AD-778 678

TRAILING WIRE SYSTEM APPLIED RESEARCH

Henry E. Keck

Frank J. Seiler Research Laboratory
United States Air Force Academy, Colorado

April 1974

FRANK J. SEILER RESEARCH LABORATORY

SRL-TR-74-0007

APRIL 1974

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CAPTAIN HENRY E. KECK

PROJECT 7904

AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS
BEFORE COMPLETING FORM

1. REPORT NUMBER: SRL-TR-74-0007

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle): TRAILING WIRE SYSTEM APPLIED RESEARCH

5. TYPE OF REPORT & PERIOD COVERED: Scientific - Final
March 1972 - April 1974

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): Henry E. Keck, Captain, USAF

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
Frank J. Seiler Research Laboratory (AFSC)
USAF Academy, Colorado 80840

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
DRS 61102F
7904-01-49

11. CONTROLLING OFFICE NAME AND ADDRESS:
Frank J. Seiler Research Laboratory (AFSC)
USAF Academy, Colorado 80840

12. REPORT DATE: April 1974

13. NUMBER OF PAGES: 52

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)

Same

18. SUPPLEMENTARY NOTES

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

Trailing Wire
Long Line Loiter
Airborne Towed Capsules
High Speed Winch

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

Analytical investigations into the physics of trailing long cables from fixed wing aircraft with the intent of establishing the practicality of long range, rapid reaction time, man rescue systems were conducted. A prototype system capable of towing loads up to 500 pounds at reel rates of 1000 feet per minute and with cable lengths up to 20,000 feet, was built and instrumented by personnel in the Department of Civil Engineering, Engineering Mechanics

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and Materials, Air Force Academy CO. The system was flight tested on board a C-130B aircraft at El Centro NAS CA.

Tactics for deployment of the cable system over the ground target were developed and system operation data was collected during the flight test program. Data verifying the acceptability of the mathematical model was obtained, subsequent flight test requirements to determine operational capabilities are defined, and probable roles for the Trailing Wire System in the areas of long range man rescue as well as deployment of low altitude terrain surveillance equipment are established.

TRAILING WIRE SYSTEM APPLIED RESEARCH

BY

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Project 7904-01-49

April 1974

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ACKNOWLEDGMENTS

The author wishes to acknowledge Colonels P. J. Erdle and W. E. Fluhr, past and present department chairmen, respectively, of the Department of Civil Engineering, Engineering Mechanics and Materials, United States Air Force Academy, under whose guidance and by whose personnel this research was accomplished. Contributions of Major R. W. Obermeyer, Mr. F. E. Weir and Mr. Philip Thimmesh were central to the reported research.

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INTRODUCTION

Trailing wire from fixed wing aircraft is an idea that has been experimented with since the early thirties [1,2,3,4,5]. Very little useful information developed from most early experimentation. Reasons as diverse as lack of understanding of the fundamental physics underlying the idea, improbable mission requirements, underdeveloped technology relative to the cable handling systems and professional indifference have played roles in obscuring the utility of this idea.

Any reasonable investigation into the ability of applying the trailing wire concept to technological gaps in the military expertise must begin with a rational analytical analysis of the concept itself in terms of the environment in which it will be used. This environment specifically can be described in terms of weather: IFR, VFR, winds, temperature and pressure extremes. The significant variable in this list, relative to successful operational behavior of a trailing wire system, is wind. Alternatively, without the use of relatively exotic and expensive ancillary equipment, IFR conditions are a limiting variable insofar as they affect location of the ground target from altitude.

The basic mathematical analyses employed to predict the behavior of the trailing wire system during this study were performed by Crist and Hinnerichs [6] and Crist and Hanson [7] in 1971. The analyses divulge both the steady state and the dynamic behavior of a long line trailing from an orbiting aircraft and provide the capability to study wind effects on the wire. Numerous other studies in recent years have been performed concerning wind effects on the dynamic behavior of long towed cables [8,9,10]. Additionally, a significant variable in the behavior of the towed line is the stability of the towing aircraft itself [11]. A comprehensive analysis of the effects on dynamic stability caused by wind, line length, line density, towing parameters and towed weight is currently in progress at the University of Michigan by Capt. J. J. Russell as a partial requirement for the PhD degree.

The references cited above adequately describe the behavior from an analytical point of view. The emphasis of this report will be the practical aspects of deployment, stabilization and target accuracy as observed during testing at El Centro NAS, CA. Before discussing the flight tests a brief description of the apparatus will be given. A full description of the trailing wire apparatus, including photographs and schematics, is contained in Appendix B.

The trailing wire equipment (i.e., winch, safety mechanisms, operator console, instrumentation and docking devices) was permanently mounted on a 9 x 20 foot aluminum pallet of the type utilized in cargo extraction equipped C-130 aircraft. The system was mechanically self contained and required approximately 30 minutes to be loaded into a C-130 (equipped with a cargo deck roller system). A single electrical connection to the aircraft main power buss was the only additional action required to make the system operationally ready. During flight tests the C-130 cargo ramp was lowered, the upper door opened and the trailing wire pallet was drifted to the edge of the open cargo ramp and secured with the aft end of the pallet extending approximately 8 inches beyond the ramp. All launch, trailing and docking operations were accomplished in this configuration. Right circular cones, subsequently referred to as capsules, were towed by 1/8 inch steel cable at lengths of up to 14,000 feet. To prevent capsule spin (due to cable torque), the capsules were ballasted asymmetrically by fastening lead ingots on the inside of the capsule in a single quadrant.

FLIGHT TESTS

The first flight test at El Centro was conducted on 15 Nov 72 using a small capsule (18 inch diameter base, 30 inch height) ballasted to a flight weight of 117 pounds. This flight was performed to orient the aircrew to the mission profile (i.e. 10,000 feet AGL and continuous orbit at a nominal 30 degree bank angle), to determine flight qualities of the asymmetrically ballasted capsule and to determine the adequacy of launching and docking procedures.

Primary observation from this flight was that with only a ground target to orbit on, the aircrew would have significant difficulty in flying uniform, relatively small radius orbits. The greatest difficulty encountered was that when the orbit bank angle was tightened up to 30 degrees the pilot lost visual contact with the target because of location of side windows in the C-130. The natural tendency was to increase the bank angle to get the target back in view. This caused a spiralling in towards the center of the orbit with resulting flight conditions which could not be maintained. Wind conditions further complicated this problem. The practical difficulty of properly orienting the aircraft with respect to the ground target continued throughout the flight test program. Several tactics were experimented with in an effort to obtain orbital flight of the aircraft which would least interfere with capsule behavior.

Two flights were conducted in February 1973. No wire was trailed on either flight due to restricted time on the test range. However, there was sufficient time to study flight techniques and it was found that an observer stationed to the left of the pilot was able to continuously observe the ground target and call bank angles to the pilot thereby controlling aircraft orbit with somewhat greater accuracy than the pilot could alone. Although this technique represented an improvement, it was extremely difficult to make corrections to the bank angle to allow for wind effects.

In June 1973 a fourth flight was conducted. Mission altitude was 10,000 feet AGL. A radar altimeter was to be utilized on this flight and a small capsule, ballasted to 100 pounds was flown. The power supply for the altimeter failed prior to capsule launch and no altimeter data was obtained. The mission was flown without the altimeter and 13,000 feet of cable was deployed during the test. Extremely bad ground haze on the desert floor interfered with the test and the ground observers were never able to locate the capsule. Further work was done on the concept of observer direction of the orbital path of the aircraft with the net result being that at best, during periods of strong winds at altitude, there was minor improvement to be had by using an observer once the aircraft pilot had learned enough about the orbiting technique not to spiral into the center of the orbit when he lost visual contact with the target.

The final four flights of the test series, tests 5 through 8, were flown in October 1973 utilizing a large capsule (4 foot diameter base, 5 foot height) to simulate man rescue requirements. Particulars from this set of tests are summarized below.

Test Number 5: Mission altitude - 10,000 AGL. The towed load was a large capsule, equipped with radar altimeter, strobe beacons and lead ingots bringing the flight weight to 300 pounds with C.G. well forward toward the capsule apex. The altimeter power supply failed prior to capsule launch and was inoperative throughout the mission. Although there was again haze on the desert floor the size of the large capsule made identification throughout the capsule deployment significantly easier and it was assessed that the strobe beacons were not necessary for this size towed load.

Throughout the flight the capsule towed stably with no spin noticeable by the ground or air crews. Techniques were studies for altering the aircraft ground track to compensate for wind effects on the location of the capsule ground track. The aircraft was flown in fixed orbit over identifiable land markings upwind from the ground target. It was not possible to quantitatively assess the effects of altering the aircraft orbit location, but qualitative improvement in target accuracy wasn't significant because of unknown wind variations from 0 to 10,000 feet AGL and inability to estimate distances from 10,000 feet.

During the docking phase, the capsule "rode" noticeably high on the slip stream behind the open cargo ramp of the C-130. Upon slowing the capsule to a reasonable, relative approach speed the cable tension was sufficiently reduced to allow the nose heavy capsule to dive towards the aircraft. The capsule was about 3 feet outboard at this point and as it dove, it cut the tow cable on the edge of the pallet and free fell to the ground, impacting apex first in a near vertical attitude and penetrating approximately 2 feet. All equipment in the capsule was destroyed but the capsule itself remained structurally intact. The remaining flights were flown without the altimeter and strobes.

Test Number 6: Mission altitude 10,000 AGL. The large capsule was reballasted to 425 pounds using lead ingots all placed in one quadrant of the cone. The CG was moved aft to approximately 60% of the cone length from the apex. Up to 13,000 ft. of cable was deployed.

Cinetheodolite data was collected for two phases of the test: (1) steady state orbit (approximately 2 revolutions), and (2) capsule liftoff from the ground. This data is summarized in Appendix A. Study of the data indicates that the capsule never descended into a permanent orbit over the target area. This was attributed to the operational altitude of the mission and the relatively large weight of the capsule. The latter factor contrives to keep the capsule in the aircraft orbit. This, in combination with the "short" cable, does not allow sufficient energy in the trailed system to be lost to enable the capsule to achieve a reasonably small ground orbit.

Wind effects were quite noticeable during the two orbit data phase, causing an altitude variation of approximately 4500 feet. This, and the diameter of the capsule ground track indicates that the capsule was not in a stable orbit configuration. This behavior was predicted by the computer analysis.

The instability of the orbit makes it extremely difficult to control capsule proximity to the ground so that a capsule "landing" was little more than a controlled crash. However, the cinetheodolite data sought (for the second case) was for liftoff characteristics. It can be seen, from appendix A, that even though the aircraft was not flown out of orbit nor cable reeled in, the liftoff flight path of the capsule was very steep. Computer analysis indicates that had the aircraft been flown straight out of orbit, and had the capsule been stably on the ground prior to liftoff, the flight path would have been vertical for approximately 2000 feet (based on the operational altitude of the aircraft during this mission). Capsule docking on this and subsequent flights was quite stable and the capsule could be stopped at any point in the slip stream with no loss of stability.

Test Number 7: Mission altitude was 12,000 feet AGL in an attempt to obtain a permanent capsule orbit. New tactics for getting the capsule over the target were attempted. Capsule landing practice was performed. Cable length during the mission was 13,600 feet.

Since aircraft orbit stability continued to be one of the most influential factors on the behavior of the towed capsule, this mission was flown in the following sequence. With capsule and 13,600 feet of cable deployed, the aircraft was flown approximately 5 miles upwind from the ground target. At this point the aircraft was put into a 30 degree bank and allowed to drift downwind over the target. The best target accuracy was obtained by this method, and during the drifting phase, the ground crew reported the capsule [illegible] the target for approximately two full orbits. Capsule altitude varied from approximately 50 to 1000 feet and capsule orbit radius was approximately 700 feet.

This drift maneuver was performed twice. During the second pass over the target a soft landing was attempted by gradually decreasing aircraft altitude. Increasing cable length by operating the winch was not possible because the rollers on the rear vertical roller assembly (see Appendix B) proved to be too soft. The cable cut the roller surfaces and buried itself in the roller material. Since cable damage was feared, it was decided that a soft landing of the capsule would have to be accomplished by altering the aircraft altitude. The pilot was requested to lose 300 feet gradually and hold until landing was accomplished, and then to descend another 500 feet to provide sufficient slack to keep the capsule stationary on the ground. The request was misunderstood and the aircraft altitude was decreased by 700 feet before capsule impact. The capsule impacted sufficiently hard to sever the tether and the flight test was terminated.

Test Number 8: This flight provided no data due to tow cable damage. The capsule and 12,000 ft of cable were dropped from the aircraft and the capsule was destroyed on impact.

During these four flights, cable tension, cable speed and voice transmissions were collected on magnetic tape. Furthermore, aircraft, ground target and long range photographic data were collected. These records, along with the tabular data reduced from the cinetheodolite coverage are available at the Department of Civil Engineering, Engineering Mechanics and Materials, USAF Academy, Colorado 80840.

FINDINGS AND RESULTS

Results of the flight testing at El Centro are summarized as follows:

a. Qualitative flight behavior of both the large and small capsules verifies that the analytical studies and resulting computer programs predict the behavior of the reported trailing wire system with sufficient accuracy to be used in system design.

b. Target accuracy can be best achieved by flying a constant bank angle, drifting orbit with landing maneuver accomplished when the capsule arrives over the target. Accuracies of within 1/4 mile can be obtained by this method when used in conjunction with voice information from the ground party. For large, heavy capsules, aircraft altitudes in excess of 12,000 feet AGL will decrease capsule orbit radius significantly. Wind does not appreciably change the capsule ground track size but does change ground track shape and orientation relative to the aircraft. The most stable aircraft orbit possible is an essential factor in minimizing altitude changes of the capsule. To this end the drifting, constant bank orbit is recommended since it is easier to accomplish than a constant location orbit. The drifting orbit technique further minimizes capsule altitude variation because the aircraft upwind portion of the orbit (which causes the excitation force) is shortened.

c. A radar altimeter or alternate device must be employed to give indication of capsule altitude relative to local ground level. In spite of this information, capsules should be designed to a minimum of 25 g's to adequately withstand landing impact.

d. Following landing maneuvers, approximately 700 feet of cable slack must be created as rapidly as possible; either by reeling out or lowering of aircraft's orbit. This is essential to keep the capsule stationary on the ground for personnel pick-up.

e. Cables fabricated without a braided jacket should not be considered for use in trailing wire applications. Single strand failures during reel operations can render the cable immobile - preventing retrieval.

f. Capsules must be ballasted to obtain a parameter of capsule weight to projected flat plate side area of at least 40 lb/ft^2. Additionally for capsules in the shape of right circular cones, the center of gravity should be approximately 2/3 of the capsule length aft of the apex. These considerations are necessary in order to assure stable towing characteristics when the capsule is in the aircraft slip stream (e.g., during docking). Spin stability can be assured if ballast is placed asymmetrically relative to capsule cross section. For additional commentary see Appendix B.

g. Winch reel rates of no less than 1000 feet/minute under maximum load must be possible. A means of reeling cable in or out while in orbit which is non-damaging to the cable must be provided.

h. During orbiting operations with long cable lengths and heavy towed loads, the cable pulls sharply to the inboard side of the orbit. A vertical roller system was used to prevent cable contact with the side of the aircraft. The height at which the cable exits the aircraft is not fixed but varies up and down as the relative wind vector (and consequently, the aircraft bank angle) varies. This scrubbing motion can cause severe abrasive damage to the roller surfaces and the rollers will, in turn, damage the cable. Additional comments are contained in Appendix B.

i. Palletized winch and docking mechanisms provide the ultimate in flexibility relative to reaction time of aircraft, ability to utilize aircraft in other (primary) roles, minimal aircraft modification, and ease of maintenance and storage of the trailing wire system.

j. Additional research should be conducted in the following specific areas: (1) Altitude stabilization via winch control; both manual and servo operation utilizing radar altimeter information. (2) Orbit stability and size improvement commensurate with target accuracy at altitudes above 12,000 feet AGL. (3) Operational characteristics in high wind environments (40 to 60 knots). (4) Sensor systems required to produce IFR target accuracy. Of these items, (1) and (2) can be accomplished with minimum time and money by making use of existing equipment: winch, control console, safety equipment and instrumentation. These items are in storage at the department of Civil Engineering, Engineering Mechanics and Materials, USAF Academy, Colorado 80840.

CONCLUSIONS

The trailing wire application outlined in this report gives promise in the areas of long range, rapid reaction, man rescue operations and low altitude terrain surveillance/reconnaissance missions. Additional testing must be accomplished in the areas of target accuracy, maximum wind limitations and tow aircraft optimum flight altitudes and airspeeds. Additionally, to provide IFR capabilities, investigations into target sensor technology must be conducted - possibly starting with the systems developed for C-130 gunship operations.

Testing under this program indicates that minimum equipment and crew training expense is involved in attaining rescue and/or surveillance capability and minimal aircraft modification is necessary to make current cargo aircraft compatible with such mission requirements.

It has been established that aircraft operational altitudes are sufficiently high that employment of the trailing wire concept for both rescue and surveillance over enemy territory can be accomplished with reasonable safety from ground fire (a benign airspace is assumed).

Rescue capsule weight requirements allow the application of substantial armor plate (in the form of ballast) for personnel protection. The capsule provides a protective environment for the occupant during flight, while the ground liftoff trajectory of the capsule minimizes its potential as a target and the possibility of dragging damage (through trees, etc).

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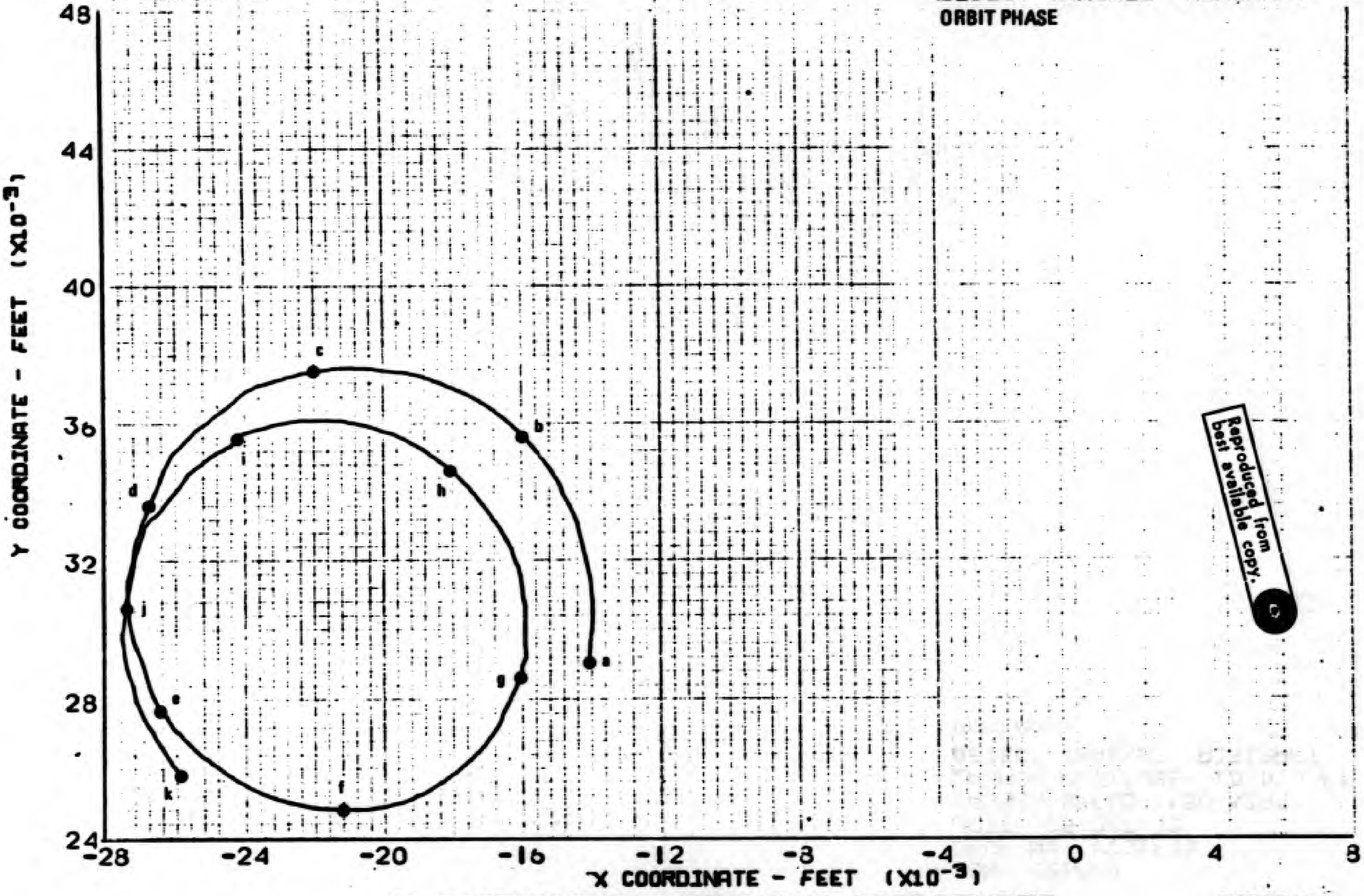
APPENDIX A

APPENDIX A

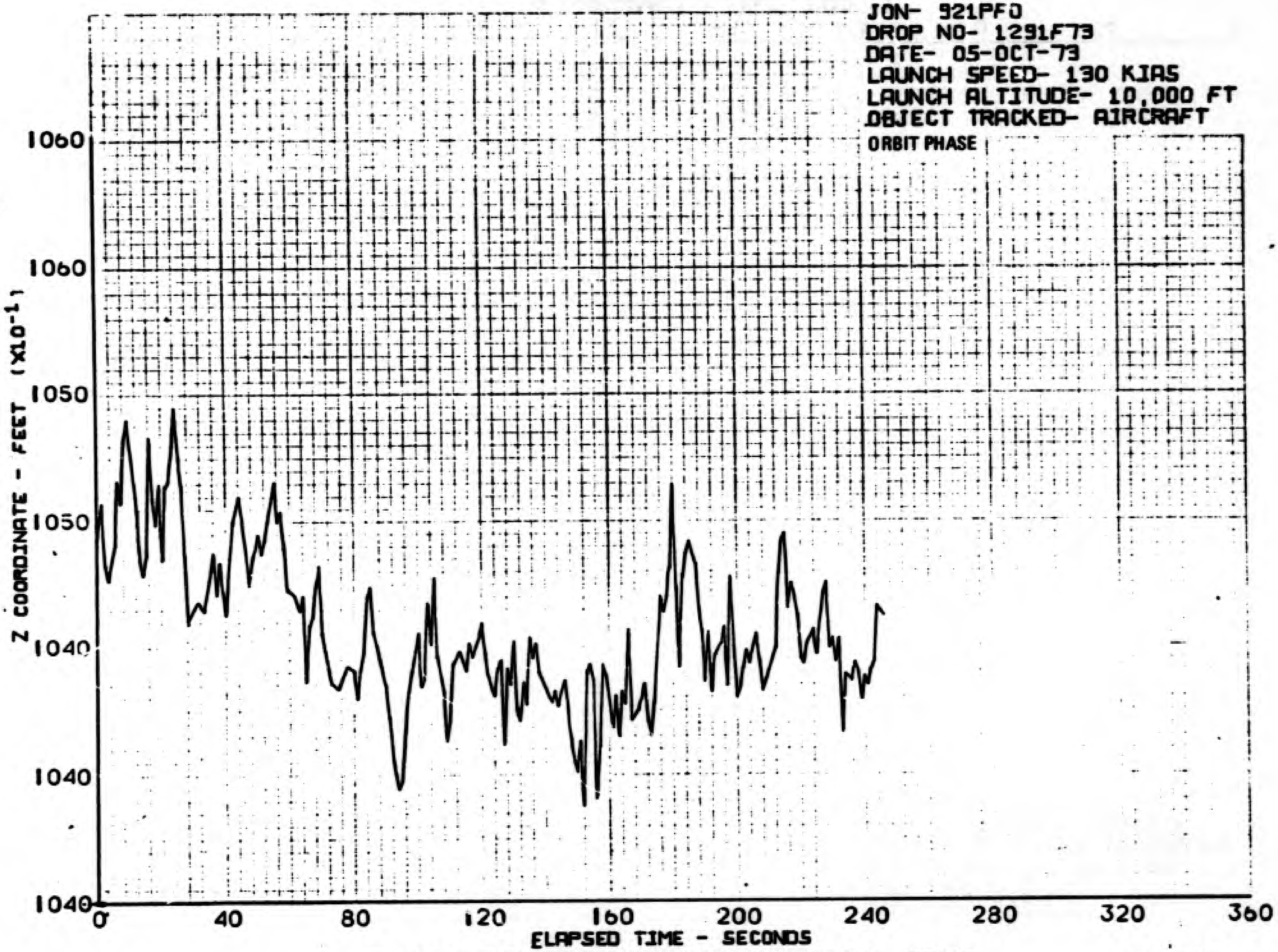
The following charts are a graphical summary of the cinetheodolite data collected at El Centro, NAS during flight test number 6. Tabular data, from which the graphs were extracted are available through the Department of Civil Engineering, Engineering Mechanics and Materials, USAF Academy, CO 80840. The notation a,b,c,..... indicates the same time on each curve from the beginning of the data runs. The time interval of these points is 25 seconds.



JON- 921PFO
DROP NO- 1291F73
DATE- 05-OCT-73
LAUNCH SPEED- 130 KIAS
LAUNCH ALTITUDE- 10,000 FT
OBJECT TRACKED- AIRCRAFT
ORBIT PHASE

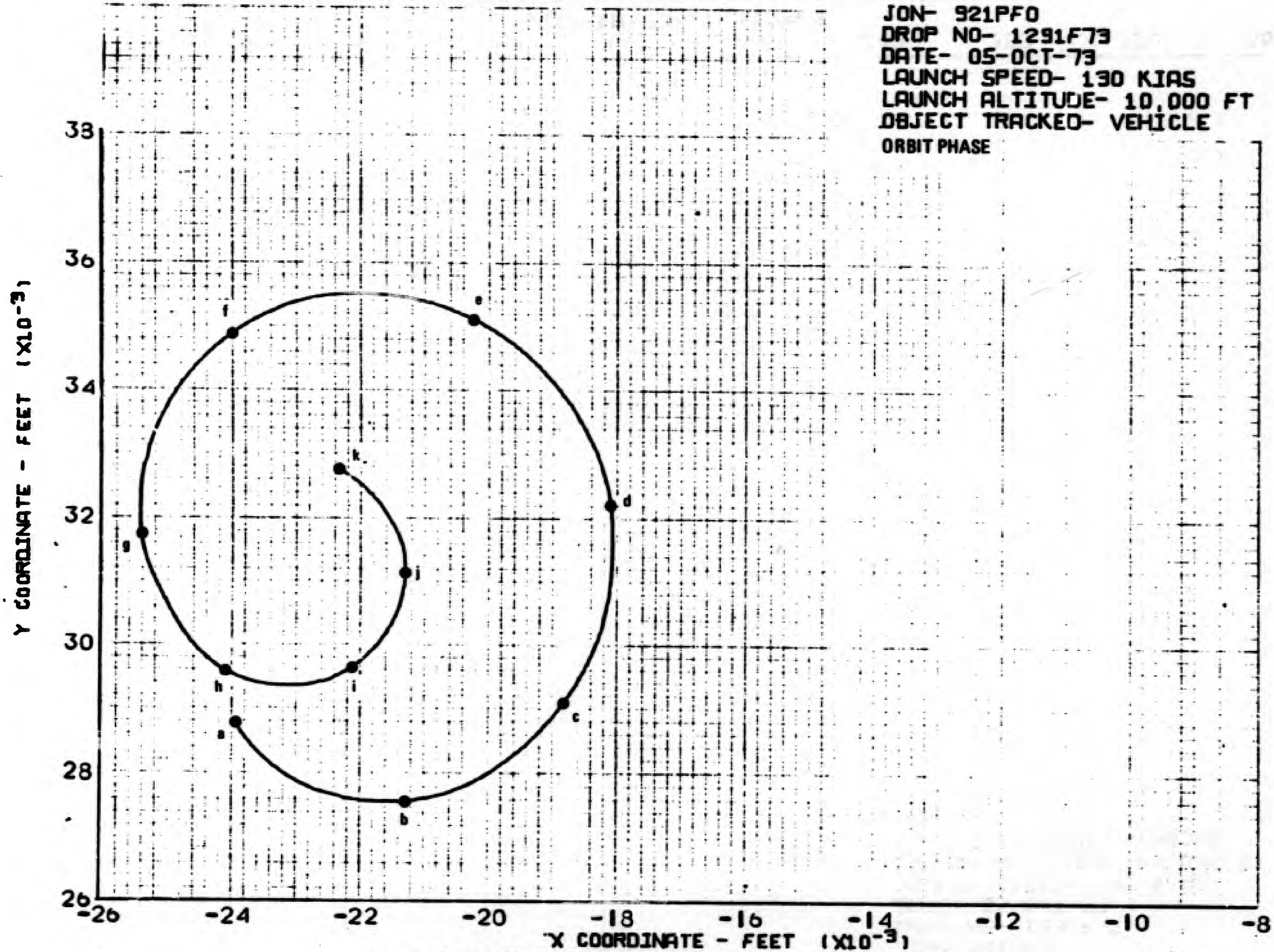
Y COORDINATE VERSUS X COORDINATE

FIGURE 1A


JON- 921PFO
DROP NO- 1291F73
DATE- 05-OCT-73
LAUNCH SPEED- 130 KIAS
LAUNCH ALTITUDE- 10,000 FT
OBJECT TRACKED- AIRCRAFT

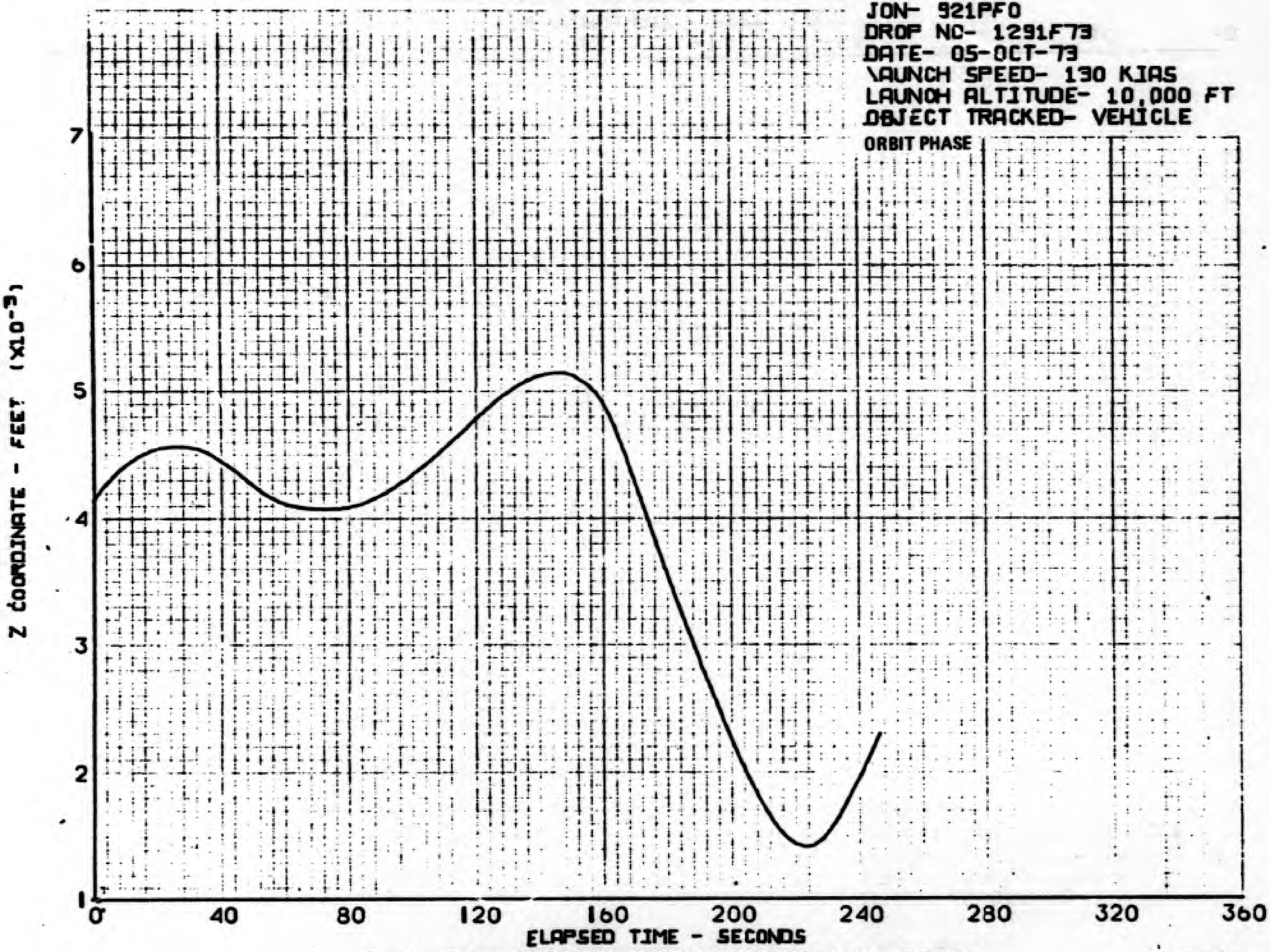
Z COORDINATE VERSUS ELAPSED TIME

FIGURE 2A



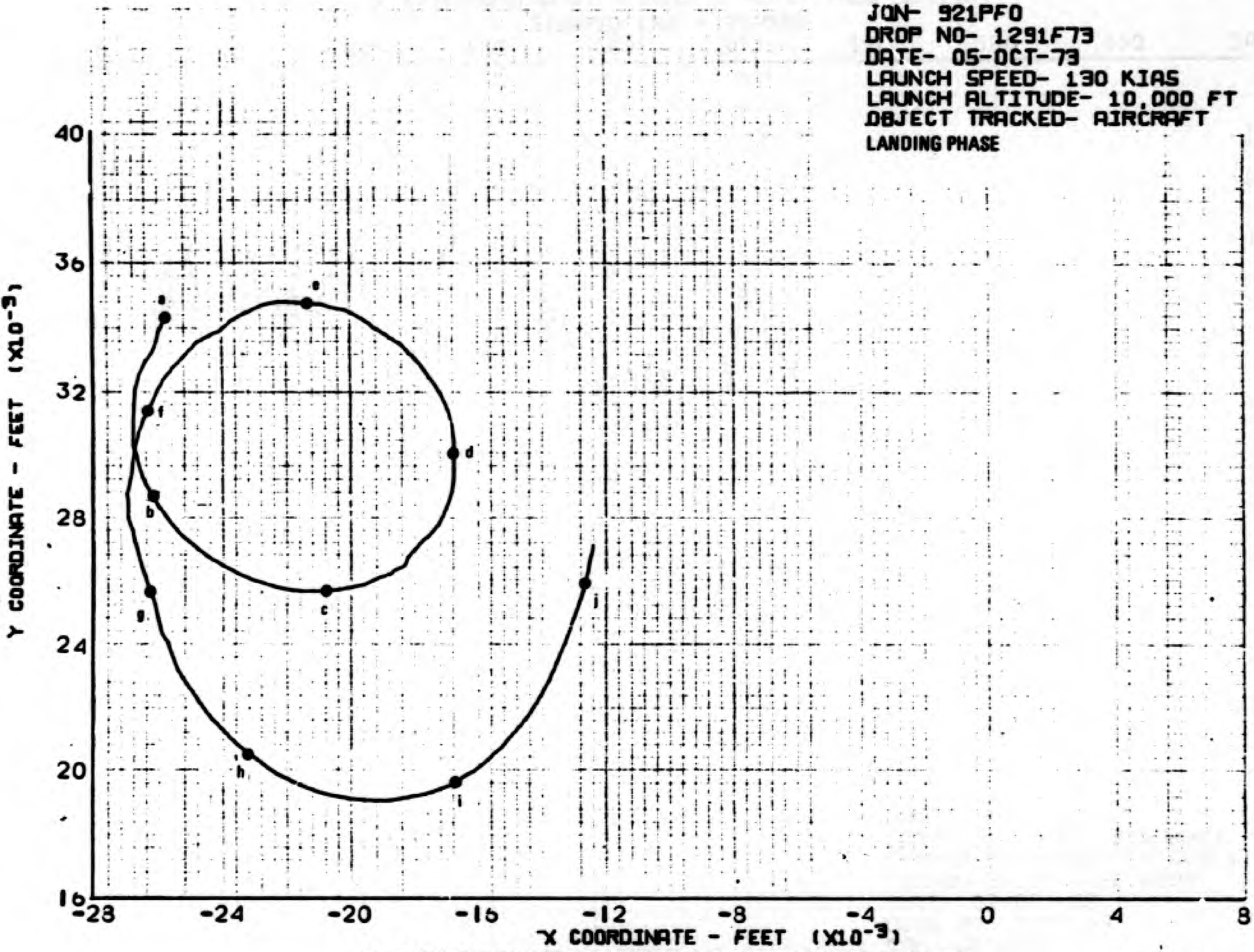
Y COORDINATE VERSUS X COORDINATE

FIGURE 3A



Z COORDINATE VERSUS ELAPSED TIME

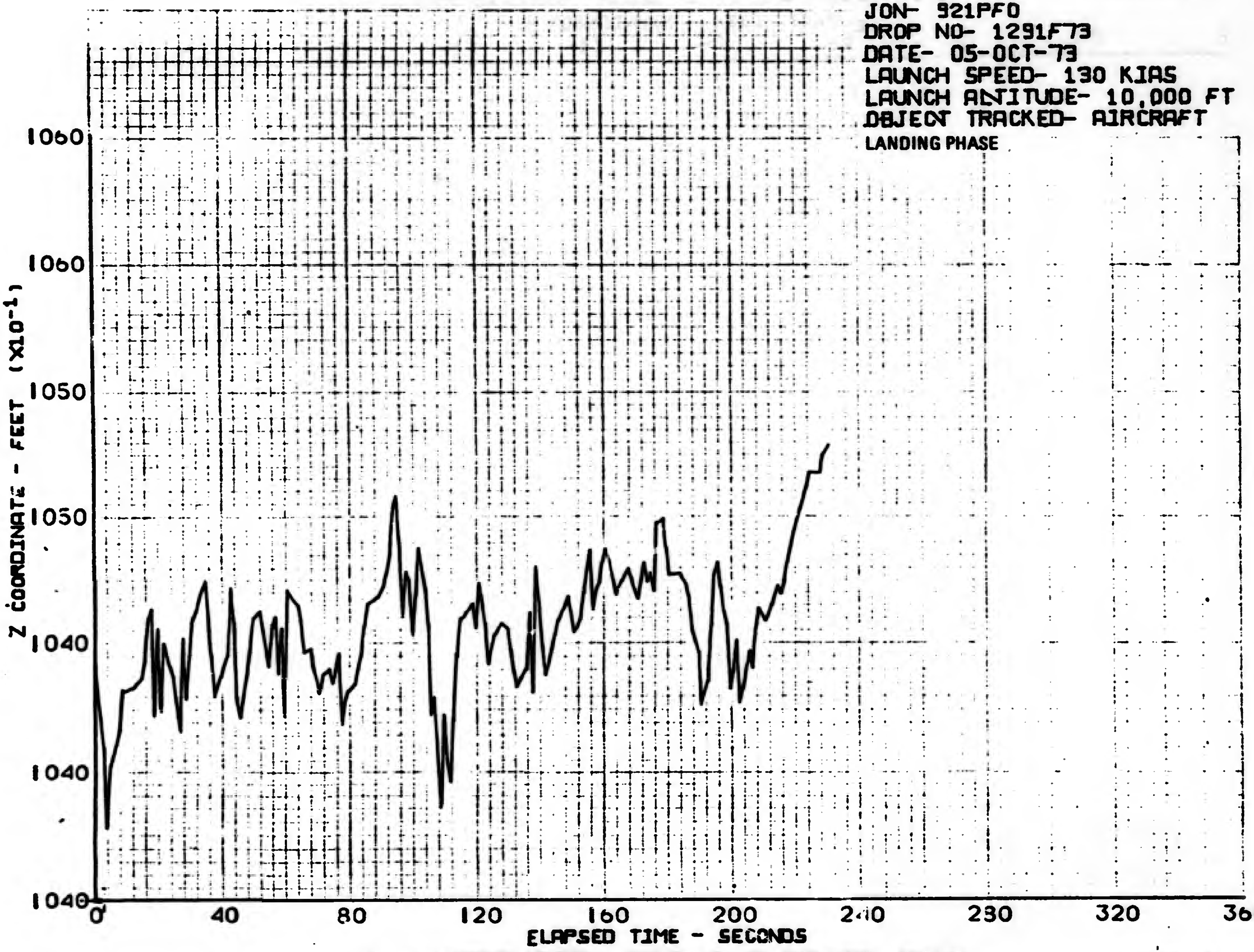
FIGURE 4A



JON- 921PF0
DROP NO- 1291F73
DATE- 05-OCT-73
LAUNCH SPEED- 130 KIAS
LAUNCH ALTITUDE- 10,000 FT
OBJECT TRACKED- AIRCRAFT
LANDING PHASE

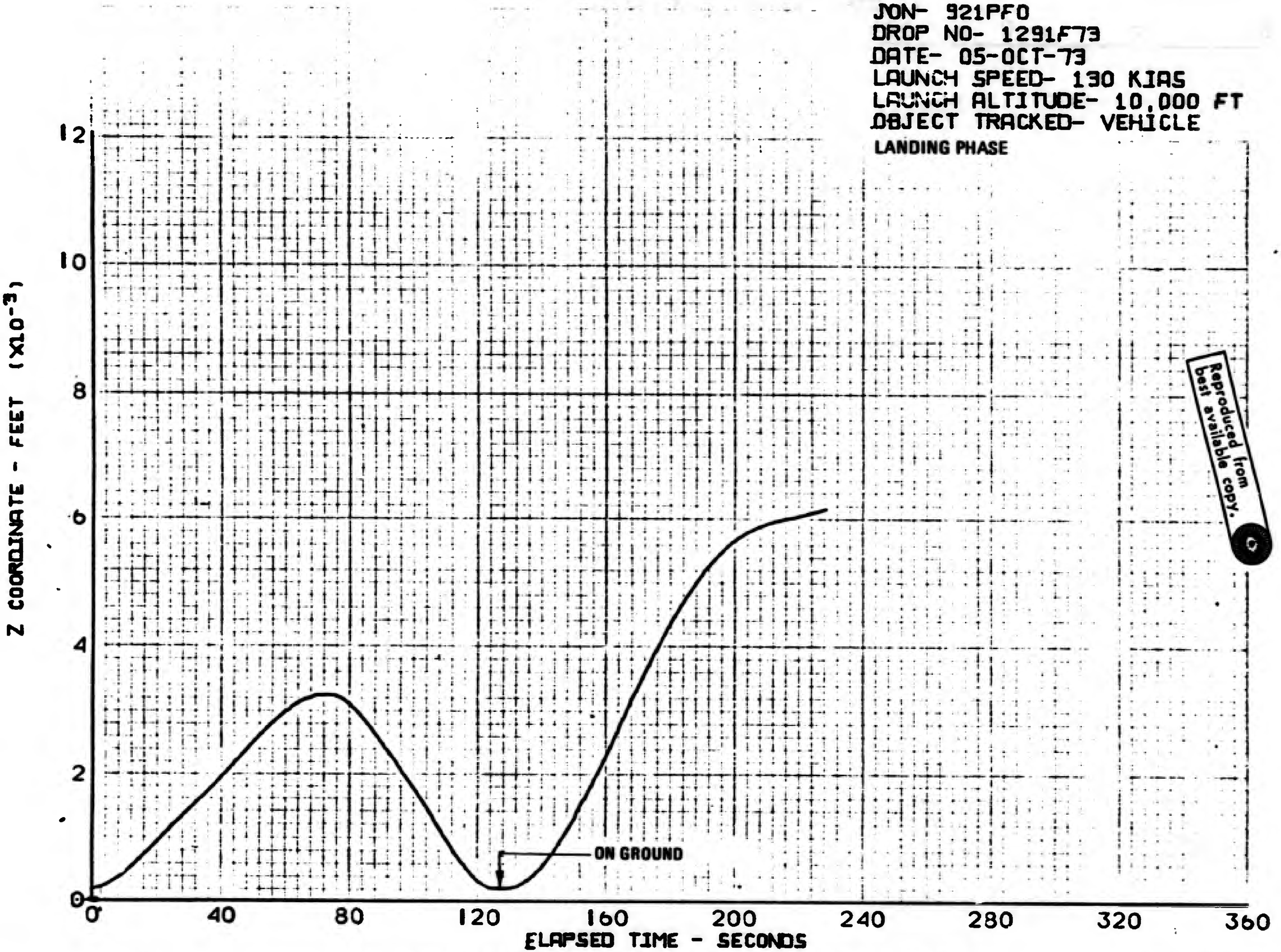
Y COORDINATE VERSUS X COORDINATE

FIGURE 5A



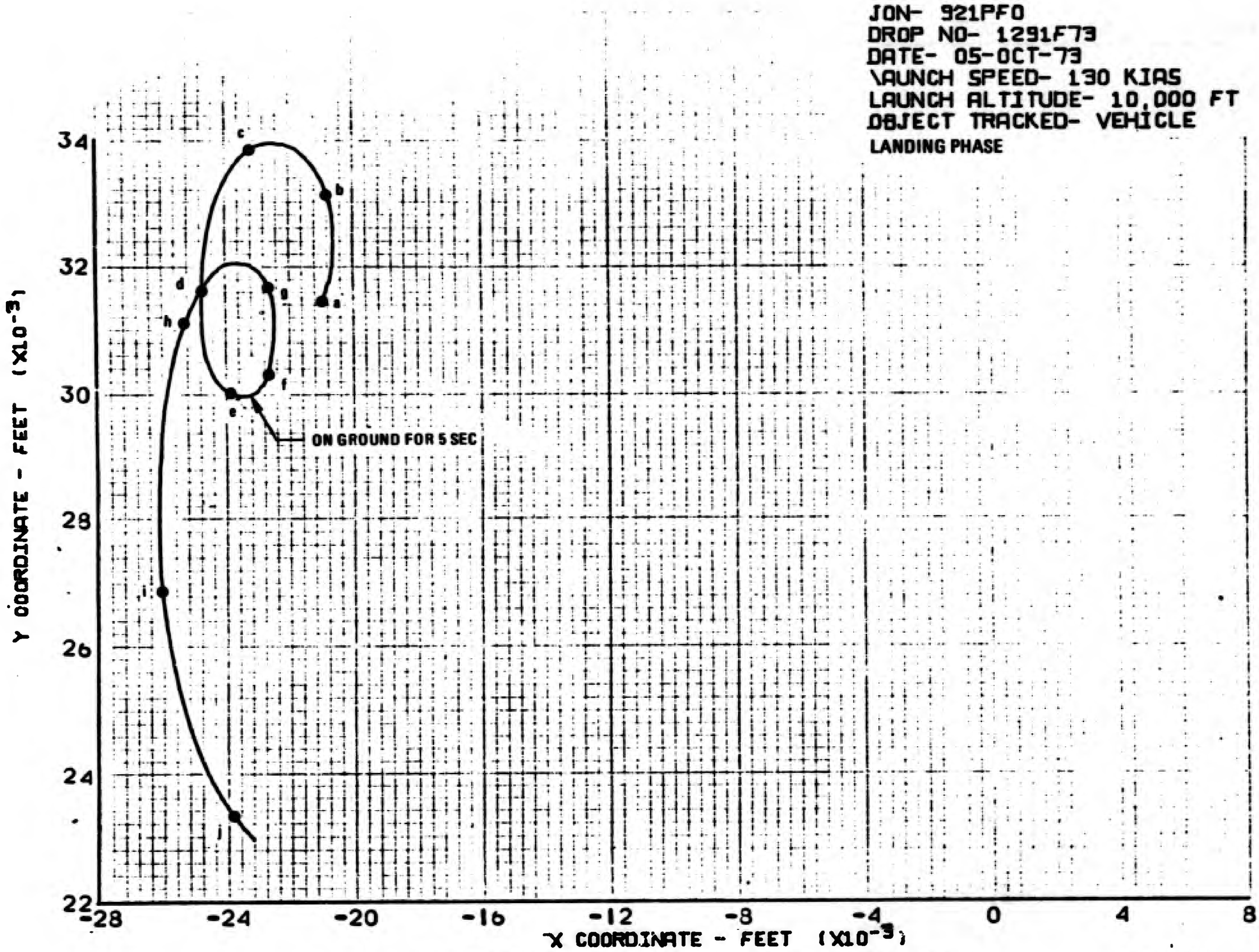
Z COORDINATE VERSUS ELAPSED TIME

FIGURE 6A



Z COORDINATE VERSUS ELAPSED TIME

FIGURE 7A



Y COORDINATE VERSUS X COORDINATE

FIGURE 8A

APPENDIX B

APPENDIX B

SYSTEM DESCRIPTION

The cable winch, control and safety apparatus, and docking mechanism were installed on a 9x20 ft aluminum pallet (referred to as a metric platform) of the type used for parachute extraction from C-130 aircraft equipped with cargo floor roller systems. This approach to equipment installation provided several advantages. The complete system was self-contained on the pallet. Installation of equipment on the platform was permanent, entailed no mechanical modifications to the aircraft and eliminated the usually lengthy procedures required for aircraft modification. Maintenance of the trailing wire apparatus did not require aircraft down time since the pallet was stored and worked on in a hanger. Installation of the trailing wire metric platform into the C-130 could be accomplished in approximately 30 minutes and required no special mechanical procedures. Once installed in the aircraft, the system required a single electrical plug connection to aircraft power to be operationally ready. The obvious advantages of such a configuration are rapid reaction time, universal adaptability to C-130 cargo extraction equipped aircraft, simple and inexpensive modification to aircraft electrical system to provide power for the system, and maintenance and storage capability for the winch and associated equipment in hangar areas during which time the aircraft is available for other missions.

Discussion of the system configuration and component function and performance capabilities will be discussed in the following order: (1) Winch, controls and safety mechanisms, (2) Cables, (3) Towed loads, (4) Cable guide and docking mechanism and (5) Instrumentation. General layout of the equipment on the metric platform is shown in Figure 1 and Photographs 1 & 2. Throughout the ensuing discussion it is essential to bear in mind that all equipment utilized was selected on the basis of its merit relative to operational simplicity, cost, availability and maintainability. Simplicity - defined as the most direct and unencumbered method of performing the required task was in all cases the primary factor. This approach was enforced because of the philosophy that simplicity implies service dependability.

Winch, Controls and Safety Mechanisms

The cable winch was located at the extreme forward end of the pallet. The winch is driven by either one or two 9 1/2 horsepower DC motors which supply power thru a chain and sprocket reduction train to the main shaft. The two motor configuration is utilized for towing heavy loads (500 lb capsule and up to 18,000 ft of cable weighing 30 lb per 1000 ft). The winch rate varies from approximately 800 ft/min (towing a dead load of 1200 lb) to 1000 ft/min as the load decreases. The motors are controlled in four speed ranges and require 400 amps DC each to retrieve a 1200 lb load at the maximum steady state reel rate.

The cable is pulled by the storage drum which is satisfactory for steel cables. A dual capstan drive with constant cable tension to the storage drum of approximately 100 pounds would produce less wear on the cable. Work on such a configuration was started, however, not completed or tested. The chain and sprocket reduction from the drive motors drive a level wind mechanism. The level wind progression rate (for different cable diameters) as well as the amount of speed reduction from the motors to the main shaft is adjustable by changing sprocket sizes. The amount of reduction is primarily dictated by the torque required. With the torque requirement satisfied, the maximum reel rate is fixed. The higher the torque, the lower the reel rate.

The main brakes for the winch consist of two Lincoln automotive front wheel disks and calipers mounted on the main shaft. The hydraulic pressure to each brake caliper is applied separately by a split section master cylinder. The winch is speed controlled by brake application in the reel-out mode and power application (and braking) in the reel-in mode. Speed is monitored by means of a one foot circumference "counter wheel" which is driven by the cable and which, in turn, drives a tachometer generator which produces a rate signal in feet per second. The cable speed and footage count are displayed on the operator console.

Two proven means exist for positive, long term, primary control of the reel rate. (1) The hydraulic disk brakes are the normal method of winch control. There is a noticeable heat build-up by this means of control when deploying heavy loads with long cable lengths (e.g.; 450 lbs, 13,000 ft of cable) and forced air cooling is desirable. (2) Reverse speed control on the drive motors quite effectively controls the reel rate.

Loss of electrical power on board the aircraft could result in an inability to bring trailed cable back on board. Additionally, loss of primary hydraulics could result in a run-away condition of the winch. The extreme danger which would be encountered in the event of any of these possibilities prompted the employment of three additional devices in the field configuration. These were: (1) A friction drag brake (2) A high speed cable cutter and (3) A hand operated cable-cutter. The first two devices were permanently installed on the cutter table; see Figures 1B and 11B.

The friction drag brake is actuated by a separate, self-contained hydraulic system. It was included in the system to provide a redundant method of halting or controlling a runaway by means of applying a friction clamp directly to the cable. This device would prevent loss of cable and towed load from the aircraft and the possible damage such items could cause at the ground in populated areas. The friction drag brake was designed to act on the cable itself at a position independent of the winch. The reasoning for this was simply that the cable causes the runaway of the winch, and a runaway winch provides no base for control of the cable.

The high speed cable cutter was devised as a last means of controlling a runaway situation. This mechanism is also located away from the winch in an effort to provide a stable base for its operation in case of total winch failure. The cutter is activated by a separate hydraulic system which forces two high strength steel bits into the cable. This cutter obtains additional self-actuating closure force from the cable motion and would only have been used to sever the cable in an uncontrollable runaway situation. Both systems were successfully ground tested at reel rates of 2000 ft/min and tensions up to 1500 lb.

The remaining "safety device" was simply a reliable hand-operated cable cutter - to be utilized in the event towed cable could be held stationary but not brought back on board. Considering the redundancy of winch controls, the latter seemed the most likely mode of failure, if failure were to occur at all.

Cables

The project utilized two cables during flight tests at El Centro. Both cables were essentially 1/8 inch in diameter and had average breaking strengths of 2300 lb and a weight of 30 pounds per 1000 ft.

One of these cables was an inexpensive, torque stabilized, braided aircraft cable. Its primary purpose throughout the project was for initial functional flight testing of the equipment. It subsequently served as a back-up cable in case of damage to the primary cable.

The primary cable was a specially fabricated, torque stabilized wire rope. It was constructed of 23 strands of wire wound counterclockwise directly in contact with 19 strands wound clockwise, neither layer being braided or woven in any manner. In the core of these two lays of wire was placed an insulated copper conductor. The wire, specially fabricated as it was, was intended for research application only. The conductor was provided to allow for passage of instrumentation or power signals between aircraft and the capsule.

Towed Loads

Test flights were conducted at El Centro NAS, with two size capsules. Initial work was conducted with a conical capsule of 18 inch base and 30 inch height. This capsule was ballasted with lead to a flight weight of 100 pounds and was used only to "shake down" the system and for initial training flights for both project and air crew personnel. However, this capsule size and weight could conceivably have simulated an electronic surveillance package.

The primary capsule was a right circular cone of base 4 ft and height 5 ft. This capsule was flown at weights of 300 and 425 pounds. Its size and weight was conjectured to be commensurate with man rescue operations.

Both capsules were equipped with a cable attachment mechanism having a thrust bearing that allowed the capsule to rotate freely on the tow line. The mechanism also contained an insulated slip ring to allow the cable center conductor to be electrically connected to capsule instrumentation.

Ballast in the capsules was installed asymmetrically. This configuration plus the freedom of the capsule to rotate proved sufficient to isolate the capsules from cable twisting loads. Photographic and visual observations of the capsules close to the aircraft and the ground indicated there was no capsule spin. This is significant for either manned or surveillance package operation.

Docking stability of the towed capsules is of obvious importance. Any capsule large enough to carry a man will necessarily produce lift. From field testing, two requirements to safely accomplish capsule docking have emerged: (1) precise, easy control of the winch and (2) weight and balance of the capsule. The first requirement needs no further emphasis. With regard to the second requirement, it has been found that a ratio of capsule weight to flat plate projected area of the side of the capsule is a useful parameter. This ratio should be on the order of 40 pounds per square foot or more. This parameter by itself will not assure stable passage through the aircraft slip stream. Experience has shown that the C.G. of conical shaped cpasules must be located about two thirds of the capsule length aft of the tow point (apex). Such a weight and balance configuration towed stably during launch, all flight phases, through landing on the ground and during docking on the aircraft. The towing characteristics in the slip stream were such that the capsule could be halted at any distance from the aircraft without wake flow disturbing the attitude or stability of the capsule.

Cable Guides and Docking Mechanisms

The cables used in the field tests were frequently employed at loads of 1/2 of ultimate strength. Such load conditions cause rapid deterioration of the cable if it is not properly protected from abrasion. Some wear on the cable at the winch take-up drum was unavoidable due to the laying up of cable under high tension. During operation, the cable must pass off the drum, through the level wind, through the safety devices and tension meter on the cutter table and overboard the aircraft. The cable was guided and protected along this routing by barrel roller assemblies and pulleys.

Due to the geometry of the aircraft orbit and the towed cable, the cable pulled noticeably toward the inboard side of the aircraft during orbiting maneuvers. If unrestrained, there is a possibility that the cable could contact the side of the aircraft or possibly foul itself in the cargo ramp opening. This tendancy to pull to the inside intensifies when the cable is towed upwind. To preclude wide divergence in the towing angle and possible damage to aircraft or cable, a vertical roller assembly was installed at the extreme aft end of the pallet. (See Figure 10B). The assembly so located does not interfere with the docking of capsules. Additionally, the cable is free to tow straight aft during straight line flight.

Flight tests demonstrated that selection of the vertical roller material is critical. The cable slides up and down the rollers depending on aircraft bank angle and free stream wind velocities. This type of cable motion will rapidly abrade most surfaces. The roller surface material should either be extremely hard or be soft with a tough surface. Hard surfaced rollers will not pit and roughen due to cable motion and therefore will not damage the cable strands. On the other hand, a soft roller with a tough surface will not damage the cable due to slipping contact and the toughness will prevent the cable from cutting into the roller.

Figures 9B, 10B and 12B show the docking mechanism. The unit is extremely simple, inexpensive, suitable to a broad size range of towed capsules and provides an adequate anchor point for the capsule during normal flight operations. Flight test operations have shown that no additional devices are required for safe launch or docking. The boat roller assembly shown in Figure 12B reduces capsule sliding resistance during docking and protects the cable during deployment until the cable starts to fly and lifts free of the roller.

Instrumentation

Data displayed at the winch operator console (Figure 13B) consisted of deployed cable footage, cable speed, cable tension, DC voltage and amperage to the motors, radar altimeter read out and a light display indicating motor power setting. Refering to Figure 13B, the following items are also visable: (1) foot pedal for main winch brake, (2) hand brake to permanently set brakes, (3) motor speed selector and (4) actuator levers for cutter table safety devices. Also apparent is the strategic location of the operator, enabling him to see docking maneuvers as well as the entire run of cable from the winch at his left to where it passes off the aircraft.

Cable speed and footage information were obtained by means of a cable driven, 1 foot circumference pulley which counted the footage passed and also drove a tachometer generator which produced a rate signal in feet per second, Figure 14B. Although there must inevitably be slippage in this mechanism the footage error was repeatedly less than 1/4% on a round-trip basis of 28000 ft of cable.

The altimeter display derived its signal from a radar altimeter mounted in the capsule. This altimeter measured relative distance between the capsule and the ground and had a service ceiling of 2000 ft. The signal was amplified and transmitted up the towing cable through the insulated conductor to the winch. A slip-ring mechanism on the winch main shaft transfered the signal from the insulated conductor to the winch operator console.

Motor amperage was measured at the relay control boxes containing the stepping resistors for motor speed control. Figures 2B thru 8B show block diagrams and schematics of the motor control and instrumentation systems.

A four channel instrument recorder was used during three flight tests to record radar altimeter data, cable tension, cable speed and voice transmissions associated with the missions. The voice transmissions recorded were of pilot, ground crew and winch crew conversations and provided an adequate method of annotating oscillograph records of the other three channels of data.

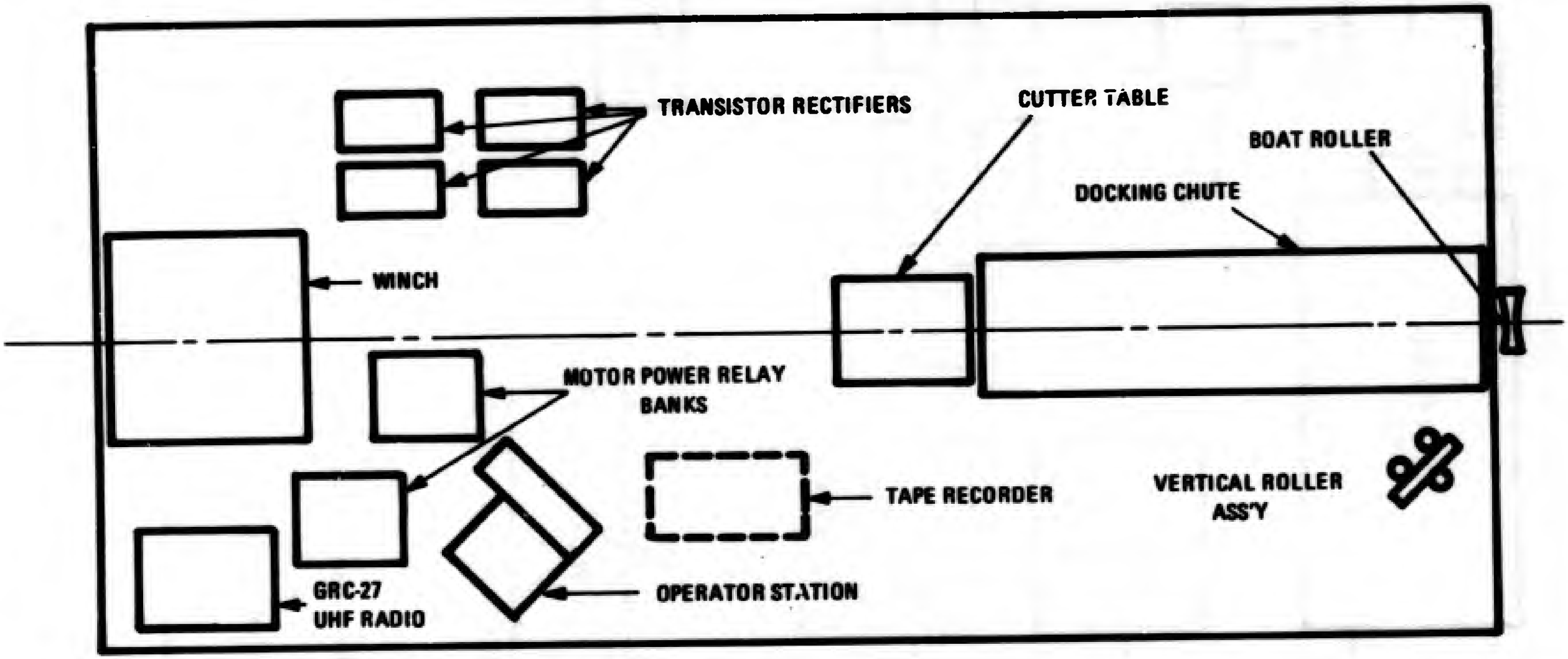


Figure 1B. METRIC PLATFORM EQUIPMENT LAYOUT

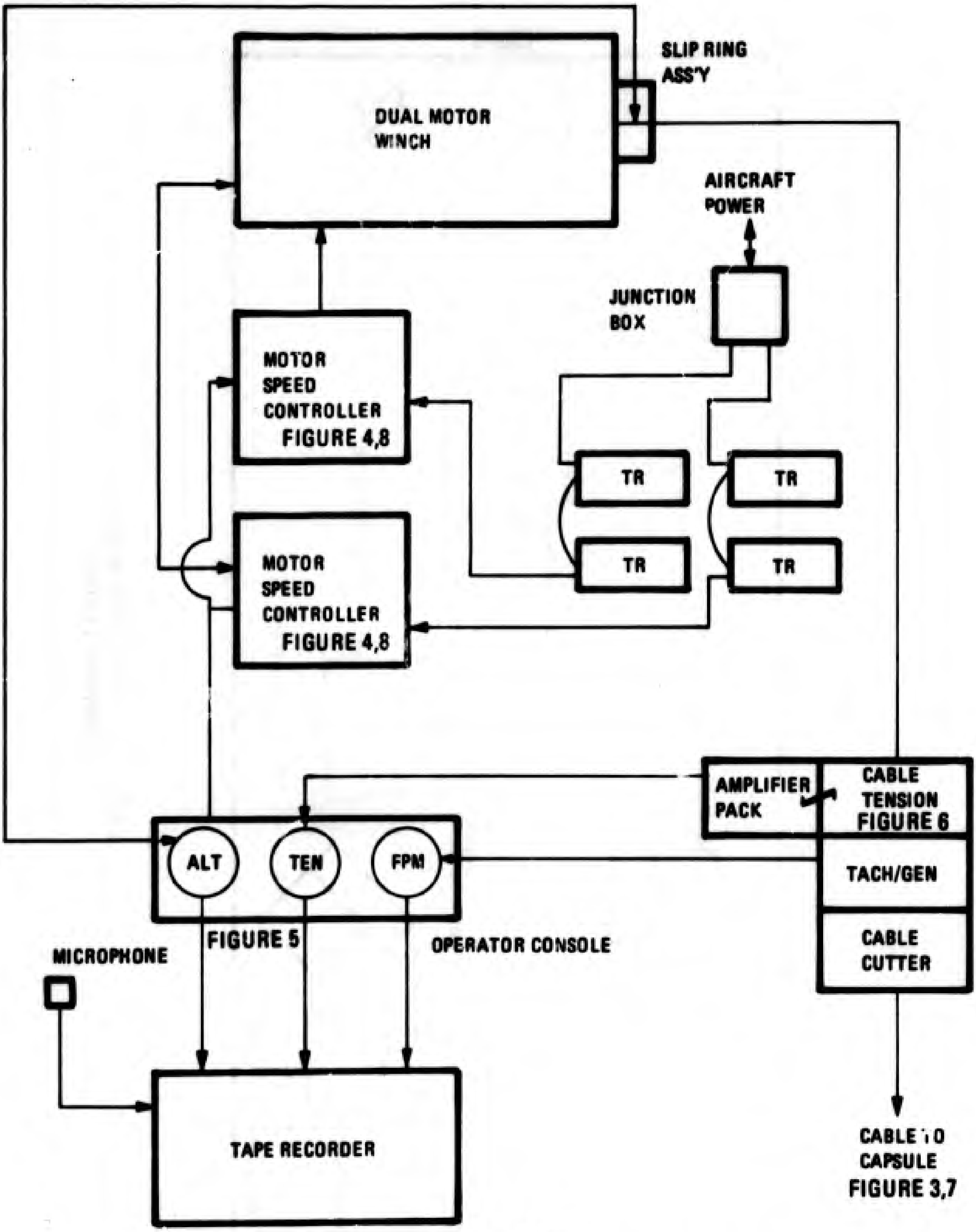


Figure 2B.
BLOCK DIAGRAM TRAILING WIRE WINCH SYSTEM

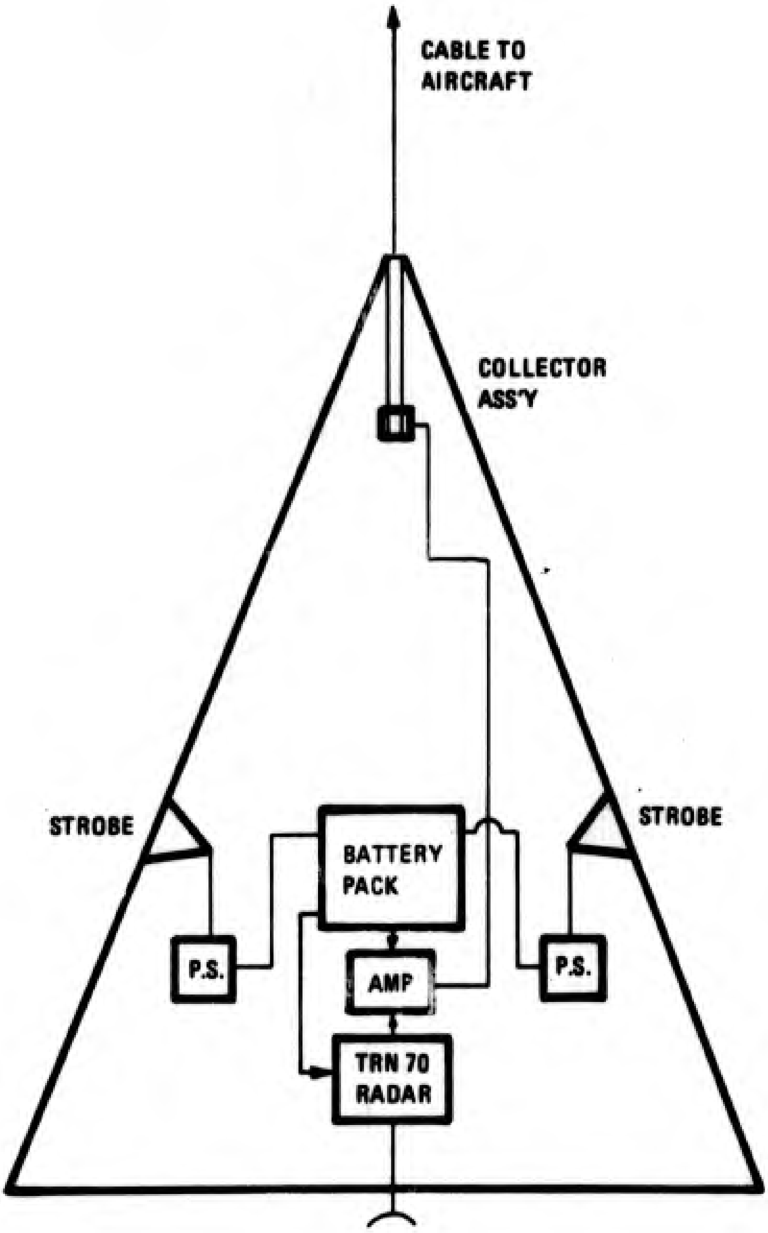


Figure 3B.
BLOCK DIAGRAM OF CAPSULE INSTRUMENTATION

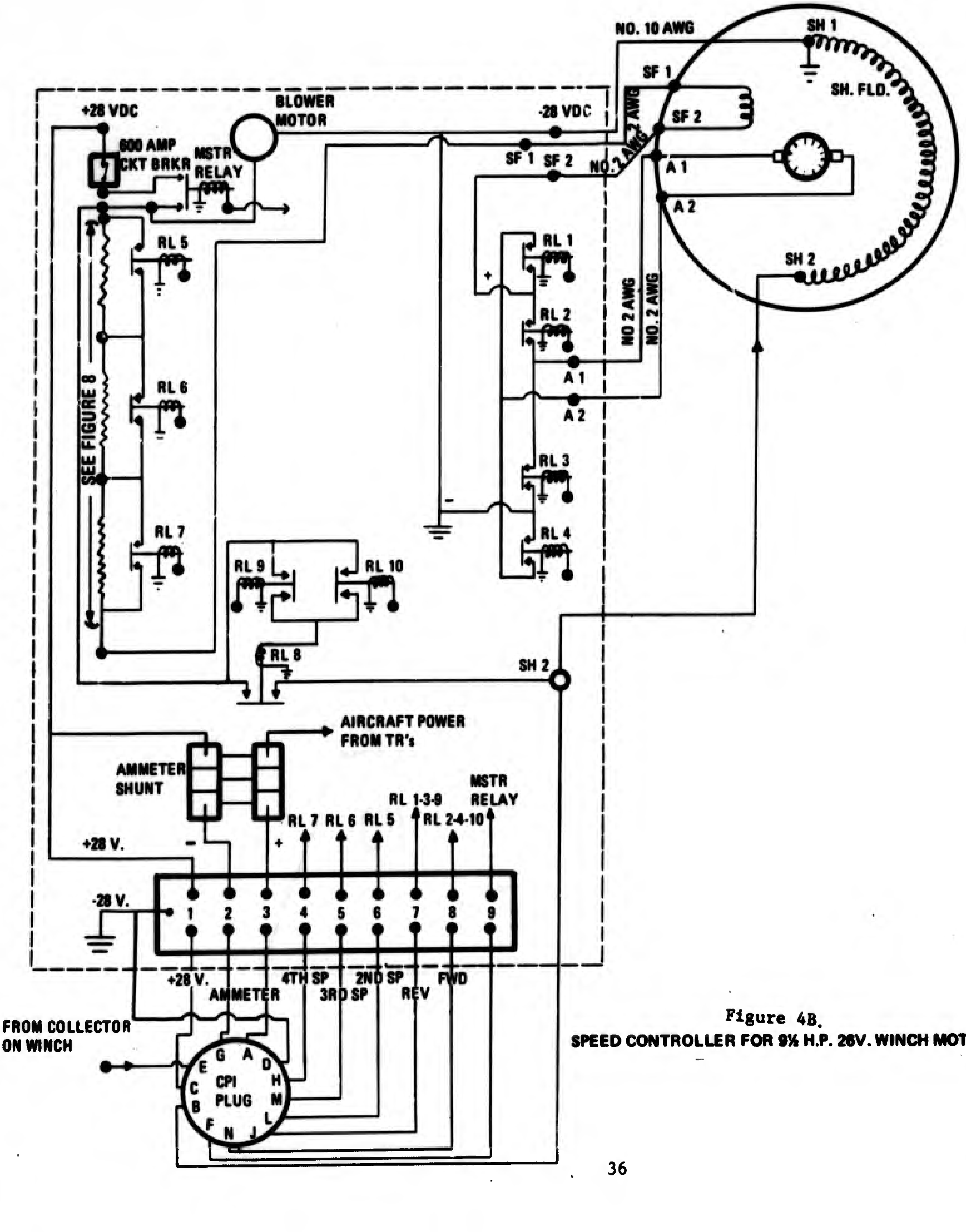
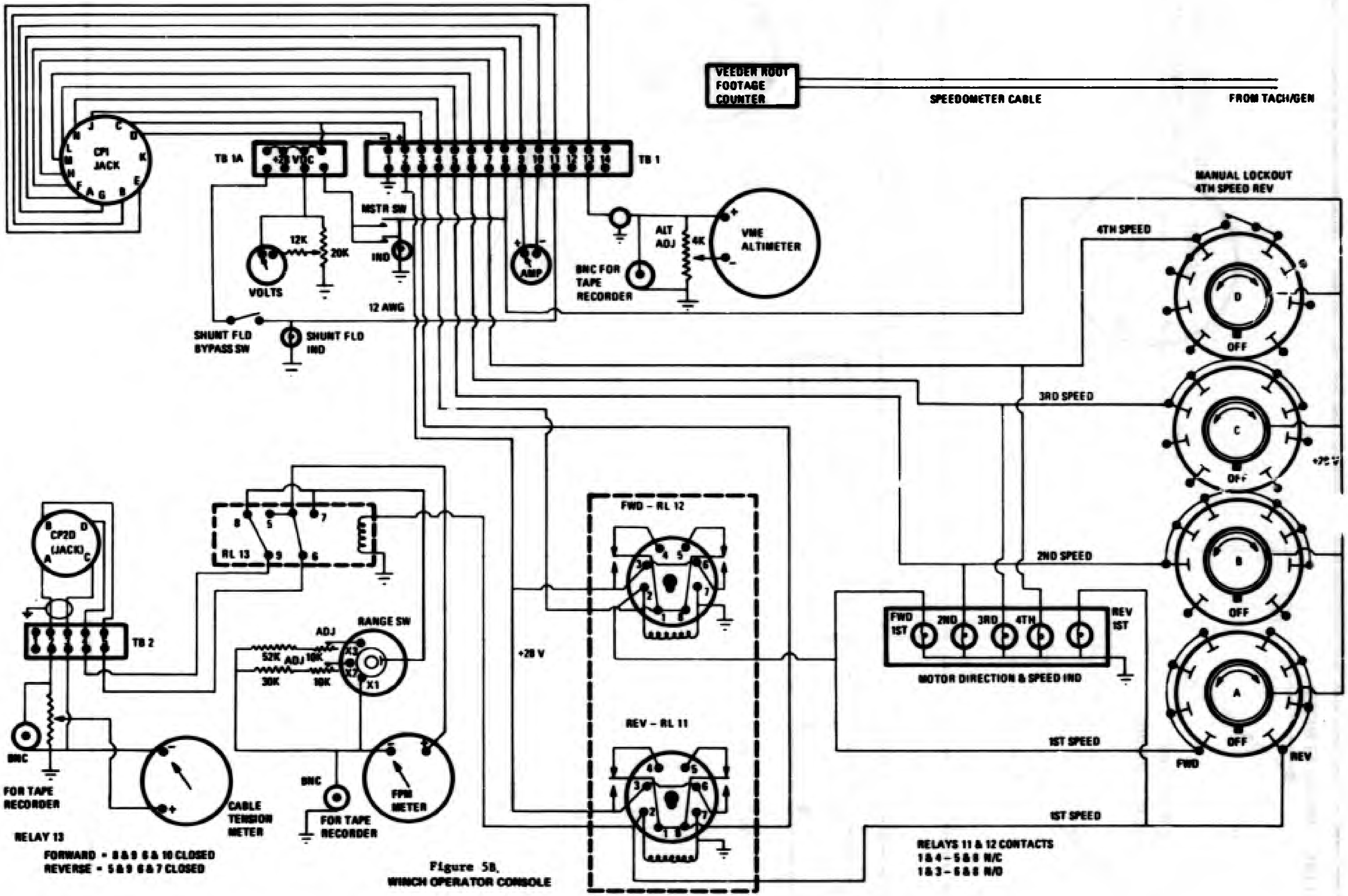


Figure 4B.

SPEED CONTROLLER FOR 9½ H.P. 26V. WINCH MOTOR



RELAY 13
FORWARD - 8 & 9 6 & 10 CLOSED
REVERSE - 5 & 9 6 & 7 CLOSED

RELAYS 11 & 12 CONTACTS
1 & 4 – 5 & 8 N/C
1 & 3 – 6 & 8 N/O

Figure 58.
WINCH OPERATOR CONSOLE

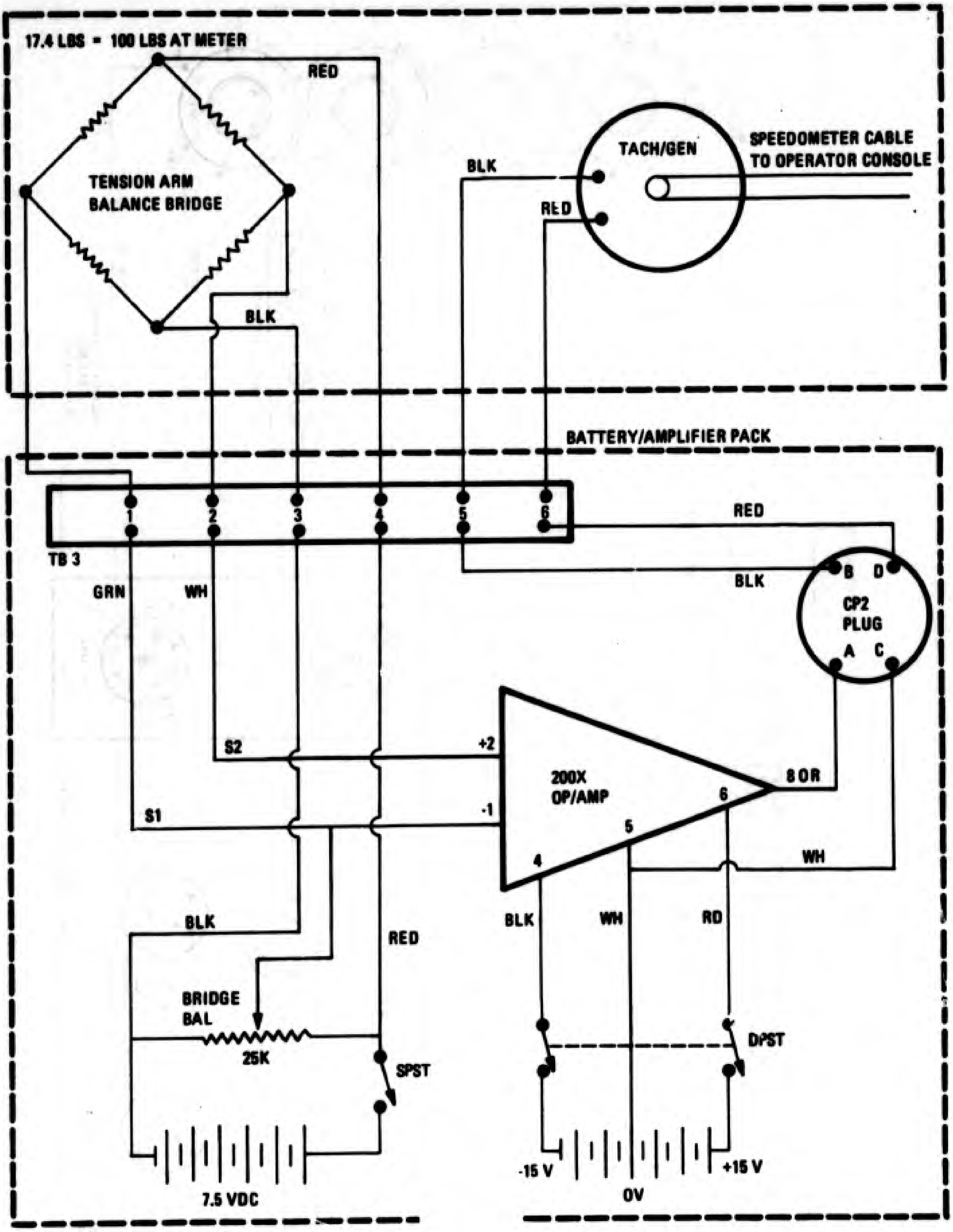


Figure 6B.
CUTTER TABLE INSTRUMENTATION

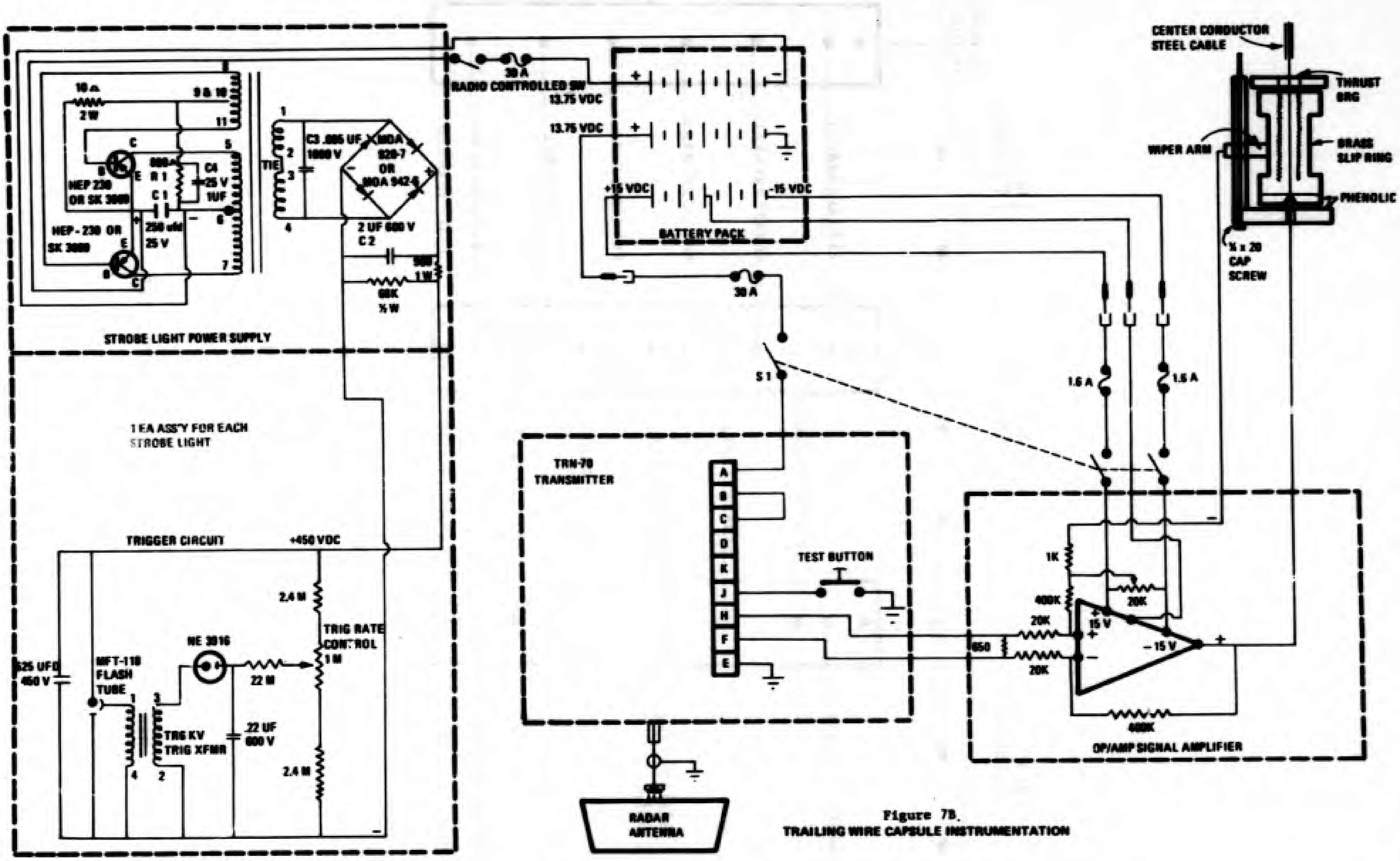
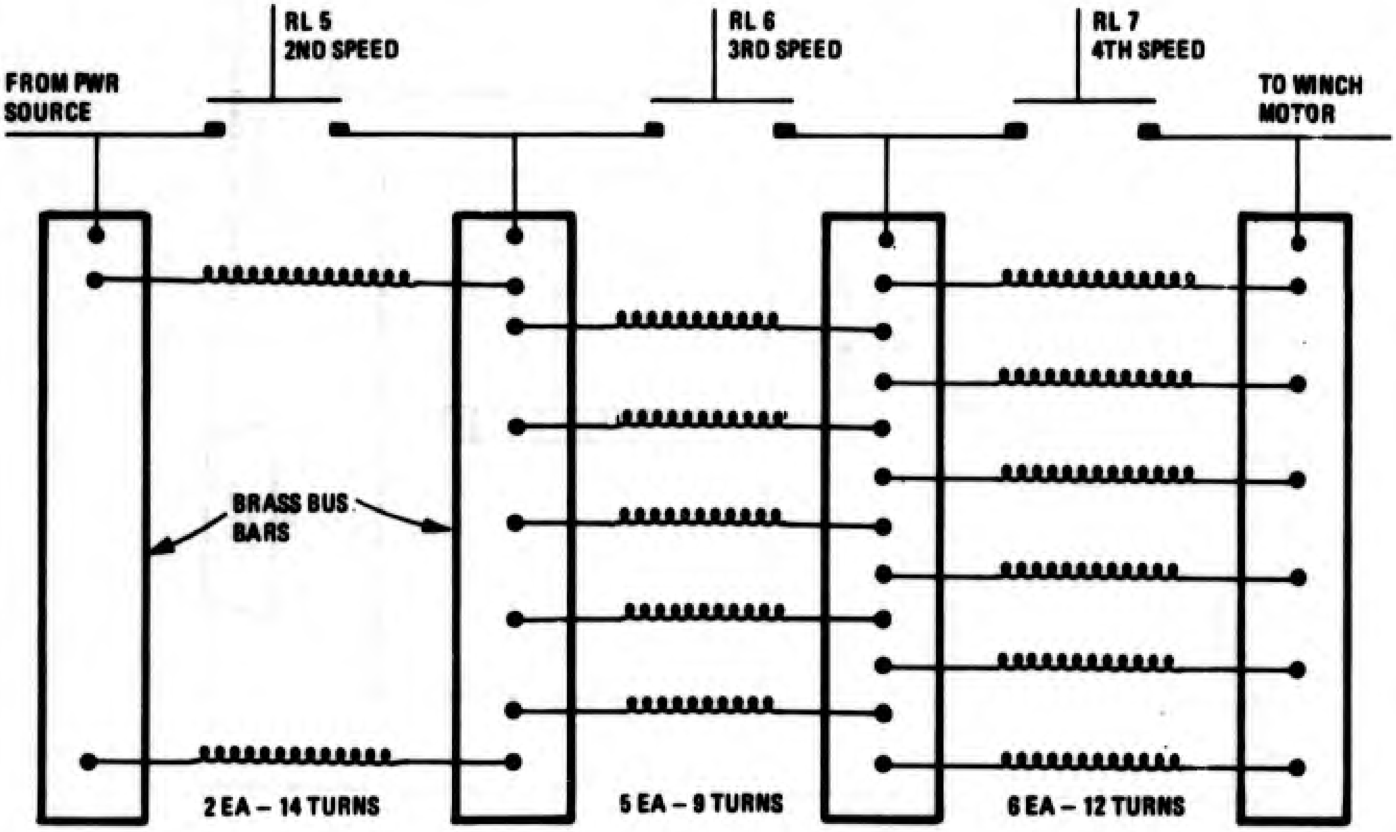


Figure 7B.
TRAILING WIRE CAPSULE INSTRUMENTATION



ID OF RESISTANCE COILS = 7/8"

NO. 12 AWG RESISTANCE WIRE

APPROX .067Ω PER FOOT

RL 5-6-7 OPEN = 1ST SPEED
RL 5 CLOSED = 2ND SPEED
RL 5-6 CLOSED = 3RD SPEED
RL 5-6-7 CLOSED = 4TH SPEED

Figure 8B.
RESISTANCE BANK FOR MOTOR SPEED CONTROLLER

BEST
POSSIBLE
SCAN

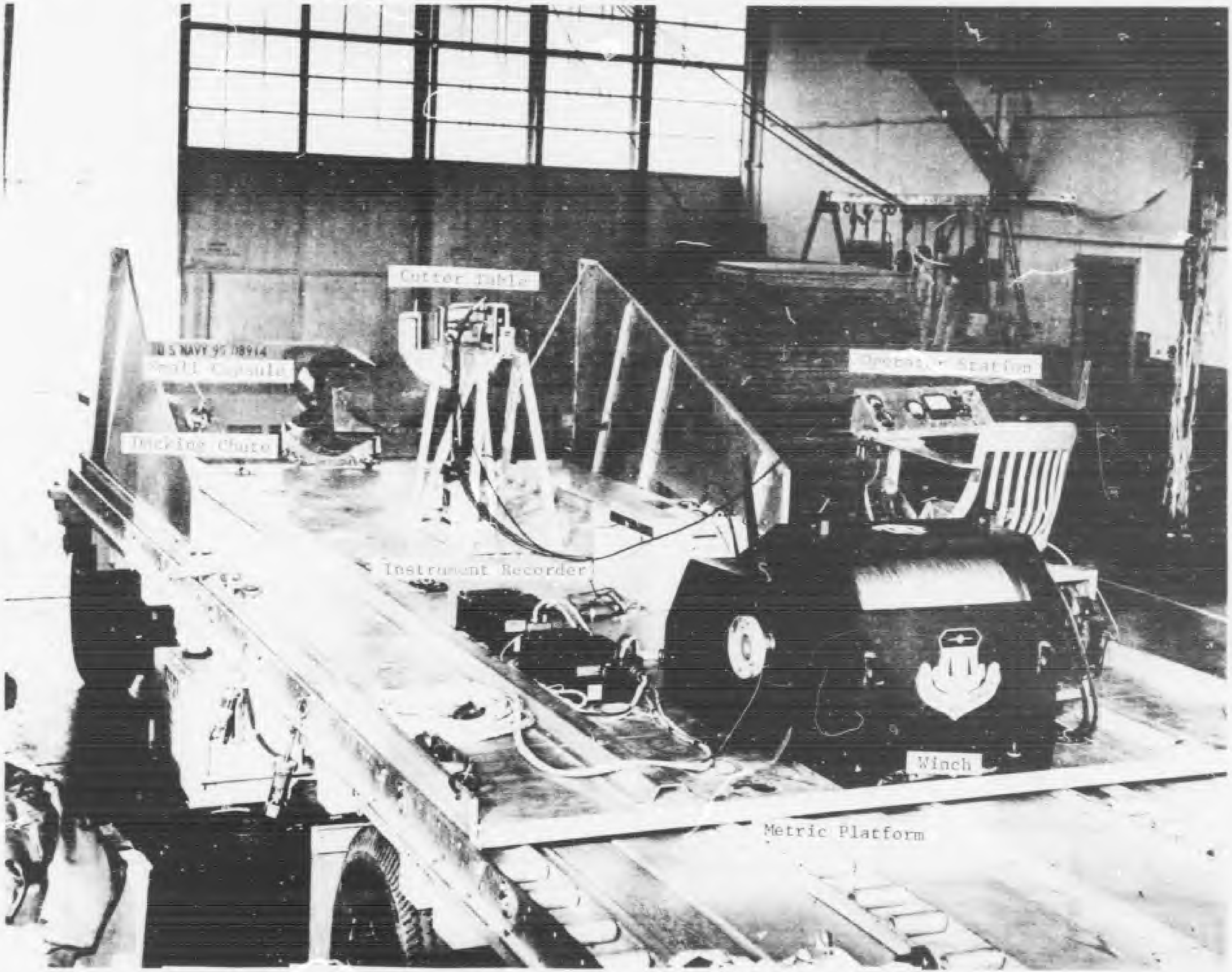


Figure 9B. Photograph 1. View Aft of Trailing Wire Metric Platform

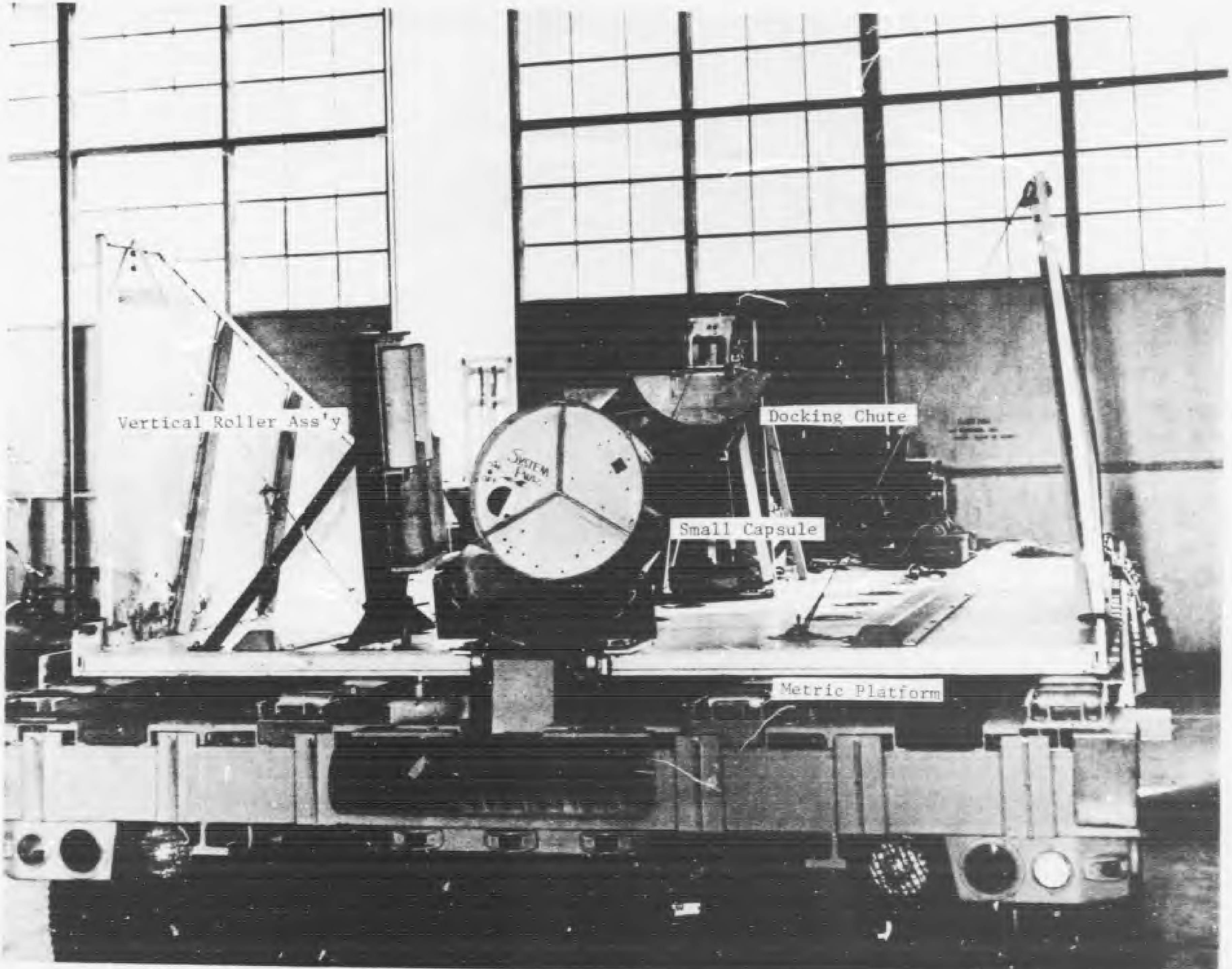


Figure 10B. Photograph 2. View Forward Trailing Wire Metric Platform

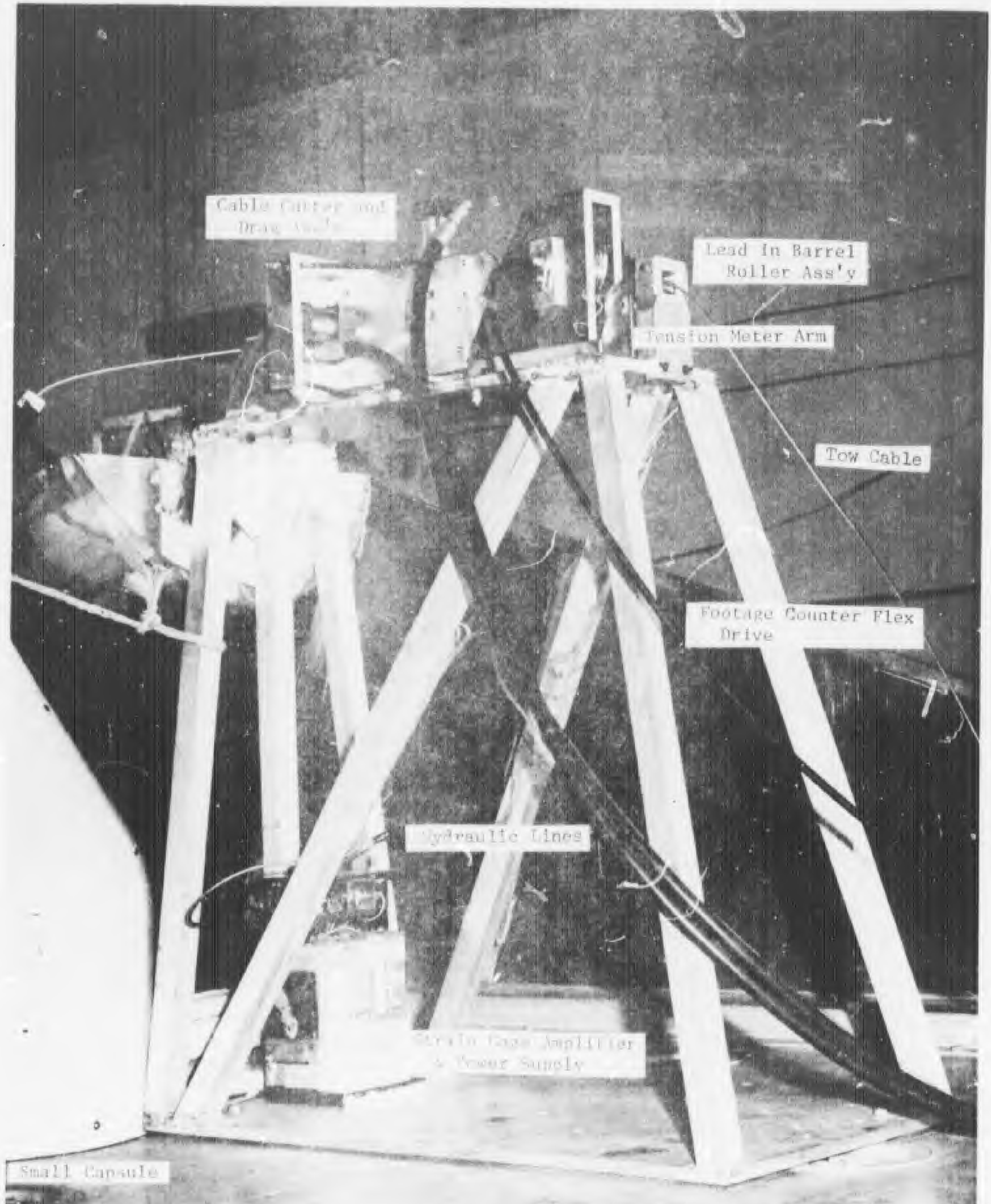


Figure [illegible] Photograph [illegible]

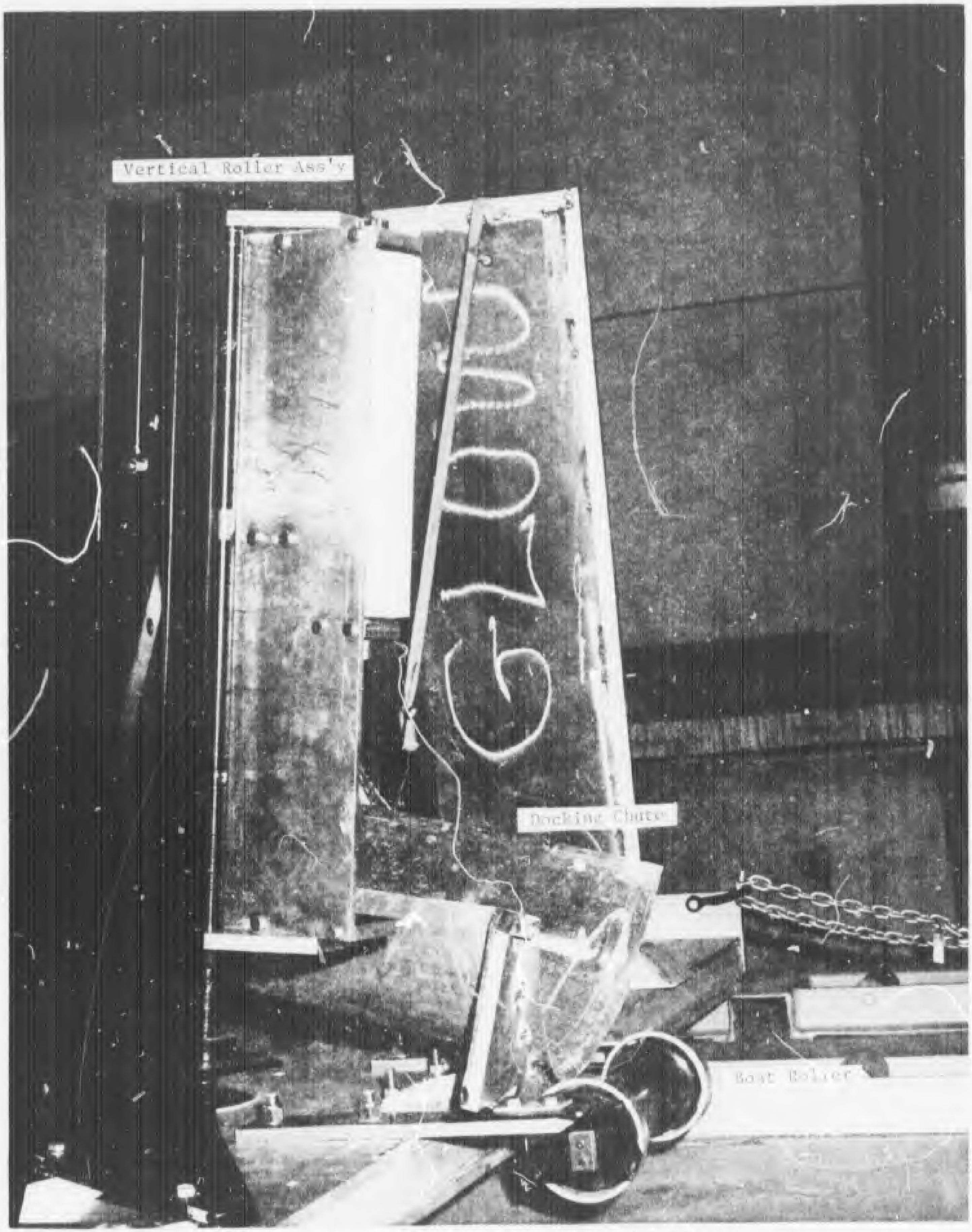


Figure 15. Underside of Docking Chute - Aft End

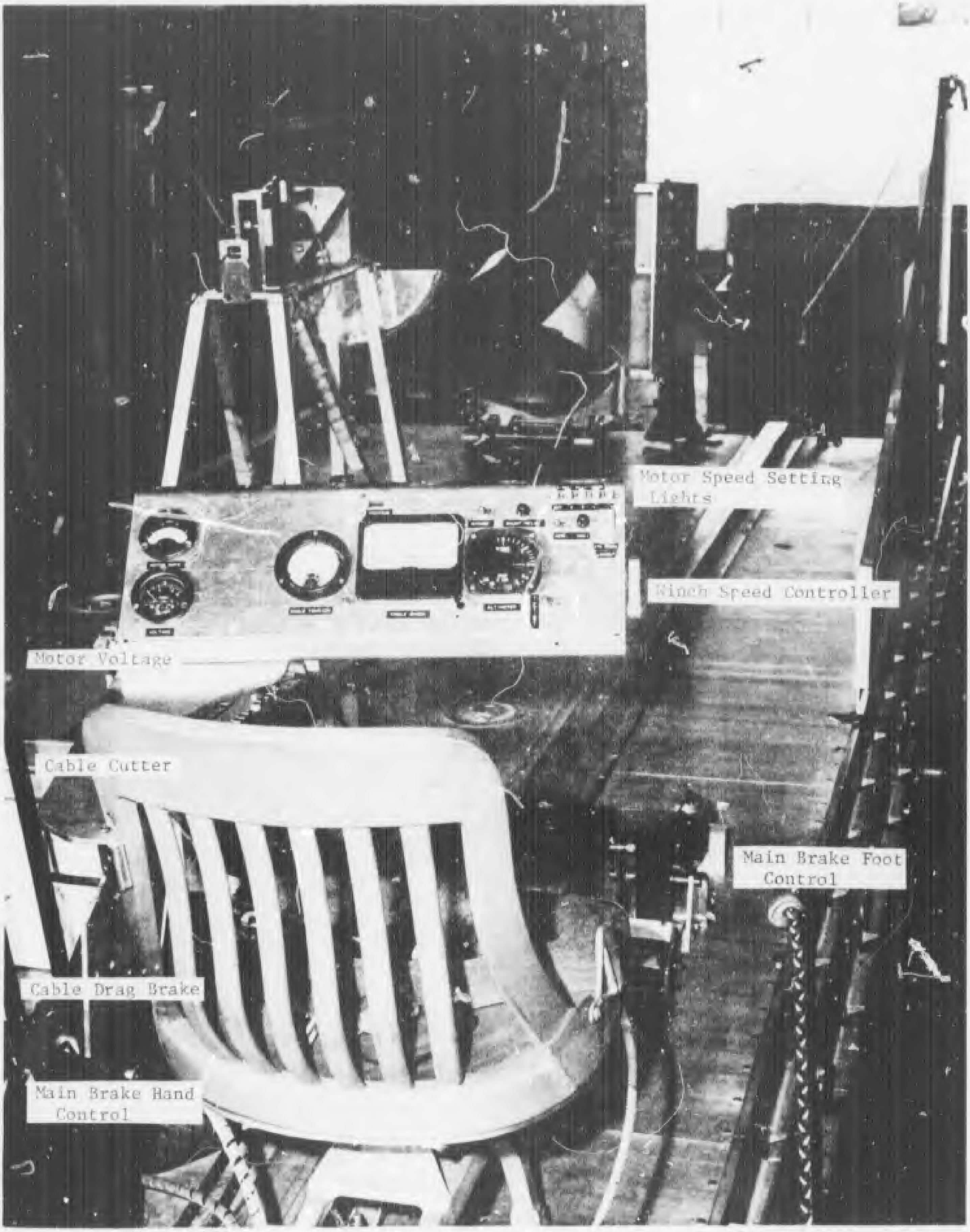


Figure 13B. Photograph 5. Winch Operator Console

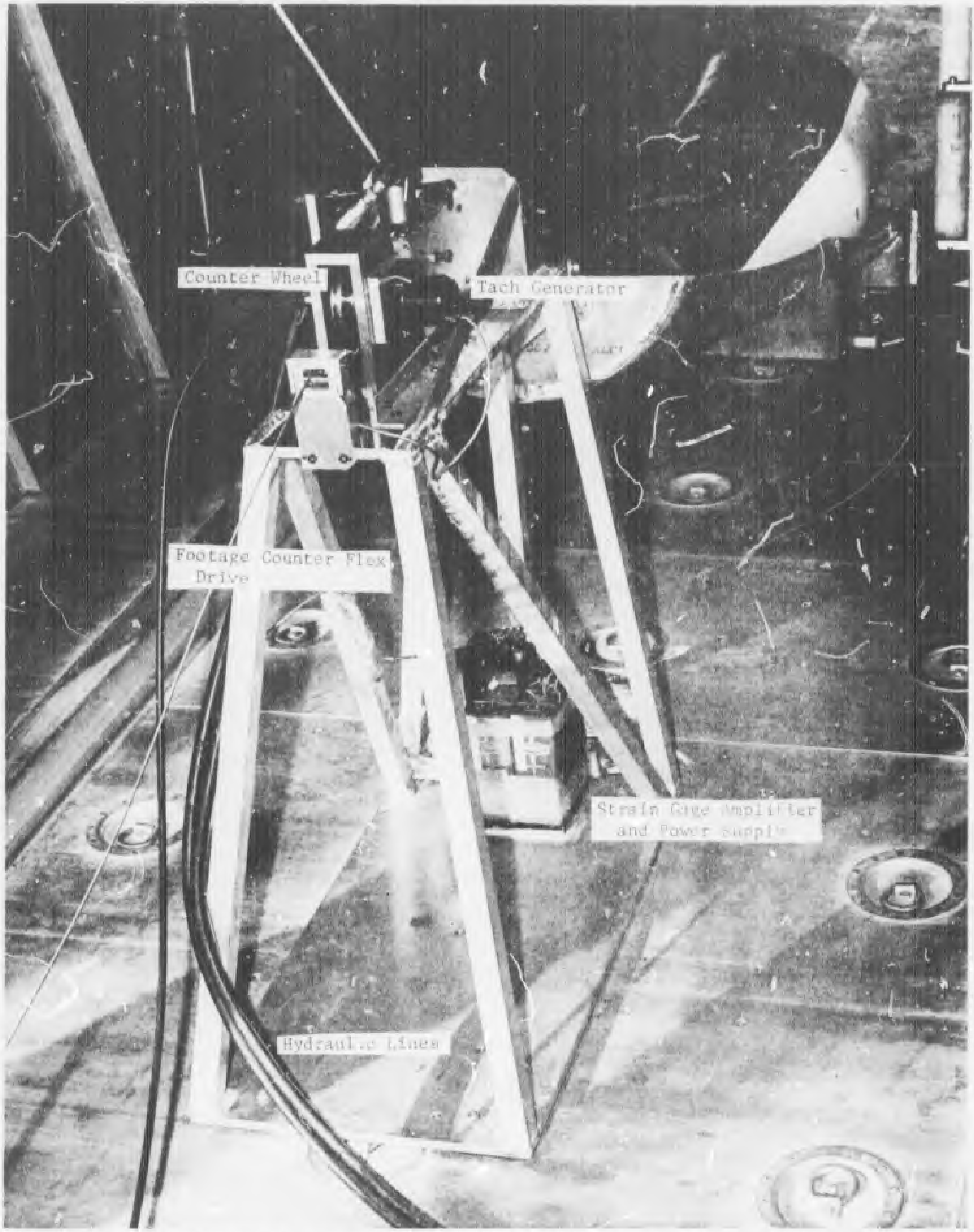


Figure 14B Photograph 6. Tension Meter, Tach Generator and Footage Counter