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AERODYNAMIC EVALUATION OF SMALL WING-TIP TANKS ON A DC-3 AIRCRAFT

<u>FOR LIMITED DISTRIBUTION</u>

by

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SUMMARY

An investigation of the effect of small wing-tip tanks on the flight characteristics of a DC-3 type aircraft has been accomplished. A CAA Technical Development and Evaluation Center DC-3 aircraft, N-182, was subjected to a flight-test program which included: (1) a series of power-on and power-off stalls using several flap settings with gear up and gear down, and (2) a series of climbs at normal and lower than normal airspeeds.

After data reduction, it was concluded that:

1. There is neither a beneficial nor an adverse effect on the stalling speed of the aircraft.

2. There is neither a beneficial nor an adverse effect on the rate of climb of the aircraft.

3. There is a slight improvement in the controllability or handling characteristics of the aircraft at and near the stalling speed, especially noticeable in the landing configuration power-off condition.

INTRODUCTION

In the course of an evaluation of several different high intensity, external aircraft lights, a unit consisting of an oscillating sealed-beam lamp housed in a streamlined "tank," located one at each wing tip of a DC-3 aircraft, was tested in flight. During the first flight test it was noted by the pilots that there seemed to be better lateral control of the airplane at low airspeeds than had existed prior to the installation of the tip tanks. Also, the stalling speed appeared to be somewhat lower than normal.

In view of the possible existence of these benefits, further testing under carefully controlled conditions seemed warranted. This report describes these tests.

PREPARATION FOR TESTING

The tests performed on airplane N-182 were unique in that comparative rather than absolute values were the goal. Because atmospheric conditions and aircraft gross weight could not be kept constant for all tests, all data had to be reduced to a common base from which results then could be tabulated for comparative purposes. Indicated airspeed, indicated power settings, etc., were not corrected to calibrated readings because the indicated readings would have the same error, if any, on all tests and would give accurate results for comparison.

To initiate preparation, the aircraft was weighed. This weight included all of the equipment which is normally carried in the airplane plus full tanks of gasoline and oil. Each additional component added thereafter to accomplish the test program was weighed so that an accurate aircraft gross weight might be recorded for each test.

The altimeter was calibrated at the Allison Flight Research Division of General Motors Corporation. This was the one exception in requiring calibrated readings, as the altimeter had to double as a barometer.

In order to insure airspeed indications suitable for comparison, some type of pitot head was needed which would be relatively immune from errors resulting from changes in angle of attack. A swivel-mounted, self-aligning pitot head and trailing bomb combination was not available; consequently, another type of head, accurate within ±2 per cent from -10° to +25° in angle of attack, was secured on loan from the NACA Langley Aeronautical Laboratory, Langley Field, Virginia. This pitot head was mounted, as recommended, on a boom one fuselage diameter (approximately 8 feet) ahead of the aircraft nose door along the longitudinal axis extended. It was rigidly fastened to the forward bulkhead internally and was secured externally by three guy wires at a point calculated to eliminate turbulence- or vibration-excited waves from being set up on the boom. This installation is shown in Fig. 1.

It was deemed necessary to observe wing-tip airflow characteristics. Again, for comparative purposes, these observations were made first without tip tanks and then with the tanks in place. Pieces of yarn 12 inches long were applied to the entire upper surface of the starboard wing-tip section, one piece to every square foot of area, as shown in Fig. 2. Also, three pieces were applied directly to the starboard tank when it was in place.

A system of recording the information was installed to allow simultaneous observation of the instrument panel and the tuft-equipped wing-tip area. The photo-panel technique was employed in the cockpit using a Varitron 70-millimeter camera, Fig. 3, focused on the pilot's flight instruments. A second Varitron camera was located at the rear-most starboard cabin window, fitted with a telescopic lens and focused on the wing-tip area to be observed. See Fig. 4. Varitron cameras were used because of their electronic shutter-triggering and automatic film-advancing features. By installing an electronic sequencer, Fig. 5, it was possible to trigger each camera simultaneously at intervals ranging from five seconds down to one second. For data reduction purposes, a frame-by-frame direct comparison between pictures of wing-tip airflow and cockpit instrument indications was possible. Figure 6 shows a picture taken with the cockpit camera, and Fig. 7 shows a picture taken simultaneously by the camera photographing the wing tip. To augment these records, a hand-held Eastman Cine Special camera was used to take moving pictures of the tip area at the rate of 64 frames per second. By studying these movies, it was possible to visualize the stall progression and the behavior of the boundary layer airflow.

DESCRIPTION OF TESTS

The object of the first portion of the flight tests was to determine if the presence of the tip tanks raised or lowered the stalling speeds, or benefited or hindered the low speed handling characteristics of the airplane. This was accomplished by subjecting the aircraft to two similar series of stalls. The first series of stalls was accomplished to test the conventional airplane and form criteria on which to base the comparison. The second series of stalls was performed with the tip tanks installed.

For these tests to be comparative, engine horsepower had to be kept constant and a history of gross weight versus time had to be recorded. The horsepower was maintained constant by use of the Pratt and Whitney engine calculator. The gross weight history curve, based on the fuel consumption, is shown in Fig. 8. Also, see data given in Table I. A stopwatch located on the photo-panel was started as soon as take-off power was applied, and it ran continuously throughout each test. The gross weight at the time each stall was performed could be calculated from the elapsed time and the fuel consumed as determined by the engine calculator. Since this same method of calculation was used in each test, the accuracy afforded by the engine calculator was considered sufficient for comparative purposes. Since the same pilots occupied the same stations during all tests, differences in technique did not enter into the problem.

TABLE I

FUEL CONSUMPTION RATES

Aircraft Operation	Gallons Per Hour Per Engine
Take-Off	140
First Reduction	90
Climb (Normal)	61.5
Power-On Stalls	45.5
Power-Off Stalls	22.75
Climb (725 hp)	66.5
Glide	25.5

All stalls were approached slowly and smoothly in calm, stable air which enabled the pilot to achieve the same repeatability as was accomplished on a test of three identical stalls to determine the minimum possible spread of results. No spread existed under these conditions. Stall data are shown in Table II.

The second portion of the test program was to evaluate climb performance before and after tip tanks were installed. Again, the same methods and procedures were used. These tests were performed in calm, stable air over an altitude span of 1500 feet. Engine power settings were set as determined by the engine calculator, and the climb to be investigated was carefully established at least 200 feet below that altitude where the recording equipment was actuated. This procedure allowed the aircraft to stabilize in the climb before entering the recorded portion of the test. The climb was then continued to a point about 100 feet above the final test altitude to eliminate any chance of errors caused by leveling off too soon. This test was conducted at the airspeeds shown in Table III. Rate-of-climb results are given in Tables III, IV, and V. A gross weight history curve is shown in Fig. 9. A glossary containing an explanation of standard notations and symbols is given at the end of this report.

DISCUSSION OF RESULTS AND CONCLUSIONS

As can readily be seen from Table II, the greatest variation in stalling speed was two miles per hour (mph). This occurred only once. Otherwise, two cases of one-mph difference were noted, one in favor of

TABLE II

STALL DATA FROM FILMS OF FLIGHT TEST

Stall*	Tanks Off				Tanks On			
	Airspeed (mph)	Time (Min.-Sec.)	Altitude (feet)	Manifold Pressure at 1900 rpm (Inches Hg)	Airspeed (mph)	Time (Min.-Sec.)	Altitude (feet)	Manifold Pressure at 1900 rpm (Inches Hg)
START	--	12:10	5100	26.5	--	13:05	5600	26.5
ON 1	77	12:45	5500	26.5	78	13:50	5900	26.5
ON 2	77	15:30	5500	26.5	77	15:40	5900	26.5
ON 3	71	17:05	5300	26.5	70	17:35	5800	26.5
ON 4	65	18:25	5100	26.5	65	20:00	5300	26.5
OFF 1	77	21:15	5000	10.0	77	21:40	4900	10.0
OFF 2	76	23:45	4900	10.0	76	23:20	4700	10.0
OFF 3	72	27:05	5000	10.0	74	24·40	4300	10.0
OFF 4	70	30:50	4800	10.0	70	29:50	5000	10.0

*ON 1 = Power on, gear up, flaps up.
ON 2 = Power on, gear down, flaps up.
ON 3 = Power on, gear down, one-half flaps.
ON 4 = Power on, gear down, full flaps.

OFF 1 = Power off, gear up, flaps up.
OFF 2 = Power off, gear down, flaps up.
OFF 3 = Power off, gear down, one-half flaps.
OFF 4 = Power off, gear down, full flaps.

TABLE III

CLIMB DATA FROM FILMS OF FLIGHT TEST

Tip Tanks Off

Airspeed (mph)	Time Required for 1500-foot Climb (Min.-Sec.) Start	Finish	Total Time Required for Climb Power (Min.-Sec.) Start	Finish
120	06:55	10:00	06:32	10:28
110	15:28	18:08	14:53	18:25
100	23:34	26:25	23:10	26:30
90	32:18	35:35	32:00	35:35

Tip Tanks On

Airspeed (mph)	Time Required for 1500-foot Climb (Min.-Sec.) Start	Finish	Total Time Required for Climb Power (Min.-Sec.) Start	Finish
120	09:42	12:32	09:42	12:37
110	17:09	19:48	17:09	19:54
100	23:53	26:33	23:45	26:44
90	32:22	35:34	32:05	35:34

tanks off and one in favor of tanks on. Examination of the curves in Fig. 8 reveals that the gross weight was practically the same at each increment of time during each test. Therefore, it is evident that there exists neither a beneficial nor an adverse effect on the stalling speed of the aircraft resulting from the installation of the tip tanks.

The rate-of-climb tests gave similar results as indicated by Tables III, IV, and V. Rate of climb, being more difficult to measure than stalling speeds, shows somewhat more spread in results; however, the difference in results before and after tank installation is so small that the same conclusions can be drawn as before.

TABLE IV

REDUCTION OF FLIGHT-TEST DATA ON CLIMBS

Tanks Off

Airspeed	H_{pr} (feet)	t (min.)	$\frac{dH}{dt}$ (fpm)	Vr (mph)	$M-\sqrt{K}$	tr (°C.)	tc (°C.)	V_c (mph)	V (mph)	σ	H_d (feet)	t_s (°C.)	$\frac{T_c}{T_s}$	$\left(\frac{R}{C}\right)_1$ (fpm)	$\left(\frac{R}{C}\right)_2$ (fpm)
120	5500	3.08	486	120	.174	17	15.5	762	132	.816	6800	4	1.043	507	507
110	5500	2.67	560	110	.160	17	15.5	762	122	.816	6800	4	1.043	584	584
100	5500	2.85	526	100	.145	17	15.75	762	110	.815	6800	4	1.043	550	550
90	5500	3.28	459	90	.130	17	16.0	762	99	.815	6800	4	1.045	480	480

Tanks On

Airspeed	H_{pr} (feet)	t (min.)	$\frac{dH}{dt}$ (fpm)	Vr (mph)	$M-\sqrt{K}$	tr (°C.)	tc (°C.)	V_c (mph)	V (mph)	σ	H_d (feet)	t_s (°C.)	$\frac{T_c}{T_s}$	$\left(\frac{R}{C}\right)_1$ (fpm)	$\left(\frac{R}{C}\right)_2$ (fpm)
120	5500	2.84	529	120	.174	12	10.0	754	131	.832	6200	4	1.02	539	536
110	5500	2.66	562	110	.160	14	12.5	758	121	.826	6400	4	1.03	579	577
100	5500	2.67	562	100	.145	13	11.5	756	109.5	.828	6300	4	1.028	576	576
90	5500	3.2	469	90	.130	14	12.75	758	98.6	.823	6500	4	1.03	482	482

*See Glossary.

TABLE V

CORRECTED RATE-OF-CLIMB COMPARISON

Airspeed (mph)	Tanks Off (fpm)	Tanks On (fpm)	Differential (fpm)
120	507	536	(+29)
110	584	577	(- 7)
100	550	576	(+26)
90	480	482	(+ 2)

One other factor did not prove to be quite so inconspicuous. This was low speed controllability. Installation of the tip tanks had an effect similar to increasing the aspect ratio. As was noted from the wing-tip airflow analysis, the stall onset was moved slightly inboard, thereby allowing the tip of the aileron to be in a region of laminar flow at lower airspeeds and higher angles of attack. A region of high turbulence was shown to exist at the surface of the tip tank. Further observations lead to the conclusion that a pressure pattern existed around the tank, creating a secondary longitudinal or axiswise flow which tended to neutralize the characteristic outboard diversion of streamlines on this particular wing tip. This outward diversion, teamed with another inherent flow condition whereby air of higher pressure flows from beneath the tip in a spanwise direction to the lower pressure region above the tip, caused very abrupt loss of aileron control at stall onset. Far from the ideal situation where a wing stalls from some point inboard and progresses outboard to the tip, just the opposite situation exists on the standard wing. The logical conclusion, therefore, appears to be that the small tip tank diverts enough air back over the trailing edge of the tip and the end of the aileron to give the aircraft slightly better control about the longitudinal axis. In the landing configuration, gear down and full flaps, power-off situation, aileron control was maintained throughout the stall. This was not experienced with the conventional wing tip. Slow flight with the tip tanks installed was demonstrated to several groups of interested people, including a number of DC-3 pilots, and all agreed that there appeared to be a greater margin of controllability than is normally experienced in a standard DC-3 airplane.

It seems probable that the use of tip tanks, properly designed to offset the poor wing-tip aerodynamics of the DC-3 wing, should result in greater aerodynamic efficiencies, affording lower stalling speeds and better low airspeed control.

GLOSSARY

EXPLANATION OF STANDARD NOTATIONS

H_{pr}	Observed pressure altitude, in feet above msl.
t	Elapsed time of test, in minutes.
$\frac{dH}{dt}$	Rate-of-climb curve at H_{pr}, in feet per minute.
V_r	Observed airspeed, in miles per hour.
M	Mach number at V_r.*
K	Recovery factor for free air temperature-pickup calibration.
t_r	Observed free air temperature, in °C.
t_c	Temperature resulting from M K and t_r corrections,* in °C.
V_c	Speed of sound at t_c,* in miles per hour.
Hg	Inches of mercury.
V	M x V_c, in miles per hour.
σ	Density ratio* for t_c and H_{pr}.
H_d	Density altitude* for σ, in feet.
t_s	Standard free air temperature* H_{pr}, in °C.
$\frac{T_c}{T_s}$	Ratio of absolute corrected temperature T_c(°K) to absolute standard temperature T_s(°K).
$\left(\frac{R}{C}\right)_1$	Corrected rate of climb $\left(\frac{dH}{dt}\right)\left(\frac{T_c}{T_s}\right)$, in feet per minute.
$\left(\frac{R}{C}\right)_2$	$\left(\frac{R}{C}\right)_1$, corrected for difference in gross weight from graph, in feet per minute.

*Benson Hamlin, "Flight Testing Conventional and Jet Propelled Airplanes," Macmillan Company, New York, 1946, Figs. 8:1, 8:2, and 8:3.

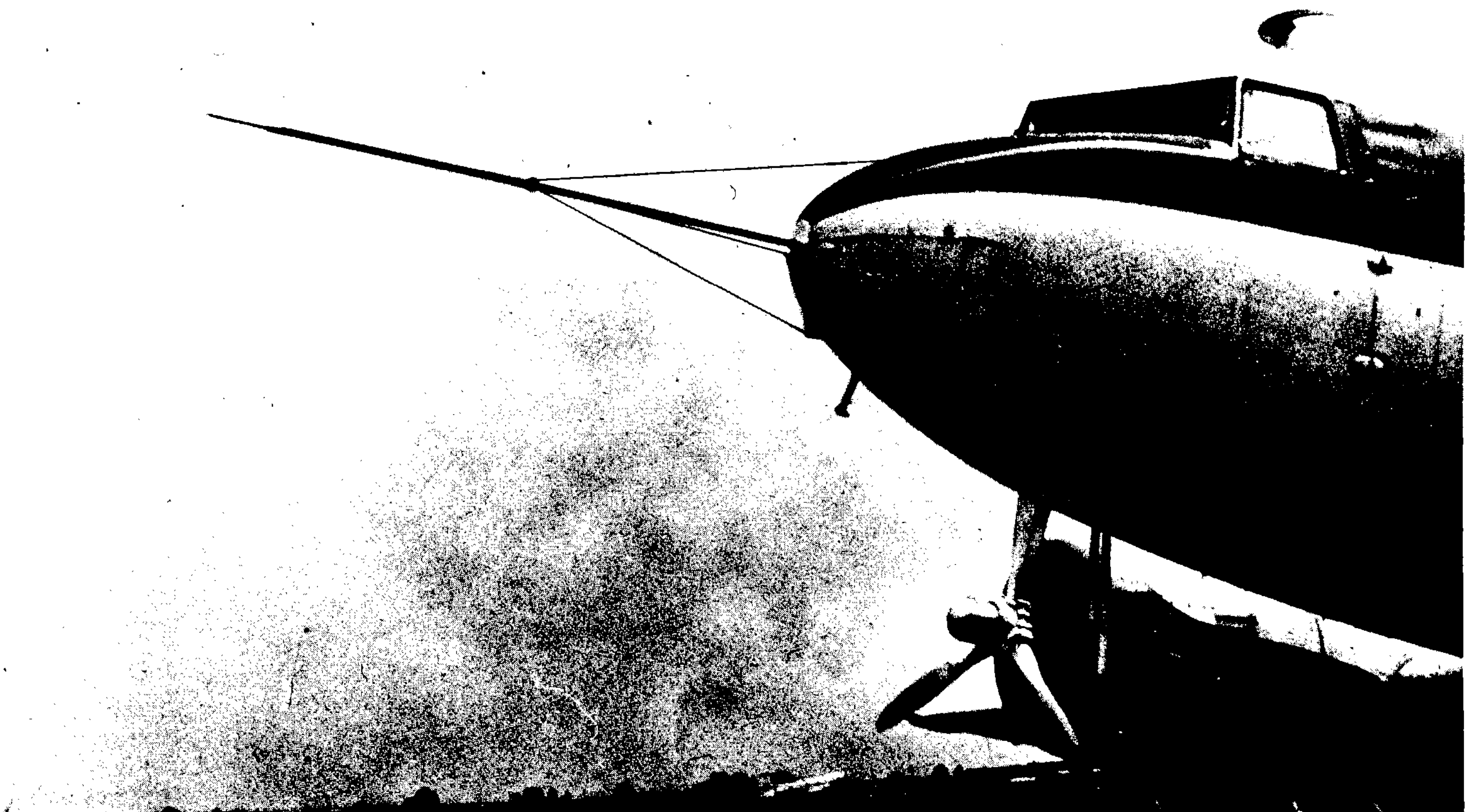

Fig. 1 Pitot Head and Boom Installation

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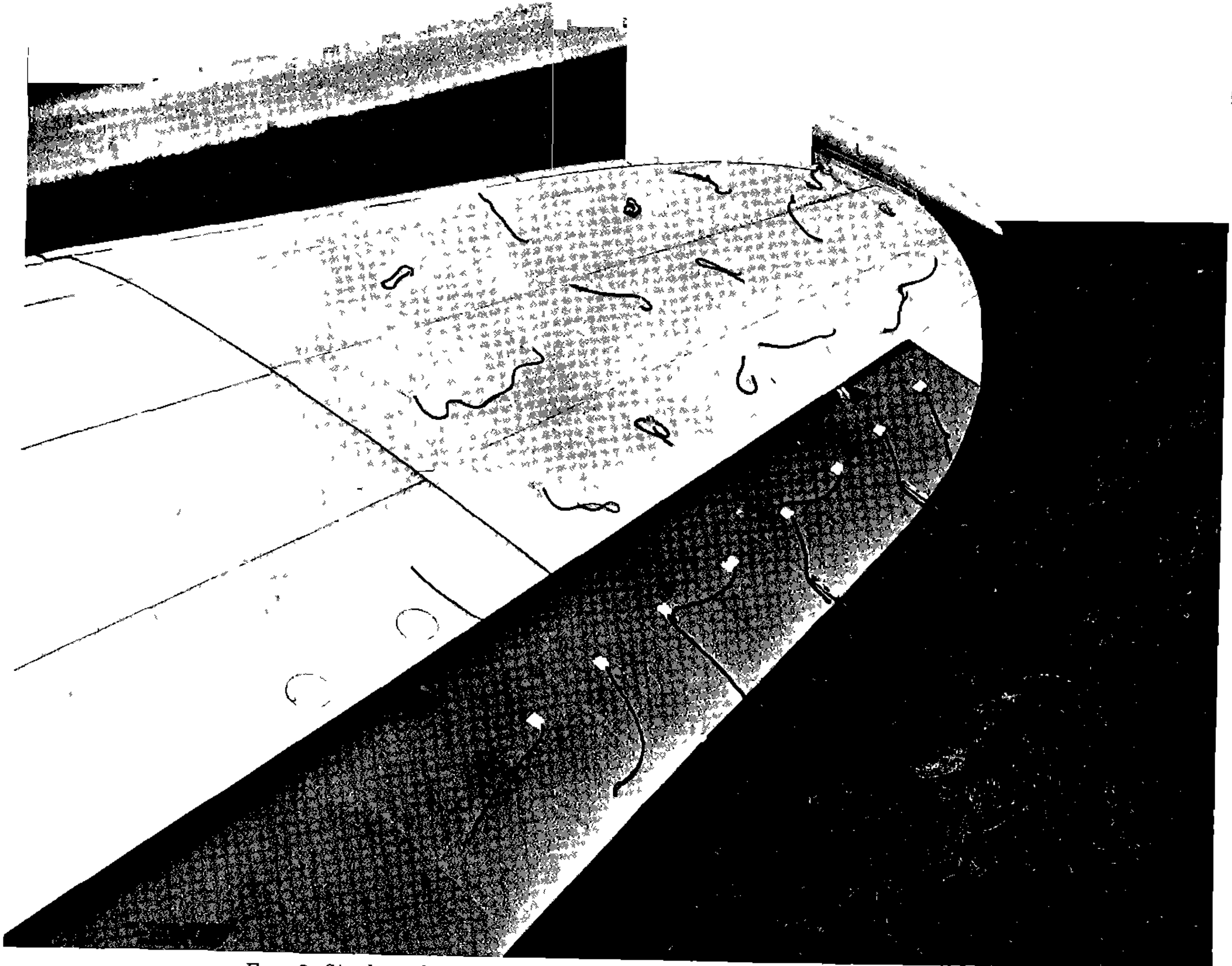

Fig 2 Starboard Wing Tip and Tip Tank Showing Yarn Tuft Locations

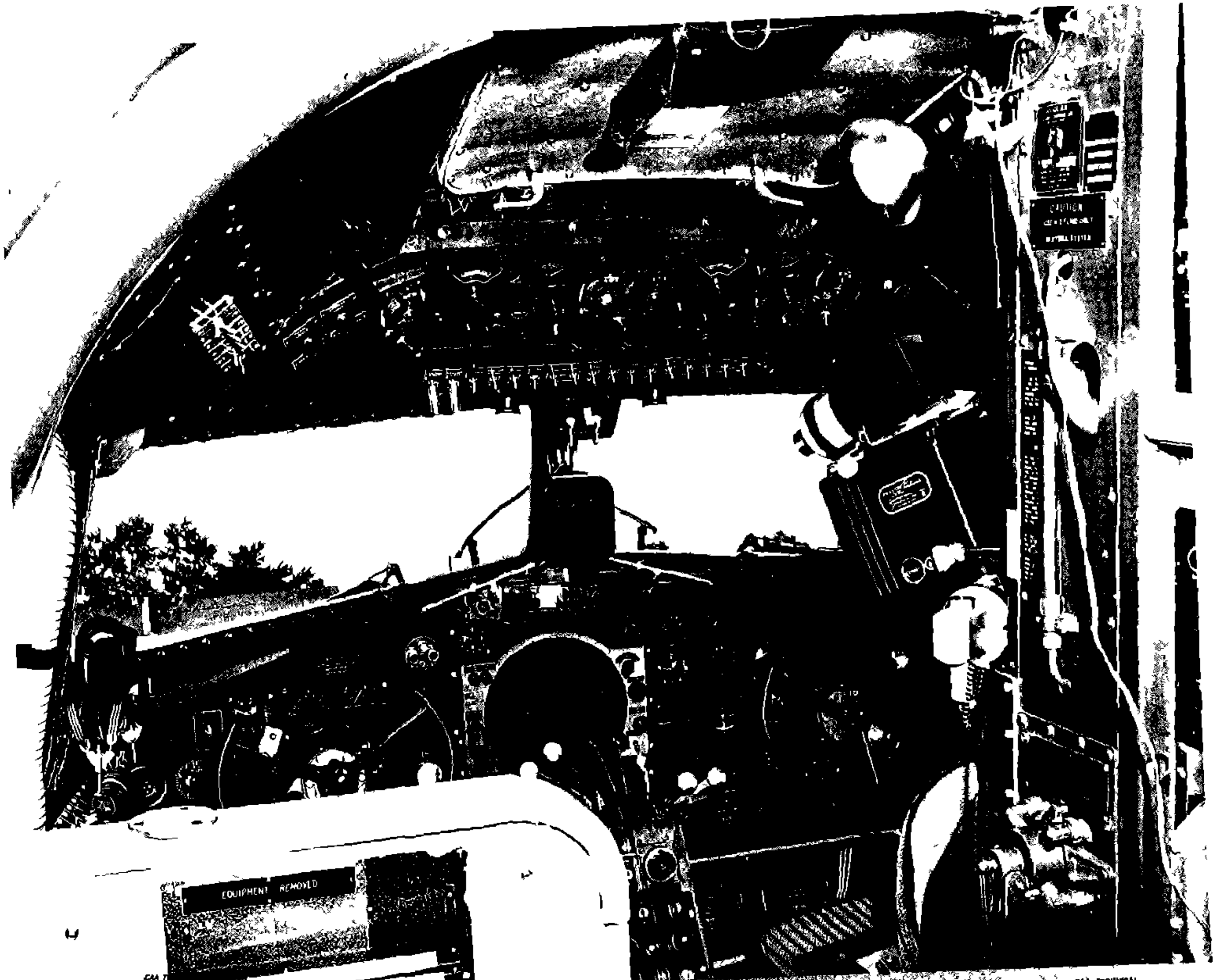

Fig. 3 Cockpit Camera Installation

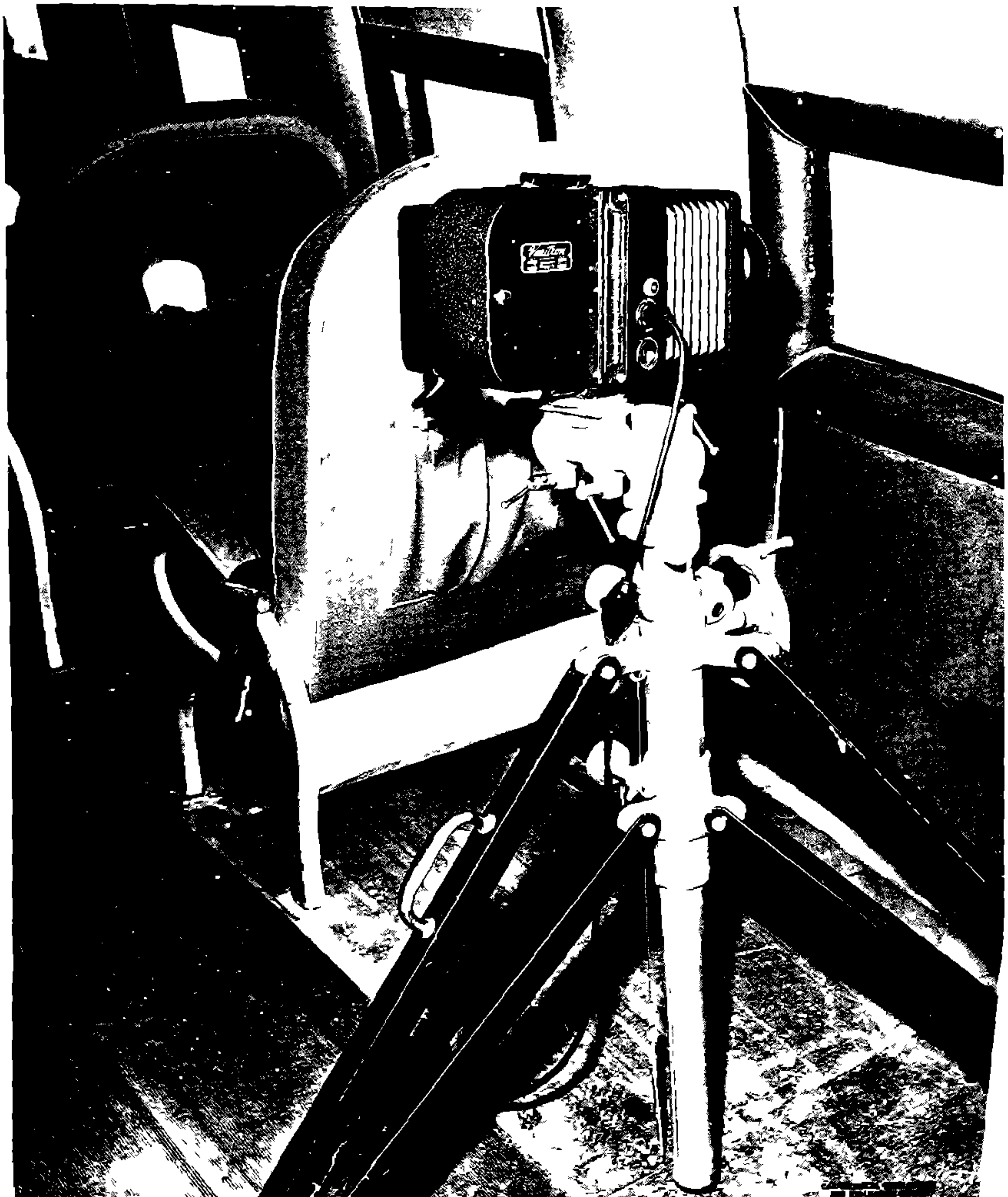

Fig 4 Telescopic Camera at Starboard Cabin Window Photographing the Wing-Tip Area

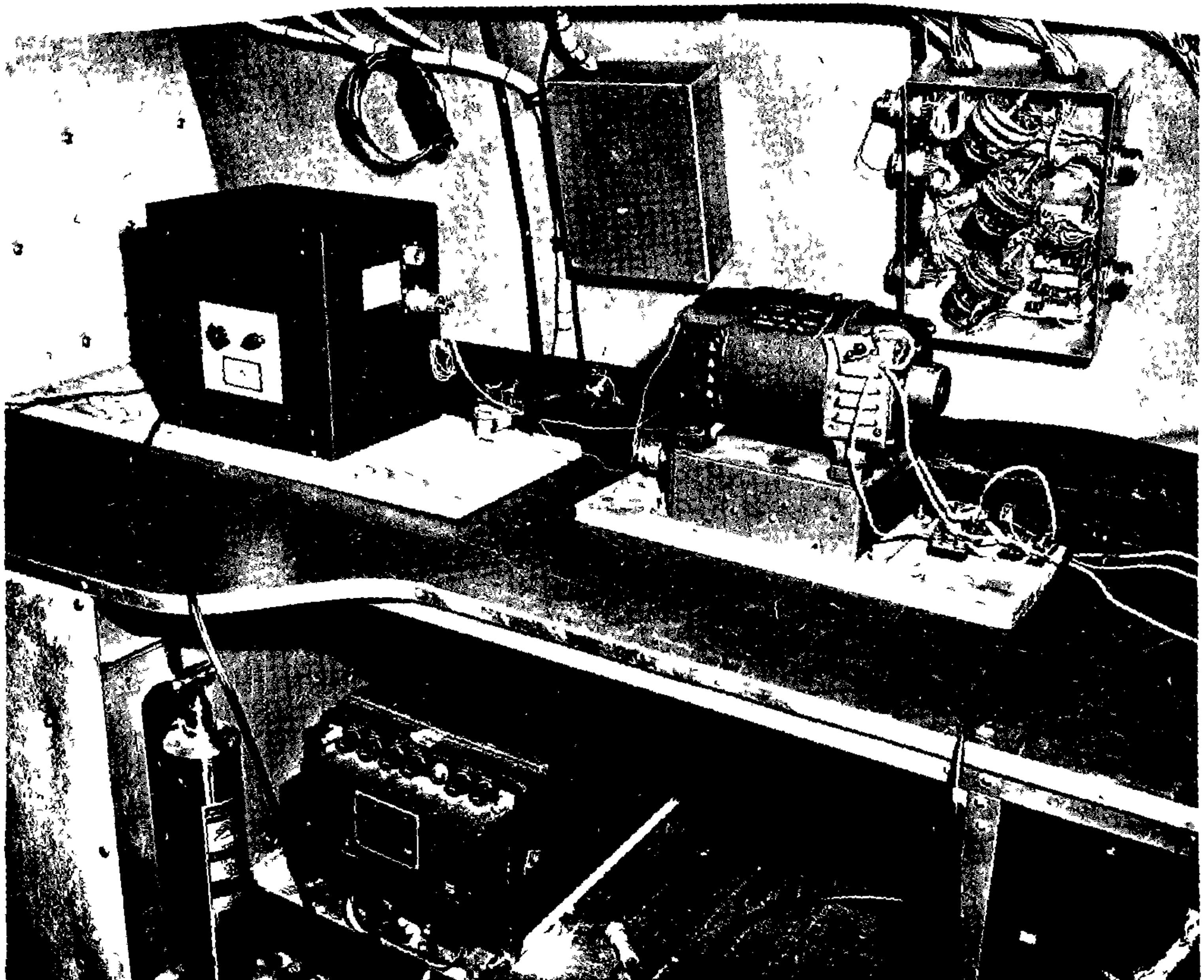

Fig 5 Power Supply and Sequencing Mechanism

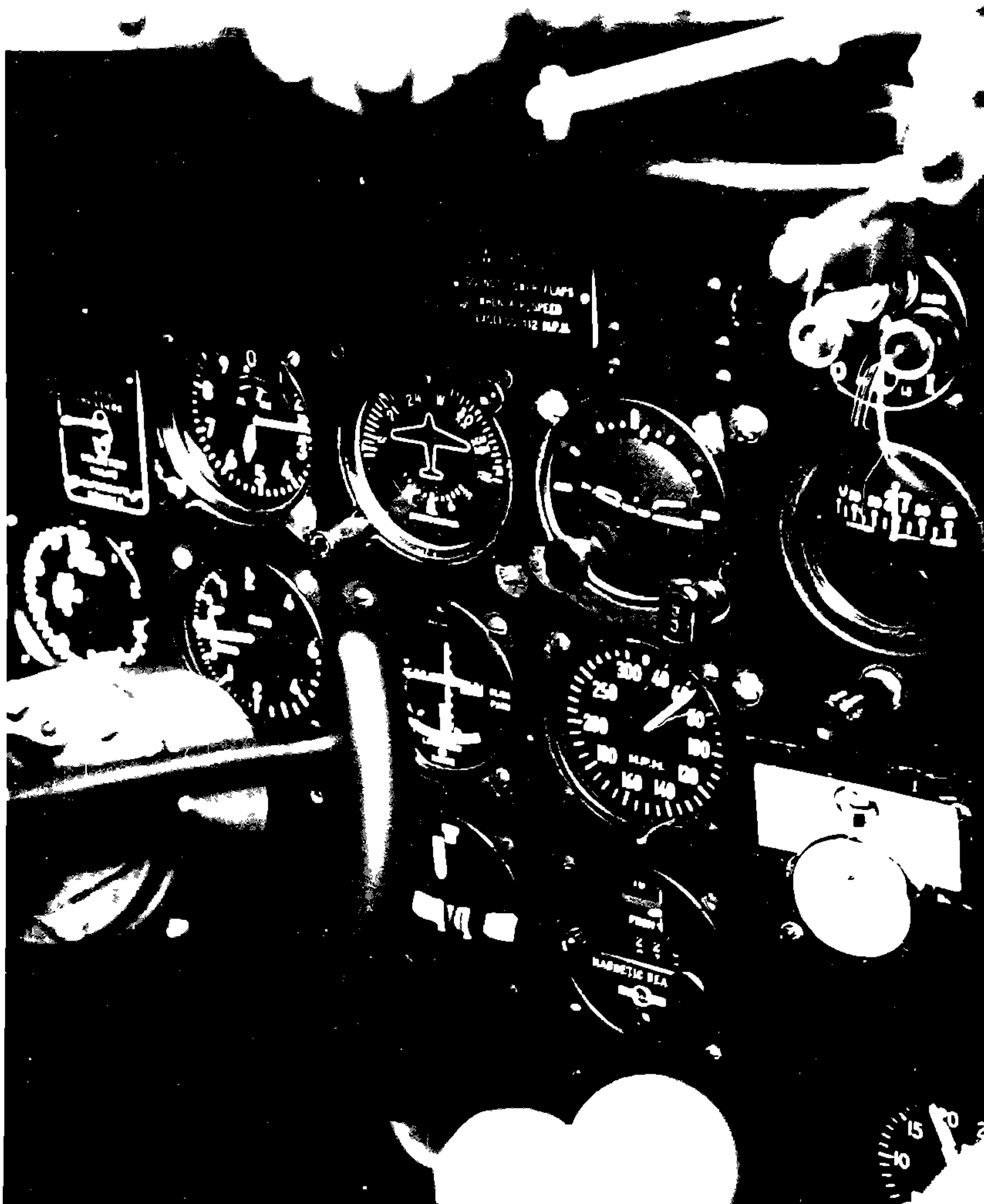

Fig 6 Picture Taken at Point of Stall by Cockpit Camera

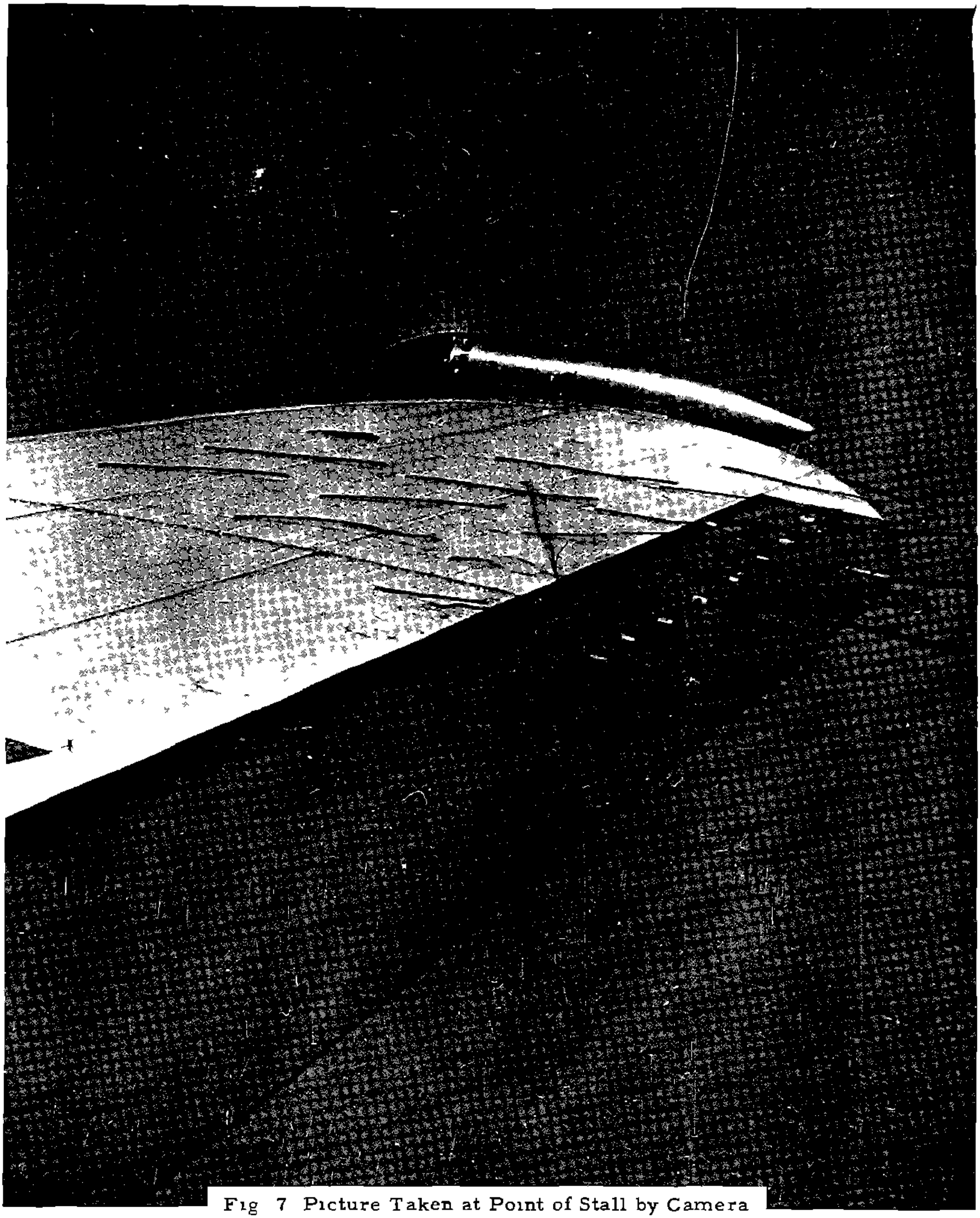

Fig 7 Picture Taken at Point of Stall by Camera Photographing Starboard Wing-Tip Area

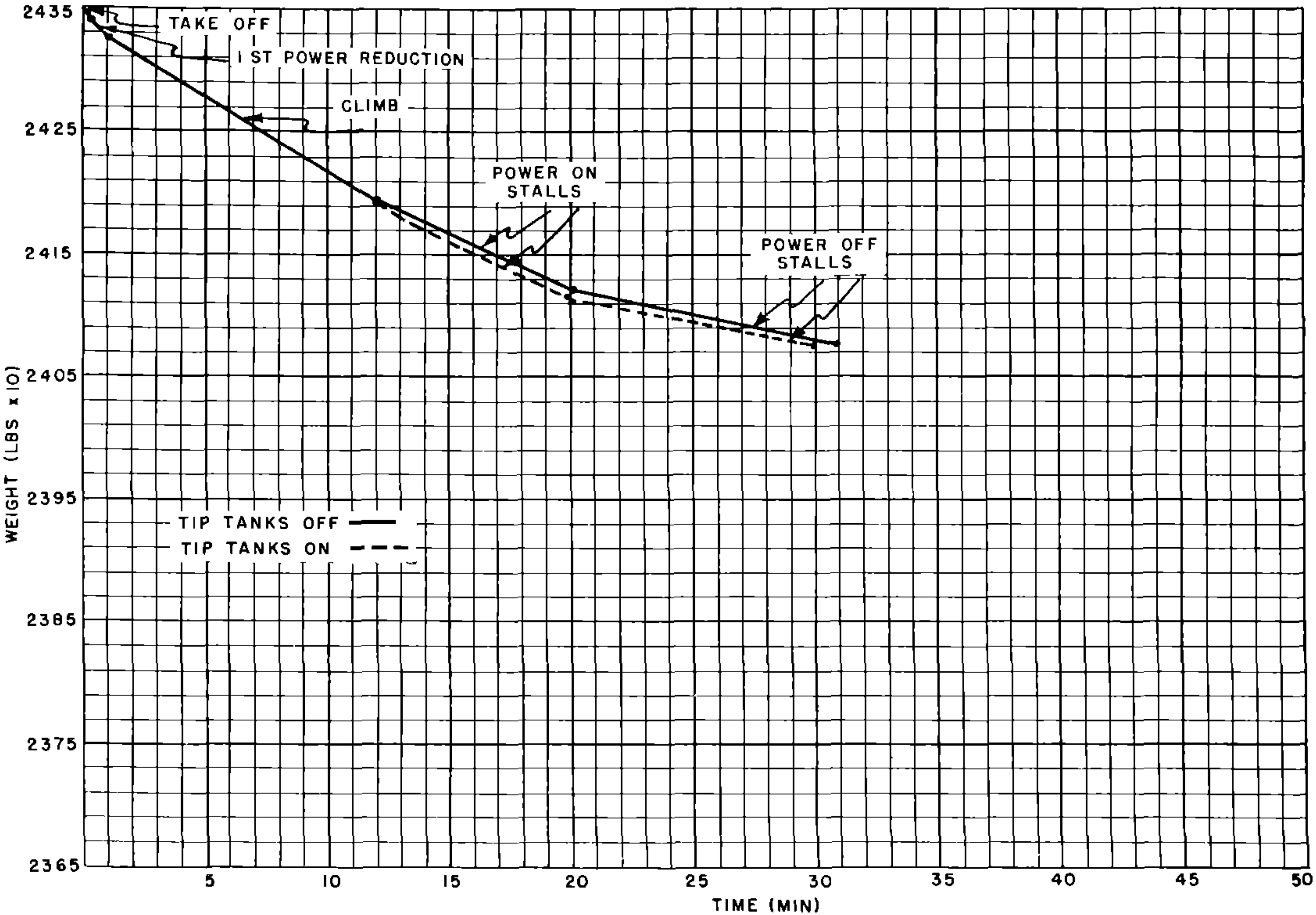

FIG 8 STALL TEST, N-182 (GROSS WEIGHT VARIATION VERSUS FLIGHT TIME)

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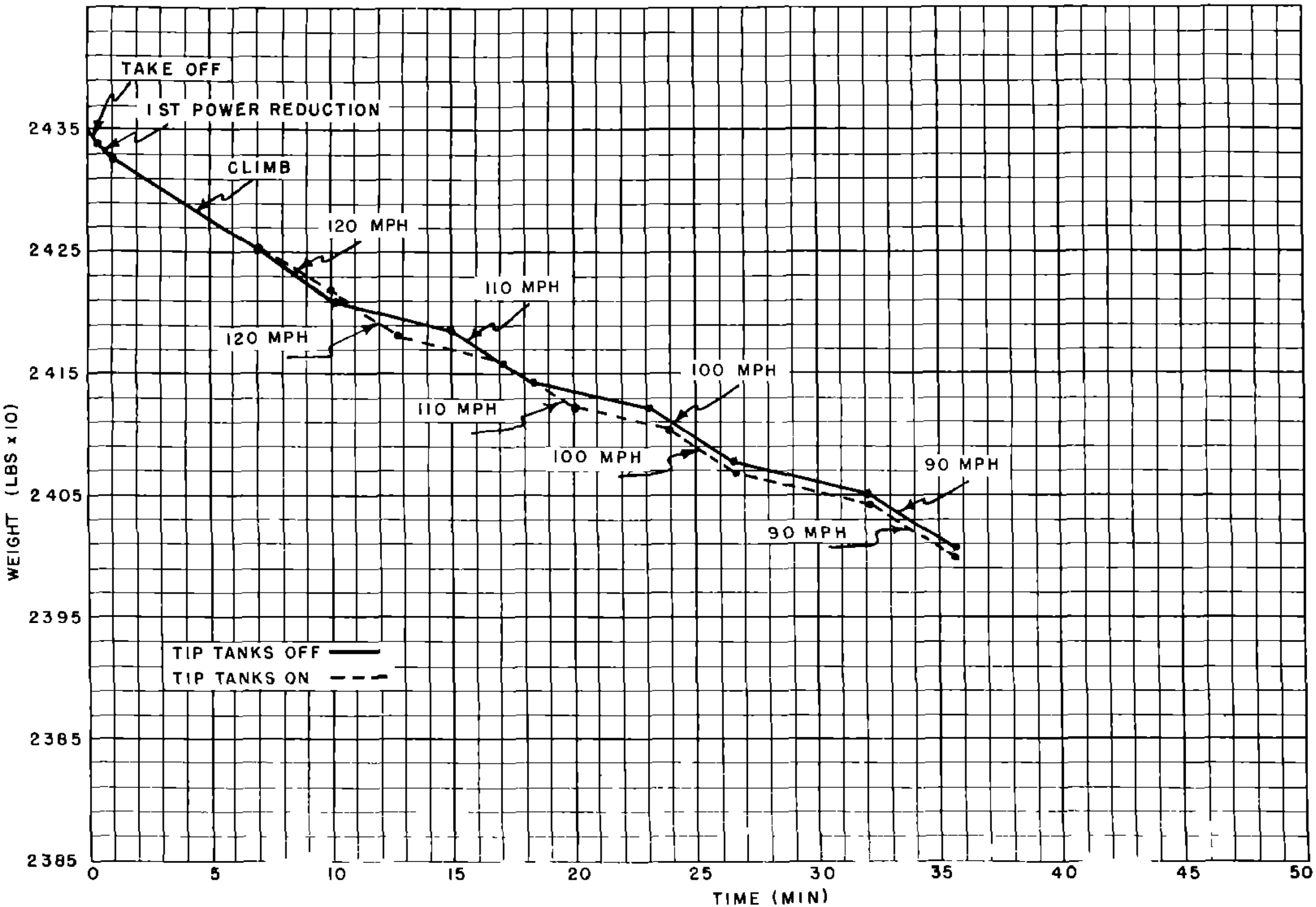

FIG 9 CLIMB TEST, N-182 (GROSS WEIGHT VARIATION VERSUS FLIGHT TIME)

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