

# Research on Minimum Unstick Speed Flight Test Method for Civil Aircraft

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**Abstract.** The minimum unstick speed ( $V_{MU}$ ) is defined as the calibrated airspeed at which an aircraft can safely lift off and continue its takeoff without any difficulties. The  $V_{MU}$  flight test, characterized by low-speed and high angle of attack under the influence of ground effect, poses significant challenges and high risks, making it one of the most hazardous flight test subjects in civil aircraft flight test. The research on  $V_{MU}$  flight test methods for civil aircraft is of utmost importance in strengthening the foundation of flight test technology, improving flight test efficiency, and ensuring flight test safety.

**Keywords:** Minimum unstick speed; Thrust-to-weight ratio; Flight Test.

## 1. Overview

According to civil aviation regulations, the applicant must select a nose-wheel lifting speed that is sufficiently safe, and the aircraft's liftoff speed must maintain a sufficient speed margin from the minimum unstick speed. In other words, the minimum unstick speed is one of the critical limiting speeds in determining the safe take-off speed of an aircraft<sup>[1]</sup>. Technical preparations for the minimum unstick speed flight test are prerequisites for safely conducting flight tests. Sufficient technical preparations must be made before the experiment begins, including the design of flight test methods, the tackling of piloting techniques, and the control of flight test risks.

## 2. Analysis of Airworthiness Regulations

Airworthiness regulations stipulate different requirements for two distinct types of flight test: those limited by geometry and those limited by pitch authority<sup>[2]</sup>.

For  $V_{MU}$  (Minimum Unstick Speed) flight test limited by pitch authority, the criteria primarily include: the relationship between the unstick speed and the AFM (Aircraft Flight Manual) takeoff speed; the pitch attitude of the aircraft after liftoff should not decrease; and the aircraft must be fully controllable after leaving the ground effect. Additionally, a safe demonstration flight should be conducted<sup>[3]</sup>.

For aircraft limited by geometric configuration, the airworthiness regulations specify a speed margin between  $V_{MU}$  and  $V_{LOF}$  (Velocity for Liftoff) and clearly state that if the aircraft is geometrically constrained, it must be for the entire takeoff envelope. Furthermore, there are requirements for the timing of the aircraft's lower rear surface contacting the runway. Limits are also imposed on the pitch attitude after liftoff, the amount of speed increase, and the horizontal distance from the initial takeoff point to a height of 35 feet above the takeoff surface.

## 3. Determination of Flight Test Type

The type of flight test for the minimum unstick speed ( $V_{MU}$ ) is related to the aircraft's geometric characteristics, stall behavior, and elevator control effectiveness<sup>[4]</sup>. It is necessary to determine the type of  $V_{MU}$  flight test for a given aircraft before conducting flight tests. Currently, aircraft whose  $V_{MU}$  is limited by stall behavior are rare, and the  $V_{MU}$  of mainstream aircraft is typically limited by geometry or pitch authority. The main difference between the two types is:

For aircraft limited by geometry, after lifting the nose wheel, the tail of the aircraft contacts the ground before reaching the maximum lift coefficient for the takeoff configuration, and the aircraft's nose-up attitude cannot continue to increase.

For aircraft limited by pitch authority, after lifting the nose wheel, the tail of the aircraft does not touch the ground, nor does it reach the attitude corresponding to the maximum lift coefficient. Alternatively, the aircraft may require additional nose-up trim to achieve a tail-strike condition.

## **4. Flight Test Methodology**

Before conducting the flight test, the target N1 engine speed is calculated based on the thrust-to-weight ratio (T/W), aircraft weight, and ambient temperature conditions. For aircraft where the minimum unstick speed ( $V_{MU}$ ) is limited by pitch authority, it is necessary to use an appropriate additional nose-up trim or adjust the center of gravity towards the rear of the allowable center of gravity forward limit.

The aircraft taxis to the takeoff line and begins rolling from a stationary state. At the predetermined speed, the pilot pulls the control column to its full aft position, and simultaneously reduces the throttle of both engines to the position corresponding to the specified T/W ratio. This continues until the nose wheel starts to lift. The pilot observes the tail skid pre-ground contact indicator in the cockpit, adjusts the control column input accordingly, and maintains the tail skid in contact with the ground (this can be judged based on the tail skid ground contact indicator in the cockpit). The tail skid contact attitude is maintained until the aircraft lifts off. The lift-off attitude is maintained until the aircraft leaves the ground effect, and the pitch attitude after becoming airborne is kept no less than the lift-off attitude. The flight test employs a full-engine operating state simulating the critical engine shutdown thrust, and does not conduct a single-engine  $V_{MU}$  flight test.

## **5. Piloting Techniques**

### **5.1 Crew Responsibilities**

The  $V_{MU}$  (Minimum Unstick Speed) flight test crew typically consists of three members: Test Pilot 1, Test Pilot 2, and an Observer. The division of crew responsibilities can be arranged according to the crew's preferences, and there are two mainstream arrangements.

In the first arrangement, Test Pilot 1 is responsible for controlling the sidestick to manage the aircraft's pitch and roll attitudes. Test Pilot 2 is responsible for safety observations and correcting any deviation from the intended flight path. The Observer is responsible for setting and adjusting the initial thrust during the takeoff roll, monitoring the engines, and checking the checklist and test procedures.

In the second arrangement, Test Pilot 1 is in charge of both the test maneuvers and flight safety, including controlling the sidestick and making decisions. Test Pilot 2 handles the engine thrust control and conducts safety observations. The Observer does not participate in control operations but provides reminders about instrument parameters.

### **5.2 Pitch Attitude Establishment**

Selection of pull-up timing: Statistical comparisons show that when pulling the sidestick at speeds between 30-50 knots, it takes some time for sufficient control effectiveness to be established before the aircraft's nose wheel lifts. Data from pulling at speeds above approximately 80 knots indicates that the nose can lift in about 0-2 seconds.

Pull-up and back-off inputs: As the aircraft accelerates to the predetermined speed, the throttle is reduced and the sidestick is pulled to its full aft position to quickly establish a high pitch attitude and make the tail skid contact the ground. Typically, the sidestick is then returned to about halfway to maintain the tail skid in contact with the ground until the aircraft lifts off.

### 5.3 Thrust Control

The target thrust is determined through theoretical calculations or climb gradient check flights. During the test, the throttle must be quickly and accurately reduced from TOGA (Take-Off/Go-Around) to the target position. Marking the target thrust position beforehand can provide a reference for the pilot controlling the throttle.

Throttle reduction timing: The primary considerations for determining the throttle reduction timing are speed and thrust-to-weight ratio (T/W). The timing of throttle reduction and sidestick pull-up are closely related. Generally, the throttle should be reduced to the expected position at a speed 20-40 knots below the expected  $V_{MU}$  to achieve the target T/W ratio. With a high T/W ratio, the throttle can be reduced and the sidestick pulled back at a lower speed ( $V_{MU}-40$ ) to avoid missing the tail skid contact or grounding after liftoff. Conversely, with a low T/W ratio, the throttle reduction and sidestick pull-up should be delayed as much as possible, typically around  $V_{MU}-20$ , for safety reasons. At low T/W ratios, the aircraft accelerates slowly, and pulling the nose wheel up too early at low speeds and high angles of attack can lead to stall and increase runway length requirements..

## 6. Ground Monitoring

During the flight test, ground monitoring primarily focuses on two aspects: safety monitoring and initial judgment of data validity. Safety monitoring involves overseeing the aircraft's attitude, taxiing direction, and other relevant factors. Immediate warnings will be issued for potential deviations from the runway centerline or excessively low speeds. Regarding data validity, only preliminary results can be provided, such as verifying if the speed at liftoff and the post-liftoff pitch attitude meet regulatory requirements.

## 7. Flight Test Risk Assessment and Control

Among the risks associated with the minimum unstick speed ( $V_{MU}$ ) flight test, two key areas of concern are aircraft overrun/deviation from the runway and tail structure damage<sup>[5]</sup>.

For flight test with a low thrust-to-weight ratio (T/W), the risk of the aircraft overrunning or deviating from the runway is higher. Under these conditions, the aircraft spends a longer time running in a high-attitude configuration compared to higher T/W ratios. During this extended taxi time, the pilot's visibility may be restricted, needing one of the crew members to observe the external environment. Ground monitoring personnel provide runway deviation warnings based on monitoring data curves or video. Before conducting the flight test, it is crucial to adequately assess the longest runway length required for low T/W conditions. Selecting airports with longer and wider runways can help mitigate the risk of overrun/deviation.

For flight test with a high T/W ratio, the probability of tail structure damage is greater than that with a low T/W ratio. Under high T/W conditions, the aircraft gains speed faster, and lift increases rapidly. To achieve tail skid contact, the pilot needs to pull up the nose at a faster rate to avoid the scenario where the aircraft has already lifted off while the tail skid has not yet contacted the ground. Excessive maneuvering can lead to the tail skid touching the ground excessively, even resulting in tail structure damage. To prevent this, the pilot can consider pulling the sidestick to its full aft position earlier, waiting for the aircraft to pitch up, and prioritizing a safe takeoff without overfocusing on tail skid contact.

## 8. Conclusion

Given the high-risk nature of the minimum unstick speed ( $V_{MU}$ ) flight test, risk control must be implemented during the design of the flight test engineering. A gradual approach can be considered, such as gradually exploring the thrust-to-weight ratio (T/W) from its intermediate value to both

ends, gradually increasing the flight test risk from low to high. Test pilots should have sufficient psychological preparation and anticipation to complete the task. In terms of flight test progress management, it should neither be overly cautious nor advance blindly.  $V_{MU}$  flight test are not limited by the aircraft's heavy weight and can be conducted by simply selecting different T/W ratios. Each flight is equivalent to one take-off and landing, and if weather conditions permit, multiple flights can be conducted in a single day. Therefore, in the  $V_{MU}$  flight test process, there is no need to rush. Steady progress is more beneficial to successfully completing the flight test mission.

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