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A.R.C. Technical Report

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Full Scale Spinning Tests on the Percival Provost Mk.I including the Inverted Spin

By

T. H. Kerr, B.Sc., A.F.R.Ae.S.

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SUMMARY

Instrumented spinning tests on this aircraft were completed in both the normal and inverted attitudes. The normal spin showed the characteristics of the smooth and oscillatory type depending upon the control configuration; being oscillatory with pro-spin aileron and smooth with anti-spin aileron. The recovery was satisfactory in each case.

Inverted spins of up to six turns were completed and showed satisfactory characteristics both for the spin and the recovery.

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1 Introduction

It has been recognised for some time that the spin and recovery standards used in the spinning tunnel gave results which were far from correct for the full scale spin of some aircraft. The largest discrepancies appeared to occur when the ratio of the pitching to rolling moments of inertia was different from unity i.e. $B/A \ll 1$ or $B/A \gg 1$.

When B/A was large, two marked differences between the model and full scale spin and recovery became apparent.

(i) The recovery from the full scale spin was much easier than the model standards predicted.

(ii) The full scale spin was often extremely oscillatory, showing large changes in the rates of roll and pitch during the spin.

In order to investigate these effects a series of spinning tests on several aircraft have been started and the tests described in this note on the Provost were one of this series. The inverted spin and recovery characteristics were also investigated and are of special interest as these tests are probably the first recorded results in the inverted spin in this country.

The Provost is a 2-seat single engined elementary trainer. A G.A., photographs, and aerodynamic data sheet are given in Figs. 1 and 2 and Table I.

2 The aircraft loading and instrumentation

The aircraft was flown at two C.G. positions in the course of the tests, the corresponding weights and calculated inertia distribution are given in the following table.

TABLE II

Aircraft Loading

Weight lb	C.G. position	Moments of inertia	
4250	0.271 SMC		
4325	0.297 SMC		
		A 64,924	Firm's calculations
		B 131,035	
		C 183,175	

The weights and C.G. positions quoted here apply strictly to the start of the series of spins for each flight. However, since the fuel used during the tests on each flight was only about 10 gallons, the C.G. shift and charge in weight were small.

The instrumentation used is detailed in the table below.

/Table

TABLE III

Instrumentation

Quantity to be measured	Instrument used	Range
Angular velocity about body axes	Roll gyro p'	±5 rad/sec
	Pitch gyro q'	±1.75 rad/sec
	Yaw gyro r'	±4 rad/sec
Acceleration along body axes	Acceleration x'	±1g
	" y'	±1g
	" z'	-1 to +5g
	For inverted spins	and -5 to +1g
Rate of descent	Altimeter	
Control angles	Rudder)desynns Elevators)	

These instruments were arranged in a standard auto-observer and photographed by a Bell and Howell 35 mm camera at 8 frames/second.

3 The flying technique

The entry to the spin in all cases was from a straight 1 g stall. The control movements used during the spins and recoveries were:-

(i) Normal recovery

At the stall, full pro-spin rudder and elevator fully up were applied with the ailerons maintained neutral. For the recovery, full opposite rudder was applied followed by the movement of the control column forward until the spin stopped. When the spin stopped the controls were centralised, This is the standard R.A.F. technique for the spin and recovery.

(ii) Use of aileron

Conditions as for (i) except that the ailerons were applied fully pro- or anti-spin throughout the spin and recovery.

(iii) Rudder only recoveries

Conditions as for (i) except that the elevators were maintained in the up position throughout or held against some predetermined artificial stop.

(iv) Spins with flap down

Conditions as for (i) with flap down.

(v) Spins with engine on

Conditions as for (i) with engine on

(vi) Spins inverted

(See section 6.0)

4 The spin

In the normal spinning condition (ailerons neutral) this aircraft appeared to be on the borderline between the oscillatory and smooth spin and quite often some small difference in the entry conditions would make one spin oscillatory and the next smooth. This aspect is discussed in the following sections for various control configurations in the spin. A summary of the characteristics of the spin is given in Table IV. The method of analysis of the results to obtain the more important parameters of the spin is given in Ref.1.

4.1 The normal spin. (Ailerons neutral, engine idling)

Auto-observer records of two sustained spins, one to port and one to starboard, are shown in Figs. 3 and 4. In the spin to port, the oscillations in the rates of rotation about body axes in the incipient spin are slowly damped out and a smooth spin developed by the fifth turn; on the other hand, these oscillations in the spin to starboard are maintained throughout the spin at approximately constant amplitude. The mean rate of pitch and therefore wing tilt was very much greater in the spin to starboard. This involves large anti-spin inertia couples which are destabilising to the yawing equilibrium in the spin and thus the oscillations tend to be maintained. From the pilots point of view the aircraft could be described as "wallowing" in the spin with the wing tilt changing from the outer wing 20 to 30 degrees up, relative to the horizon, to the outer wing slightly down. The motion is not nearly as violent as the fully developed oscillatory spin described later. When the C.G. was moved to the aft position the amplitude of the oscillations was, in general, increased to the fully developed oscillatory spin although occasionally a smooth spin would develop in a spin to port. A typical auto-observer record of the spin with the C.G. in the aft position is shown in Fig.5.

A summary of the main features of the spins are shown in Figs.17-20. Figs. 17-20 are fairly self explanitory and should prove to be most useful in the comparison of these full scale results with model tests.

Fig.19 shows that there is a fairly wide asymmetry between the wing tilts in the spins to port and starboard. It is not normal to expect such a wide difference and it must be attributed to asymmetry in the aircraft itself, rather than slipstream or polar moments due to the engine and propeller. Some small asymmetry in the aircraft was probably accentuated by the aircraft being almost on the boundary between the smooth and oscillatory spins.

In the oscillatory spins, the mean wing tilt is always much greater than for a similar smooth spin and it was a characteristic of this aircraft that the spins to port were always smoother than the spins to starboard.

4.2 The effects of aileron application on the spin

The effects of aileron application on the spin of this aircraft were similar to those experienced on the Boulton Paul Balliol (ref.1) Anti-spin aileron reduced the average angle of positive wing tilt and smoothed the spin. A typical auto-observer record is shown in Fig.6. The anti-spin aileron was applied, approximately 2 seconds after full pro-spin rudder was applied, and was maintained in the anti-spin direction until the recovery was completed. The two second delay was necessary before applying aileron, as in some cases, if the aileron was applied at the stall it prevented a spin developing and the aircraft entered a stalled spiral.

It is particularly interesting to note that the incidence of the spin using anti-spin aileron is less than the average for the spin with ailerons neutral and this is probably associated with the reduced rate of rotation experienced during these spins. The application of pro-spin aileron almost invariably produced a full oscillatory spin; auto observer records are shown in Figs. 7 and 8. Very high rates of descent are experienced in this type of spin, being up to 30% higher than that for the smooth spin at the same mean incidence.

4.3 The spin, engine on

A check was made of the spinning characteristics of this aircraft when cruising power was maintained throughout the spin and an auto observer record is shown in Fig.9. The most important change in the characteristics of the spin was the increase in the mean radius of the spin by approximately 60%. A change of this type was expected from considerations of the equilibrium of the spin.

4.4 The spin, flaps down

As an initial check, eight turn spins with take-off flap down were tried and after it had been shown that the characteristics of the spin and recovery were little changed eight turn spins using full flap were recorded.

The aircraft was very reluctant to enter the spin and the first turn required eight seconds to complete. The rate of rotation throughout the spin was slow with some airframe judder and mild pro-spin aileron match. Recovery was normal, no difficulty was experienced in keeping the I.A.S. below the maximum allowed with flaps down even during the recovery dive.

4.5 Spins with restricted elevator travel and with the elevator moved down during the spin

During the spinning trials on the Provost at A & AEE, it was found that if the up travel of the elevators was restricted, then the spin becomes much smoother than when the elevator is allowed its full travel. No obvious explanation of this characteristic was deduced at the time and it was decided that further tests should be made during this investigation at R.A.E.

The elevator travel was therefore limited in two different ways.

(i) After the spin had become established with full up elevator, the elevator was moved down to some predetermined position and then held fixed for the remainder of the spin.

(ii) An artificial stop was provided so that the elevator travel was reduced at all times.

The change in rate of rotation, incidence, and the oscillatory character of the spin were similar for a given elevator movement whether the elevator angle was limited to a particular angle before the stall or moved after several turns of the spin.

Typical examples of the effects on the spin of moving the elevator down are shown in Figs. 10 and 11. In Fig.10, for a change in elevator angle of 34°, the incidence of the spin and therefore the rate of descent remains almost unchanged; the rate of rotation and λ were increased from 2.26 to 3.26 radians/second and 0.284 to 0.41 respectively. In Fig.11 the spin was smoothed considerably and the incidence was increased.

When the elevator travel was limited to -19°, it was impossible to reduce the aircraft speed to the 1 g stall but when full rudder was applied, the aircraft could enter a very steep spin, which, in general, flattened progressively to 45° incidence. On one occasion, in a spin to starboard, a very steep spin with a very high rate of rotation developed.

A summary of the rates of rotation as a function of elevator angle for the steady spin is given in Fig. 20.

5 The recovery

5.1 The normal recovery

The recovery from the spin was in all cases very satisfactory and was completed in an average time of 3 seconds or one turn of the spin. A common characteristic of the recovery from the smooth spin was an increase in the rate of roll to approximately 3 radians/second before recovery was completed. (Figs. 3 and 4).

5.2 The recovery, rudder only

The recovery, in this case, was borderline between recovery and non-recovery. After application of anti-spin rudder, the rate of rotation in the spin gradually decreased until the aircraft was rotating in a wide spiral at a rate of one turn in 6-8 seconds. This condition appeared to be stable, although on a few occasions the spin stopped completely. A typical example of this type of recovery is shown in Fig. 12.

5.3 Recoveries using pro- and anti-spin aileron

Pro- and anti-spin aileron appeared to make little difference to the time required to recover from the spin; this remained approximately the same as that for ailerons neutral. Although the time is unchanged the mode of recovery is markedly altered. In the anti-spin aileron recoveries the rates of rotation about body axis fall off steadily from the steady spin values to zero; whereas in the pro-spin aileron recoveries the aircraft generally completes one further oscillation to complete the recovery.

6 The inverted spin and recovery

Although the aircraft had not previously been spun inverted, it was very desirable that inverted spins should be investigated to provide confirmation of the tunnel predictions that recovery should be as easy or easier than from the normal spin.

6.1 The technique

The spin was normally entered from an inverted glide, the control column was pushed fully forward until the aircraft was at the point of the stall and then full pro-spin rudder was applied. The controls were kept in this position until recovery was required. For recovery full opposite rudder was applied and the control column moved back until the spin stopped. After the spin stopped, the controls were centralised and a normal pullout was completed.

6.2 Results

Two, four and six turn spins in each direction were completed. Time histories of a two and four turn spin and six turn spins to port and starboard are shown in Figs. 13, 14, 15 and 16.

The only special feature of the spins was the very high rate of rotation during the first turns. This may have been due to the relatively small elevator angle applied at the inverted stall.

The recovery was very satisfactory and the spin had in each case almost stopped in $1\frac{1}{2}$ seconds, before the elevators were moved.

Two important physiological effects were emphasised by these tests:-

(i) When the pilot is strapped in tightly it needs a very long reach to be able to grip the control column when it is on the forward stops. If the control column is not held in that position but further back, then the rate of rotation will be higher than normal with some increase in the negative 'g' which may be dangerous.

(ii) During the six turn spins approximately -2.25 total 'g' was applied to the pilot's head for 16 seconds. This was not serious or really important in itself but its effects were felt during the pullout after the recovery from the spin. During these pullouts both pilot and observer noticed appreciable reduction of their blackout thresholds and it was estimated that the blacking out occurred or was about to occur at 3 g. Provided that pilots are warned, this effect should not be serious.

7 Tuft photography

Tufts were fitted to the starboard wing tip (Fig.2), tailplane, fin and rudder, and could be photographed from the cockpit during the spin by a hand-held cine camera used by the observer. The photographs of the tufts on the tail-unit during the smooth or oscillatory spin did not show any marked differences in the type of flow between the different types of spin.

The tuft photography on the starboard wing tip was much more successful. During the fully developed oscillatory spin, the tufts showed the rising wing tip to be stalling and unstalling during each turn of the spin. Fig.8 shows some examples of the tuft photographs during the eight turn spin to port, Fig.7.

It was interesting to note that during the spin to starboard, Fig.3 during the milder oscillations of the "wallowing" spin, the wings remained fully stalled throughout the spin.

8 Conclusions

The spinning tests on the aircraft have been valuable in obtaining a better understanding of many aspects of the spin and recovery of an aircraft having an inertia ratio ($^B/_A$) of 2.

The more important observations were:-

(i) The normal spin showed the characteristics of the smooth and oscillatory types depending upon the control configurations used. The recovery was satisfactory in each case.

(ii) During the oscillatory spin the rising wing tip stalls and unstalls during each turn of the spin.

(iii) The oscillatory spin can be smoothed by applying either anti-spin aileron or down elevator. Both of these control movements give a decrease in wing tilt and an increase in the outward side slip in the spin.

(iv) The inverted spin on this aircraft was entered from an inverted glide, and was a smooth spin at 45° incidence. The recovery by correct control movement was rapid and satisfactory.

These results will provide another series of full scale tests with which model spinning tests can be directly compared and this will greatly assist in the derivation of new model spinning standards.

REFERENCES

No.	Author	Title, etc.
1	T. H. Kerr and D. R. Dennis	A comparison of the model and full scale spinning tests on a conventional straight wing aircraft (Balliol Mk.II) with special reference to the oscillatory nature of the spin. R.A.E. Report No. Aero 2480 Feb. 1953. ARC 15971.

TABLE I

Aerodynamic data sheet for Percival Provost W.G.503

GENERAL		
Weight	lb.	4300
Engine Alvis Leonides		2500
Take-off H.P.		540/560
Wing Loading	lb/ft^2	20.1
Moment of inertia, A,	lb/ft^2	64942
Moment of inertia, B,	lb/ft^2	131035
Moment of inertia, C,	lb/ft^2	183175
C.G. position aft of datum		19.04"
At 28.5% S.M.C. below datum		10.53"
Relative density at 15,000 ft	$^m/_p$ Sb	11.85

WINGS		
Area	sq ft	214
Span	ft	35.17
Mean chord	ft	6.08
Root chord	ft	7.63
Tip chord	ft	4.33
Root section		N.A.C.A. 23015 Modified
Tip section		N.A.C.A. 4412 Modified
Aspect ratio		5.78
Angle to thrust line	(at Root	3°
	(at Tip	0°
Dihedral		6°

FLAPS		
Type		N.A.C.A. Slotted
Flap span	ft	6.53
Flap chord	ft	1.41 Constant

LONGITUDINAL CONTROL		
Tail area	S' sq ft	48.6
Elevator area aft of hinge line	sq ft	17.8
Tail arm	ℓ' ft	17.6
Tail setting to thrust line		Zero
Elevator angle	(Up	34°
	(Down	14.5°

DIRECTIONAL CONTROL		
Fin & Rudder area (gross)	sq ft	35.09
Rudder area aft of hinge line	sq ft	9.26
Rudder angle	(Port	35°
	(Stbd.	35°

LATERAL CONTROL		
Type Set back hinge		
Area (each aft of hinge)	sq ft	9.07
Chord	ft	1.21
Span	ft	7.48
Aileron angle	(Up	25°
	(Down	15°

PROPELLER		
Diameter	ft	9
No. of blades		3
Solidity at 0.7 radius		0.088

TABLE IV

Characteristics of the spin and recovery of the Percival Provost M.K.1 W.G.503

Spin	Elev. Angle	α	Ω	χ	θ_y	R_D	R	λ	γ	Recy.	Time to Recover Secs.	Fig. No.
9 Turn Port	-34°	45°	2.27	+3.5°	+2.8°	144	6.25	0.277	5.5°	N	2.5	3
8 Turn Starboard	-34°	41°	2.11	+18°	+13.6°	167	7.85	0.222	6.0°	N	3.0	3
8 TP Pro-spin Aileron		40°	2.46	+22.6°	+17°	200	7.3	0.216	5.0°	N PSA	2.0	8
8 TS Anti-spin Aileron		33.5°	2.05	+7°	+5.8°	170	10.56	0.212	7.0°	N ASA	2.5	6
8 TS Pro-spin Aileron										N PSA	3.5	7
8 TP Anti-spin Aileron		38.5°	2.17	-3°	-2.3°	154	7.94	0.248	6.5°	N ASA	3.5	
8 TS 2600 rpm - 2 Boost		52°	1.93	+19°	+11.5°	140	10.0	0.242	8.0°	N Engine on	3.5	9
8 TP 2600 rpm - 2 Boost		33.5°	2.26	+16.5°	+12.7°	160	12.43	0.248	10.0°	N Engine on	4.4	
8 TS Full Flap		41.5°	2.18	+17°	+12.7°	130	7.83	0.294	7.5°	N	3.2	
8 TP Full Flap		4.6°	2.45	+5.5°	+4.5°	150	5.78	0.287	5.5°	N	3.8	
8 TP		44°	2.38	+6.5°	+4.7°	140	6.19	0.299	6.0°	R.O	13.0	
6 TP Elevator Neutral	0°	45°	3.26	+2.5°	+1.8°	140	3.91	0.408	5.0°	Elev.N	3.7	10
Elevator up		47°	2.26	+8°	+5.5°	140		0.284		Elev. N		10
6 TP		39°	2.84	+10°	+7.8°	140	5.72	0.356	6.5°	S.O.		
8 TS Stick moved slightly fwd.		42°	2.47	+17°	+12.6°	160	6.32	0.271	6.0°	N	2.5	11
8 TS " "	-24°	41°	2.52	+18°	+13.6°	140	6.25	0.316	6.5°	N	2.5	
8 TS Stick moved slightly fwd. from stall	-12°	36°	2.80	+17.5°	-14.2°	140	6.23	0.351	7.0°	N	3.0	
8 TP Aft C.G.		43°	2.19	+3.5°	+2.6°	150	6.58	0.257	5.5°	N	3.5	5
8 TS Stick moved slightly fwd.	-21°	42°	2.47	+17.0°	+12.6°	140	6.22	0.310	6.5°	N		
8 TS Stick moved slightly fwd. after 3 turns	-21°	41°	2.49	+17.0°	+11.2°	180	6.65	0.238	5.5°	N		
8 TS Aft C.G.										N	2.5	
8 TS Aft C.G.										N	2.0	
8 TP Aft C.G.										N	3.0	
8 TP Elevator restricted 3°	-31°	43.5°	2.47	+6.5°	+4.7°	134	5.36	0.324	6.0°	N	3.5	

TABLE IV (CONT.)

Spin	Elev. Angle	α	Ω	χ	θ_y	R_D	R	λ	γ	Recy.	Time to Recover Secs.	Fig. No.
8 TS Elevator restricted 3°	-31°	45°	1.98	+19.0°	+13.0°	143		0.243		N	3.4	
8 TS Elevator restricted 10°	-22°	38.5°	2.62	+22°	+17.2°	150	6.09	0.307	6.0°	N	3.5	
8 TP Elevator restricted 10°	-22°	46°	2.72	+3.5°	+2.4°	143	5.08	0.334		N		
8 TS Elevator restricted 18°	-15°	21.5°	3.61	+22°	+20.4°	154	5.6	0.412		N	1.9	
8 TP Elevator restricted 18°	-18°	42.5°	2.63	+8°	+5.9°	134	7.0	0.345		N	3.2	
6 TS Elevator restricted 10° - ASA	-26°	35°	2.26	+3.0°	+2.5°	160	8.37	0.248		N ASA	1.5	
6 TS Elevator restricted 10° - PSA	-26°	26°	2.45	+26°	+23°	170				N PSA	1.5	
6 TP Full Flap											3.8	
6 TS Full Flap		39°	2.37	+20°	+15.5°	160	7.12	0.260		N	4.4	
8 TP 2000 rpm - 2 Boost after 4 turns		37°	2.47	+10°	+8°	172	9.1	0.252		N Engine on	3.2	
2 TS Inverted Spin										N Inverted	2.0	
4 TP Inverted Spin										N Inverted	2.5	13
4 TP Inverted Spin										N Inverted	2.5	
4 TS Inverted Spin										N Inverted	1.8	14
6 TP Inverted Spin		-37°	2.75	1.5°	-1.2°	150	4.62	0.322		N Inverted	3.0	15
6 TS Inverted Spin		-41.5°	3.01	3°	2.25°	140	3.76	0.377		N Inverted	2.5	16

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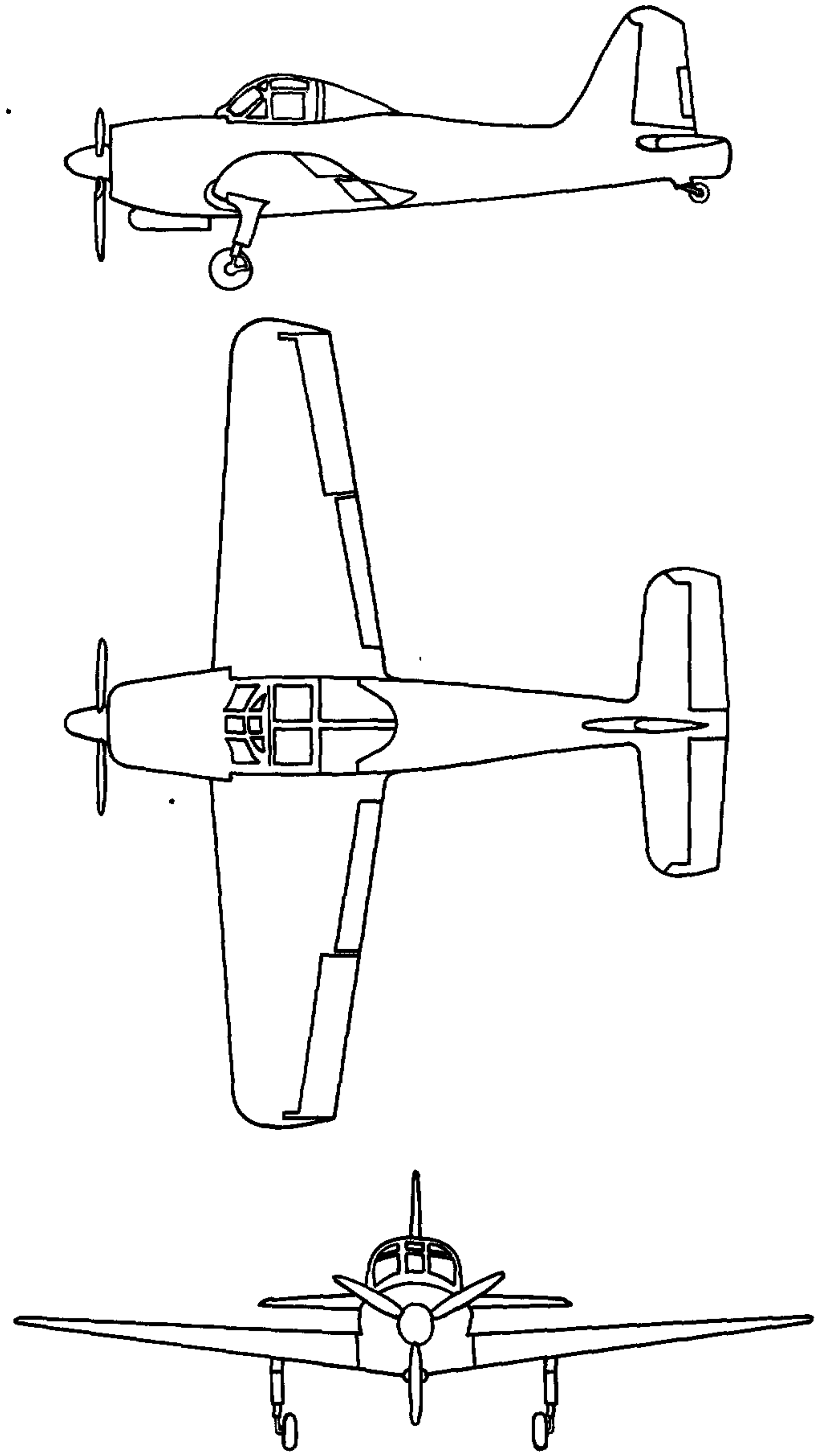
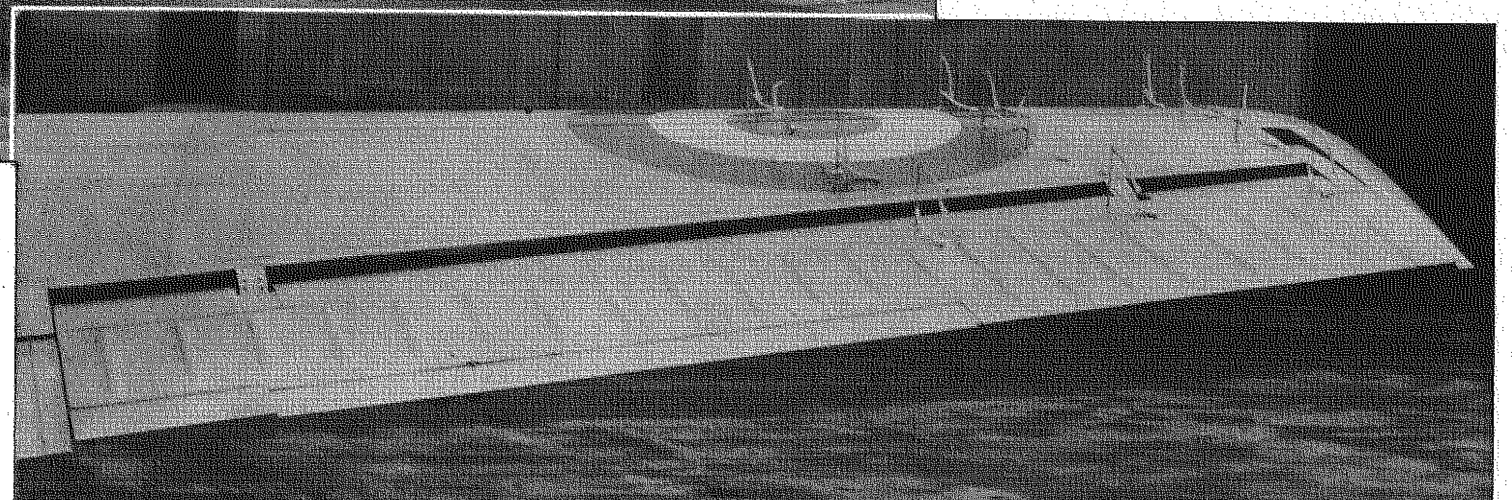


FIG.I. G.A. PERCIVAL PROVOST.
W.G. 503.

FIG.2

PERCIVAL PROVOST Mk.1



SHOWING WING TUFTS

FIG.2

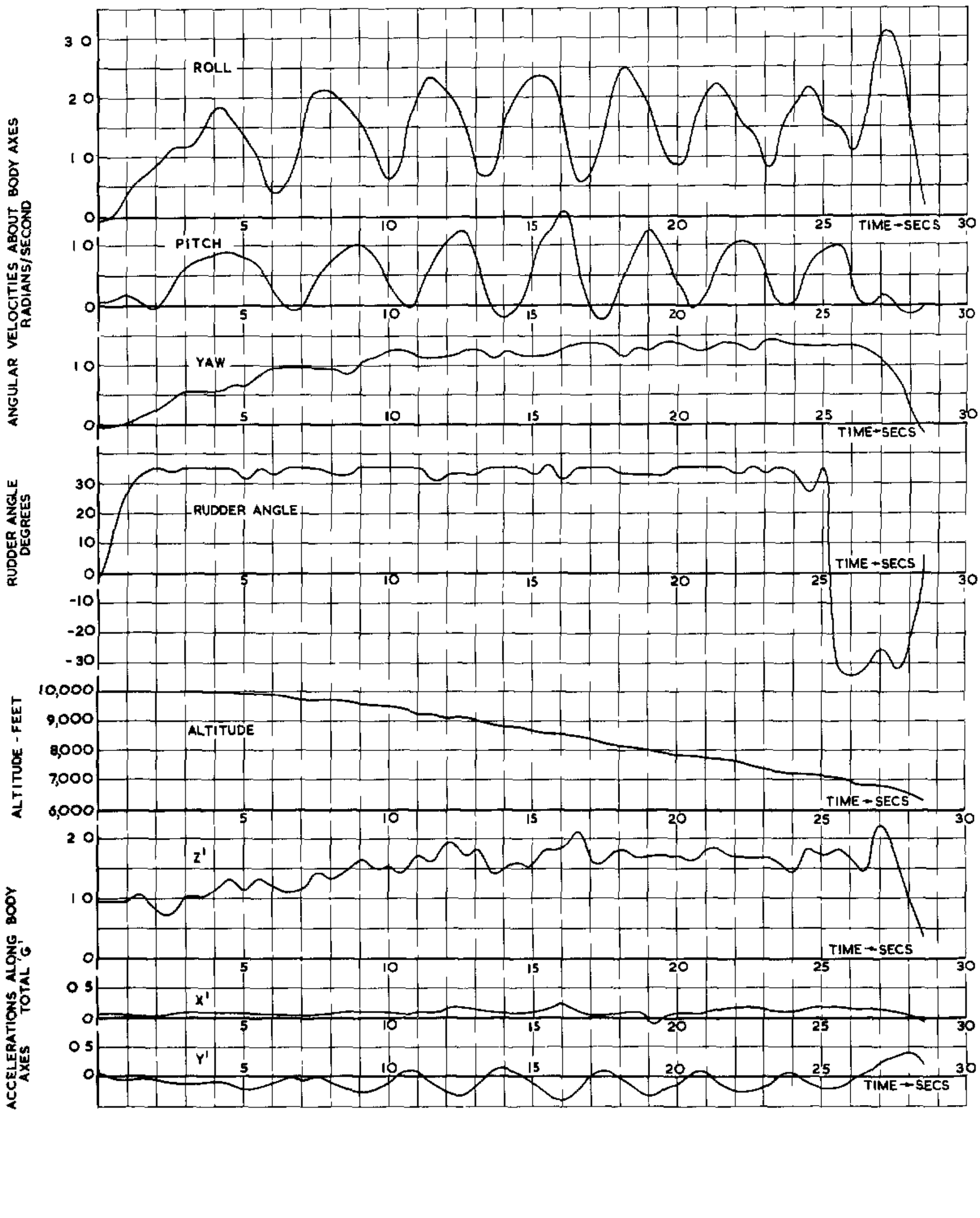


FIG. 3. EIGHT TURN SPIN TO STARBOARD
AILERONS NEUTRAL.
PROVOST W.G. 503.

FIG. 4

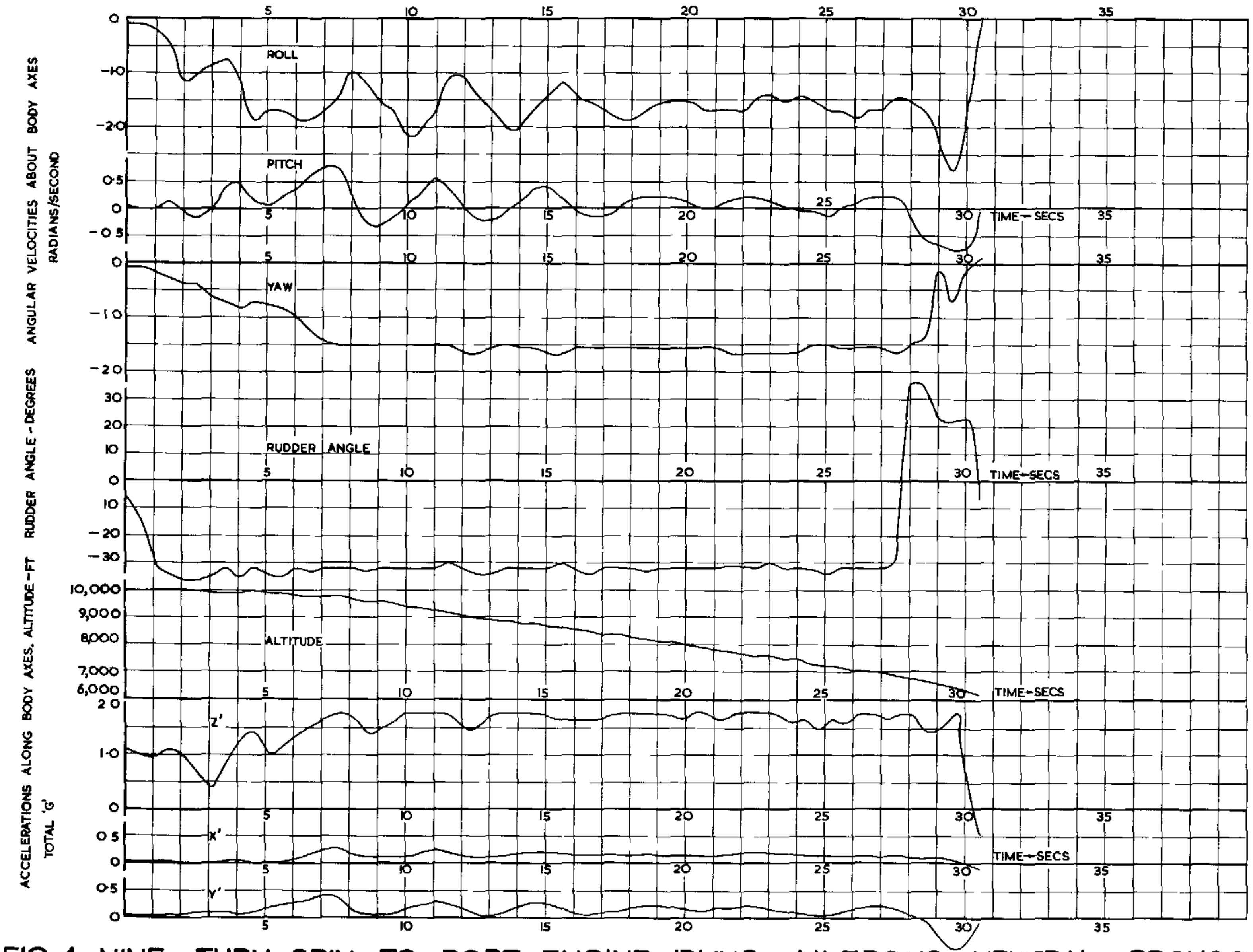


FIG. 4. NINE TURN SPIN TO PORT ENGINE IDLING. AILERONS NEUTRAL. PROVOST WG. 503.

FIG. 5.

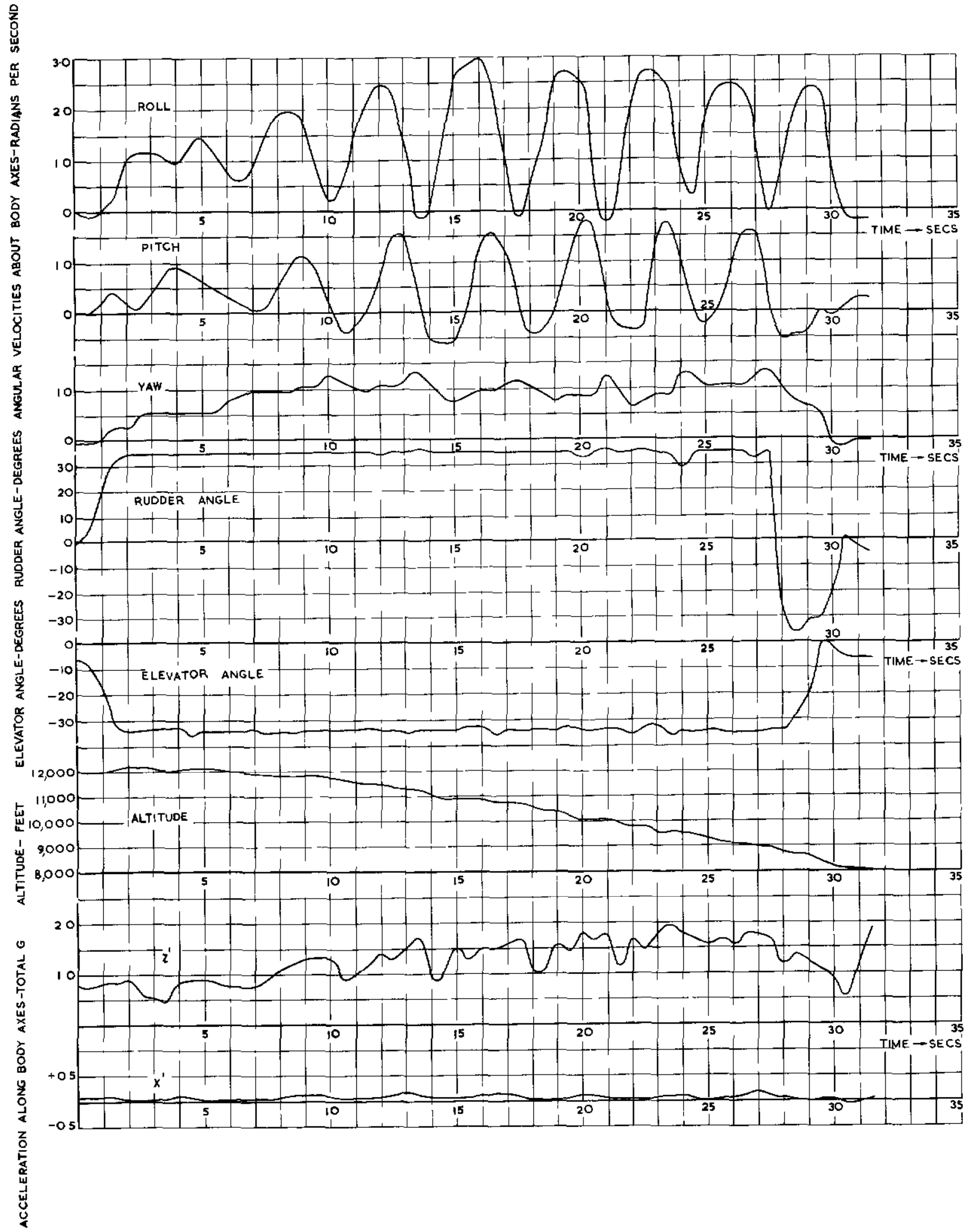


FIG. 5. EIGHT TURNS TO STARBOARD C.G. AFT.

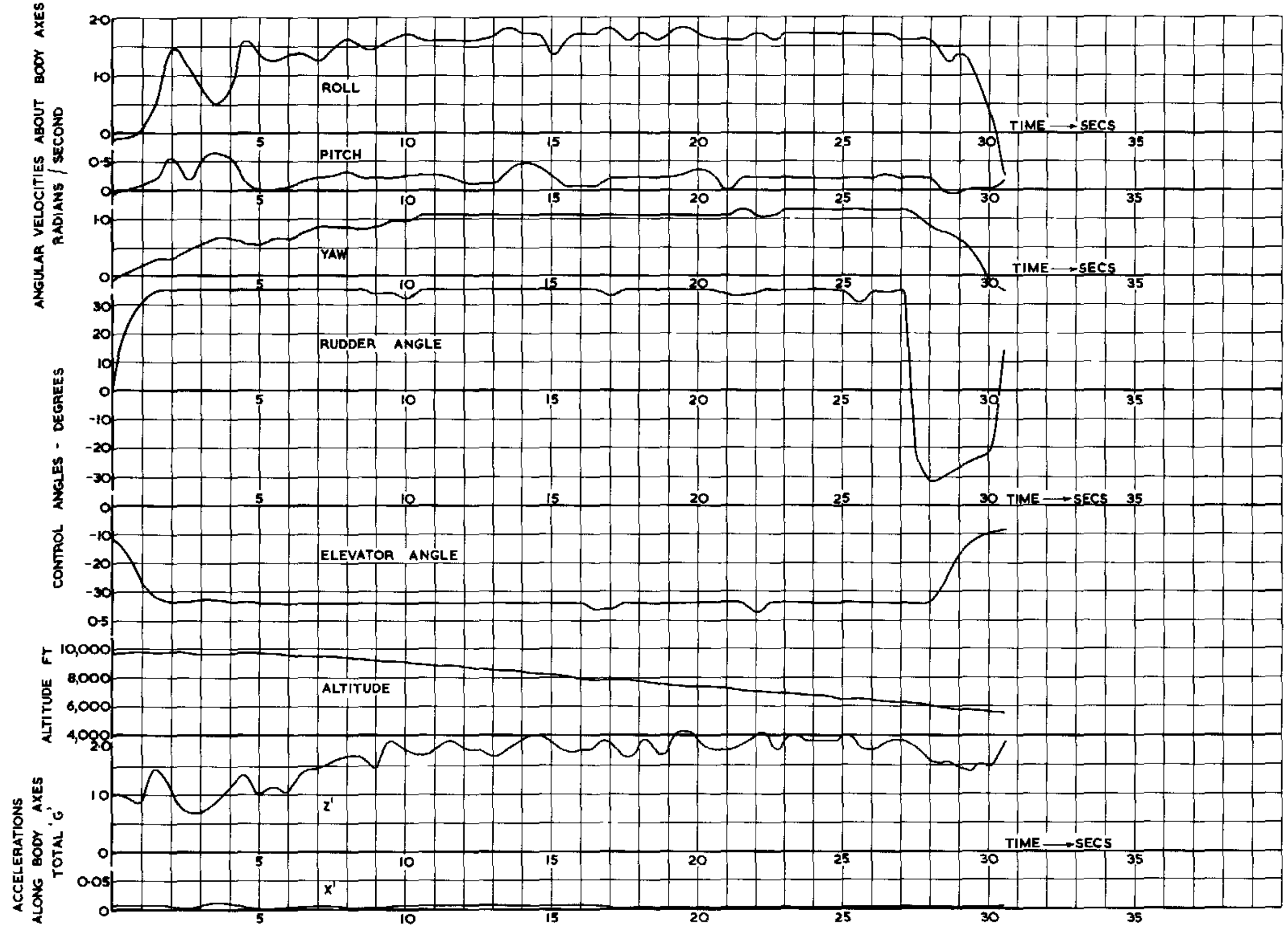


FIG 6 EIGHT TURN SPIN TO STARBOARD ANTI-SPIN AILERON APPLIED AFTER FIRST HALF TURN OF SPIN AND HELD THROUGHOUT SPIN AND RECOVERY
PROVOST W G 503

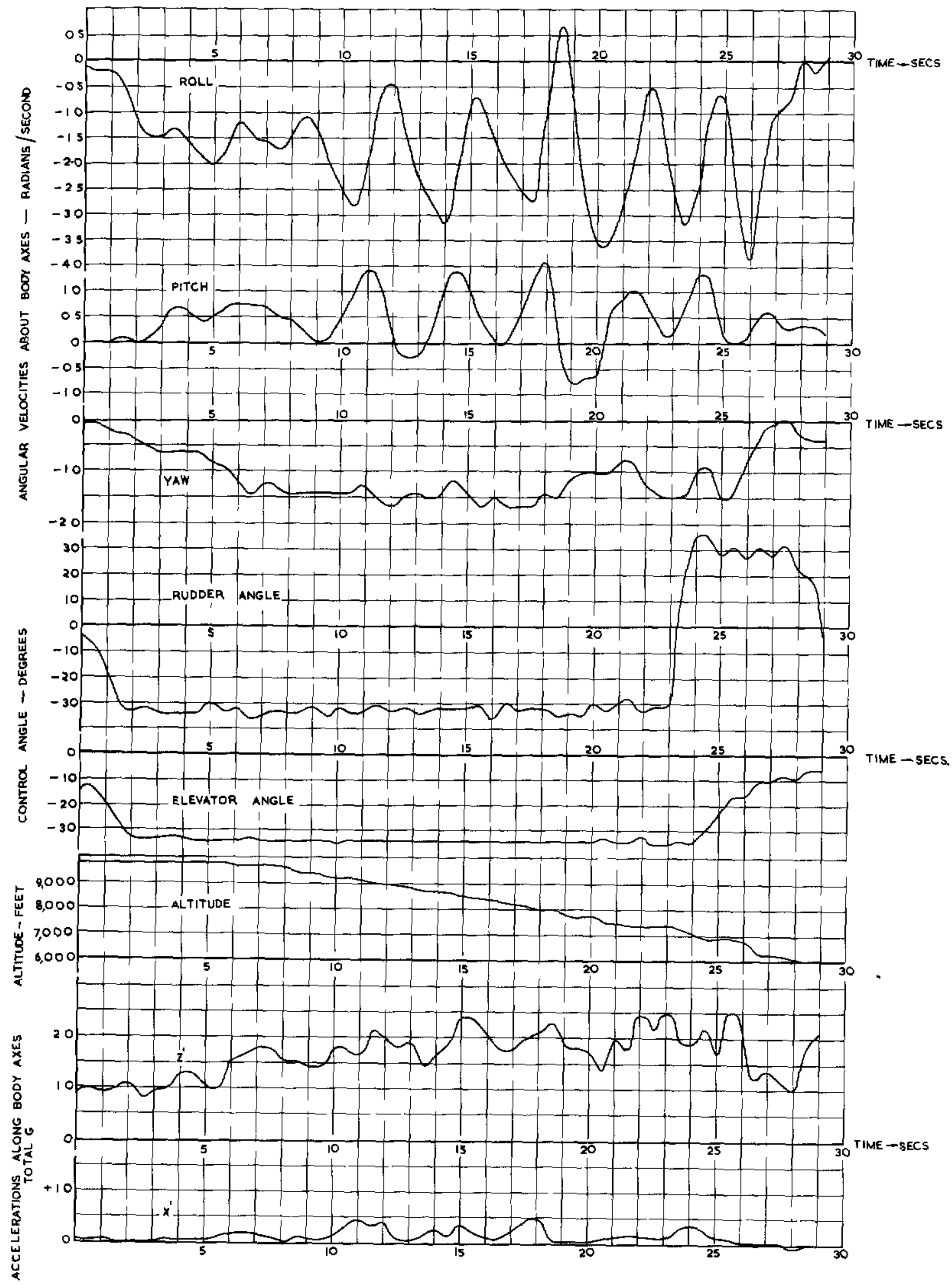
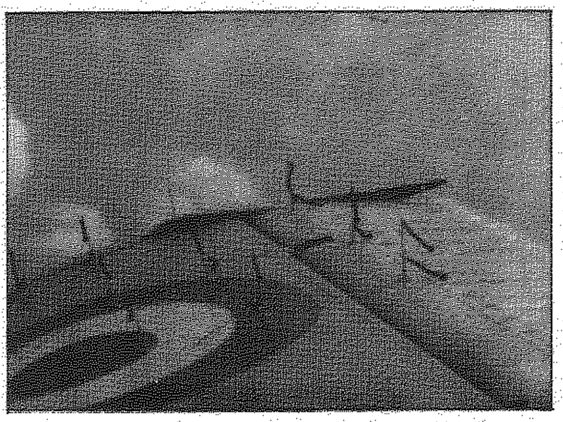


FIG. 7. EIGHT TURN SPIN TO PORT. PRO-SPIN AILERON THROUGHOUT SPIN & RECOVERY.

FIG.8



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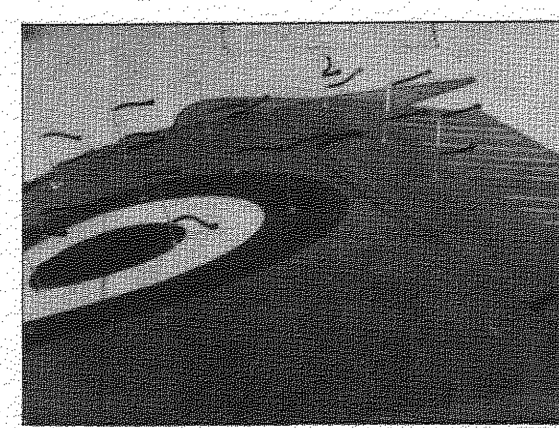

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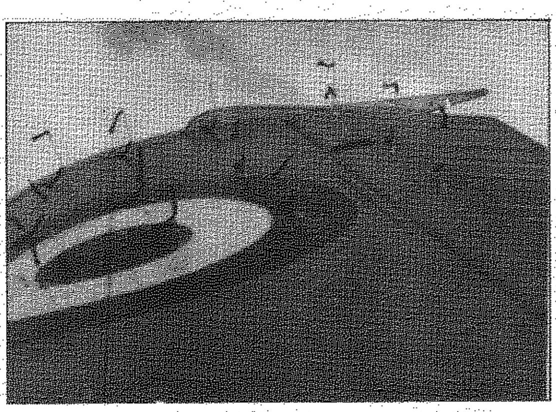

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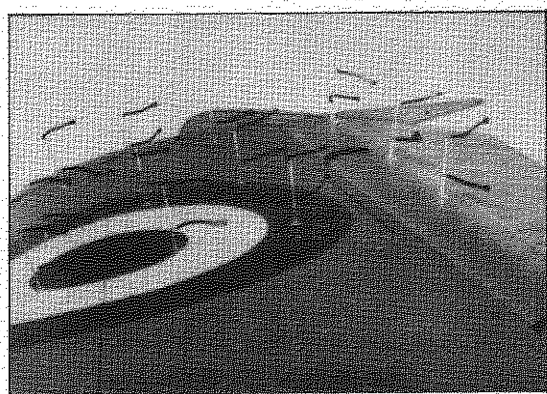

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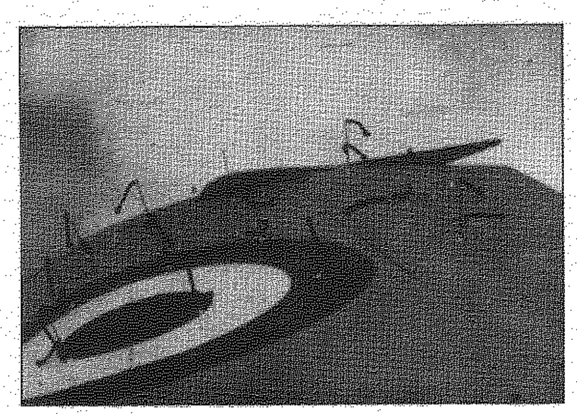
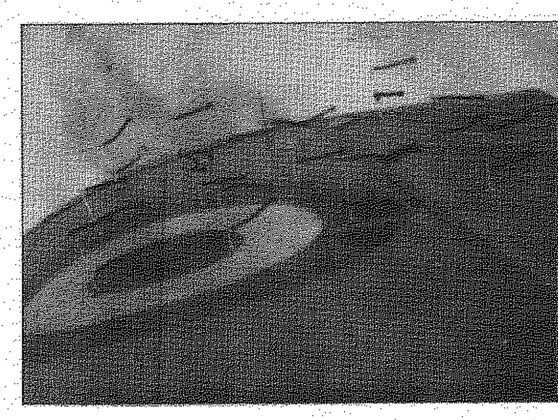


TIME: 22.0 secs.



TIME: 23.5 secs.

(SYNCHRONISED IN TIME WITH FIG.7)

FIG.8. TUFT PHOTOGRAPHS OF STARBOARD WING-TIP DURING AN OSCILLATORY SPIN TO PORT

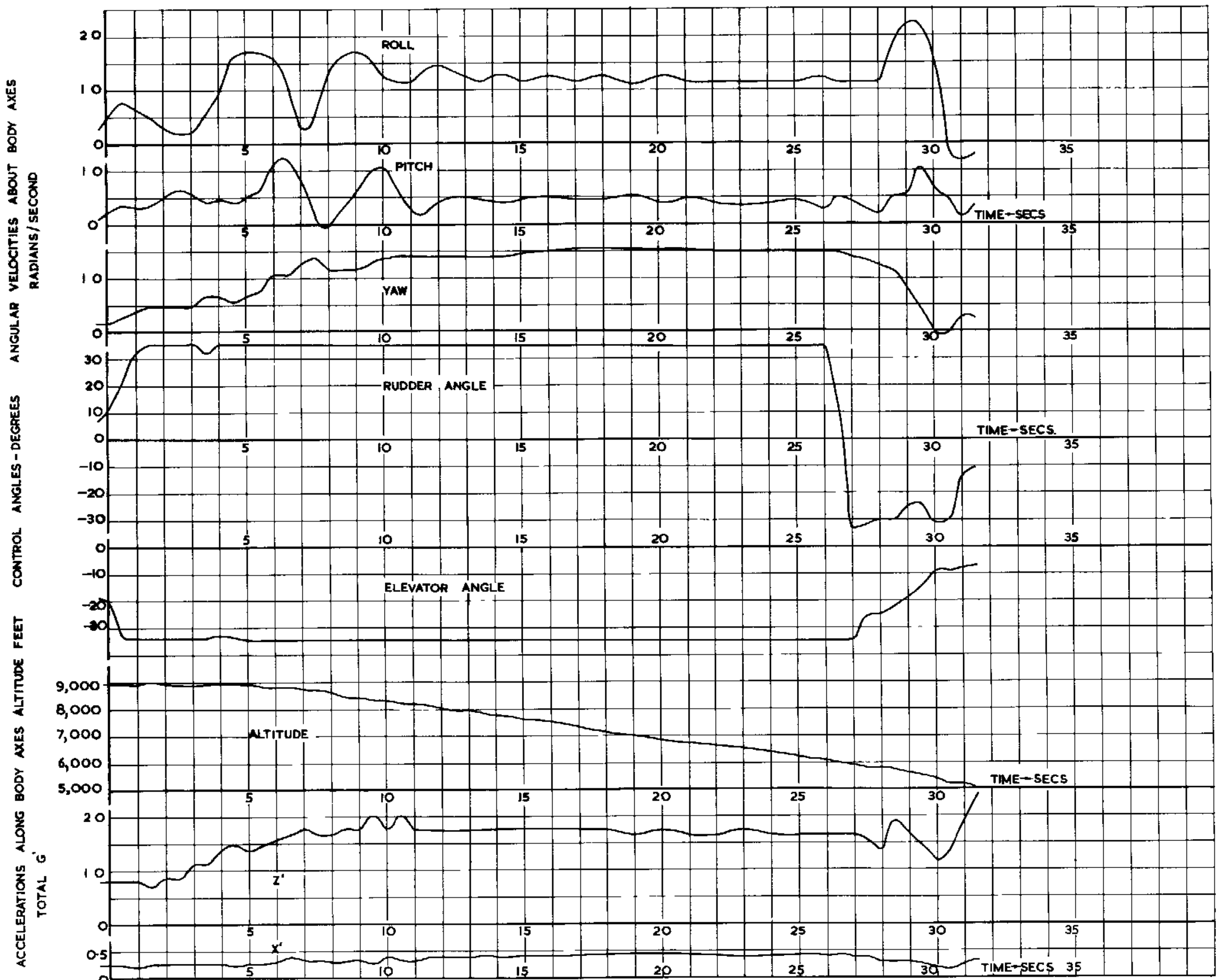


FIG. 9. EIGHT TURN SPIN TO STARBOARD. 2,600 R.P.M. — 2 BOOST. PROVOST W.G. 503.

FIG. 10.

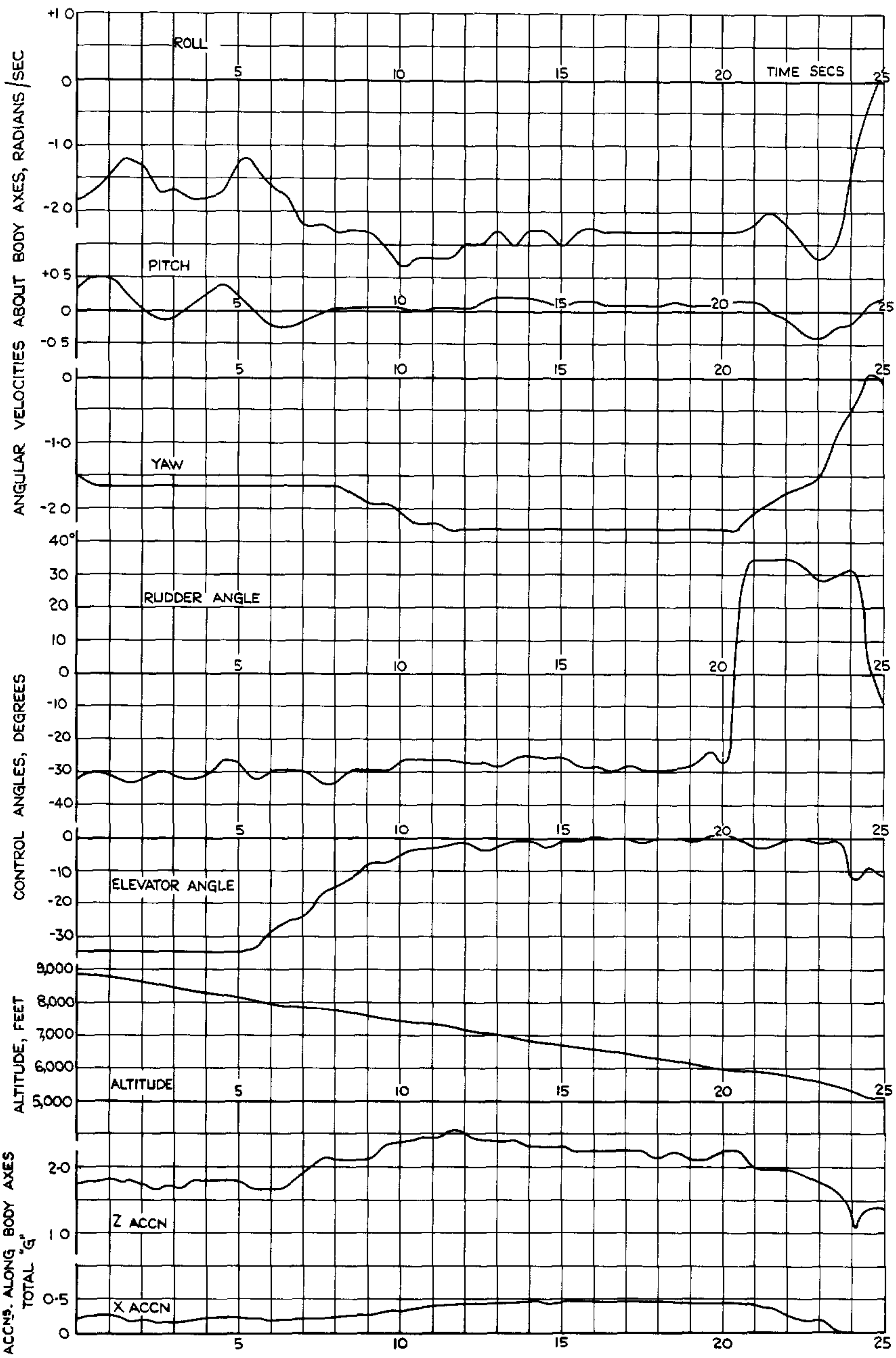


FIG. 10. 6 TURN PORT, ATTEMPTED RECOVERY ELEVATORS ONLY. PROVOST W.G. 503.

FIG. 11

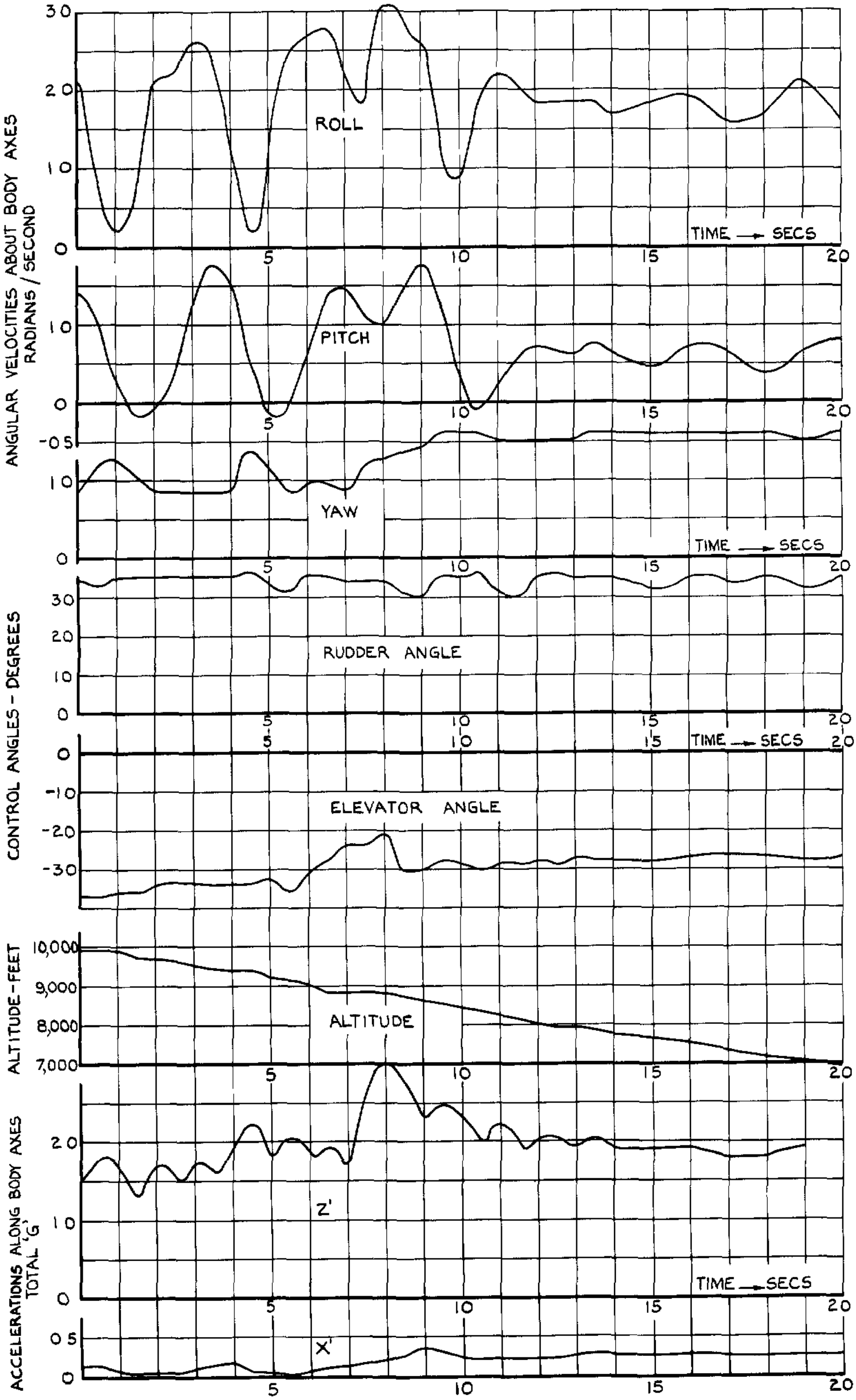


FIG. 11. EIGHT TURN SPIN TO STARBOARD STICK MOVED APPROX 2" FWD. AFTER 4 TURNS. PROVOST W.G. 503.

FIG.12.

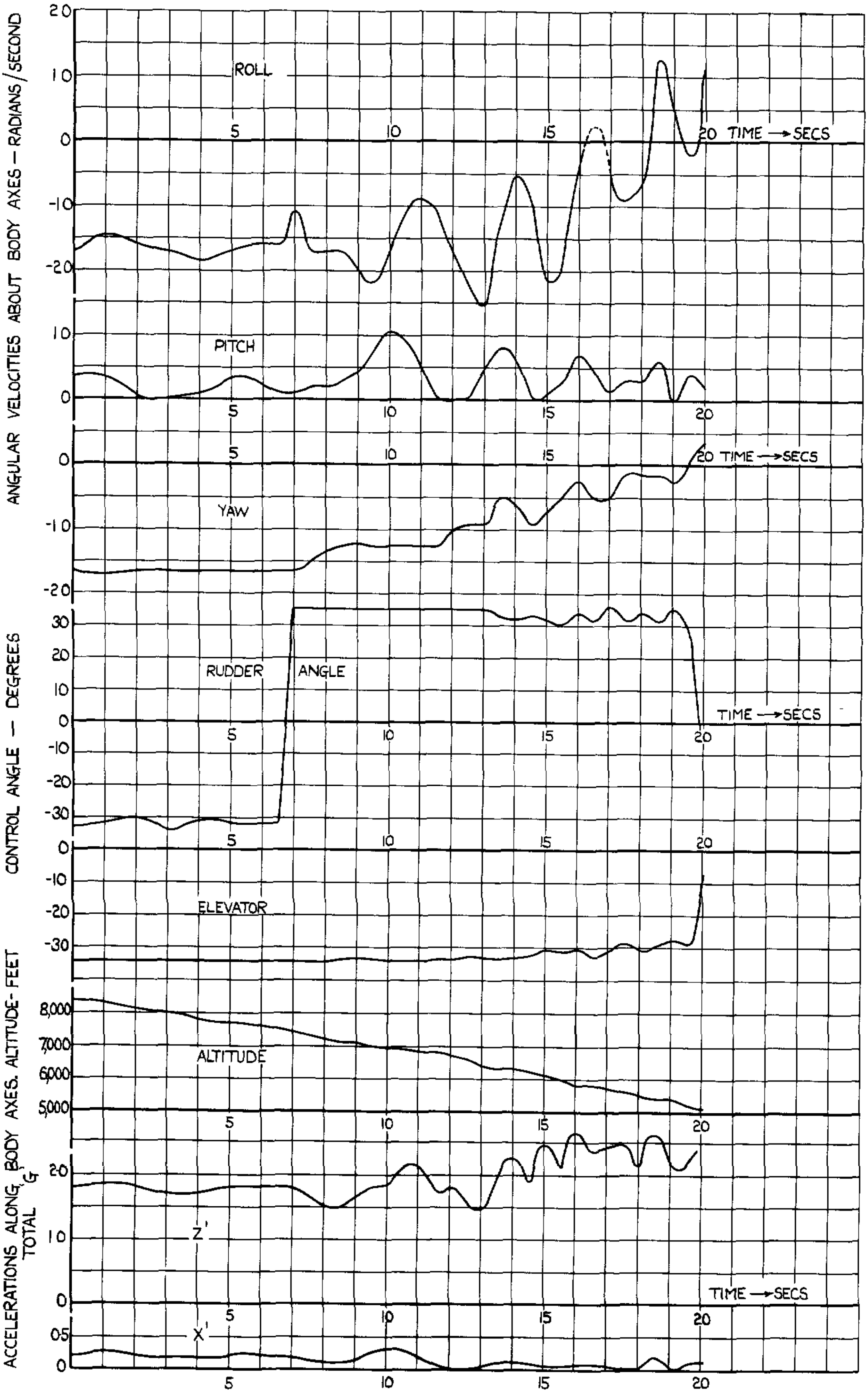


FIG.12. EIGHT TURN SPIN TO PORT RUDDER ONLY RECOVERY. PROVOST W G. 503.

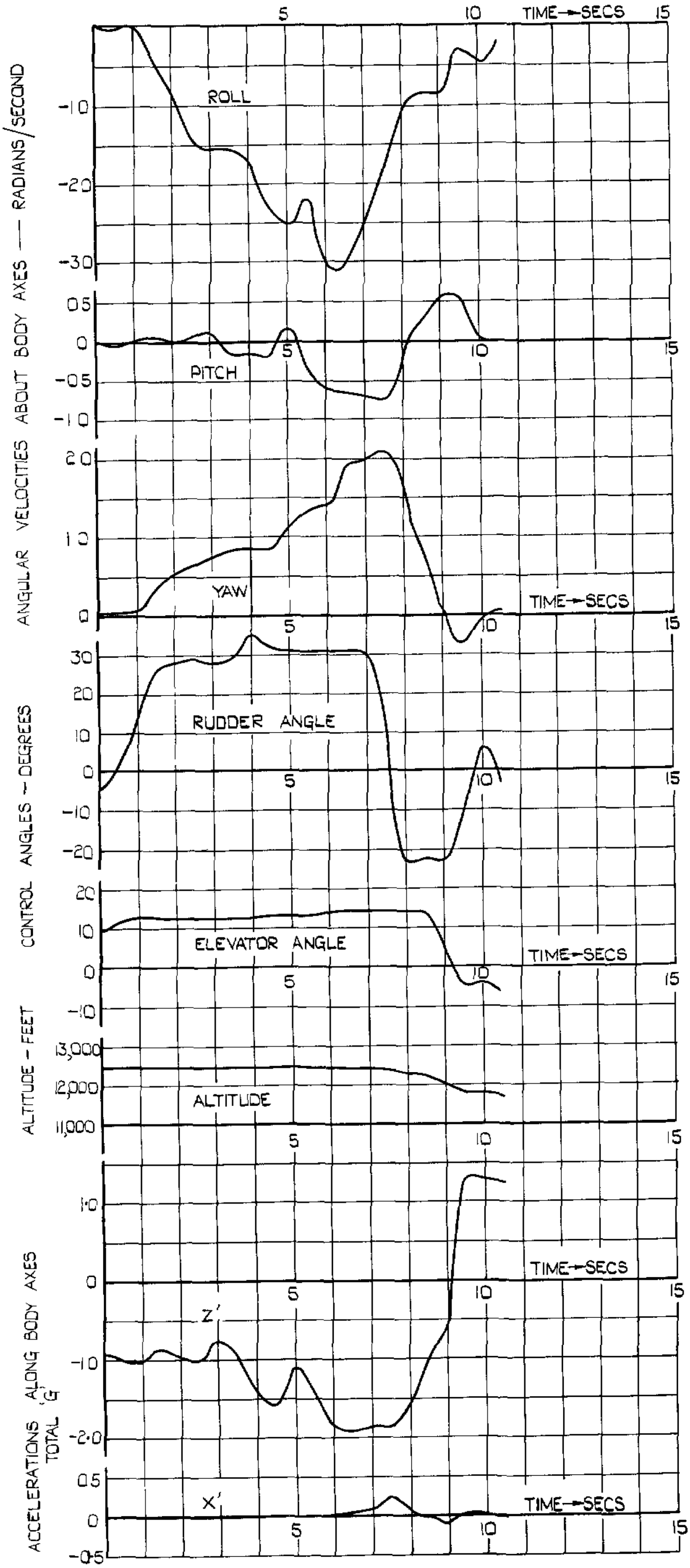


FIG.13. TWO TURN STARBOARD INVERTED SPIN.

FIG. 14.

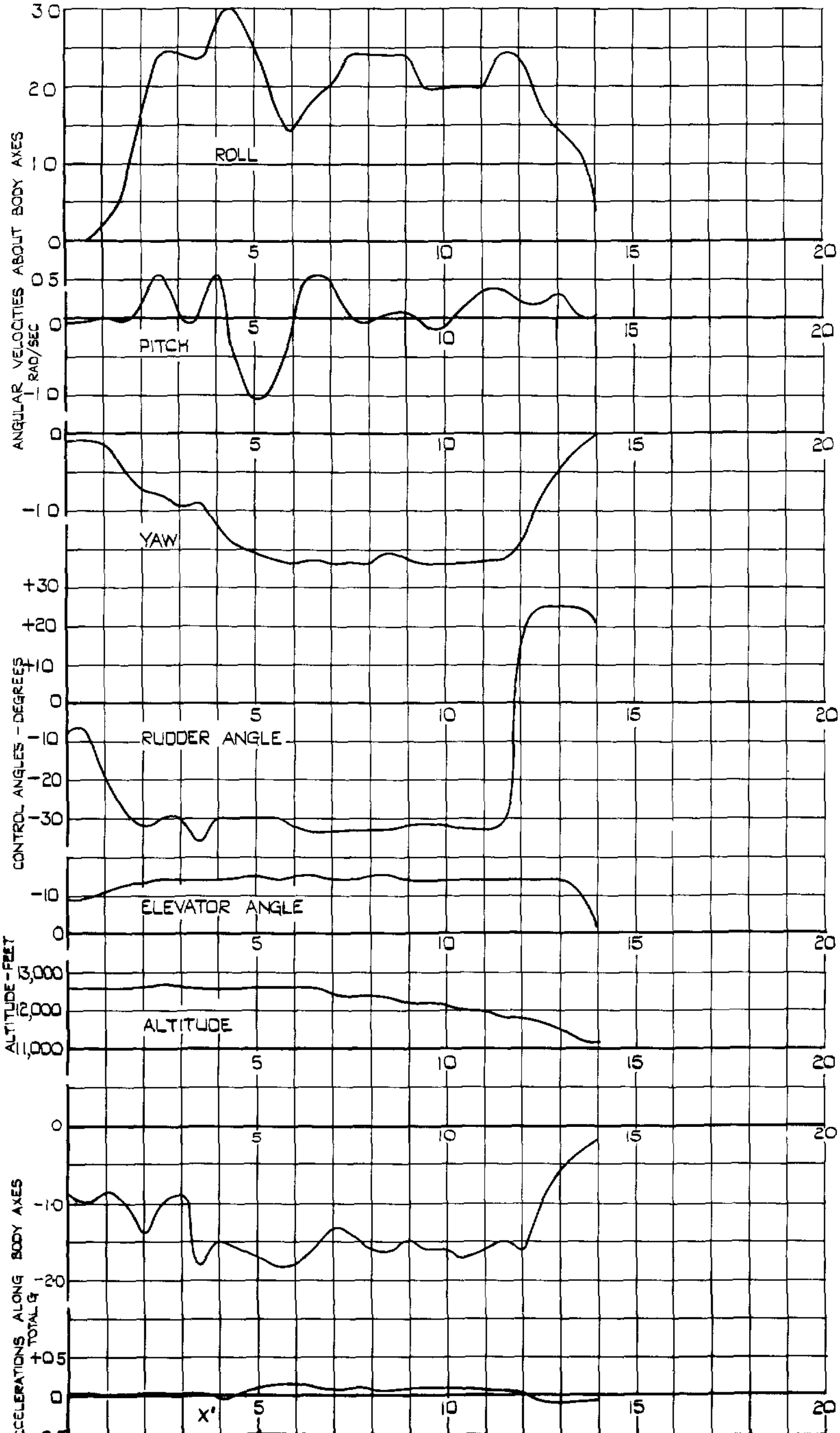


FIG. 14. FOUR TURN PORT INVERTED SPIN.

FIG. 15.

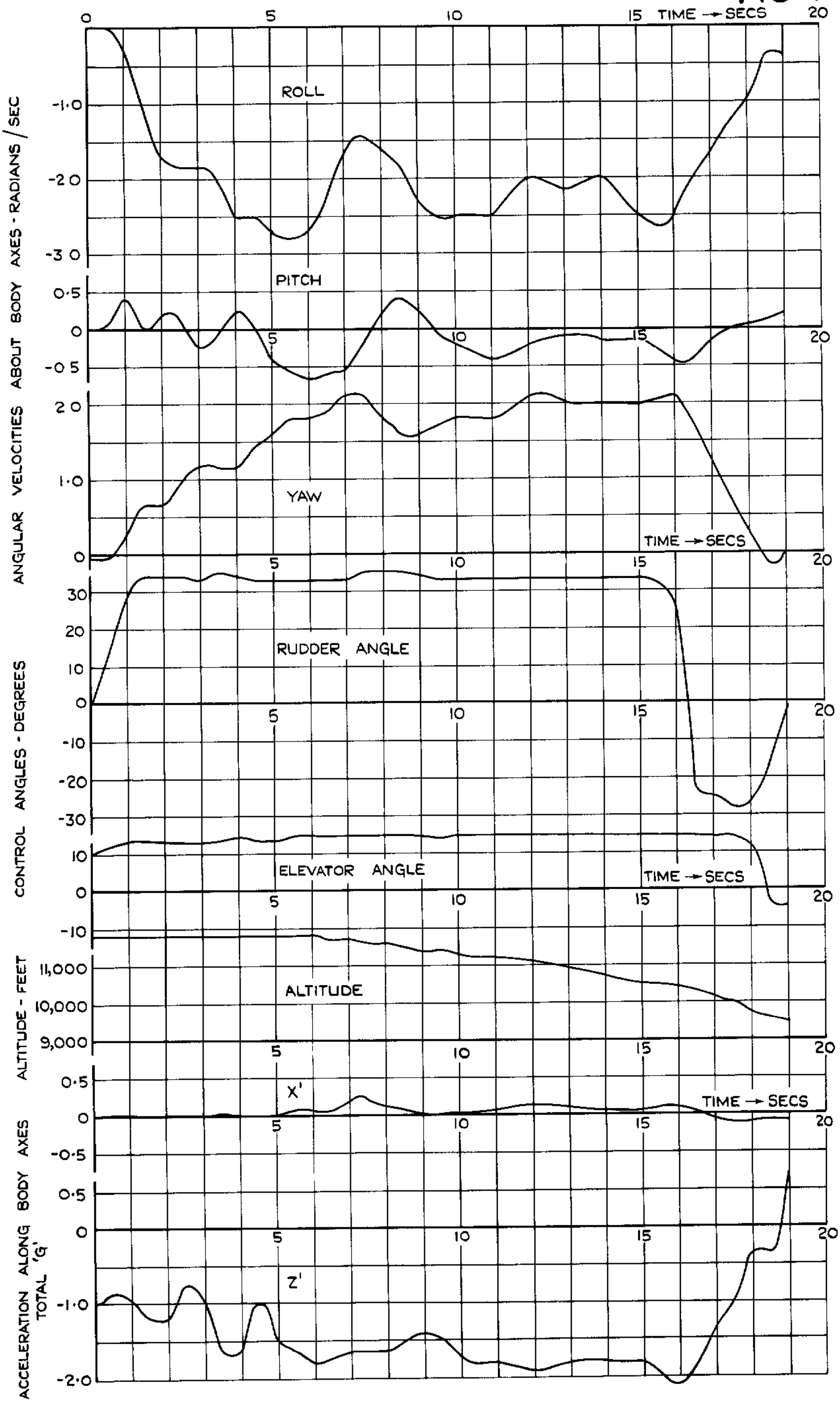


FIG. 15. SIX TURN INVERTED SPIN TO STARBOARD.

FIG. 16.

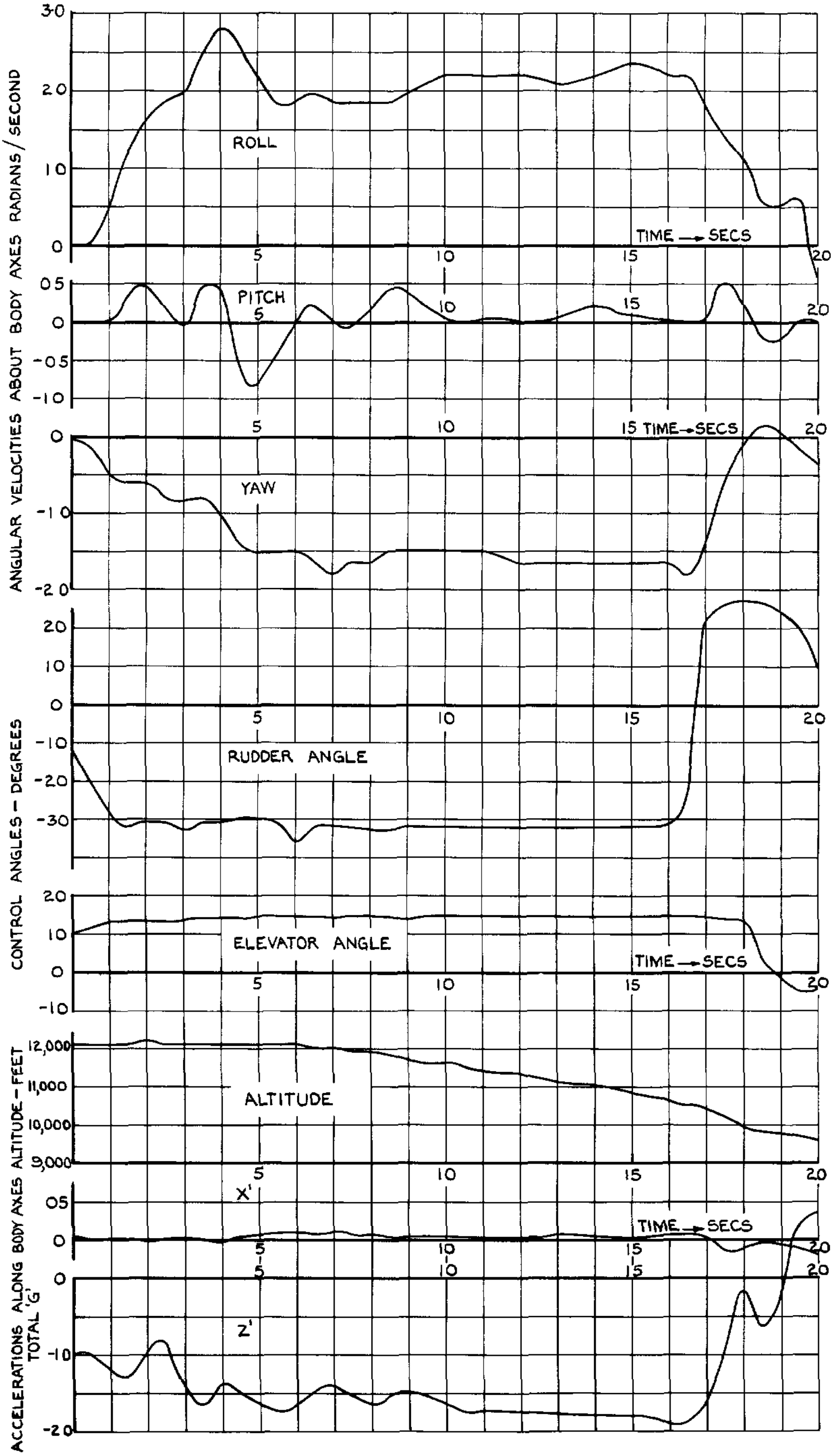
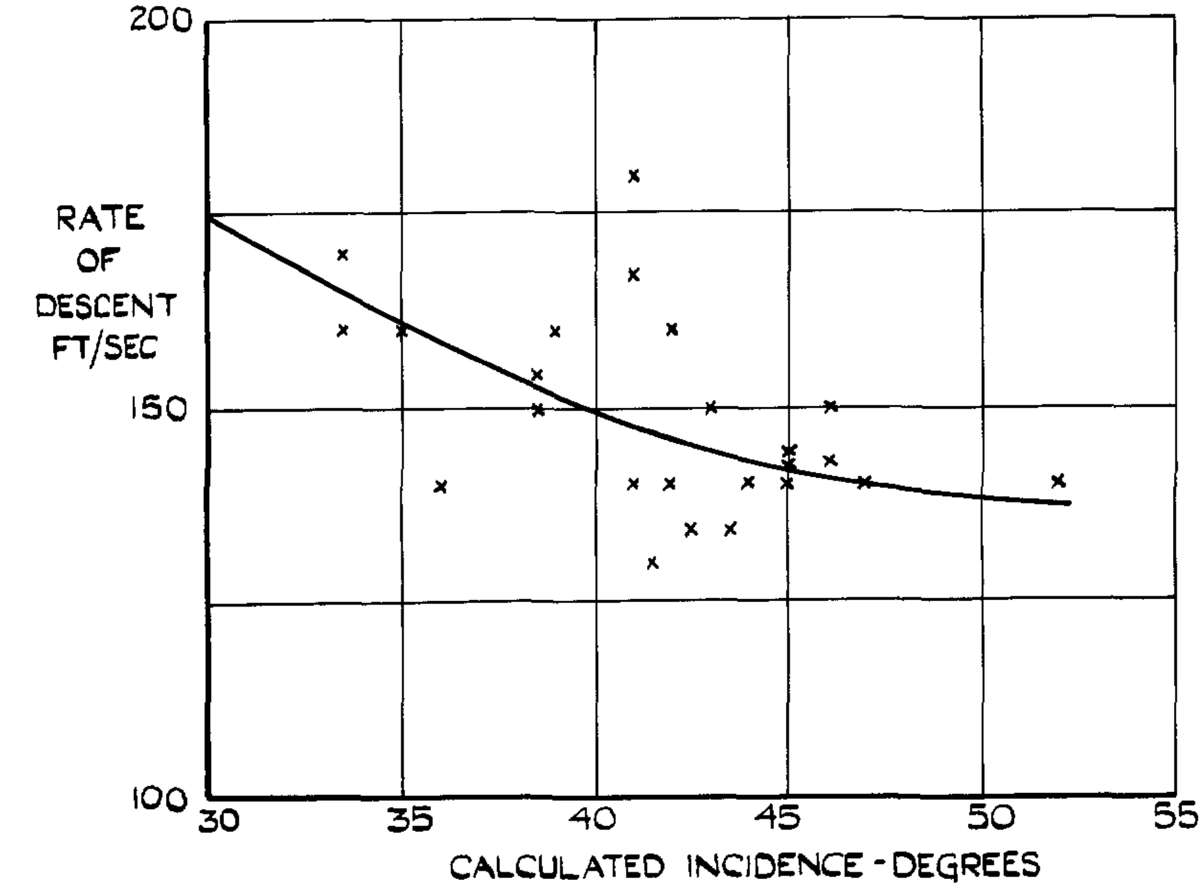


FIG. 16. SIX TURN INVERTED SPIN TO PORT



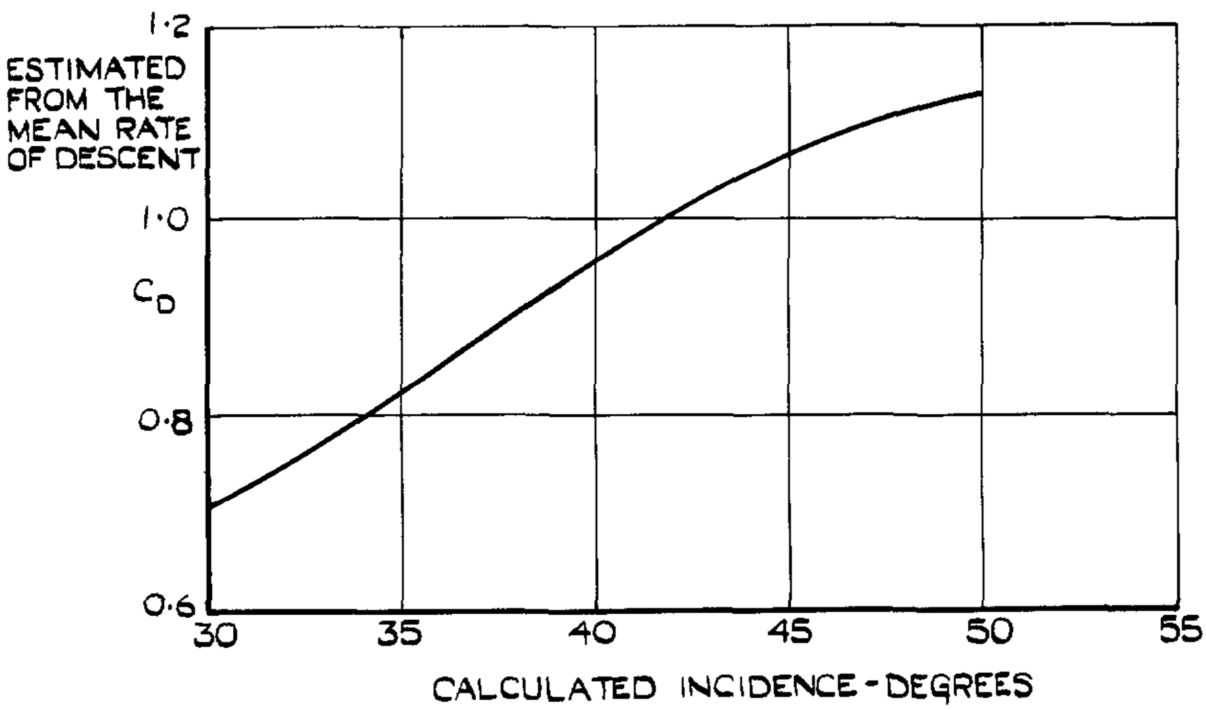


FIG. 17. RATE OF DESCENT AND DRAG COEFFICIENT AS A FUNCTION OF INCIDENCE IN THE SPIN.

PERCIVAL PROVOST. W.G. 503.

FIG. 18.

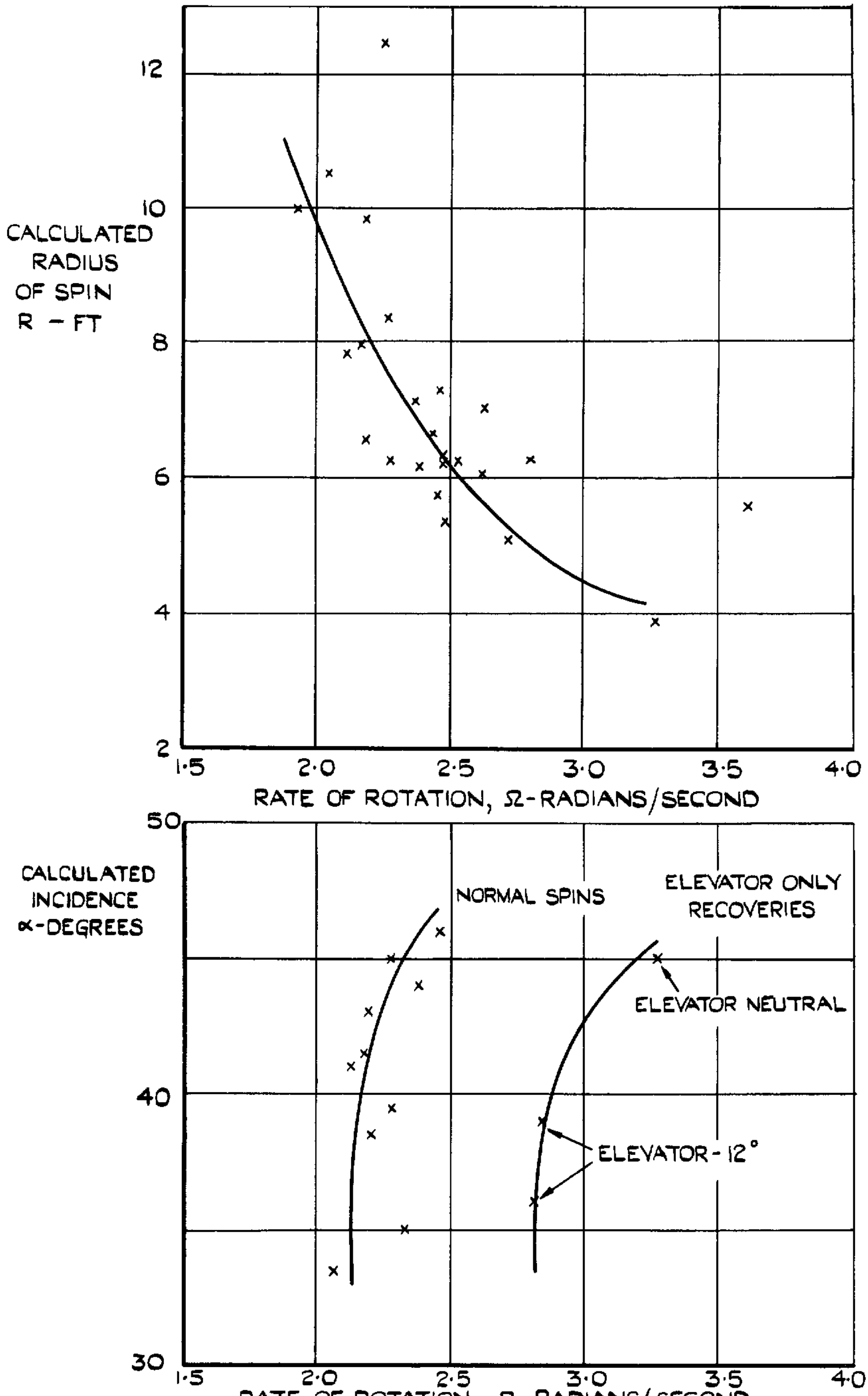


FIG. 18. INCIDENCE AND SPIN RADIUS AS A FUNCTION OF THE RATE OF ROTATION IN THE SPIN. PERCIVAL PROVOST. W.G. 503.

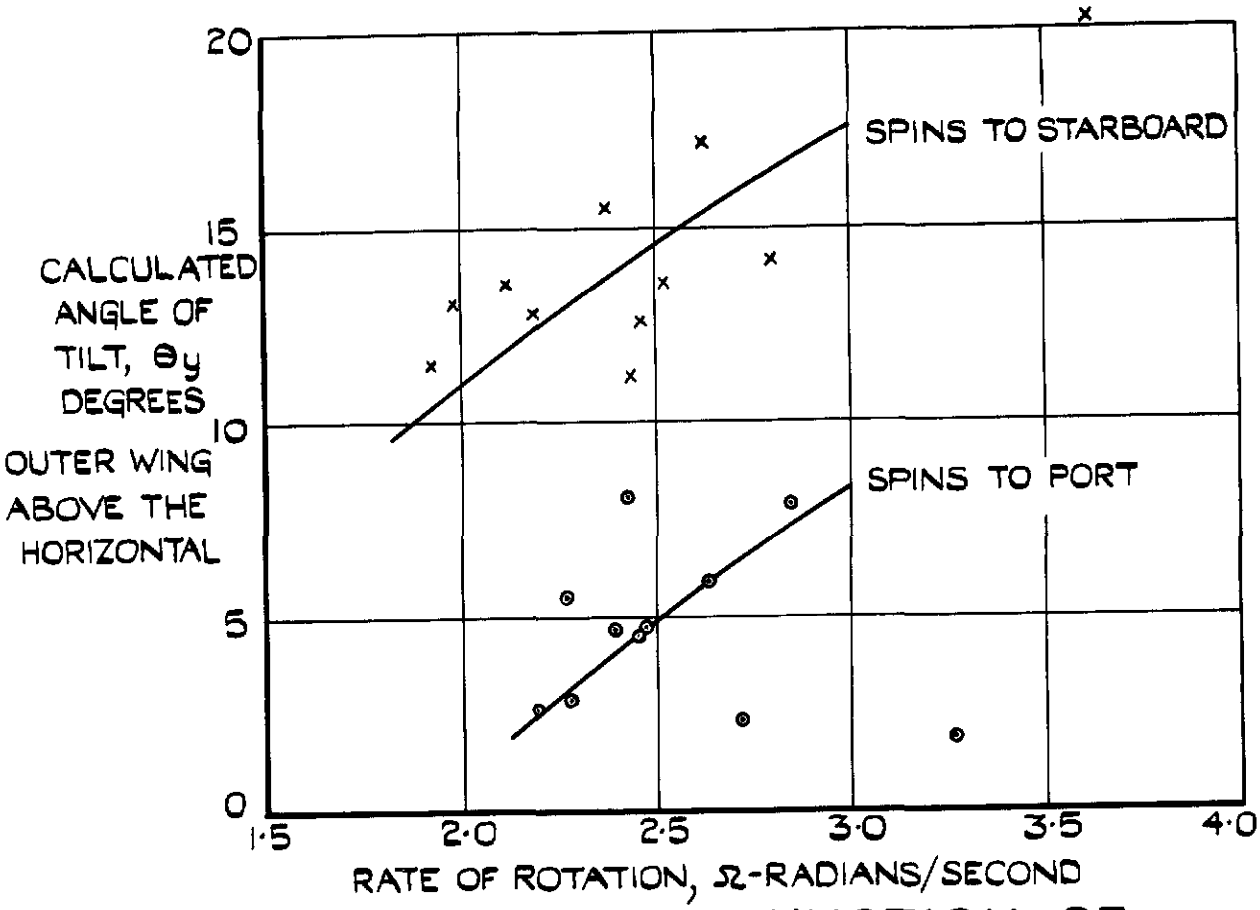


FIG. 19. WING TILT AS A FUNCTION OF RATE OF ROTATION IN THE SPIN.

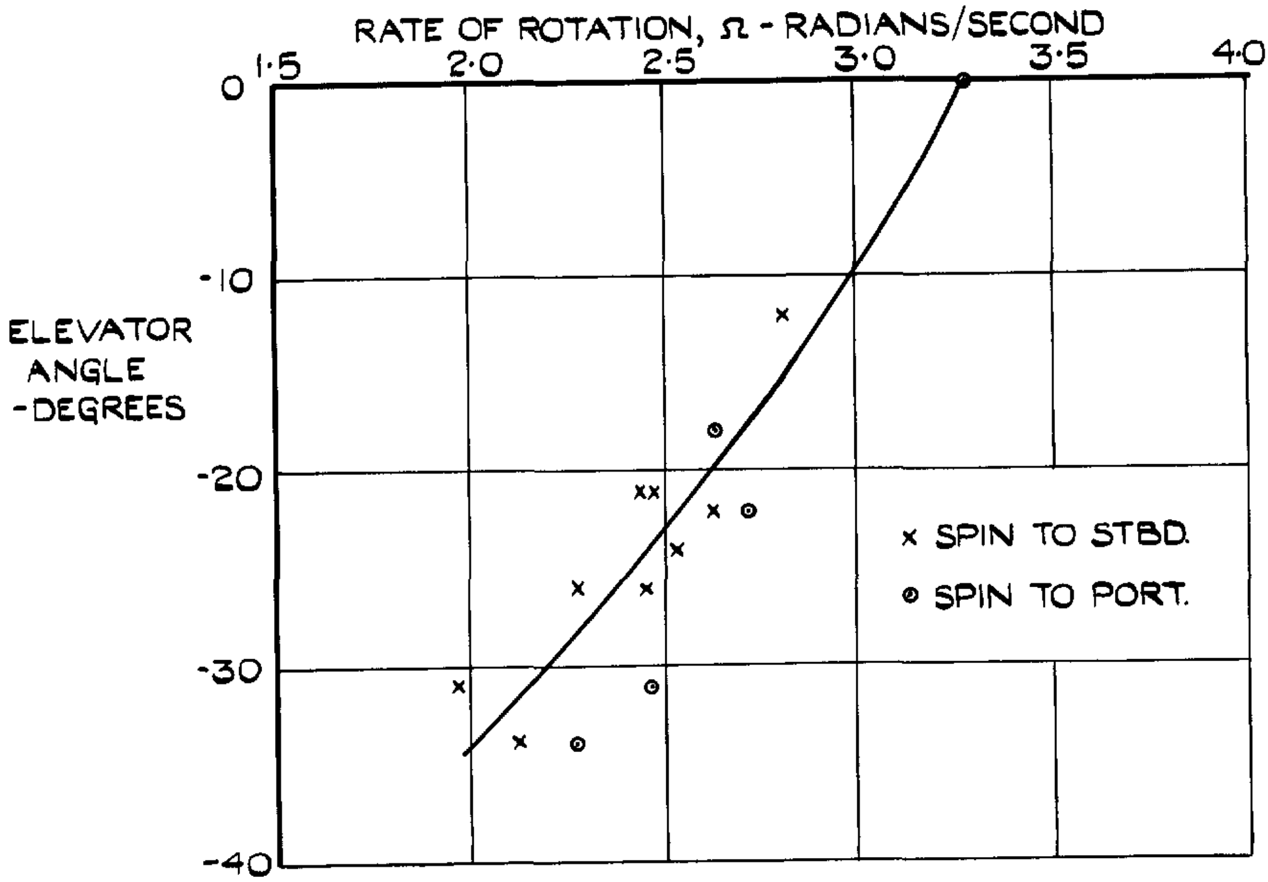


FIG. 20. RATE OF ROTATION AS A FUNCTION OF ELEVATOR ANGLE ON THE SPIN.

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