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# What is stall? How a pilot should react in front of a stall situation

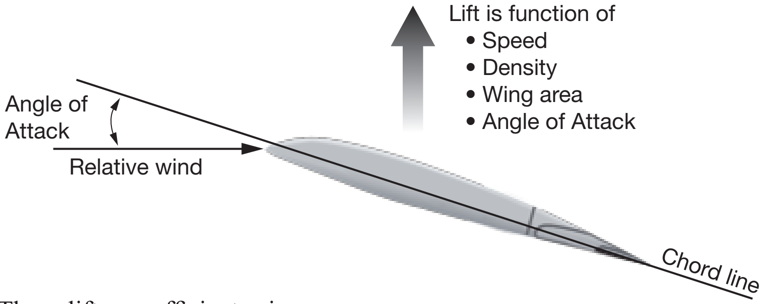
## 1. Introduction

The worldwide air transport fleet has recently encountered a number of stall events, which indicate that this phenomenon may not be properly understood and managed in the aviation community. As a consequence, the main aircraft manufacturers have agreed together to amend their stall procedures and to reinforce the training. A working group gathering Authorities and aircraft manufacturers will publish recommendations for harmonized procedures and appropriate training. This article aims at reminding the aerodynamic phenomenon associated to the stall, and the recently published new procedures.

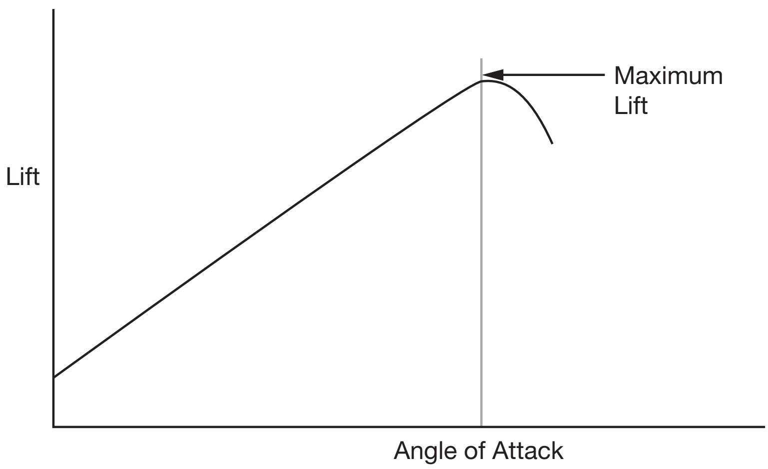
## 2. The lift

A wing generates a lift equal to $1/2\rho SV^2Cl$.

With:
$\rho$ = air density
S = wing surface reference
V = True Air Speed
Cl = lift coefficient of the wing



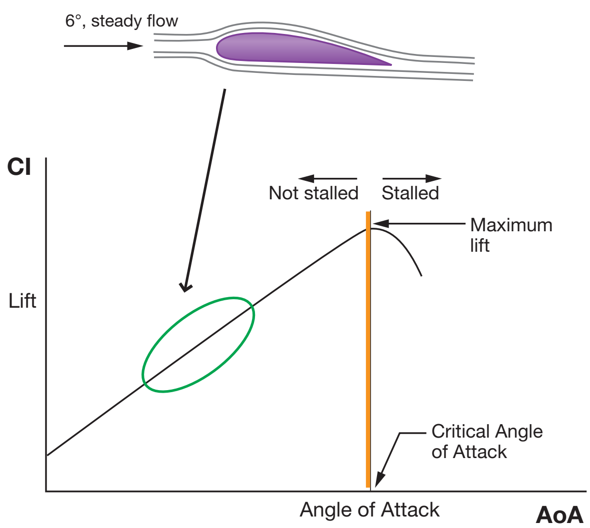

The lift coefficient increases as a function of the Angle of Attack (AoA) up to a value, called Maximum lift, where it starts to decrease.



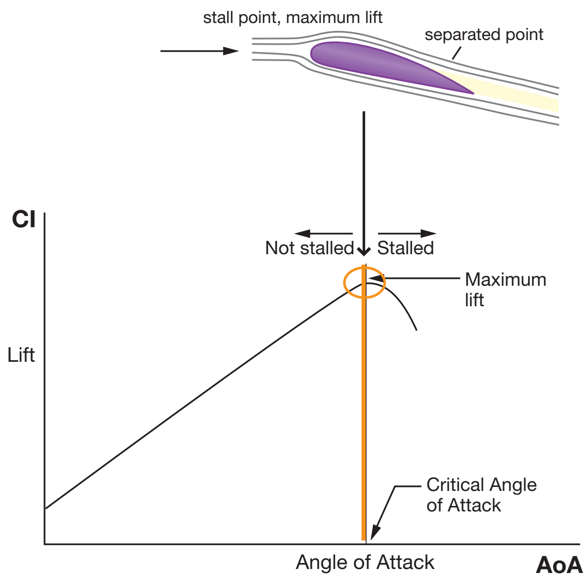

For a given configuration, a given speed and a given altitude, the lift is only linked to the AoA.

## 3. The stall phenomenum

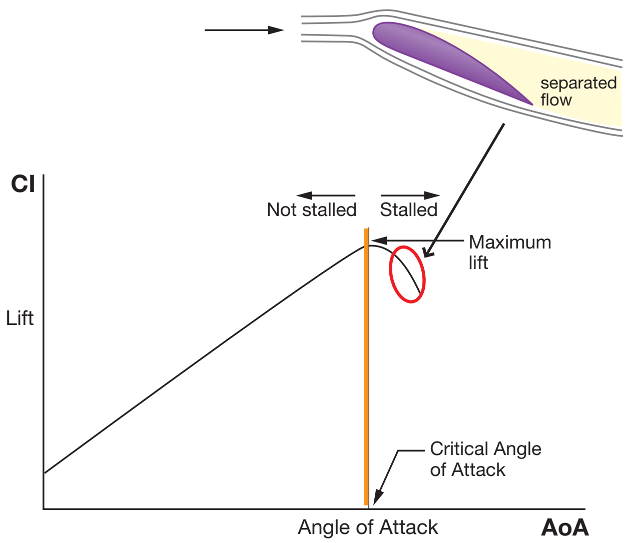
The linear part of the curve corresponds to a steady airflow around the wing.



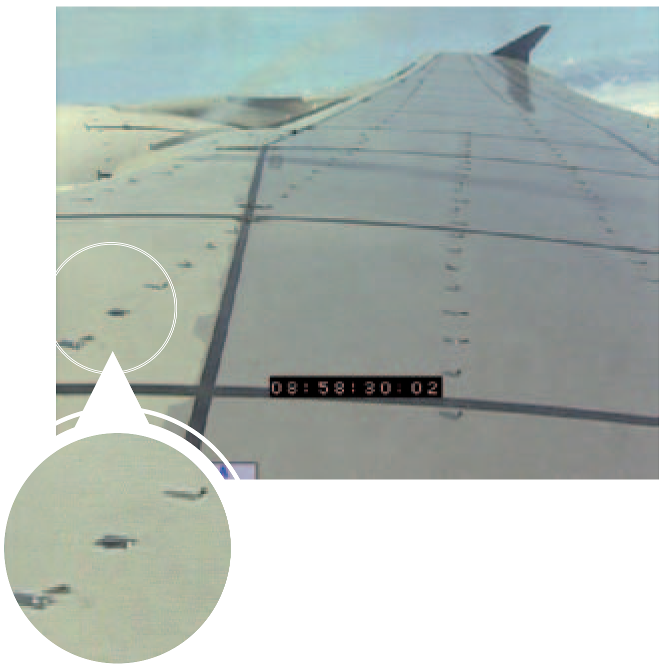

When the AoA reaches the value of the maximum Cl, the airflow starts to separate.




Beyond this point, the lift decreases as the flow is separated from the wing profile. The wing is stalled.




On this picture (extracted from a video footage), the erratic positions of the flow cones on this A380 wing during a stall test show that the flow is separated.



# 4. Some important things to remember about the stall

► For a given configuration and at a given Mach number, a wing stalls at a given Angle of Attack (AoA) called AoA STALL. When the Mach number increases, the value of the AoA STALL decreases.

► When approaching the AoA STALL, the wing generates a certain level of buffeting, which tends to increase in level at high Mach number.

► When the AoA increases and approaches the AoA STALL, in certain cases, a phenomenon of pitch up occurs as a result of a change in the distribution of the lift along the wingspan. The effect of the pitch up is a self-tendency of the aircraft to increase its Angle of Attack without further inputs on the elevators. Generally, for a given wing, this phenomenon occurs at a lower Angle of Attack and is more prominent when the Mach number is higher.

► The only mean to counter the pitch up is to apply a nose down elevator input.

► When the aerodynamic flow on the wing is stalled, the only possible mean to recover a normal flow regime is to decrease the AoA at a value lower than the AoA STALL.

► Stall is an AoA problem only. It is NOT directly a speed issue.

*Knowing those two last characteristics is absolutely paramount, as they dictate the only possible way to get out of a stall.*

**Figure 1**
*In NORMAL LAW, the EFCS limits the AoA to a value lower than AoA STALL*

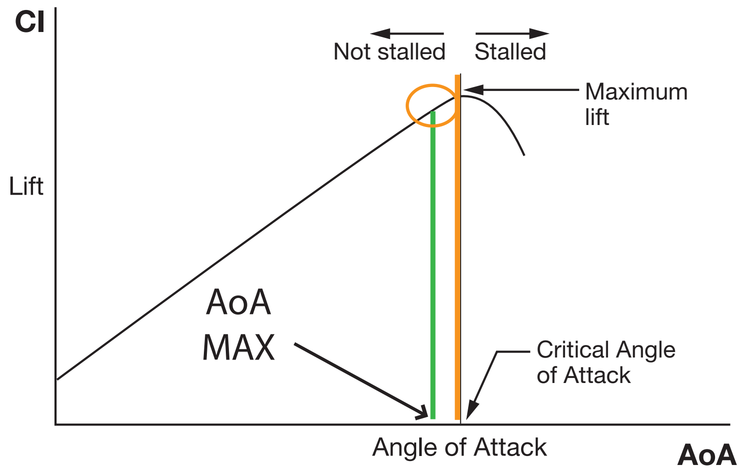
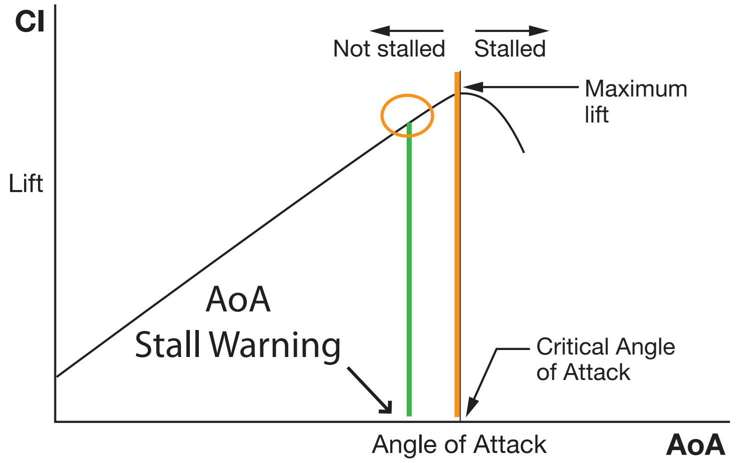



**Figure 2**
*In ALTERNATE and DIRECT LAW, the aural Stall Warning is set at a value lower than AoA STALL*




# 5. Protections against the stall in NORMAL LAW on FBW aircraft

In NORMAL LAW, the Electronic Flight Controls System (EFCS) takes into account the actual AoA and limits it to a value (AoA MAX) lower than AoA STALL (fig. 1).

The EFCS adjusts the AoA MAX limitation to account for the reduction of the AoA STALL with increasing Mach number.

Equally, for a given Mach number and a given AoA, the EFCS takes into account the natural pitch up effect of the wing for this Mach number and this AoA, and applies on the elevators the appropriate longitudinal pre-command to counter its effect.

# 6. Protections against the stall in ALTERNATE and DIRECT LAW on FBW and conventional aircraft

On FBW aircraft, following certain malfunctions, in particular in case of sensor or computer failure, the flight controls cannot ensure the protections against the stall. Depending on the nature of the failure, they revert to ALTERNATE LAW or to DIRECT LAW.

In both cases, the pilot has to ensure the protection against the stall, based upon the aural Stall Warning (SW), or a strong buffeting which, if encountered, is an indication of an incipient stall condition.

The conventional aircraft are permanently in DIRECT LAW, and regarding the stall protection, they are in the same situation as the FBW aircraft in DIRECT LAW.

In both ALTERNATE and DIRECT LAW, the aural SW is set at a value called AoA Stall Warning (AoA SW), which is lower than the AoA STALL (fig. 2).

The triggering of the Stall Warning just means that the AoA has reached the AoA SW, which is by definition lower than the AoA STALL, and that the AoA has to be reduced.

Knowing what the SW is, there is no reason to overreact to its triggering. It is absolutely essential for the pilots to know that the onset of the aural Stall Warning does not mean that the aircraft is stalling, that there is no reason to be scared, and that just a gentle and smooth reaction is needed.

The value of the AoA SW depends on the Mach number. At high Mach number, the AoA SW is set at a value such that the warning occurs just before encountering the pitch up effect and the buffeting.

If the anemometric information used to set the AoA SW is erroneous, the SW will not sound at the proper AoA. In that case, as mentioned above, the clue indicating the approach of the stall is the strong buffeting. In the remainder of this document, for this situation, "SW" must be read as "strong buffeting".

## 7. Margin to the Stall Warning in cruise at high Mach number and high altitude

Typically, in cruise at high Mach number and high altitude, at or close to the maximum recommended FL, there is a small margin between the actual cruise AoA and the AoA STALL. Hence, in ALTERNATE or DIRECT LAW, the margin with the AoA SW is even smaller.

The encounter of turbulence induces quick variations of the AoA. As a consequence, when the aircraft is flying close to the maximum recommended altitude, it is not unlikely that turbulence might induce temporary peaks of AoA going beyond the value of the AoA SW leading to intermittent onsets of aural SW.

Equally, in similar high FL cruise conditions, in particular at turbulence speed, if the pilot makes significant longitudinal inputs, it is not unlikely that it reaches the AoA SW value.

For those reasons, when in ALTERNATE or DIRECT LAW, it is recommended to fly at a cruise flight level lower than the maximum recommended. A 4,000 ft margin is to be considered. Then, for the same cruise Mach number, the IAS will be higher, the AoA will be lower, and therefore the AoA margin towards AoA SW will be significantly increased.

In addition, as in RVSM space the use of the AP is mandatory, any failures leading to the loss of the AP mandates to descend below the RVSM vertical limit.

## 8. Stall Warning and stall

The traditional approach to stall training consisted in a controlled deceleration to the Stall Warning, followed by a power recovery with minimum altitude loss.

Experience shows that if the pilot is determined to maintain the altitude, this procedure may lead to the stall.

A practical exercise done in flight in DIRECT LAW on an A340-600 and well reproduced in the simulator consists in performing a low altitude level flight deceleration at idle until the SW is triggered, and then to push the THR levers to TOGA while continuing to pull on the stick in order to maintain the altitude.

The results of such a manoeuvre are:

- In clean configuration, even if the pilot reacts immediately to the SW by commanding TOGA, when the thrust actually reaches TOGA (20 seconds later), the aircraft stalls.
- In approach configuration, if the pilot reacts immediately to the SW, the aircraft reaches AoA stall -2°.
- In approach configuration, if the pilot reacts with a delay of 2 seconds to the SW, the aircraft stalls.

This shows that increasing the thrust at the SW in order to increase the speed and hence to decrease the AOA is not the proper reaction in many cases (this will be developed in the following chapter).

In addition, it is to be noticed that, at high altitude, the effect of the thrust increase on the speed rise is very slow, so that the phenomenom described above for the clean configuration is exacerbated.

Obviously, such a procedure leads to potentially unrecoverable situations if it is applied once the aircraft has reached the aerodynamic stall (see next chapter).

Even if the traditional procedure can work in certain conditions if the pilot reacts immediately to the SW, or if he is not too adamant on keeping the altitude, the major issue comes from the fact that once the Stall Warning threshold has been crossed, it is difficult to know if the aircraft is still approaching to stall or already stalled. Difference between an approach to stall and an actual stall is not easy to determine, even for specialists.

Several accidents happened where the "approach to stall" procedure was applied when the aircraft was actually stalled.

For those reasons, the pilots should react the same way for both "approach to stall" and "stall" situations.

## 9. How to react

What is paramount is to decrease the AoA. This is obtained directly by decreasing the pitch order.

The pitch control is a direct AoA command (fig. 3).

The AoA decrease may be obtained indirectly by increasing the speed, but adding thrust in order to increase the speed leads to an initial adverse longitudinal effect, which trends to increase further the AoA (fig. 4).

It is important to know that if such a thrust increase was applied when the aircraft is already stalled, the longitudinal effect would bring the aircraft further into the stall, to a situation possibly unrecoverable.

Conversely, the first effect of reducing the thrust is to reduce the AoA (fig. 5).

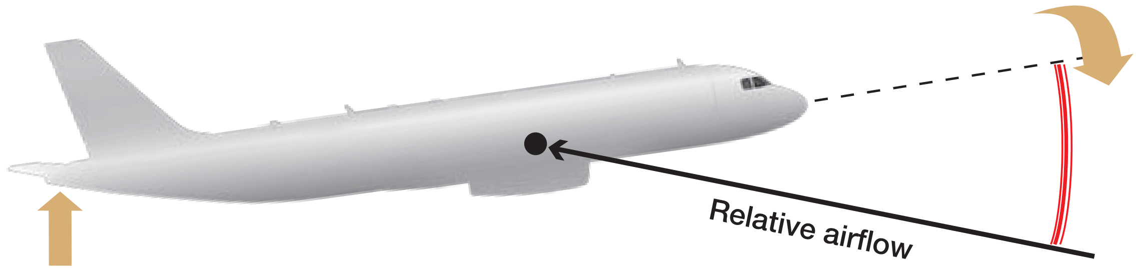



**Figure 3**
*Pitch control is a direct AoA command*

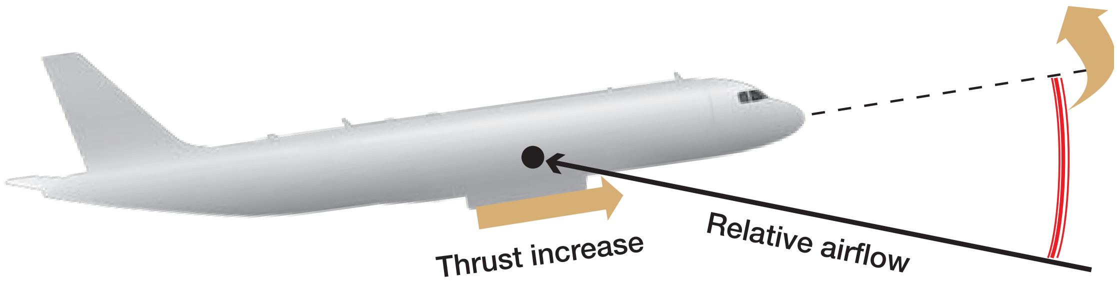



**Figure 4**
*Adding thrust leads to an increase in AoA*

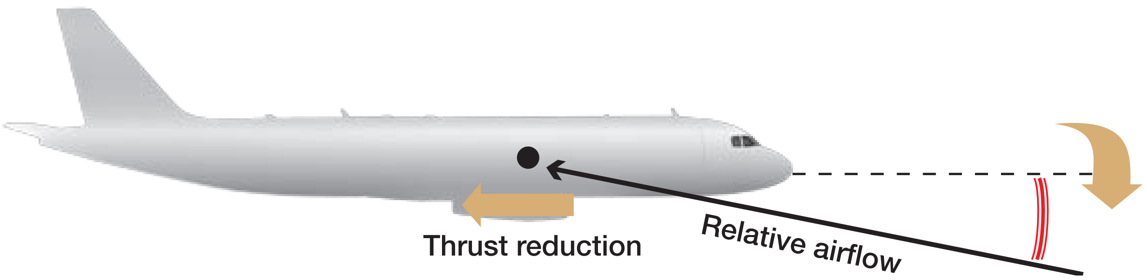



**Figure 5**
*Reducing thrust leads to a decrease in AoA*

**In summary:**

FIRST: The AoA MUST BE REDUCED. If anything, release the back pressure on stick or column and apply a nose down pitch input until out of stall (no longer have stall indications). In certain cases, an action in the same direction on the longitudinal trim may be needed. Don't forget that thrust has an adverse effect on AoA for aircraft with engines below the wings.

SECOND: When the stall clues have disappeared, increase the speed if needed. Progressively increase the thrust with care, due to the thrust pitch effect.

In practice, in straight flight without stick input, the first reaction when the SW is triggered should be to gently push on the stick so as to decrease the pitch attitude by about two or three degrees in order to decrease the AoA below the AoA SW.

During manoeuvres, the reduction of the AoA is generally obtained just by releasing the backpressure on the stick; applying a progressive forward stick inputs ensures a quicker reduction of the AoA.

If the SW situation occurs with high thrust, in addition to the stick reaction, reducing the thrust may be necessary.

## 10. Procedure

As an answer to the stall situation, a working group gathering the FAA and the main aircraft manufacturers, including Airbus, ATR, Boeing, Bombardier and Embraer, have established a new generic procedure titled "**Stall Warning or Aerodynamic Stall Recovery Procedure**" applicable to all aircraft types.

This generic procedure will be published as an annex to the FAA AC 120.

This new procedure has been established in the following spirit:

- One single procedure to cover ALL stall conditions
- Get rid of TOGA as first action
- Focus on AoA reduction.

### Generic Stall Warning or Aerodynamic Stall Recovery Procedure

**Immediately do the following at the first indication of stall (buffet, stick shaker, stick pusher, or aural or visual indication) during any flight phases *except at lift off*.**

**1. Autopilot and autothrottle............................ Disconnect**

**Rationale:** While maintaining the attitude of the aircraft, disconnect the autopilot and autothrottle. Ensure the pitch attitude does not change adversely when disconnecting the autopilot. This may be very important in mis-trim situations. Manual control is essential to recovery in all situations. Leaving one or the other connected may result in in-advertent changes or adjustments that may not be easily recognized or appropriate, especially during high workload situations.

**2. a) Nose down pitch control… Apply until out of stall (no longer have stall indications)**

**b) Nose down pitch trim.................................. As needed**

**Rationale:** a) The priority is reducing the angle of attack.

There have been numerous situations where flight crews did not prioritize this and instead prioritized power and maintaining altitude. This will also address autopilot induced full back trim.

b) If the control column does not provide the needed response, stabilizer trim may be necessary. However, excessive use of trim can aggravate the condition, or may result in loss of control or in high structural loads.

**3. Bank..............................................................Wings Level**

**Rationale:** This orientates the lift vector for recovery.

**4. Thrust...............................................................As Needed**

**Rationale:** During a stall recovery, many times maximum power is not needed. When stalling, the thrust can be at idle or at high thrust, typically at high altitude. Therefore, the thrust is to be adjusted accordingly during the recovery. For engines installed below the wing, applying maximum thrust can create a strong nose up pitching moment, if speed is low. For aircraft with engines mounted above the wings, thrust application creates a helpful pitch down tendency. For propeller driven aircraft, thrust application energizes the air flow around the wing, assisting in stall recovery.

**5. Speed Brakes........................................................Retract**

**Rationale:** This will improve lift and stall margin.

**6. Bank..............................................................Wings Level**

**Rationale:** Apply gentle action for recovery to avoid secondary stalls then return to desired flight path.

### Revision of Airbus' Operational documentation

Airbus has updated its operational documentation in order to reflect the changes introduced by the new generic stall recovery procedures. In order to allow simultaneous fleetwide introduction, the procedure was provided via Temporary Revision.
This information was provided together with an FCTM update advance copy and FOT 999.0044/10, on May 12, 2010.

**A300:**
A300 FCOM volume 8GE Temporary Revision number 219-1
A300 FCOM volume 8PW Temporary Revision number 051-1
A300 QRH Temporary Revision number 076-1

**A300FFCC:**
A300FFCC FCOM volume 2 Temporary Revision number 052-1
A300FFCC QRH Temporary Revision number 025-1

**A300-600/A300-600F:**
A300-600/A300-600F FCOM volume 2 Temporary Revision number 002-2
A300-600/A300-600F QRH Temporary Revision number 217-1

**A310:**
A310 FCOM volume 2 Temporary Revision number 004-2
A310 QRH Temporary Revision number 224-1

**A318/319/320/321:**
FCOM volume 3 Temporary Revision number 323-1
QRH Temporary Revision number 727-1

**A330:**
FCOM volume 3 Temporary Revision number 552-1
QRH Temporary Revision number 353-1

**A340:**
FCOM volume 3 Temporary Revision number 512-1 (A340-200/-300)
FCOM volume 3 Temporary Revision number 513-1 (A340-500/-600)
QRH Temporary Revision number 369-1

**A380:**
FCOM Procedures / Non-ECAM Abnormal and Emergency Procedures / Operating Techniques

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