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LONGITUDINAL HANDLING IMPROVEMENTS OF PILATUS PC-9 ADVANCED TURBO TRAINER

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Abstract

The Pilatus PC-9 advanced turbo trainer was designed to offer a cost-effective alternative to jet training aircraft. Simplicity, on the one hand, imposed manually operated control surfaces, whereas on the other hand, the aerodynamics designer had to reconcile the requirements for low maneuver stick force gradients with the demand for stick-free longitudinal stability at speeds up to 300 knots: all this over a wide c.g. excursion.

The PC-9 received its Swiss Civil Certification, based on FAR Part 23 in September 1985, and therefore, the requirements for longitudinal stability and control were met. Whilst these requirements are acceptable for the majority of FAR Part 23 aircraft, they are less appropriate for an aircraft capable of +7g/-3.5g, a max. operating Mach number of 0.68 and a service ceiling of 38,000 ft (FAR max. operating height = 25,000 ft).

Reference was made to U.S. Military Specifications and, in order to achieve these requirements, modifications to the elevator and longitudinal control circuit were needed.

A preliminary study was performed and, using that as a basis, a new elevator aerodynamic balance and control circuit were designed and extensively tested in flight. The MIL-Spec. goals were reached by further modification based on comparative data between theory and flight test results.

The paper emphasizes the comparative aspect of the investigation, consisting of a systematic validation of Data-Sheet semi-empirical data on elevator aerodynamic balance against in-flight measured stick force gradients and longitudinal handling characteristics.

Introduction

The Pilatus PC-9 is a second generation turbo-prop trainer (see Ref. 1) designed to offer performance that makes it a cost-effective alternative to jets in the basic/advanced training syllabi.

Performance, however brilliant it may be, is only one aspect of the aircraft's characteristics: handling qualities of trainers of this category are, today, just as important. In line with Pilatus' policy of continuous product improvement it was decided to bring the PC-9 longitudinal handling qualities as close as possible to MIL-F8785C requirements and still satisfy FAR 23 requirements for civil certification. To achieve this, a theoretical investigation was performed and a new elevator aerodynamic balance and control circuit were designed, implemented in the PC-9 aerodynamic prototype and tested in flight.

Objectives

The main objectives driving the program for the improvement of the PC-9 longitudinal handling qualities were:

1. Reducing the c.g. influence on the stick force per g gradient.
2. Increasing the stick force per speed gradient in order to improve the aircraft trimmability at speeds up to 300 knots at the rearmost c.g. position.

Several requirements for handling qualities were reviewed. On the basis of MIL F8785C handling qualities (see Ref. 2), but still keeping in mind FAR 23 requirements for civil certification (see Ref. 3), the following goals were set for stick force per g:

- Max. stick force per g = 10 lbf/g at foremost c.g.
- Min. stick force per g = 4.2 lbf/g at rearmost c.g.

Both MIL F8785C and FAR 23 regulations do not specify a minimum value for the stick force per speed gradient. The only indications are that it must be positive and large enough to give the pilot a satisfactory control feel (see Ref. 3 para. 23.173). With reference to the opinions expressed by Pilatus pilots the following goal was set on stick force per speed :

- Min. stick force per speed = 1 lbf/10 kt at rearmost c.g.

This limit was selected in order to have a satisfactory control feel at high speed and at the same time to avoid large control force variations during aerobatic maneuvers.

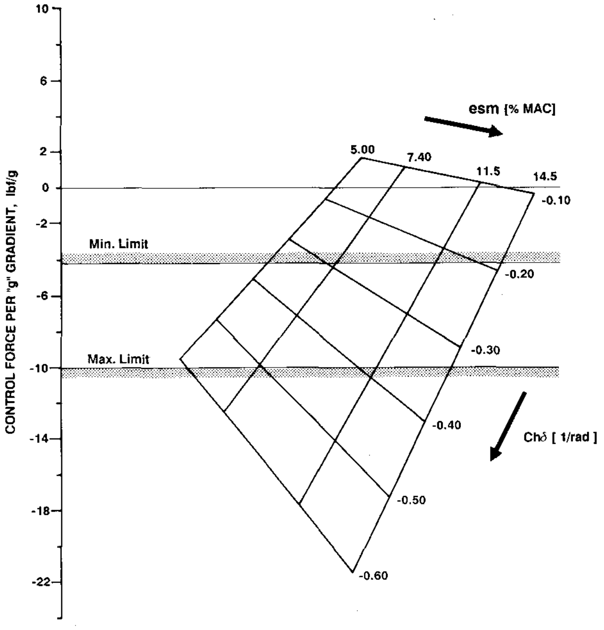

FIGURE 1 : STICK FORCE PER g VARIATION WITH esm AND Chδ

Theoretical investigation

In order to reduce the c.g. influence on the stick force per g and to increase the stick force per speed gradient, a theoretical analysis, supported by the available flight test data, was conducted.

Figure 1 shows the stick force per g gradient as a function of Ch_δ , and the equivalent static margin (esm), defined as:

$$esm = \frac{x_n - x_{cg}}{mac} \cdot \frac{Weight}{MTOW}$$

Figure 2 shows the stick force per speed gradient as a function of Ch_δ, and the equivalent static margin. No parametric analysis has been performed on Ch_α, because the design target value of this parameter was set close to zero to avoid variations in control forces during maneuvers. A Ch_α value close to zero also reduces the variations of the control forces due to changes of aircraft configuration and power setting.

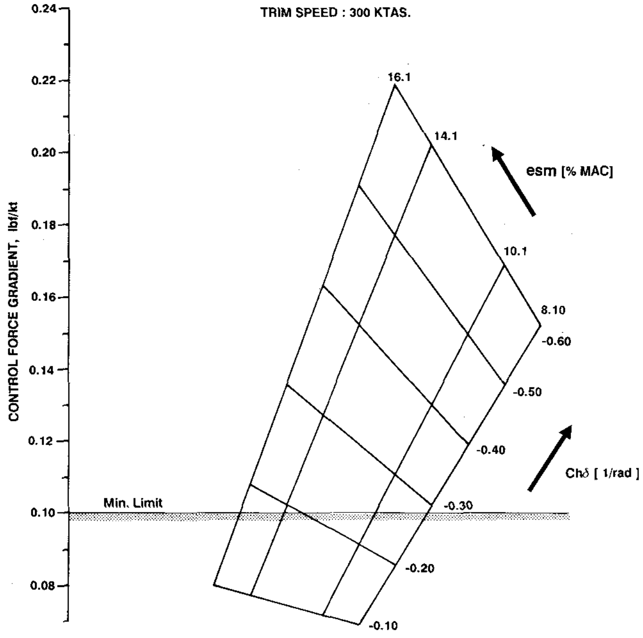

FIGURE 2 : STICK FORCE PER SPEED VARIATION WITH esm AND Ch_δ

Figures 1 and 2 illustrate how a decrease of Ch_δ value reduces both the c.g. influence on stick force per g and the stick force per speed gradient.

Compensation for the decrease of the stick force per speed gradient, consequent to a reduction of Ch_δ, was achieved by an adequately sized download spring introduced in the elevator control circuit.

The Ch_δ reduction had to be obtained without any considerable variation in Ch_α, as its value was already close to the target value. This was obtained through the replacement of the standard elevator unshielded horns with a shielded version which is less sensitive to the variation of angle of attack.

Provision was also made to install a bob weight in order to shift the entire stick force per g envelope. In order to reach the goals with minor changes in the aircraft structure, the following modifications were considered:

1. Design of elevator shielded horns.
2. Installation of stiffer download spring.
3. Installation of a bob weight.

The shielded horns were designed by using semi-empirical Data-Sheet methods (see Ref. 4) together with flight test results available at Pilatus.

The elevator and control circuit modifications are shown in Figure 3. Figure 4 illustrates the PC-9 unshielded elevator horn (horn no. 1) compared with the two shielded versions tested in flight (horn no. 2 and horn no. 3).

Flight test campaign

A flight test campaign was conducted in order to validate the theoretical results and arrive at the final modified configuration. The first flight test phase aimed to assess the stick force per g and stick force per speed with the modified elevator aerodynamic balance.

Horn No. 2 was installed on the aircraft and tested. The first results concerning stick force per g and stick force per speed agreed with the analytical calculations, however the introduction of the new horns led to the following side-effects:

1. A serious elevator 'snatching'.
2. A considerable lightening of the stick force following a power decrease in approach configuration.

The elevator snatching was found to be caused by the flow interaction between elevator horn and shield. This problem

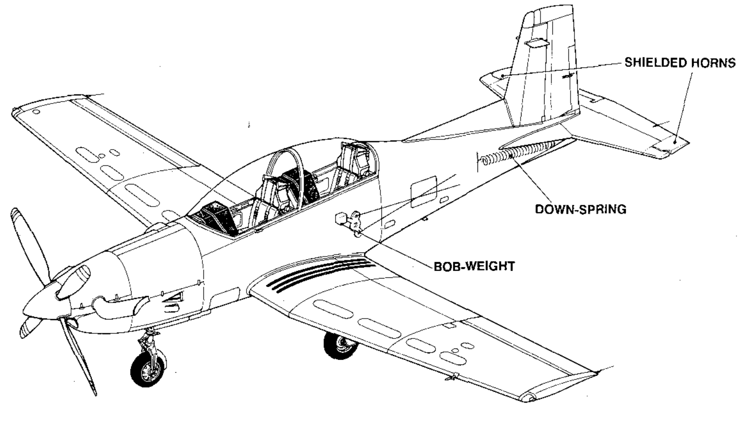

FIGURE 3 : ELEVATOR AND CONTROL CIRCUIT MODIFICATIONS

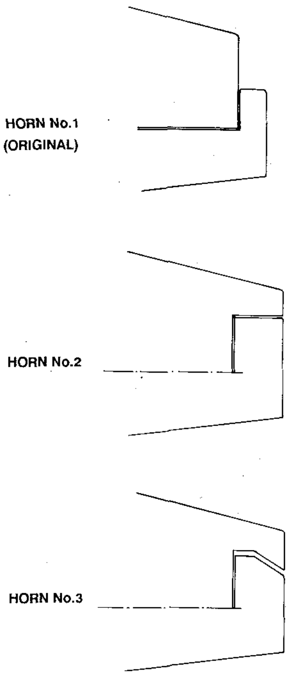

FIGURE 4 : ELEVATOR HORNS MODIFICATIONS

was solved by increasing the gap size between horn and shield from 5 to 20 mm.

The second effect is probably due to the concentration of the aerodynamic balance in the horn area. As the horns lie outside of the propeller slipstream, their effectiveness is proportionally much greater with engine power set to idle than it is with higher power settings, hence the reduction in stick force during a landing approach. To eliminate this problem it was decided to reduce the horn size.

As can be seen from Figure 4 the horn size was reduced by cutting a part of the horn leading edge at 45° in order to retain an efficient front location for the static mass balance of the control and to allow a gradual protrusion of the horn from the shield.

Horn No. 3 was then installed on the elevator and flown.

Data comparison

Figure 5 shows the measured and the computed stick force per g for horn no. 3 compared with the measured stick force per g for horn no. 1.

From Figure 5 it can be seen that considerable reduction of stick force per g variation with esm (proportional to c.g.) was obtained with horn no. 3. It is interesting to note that the reduced sensitivity in c.g. travel is bigger than predicted.This can probably be attributed to uncertainties in the estimation of some aerodynamic derivatives, as well as shortcomings of the theory with respect to Mach and Reynolds effects. Additional flight tests performed with different stabilizer angle settings have shown a marked sensitivity of the stick force per g to this parameter only for shielded horns. The cause of this phenomena can also be attributed to the flow interaction between shield and horn. This interaction, not considered in the theoretical investigation, gives one more degree of freedom in the design of the optimal elevator aerodynamic balance. The amount of bob weight can be reduced, for instance, by selection of a different stabilizer angle.

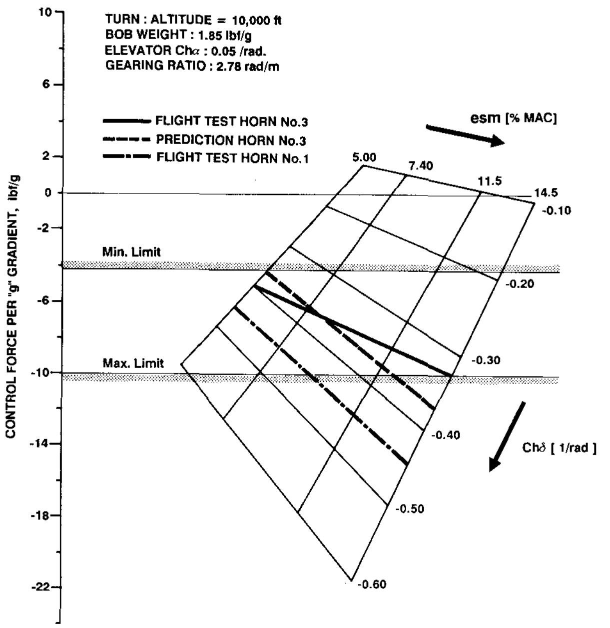

FIGURE 5 : STICK FORCE PER g, CORRLATION BETWEEN FLIGHT TESTS AND THEORETICAL CALCULATIONS

The measured and calculated stick forces per speed gradient at high speed cruise for horn no. 3 are given in Figure 6. The measured stick force per speed gradient differs slightly whether measured in accelerating or decelerating flight. In Figure 6 the close agreement between predicted and measured stick force per speed travel with esm can be seen.

Conclusions

In order to reduce the c.g. influence on the stick force per g and to increase the stick force per speed gradient on the Pilatus PC-9 Advanced Turbo Trainer, a theoretical analysis supported by the available flight test data was conducted. On the basis of this a new elevator aerodynamic balance and control circuit design was defined and extensively tested in flight.

The MIL-Spec. goals were reached by further modifications based on comparative data between theory and flight test results.

The requirement for low maneuver stick force per g gradient, together with stick-free stability at high speeds can be obtained for wide c.g. excursions with a manually operated control by careful design of both the elevator aerodynamic balance and the longitudinal control circuit.

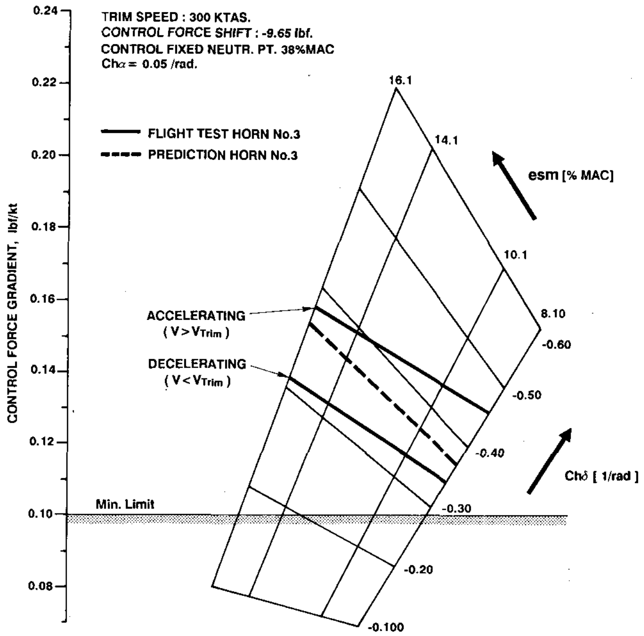

FIGURE 6 : STICK FORCE PER SPEED, CORRELATION BETWEEN FLIGHT TESTS AND THEORETICAL CALCULATIONS

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