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SPIN BEHAVIOUR OF THE PILATUS PC-7 TURBO TRAINER

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ABSTRACT

Training aircraft must have safe, reliable spin characteristics. During the development of the PC-7 Turbo Trainer great importance was placed on this requirement. The programme started with a spin tunnel model in the vertical wind-tunnel at the Institute of Fluid Mechanics in Lille, France. This showed the change in spin characteristics with the introduction of various modifications. These modifications were made on the prototype aircraft and a long series of spin testing was begun.

The paper presents the results of these tests, illustrating the differences in spin behaviour with each of the modifications. The resulting configuration has been investigated in more than 1500 spins under all conceivable entry and exit configurations. The results are well documented and numerous parameters (accelerations, forces, stresses, angles etc.) have been simultaneously recorded and are presented and discussed in the paper.

INTRODUCTION

The Aircraft

The PC-7 Turbo Trainer is a turbine powered, low wing, tandem seat, high performance aircraft for wide spectrum training. The PC-7 Turbo Trainer is fitted with a Pratt & Whitney PT6A-25A engine driving a Hartzell, 3 blade, constant speed propeller.

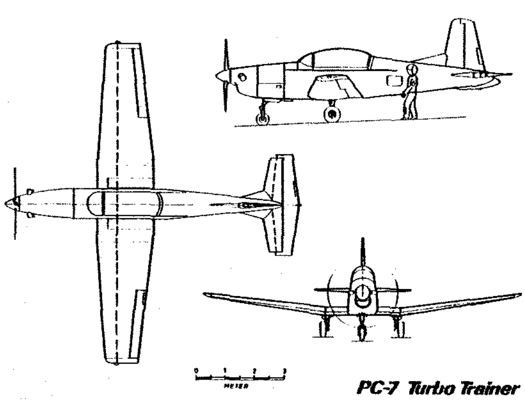


Figure 1

Wing span	10.400 m
Length	9.775 m
Height	3.210 m
Wing area	16.600 m^2
Wing loading	114.500 kg/m^2

	Aerobatic	Utility
Maximum weight	1900 kg	2700 kg
Centre of gravity	18-28 % mgc	22-28 % mgc
Limit load factor	+6/-3 g	+4.5/-2.25g
V_{MO}	270 kts	270 kts
V_A	175 kts	189 kts
V_{SO}	64 kts	74 kts

Airworthiness

The aircraft is certified to FAR Part 23 in the aerobatic and utility categories. This paper shows the spin behaviour for the aerobatic category only. An aerobatic category airplane must in general meet the following requirements:

- The airplane must recover from any point in a spin, in not more than one and one-half additional turns after normal recovery application of the controls. Prior to normal recovery applications of the controls, the spin test must proceed for six turns.

- It must be impossible to obtain uncontrollable spins with any use of the controls.

SPIN TUNNEL TESTS

During the development of the PC-7 Turbo Trainer great importance was placed on the above requirements. The programme started with a spin tunnel model in the vertical wind tunnel at the Institute of Fluid Mechanics in Lille, France. A baseline model (see Fig. 2) in the scale 1:14 was used to investigate the influence to the spin characteristics of empenage modifications, changes of moments of inertia and different centre of gravity positions.

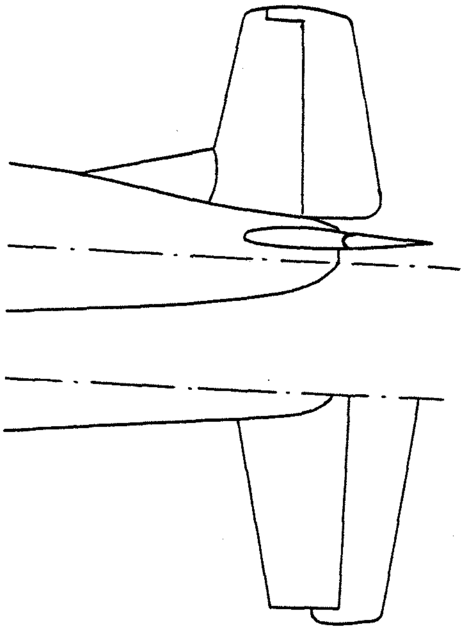


Figure 2. Empenage of the Baseline Model

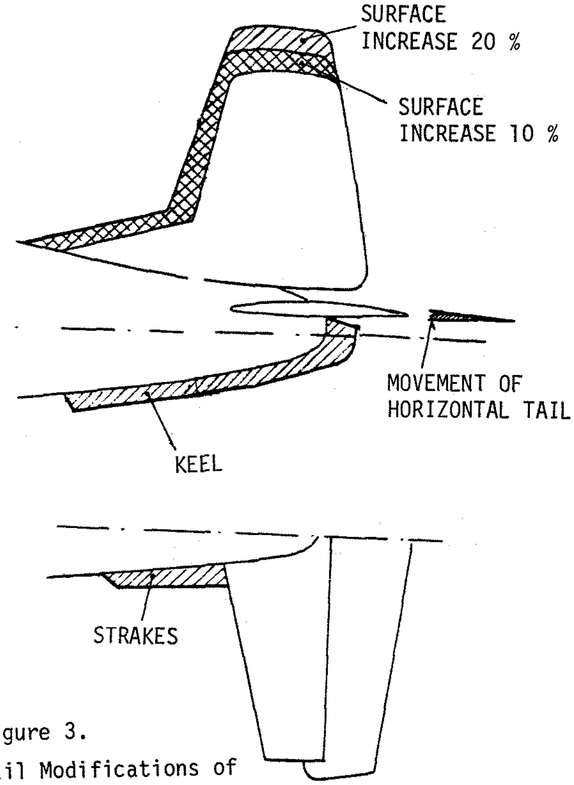


Figure 3.
Tail Modifications of the PC-7 Model

Initial tests showed that this configuration cannot meet the FAR requirements. Different types of spins could be stabililized with this configuration:

Nose down attitude	Time per turn(sec.)	No. of turns to recover	Description
> 50°	3.0	1	steep and slow, recovery O.K.
~ 45°	~ 2.5	-	relatively steep
~ 30°	2.0	2.5	relatively flat, recovery too long
10°	1.4	6	flat and fast, unacceptable

Table 1

Investigated Modifications

The following modifications and combinations of them have been tested on the PC-7 model (see Fig. 3):

- Surface increase of the vertical tail
- Rearward movement of the horizontal tail
- Lateral strakes
- Keel underneath the fuselage

Most of the above configurations have been investigated to avoid a flat and fast spin. The following test results were found:

Modifications	Effect
• Surface increase of the vertical tail by 10 % or 20 % • Keel • Strakes	weak, a flat and fast spin can still be established
• Rearward movement of horizontal tail by 280 mm • Rearward movement of horizontal tail by 280 mm and strakes	moderate, a flat spin was not observed but can be forced
• Rearward movement of horizontal tail by 280 mm and surface increase of 10 % or 20 % • Rearward movement of horizontal tail by 280 mm and keel	good, a forced flat spin is not maintained; steeper and slower spinning

Table 2

The influence of an asymmetric centre of gravity position in the Y-axis has also been investigated.

These tests confirmed the positive influence of the rear position of the horizontal tail. An asymmetric centre of gravity position in the direction of the outer wing showed a detrimental influence, but is negligible if the eccentricity is less than 100 mm.

Based on these test results a modified configuration was proposed and tested more in detail.

1. Increased surface of the vertical tail by 10 %
2. Horizontal tail moved rearward by 280 mm
3. Rear fuselage extended by 280 mm

In addition the eccentricity of the centre of gravity was limited to 80 mm.

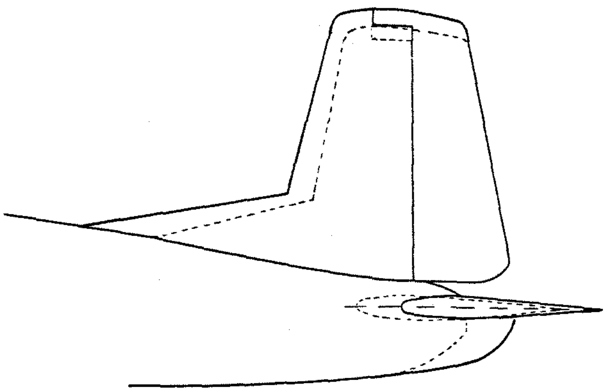


Figure 4. Modified Tail of PC-7 Model

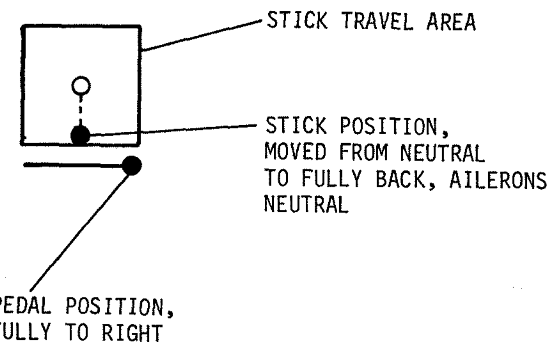
With the modified model six series of spin tests have been conducted.

Table 3 shows an extract of the test results. Five normal spins and one inverted are shown with variations of the moment of intertia and centre of gravity position.

In any case of these tests no flat spin could be established. The spin characteristics are very good and recovery can be made within 1 to 2 turns. The attitude is about 45° nose down and turn rate 2.5 to 3.5 sec./turn.

It is shown that the spin is faster with an increased moment of intertia and also faster and steeper with a forward centre of gravity position.

Note: Entry procedure is indicated by the following key:



Recovery was always made by fully opposite rudder and stick to neutral position.

Spin entry	Spin	Mass (kg)	MOI [kgm^2]	c.g. [%]	Nose down attitude	Time per turn	No. of turns for recovery	Eccentricity of c.g.	Number of tests
	normal	1800	2040	18	48°	2.2	1 1/2	symmetric	17
	normal	1800	2040	32	37°	3.6	1 1/2	symmetric	19
	normal	1920	3900	25	42°	2.3	1 3/4	symmetric	15
	normal	1800	2040	25	48°	2.2	1 3/4	80 mm to outer wing	15
	normal	1800	2040	25	65°	1.5	1 1/4	80 mm to inner wing	15
	inverted	1800	2040	25	47°$\pm$7	2.8	1/2	symmetric	15

Table 3. Wind-tunnel Test Results with modified PC-7 Model

FLIGHT TEST

Prototype Aircraft

When the wind tunnel tests were finished and analysed a four-month spin test programme started with the prototype aircraft to confirm the expected spin behaviour. The prototype aircraft was modified to reflect the final configuration established during the model testing (see Fig. 4).

For safety reason the first flights were made with a wooden keel underneath the fuselage, hoping that it could be removed finally.

The first discrepancy was observed immediately during flight test in the difference between the spin to the left and to the right. The right spin was smoother, less oscilatory and steeper. Recovery was made in 1/4 turn from a right spin and 1/4 to 3/4 turn from a left spin. The difference was caused by the turboprop installation which has a much higher idle propeller rotational speed and residual thrust than a piston engined aircraft. It was also found that the aileron position during spin has a higher effect than predicted, probably because control gaps were not simulated in the tunnel model. The outspin-aileron config. to the left took 1 1/2 turns to recover compared with 1/4 to 3/4 turn for normal spins. Spinning to the right with outspin-ailerons was not possible, the gyroscopic effect of the engine and propeller in addition to the effect of the ailerons were higher than the rudder effect to produce a spin. The wooden keel has then been reduced step by step to zero to find the optimum size.

The influence of increasing the moments of intertia have also been flight tested. Wind-tunnel tests show that now the spin should become steeper and faster, but this was not true. The attitude was much flater (30°) and even with the full size keel 2 1/2 turns were necessary to recover after a 6-turn spin with outspin ailerons.

Although the lateral strakes did not promise an advantage from the wind-tunnel tests, they have been flight-tested. Two long strakes were fitted in front of the horizontal tail in addition to the keel. This brought the best improvement: the spin was steeper (40° to 45°) and recovery was made in 1 1/4 turns from a left spin with outspin ailerons. These strakes have also been reduced stepwise because they affected the longitudinal static stability in a negative sense. Finally an optimised empenage configuration was found including keel, strakes, surface increase and moving the horizontal tail rearwards (see Fig. 5).

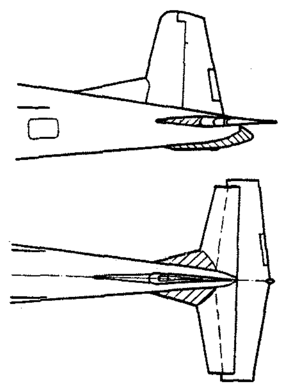


Figure 5.
Final Empenage Configuration for the PC-7 Production Aircraft

Configuration	Wind-tunnel Test	Flight Test
- Vertical tail surface increase by 10 % - Keel - Lateral strakes	weak, flat spin was still possible	- only tested in combinations - good, slow spin - very good, steeper, immediate recovery
- Horiz. tail rearward by 280 mm - Horiz. tail rearward by 280 mm and lateral strakes	moderate, no more flat and fast spin	- good - very good, 1/4 turn less to recover
- Horiz. tail rearward by 280 mm and vertical tail surface increased by 10 % or keel	good, the model tends to a steeper and slower spin	confirmed
- Effects of ailerons	relatively weak	Spins with crossed ailerons need more than 1 1/2 turn to recover
- Increased moment of inertia	steeper and faster	flater and slower
- Effect of c.g.	forward c.g. = steeper and faster	negligible
- Propeller gyroscopic effect	not simulated	recovery 1/2 turn more, difference between left and right spins
- Inverted spins	stable spin, only possible with crossed ailerons	confirmed

Table 4. Discrepancies between Wind-tunnel- and Flight-test

During the development flight test programme a few modifications were made to the aircraft which affected the spin behaviour more or less. These modifications were for example:

modified wingtips, reduced elevator deflection from -28° to -20° with the same stick travel, increased rudder chord by 50 mm over the whole length, increased dihedral angle from 3° to 7°.

Production Aircraft

This part of the paper includes flight test results representing the spin behaviour of the PC-7 production aircraft which was certified in 1978 under FAR part 23. Some 1500 spins have been flown to prove that the aircraft can be recovered from any point in a spin and no uncontrollable spins can be obtained with any use of the controls. Normal spins left and right, upright and inverted, and the influence of pilots recovery action to the spin recovery are presented.

A normal spin entry is made with the idle power setting, all trims at neutral position, then the speed must be reduced by pulling back the stick near to the stall speed which is 70 kts for this configuration. Some knots above this speed (at ca. 75 kts.), the rudder must be deflected fully into the required spin direction and at the same time the stick must be pulled fully back, ailerons neutral. The aircraft starts now spinning by pitching further up and rolling over into the spin. The first 3 turns are oscillating about all 3 axis and then the aircraft is stabilized with a nose down attitude of about 50° and a turnrate of 2.0 sec./turn to the right and 2.5 sec./turn to the left. The speed indication is then stabilised at about 105 kts. and the acceleration N_Z at 1.4 g. Very little oscillations are still present and can be neglected for flight test analysis.

Exactly at the end of the sixth turn, recovery action was applied by moving the rudder fully into opposite direction and pushing the stick forward slightly over the neutral position. A left spin is then stopped in 1 1/2 additional turns and right spin in 1 1/4 turns. Pull-out can be made with 3.0 g and a speed of about 145 kts. The total altitude loss for a six-turn spin including the pull-out is 3600 ft for a left spin and 3400 ft for a right spin.

Detailed investigations of the recovery procedure showed interesting results:
Due to the control cable tension it takes 0.75 seconds after the stick starts to move forward until the elevator starts to deflect. With an average turn rate of 2.5 sec./turn this results in more than 1/4 of a turn until the elevator starts to become effective. By investigating the influence of the elevator deflection on the recovery-turns the following graph was obtained:

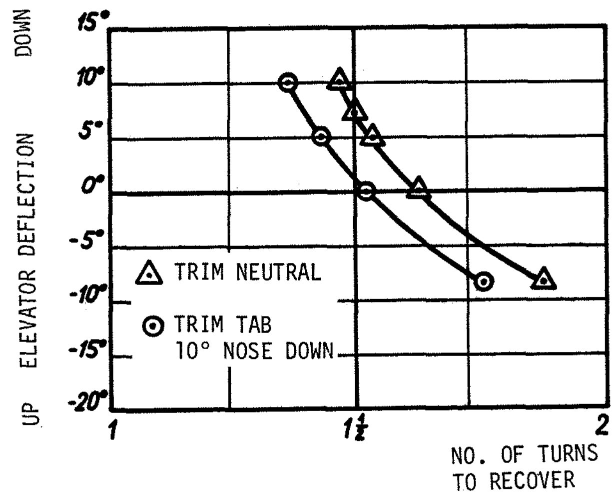
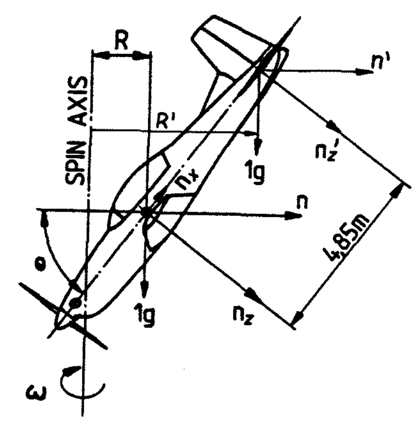


Figure 6.

Influence of Elevator Deflection on Recovery-turns, after a 6-turn spin to the left

This shows that the recovery-turns may be shortened by pushing the stick fully forward. By trimming the aircraft nose down (and hence assisting the pilot's push force), the above curve then moves to the left.

To determine the attitude of the aircraft during a spin from measurements on three accelerometers, the following method was used:



Measured values are: n_x

n_z

n_z'

T = time per turn

$$n = 9{,}81 \sqrt{n_x^2 + n_z^2 - 1^2} \quad [m/s^2]$$

$$R = \frac{n}{\omega^2} \quad [m]$$

$$\omega = \frac{2\pi}{T} \quad [rad/s]$$

$$\theta = \cos^{-1}\left(\frac{R' - R}{4{,}85}\right) \quad [deg.]$$

Figure 7

Flight No.	Spin Entry	Number of Turns to Recover	Time per Turn	Total Altitude-Loss	N_x [g]	N_Z [g]	N_Z' [g]	Turn-rate [rad/s]	Horizont. Radius R [m]	Pitch-angle θ [deg.]
220	normal left	1.50	2.52	3610	0.003	1.34	2.94	2.50	1.39	52.5°
220	normal right	1.38	2.12	3380	0.05	1.53	3.65	2.97	1.30	57.2°
256	inverted left pedal	0.95	2.25	4000	~ 0	-1.57	-2.8	2.79	1.52	68.6°
256	inverted right pdl.	0.85	2.51	4200	~ 0	-1.43	-2.75	2.50	1.60	60.2°

Table 5. Spin Test Results

The entry procedure for inverted spins is somewhat different to the normal spin, not only because it is inverted. For inverted spins it was defined that a spin with the left pedal is called a left spin and outspin aileron is defined when the aileron is deflected into opposite direction of the pedal. If we look to the aircraft from outside this is in fact not true: if the left pedal is deflected the aircraft spins to the right and opposite aileron gives an inspin configuration, but for the pilot it is more convenient to use the definitions which he can see.

During flight testing the inverted spin was always entered from a stabilized inverted flight at 90 kts. With the power on idle position and all trims neutral the speed must be reduced by pushing the stick forward, when the speed indication drops below zero (because the pitot tube is now above the wing), the rudder must be fully deflected and the aileron must be deflected 1/2 opposite and hold in this position during spinning. If the aileron is not deflected opposite to the rudder it is not possible to produce a stable spin, the aircraft turns over into normal attitude after 3/4 of a turn.

Once an inverted spin is stabilized the aircraft has a nose down attitude of about 60° and turn-rate is 2.5 sec./turn with right pedal and 2.25 sec./turn with left pedal. The acceleration N_Z is stabilized at -1.4 g to -1.6 g and the speed indication is below zero.

Due to the fact that the vertical tail is now downwards in an undisturbed airflow, recovery from spinning is very effective and can be made with 3/4 of a turn from a right spin and within 1 turn from left spin. Pull-out is made with about 3.0 g and a speed of 160 kts. Altitude loss for a six-turn spin including recovery and pull-out is 4200 ft.

The spin can also be stopped by using the elevator or the rudder alone.

During certification flight testing of the inverted spins, the test-aircraft was equipped with strain gauges and accelerometers on the tail to measure the tail loads. These data are shown in Fig. 8 and 9 and show very interesting results, especially by comparing normal and inverted spins (see Table 7).

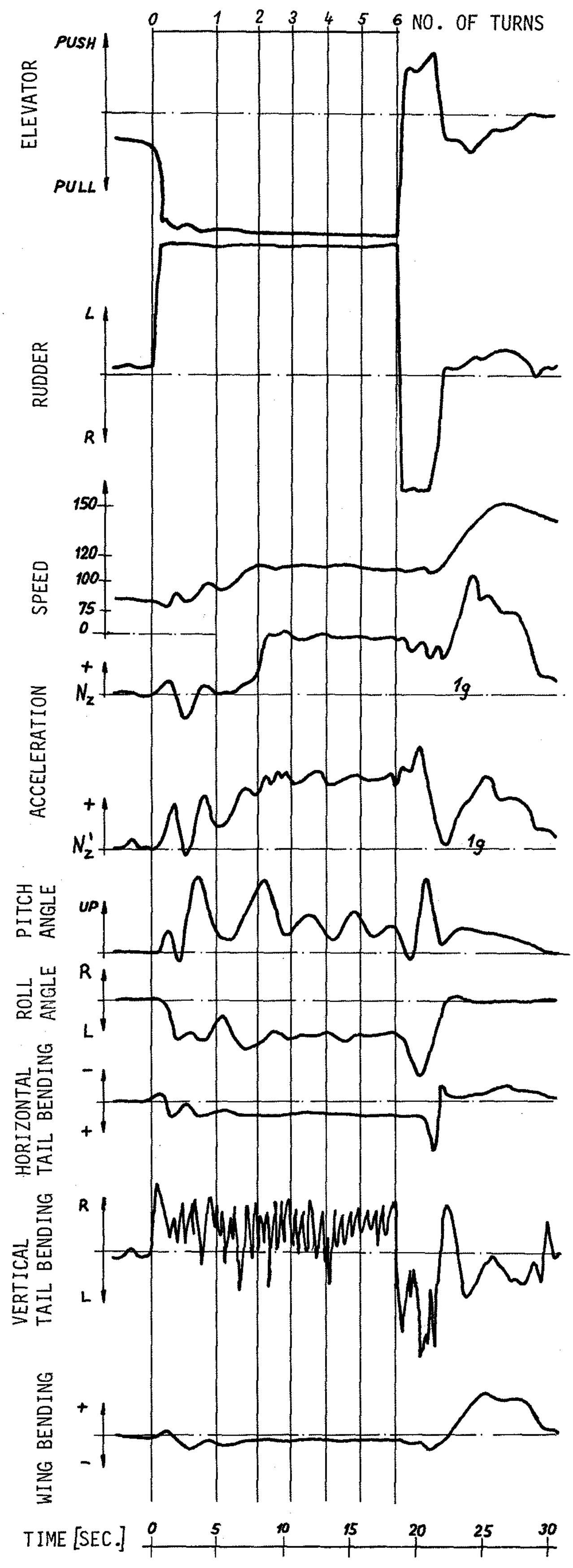


Figure 8. Normal Spin left

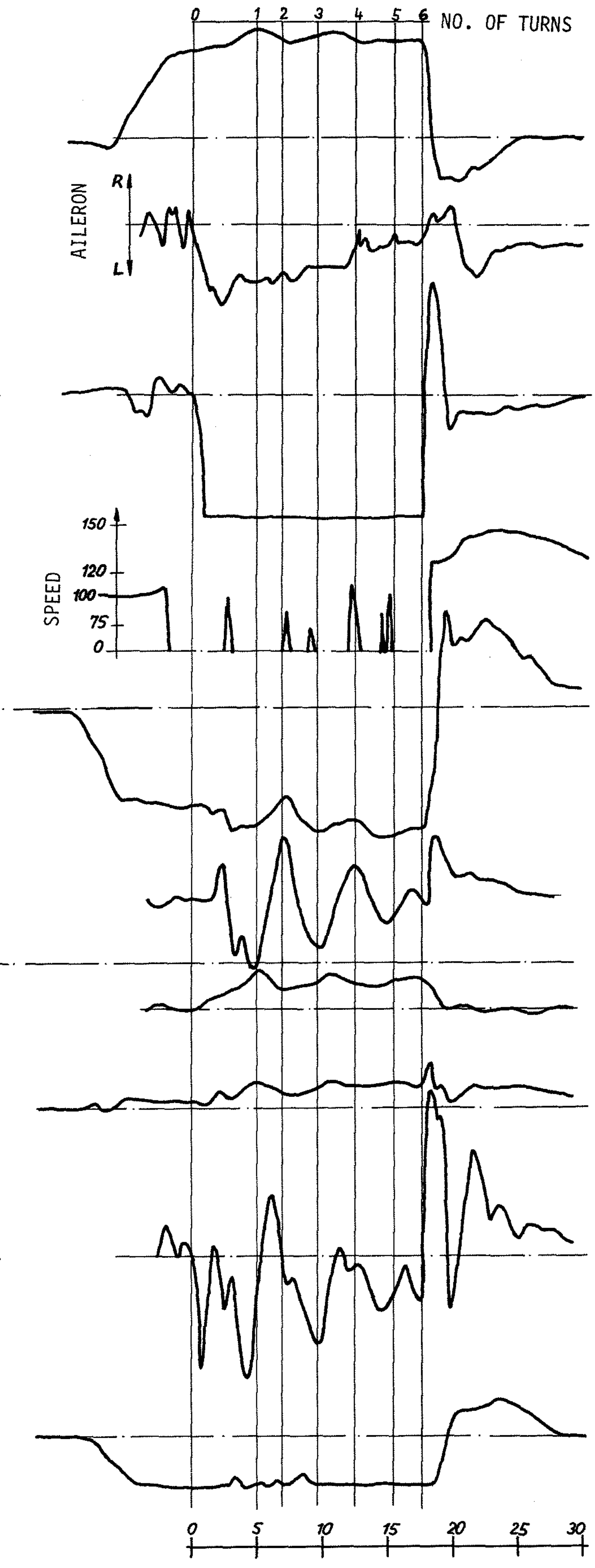


Figure 9. Inverted Spin right Pedal

Differences between Normal and Inverted Spins in the Tail Loads:

Measurement Point	Normal Spin	Inverted Spin
Vertical tail bending	- little oscillations - vibrations due to turbulent airflow	- oscillating - no vibrations, tail is in the undisturbed airflow
Horizontal tail bending left and right side of the tail	- vibrations - asymmetric bending when recovering - during stable spin: positive bending 	- vibrations - symmetric bending when recovering negative bending 
Wing bending horizontal flight, ~100 kts, + 1 g, is defined as neutral = zero bending	- Spin: neutral no bending - Pull-out: positive bending simultaneously with "g" load	- negative bending due to inverted flight, some oscillations - positive bending simultaneously with "g" load
N_Z' on frame 11	- Stable spin: left 2.95 g right 3.65 g	left -2.8 g right -2.75 g
N_Z in c.g. position	- Stable spin: left 1.34 g right 1.53 g	left -1.57 g right -1.43 g

Table 7

CONCLUSIONS

Spin-tunnel tests are very helpful to show where critical spin characteristics may occur, but a complete and correct forecast is not possible. Care should be taken in analysis of results from model testing of this kind, especially for turboprop aircraft.

In general the model had a steeper nose down attitude and was faster turning than the prototype aircraft but the recovery turns were well represented.

Flight testing on the production aircraft showed that the number of turns for recovery may be influenced by the pilot's recovery action. Pushing the stick over the neutral position can shorten recovery by 1/4 turn.

Recovery from an inverted spin is more effective as from a normal spin because of the unshielded vertical tail configuration. Orientation can be a problem for the pilot during inverted spins, flight tests should be observed from the ground to give a help to the pilot.

The PC-7 Turbo Trainer has a very nice and safe spin behaviour even inverted and can be recovered from any point in a spin. No uncontrollable spins can be developed. The PC-7 is particularly suited for aerobatic training.

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