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63-2-5

ASTIA 297845

NAVWEPS REPORT 8068
NOTS TP 3074
COPY 99

SKYTOP-2 VERTICAL STATIC FIRING AND ALTITUDE-SIMULATION FACILITY

by

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NAVAD 100

ABSTRACT. This report describes the design, installation and checkout of the Naval Ordnance Test Station's SKYTOP-2 vertical static-firing and altitude-simulation facility. Included are data on the vertical truss/test-stand assembly and the rocket-exhaust diffuser used for altitude simulation. Calibration and performance data from four full-scale POLARIS second-stage firings are presented.

MAR 11 1963

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U. S. NAVAL ORDNANCE TEST STATION

China Lake, California

February 1963

U. S. NAVAL ORDNANCE TEST STATION

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FOREWORD

The work presented in this report was begun early in 1961 when a need was seen for static tests of the A-3 second stage at altitude in the vertical position. The possibility of such a need was foreseen in the original design of the Skytop-2 static firing bay, which was designed for tests in both the horizontal and vertical nozzle-down attitude. Thus, with this bay, and the appropriate superstructure, a motor may be tested in any attitude. Of particular significance is the success of the diffuser for altitude simulation. The brief, preceding, applied-research study using models and cold gas provided a sound basis for the aerodynamic design, which is now being used by other agencies.

This work was supported by Task Assignment SP 71401.

Released by
FOY McCULLOUGH, JR., Head,
Test & Evaluation Div.
30 January 1963

Under authority of
J. T. BARTLING, Head,
Propulsion Development Dept.

NOTS TECHNICAL PUBLICATION 3074
NAVWEPS REPORT 8068

Published by Propulsion Development Department
Collation Cover, 32 leaves, abstract cards
First printing 260 numbered copies
Security classification UNCLASSIFIED

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NEGATIVE NUMBERS OF ILLUSTRATIONS

Fig. 1a, LHL L060907	Fig. 6-39, none
Fig. 1b, LHL L060908	Fig. 40, LHL L067691
Fig. 2, LHL L053809	Fig. 41, LHL L067694
Fig. 3, LHL L076028	Fig. 42-54, none
Fig. 4, LHL L062984	Fig. 55, LHL L073179
Fig. 5, LHL L076136	Fig. 56-58, none

INTRODUCTION

The SKYTOP test facility was built to statically test both production and fleet-return POLARIS rocket engines. The facility presently consists of two main firing bays, a single control building that services both bays, a preparation and conditioning building, a simple high-explosive firing bay, a high-capacity water storage and pumping installation, an inert storage building, test stands, handling equipment, altitude-simulation equipment, and collateral test instrumentation and transducers. The facility also provides an R&D capability for programs other than POLARIS.

Design of the second SKYTOP static-firing bay, started by NOTS in November 1959, was directed toward:

1. Providing a duplicate, backup facility for SKYTOP-1, incorporating experience from SKYTOP-1.
2. Providing a bay as highly resistant to damage as practicable.
3. Providing a vertical, nozzle-down testing capability for the POLARIS program, and
4. Providing maximum capability for other test programs without penalty to the POLARIS program.

Within the above guidelines, NOTS and the Ralph M. Parsons Company of Los Angeles, California, completed the basic SKYTOP-2 facility design in May 1960. Construction of the bay was begun in June 1960, and provides both horizontal and vertical firing pads.

OVER-ALL FACILITY CAPABILITY

Figures 1-A and 1-B show the second bay completed in October 1960. The horizontal firing pad is capable of withstanding a steady-state load of up to 1,000,000 lbs, or a momentary overload of 10,000,000 lbs with appropriate test stand and buttress. The vertical pad at the aft end of the bay will support a force of 200,000 lbs, either upward or downward. Over-all size of the concrete horizontal pad is 30 x 75 ft, with a thickness of 6 ft. The asphalted work area surrounding the pad is 120 x 180 ft.

Although advanced test-stand design generally includes a thrust buttress, and, since this is a major item of facility cost, no permanent,

integral buttress was provided in the pad. Instead, drilled and tapped armor-plate mounting strips were installed in the pad at two locations to permit attachment of a removable buttress. An interim armor-plate buttress capable of restraining a thrust of 500,000 lbs was provided. The two buttress attachments were located on the forward end of the pad to permit the positioning of the engine nozzle exit plane close to the vertical pit, in order to minimize erosive exhaust damage when firing horizontally.

Underground, and approximately 50 ft forward of the pad, are the equipment and cable-termination rooms. The equipment room houses the power supplies, breaker panels and transformer, relay boxes, high-pressure nitrogen bottles, air-compressors, deluge valving, hydraulic control equipment, and air-conditioning for the termination room. The adjacent termination room provides a termination point for control and instrumentation cabling coming from the bay and control room. Here also are the arming and firing power supplies, closed-circuit TV monitor, safety-plug panel, and squib-checking facilities. The building is designed to withstand an impulsive overpressure of 30 psi, i.e., complete detonation of a very large engine in the bay, without damage.

All utilities for SKYTOP-2 are brought into the bay via two underground trenches, one on either side of the pad. At three locations along the length of each trench, each separate utility is provided with a quick-disconnect fitting in order to permit ready access and maintain minimum utility exposure anywhere in the bay. High-pressure air and nitrogen, 110 VAC-1 ϕ -20A, 220 VAC-3 ϕ -30A, 440 VAC-3 ϕ -30A, low-volume cooling-water supply and return, and communications fittings are available at each location. Running parallel to each trench is a 12-inch diameter water deluge line, also stubbed in at three locations on each side of the bay. Flow in these 10,000 gal/min deluge lines is remotely controlled from the fire-control console in the control room by means of two solenoid-actuated valves located in the equipment room. Cooling-water lines provided in the trench circulate water at rates up to approximately 100 gal/min between the bay and a small cooling tower located on the road into the bay.

Instrumentation access in the bay is provided by means of four underground pits, two located near the vertical end and two adjacent to the horizontal firing positions. Distributed between the four pits are 120 low-level channels, 48 high-level channels, 13 servo-command/control channels (basically a four-servo system), 8 control-relay channels, 2 high-amperage power boxes, 2 firing power boxes, and 140 thermocouple channels.

Deluge water for bay cooling and emergency use is provided from two 30,000-gal storage tanks by means of two 6,000-gal/min diesel-powered pumps located near the control room. An alternate 1,100-gal/min pump provided for Bay-1 is also available.

A recent addition to SKYTOP-2 is a low-thrust pad oriented parallel to the original installation. This pad is equipped with horizontal altitude-simulation equipment for POLARIS second-stage engine firings. The equipment is described briefly below.

Control-room instrumentation for SKYTOP-2 is centered around three basic data-recording systems, as shown schematically in Fig. 2. First is the analog tape system. Four Ampex FR-600 14-channel tape recorders provide 52 wide-band FM data channels and four voice channels. Two Ampex FR-100B 13-channel tape recorders provide, through multiplexing, all 120 land-line channels with tape recording capability. All data channels on each test are recorded on analog tape, these tapes then serving as a back-up record of the complete test in the event of failure of the primary digital recorder or damage to a primary tape. Playback equipment is available for multiplexed or FM-recorded analog data for the purpose of examining single channels on oscillographs or for digitizing.

Second is the digital system. Because of the massive quantities of data from each test, some rapid means of data assessment is necessary. The IBM 7090 computing facility can perform this rapid assessment if the data are presented in a language and form acceptable to the computer. This, and the requirement for high accuracy, led to the NOTS development of the Digital Data Processor (DDP). The DDP samples the incoming analog data in a particular programmed manner and sends these samples to an Ampex FR-300 digital tape recorder. Simultaneously, selected channels are micro-waved directly to the computer for real-time assessment and, ultimately, for control of the DDP scan rate on certain critical channels. A total of 12,500 samples per second is taken by DDP.

The third recording system consists of the "quick look" oscillographs. At present two Minneapolis-Honeywell Visicorders and several CEC oscillographs are in use. Annotated analog traces from these devices are usually available within an hour after firing.

Considerable detail is omitted in the above instrumentation description. Additional information is available in a report on the interim digital data processor (Ref. 1), and in a report now in preparation describing the instrumentation as well as in various NOTS procurement specifications.

TEST EQUIPMENT

Above ground at SKYTOP-2 are the various structures necessary for restraining the POLARIS engines during firing. At present two 6-component thrust mounts are available at SKYTOP-2, one for horizontal and one for vertical use.

The horizontal assembly (Fig. 3) consists of a large steel tank which encloses an Alinco 6-component thrust mount. Access to the tank is by means of a large door in one end which permits moving the thrust-mount/engine assembly in and out during test preparation. The opposite end of the tank is designed to permit attachment of an exhaust diffuser for altitude simulation. A mechanical vacuum pump permits evacuation of the tank and diffuser prior to firing. Detailed information on the horizontal assembly firing history is available in Ref. 2 and 3.

In early 1961, at the request of the BuWeps Special Projects Office, NOTS initiated the design of a vertical test stand and altitude simulator for SKYTOP-2. This equipment was to be used for testing POLARIS A3 second-stage engines and thrust-vector-control hardware at simulated altitudes up to 100,000 ft. A rocket exhaust diffuser was chosen for the altitude simulator, and a working model was designed in order to study the exact configuration (Fig. 4). This model study is described in Refs. 4 and 5.

The full-scale simulator design selected consists of a venturi-shaped, second-throat-type exhaust diffuser mounted to the base of the rocket engine by means of a flexible Fiberglas silastic rubber bellows (Fig. 5). The diffuser is rigidly supported, while the engine is floating above it on a vertically oriented, 6-component thrust mount, hence the bellows link. This method of mounting is essential to the measurement of thrust-vectoring force. A vacuum-tight equipment ring is interposed between the upper surface of the diffuser and the bellows in order to provide instrumentation and cabling access to the engine base area.¹

To accommodate the relatively long diffuser and to support the thrust mount and the various thrust loads anticipated in the vertical attitude, a large supporting structure was designed. The design was completed in May 1961, and fabrication and installation were completed by the NOTS Public Works Department in August 1961. The truss, as this structure is termed, measures 35 ft high and 27 ft wide at the base. It consists essentially of two main triangular H-beam back-braces, two side H-beam back-braces, and a 4-section face plate of 1-inch-thick mild steel. The face plate is drilled to permit mounting the thrust stand vertically, with or without diffuser. Additional provision is made for mounting a similar first-stage A1 or A2/A3 stand without diffuser, and for the in-place calibration hardware for each stand.

The diffuser used initially at SKYTOP was a second-throat type generally similar to those previously used at other activities. The contraction ratio was approximately 1.81 with a half angle of 6° , the over-all L/D was

¹ The 6-component thrust mount used in the SKYTOP-2 vertical stand was designed and built by the Baldwin-Lima-Hamilton (BLH) Corporation, Waltham, Mass. Although the mount was originally designed for horizontal use, it was adapted to vertical use as well.

approximately 7.1, the second throat L/D was 6.0, and a 2.4:1 subsonic diffuser of 6° half angle was employed. The total diffuser length was 26.5 ft. Model data indicated that this configuration should run above 50,000 ft at engine peak pressure. The diffuser consists of a 0.10-inch-thick Type 321 stainless steel liner of the above configuration. The liner is helically wrapped with a steel baffle on the exterior to direct cooling-water flow. The liner and baffle are surrounded with a 0.25-inch-thick mild steel water jacket which contains appropriate plumbing connections. Approximately 6,000 gal/min of cooling water are directed through the water jacket during firing. The water exits in a film inside the tube at the juncture of the second throat and subsonic diffuser and is swept out with the exhaust. The subsonic end consists of 0.5-inch-thick mild steel and is not jacketed. Detailed mechanical design of the diffuser system was accomplished by the Marquardt Corporation, Van Nuys, California.

The base-mounted diffuser approach, adopted by the Station for reasons of cost, time and operational convenience, is unique in large rocket engine testing. Essential to the success of the complete thrust-mount/diffuser system is the coupling between the engine and diffuser, for which the Station designed a bellows seal device. It consists of a molded, silastic-impregnated, Fiberglas bellows, mounting and support rings, with 0.10-inch-thick interleaving stainless-steel heat shields on the interior. The design of this device will be the subject of further study in the near future, in order to determine the bellows compliance under vacuum as a function of its design.

The third diffuser-system element is the equipment ring. This provides the vacuum-line inlet for initial drawdown to the desired ignition altitude, the transducer mounting fittings for determining diffuser performance, the water spray manifold for post-firing quench of the engine-base area, and the vacuum-tight electrical connectors for cabling access to transducers and to servo-controls on the engine base.

Auxiliary diffuser equipment consists of work-area platforming, deluge plumbing, hydraulically controlled mounts for elevating and lowering the diffuser during test preparation, and vacuum pump and control valves for evacuating the diffuser to altitudes of up to 100,000 ft prior to firing. Seal doors are provided on the diffuser exit to permit the prefiring evacuation. These doors are held in place by a special jack until the tube is partially evacuated, at which time the jack is released and the door is entirely supported by atmospheric pressure.

TEST RESULTS

The assembly of the BLH second-stage thrust mount proved to be quite a problem. Manufacturing defects and missed tolerances made assembly very difficult, requiring considerable rework both by NOTS and BLH. Alignment

and in-place horizontal calibration of the stand was completed only with difficulty, for similar reasons. Detailed assembly and calibration procedures are available in Ref. 6. The calibration method and hardware proved so cumbersome that no attempt was made to undertake such work after the stand was mounted vertically on the truss.

Typical calibration curves for the initial setup are presented in Figs. 6-38, which include the interaction forces and stand deflections experienced in this first-time setup. Although actual force levels are shown, curve shapes are only "typical" since each stand realignment produces a unique set of exact calibration curves. Initial bias loads attributable to the mass of various cradle components, handling harness, and the engine itself also vary with each realignment and assembly. The curves represent two runs on each strut being calibrated. No means was available for preloading the main thrust axis during lateral axis calibration, which the Station believes is essential to a complete, in-place calibration. However, this fact was not recognized during procurement of the BLH equipment. Further, no means of calibrating the main thrust axis in tension was provided. Due to the physical arrangement of the BLH thrust mount, the roll-strut (FY3) calibration required placing the calibration strut midway between the aft yaw strut (FY2 and FY3); hence these latter curves include a sizeable increment of interaction attributable to the simultaneous load on FY2.

Assembly of the vertical test stand was completed on 3 October 1961. On 4 and 5 October a series of four deflection runs was made using the TWANGER hardware (Figs. 39 and 40). The purpose of this effort and the later two TWANGER firings was to structurally check out the BLH mount/truss assembly. A concrete-filled dummy engine was mounted in the stand to simulate the mass of an actual live engine. The TWANGER assembly consisted of an attaching ring and strongback on the dummy engine, and a tie-down and jacking arrangement at deck level. A single rod connected these two parts through an explosive bolt device (Fig. 41). By means of hydraulic jacks the main thrust axis then could be loaded in the downward (tension) direction to a level approximating the maximum loads to be expected from the diffuser. When the explosive bolt was actuated with the stand thus tensioned, the resulting oscillations were observed on all six stand load cells and on several accelerometers. Deflection runs up to full thrust level were made preceding the actual firing, to determine that the stand was secure on the truss, that the truss would sustain this static load with little deflection, and to obtain load-deflection and interaction data for later analytical work. Complete details of this work are contained in Ref. 7. Figures 42-48 present the deflection and interaction data obtained from this work. Not shown are the analog firing recordings, which showed the fundamental frequency in the main thrust axis of the fully-loaded stand to be approximately 15 cps.

The diffuser installation was completed on 9 November 1961. A check-out firing with Aerojet-General Corporation engine 2PA1-69 was successfully completed on 15 November (ST-43). For this firing the engine was prepressurized

and the diffuser evacuated to a level of 86,000 ft, where seal-door leakage prevented further evacuation. Complete details on this test are available in Ref. 8.

At ignition, a pressure surge of very short duration was noted as the seal-door released. Hard pumping at a steady level of approximately 60,000 ft began within 0.25 sec of ignition. Ballistic performance was normal, and as pressure decayed in the rocket engine, the altitude level gradually increased to approximately 70,000 ft at the point of unstaring (182 psig). Engine base pressure measurements indicated some flow reversal due to altitude during firing, as expected.

Diffuser aerodynamics and heat transfer with the engine were completely satisfactory. No evidence of overheating was noted on any facility or diffuser equipment. Generally, neither the water nor diffuser skin temperature increased significantly over the tube length during firing. A temperature of approximately 1200° F at 40 sec was measured in the base area cavity.

The main thrust trace was unusual, as expected. With the diffuser vacuum creating a reverse force on the engine, the entire run was in tension. To obtain main thrust data on this stand a continuous, full-burn-time correction for diffuser vacuum had to be calibrated for, and applied during data reduction.

The chief area of interest in this first firing, aside from diffuser performance, was side-force performance of the BLH thrust mount. Since this firing was a ballistic shot with no thrust vectoring, it would be expected that interaction forces due to main thrust would be observed with levels similar to those of the previous calibrations. This was not the case, however. Considerable ringing was noted on all side-force transducers. For several seconds following ignition this oscillation followed the main thrust frequency; then each strut lapsed into its apparent natural frequency under the influence of some unknown oscillatory load. It is believed that at least part of this ringing was attributable to binding which developed between the upper and lower bellows heat shields. Additional factors which could contribute individually or in combination to these forces are (1) vibration of asymmetric cradle masses (inherent in the stand design), (2) pressure oscillations in the diffuser (not detected on gages used), (3) malalignment of the engine, the diffuser, or their combination, and (4) truss vibration. Since no horizontal firings or vertical firings without diffuser were ever made with this thrust mount, no comparisons of this kind can be made to help isolate the cause of ringing. Modification of the bellows heat shields to provide positive clearance, and a very careful alignment, did slightly reduce the ringing amplitude on several subsequent firings, but it was still quite evident.

A second firing was made on 12 March 1962 (Ref. 9) using Aerojet engine 2PAL-70 (ST-51). The test setup was nearly identical with the previous one.

and test results were very nearly the same. Diffuser performance was slightly improved over the first firing. An altitude of approximately 80,000 ft was achieved at the diffuser unstart point (180 psig).

Figures 49-52 present the diffuser performance at ignition (0 - 1.2 sec) for these first two firings (ST-43 and ST-51), together with an expanded plot of the engine chamber pressure over the same interval.

A third firing, using ABL POLARIS A3 engine RH434 on the vertical stand (ST-44), was unsuccessful (Ref. 10). This engine employed fluid injection throat vector control. Vacuum was lost at approximately 3 sec after ignition. Two events, singly or together, caused this malfunction. First, since the diffuser was fired for the first time with no prefiring evacuation, the bellows was unstressed to its fullest extent (Fig. 53 and 54). Two large tears were found in the bellows fabric after firing. (Because this was the third firing using this bellows, a fresh coating of PR-1910 silastic rubber compound had been applied on the inner fabric surface to augment its heat resistance.) Secondly, the diffuser liner burned through in a number of small spots in the entrance section, releasing a considerable amount of water into the diffuser. Some of the water feeding back into the base area of the tube, could have flashed and broken the vacuum. Since the vacuum loss occurred within 3 sec of ignition, and since the entrance section burnthroughs all occurred well within the point of first impingement, it is believed that the bellows tears under the impact of ignition were the first event to occur. Motion picture coverage, although not too clear, supports this theory.

Burnout spots in the entrance section occurred uniformly beneath each nozzle and were located in the areas of highest heat sink, i.e., where the helical water baffle passed beneath each nozzle on the outside surface of the inner liners (Fig. 55).

Following the third firing a study of the diffuser water-deluge system was conducted, as reported in Ref. 11. The water system was instrumented carefully from end to end, and it was found that approximately 6,000 gal/min of water were flowing at a pressure in the diffuser of less than 10 psig. Successive weldings at the tube water exit incrementally raised the water pressure to over 55 psig without collapsing the inner liner. As a result of this study, which confirmed suspicions already in mind, a water flowmeter was installed in the deluge line, diffuser dimensions were altered to increase the cooling water pressure flow rate in the tube, and refinements were made in the water-helix welds on the next tube. At the same time the SKYTOP water system was expanded from 6,000 to 12,000 gal/min.

Additionally, it was concluded that the metal oxide slag formed during propellant combustion was condensing on the stainless steel liner and causing burnout. Metallographic analysis of stainless steel liner samples taken from the burned out areas of the third firing showed that a chemical

reaction had taken place between the high-temperature metal oxide or free metal from the exhaust stream and the stainless liner. Further tests are planned to investigate this chemical attack.

As a result of the third firing test and the subsequent investigations it was decided that a protective insert in the diffuser entrance section was the only means of guaranteeing operation throughout burning. Accordingly, a new diffuser being fabricated at Production Steel, Inc., Los Angeles, was modified to receive a protective insert. This insert was made of ATL graphite billets assembled and machined to the required shape.

On 22 July 1962, the fourth test on the vertical stand, and the first employing the graphite entrance section in the base-mounted diffuser, was successfully completed with ABL POLARIS A3 engine RH484, ST-60 (Ref. 11). Maximum altitude was achieved just prior to unstart at 59.0 sec (Fig. 56). The level was 73,300 ft at an engine chamber pressure of 119 psig. In mid-burning and during vigorous thrust-vectoring the altitude reached a minimum level of approximately 37,000 ft. However, when the thrust vector program was stilled at 43 sec, hard pumping took place down to the above-stated maximum at unstart. It is of interest to note this system's sensitivity to freon injection thrust-vectoring, as shown in Figs. 57 and 58. This is not noted in a cabin system due to the volumetric damping of the cabin cavity. Some bulging occurred in the thin inner liner in the region of the second throat, probably resulting from a combination of high water pressure behind the hot steel, and thermal expansion. Approximately 9800 gal/min of cooling water were used on this test. Graphite section performance was satisfactory. The graphite was found to be eroded approximately 1.5 inches deep in an area under each nozzle. Some cracking occurred in the graphite, probably as a result of cooling and water quench after firing. It was not possible to reuse this section. Due to the high cost of machining this first-time insert, new methods of forming these parts are being investigated. Additionally it is planned to investigate alternate materials as another approach to cost reduction.

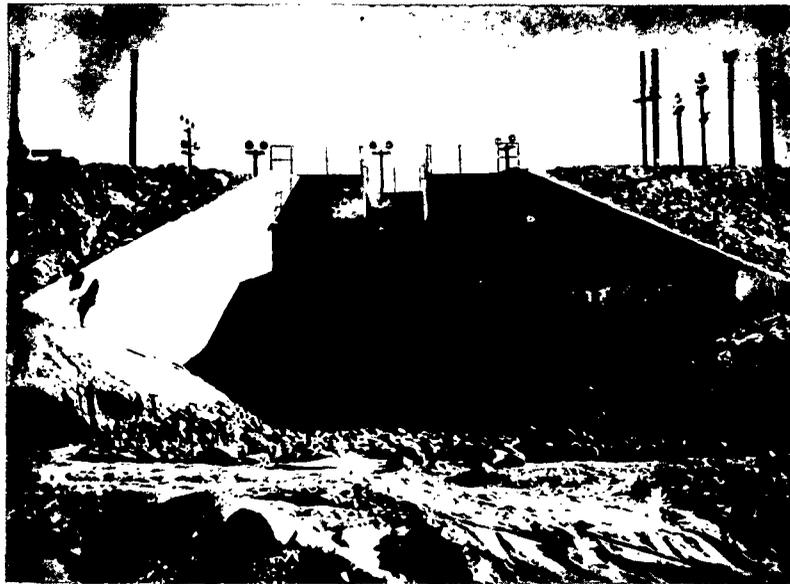
Table 1 and Figure 58 summarize the four vertical firings discussed, and illustrate the ignition action in each case.

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(a) Horizontal pad.



(b) Vertical pad.

FIG. 1. Skytop 2 Firing Bay, October 1960.

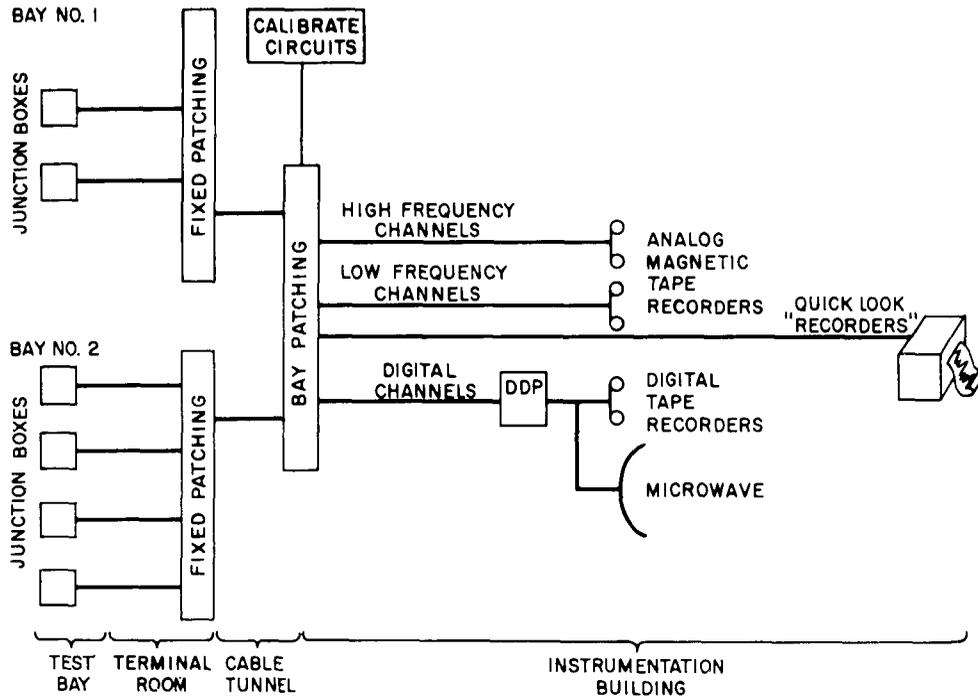


FIG. 2. Skytop Instrumentation Schematic.

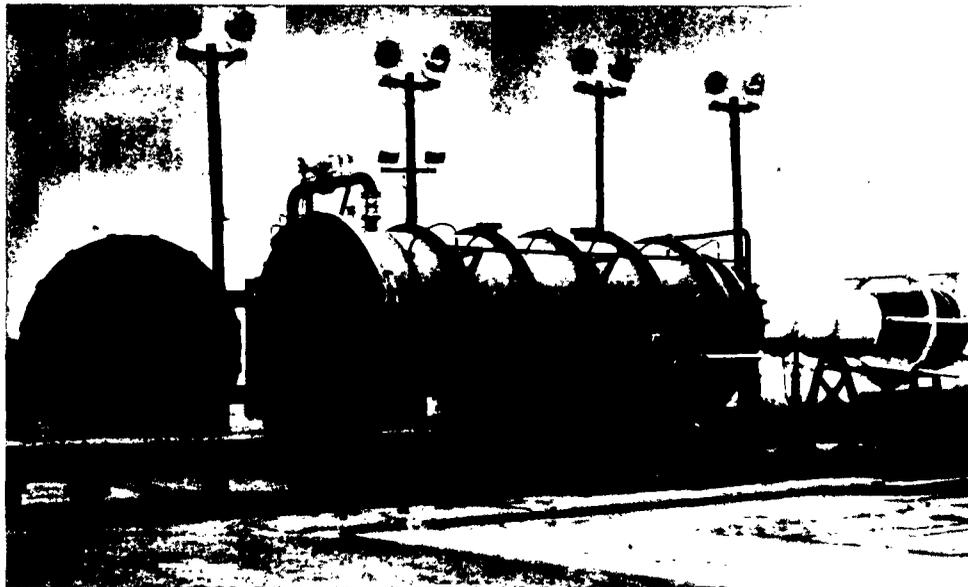


FIG. 3. Horizontal High-Altitude Simulator.

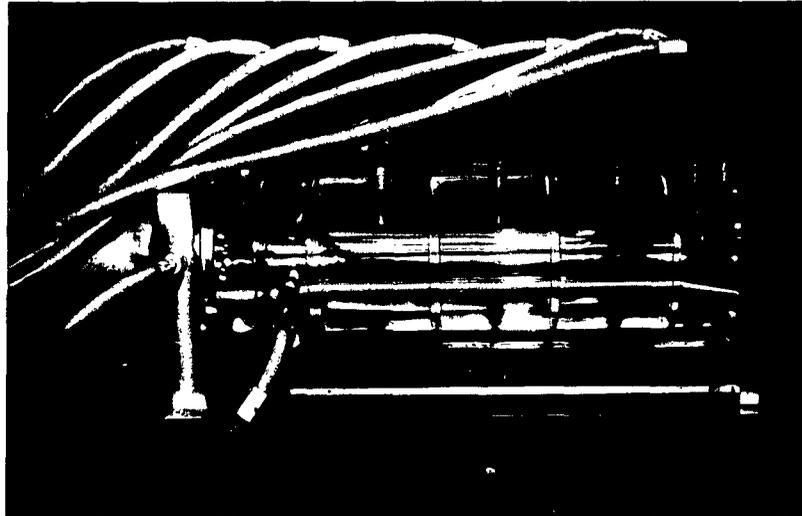


FIG. 4. Rocket Exhaust Diffuser Model.



FIG. 5. Full-Scale Vertical Stand and Rocket Exhaust Diffuser, Skytop 2.

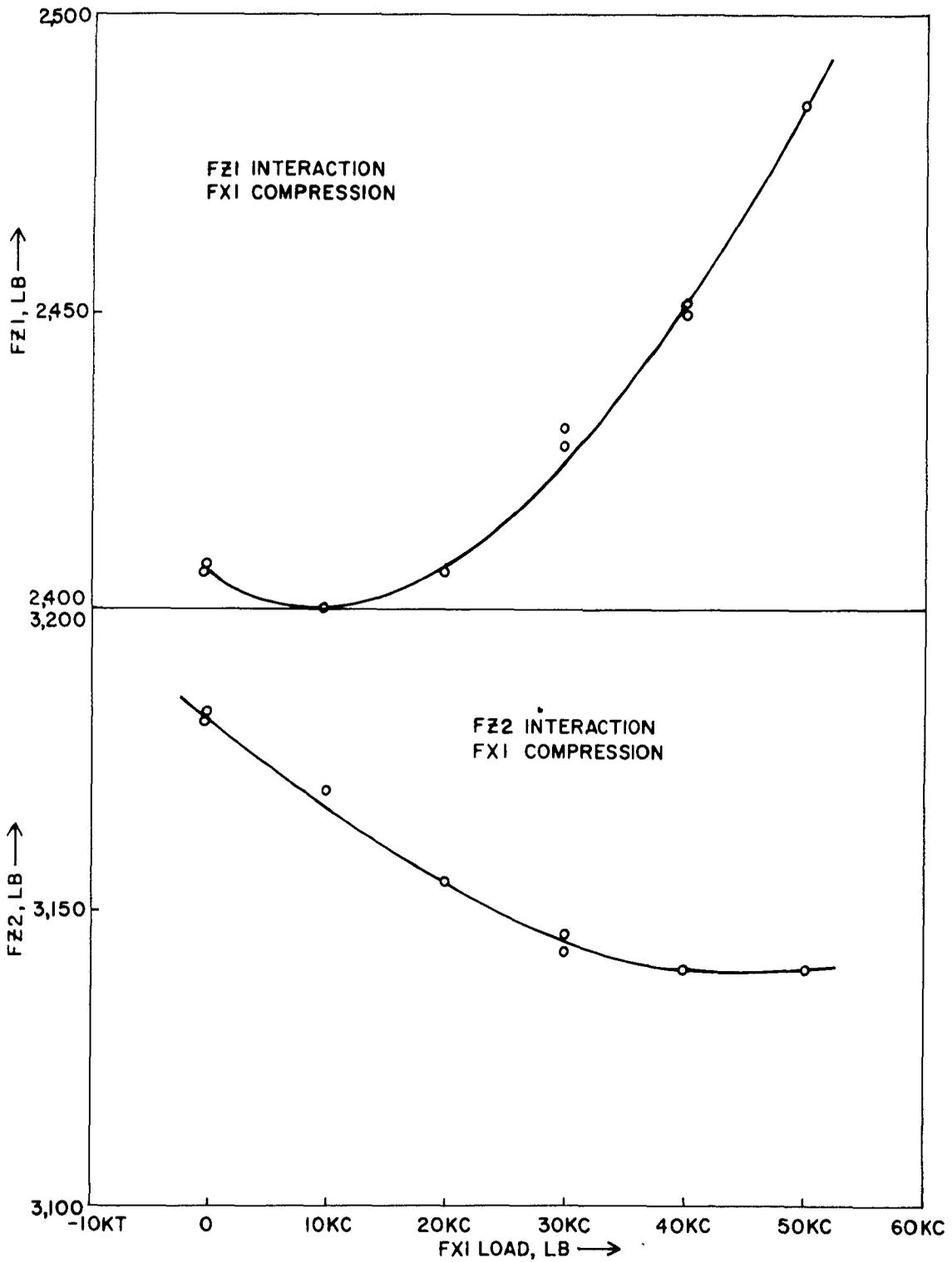


FIG. 6. Calibration Curves of Interaction Forces. Top, FZ1 interaction, FX1 compression; bottom, FZ2 interaction, FX1 compression.

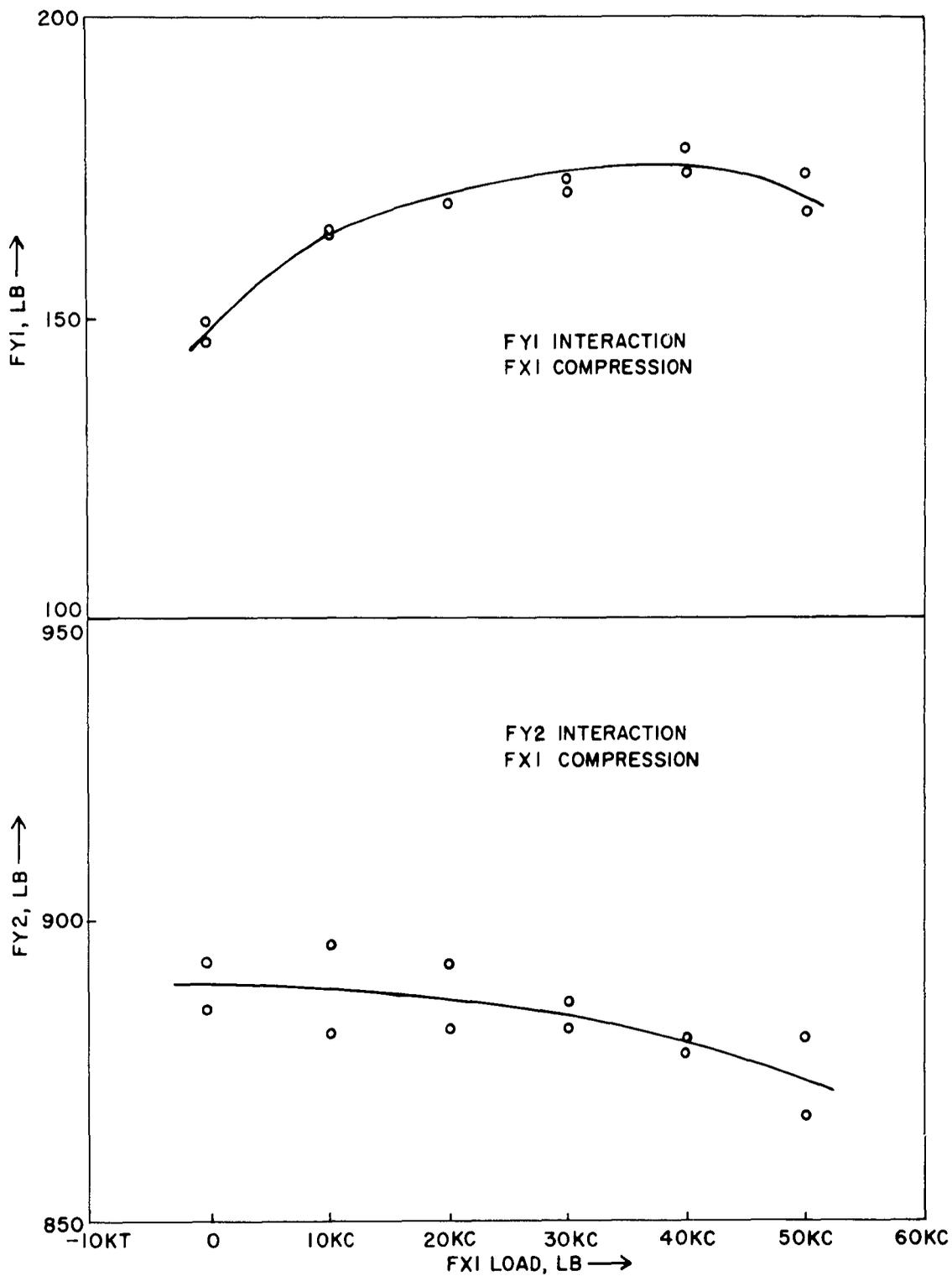


FIG. 7. Calibration Curves of Interaction Forces. Top, FY1 interaction, FX1 compression; bottom, FY2 interaction, FX1 compression.

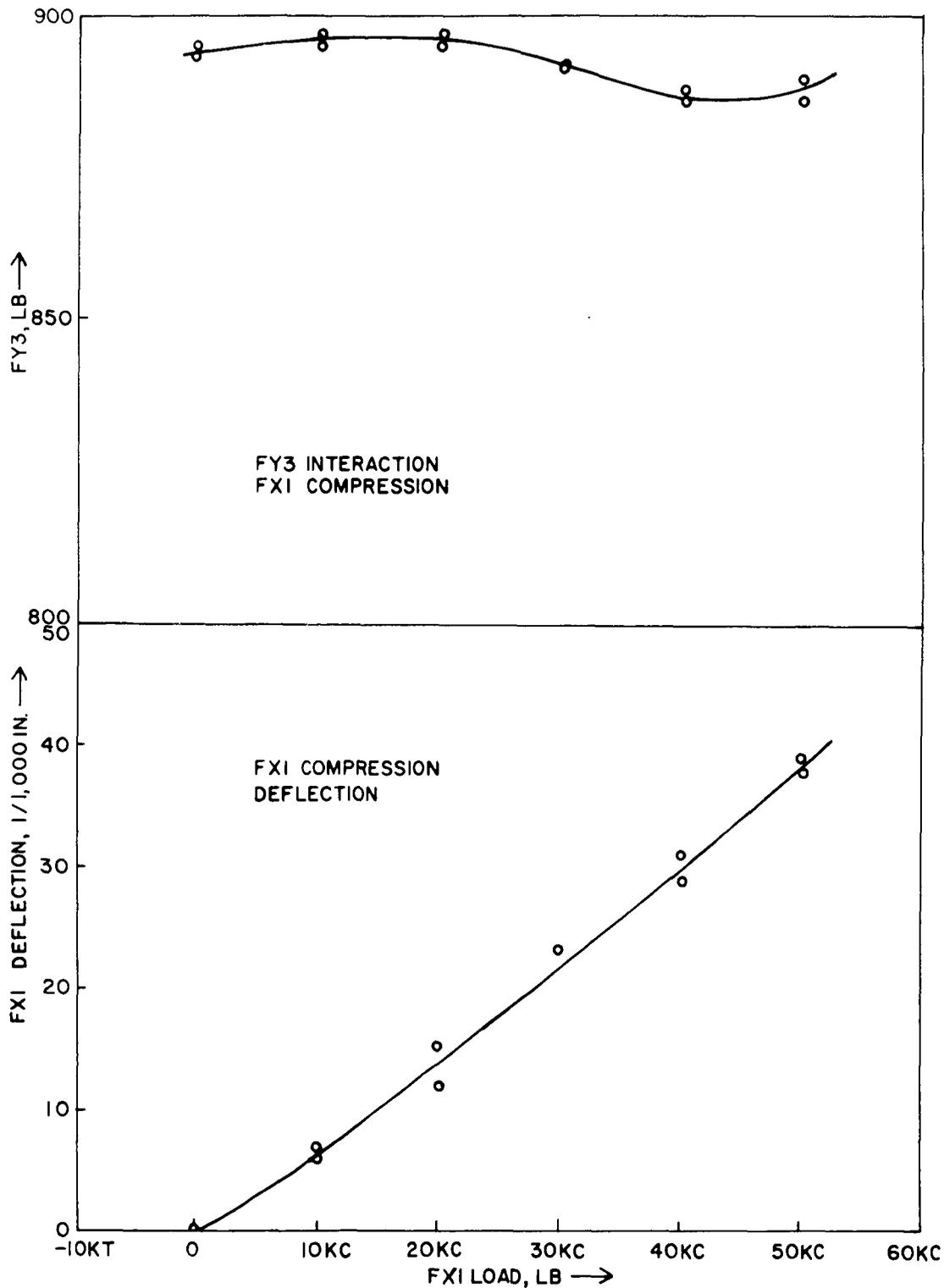


FIG. 8. Calibration Curves of Interaction Forces. Top, FY3 interaction, FXI compression; bottom, FXI compression, deflection.

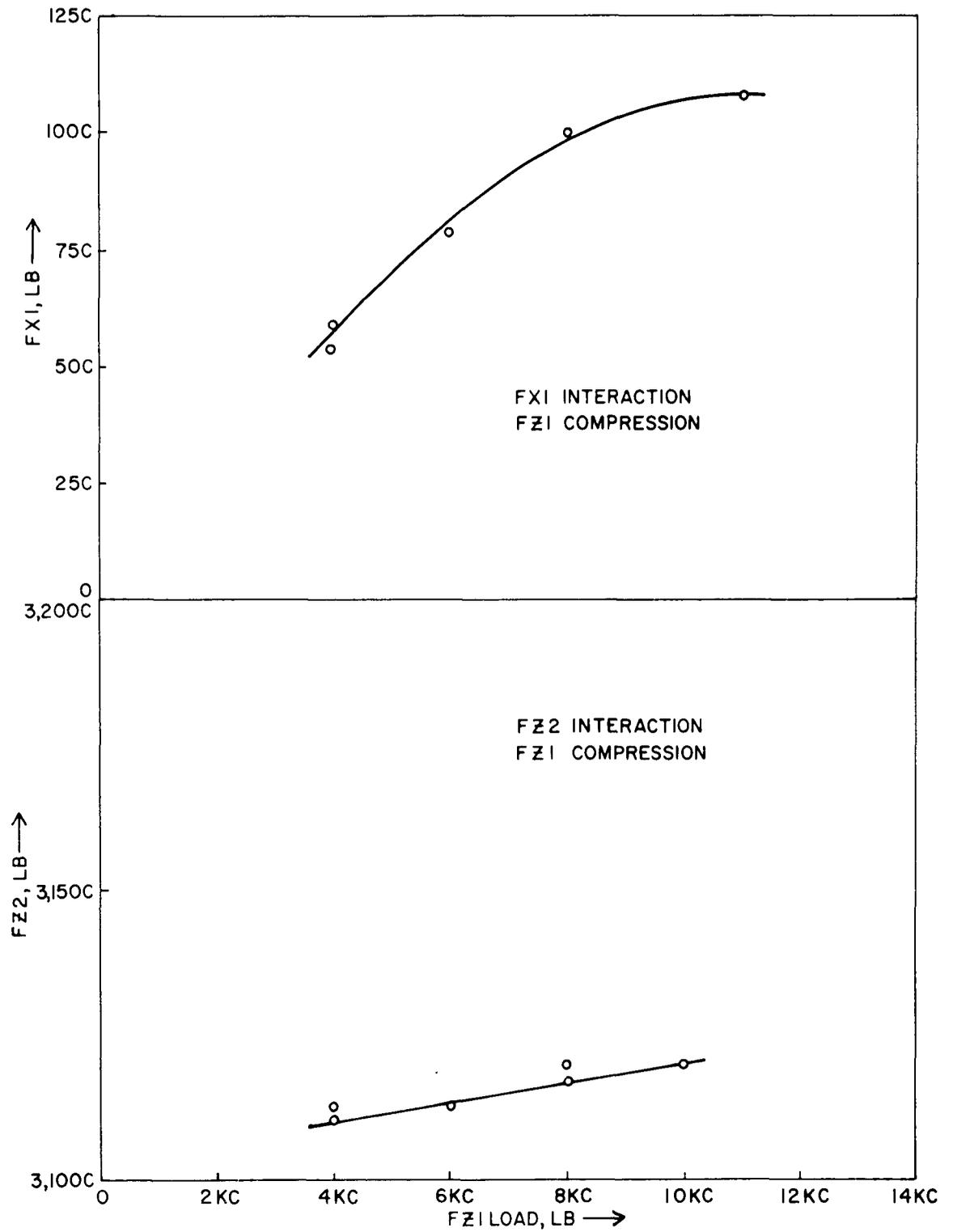


FIG. 9. Calibration Curves of Interaction Forces. Top, FX1 interaction, FZ1 compression; bottom, FZ2 interaction, FZ1 compression.

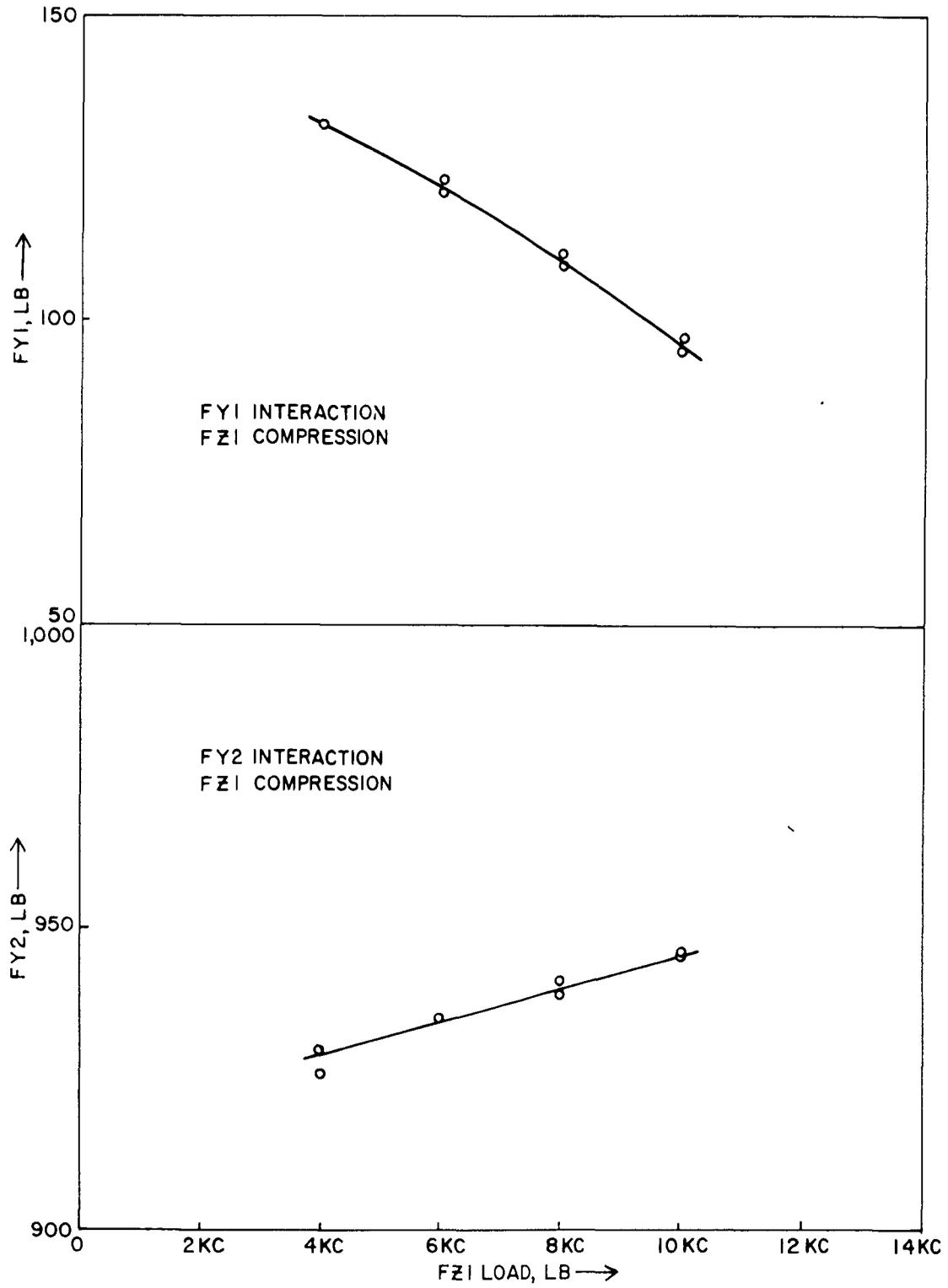


FIG. 10. Calibration Curves of Interaction Forces. Top, FY1 interaction, FZ1 compression; bottom, FY2 interaction, FZ1 compression.

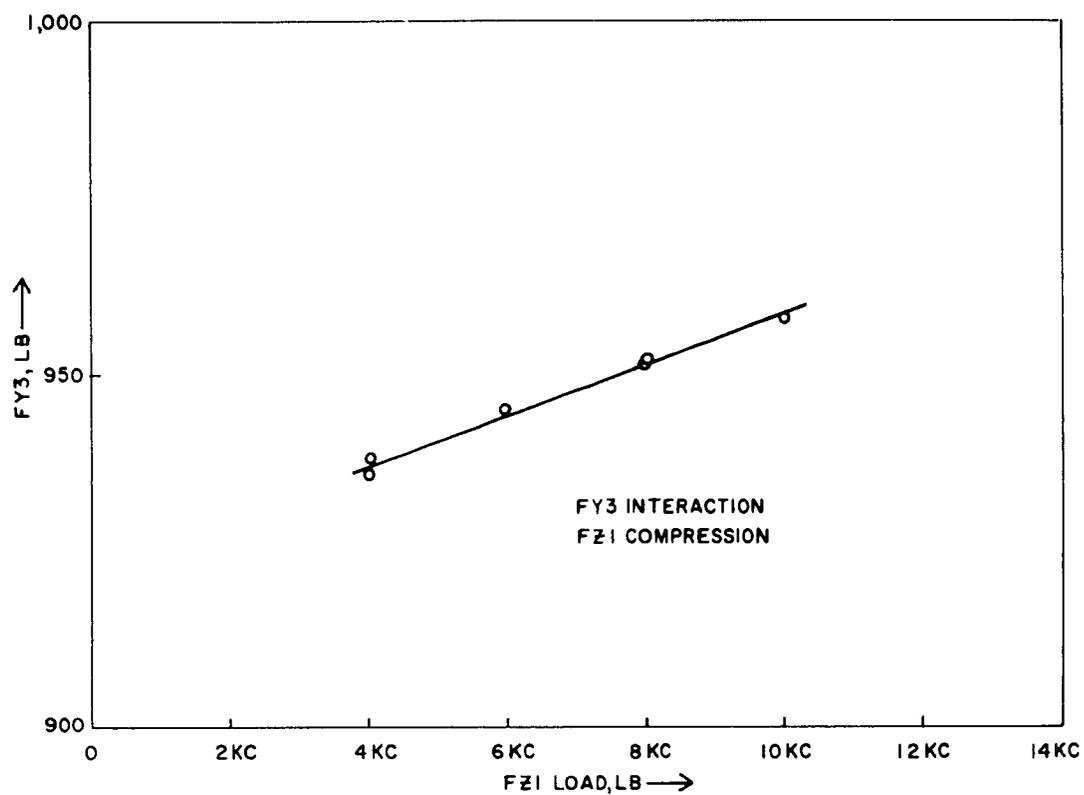


FIG. 11. Calibration Curve of Interaction Forces. FY3 interaction, FZ1 compression.

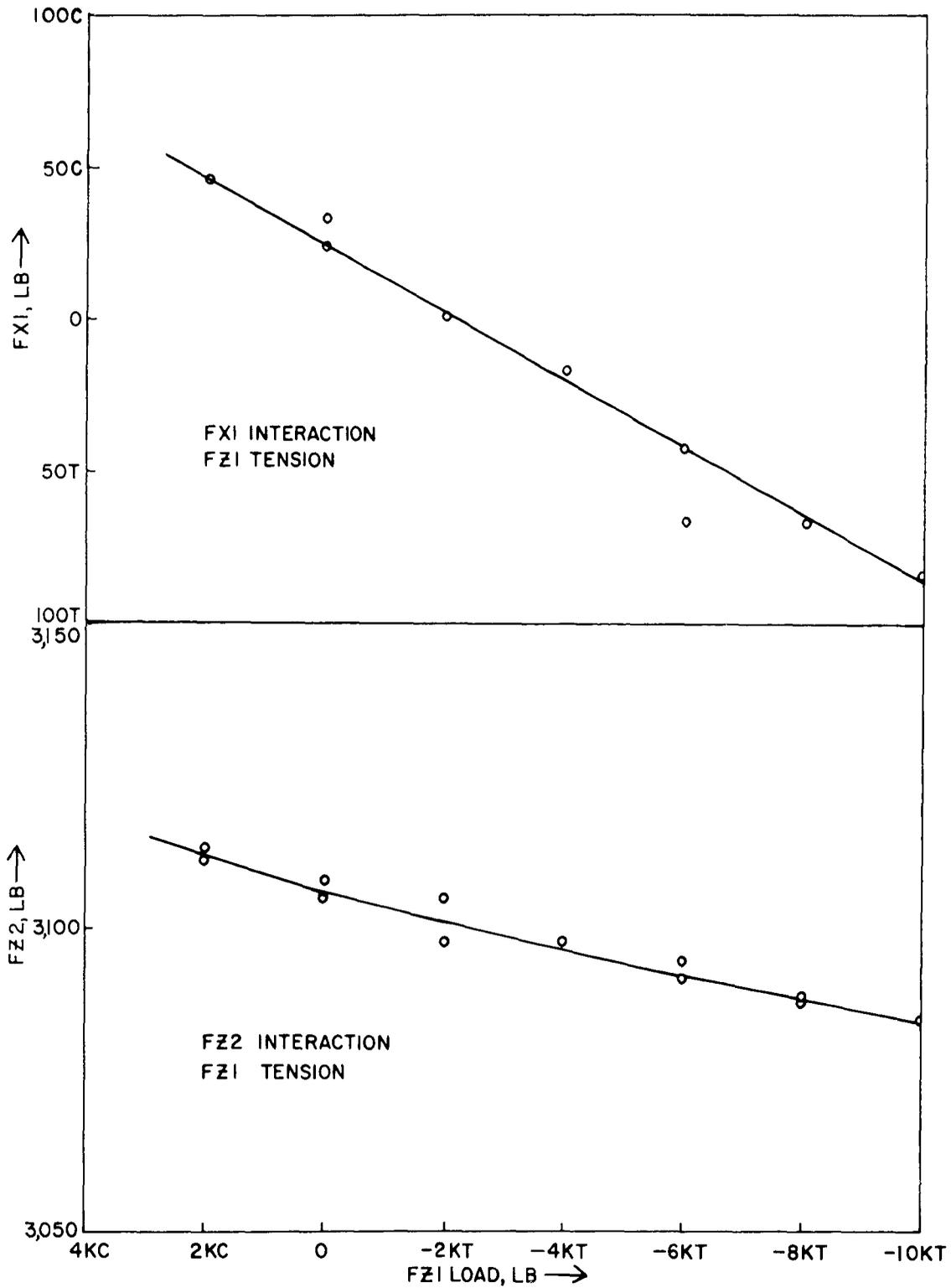


FIG. 12. Calibration Curves of Interaction Forces. Top, FX1 interaction, FZ1 tension; bottom, FZ2 interaction, FZ1 tension.

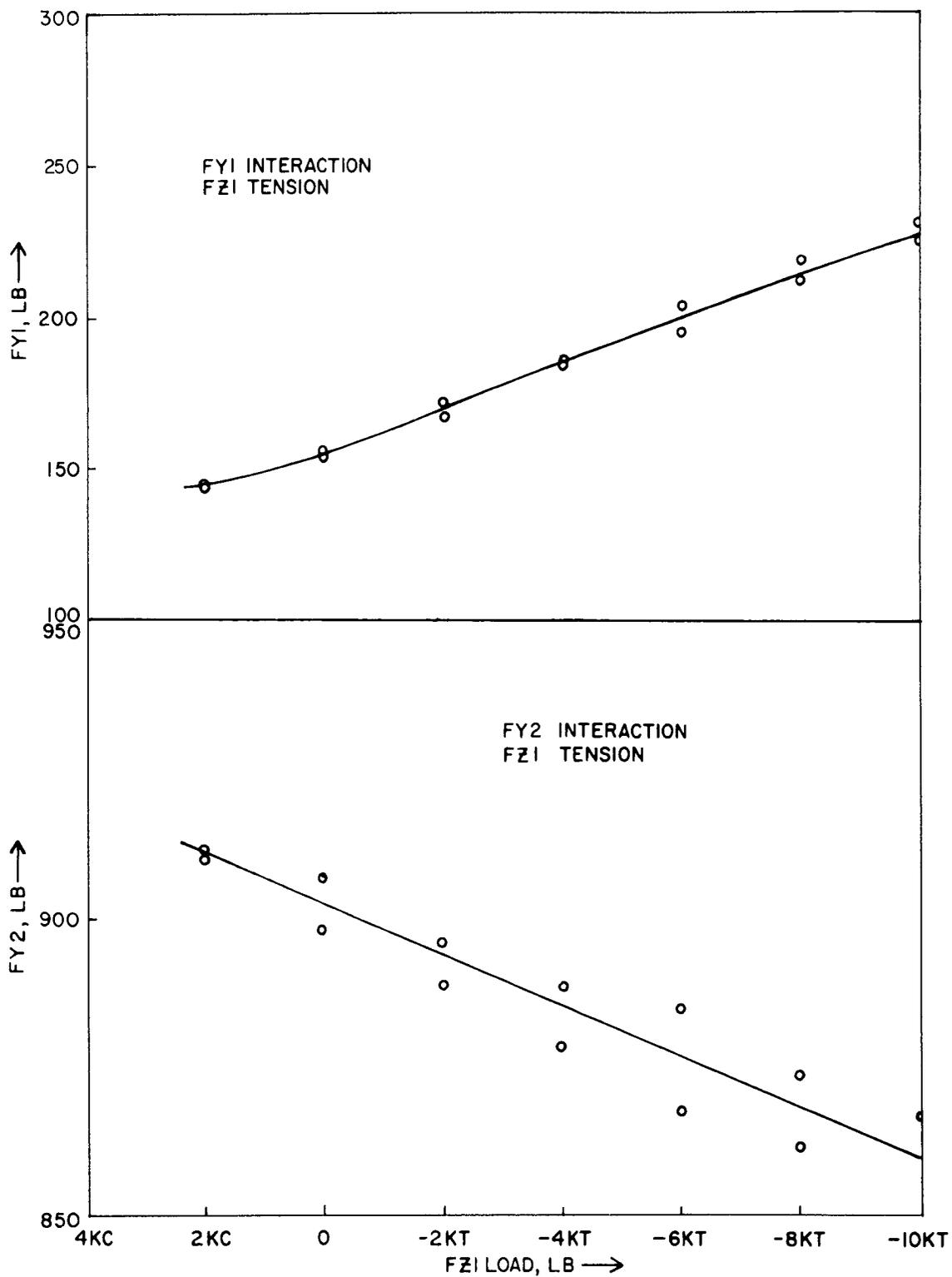


FIG. 13. Calibration Curves of Interaction Forces. Top, FY1 interaction, FZ1 tension; bottom, FY2 interaction, FZ1 tension.

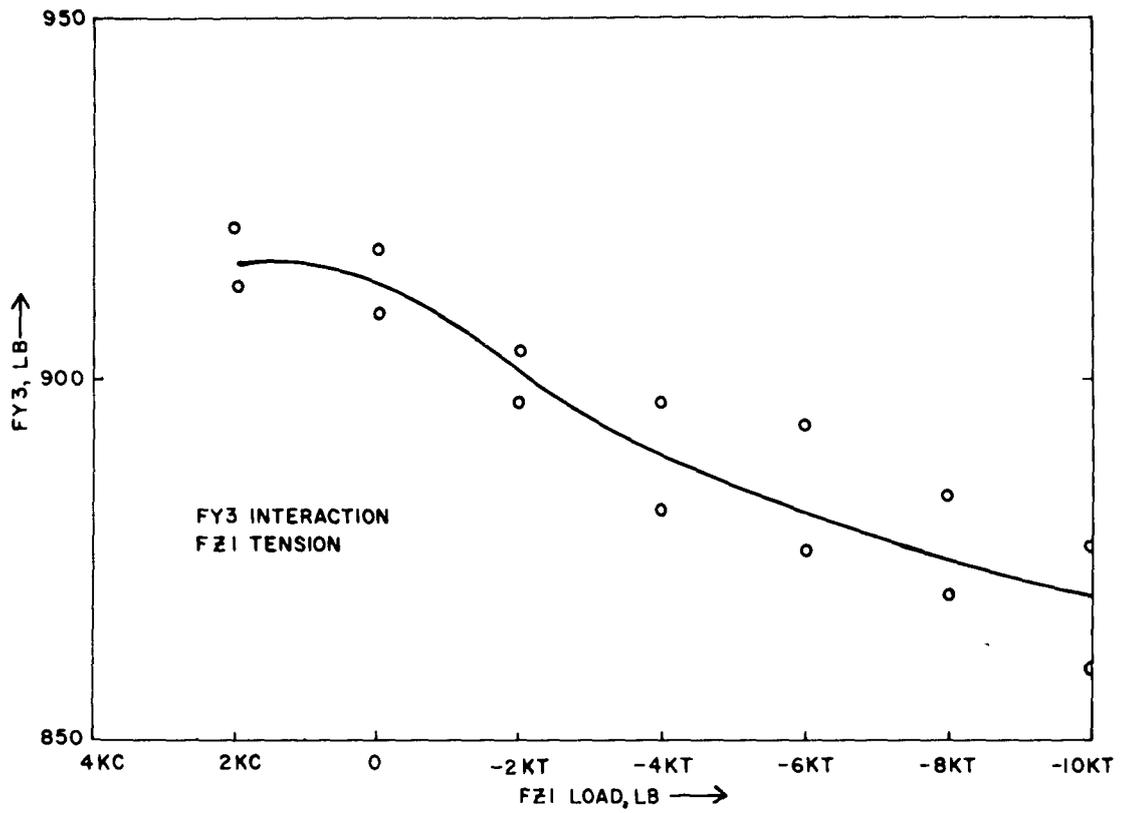


FIG. 14. Calibration Curve of Interaction Forces.
FY3 interaction, FZ1 tension.

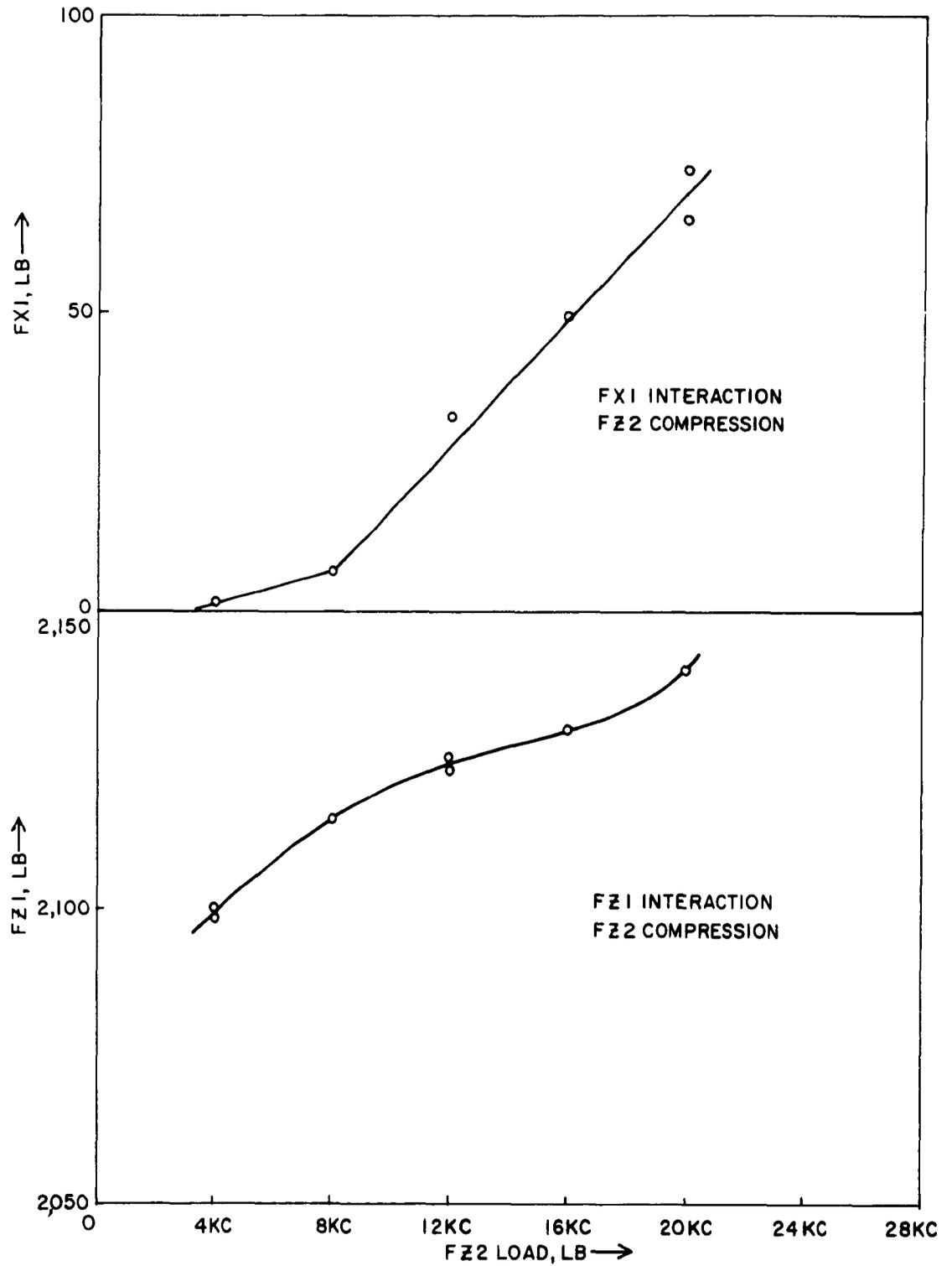


FIG. 15. Calibration Curves of Interaction Forces. Top, FX1 interaction, FZ2 compression; bottom, FZ1 interaction, FZ2 compression.

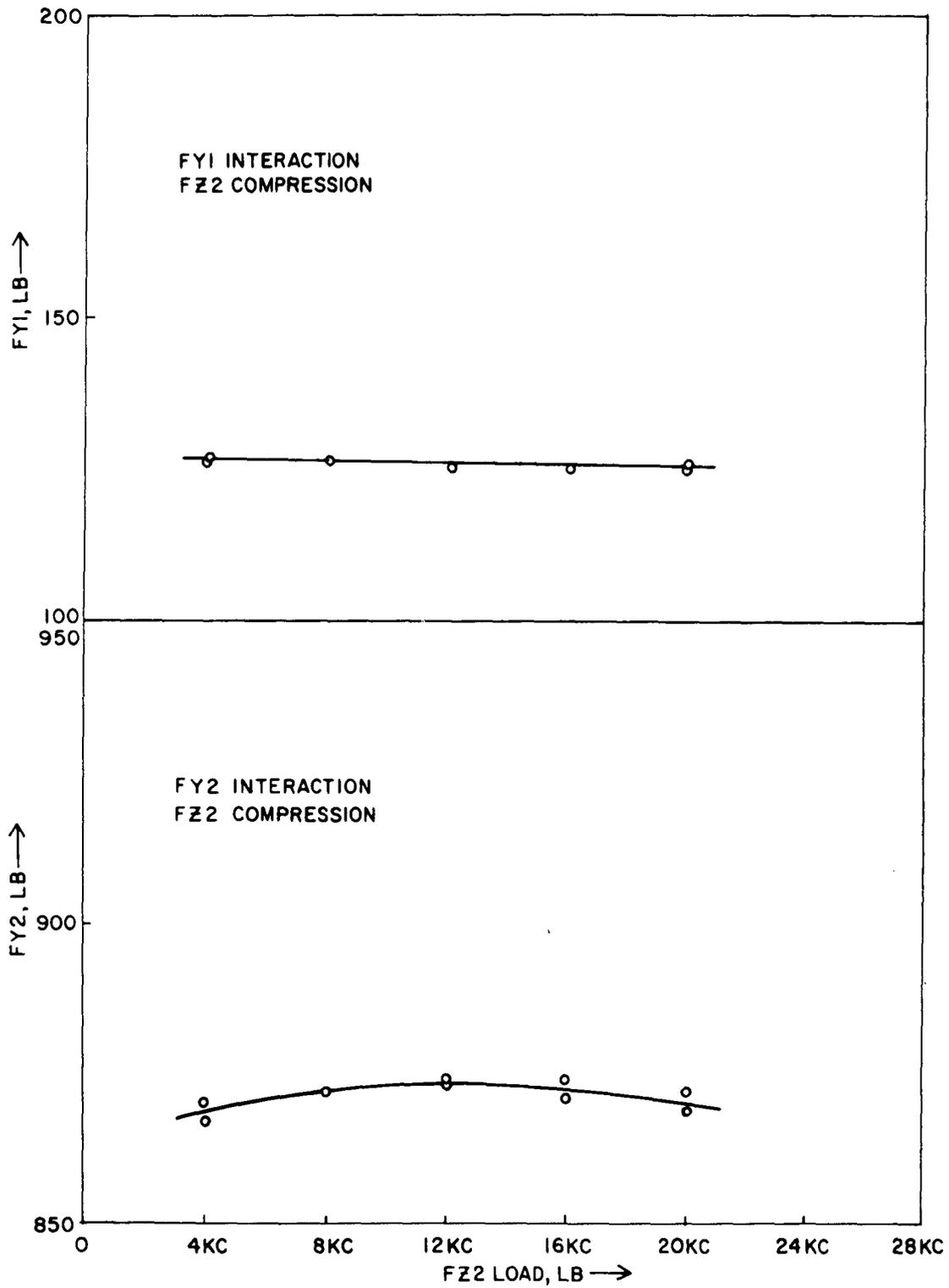


FIG. 16. Calibration Curves of Interaction Forces. Top, FY1 interaction, FZ2 compression; bottom, FY2 interaction, FZ2 compression.

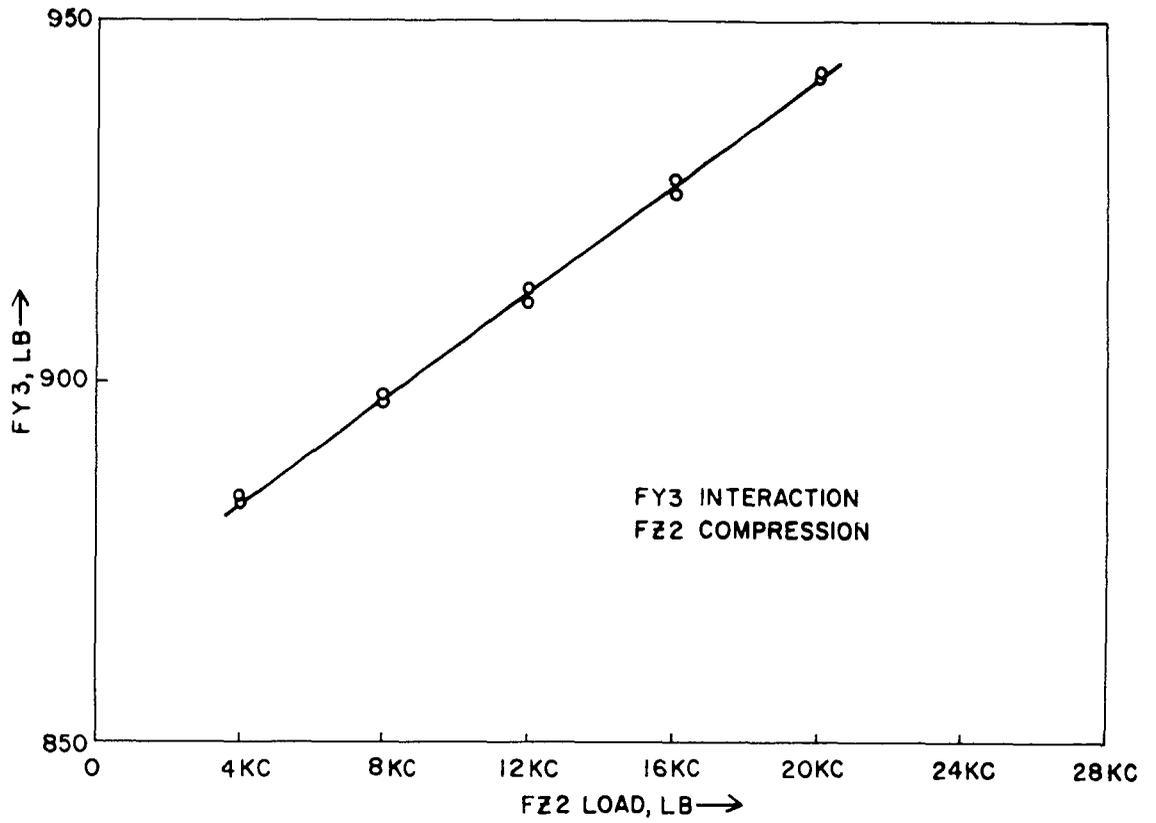


FIG. 17. Calibration Curve of Interaction Forces.
FY3 interaction, FZ2 compression.

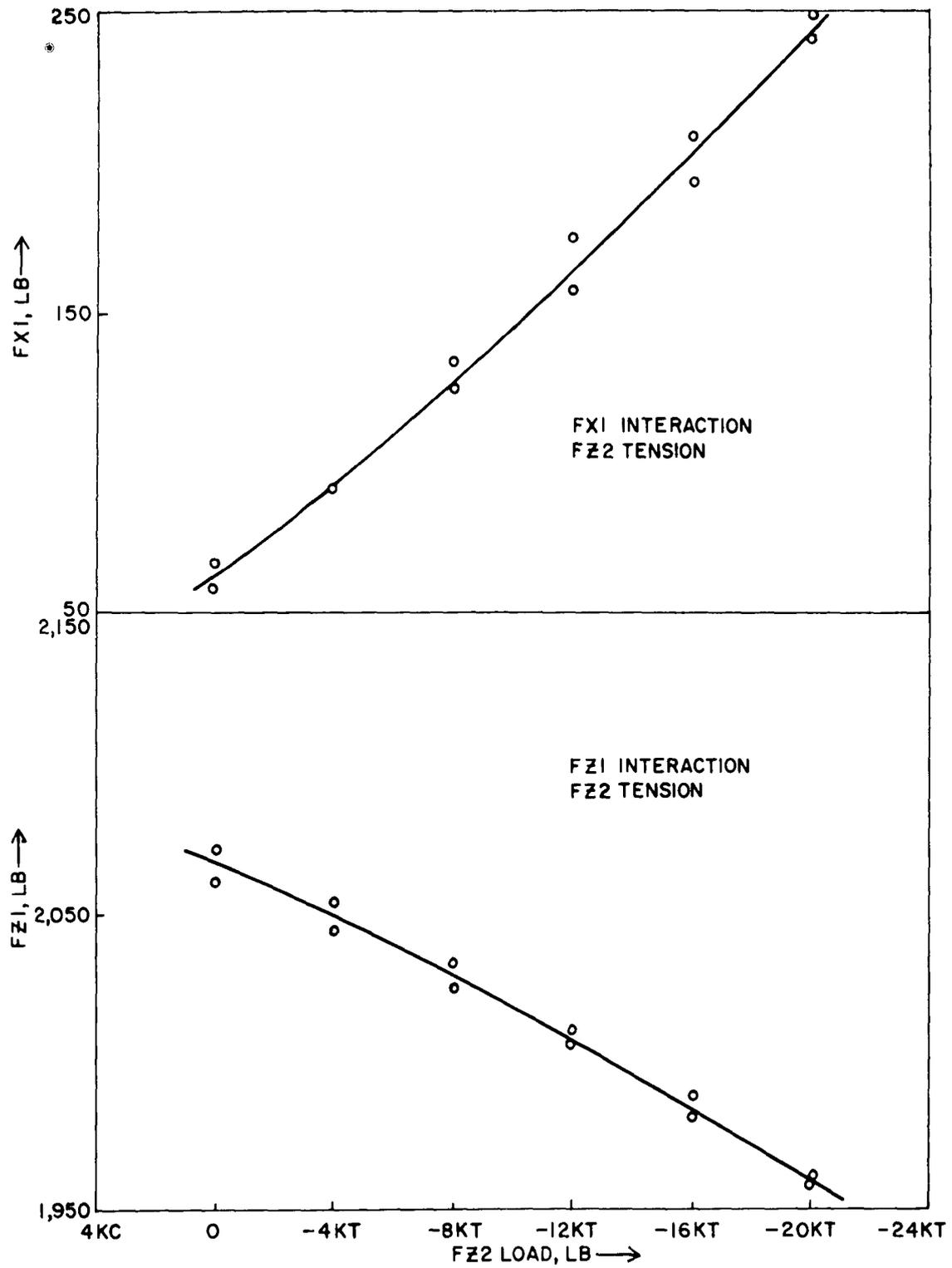


FIG. 18. Calibration Curves of Interaction Forces. Top, FX1 interaction, FZ2 tension; bottom, FZ1 interaction, FZ2 tension.

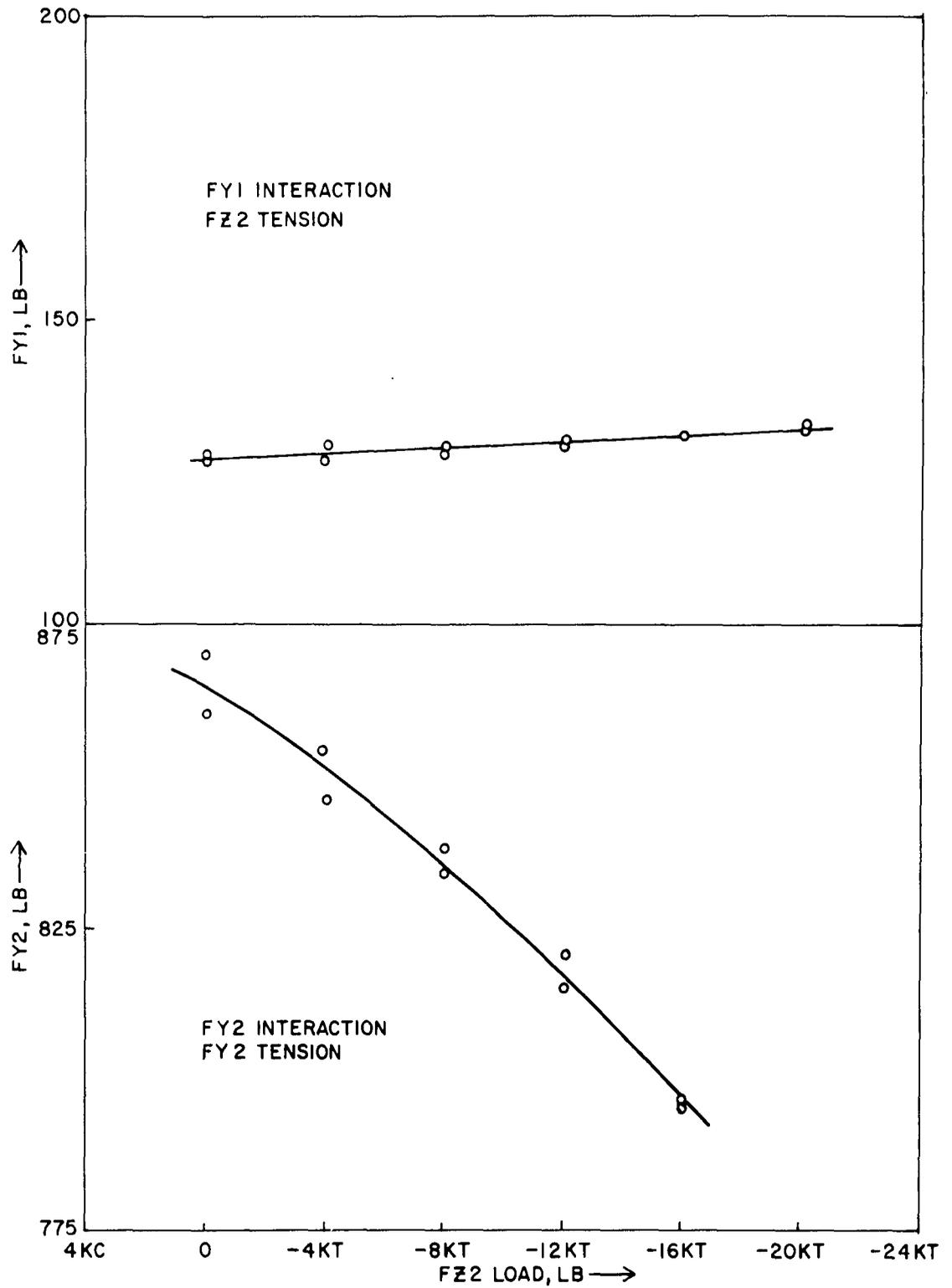


FIG. 19. Calibration Curves of Interaction Forces. Top, FY1 interaction, FZ2 tension; bottom, FY2 interaction, FY2 tension.

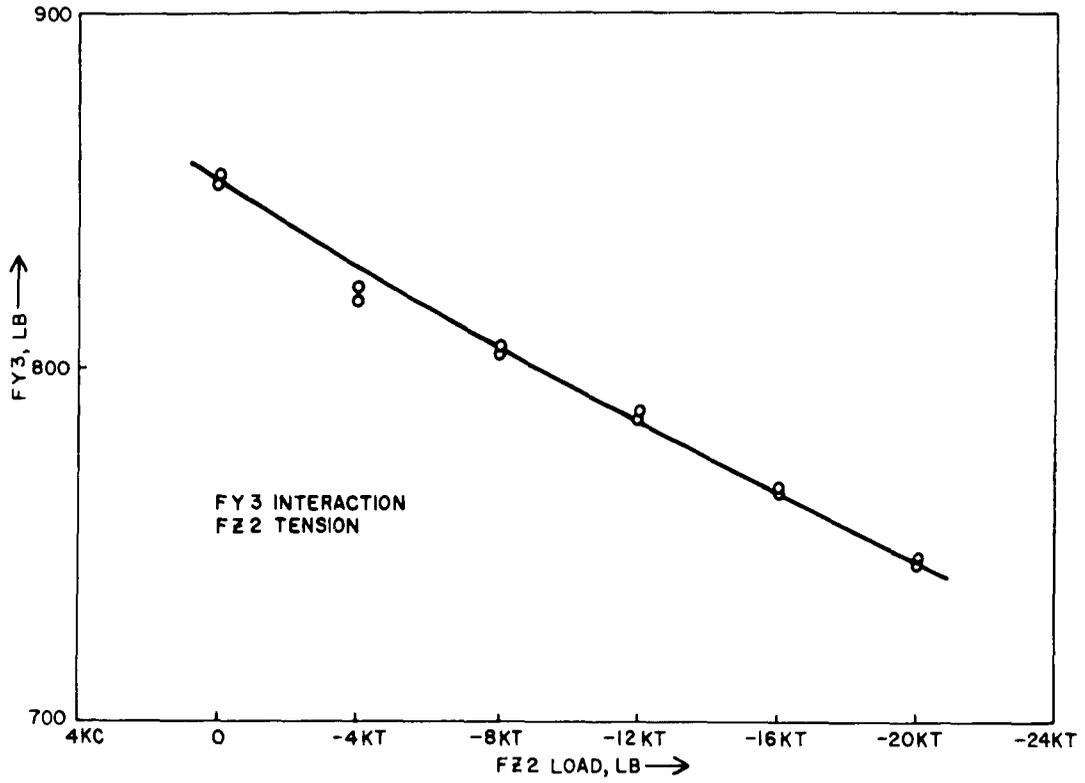


FIG. 20. Calibration Curves of Interaction Forces.
FY3 interaction, FZ2 tension.

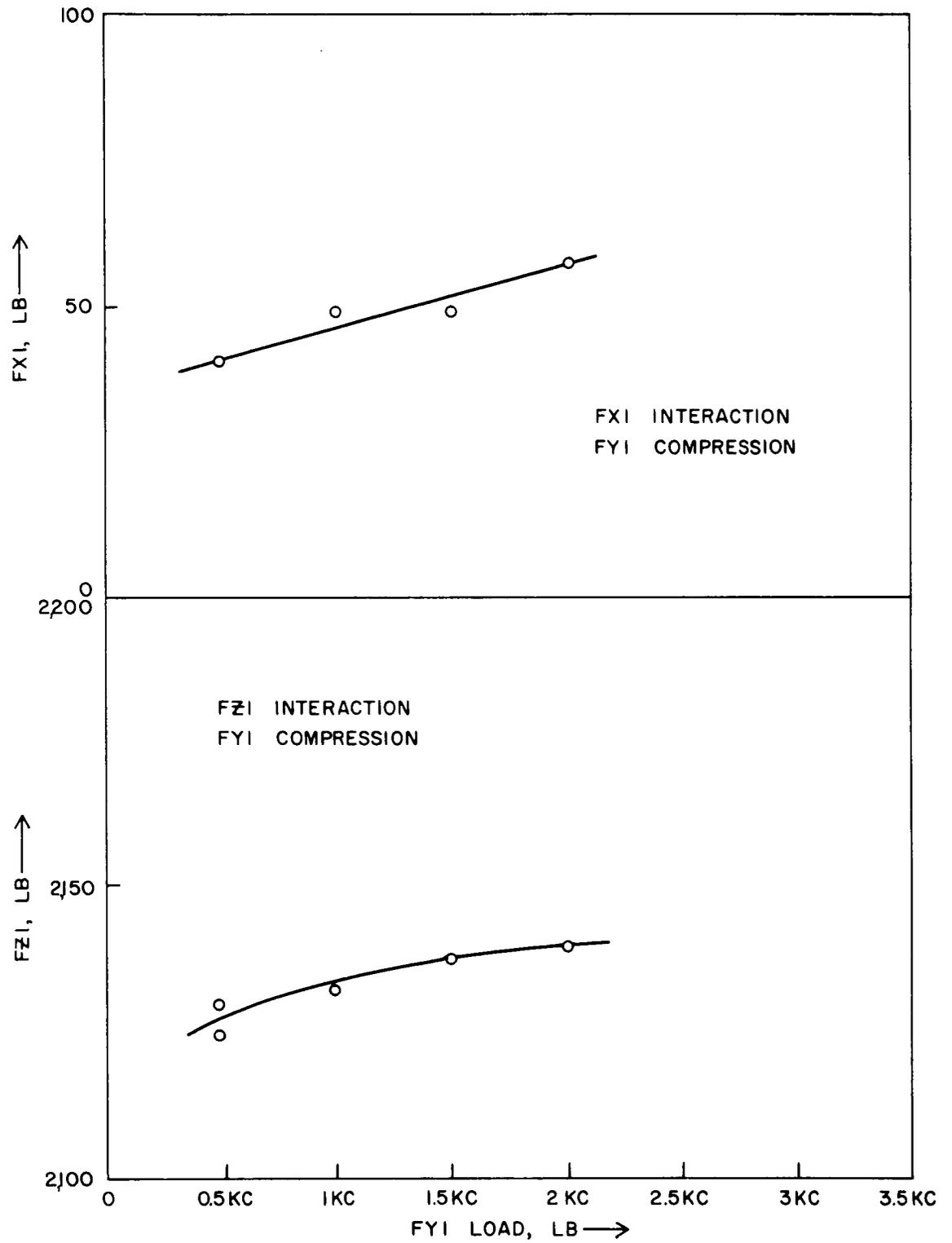


FIG. 21. Calibration Curves of Interaction Forces. Top, FX1 interaction, FY1 compression. bottom, FZ1 interaction, FY1 compression.

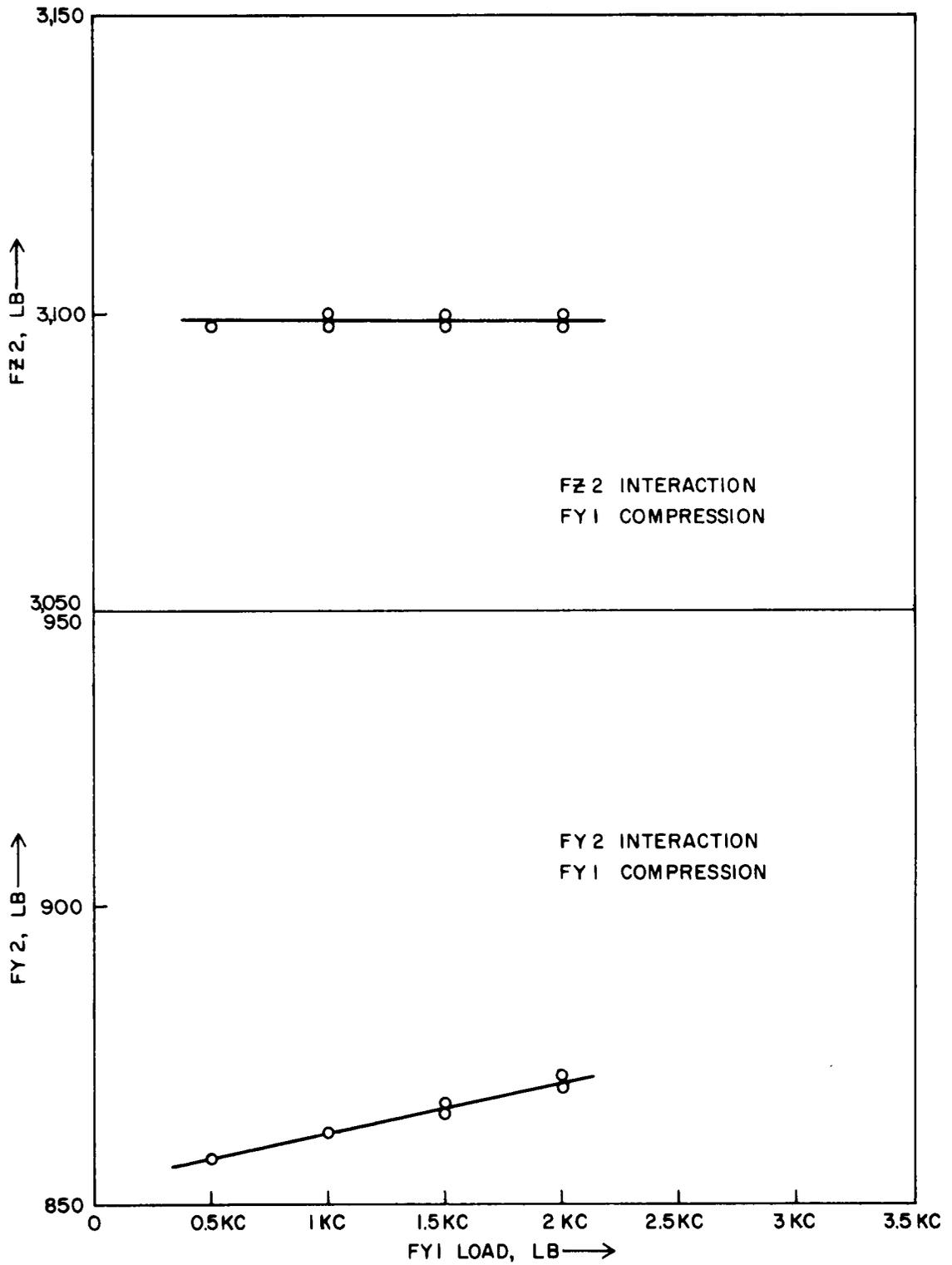


FIG. 22. Calibration Curves of Interaction Forces. Top, FZ2 interaction, FY1 compression; bottom, FY2 interaction, FY1 compression.

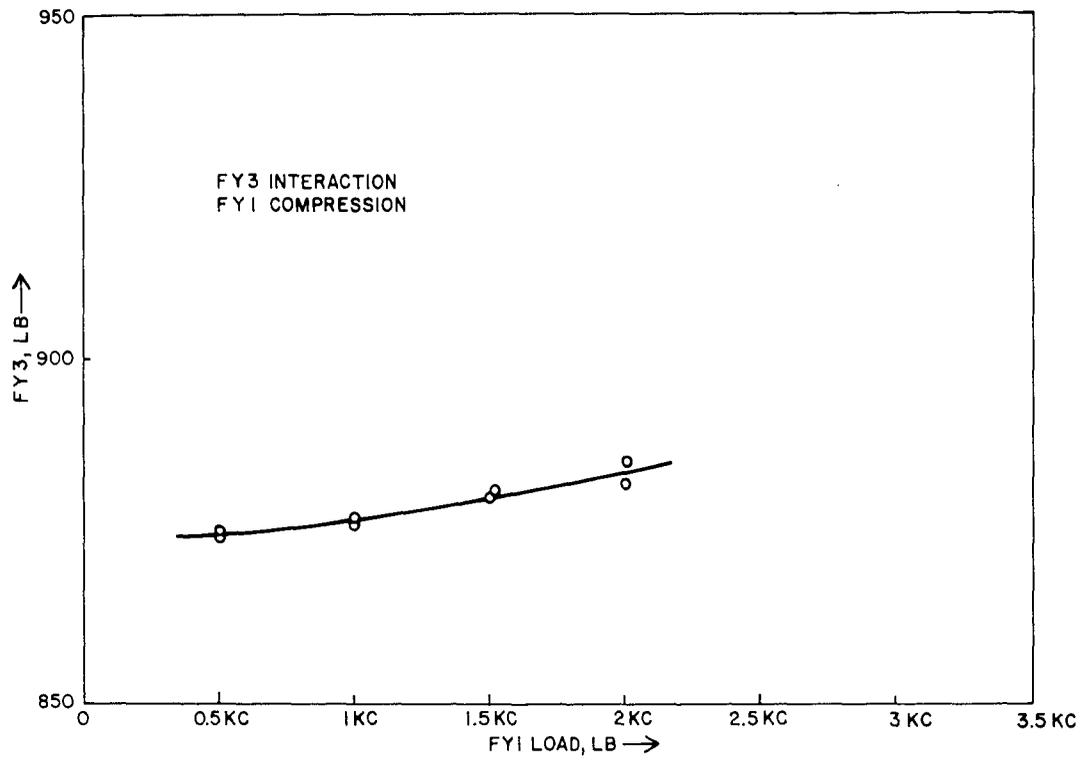


FIG. 23. Calibration Curve of Interaction Forces.
FY3 interaction, FY1 compression.

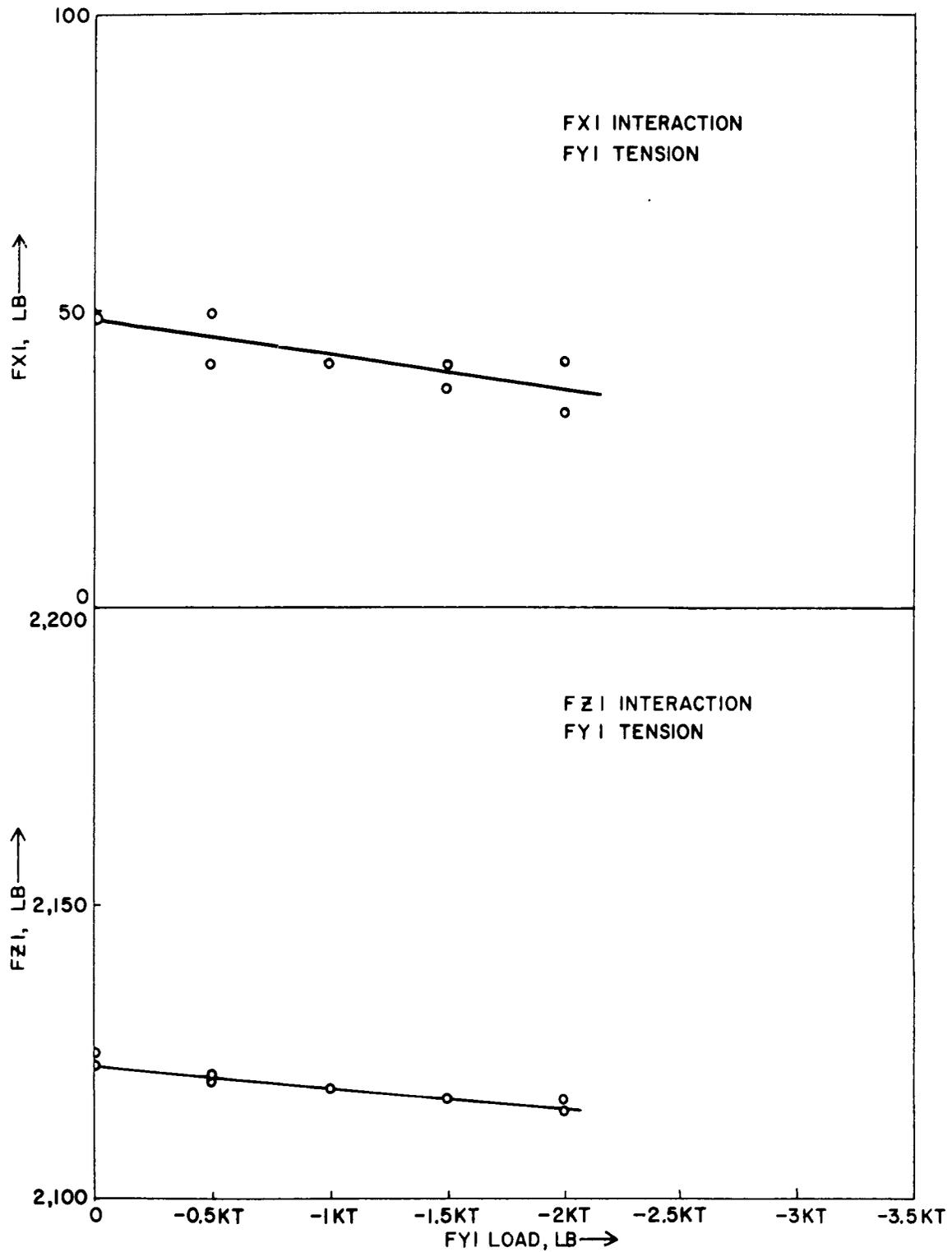


FIG. 24. Calibration Curves of Interaction Forces. Top, FX1 interaction, FY1 tension; bottom, FZ1 interaction, FY1 tension.

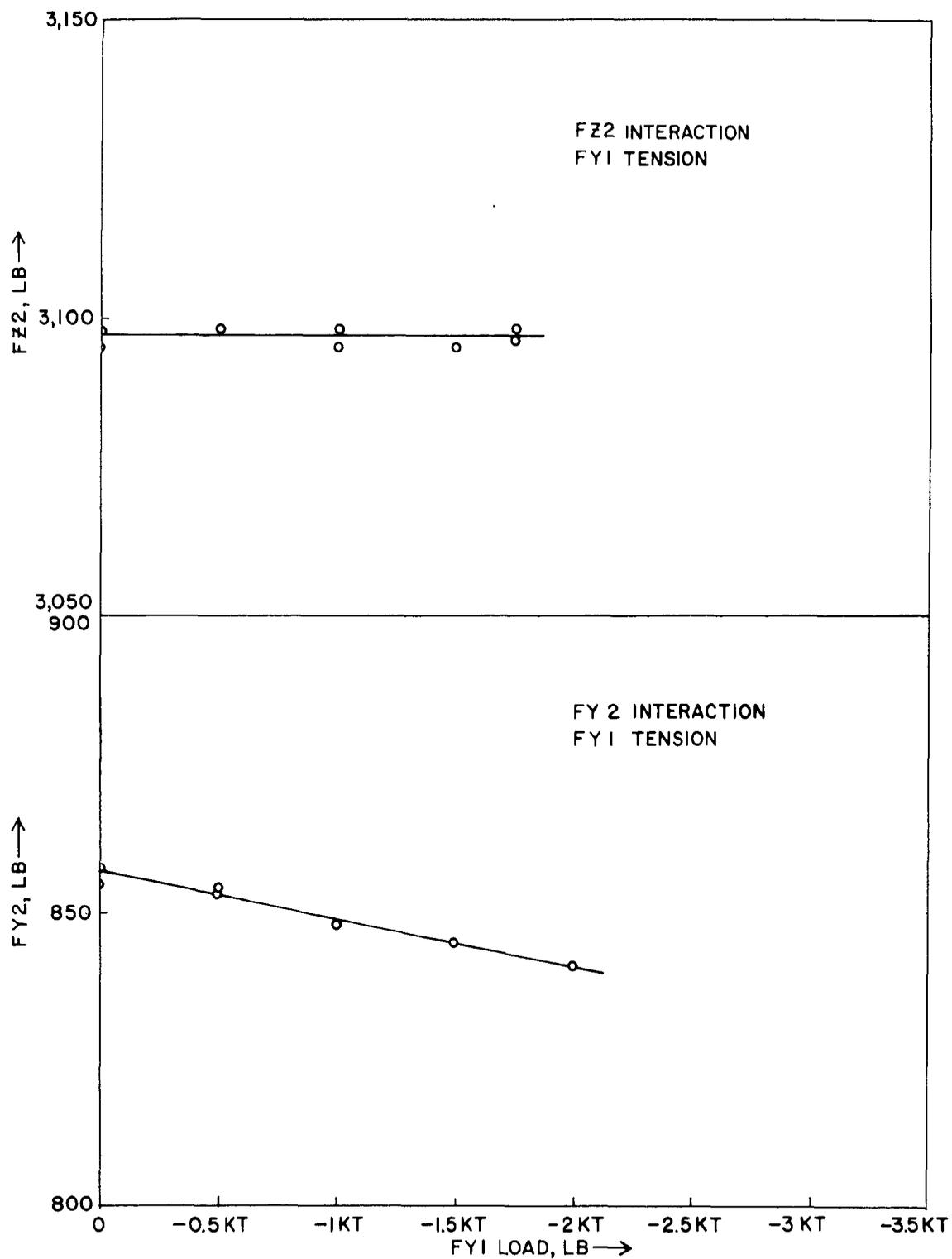


FIG. 25. Calibration Curves of Interaction Forces. Top, FZ2 interaction, FY1 tension; bottom, FY2 interaction, FY1 tension.

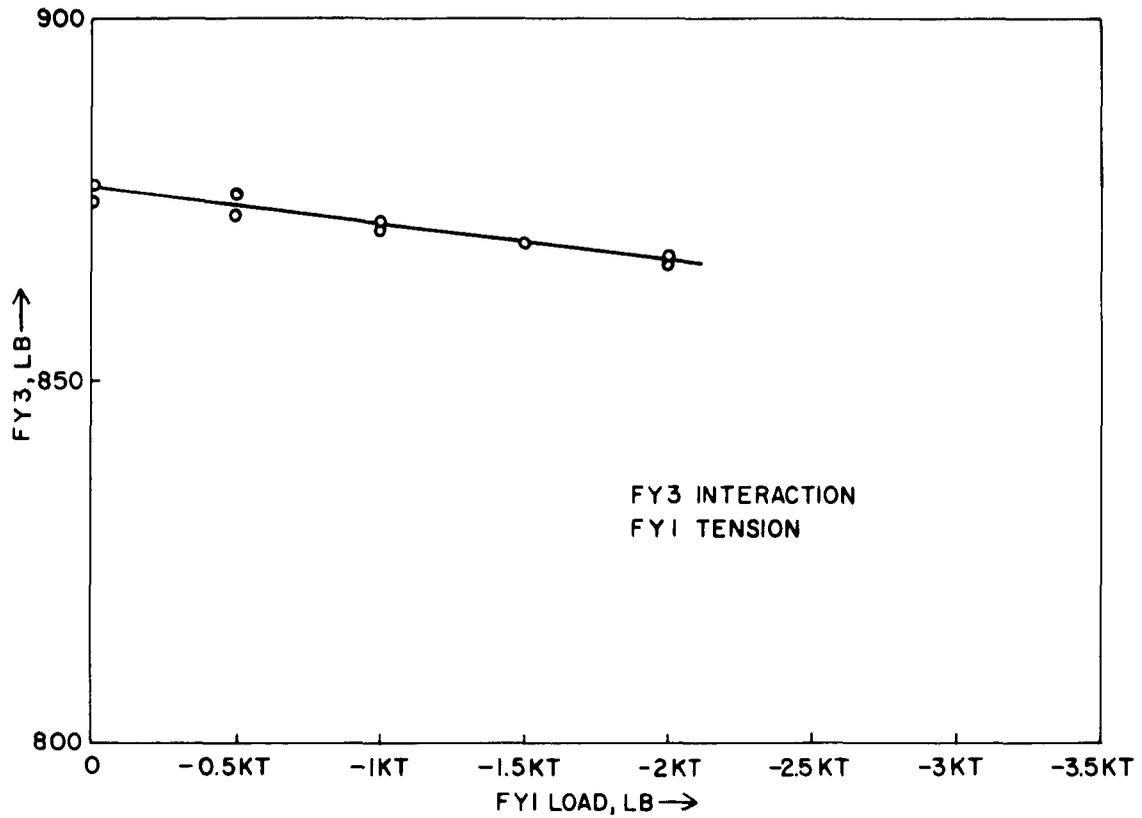


FIG. 26. Calibration Curve of Interaction Forces.
FY3 interaction, FYI tension.

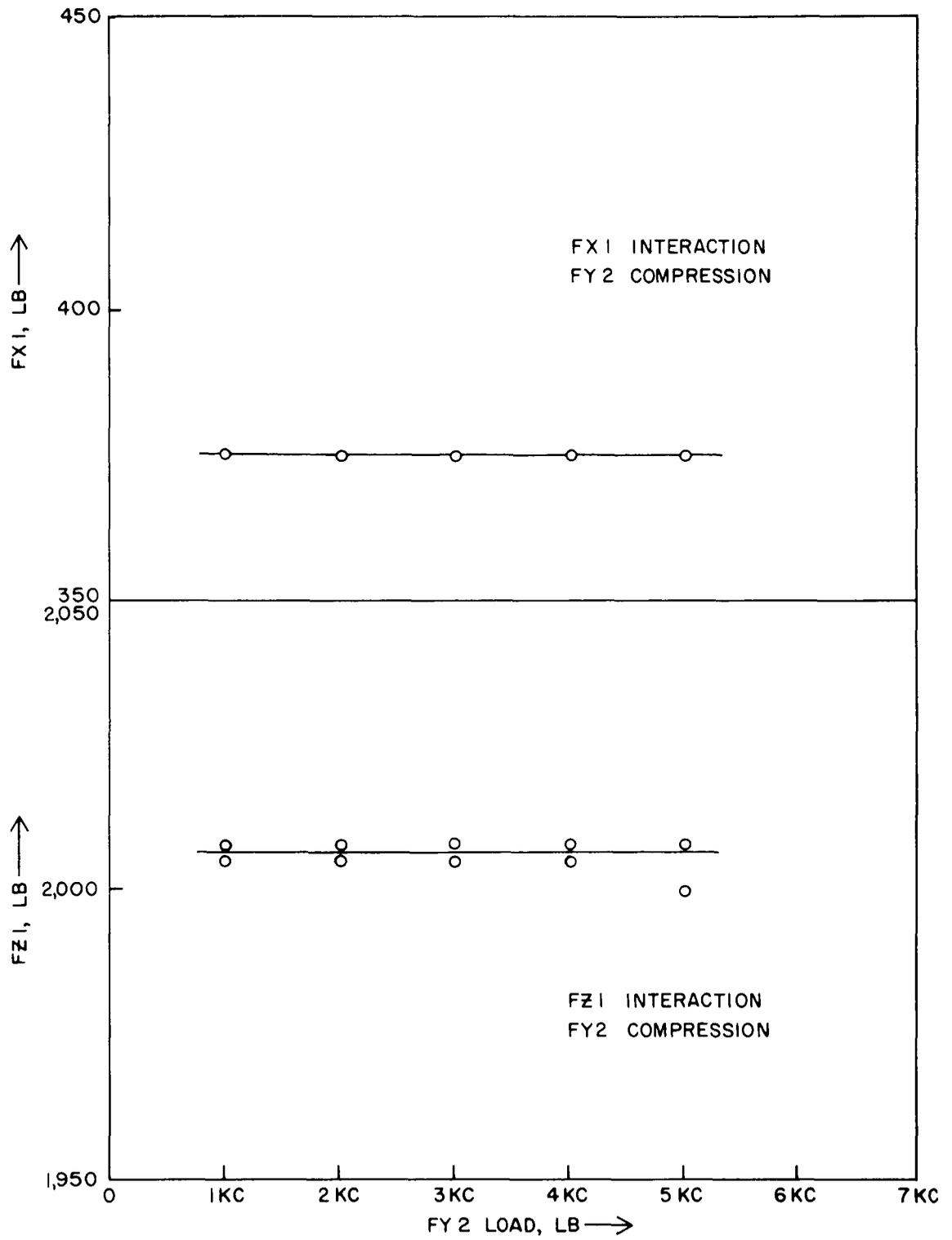


FIG. 27. Calibration Curves of Interaction Forces. Top, FX1 interaction, FY2 compression; bottom, FZ1 interaction, FY2 compression.

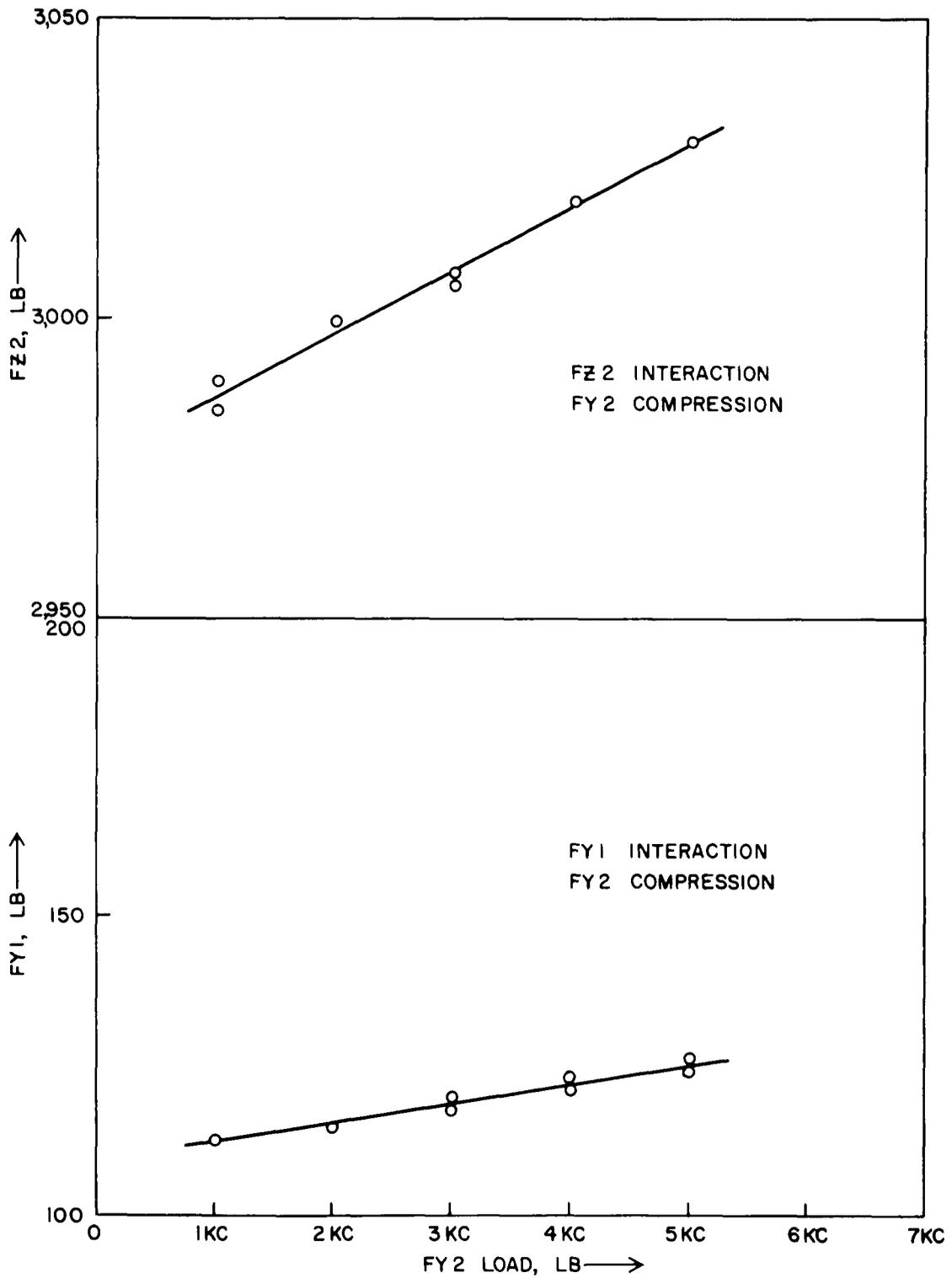


FIG. 28. Calibration Curves of Interaction Forces. Top, FZ2 interaction, FY2 compression; bottom, FY1 interaction, FY2 compression.

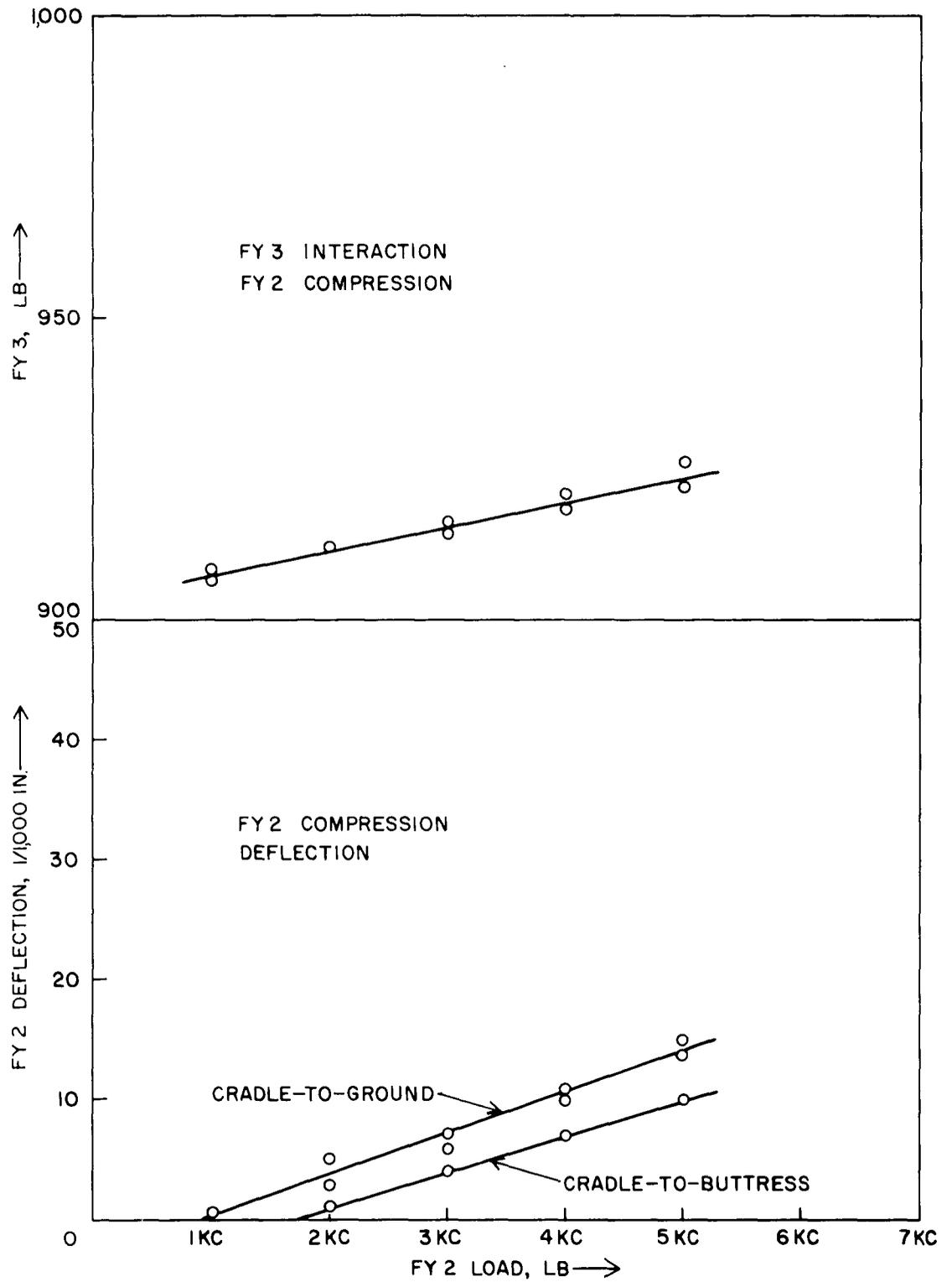


FIG. 29. Calibration Curves of Interaction Forces. Top, FY3 interaction, FY2 compression; bottom, FY2 compression, deflection.

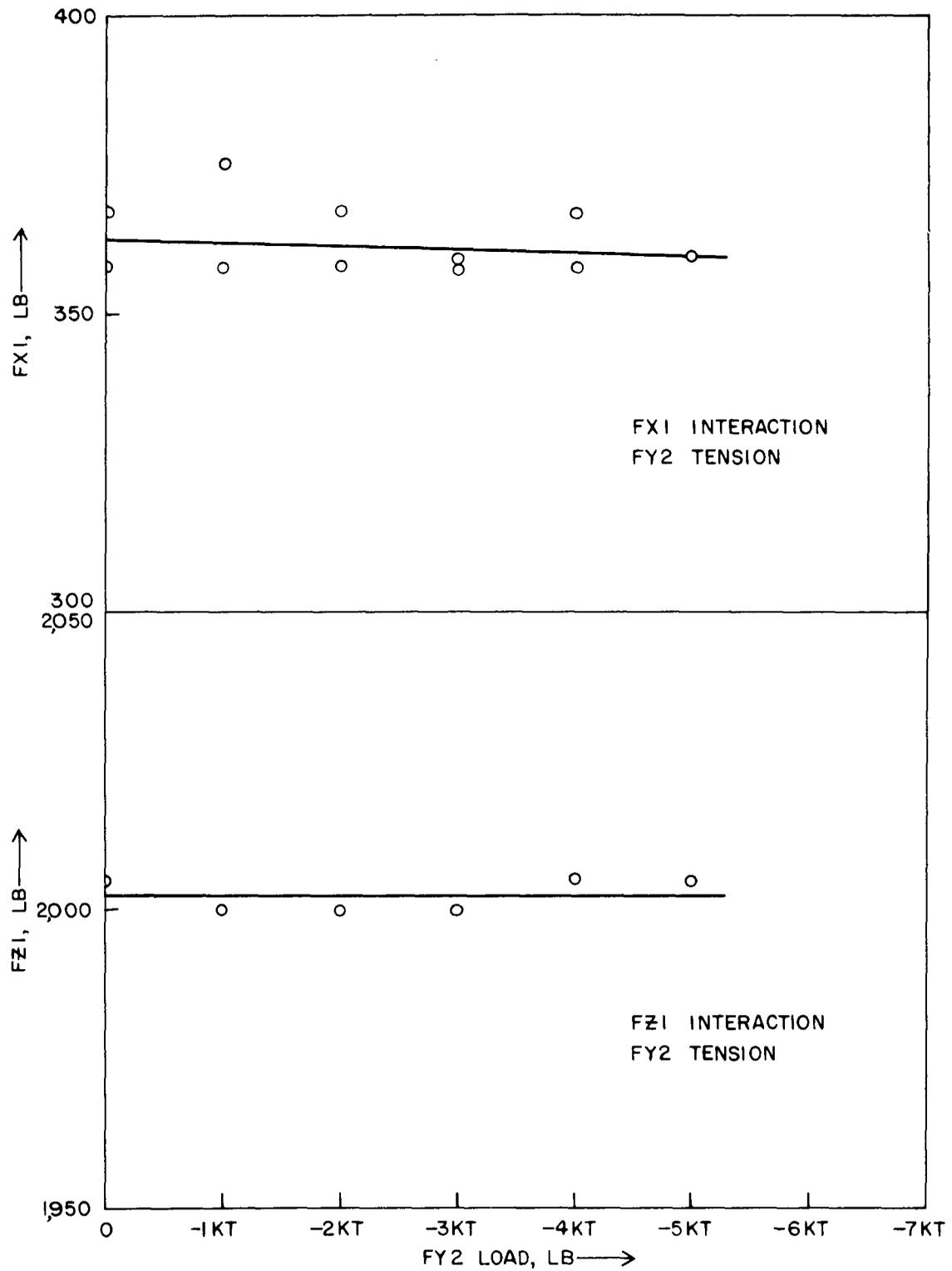


FIG. 30. Calibration Curves of Interaction Forces. Top, FX1 interaction, FY2 tension; bottom, FZ1 interaction, FY2 tension.

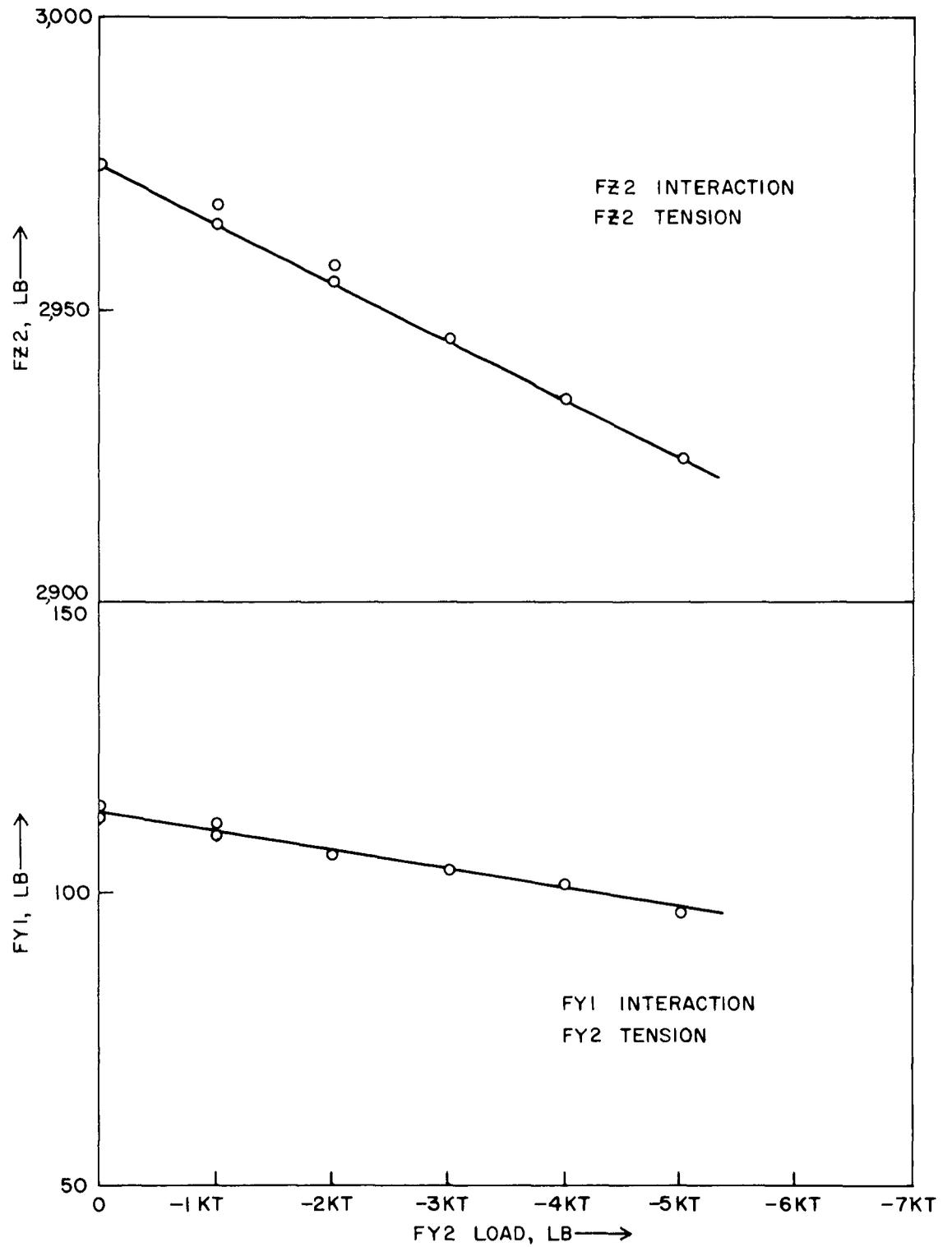


FIG. 31. Calibration Curves of Interaction Forces. Top, FZ2 interaction, FZ2 tension; bottom, FY1 interaction, FY2 tension.

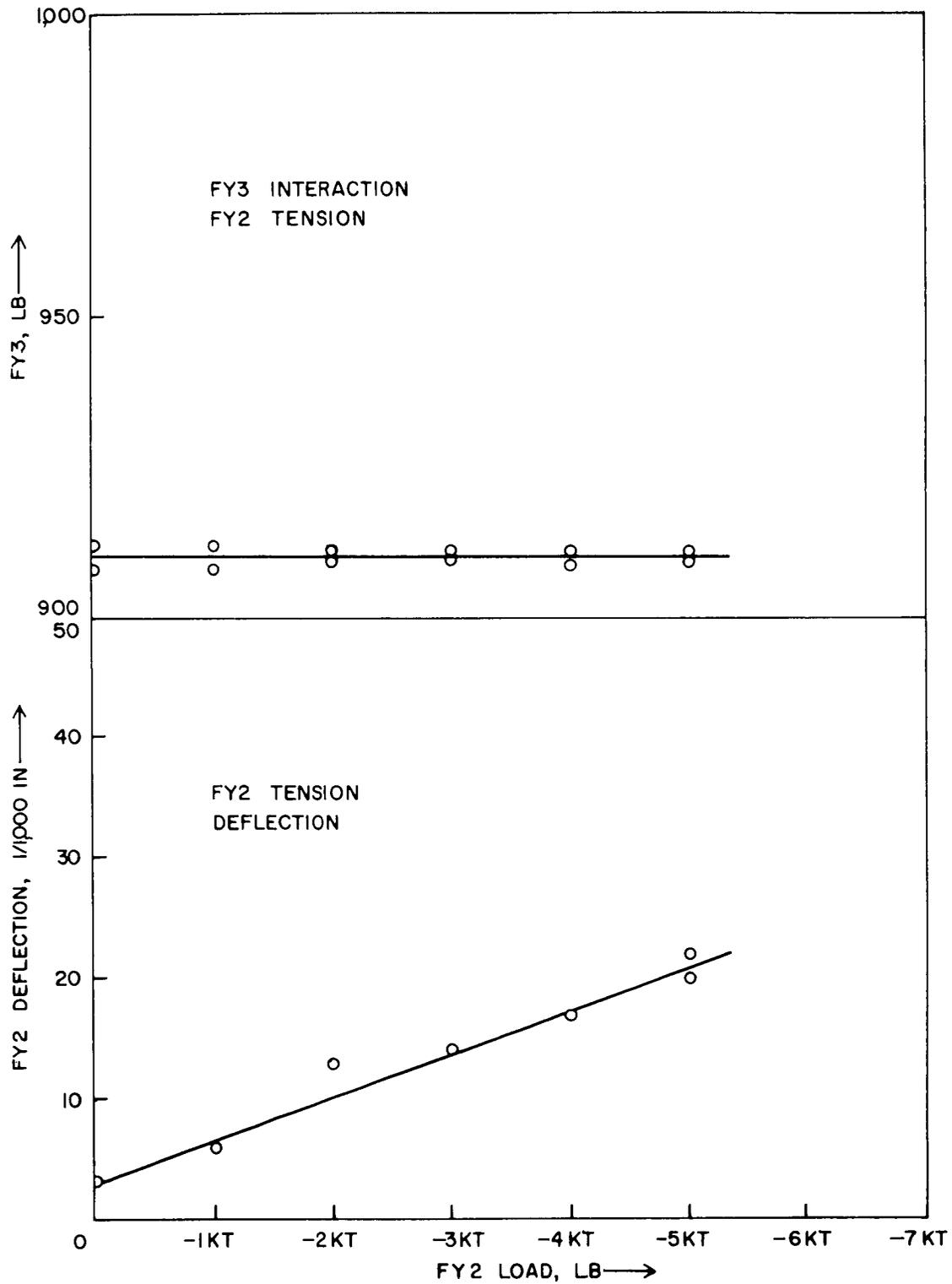


FIG. 32. Calibration Curves of Interaction Forces. Top, FY3 interaction, FY2 tension; bottom, FY2 tension, deflection.

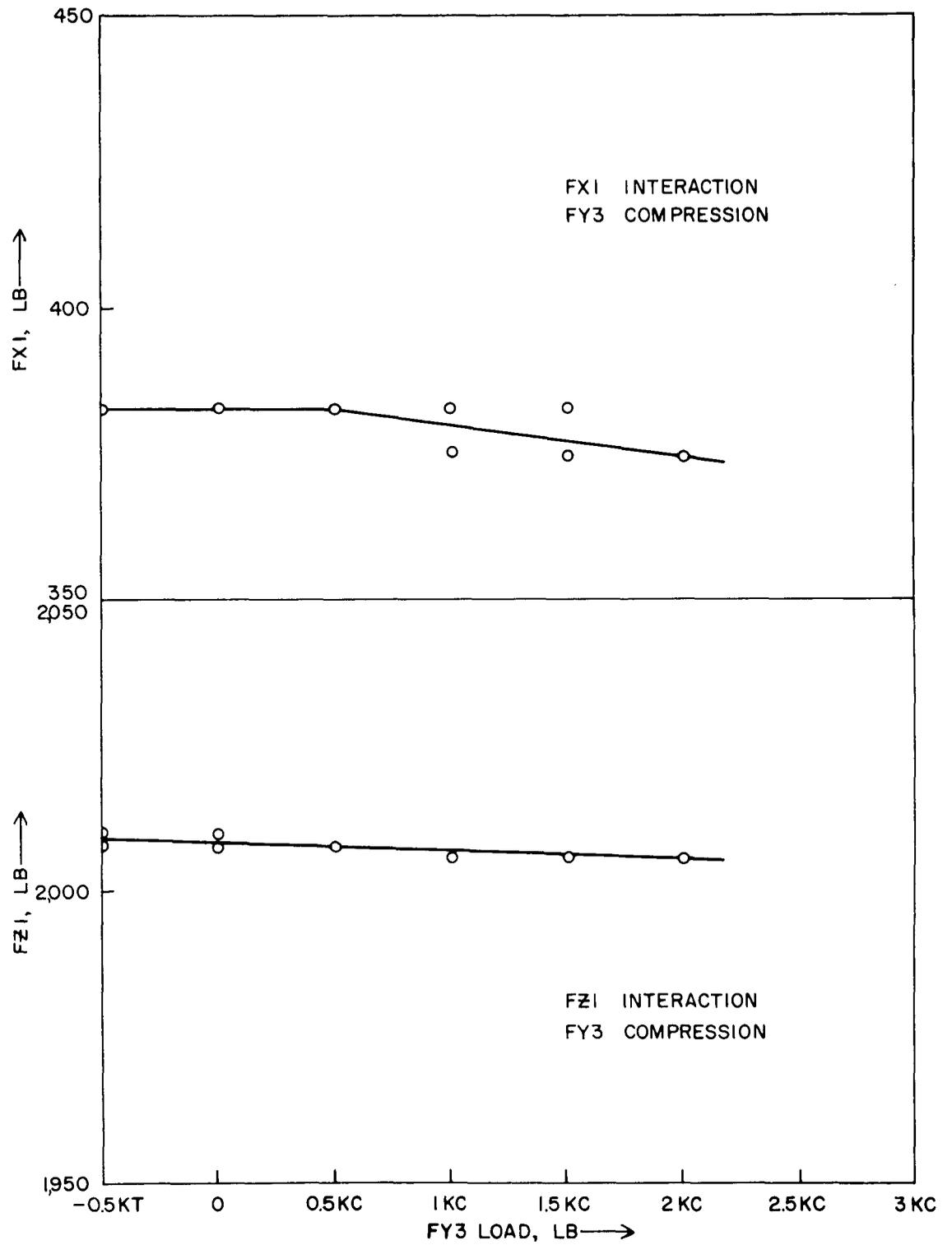


FIG. 33. Calibration Curves of Interaction Forces. Top, FX1 interaction, FY3 compression; bottom, FZ1 interaction, FY3 compression.

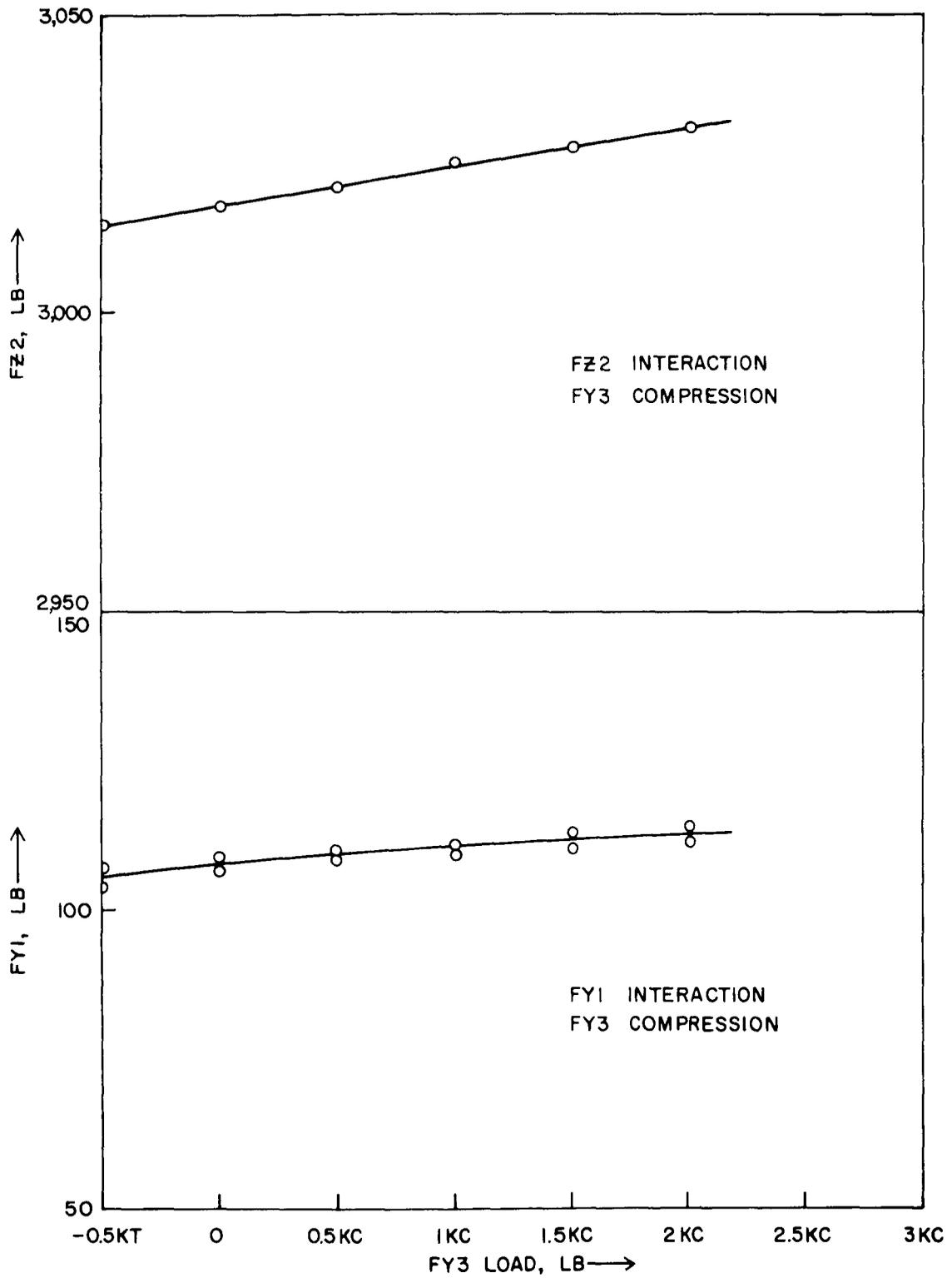


FIG. 34. Calibration Curves of Interaction Forces. Top, FZ2 interaction, FY3 compression; bottom, FY1 interaction, FY3 compression.

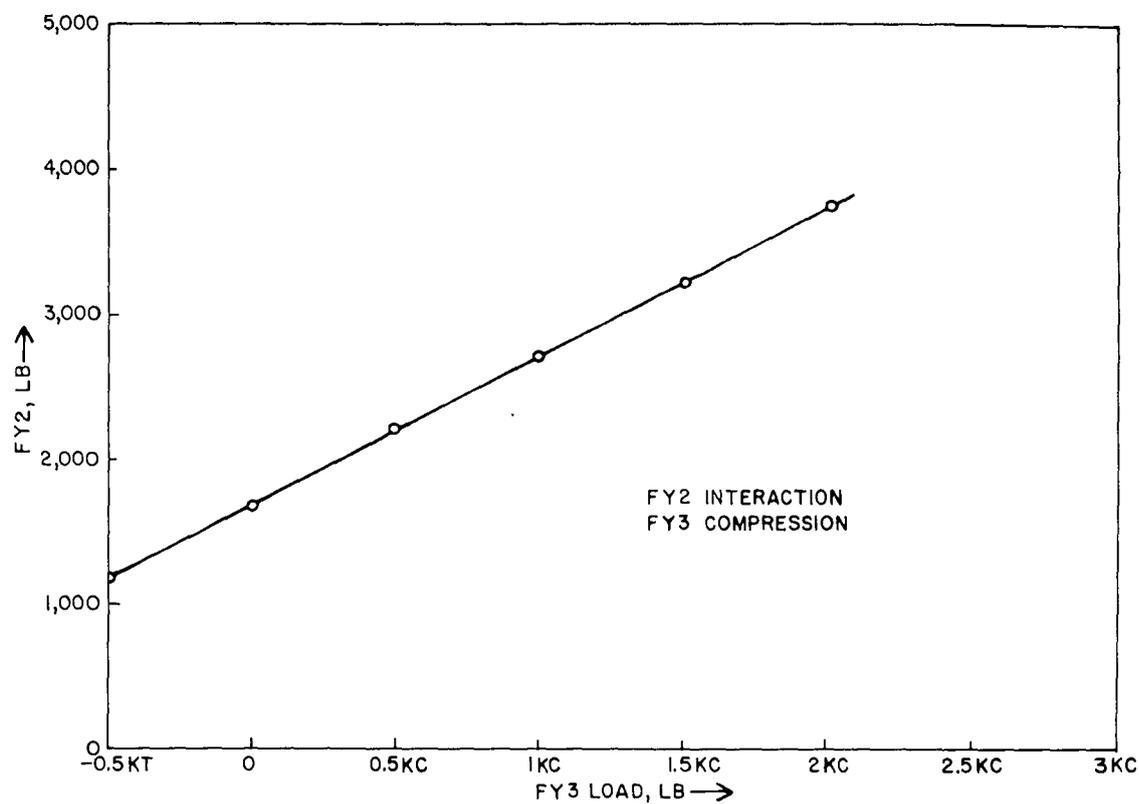


FIG. 35. Calibration Curve of Interaction Forces.
FY2 interaction, FY3 compression.

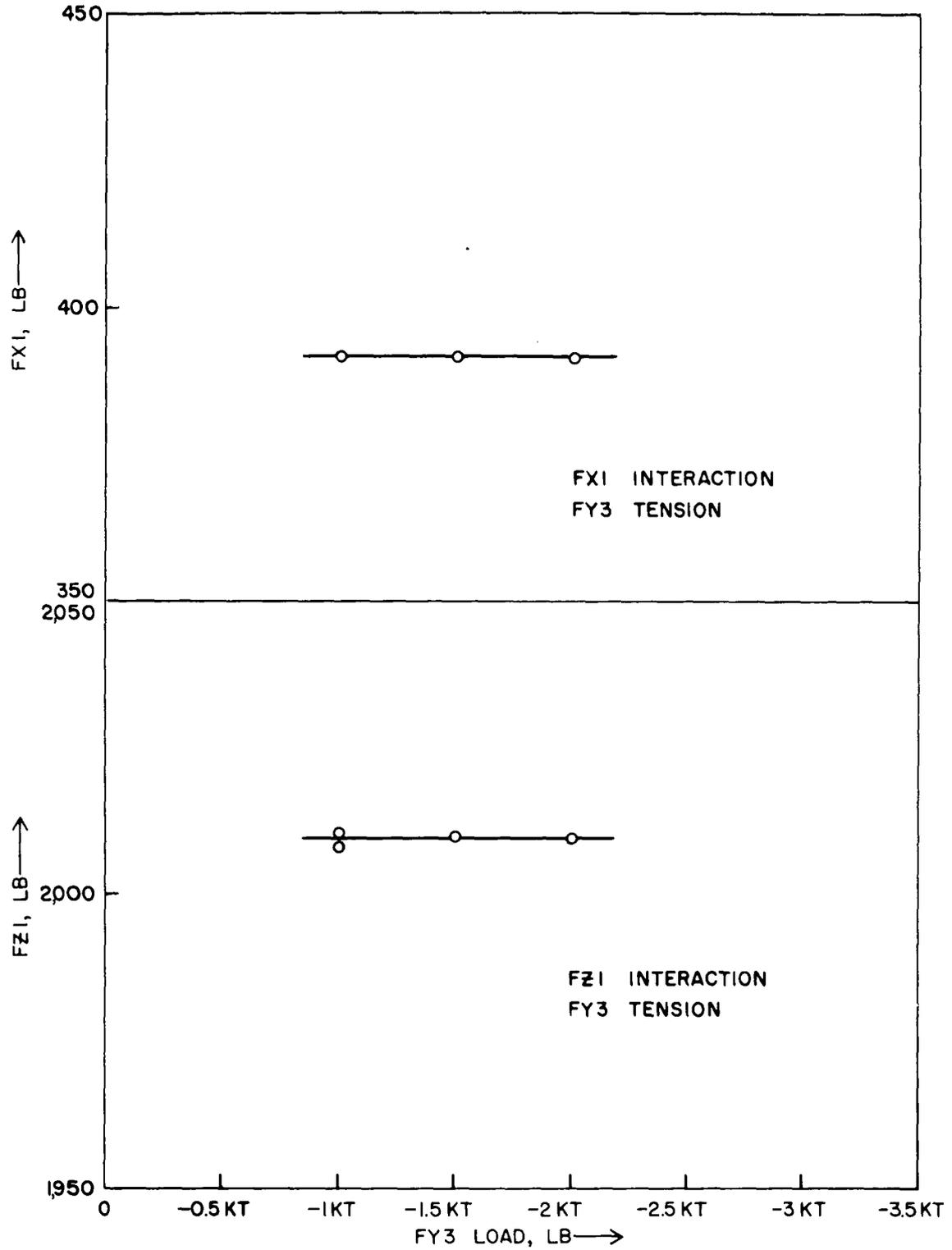


FIG. 36. Calibration Curves of Interaction Forces. Top, FX1 interaction, FY3 tension; bottom, FZ1 interaction, FY3 tension.

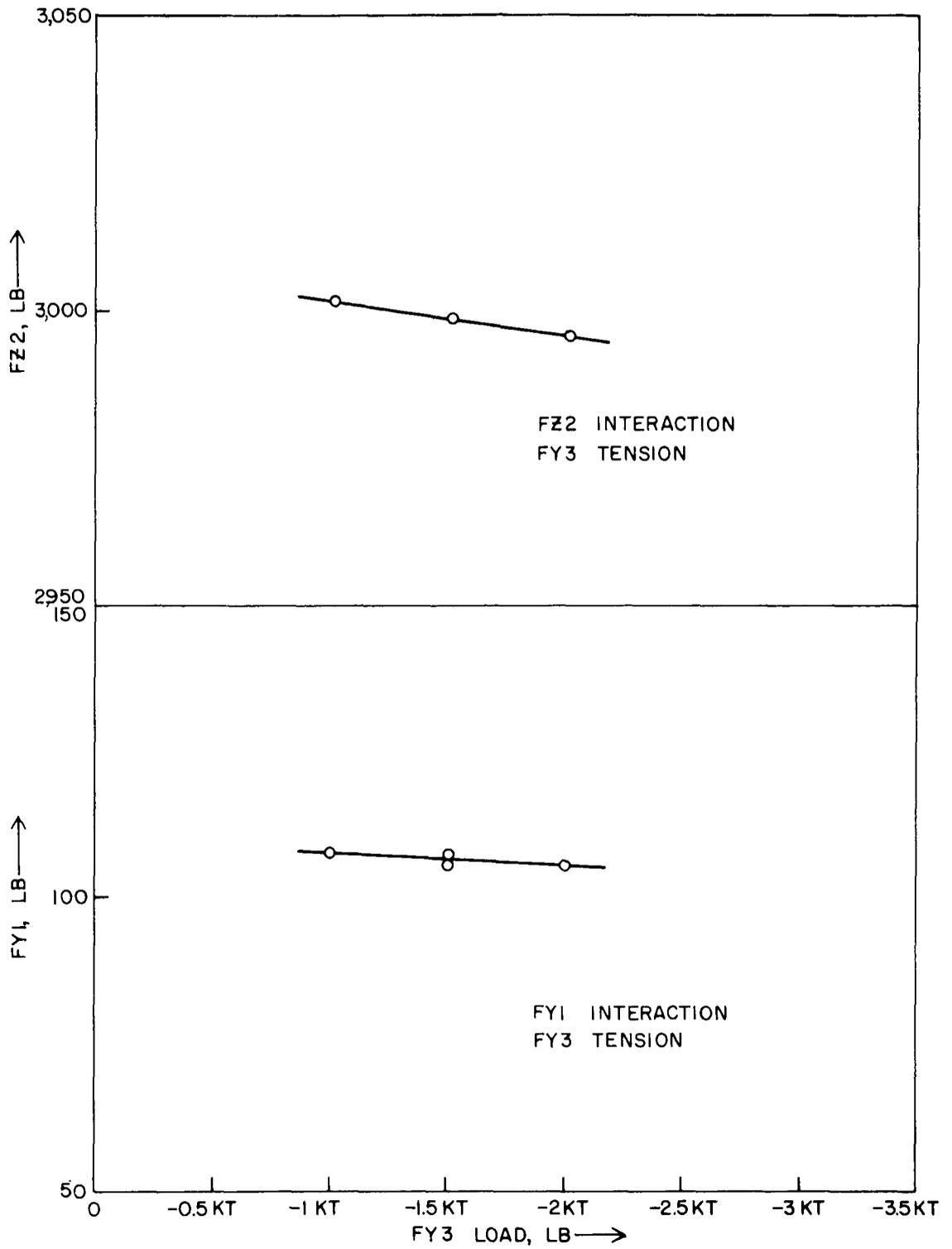


FIG. 37. Calibration Curves of Interaction Forces. Top, FZ2 interaction, FY3 tension; bottom, FY1 interaction, FY3 tension.

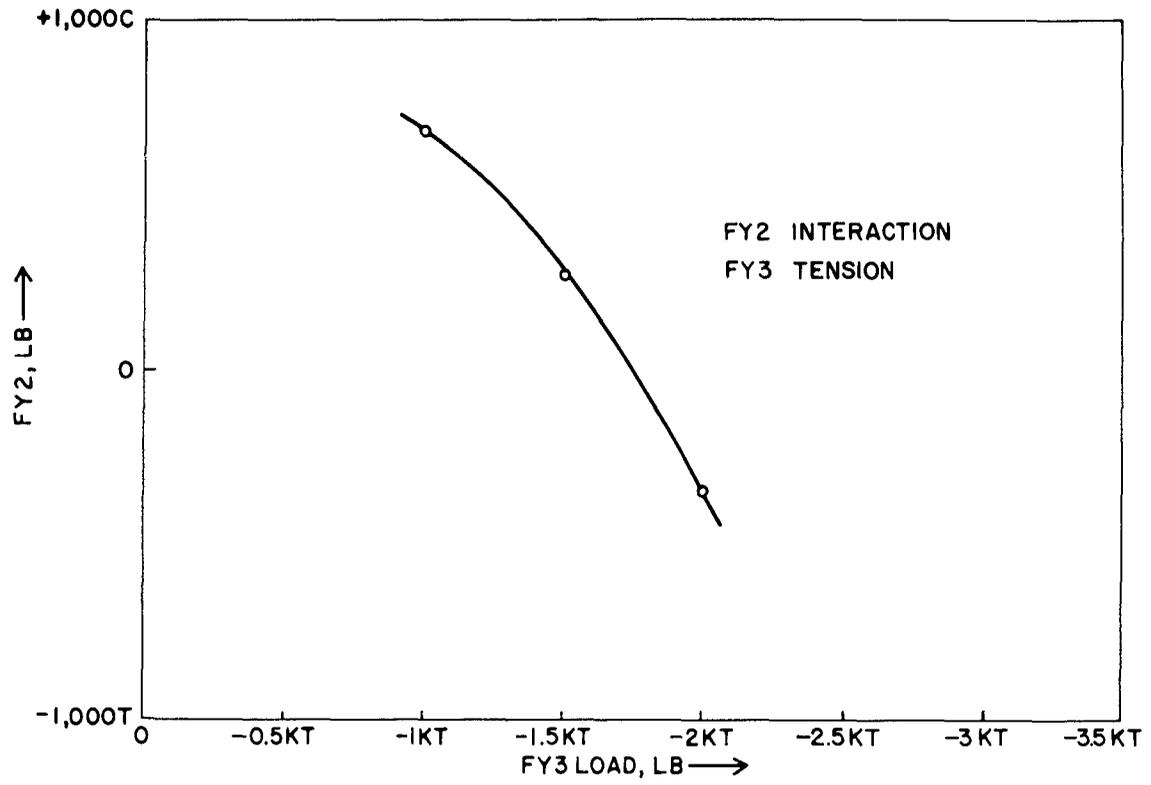


FIG. 38. Calibration Curve of Interaction Forces.
FY2 interaction, FY3 tension.

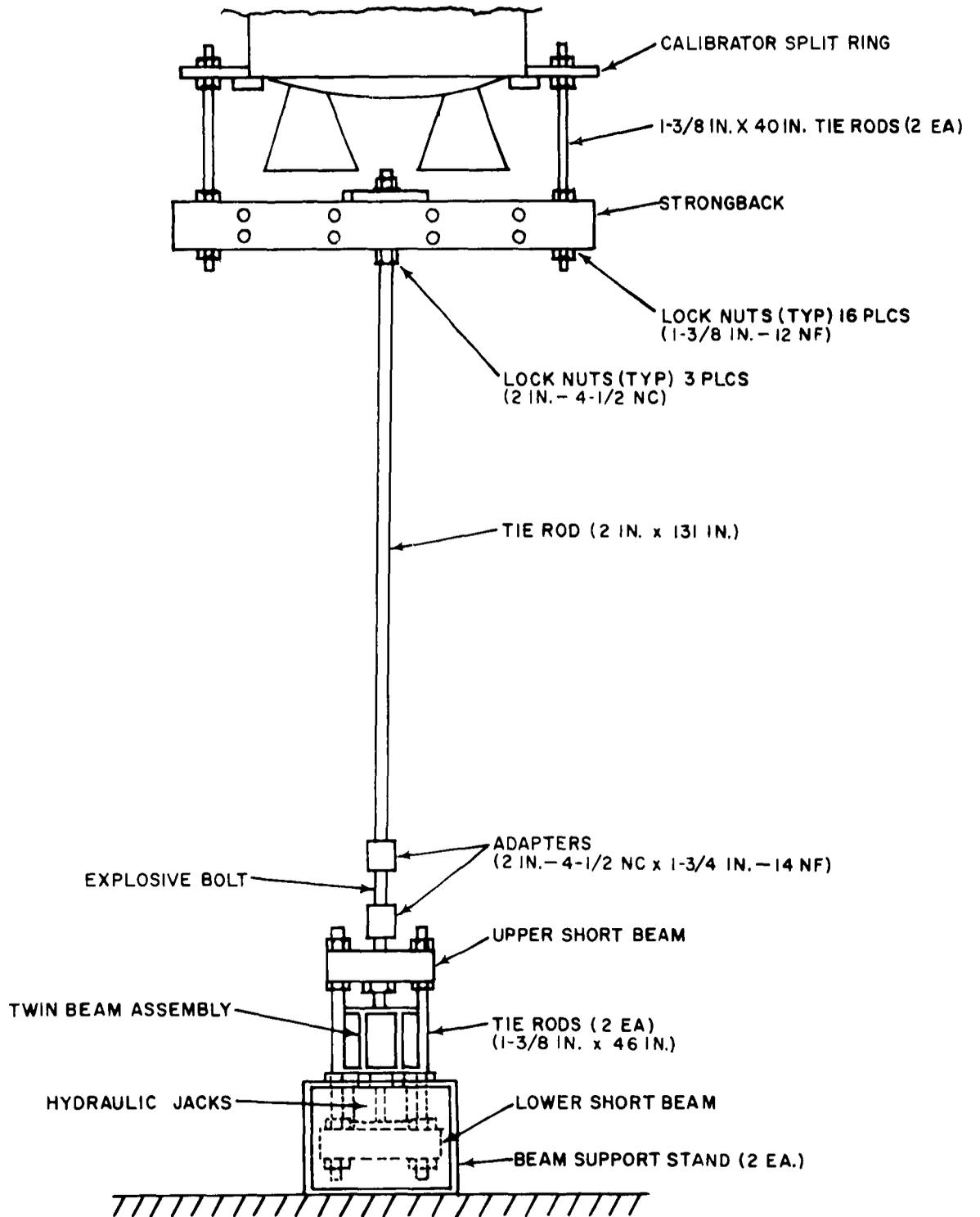


FIG. 39. Twanger Assembly Schematic.

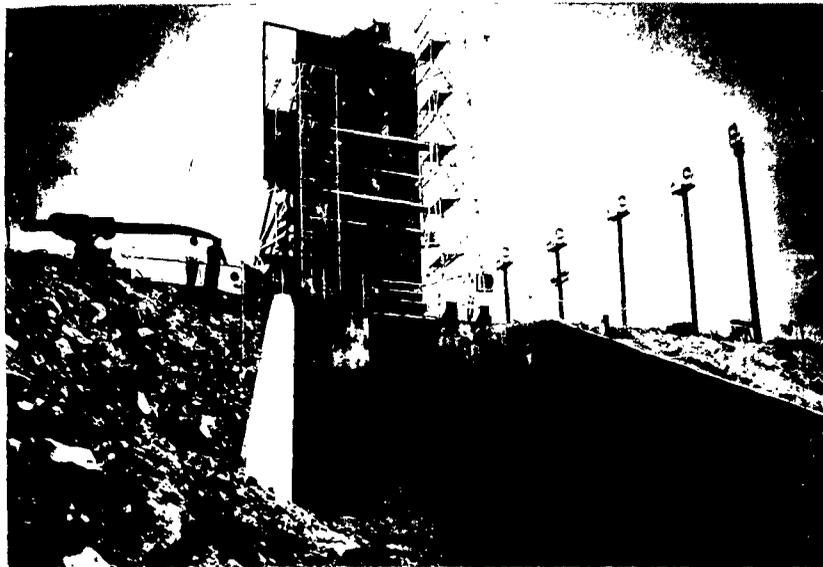


FIG. 40. Twanger Hardware During Assembly.

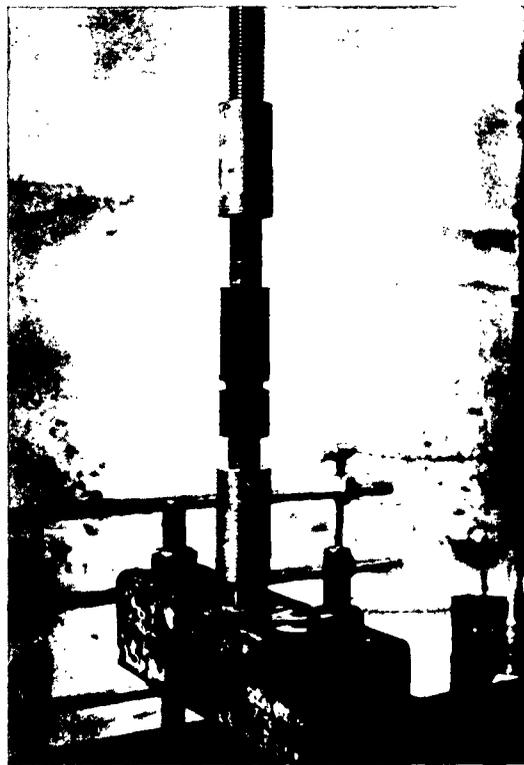


FIG. 41. Twanger Assembly, Explosive Bolt.

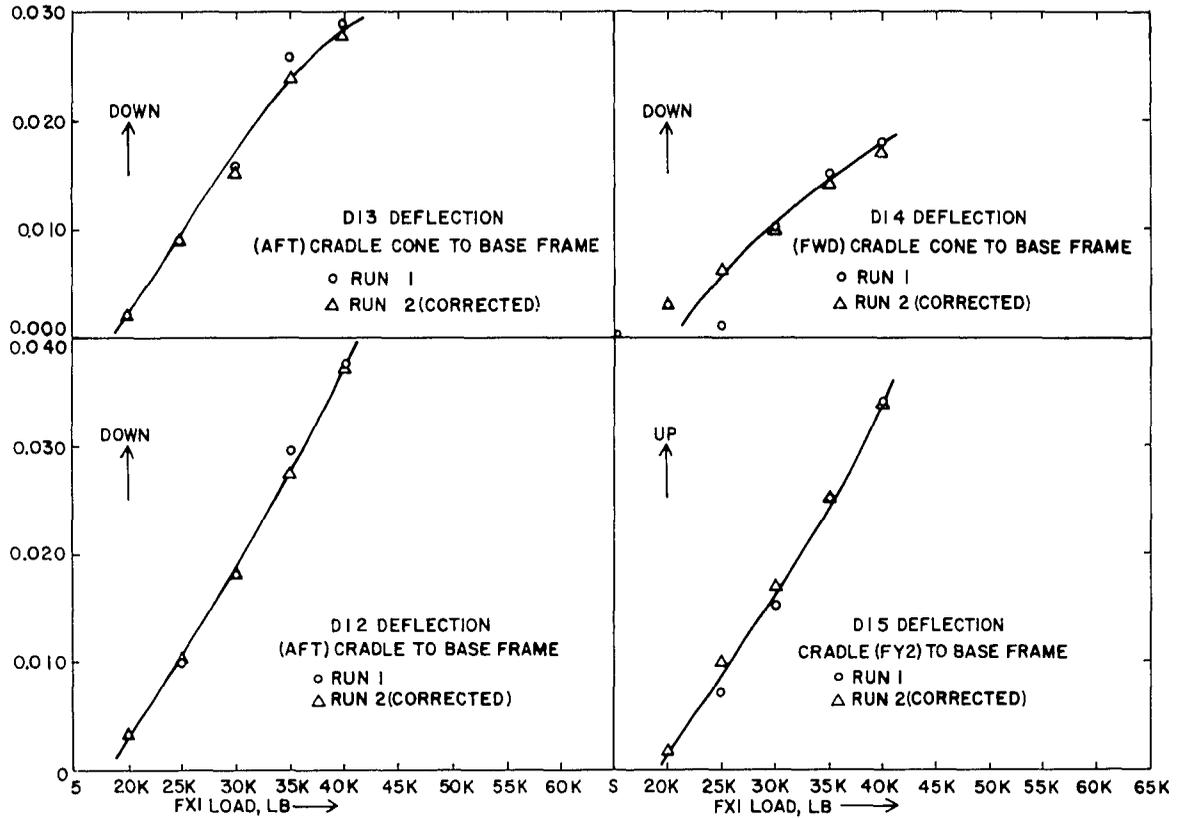


FIG. 42. Test Stand Deflections Using Twanger Hardware, Runs 1 and 2.

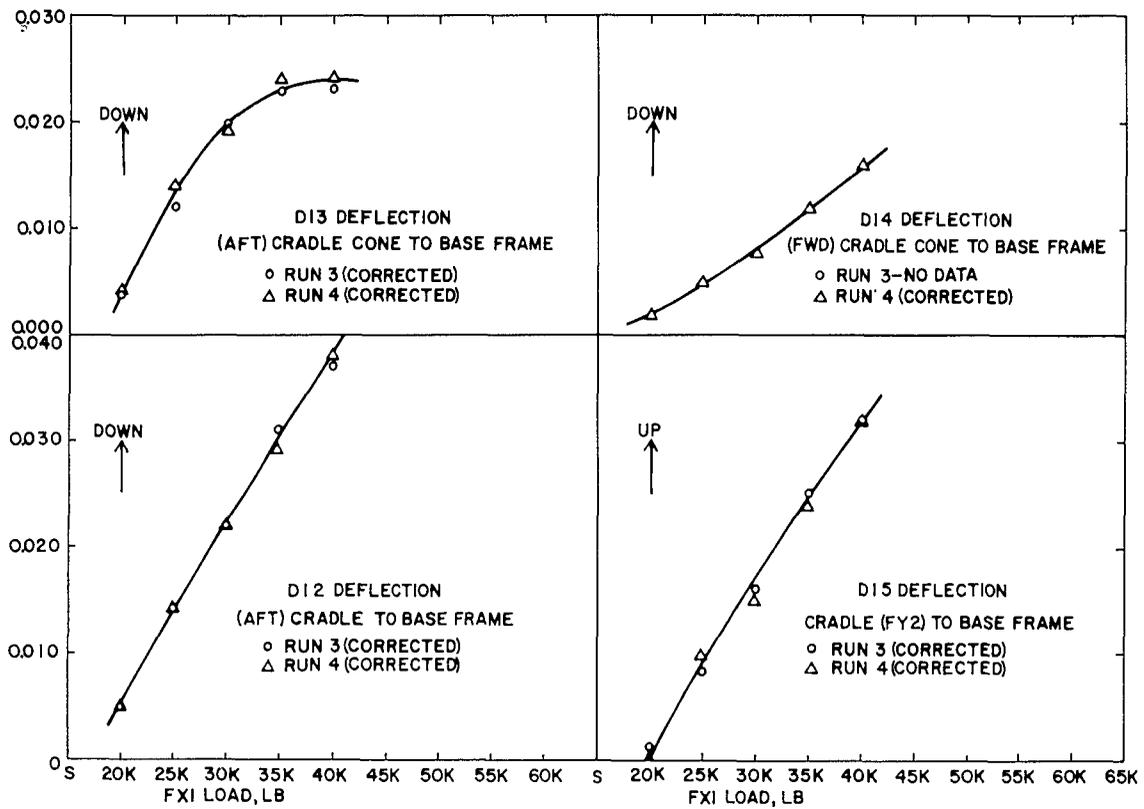


FIG. 43. Test Stand Deflections Using Twanger Hardware, Runs 3 and 4.

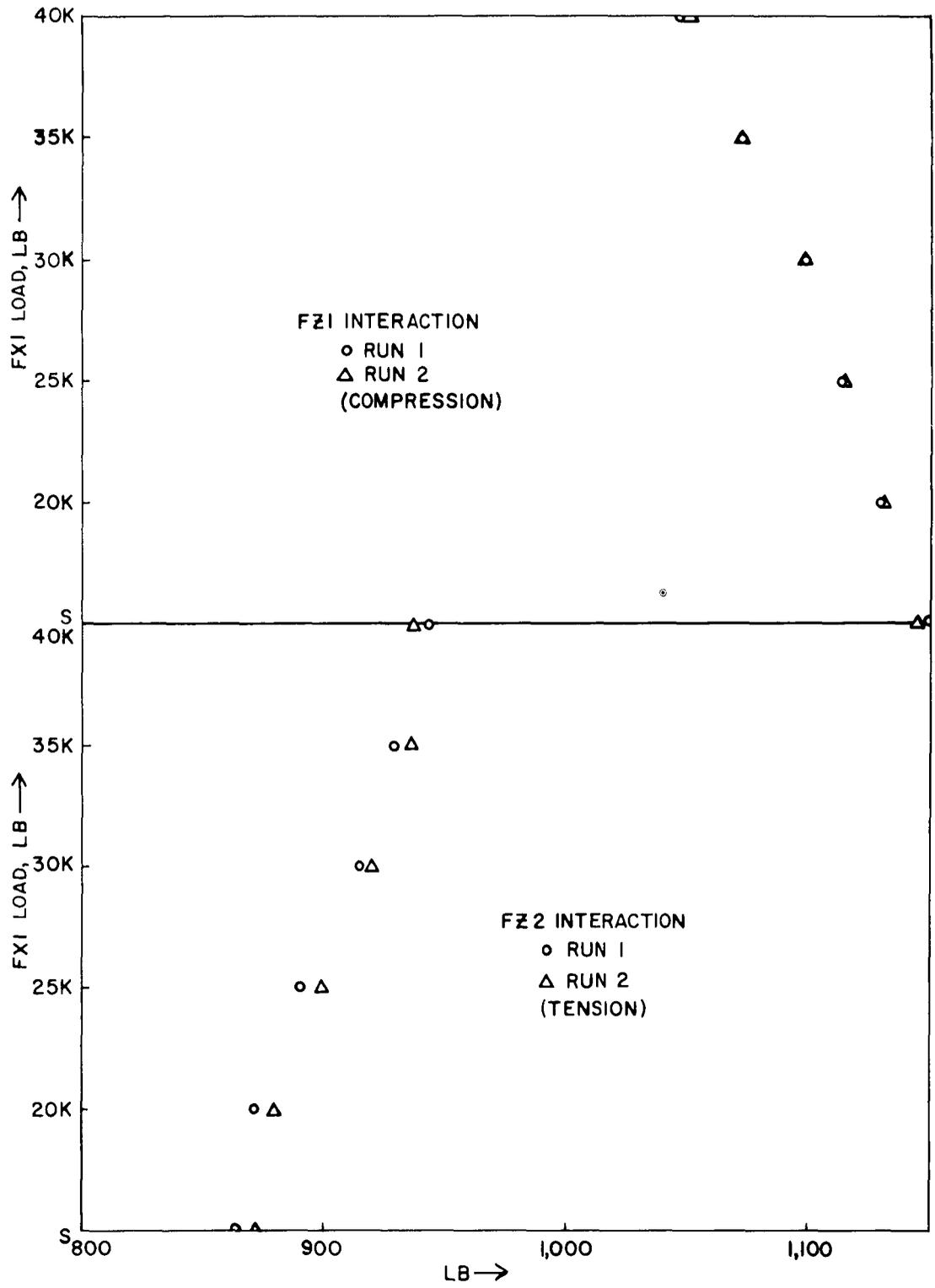


FIG. 44. Vertical Load Interaction Data.

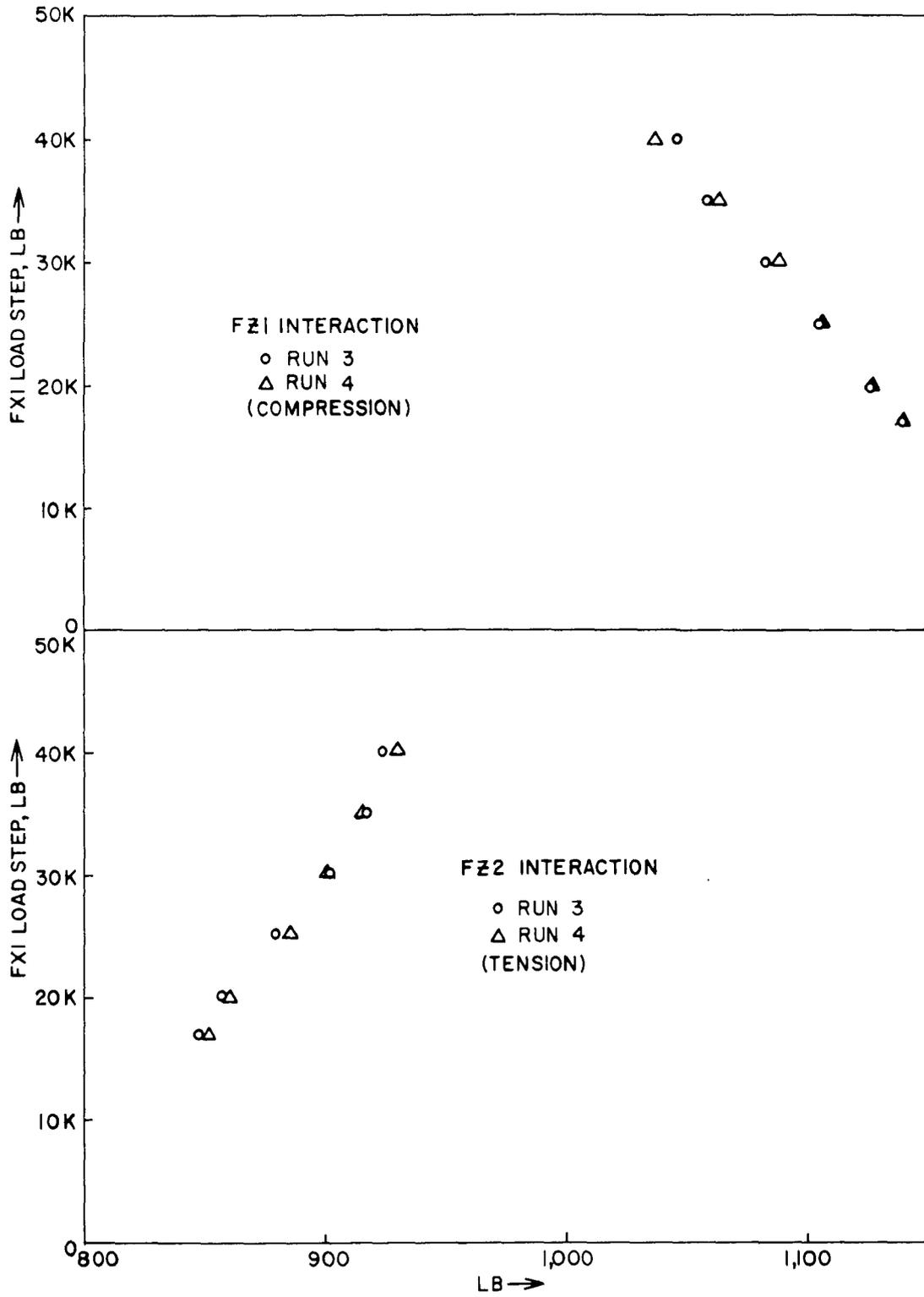


FIG. 45. Vertical Load Interaction Data.

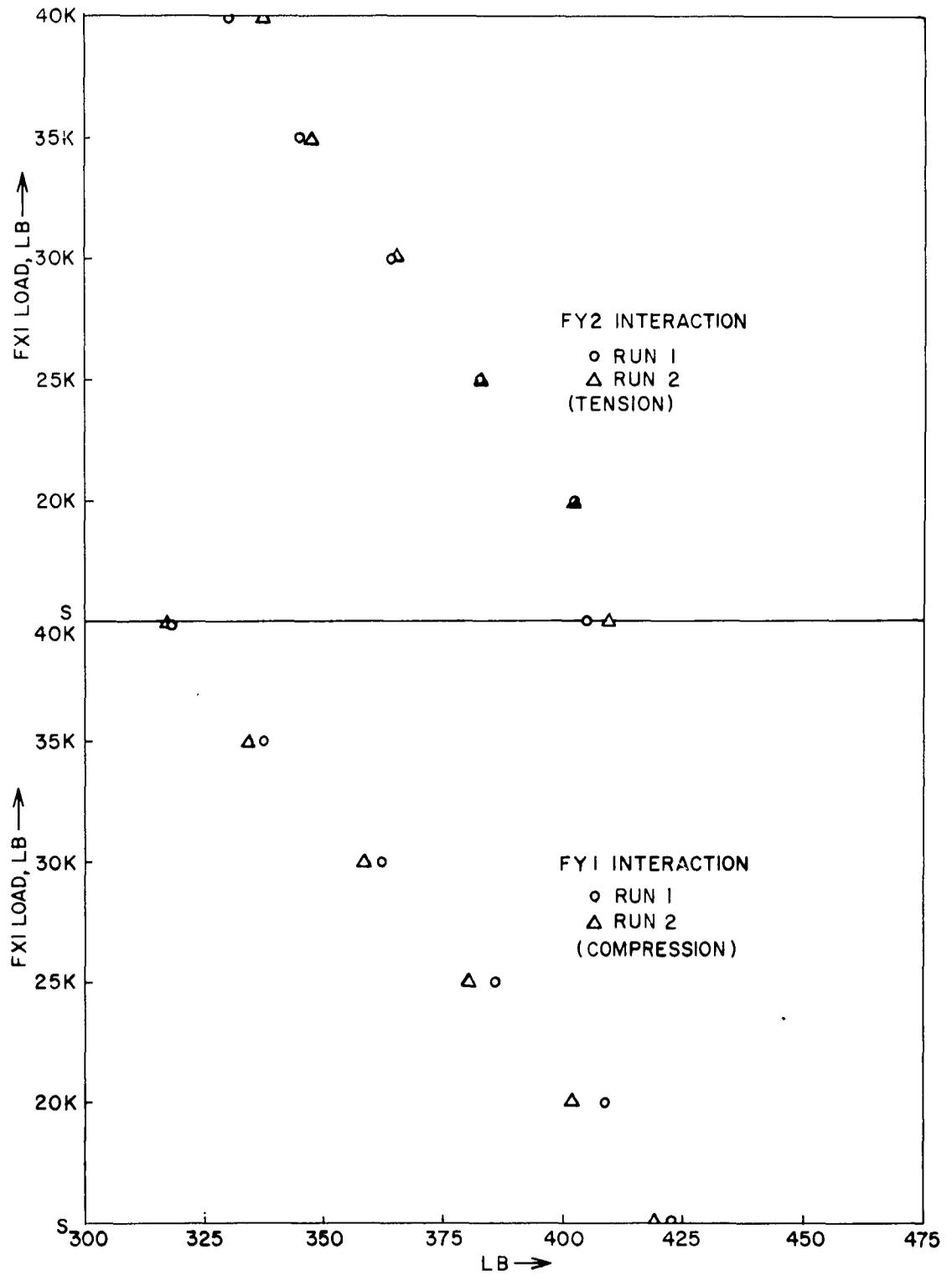


FIG. 46. Vertical Load Interaction Data.

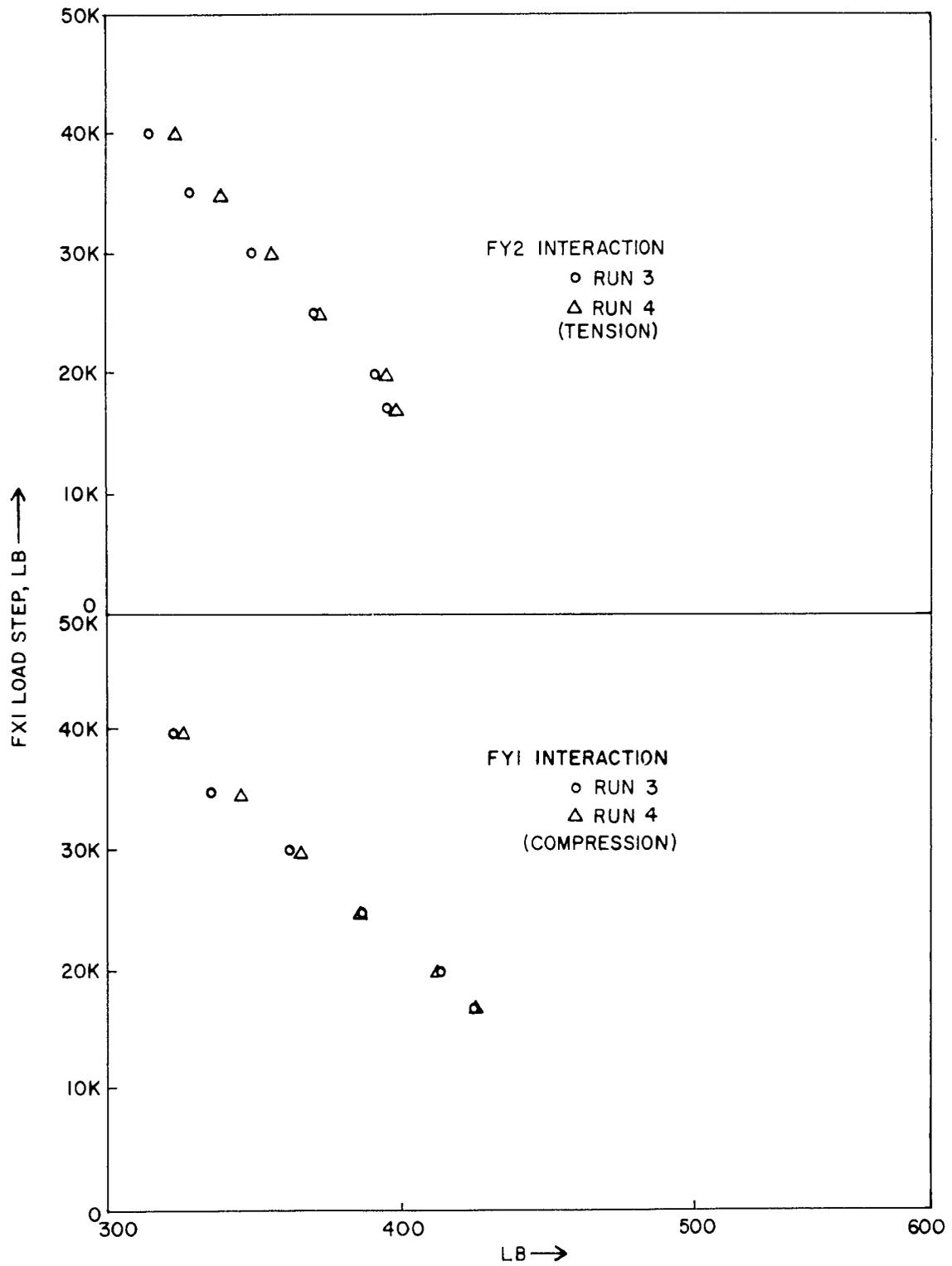


FIG. 47. Vertical Load Interaction Data.

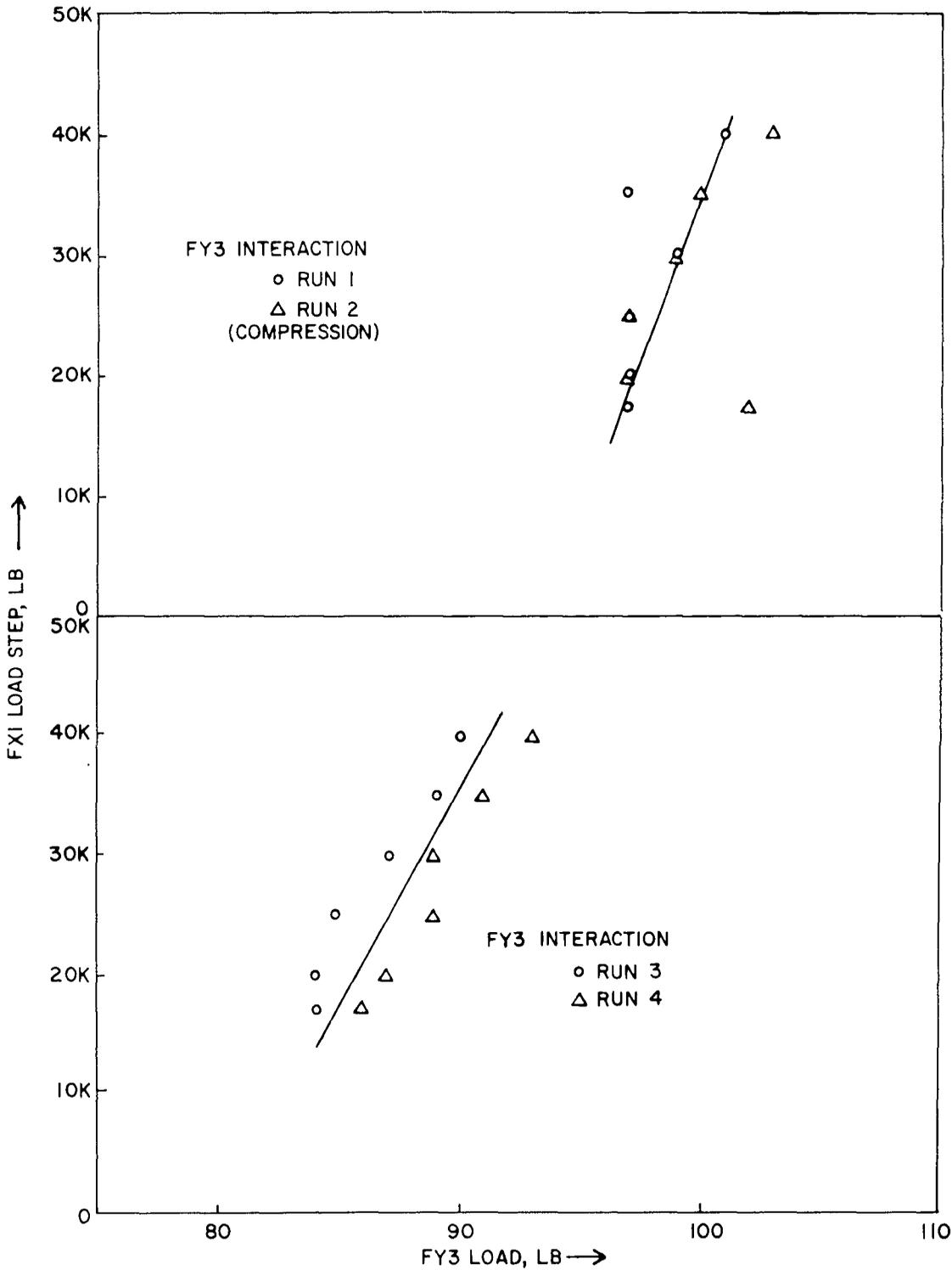


FIG. 48. Vertical Load Interaction Data.

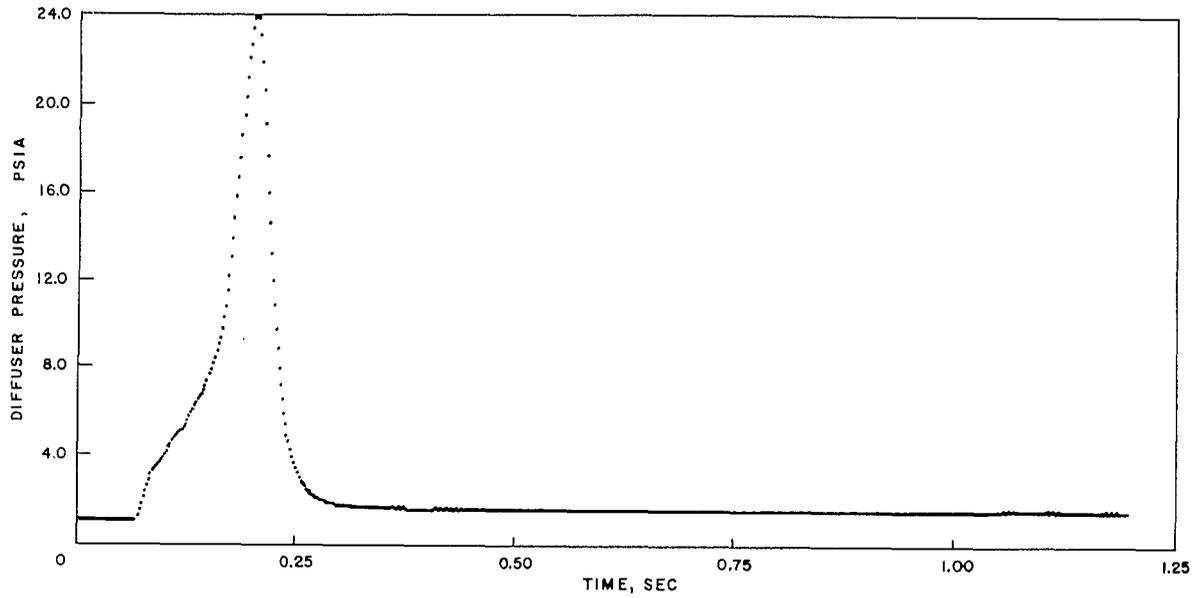


FIG. 49. Diffuser Pressure Versus Time, ST-43.

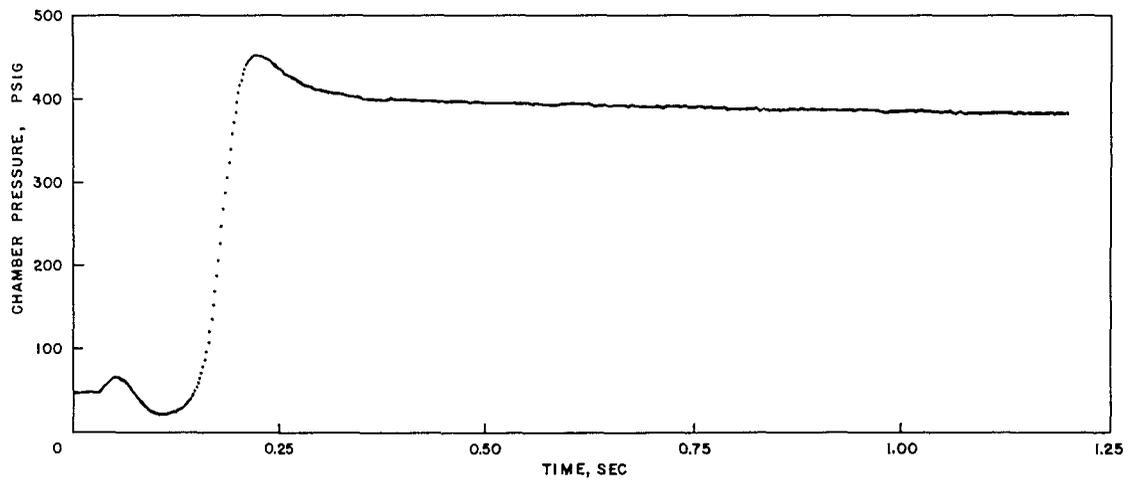


FIG. 50. Engine Chamber Pressure Versus Time, ST-43.

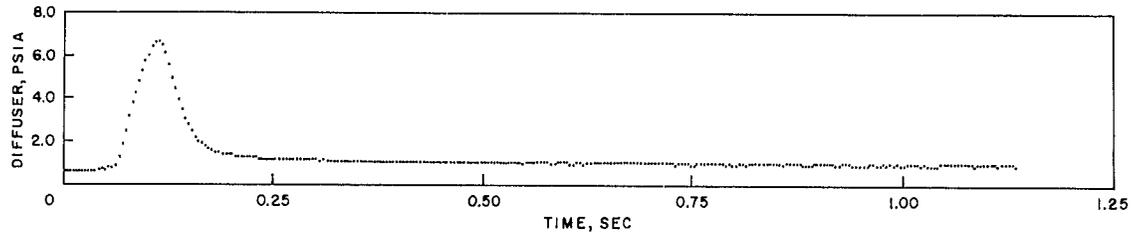


FIG. 51. Diffuser Pressure Versus Time, ST-51.

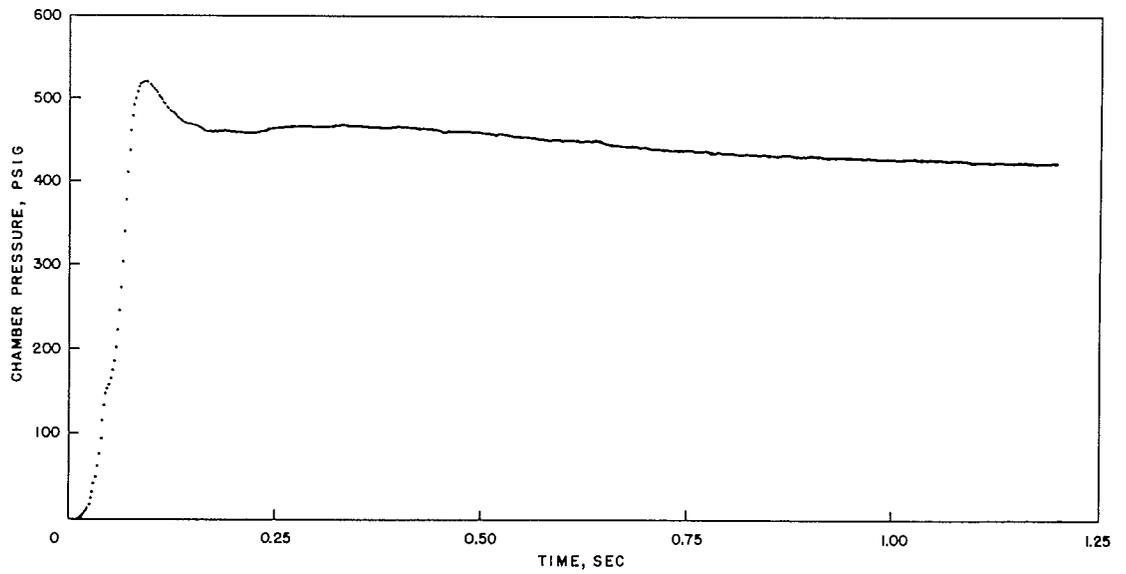


FIG. 52. Engine Chamber Pressure Versus Time, ST-51.

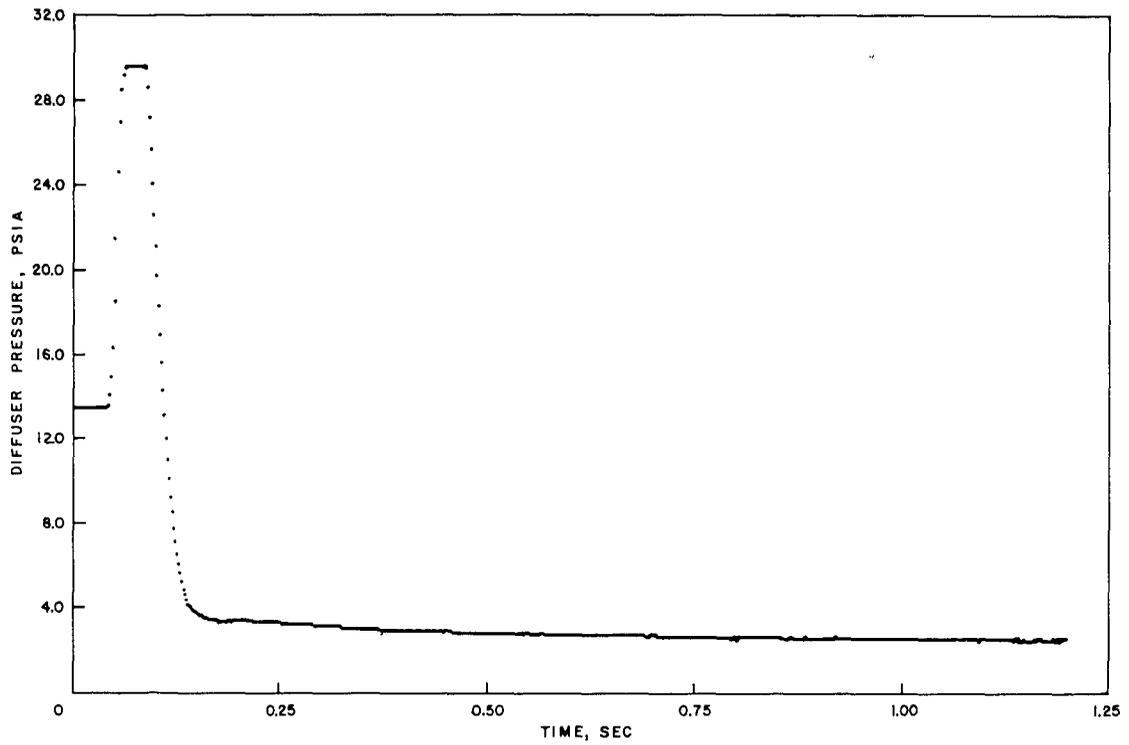


FIG. 53. Diffuser Pressure Versus Time, ST-44.

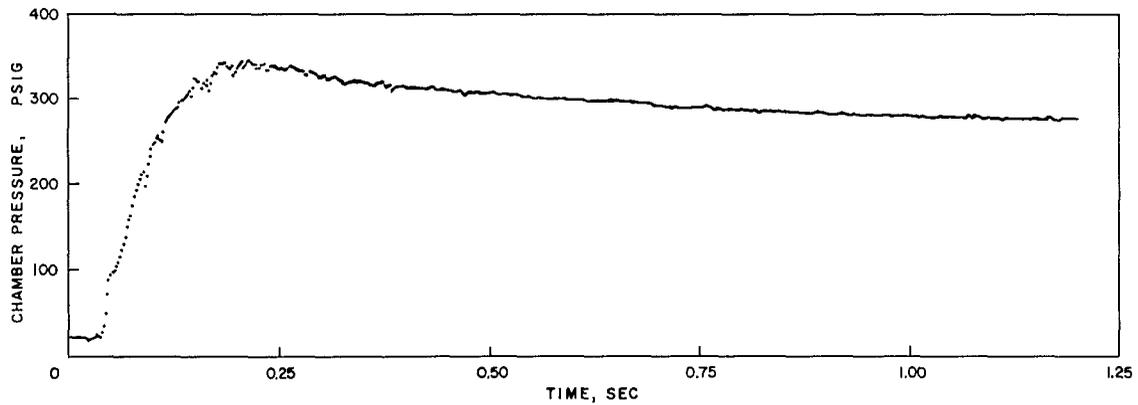


FIG. 54. Engine Chamber Pressure Versus Time, ST-44.

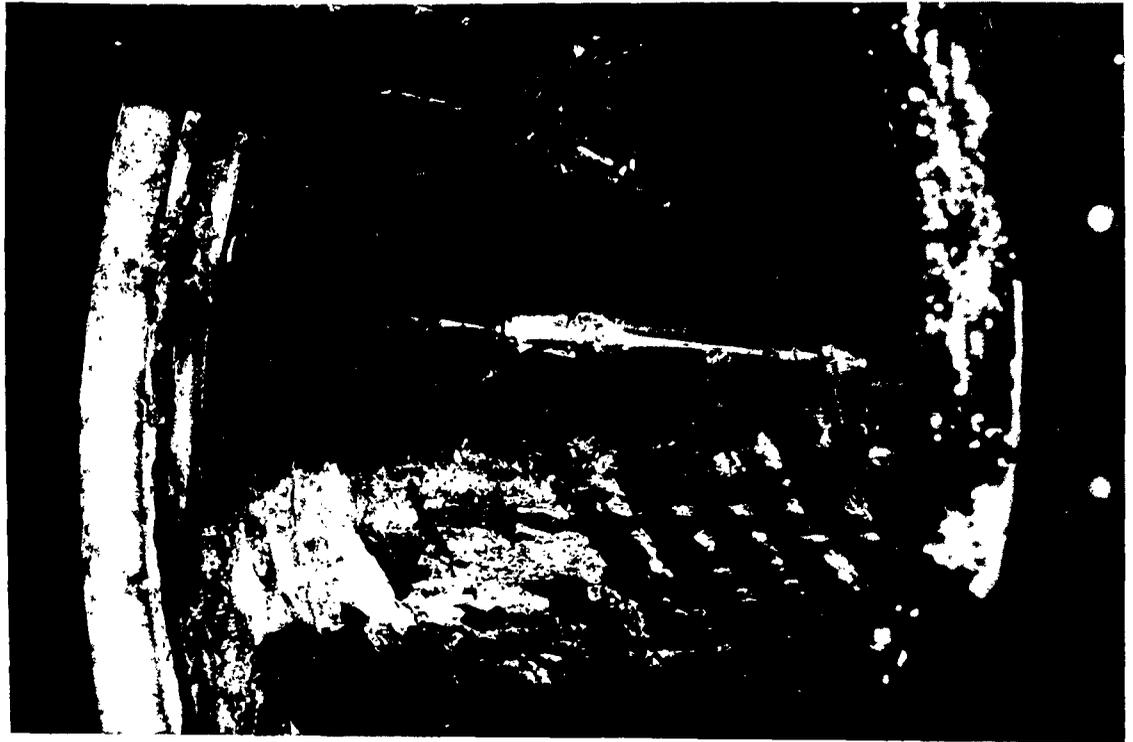


FIG. 55. Entrance Section Burnout of Stainless Steel Diffuser Liner.

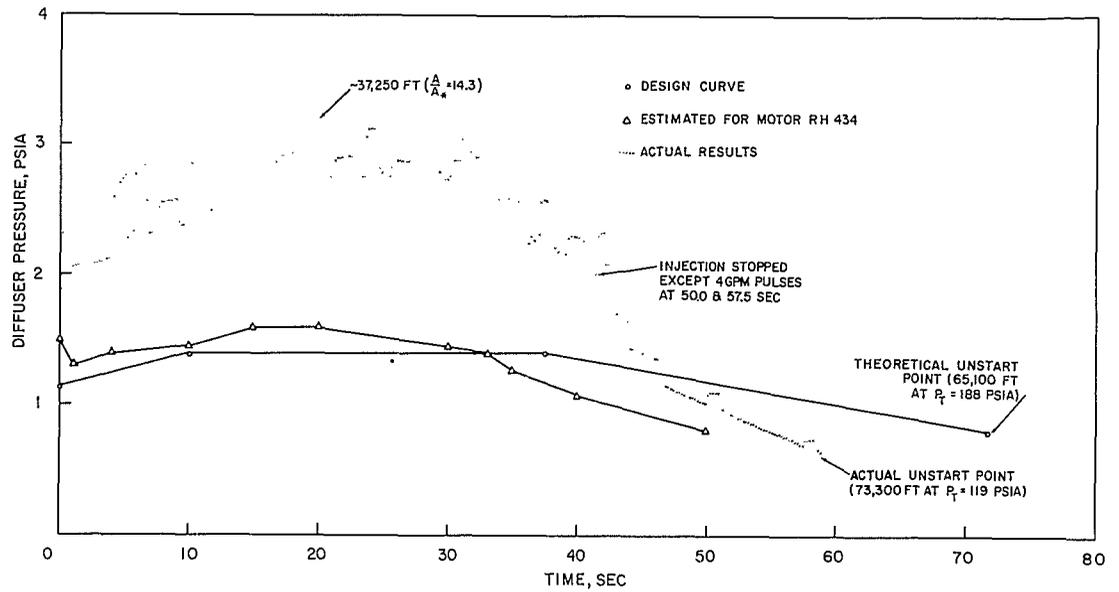


FIG. 56. Diffuser Performance, ST-60.

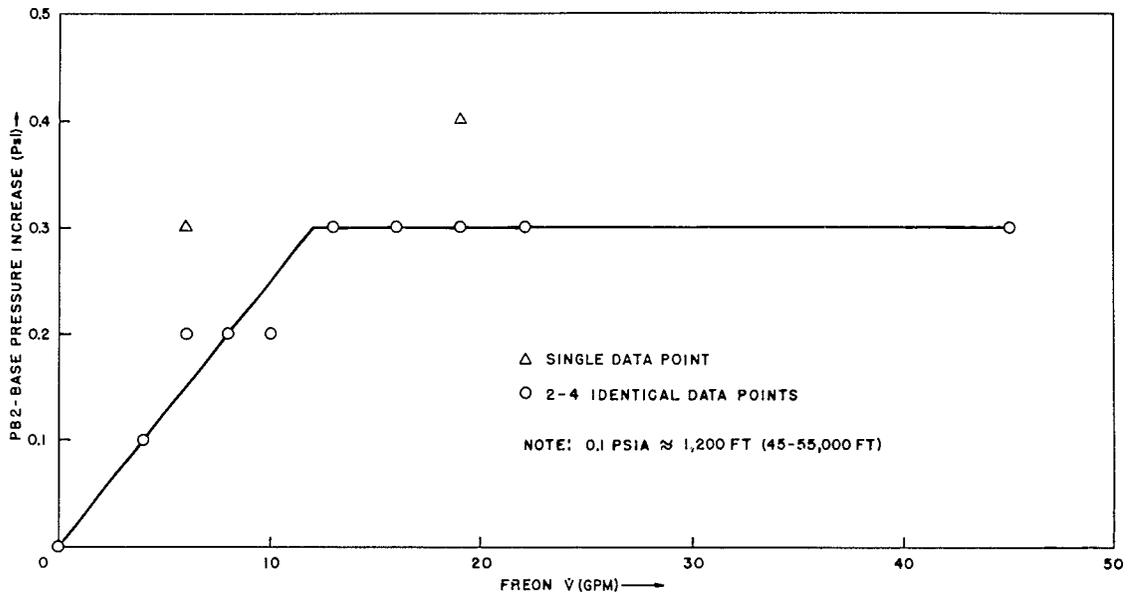


FIG. 57. Freon Injection Effect, ST-60.

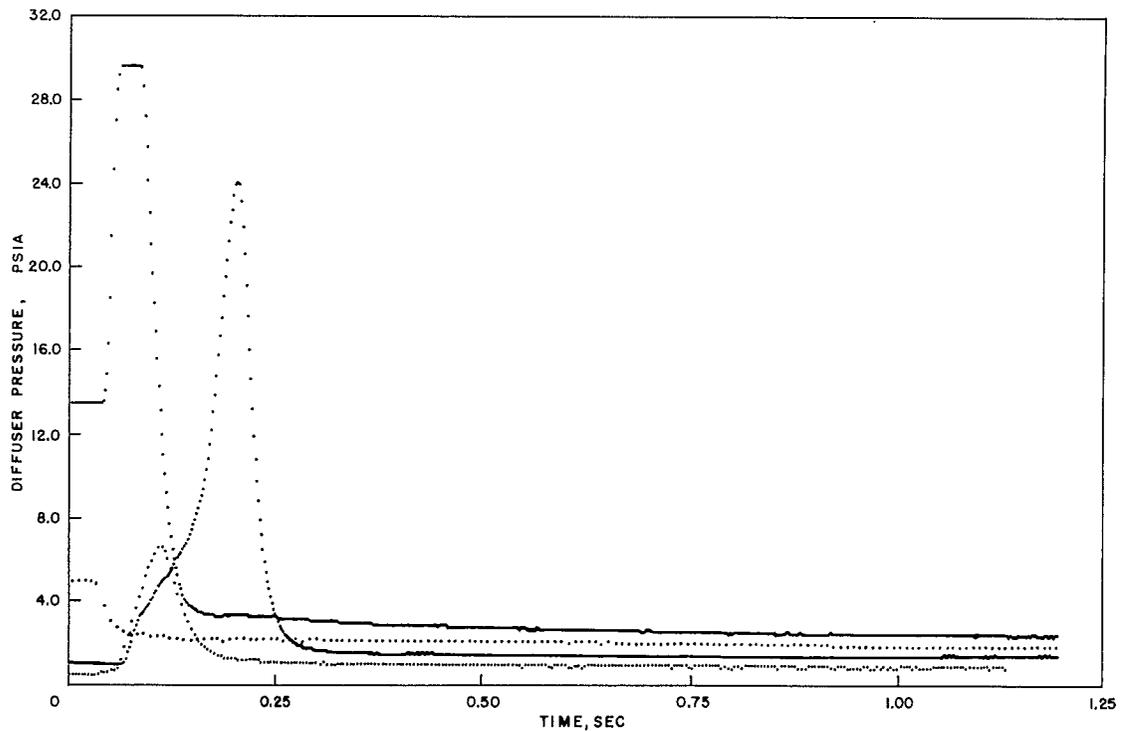


FIG. 58. Diffuser Pressure Versus Time, ST-43, ST-51, ST-44, and ST-60.

TABLE 1. NOTS DIFFUSER PERFORMANCE SUMMARY

Test	Date	Engine	Diffuser	Performance					Prefire Level	Remarks	
				Min (ft)	PC (psig)	t _b (sec)	Max (Unstart) (ft)	PC (psig)			t _b (sec)
ST-43	11/15/61	2PAL-69	*	60,000	~400	~30	72,000	182	61.4	85,000	Successful checkout
ST-51	3/12/62	2PAL-70	*	60,000	~400	35	80,000	180	60.0	85,000	Successful checkout
ST-44	4/4/62	RH-434	*	43,000	260	~3	Ambient	Burnout - fluid injection
ST-60	7/22/62	RH-484	**	40,000	375	15-20	73,300	119	59.0	70,000	Successful fluid injection

* NOTS original design - Water-jacketed, film cooled in subsonic end, 0.10-inch stainless liner. Marquardt/Galloway.

** NOTS modified design - Water-jacketed, graphite entrance section, film cooled in subsonic end, 0.10-inch stainless liner. Marquardt/Production steel. Slightly shorter second throat.

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ABSTRACT. This report describes the design, installation and checkout of the Naval Ordnance Test Station's SKYTOP-2 vertical static-firing and altitude-simulation facility. Included are data on the vertical truss/test-stand assembly and the rocket-exhaust

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