AD-A093 758 AERONAUTICAL SYSTEMS DIV WRIGHT-PATTERSON AFB OH F/G 20/11

COMPARISON OF FLIGHT LOAD MEASUREMENTS OBTAINED FROM CALIBRATED--ETC(U)

OCT 80 J W RUSTENBURG

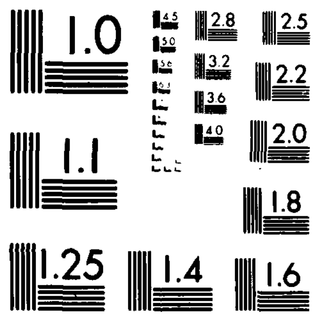
UNCLASSIFIED ASD-TR-80-5038 NL

END

DATE FILMED

2 81

DTIC



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

ASD-TR-80-5038

LEVEL II (12)

AD A093758

COMPARISON OF FLIGHT LOAD MEASUREMENTS OBTAINED FROM CALIBRATED STRAIN GAGES AND PRESSURE TRANSDUCERS

JOHN W. RUSTENBURG
Structures Division
Directorate of Flight Systems Engineering

October 1980

Approved for Public Release; Distribution Unlimited

DEPUTY FOR STRATEGIC SYSTEMS
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This technical report has been reviewed and is approved for publication.

JOHN W. RUSTENBURG
Aerospace Engineer
Flight Systems Engineering

FREDERICK G. NEFF
Chief, Flight Systems Division
Directorate of Systems Engineering
Deputy for Strategic Systems

FOR THE COMMANDER:

JOHN L. KURZENBERGER, Col, USAF
Director, Systems Engineering
Deputy for Strategic Systems

"If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization please notify ASD/YYEF, *W-P AFB, OH 45433 to help us maintain a current mailing list".*

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

AIR FORCE/56780/2 December 1980 — 150

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: ASD-TR-80-5038	2. GOVT ACCESSION NO.: AD-A093 758
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): Comparison of Flight Load Measurements Obtained from Calibrated Strain Gages and Pressure Transducers	5. TYPE OF REPORT & PERIOD COVERED: Final Report. Nov 76-Feb 77
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): JOHN W. BUSTENBURG	8. CONTRACT OR GRANT NUMBER(s): 52
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Aeronautical Systems Division (ASD/YYEF) Wright-Patterson AFB OH 45433	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: System 139A
11. CONTROLLING OFFICE NAME AND ADDRESS: Aeronautical Systems Division (ASD/YYEF) Wright-Patterson AFB OH 45433	12. REPORT DATE: Oct[redacted]80
	13. NUMBER OF PAGES: 61
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Flight Load Measurements
Flight Load Survey
Load Measurement Techniques
Wing Loads
Maneuver Loads

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Net shear, bending moment, and torsion at one wing station derived from concurrent strain gage and pressure transducer measurements are compared. Comparisons are made for results from normal and abrupt symmetrical pullup/pushdown, and rolling pullout maneuvers at subsonic and supersonic speeds and four wing sweeps. With few exceptions good to very good correlation is shown.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

FOREWORD

This report was prepared by John W. Rustenburg, Flight Systems Engineering Division, Deputy for Strategic Systems, under System 139A, B-1.

The flight loads data presented in this report were obtained during B-1 flight load survey testing at the Air Force Flight Test Center EAFB during the period of November 1976 thru February 1979.

The intent of the report is to publish "lessons learned" during the B-1 program.

The assistance of Miss S. A. Searcy in the preparation of this report is gratefully acknowledged.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

SECTION I

INTRODUCTION

Structural load measurements in support of flight load survey or flight demonstration programs conducted on USAF aircraft have been made by either the strain gage method or pressure survey method. In general, either one or the other method was chosen and the same measuring system was installed on all aircraft designated for structural flight tests. In a few flight tests programs, both methods have been used. In those cases, the aircraft with a strain gage installation was used primarily to measure structural loads in support of a flight load survey and demonstration, while the aircraft installed with pressure transducers was used to measure lifting surface aerodynamic pressures in support of other disciplines such as flutter, stability, and performance. Rarely, if ever, were identical conditions flown on the aircraft with different instrumentation systems to provide a direct comparison of structural loads as derived from the measurements of the two systems.

Some comparisons of concurrent strain gage and pressure transducer measured flight loads on a single aircraft have been published for a relatively small propeller driven fighter type airplane (Ref 1.), a drone aircraft (Ref 2.), and for research vehicles (Ref 3. and 4.). Similar comparisons of concurrent load measurements on a large flexible aircraft have not been available. Such comparisons may be helpful in system selection for application in future aircraft structural flight loads testing.

The B-1 Number 2 aircraft was instrumented to conduct a complete flight and ground operations load survey in accordance with the requirements of Reference 5. This instrumentation included installation of pressure transducers at seven wing outer panel spanwise stations for the measurement of aerodynamic pressure distributions, as well as strain gages at one station for the measurement of wing outer panel net shears, bending moment and torsion. Measurements were obtained simultaneously from both systems during the performance of specific flight maneuvers. The instrumentation systems used, and the lifting surface net loads (shear, bending moment, torsion) derived from the simultaneous measurements will be reviewed to provide information helpful to the engineer responsible for the evaluation and selection of competing flight load measurement techniques.

SECTION II

INSTRUMENTATION

The B-1 Number 2 aircraft was instrumented for the measurement of flight loads. This instrumentation included pressure transducers on the right movable wing outer panel and the left and right wing center section. Strain gages were installed at various locations on the fuselage, empennage, nacelle, structural mode control system, flap tracks and at one wing station on each movable wing outer panel. In addition to the instrumentation required for load measurements, the airplane was provided with instrumentation necessary to define maneuver condition parameters such as surface positions, accelerations and rates, gross weight and c.g. location, speed, altitude, angle of attack, etc. Figures 1, 2 and 3 show the general load measuring instrumentation location. For purpose of this report, only the instrumentation installed in the outer wing panels will be reviewed in more detail.

A. Pressure Transducers

Figure 4 presents a more detailed view of the 99 pressure tap locations at the 7 stations of the right hand wing outer panel. Opposite taps on the upper and lower surfaces were connected to single transducers which measured the differential pressure. Tubes connecting the taps and transducers were all 48 inches long with an I.D. of approximately 0.14 inch. The frequency response of the transducers was $\geq 4.0\ H_Z$ when installed with the 48" lines. (It was essentially flat for tube lengths from 12 to 55 inches). Time lag was $<$ 11.0 milliseconds (.011 seconds) and identical for all transducers. The pressure ranges of the transducers varied depending on the expected pressures at their installed locations. Expected accuracy was less than or equal to 2% of full range when full range was less than 17 psi, and equal to 1% of full range when full range was equal to or greater than 17 psi.

B. Strain Gages

The strain gage instrumentation was installed at station XRS 354. This was the most inboard station on the wing outer panel at which strain gages could be installed without reaction from the aerodynamic seals when the wings were in the aft swept position. Figure 5 presents the approximate location of the strain gages on the wing box. As shown, both shear rosette and axial gages were employed. The strain gages were calibrated to determine swept axis net shear, bending moment, and torsion at left and right wing station X_{RS} 354. As indicated in Figure 5 not all gages were used in the loads measurement. Normally gages on the lower (tension) surface would be preferred. However, in this case, the calibration showed trivial error differences between measurements from upper and lower surface gages with the upper gages showing better accuracy for aft c.p. conditions. Considering the possible long term effect of the many refuel access door cutouts existing in the lower surface, the upper gages were chosen for flight loads measurement.

The most commonly used calibration technique requires the application of incremental loads at a number of individual loading points, one at a time. This point load calibration is not completely satisfactory since it calibrates the system for only a portion of the loads ultimately attained in actual flight test operations. A more ideal way of performing a calibration is through the application of a series of distributed loads representative of actual loading conditions. This method is not often used because it requires a static test fixture and is more time consuming, complicated and costly. The decision to submit the B-1 aircraft to a limit load proof test afforded an ideal opportunity of calibration using distributed loads representative not only of actual flight conditions but of predicted critical design conditions as well. Calibration tests were run in conjunction with the limit load proof tests where load magnitudes and center of pressure locations were compatible. Additional special calibration conditions, not compatible with proof test conditions, were run separately to complete the calibration. Table I shows the proof load and calibration conditions used for calibration of the wing outer panel strain gages. The data obtained from the strain gages during proof load and calibration tests were used to establish equations relating flight test strain gage readings to structural loads. Figures 6, 7 and 8 show expected accuracies for the wing outer panel shear, bending moment and torsion.

SECTION III

FLIGHT TEST PROGRAM

The flight test program as planned consisted of a flight load survey in accordance with the requirements of Reference 5. A flight load survey includes the performance of specified maneuvers over a matrix of speed-altitude points covering the flight envelope of the aircraft for the purpose of defining or substantiating critical flight conditions. The program consisted of two phases. The initial phase comprised the survey of the flight envelope with maneuvers performed to 80% of limit load on the primary structural components. The final phase comprised the demonstrations to 100% of limit load of the critical conditions as determined by analysis and from initial phase results. The test maneuvers included smooth and abrupt symmetrical pullup/pushdown, rolling pullout, and yawing maneuvers. The symmetrical pullup maneuvers were accomplished as steady wind-up turns. The appendix presents descriptions of the pilot techniques used in performance of the required airloads maneuvers. Flight loads data was obtained for wing sweep positions of 15, 25, 55 and 67.5 degrees. For the 15-degree wing sweep position data was obtained in the landing configuration as well as for the clean aircraft. In addition, some tests with and without speed brake extension were performed.

Cancellation of the B-1 program forced a restructuring of the flight loads test which did not allow completion of all test runs as originally planned. Nevertheless a large number of subsonic conditions was completed during the initial and final phases of the flight loads testing program. Supersonic conditions were not performed to 100% of limit load, but a limited number of conditions was completed during the initial phase. The completed test runs provide the data base from which conditions may be selected for analysis of concurrent loads derived by the strain gage and pressure survey methods.

SECTION IV

FLIGHT LOAD COMPARISON

Determination of structural loads using pressure measurements requires considerable data processing. Because of the large number of test conditions available, and funding constraints of the restructured program, the reduction of pressure data for all initial and final phase conditions was impractical. However, structural loads were derived from strain gage and pressure measurements for all subsonic final phase conditions completed. From initial phase data similar loads were derived for two supersonic conditions and certain maneuvers at subsonic speeds which were not completed in the final phase to 100% of limit load. Inclusion of the two supersonic conditions will allow limited comparison between subsonic and supersonic results. Table II presents a summary of the conditions and maneuvers for which data will be reviewed. Conditions with speed brakes extended are not included. Program difficulties with the geometry for this configuration prevented acceptable pressure data reduction.

Yawing maneuvers are not included because the wing loads remained low and near the 1.0 g level and pressure data was consequently not reduced. The rolling pullout maneuver data includes results from both coordinated and uncoordinated rolling maneuvers. The automatic flight control system tends to minimize differences in the aircraft's response due to coordinated and uncoordinated rolls and the resulting wing loads are very similar.

A. Evaluation Criteria

Since the primary purpose of this study is to compare loads derived from two different measurement techniques, the loads will be compared to each other, rather than to the predicted analytical loads. Figures 11 thru 13 present load comparisons for normal symmetrical pullup and pushdown maneuvers. Figure 14 presents the comparison for an abrupt symmetrical pullup, and Figures 15 thru 17 present the load comparison for rolling pullout maneuvers. The solid lines in these figures represent 100 percent agreement between the loads derived from strain gage and pressure transducer outputs. The deviation of a data point from this solid line can be viewed as an error in loads from pressure measurements, an error in loads from strain gage measurements or an error in both. If it is assumed that the error can exist in either load measurement, the error is evaluated by the deviation perpendicular to the solid line. The magnitude of this error may be conveniently expressed as a percentage of the maximum limit load. The design limit load predicted at the strain gage station (the station at which loads are being compared) were: shear +152,000 lbs and -50,000 lbs; bending moment +31,300,000 inch-lbs and -10,300,000 inch-lbs; and torsion +5,000,000 inch-lbs and -3,250,000 inch-lbs. To evaluate the "goodness" of the loads agreement, a rating system based on a given percentage of predicted design limit load is proposed. Table III presents the proposed evaluation criteria.

B. Normal Symmetrical Pullup/Pushdown Maneuvers

Shear load comparison for normal symmetrical pullup and pushdown maneuvers for all flight conditions of Table II are presented in Figure 11. For the symmetrical pullups, the agreement between the loads from strain measurements and pressure measurements is judged in accordance with the evaluation criteria of Table III to be very good for all cases except Mach 1.20. The agreement for the Mach 1.20 case is judged as good. The agreement for the symmetrical pushdown is also very good, except for the wing sweep aft (67.5°) configuration at speeds of Mach 0.85 and 0.95. The agreement at Mach 0.85 is from fair to good, while at Mach 0.95 good agreement was obtained.

Bending moment comparisons are shown in Figure 12. For the symmetrical pullup maneuver, the agreement between loads from the two measurement systems is generally rated as good to very good, except for the Mach 1.20 condition. At this condition the overall agreement is judged as only fair. For the symmetrical pushdown maneuver the bending moment agreement is similar to the agreement attained for shear; that is, very good for all conditions except Mach 0.85 and 0.95 for the wings 67.5° configuration. For these speeds the agreement is judged as poor.

Comparison for torsion values are presented in Figure 13. Although there appears to be less agreement of torsion values when compared with the figures for shear and bending moment, this is partially an illusion created by the relatively large scale used. Nevertheless, some scatter is evident in the data from the full flaps down configuration represented by condition A of Table II, with individual points varying from poor to very good agreement. Considerable variation was also evident in the data from the transonic condition I with agreements from poor to good. For the symmetrical pullup maneuver, both conditions are judged overall as fair to good. All other conditions are judged to be from good to very good. For the pushdown maneuver, the transonic condition again shows data scatter from poor to good. In contrast the flaps down conditions show good to very good agreement for this maneuver.

C. Abrupt Symmetrical Pullup

Correlated net loads for an abrupt symmetrical pullup for one flight condition (condition H of Table II) are presented in Figure 14. The limited data shows very good agreement for the shear, bending moment and torsion as derived from strain gage and pressure transducer measurements. This agreement is identical to that obtained from the normal symmetrical pullup for this flight condition. Although the abruptness of the maneuver primarily influences the horizontal tail loads, Figure 10 shows rapid changes in wing loads for the abrupt maneuver when compared to Figure 9 for the normal maneuver. Since very good correlation was obtained between strain gage and pressure loads for both the normal and abrupt maneuvers, it is concluded that the pressure measurement system was not affected by demonstrable lag effects.

D. Rolling Pullout Maneuver

For the flight conditions for which rolling pullout maneuver loads were derived from both strain and pressure measurements, only two data points per maneuver were available. Comparison of the shears, bending moments, and torsions for the rolling pullout are compared in Figures 15, 16 and 17 respectively. The agreement for shear loads is very good, for bending moments good to very good, and for torsions it is judged to be good.

E. Additional Evaluation

For the shear comparisons of Figures 11 thru 17, the data points are scattered equally about the 100% agreement line with approximately an equal number of points on both sides. For the bending moment and torsion comparison approximately 55 percent of the datapoints are to be right of the solid line versus 38 percent to the left and the remaining points falling directly on the line. Thus, indicating a bias toward more positive net loads for the pressure measurement system when compared to loads derived from the strain gage data. It is not possible to definitely identify the reasons for this apparent bias or establish which measurement system provides the more correct results. However, the following reflections may provide some insight.

First, for the strain gage system, Figures 7 and 8 show a high degree of correlation between the applied calibration load and the measured load from the final calibration equations for bending moment and torsion. The accuracy of these equations would be degraded for loading conditions and center of pressure locations considerably different from the calibration loads. However, although centers of pressure of the measured loads have deviated from prediction they have been within the calibration c.p. envelope. Thus the accuracy shown in the figures should be applicable. Though the calibration equation for the strain gages provide a direct determination of the net loads, these loads are incremental loads from some reference. For the loads in this report, this reference was taken as the ground condition prior to take-off. Any errors in determining the loads at the strain gage station at this reference condition are transferred to the total net load determined for the flight condition. As the ground loads were measured during periods when the aircraft was at rest without aerodynamic inputs, and the landing gear reactions were well inboard from the strain gage station, these loads were easily calculated and good accuracy would be expected.

On the other hand, the accuracy of the pressure measurement derived loads is not only affected by the accuracy of the transducers and the data recording system, but to a large extent by the data processing. This data processing includes simulation of the pressure distribution by curve fitting of the measured pressures, assumptions for compensating for the loss of individual pressure signals, estimates of wing outer panel mass distributions for the time increment of interest, and integration procedures to determine shear, bending moment and torsion at the station of interest. Each of these are possible contributors to error which are not factors in the loads determined from strain gage data.

Based on the considerations mentioned, any errors are most likely expected in the net loads calculated from pressure measurements.

SECTION V

CONCLUSIONS

Comparison of net shear, bending moment, and torsion at one wing station derived from concurrent strain gage and pressure transducer measurements shows with a few exceptions good to very good correlation. This correlation would indicate that either system is acceptable for flight load measurements. Choice of one system or the other would be predicated on other considerations such as past experience with one or the other system, requirements for net or aerodynamic loads, structural considerations, etc. The correlation is also consistent throughout the wing sweep range. Since the strain gage station is outboard of the wing pivot, differences due to lack of calibration at intermediate sweep positions were not expected.

Comparison of loads for a normal and an abrupt maneuver does not indicate a demonstrable lag effect in the net loads from the pressure measurement system used. Thus a pressure measurement system as described can be used with confidence for the measurement of airloads during rapid maneuvers.

Data processing to determine net loads from aerodynamic pressure measurements is very extensive and time consuming. The determination of loads for many conditions such as is required in a flight load survey, therefore, becomes expensive and slow. Because of data processing requirements, this approach to load measurements is also not very amenable to real time monitoring. If the use of aerodynamic pressure measurements is the preferred or required method, the addition of some calibrated strain gages as was done in this program can circumvent the problem associated with lengthy data processing and real time monitoring. For this program the loads at one wing station were derived from strain gage responses during the flight load survey to aid in defining critical loading conditions and to allow real time monitoring of load levels. Distributed loads were obtained from aerodynamic pressure measurements primarily for demonstration of the critical conditions. The value of this approach must be evaluated against the duplication in load measurements and the cost of calibrating the strain gages. In the case of the B-1 program, the application of load during the proof load program allowed simultaneous calibration of the strain gages.

REFERENCES

1. William S. Aiken, Jr., Donald A. Howard, NACA TN 1967, A Comparison of Wing Loads Measured in Flight on a Fighter-Type Airplane by Strain Gage and Pressure Distribution Methods, Nov 1949.

2. Clinton V. Eckstrom, NASA TN-D-8349, Flight Load Measurements Obtained from Calibrated Strain Gage Bridges Mounted Externally on the Skin of a Low Aspect Ratio Wing, December 1976.

3. Ming H. Tang, William J. Sefie, Robert G. Sheldon, NASA Technical Paper 1331, Comparison of Concurrent Strain Gage and Pressure Transducer Measured Flight Loads on a Lifting Reentry Vehicle and Correlation with Wing Tunnel Predictions, October 1978.

4. Earl R. Keener, Chriss Pembo, NASA TM X-712, Aerodynamic Forces on Components of the X-15 Airplanes, 1962.

5. MIL-A-8871 (USAF), Airplane Strength and Rigidity, Flight and Ground Operations Tests, 8 Oct 1968.

APPENDIX

PILOT TECHNIQUE - AIRLOAD MANEUVERS

TP/PS	Pilot Technique
Normal symmetrical pullup (windup turn)	Perform a gradual windup turn to the required load factor level and hold for approximately 5 seconds maintaining required mach number with power setting adjustment when thrust is available. When possible, maintain altitude within 1,000 feet of the test altitude. Maintain zero sideslip throughout maneuver.
Normal symmetrical pushdown	Perform gradual pushover to required load factor and return smoothly to a 1.0 g condition. The initial 1.0 g trim may be established with a climb angle, if necessary, to avoid excessive dive angle, altitude loss, or speed increase during maneuver. Power setting may also be reduced to avoid overspeed.
Landing approach pullup (windup turn)	Perform a gradual windup turn to the required load factor and hold for approximately 5 seconds maintaining required speed with power setting adjustment. Maintain altitude within 1,000 feet of test altitude. Maintain zero sideslip.
Landing approach rolling pullout	Abruptly displace roll control to the required position to initiate roll maneuver. Abruptly check roll with oppositely directed roll control such that the bank angle of 60 degrees is reached but not exceeded. The pitch control shall be used to avoid exceeding a load factor of 1.3 g. Directional control shall be used to coordinate maneuver.
Rudder kick with abrupt return (yaw)	Abruptly apply left rudder control to the required position and hold until a steady sideslip attitude is obtained. Once this is accomplished the rudder control shall be abruptly returned to the neutral position. During this maneuver the lateral control shall be used to maintain a wings level attitude.

PILOT TECHNIQUE - AIRLOAD MANEUVERS

TP/PS	Pilot Technique
Rudder kick for landing approach (yaw)	Abruptly apply left rudder control to the required position and hold until a steady sideslip attitude is obtained. Once this is accomplished the rudder control shall be abruptly returned to the neutral position. During this maneuver the lateral control shall be used to maintain a wings level attitude
Abrupt symmetrical pullup	Abruptly apply an aft stick movement pitching the aircraft noseup and check maneuver by abruptly returning the stick to the initial trim position. If possible, the maneuver shall be checked such that the required load factor is reached (but not exceeded) at about the same time as stick has been returned to the initial trim position.
Abrupt symmetrical pullup with abrupt checking	Abruptly apply an aft stick movement pitching the aircraft noseup. Check the maneuver by abruptly returning the stick past the initial trim position to a forward travel equal to approximately one-half of the aft travel used and then return stick to initial trim position. If possible, the maneuver shall be checked such that the required load factor is reached (but not exceeded) at about the same time as the stick has reached the most forward position.
Abrupt symmetrical pushdown with abrupt checking	Abruptly apply a forward stick movement pitching the aircraft nose-down. Check the maneuver by abruptly returning the stick past the initial trim position to an aft travel equal to approximately one-half of the forward travel used and then return stick to initial trim position. If possible, the maneuver shall be checked such that the required load factor is reached (but not exceeded) at about the same time as the stick has reached the most aft position. The maneuver may be initiated with the aircraft in a slight climb to avoid overspeed or excessive dive angle.

PILOT TECHNIQUE - AIRLOAD MANEUVERS

TP/PS	Pilot Technique
Abrupt coordinated rolling pullout	At the required mach/altitude point, establish a steady turn at a bank angle corresponding to the required load factor. This initial bank angle shall be opposite to the required roll maneuver direction (i.e., a left roll maneuver direction requires an initial bank angle to the right). Abruptly roll aircraft through twice the initial bank angle equal and opposite the initial value using the required lateral stick displacement. Abruptly check the roll by application of an oppositely directed roll control such that the final bank angle is not exceeded. During the roll, the directional control shall be applied to coordinate the maneuver and the pitch control shall be held constant except for changes which are necessary to avoid exceeding the required test load factor.
Abrupt uncoordinated rolling pullout	At the required mach/altitude point, establish a steady turn at a bank angle corresponding to the required load factor. This initial bank angle shall be opposite to the required roll maneuver direction (i.e., a left roll maneuver direction requires an initial bank angle to the right). Abruptly roll aircraft through twice the initial bank angle to a bank angle equal and opposite the initial value using the required lateral stick displacement. Abruptly check the roll by application of an oppositely directed roll control such that the final bank angle is not exceeded. The pilot's directional and pitch control positions shall be held constant during the roll except for changes which are required to avoid exceeding the test load factor.

TABLE I SUMMARY OF CALIBRATION CONDITIONS FOR WING OUTER PANEL

Wing Sweep	Test Condition	Type of Test*
67.5° ↓	Supersonic Cruise	P,C
	Abrupt Roll, Heavy Weight, Left	P,C,R
	Abrupt Roll, Heavy Weight, Right	C
	3 "g" Terrain Following	P,C,R
15° ↓	2 "g" Flaps Down	P.C.R
	1 "g" Wing Aft CP & RPA Gust, Right	C
	1 "g" Wing Aft CP & RPA Gust, Left	C
	70 Degrees Spoiler	P,C,R

*(P) Proof Test
(C) Calibration
(R) Rigidity Test

TABLE II FLIGHT LOAD CONDITIONS

Conditions	Wing Sweep	M. No or IAS	Altitude (1000 ft)	Flaps/Slats (degrees)	Maneuver Type*
A	15	225	7.5	25/20	SPU, SPD, RPO
B	↓	340	8.5	9/20	SPU, SPD
C		.55	7.5	0/0	SPU, SPD, RPO
D	↓	.70	17	↓	SPU
E	25	.70	11.5		SPU, SPD, RPO
F	↓	.70	17		SPU
G	55	.85	7.5		SPU, SPD, RPO
H	67.5	.85	5.0		SPU, SPD, ASPU, RPO
I	↓	.95	5.0		SPU, SPD
J		1.20	17		SPU
K	↓	1.60	38	↓	SPU, SPD

* SPU = Normal Symmetrical Pullup   SPD = Normal Symmetrical Pushdown
ASPU = Abrupt Symmetrical Pullup   RPO = Rolling Pullout

TABLE III EVALUATION CRITERIA

Load	Design Limit Load @ XRS 354	Rating		
		Very Good	Good	Fair
Shear	+152,000 lbs -50,000 lbs	±5%	±10%	±15%
Bending Moment	+31,300,000 inch-lbs -10,300,000 inch-lbs	±2%	±5%	±8%
Torsion	+5,000,000 inch-lbs -3,250,000 inch-lbs	±2%	±5%	±8%

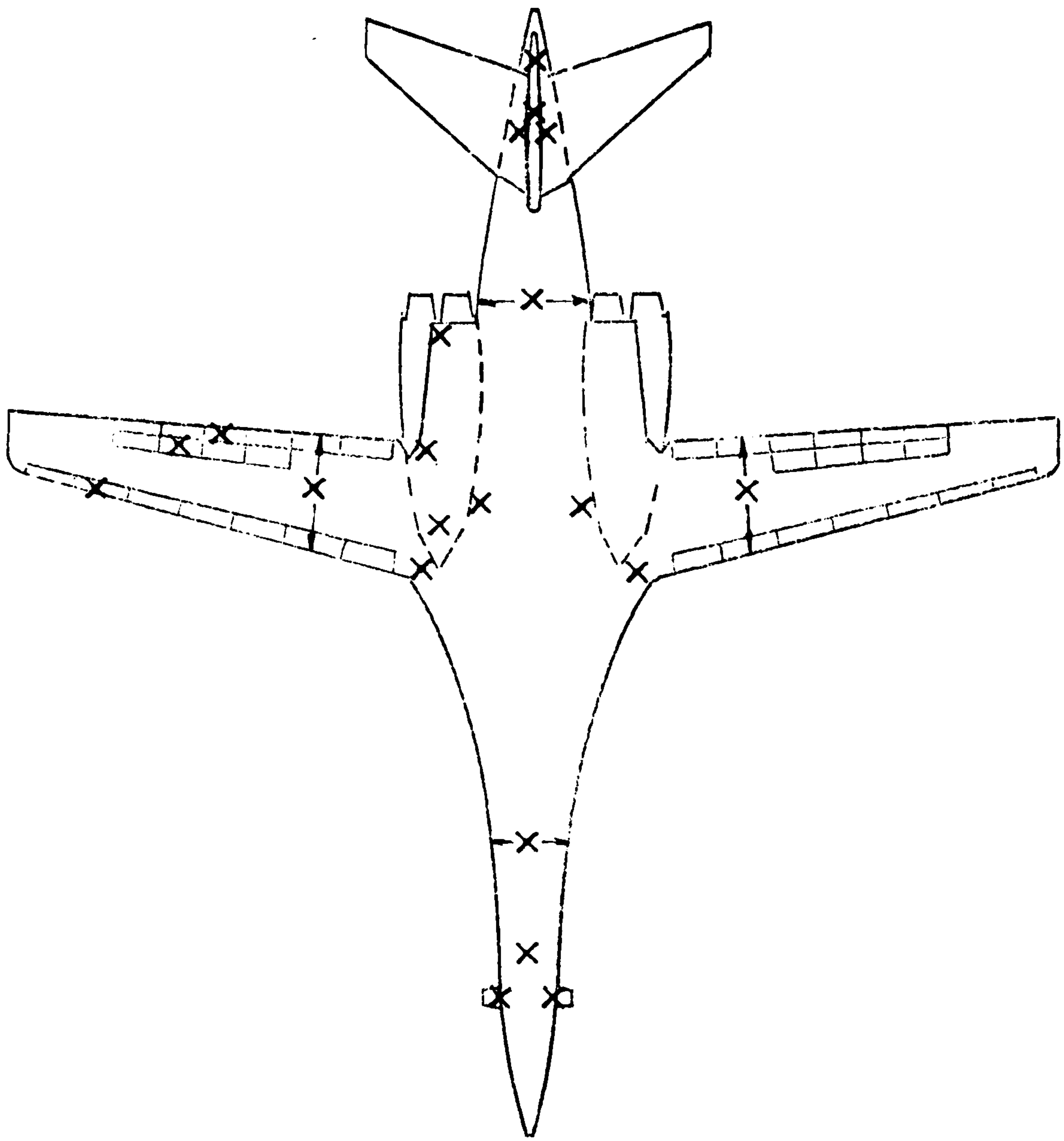


Figure 1   Strain Gage Measurements Locations

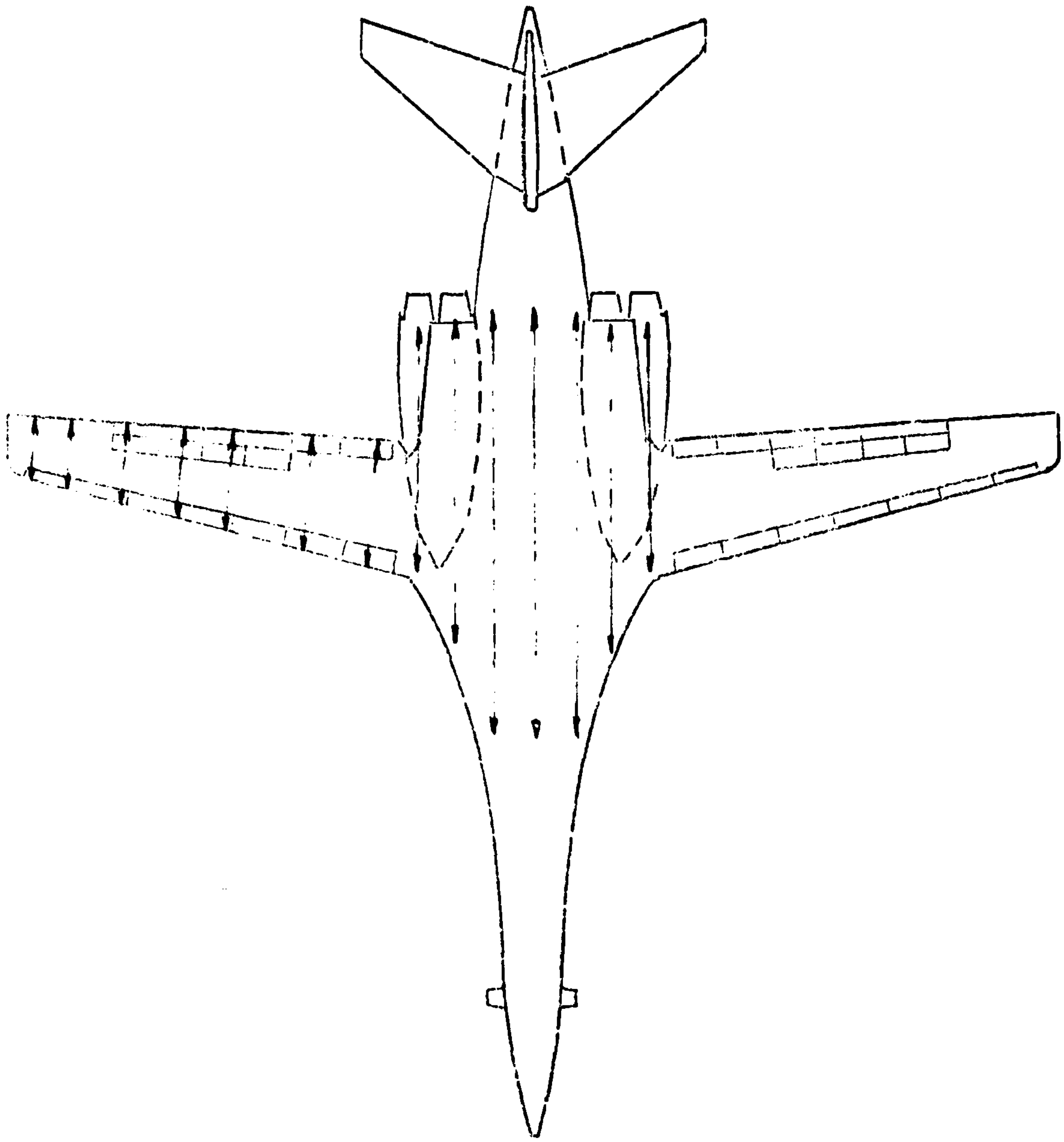


Figure 2 Pressure Measurement Locations

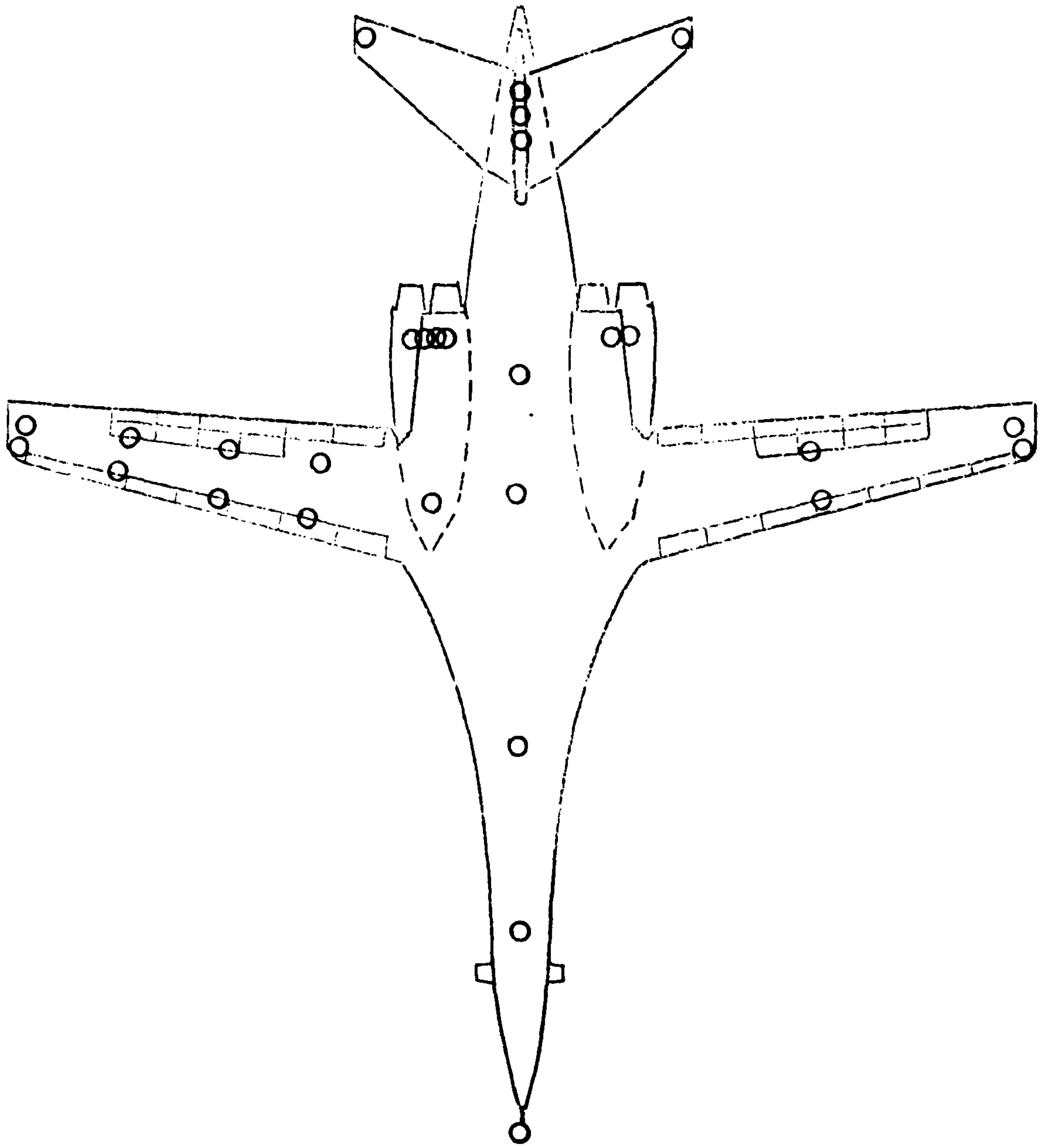


Figure 3 Acceleration Measurement Locations

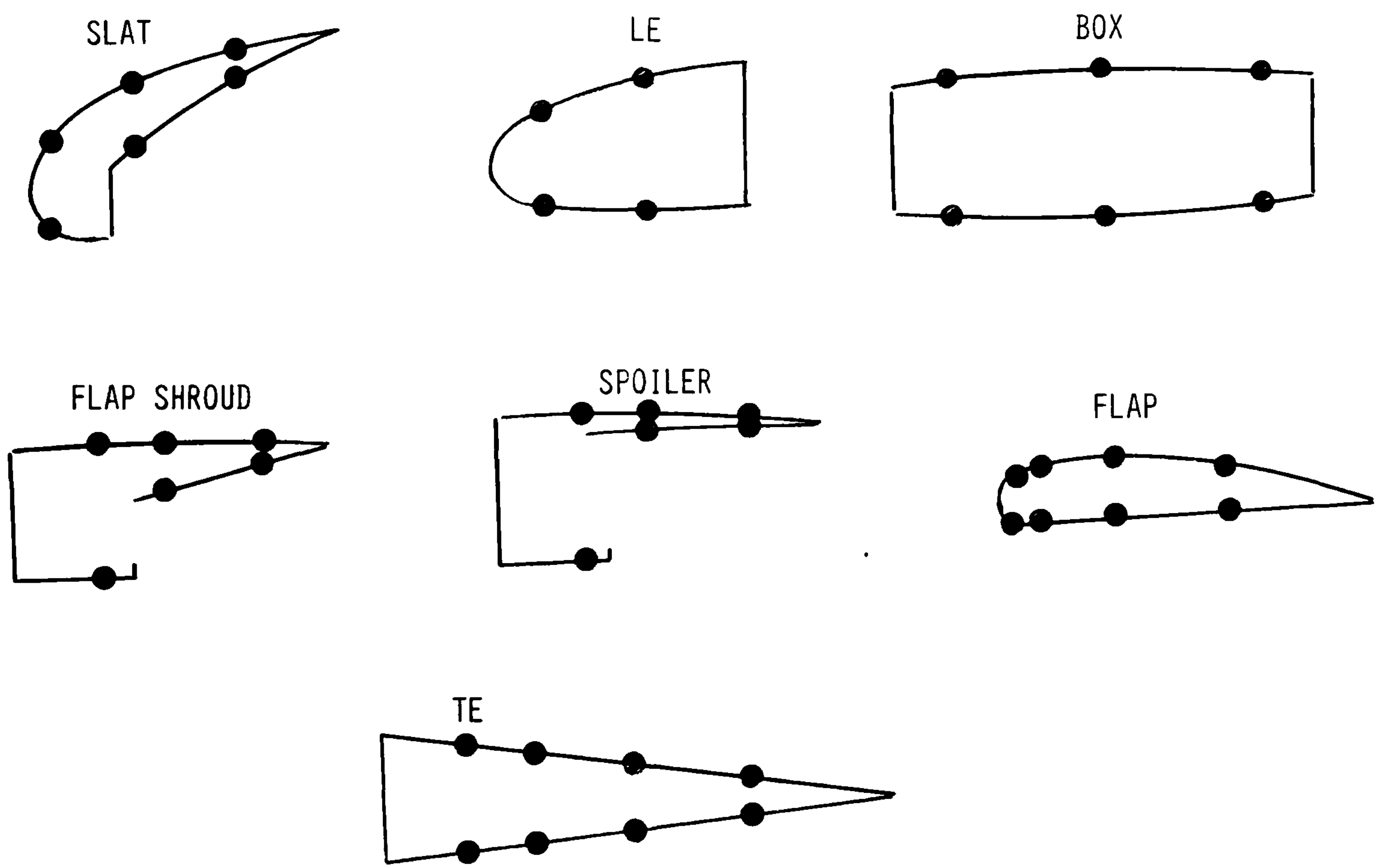


Figure 4 Movable Wing Pressure Orifice Locations

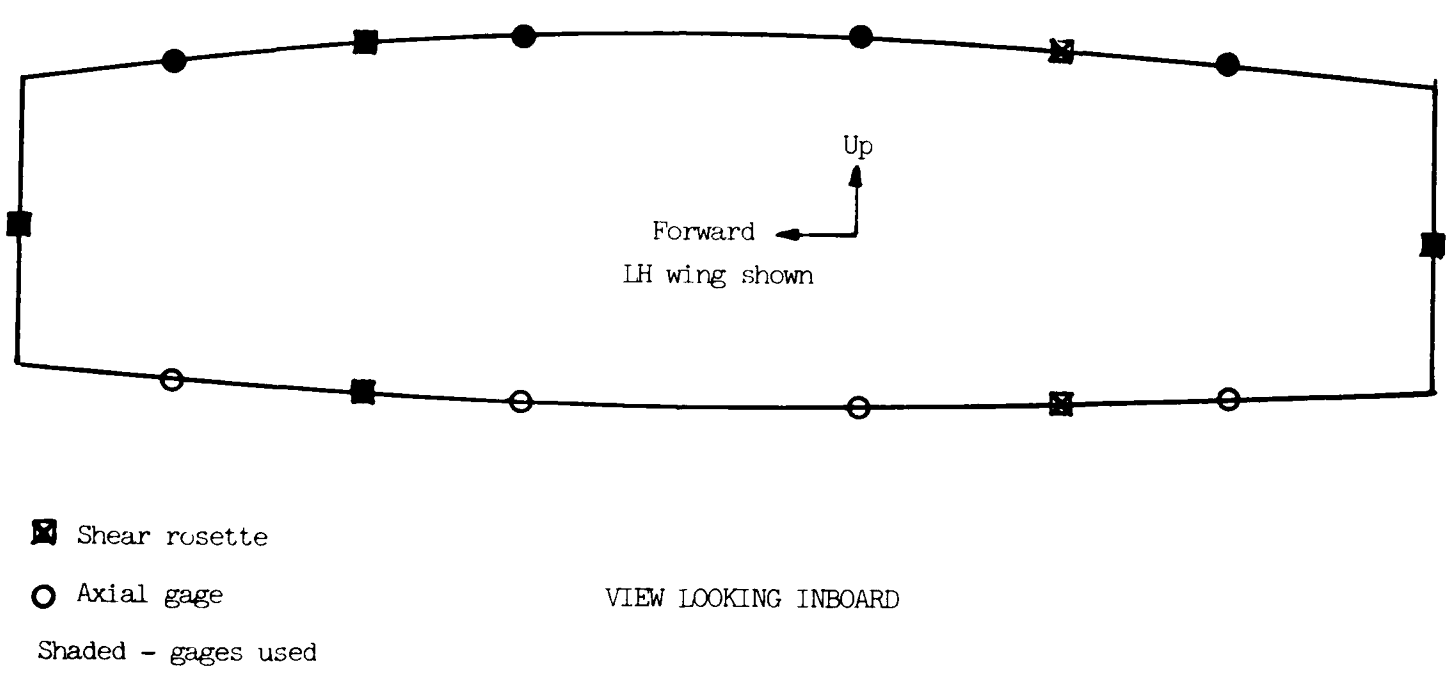


Figure 5 Location of strain gages at wing station X_{RS} 354

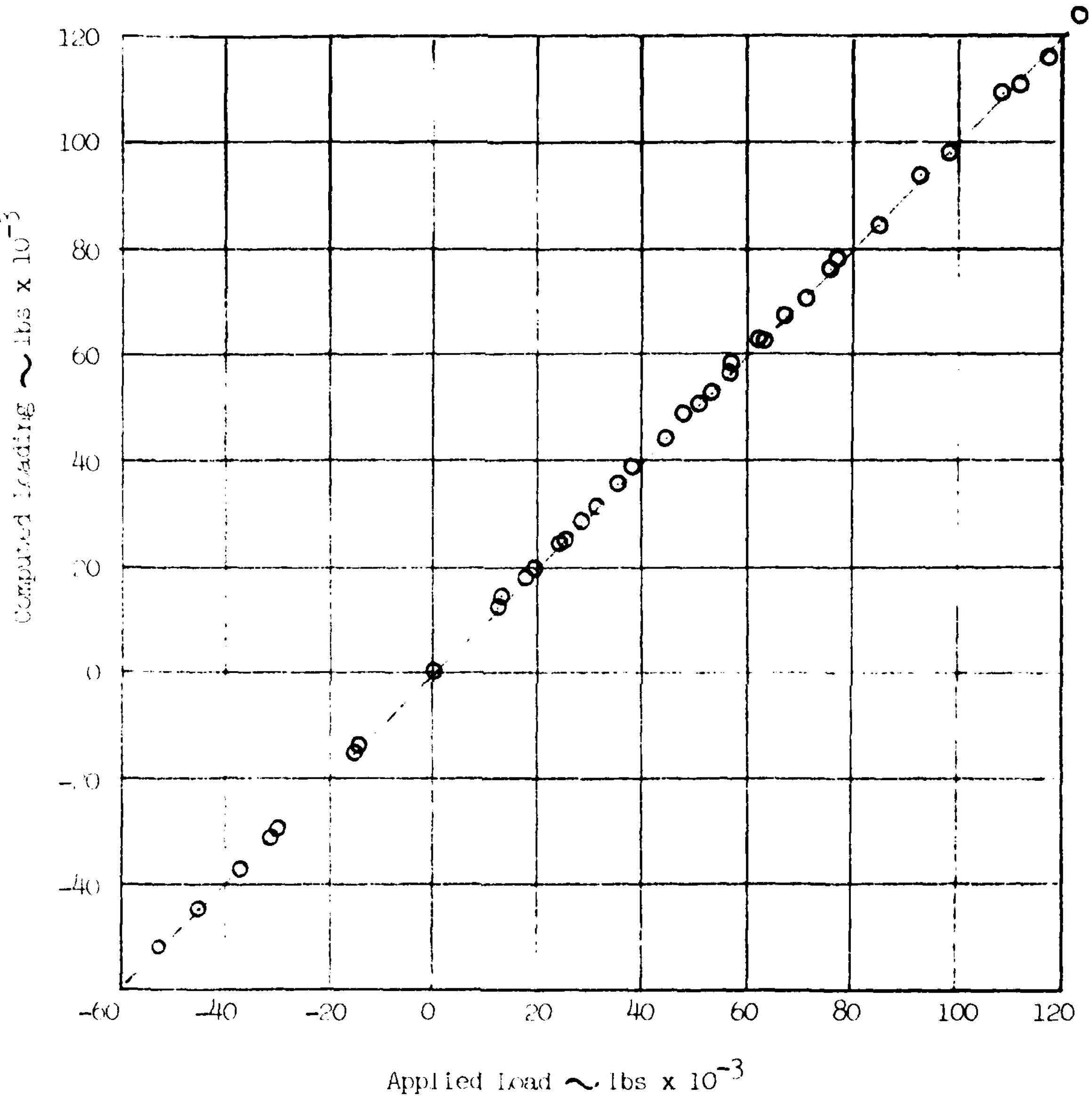


Figure 6 Computed Load vs Applied Load for Shear Measurements at XRS 354

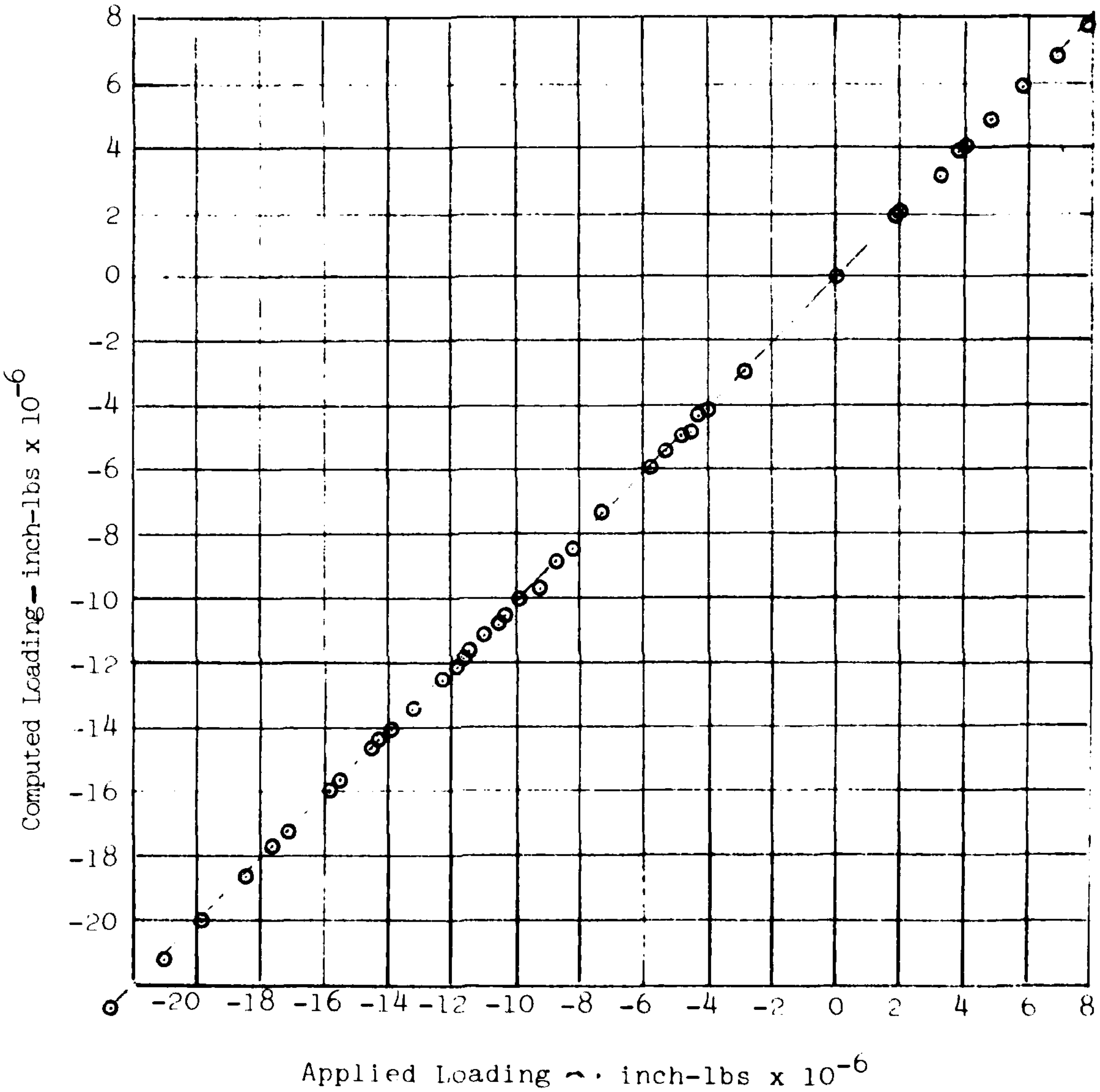


Figure 7 Computed Load vs Applied Load for Bending Moment at XRS 354

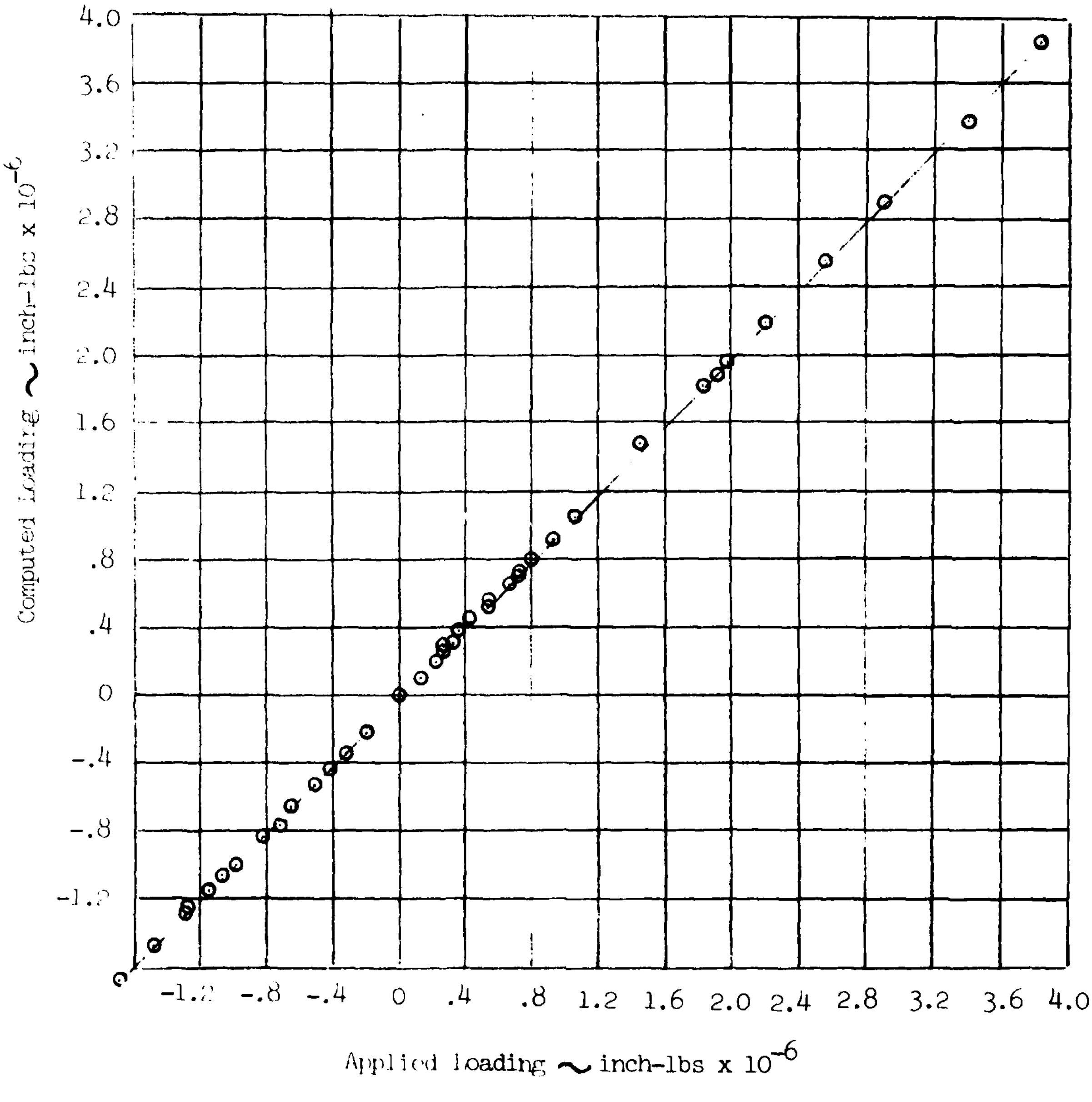


Figure 8 Computed Load vs Applied Load for Torsion at XRS 354

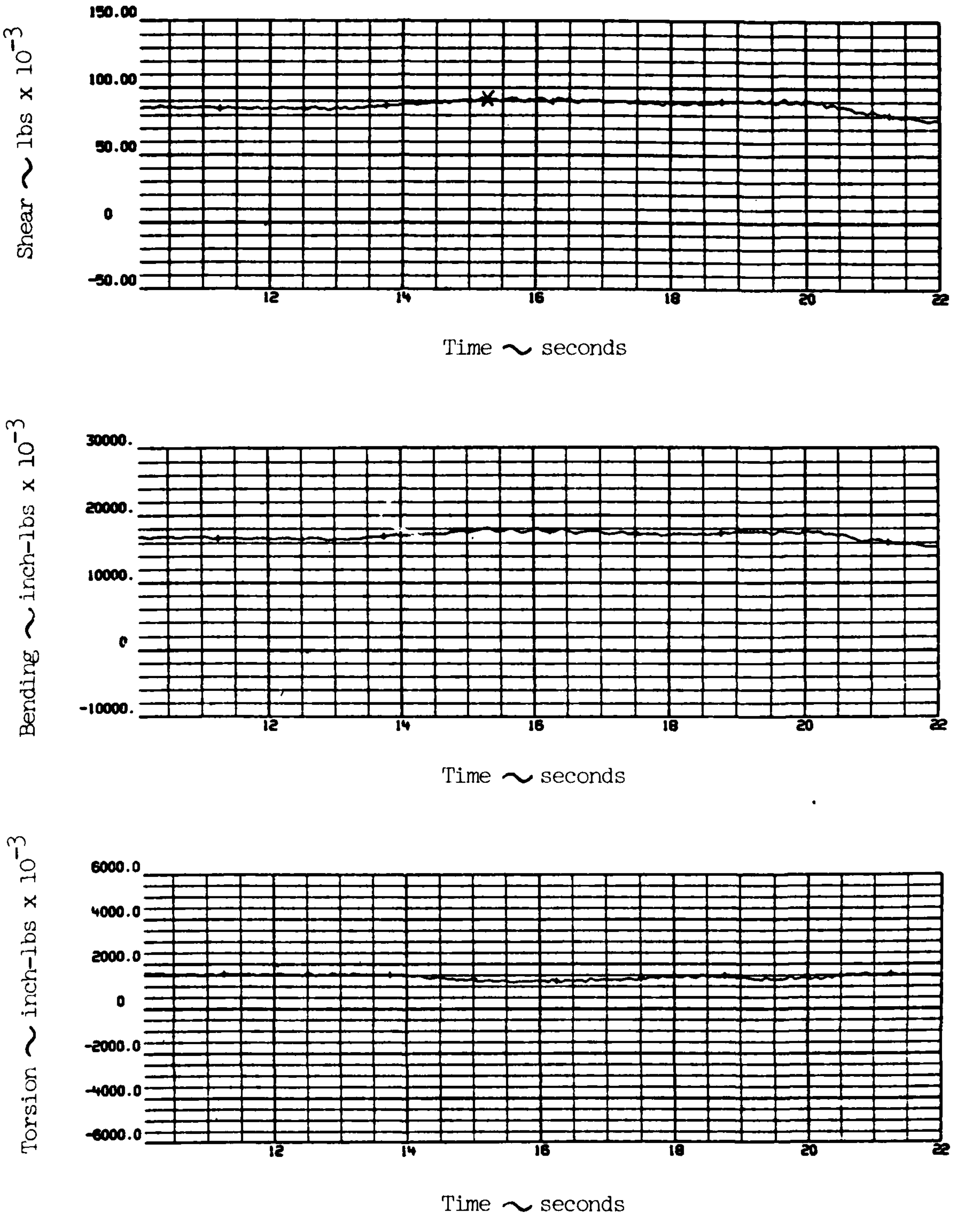


Figure 9 Net Load Time History for a Normal Symmetrical Pullup

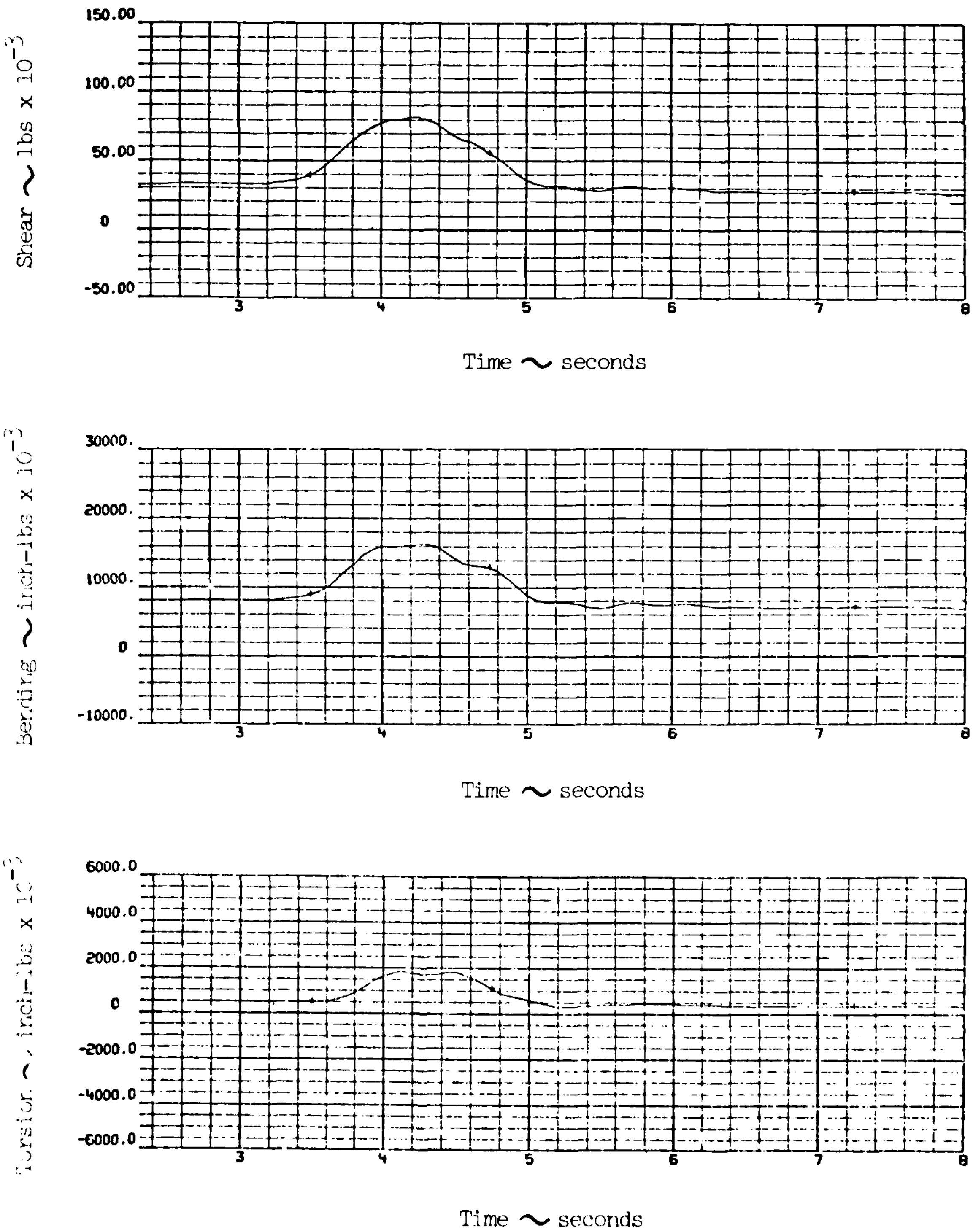


Figure 10 Net Load Time History for an Abrupt Symmetrical Pullup

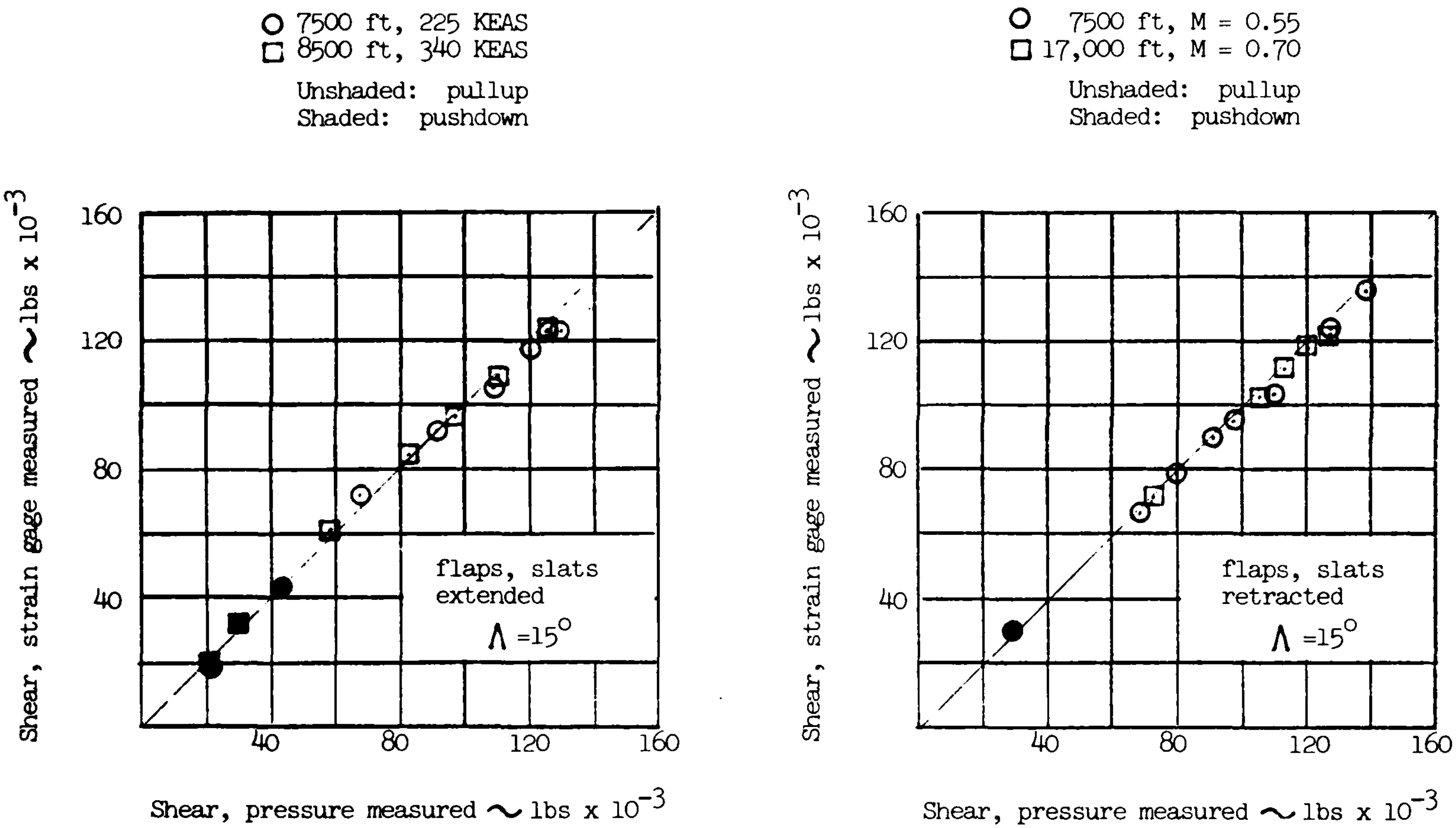


Figure 11 Net Wing Shear Comparison for Symmetrical Pullup and Pushdown Conditions

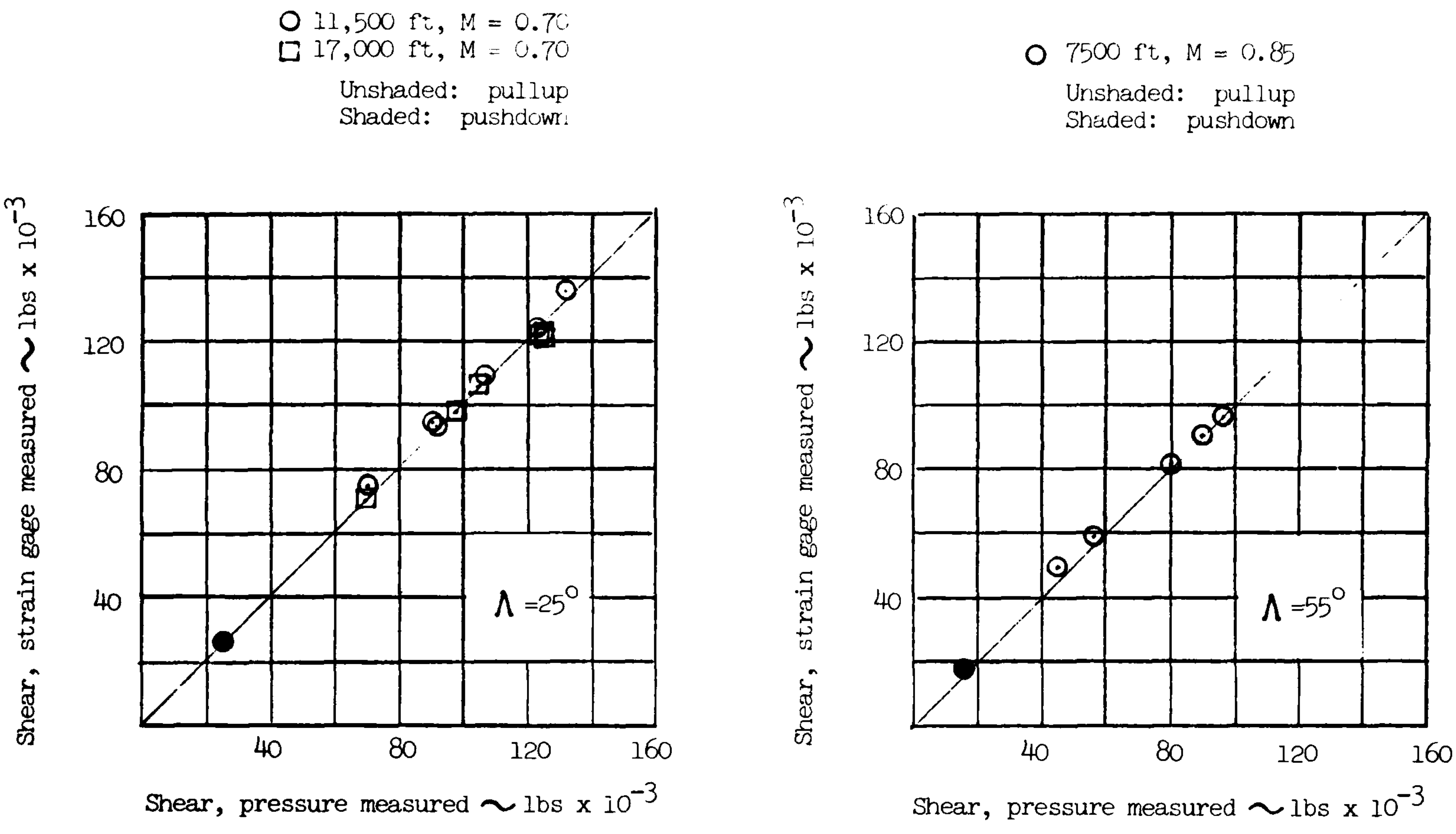


Figure 11 cont'd   Net Wing Shear Comparison for Symmetrical Pullup and Pushdown Conditions

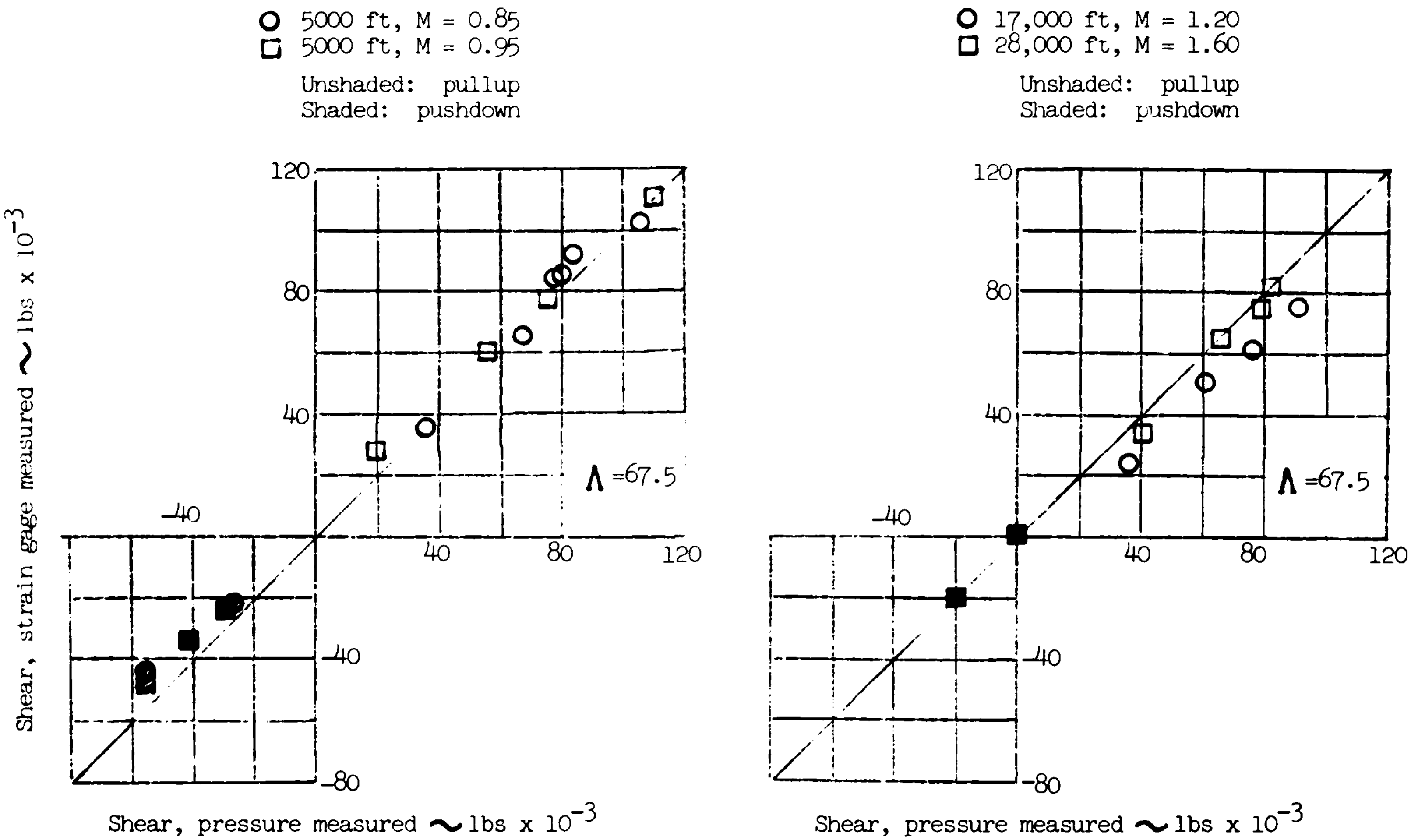
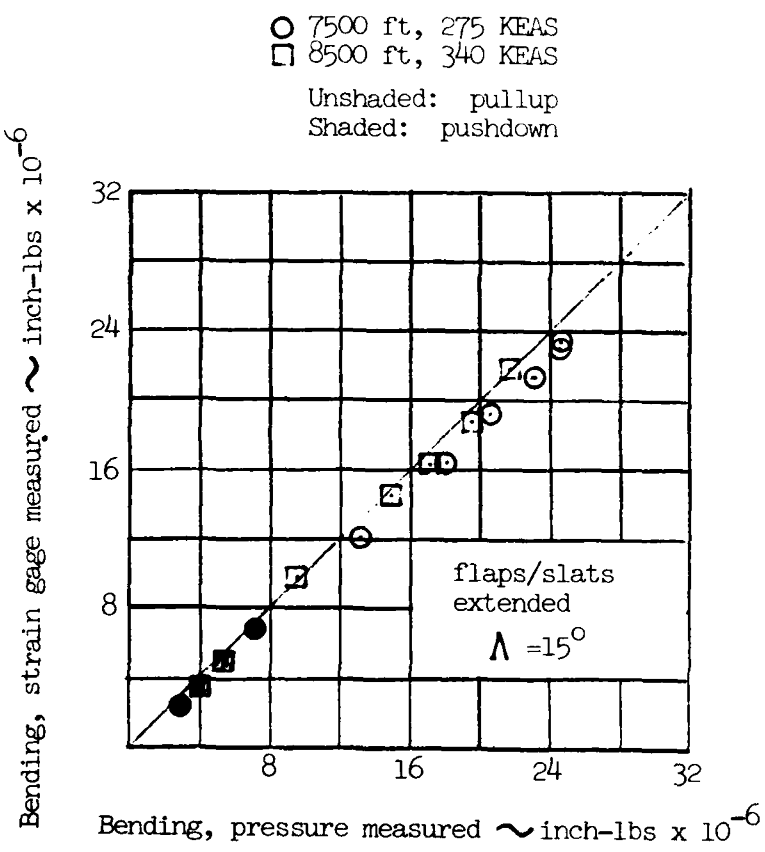


Figure 11, Cont'd Net Wing Shear Comparison for Symmetrical Pullup and Pushdown Conditions



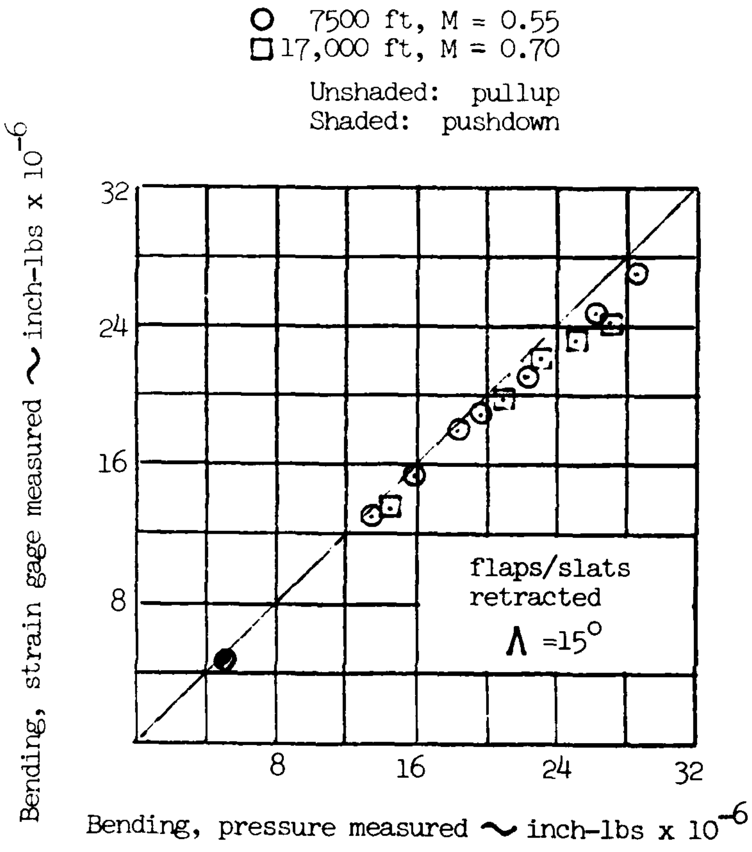


Figure 12 Net Wing Bending Moment Comparison for Symmetrical Pullup and Pushdown Conditions

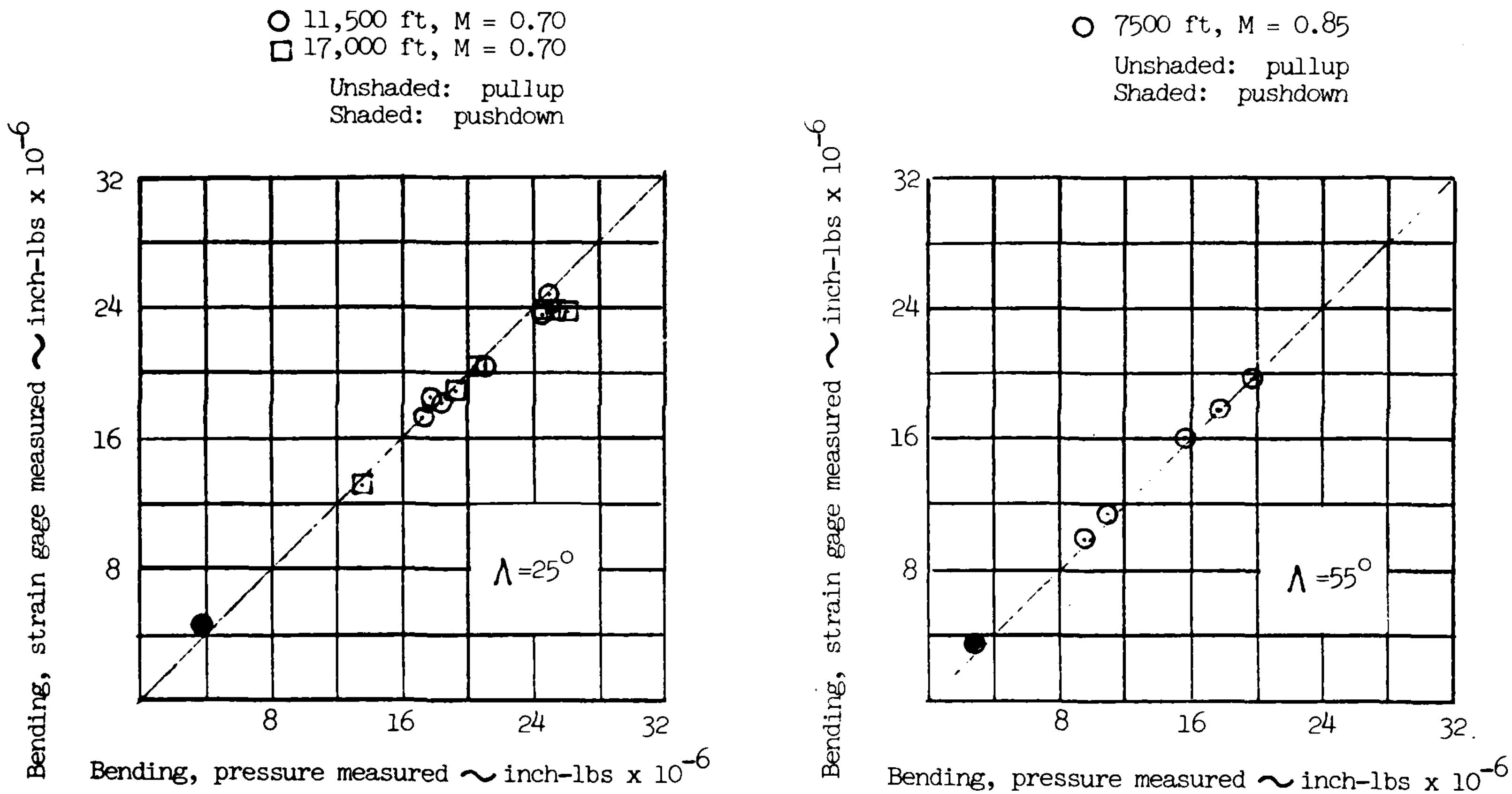


Figure 12 cont'd Net Wing Bending Moment Comparison for Symmetrical Pullup and Pushdown Conditions

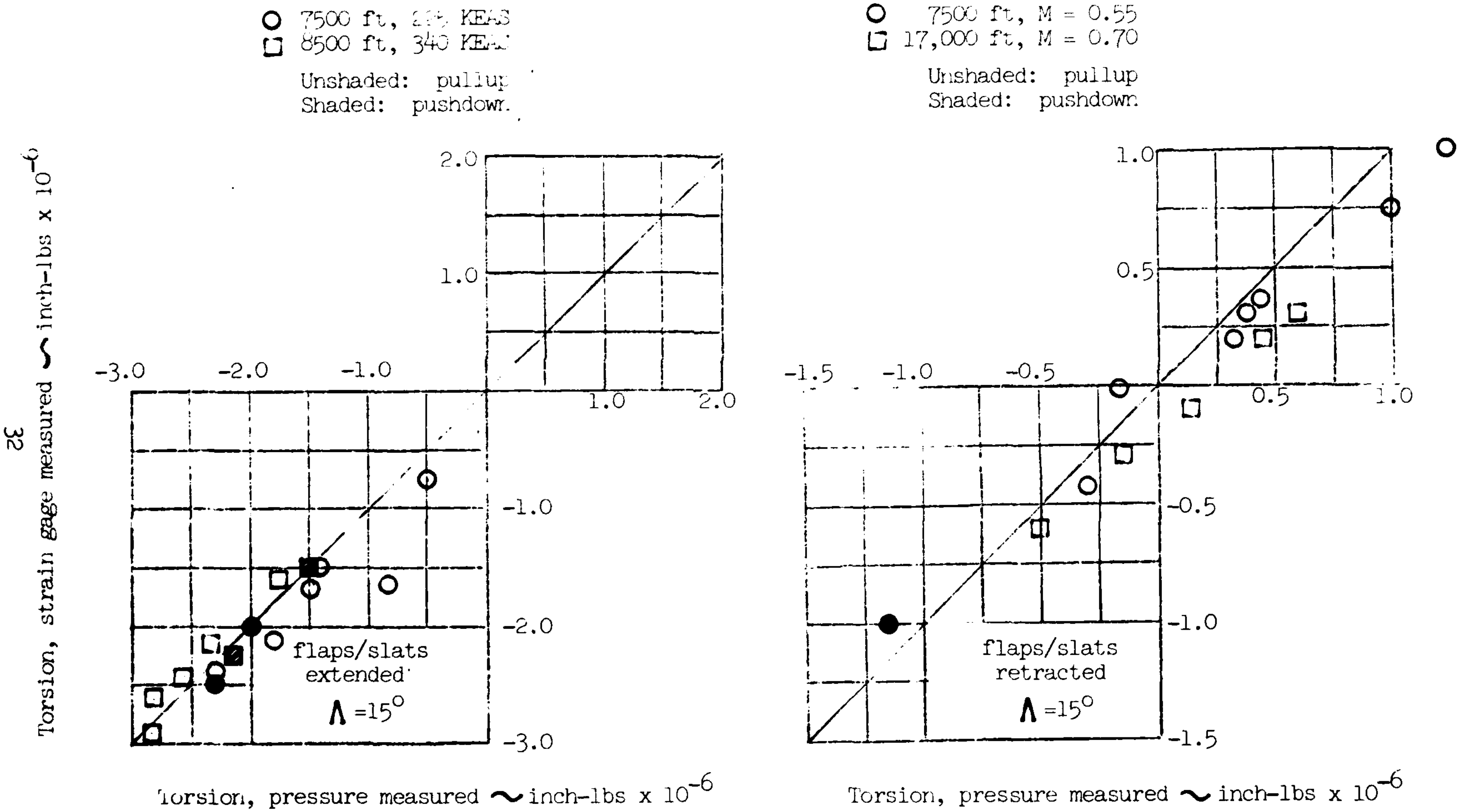


Figure 13 Net Wing Torsion Comparison for Symmetrical Pullup and Pushdown Conditions

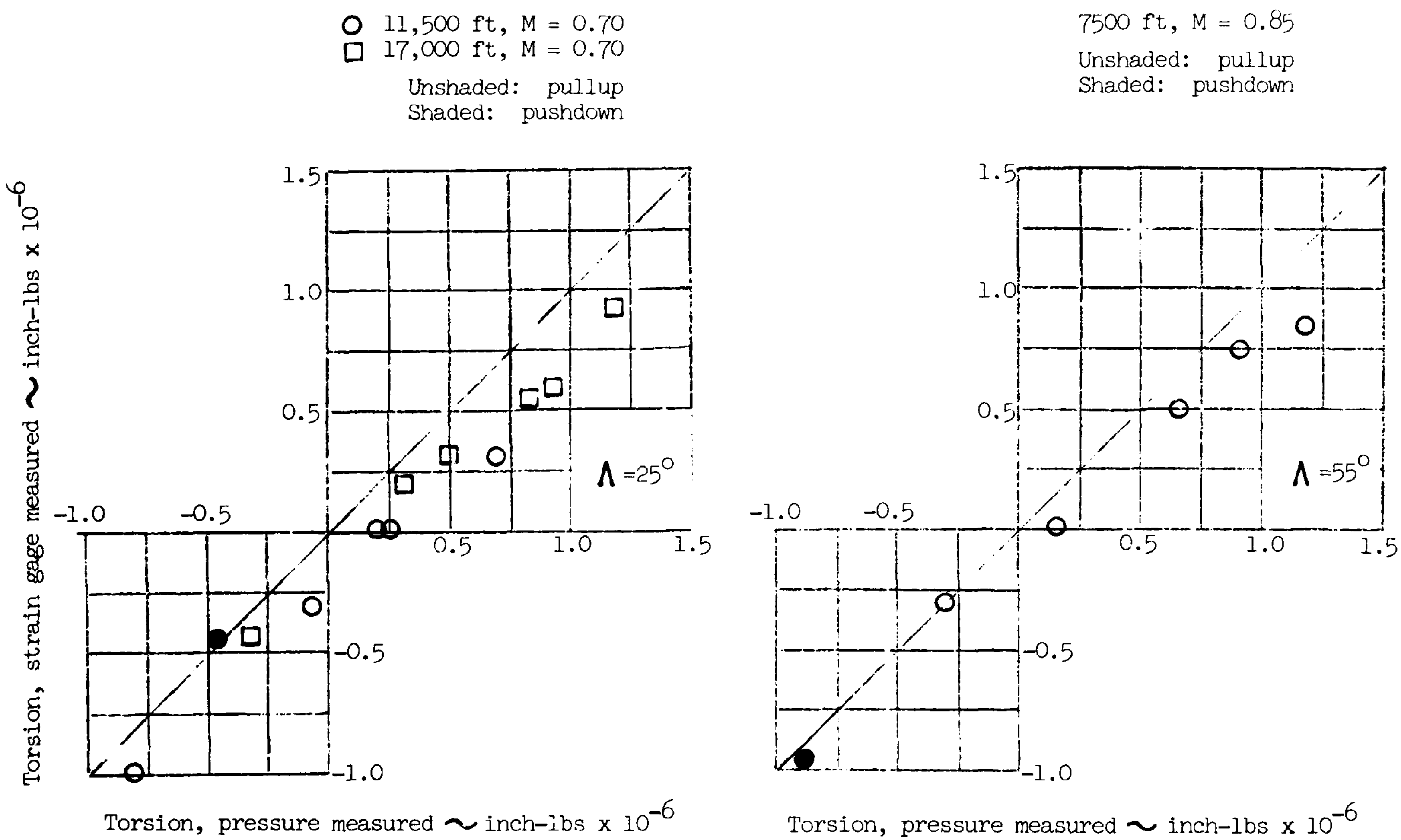


Figure 13 cont'd Net Wing Torsion Comparison for Symmetrical Pullup and Pushdown Conditions

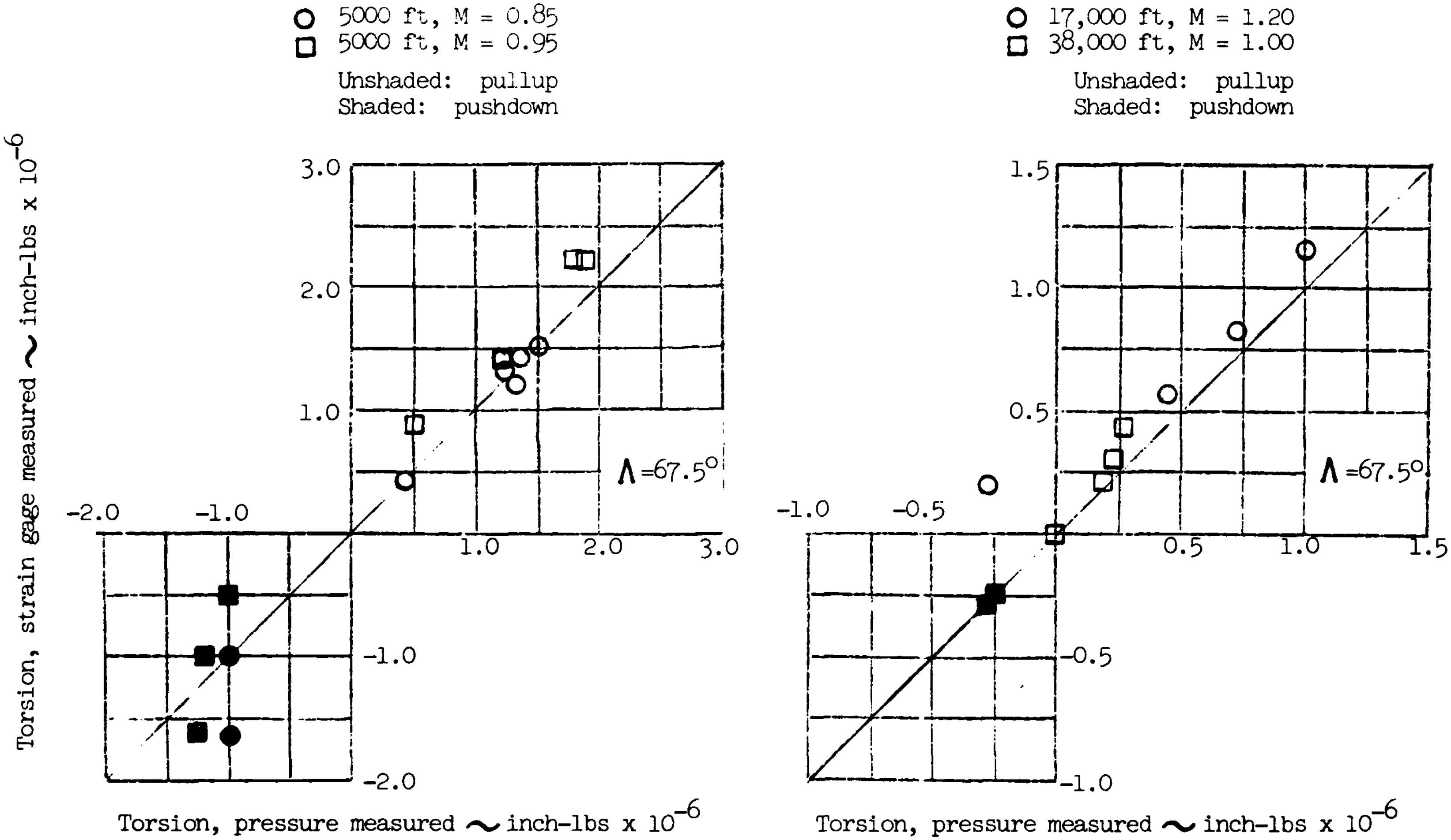


Figure 13 cont'd   Net Wing Torsion Comparison for Symmetrical Pullup and Pushdown Conditions

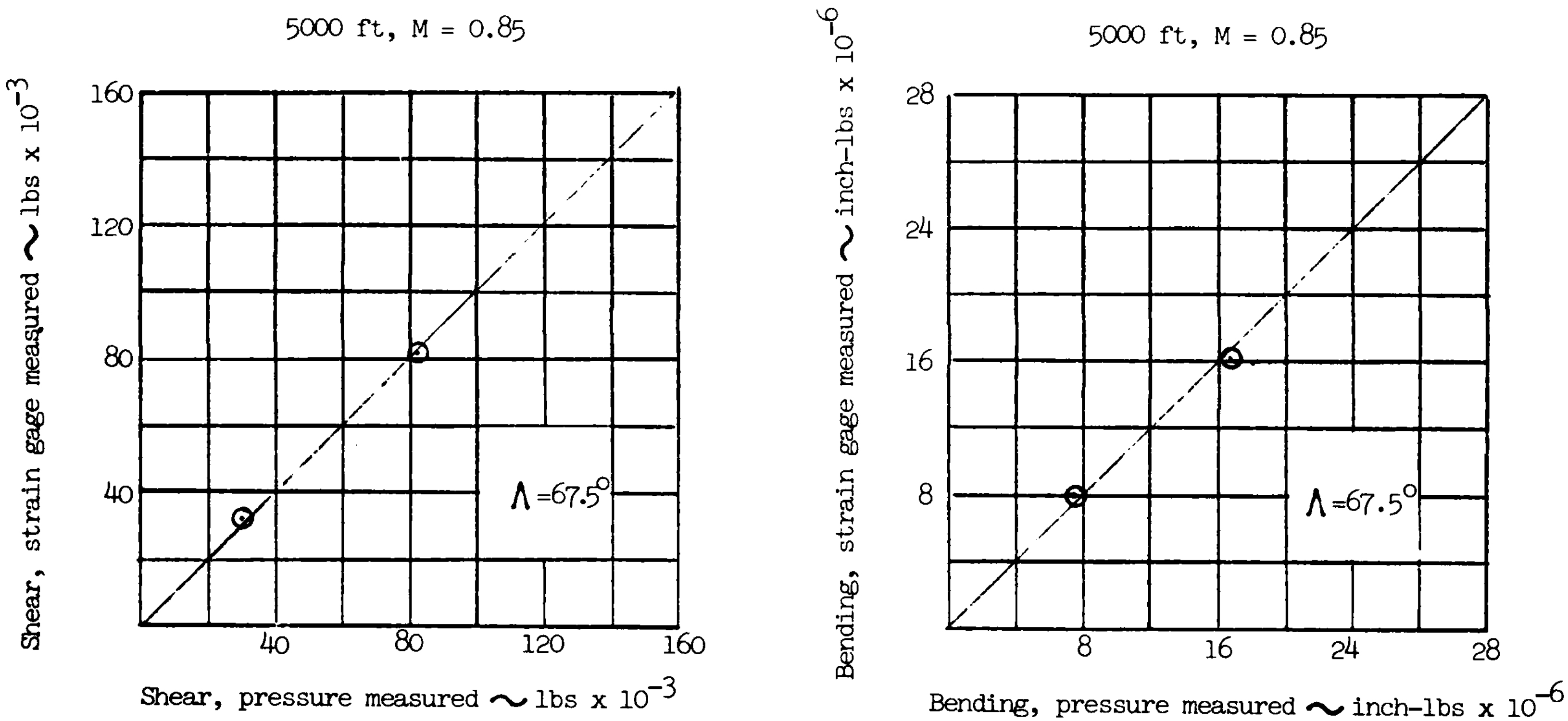


Figure 14 Net Wing Load Comparison for Abrupt Symmetrical Pullup

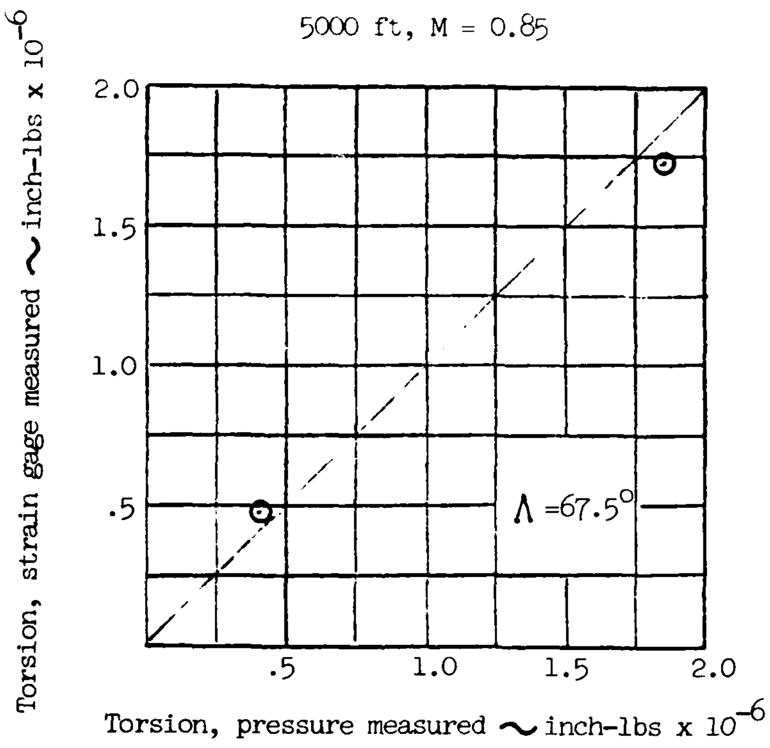


Figure 14 cont'd Net Wing Load Comparison for Abrupt Symmetrical Pullup

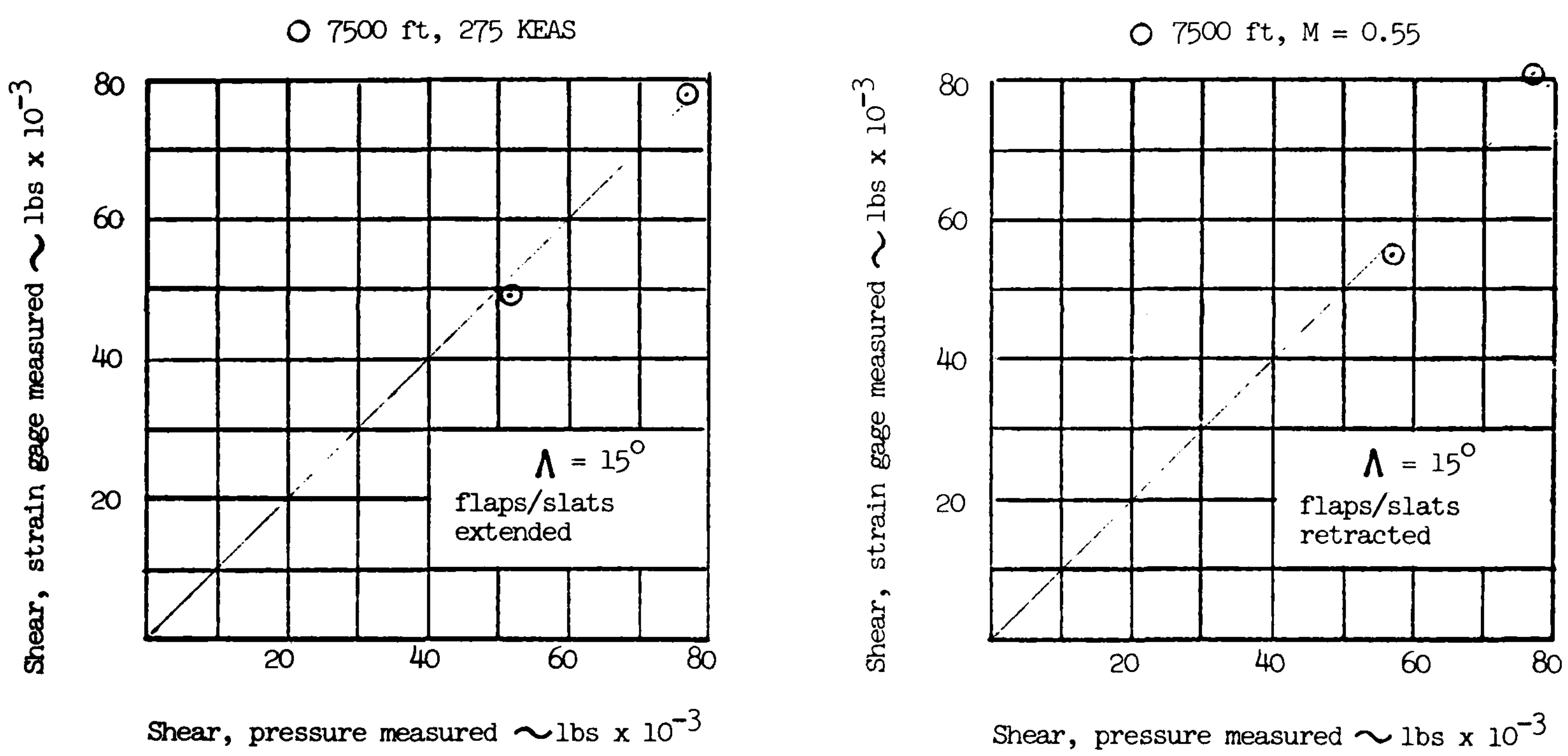


Figure 15 Net Wing Shear Comparison for Rolling Pullout

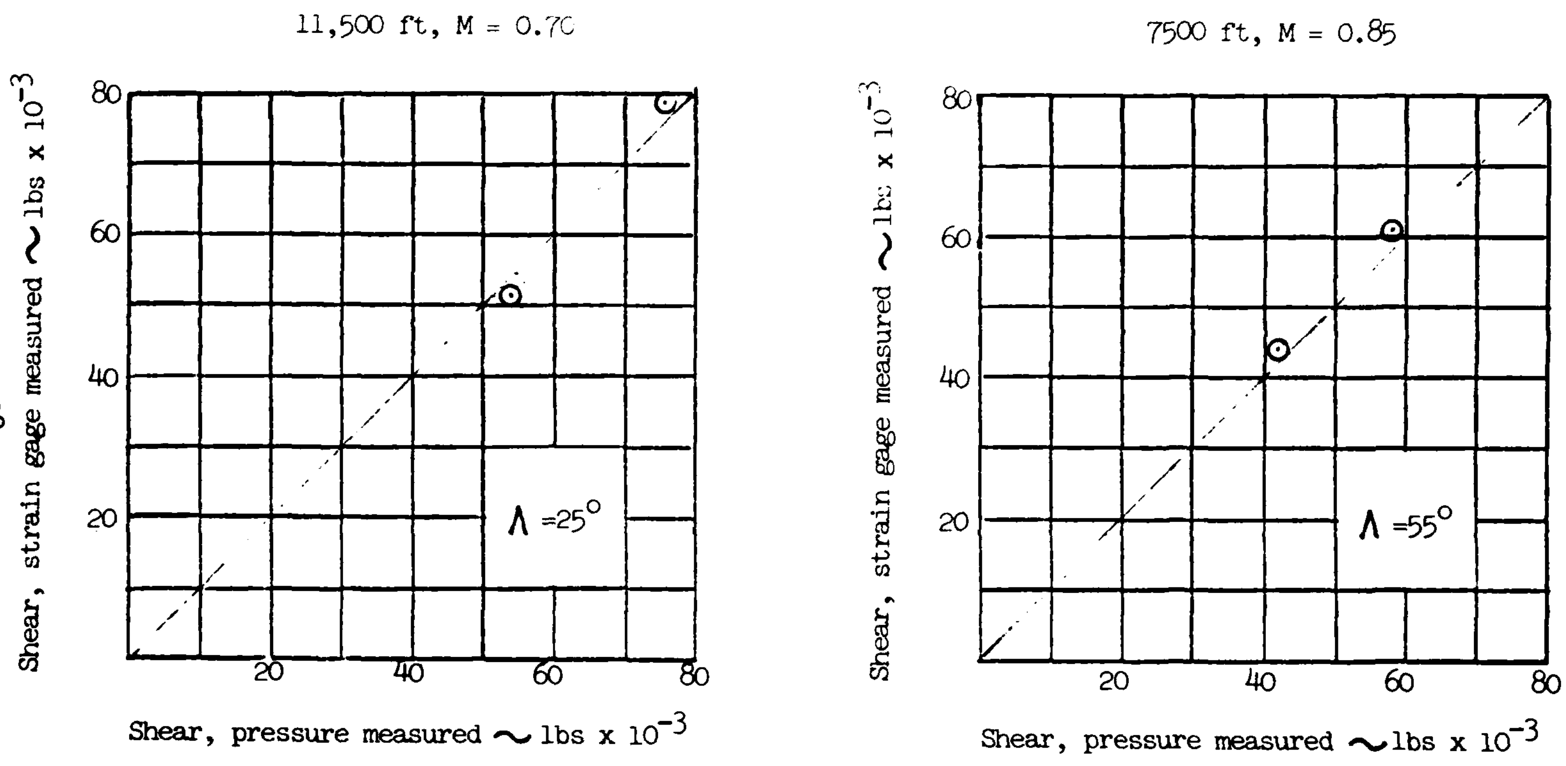


Figure 15 cont'd   Net Wing Shear Comparison for Rolling Pullout

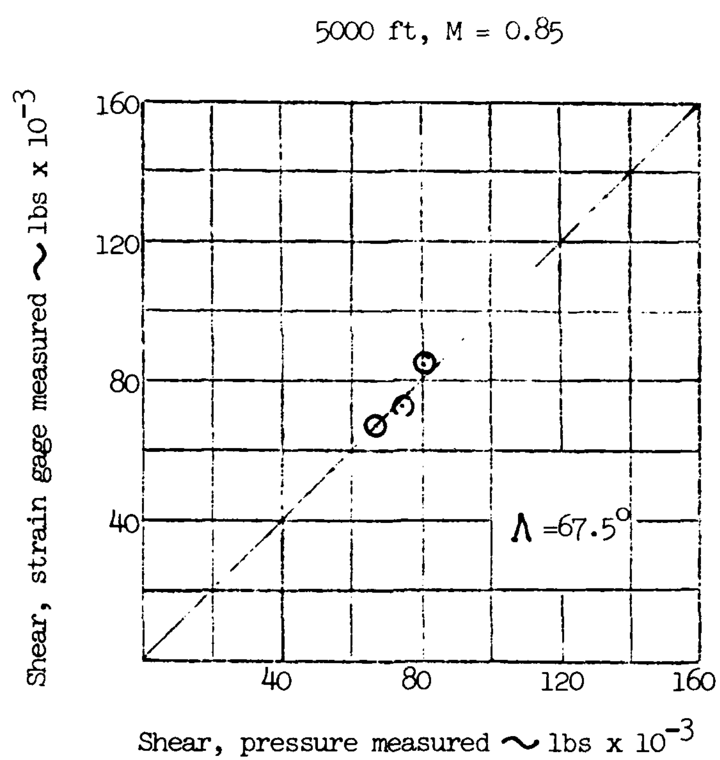


Figure 15 cont'd   Net Wing Shear Comparison for Rolling Pullout

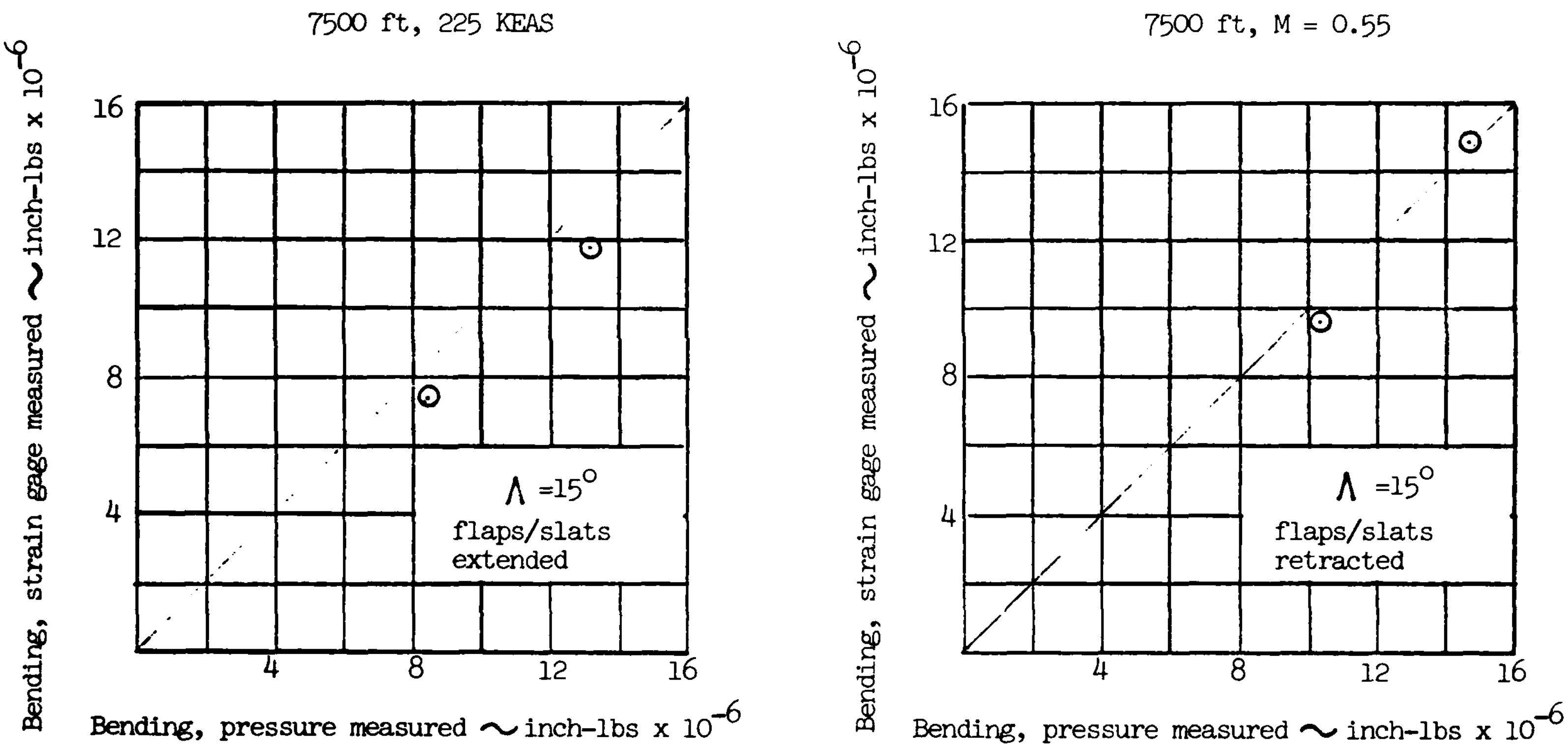


Figure 16 Net Wing Bending Moment Comparison for Rolling Pullout

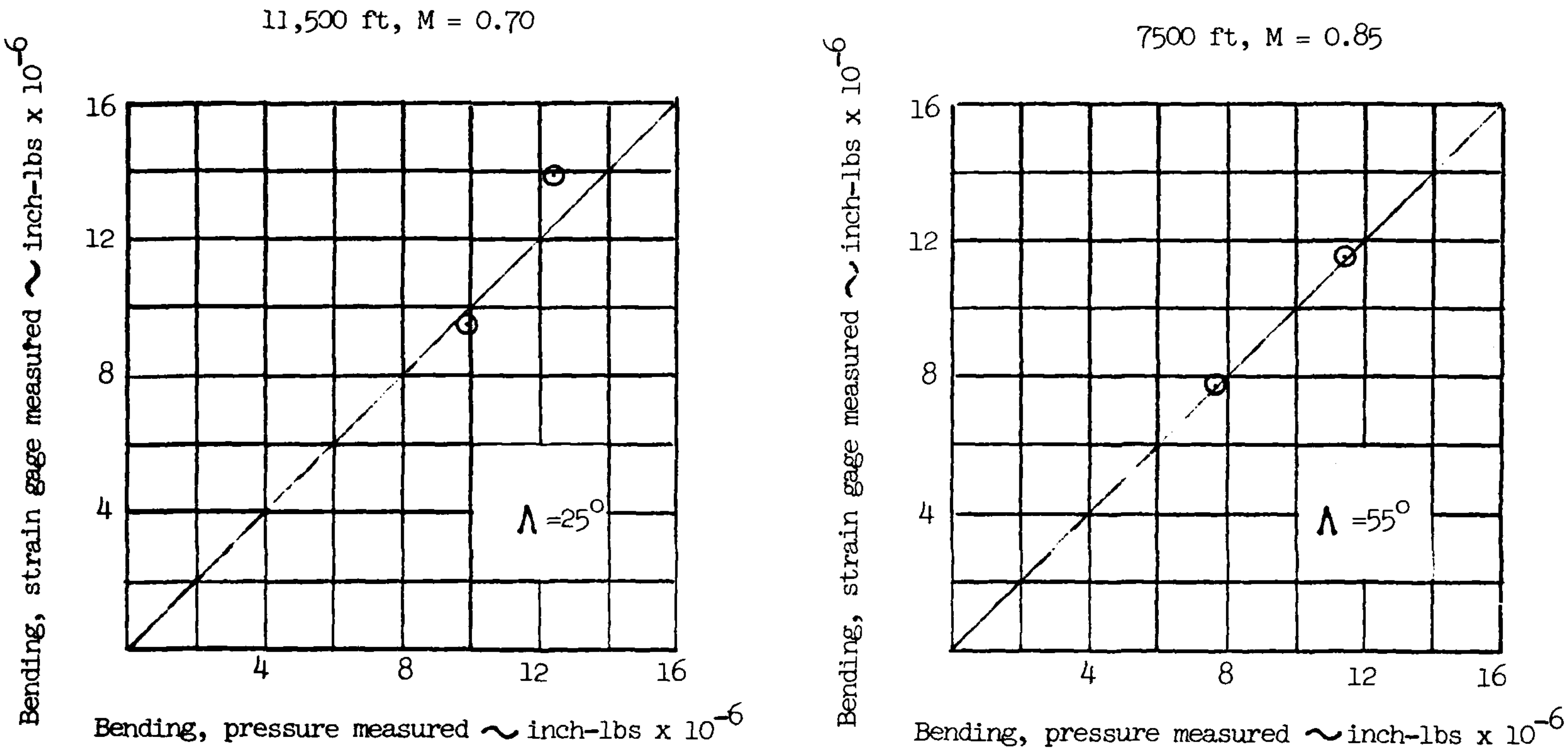


Figure 16 cont'd   Net Wing Bending Moment Comparison for Rolling Pullout

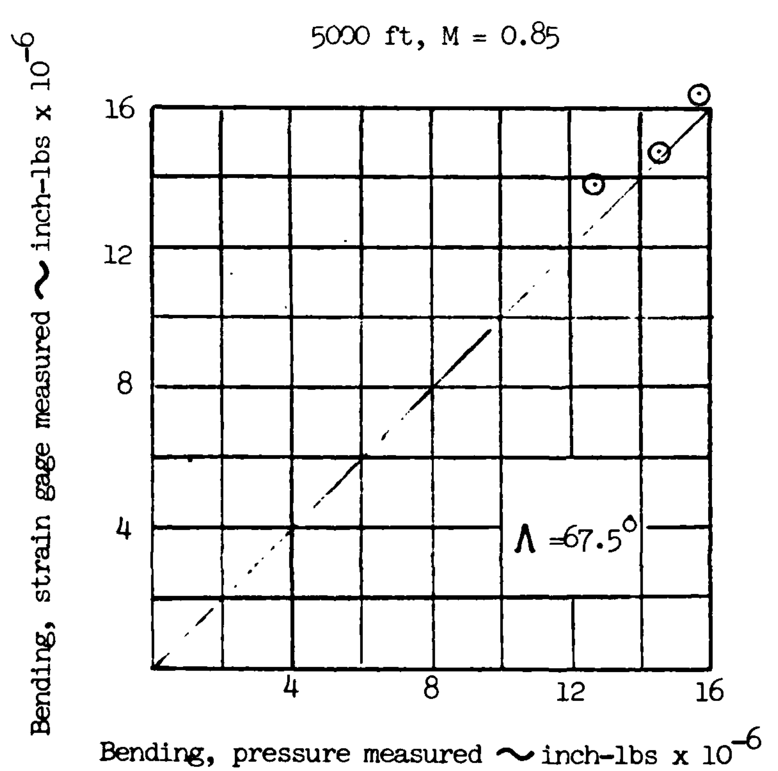


Figure 16 cont'd   Net Wing Bending Moment Comparison for Rolling Pullout

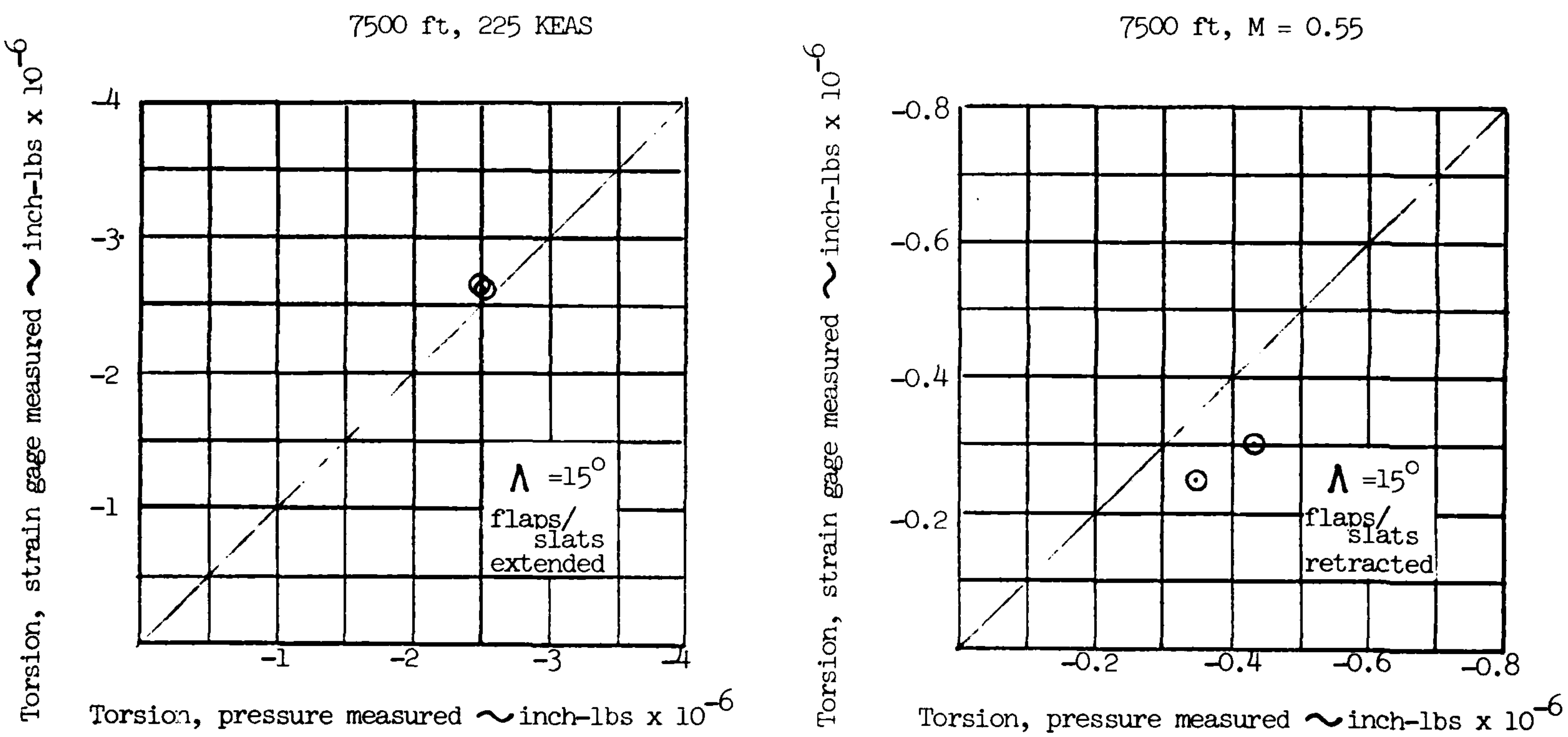


Figure 17 Net Wing Torsion for Rolling Pullout

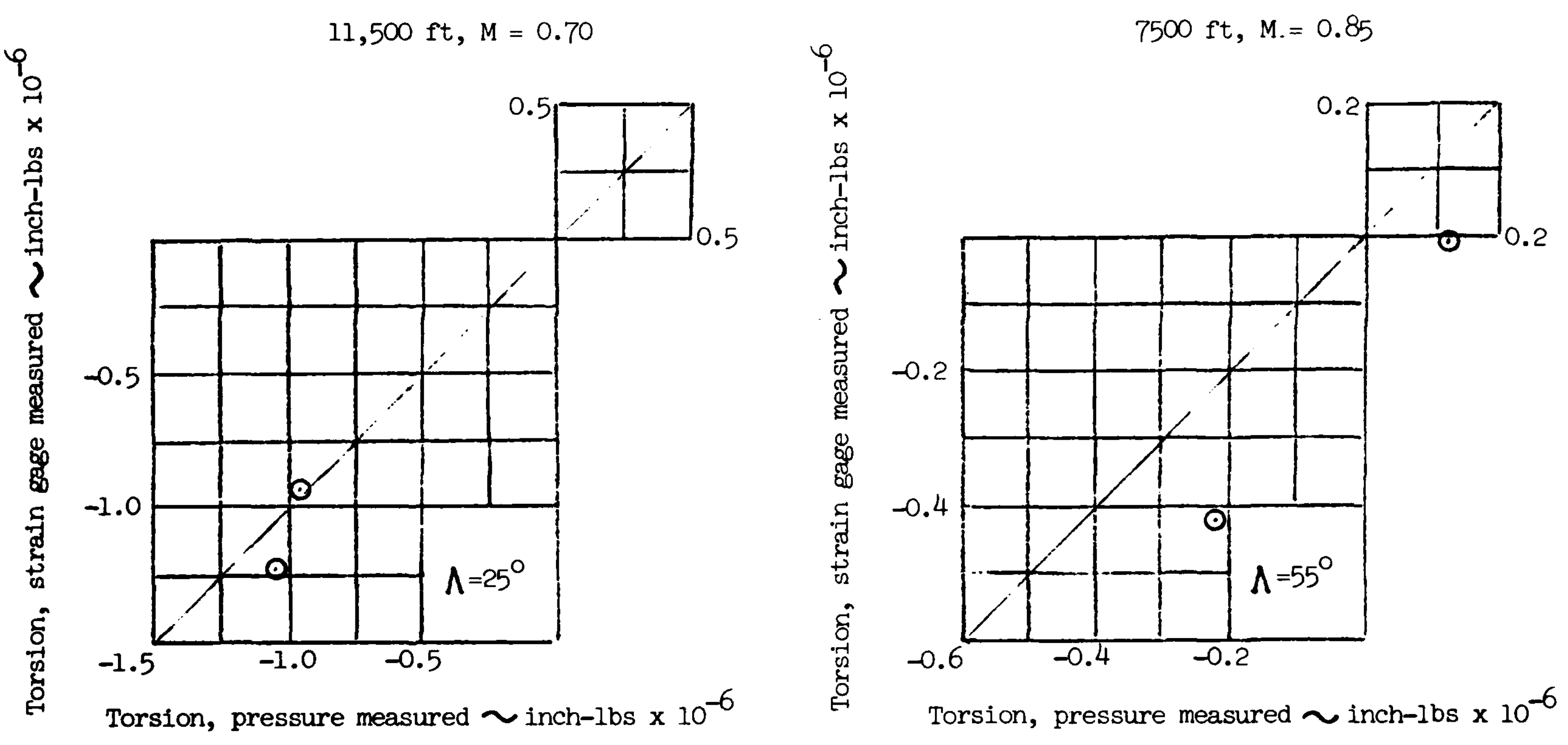


Figure 17 cont'd Net Wing Torsion Comparison for Rolling Pullout

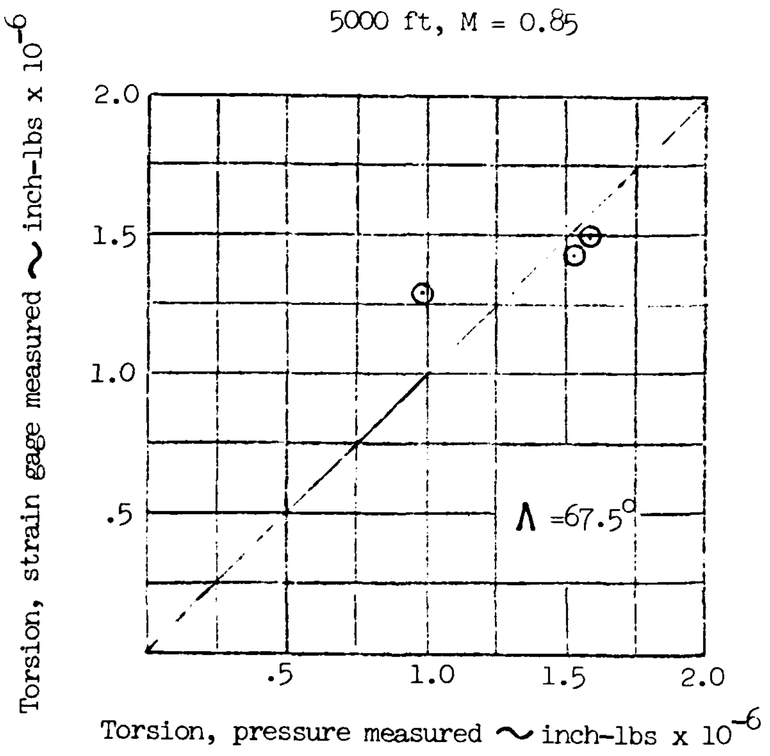


Figure 17 cont'd   Net Wing Torsion Comparison for Rolling Pullout

☆U.S.Government Printing Office: 1980 — 757-002/241

DATE
ILMED
8