C-130 Discussion Items

DISCLAIMER

This paper is intended to inspire discussion on C-130 techniques. Its intended audience is C-130 aircrew. It does not intend to change any operating procedures, and does not provide guidance to fly beyond the operating limits defined in the technical orders (Dash-1 or Dash-1-1). Do not violate official Air Force guidance in an effort to follow these techniques or validate these maneuvers. Some of the maneuvers presented here are at the aerodynamic limits of the aircraft and should not be attempted. All data obtained for this paper was acquired during Air Force sanctioned testing or as opportune data during an Air Force test.

Bottom line: Don't try this at home.

Questions or Corrections: Call Maj Grant Mizell, USAF

Vmca

As defined in T.O. 1C-130X-1-1, minimum control speed is the lowest speed at which the aircraft can maintain directional control subject to the constraints of:

- #1 engine windmilling on NTS
- The remaining engines at full power
- Gear Down
- Flaps 50%
- 5 degrees of bank into the good engines
- Less than 180 lbs (150 lbs for FAA certified aircraft, C-130J) rudder force
- Etc.

What exactly does “maintain directional control” mean?

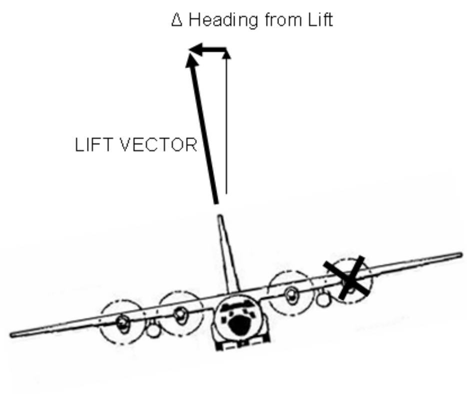
Directional control is the ability to maintain a heading, using less than 180 lbs of rudder force or full deflection, whichever comes first, AND less than ¾ control deflection from the yoke (approximately 90 degrees of wheel throw). Directional control is important when at low altitude, where obstacles may be a factor, or when on an approach, missed approach or where ground track is important. Directional control may not be important when the pilot recognizes the heading change and has chosen to accept a deviation from ground track. In some instances, C-130 Vmca may be defined based on achieving the ¾ yoke deflection. In these cases, the aircraft will be aileron limited even with 5 degrees of bank into the good engines.

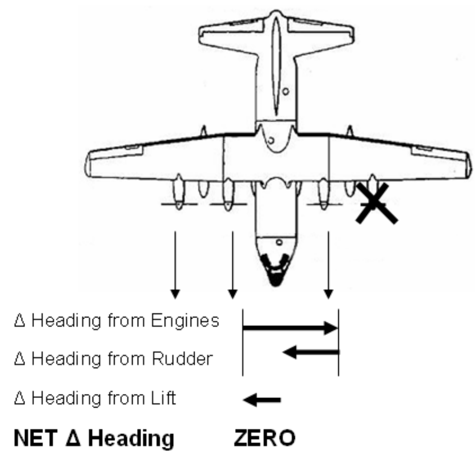
Why does Vmca increase if the 5 degrees of bank is removed?

Here are some simplified aerodynamic principles (more discussion in the Aero portion of this document):
An aircraft turns in bank because the lift vector tilts sideways. In level flight, the lift vector is only up. In banked flight, as the lift vector tilts, one component is up and the other component is to the side.
Next, the rudder creates a constant yaw with constant speed and force. That means, if the pilot holds in 180 lbs of force, and the aircraft is flying 100 knots (hypothetical Vmca), the rudder will generate a certain, constant amount of yaw.
Assume, the number one engine is out, and the torque difference from #4 at full power and #1 windmilling on NTS (about -600 lbs) is constant. Our math becomes easy.

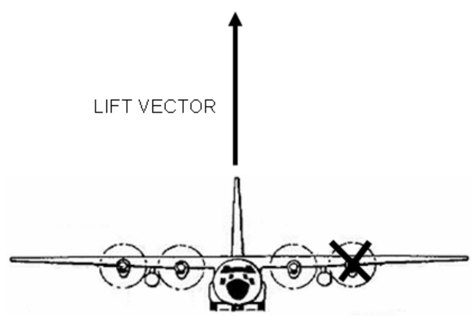
The aircraft will turn or not turn based on the three vectors discussed: (1) The turn induced by the engine asymmetry; (2) The turn induced by the rudder; (3) The turn induced by the bank.

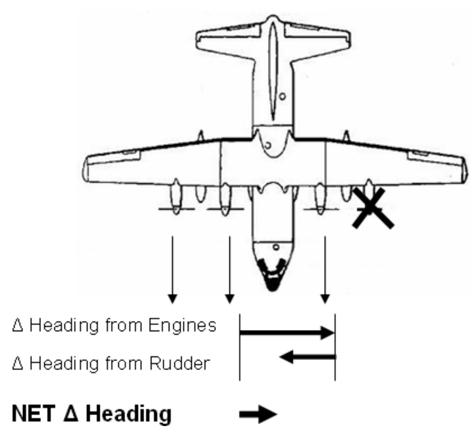
The definition of Vmca is 5 degrees of bank and 180 lbs or rudder AND ZERO HEADING CHANGE. That definition is graphically displayed below.



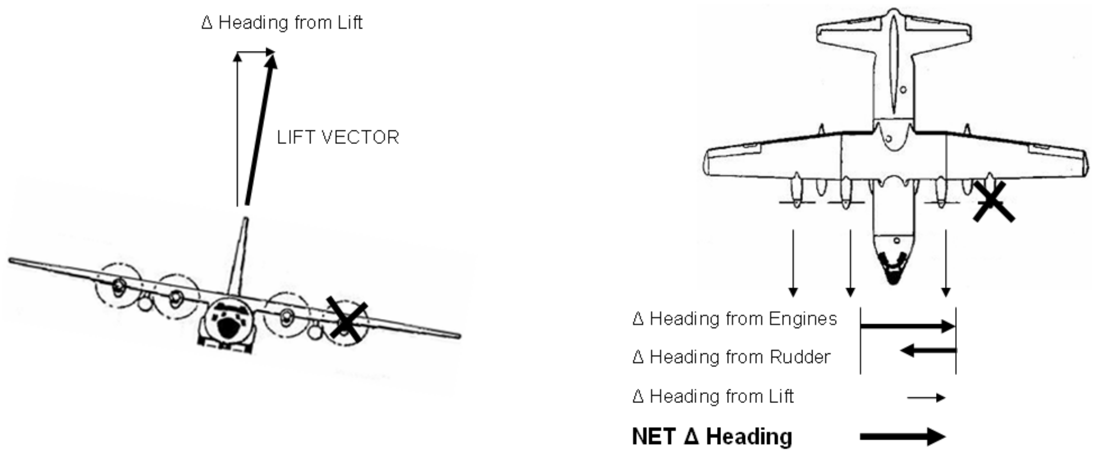


Since at constant airspeed the rudder yaw and engine yaw is constant, we can see what happens when bank is removed (wings level - below). The heading change from the lift vector is removed and the aircraft begins to turn. The pilot now has three options: increase airspeed in order to make the rudder more effective (and stop the turn), increase bank to counteract the turn using the lift vector, or accept the heading change. According to the Dash-1-1, the pilot would have to accelerate 11 knots to generate enough extra rudder yaw.

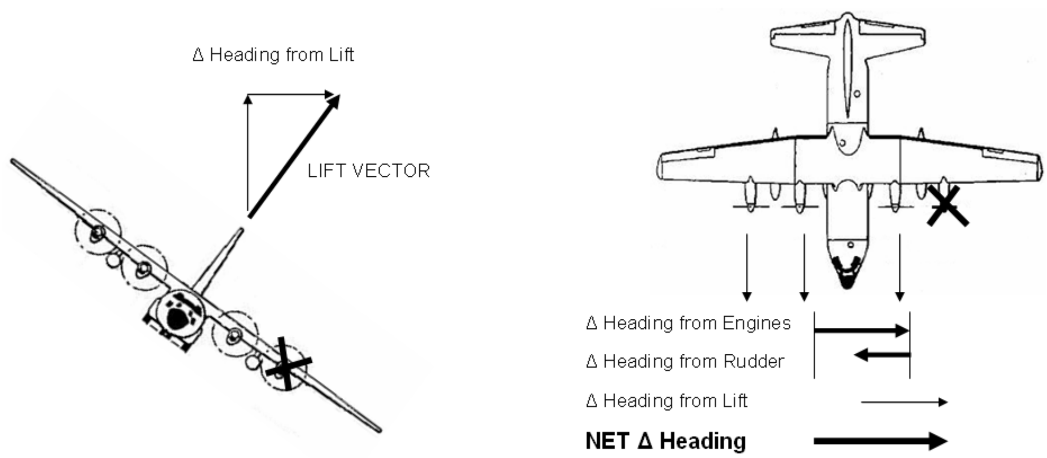




Next, let's look at the 5 degree adverse bank picture (below). The lift vector now generates a heading change in the wrong direction and induces a larger turn. Again, according to the Dash-1-1, the pilot would have to accelerate 37 knots to generate enough rudder force to counteract this turn.



Lastly, look at an extreme scenario (below). The aircraft is in 60 degrees of bank into the dead engine. The result is a large turn in the direction the aircraft is banking.

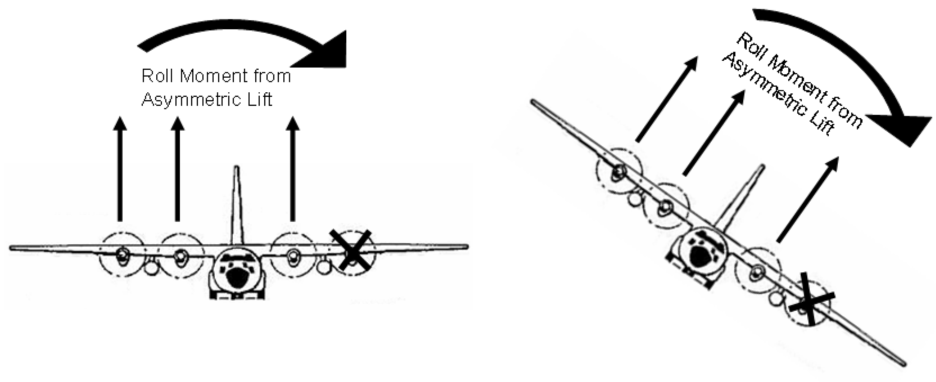


What does this mean to the pilot?

Banking into a dead engine does not mean the aircraft will become uncontrollable. What it means is that the aircraft will turn in the direction of bank (hopefully that was the pilot's intent).

What are the dangers of banking into the dead engine?

Since the C-130 is a "blown lift" aircraft, meaning additional lift is generated over the wing of an operating engine, the lift generated by three engines at full power and one engine out is asymmetric. More lift will be generated over the right wing (in the case of #1 out) which will require aileron to counter.



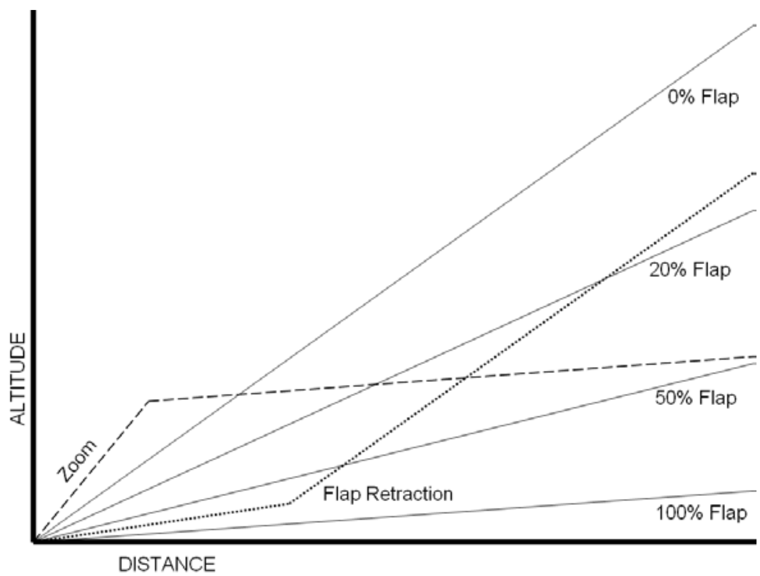
Whether at 5 degrees of bank into the operating engines, wings level, or 45 degrees of bank into the dead engines, this asymmetric lift is not significantly different.

What the pilot will note, however, is that the plane rolls faster when rolled into the dead engines, slower when rolled into the good engines, and that to maintain wings level, some amount of aileron will have to be held into the operating engines. Hence, the danger is that rapid roll rates will take longer and be more difficult to counter when operating near Vmca.

Bottom line: bank into the dead engine (if you want to turn that way) is OK, but roll slowly so you have enough aileron authority to stop and/or reverse the roll.

Obstacle Clearance

There are many techniques for getting maximum climb performance from the C-130. The use of any of these techniques depends on the situation the pilot finds himself in. If obstacle clearance is a factor immediately after takeoff, the Dash-1-1 should be followed in order to get the best instantaneous climb from the aircraft's current configuration (usually 50% flap). HOWEVER, the 50% flap configuration is not the aircraft's best steady state angle of climb speed.
Climb out in the aircraft depends on a number of variables, but most importantly it depends on drag. While pilot often think that flaps buy them more lift, they also generate more drag.



Examine the chart above and then consider the following examples.

For maximum instantaneous climb, a zoom trades kinetic energy (airspeed) for potential energy (altitude) the fastest. However, once at a slower speed, the aircraft kinetic energy is much lower and the aircraft may be on the back side of the power curve. Physics gives us a fixed ratio for a zoom (1 knot per 100 knots kinetic trades for 9 feet potential – so a 10 knot zoom at 210 knots will yield 180 feet), but does not account for thrust and drag (a high power setting may result in more altitude, and flight idle may result in less). **Zoom climbs are good for instantaneous altitude (a few hundred feet)** but you run out of airspeed quickly, so they are NOT good for extended climb.

CLIMB ANGLE	1.2 Vs	1.1 Vs	1.05 Vs
0% Flap	3.49	3.8	3.7
20% Flap	3.23	3.52	2.83
50% Flap	2.89	2.83	2.5

All things being equal, the best climb angle is at 0% flap, between 1.1 and 1.2 Vs.

If at cruise speed/configuration and best angle of climb becomes required, the pilot should zoom to 1.2 Vs at 0% flaps and then continue climb at 1.2 Vs. While 1.1 Vs can get the pilot a better climb, 1.2 Vs is safer because it maintains a larger stall margin (see stall discussion). Below 1.1 Vs, the climb drops off again as the plane finds itself on the backside of the power curve and generates more AOA induced drag.

If in takeoff configuration, and obstacles are a factor, the pilot should fly Dash-1 obstacle clearance speed at 50% flap. The reason for this can be seen on the diagram. While 0% flap generates a better climb, the length of time it takes to accelerate the 15 knots and retract the flaps is not spend climbing and therefore leaves the plane at risk for hitting the obstacle. If the obstacle is sufficiently far from the departure end of the runway, it MAY be beneficial to clean up and fly 0% flap 1.2 Vs.

Does 20% flaps get the pilot anything extra?

20% flaps is less drag than 50% flaps, but still more than 0% flaps. As seen in the data sample, 20% give a better climb rate than 50% but not better than 0%. If the pilot has the airspace to accelerate to 20% flap speeds, he might as well go all the way to 0% flaps. Additionally, there's no point in tracking 20% flaps to try to get any extra altitude.

What if you're in a box canyon and IMPACT IS IMMINENT?

Now, you're on your own. Here, the best thing may be to zoom to the slowest airspeed possible. That last few knots of zoom might be the 50 feet needed to clear the obstacle, and if you do hit the side of terrain, your highest chances of survival rest at lower airspeeds. CAUTION: timing would be essential in this situation. If the plane is stalled, the resulting departure and/or descent rate could be worse than impact at a few knots faster. See stall discussion, below.

BOTTOM LINE: Fly the aircraft as far into the crash as possible without stalling. Contact the ground wings level with as low of vertical velocity as possible.

Stall

The C-130 is a very forgiving airplane, but there have been a number of mishaps in previous years that have shown the dangerous parts of the operating envelope.

Inherently, most pilots flying the C-130 will never approach stall. Even FCF pilots only train to the “approach to stall” or the initial buffet. The C-130 has a very good natural stall warning (excluding the C-130J which has a stick pusher). However, once in a stall, the plane becomes much less predictable.

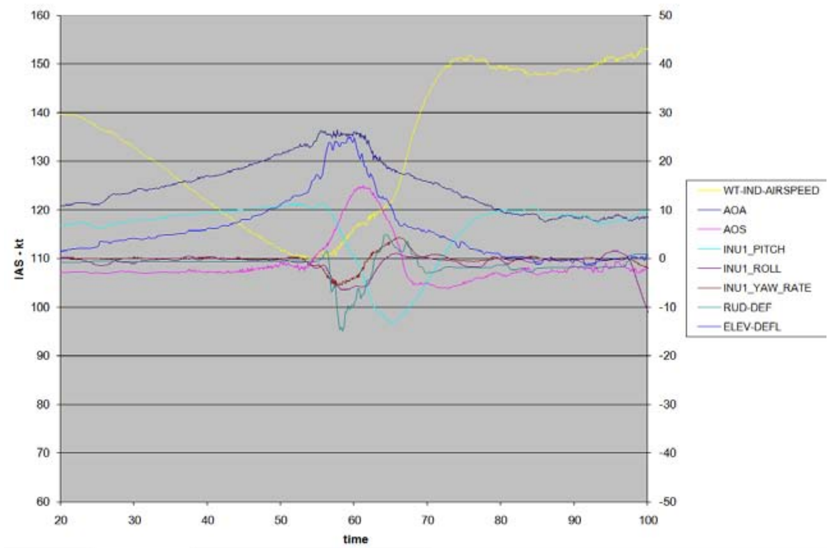


Figure 1: 0% Flap, Power Off, Heavy Wt Stall

Figure 1 shows a very typical power off stall. The flying characteristics of the plane are very benign all the way up to full stall. A significant buffet was experienced 10 knots prior to stall. 3 knots above stall, a deterring buffet was experienced, giving a clear signal to the crew that stall was imminent. Immediately before stall, a yaw acceleration was detected by the data, but nearly imperceptible to the crew. A high descent rate as well as g-break was experienced and the aircraft was recovered with minimum altitude loss.

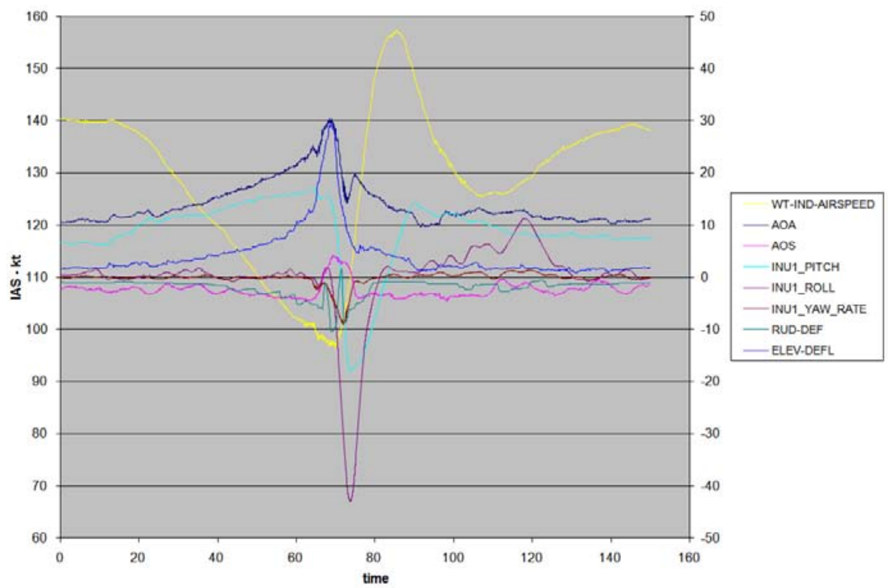


Figure 2: 0% Flap, Power ON, Hvy wt stall

While power on added significant stall margin (in this case, 12 knots), it is easy to see the inherent risk realized in power on stall. Due to blown lift, the aircraft is now at "safe" flying speed when previously power-off stalled, but if deceleration is continued a few more knots, the yaw becomes more significant and the left wing stalls before right, resulting in an uncontrollable and significant left roll. The pilot is left recovering from a nose low, high bank unusual attitude, resulting in large altitude loss and airspeed gain.

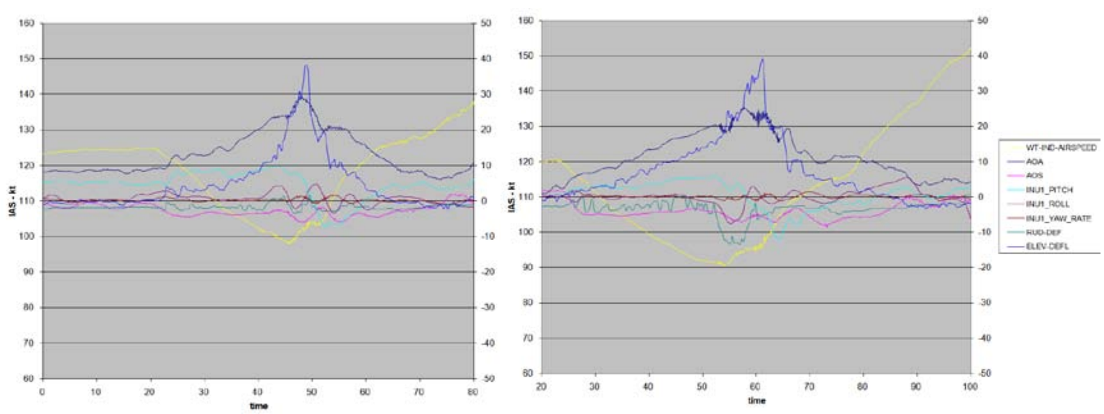


Figure 3: 50% and 100% Flap, Power-off Stall

The 50% and 100% flap stalls in the power-off configuration were very similar to the 0% flap. Stall warning was decreased with flaps. At 50% flaps, the significant buffet was felt only 5-6 knots above stall, and 100% flap stall only exhibited 2-3 knots of buffet before g-break. This highlights the need to recover IMMEDIATELY upon stall buffet to prevent g-break and altitude loss. Additionally, the 100% flap stall had increased yaw just prior to stall, causing a risk for more significant departure.

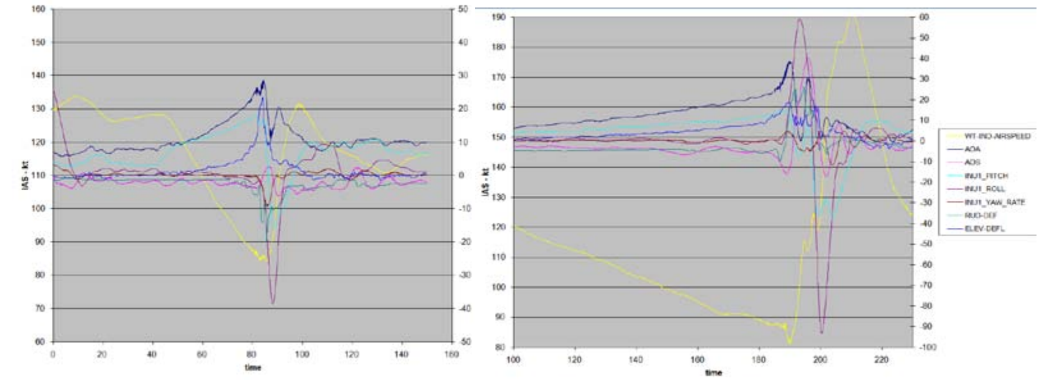


Figure 4: 50% and 100% Flap, Power-ON Stall

50% and 100% flap stalls with power on present a much larger hazard to the crews. Similar to 0% flap, but with less buffet warning, the left wing stalls first resulting in large, uncontrolled bank excursions and subsequent nose low attitudes. In some cases, the aircraft remained uncontrollable until the bank exceeded 100 degrees and the nose approached 75 degrees down. This caused massive altitude loss and overspeed of airframe components.

The approach to stall at 50% and 100% configurations also exhibited high descent rates. Even power on, VVI of approximately 4000 fpm was unavoidable 3-5 knots before stall. Here, lowering the nose with small airspeed gains would have decreased the descent rate and prevented the stall simultaneously.

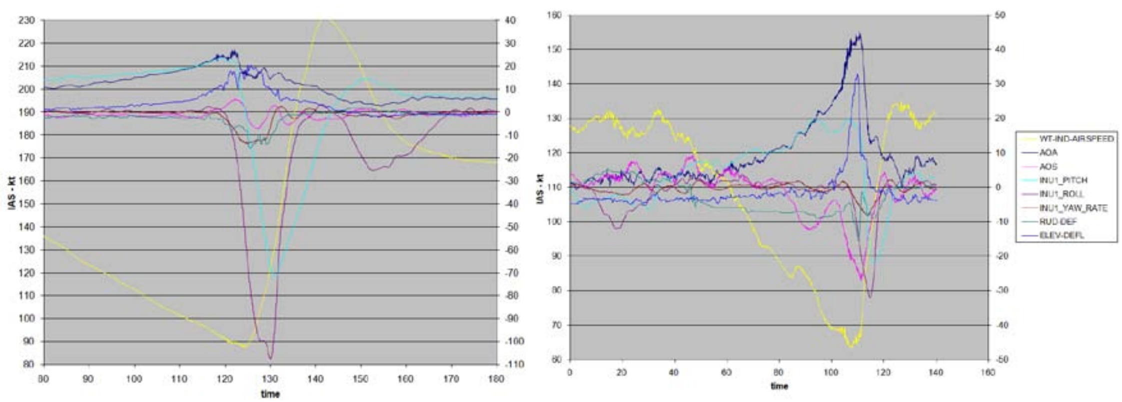


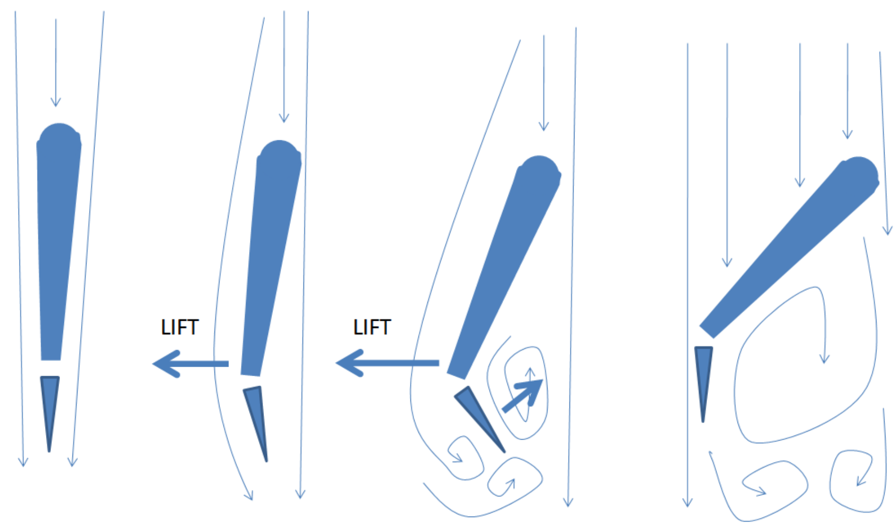
Figure 5: 0% and 100% Flap, Power-ON, Light wt Stalls

Through the stall testing, there were numerous "outlier" stalls. In contrast to the previous plots, Figure 5 shows an example of large departure at 0% flap. At 0% flap, airspeed increase is less of a problem since overspeed concerns are minimal, but the bank and nose low altitude loss was extreme. Additionally, the 100% flap power-on stall was very benign, allowing the crew to achieve an extremely low airspeed without violent departure.

BOTTOM LINE: The C-130 stall is very unpredictable and potentially violent. DO NOT ATTEMPT TO STALL THE C-130 and if a stall is suspected or buffet is encountered, RECOVER IMMEDIATELY by lowering the nose and applying power as necessary. A good rule of thumb is to never decrease airspeed below touchdown speed (1.2 Vs) power off, or Max Effort Take-off Speed (Vmeto) when power on.

Fin Stall

Fin stall is an often misunderstood phenomenon. The tail of the aircraft is like a wing. Just as a wing stalls when the Angle of Attack is too high, the tail will stall when the angle of attack (of the tail) or Sideslip of the aircraft is too high. When this happens, much like a wing stall, the tail will lose effectiveness.



The first picture depicts the rudder in straight (no sideslip) flight. The second shows normal rudder deflection. As the deflection increases excessively, the airflow stalls and the low pressure behind the rudder may pull the further than the pilot intended. This is known as “Rudder Force Lightening” (often confused with “Hard Over”, a hydraulic phenomena). If rudder force lightening is not quickly countered with positive rudder control, it could result in more extreme sideslip angles and finally “Fin Stall”. In Fin Stall, the aircraft will experience significant airframe buffet and the rudder becomes less effective. As the Dash-1 mentions, side effects include loss of control effectiveness, loss of lift, increased drag, and possible fuel starvation due to high side loads.

IN ALL CASES, rudder force lightening and fin stall will be accompanied by high side slip angles.

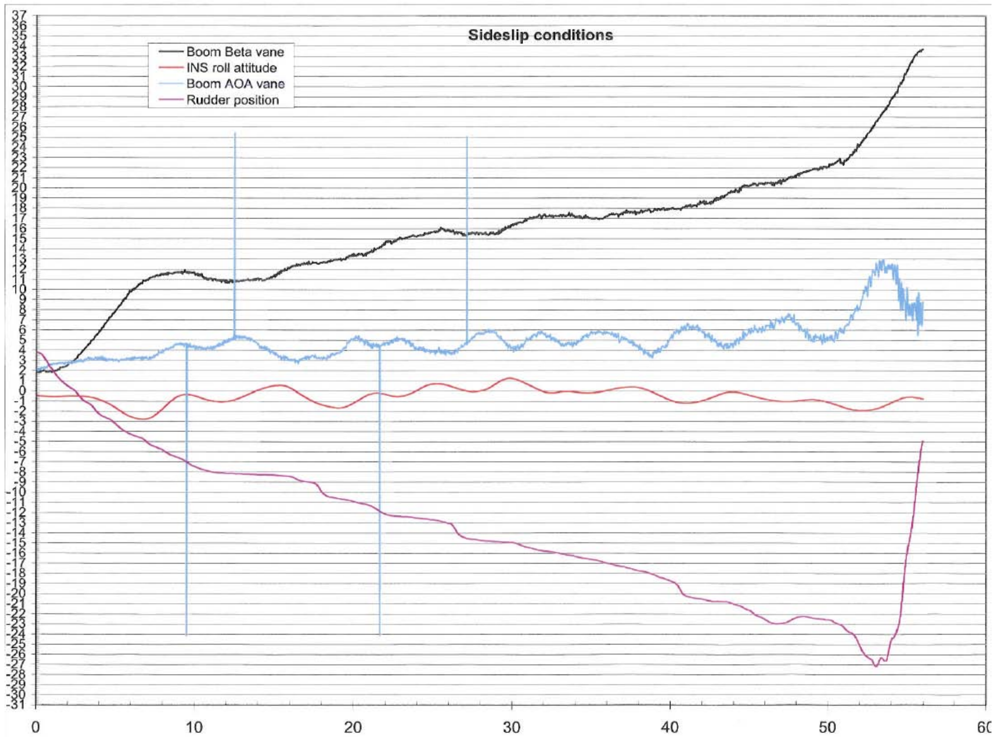


Figure 6: Fin Stall at 23 degrees sideslip

The chart above shows rudder force lightening followed immediately by fin stall. It was accomplished during intentional sideslips. Exceeding 10 degrees of sideslip was uncomfortable for all crew involved and should be a point when normal aircrew brings the condition to the attention of the pilot. The rudder force lightening can be seen where the relatively stable rudder increase rapidly jumps through 25 degrees of sideslip. By the time the sideslip is pulled over to 33 degrees, the aircraft is in a fin stall. The recovery was quick and simple: reduce rudder force and/or use opposite rudder force to bring the aircraft back to coordinated flight. DO NOT apply full opposite rudder as this could result in structural damage to the aircraft and/or aircraft departure. Apply only as much rudder as required to regain aircraft control, then smoothly re-center the ball.

Fin stall is actually somewhat difficult to achieve and the aircrew should get multiple warnings before finding themselves in such a condition. It is easier to achieve when slower because the rudder will have less airflow over it, meaning it will contribute less to aircraft directional stability. Fin stall is also more prevalent at high power settings, because the thrust produced away from the aircraft centerline also contributes to lower aircraft directional stability. Mostly, though, fin stall requires either excessive rudder force or a large out of trim condition (caused by one or two engines out on the same side), or both.

The way to differentiate between fin stall and wing stall (normal stall) is “use your pilot sense”. If the copilot is falling sideways out of his seat, then correct the out-of-trim condition with the rudder or by pulling back asymmetric throttles. If the yoke has contacted the copilot’s stomach, relax back-stick pressure.

If altitude permits, you are never wrong to reduce the angle of attack (relax back stick), pull the throttles to idle, and using rudder, maintain coordinated flight.

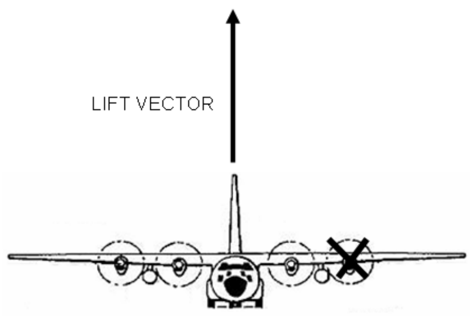
Aircrew, in general, should not input rudder to the point of rudder force lightening or fin stall. Should either be encountered, the pilot should immediately and positively return the rudder toward the neutral position. The pilot SHOULD NOT apply rapid or excessive opposite rudder since this could induce yaw accelerations in the opposite direction and loss of aircraft control. Additionally, if high power settings or high asymmetric power is applied, consideration should be made to reducing the power on outboard engines. If any other crew member notices a high lateral acceleration (side force on the aircraft, noticeable from things sliding across the flight deck or cargo compartment floor, or having to hold on to prevent yourself from flying across the floor), they should notify the pilot or copilot who should then “center the ball”.

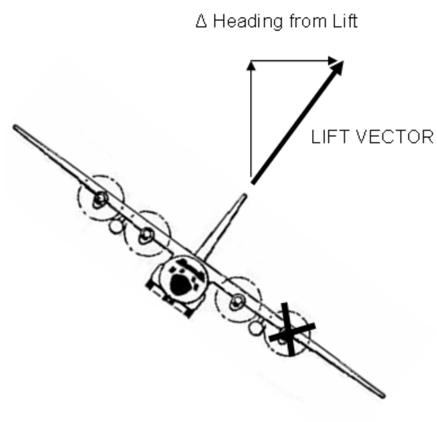
BOTTOM LINE: In most cases, centering the rudder will alleviate Fin Stall. If engine out, “center the ball”. If both of these are accomplished, you’re probably in a normal stall, so “max, relax, roll”.

Aerodynamic Discussion

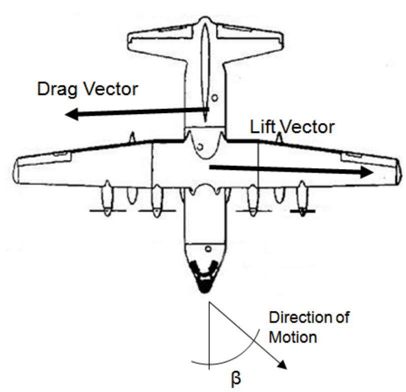
(Thanks to Mr. Dave Fedors)

Unlike a ship, which uses a rudder, the primary means to turn an aircraft is the use of bank angle. When you bank an aircraft, the lift vector is tilted:



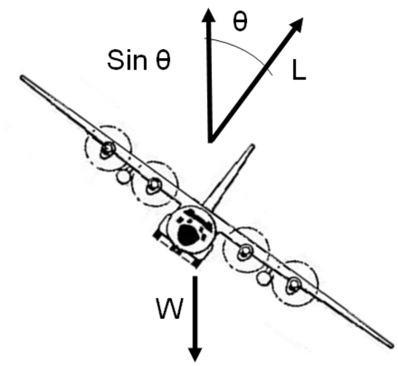


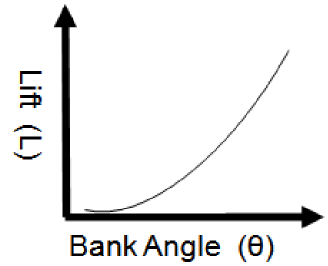
When the lift vector is tilted, it can be resolved into two components, one vertical, acting against gravity, and a second horizontal component acting in the direction the aircraft is banked. This horizontal component acts as side force, and generates a momentary acceleration in the direction the aircraft is banked. As the aircraft accelerates sideways, an opposing drag force is generated against the sideways acceleration. Eventually, the drag force will build up so that it equals the sideways component of lift. At this point, the aircraft will be in a steady state side slip. Now, because of the vertical tail, the side force generated by the sideslip is not in line with the lift force, and a turning moment is generated. Because of the directional stability, the aircraft rotates to keep the sideslip angle small. This rotation is the yaw or turn rate.



One other complication:
In order to keep the aircraft from descending when the lift vector is tilted, the vertical component must remain equal to the weight of the aircraft. This is done by increasing the total length of the lift vector and is described by the following relationship:

$W = L \sin \theta$ or $L = W/(\sin \theta)$





If we keep airspeed constant during the turn, the only way to increase lift is to increase angle of attack. Increasing angle of attack also increases induced drag, so power will have to be increased maintain airspeed and altitude as bank angle increases. Turn performance will be practically limited by the wing stall, power available, or aircraft g limit.

When an engine fails (with no other pilot inputs), it has three effects:

1. Power loss, will result in descent
2. The operating engines will generate a yaw rate
3. The resulting yaw rate will result in sideslip, and if the aircraft is laterally stable, it will start to roll

With an engine failure, in order to return the aircraft to equilibrium, we need to counteract the yawing moment caused by the operating engine. There are two ways to do this:

1. Retard the asymmetric engine to idle, reducing the asymmetric moment. This is procedure on some aircraft, like the KC-135, when an engine is lost and performance permits (which it does at practical landing weights). In two engine aircraft and for most other power limited aircraft, this is not a practical solution.
2. Generate a yawing moment to oppose the asymmetric engine using aerodynamic forces. For aircraft with a vertical tail, the vertical tail dominates the rest of the aircraft when it comes to generating aerodynamic yawing moments. The vertical tail works as a lifting surface and there are two ways for it to generate a lifting force:
    a. Change camber: which is a function of pushing the rudder pedals
    b. Change angle of attack: in the case of a vertical stabilizer, this means changing the angle of side slip

Aerodynamically then, we have two tools to counter the asymmetric moment caused by the operating power plant:

1. Rudder deflection, and
2. Side force caused by side slip. Side slip is generated by bank angle.

There are infinite combinations of rudder deflections and bank angles which result in an aircraft in equilibrium with an operating asymmetrical engine, but some result in excessive side slips or bank angles.

Vmca is defined by convention as:

1. Full rudder, or maximum rudder obtainable with a set rudder force (180 lbs for legacy C-130, 150 lbs for FAA or C-130J)
2. Five degrees of bank. This is a compromise between taking advantage of the large yawing moments generated in side slip and the drag penalty from the additional induced drag from operating at higher angle of attack.