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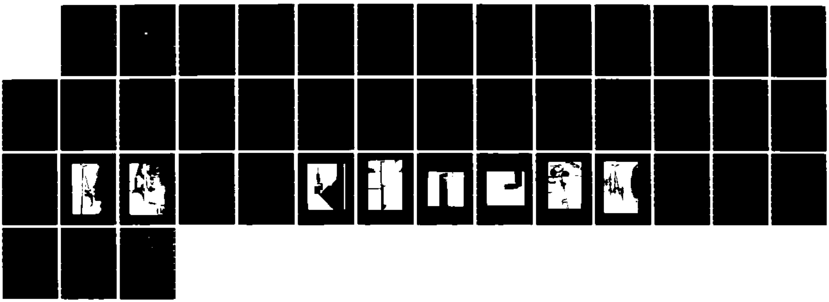

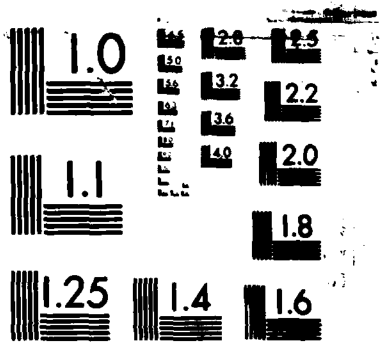

MICROCOPY RESOLUTION TEST CHART
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AD-A167 811

NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

DESIGN OF A VERTICAL THRUST STAND
FOR A REMOTELY PILOTED
MODEL HELICOPTER

by

Theodore John Urda

March 1986

Thesis Advisor: D.M. Layton

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REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Naval Postgraduate School 6b. OFFICE SYMBOL (If applicable) Code 67	7a. NAME OF MONITORING ORGANIZATION Naval Postgraduate School
6c. ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000	7b. ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO / TASK NO / WORK UNIT ACCESSION NO

11. TITLE (Include Security Classification)
DESIGN OF A VERTICAL THRUST TEST STAND FOR A REMOTELY PILOTED MODEL HELICOPTER

12. PERSONAL AUTHOR(S)
URDA, Theodore J.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Master's Thesis	FROM ____ TO ____	1986 March	42

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)
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20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL LAYTON, DONALD M.	22b. TELEPHONE (Include Area Code) Ext 2997 / 22c. OFFICE SYMBOL 67Ln

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

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Design of a Vertical Thrust Test Stand for a Remotely Piloted Model Helicopter

by

Theodore J. Urda
Lieutenant, United States Navy
B.S., Illinois Institute of Technology, 1978

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
March 1986

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Donald M. Layton, Thesis Advisor

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Dean of Science and Engineering

ABSTRACT

This paper discusses the necessary functional characteristics for the design of a test stand to measure the vertical thrust of a remotely piloted model helicopter as a function of power output, in different degrees of ground effect. A number of potential design choices are presented along with possible instrumentation schemes to obtain both the power output and the lifting force generated by the Heli-Star model helicopter equipped with a Gold Cup HP.61 engine. Included are the results of preliminary validation testing of the test stand design chosen and a discussion of the methods used to eliminate or control vibrations which hampered the utility of the test stand. Recommendations for possible future modifications are also included.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

The author wishes to acknowledge Glen Middleton and Ron Ramaker for their work in fabricating the components for the test stand and Ted Dunton for his assistance with the instrumentation. The author also wishes to thank his wife, Brenda, for all of her support during the last two years.

I. INTRODUCTION

A. GENERAL HISTORY

The modern day helicopter has evolved from an assortment of machines that were made in an attempt to achieve vertical flight. Sir George Cayley flew an improved version of a French model helicopter designed by Launoy and Bienvenu in the early nineteenth century. Paul Cornu, also a Frenchman, constructed a tandem rotor helicopter which became airborne briefly as early as 1907. However the evolution of the helicopter into the realm of practical usage was delayed until 1939. It was then that Igor Sikorsky solved stability and control problems which had impeded the progress on earlier attempts at vertical flight. Sikorsky is credited with designing, building and flying the first practical helicopter, the VS-300, which had superior controlability and payload potential. This accomplishment is what launched the helicopter industry. An important point worthy of note is that some of these original helicopter designers; Cayley, Launoy and Bienvenu, recognized the value of using scaled down helicopters in their early work and did just that.

B. OBJECTIVE AND SCOPE

The unique feature of the helicopter that has substantiated its utility through the years is its ability to lift off the ground vertically, without the requirement for the spaciousness of a runway, or even a prepared surface. As such, the vertical lifting capacity of helicopters has become a significant performance parameter. It is the measurement of this lifting capability that was the objective of this project. Specifically it was desired to measure the vertical lifting capacity of a scaled down remotely controlled model helicopter in varying degrees of ground effect. To do so required the use of a test stand. This paper will describe the design, instrumentation, equipment, problems, and techniques used as well as preliminary results of testing the vertical lift capacity of a remotely piloted model helicopter.

C. RECENT PROGRESS

The British Aerospace Corporation has recently conducted research to assess the feasibility of using model aircraft technology to form the basis for military applications for other than the traditional target role of remotely piloted vehicles. Their testing involved the use of a Kavan Jet Ranger model helicopter. The manufacturer's specifications for this model reflect a payload capacity of 50% of the 4.5 to 5.0 kilogram (9.9 to 11.0 pound) flight weight. The British Aerospace Corporation modified the Jet Ranger and was able to increase hovering lift by up to 2.7 kilograms (5.9 pounds) [Ref. 1].

The project reported here is a continuation of the work of Major Charles J. Hintze, United States Army. In 1985, Major Hintze constructed a Heli-Star radio controlled model helicopter for the Aeronautical Engineering department of the Naval Postgraduate School [Ref. 2]. Figure B.1 is a photograph of the Heli-Star. The objective of his efforts were to investigate the similarities and differences between a scaled down radio controlled helicopter and a full scale helicopter. He also suggested the possibility of using a relatively inexpensive helicopter to conduct performance testing on an academic level. As such, the major emphasis of this project was to design and build a vertical thrust test stand for the Heli-Star in order to accurately measure its lifting capability and to conduct initial hover testing. The objective of these tests was to obtain results which would validate the accuracy of the instrumentation and the utility of the vertical thrust test stand.

D. FUTURE USE

The utility of the test stand also has potential for usefulness beyond the scope of this project. It is envisioned that the vertical test stand and helicopter could be used as an experimental training device for introductory level aeronautical engineering courses. Additionally, it could be used by individuals doing performance studies. An example of this might be to assess the impact of varying the geometry of the main rotor blades. Another benefit of obtaining data on the performance of a model helicopter would be that of applying it to a remotely piloted vehicle for covert military missions. The inherent small size of the Heli-Star model helicopter provides an extremely small radar cross section which would make it virtually undetectable to enemy radar. Recently, radio controlled drones have been utilized in the middle east by Israel against Syrian surface-to-air radar sites. The success rate was sufficiently high so as to invoke increased interest in these types of programs. The question that remains to be answered is the payload carrying capability of scaled-down remotely piloted helicopters. The purpose of this project was to provide a means for which to answer this question and to obtain some initial test results.

II. APPROACH TO THE PROBLEM

A. OVERVIEW OF REQUIREMENTS

In order to accomplish hover performance evaluations, it was deemed necessary to obtain both the power output of the helicopter's engine and the lifting force generated by the helicopter's main rotor system simultaneously in order to correlate the two. It was therefore necessary to instrument the test stand as well as the helicopter to obtain the two readings. The following sections will describe in further detail a number of possible methods to instrument the helicopter, the drawbacks of the methods not utilized, along with the rationale for the method chosen. The same will be done for the vertical thrust test stand.

B. ENGINE POWER OUTPUT OPTIONS

1. Separate Engine Tests

In order to evaluate the vertical liting capability of the Heli- Star radio controlled helicopter, a number of preliminary objectives had to be accomplished. First of all, it was necessary to have the power output of the engine available on a real-time basis. Three options were considered to accomplish this. One option was to remove the engine from the helicopter and conduct separate tests of the engine with the use of a dynamometer. This option was not highly favored due to the relative expense of the dynamometer and the time and labor involved in the dismantling and reassembly of the helicopter.

2. Torque and Rotational Velocity Measurements

A second option was to instrument one of the drive shafts on the helicopter with strain gages. The strain gages would be rigged so as to provide an indication of the torque being produced. Instrumentation for a readout of the rotational velocity would also be incorporated.

The product of the torque and the rotational velocity would then be an indication of the power output. This option was not favorable due to the difficulty envisioned in instrumenting the rotating drive shaft. The relatively small size of the shaft and the difficulty in creating a wiring harness to accommodate the rotating aspect of the shaft made this option the least favorable of the three.

3. Engine Data and Rotational Velocity Measurements

The third option was to use data from the manufacturer of the engine which related the power output of the engine to its rotational velocity. The only instrumentation required would be for the purpose of obtaining an RPM sensing of either the engine or one of the drive shafts. It was decided that this option was the choice which would prove to be the easiest to incorporate while at the same time provide sufficient accuracy for the use intended. Figure B.2 shows the installation of the R.P.M. sensor and Figure B.3 shows the relationship between the engine R.P.M. and its power output.

C. THE VERTICAL THRUST TEST STAND OPTIONS

The next objective was to design the vertical thrust test stand to which the Heli-star helicopter would be attached. A number of potential designs were considered, each with their own positive and negative aspects. A variety of different problems with the features of the helicopter also had to be taken into account, as well as the proficiency of the operator-pilot.

1. Tethered Flight

One idea for a vertical thrust test stand design was to attach the Heli-Star to a length of tether. The other end of the tether would be attached to either a load cell or a tension scale. The flexible tether would permit the helicopter to be flown in a free-flight mode, thus requiring the proficiency of a skilled operator-pilot to maintain the helicopter in a position centered over the tether's lower attachment point. The tether would be a measured length in order to specify beforehand what the exact hover height would be above the ground plane. This design is similar to designs presently utilized for full size helicopters. This idea seemed to be a fairly viable option until a more in depth study was done on the degree of proficiency that would be required to hover the helicopter in the above prescribed manner. It was estimated that the flight time required to obtain a sufficient degree of proficiency for this purpose was greater than the time available for the project. Additionally, the ever-present possibility of accidentally crashing the helicopter while learning how to fly it was also a major consideration in searching for alternate vertical thrust test stand designs.

As such, it was decided early on that it would be prudent to choose a vertical thrust test stand design which would permit the helicopter to be rigidly fixed to the stand. This feature would hopefully alleviate any possibility of crashing the helicopter, and would also eliminate the need for the operator-pilot to accrue vast amounts of proficiency in flying the helicopter.

2. The Sliding Shaft Design

With this criteria in mind it was determined that one solution method would be to use a rigid shaft instead of the flexible tether. The helicopter would be securely attached to the top of the shaft. At first, it was thought that the helicopter would be used to lift the shaft from a position from which the helicopter was sitting on the ground plane to a some hover height above the ground, still within ground effect. Preliminary calculations were later made which indicated that the lifting capability of the helicopter was probably insufficient to lift the shaft at all, resulting in the abandonment of this method. However the utility of the shaft was considered usable in another fashion.

The final design concept decided upon would utilize the shaft and its low friction bearing assembly to stabilize the helicopter. However, the helicopter would not be required to lift the weight of the shaft. Instead, the helicopter would be used to pull on the shaft. In turn, the lower end of the shaft would be attached to a load cell. The pull of the shaft on the load cell would then be used to indicate the lifting capability of the helicopter. Supporting the lower end of the shaft and the load cell would be an assembly which would be adjustable so as to permit variations in the helicopter's hover height above the ground plane. Because of this variability, it would allow the helicopter to be tested in different degrees of ground effect. Figure B.4 is a schematic drawing depicting the functional components of the test stand.

3. Solution to Functional Problems

There were, however, functional problems recognized with this design. In order to start the engine of the helicopter, an external electric motor is used. The shaft of the electric starter motor is affixed with an annular rubber clutch surface. This rubber tipped end of the starter motor shaft is then pressed against an aluminum cone-shaped clutching surface on the helicopter. Power to the electric starter motor is supplied by squeezing a pressure switch on the starter. As the starter motor is rotating in order to cause the engine to turn over, sufficient friction between the two clutching surfaces must be present. This friction is generated by a fairly large amount of downward force on the helicopter. This force would not normally be a problem in and of itself, however, the load cell chosen for use was the Interface, Super-Mini load cell, model number SM-25 which was only rated at 25 pounds of force with a 150% maximum useable limit. It was estimated that the combined weight of the six foot steel shaft, the helicopter itself, miscellaneous mounting pieces and the unknown downward force of the starter motor would exceed the 37.5 pound maximum limit of the load cell. Therefore, it was necessary to design the vertical thrust test stand so as to provide a means to avoid damaging the load cell by applying too much force to it. This was accomplished by incorporating a quick release feature to the lower support bracket. Figure B.5 depicts the lower support bracket assembly.

4. Torsion Problem and Solution

In addition to the tensile-compressive limitations, the load cell could be damaged by applying too much torsion to it. The torsional limit for the SM-25 load cell is 10 inch-pounds. This amount of torque can be exceeded, for example, during installation of the load cell if the torque applied to the attachment screw becomes excessive. Initially there was concern that torsion from the helicopter could cause damage as well. This would happen if there was ever a large disparity between the torque generated by the main rotor system and the anti-torque generated by the tail rotor. The probability of this happening was reduced by simply assuring that the attachment screw between the load cell and the lower adapter for the shaft is not securely tightened. In fact, it is best if the screw is backed out between one and two revolutions. By doing so it permits the helicopter to yaw, or pivot, on the test stand while being tested. The fact that the helicopter can now pivot in yaw provides an additional benefit. Since it is desired to test the helicopter in balanced flight (in other words, the main rotor torque balancing the anti-torque of the tail rotor), by permitting freedom of movement in yaw, the pilot-operator can now detect an imbalance in torque by noting an existing yaw rate and then correct the situation by adding more or less tail rotor thrust as necessary.

III. THE FINAL DESIGN CHOICE

A photograph of the final design decided upon is shown in Figure B.6. The figure shows the vertical thrust stand as seen from below the test platform. The six foot long shaft is supported in three places: by two pillow block bearings which guide the shaft as it is adjusted up and down, and on the bottom as seen in Figure B.5 A photograph of the upper pillow block bearing is shown in Figure B.7, and a photograph of the second pillow block bearing which was added to reduce shaft vibrations is shown in Figure B.8. A load cell-to-shaft adapter is mounted on the lower end of the shaft which permits attachment of the load cell. The load cell is held in place by a bracket assembly which, in turn, is attached to a support stanchion also visible in Figure B.5. The bracket assembly is designed so that it can be removed from the support stanchion quite easily and relocated by moving it vertically to a higher or lower elevation. The helicopter is mounted on top of the shaft by the attachment pieces shown in Figure B.9. By moving the shaft up and down, the helicopter is moved vertically into and out of ground effect. Figure B.10 shows the Heli-Star model helicopter mounted on top of the vertical thrust test stand.

IV. WIRING AND CALIBRATION OF THE LOAD CELL

A. LOAD CELL CIRCUITRY

A schematic for the wiring of the load cell is shown in Figure B.11. The load cell selected for use was the Interface, Inc., Super-Mini load cell, model number SM-25. The internal make-up of the load cell consists simply of a Wheatstone bridge circuit. A direct current voltage source is used to excite the bridge circuitry and a Fluke digital voltmeter is used to measure the output voltage. Due to the nature of the Wheatstone bridge in a load measuring system, the overall sensitivity is increased by using as high a voltage as is safe for the load. The specification sheet for the SM-25 load cell recommends an excitation voltage of no greater than 10 volts D.C. Therefore, in order to obtain relatively high sensitivity and still assure a margin of safety for the load cell, an excitation voltage of 9.0042 plus or minus .0003 volts D.C. was chosen.

B. LOAD CELL CALIBRATION

Prior to performing actual hover tests, it was necessary to calibrate the load cell. This entailed determining the relationship between the force on the cell and the output voltage reading. Calibration was accomplished by placing weights on the load cell in one pound increments and recording the output voltage. The raw data for the calibration for an excitation voltage of 9.0045 volts D.C. is shown in Table A.1 and the calibration curve is shown in Figure B.12. It should be recognized that by selecting a different excitation voltage the potential exists for making the output voltage readout and the force on the load cell correspond in a one-to-one relationship. In other words, a difference in voltage of 3 millivolts could be made to correspond to a difference in lift of 3 pounds. It is not absolutely necessary to do this, however, it would make it easier for the operator-pilot to more rapidly ascertain the power level that the helicopter is operating at. This would permit the actual testing to progress somewhat more expediently, reducing the amount of time the helicopter's engine is at a high power level, emitting exhaust in the confined environment in which the test stand is located.

V. RESULTS OF PRELIMINARY VALIDATION TESTING

A. LATERAL HELICOPTER VIBRATIONS

Testing of the vertical thrust test stand was carried out primarily to gain insight into any unforseen difficulties that might exist with the test stand. During an earlier free flight hover of the helicopter, minor damage was sustained to the framework and rotor blades. Upon mounting the helicopter on the test stand and attempting to operate it, fairly sizeable snake-like lateral oscillations of the fuselage occured. These oscillations were in actuality the nose of the helicopter swaying from left to right with respect to the empenage. Since the servos for the controls are located in the nose, as the nose shifted from side to side, it would alternately pull and push on the control rod to the engine's throttle. This then resulted in power fluctuations as the throttle was alternately opened and closed thereby simultaneously increasing and decreasing the torque applied to the main rotor system. This seemed to cause the nose to continue its cyclic swaying in a self-sustaining chain of events. Testing was suspended until the airframe was stiffened in order to assure satisfactory rigidity. The lateral oscillation problem was corrected by the stiffening as evidenced by the success of future tests.

B. SHAFT VIBRATIONS

Additional test runs were then conducted. As the tests progressed, the power settings were increased to bring the helicopter closer and closer to flight rotor speed. During one particular test run, harmonic oscillations of the shaft, caused most likely by an imbalance of the main rotor system resulted in what appeared to be primarily lateral oscillations of the entire helicopter along with the shaft in a beam-bending mode. The vibrations were strong enough so as to discontinue testing until an additional (second) pillow block was installed in order to restrain the shaft from bending. Later tests demonstrated that this solution method proved to be adequate for the shaft bending vibrations, however, the helicopter still had fairly sizeable vibrations from the main rotor system. It was at this point that a decision was made to replace the existing rotor blades with a new pair in order to eliminate, or at least reduce the mass imbalance as well as aerodynamic imbalance suspected to exist on the original damaged blades.

C. REPLACEMENT BLADES AND STABILIZER BAR STRAIGHTENING

A new pair of blades was obtained to replace the original blades. After having installed the new blades, the pitch settings were checked to assure that both blades had equal amounts of positive angle of attack. Additionally, the pitch settings were adjusted so as to have approximately 0 degrees of angle of attack at a low throttle setting (idle) and about 6 degrees angle of attack for a 50% throttle setting. These settings were not in accordance with [Ref. 2: p. 32] but instead were recommended settings from local model helicopter enthusiasts. While these adjustments were being made it was noted that the stabilizer bar was bent. Therefore, in order to eliminate it as a possible source of vibrations, it was removed and straightened before being reinstalled.

D. SUCCESSFUL VALIDATION TEST RESULTS

Upon completion of these repairs, the validation testing was continued. During the tests that followed, the helicopter was sufficiently free of vibrations to permit the power to be increased to the point where the lift being generated was greater than the weight of the helicopter. The voltage readings were correlated to a lifting force of nearly 3 pounds. This result then validated the basic utility of the test stand. However, even this result was not achieved without some relatively minor concern. During one of the high power runs, the forward end of the lower servo tray was noted to be vibrating vertically in a beam bending mode, apparently caused by a resonance with the rotor system. It is felt that this problem can be fixed fairly readily with the incorporation of an additional balsa wood brace placed diagonally from the forward edge of the lower servo tray to the center support of the upper servo tray.

E. ACCURACY OF INSTRUMENTATION

The consistency of the readings from the Monsanto digital counter for the R.P.M. output were considered to be excellent. On the other hand, the consistency of the readings from the Fluke digital voltmeter for the load cell were only considered to be acceptable. The digital voltmeter readings were not without a moderate level of fluctuation. This result was expected and due of course to the vibrations of the helicopter being transmitted down to the load cell through the shaft. It is felt that the experimenter, by observing the fluctuating readings, should be able to mentally average the individual readings and obtain a result within two tenths of a millivolt which corresponds roughly to two tenths of a pound.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. UTILITY OF THE TEST STAND

The results of the validation testing indicate that the test stand design chosen is effective as far as achieving the objectives it was designed for, although there is room for improvement. Vibrations have always been a problem in full size helicopters, and vibrations from the Heli-Star model helicopter have proven to be the source of problems for this project as well.

B. RECOMMENDATIONS FOR POSSIBLE IMPROVEMENTS

The sensing for the R.P.M. of the engine has been highly reliable and has not been subject to inaccuracies caused by vibrations. In contrast to the R.P.M. sensing, the load cell is subjected to the full impact of the vibrations from the Heli-Star helicopter. The voltage output from the load cell is the summation of two components. One component is due to the static lift force and the other component is caused by the vibrations of the helicopter resulting in fluctions to the otherwise steady load cell output voltage. This analog load cell output voltage is fed into the Fluke digital voltmeter. Experience in operating the test stand has shown that the direct current sampling rate of the voltmeter is so fast that it readily senses the changes in the direct current voltage caused by the vibrations and displays voltages which fluctuate with a greater magnitude than is desired. To improve the accuracy of the load cell voltage readout it is desirable to eliminate this fluctuation in the output. In order to accomplish this, it is recommended that a Pacific Instruments transducer amplifier be incorporated into the load cell circuitry. This would be used to filter out the undesirable alternating current component (noise) of the load cell output voltage, thereby leaving only the direct current, which is an indication of the lift force.

APPENDIX A

LOAD CELL CALIBRATION TABLE

TABLE I

LOAD CELL CALIBRATION DATA

Weight on Load Cell (lbf)	Load Cell Output Voltage (mV D.C.)
0.	.000187
1.	.001317
2.	.002438
3.	.003587
4.	.004707
4.315	.005071
5.	.005857
5.315	.006194
6.	.006976
6.315	.007315
7.315	.008460
8.315	.009578
9.315	.010724
10.315	.011848
11.315	.012970
12.315	.014104
13.315	.015220
14.315	.016362
15.315	.017480
16.315	.018597
17.315	.019663

APPENDIX B

FIGURES, PHOTOS, AND GRAPHS

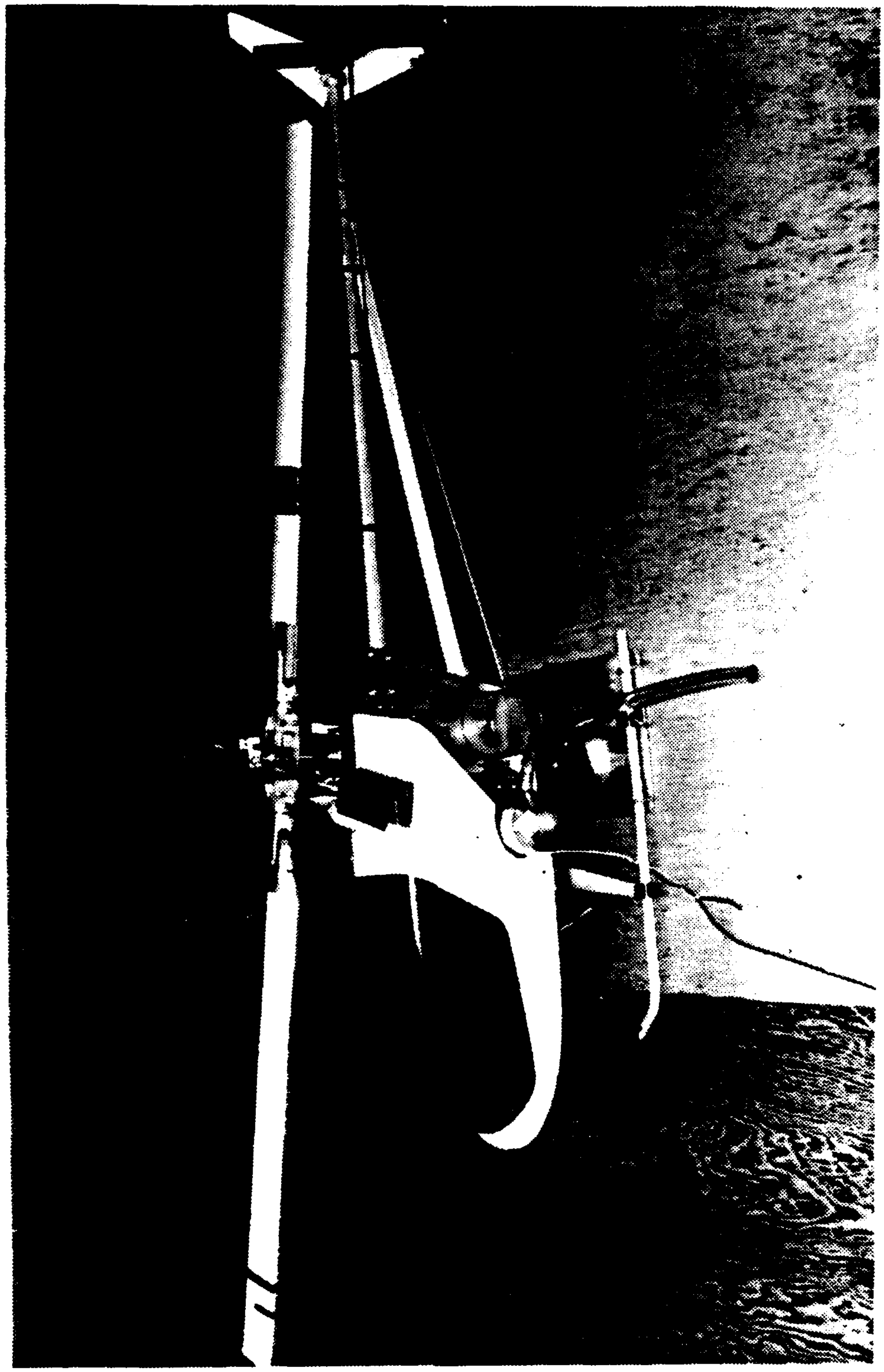

Figure B.1 The Heli-Dtar Model Helicopter

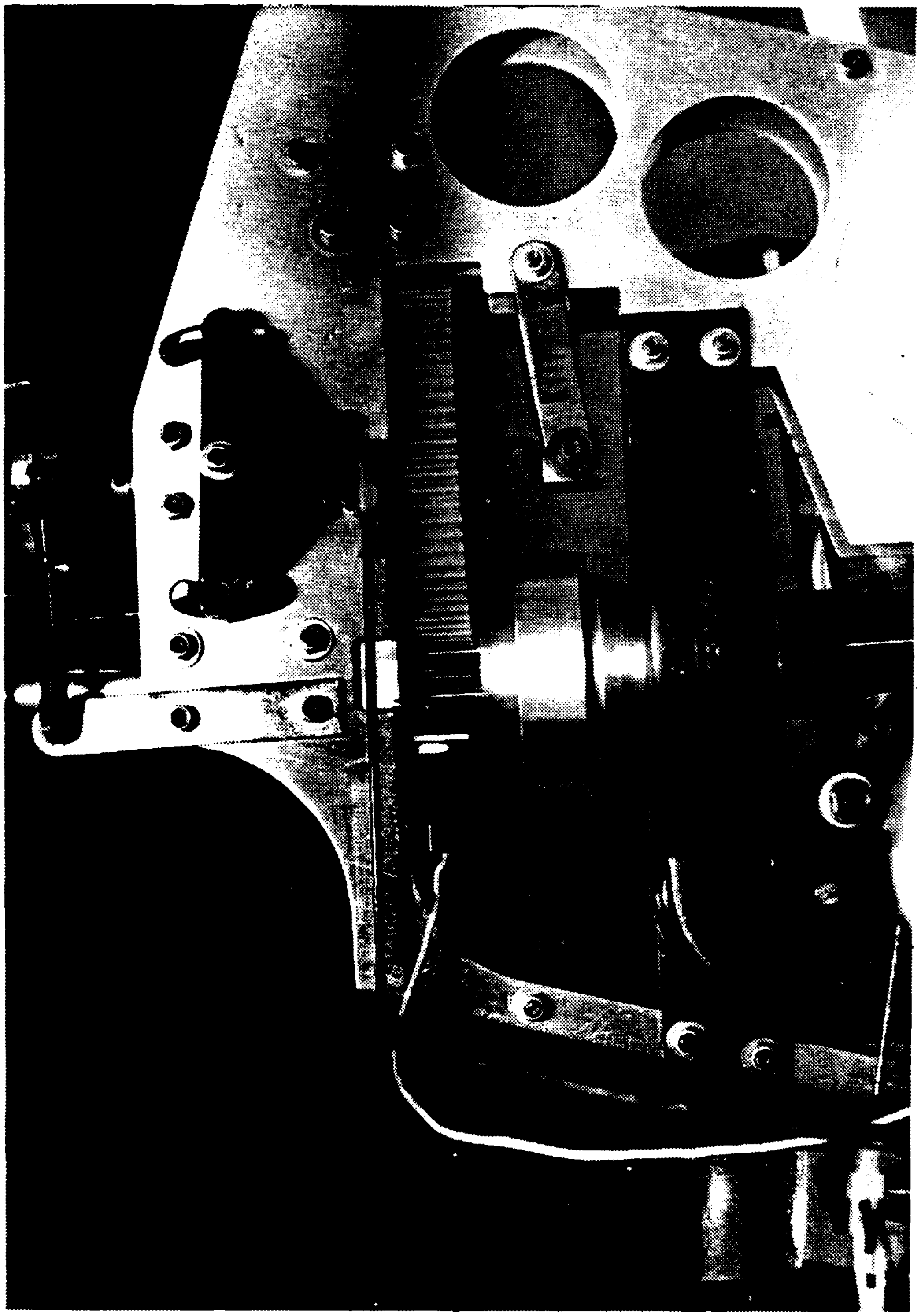

Figure B.2 The Installation of The R.P.M. Sensing Transducer

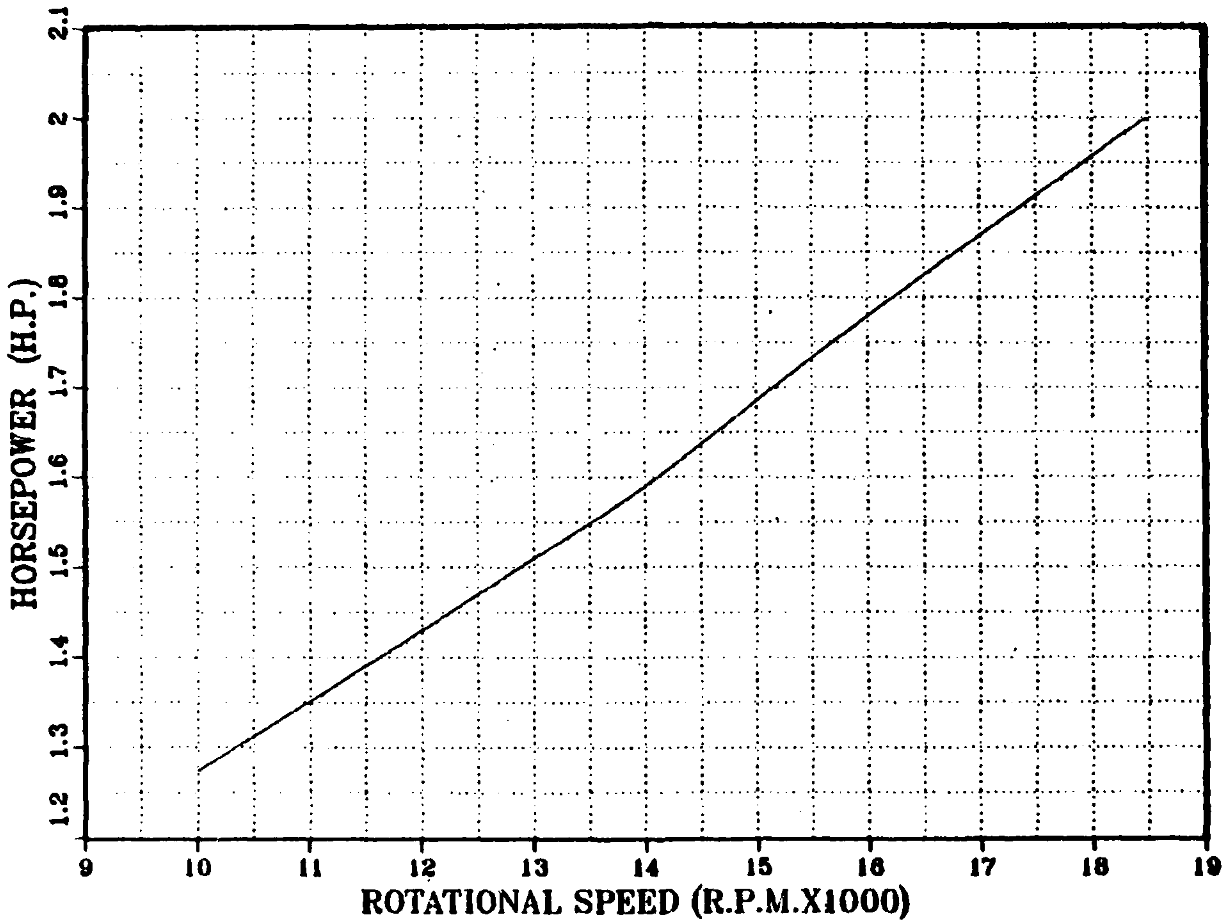

Figure B.3 Power vs. R.P.M. Curve for the HP.61 Engine

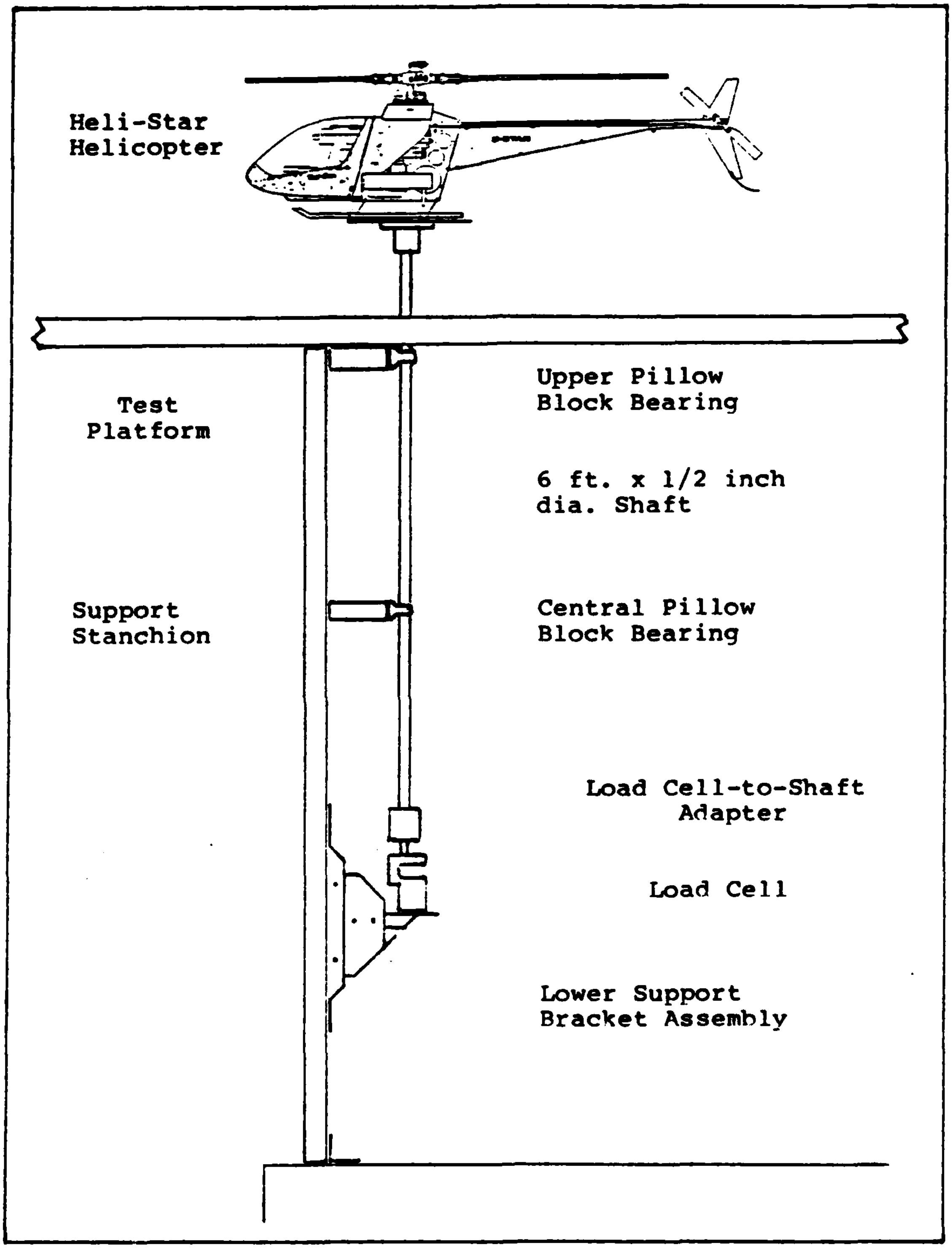

Figure B.4 Functional Relationship of Test Stand Components

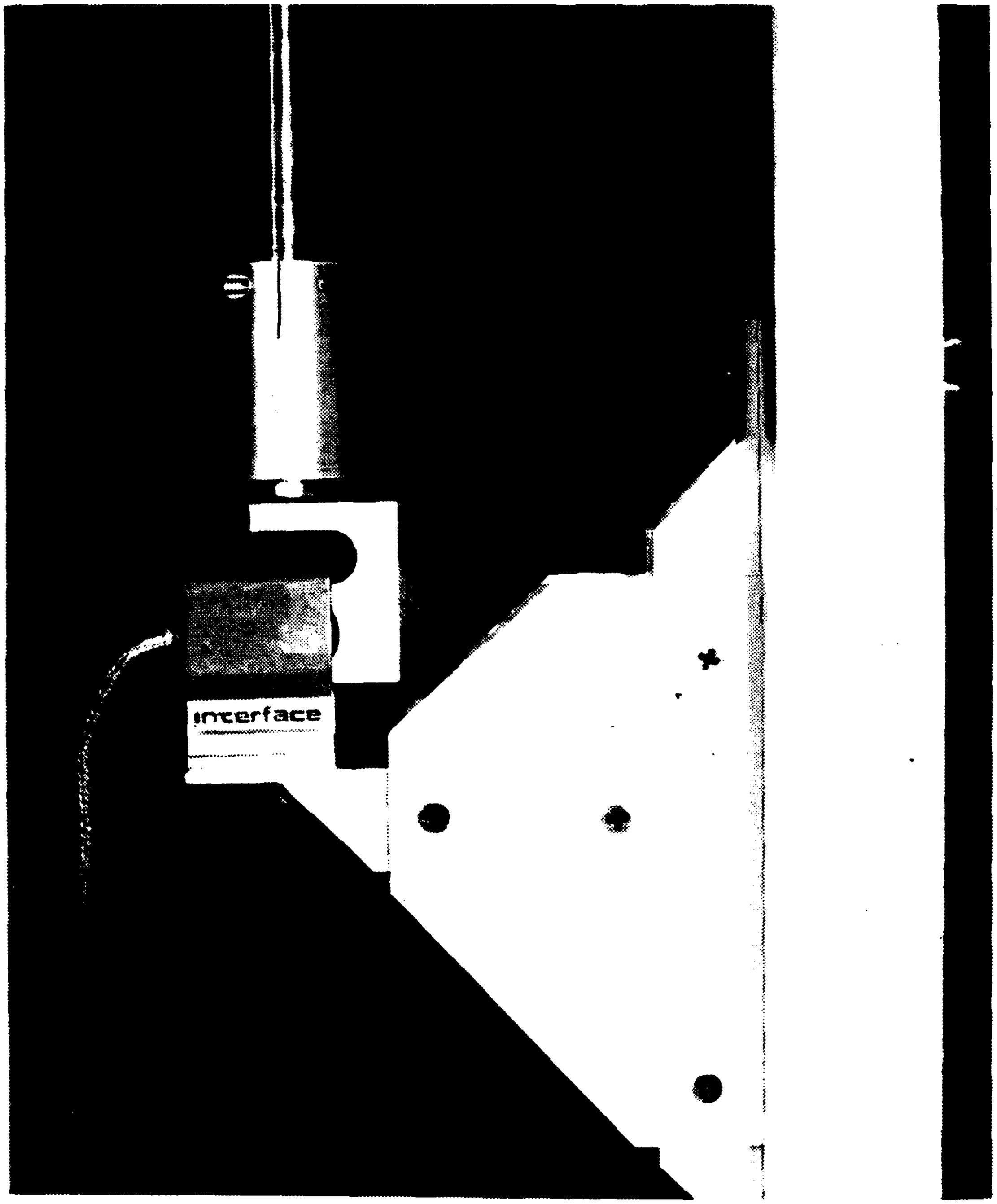

Figure B.5   Lower Bracket Assembly

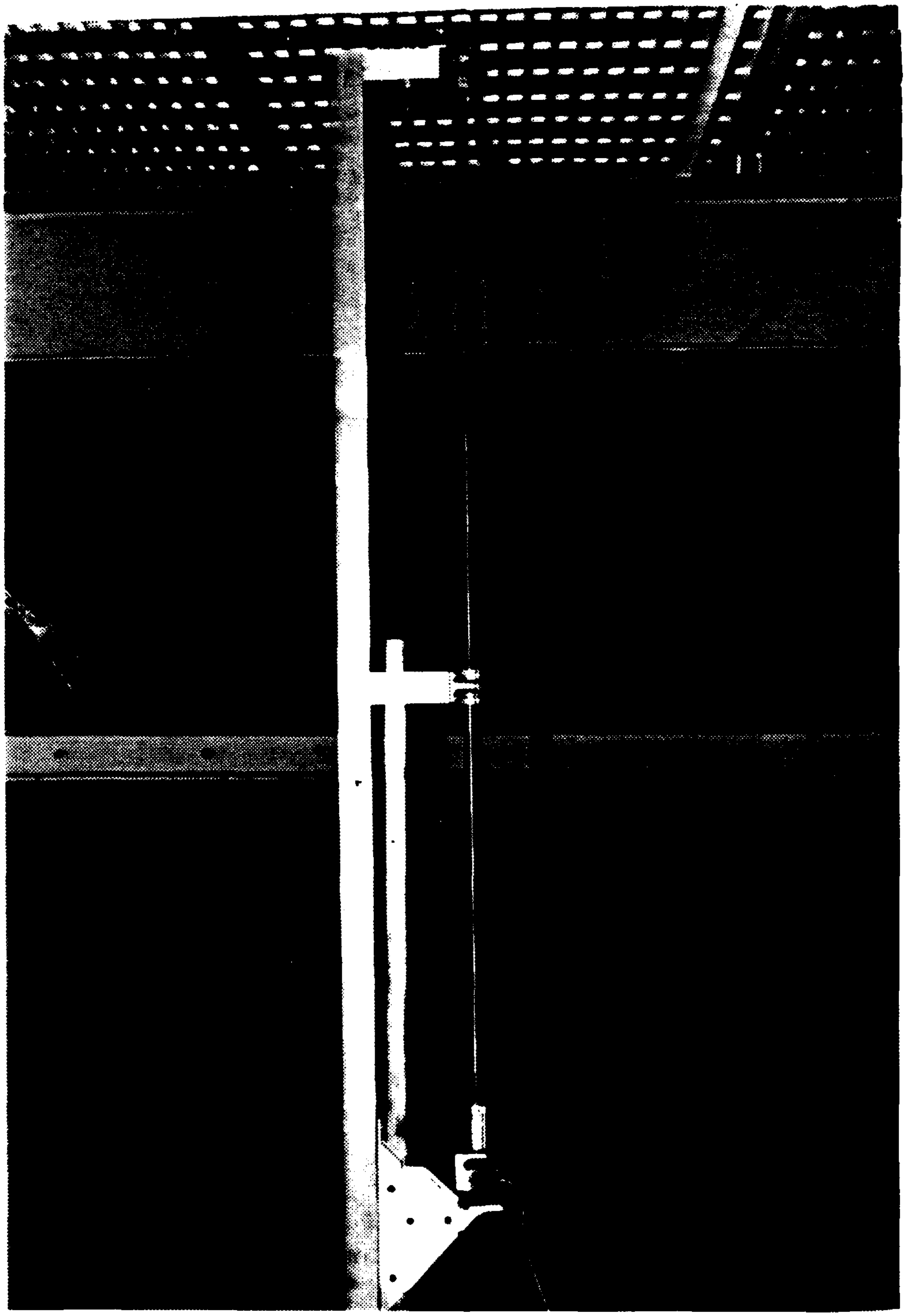

Figure B.6   The Vertical Thrust Test Stand

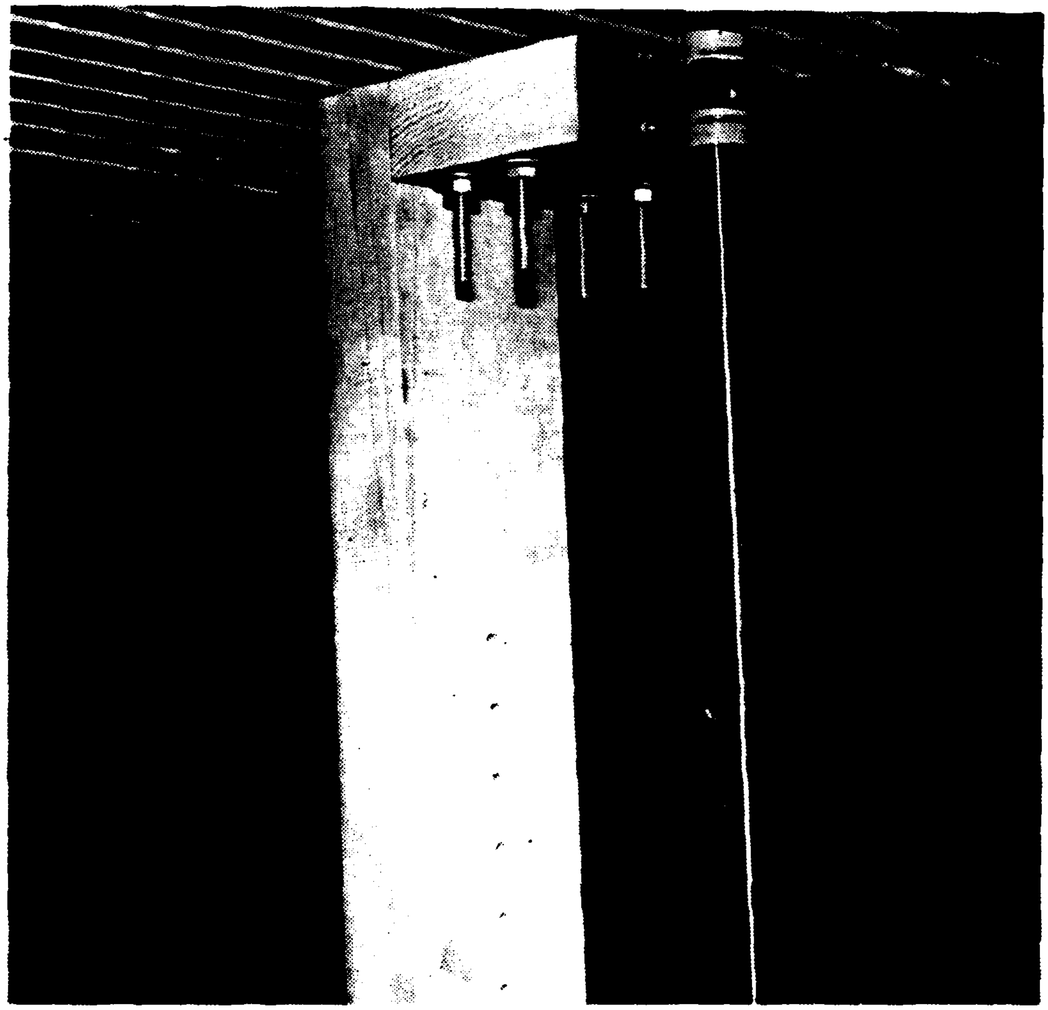

Figure B.7   The Upper Pillow Block Bearing

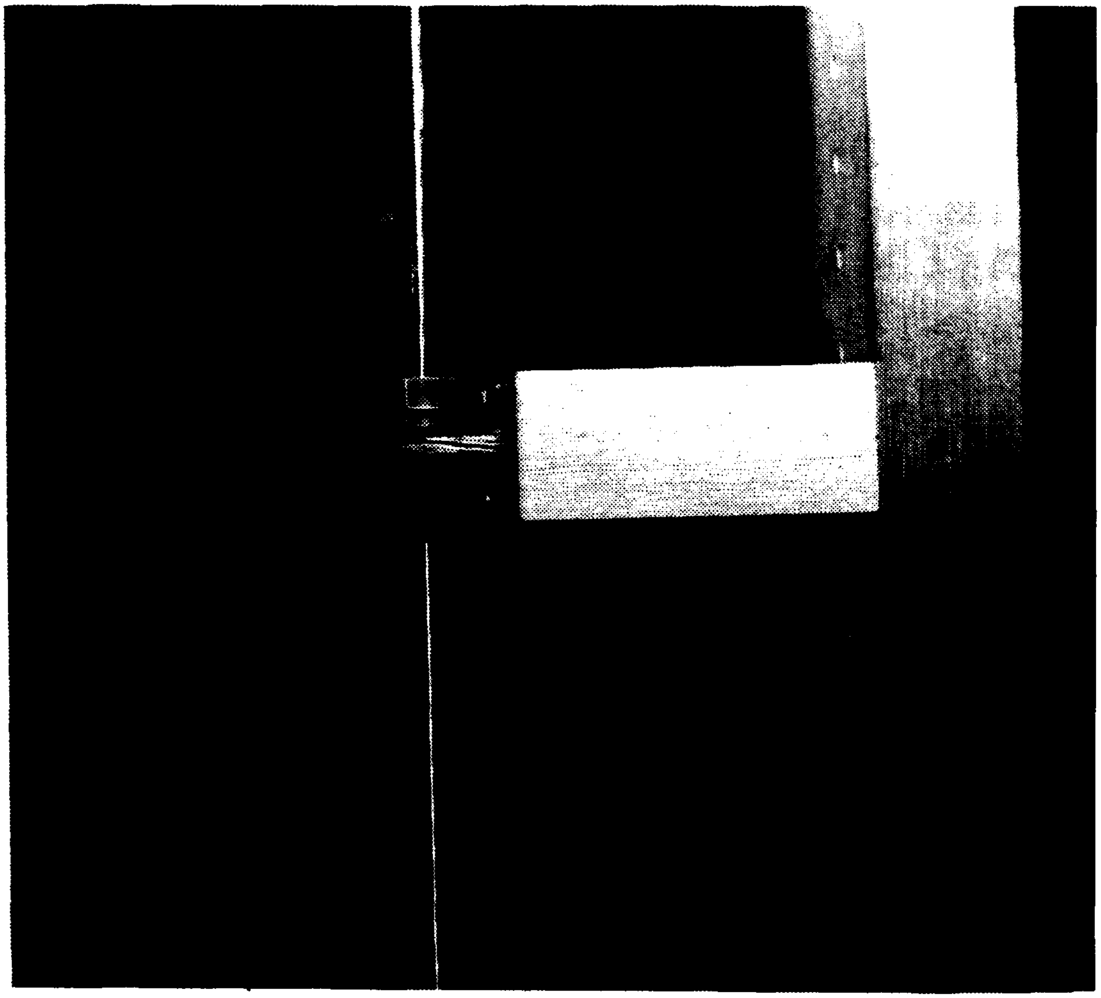

Figure B.8 The Central Pillow Block Bearing

Figure B.9   Skid Plate-to-Shaft Adapter Assembly

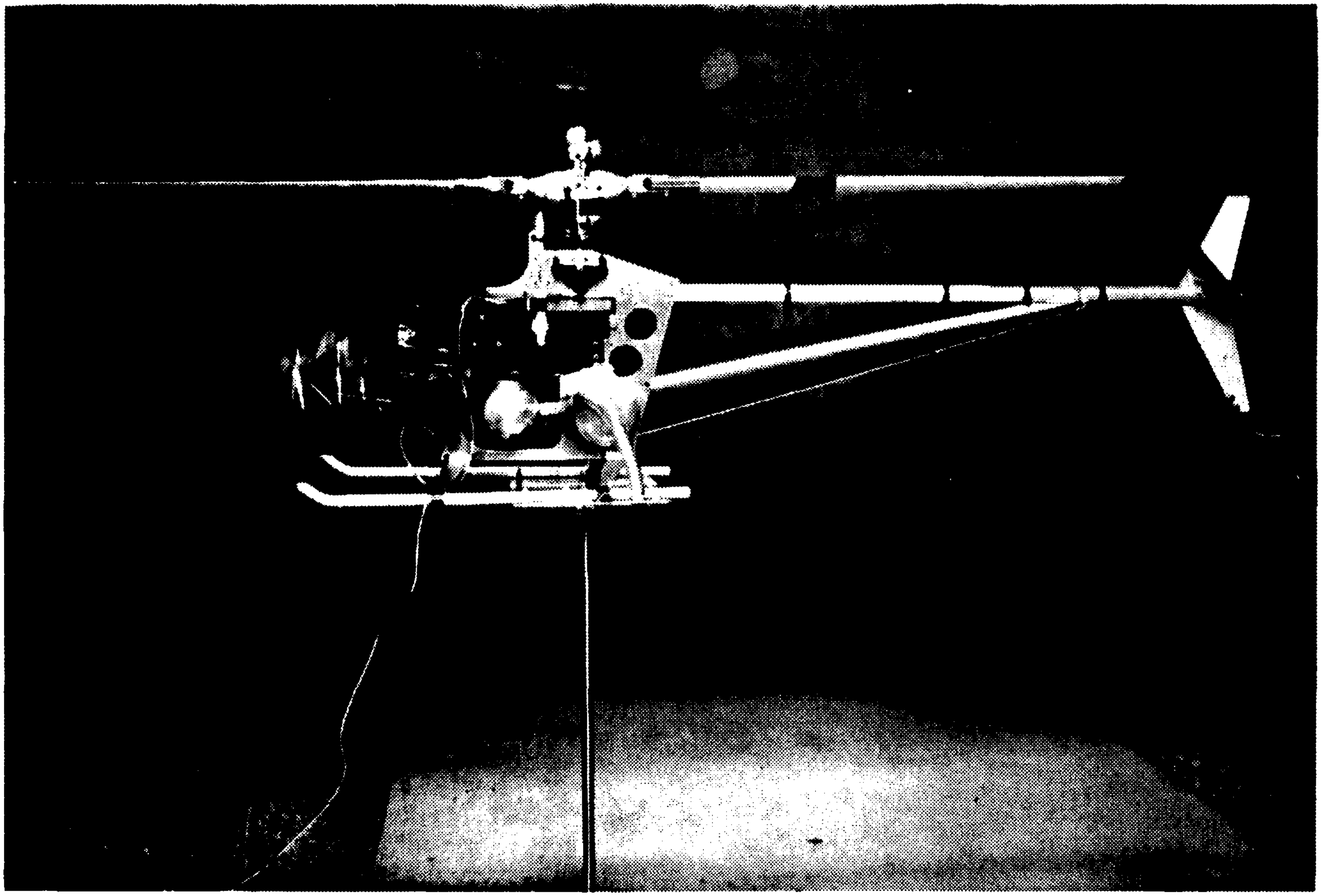

Figure B.10 The Heli-Star Helicopter Mounted on Vertical Stand

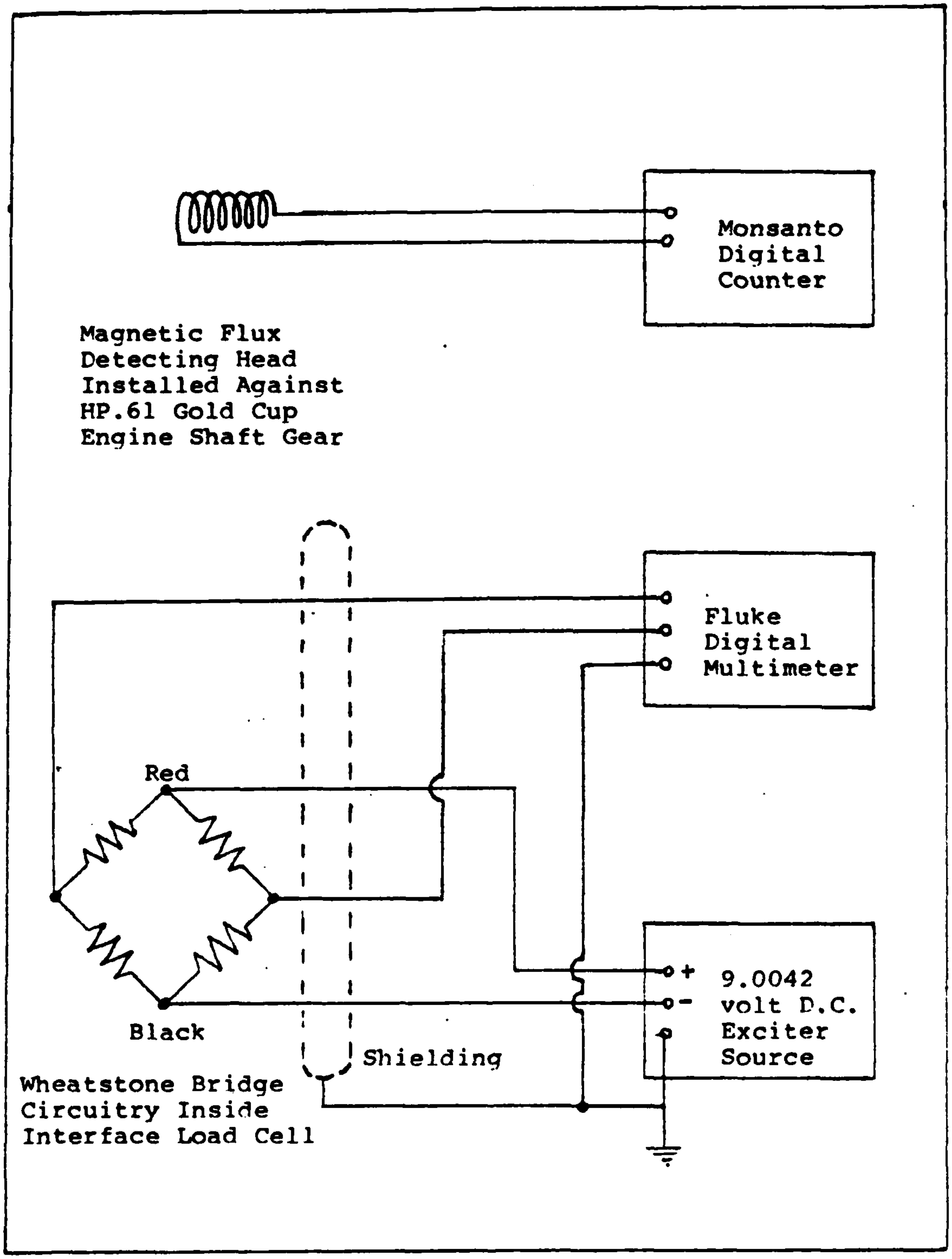

Figure B.11 Wiring Diagram

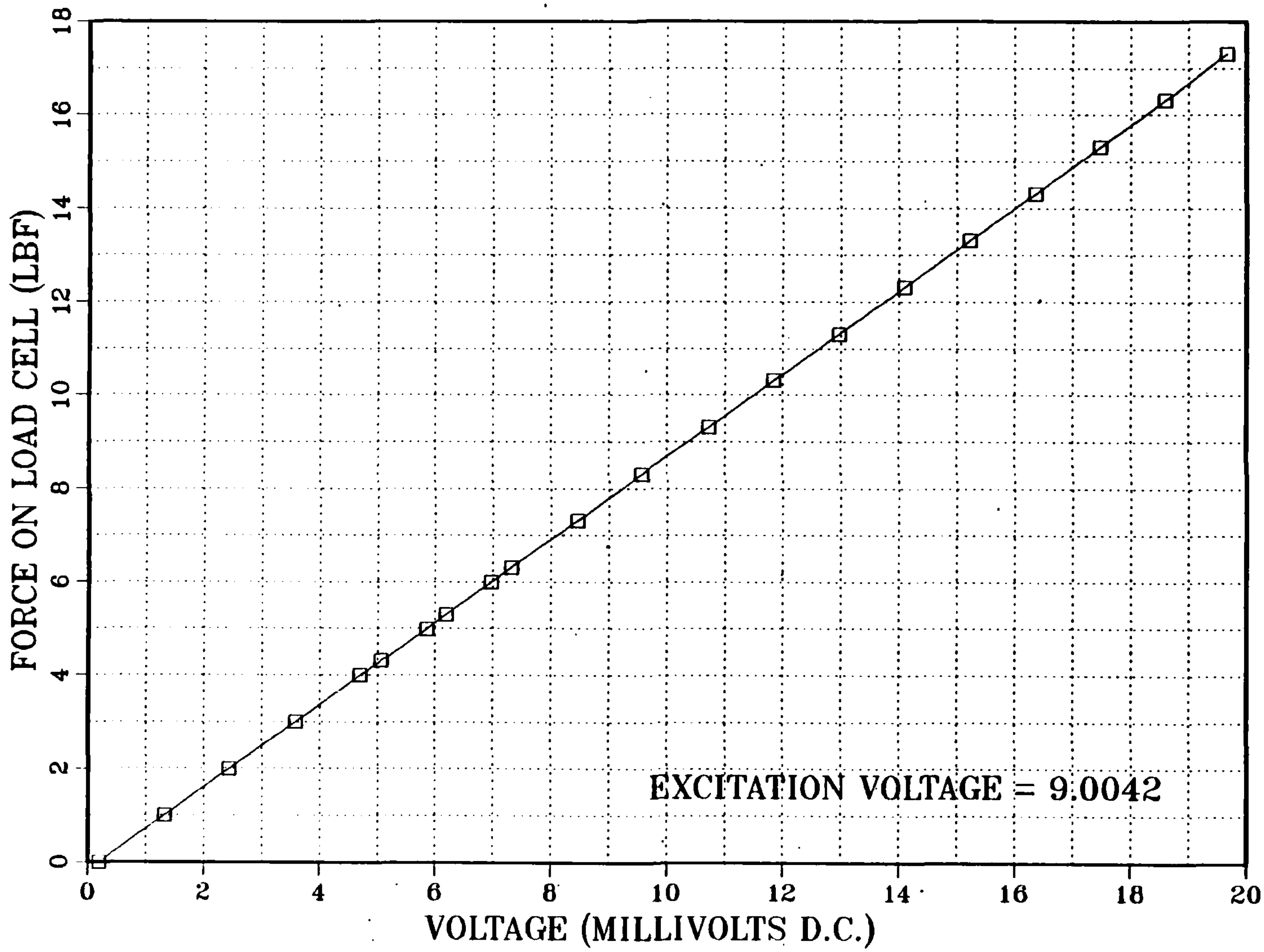

Figure B.12 Load Cell Calibration Curve

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