V_{mca}
(and the conditions that affect it)

V_{mca}, the minimum airspeed at which an airborne multiengine airplane is controllable with an inoperative engine under a standard set of conditions, is arguably the most important piece of aeronautical knowledge a multiengine pilot must understand. Unfortunately, most of the texts that are commonly available treat this subject inadequately. The purpose of this discussion is to provide thoughtful insight on the conditions under which V_{mca} is determined and how they affect the airspeed known as V_{mca}.

When a manufacturer of a light multiengine airplane certifies that aircraft, one of the limitations that must be established as a condition of certification is V_{mca}. Every manufacturer is bound to the same set of criteria when determining this limitation. Those conditions are (in no particular order):

1. Critical engine at idle power setting.
2. Critical propeller windmilling.
3. Operating engine producing maximum thrust.
4. Landing gear up (normally).
5. Flaps up (normally).
6. Aircraft loaded at the most aft allowable center of gravity.
7. Aircraft loaded to the maximum gross weight.
8. Up to five degrees of bank toward the operating engine.
9. Atmospheric conditions normalized to standard day at sea level pressure.

With these conditions observed, airspeed is decreased until heading cannot be maintained. That airspeed is noted, and subsequently marked by a red radial on the airspeed indicators of the production models.

When an airman seeks certification in a multiengine (usually a light twin-engine) airplane, that pilot must be prepared to demonstrate knowledge of V_{mca} and the principles of single-engine flight, and also must demonstrate V_{mca} in flight. Essential to successful completion of these tasks is an understanding of how each of these criteria affects the value of V_{mca}.

Let's set the ground rules first. What does this V_{mca} limitation mean? The manufacturer guarantees that as long as the airplane is operated legally at an airspeed above V_{mca}, heading (a constant compass reading) can be maintained. That is the ONLY guarantee. The ability to climb, or even to maintain altitude, is NOT guaranteed, and plays no part in the concept of V_{mca}. HEADING ONLY!

That means that V_{mca} is a limitation on the ability to control the airplane around its vertical axis. The only flight control that can control the airplane around its vertical axis is the rudder. Once the rudder is at full deflection toward the operating engine, V_{mca} has been achieved. Since the above criteria constitute the worst-case scenario, then this condition represents the situation where V_{mca} will be its highest value.

Refer to **Figure 1** below:

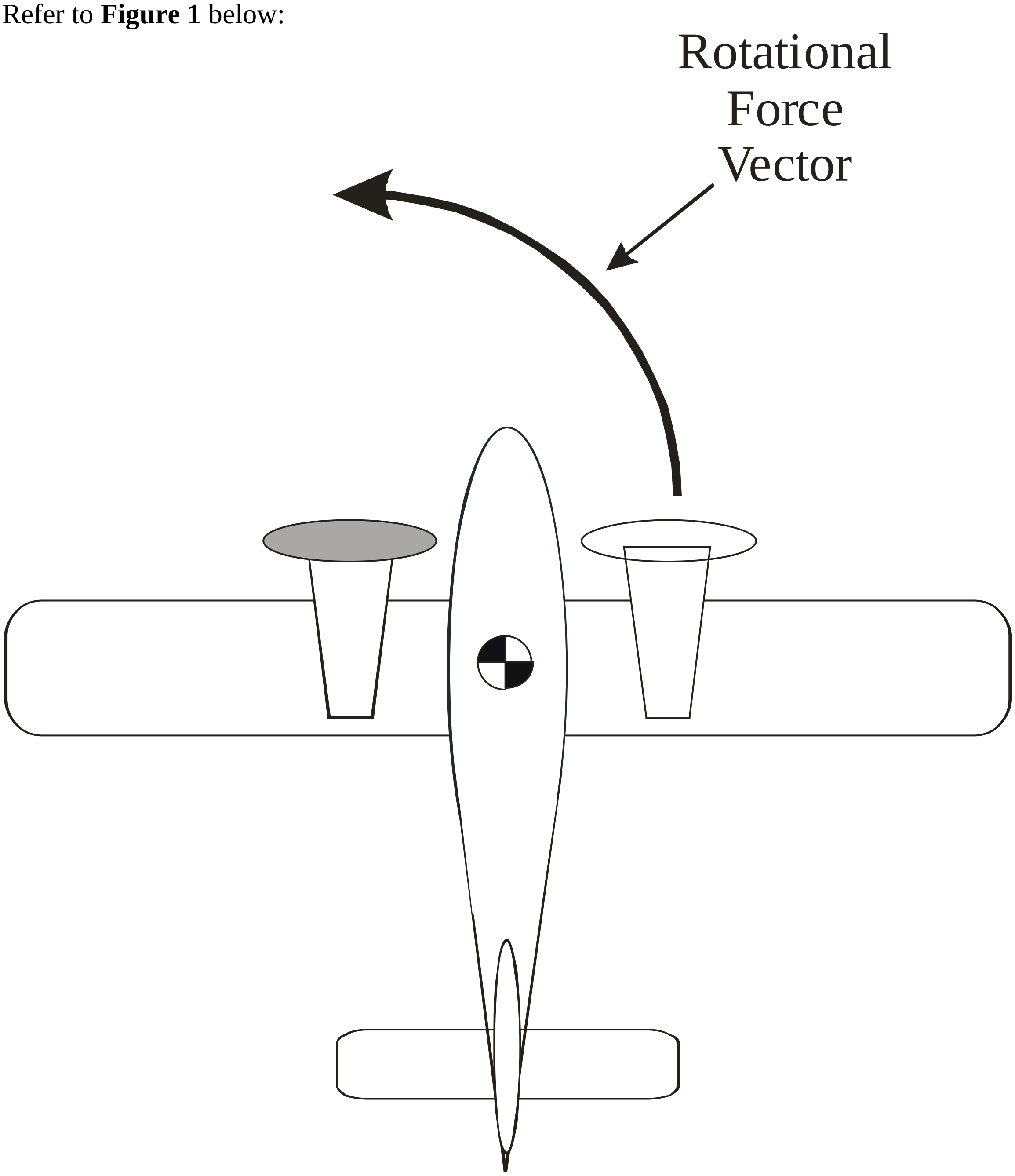

Figure 1

In this illustration, the critical left engine is inoperative. The resulting dynamic imbalance produces a yawing effect around the airplane's center of gravity. Rudder deflection to the right will be required to counteract and neutralize this rotational force vector and re-establish a constant heading. Any force that increases the rotational force vector will increase the value of V_{mca} because full rudder deflection will be reached sooner as airspeed is decreased. Any force that decreases the rotational force vector will have to opposite effect, decreasing the value of V_{mca}. When all of the listed certification conditions have been met, the rotational force vector is at its maximum value. Any legal or possible deviation from these conditions will cause the rotational force to decrease and lower V_{mca}.

Now let's consider each of the standard criteria used for the determination of V_{mca}, and see how each one causes V_{mca} to be at its maximum value.

Critical engine at idle power setting

When the critical engine is running at idle power, *asymmetrical thrust* is increased. This causes the rotational force vector to increase, increasing V_{mca}. The only way to vary this element is to increase power on this engine. That would have the effect of decreasing the rotational force vector, requiring less rudder force to neutralize it, and thereby lowering V_{mca}.

Critical propeller windmilling

When the critical propeller is windmilling, *asymmetrical drag* is produced, increasing the value of the rotational force vector. The amount of drag produced by this configuration is massive, equaling the amount of drag that would be produced by a disc of plywood the same size as the propeller disc. If the pilot reduces this drag by feathering the propeller, the rotational force vector would be reduced, lowering V_{mca}.

Operating engine producing maximum thrust

The operating engine does its part to increase V_{mca} by increasing *asymmetrical thrust*. This condition, coupled with idle power on the inoperative engine, results in maximum *asymmetrical thrust*. If power is reduced on this engine, the rotational force vector will be diminished, making it easier for the rudder to maintain heading, lowering V_{mca}.

Landing gear up

The landing gear, when it is retracted, contributes to the increase in V_{mca} by altering *asymmetrical drag*. Refer to **Figure 2** below:

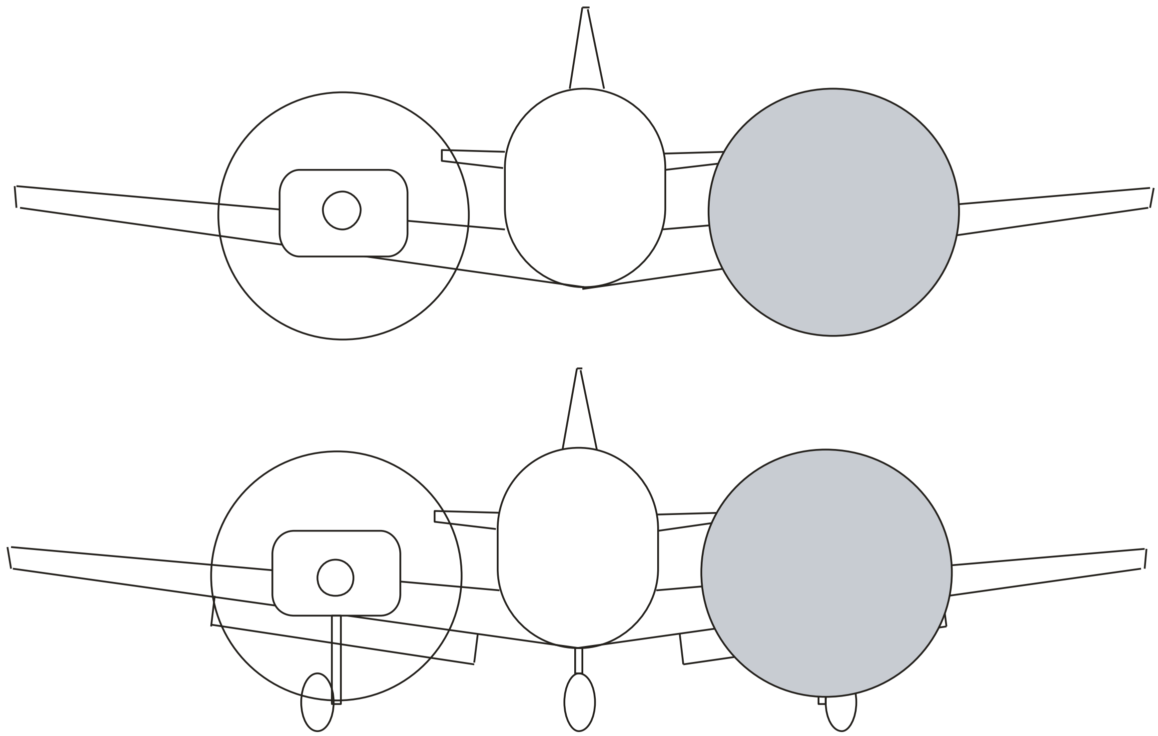

Figure 2

Both airplanes have the left engine failed with the propeller windmilling, and the right engine operating at maximum thrust. In the case of the upper airplane, the *asymmetrical drag* created by the windmilling propeller increases the yawing moment, increasing V_{mca}. However, the flat-plate drag created by the windmilling propeller on the lower airplane blocks airflow over the extended main landing gear on the left side, effectively nullifying any drag that might otherwise be developed by that gear. At the same time, the right main landing gear is extended into the increased airflow produced by the operating engine that is developing maximum thrust. More drag is being produced by the main landing gear on the right side of the airplane, countering the yaw to the left, decreasing the rotational force vector, and lowering V_{mca}.

Flaps up

The same *asymmetrical drag* principle applies to the flaps. The extended right flap on the lower airplane in **Figure 2** above is producing more drag than its blanketed mate on the left, impeding the yaw to the left, and lowering V_{mca}.

Aircraft loaded at the most aft allowable center of gravity

The location of the center of gravity of the airplane influences the value of V_{mca}. When the CG is located aft, as shown on the airplane on the right in **Figure 3** below, *controllability* is minimized because the rudder is acting at the end of a shorter lever arm (shown in blue), thereby limiting its ability to counter the yawing effect. In this loading condition V_{mca} is at its highest value.

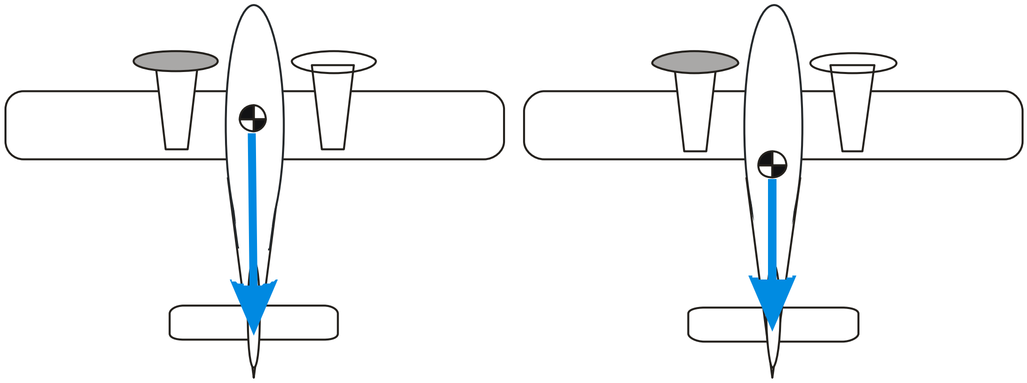

Figure 3

If the CG is moved forward from its aft limit, as shown on the airplane on the left, the lever arm changes so that the effectiveness of the rudder is increased. Thus, any forward movement of the center of gravity will result in a decrease in V_{mca}.

Aircraft loaded to the maximum gross weight

The maximum gross weight condition affects V_{mca} by having an impact on the rudder's ability to *control* the airplane's stability around its vertical axis. Most texts claim that, increased aircraft weight decreases V_{mca}. This discussion will serve to claim that the opposite is true. However, both claims are true, depending on different circumstances.

Newton's first law states that a body that is at rest tends to remain at rest, while a body that is in motion tends to remain in motion. Those masses are said to have inertia. Furthermore, the greater a body's mass, the greater it's inertia. A heavily loaded multiengine airplane has more inertia that a lightly loaded one.

When a multiengine airplane is undergoing the certification process, a test pilot flies the airplane in order to determine a value for V_{mca}. The pilot configures the airplane for the V_{mca} demonstration, then reduces the power on the critical engine and increases power on the operating engine. This pilot knows exactly when the yaw will occur, and applies rudder to counteract it before the airplane has an opportunity to establish a yawing motion. If the airplane has a greater mass, it will have a greater resistance to yawing than a lighter aircraft, and less rudder will be required to maintain heading. In this scenario, higher weight results in lower V_{mca}. Vmca has now been determined under relatively ideal conditions.

But let's look at a more realistic scenario. A multiengine airplane experiences a sudden failure of the critical engine while in flight. The airplane begins to yaw to the left, regardless of its mass. The surprised pilot then applies right rudder in order to stop the yawing motion, stabilize the airplane around its vertical axis and then maintain a constant heading. A heavier airplane will require more rudder effect to accomplish this. At some point, the rudder may reach full deflection, and V_{mca} will be reached. This will occurred at a higher airspeed for a heavier airplane.

Up to five degrees of bank toward the operating engine

Holding a bank in the direction of the operating engine may increase the performance of the multiengine in some respects, but it definitely raises V_{mca}. If a pilot suddenly loses engine power on one side, the first consideration must be to maintain control of the airplane and climb, hold altitude, or at least minimize the descent rate. The best way to do that is by flying in a coordinated fashion. Banking up to five degrees into the operating engine will allow the pilot to align the relative wind with the longitudinal axis of the airplane. This decreases the overall drag that would otherwise result from the increase in "wetted area" caused by the oblique airflow across the airframe in uncoordinated flight. However, this does not help with V_{mca}.

Refer to **Figure 4** below:

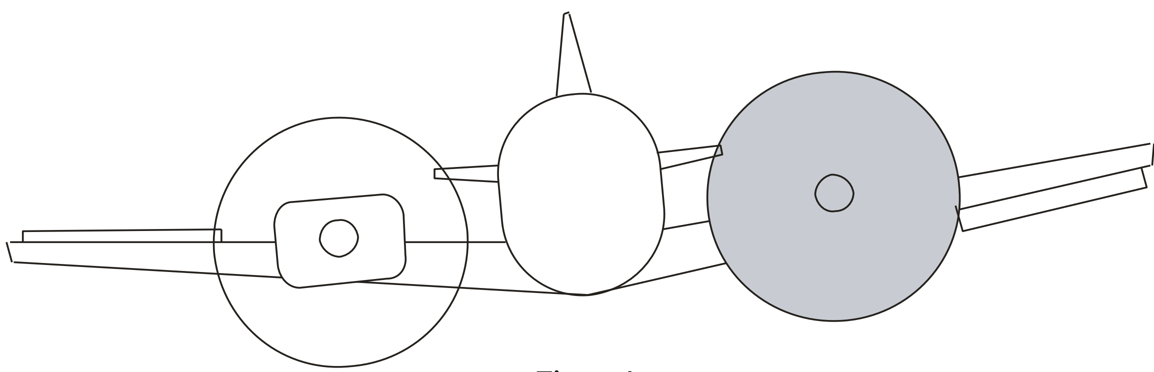

Figure 4

The pilot of this airplane has banked five degrees in the direction of the operating engine in an attempt to maintain coordinated flight. In order to maintain that bank, the aileron controls must be held in a bank to the right. As pictured the left aileron is deflected downward to increase lift at the left outboard wing, and the right aileron is deflected upward to decrease lift at the right outboard wing. The result is that drag is increased on the left and decreased on the right, increasing the yawing moment to the left. The *asymmetrical drag* increases the rotational force vector and raises V_{mca}.

Atmospheric conditions normalized to standard day at sea level pressure

The standard day/sea level condition raises V_{mca} by enhancing both *asymmetrical thrust* and *asymmetrical drag*. The higher air density found in this condition provides more molecules of oxygen per unit volume ingested by the operating engine, increasing the power produced by that engine. The higher air density also increases the efficiency of the propeller on that engine. The combination results in increased asymmetrical thrust.

At the same time, the increased air density of the relative wind provides more molecules of air gases per unit volume that are impacting the windmilling propeller on the critical engine. This increases asymmetrical drag,

While the effect of the increase in asymmetrical thrust nearly eclipses the effect of the increase in asymmetrical drag, the combination of the two serve to increase the yaw to the left, increase the rotational force vector, and raise V_{mca}.

The effect of each of these elements of V_{mca} criteria can be expressed in terms of *asymmetrical thrust*, *asymmetrical drag*, or *controllability*, or a combination.

This discussion began with the statement that V_{mca} is arguably the most important piece of aeronautical knowledge a multiengine pilot must understand. It is vitally important that the concept of V_{mca} is recognized as affecting only one performance parameter of multiengine flight: stability around the vertical axis, the ability to maintain a constant heading. The fully aware multiengine pilot will understand how all the factors that affect V_{mca} affect the overall performance of a multiengine airplane in single-engine flight. That is the true goal of the understanding and demonstration of V_{mca}.