C-130 Reduction in Directional Stability at Low Dynamic Pressure and High Power Settings

The C-130 experiences a marked reduction of directional stability at low dynamic pressures, high power settings, and at elevated side slip angles. This reduction in directional stability is manifested to the pilot as a low rudder force gradient (small rudder forces produce large side slip angles). There are several contributors to this reduction in directional stability; one is the normal force produced by the propellers when the propeller is at an angle to the oncoming flow:

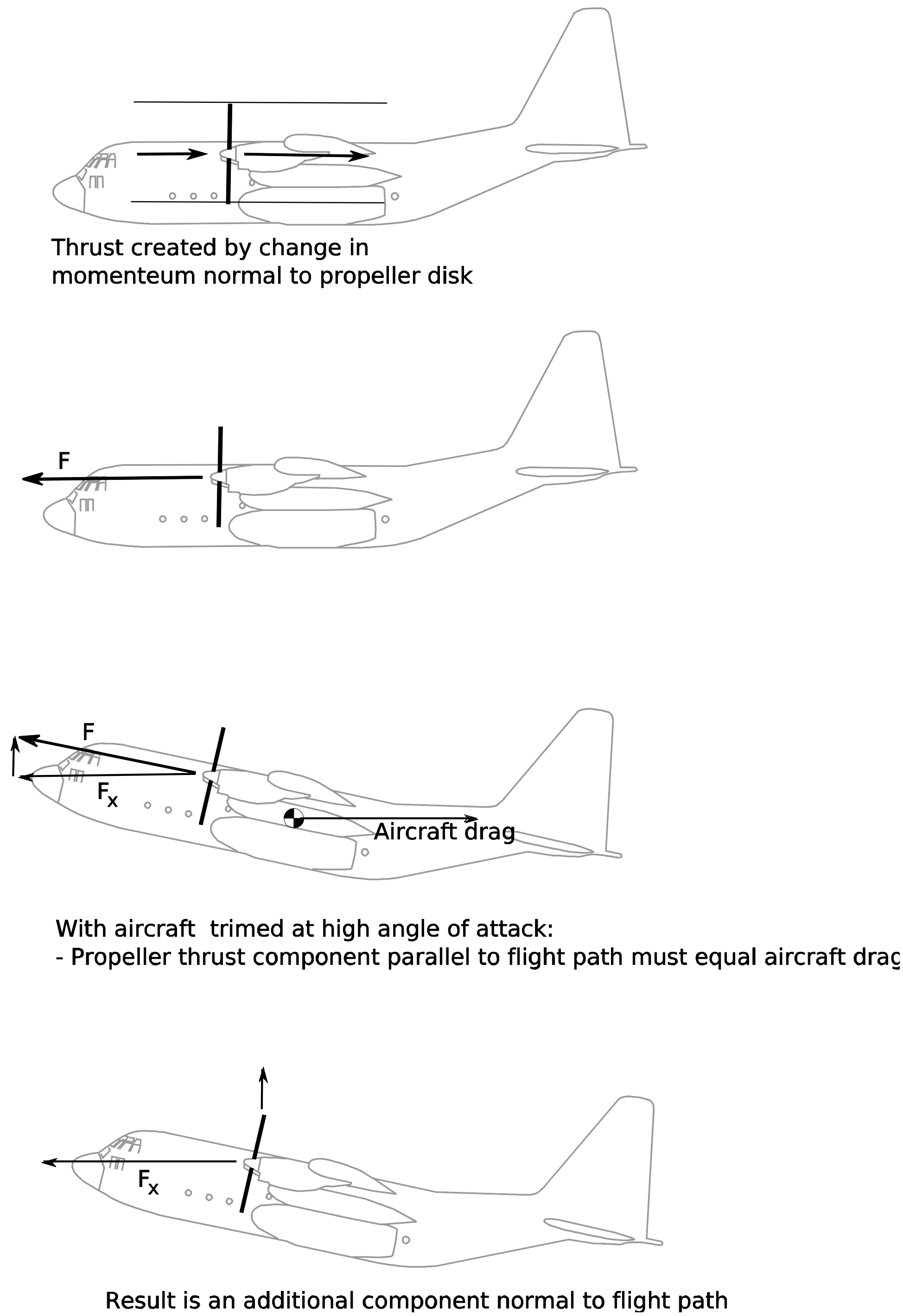


Figure 1. Propeller Normal Force due to momentum change

This same effect is present when the aircraft is in side slip, and is manifested as a side force:

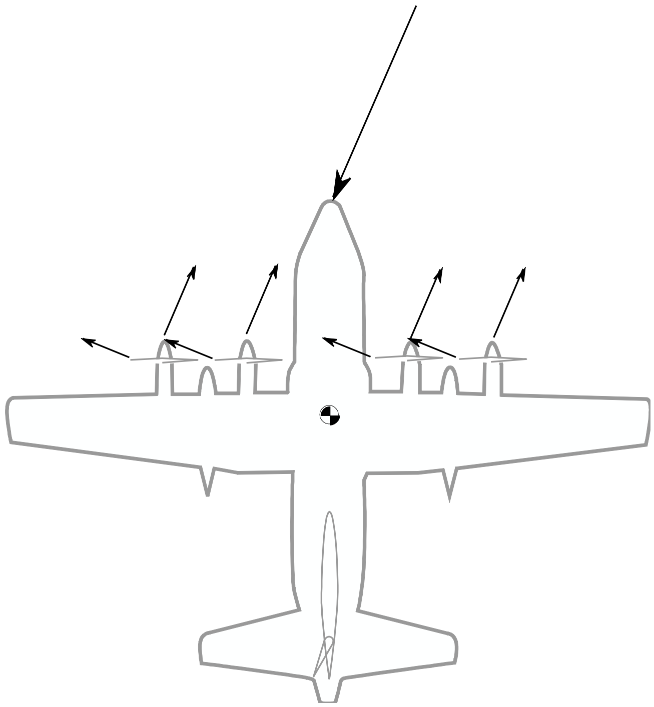


Figure 2. Propeller Normal Force in Slide Slip

On the C-130, with tractor propellers located forward of the center of gravity, the propeller normal force is directionally destabilizing (creates a couple (force times distance) that increases as the side slip angle increases.

The propeller wake has two effects which tend reduce the side slip seen by the vertical tail, hence reducing tail effectiveness and directional stability. These effects are strongest at high power settings and low airspeed (low dynamic pressure).

The first is entrained flow:

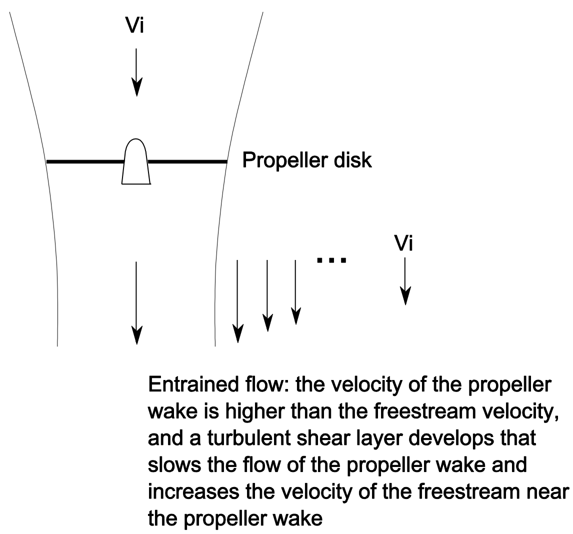
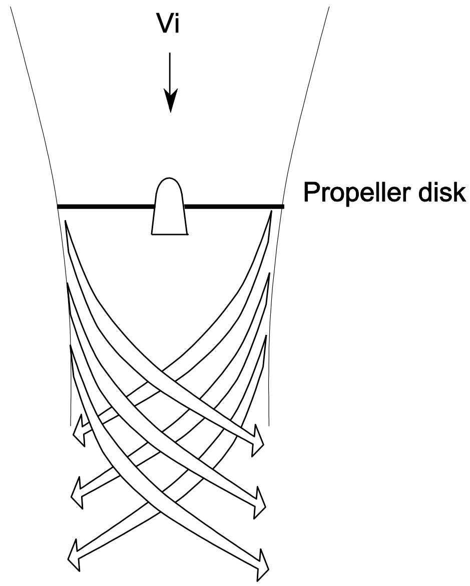


Figure 3. Entrained Flow

The second is the helical or corkscrew flow of the propeller wake. The helical flow results in leftward velocity component seen by the vertical tail, even with the aircraft is in zero side slip:



Helical (corkscrewing) flow effect behind propellers provides a lateral velocity component above the wing to the right.

Figure 4. Helical Flow

These effects all combine at low airspeed, high power settings to reduce the directional stability of the aircraft; the propeller normal force producing a destabilizing couple and the propeller wake effects decreasing the side slip angle seen by the vertical tail:

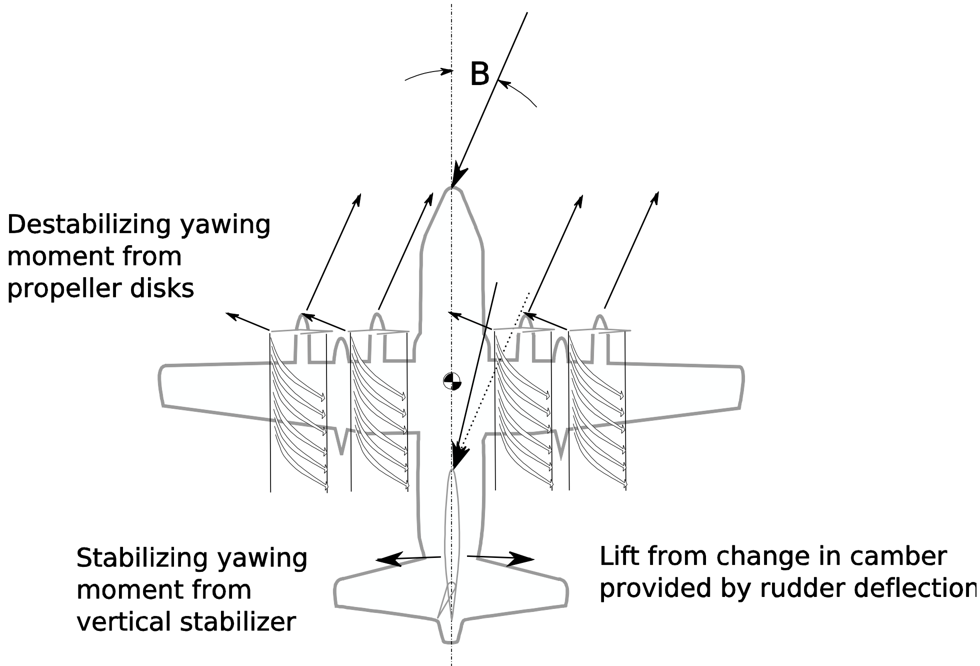


Figure 5. Reduction in directional stability at high power settings

The conditions where the reduction in directional stability are most likely to occur are:

- Low speed (aerodynamic controls are less effective, control feel is function of dynamic pressure).
- Flaps 50% (high rudder boost, allows generation of larger side slip angles)
- Gear up (Landing gear down is stabilizing)
- High power settings (more momentum change across the propeller disk, larger destabilizing normal force)
- Left rudder pedal inputs, right side slip

The primary indication to the pilot of the reduced directional stability is the reduction in rudder pedal force gradient, in some cases only 25 pounds of rudder force are needed to command 25 degrees of side slip. The cockpit side forces that might provide warning to the pilot of high side slip are too low to be noticeable at the low airspeeds where rudder force lightening is most likely to happen.

In the flight regime where the C-130 exhibits the reduced directional stability, there is also a marked reduction in yaw-rate damping (in normal flight regimes, the C-130 has excellent yaw damping. When C-130 pilots complain about poor yaw damping at low speeds, what they are usually noticing is the strong adverse yaw from the ailerons). A system exhibits damping if motion of the system produces a force that opposes the motion. Stability refers to a force that arises depending on the *position* of the system; while damping refers to a force that arises depending on the *velocity.* Normally, the forces developed by the vertical tail in side slip tend to oppose further increase in side slip, providing damping of the yaw rate. This is noticeable to the pilot when a rudder input is made to increase side slip. In a well damped system, the aircraft will immediately stabilize at the new side slip angle. In the flight regime where the C-130 exhibits the reduced directional stability, rather than immediately stabilizing at the new side slip, the side slip angle will tend to increase for long after the pilot's initial input.

The C-130 elevator, ailerons, and rudder are "boosted" by independent, reversible hydraulic booster packs, one for each surface powered by the utility hydraulic system and one powered by the booster hydraulic system. The boost function functions to apply additional hinge moment to the control surface. Although hydraulically powered, the flight control system is reversible, as the control surfaces are mechanically connected to the rudder pedals and yoke, and forces felt by the pilot are provided by the aerodynamic loads on the control surface. As a result, at low dynamic pressure the control forces are reduced.

The hydraulic pressure available to the rudder is scheduled with flap lever position. When the flap lever is less than 15%, the hydraulic pressure available to the rudder is reduced to 1100-1300 psi. When the flap lever is extended beyond 15%, full hydraulic system pressure (3000 psi) is available to the rudder booster packs.

When the rudder boost is in the high range, large rudder inputs can cause large side slip angles. Coupled with the low rudder force gradient (pilot is used to using 120-150 lbs to get to 10° of side slip, now it may only takes 25 lbs to get to 15°) and low yaw rate damping (an abrupt rudder input will cause a large side slip excursion well beyond the equilibrium side slip), it should be clear that the rudder and side slip characteristics are quite different those experienced in the normal flight regimes.

The pilot will experience the rudder force lightening when the rudder pedals begin to move easily and side slip continues to increase. If the pilot continues with rudder pedal input, the rudder pedal force will continue to decrease until the rudder floats towards full deflection by itself as the rudder is held in the deflected position by lower pressure of the separated air flow. This is a stable condition as far as the aircraft is concerned, as the rudder deflection provides the side slip and this side slip holds the rudder deflected. To the pilot, the rudder pedal will appear “locked” at full deflection. This rudder over balance condition can start as low as 17 to 21 degrees of side slip.

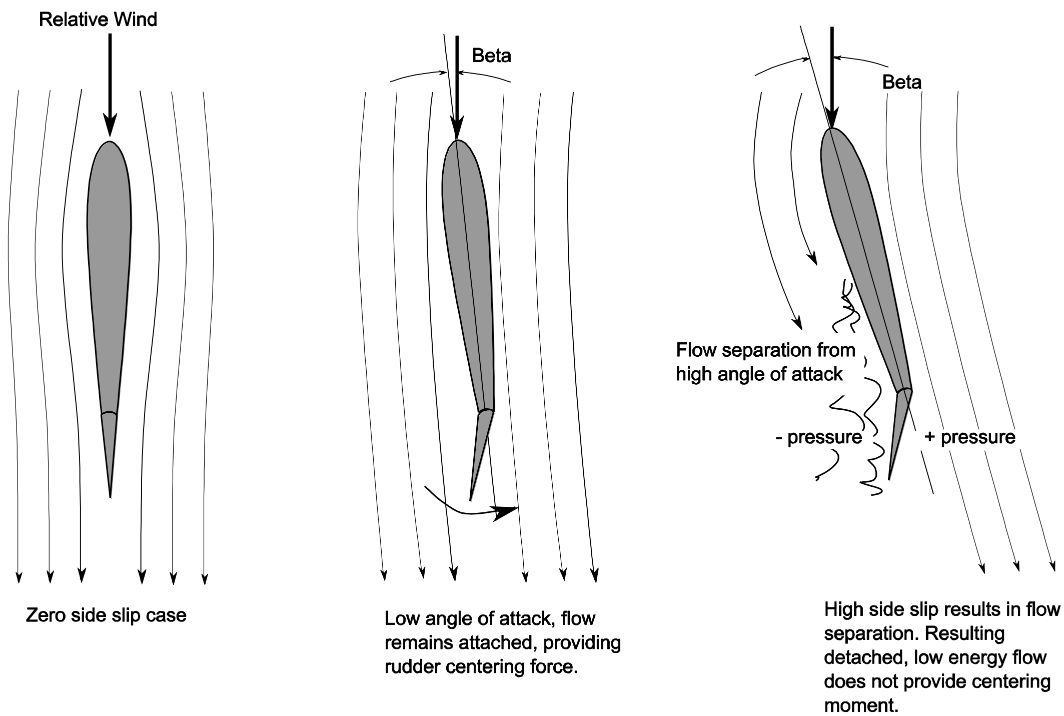


Figure 6. Rudder Force Reversal (Rudder “Overbalance”)

While the rudder appears locked, the pilot still has control of the rudder by pushing on the opposite rudder. The pilot should recover from the condition by pushing on the opposite pedal until he is able to hold the rudder in the neutral position.

With symmetric power, above 150 knots the side forces and rudder pedal forces are so high it is difficult to reach the rudder over balance condition.

To avoid over control, excessive side slip angles, and rudder overbalance (reversal in rudder pedal forces, aka “rudder lock”), the pilot must anticipate and recognize the low rudder force gradient.
At high speeds (above 150 knots), moderate buffet on the vertical fin occurs before rudder over balance. At low speeds, the buffet is reduced and may not be noticeable before encountering rudder overbalance. Even if buffet occurs, it may not be possible for the pilot to arrest the beta excursion before the rudder overbalance occurs due to the low rudder pedal force gradient. As a result, natural airframe warning of the impending directional instability inadequate, since the buffet from the vertical tail may or may not accompany the directional instability. at low airspeed there is a lack of side force which might otherwise alert the pilot that a high side slip condition is developing.

Flight test data from an HC-130H test conducted in 1966 shows a consistent, abrupt, but controllable pitch up occurring at buffet onset. C-130J testing experienced both pitch up and subtle nose down pitching moments accompanying the rudder overbalance condition.

When rudder overbalance occurs, neutralizing the rudder pedals will not recover the aircraft. The pilot must actively push on the opposite rudder to bring the rudder back towards center. This may require 50 (slow speeds) to 200 (180 knots) pounds of rudder force. If recovery from rudder overbalance is not accomplished promptly, the airplane can reach an extreme side slip and may roll to a high angle of bank. If the aircraft is stalled with large side slip, the resulting departure may not be recoverable.

With the aircraft at large slide slip angles, drag becomes very high. As a result, high sink rates can develop.

The low aspect ratio of the C-130’s vertical stabilizer makes it difficult to precisely define the “stall” condition or exact maximum lift coefficient

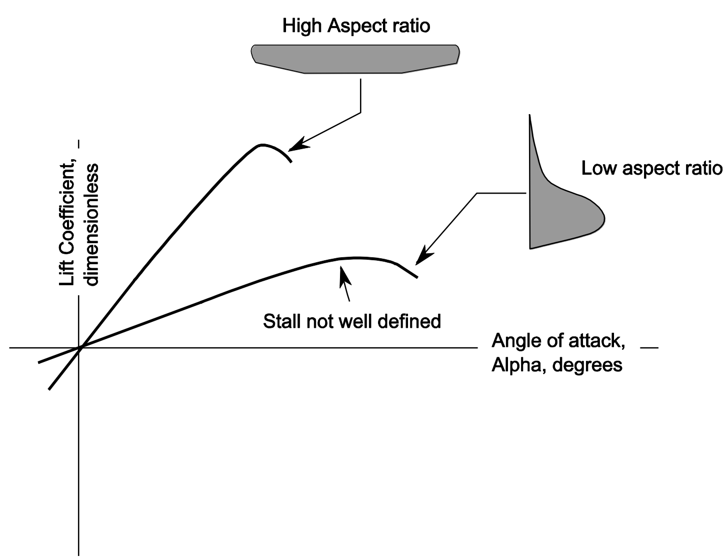


Figure 7. Rudder Angle of Attack verses Lift Coefficient

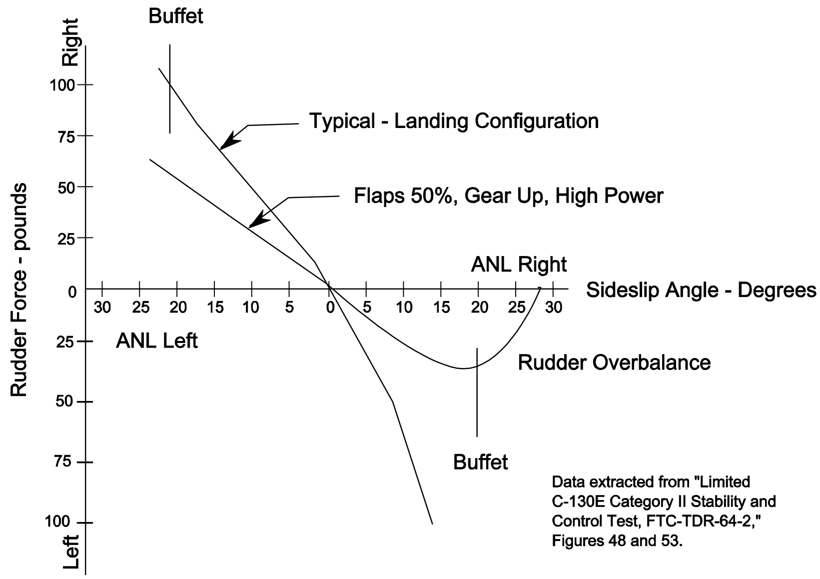


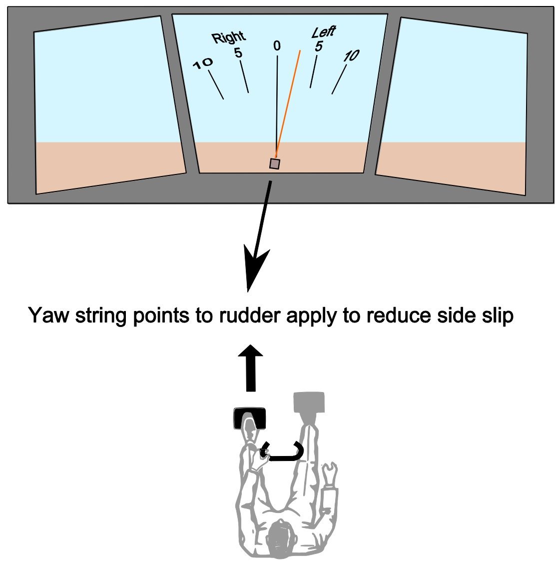
Figure 8. Rudder Force Gradient

Recovery from the rudder over balance condition:

- Push on the opposite rudder pedal to return and hold the rudder in the neutral position
- Roll to a wings level attitude
- The C-130H Flight Manual (T.O. 1C-130H-1) directs retarding all throttles *towards* FLIGHT IDLE during the recovery from fin stall. The C-130J Flight Manual (T.O. 1C-130J-1) Rudder Overbalance recovery does *not* include a step to reduce power

C-130J flight test demonstrated that reducing power is not required to recover from the excessive sideslip/rudder overbalance condition. While reducing power will reduce the directionally destabilizing momentum flow through the propeller disk, it is highly possible that the aircraft is below power off stall (maximum effort obstacle clearance speed), and too much reduction in power may result in a stall and departure. As a result, the pilot should *smoothly* reduce the angle of attack, if altitude and flight conditions permit, while retarding the throttles. The increase in airspeed associated with a reduction in angle of attack will improve the directional stability of the aircraft. Avoid an abrupt push-over to a negative g condition during recovery, as this may result in a reduction in maneuvering stability (nose down pitch rate continues even when elevator is applied in the nose up direction). With a large nose down pitch rate, the large pitch inertia of the aircraft and longitudinal rotation effects on elevator hinge moments cause a time lag in the aircraft's pitch response. These maneuvering flight characteristics could result in a negative g overload and excessive nose down pitch attitude.

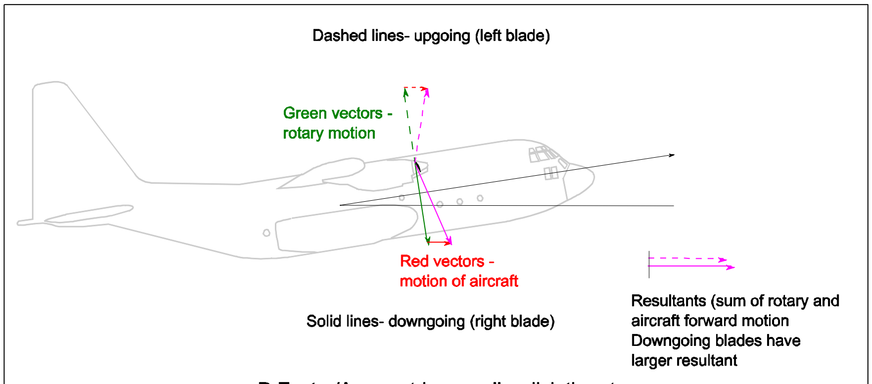
Because of the low rudder forces, low side force, and reduced yaw rate damping, it is easy to over control the rudder during recovery. Ideally, recovery should be made with reference to side slip information:



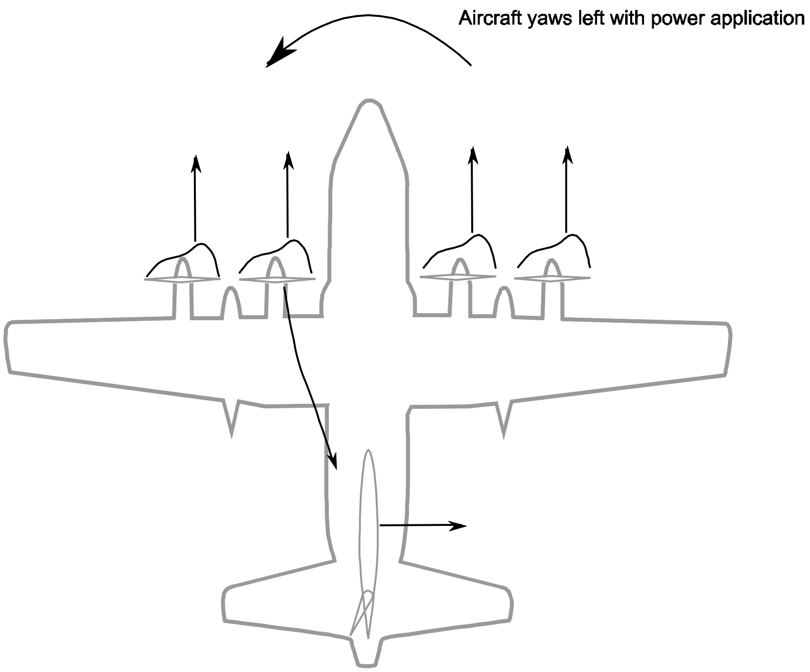
The design of the C-130 is such that high side slip angles are not accompanied by strong rolling moments from the side slip. During testing, angles of side slip as high as 40 degrees were observed without a roll off.

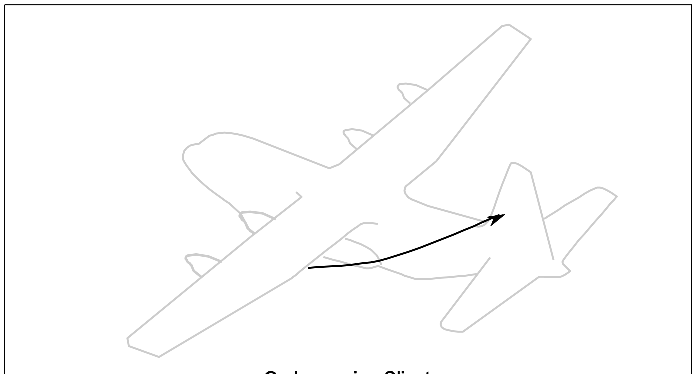
Recovery from a side slip excursion may require up to 5000 feet of altitude.

The addition of power normally causes right side slip, and could potentially cause a large side slip excursion if an abrupt power application was made without coordinating rudder:



P-Factor/Assymetric propeller disk thrust





Corkscrewing Slipstream

Rudder over balance has occurred at airspeeds up to 180 knots. At higher airspeeds, there is a risk of structural overload/damage/separation of the vertical stabilizer if the rudder is suddenly deflected at high side slip:

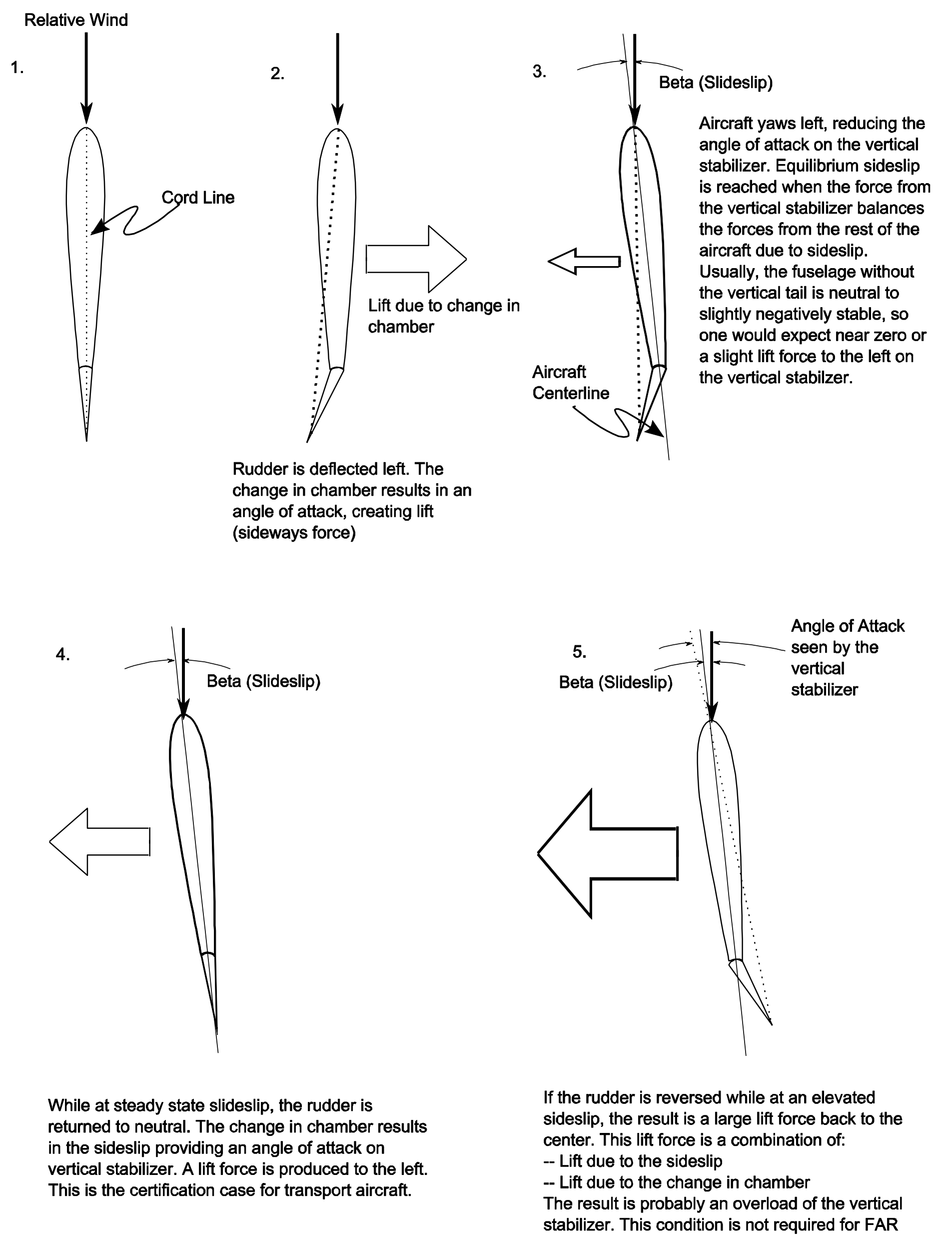


Figure 9. Possible Vertical Fin Overload with Rudder Reversal in Slide Slip

It is not safe to demonstrate the reduction in directional control in the aircraft without a real time display of side slip. Additionally, very small rudder inputs should be made, allowing the side slip to stabilize, before making further inputs. Avoid even moderate yaw rates due to the possibility of overshooting due to the low yaw rate damping.

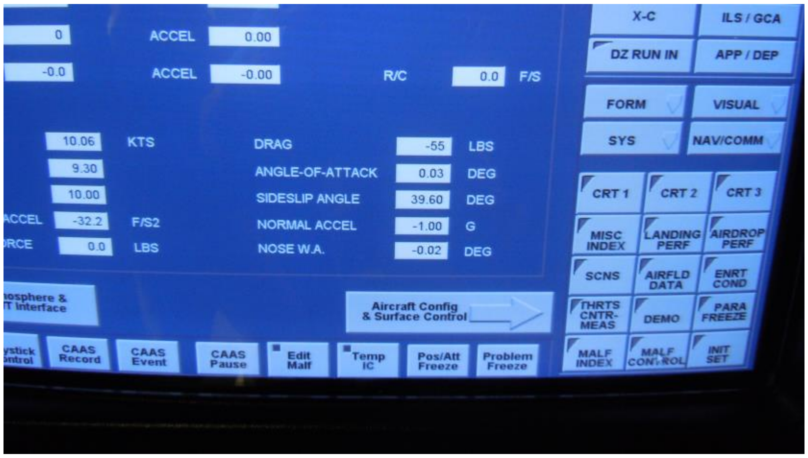
Experiencing C-130 slow speed directional stability in the simulator
The reduction in directional stability characteristic can be demonstrated in the C-130H simulator, using these procedures that simulate a light weight, maximum effort takeoff after landing gear retraction. The simulator models one condition, and is therefore only approximately accurate for any specific flight condition. Of note, the C-130J simulator side slip characteristics are only modeled up to the point that the aircraft gets the “LEFT/RIGHT SIDE SLIP” special alert, so there is no further modeling of directional stability characteristics beyond the special alert.

1. Configure the simulator at Little Rock AFB, AR, Runway 25 with a gross weight of < 105,000 lbs, temperature < 15C, in VMC conditions.

2. After takeoff, retract the landing gear but leave the flaps extended to 50% and climb to 1,500 to 2000 ft AGL.

3. Slow to charted maximum effort obstacle clearance airspeed ~ 90-95 KIAS and advance the throttles to takeoff power. You will need to pitch the aircraft up 12-16 degrees to maintain airspeed.

4. [H-Model] Have someone monitor the side slip angle on the simulator display by going to MISC INDEX, selecting TEST INDEX, CONTROL LOADING, A/C FLIGHT SCHEDULES AND DATA.



Sideslip Angle display in Minneapolis H2 Simulator

5. Slowly add LEFT rudder while keeping the heading constant. A slight amount of right bank will be required.

6. At about 15-16 degrees side slip, the side slip will begin increasing without additional rudder. This is point at which the directional control becomes neutral.

7. To recover, slowly center the rudder, pushing on the opposite rudder, until the rudder can be held in the neutral position. Recovery may be aided by smoothly reducing the angle of attack (altitude and terrain permitting), increasing airspeed, and slowly and smoothly making a small to medium throttle reduction.

David Fedors/27 May 2011/(661) 275-7037

References

- T.O. 1C-130H-1, *C-130H Flight Manual*
- T.O. 1C-130J-1, *C-130J Flight Manual*
- Martin, Kenneth and William R. Lowe, *Limited C-130E Category II Stability and Control Tests*, FTC-TDE-64-2.
- Keith, Leroy A., Alllen G. Rydman, and Gervasio Tonni., *HC-130H Category II Performance and Limited Stability and Control Tests*, FTC-TR-66-23.