ENGINE MALFUNCTIONS & PROCEDURES

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Manufacturer documentation takes precedence in all cases.
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Last Update: 18 SEP 2017
Applicability:

737 NG

OPINIONS

This document contains some operational opinions based on experience and research.

PRIMARY REFERENCE: *TURBOFAN ENGINE MALFUNCTION RECOGNITION AND REPSONSE – FINAL REPORT* (FAA ENGINE AND PROPELLOR DIRECTORATE)
WEB LINK:
http://www.faa.gov/aircraft/air_cert/design_approvals/engine_prop/media/engine_malf_report.doc

CFM56-B7 ENGINE

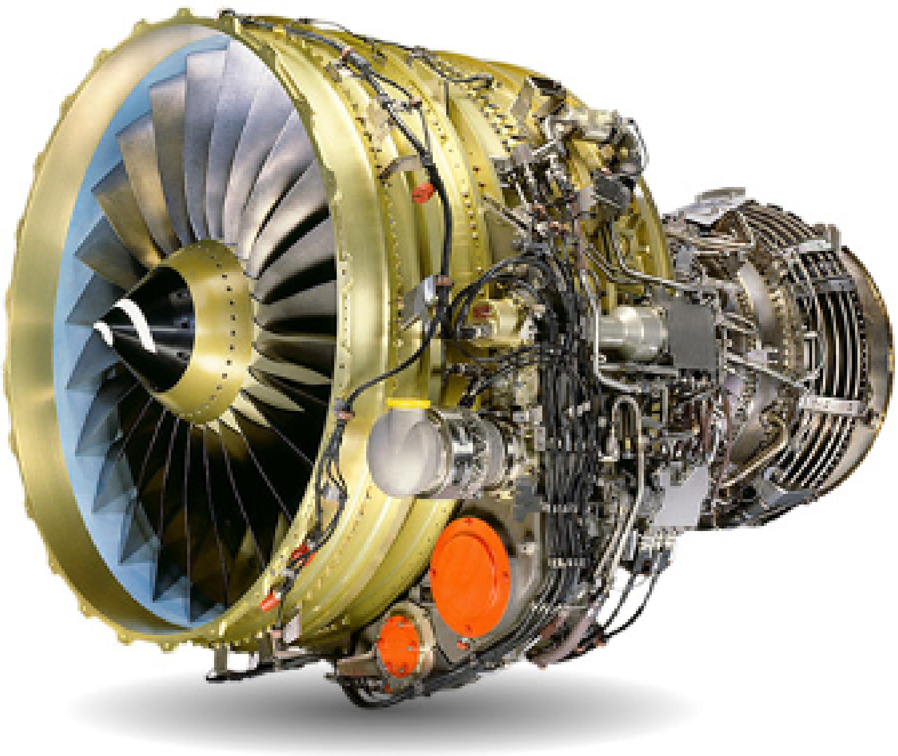
The CFM56 web page is here: http://www.cfmaeroengines.com/engines/cfm56-7b

This video shows how the engine works:
https://www.youtube.com/watch?v=KjYw0GdRpm0

CFM International is a 50/50 joint venture between French Snecma Moteurs and American General Electric.
The CFM56 engine entered service in the mid 70's and over 28,000 have been made. The CFM56-B7 engine variant entered service in the mid 90's and is the most popular engine on the 737. There are over 8000 of them in service. It has been touted as the most successful commercial jet engine to date. It weighs about 2.3 tons and has a bypass ratio of about 5:1.

CHECKLIST VARIATION

Some of the checklists herein may have variations from *your* airline's checklists.



CFM56-7B (CFM website)

Here's a great video on the development of the jet engine:
https://www.youtube.com/watch?v=7JFUWgHVX5E

Relevant Bulletins, Reviews and other Documents:

FCTM-737-TB-08 R6 Common Engine Fire/Failure/Malfunction Procedure (optional bulletin)
FCTM-737-TB-12 Convective Weather Ice Crystals Associated with Engine Power Loss
(Also FCOM SUPP.PROC 16 – Adverse Weather)
FCTM Flight Operations Bulletin 737-xxx-01 CFM57-7 Fuel Leaks (optional bulletin)
FCTM-737-TB-05 Illumination of Engine Control Light
FCTM Flight Operations Review 737-13 Engine Vibration Procedures
FCTM Flight Operations Reviews 737-14 Loss of an Engine Parameter Indication While Inflight
FCTM Flight Operations Reviews 737-15 Low Oil Quantity
FCTM Flight Operations Reviews 737-16 Blue Ice
FCTM Flight Operations Reviews 737-33 Flight Crew Considerations for Engine Inflight Shutdown
FCTM Flight Operations Reviews 737-34 Flight Crew Considerations for Engine Surge

DOCUMENT PURPOSE

To aid in correct recognition of engine problems so as to apply proper remedial action.

POSSIBLE ENGINE MALFUNCTIONS

(checklist titles in green)

Some of these can occur in combination.

BIRD/FOD INGESTION
FLAMEOUT (including from fuel starvation) (Engine Failure or Shutdown NNC)
THRUST ROLLBACK (Engine Failure or Shutdown NNC)
LOSS OF THRUST LEVER RESPONSE (Engine Limit or Surge or Stall NNC)
FIRE WARNING (Engine Fire or Severe Damage or Separation NNC)
SEVERE ENGINE DAMAGE (Engine Fire or Severe Damage or Separation NNC)
MINOR ENGINE DAMAGE
SEIZURE (Engine Fire or Severe Damage or Separation NNC)
REVERSER INADVERTANT DEPLOYMENT IN FLIGHT (NNC)
REVERSER UNLOCKED (NNC)
ENGINE SEPARATION (Engine Fire or Severe Damage or Separation NNC)
COMPRESSOR STALL (Engine Limit or Surge or Stall NNC)
COMPRESSOR SURGE (Engine Limit or Surge or Stall NNC)
ENGINE HIGH VIBRATION (NNC)
TAILPIPE FIRE (NNC)
ENGINE LOW OIL PRESSURE (NNC)
ENGINE HIGH OIL TEMPERATURE (NNC)
ENGINE OIL FILTER BYPASS (NNC)
ENGINE LOW OIL QUANTITY (**no** specific NNC)
INCREASE IN ENGINE OIL QUANTITY (**no** specific NNC)

Note: **LOSS OFF THRUST on BOTH ENGINES** is addressed in a different document.

RARITY

Because of advances in engineering and high reliability, an engine failure or significant malfunction is extremely rare.

ENGINE USABILITY AFTER A MALFUNCTION

Modern jet engines are very resilient. After a major malfunction and even damage, an engine can remain usable.

PRIMARY PILOT TASK FOLLOWING AN ENGINE MALFUNCTION

Fly the aircraft. A damaged, stalled or failed engine can wait so that pilot attention is given to the primary energy state and flight path of the aircraft. Even an engine fire can wait until the aircraft is out of a critical flight stage.

⚠ **** FLY THE AEROPLANE, NOT THE ENGINE ****

PRIMARY INDICATIONS OF ENGINE FAILURE

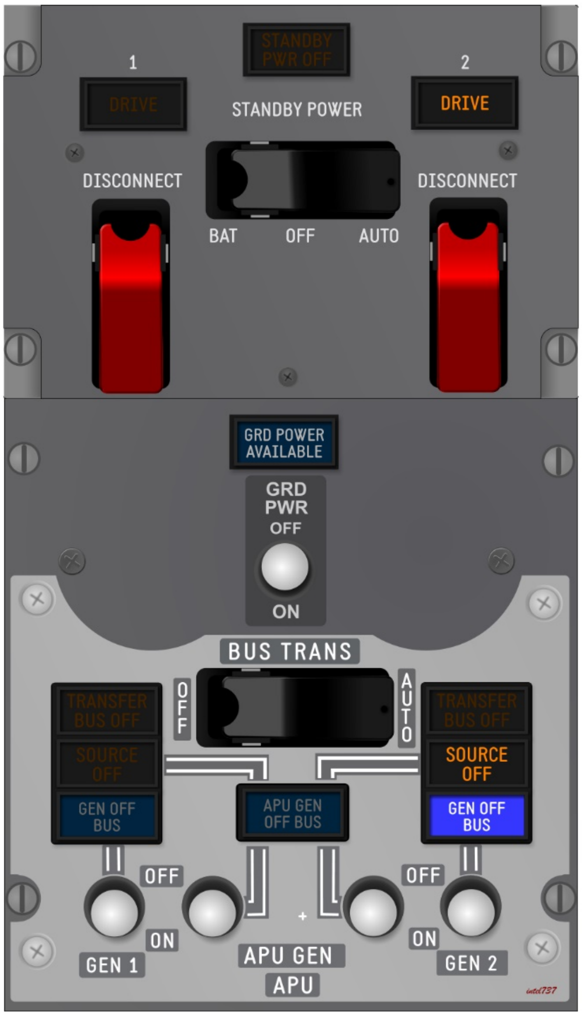
1. If the engines are at power above idle – a degree of yaw will be experienced
2. There may be abnormal or red indications on the engine parameter dials
3. There may be abnormal sounds from the engine – depending on the cause of the failure
4. Crew, passengers, the tower, or other aircraft may observe engine damage
5. There may be odors in the cabin from the air-conditioning system
6. There may be vibration through the airframe

There is no engine failure-related rudder channel in the FCC, so following an engine loss of thrust with the autopilot engaged, the autopilot will input aileron to maintain the programmed track (LNAV, HDG SEL, etc). The autopilot will input elevator to maintain the commended pitch mode, eg. straight and level flight. At cruise altitude and thrust, this will be subtle and slow. At some point, the autopilot will drop out (let go) and the ailerons revert to the manual trim setting of at or near zero (the trim channel in the autopilot is separate to that used for manual aileron trim – the autopilot has its own electric signal/hydraulic drive aileron servos). Undetected, this autopilot release can result in an airplane upset (immediate roll and loss of altitude).

It is important for pilots to recognize an engine failure early on, and apply rudder or rudder trim to compensate for the asymmetric thrust. Rudder and/or rudder trim can be applied with the autopilot engaged. Aileron trim cannot! (a limitation) At cruise levels, thrust is only a small percentage of that generated at takeoff. So only a ‘breath’ on the rudder is required to centralize the control column (neutral on the yolk roll index should be with about 1-2 units of rudder trim at normal cruise altitude and power).

SECONDARY INDICATIONS OF ENGINE FAILURE (ANY CAUSE)

The auxiliary services from that engine drop off line:
The first will be the electrical system.



GEN OFF BUS light (blue) and SOURCE OFF light illuminate first (with master caution and ELEC annunciator) followed soon by the DRIVE light.

ORDER

GENERATOR (usually the first). **"SOURCE OFF"** light. The bus tie system connects the failed engine-side bus to the main bus of the live engine-side.

The next should be the generator drive light **"DRIVE".**

Next is the HYDRAULICS **"LOW PRESSURE"** light on engine-driven hydraulic pump. (see next diagram)

Engine-driven Hydraulic Pump Low Pressure comes next (note: master caution ELEC is on from the earlier indication)

Further indications:

- BLEED AIR (see below)
- LOW ENGINE OIL PRESSURE INDICATION (likely)

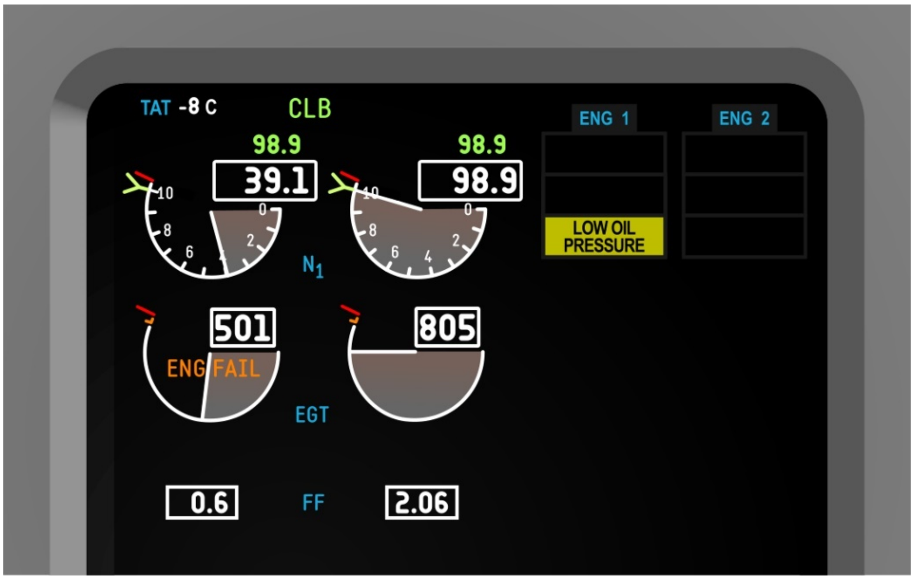
Because some of these systems feed other aircraft systems, the fault indications across the cockpit will be numerous and possibly complex.

After managing the aircraft flightpath, proper time must be given to diagnosis.

GOOD CHECKLIST

The engine failure/shutdown checklist not only secures the engine, but also deals with the secondary failures (eg. APU on for electrics). The hydraulics on the failed engine side remain powered through the secondary electrical pump. Only one pack operates (in high flow, after checklist switching) through the bleed system of the remaining engine.

The **ENGINE FAIL** bezel in the N1 gauge means: engine operating below idle (50% N2), with both engine start levers in the IDLE detent position.

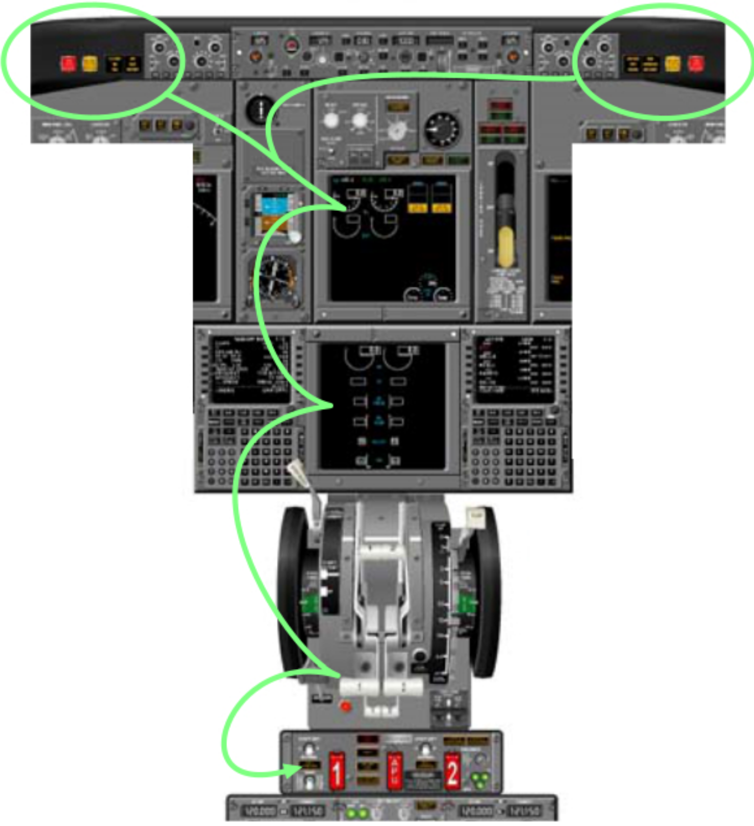


ENG FAIL Bezel (in EGT gauge)

"ENG FAIL" DOES NOT NECESSARILY MEAN STRAIGHT ENGINE FLAMEOUT

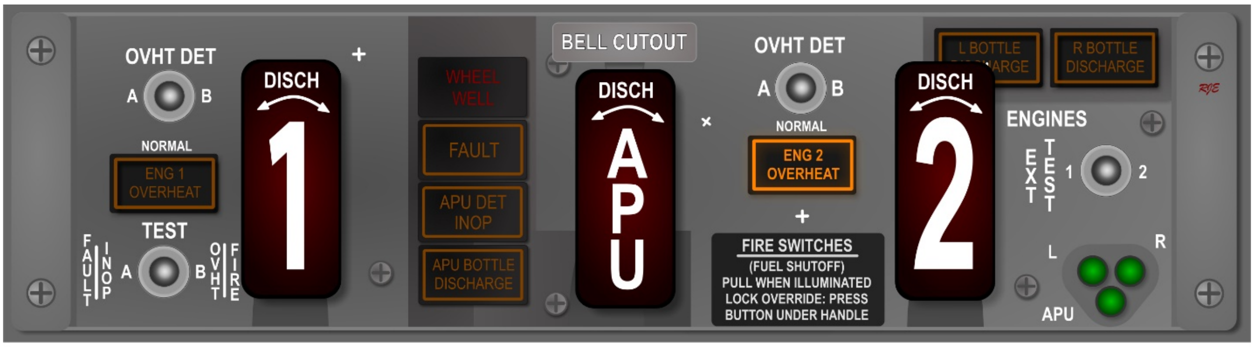
Be careful of the ENGINE FAIL bezel as it will appear also if there is severe engine damage, when the engine winds down or stops abruptly.

In the identification process, pilots see ENGINE FAIL and call it out as a straight "engine failure". Look at **all** of the indications: see if N1 and N2 are spinning. Look at the EGT. Look at the oil temperature and pressure. Look at the engine vibration meters and consider airframe vibration. **Continue the identification process right down to the fire panel, looking for an engine overheat light and if the fire warning switch is lit. Be <u>thorough</u> in the identification process.**



The “identify” process scans all the way to the fire panel

Flow the observation process from top to bottom, all the way to the fire panel. The engine overheat lights are somewhat in hiding!

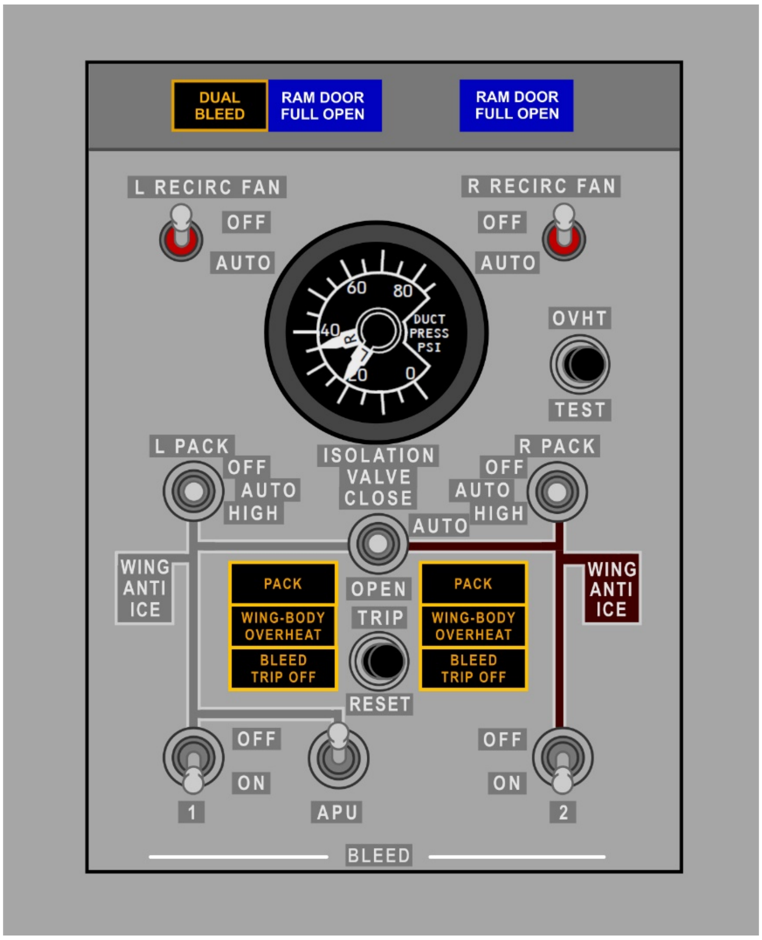


You might miss an engine overheat light if you don’t scan the fire panel carefully

Also glance at the master caution annunciator panels and see what systems they direct you to look at. In the case of engine overheat, the OVERHEAT annunciator should be lit.

WHAT HAPPENS TO THE BLEED AIR AND AIR CONDITIONING WITH AN ENGINE FAILURE?

The diagram below shows (in red) the lost bleed source for a failure of engine 2.

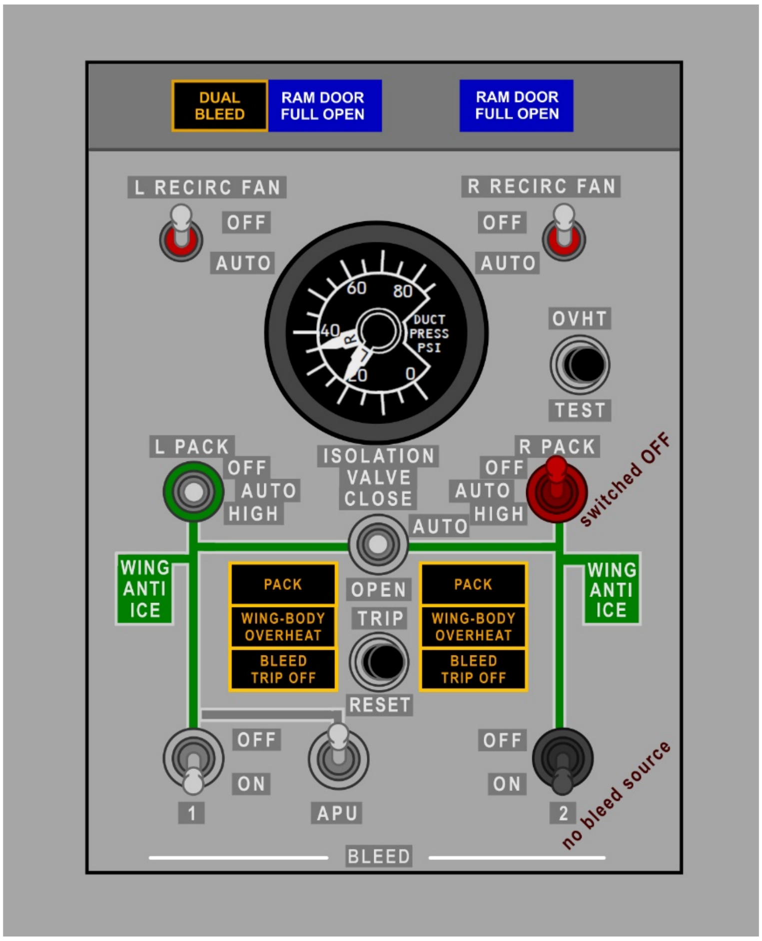


Engine 2 Failure: lost bleed source

Because the bleed switches are both **on** and the pack switches are both **on**, the isolation valve remains **closed** (with the isolation valve switch on the AUTO position – as it normally is inflight).

The Engine Failure or Shutdown (and other related engine securing checklists such as engine fire, severe damage or separation) directs the pack on the side of the failed engine to be switched OFF. The isolation valve then opens and air is supplied to the right-side wing anti-ice duct, in case that is needed for flight through icing conditions.

Engine anti-ice is supplied <u>within</u> the engine, for each engine, and is not affected by bleed panel switching. The failed engine will have no engine anti-ice available, but that doesn't matter.



The isolation valve (switch in AUTO position) opens when the right pack is switched off – proving air for the right-side wing anti-ice if needed

Since the right pack is switched off, the left pack goes to HIGH FLOW (PACK switch still in AUTO). There is no cockpit indication of a pack in high flow.

FLIGHT UNDER AN MEL WITH ONE PACK INOPERATIVE – BEWARE!

If a pack is inoperative or has tripped off, an engine failure on the side of the only operating pack will result in no packs operating. The aeroplane will depressurise over the course of some minutes. This is part of the reason that the MEL for pack inoperative calls for cruise at no higher than FL250 – the aeroplane naturally depressurizes more slowly than at altitudes higher up.

OTHER

EEC OFFLINE

When an engine fails, as N2 drops through 15%, the EEC de-energizes and some of the engine indications go blank (eg. EGT). To re-energize the EEC and bring up the engine instruments, select CONT on the relevant engine start switch.

LOWER DISPLAY UNIT (DU) POP-UP

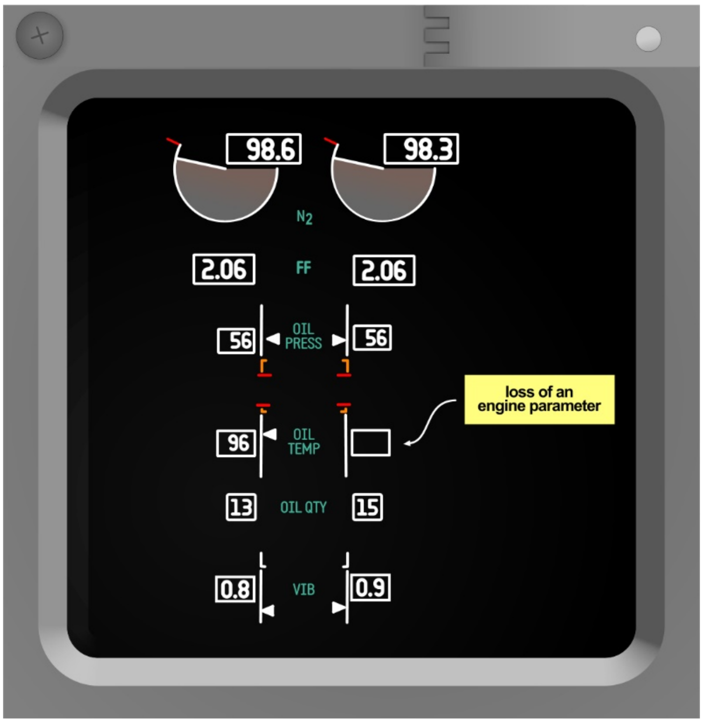
The Lower DU will automatically turn on/pop up when:
- an engine start lever is moved to cut-off whilst in flight
- when an engine fails whilst in flight
- when a secondary engine parameter exceeds normal operating range (at any time). This is especially useful for engine limit indications whilst on the takeoff roll.

ENGINE PROBLEMS – FIRST INDICATION BY GUAGE DIFFERENTIAL

Engine problems can be more easily noticed by observing a differential between engine 1 and engine 2 indications, rather than by directly observing the indications themselves. The *difference* in engine indications is the eye-catcher. The ensuing identification process looks more closely at the specific indications for problem diagnosis. When certain limits are exceeded (eg. N1, N2 and EGT), the gauge itself turns red.

LOSS OF AN ENGINE PARAMETER INFLIGHT

IMPORTANT Flight Operations Review 737-14 (FCTM)
With loss of an engine parameter inflight (gauge blank or reading zero), an engine shutdown is NOT necessary if all other parameters are normal. Operate the engine normally.



Loss of an Engine Parameter

FLIGHT CREW CONSIDERATIONS FOR ENGINE SHUTDOWN INFLIGHT

The Boeing philosophy for engine shutdowns is described in the *Operations Manual Non-Normal Checklist Introduction*.

IMPORTANT *"Checklists prescribing an engine shutdown must be evaluated by the Captain to ascertain whether an actual shutdown or operation at reduced thrust is the safest course of action. Consideration must be given to probable effects if the engine is left running at minimum required thrust."*

- An engine running at idle still provides essential services such as electrics, hydraulics and limited bleed air.
- An engine running at idle still provides some redundancy of thrust if the remaining engine fails.

SPECIFIC ENGINE PROBLEMS

BIRD/FOD INGESTION

INDICATIONS OF BIRD INGESTION

(many of these featured in the US AIRWAYS Flight 1549 double engine failure due birdstrike with Captain Chesley Sullenberger)
* "thud" sounds
* engine abnormalities, possibly high or variable EGT, abnormal N1 or N2, high vibration, complete loss of thrust/thrust lever response
* odors through the air conditioning system
* yaw associated with rapid loss of engine thrust on one side
* engine surge and/or stall

There may be other structural damage such as flap damage

Anecdotally, small birds do not cause engine damage, even if they go through the engine core.
In the US Airways accident, the A320 flew through a flock of magpie geese. These have a wingspan of around 1.6 metres (~5 feet).

If a surge occurs, throttling back the engine may be enough to clear the engine and reset airflow.

Research has validated the need to fly the aircraft first, establishing a stable flightpath before dealing with the engine problems resulting from birdstrike. Stable flight is a high priority, leading to a safe outcome.

Any engine abnormality should be addressed using the relevant checklist(s).

Situations resulting from a birdstrike may include engine flameout, engine severe damage, engine fire or overheat, engine surge or stall and/or engine indications above limits. The aircraft may be physically damaged in other places leading to control problems. If the flaps are damaged, then a flap asymmetry or disagree might result when they are extended or retracted. Cockpit window damage is another possibility (use the specific NNC for that). Radome damage may cause erroneous speed indications (Airspeed Unreliable NNC). The document on *Birdstrike* contains more information.

FLAMEOUT

This might be from:
- a malfunction

- engine damage
- ice in the engine,
- fuel starvation (no fuel, frozen fuel, aeration in the fuel lines, clogged fuel filter).

Unless severely damaged, most likely the engine will wind down steadily in the airflow (wind milling effect).

THRUST ROLLBACK
This may occur from:
- flameout
- fuel problems as listed above in FLAMEOUT
- engine damage/failure

Manage the flight path first.
The engine failure/shutdown non-normal checklist applies.

LOSS OF THRUST LEVER RESPONSE
This may occur from:
- major EEC failure
- hydro-mechanical fuel unit failure
- throttle quadrant damage
- engine compressor stall
- engine failure

The Engine Limit or Surge or Stall (memory) checklist is the checklist to apply on identification of the correct engine. It leads to shutting the engine down if there is no recovery.

FIRE WARNING or ENGINE OVERHEAT
The engine mount provides, in part, a barrier between the engine and aircraft wings and structure. This gives time for the pilot to stabilize the aircraft flight path before executing the Engine Fire or Severe Damage or Separation non-normal checklist.

**** Do not perform the engine fire checklist unless an engine fire warning occurs.**

THE ENGINE FIRE WARNING SWITCHES – ROTATE FULLY!
When a checklist directs that the engine fire switch be “rotated to the stop and held for 1 second” it needs to be held at the stop so that the fire bottle squib actually **fires** (look for the bottle discharged light). This is a common mistake in the simulator – the fire bottle is not fully rotated, or held in position properly and the bottle does not discharge.

The 30 seconds begins not when the switch is rotated, but rather when the bottle discharge indication occurs. So always check that the bottle has discharged before starting the clock. If it has not discharged, firstly ensure that the fire warning switch handle has been fully rotated. If the handle has been positively held in the stop for at least 1 second and the bottle has not discharged, then do a lights check and see of the bottle discharge light is inoperative. If the light is not at fault, then immediately fire the *other* bottle. In the case of the engine fire, the fire extinguishing agent must be put to work as soon as possible.

SEVERE ENGINE DAMAGE

Engine damage *may* be confirmed by visual observation from the cabin. Cabin crew or passengering pilots may send a report to the flight deck. Do not act on visual damage reports alone, unless the source is proven credible. Always assess engine parameters for confirmation of engine damage. An engine which shows external damage may still operate normally – so use it normally then (although always have a ready contingency plan should the engine malfunction or fail).

A compressor surge or stall at high engine thrust settings, will cause jolting or shuddering of the aircraft and may be confused with engine damage. If the engine fails after a surge/stall, then discerning the difference between engine surge/stall and engine damage may be very difficult. Try to visually assess the engine if possible – this may be difficult if only a two-pilot operation. The checklist must be executed without undue delay.

The engine severe damage checklist is possibly irreversible, so if unsure of damage, run the Engine Limit or Surge or Stall memory checklist first. If the engine does not recover, then severe damage is more the likely case.

MINOR ENGINE DAMAGE

The engine may continue to be used. Be aware though that the engine might fail at any time, possibly in a catastrophic manner. Minor engine damage might be indicated by high vibration. A shutdown in this case might be an overreaction, but be mindful that the engine reliability is certainly reduced.

ENGINE SEIZURE

Engine seizure is classified as ENGINE SEVERE DAMAGE. The appropriate memory checklist applies. Any or all rotors in the engine may seize.

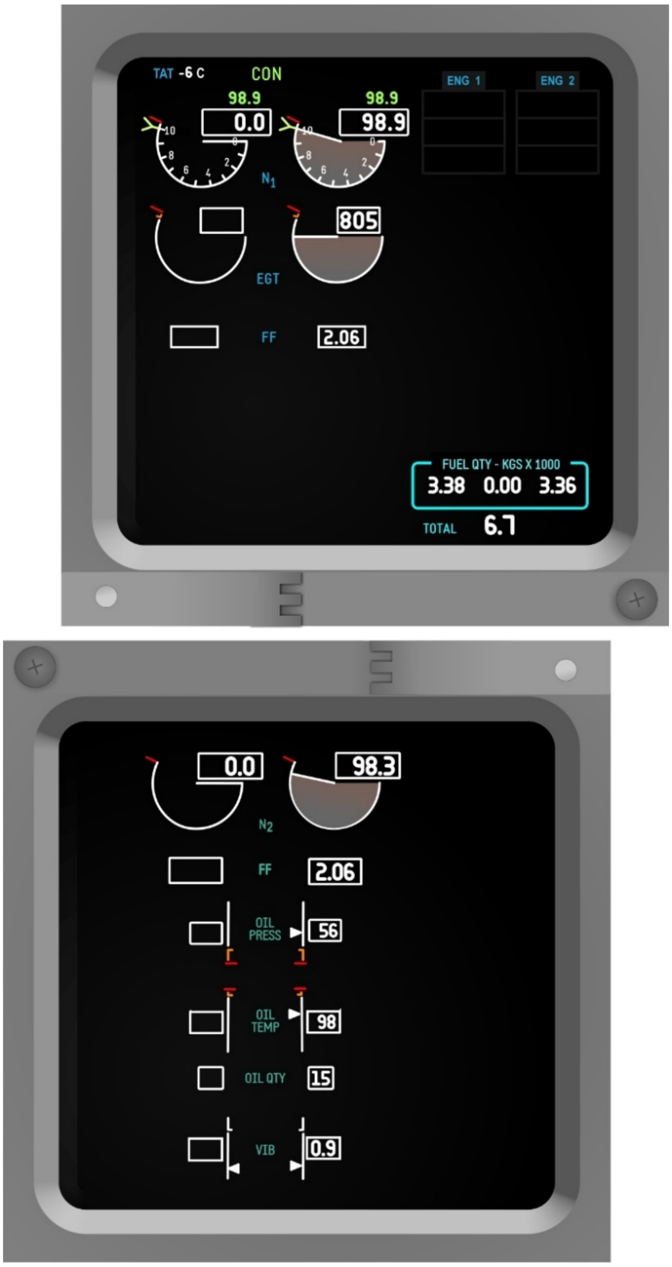
IMPORTANT With forward motion in flight, N1 should always be turning.

IMPORTANT At low speeds and after the engine has not been running for a time, N2 may legitimately wind down to zero. This does not necessarily mean engine severe damage, although it still may be. With any rotor indicating zero, be mindful or the possibility of engine damage. Be mindful also that the rotor speed sensor could be damaged or faulty and not transmitting rotor RPM (this case then becomes a loss of an engine parameter). With no yaw, no loss of thrust or airspeed and no other abnormal indications, loss of N1 or N2 indications or a reading of zero – is most likely a sensor or sensor wire fault – do not shutdown the engine.

ENGINE SEPARATION

When the engine has separated, many of the engine parameters are lost on the upper and lower DU:
- N1 is zero
- N2 is zero
- EGT is blank
- Fuel Flow
- Oil quantity, temperature and pressure are blank

This information is normally provided by the engine-mounted EEC. Since the EEC has gone with the engine, no information is presented for display.



Left Engine Separated

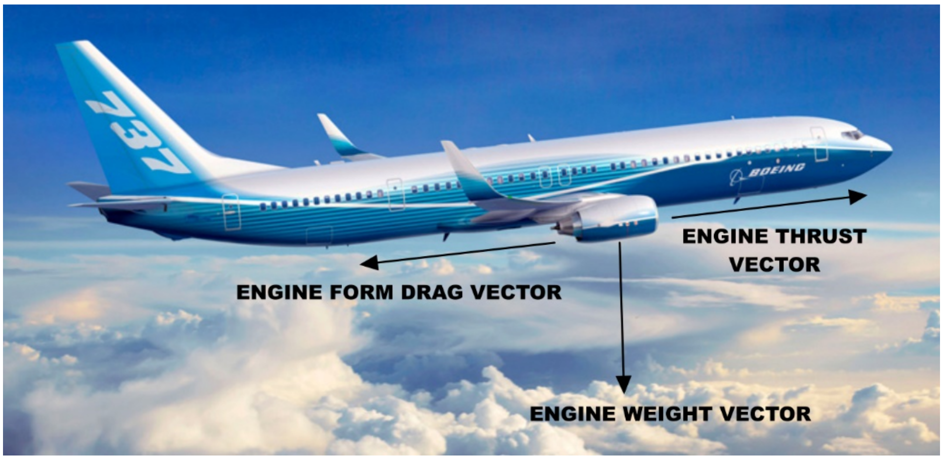
Engine separation may be observed from the cabin by cabin crew or by passengering pilots. It may also be observed from external sources such as tower or other aircraft. On takeoff, engine separation greatly affects performance, and because several tons of engine are missing on one side – lateral balance is affected. Also, there is the absence of drag created by a dead engine. Naturally (after takeoff and with an engine separation), ATC will have to be advised and the runway will be closed due to the debris.

The aircraft aerodynamics of an engine separated are *greatly different* to that of an engine failure.

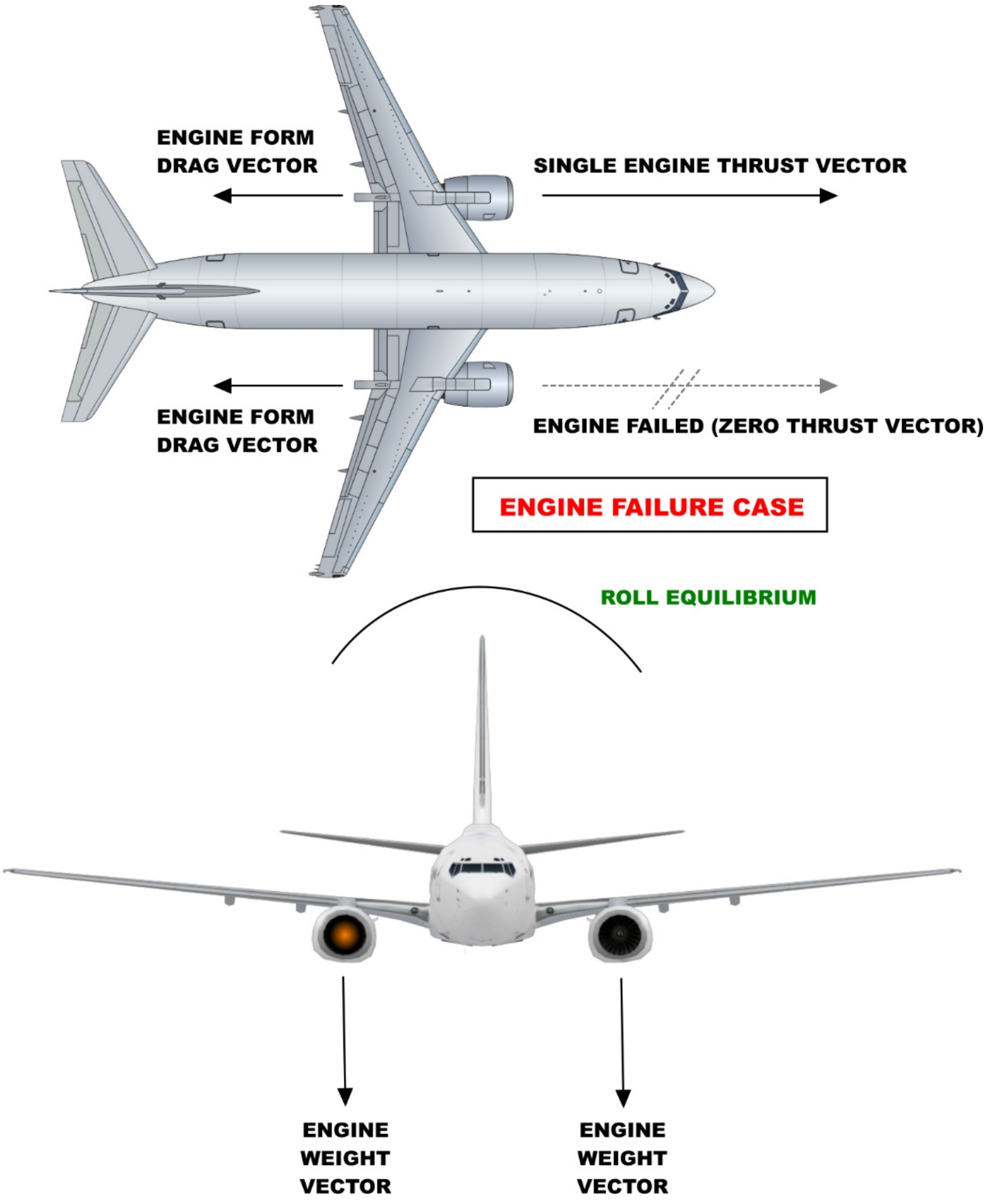
The loss of an engine means the loss of significant form drag and the loss of several tons of engine weight on the wing. The end result is that you may have to trim rudder far less than with a normal engine failure or shutdown. With low power on the remaining engine, you may have to trim *towards* the lost engine. The loss of weight requires significant aileron to counter the resulting roll.

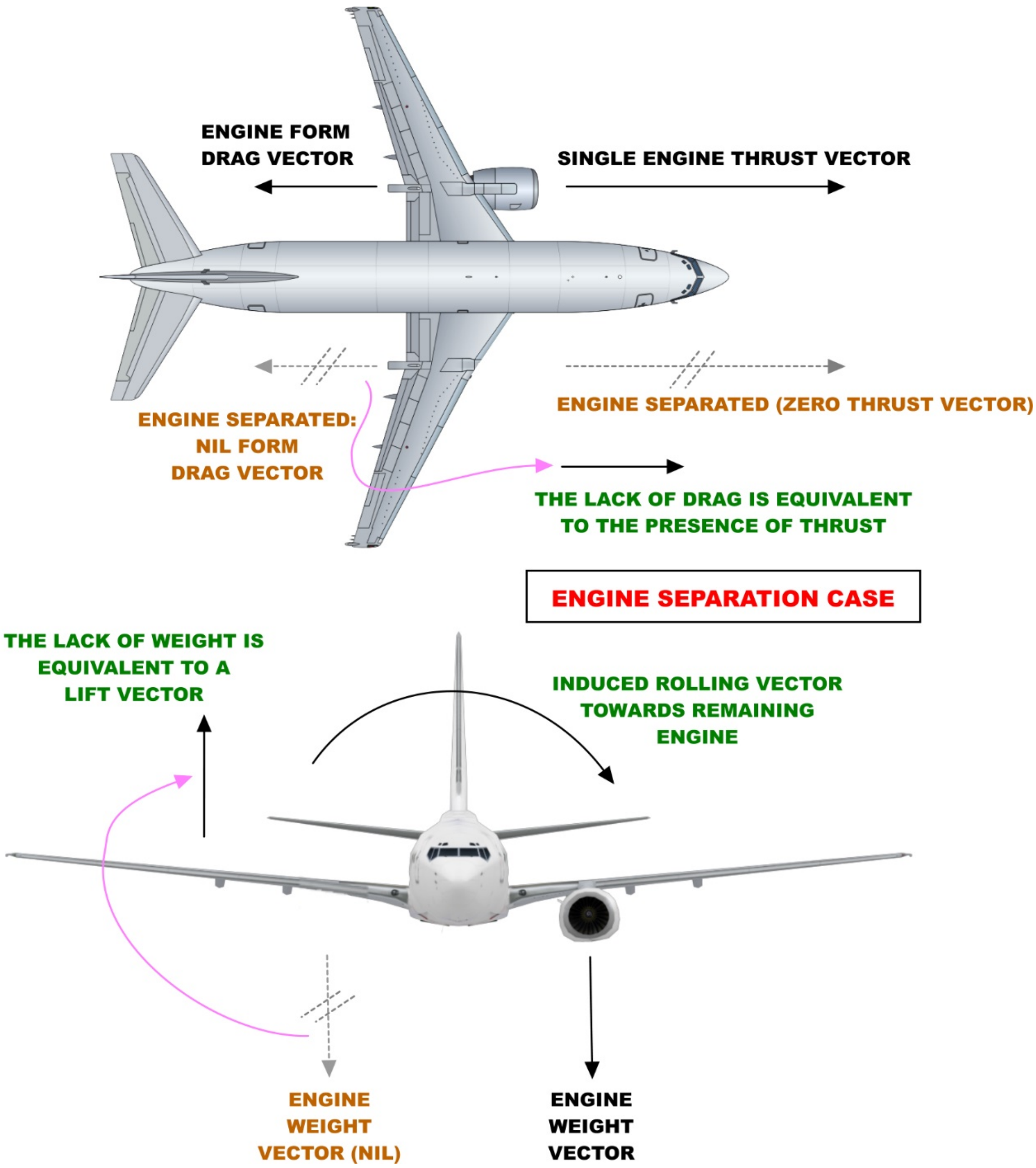
The lower the live engine thrust, the more this effect applies. It may feel and look odd in the simulator (depending how the simulator flight software is programmed) but it should be correct!

Here's some diagrams to explain the physics – *as I understand it.*



Normal engine physics vectors


ENGINE FORM
DRAG VECTOR
SINGLE ENGINE THRUST VECTOR
ENGINE FORM
DRAG VECTOR
ENGINE FAILED (ZERO THRUST VECTOR)
ENGINE FAILURE CASE
ROLL EQUILIBRIUM
ENGINE
WEIGHT
VECTOR
ENGINE
WEIGHT
VECTOR


ENGINE FORM
DRAG VECTOR
SINGLE ENGINE THRUST VECTOR
ENGINE SEPARATED:
NIL FORM
DRAG VECTOR
ENGINE SEPARATED (ZERO THRUST VECTOR)
THE LACK OF DRAG IS EQUIVALENT
TO THE PRESENCE OF THRUST
ENGINE SEPARATION CASE
THE LACK OF WEIGHT IS
EQUIVALENT TO A
LIFT VECTOR
INDUCED ROLLING VECTOR
TOWARDS REMAINING
ENGINE
ENGINE
WEIGHT
VECTOR (NIL)
ENGINE
WEIGHT
VECTOR

CABIN CREW OR PASSENGER REPORTS OF ENGINE DAMAGE OR LEAKS

It is better to have a qualified person to assess the engine, before taking any action in the absence of cockpit abnormal indications. 'Leakage' reported in the vicinity of an engine may be condensed water or de-icing fluid. It still could be fuel or hydraulic fluid from a leak, in which cases, there would be a cockpit indication in time.

REVERSER INADVERTANT DEPLOYMENT IN FLIGHT

This is far less likely nowadays due the various physical and electronic logic preventions installed. A reverser unlocked caution is more likely on taxi-in after landing when the reversers have not stowed properly after normal use. In flight, the following checklists apply:

NNC **BASIC CHECKLIST FLOW**

REVERSER **REVERSER**

NOT FOR OPERATIONAL USE

Condition: a fault occurs in the reverser system

Note: Additional system failures may cause in-flight deployment

1. *Expect normal reverser operation after landing*

■ ■ ■ ■

NNC **BASIC CHECKLIST FLOW**

REVERSER UNLOCKED (IN FLIGHT)

NOT FOR OPERATIONAL USE

Condition: The amber REV indication shows with uncommanded reverse thrust.

Note: Only multiple failures could allow the engine to go into reverse thrust. Unstowed reverser sleeves produce buffet, yaw, roll and increased airplane drag.

1 Check movement of the forward thrust lever on the affected engine.
The EECs prevent power above idle if the related thrust reverser has moved from the stowed position.

Warning! Do not actuate the reverse thrust lever.

2 Choose one:

*- Engine **responds** to forward thrust lever movement **and no** buffet or yaw exists: Continue normal operation.*

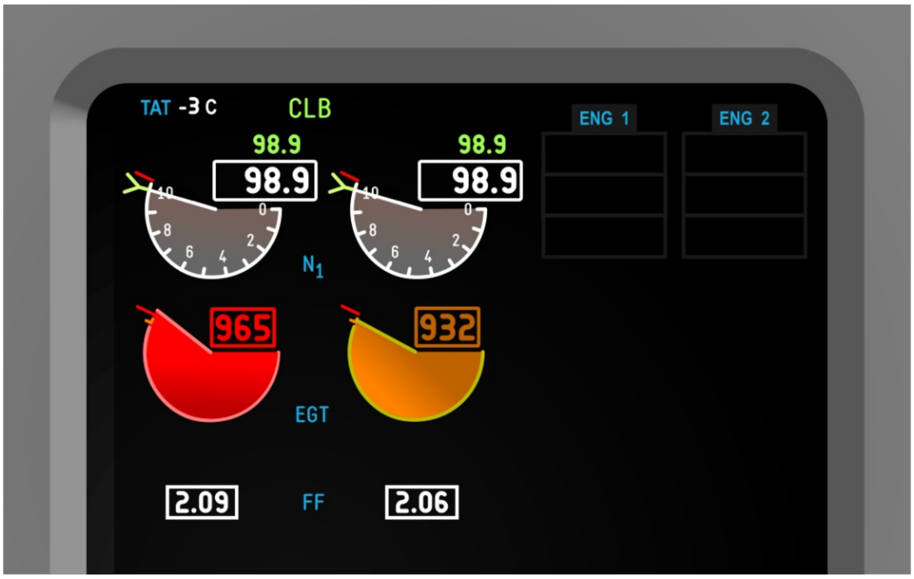
■■■■

*- Engine does **not** respond to forward thrust lever movement **or** buffet or yaw **exists**:*

►►Go to the Engine Failure or Shutdown checklist on page 7.14

■■■■

ENGINE LIMIT INDICATIONS



EGT exceedences: the left engine is above the redline (950°C), the right engine is above the maximum continuous limit (950°C - caution range)

Note: even if the EGT cools below the redline (left engine here), the numbers box remains red after shutdown. This is reset on the next engine start or if the relevant has the start switch selected to CONT (re-initializing the EEC). An engineering inspection is required post-flight.

COMPRESSOR STALL AND COMPRESSOR SURGE

At low altitude and high power settings, compressor surge/stall is almost always accompanied with a loud BANG. This may repeat as continuous BANGING. Because of the immediate loss of thrust on that side, a large and violent yaw can be experienced when the engines are at high power settings. This is a real attention-getter. Some crews, experiencing engine surge/stall have likened the sound and jolt as a bomb going off, or the aircraft falling apart.

At high altitude and cruise power settings, engine surge is less likely due to steady state, but the bangs may be muffled and less noticeable. High altitude engine surges would rarely occur during steady engine power settings, but rather when power is advanced for enroute climb. Modern engines would seem resilient to this, compared to earlier designs. Ingestion of ice crystals, or turbulence, might be a cause of engine surge or stall at high altitudes .

I've seen (as an S/O) an engine surge on the 767 at 1,000 feet after takeoff, with takeoff power. There was a loud bang and a big shudder through the airframe. After getting control of the engine, fuel was dumped and the aircraft was returned for landing. It was taken to the hangar for examination and it was later found that, during engine maintenance the night before, the N2 stator vanes were incorrectly adjusted by the maintenance engineers.

See this great Boeing video: https://www.youtube.com/watch?v=MQWYhsYfMxE

IMPORTANT Current simulator training does not give the physical and aural impact of engine surges/stalls and leads to a false sense of reality when it happens in the aircraft.

Fly the aircraft first, then direct attention to the engine parameters to identify the problem.

EGT may be high and variations in N1 and N2 can occur and change rapidly. Engine vibration is not likely (according to tests) but still possible. As a general rule, EGT *increases* during a surge/stall because without stall/surge, normal airflow through the engine, cools the engine.

Often surge and stall is accompanied by flames shooting out of the front and/or back of the engine. When airflow through the engine is disrupted, the high-pressure air and burning fuel in the engine must escape and it does so rapidly through either or both of the front and back of the engine. This long sheet of flame can be confused with an engine fire by observers.

To clear an engine surge or stall, reduction of thrust is generally required – to re-establish proper airflow through the engine. On rare occasions, a thrust increase will clear the engine and restore normal operation. Depending on the cause of the surge/stall, the engine may clear itself spontaneously whilst the crew are identifying the problem. If the surge or stall does not recover with thrust reduction, the NNC directs an engine shutdown. If the engine only surges at higher power settings, operate the engine for the remainder of the flight on a lower (surge-free) power setting.

NNC ENGINE LIMIT OR SURGE OR STALL - BASIC CHECKLIST FLOW

Engine Limit or Surge or Stall

NOT FOR OPERATIONAL USE

Condition: *One or more of these occur:*
•Engine indications are abnormal [may mean surge or stall, or in fact, engine damage]
•Engine indications are rapidly approaching or exceeding limits [engine limit case]
•Abnormal engine noises are heard, possibly with airframe vibration [engine surge or stall case]
•There is no response to thrust lever movement or the response is abnormal [engine stalled case]
•Flames in the engine inlet or exhaust are reported [engine surge case]

Objective: *To attempt to recover normal engine operation or shut down the engine if recovery is not possible.*

1 Autothrottle (if engaged) . . . . .Disengage
2 Thrust lever (affected engine) . . . . Confirm. . . . .Retard until engine indications stay within limits or the thrust lever is closed
- [end of memory items]

3 Choose one:

*- Engine indications are **stabilized and** EGT is **stabilized or decreasing**: **Go to step 4***
*- Engine indications are **abnormal or** EGT continues to **increase**: **Go to step 6***

For step 4: Check that RPM and EGT follow thrust lever movement. [this indicates that the airflow through the engine is not stalled]

4 Thrust lever (affected engine). . . . . Advance slowly [to prevent restall or surge]

5 Run the engine normally or at a reduced thrust setting that is surge and stall free.
■ ■ ■ ■

6 Engine start lever (affected engine) . . . . . . Confirm . . . . . CUTOFF
7 PACK switch (affected side) . . . . OFF
This causes the operating pack to regulate to high flow in flight with flaps up.

8 Choose one:

*- APU is **available** for start:*
  APU . . . . START
  ***When** APU is running:*
  APU GEN switch (affected side) . . . . .ON
  *►► **Go to step 9***
*- APU is **not** available:*
  *►► **Go to step 9***

9 Balance fuel as needed.

10 Transponder mode selector . . . . TA ONLY
  This prevents climb commands which can exceed single engine performance capability.
11 ISOLATION VALVE switch. . . . . Verify AUTO
  This ensures bleed air is available to both wings if wing anti-ice is needed.
12 A restart may be attempted if there is N1 rotation and no abnormal airframe vibration.

13 Choose one:

*Restart **will** be attempted: **Go to the Engine In-Flight Start checklist on page 7.20***

■ ■ ■ ■

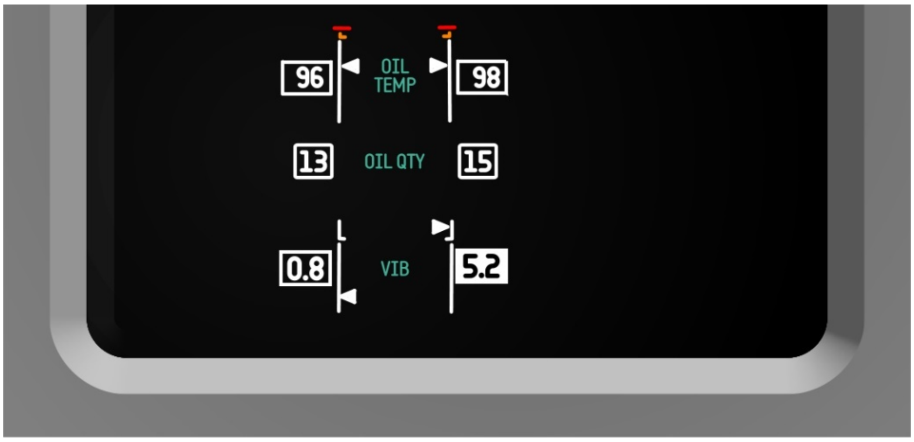
*Restart will **not** be attempted: **Go to step 14***

14 Plan to land at the nearest Available Airport.
Note: Do not use FMC fuel predictions. [FMC distance and times, based on programmed speed and altitude, will be correct. Fuel estimates assumes both engines working, so those will be incorrect]

►►***Go to the One Engine Inoperative Landing checklist on page 7.26***
■ ■ ■ ■

ENGINE HIGH VIBRATION

Refer also: (FCTM) Flight Operations Review 737-13
The engine vibration meters detect vibration in the low and high pressure engine rotors.



High Engine Vibration (note the inverse video display)

Engine high vibration may be an indication of (developing) engine damage. The non-normal checklist directs the actions. Other engine parameters must be carefully assessed. Engine vibration and airframe vibration may be confused with each other. Engine vibration may still be felt through the airframe. Abnormal engine indications with airframe vibration may be an indication of engine severe damage (see the condition statement for the Engine Fire or Severe Damage or Separation NNC).

With no other abnormal indications, engine vibration is likely caused by ice build-up on the engine components. In the absence of icing conditions, suspect a partial mechanical failure such as bearing damage. A catastrophic failure may ensue thereafter.

Reducing thrust on an engine with indicated high vibration may reduce the vibration. In which case, be considerate of leaving the engine running at a lower power. There are no absolute limits for engine vibration indications, although beyond 4 units is what is deemed excessive. The gauge strip on the lower DU of our aircraft does not seem to have any amber or redline. However, FCOM says the following; indicating a red line limit:

There are times when the vibration meters are not to be read 'formally': from the Ops Review:
On aircraft with AVM procedures (ie a checklist), Flight Crew should also be made aware that AVM indications are not valid:
- while at takeoff power settings
- during power changes
- or until after engine thermal stabilization.

High AVM indications can also be observed during operations in icing conditions.

After an engine shutdown, the engine may still be exhibiting high vibration due to damage. The windmill speed of a damaged engine may have a natural resonant vibration through the airframe. This should pose no risk to the structure of the rest of the aircraft.

Don't confuse this with airframe vibration, although don't rule out airframe vibration due to physical damage if there is a feasible cause – eg. Birdstrike.

Note: some aircraft have a DU 'pop-up' when the vibration exceeds a certain value

NNC **BASIC CHECKLIST FLOW**

Engine High Vibration

NOT FOR OPERATIONAL USE

Condition: *The vibration level is more than 4.0 units. Airframe vibration may or may not be felt.*

Choose one:
*- In **icing** conditions: **Go to step 2***
- Not** in icing conditions: **Go to step 6

2 ENGINE START switch (affected engine) . . . . FLT
3 Autothrottle (if engaged) . . . . .Disengage

Do the following on one engine at a time.

4 Thrust lever (affected engine) . . . . Retard to 45% N1 for five seconds, then slowly advance to a minimum of 80% N1 while monitoring engine vibration. [This is to shake ice off the engine rotors]

5 Choose one:

*- Vibration **decreases**: Continue normal operation. [the problem was ice on/in the engine]*

■ ■ ■ ■

*- Vibration does **not** decrease: **Go to step 7***

[possible engine damage]
6 Autothrottle (if engaged). . . . . .Disengage
7 Thrust lever (affected engine) . . . . Confirm. . . . . . Retard to maintain vibration levels below 4 units or until the thrust lever is closed

Note: *If the VIB indication does not decrease when the thrust lever is retarded, check other engine indications on the affected engine. If other engine indications are normal, run the engine at reduced thrust.*

■ ■ ■ ■

DIFFERENT EGT READINGS BETWEEN ENGINES

Sometimes the EGT readings between the engines at various flight stages can read differently – maybe up to 20% difference. One reason for this is that one of the engines on the wing is old and the other one is new. Differing EGT readings does not necessarily indicate a fault, nor does it require any crew actions if the readings are within normal limits.

TAILPIPE FIRE

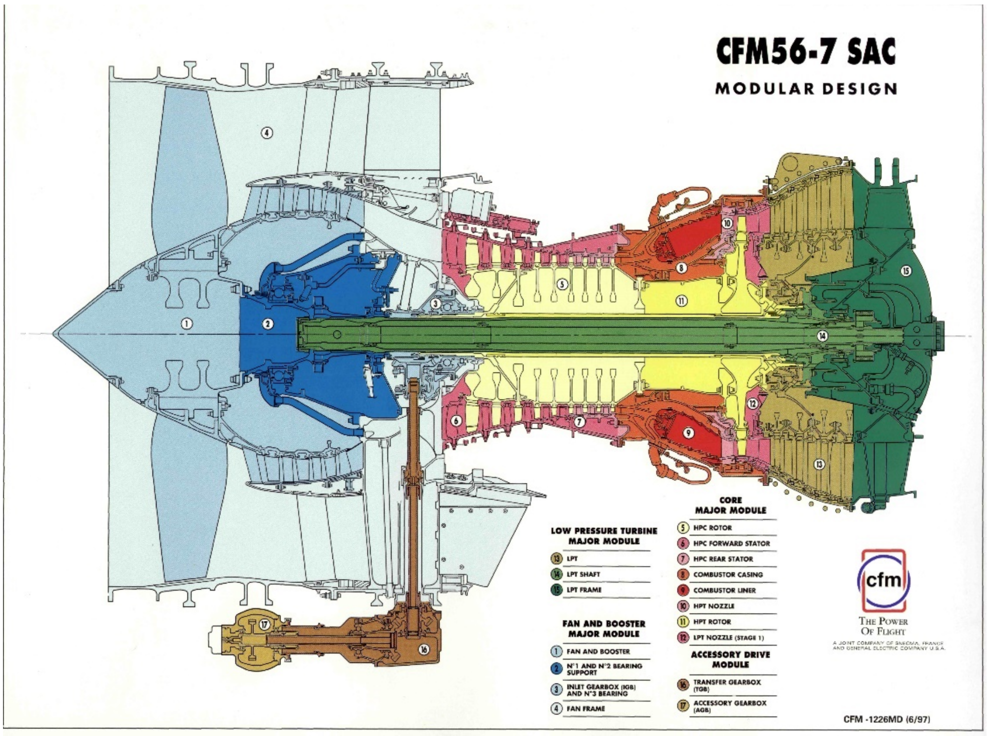
An artistic impression of a tailpipe fire

Also called "torching". This occurs generally on the ground and is not to be confused with an engine fire. Historically, tailpipe fires have occurred during engine starting or engine shutdown. After an engine is running normally, there is continuous fuel burning and rotor motion such that only a significant engine malfunction or internal airflow disruption would cause a tailpipe fire. A major engine surge or stall could result in intermittent tailpipe fire.

IMPORTANT The response to an *engine fire* is very different to the response for a *tailpipe fire*. With an engine fire, part of the actions involve shutting off high pressure air to and from the engine. For a tailpipe fire, bleed air to the engine is needed to motor the engine to clear the fuel (or oil) out of the tailpipe. The engine fire extinguishing agent is **not** effective in the tailpipe area.

Tailpipe fires can be the result of fuel feed faults during startup; if too much fuel is fed to the engine during windup, some of it can be ejected and ignited in the tailpipe. Another reason is with a mishandled wet start; excess fuel in the tailpipe ignites once the engine experiences ignition.

Here's a video of a tailpipe fire:
https://www.youtube.com/watch?v=GnrFvrsidKo



CFM-56 Cross-section (CFM website)

The compressed air and fuel mixture is normally burnt in the combustion chamber (red section above) and the pressurised hot exhaust gas is used primarily to drive the high-pressure turbine (HPT) rotors (beige colour above). If fuel is not bunt in the combustion process, it may be passed through the HPT and into the exhaust area of the engine and ignite, resulting in many cases in a visible sheet of flame.

There is most likely **no** cockpit indication of a tailpipe fire. There are four separate dualized (8 total) engine fire/overheat detector loops inside the engine cowl, wrapped around parts of the core of the engine – 2 around the fan case, and 2 around the section where the high pressure turbine joins the combustion chamber. An engine tailpipe fire will be reported by visual observation from the tower, another aircraft, or (more likely) the engineer on the nose gear headset during engine start or shutdown. It is possible that the cabin crew could observe a tailpipe fire from within the cabin.

⚠ An untrained person might report a tailpipe fire as an *engine fire.*

Depending on the location of the fire within the tailpipe, EGT may display as increased.

TAILPIPE FIRE CHECKLIST

The procedure to address an engine tailpipe fire is totally different to that used for and engine fire overheat condition.

BASIC CHECKLIST FLOW

Whilst the PM is accessing the checklist, a call to the ARFFS should made without delay. You would want them in attendance as soon as possible.

Engine Tailpipe Fire

NOT FOR OPERATIONAL USE

Condition: An engine tailpipe fire occurs on the ground with no engine fire warning.

1 Engine start lever (affected engine) . . . . CUTOFF
2 Alert Order PA . . . . Announce "Attention! All passengers remain seated and await further instructions." [this indicates to the cabin crew that you are aware of the fire/problem and addressing it. The alert PA is to avoid a cabin initiated evacuation]

3 Choose one:

*Bleed air is **available**: **Go to step 4***
*Bleed air is **not** available: Advise the tower. [nothing else you can do. Attempt contact with any party on the ground who can advise the state of the engine. Is it getting better or worse? Consider an evacuation]*

■ ■ ■ ■

[using bleed air and the engine starter to spin and clear the engine of unburnt fuel]
4 PACK switches (both) . . . . OFF
5 ISOLATION VALVE switch. . . . . AUTO
6 Engine BLEED air switches (both) . . . . .ON

7 Choose one:

*APU is **running**:*
APU BLEED air switch . . . . .ON
*►► **Go to step 8***
*APU is **not** running:*
*►► **Go to step 8***

8 Choose one:

*Affected ENGINE START switch is in **GRD**: [engage the starter]*

*►►**Go to step 9***

*Affected ENGINE START switch is **not** in GRD:*

Allow the affected N2 to decrease below 20%.

ENGINE START switch (affected engine) . . . . .GRD

*►►**Go to step 9***

9 Advise the tower. [who engage ARFFS; don't forget to mention fire!]

*10 **When** the tailpipe fire is extinguished:*

ENGINE START switch (affected engine) . . . . AUTO

■ ■ ■ ■

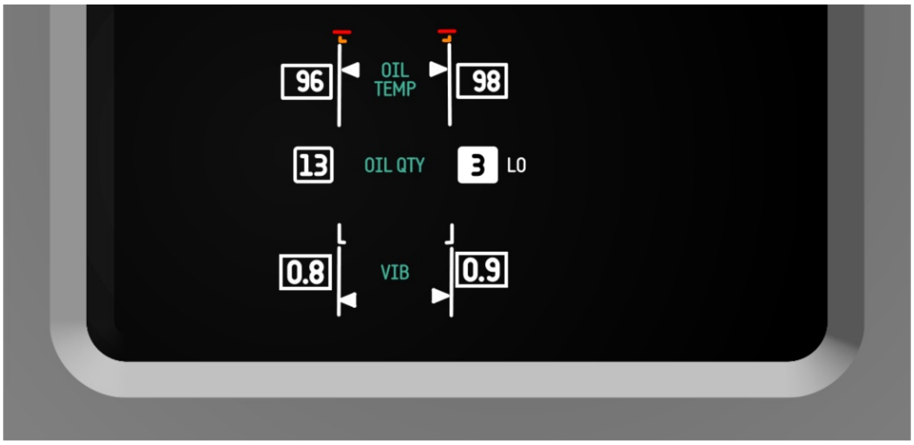
ENGINE START ATTEMPTS WITH IGNITER FAULTS

This is one case where a tailpipe fire becomes more likely.
If an igniter has failed, the start will be a wet start. Any subsequent start attempts will have a risk of tailpipe fire if the unburnt fuel has not been cleared properly. After a wet start event, the engine should be motored to clear unburnt fuel before any further fuel is added, along with ignition from a working igniter.

ENGINE OIL ABNORMALITIES

LOSS OF ENGINE OIL QUANTITY IN FLIGHT

This is indicated by the oil quantity display in inverse black and white, with the word “LO” adjacent to the oil quantity display.



Low Oil Quantity Indication

A steady decrease in oil quantity could indicate an oil leak or a high oil consumption due to engine damage.

Depending on the age and condition of the engine, normal oil consumption rates are far below 1L/Qtz per flight hour. Note 1L ~ 1 Qtz.

A large INCREASE in oil quantity might be from fuel leaking into the oil system. The aircraft should be grounded if this occurs.

A loss of oil quantity in the engine might be indicated by a number of confirming parameters:
* oil quantity reading low or zero
* oil pressure reading low on gauge and amber OIL LOW PRESSURE bezel light on the upper DU
* high oil temperature

If these indications do not occur together, take careful consideration before shutting down the engine.

A sudden zero indication of oil quantity without any other abnormal indications is probably a failure of the oil quantity sensor, or discontinuity in the associated wiring or electrical connector plugs.

If a slow loss of engine oil is occurring, the oil pressure will reduce over time – so anticipate an engine shutdown. It’s better to shut down the engine in a controlled manner rather than have it fail catastrophically at an inopportune time. A timely shutdown also saves the engine.

There is no MINIMUM oil quantity when INFLIGHT. For the engine variant I fly, Boeing now specifies a minimum of 12 L prior to flight (the FO checks this as part of the preflight flow). The official figure is about 11.6 L, but the oil quantity display does not have a decimal place.

There is **no** NNC for engine low oil quantity.

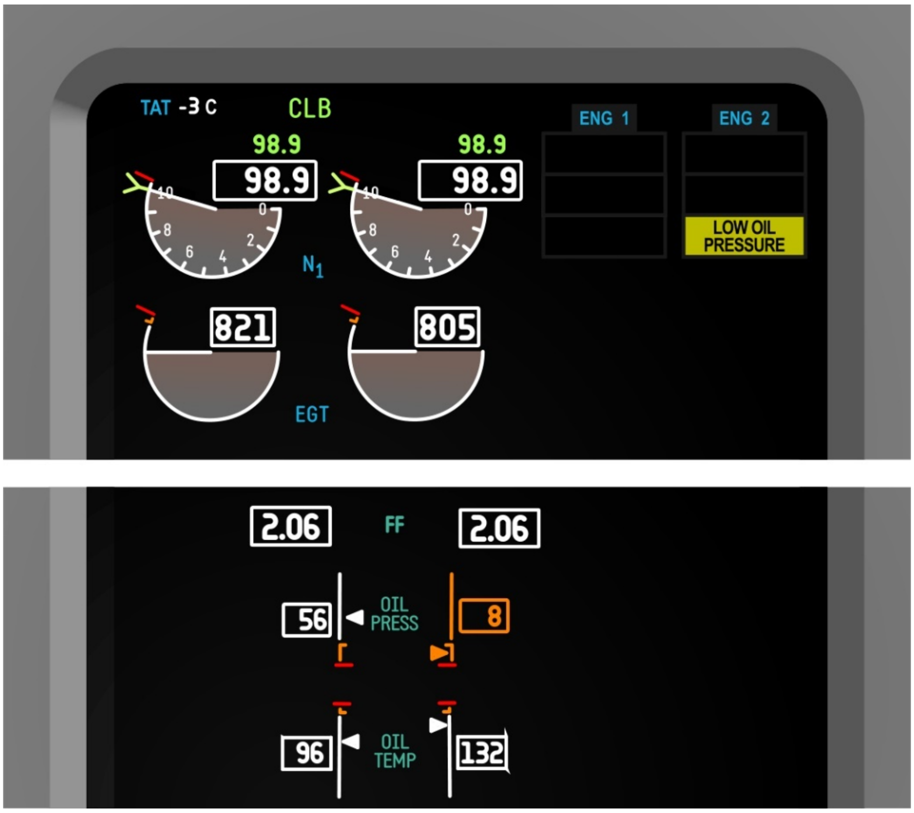
The manufacturer says that an engine can run effectively inflight with about 6 L of oil.

The oil-related non-normal checklists are:
* ENGINE LOW OIL PRESSURE
* ENGINE OIL FILTER BYPASS
* ENGINE HIGH OIL TEMPERATURE

The oil <u>pressure</u> is determined by 2 separate sensors. One is for the low oil pressure bezel <u>light</u> (on the upper DU) and the other for the oil pressure vertical strip <u>gauge</u> on the lower DU.

Low oil pressure determination is variable: for N2 below 65%, there is no amber band on the oil pressure gauge. With N2 above 65%, the amber band begins at a PSI number dependent on actual N2.

NNC ENGINE LOW OIL PRESSURE - BASIC CHECKLIST FLOW **(not for operational use)**



Low Engine Oil Pressure (shown by **both** sensors: bezel (upper DU) and gauge (lower DU)

ENGINE LOW OIL PRESSURE

NOT FOR OPERATIONAL USE

Condition: *The engine oil pressure is low. The LOW OIL PRESSURE alert may or may not be illuminated.*

Choose one:

- Engine oil pressure is in the ***amber band*** *with* ***takeoff thrust*** *set:*

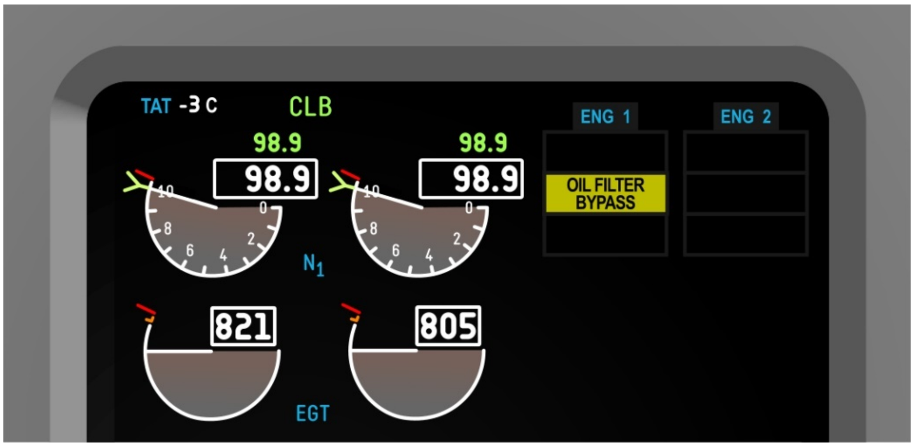
Do ***not*** *takeoff. [this would be a default indicator to reject a takeoff; thrust set, then engine low oil pressure indication. It is a pseudo memory procedure]*

■ ■ ■ ■

- Engine oil pressure is ***at or below*** *the* ***redline****:* ***Go to the Engine Failure or Shutdown checklist on page 7.14***

■ ■ ■ ■

OIL FILTER BYPASS - BASIC CHECKLIST FLOW



Oil Filter Bypass Indication

ENGINE OIL FILTER BYPASS

NOT FOR OPERATIONAL USE

Condition: The OIL FILTER BYPASS alert indicates oil filter contamination can cause oil to bypass the oil filter.

1 Autothrottle (if engaged). . . . . .Disengage

2 Thrust lever (affected engine) . . . . . . Confirm . . . . . . Retard slowly until the OIL FILTER BYPASS alert extinguishes or the thrust lever is closed

3 Choose one:

*- OIL FILTER BYPASS alert **extinguishes**: Run the engine at reduced thrust to keep the alert extinguished.*

■ ■ ■ ■

*- OIL FILTER BYPASS alert **stays illuminated**: **Go to the Engine Failure or Shutdown checklist on page 7.14***

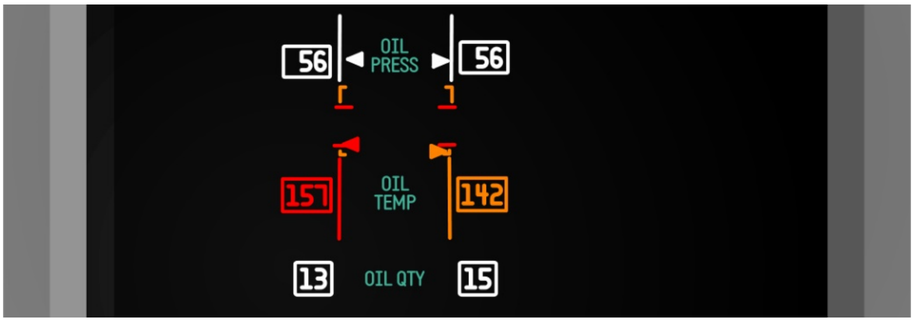
■ ■ ■ ■

HIGH OIL TEMPERATURE INDICATION

This indicates some unnatural source of heat in the engine (eg. a bearing problem). Engine damage, loss of oil quantity, hot bleed air leaking in to the oil system and sump fire, are some possible causes. Note that engine oil temperature above the redline is also an 'engine limit' scenario. The Engine Limit or Surge or Stall non-normal checklist can also apply. And it happens to be the same procedure as the checklist below; both lead to shutting down the engine, if retarding thrust does not solve the problem. The oil pump flow is engine RPM-dependent, so an *increase* in thrust may actually resulting a cooler and stronger flow of oil through the engine. You will note that when engine power is increased, oil pressure increases.

If the temperature is in the (amber) caution range only, there are a few actions that may assist. One is to climb to a higher altitude where the OAT is lower. Another is to get out of a convective cloud, where temperature can be up to 15 degrees warmer than the surrounding air mass. These might cool the whole engine and bring the oil temperature down with it.

HIGH OIL TEMPERATURE - BASIC CHECKLIST FLOW



High Oil Temperature Indication (left engine: above redline, right engine: in caution range)

Engine High Oil Temperature

NOT FOR OPERATIONAL USE

Condition: The engine oil temperature is high.

*- If Temperature is **at or above** the **redline**: go to the **Engine Failure or Shutdown** checklist on page 7.14*

*- If Temperature is in the **amber band**:*
Disengage the autothrottle
Thrust lever (affected engine)…… Confirm ….. Retard slowly until the engine oil temperature is within normal operating range or the thrust lever is closed

*- If the oil temperature is in the amber band for 45 minutes or **less**: run the affected engine at a thrust setting that keeps the oil temperature within the normal operating range.*

*- If the oil temperature is in the amber band for **more than** 45 minutes: go to the **Engine Failure or Shutdown** checklist on page 7.14* ■ ■ ■ ■

OTHER

HIGH FUEL FLOW INDICATION

May be an indication of a fuel leak between the fuel metering unit and the engine nozzles.

ENGINE AFFECTED BY ICE CRYSTALS

Flight Operations Technical Bulletin 737-TB-12 & FCOM SUPP.PROC 16 - ADVERSE WEATHER

Minute ice crystals may be present to the side of, or above thunderstorms or other highly convective clouds when in IMC. Typically, turbulence is experienced in these periphery cloud formations. The TAT reads quite differently to that expected and is often near zero degrees (C).

Ice crystals cannot be detected by aircraft weather radar but recent satellite technology can detect their presence.

These crystals bounce off the airframe but when they hit the engine, the warmer engine components cause them to melt and adhere to the parts of the engine. Layers of ice can form as more ice crystals are ingested. Engine power loss has occurred as a result and this has been at levels between 11,000' and normal cruise levels.

⚠ If engine performance is affected, ensure that the anti-ice is selected ON. Avoid thunderstorms by at least 20 miles and fly upwind of them. Do not fly over the top of thunderstorms or towering cumulus clouds in IMC. If the air is clear over the top of a thunderstorm then it can be overflown – a possibility more relevant though, to corporate aircraft with high altitude capability.

REVERSER AND/OR ENGINE CONTROL LIGHTS ON AFTER STOWING REVERSE ON LANDING

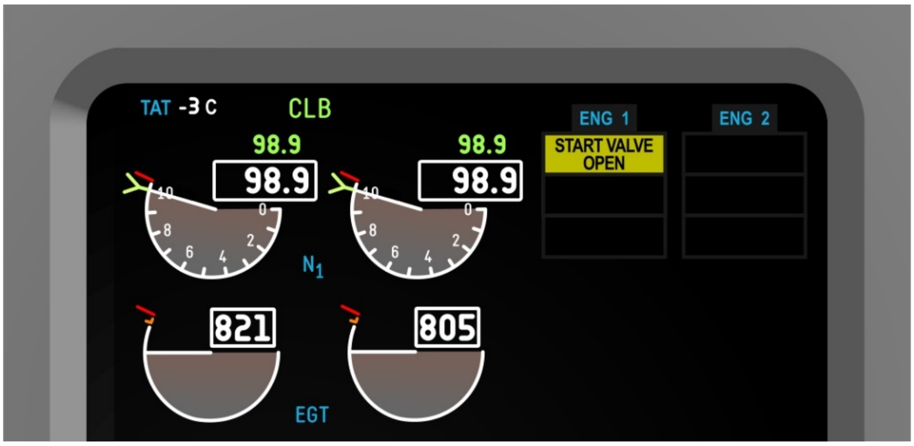
Flight Operations Technical Bulletin 737-TB-25 (FCTM) applies.
If the reversers are stowed too slowly (>8 seconds or >16 seconds are key figures) after landing then the reverser lights may come on and also the engine control lights. Depending on how slow the reversers are stowed (from idle detent to down detent), the problem may be rectified by cycling the reversers. An engine control light must be attended by engineers, after docking and engine shutdown.

FUEL LEAK OUT OF THE BOTTOM IF THE ENGINE DURING ENGINE WIND-UP AND START

Fuel may be leaking from the engine drain area immediately after engine start.
FCTM Flight Operations Bulletin 737-xxx-01 (option) applies. Cold weather may exacerbate the problem. A leak rate of up to 90 drops per minute is acceptable for dispatch. So after engine start, if fuel is leaking at a rate of up to 90 drops per minute, the ground engineer should remain on the headset and monitor the engine for up to 5 minutes with it running at idle. If the leak rate remains at less than 90 drops per minute, or stops, the aircraft can dispatch normally. If the fuel leak rate is more than 90 drops per minute or is a stream of fuel, at any time after engine start, the engine should be shut down.

With a fuel leak experienced after engine start, the problem may be remedied by a shutdown and restart of the engine. If that does not work, engineering attention is required. A conservative approach is recommended overall.

START VALVE OPEN



Start Valve Open Indication

This condition is also addressed in the *Engine Starting* document. It is most likely to occur when the engine start valve fails to close after an engine start sequence.

The START VALVE OPEN indication occurs when air pressure between 10-45 PSI is supplied to the starter air line and the butterfly start valve is ajar (greater than 3.5 degrees open). It is possible that a faulty valve can be commanded closed, but not actually fully closed (I have seen it). If the START VALVE OPEN bezel blinks for 10 seconds before remaining on, it means that the start valve has opened without any logic command to open it.

The NNC first attempts to manually switch off the engine starter by selecting the start switch to AUTO: closing the engine start valve. If that doesn't work, bleed air must be removed from the starter line, to avoid engine starter damage. The engine starter is connected to the N2 accessory drive system.

START VALVE OPEN - BASIC CHECKLIST FLOW

START VALVE OPEN

NOT FOR OPERATIONAL USE

Condition: The START VALVE OPEN alert indicates the start valve fails to close.

1 ENGINE START switch . . . . AUTO

2 Choose one:

*- START VALVE OPEN alert **extinguishes**:*
■ ■ ■ ■

*- START VALVE OPEN alert **stays illuminated**: **Go to step 3***
[steps 3-5 remove air from the starter line]
3 ISOLATION VALVE switch . . . . CLOSE
4 PACK switch (affected side) . . . . OFF
This causes the operating pack to regulate to high flow in flight with flaps up.
5 Engine BLEED air switch (affected side) . . . . OFF

6 Choose one:

*- START VALVE OPEN alert stays illuminated for **engine 1**:*
APU BLEED air switch . . . . OFF
►►***Go to step 7***

*- START VALVE OPEN alert stays illuminated for **engine 2**:*
►►***Go to step 7***

7 Choose one:

***In flight**:*
WING ANTI-ICE switch . . . . OFF
This prevents possible asymmetrical ice buildup on the wings. Avoid icing conditions where wing anti-ice is needed.
■ ■ ■ ■

*On the **ground**:*
Ground air source (if in use) . . . . Disconnect
Engine start lever (affected engine) . . . . CUTOFF
■ ■ ■ ■

COMPRESSOR WASHES

This video shows how a compressor wash is done:
https://www.youtube.com/watch?v=YAeG2VcTXtg

Compressor washes are performed as per engine manufacturer recommendations to remove contaminants from the engine compressor and stator blades. Cleaner blades mean better aerodynamic performance. The cleaner components also improve engine thermal efficiency. Regular compressor washes optimize engine performance.

Compressor washes should be annotated in the aircraft techlog. For the first flight after a compressor wash, there can be expected to be a chemical odor through the packs and into the cabin, on engine starting and most especially on setting of takeoff thrust. I warn the cabin crew about the likelihood of a chemical smell on takeoff and initial climbout, and explain why it occurs. The odor is not supposed to adversely affect one's health! It is unusual to have the smell remain beyond the takeoff and climb of the first flight. A [engine] *bleed off* takeoff (APU supplying bleed) may be an option to reduce the cabin smell during the departure.

A new compressor wash system with detergent recovery.

MANAGEMENT

PERIODIC ENGINE PARAMETER VIEWING

Whilst engine limits or problems will be graphically (and possibly aurally) brought to the attention of the pilots, it is beneficial to periodically assess the upper and lower DU pages and the SYS page for engine performance. This involves a regular scan of these of these, and indeed all of the cockpit panels during cruise. Many airlines have this a written policy. In doing so, you may detect a developing problem before it becomes an emergency or otherwise out of hand.

ENGINE LIMIT (OR SURGE OR STALL) CHECKLIST VERSUS SPECIFIC REFERENCE CHECKLIST

In the case of N1 or N2 going over redline, there is no specific reference checklist, so the Engine Limit or Surge or Stall non-normal checklist is used. In the case of engine oil temperature redline or engine oil pressure redline, there is a specific reference checklist. But these are also engine limit cases – so which checklist do you use? There is no straightforward answer to that question. The Engine Limit or Surge or Stall non-normal checklist will have thrust reduction as a priority and will take the workload off the engine. It may even bring an overtemperature into limits. Reducing thrust may avoid engine damage. The specific reference checklists direct an engine shutdown and this will take significantly more time as the checklist is found and the actioned in a timely manner – including setting up MCP, AP modes, Max continuous thrust, etc, as the checklist proceeds to shut down the engine. Using the reference checklist allows more time to manage the engine shutdown, yet there is more time for the engine to irrevocably damage itself. This is the quandary!

Note that with an engine limit, the **PF** does not need to wait for the checklist to be read to roll back thrust, after identification of the problem is agreed by both pilots.

FLIGHT PATH MANAGEMENT

If an engine rolls back or fails unexpectedly, flight path management is the primary concern.

- set attitude
- set thrust on the live engine to maintain a suitable speed (slowing down might be of benefit)
- use CON on the N1 limit page (or engine-out climb or cruise pages) as a maximum thrust setting if required to maintain speed
- be aware of maximum altitude capability of the aircraft if the failure occurs in cruise or high in the climb (VNAV ENG OUT page)

PREPARATION FOR A CONTROLLED ENGINE SHUTDOWN

⚠ When an engine shutdown is directed by a checklist, it is rather foolish to just start the engine failure/shutdown checklist and **then** think about flight path management as the thrust lever is retarded to idle. The flight state on one engine should be considered before the checklist is begun, or at least before you action the shutdown by reducing thrust & setting the start lever to cutoff. Some considerations should be:

- what's happening in the cabin? Is there a service in progress? Consider seating everyone down. Signs ON
- APU start in advance for use of the generator
- TCAS traffic selector to BLW
- weather radar: consider weather below
- anti-ice required?
- airspace below: will you be OCTA? (eg. descent below FL245 in middle Australia)
- effect on endurance and fuel burn to destination
- ATC: clearance to a lower level pre-approved
- Maximum E/O altitude
- E/O drift-down speed
- CON thrust on live engine: what N1?
- ready for rudder/rudder trim input

When the checklist prescribes a cooldown of the engine prior to shut down – some of this can be done. Before the power is set to idle, at the very least, CON setting should be known and ready to set on the live engine. Engine-out max altitude should be known and set on the MCP ready for level-off or for descent and rudder/rudder trim input should be anticipated.

As part of the engine failure/shutdown non-normal checklist, (**PM**) close the thrust lever slowly. This is for 2 reasons:

- if the wrong engine is chosen, flight control is not lost as the thrust does not have to be put back up from idle
- it allows easier flightpath control for the **PF** and transition to single engine flight, if the engine was not already shutdown

ENGINE INFLIGHT START CHECKLIST

Manufacturers say that engine starts are not *assured* outside the in-flight start envelope. Depending on the engine condition and the environmental conditions, an engine restart may not be assured at all. Conversely, this does not mean that an engine restart cannot be achieved **outside** the published in-flight start envelope, using either windmill or crossbleed start methods.

As always, the important thing is to fly the aircraft first and the **PF** should be devoted to flightpath, navigation and configuration management. The Engine In-Flight Start checklist is straightforward enough and the **PM** would run this end-to-end, until either engine is restarted, or the restart attempt is abandoned and the Engine Inoperative Landing checklist is pursued.

ENGINE IN-FLIGHT START BASIC CHECKLIST FLOW

Engine In-Flight Start

NOT FOR OPERATIONAL USE

Condition: An engine start is needed and all of the following are true:
*•There was **no** engine fire*
•There is N1 rotation
*•There is **no** abnormal airframe vibration.*

Note: Oil quantity indication as low as zero is normal if windmilling N2 RPM is below approximately 8%.

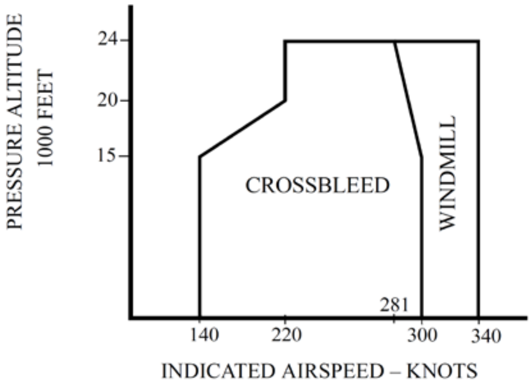
*1 Do this checklist **only** after completion of the Engine Failure or Shutdown checklist or as directed by the Engine Limit or Surge or Stall checklist or by the Loss of Thrust on Both Engines checklist.*

*2 Check the In-Flight Start Envelope. X-BLD or XB indication may not match the envelope. Starts are not **assured** outside of the In-flight Start Envelope.*

Note: For engines shut down one hour or more, or if EGT is less than 30°C, attempt a restart:
•At an altitude at or below 20,000 feet
•With airspeed at or above 220 knots
•Using a crossbleed start.

If the N2 is less than 8%, ENGINE START switch must be in CONT to display the EGT

IN-FLIGHT START ENVELOPE



3 Thrust lever (affected engine) . . ……... . . . Confirm . . . . Close
4 Engine start lever (affected engine) . . . . . . Confirm . ….. . . . CUTOFF

5 Engines can accelerate to idle very slowly, especially at high altitudes or in heavy precipitation. If N2 is steadily increasing and EGT stays within limits, do not interrupt the start.

6 Choose one:

*7 **When** N2 is at or above 11%:*
Engine start lever (affected engine) . . . . IDLE detent

Monitor EGT to ensure it does not rise rapidly or exceed the start limit of 725° C during the start attempt.

Windmill start:
ENGINE START switch (affected engine) . . . . FLT

Crossbleed start:
PACK switch (affected side). . . . . OFF
DUCT PRESSURE . . . . . . Minimum 30 PSI
Advance the thrust lever to increase duct pressure if needed.
ENGINE START switch (affected engine) . . . . .GRD
***When** N2 is at or above 11%: Engine start lever (affected engine) . . . . IDLE detent*
Monitor EGT to ensure it does not rise rapidly or exceed the start limit of 725° C during the start attempt.

Choose one:

*- EGT **increases** within 30 seconds **and** a normal start occurs: **Go to step 10***

*- EGT does **not** increase within 30 seconds **or** another abort start condition as listed in the Normal Procedures occurs:*
Engine start lever (affected engine) ……... . .Confirm . ….. . CUTOFF
ENGINE START switch (affected engine) . . . . AUTO

***Note:** If the engine has been shutdown for more than one hour, multiple start attempts can be needed.*

9. Plan to land at the nearest Available Airport.
Note: *Do not use FMC fuel predictions.*

Go to the One Engine Inoperative Landing checklist on page 7.26
■ ■ ■ ■

10 Engine GEN switch (affected side) . . . . .ON
11 PACK switch (affected side) . . . . AUTO
12 ENGINE START switch . . . . .As needed
13 APU . . . . .As needed
14 Transponder mode selector . . . . .TA/RA
■ ■ ■ ■

REVERTING SYSTEMS AND CONFIGURATION AFTER A SUCCESSFUL ENGINE RESTART

The Engine In-Flight Start checklist takes care of system reversions after a successful single engine restart.
These include:
- Electrics
- Air systems
- Engine Start Switches
- Transponder modes

Note: hydraulic systems should recover without any switching.
Other systems, such as the yaw damper, may have tripped offline.

A good airmanship procedure, after an engine inflight restart is to add the following:
- a total panel scan: looking for orange lights
- a RECALL to bring up any latent systems failed or offline
- a scan of the circuit breaker panels to see if anything has tripped off

Any system faults found, should be addressed using the relevant non-normal checklists. The non-normal checklist procedures assume that all switches are in their normal state (see NNC introduction). It is appropriate, in some cases, to just switch some systems back on. Take time; think about it!

In certain checklists, such Volcanic Ash, Loss of Thrust on Both Engines, there are no reversionary actions. Examining the Volcanic Ash checklist, if thrust is lost on both engines, and subsequently they are restarted, the **checklist must be run in reverse** to reconfigure the systems (and especially for pressurisation if you have gone to *manual* mode because of cabin depressurisation). A panel scan (etc) as above is also recommended.

ONE ENGINE INOPERATIVE LANDING CHECKLIST

This checklist is directed from other checklists where an engine has been shut down or has failed. The checklists sets up the aircraft for a single engine landing and it includes systems configurations and some management guidelines.

In cases where the engine is not shutdown, but run at a lower thrust setting, parts of the checklist still apply.

An example would be high a high oil temperature indication and running the engine at idle keeps the oil temperature within the normal operating range. It could similarly apply with the engine overheat indication or the surge/stall condition. An engine at idle offers no performance-based assistance in the approach or go around so the *One Engine Inoperative Landing* checklist applies.

NNC

ENGINE IN-FLIGHT START BASIC CHECKLIST FLOW

One Engine Inoperative Landing

NOT FOR OPERATIONAL USE

Condition: Landing must be made with one engine inoperative.

1 Plan a flaps 15 landing.
2 Set VREF 15 or VREF ICE.

Note: If any of the following conditions apply, set VREF ICE = VREF 15 + 10 knots:
- *Engine anti–ice will be used during landing*
- *Wing anti–ice has been used any time during the flight*
- *Icing conditions were encountered during the flight and the landing temperature is below 10° C.*

Note: When VREF ICE is needed, the wind additive should not exceed 10 knots.

3 Check the Non-Normal Configuration Landing Distance table in the Advisory Information section of the Performance Inflight chapter.

4 Maintain VREF 15 + wind additive or VREF ICE + wind additive on final approach to assure sufficient manoeuvre margin and speed for go-around. The minimum wind additive is 5 knots.

5 When engine anti-ice is needed, use on the operating engine only.
6 Checklist Complete Except Deferred Items

Descent Checklist
Pressurization. . . . . LAND ALT ___
Recall . . . . Checked
Autobrake . . . . ___
Landing data . . . . ***VREF 15 or VREF ICE ___, Minimums ___***

Approach briefing . . . . Completed

Additional Go-Around Thrust *[this configures the bleed panel so that the APU supplies a single pack with bleed air and the live engine has more thrust available, with its bleed switched off. If time is urgent, and the go around path is without significant terrain, these steps can be skipped]*

Choose one:

*Additional go-around thrust is **needed**: **Go to No Engine Bleed Landing below***
*Additional go-around thrust is **not** needed: **Go to Go-Around Procedure Review Below***

No Engine Bleed Landing

***When** below 10,000 feet:*
WING ANTI-ICE switch . . . . OFF
ISOLATION VALVE switch . . . . CLOSE
BLEED 1 air switch . . . . OFF

Do not open the APU bleed air valve if the engine fire switch is illuminated.

APU BLEED air switch . . . . .ON
Left PACK switch . . . . AUTO
BLEED 2 air switch . . . . OFF

Go-Around Procedure Review
Do the normal go–around procedure except:
*- Use **flaps 1**.*
- Maintain VREF 15 + 5 knots or VREF ICE + 5 knots until reaching flap retraction altitude.
- Limit bank angle to 15° when airspeed is less than VREF 15 + 15 knots or VREF ICE + 5 knots or the minimum manoeuvre speed, whichever is lower.
- Accelerate to flaps 1 manoeuvring speed before flap retraction.

Approach Checklist
Altimeters . . . . ___

Additional Deferred Item
GROUND PROXIMITY
FLAP INHIBIT switch . . . . FLAP INHIBIT

Landing Checklist
Speedbrake . . . . ARMED
Landing gear . . . . Down
*Flaps. . . . . **15, Green light***

■ ■ ■ ■

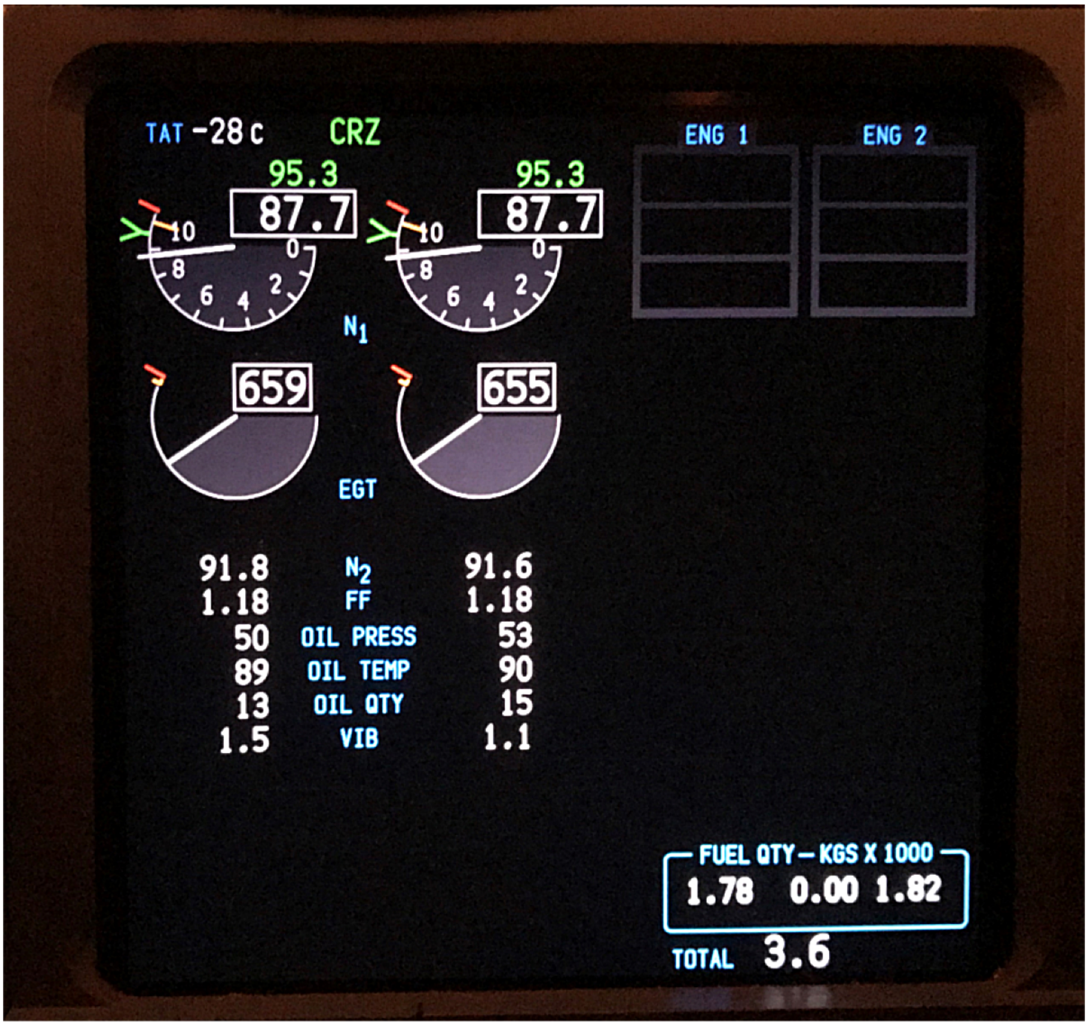
COMPACT ENGINE DISPLAY

If the lower DU fails, the upper DU will not change its regular display of N1 and EGT. Selecting the ENG button will cause the upper DU to show the *compact engine display*. This includes all engine parameters with the normal content of the lower DU in a text-type format. The SYS display selects the normal lower DU content display to the upper DU.

The compact display can be *forced* by selecting either ND to the lower DU and then selecting ENG.

Selecting the Captain's ND to the lower DU

Selection of ENG then gives the compact engine display on the upper DU (see next diagram)



The compact engine display (upper DU)