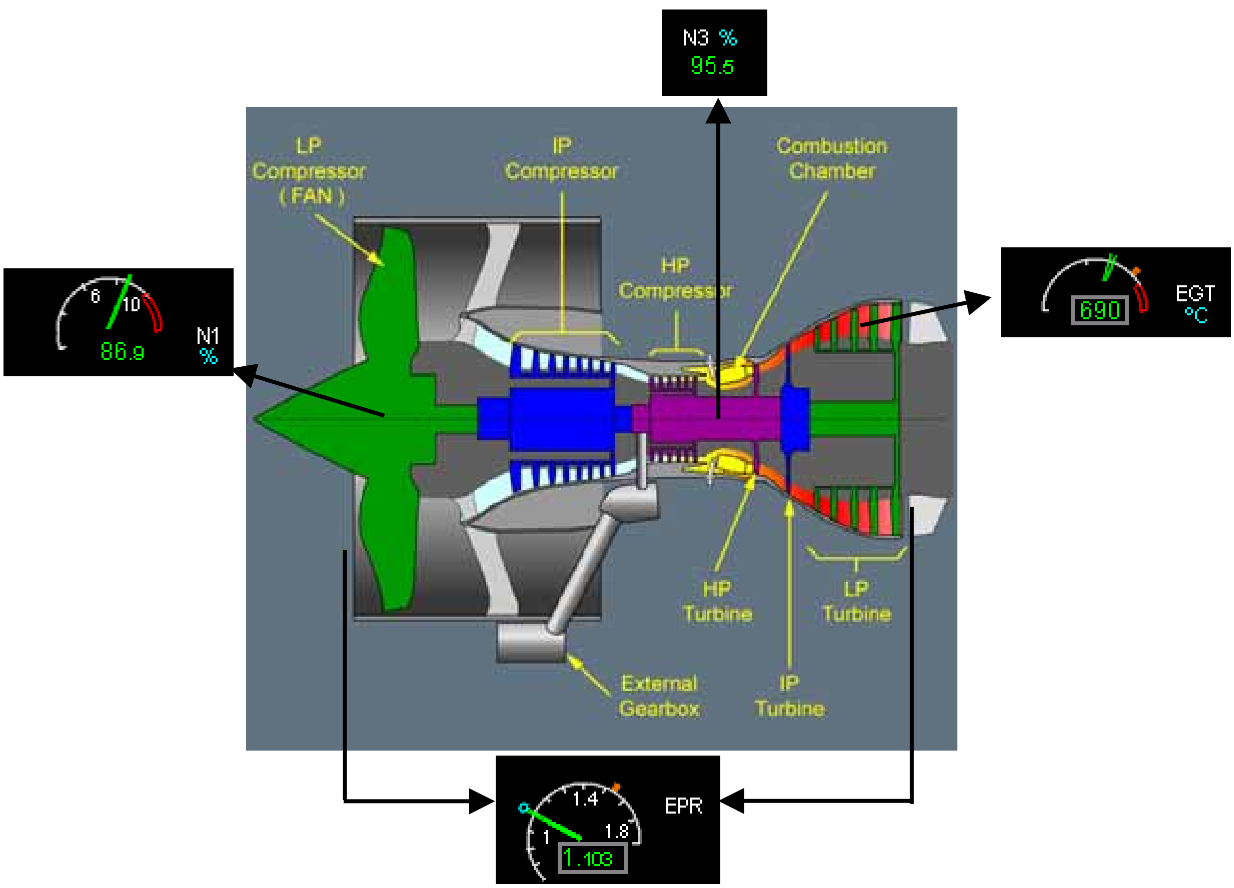

Figure 2

Main Engine Parameters (Rolls-Royce Engine Example)

EPR / N1

EPR and N1 are both representative of the engine thrust. Consequently, depending on the engine type, either N1 or EPR is used as the primary thrust parameter (when EPR is the primary thrust parameter, N1 is used as a backup).

Note:

On the A380, a new parameter called THRUST provides an easy interpretation of available thrust (0% = windmiling thrust; 100% = TOGA thrust (bleeds off), whatever the external conditions (temperature and altitude))

A low EPR (or N1) can be the sign of an engine flameout.

Rapidly fluctuating EPR (or N1) can be the sign of an engine stall.

N2 (or N3 for RR engines)

The N2 (or N3 for RR engines) is used to monitor the engine start/relight sequence.

Rapidly fluctuating N2 (or N3) can also be the sign of an engine stall.

EGT

A high EGT can be the sign of:

- An ageing engine
- An engine stall
- A tailpipe fire
- An engine failure.

III.2 Secondary Engine Parameters

The other engine parameters are fuel flow, engine vibrations, oil quantity/temperature/ pressure, and nacelle temperature.

Fuel Flow is usually displayed with the main engine parameters on the EWD or on the center panel.

The other secondary engine parameters are displayed on the ECAM System Display (SD), on the center panel, or on the Flight Engineer's station. These parameters (in particular oil pressure and temperature) should be monitored throughout the flight, amongst others, during the periodic cruise check.

On all Airbus aircraft (except the A300 B2/B4), when a parameter drifts out of its normal range, the Engine SD will be automatically displayed and the parameter will pulse (in green). This is referred to as an ECAM advisory.

IV Identifying Engine Malfunctions

Most engine malfunctions can be easily identified, thanks to dedicated warnings/cautions or indications. However, some malfunctions are harder to identify, and require some flight crew knowledge, in order to properly understand and handle them.

IV.1 Engine Fire

An engine fire is easy to identify, and is also sometimes referred to as an "external fire", or "nacelle fire" because it occurs inside the engine nacelle but out of the engine core and gas path.

An engine fire can occur at any time, both on ground and in flight.

It is usually due to inflammable fluid coming into contact with very hot engine parts, such as the compressor, turbine or the combustion chamber casings. This can be caused by:

- Leaks
- The rupture of a pipe (e.g. caused by the rupture of a rotating part of the engine)
- A damage affecting the accessory gearbox
- The rupture of the combustion chamber, that can lead to a torch flame.

When the inflammable fluid comes into contact with the hot engine parts, the fire will auto-ignite. These inflammable fluids are:

- Fuel (Auto inflammation at 230°C)
- Oil (Auto inflammation at 260°C)
- Hydraulic Fluid (Auto inflammation at 450°C).

Engine fire detection is based on temperature sensors (loops) located in sensitive areas around the engine and in the pylon (**Figure 3**). This location differs for each engine type, based on the engine's characteristics.

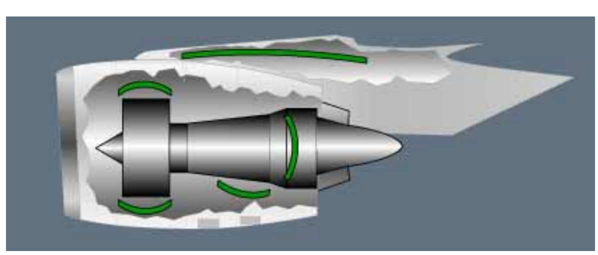

Figure 3

Typical Fire Detection Sensors (Loops) Location

The fire detection sensors are on two identical fire detection loops.

When an engine fire is detected, a warning triggers. The procedure requests to:

- Shut down the engine
- Isolate the engine with the ENG FIRE pushbutton/handle (shuts hydraulic, pneumatic and fuel lines, disconnects electric power)
- Discharge the fire agents.

Note:

The principle of the engine fire detection also means that spurious fire warnings can be triggered if hot air is blown on the fire detection loops (e.g. hot bleed air duct rupture, or combustion chamber cracks).

As long as the engine fire is detected, apply the ENG FIRE procedure.

If an engine fire occurs during takeoff or go-around, the PF shall first establish and stabilize the aircraft on a safe climb path and then proceed with the ENG FIRE procedure.

IV.2 Engine Tailpipe Fire

Contrary to the engine fire, the engine tailpipe fire is harder to identify, and is sometimes confused with an engine fire. It is also referred to as an "internal fire" (i.e. located in the gas path).

A tailpipe fire will only occur on ground, during engine start or engine shutdown.

It is due to an excess of fuel in the combustion chamber, the turbine or the exhaust nozzle, that ignites. It can result in a highly visible flame coming from the exhaust, or in some smoke coming out of the engine (exhaust or inlet).

Figure 4

Engine Tailpipe Fire

Whereas the tailpipe fire can be very spectacular, it usually has very little impact on the engine. Indeed, it occurs in a part of the engine that is designed for very high temperatures (1000 to 1200°C). However, it can have an impact on the aircraft itself (e.g. damage to the flaps).

In the event of a tailpipe fire, there is no cockpit alert. The only indication may be a rising EGT, due to the fire in the turbine. Therefore, tailpipe fires are more often visually detected by cabin crew, ground crew or ATC. However, because cabin crew, ground crew, or ATC usually do not know the difference between an engine fire and a tailpipe fire, they usually report an engine fire to the flight crew. As a consequence, the flight crew often applies the engine fire procedure, instead of the engine tailpipe fire procedure.

The engine tailpipe fire procedure requests to:

- Shut down the engine in order to stop the fuel flow
- Dry crank the engine to remove the remaining fuel.

Do not use the ENG FIRE pushbutton (except for A300/310) or the AGENT DISCH pushbuttons because:

- Pushing the ENG FIRE pushbutton will cut the FADEC power supply. This prevents the dry crank sequence, which is the only effective action against a tailpipe fire
- The fire agents will be discharged outside of the engine core, in a part of the engine that is not affected by the tailpipe fire (**Figure 5**). Discharging the fire agents will have no negative impact on the engine, but may lead to delays or cancellation, if no fire extinguisher bottle spare is available.

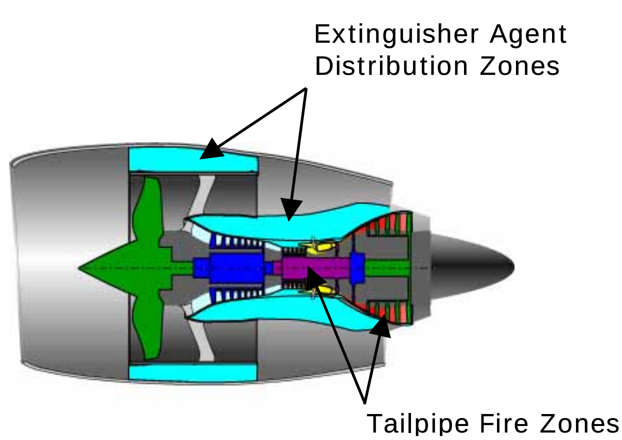

Figure 5

Tailpipe Fire Zones

The engine tailpipe fire procedure should be sufficient to stop the fire. The intervention of the fire brigade should therefore be a last resort (or if no bleed is available to dry crank the engine), because the ground fire extinguishing agent can cause serious corrosive damage. Following the use of ground fire extinguishers, maintenance action is due (the engine might be removed for a maintenance inspection).

In-service events show that engine tailpipe fire may lead to a precautionary, but unwarranted, emergency evacuation.

IV.3 Engine Stall

An engine stall (also called engine surge) is in fact a compressor surge that can be caused by:

- An engine deterioration (e.g. compressor blade rupture, or high wear)
- Ingestions of foreign objects (e.g. bird ingestion) or ice
- A bleed system malfunction
- A malfunction of the engine controls: Fuel scheduling or surge protection devices.

In a jet engine, air compression is achieved aerodynamically, as the air passes through the stages of the compressor. If the air flowing over a compressor blade stalls, the airflow is disrupted, and the compressor can no longer compress the incoming air. The high-pressure condition existing behind the stalled area may create a flow reversal towards the compressor air inlet, thus resulting in an immediate and large thrust loss.

During takeoff and high power settings, the engine stall is characterized by:

- One or more loud bangs
- Instant loss of thrust, resulting in a yaw movement
- Engine parameter (EPR/N1, N2 (or N3)) fluctuations and EGT increase
- Visible flames from the inlet and/or from the tailpipe.

(Source: FAA video Turbofan Engine Malfunction Recognition and Response)

Figure 6

Engine Stall at Takeoff

Flight crews who have experienced an engine stall at takeoff report that the bang is louder than any other noise they had previously heard in the cockpit. It is often compared to a shotgun being fired a few meters away.

Because of the noise and yaw movement of an engine stall, flight crews sometimes incorrectly identify the occurrence as a tire burst, or as a bomb. In-service events show that a misinterpretation of an engine stall may result in rejecting the takeoff above V1, causing a runway overrun.

At low power (e.g. at thrust reduction at top of descent), the engine stall is characterized by:

- One or more muffled bangs
- Engine vibrations
- Engine parameter fluctuations and EGT increased.

An engine stall can result in an EGT overlimit condition because the airflow downstream of the combustion chamber is not sufficient to ensure the cooling of the turbine.

Engine stalls are harder to detect at low power.

The engine stall can be:

- Recoverable without crew action
- Recoverable with crew action (or FADEC action)
- Not recoverable.

Recoverable stall without crew action

One or more loud bangs can be heard; the parameters fluctuate but quickly return to normal. In most occurrences, the parameters are back to normal when the flight crew checks the engine parameters. Consequently, it is hard to determine which engine has stalled.

Engine operation can be checked by smoothly moving the thrust levers, one at a time, to check the related engine response and stall-free operation.

Note that most recent engines include a stall detection system.

Flight crews should report the occurrence for immediate maintenance action.

Recoverable stall with crew action (or FADEC action)

Parameter fluctuations and bangs continue as long as the flight crew (or the FADEC) does not retard the thrust lever, as per the ENG STALL procedure of the QRH or the ECAM.

If the stall disappears at thrust reduction and the engine parameters are normal, the flight crew can advance the thrust levers slowly, as long as the stall does not reoccur.

If the stall reappears, keep the engine thrust below the stall threshold.

Flight crews should report the occurrence for immediate maintenance action.

Non recoverable stall

One or two bangs are heard and the engine will decelerate to zero power, as if the fuel had been cut-off.

Bring the affected engine thrust levers to idle and shutdown the engine.

A non-recoverable stall can be accompanied by severe engine damage, if it is not identified and corrected by the flight crew, and may lead to an engine failure.

IV.4 Engine Flameout

The combustion process has stopped. This can be due to many reasons such as:

- Fuel starvation
- Volcanic ash encounter
- Heavy rain/hail/icing
- Engine stall
- Control system malfunction

Flying at high speed and low engine thrust through heavy rain or hail increases the risk of flameout.

The engine flameout will trigger a caution on the ECAM (if applicable).

When no caution is available, an engine flameout is detected by:

- A rapid decrease in EGT, N2 (N3 on RR engines), Fuel Flow, and N1
- The loss of the associated electrical generator.

On most FADEC equipped engines, continuous ignition will be automatically selected when a flameout is detected. This ensures an automatic relight, if conditions permit.

IV.5 Engine Vibrations

Engine vibrations may be caused by:

- Engine unbalance
- Birdstrike or FOD causing blade deformation (**Figure 7**)
- Compressor blade loss
- Icing conditions (ice may build up on the fan spinner and blades).

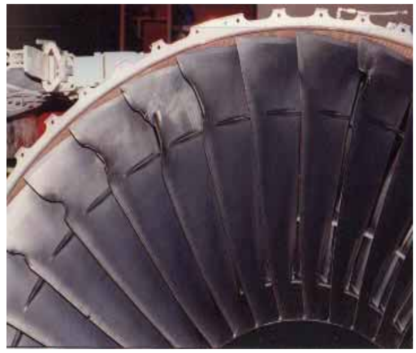

Figure 7

Fan Damage After a Birdstrike

In case the vibration level exceeds a certain level, the ECAM advisory function (if applicable) will automatically highlight the affected engine.

When such a level of vibration is reached, there is potentially a loss of some mechanical integrity of the engine (blade rupture, imbalance, …).

As a general rule, it is recommended to:

- Crosscheck the affected engine parameters (N1, N2, EGT, Oil press…) with the other engine(s)
- Reduce the thrust level of the affected engine below the advisory level if flight conditions permit.

A high N1 vibration level may be accompanied by perceivable airframe vibration.

A sudden increase of the vibration level indicates a possible deterioration of the engine. During takeoff, the vibration indication should be stabilized once takeoff thrust is set. If the advisory threshold is reached, a low speed rejected takeoff may be considered.

The vibrations should not vary significantly during the takeoff roll. If it suddenly increases significantly, a rejected takeoff may be considered depending on the circumstances.

Vibrations alone should not lead to an in-flight shutdown.

IV.6 Engine Parameter Overlimits (N1, N2, N3, EGT)

EGT Exceedance

The EGT redline is the only redline that can be exceeded occasionally without any malfunction of the engine.

Due to the thermal inertia of the engine, the EGT reaches a peak at the end of the takeoff roll, close to rotation or just after lift-off. The difference between the maximum permissible EGT (red-line) and the peak EGT during takeoff (with TOGA thrust) is called the EGT margin. This EGT margin should be monitored by a dedicated engine monitoring program.

As the engine ages, due to normal engine wear, the EGT margin will get smaller (**Figure 8**). Indeed, due to a loss of efficiency, the engine will burn more fuel, which will lead to a higher EGT. Consequently, the EGT margin is used as a parameter to monitor the engine's health.

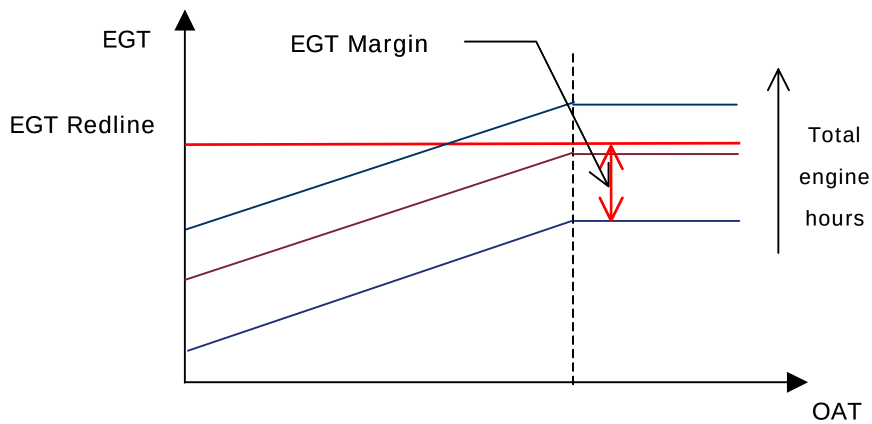

Figure 8

Evolution of the EGT with OAT and Engine Wear

The outside conditions also have an impact on the EGT.

This means that, exceptionally, the engine may exceed the EGT redline without any failure. In this case, the engine continues to deliver its thrust. Consequently, if the flight crew notices an EGT exceedance during the takeoff roll, the flight crew continues the takeoff and establishes the aircraft on the initial climb path, before applying the procedure.

Note:

A limited number of small EGT exceedances may be allowed (as per the Aircraft Maintenance Manual), but must be reported in the logbook.

However, if the EGT suddenly increases when setting takeoff thrust, it is most likely the symptom of a severe engine failure.

N1, N2, N3 Exceedance

N1, N2, N3 exceedances correspond to a malfunction of the engine.

The associated procedure is usually to reduce thrust to return below the limits, and to shutdown the engine if it is not possible to return below the limits, or depending on the level of exceedance.

IV.7 Oil Low Pressure / Oil Low Level

In service experience shows that some rejected takeoffs and in-flight shutdowns have been commanded because of a low oil level. However, a low oil level alone is not a symptom of an engine malfunction.

On the other hand, a low oil pressure is the sign of an imminent engine failure. Therefore, the published procedure must be applied.

IV.8 Reverser Unlocked

The full deployment of a thrust reverser in flight is a potentially catastrophic situation, which can lead to the loss of control of the aircraft.

Therefore, the system is designed with adequate redundancy to ensure that the reversers will deploy on ground only. There are three lines of defense (the details may vary with aircraft and engine type) which:

- Lock the thrust reverser in the stowed position (with primary and secondary locks)
- Isolate the thrust reverser deployment system.

However, should a reverser be out of its fully stowed position, a REV UNLOCKED alert will trigger:

- The first action is to reduce the thrust of the affected engine to idle (even if already automatically reduced), and the aircraft speed (if applicable). This minimizes the effect of a potential deployment. The affected engine must remain at idle for the rest of the flight (i.e. even in the absence of buffet)
- The detection of buffet is the sign that the thrust reverser is at least partially deployed. If detected, the flight crew should reduce the aircraft speed, and shut down the affected engine.

V Operational Recommendations

This section provides flight crews with an overall awareness and understanding of the main strategies to adopt in the case of an engine malfunction:

- Stabilize the aircraft trajectory
- Positively identify the affected engine, and the malfunction
- Apply the published procedure.

It also provides guidelines on the prevention of unnecessary in-flight shutdowns, while confirming the flight crew's authority to take a precautionary decision/action, depending on prevailing conditions.

Fly the Aircraft, not the Engine

Fly, Navigate, Communicate and Manage – in that order, as fostered by the Airbus Operational Golden Rules.

This also applies in case of any engine malfunction. The priority is to stabilize the aircraft trajectory before taking any action on the engine. Even in case of an engine fire, stabilizing the aircraft trajectory before applying the associated procedure may lead to further engine damage but will not affect safety.

The engines are certified in extreme conditions, in order to provide enough reaction time to the crew to stabilize the aircraft, in case of a major engine malfunction, prior to performing the associated procedure.

For example, the engine's resistance to bird ingestion is tested. In accordance with the FAR 33's requirements, an engine at takeoff thrust must be able to withstand the strike of a 3.65 kg bird, without catching fire, without releasing hazardous fragments through the engine casing or without losing the ability to be shut down. It must also be able to withstand the simultaneous ingestion of several (up to 4) smaller birds (around 1kg), without losing more than 25% of thrust.

Similarly, during certification, the engine must be run during 5 minutes, with N1 and N2 (N3 if applicable) at the red line, and EGT 42°C above the red line. Following this run, the engine must be serviceable.

(Source: FAA video Turbofan Engine Malfunction Recognition and Response)

Figure 9

Engine Certification Tests

No RTO above V1

In line experience shows that engine malfunctions during takeoff occasionally lead to rejected takeoffs above V1, which have caused runway excursions, ranging from incidents to fatal accidents/hull losses.

The most frequent cause of rejected takeoff above V1 is the engine stall. The flight crew is usually startled by the loud bang and the yaw movement, and consequently believes the aircraft is not airworthy. In all the reported cases, the aircraft actually was fit to fly.

Similarly, engine fire warnings have also led to rejected takeoffs above V1.

From a system point of view, the engine is certified to ensure that it can sustain an engine fire for a few minutes without affecting the safety of the aircraft. From a performance point of view, engine failure at or after V1 is taken into account in the takeoff performance computation. However, in many engine failure cases, the engine is still able to deliver some thrust during a significant period of time.

If not sure which Engine is malfunctioning, keep-it running

Several accidents or incidents have been caused by a rushed decision to shutdown an engine, due to the inability to correctly assess which engine was malfunctioning.

If the analysis of the instruments is not enough, the crew should smoothly move the thrust levers and check the proper variation of the engine parameters.

If possible, keep the Engine running

In-service experience shows that, when the flight crew notices a drift of the engine parameters (EGT, vibrations, advisory level, etc…), they often decide to perform a preventive engine shutdown.

However, unless a procedure requires an engine shutdown, it is usually preferable to keep the engine running.

Even at idle, the engine:

- Provides electric, hydraulic and bleed power redundancy
- Produces less drag than a windmilling engine.

An ECAM advisory (if applicable) is an indication that a parameter is still in its normal range but is drifting away. It is meant for crew awareness (attention getter) and monitoring. The guidelines associated to the advisory conditions are provided in the FCOM/QRH. Consequently, except for engine vibrations, no action should be taken based only on the advisory.

If possible, restart the Engine

If the engine has failed or flamed out, and there is no indication of engine damage, it is always possible to attempt to restart the engine.

Engine damage can be suspected if some of the following symptoms are observed:

- Rapid increase of EGT above the red line
- Important mismatch of rotor speeds (N1 vs. N2 or N3) or absence of rotation
- Abnormal oil pressure/temperature
- Loud noise
- Fumes or burning smell in the cabin.

If a visual check is possible, the crew should look for damage to the engine cowling or aircraft structure, or missing engine parts.

VI Summary of Key Points

- During their career, most pilots will experience engine malfunctions, but most of them will never encounter a severe engine malfunction leading to an in-flight shutdown
- Reported in-service events show that incorrect crew response to an engine malfunction has remained constant for many years
- Full flight simulators are very powerful training tools but are not fully representative of engine malfunctions and their consequences.

Therefore, to safely and efficiently manage engine malfunctions, flight crews should:

- Stabilize the aircraft trajectory before dealing with the malfunction
- Never rush to shutdown the affected engine during critical flight phases: Engines have been certified in extreme conditions
- Know how to identify various engine malfunctions and their consequences.

Any engine malfunction should be reported to the maintenance.

Airlines should consider the various references provided by the manufacturer's operational documentation and by the industry to address, at all stages of the training, engine related indications and their relation to engine malfunctions.

VII Associated Flight Operations Briefing Notes

The following Flight Operations Briefing Notes provide expanded information on:

- **Operations Golden Rules**
- **Birdstrike Threat Awareness**
- **Volcanic Ash Awareness**
- **Revisiting the Stop or Go Decision**

VIII Airbus References

- Flight Crew Operating Manuals (FCOM) – Abnormal and Emergency Procedures – Power Plant
- A300-600/A310 FCOM Bulletins - Preventing Unnecessary In-Flight Shutdowns
- A330/A340 FCOM Bulletins - Preventing Unnecessary In-flight Shutdowns
- A320 Family & A330/A340 Family & A380 Flight Crew Training Manuals (FCTM) – Abnormal Operations

IX Additional Reading Materials / Website References

- Flight Safety Digest November-December 1999 - Propulsion System Malfunction Plus Inappropriate Crew Response (PSM+ICR)
- Flight Safety Digest March 2001: Understanding Airplane Turbofan Engine Operation Helps Flight Crews Respond to Malfunctions

  Note: These documents can be found on the Flight Safety Foundation website: ***http://www.flightsafety.org/ao_home.html***.

- FAA Training Material (Video) – Engine Malfunctions, Recognition and Response

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