Print

NASA TECHNICAL MEMORANDUM

NASA TM X- 71928

COPY NO.

NASA TM X- 71928

PRELIMINARY RESULTS OF FLIGHT TESTS

OF VORTEX ATTENUATING SPLINES

By

Earl C. Hastings, Jr.; Robert E. Shanks; Robert A. Champine;

W. Latham Copeland; and Douglas C. Young

March 1974

(NASA-TM-X-71928) PRELIMINARY RESULTS OF FLIGHT TESTS OF VORTEX ATTENUATING SPLINES (NASA) 41 p HC $5.25 CSCL 01A

N74-20637

Unclas

G3/01 35316

This informal documentation medium is used to provide accelerated or special release of technical information to selected users. The contents may not meet NASA formal editing and publication standards, may be revised, or may be incorporated in another publication.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LANGLEY RESEARCH CENTER, HAMPTON, VIRGINIA 23665

1. Report No. TM X- 71928	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle: Preliminary Results of Flight Tests of Vortex Attenuating Splines		5. Report Date
		6. Performing Organization Code
7. Author(s) Hastings, Earl C., Jr.; Shanks, Robert E.; Champine, Robert A.; Copeland, W. Latham; and Young, Douglas C.		8. Performing Organization Report No.
9. Performing Organization Name and Address: NASA Langley Research Center, Hampton, VA 23665		10. Work Unit No. 501-06-12
		11. Contract or Grant No. N/A
12. Sponsoring Agency Name and Address: National Aeronautics and Space Administration, Washington, DC 20546		13. Type of Report and Period Covered: NASA Technical Memorandum
		14. Sponsoring Agency Code

15. Supplementary Notes

Interim release of material to be combined with additional material and converted to an NASA Technical Note

16. Abstract

Flight tests have been conducted to evaluate the effectiveness of a wingtip vortex attenuating device, referred to herein as a spline. Vortex penetrations were made with a PA-28 behind a C-54 aircraft with and without wingtip splines attached and the resultant rolling acceleration was measured and related to the roll acceleration capability of the PA-28. Tests were conducted over a range of separation distances from about 5 nautical miles (n. mi.) to less than 1 n. mi.

Preliminary results indicate that, with the splines installed, there was a significant reduction in the vortex induced roll acceleration experienced by the PA-28 probe aircraft, and the distance at which the PA-28 roll control became ineffective was reduced from 2.5 n. mi. to 0.6 n. mi., or less. There was a slight increase in approach noise (approximately 4 dB) with the splines installed due primarily to the higher engine power used during approach. Although splines significantly reduced the C-54 rate of climb, the rates available with four engines were acceptable for this test program. Splines did not introduce any noticeable change in the handling qualities of the C-54.

17. Key Words (Suggested by Author(s)) (STAR category underlined): Vortices; Vortex attenuation; Flight tests; Full scale; Noise	18. Distribution Statement: Unclassified; Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	41	$5.25

*Available from: The National Technical Information Service, Springfield, Virginia 22151; STIF/NASA Scientific and Technical Information Facility, P.O. Box 33, College Park, MD 20740

PRELIMINARY RESULTS OF FLIGHT TESTS

OF VORTEX ATTENUATING SPLINES

By Earl C. Hastings, Jr.; Robert E. Shanks; Robert A. Champine; and W. Latham Copeland
Langley Research Center

and Douglas C. Young
Wallops Station

SUMMARY

Flight tests have been conducted to evaluate the effectiveness of a wingtip vortex attenuating device, referred to herein as a spline. Vortex penetrations were made with a PA-28 behind a C-54 aircraft with and without wingtip splines attached and the resultant rolling acceleration was measured and related to the roll acceleration capability of the PA-28. Tests were conducted over a range of separation distances from about 5 nautical miles (n. mi.) to less than 1 n. mi.

Preliminary results indicate that, with the splines installed, there was a significant reduction in the vortex induced roll acceleration experienced by the PA-28 probe aircraft, and the distance at which the PA-28 roll control became ineffective was reduced from 2.5 n. mi. to 0.6 n. mi., or less. There was a slight increase in approach noise (approximately 4 dB) with the splines installed due primarily to the higher engine power used during approach. Although splines significantly reduced the C-54 rate of climb, the rates available with four engines were acceptable for this test program. Splines did not introduce any noticeable change in the handling qualities of the C-54.

INTRODUCTION

The introduction of the wide-bodied jumbo jet into airline service has accentuated the problem of wingtip vortex effect on aircraft in trail. A number of encounters are on record and at least one training accident has been attributed directly to the trailing vortex problem. A number of flight tests have been undertaken which verified the intensity of the problem with the larger aircraft (e.g., ref. 1 and 2).

Small-scale facilities have been utilized to study proposed solutions to the problem and the results to this point have been encouraging. One proposed device for attenuating the vortex is the wing-mounted spline (ref. 3) developed by Mr. James C. Patterson of the Langley Research Center. The device is mounted behind the vortex of the generating aircraft and operates to disrupt the core of the vortex and modify its character. Although ground tests had shown a large reduction in the vortex intensity behind the spline, there were questions concerning scale effects in translating the laboratory test results to flight conditions.

The primary objective of the tests described in this report was to verify these trends in full-scale flight. In addition to spline vortex attenuation tests, this program also included measurements of noise with the splines installed and the effects of spline drag on the performance of the vortex generating aircraft. As will be noted later, the results presented in this report have not yet been fully corrected. However, since a more refined analysis is not expected to significantly change the trends of the data and, since these trends are of significance, these data are presented in preliminary form for the use of those who may have a particular interest.

SYMBOLS

$\bar{c}_w$ wing mean aerodynamic chord, ft

p roll rate, deg/sec; right wing down is positive

$\dot{p}$ roll acceleration, rad/sec^2; increasing rate is positive

r yaw rate, deg/sec; nose right is positive

δ aileron deflection, deg; trailing edge up is positive

ϕ roll angle, deg; right wing down is positive

Abbreviations:

dB decibel, unit of measure of sound pressure level, ref. 0.0002 dyne/cm^2

EPNL effective perceived noise level

OASPL overall sound pressure level

TEST DESCRIPTION

As noted earlier, this report presents preliminary results of the effects of splines on vortex attenuation, noise measurements, and C-54 performance. Test descriptions of each of these are presented in the following subsections.

Vortex Attenuation

Since the primary objective of this project was to evaluate the effect of splines on the characteristics of a baseline vortex, the utilization of a specific generating aircraft was not deemed critical. Consequently, a McDonnell Douglas C-54G (NASA 438), operated by the Wallops Station, was chosen on the basis of immediate availability. This choice made possible an early start of flight tests, thus, expediting the availability of test results.

Figure 1 gives some dimensions of the basic C-54G aircraft and some additional characteristics of NASA 438, after modification, are given in Table I.

For this project, the aircraft was modified as follows:

- Spline attachment pods were mounted at each wingtip.
- A spline jettison system was installed.
- An internal, pressure fed, vortex visualization system (VVS) was installed in the aircraft.
- A photographic panel, consisting of a clock, a vertical speed indicator, an altimeter, and an airspeed indicator was also installed in the aircraft.

Figure 2 is a sketch of the pod/spline assembly used in this project. Data from the Langley 8-foot transonic tunnel indicated that the spline should be located 50-percent $\bar{c}_W$ behind the tip and have a diameter of 55-percent $\bar{c}_W$. When scaled up to the $\bar{c}_W$ of the C-54 aircraft, the pod length aft of the tip was 82 inches and the spline diameter was 90 inches. In addition to the 90-inch-diameter spline, a 72-inch-diameter spline was also fabricated and tested in this program. Although it was preferable to mount the splines inboard of the wingtip, the requirement to reduce the complexity of design modifications in the interest of time dictated a tip location for the spline on the C-54 aircraft.

Figure 3 is a photograph of the C-54 in flight with the pods and splines attached. A closeup photograph of this assembly is shown in figure 4. The splines for these exploratory tests were not retractable and were attached to the pods by explosive bolts which, in an emergency, could be actuated by the pilot's jettison switch.

A sketch of the vortex visualization system (VVS) is shown in figure 5. Diatomaceous earth is loaded into each of three hoppers which are manifolded together and mounted to the seat rails in the passenger compartment of the C-54. Four 2,000-psi nitrogen bottles were used to pressurize the hoppers. The pressure was regulated to 50 to 75 psi and the downstream side of the regulator had a relief valve as a safety feature. A 1-inch discharge tube was routed along the bottom of the right wing and terminated at the end of the pod. Part of the discharge tube can be seen in figure 4.

The vortex probe aircraft used in this project was the standard Piper PA-28 shown in figures 6 and 7. Some pertinent characteristics are given in Table II. Table III lists the data output, in engineering units, from the onboard data instrumentation system. For these tests, the following special apparatus was also installed:

- Onboard Distance Measuring Equipment (DME) to display and record the separation distance between the two aircraft.

- An S-band radar tracking beacon.

- A fixed, 16-mm motion picture camera operated by a pilot controlled switch.

In order to isolate spline effects, it was necessary to maintain constant test conditions to the greatest practical extent. Table IV lists the nominal flight-test conditions and the maximum measured deviations for the tests reported in this report. The effects of these deviations have not been evaluated in this analysis.

On a typical penetration flight, the two aircraft would rendezvous off shore northeast of Wallops Station and the desired airspeeds, heading, altitude, and C-54 configuration would be established. At this point, the PA-28 records, DME, and camera were turned on and the C-54 began to emit a vortex smoke trail from the right wingtip. While the PA-28 orbited, or trailed, the C-54 maintained a constant heading, airspeed, and altitude. When the desired separation distance had been established, the PA-28 would approach the vortex trail along essentially a parallel course. Penetrations were then made at a shallow angle from just above or below the trail.

Two piloting techniques were used once the vortex had been penetrated. To collect data on vortex induced roll acceleration, the PA-28 pilot would attempt to hold the ailerons neutral and the aircraft was allowed to roll until thrown out of the vortex. To collect data on roll control effectiveness, the PA-28 pilot used the ailerons and tried to maintain a wing-level attitude while in the vortex. Typical time histories of both of these test techniques are shown in figures 8 and 9.

The vortex induced roll acceleration data, $\dot{p}$, presented in this report, were determined by taking slopes of the uncorrected roll rate over short time intervals where the recorded values of aileron deflection were small, as illustrated in figure 8. All values of $\dot{p}$ presented in this report were determined at total aileron deflections of less than 10°.

A complete analysis must include the effects of aileron deflection, deviations from the test conditions of Table IV, as well as instrumentation errors. However, to expedite transmittal of these preliminary data, these corrections have not been included in this analysis.

Noise Measurements

The noise measuring station was a self-sufficient, mobile van in which the instrumentation necessary for data acquisition was installed. The noise measuring station was located on the runway centerline extended approximately 3,600 feet from runway threshold and the target altitude at this station was 375 feet. Communications between the operations center (airport control tower) and noise measuring station were accomplished by radio transceivers.

The microphones were the conventional condenser type having a frequency response flat to within ±2 dB over the frequency range of 5 Hz to 20 KHz. The microphones were positioned 5 feet above ground level, the longitudinal axis being parallel to the ground and generally perpendicular to the vertical projection of the flightpath. Microphone wind screens were used at all times. The output of the microphone along with voice and timing signal was recorded on a multichannel FM tape recorder located at the measuring station. The entire sound measurement system was calibrated in the field by means of a conventional discrete-frequency calibrator at the beginning and end of each day of flight tests.

The analog tape recordings obtained during the flight tests were processed through a data reduction and analysis system to compute the overall noise levels, one-third octave band levels, and the effective perceived noise levels.

The flight tests for sound measurements were made for two purposes. The first was to assess the aerodynamic noise of the splines by flying the clean airplane (landing gear and flaps retracted) over the measuring station with the splines off and with the splines on, using the same power settings. For the splines-off case, the flightpath was level but, for the splines-on case, it was necessary to use a 3° glidepath to compensate for the spline drag in lieu of a power increase. These conditions are given in Table V.

The second purpose was to determine the change in landing approach noise resulting from different power settings for the same approach conditions, namely 15° flap angle, 110-knot speed, and 3° glidepath angle. As shown in Table V, the approaches with splines required appreciably more power than those without the splines.

The runs were all made in the same direction, from west to east, and passed over the noise measuring station at approximately 375 feet altitude. The flights were made visually without electronic guidance, but the aircraft was tracked with radar (FPS-16) to determine the actual flightpaths. The position above the van for each run was determined from the radar data and used to correct the overall sound pressure levels to the nominal altitude of 375 feet.

C-54 Performance Evaluation

For this flight program, special C-54 instrumentation was limited to four standard cockpit type instruments (airspeed indicator, altimeter, inertial vertical speed indicator, and chronometer) mounted in an enclosed, self-illuminated housing installed in the C-54 instrument racks. On command, data from these instruments were recorded by a 35-mm camera which photographed the instruments once per second. The special pressure instruments were connected to existing aircraft pilot static system lines.

Other C-54 data were recorded in flight from standard instruments in the cockpit. Data recorded in this manner included

- Indicated airspeed, vertical speed - for backup rate-of-climb data.
- Manifold pressure, engine rpm, carburetor air temperatures - for determination of brake horsepower from engine calibration curves.

A typical C-54 performance test sequence was as follows:

1. If splines were installed, a dive test was conducted through a range of airspeeds up to the limit value defined by the "splines on" structural analysis. The purpose of the test was to verify wing/spline structural integrity and determine if deleterious flutter or vibration existed in the test speed range.

2. Power-off stall tests to onset of buffet for the clean configuration and the takeoff configuration.

3. Four-engine rate-of-climb checks at 10 KIAS increments from 100 KIAS to maximum straight and level airspeed at maximum power in the takeoff configuration.

4. Four-engine and simulated three-engine rate-of-climb checks at 10 KIAS increments from 100 KIAS to maximum straight and level airspeed at maximum except takeoff (METO) power in the clean configuration.

Climb tests were accomplished by attaining a stable rate of climb at a constant airspeed and recording data for a 60-second period during the climb. For a given configuration, the climb test sequence became a set of sawtooth climbs with the airspeed of the recorded ascent increasing at 10 KIAS increments.

Atmospheric data for performance flights were determined from Weather Bureau records. Weight data were derived from basic weight and balance data and fuel measurements taken before and after each flight.

Following each flight, the film records were analyzed to determine stall airspeed and rate of climb. The stall airspeed was taken at the instant when the vertical speed dropped sharply. The calibrated airspeed was taken from cockpit airspeed calibration placards and from reference 4.

In this report, "predicted" and "flight test" rate-of-climb data are given. "Predicted" values were derived by taking measured data for the C-54 without splines, normalizing this to a weight of 55,000 pounds, sea level and standard day, and adding flat-plate spline profile drag to predict the spline effect. The normalization required construction of a drag polar using measured rate-of-climb data and (since engine performance was not measured) engine calibration curves from reference 4. Data labeled "flight tests" are directly from recorded rate-of-climb measurements normalized in the same manner.

TEST RESULTS

The following subsections present the results of the vortex attenuation, noise measurements, and C-54 performance evaluation, respectively.

Vortex Attenuation

In this report, the effects of splines on the C-54 vortex are presented in terms of two parameters. The first is the vortex induced roll acceleration, $\dot{p}$, on the penetrating aircraft with neutral (or nearly neutral) ailerons and the second is the separation distance at which the full control throw of the penetrating aircraft was insufficient to overcome vortex induced roll velocity. The first parameter is important since it is an indication of vortex induced aerodynamic loads (as opposed to aileron induced aerodynamic loads) and the roll control separation distance is important since it relates to the following pilot's ability to recover from a vortex encounter.

Uncorrected values of roll acceleration, $\dot{p}$, for the PA-28 are shown in figure 10 for penetrations of attenuated and unattenuated vortices. The highest value of $\dot{p}$ from flight tests of the PA-28 in undisturbed air and with maximum aileron deflection is also shown. Although there is a large amount of scatter in the test data (probably a result of being unable to repeatedly penetrate the center of the vortex), the data are felt to show valid and significant trends.

Without splines, the vortex effect increased rapidly as separation distance decreased from about 5 n. mi. and, at about 3 n. mi., the vortex induced roll acceleration became larger than that experienced by the PA-28 performing rolls with maximum aileron deflection. With either the 72-inch-diameter of the 90-inch-diameter splines installed on the C-54, the vortex induced roll acceleration was never larger than half of the aileron effect and penetrations were made safely, as close as 0.34 n. mi.

The effect of the 90-inch-diameter spline on the roll control capability of the PA-28 is shown in figures 11 and 12. Figure 11 is the recorded time history of penetrations of the unattenuated, flaps retracted, vortex at 2.19 n. mi. behind the C-54. It can be seen that between about 12 and 13 seconds, with the ailerons fully deflected (40°) to produce a positive roll acceleration, the roll acceleration is actually negative. The same effect can be seen between about 28 and 30 seconds. Here, with the ailerons again fully deflected for a right-hand roll, the roll attitude is, in fact, changing in the opposite direction and the roll acceleration is again negative rather than positive. These results indicate that, at this distance, the vortex overpowered the PA-28 roll control when splines were not installed on the C-54.

Data recorded during penetration of the attenuated (splines on) vortex at 0.84 n. mi. are shown in figure 12. These data show that the PA-28 roll control is positive at this distance using only about 25 percent of the total aileron deflection available. Other recorded data, not presented, show the same effect at separation distances as close as 0.62 n. mi. These results are supported by the test pilot's assessment that without attenuation roll control became ineffective at about 2.5 n. mi., but with attenuation (either by 72- or 90-inch-diameter splines) roll control was positive at separation distances less than 1 n. mi.

Noise Measurements

The noise measurement results obtained during the tests are presented in figures 13 and 14 in the form of typical noise time histories and noise spectra, respectively. In addition, maximum noise values for overall sound pressure levels (measured and corrected to an altitude of 375 ft) and effective perceived noise levels are given in Table VI for all the test runs. These values are summarized in Table VII as averages for the five runs for each condition. The atmospheric conditions prevailing during the flights are given in Table VIII.

In figure 13 are presented typical time histories of sound pressure levels for the C-54 without splines and with the 90-inch-diameter splines as measured at the noise measuring station during the flight tests. Data from the constant power flybys (aircraft with gear and flaps retracted) are given in figure 13(a) and from the landing approaches (aircraft with gear down and 15° flap angle) are given in figure 13(b). These time histories were plotted from data obtained at the 1/2-second sampling rate of the airplane flyover. The zero on the time scale corresponds to the time at which the airplane is directly over the noise measuring station.

In figure 13(a), it can be seen that the noise levels for the flyby operations reach a maximum approximately 3 seconds before the airplane is directly over the noise measuring station for both conditions (with and without vortex spoilers). Similar results are shown in figure 13(b) for the landing approach configuration operations with maximum noise levels occurring approximately 5 seconds before the airplane is directly over the noise measuring station.

In figure 14 are presented typical noise spectra taken at the time of occurrence of the maximum overall sound pressure level in the noise time histories of figure 13. Plotted in figure 14 are the one-third octave band levels as a function of frequency as measured at the microphone location during flyby and approach operations of the airplane with and without the splines.

The data of Table VII for the constant power flybys show that the corrected overall sound pressure levels are virtually the same for the airplane with and without splines; hence, there is no detectable aerodynamic noise attributable to the splines for the conditions of these tests. Comparison of the results for the landing approaches given in this same table, however, show that the splines resulted in appreciably higher noise, approximately 4 dB for the corrected overall sound pressure level. This difference is, of course, attributed to the higher engine power conditions required to overcome the drag of the splines. (See Table V.)

C-54 Performance Evaluation

Results of this evaluation are given in terms of the effects of splines on

1. Power-off stall speed - takeoff and clean configurations

2. Rate of climb - takeoff configuration using maximum power

3. Rate of climb - clean configuration using "maximum except takeoff" (METO) power

Power-off stall speeds.- The results of the measured power-off stall speeds and values predicted from reference 4 are listed in Table IX. Stall speeds for the clean (no flaps) and the takeoff configuration (15° flaps) are normal. The splines do not appear to alter the C-54 stall airspeeds. Minor differences between measured values and reference 4 can be attributed to errors in chart interpolation, instrument indications, and pilot technique.

Rate of climb - takeoff configuration and maximum power.- Predicted and flight-test data are shown in figure 15 for the C-54 with and without splines for the takeoff configuration (gear down, flaps 15°) and four engines at maximum power. For consistency, all test data are normalized to a 55,000-pound weight and a sea level, standard day. The data show excellent agreement between predicted and test data. The rate of climb with the 90-inch-diameter splines is 740 feet/minute at 110 knots and 470 feet/minute at 120 knots. Values for the 72-inch-diameter splines are 130 feet/minute higher at both of these airspeeds. For these tests, the minimum acceptable rate of climb was considered to be 200 feet/minute. Using this criteria, acceptable rates of climb with the 90-inch-diameter splines are available up to an airspeed of about 130 knots in the takeoff configuration with four engines operating.

Although three-engine tests were not performed with the takeoff configuration, predictions of rate of climb were made. The four-engine test data from figure 15 were adjusted for a 25-percent reduction in available power and the addition of windmilling propeller drag from reference 4. The calculations indicated that, with either size spline installed, the rate of climb was unacceptable for this condition. It should be noted, however, that due to the spline jettison feature, this situation was hazardous only if an engine failure and a spline jettison failure occurred simultaneously (with gear and flaps down).

Rate of climb - clean aircraft with METO power.- Figure 16 presents predicted and test data for the clean (flaps up, gear up) configuration with four engines with and without splines. At 110 knots, the test data are essentially 1,000 feet/minute with both the 72-inch- and 90-inch-diameter splines. At 130 knots, test data are 700 feet/minute and 500 feet/minute for the 72-inch and 90-inch splines, respectively.

Comparison of predicted and test data for this configuration, unlike the preceding flaps 15° case (where agreement was good), shows that the spline effect is overpredicted at the lower airspeeds. Although limited test instrumentation in the C-54 precluded a rigorous analysis of this effect, it may result from uncertainties in power available, or reduced C-54 drag due to lift with splines installed.

Data for the clean configuration with and without splines are shown in figure 17 for three-engine performance. Test data were based on flight tests with a simulated engine-out/feathered propeller situation. The figure shows that, although all predicted values were unacceptable, the flight-test results indicated acceptable values for both size splines up to 120 KIAS. It is apparent here, as in the four-engine case, that the rate of climb from test results was better than predicted by adding spline drag to the basic C-54 flight-test data.

All of the performance test results with splines on show essentially the same result; splines significantly reduce the available rate of climb. However, for all cases except the three-engine takeoff, an acceptable rate of climb was possible with the splines at the C-54 test weight used in this program. According to the C-54 pilots, there were no noticeable changes in handling qualities due to the installation of the splines, regardless of size or C-54 configuration. No spline-induced flutter or vibration was noted on any flight.

CONCLUDING REMARKS

A preliminary analysis of flight-test data using a C-54, with and without splines, and a PA-28 probe aircraft indicates the following results:

1. Splines significantly reduce the vortex induced roll of the trailing aircraft at all separation distances between about 4.0 n. mi. and 0.34 n. mi.

2. Splines reduced the separation distance for positive PA-28 roll control from about 2.5 n. mi. to 0.6 n. mi., or less.

3. There was no detectable aerodynamic noise produced by the splines at an airspeed of 115 KIAS; the increase in overall sound pressure level from increased power settings for the landing approach with splines was approximately 4 dB; and the maximum noise occurred 3 to 5 seconds before the C-54 was directly over the measuring station.

4. Although splines significantly reduced the C-54 rate of climb, the four-engine climb performance was acceptable for this test program.

5. There were no noticeable changes in the handling qualities of the C-54 due to splines.

REFERENCES

1. Andrews, William H.; Robinson, Glenn H.; and Larson, Richard R.: Exploratory Flight Investigation of Aircraft Response to the Wing Vortex Wake Generated by Jet Transport Aircraft. NASA TN D-6655, 1972.

2. Verstynen, Harry A., Jr.; and Dunham, R. Earl, Jr.: A Flight Investigation of the Trailing Vortices Generated by a Jumbo Jet Transport. NASA TN D-7172, 1973.

3. Patterson, J. C., Jr.: Lift-Induced Wing-Tip Vortex Attenuation. Presented at the AIAA 12th Aerospace Sciences Meeting, Washington, D. C., AIAA Paper No. 74-38, January 30-February 1, 1974.

4. Flight Manual: USAF Series C-54, EC-54, HC-54, and TC-54. USAF Tech. Order 1C-54D-1.

TABLE I

CHARACTERISTICS OF THE MC DONNELL DOUGLAS

C-54G TEST AIRCRAFT (NASA 438)

Empty operational weight, lb	49,150
Wing area, ft^2	1,462.0
Wing mean aerodynamic chord, ft	13.61
Wing aspect ratio	9.44
Wing incidence (root), deg	+4
Wing incidence (tip), deg	+1
Horizontal tail area, ft^2	324.9
Vertical tail area, ft^2	179.3
Engine data	
Type	Pratt and Whitney R-2000 D-5
Takeoff power	1,450 BHP/engine
Maximum except takeoff (METO) power	1,200 BHP/engine
Propeller data	
Type	Hamilton Standard constant speed
Gear ratio	2:1
Activity factor	100
Diameter, ft	13.0

TABLE II

CHARACTERISTICS OF THE PIPER PA-28 TEST AIRCRAFT

Weights	
Empty operational weight, lb	1,761
Gross takeoff weight, lb	2,225
Roll moment of inertia (approx.)	
At empty weight, slug-ft^2	800
At gross takeoff weight, slug-ft^2	1,200
Aileron area (total), ft^2	10.62
Maximum aileron deflection (total), deg (approx.)	40
Engine data	
Type	Lycoming O-360-A3A
Rated horsepower	180
Propeller data	
Type	Sensenich M76EMMS
Diameter, ft	6.3

TABLE III

PA-28 INSTRUMENTATION

Roll rate	deg/sec
Yaw rate	deg/sec
Pitch rate	deg/sec
Lateral acceleration	g
Normal acceleration	g
Longitudinal acceleration	g
Roll attitude	deg
Pitch attitude	deg
Angle of attack	deg
Angle of sideslip	deg
Aileron position (left)	deg
Aileron position (right)	deg
Rudder position	deg
Stabilator position	deg
Flap position	deg
Throttle position	percent
Heading	deg
Airspeed (indicated)	knots
Altitude	ft

TABLE IV

TEST CONDITIONS FOR VORTEX PENETRATIONS

Parameter	Nominal condition	Measured deviation
C-54 weight	55,000 lb	-500; +1,000 lb
C-54 airspeed	115 KIAS	±3 KIAS
PA-28 weight	2,093 lb	±132 lb
PA-28 penetration airspeed	90 KIAS	±5 KIAS
Test altitude	7,000 ft, or higher if required to be 2,000 ft above temperature inversion altitude	- -

TABLE V

C-54 OPERATING CONDITIONS FOR NOISE MEASUREMENT TESTS

Flight conditions			Engine conditions		
	Splines	Glidepath, deg	Manifold pressure, in. Hg	Rpm	Brake horsepower per engine
Flyby: Gear and flaps retracted, 115 knots	Off	0	26	2,115	590
	On	3	26	2,115	590
Landing approach: Gear down, 110 knots	Off	3	22	2,300	475
	On	3	30	2,550	805

TABLE VI

MAXIMUM NOISE VALUES DURING FLYBY AND APPROACH OPERATIONS

WITH AND WITHOUT 90-INCH-DIAMETER SPLINES

(a) Flyby: Gear and flaps retracted, 115 knots

Run No.	Without splines			With splines		
	OASPL, dB		EPNL, dB	OASPL, dB		EPNL, dB
	Measured	Corrected*		Measured	Corrected*	
1	103	104	84	107	104	86
2	103	104	85	104	102	85
3	102	104	84	103	102	86
4	101	100	83	103	102	84
5	104	105	84	105	105	88

(b) Landing approach: Gear down, flaps 15°, 110 knots

Run No.	Without splines			With splines		
	OASPL, dB		EPNL, dB	OASPL, dB		EPNL, dB
	Measured	Corrected*		Measured	Corrected*	
1	102	102	83	106	105	90
2	103	101	86	107	107	91
3	100	101	83	104	105	87
4	103	102	84	106	106	88
5	99	100	82	106	105	90

*Corrected for slant range.

TABLE VII

SUMMARY OF SOUND MEASUREMENT RESULTS

Flight condition	Sound (average of five runs)					
	OASPL, dB*			EPNL, dB		
	Splines		Difference	Splines		Difference
	Off	On		Off	On	
Flyby: Gear and flaps retracted, 115 knots	103.4	103.0	0.4	83.9	85.8	1.9
Landing approach: Gear down, flaps 15°, 110 knots	101.2	105.6	4.4	83.8	89.3	5.5

*Corrected for slant range.

TABLE VIII

SURFACE AND UPPER AIR ATMOSPHERIC CONDITIONS FOR TEST PERIODS

Date	Upper air data									Surface winds		
	Altitude		Atmospheric pressure		Temperature		Relative humidity, percent	Wind velocity, knots	Wind direction*, deg	Time of day	Velocity, knots	Direction*, deg
	m	ft	n/m^2	lb/ft^2	°K	°F						
12-6-73	4	13	101,410	2,118	285	53	83	10	270	0800	9	320
0722 EST	121	397	100,000	2,089	285	53	80					330
	273	895	98,200	2,051	285	53	76	20	304	0900	9	330
	797	2,614	92,200	1,926	280	45	100	16	297			
12-7-73	4	13	102,800	2,147	276	38	66	10	340	0800	4	345
0740 EST	228	748	100,000	2,089	276	37	45	25	355			
	607	1,991	95,400	1,992	273	32	50	28	346	0900	9	350

*Direction from which wind is blowing.

TABLE IX

C-54 STALL SPEEDS (POWER OFF)

WITH AND WITHOUT SPLINES

	TAKEOFF CONFIGURATION			CLEAN CONFIGURATION		
	WT (LB)	MEASURED V_s (KIAS)	PREDICTED V_s (KIAS)	WT (LB)	MEASURED V_s (KIAS)	PREDICTED V_s (KIAS)
NO SPLINES	54,600	79	77	53,600	92	88
72-INCH SPLINES	54,450	79	77 (no splines)	54,550	91	89 (no splines)
90-INCH SPLINES	55,600	80	78 (no splines)	55,500	94	90 (no splines)

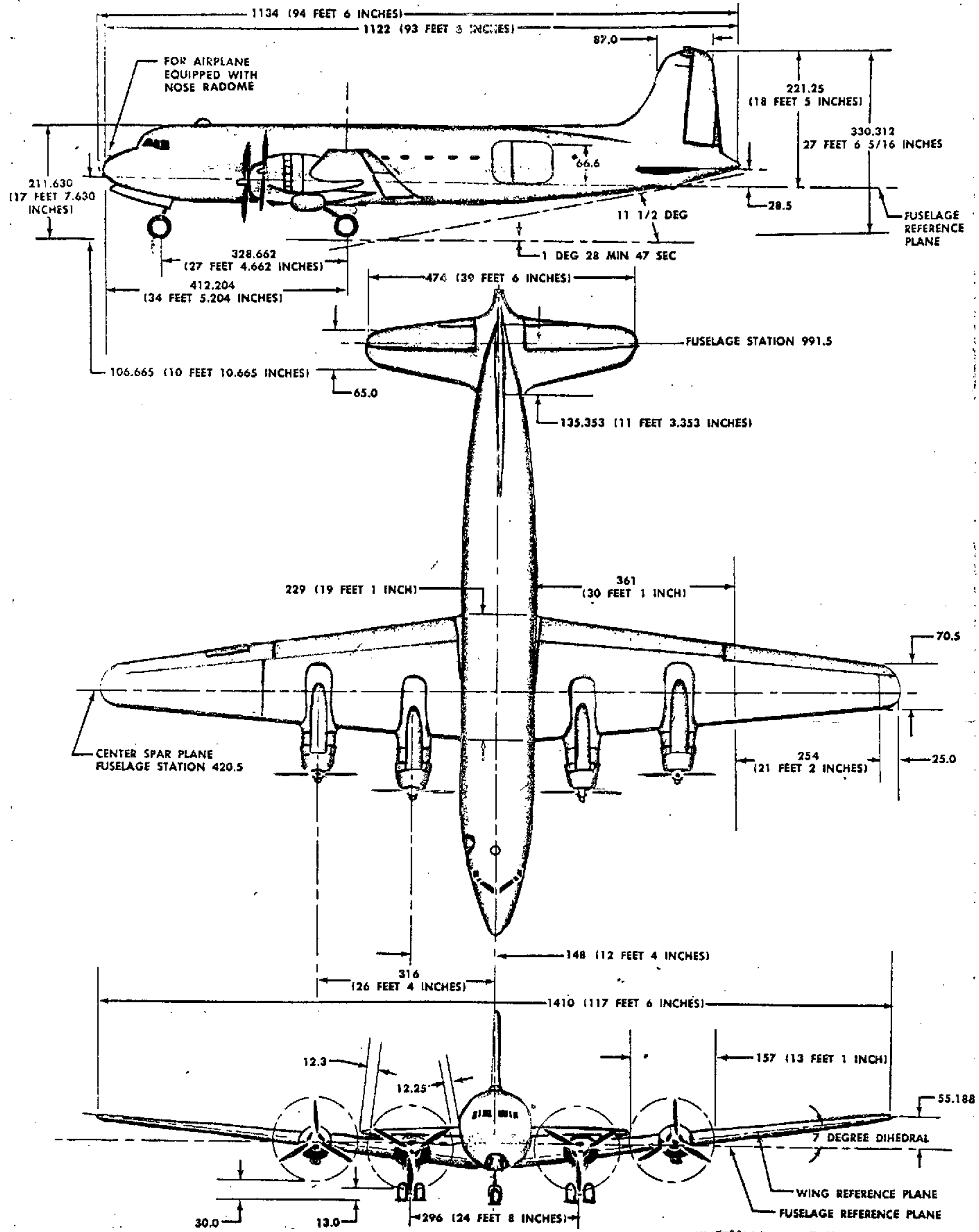


Figure 1. - Diagram of the unmodified C-54 aircraft.

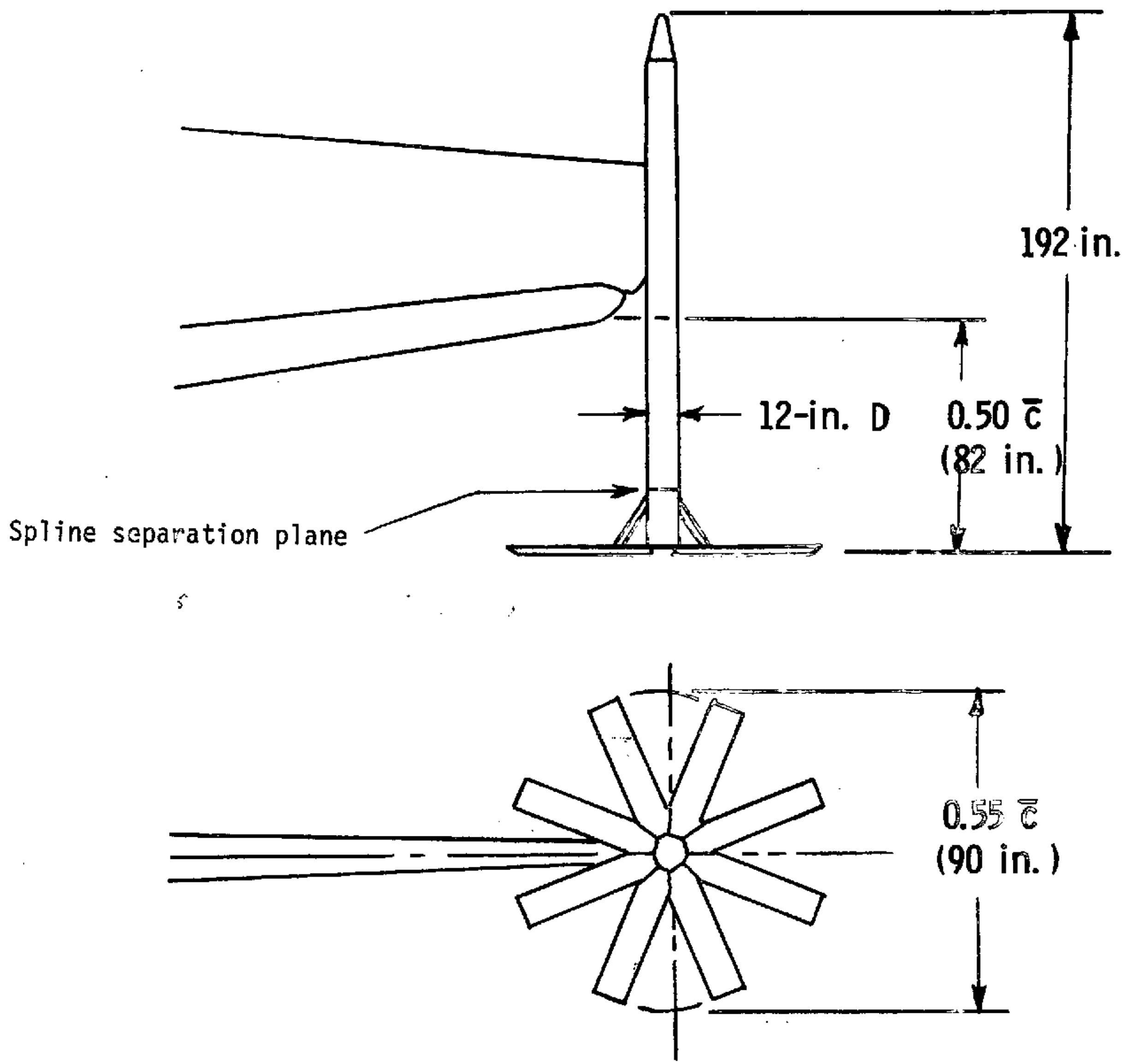


Figure 2. - Diagram of pod/spline arrangement.

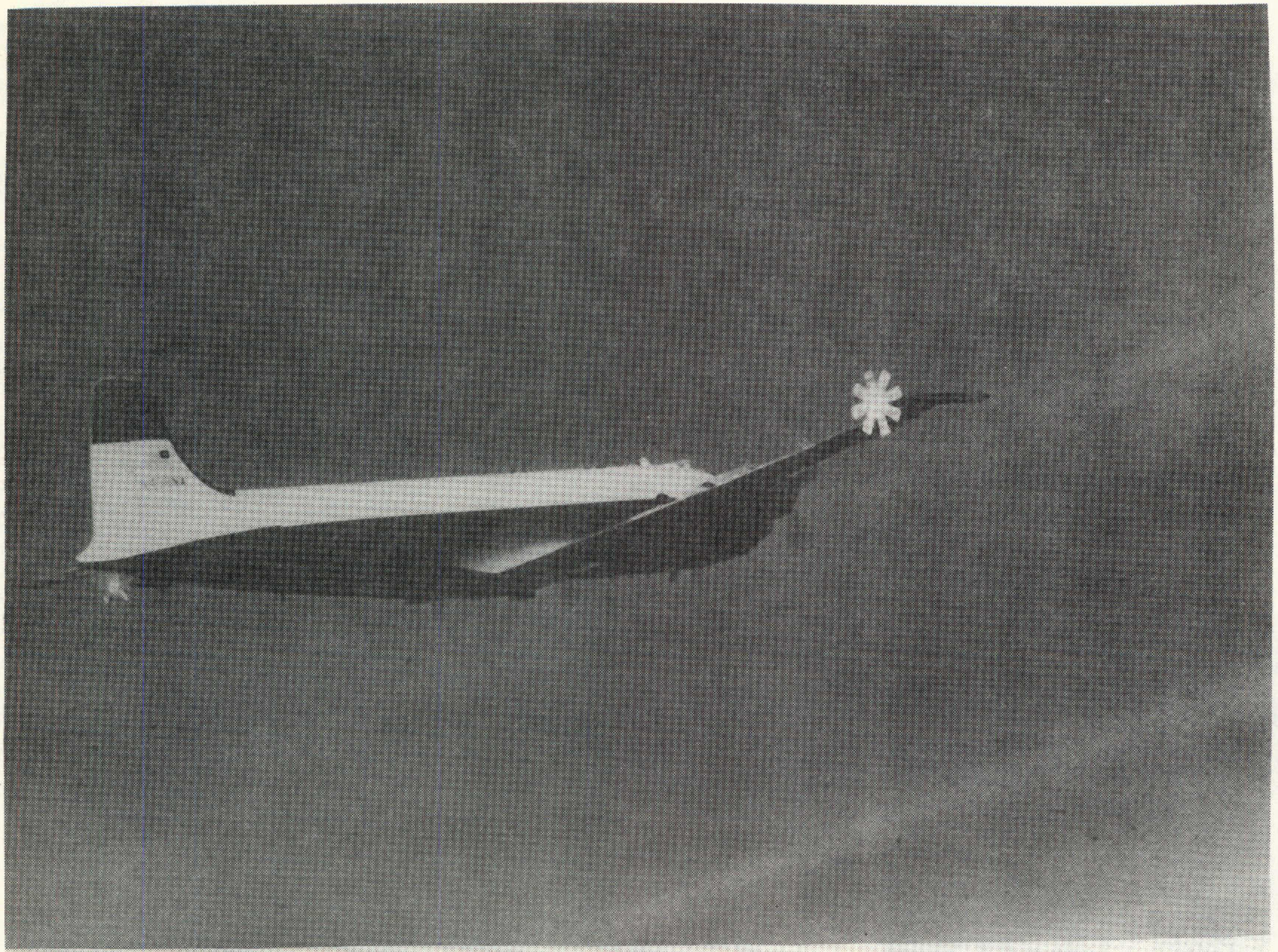


Figure 3. - C-54 aircraft with splines installed.

24

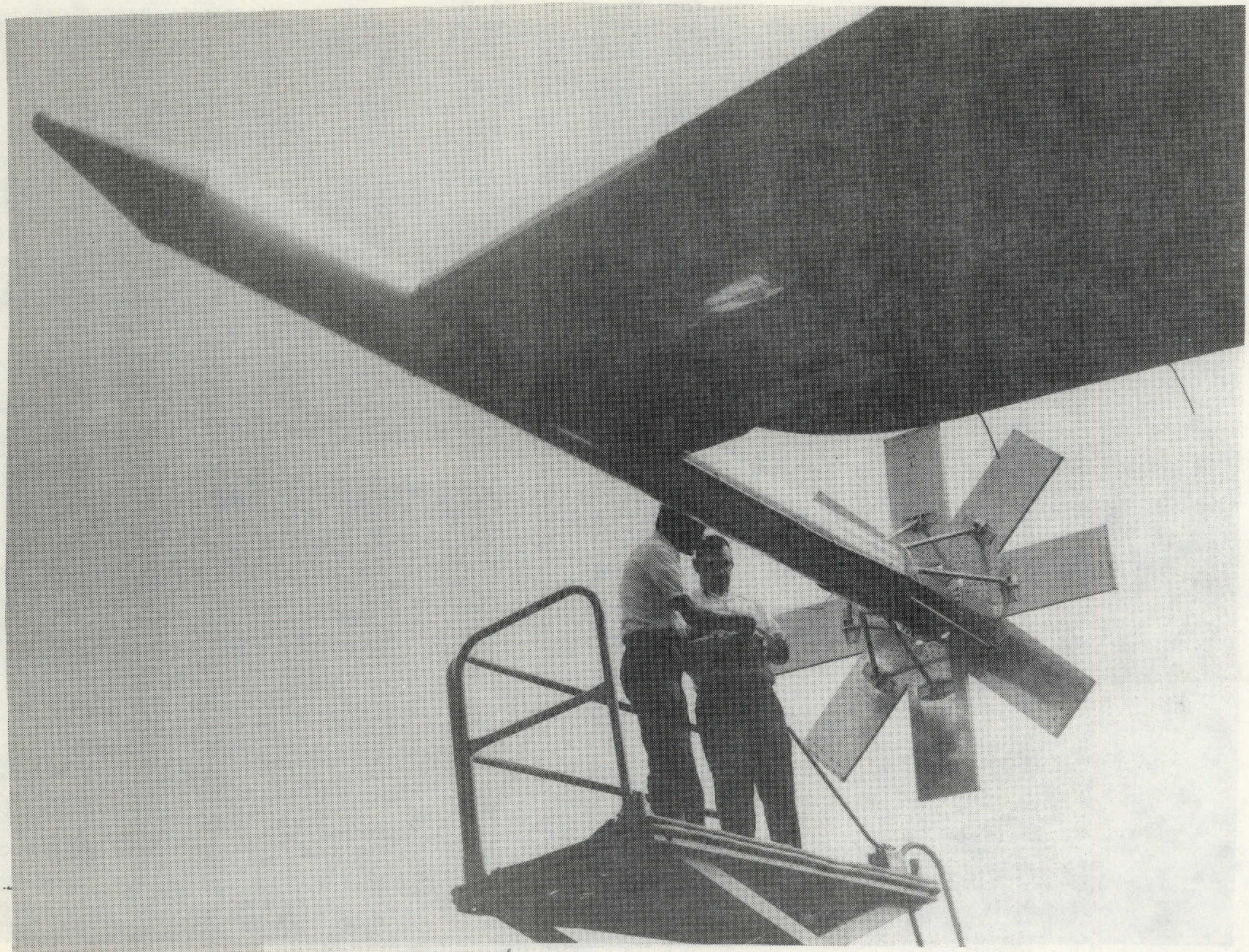


Figure 4. - Pod/spline assembly on C-54 wingtip.

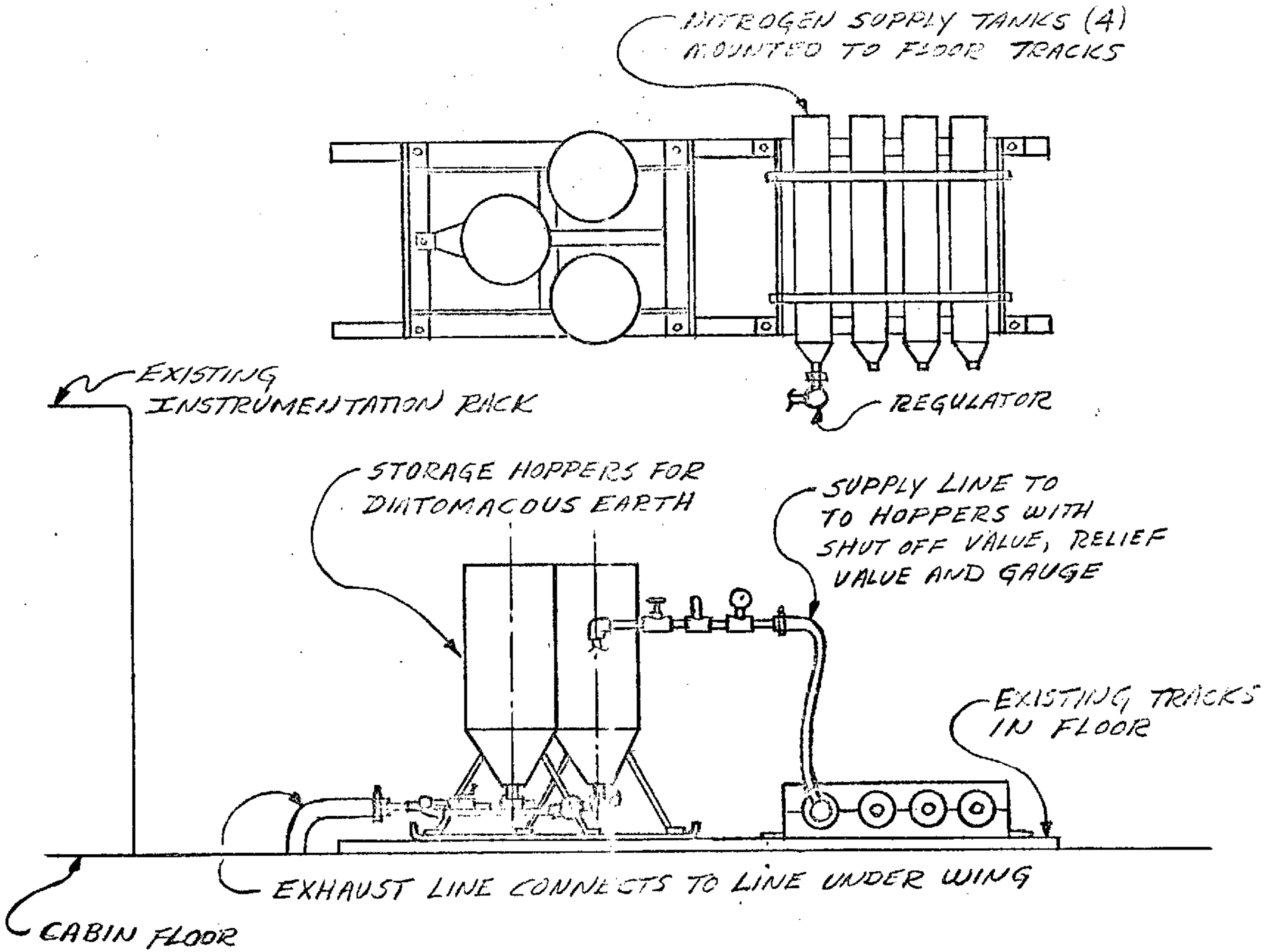


Figure 5. - Diagram of vortex visualization system.

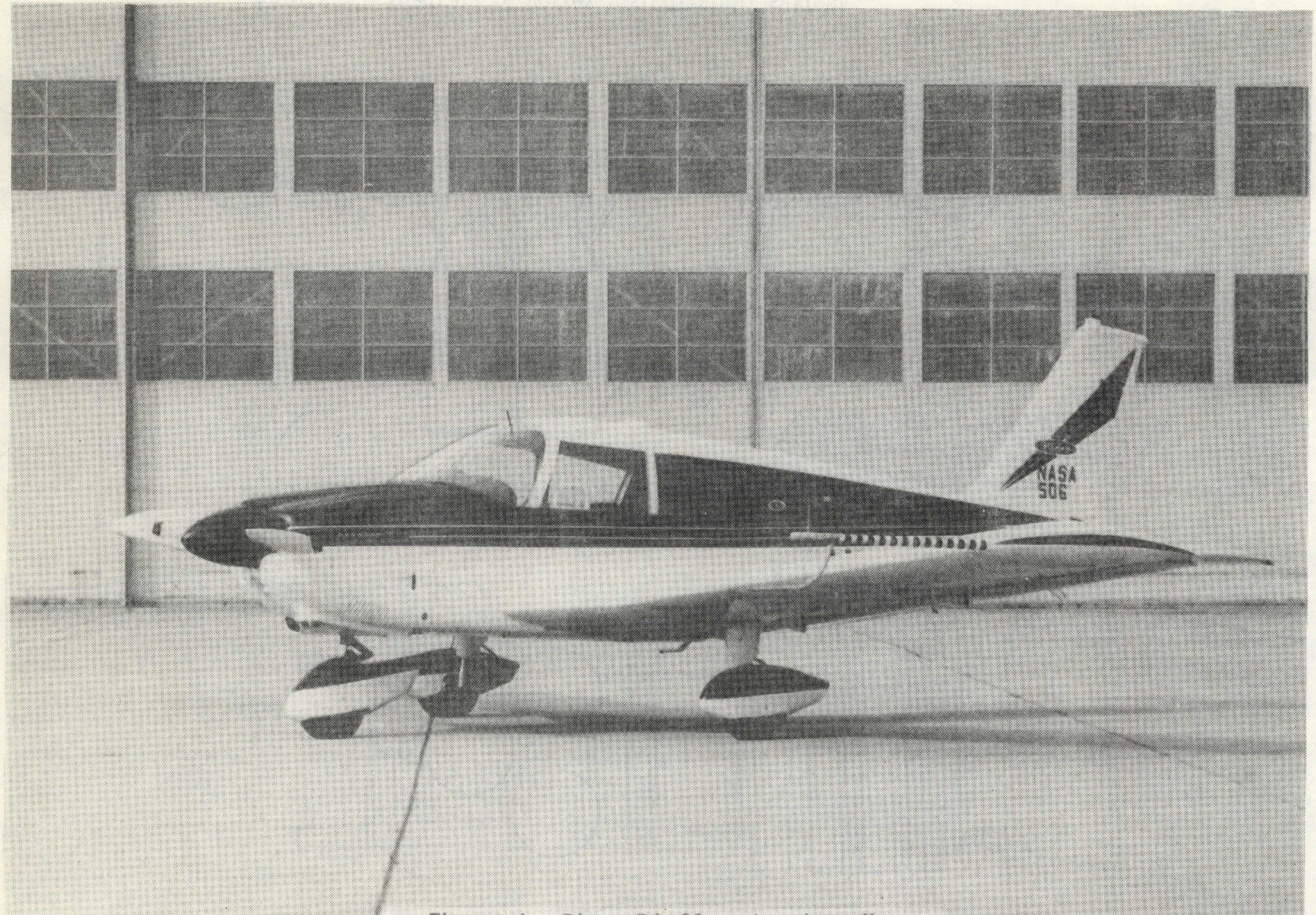


Figure 6. - Piper PA-28 probe aircraft.

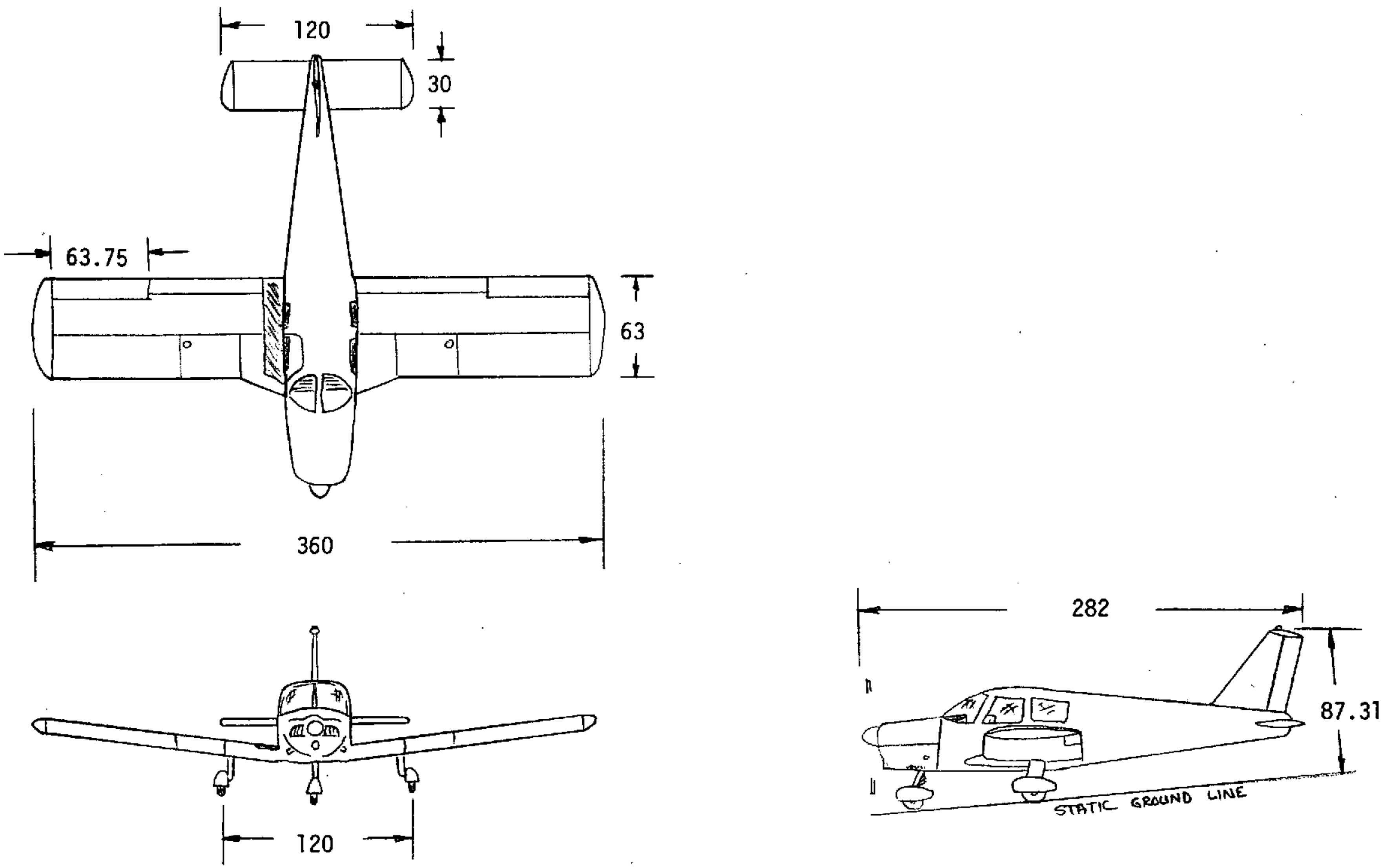


Figure 7.- Drawing of the Piper PA-28 test probe aircraft. (All dimensions are in inches.)

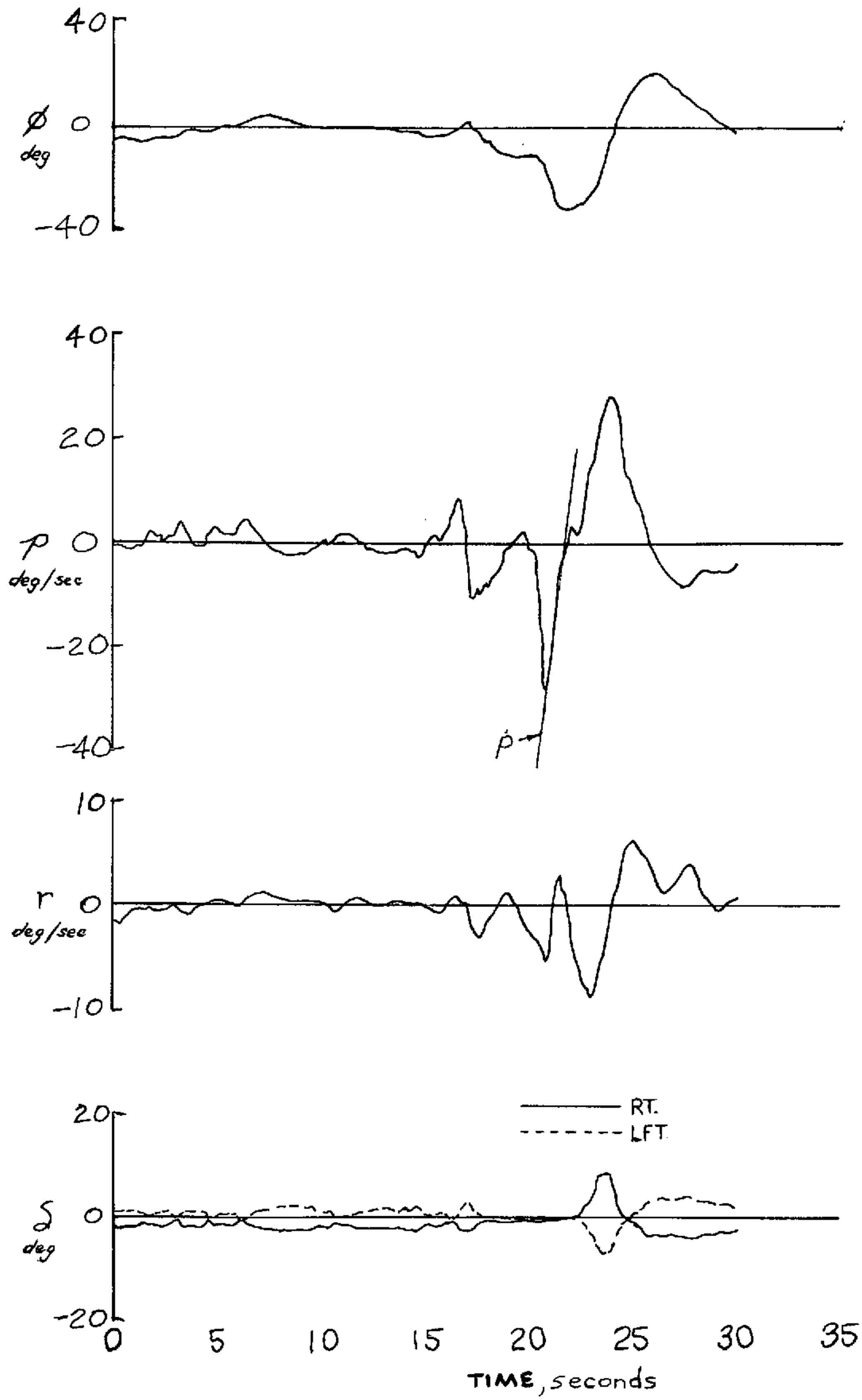


Figure 8. - Typical time history of penetrations with ailerons neutral.

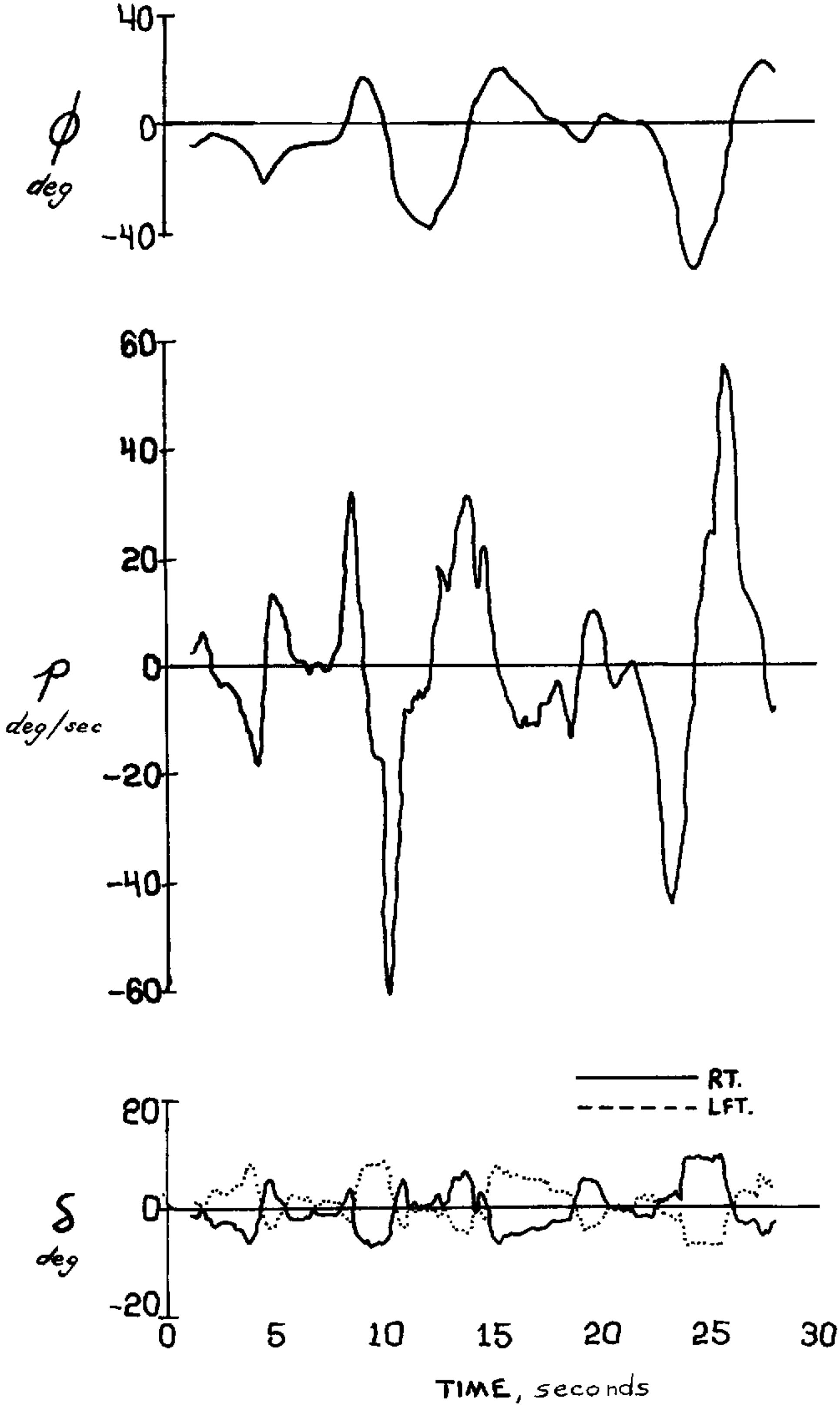


Figure 9. - Typical time history of penetrations with ailerons active.

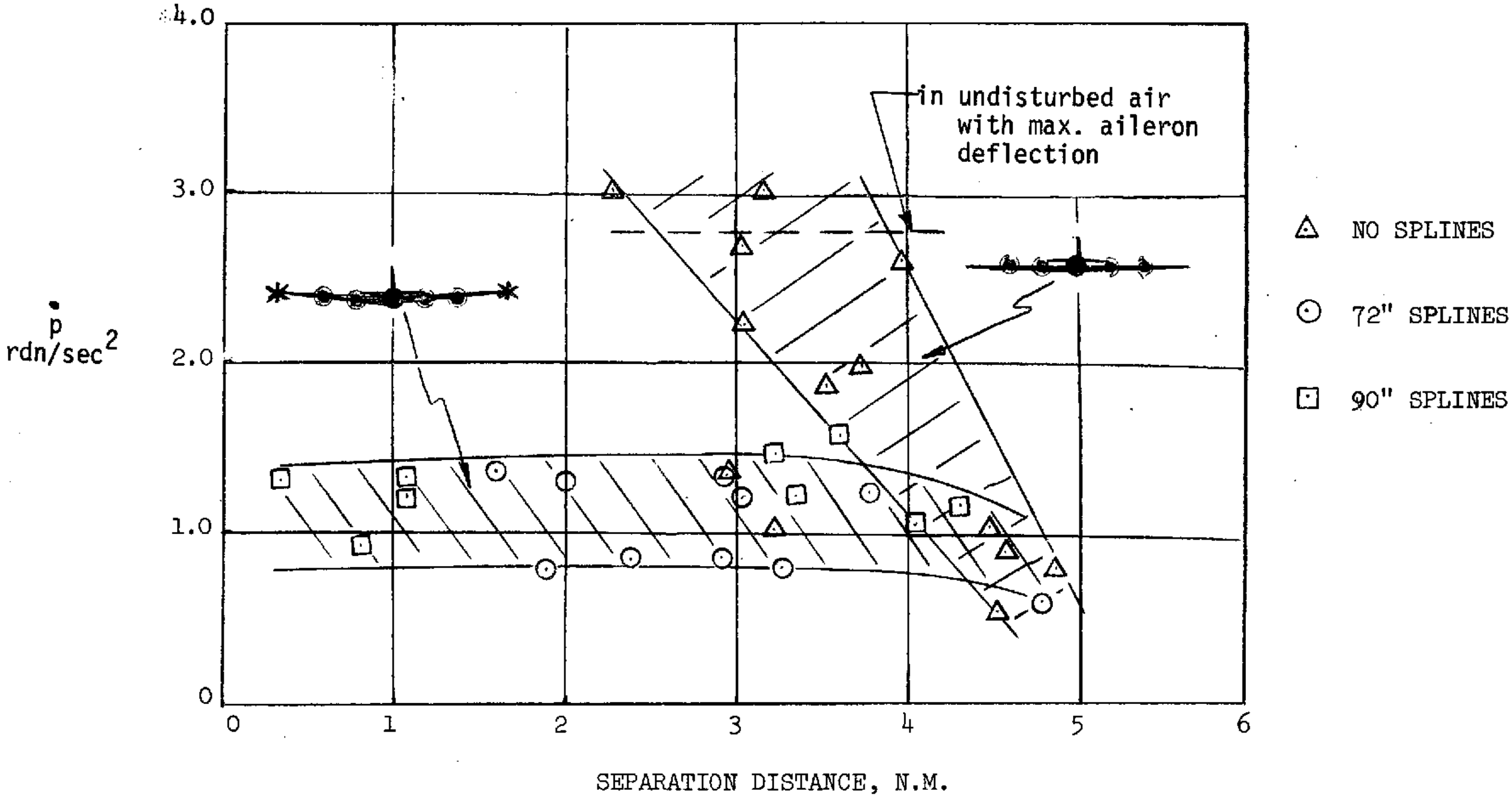


Figure 10.- Comparison of measured roll acceleration with and without splines.

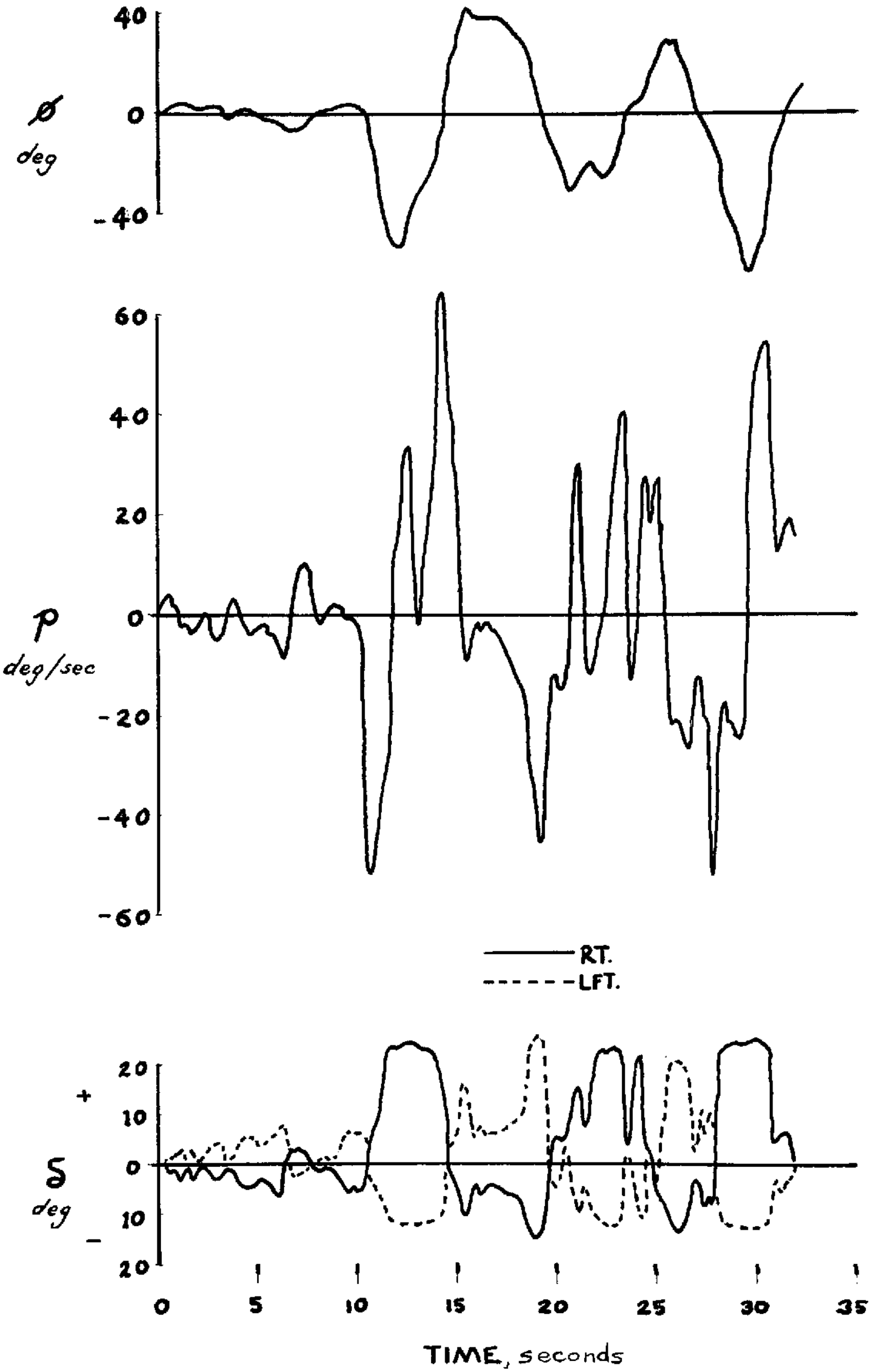


Figure 11. - Time history of penetration without splines at 2.19 n.m.

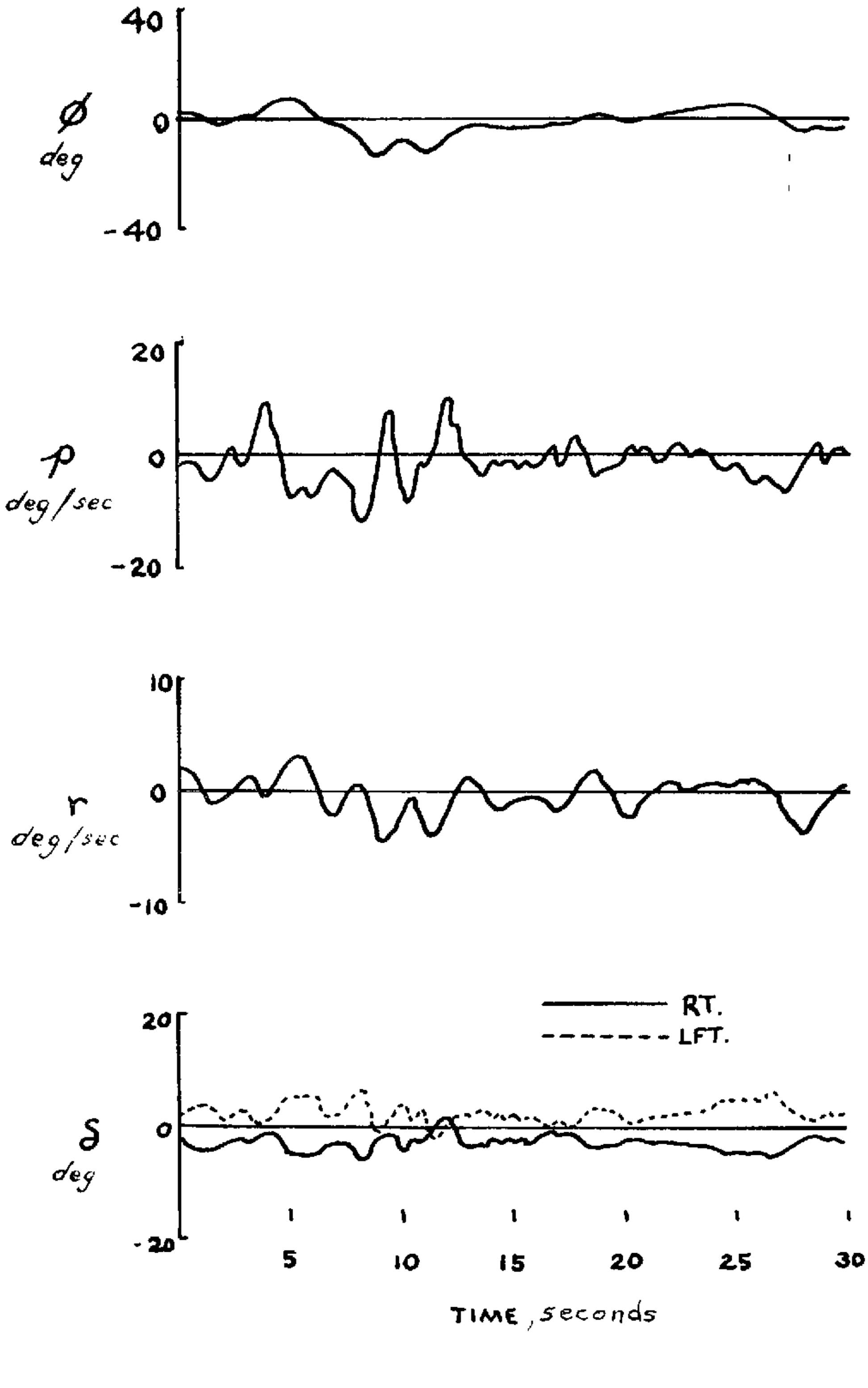
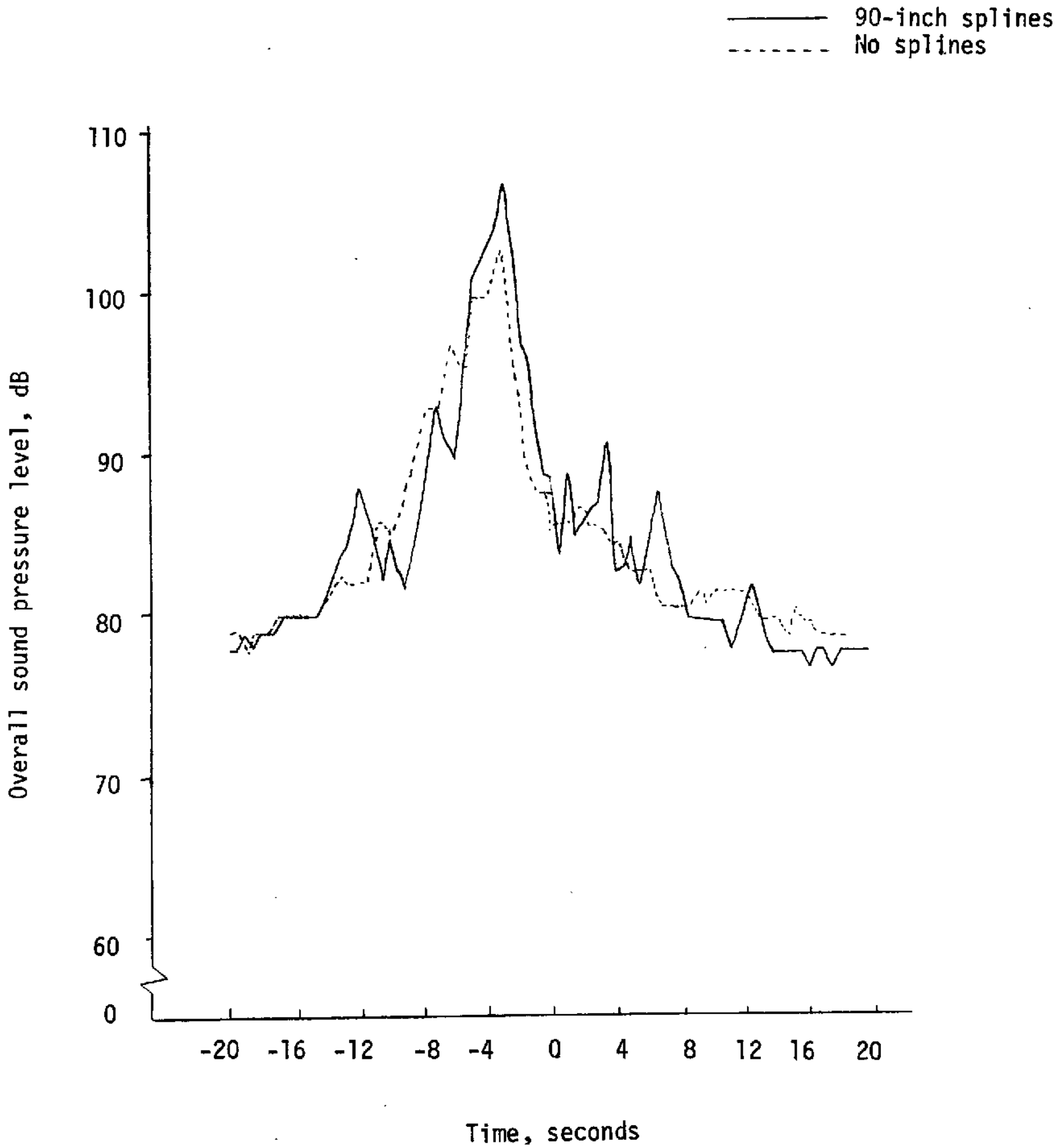
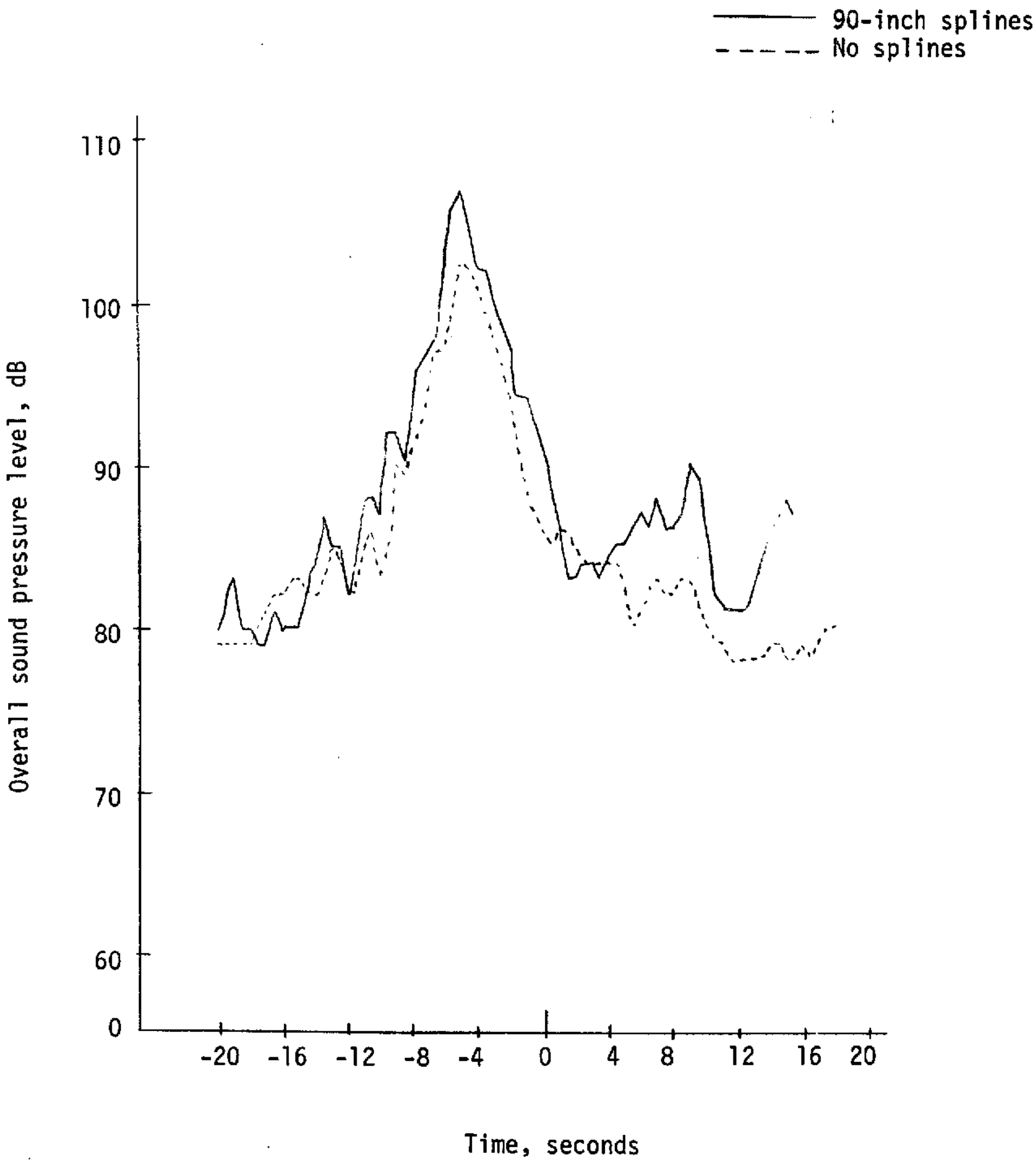


Figure 12. - Time history of penetration with splines at 0.84 n.m.



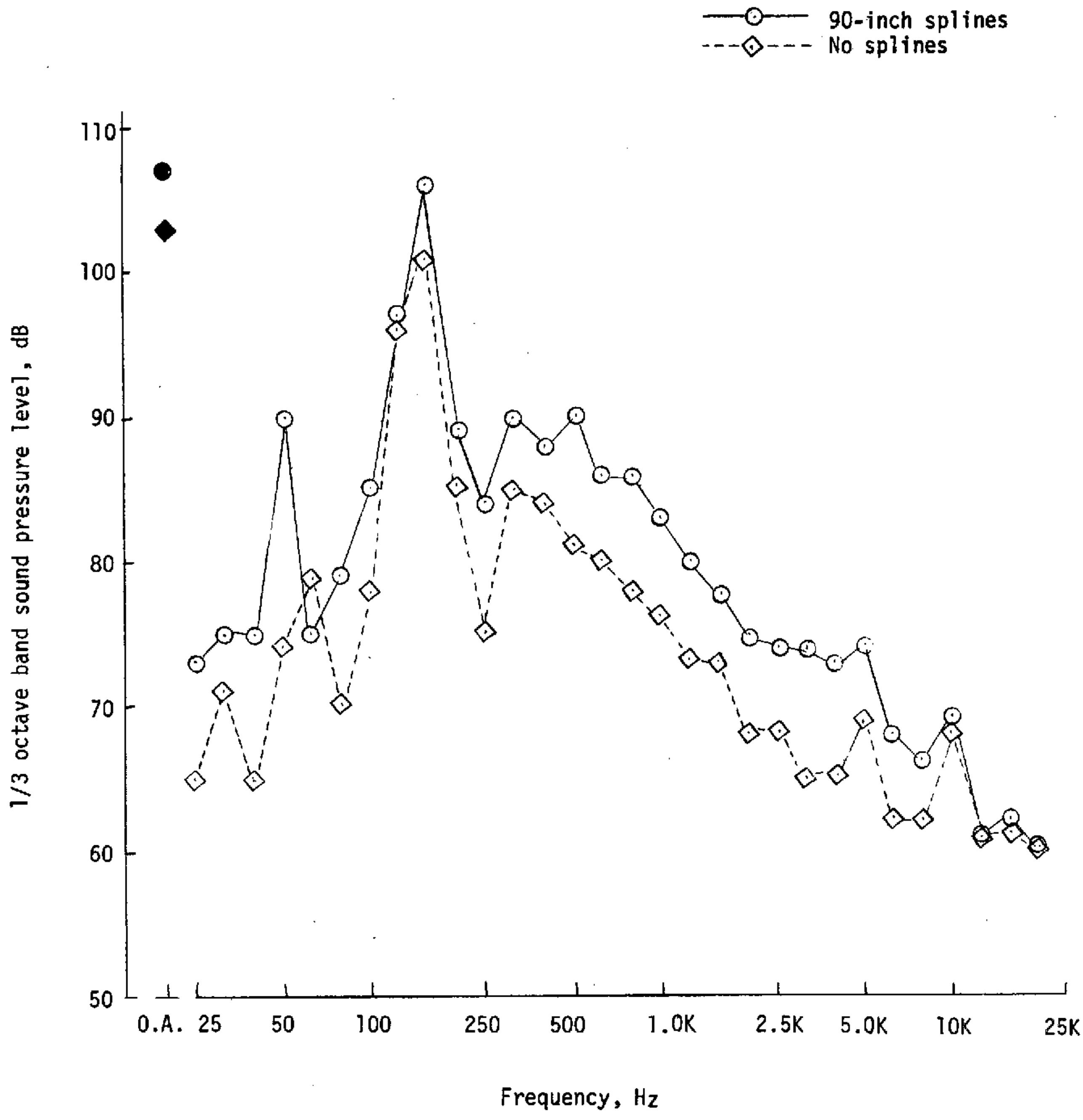
(a) Flyby

Figure 13.- Typical time histories of noise measured at ground station during flyby and approach operations with and without splines.



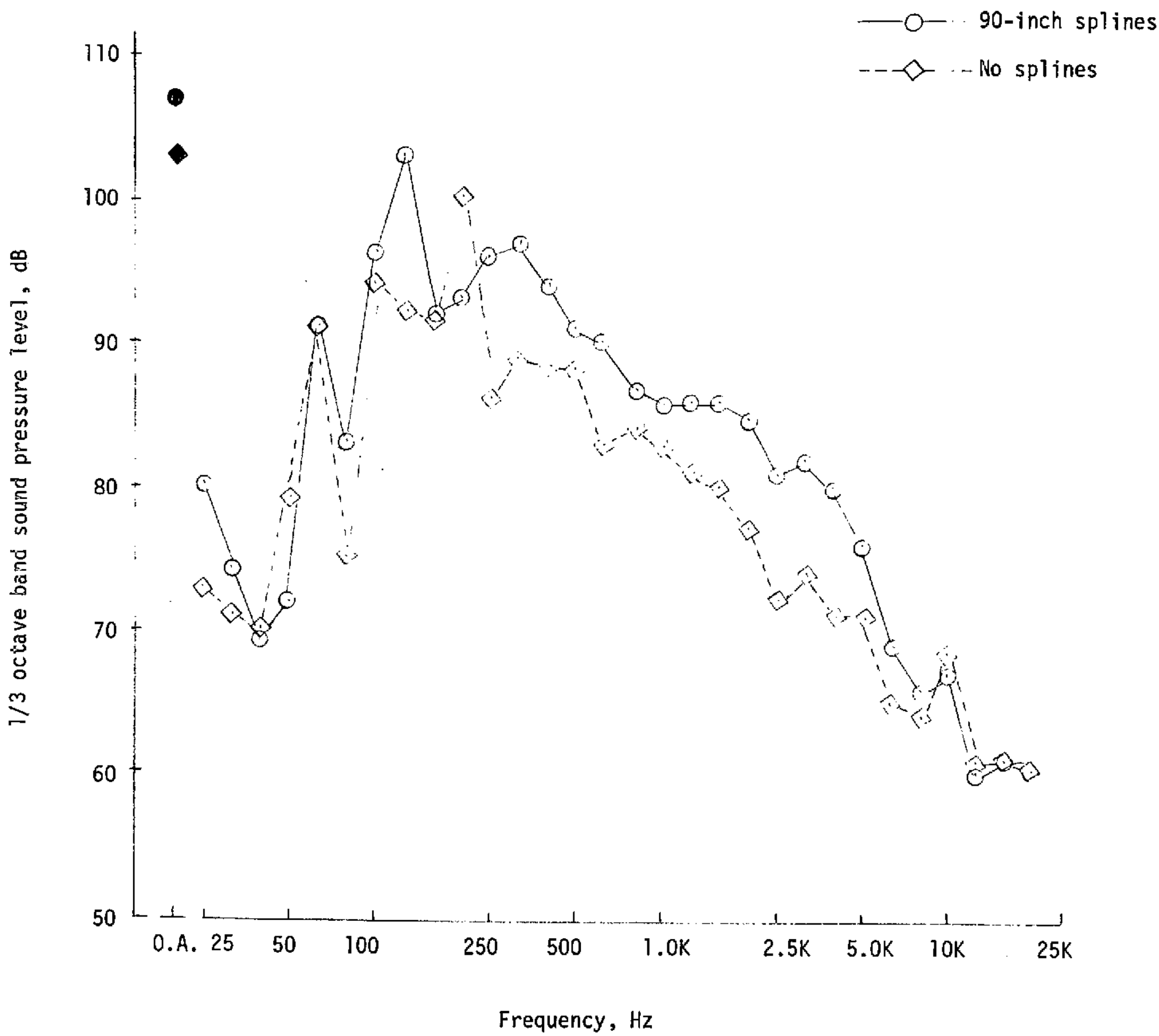
(b) Approach

Figure 13.- Concluded.



(a) Flyby

Figure 14.- One-third-octave band spectra as measured at microphone location during flyby and approach operations with and without splines.



(b) Approach

Figure 14.- Concluded.

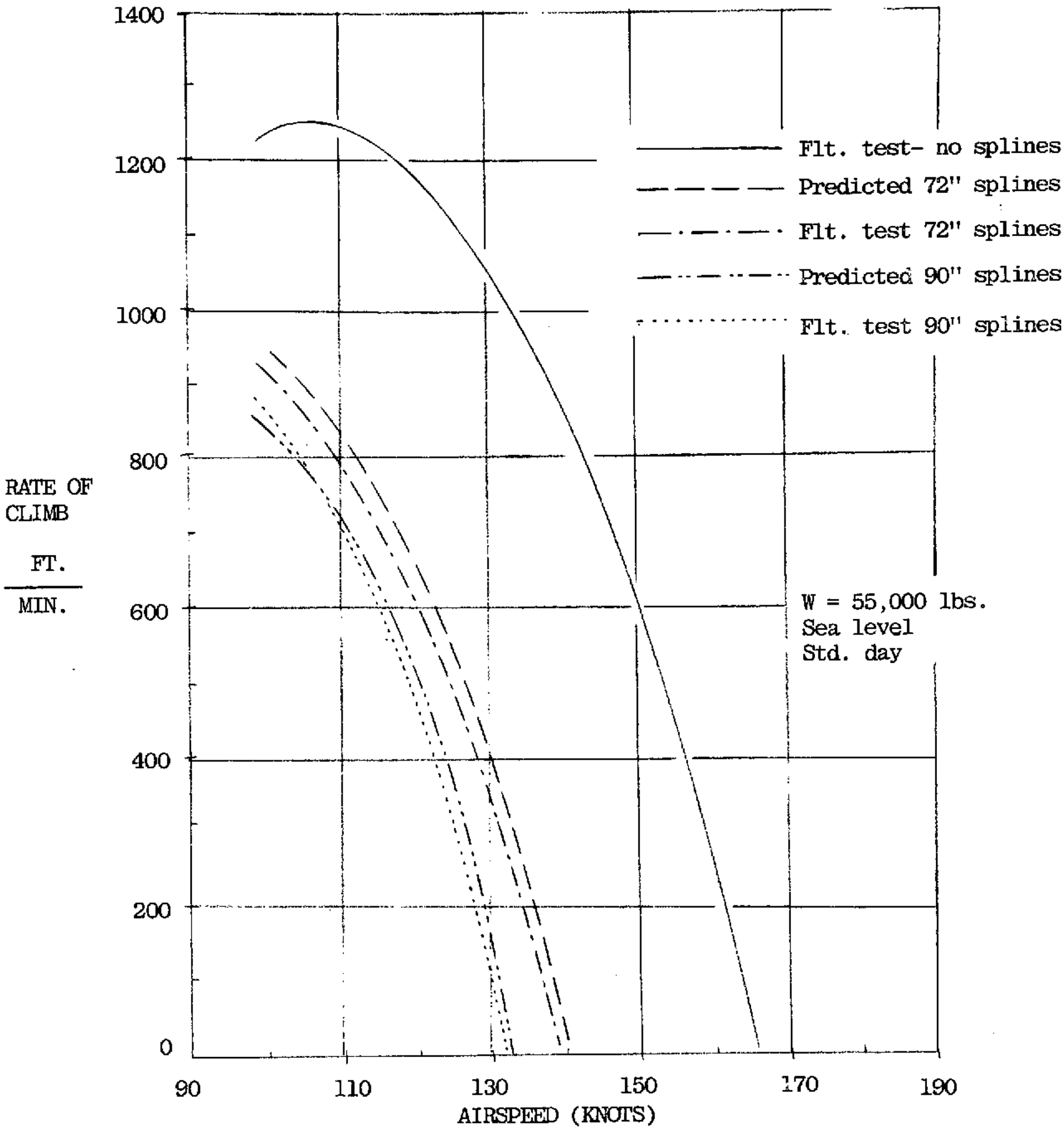


Figure 15.- Rate of climb for the takeoff configuration (gear down, 15° flaps), maximum power, 4 engines.

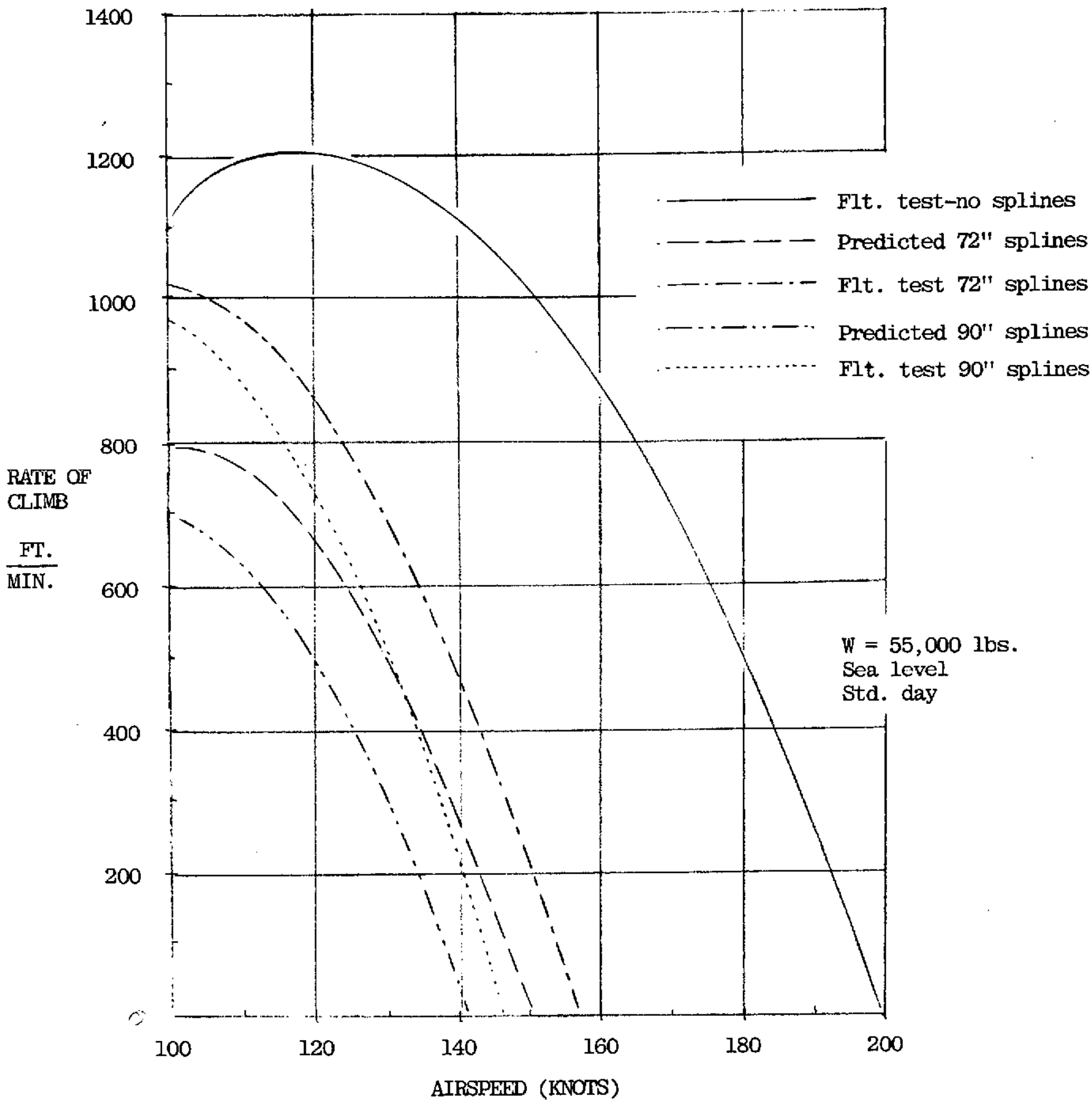


Figure 16.- Rate of climb for the clean configuration (gear up, flaps up), METO power, 4 engines.

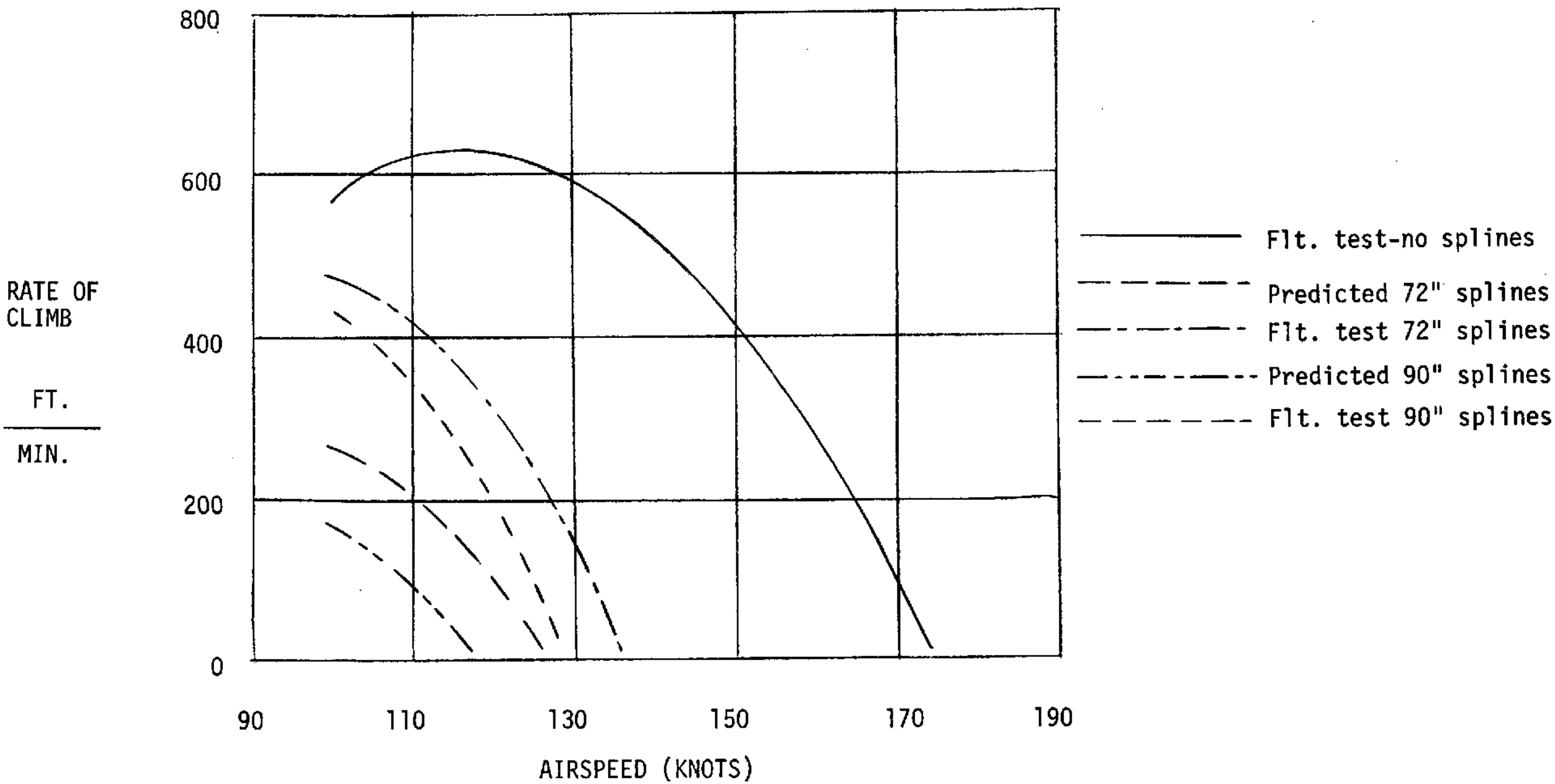


Figure 17.- Rate of climb for the clean configuration (gear up, flaps up), METO power, 3 engines and feathered propeller.