Engine Failure Analysis : A New Paradigm

The Boeing QRH includes revised condition statements in the Engine Failure Checklists (**Engine Fail**, **Stall/Lim/Surge** and **Severe Damage/Separation**) that indicate a fundamental change in the assessment of the appropriate NNM checklist for certain engine failures. The premise behind these changes is effectively that **the actioning memory items at 400 ft after an engine failure will only be required when absolutely necessary.** Typically this means when an engine is both (a) still running; and (b) malfunctioning to the degree where aircraft flight path stabilisation is affected.

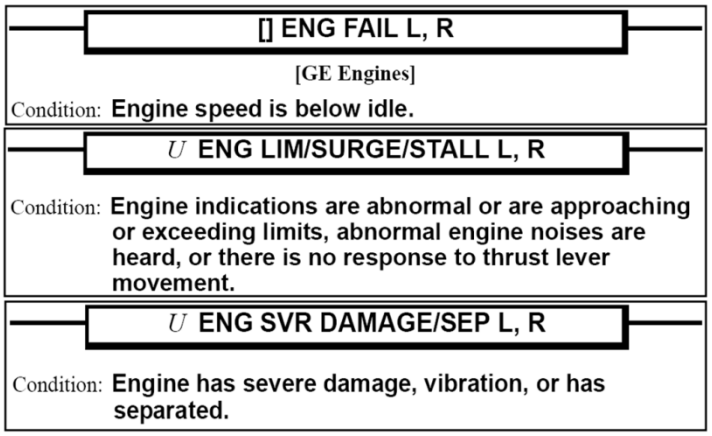
The paradigm described below is a significant shift from the attitudes of the past and will require further consultation with Boeing prior to implementation. However preliminary talks with Boeing and other operators have confirmed the following interpretation.

It is also worth noting that checklist "Recalls" have been phased out in favour of checklist "Memory Items".

Previously.

Previously the analysis of an engine failure at 400 ft focussed primarily on whether or not the engine had "severe damage". An engine was determined to be damaged if any of the following were observed:

- Zero N1, N2, N3 (damaged rotor)
- Zero Oil Pressure
- (Severe) Vibration, whether evident through the airframe or EICAS engine display
- Removed engine instruments (indicating an engine separation)



In this event the condition "severe damage" was diagnosed and the "Engine Severe Damage/Separation Recalls L/R" were called for once navigation and flight path were stabilised at 400 ft. These memory items include "Engine Fire Switch … Pull" which closed spar and engine fuel valve, depressurised the engine driven hydraulic pump as well as shutting off hydraulic fluid.

If engine "severe damage" was not evident and a limit exceedance, surge, stall or lack of thrust lever response was detected, the "Engine Limit/Surge/Stall L/R" memory items would reduce thrust on the affected engine (potentially to idle), but leave the engine running. Again these items would be called for once flight path and navigation were stabilised after 400 ft.

Finally if the engine was assessed as a rundown or flame out condition, the engine failure checklist was determined applicable, which does not contain any memory items. The failure was left to be dealt with once the aircraft was at a safe height, clean with flight path and navigation established.

Engine Failure Analysis – New QRH, New Paradigm.

The basic premise behind the QRH condition statement alterations is essentially that the crew should not be conducting memory items at 400 feet on takeoff unless absolutely necessary. Managing memory items during the critical take of phase is certainly one of the more challenging aspects of non normal events such as an engine failure, during takeoff.

The new paradigm essentially means that **unless an engine is still running, or producing airframe vibrations, memory items are not required.** Unless an engine is either "severely damaged" ***and still running*** (and vibrating severely as a result) at 400 ft, no memory items are applicable. The engine is to be considered "Failed" (*engine speed below idle*) – no memory items are applicable.

Additionally if an engine has failed during takeoff (*engine speed below idle*) and suffered a limit exceedance as a result, the Limit/Surge/Stall checklist is not relevant. Indeed, reducing thrust on the failed engine (even to idle) achieves little.

To re-state another way – if an engine has failed (*engine speed below idle*) and suffered damage or a limitation exceedance as a result – only the Engine Failure Checklist is applicable. Let's examine this with a scenario.

Detailed Scenario Analysis.

Just after rotation, an engine failure occurs which includes the sound of damage ("Bang"), vibration and loss of thrust. By the time the crew have dealt with the flying and reviewed engine instrumentation at 400 ft, the engine is windmilling, N2 is zero, with moderate vibration evident on the engine instrumentation only.

What checklist? Recall / Memory Items?

Note that the important part of this failure description is that right now (400 ft) the engine has failed and is below idle.

❑ Engine Severe Damage/Separation

Q : Is there airframe vibration with unusual engine displays?

Q : Or has the engine separated?

Eng Svr Damage/Sep L, R	
Condition:	One or more of these occur: • Airframe vibrations with unusual engine displays • Engine separation

The engine is damaged (N2 is Zero) but that's no longer in the condition statement. Whether it's severely damaged is subjective (and although in the title, this is not in the condition statement) – but in any event, it's no longer running. Eng Severe Damage/Separation is not required.

It can be seen that the "Airframe vibrations with unusual engine displays" refers to the "Engine Severe Damage" section of the checklist title. Essentially if the "(severely) damaged" engine is generating airframe vibrations AND unusual engine displays – it needs to be shut down (and secured), hence the application of memory items at 400 ft. In most cases, airframe vibrations imply the engine is still running.

But if there is no airframe vibration (whether or not the engine is below idle) or no unusual engine displays, then the Eng Severe Damage/Separation checklist is not applicable and no memory items are required.

❑ Engine Limit/Surge/Stall

Q : Are the engine displays unusual (limit exceedance) or are they about to exceed (limit exceedance)?

Q : Or is there unusual engine noises (surging, stalling)?

Q : Is there lack of response to thrust lever movement?

Eng Lim/Surge/Stall L, R	
Condition:	One or more of these occur: • Engine displays are unusual • Engine displays are quickly nearing or show an exceedance • Unusual engine noises are heard • There is no response to thrust lever movement

In this case - not anymore. You could perhaps interpret the Zero N2 as "unusual". But basically – No.

The issue of N2 zero being "unusual" also ties into another variation on this theme - if the engine had suffered an EGT exceedance during the same failure. Thus at 400 ft the engine is windmilling (except the N2 at Zero), EGT is low – but shows a previous exceedance. The crew could act on the limit exceedance (*can it be assumed that an historical exceedance meets the condition of "Engine displays are quickly nearing or show an exceedance?"*) and run the memory items of this checklist. What purpose does it serve? The checklist reduces thrust back to idle. It does not shut off the fuel (Fuel Control Switch) or pull the engine fire switch.

❑ Engine Fail

Q : Is the engine speed below idle?

[ ] ENG FAIL L, R	
Condition:	Engine speed is below idle.

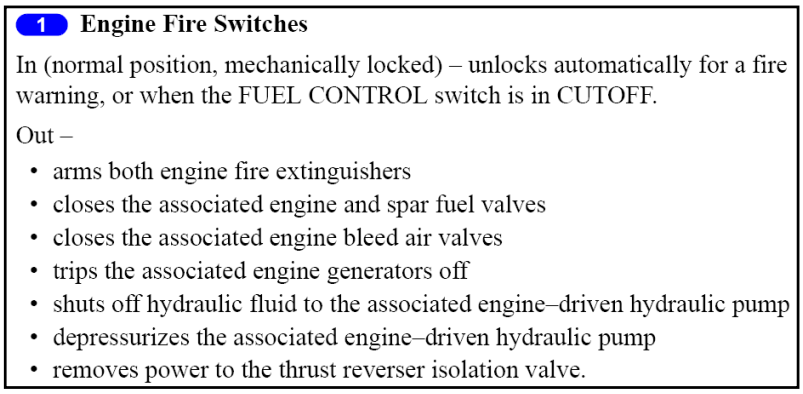
Yes, it is. In fact for almost all simulated failures, by the time you get to 400 ft, engine speed is below idle.

In this event the crew would leave the failure to be dealt with by the annunciated Engine Fail checklist, one the aircraft is clean and at a safe altitude with flight path and navigation stabilised.

Summary

It can be see that many of the failures that are currently dealt with by memory items at low altitude will now be handled by the **Engine Fail Checklist** (without memory items) at a much higher altitude.

It should be noted that an engine previously treated as having "severe damage" (N1/N2/N3 zero, windmilling after a failure with Oil Pressure zero, etc) will now be treated as a "Failed Engine" as long as airframe vibrations (or "Severe Damage") are not present. The Engine Fail checklist does not require the Fire Switch to be pulled, so some of the associated actions will not be taken – notably the Hydraulic and Bleed closures. This is not to say the aircraft will be in an unsafe condition – Boeing feedback on this issue is still outstanding.



1 Engine Fire Switches

In (normal position, mechanically locked) – unlocks automatically for a fire warning, or when the FUEL CONTROL switch is in CUTOFF.

Out –

- arms both engine fire extinguishers
- closes the associated engine and spar fuel valves
- closes the associated engine bleed air valves
- trips the associated engine generators off
- shuts off hydraulic fluid to the associated engine–driven hydraulic pump
- depressurizes the associated engine–driven hydraulic pump
- removes power to the thrust reverser isolation valve.

Sim Failure Analysis

What follows is a brief look at the sim failures that exist (both now and after April's tail upgrade) and a potential review of the altered handling that might be encountered as a result of this change of engine failure management.

Note that the following is not recommended technique for these failures, nor are all failures that affect power plant included in this table. Failures with a green background will not be available until after the Tail Upgrade.

Scenario	Old	New
71G.5 ENG FAIL *Fuel control failure causing removal of fuel supply to engine.* - Engine flameout due to fuel control failure - Spool down normally - Not restartable with the malfunction	ENG FAIL checklist when clean with FP&N est.	No Change
71G.8 ENG OIL PRESS *Engine oil supply pump fails* - Internal failure of engine oil supply pump causing loss of oil pressure - Engine damage or failure if condition continues for more than approximately 60s - Engine oil temperature starts rising when the oil pressure drops below 10 psig	Lim/Surge/Stall memory items at 400 ft OR ENG OIL PRESS checklist when clean with FP&N est.	No Change
71G.9 ENG OIL TEMP *Engine oil temperature sensors indicate wrong value.* Engine oil temperature sensors are biased to a temperature higher than the redline	Lim/Surge/Stall memory items at 400 ft OR ENG OIL TEMP checklist when clean with FP&N est.	No Change
71G.14 ENG SVR DAMAGE *N2 bearing seizure.* Engine vibration increases rapidly (approximately 2s) followed by an N2 rotor seizure, causing a flameout and an N1 spool down - TAC will disconnect if the aircraft is in the air - THRUST ASYM COMP OFF light illuminates (if TAC disconnects)	Svr Dam/Sep memory items at 400 ft.	- If engine has spooled down and no airframe vibrations at 400 ft – ENG FAIL checklist when clean with FP&N est. OR - If airframe vibration continues (with unusual displays), Svr Dam/Sep memory items at 400 ft.

Scenario	Old	New
71G.15 ENG SEPARATION *Engine falls off.* - Engine becomes detached from the wing with associated loss of thrust and asymmetric performance - Engine indications reflect loss of signal - Fuel can be shut via the pylon valve - Generators associated with the engine will go off line but the bus bar integrity will remain - Pneumatics will be lost from the engine, but the duct will remain operational	Svr Dam/Sep memory items at 400 ft.	No Change
71G.16 ENG THRUST *Fan and high pressure compressor blade breakage due to foreign object ingestion.* - At high power, engine will approach N2 redline limit - Immediate cockpit indication of increased N2 speed, drastic engine vibration, asymmetric thrust on the airplane	Svr Dam/Sep memory items at 400 ft.	- If engine has spooled down and no airframe vibrations at 400 ft – ENG FAIL checklist when clean with FP&N est. OR// - If airframe vibration continues (with unusual displays), Svr Dam/Sep memory items at 400 ft.
71G.18 COMPRESSOR STALL (UNRECOVERABLE) *Compressor stall/surge.* - Loud bang with RPMs dropping and EGT rising with accompanying loss of thrust creating yaw - Effect repeated randomly if fault left selected	Lim/Surge/Stall memory items at 400 ft	No Change
71G.19 N1 OVERSPEED FOD *Severe damage (fan blade failure) due to ingestion of foreign object.* - Catastrophic engine failure but without rotor seizure - Immediate indications of severe vibration and compressor stall, survivable at idle - EGT increase of approximately 20 to 140 deg C, compared with the other engine - Might get engine fail message	Lim/Surge/Stall memory items at 400 ft	- If engine has spooled down and no airframe vibrations at 400 ft – ENG FAIL checklist when clean with FP&N est. OR// - If airframe vibration continues (with unusual displays), Svr Dam/Sep memory items at 400 ft.
71G.21 ENGINE N1 SEIZURE *N1 rotor bearing fail.* - N1 rotor seizure followed by an engine flameout and N2 spools down - TAC will disconnect if the aircraft is in the air - TAC OFF light illuminates while in-flight when a rapid loss of thrust is detected - TAC reset is possible - THRUST ASYM COMP OFF light illuminates (if TAC is disconnected)	Svr Dam/Sep memory items at 400 ft.	- If engine has spooled down and no airframe vibrations at 400 ft – ENG FAIL checklist when clean with FP&N est. OR// - If airframe vibration continues (with unusual displays), Svr Dam/Sep memory items at 400 ft.
71G.10 ENGINE STALL/SURGE (RECOVERABLE) *Engine surge.* - Engine surges above idle setting - N1, N2 and N3 fluctuate randomly with associated stall noise - At high power setting, EGT rises to overheat condition - Stall and malfunction can be cleared by retarding throttle to idle	Lim/Surge/Stall memory items at 400 ft	No Change
77G.3 FAN DAMAGE INGESTION *Foreign object damage causes a fan blade to be out of balance.* When the malfunction is selected: - Engine parameters (vibration, WF, N1 and N2) vary suddenly - Fan blade(s) have FOD damage causing vibration to increase higher than normal (above alert limit when the engine is at high power setting) - Fuel flow increases slightly - Loss of power caused by the malfunction will require throttle stagger to maintain balanced power	Lim/Surge/Stall memory items at 400 ft OR Svr Dam/Sep memory items at 400 ft.	No Change

Scenario	Old	New
77G.5 FAN IMBALANCE (FAN TRIM RANDOM) *Fan imbalance.* Fan imbalance amplitude is randomly determined at failure initiation EICAS primary display: - The vibration source indicates N1 with an increase of the vibration valve	Lim/Surge/Stall memory items at 400 ft OR Svr Dam/Sep memory items at 400 ft.	No Change
77G.8 N1 EXCEEDANCE *N1 transmitter failure causing an indication exceedance.* - Primary EICAS display indication of N1 changes to red - N1 exceedance red box appears on the EICAS - N1 indication goes to maximum	Lim/Surge/Stall memory items at 400 ft	No Change
77G.9 N2 EXCEEDANCE *The primary EICAS display indication of N2 changes to red.* - Primary EICAS display indication of N2 changes to red - N2 exceedance red box appears on the EICAS	Lim/Surge/Stall memory items at 400 ft	No Change
77G.10 EGT EXCEEDANCE *EGT transmitter failure causing an indication exceedance.* - Primary EICAS display indication of EGT changes to red - EGT exceedance red box appears on the EICAS - EGT indication goes to maximum	Lim/Surge/Stall memory items at 400 ft	No Change