PC-12 Stall Protection System

DESIGN PHILOSOPHY - A UNIQUE AIRCRAFT

The market dictated the design philosophy of the PC-12 in that it should be designed and certificated to FAR Part 23 (single engined). It should offer similar or superior climb, cruise and payload performance to turbo-prop twins, similar or superior comfort, operational flexibility in terms of short field operation, cargo door and floor as standard, single pilot operation, capable for operation under Instrument Flight Rules (IFR), at night, and flight into known icing conditions. It should offer superior safety in terms of systems reliability, crash worthiness and should possess safe and pleasant handling characteristics. It should also offer significantly reduced acquisition and operating costs.

With such a stringent design requirement, the PC-12 was always going to be a unique aircraft. It is the largest single engined aircraft currently being built. It has an operating speed envelope from a stalling speed of 61 kcas to a cruising speed of 265 ktas at FL 250, an extremely large center of gravity range from 13%mac most forward to 46%mac most rearward, and an engine capable of producing 1,200 shaft horse power. The PC-12's high power, low speed yields a very high thrust coefficient at the stall. This was a feature which created unique challenges during development flight testing, in particular stall testing.

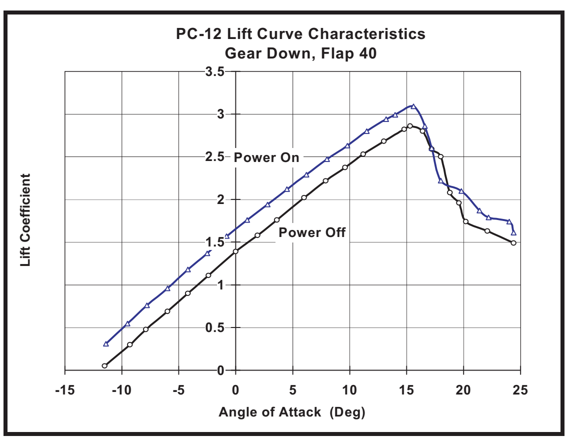
STALL - REQUIREMENTS

The FAR 23 certification requirements for stalls dictated that the maximum stall speed in the power off landing configuration may not be greater than 61 kcas. It further dictated that the stall must be characterized by either an "uncontrollable downward pitching motion of the airplane" or by the elevator control reaching the stop.

For wing level stalls, it was then required that "during the recovery part of the maneuver, it must be possible to prevent more than 15° of roll or yaw by normal use of the controls". For turning flight and accelerated stalls, "it must be possible to regain level flight without exceeding 60° of roll in either direction from the established 30° bank". Compliance had to be shown in all flap configurations and with engine power up to 75% of the maximum continuous rating.

Furthermore, § 23.207 (a) stated that "there must be a clear and distinctive stall warning, with the flaps and landing gear in any normal position, in straight and turning flight".

In order to achieve the project specification for a 265 ktas cruise speed and nevertheless fulfill the requirement of a 61 kcas Stall speed, a small wing with a high lift profile and Fowler flap system was designed with an extremely high lift coefficient. This resulted in the selection of a wing profile with a very "peaky" lift curve at its maximum point.



To cope with the extremely large center of gravity range from 13%mac most forward to 46%mac most rearward, the PC-12 was designed to utilize the advantages of a T-Tail.

STALL CHARACTERISTICS

From the start the PC-12 could meet all stall requirements, indeed the stall characteristics of the PC-12 at low thrust coefficients were benign. However, with a power setting of 75% MCP the PC-12 stalls at a speed of 45 kcas, a pitch attitude in excess of 30° nose up. In this extreme condition

the stall is finally characterized by a wing drop which at such low speed the ailerons do not have the authority to counteract.

Furthermore, in all conditions the elevator in the T-Tail arrangement maintained sufficient aerodynamic authority to control the aircraft in pitch throughout the stall. The requirement of full back stick or "uncontrollable" nose down pitch motion could not therefore be fulfilled. In conclusion, the PC-12 'power on' stall characteristics exhibited:

- No pre-stall warning
- No pitch down
- Wing drop > 15°

Characteristics which were aggravated with increased flap, power and rearward CG.

STALL SOLUTION

Flight tests were supported in parallel by a further series of wind tunnel tests in an attempt to find aerodynamic solutions, many of which were successfully tested in flight but were considered unacceptable at the relatively late stage in the

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program. Finally it was decided to prevent the aircraft from reaching the aerodynamic stall by introducing a stall protection system (stick shaker/pusher). The FAA Advisory Circular 23 8A gave indications about the operation of stick pusher systems, this information was amended by the Swiss FOCA. The final requirements becoming:

- 15°< Wing Drop < 40° Natural aerodynamic stall to be protected by 2 kts
- Wing Drop > 40° Natural aerodynamic stall to be protected by 5 kts
- Operation of the stall protection system to be mandatory for flight
- In all cases, stall warning (shaker & aural) shall operate "at a speed exceeding the stalling speed by not less than 5 knots and by not more than 10 knots or 15% of the stalling speed".

In order for the stick pusher to operate with sufficient margin from the natural aerodynamic stall and still meet the Stall speed rrequirement of 61 kts, the wing span and flap span were increased by a total of 2 meters. This modification required a completely new wing to be built, which could only be tested on the second prototype (P02) for the first time. In the meantime all stick pusher conceptual testing was developed using the first prototype (P01). The stick pusher grew in complexity throughout the development process and is now a sophisticated system using modern sensor electronics and qualified according to the latest Failure Mode and Criticality Analysis (FMCA) methods and requirements.

The system consists of two digital computers, two vane-type AOA sensors installed on the left and right wing, a single stick shaker, a single stick pusher actuator and caution devices. In correspondence to specified AOA values, each computer gives a shaker activation, pusher activation or pusher deactivation command to the actuators. The system is set up in a way that either computer can independently activate the stick shaker and audio warning, but a signal from both computers is needed to activate the stick pusher. To maintain adequate speed margins between stick shaker, stick pusher and natural stall in all conditions, the AOA values that trigger the stick shaker and stick pusher actuation depend on flap position and, with 40° flaps, on engine torque. When the airspeed is reduced below the stall warning limit, the pilot is warned of the impending stall by a strong shaking of the control wheel; if he nevertheless continues to pull and reduce speed, the stall protection system is activated and pushes the control wheel forward. The aircraft pitches down and immediately resumes normal flying, with moderate altitude loss (typically 150 to 200 ft).

A significant amount of development and certification testing was performed throughout the extremes of the weight & balance and altitude envelopes during which over 1,000 stalls were conducted. In addition a significant amount of abusive type manoeuvers (Bunts to 0g, Roller coasters and flight in turbulence) were also investigated in an attempt to inadvertently activate the pusher. The system was also tested during natural icing conditions.

It is possible to override the stall protection system by holding the control wheel back with sufficient force (approximately 50 pounds), or even to disconnect the system. In this case, the aircraft is obviously no longer protected against an aerodynamic stall; depending on the power setting and flap configuration, severe (although not unrecoverable) roll departures can occur. This is of course very dangerous in the initial and final flight phases, since even a very experienced pilot will not be able to recover from a critical aerodynamic stall departure without a severe altitude loss (up to 700 ft).

CONCLUSION

The PC-12 is unique in that it is the only aircraft of its class to be protected by a stall protection system, as normally found only on much heavier and more sophisticated aircraft. The system, developed by Pilatus, was certified through an extensive flight test program and has been proven in operation on more than 500 aircraft and more than 850,000 flight hours. It provides enhanced flight safety and peace of mind by preventing the pilot from stalling the aircraft under any flight condition, without any significant negative effect on aircraft performance.

It must be emphasized that if the stall protection system is deactivated, there is a very real risk of incurring an aerodynamic stall with potentially severe roll departures, particularly in the flaps down configuration with high power.

We hope this enables you to better understand the roll of the stick shaker/pusher system on the PC-12, and we wish you continued safe flying.

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