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Minimum control speed tests on A380

When the aircraft has an engine shut down with the 3 others at maximum thrust, it has a tendency to yaw toward the “failed” engine. The pilot can deflect the rudder and create a yaw moment in the other direction in order to maintain the heading. However, when the speed is decreasing the engines create more or less the same yaw, but the aerodynamic efficiency of the fin and the rudder are reducing. At a given speed, with wings level, the rudder is on the stop and just able to counter the effect of the engines. Then, we could say that we have reached some kind of minimum control speed as it is a limit of manoeuvrability.

On any multi-engine aircraft, below the Minimum Control speeds (VMC), there is a risk of losing the control of the plane in the case of failure of one engine (outer for a quad) with the other(s) at maximum thrust. There are several VMC: for takeoff configurations, it is called VMCA (A for Airborne), for approach, VMCL (L for Landing). On a quad, another one, VMCL-2, is associated with the failure of 2 engines on the same side, in the approach configuration. It has to be demonstrated for certification, although this last situation is mainly considered when taking off for a ferry flight on 3 engines, without passengers, and if unfortunately a failure happens on the other engine of the same side. Finally, there is a VMC covering the case of the ground acceleration at takeoff. It is called VMCG (G for Ground).

Everything is not black and white and it is not because the aircraft is flying below a VMC that control will always be lost or that a crash will inevitably occur. But what is sure is that, when reaching the VMC, the pilot is on a limit of manoeuvrability and he cannot do what he wants freely in a manoeuvring sense. Some rules of determination of the VMCs are rather strange, and it is difficult to understand which logic is behind that. Nevertheless they have been applied for a very long time and their validity has been proven by the long experience on a huge number of flight hours on all aircraft types. For all VMC airborne, there is first a static demonstration of the value, followed by dynamic tests to show that the manoeuvrability remains sufficient at this speed. VMCG is obtained only by a dynamic exercise.

By nature, determinations of VMCA and VMCL are risky flight tests, as one engine is shut down at very low altitude. On a twin, the failure of the “live” engine gives just enough time to relight the other one. On a quad, the situation is different, as in the event of the loss of the other engine on the same side as the “failed” one, the thrust on the remaining engines must be reduced immediately to avoid a loss of control.

However, the risk of failure of another engine during these tests has a very low probability. The critical issue is the execution of the dynamic tests, as it can lead very quickly to a loss of control, due to the rapid build up of side slip. Such an event occurred a very long time ago in a test flight, but fortunately control was immediately recovered and then modifications were made to the flight controls to reduce drastically this risk. Anyway, we have to be very cautious in the execution of these tests and they are only performed by well experienced test pilots.

Measurement of VMCs is not a key priority at the beginning of the development of a long range aircraft. The reason is that all these speeds are rather low and therefore do not affect takeoff and landing performances, except for operations at very low weights. This is not penalizing for an aircraft like the A380. However, it is always useful to perform some measurements at an early stage of the flight program to be sure that we will not have a bad surprise, which might have an impact on performances at higher weight than expected or could necessitate a modification of the design of the flight controls.

For the A380, we had an issue to start these tests as, during the first month of flights, we discovered that the vertical fin had to be modified. Due to the delay necessary for this modification, it was decided to postpone VMCs determination by several weeks, until we receive the improved fin.

Figure 1
VMCA determination

1. VMCA, VMCL, VMCL-2

When engines and systems are configured, we start about 20 kt above the predicted value, then, we decelerate slowly keeping heading constant. Necessary rudder increases as the speed decreases, eventually up to the stop. Further deceleration will need some bank to still keep the heading constant. The "true" VMCA is obtained when the bank angle reaches 5° in the opposite sense to the "failed" engine (fig. 1). This bank angle is very important as it allows a further speed reduction of about 5 to 10 kt, compared to the same test performed with wings levelled. Where is this strange rule coming from? It is a mystery! Maybe that, in the old times, when reliable flight test installations where not existing, somebody had imagined to have some tolerance on the bank angle, because it is true that a perfect stabilization of the bank angle is difficult when the rudder is on the stop. In doing so, he put some knots "in his pocket"! Then the tradition has been kept and officialised. This hypothesis could explain the choice of this odd 5° value.

The tests to obtain VMCL and VMCL-2 are similar.

But there is more to do. A demonstration that the roll manoeuvrability at VMC is sufficient must be performed. The rules are slightly different for VMCA and VMCL and here we will just show one example for the VMCL. At this speed, the rolling capacity is reduced on the side of the deflection of the rudder (at the opposite of the "failed" engine). The rule is that it must be possible to go from 5° bank angle on the side of the rudder deflection, up to 25° in less than 5 seconds. Whatever the type of aircraft, there are risks in this test as the side slip is building up very quickly, because it cannot be compensated by the yaw damper, the rudder being already on the stop. When passing 25° bank, the recovery must be immediate and very smooth, with the engines reduced to idle, the speed increased and the side slip carefully minimized. At the very beginning of the Fly By Wire programs, there was plenty of roll capability at low speed. But in order to avoid reaching too high side slip, the roll rate commanded by the pilot was divided by 2 to be limited at 7.5 deg/s at low speed when the flight controls computers detect a large asymmetry in thrust. This roll rate allows this test to be passed with almost no margin. The available roll efficiency to react to turbulence is not modified.

There are some other specific dynamic tests at VMCA, but the demonstration is straightforward for our aircraft.

The first VMCA and VMCL test flight on A380 were performed at the end of May 2006, unfortunately in weather conditions not ideal for these types of measurements. Some days later, with better weather, a second flight allowed us to confirm the results and also to perform VMCL-2 tests. A third and final flight was dedicated to certification. Usually, on other programs, all these tests are performed directly with the Authorities on board. However, due to some particularities of the aircraft, the decision was made to perform preliminary flights to be sure that there was no issue with what was going to be presented for certification.

There was no surprise coming from these flights and the VMCA, VMCL and VMCL-2 values were found to be as expected.

2. VMCG

The VMCG is established with a dynamic test. The aircraft is accelerated with all engines at maximum thrust, with the nose wheel steering disconnected to simulate a wet or contaminated runway. At a given speed, the outer engine is shut down with the master lever. The pilot must try to minimize the lateral excursion, using the rudder (fig. 2). As for the VMCA, at high speed a small deflection is needed. But at low speed, even with full rudder, there could be a significant deviation. By definition, the VMCG is the shut down speed for which the deviation is 30 ft.

This test must be performed in perfect weather conditions, because even a very light cross wind or some small turbulence can have an impact on the results. Generally the flight test is planned at sunrise. The first test is usually not critical, as the shut down speed is about 10 kt above the planned VMCG. Then some more trials are performed with a progressive reduction of the shut down speed, by steps of 3, 2 or even 1 kt, depending on the results. Most of the time, after about 6 tests, the 30 ft deviation is reached.

In fact, we try to have at least one result above 30 ft to be able to interpolate back to the VMCG, but we have to be careful as around VMCG, the lateral deviation is very sensitive to the engine cut-off speed.

During this series of tests, the pilot in the left hand seat is in charge of the trajectory. He tries to minimize the deviation and then completes the takeoff when the maximum deviation has been reached. The pilot in the right hand seat shuts down the engine at the planned value.

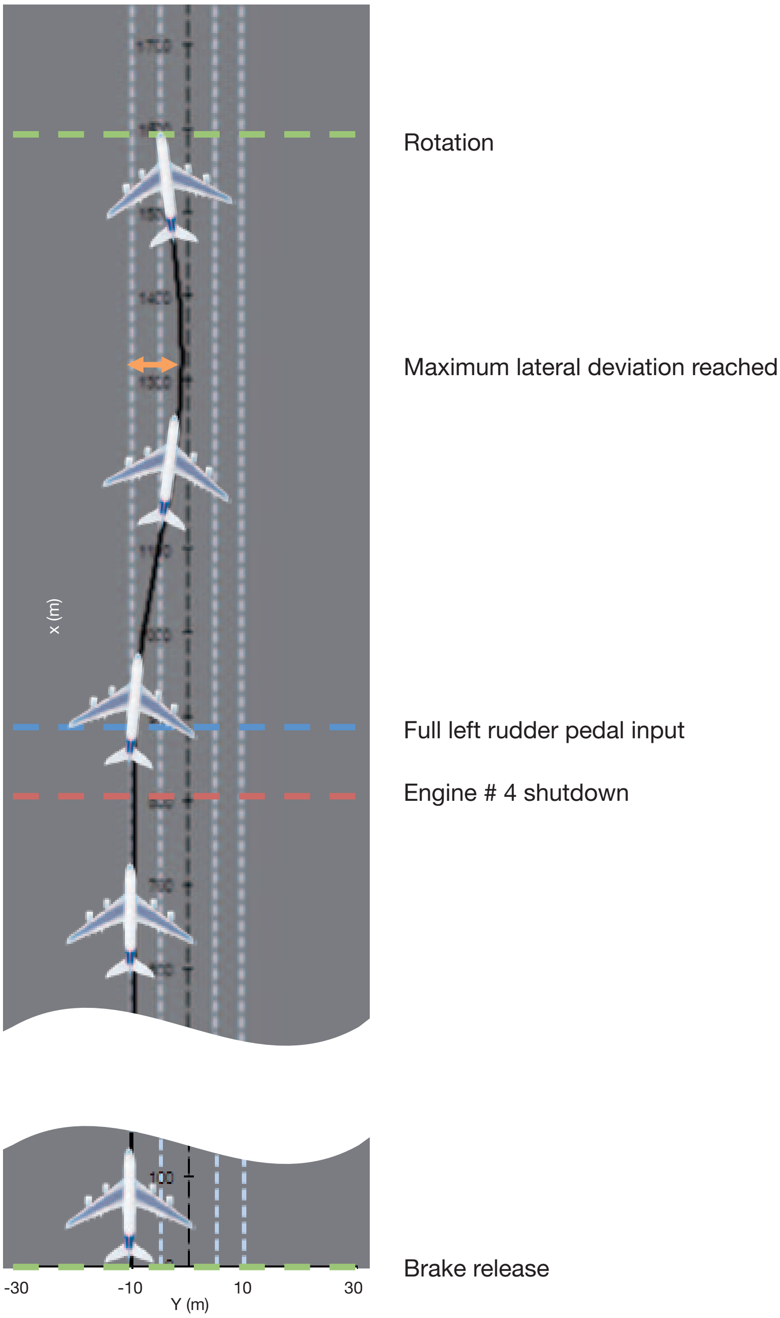


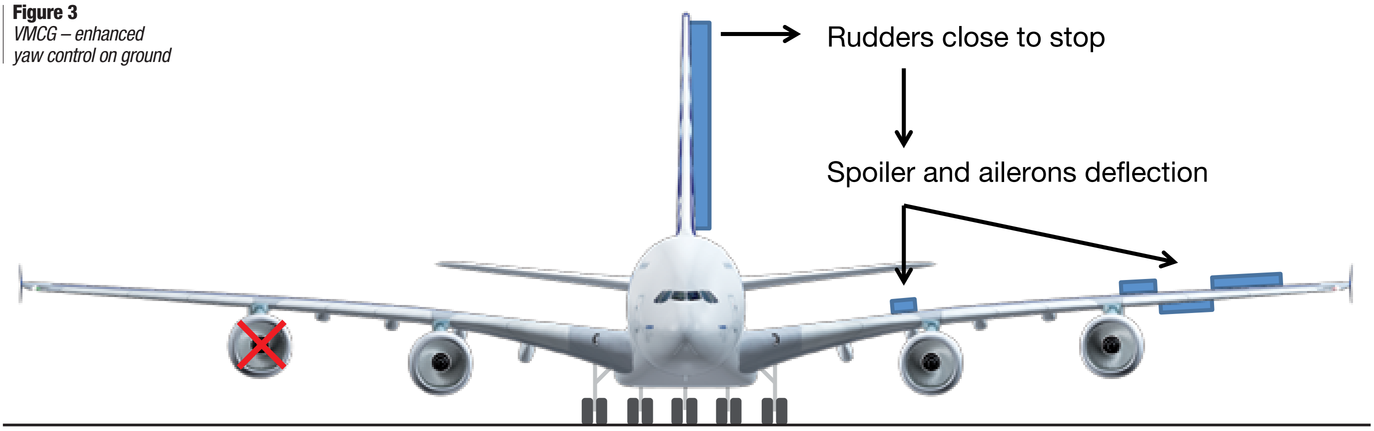
Figure 2
VMCG test

It is important to have always the same pilot doing the same action as, if there is a bias in the shut down speed, it is most probably going to be the same for all tests and the speed decrease is going to be as progressive as planned. Data reduction will then allow the analysis team to determine the right value. In the cockpit, on the jump seat, a test flight engineer monitors the engines and is in charge of the specific relight procedures generally given by the engine Manufacturers, following such shut downs at maximum thrust.

As for the VMCA, most of the time, these tests are directly used for certification, with an EASA pilot in the left hand seat and an Airbus pilot on the right. One of the reasons for minimising the number of times these tests are done, is that repeating several shut downs at maximum thrust is damaging for an engine and we try to reduce this risk. However, for the A380, due to numerous new systems features and some uncertainties on the predictions, we decided to perform a first evaluation ourselves. The initial results demonstrated that we were right.

The first VMCG flight could only be performed after the installation of the modified fin and it took place on March 30th 2006. Takeoff weight was 450 tons, configuration 3 and the predicted VMCG was 122 kt. As usual, we decided to perform the first test with the engine shut down at 132 kt, 10 kt above the predicted value. It was planned to “fail” the right outer engine, therefore we lined up the aircraft 10 meters on the left of the centre line. To help, we have on one of the Toulouse runways, full length blue lines at 5 and 10 meters on each side. This makes it easier for the handling pilot to keep precisely the distance from the centre line during the acceleration. The right engine was shut down at 132 kt as planned. At a speed about 10 kt above the VMCG, the deviation should not exceed 2 meters, but we had a surprise as the aircraft started to skid laterally and we eventually reached

Figure 3
VMCG – enhanced yaw control on ground



a deviation of 15 meters and we went on the other side of the centre line. A good demonstration that it was a sound idea to take some precautions and line up 10 meters on the left, as if we were already at the VMCG! An extrapolation let us think that the VMCG was probably at least 13 kt above the estimated value, which would have had serious adverse consequences for aircraft performance.

We landed immediately and decided to redo the test at a slightly higher speed: 134 kt. A new surprise: the deviation was almost the same, just a bit smaller. The videos were showing the tyres of the main landing gears skidding on the runway. A third test was performed at 136 kt. The deviation was 18 meters. It was increasing with the speed! Clearly, something was abnormal.

The following day, in order to understand the reasons of this strange behaviour, we tried again, but this time with a configuration 1+F instead of 3. With a lower flaps setting, we were expecting higher forces on the landing gears, which should have improved friction and therefore reduce skidding. We shut down the engine at 135 kt and the deviation reached 18 meters. Basically, no change! On top, we discovered an anomaly: because of a hidden failure, the deflection of one of the 2 rudders was too slow. Only one servo control of this rudder was active, instead of 2 in this type of situation. This was not the main reason for the huge deviation, but the system was not robust. A batch of modifications was needed before continuing VMCG tests.

To improve the situation, it was necessary to enhance the efficiency of the flight controls in yaw after an engine failure. Therefore, in order to create some additional yaw, the solution was to increase the drag on the wing which is on the side of the deflected rudders when they are close to their stop. For that, one spoiler and 2 of the 3 ailerons were fully deflected in the upper direction while the centre aileron was put down (fig. 3). Having ailerons in different directions permitted to minimize the effect on the bank angle. Some modifications were also made in the computers, allowing faster deflection of rudders in this specific situation.

Due to weather conditions, we performed the tests with all these modifications at Istres Air Base on June 14th with excellent results: the VMCG was now as planned, around 122 kt. However the exact value was finally determined during the certification flight at the beginning of September. The reason is that the value of the VMCG is very sensitive to the pilot reaction time. This one is around 0.6 seconds, but 0.1 second more or less can modify the VMCG by 1 or 2 kt. The official value is given by the tests performed by the certification pilot from EASA. The final value agreed after data reduction for the Rolls Royce engines is 119 or 121 kt, depending upon the maximum engine thrust (option chosen by the Customers), which is slightly less than the planned figures.

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