"THE DEVELOPMENT FLIGHT TEST PROGRAMME OF THE PILATUS PC-XII"

Dr O.L.P.Masefield, Vice-President Engineering
A.R.J.Taylor, Flight Test Department, Pilatus Aircraft Ltd, Switzerland

1. Abstract:

The PC-XII's high maximum lift coefficient, large centre of gravity range and high thrust to weight ratio at low speeds produce unique aerodynamic problems which had to be solved. Some of the problems were not immediately visible from the results of the wind tunnel measurements. The PC-XII prototype underwent a 300 hour development flight test programme and subsequently, together with a second aircraft representative of the series production, entered into the 400 hour certification flight test programme. Swiss certification was obtained in March 1994 with FAA expected to follow during this summer. This paper briefly presents the basic marketing and design philosophy of the PC-XII, the development programme schedule and discusses some of the problems encountered and solved in the flight test programme.

2. Introduction

With the Pilatus PC-XII and other modern single turbo-prop powered aircraft, the market has demonstrated that it accepts that there is sufficient reliability offered in an aircraft powered by a single turbine engine. Regulations are changing to allow the carriage of fare-paying passengers in such aircraft, providing that sufficient reliability and safety is demonstrated.

The Pilatus PC-XII is a unique aircraft in many ways: It is the largest single engined aircraft currently being built. It has a large operating envelope from its 61 kts stall speed to its 265 kts cruise speed at 30'000 ft. It has an extremely large centre of gravity range from 13% most forward to 46% mac most rearward limits. It has an engine capable of producing a continuous 1200 shaft-horsepower, developing a very high thrust to weight ratio at the stall. Together, these provided some interesting problems which were solved during the flight test programme.

3. Development History

The PC-XII aircraft development was initiated at the beginning of the world-wide industrial recession. Companies utilising business and utility aircraft seemed hesitant to purchase and operate expensive new twin turbo-prop aircraft.

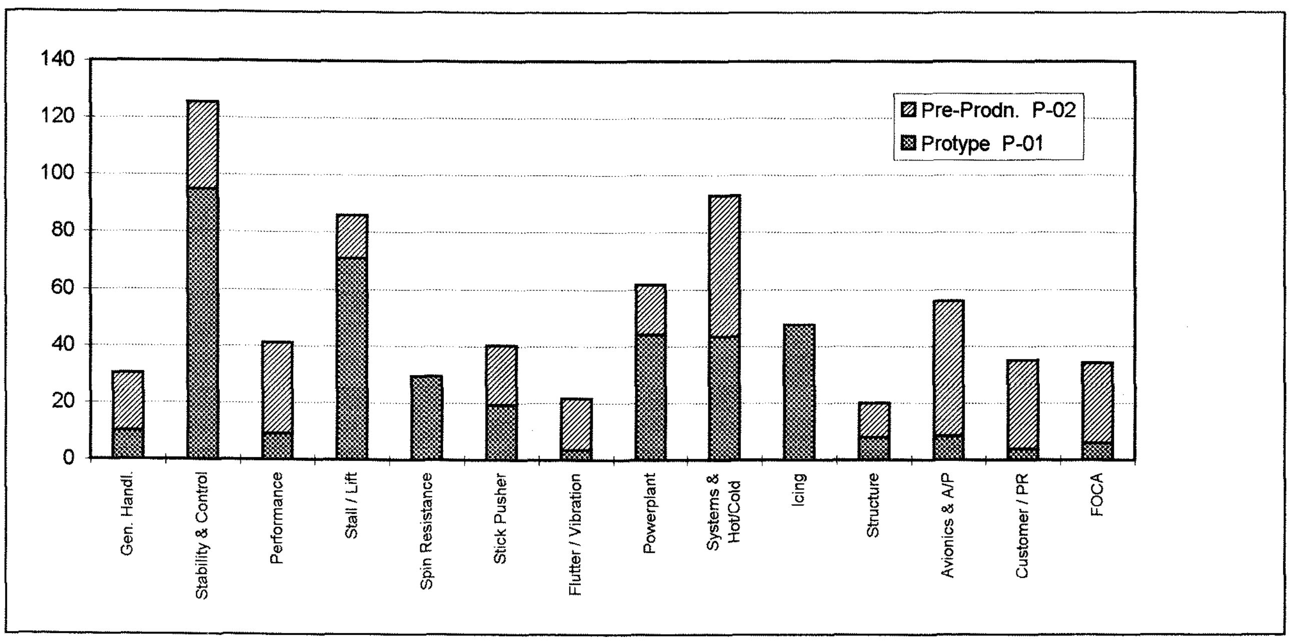

Figure 1: PC-XII Flight Test

Pilatus decided at this time to develop our presence in the civil aircraft market. On the basis of our experience with very high powered, highly manoeuvrable military turbo-prop trainer aircraft, we felt that we were ideally placed to offer the civil corporate/utility market a product which would be capable of providing a real alternative to the currently available aircraft. Both Pilatus, with the PC-6 Porter utility aircraft and our subsidiary, Pilatus Britten-Norman with their BN-2B Islander transport/utility aircraft, were present in that marketplace with designs which no longer provided the performance and comfort expected from modern transportation.

The PC-XII project was commenced in 1986 with a feasibility study. The design was conducted almost totally in the Pilatus facilities in Switzerland, with sub-contracts being placed with international equipment vendors. The aerodynamic design was confirmed in extensive wind-tunnel testing in Switzerland. The first prototype aircraft flew in May of 1991 with the first fully representative pre-production aircraft joining the certification programme in May of 1993. By the achievement of Swiss FOCA certification in March of 1994, both aircraft had accumulated more than 700 flight hours together. Numerous structure and systems testing was conducted, including the dynamic crash testing of pilot and passenger seats, an ultimate test of the wing structure, fire resistance tests on the cowling and cabin interior and HIRF/lighting and environmental testing of systems and components.

The design concept of the PC-XII included the following aspects:

- Design & demonstration according to FAR part 23
- Similar or superior climb & cruise performance to turbo-prop twins
- Similar or superior comfort (space, noise, etc.)
- Operational flexibility:
  - Short field operation
  - Cargo door & cargo floor as standard fit
  - Capability for IFR, Night and flight into known icing
  - Single crew operation
- Superior safety:
  - Systems reliability
  - Crashworthiness (amendment 36)
  - Safe and pleasant handling characteristics
- Significantly reduced acquisition costs
- Significantly reduced operating costs
- Significantly reduced environmental burden

Having achieved these targets it is sincerely believed that, with the PC-XII, Pilatus is offering a new product which improves the safety and economy of the Corporate / Utility aircraft market.

4. Flight Test Program

4.1 General

Two test aircraft were used during the development and certification flight test programme:

The prototype PC-12 aircraft S/N P-01 and
The pre-production PC-12 aircraft S/N P-02.

P-01 originally had the geometry and systems foreseen for the production aircraft, with the exception of the lack of a pressurised cabin and the associated systems. In the course of the development programme, the geometry of the aircraft also had to be adapted and some systems modified. The utilisation of the aircraft was mostly for development flying and some specific certification testing in the areas of Spin Resistance, Unusable Fuel, Icing, etc. For its utilisation in the Spin Resistance testing and later in the Icing certification, the aircraft was equipped with a production standard wing which had an increased wingspan. For the more critical tests the aircraft was equipped with a pilot's escape system.

P-02 is the pre-production aircraft, identical to the following production aircraft in virtually all respects. It conducted the majority of the certification flight testing. Its tasks were almost entirely on the certification flight testing, although some development testing took place, especially in the areas of Environmental Control System and Autopilot.

4.2 Development Test History

The areas on which the initial flight test programme concentrated were: expansion of the flight envelope, achievement of satisfactory stall characteristics (see later), flap system operating problems, vibration caused by flow separation in the junction of the horizontal and vertical tails, excessive drag, powerplant installation improvements , aileron modification to improve the force gradient and the additions of winglets, aileron/rudder interconnect spring and rear fuselage strakes to improve the lateral stability and "Dutch Roll" characteristics respectively.

Figure 1 gives a summary of the flight test utilisation of both aircraft from the time of their first flights up to the award of a type certificate. It can

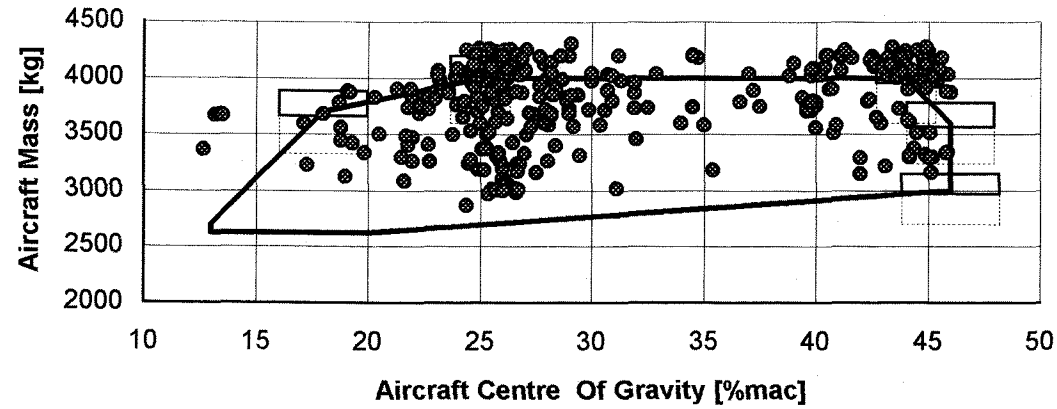

Figure 2: Centre of Gravity range tested

be seen that the major effort during the flight testing of P-01 was in the areas of stability & control and stalling / high lift / stick pusher. The latter accounted for over 25% of the total development programme and resulted in an aircraft with excellent (stick-pusher produced) stall characteristics.

The nature of the testing of P-02 is clearly visible on the same figure: Considerable effort was extended in the area of the mechanical systems in correcting problems which occurred once the aircraft was exposed to lengthy flight at high altitude/cold environment, in addition to their subsequent certification (Environmental Control, Hydraulics, etc.) and autopilot development and certification. The pressurisation system worked remarkably well without problem from the very start of the testing on P-02.

4.3 Test Envelope

The PC-12 has been tested at the critical conditions of its weight and centre of gravity envelope. As the PC-12 is a Corporate/Utility aircraft, it can be expected that it will be utilised as a "workhorse". In this role it is possible that the operator is not as careful as he ought to be in the loading of the aircraft. It has therefore been Pilatus' policy to develop and certify a sufficiently large centre of gravity envelope that an operator will not be able to load the aircraft in a dangerous c.g range in the vast majority of his operations.

Figure 2 shows the weight and c.g envelope of the PC-12 in terms of maximum weight (in kilograms) and centre of gravity (in % mean aerodynamic chord), with the flight test limitations according to FAR part 23 added in the form of boxes. The take-off mass and corresponding centre of gravity for each flight during the certification testing are marked on the figure as a dot.

The most rearward centre of gravities were typically the most critical for demonstration of longitudinal characteristics and also gave the highest pitch rates for malfunctions (autopilot, stick pusher, spin resistance, etc.). The rear c.g conditions were also utilised for all lateral / directional stabilities, producing the lowest stability gradients. The most forward centres of gravity typically gave the most critical configuration for aircraft performance and control authority and for the highest stick forces in pitch (longitudinal control, trim runaway).

To achieve the loadings shown in the above diagram in the pre-production aircraft, P-02, (the aircraft is equipped with some 100 kg of measurement equipment) it was necessary to load special ballast boxes to about 500 kg and position them in the extremities of the cabin or cockpit. In addition, sometimes it was necessary to move the aircraft battery or some other heavy equipment to achieve the extreme centre of gravity to be demonstrated in flight test. This in itself is a clear indication of the loading capability of the aircraft.

4.4 Flight Test Instrumentation

Both test aircraft were equipped with the standard production PC-12 cockpit instrumentation and with the Pilatus Flight Test PCM Data Acquisition System (DAQUS) capable of measuring up to 200 parameters. The configuration of the DAQUS was changed according to the programme being flown, with the basic parameters of aircraft handling and powerplant being retained throughout. During each test all the data were recorded on a magnetic digital tape and, in parallel, transmitted by telemetry. Some parameters were observed in real-time by the test engineer on the ground. After the flight the parameters relevant to the test were reduced, analysed and stored on diskette or magnetic tape using the appropriate software.

The majority of the flight testing was conducted from the Pilatus facility in Switzerland in conditions ranging from -10°C to +25°C and from high solar heating to falling snow or freezing rain within the time span of the development and certification testing. Additional testing was conducted out of other airfields in Switzerland for reasons of weather and at other sites throughout Europe and Iceland for special operations: Grass operation, High altitude, Hot Weather, Icing and Hot Fuel.

5. Detailed Problems & Solutions

5.1 Stalls

In order to achieve the project specification of almost 270 kts TAS cruise speed and nevertheless fulfil the FAR §23.49 requirement of a 61 kt stall speed, a small wing with a high lift profile and high lift 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.

A problem with any aerodynamically produced stall is that it will be heavily modified by the extension of wing flaps and with application of power (1200 shp on the PC-XII) which strongly changes the lift, dynamic pressure and angle of attack distributions along the wing span. As a result it was virtually impossible to achieve acceptable stalling qualities through aerodynamic means to show compliance with FAR part 23. The stall typically was identified by a rapid and large wing drop. Many flight tests were conducted with various arrangements of wing fences and the ailerons were even supported in one test series by a spoiler control, in an attempt to counteract the rolling moment. The flight tests were complemented by a series of wind-tunnel tests to confirm the flight test results and provide further alternatives.

At the beginning of the PC-XII design it was decided to select a T-Tail configuration to minimise control problems associated with flap deflections under power (strong downwash) and to minimise the propeller wash induced vibrations. The disadvantage became apparent during flight testing: the aircraft did not possess a natural pitch down at the stall. The elevator remained always powerful enough to control the pitch axis of the aircraft throughout the stall (instead of producing an "uncontrollable" downward pitching moment as required by the regulations).

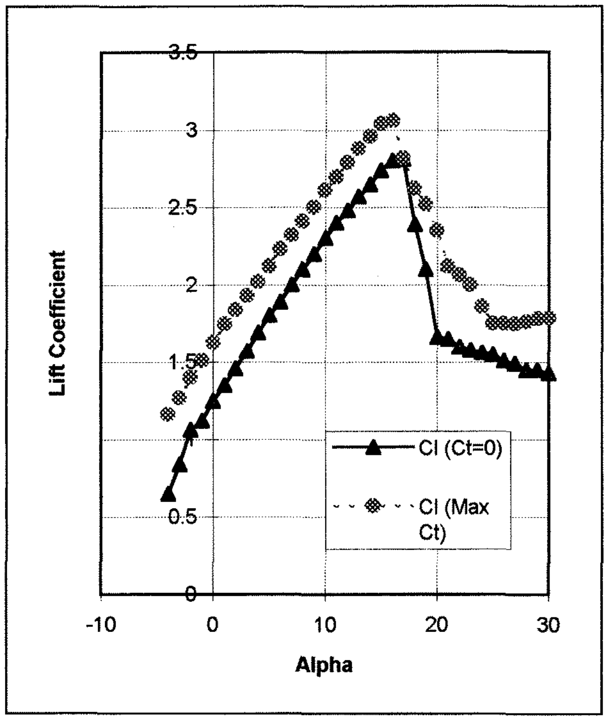

Figure 3: Lift Coefficient of PC-XII (Power on/Power off)

No aerodynamic solution could be found to the stall behaviour, so it was decided to incorporate a stall barrier (stick-pusher) system to produce a safe and predictable stall in all configurations. In order that the stick pusher system could operate at acceptable margins from the natural (aerodynamic) stall, the wing span and flap span were increased by a total of 2 metres. This modification required a completely new wing to be built, which could only be tested on P-02 for the first time. However, all the stick pusher conceptual testing was developed on P-01. The stick pusher grew in complexity throughout the development process. Now it is a sophisticated system using modern sensor electronics and qualified according to the latest Failure Mode and Criticality Analysis (FMCA) methods and requirements. As a result of the significant amount of development and certification testing, during which over 1000 stalls were conducted, it has been demonstrated that the PC-XII aircraft equipped with this stick pusher stall barrier system is significantly safer than any other similar sized aircraft which can be stalled. The PC-XII has fully attached airflow over all surfaces at its minimum flight speed (at the time the nose is automatically lowered). The aircraft is neither capable of stalling nor entering a spin.

5.2 Performance

Initially the aircraft suffered a performance loss, in the order of 20 knots compared to predictions. A lengthy review was conducted around the aircraft on the ground and in flight with wool tufts taped to the suspect areas and filmed from a chase aircraft. All the excess drag could be identified and recovered, the main areas of loss being: 1) in the lower fuselage / wing / flap junction, 2) in the vertical / horizontal tailplane junction, 3) in the gap between the flaps leading edge and wing structure, 4) in the shape and size of the wing-to-fuselage fairing and 5) in the re-shaping of the exhaust stacks. Further performance gains were possible, especially in the area of engine intake efficiency improvement, but were not included because of a potential increase in hazard after a delayed pilot recognition of icing conditions.

5.3 Stability and Control

The stability and control of the aircraft was good in almost all areas from the beginning with low power settings. Because of the very high energy of the propeller slipstream at high power settings, some stability problems were encountered at low airspeeds with high power. In particular, the lateral stability was reduced sufficiently when the flaps were fully deflected at high power settings that it was necessary to add dihedralled winglets and a light aileron-rudder interconnect spring to pass the most critical of the FAR stability demonstration tests. (The winglets had the added advantage of improving the cruise performance at the higher operating altitudes which were requested of the aircraft during the course of the development programme).

The addition of the winglets upset the harmonisation of the lateral and directional damping to such an extent that it was necessary to add rear fuselage strakes to achieve acceptable "dutch roll" characteristics throughout the operating envelope with the autopilot disconnected.

Early in the programme it was found necessary to re-design the interface of the horizontal to vertical tailplane. In this area there was local flow separation at medium speeds which caused a vibration to occur on both the rudder and elevator. Several "Band Aid" solutions were tried with vortex generators and fences before the final, more extensive, solution was accepted: The intersection was modified to accept a generous "bullet" fairing around the whole intersection. The rudder was modified to butt up against the underneath of a fairing and the elevator was split into two parts to also wipe against the sides of the fairing. Figure 4 below shows both tailplane configurations.

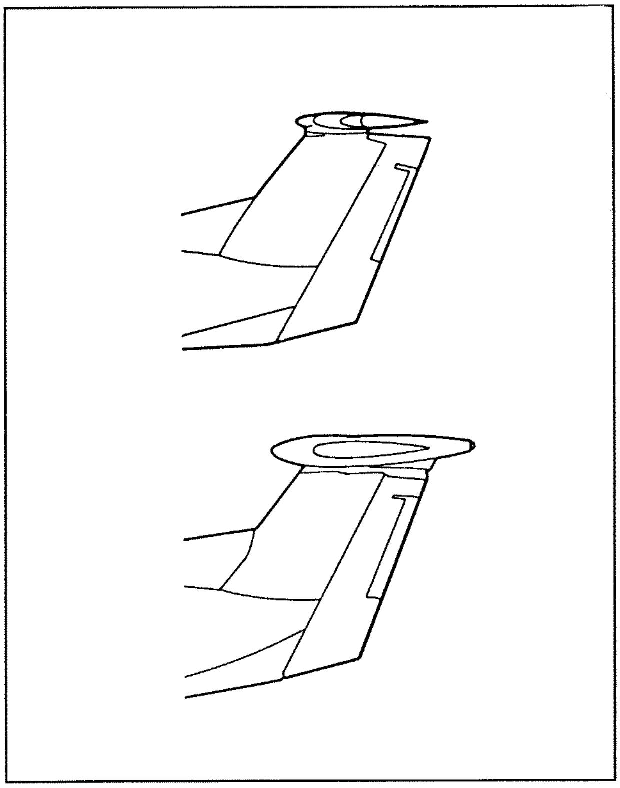

Figure 4 Tailplane Configurations
(Top: Original version)

The typical form of the LS/MS/GAW series of NASA profiles is their cusped trailing edge. This provides a significant contribution to the high lift of the profile, but also gives problems to the floating tendencies of the ailerons. Some re-design of the trailing edge had to be conducted to provide satisfactory force gradients.

5.4 Icing

The programme to demonstrate satisfactory systems function, performance, stability and controllability in icing conditions to permit "Flight into Known Icing Conditions" provided extremely interesting results in the areas of handling characteristics, systems layout and test instrumentation. Many lessons were learnt during these trials and discussions with experts around the world, whose knowledge of the icing phenomena is advancing from year to year. Fortunately the problems encountered during these tests were all of relatively minor nature and could be rectified with reasonable costs and within timescales which allowed the delivery of customer aircraft.

6. Conclusions

After the initial shake down tests, an intensive two-year flight test programme was required to produce an aircraft which today is certificated and is being introduced into service in several continents. The PC-XII is capable of meeting the most severe of modern safety and environmental regulations together with a stall / spin protection system which will make it one of the safest aircraft in its class. The PC-XII offers unsurpassed economy both in purchase costs and in operating costs. These targets have been achieved only because of a detailed and thorough test programme in addition to a competent engineering of the product.

7. References

1) Federal Aviation Regulations, Part 23 Airworthiness Standards: Normal, Utility Acrobatic and Commuter Category Airplanes, including Change 30 (Amendment 42), Effective Feb 4 1991

2) Federal Aviation Administration Advisory Circular AC23-8A, Flight Test Guide for Certification of Part 23 Airplanes

3) Pilatus Aircraft Ltd
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