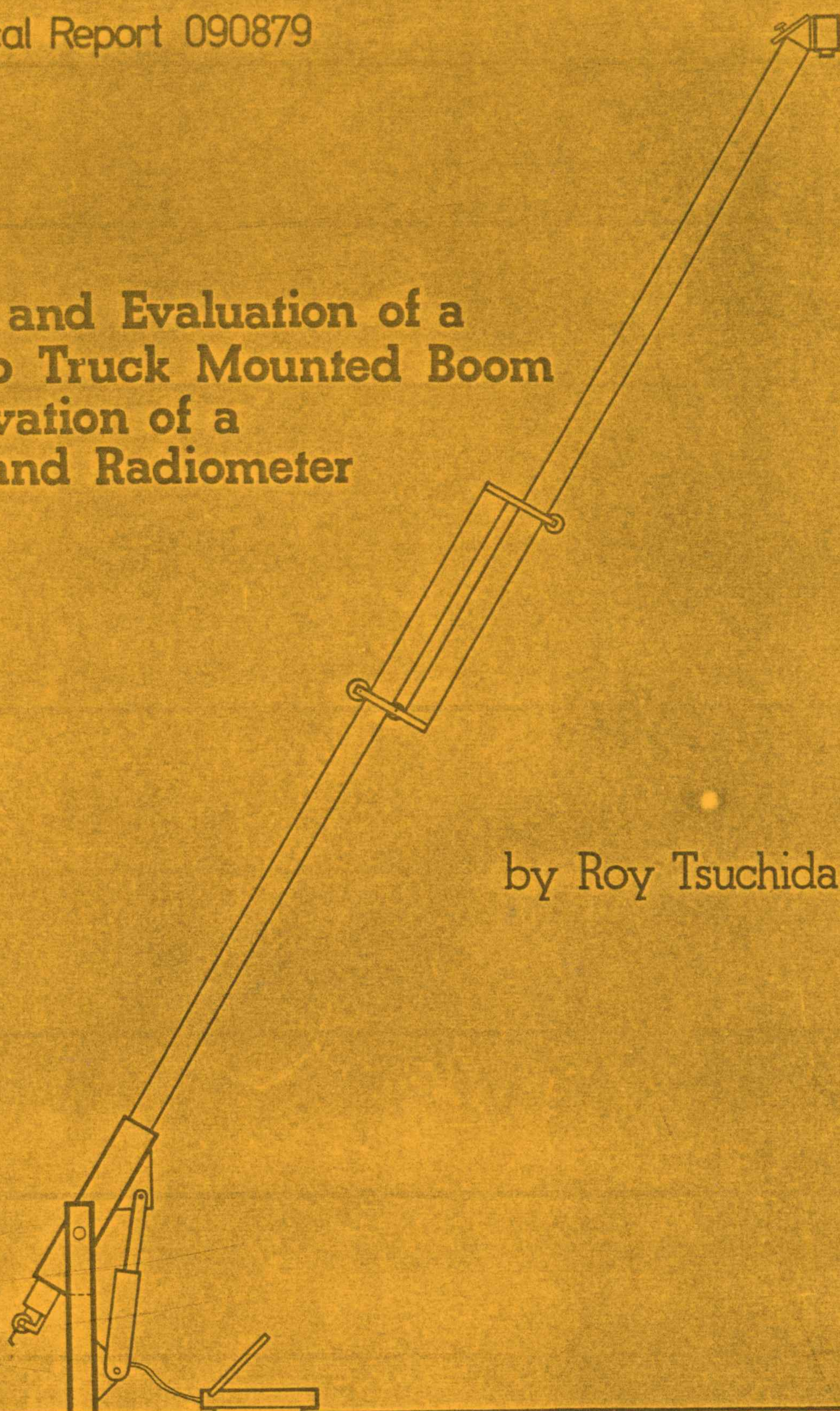
LARS Technical Report 090879

Design and Evaluation of a Pick-up Truck Mounted Boom for Elevation of a Multiband Radiometer System



by Roy Tsuchida

Laboratory for Applications of Remote Sensing
Purdue University West Lafayette, Indiana 47906 USA
1979

LARS Technical Report 090879

DESIGN AND EVALUATION OF A PICK-UP TRUCK MOUNTED BOOM FOR ELEVATION OF A MULTIBAND RADIOMETER SYSTEM

by

Roy Tsuchida

August 8, 1979

Laboratory for Applications of Remote Sensing
Purdue University, West Lafayette, IN

Star Information Form

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
090879		

4. Title and Subtitle DESIGN AND EVALUATION OF A PICK-UP TRUCK MOUNTED BOOM FOR ELEVATION OF A MULTIBAND RADIOMETER SYSTEM	5. Report Date August 8, 1979
	6. Performing Organization Code
7. Author(s) Roy Tsuchida	8. Performing Organization Report No. 090879
9. Performing Organization Name and Address Purdue University Laboratory for Applications of Remote Sensing 1220 Potter Drive, West Lafayette, Indiana 47906	10. Work Unit No.
	11. Contract or Grant No. NAS9-15466
12. Sponsoring Agency Name and Address David Pitts EOD NASA/JSC Houston, Texas	13. Type of Report and Period Covered Technical Report
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The following report describes the design process for the boom required for the Multiband Radiometer Project. Three concepts were considered for the boom design, a one-piece boom with a trolley, a folding boom and a telescoping boom. The telescoping boom was selected over the other two concepts because of its easy manual operation. The boom is designed to mount on the bed of a pick-up truck and elevate the radiometer system 25 feet above the ground and 12 feet away from the truck. The selection of the boom components is discussed with justification of the final choice. Results of performance tests and one season's operation of the completed boom are reported.

17. Key Words (Suggested by Author(s))	18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	36	

*For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA - JSC

DESIGN AND EVALUATION OF A PICK-UP TRUCK MOUNTED BOOM FOR ELEVATION OF A MULTIBAND RADIOMETER SYSTEM

ABSTRACT

The following report describes the design process for the boom required for the Multiband Radiometer Project. Three concepts were considered for the boom design, a one-piece boom with a trolley, a folding boom and a telescoping boom. The telescoping boom was selected over the other two concepts because of its easy manual operation. The boom is designed to mount on the bed of a pick-up truck and elevate the radiometer system 25 feet above the ground and 12 feet away from the truck. The selection of the boom components is discussed with justification of the final choice. Results of performance tests and one season's operation of the completed boom are reported.

TABLE OF CONTENTS

DESIGN AND EVALUATION
OF
A PICK-UP TRUCK MOUNTED BOOM
FOR
ELEVATION OF A MULTIBAND RADIOMETER SYSTEM

1. INTRODUCTION

This report describes the design process of the boom required for the Multiband Radiometer Project. The Model 100 radiometer is extended over crops by a truck mounted boom to collect crop reflectance data. The boom serves to elevate the instrument and hold it away from the truck such that only crops are within the field of view of the Model 100. In addition, the boom must also swing the unit over a calibration panel surfaced with a special reflective coating. Figure 1 shows the field position and calibration position required. Note how the elevation and the distance from the instrument to boom mount must change for each position. This report will serve to provide the reader with the design process and justification of the boom designed to meet this need.

2. DESIGN OBJECTIVES

The boom was designed under the following criteria:

(1) The boom must elevate the instrument a minimum of 25 feet above the ground and 12 feet away from the truck.

(2) The boom must position the instrument 4 to 8 feet above the calibration panel.

(3) The boom shall be manually operated by one person. The possibility of motorizing the boom operation should be considered in the design.

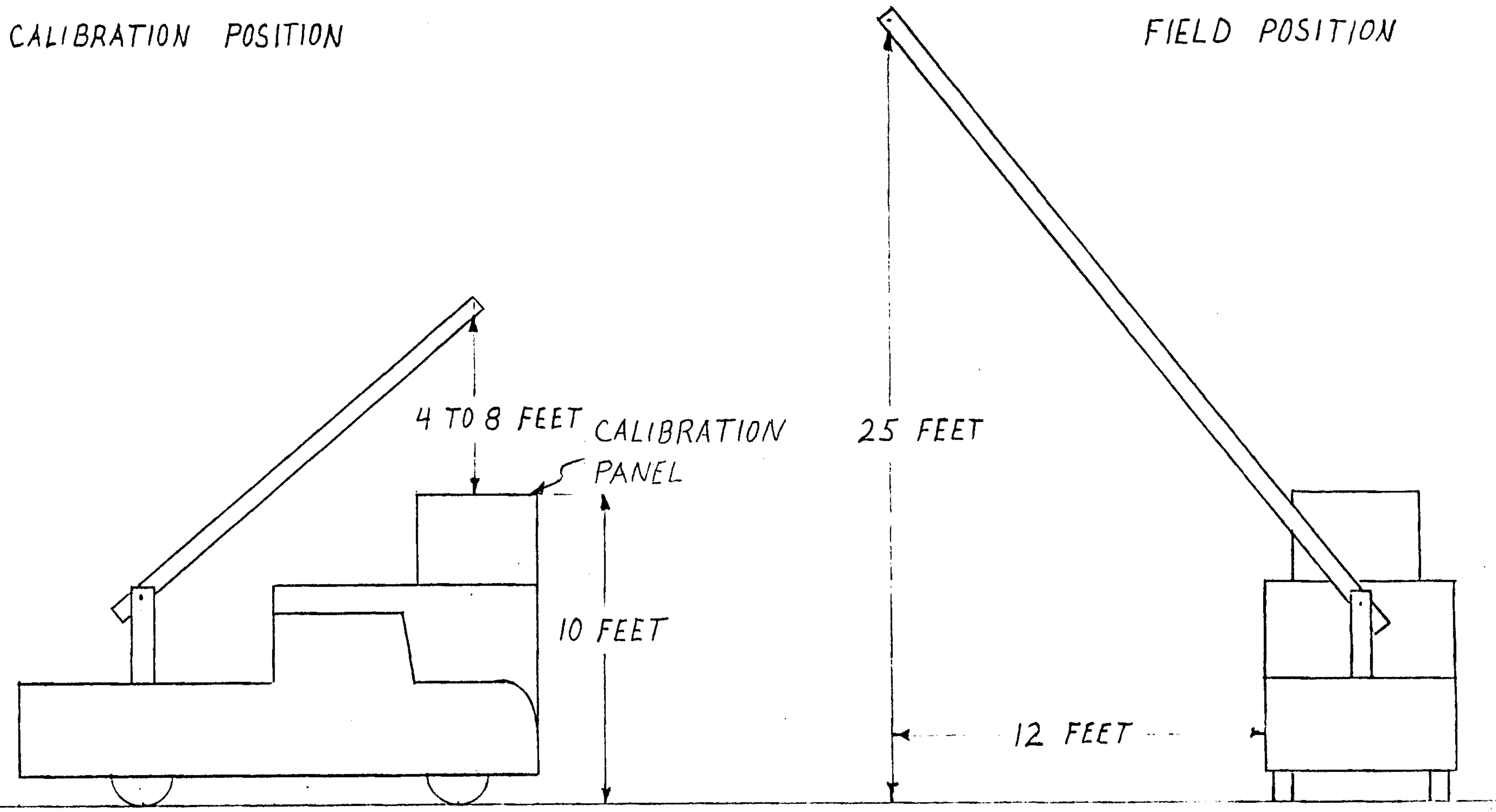

CALIBRATION POSITION
FIELD POSITION
4 TO 8 FEET
CALIBRATION
PANEL
25 FEET
10 FEET
12 FEET

FIGURE 1

(4) The boom must be readily fabricated by other remote sensing laboratories in other areas. Consideration should be given to the availability of materials and manufacturing facilities.

(5) The structure will be mounted on the bed of a truck and transportable over highways.

3. CONCEPTUAL STUDY

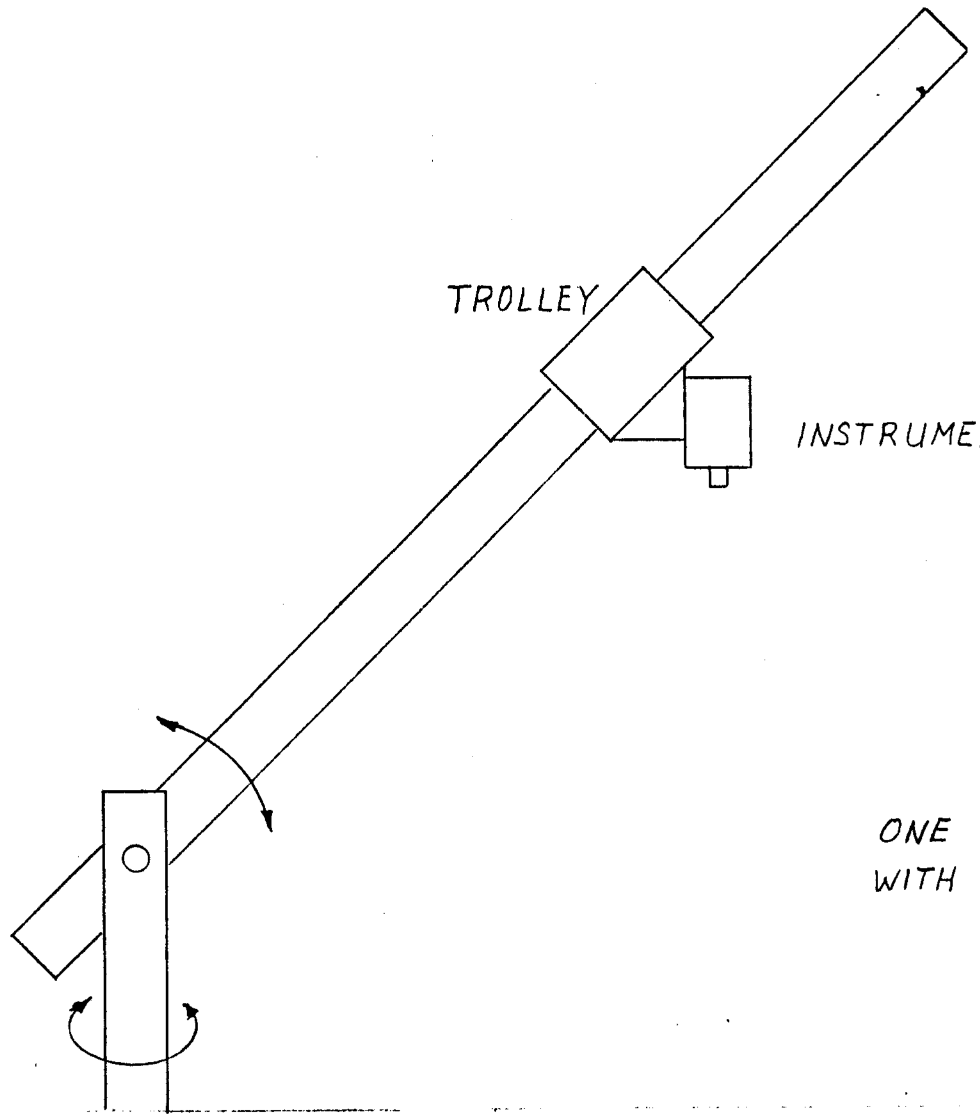
Three concepts were proposed for the boom design, a one-piece boom with a trolley, a folding boom and a telescoping boom.

(1) One-Piece Boom:

The one-piece boom diagrammed in Figure 2 consists of a beam and a trolley which moves along the beam. The beam pivots about a horizontal axis such that the boom may be transported horizontally and raised for field measurements. The boom also swings about a vertical axis which, in conjunction with the trolley, permits the instrument to be positioned over the calibration panel. The trolley carries the instrument to the end of the boom for field measurements and midway along the boom for calibration.

(2) Folding Boom:

The folding boom diagrammed in Figure 3 consists of two beams pin jointed together. The instrument is fixed to the extreme end of the upper beam. The boom pivots about a horizontal axis to allow the boom a horizontal position for transport and a raised position for field measurement. The boom is straight for field measurement to maximize the elevation and distance from the truck for a given length of beam. The elbow and the swing about a vertical axis permit the boom to locate the instrument over the calibration panel.



ONE PIECE BOOM
WITH A TROLLEY

FIGURE 2

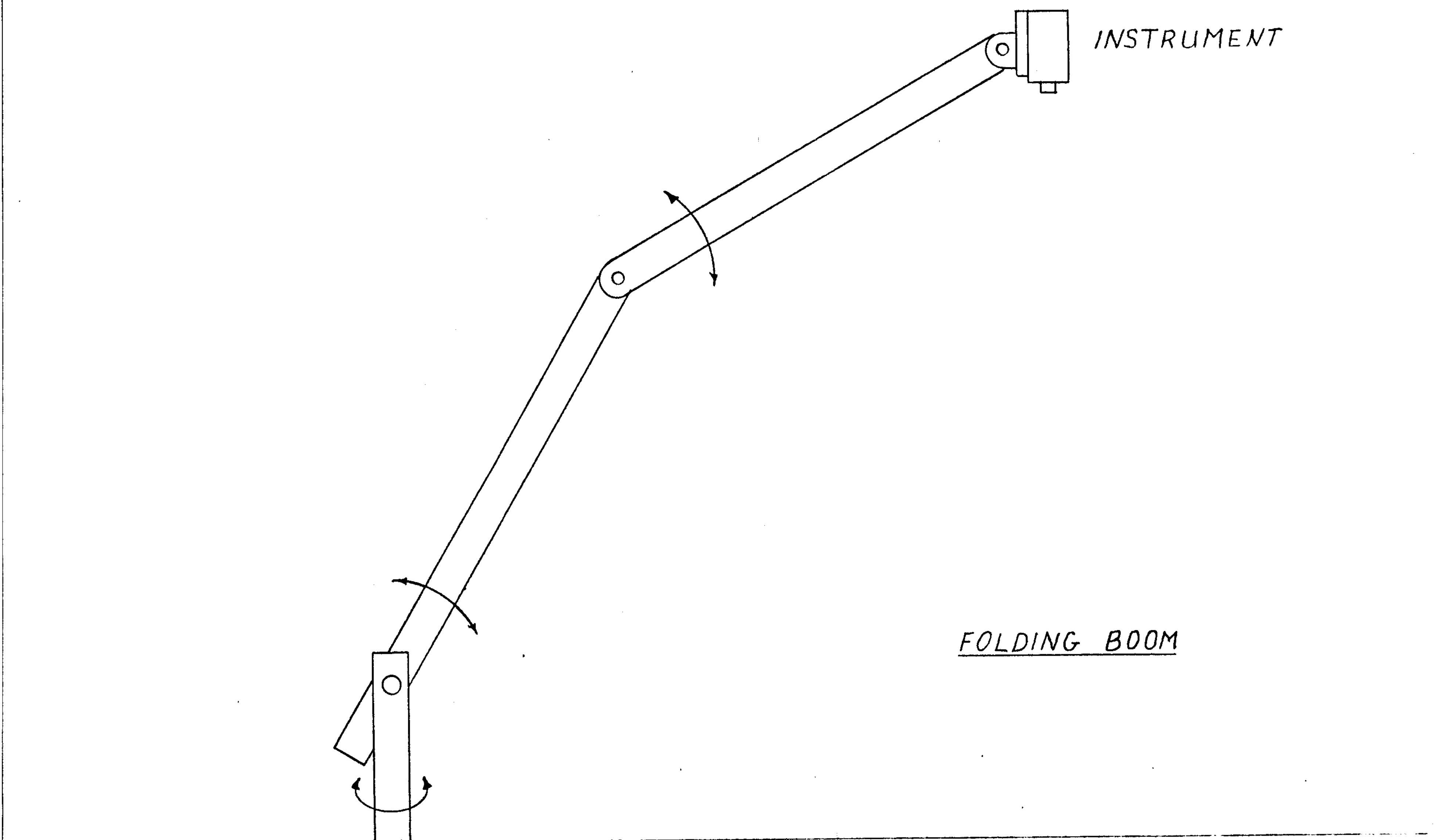


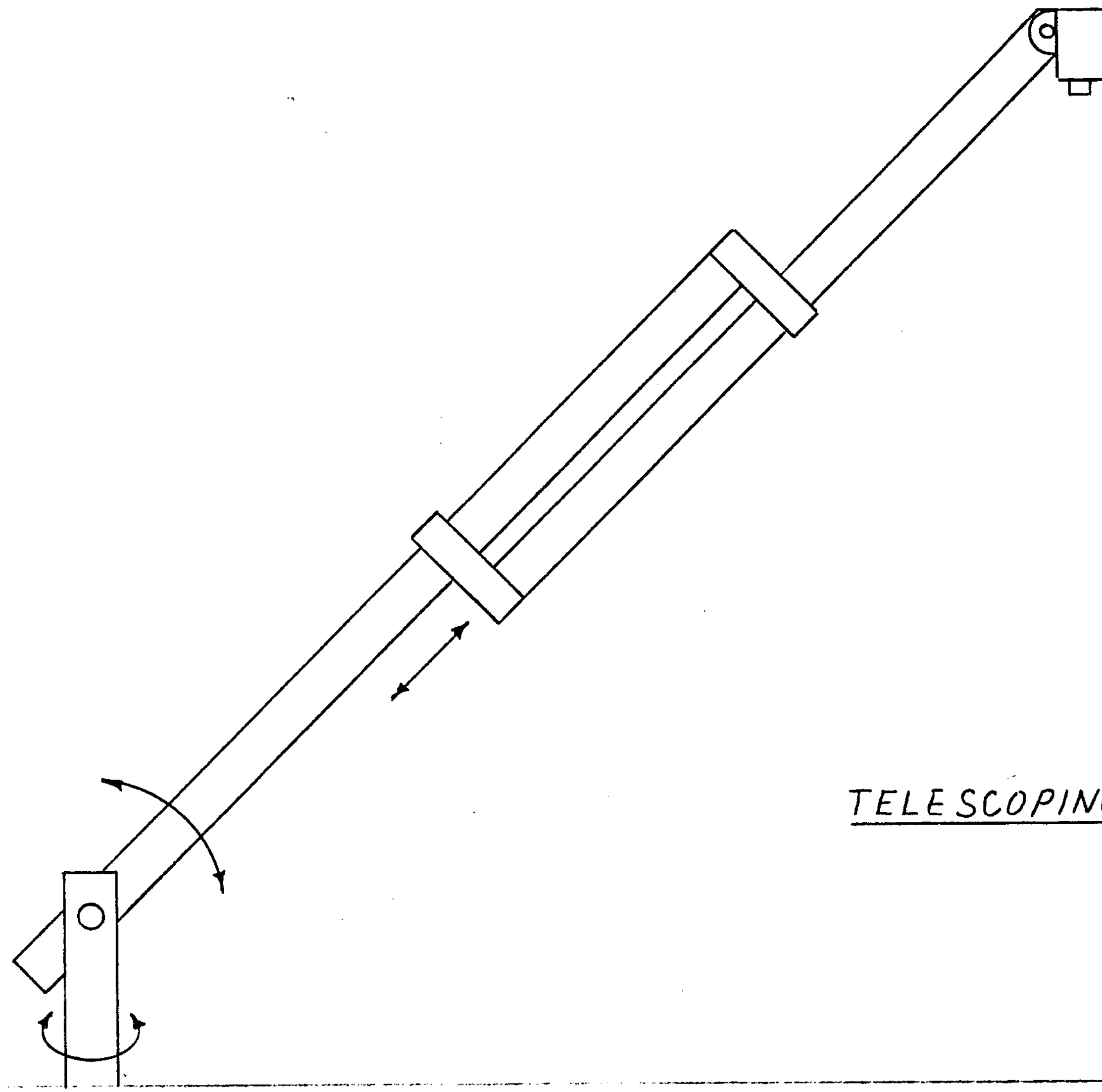
FIGURE 3

(3) Telescoping Boom:

The telescoping boom diagrammed in Figure 4 consists of two beams which slide along each other. The instrument is fixed to the end of the upper beam. The boom pivots about a horizontal axis to permit horizontal transport and an elevated field position. The boom extends to its maximum length to reach the specified height and distance for field measurements. It collapses and swings about a vertical axis to locate the instrument over the calibration panel.

4. CONCEPT EVALUATION

A comparative evaluation of the merits of each concept yields the telescoping boom as the best proposal. The basis for this conclusion is: (1) The trolley and instrument on the one piece boom rests midway on the boom during calibration. The extension of the boom beyond the trolley and instrument will cast a shadow on the calibration panel. This is an unacceptable condition due to potential shadowing of the calibration panel by the upper portion of the boom. Therefore, the one piece boom with a trolley is eliminated from consideration. (2) The folding boom requires repositioning of both arms for calibration, and calculations summarized in the appendix show that 2440 lb_f of cable tension are required to support the moment of the upper arm. (3) The telescoping boom, in contrast, requires only the extension and collapse of the upper beam to convert from the field position to calibration position. The cable tension required to support the upper beam is 76 lb_f. The simple conversion of the boom from field to calibration position and the lower cable tension required by the telescoping boom facilitate easier manual operation than the folding boom. Therefore, the telescoping boom is favored over the folding boom.



TELESCOPING BOOM

FIGURE 4

5. DESCRIPTION OF THE FINAL DESIGN

The final design of the boom is depicted in Figure 5. The boom consists of two beams. The upper beam is underslung from the lower beam. The upper beam is a rectangular aluminum tube and the lower beam is a round aluminum tube. The beams are hooked over each other by brackets attached to the ends of the beams. Polyurethane tread wheels are mounted to these brackets and slide the beams past each other. The upper beam is extended by a wire cable and winch drive and collapsed by gravity. The lower beam nests inside a mounting sleeve at the pivot. This allows the beam to rotate about its longitudinal axis and correct the yaw of the instrument. The pitch of the instrument is preset for a specified boom angle. The boom is elevated by a hydraulic cylinder and hand pump. It swings about a king post which has a pair of tapered roller bearings. The justification of the selection of these parts follows.

6. DISCUSSION OF PART SELECTION

(1) Telescoping Method:

Two telescoping configurations were considered for the boom, a nested configuration of one beam sliding inside of the other or an underslung configuration. The underslung configuration was selected over the nested configuration for two reasons.

First, nesting one beam inside of the other requires selecting beam sizes which allow the outside dimensions of one to fit the inside dimensions of the other. This requires either a close tolerance slip fit or sufficient clearance to insert bearings or rollers between the two beams. Matching sizes for a slip fit

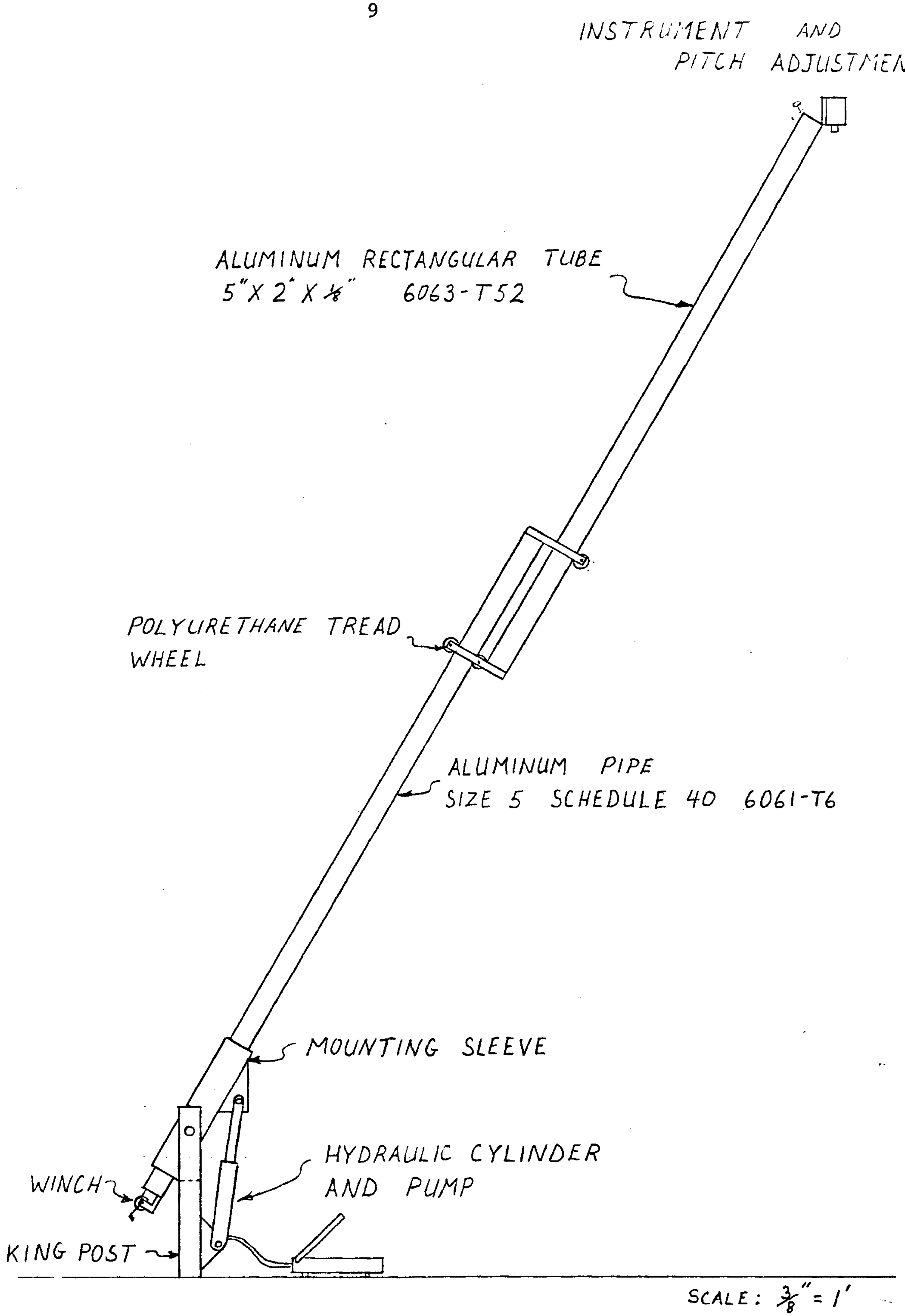

INSTRUMENT AND
PITCH ADJUSTMEN
ALUMINUM RECTANGULAR TUBE
5"X 2" X 1/8" 6063-T52
POLYURETHANE TREAD
WHEEL
ALUMINUM PIPE
SIZE 5 SCHEDULE 40 6061-T6
MOUNTING SLEEVE
HYDRAULIC CYLINDER
AND PUMP
WINCH
KING POST
SCALE: 3/8" = 1'

FIGURE 5

are not available from standard stocked material. A fit providing sufficient clearance for bearings or rollers will require one beam to be much larger than the other resulting in excess weight. An underslung configuration allows the selection of the lightest beams with sufficient strength regardless of their relative sizes to each other.

Secondly, an underslung configuration puts the sliding parts outside of the beams where they are easily accessible for maintenance and repair.

(2) Beam Selection:

There were two decisions in the beam selection - a decision between a truss type structure or a single extrusion and a decision to design the beams rigid enough to resist excessive deflection or providing external supports to prevent deflection.

The single extrusion was picked over the truss type structure because of its availability and strength. An extruded beam is available from suppliers in ready to use form. A truss on the other hand, must be constructed. The welded joints of the truss are only half as strong as the unwelded material. Thus a truss has weak spots which an extruded beam is free from. Finally, the truss does not save weight over a single extrusion.

The beams were designed with sufficient stiffness to resist excessive deflection. An external support such as a wire cable attached to the end of the beam and a two foot spreader bar at the base contributes little perpendicular force to the end of the beam compared to the axial force on the beam. The beam has a high slenderness ratio resulting in a tendency to buckle. The axial force generated by the wire cable support increases the tendency to buckle.

Therefore, the external support offers no net advantage.

(3) Telescoping Slides:

Three methods of sliding the beams along each other were considered, a sliding contact bracket, needle bearing cam followers or dolly wheels.

The aluminum beams do not provide a good bearing surface for sliding contact. Aluminum is a soft, sticky metal. An anodizing coat would improve the surface hardness. However, the sliding contact was eliminated from consideration because of the high friction and wear anticipated.

The cam followers eliminate the friction with a rolling contact. However, cam followers are made of hardened steel. The hardened steel cam follower running along the aluminum surface will chip and dent the aluminum. The metal to metal contact will also give noisy operation.

A polyurethane tread dolly wheel avoids the problems of the cam follower. The polyurethane prevents chipping and denting the aluminum beam and operates quietly. Polyurethane also resists permanent deformation, ultraviolet light and solvents. Therefore, the polyurethane tread dolly wheels were selected over the cam followers.

(4) Telescoping Drive:

A winch and cable were selected to drive the telescoping action of the boom because it is simple, readily available and easily converted to a motorized system.

(5) Elevation Drive:

Three alternatives were considered for the elevation drive, a hydraulic cylinder, worm gear or a scissors jack. The hydraulic cylinder was selected because of its reliability, tremendous force capability and wide distribution. A worm gear or scissors jack in the outdoor environment in which the boom is used will require frequent lubrication and will be prone to malfunction from rust and dirt

(6) Bearing Selection:

Three types of bearings were considered for the pivot bearing and king post bearing: bronze, ball and roller bearings. The manual operation requirement favored a rolling contact bearing over a sliding contact bearing. The bearings are also loaded statically with intermittent motion. The predominent static loading condition favors roller bearings over ball bearings because the line contact of the roller bearing produces lower contact stresses than the point contact of the ball bearings. Therefore, roller bearings were chosen for the pivot bearing and tapered roller bearings were chosen for the king post.

(7) Leveling System:

The leveling system for the probe consists of a pitch adjustment which is set for a particular boom angle and a yaw adjustment which is actuated by rotating the boom. The reference for the yaw may be located at the base of the boom. This leveling system affords simple, manual operation with accuracy within 1°. It is assumed that ultimately a servo system will be installed for a self-leveling or remote controlled leveling unit.

7. FUTURE ADDITIONS

The manual operation of the boom may be easily converted to a powered operation by replacing the hand winch with an electric winch and hand pump with a powered hydraulic pump. In addition to motorizing the boom operation, drawings are included in the blueprints for a brake for the king post rotation and the layout for a servo actuated leveling system for the instrument.

8. PERFORMANCE EVALUATION AND MODIFICATIONS

The boom was used routinely throughout the growing season at the Purdue Agronomy Farm to rapidly position the Exotech Model 100 Landsat-band radiometer over experimental plots. With this boom, the instrument was positioned 7.6 meters above the ground at a distance of 3.7 meters from the edge of the truck. Figures 6 and 7 show the boom in operation with the prototype multiband radiometers.

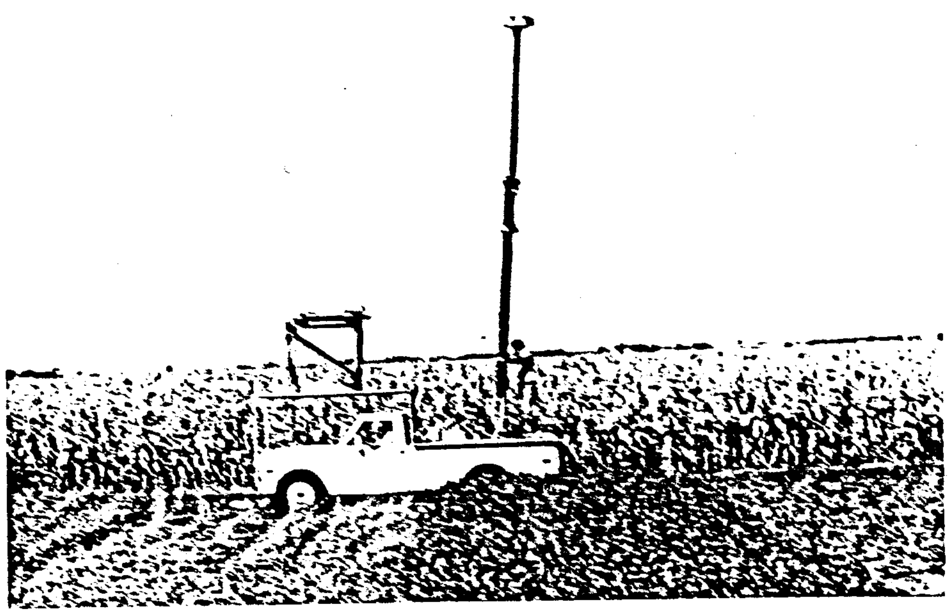


Figure 6. Truck-mounted boom positioning the multiband radiometer.

(1) Operating Characteristics

Pointing errors due to boom deflection were computed and measured to be less than 1^{o} for normal operation (lower boom at about 52^{o} elevation). The break-away torque required to rotate the boom from the calibration to the target position was determined to be about 90 pound-foot; this torque and the normal turning torque were found to be convenient for field operations with the normally used two foot lever. The upper boom required approximately 20 seconds for extension from and retraction to the calibration position and the ratchet operation was deemed to be safe. The lower boom required 60 seconds to raise to the operation position and 20 seconds to lower to the stowage position. Angular adjustment about the operation position was judged to be quite satisfactory and all operations were judged to be safe, provided operators and nearby personnel are alert and prudent. Stowage of the unit for daily transport of 10 miles on U.S. Highway 52 was easy, convenient, and safe.

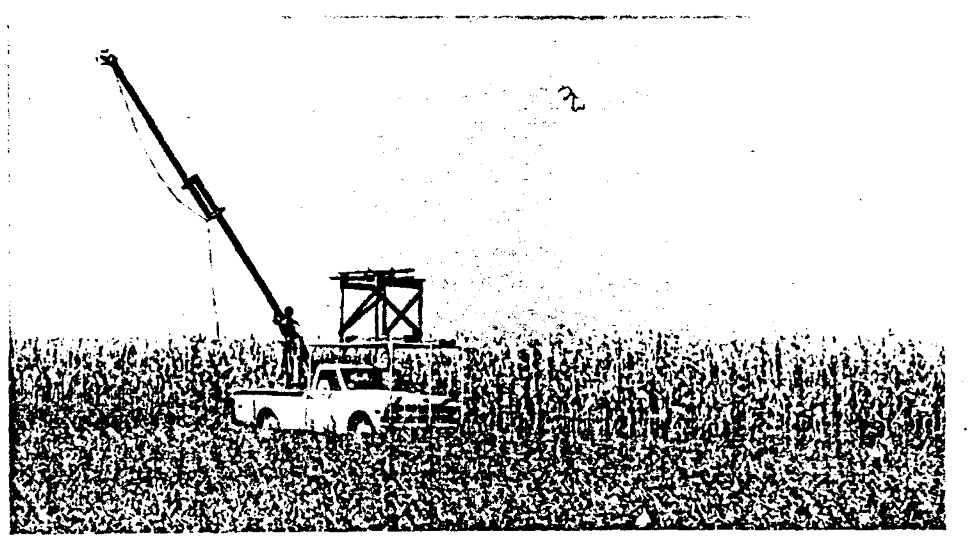


Figure 7. Photograph of truck-mounted boom with multiband radiometer viewing soybean plot.

(2) Modifications

The braking device used in the prototype design was replaced with a larger unit of the same type. The new brake will be adjusted to provide a bit more braking action to prevent boom rotation during strong wind gusts while protecting the mounting structures from severe rotational torques due to road bumps and quick stops. The guide roller bracket on the upper boom was redesigned to improve the accuracy of positioning of the upper boom.

(3) Fatigue Test

Following the growing season, the region where the mounting pin connects to the base plate was dye-penetrant tested for fatigue. No evidence of fatigue was found.

APPENDIX

A. PARTS LIST

Material	Qty.	Cost
Aluminum Rectangular Tube 5" x 2", .125" wall 6063-T52	13 ft.	$100.00
Aluminum Pipe Size 5 Schedule 40 6061-T6	18 ft.	210.00
Aluminum Pipe Size 6 Schedule 40 6061-T6	3 ft.	60.00
Aluminum Rectangle 1" x 6" 6061-T6511	6 ft.	231.00
Steel Pipe Cold Drawn 1018 Steel 3 1/8" x 9/16"	2 ft.	24.00
Enerpac RC-1014 Hydraulic Cylinder	1	138.00
Enerpac P-39 Hydraulic Pump	1	85.00
Enerpac PC-10 Pump Foot Adaptor	1	23.00
Enerpac HC-921 High Pressure Hose	1	35.00
Enerpac V-66 Safety Valve	1	80.00
Timken Type TS Tapered Roller Bearings Code 34301, Cup 34478	2	35.98
Tubular Bronze Bar Bunting BC-4452 5 1/2" x 6 1/2" x 13"	1	60.00
Torrington Heavy Duty Roller Bearing HJ-162412	2	8.82
Chicago Rawhide Seals Type HM1, No. 9859	2	2.26
Rapistan Adiprene-Tred Wheels Aluminum Core 4 x 2, Type ADARY, 5/8" axle w/bushing	6	70.00

Material costs based on 1979 prices.

A. PARTS LIST (cont.)

Material	Qty.	Cost
Aluminum Rectangle 1/2" x 2" 6061-T6	10 ft.	$ 60.00
Medium Duty Die Spring 5/8" dia. x 1 3/4" long Standard Die Supply Part No. 06M17	2	2.00
Extension Spring 5/8" dia. x 3" long x .063" Wire McMaster-Carr Supply Co. Part No. 9432K94	2	3.00
Pulley, Ball Bearings 1 1/4" x 9/32" x .163"	1	5.04
1/8" dia. Wire Rope	25 ft.	5.00
Winch	1	20.00

Material costs based on 1979 prices.

B. INDEX OF CALCULATIONS

1. LIST OF SYMBOLS

A - cross-sectional area of beam

E - modulus of elasticity

f_a - axial stress

f_b - bending stress in the extreme fibers

f_s - shear stress due to transverse load

F_a - allowable axial stress

F_b - allowable compressive bending stress in the extreme fibers

F_s - allowable shear stress

I - moment of inertia

M - moment

N - axial force

P - load force

R - radius of gyration

T - tension in cable to support upper beam

U - distance from neutral axis to extreme fiber

V - shear force

W - beam weight per length

2. BASIC EQUATIONS

Shear Stress due to transverse loading:

$$f_s = \frac{V}{A}$$

Bending Stress:

$$f_b = \frac{MU}{I}$$

Axial Stress:

$$f_a = \frac{N}{A}$$

Allowable Stress Limit for beam subjected to shear, moment and axial stresses simultaneously: (Stress Limit Factor)

$$\frac{f_a}{F_a} + \left(\frac{f_b}{F_b}\right)^2 + \left(\frac{f_s}{F_s}\right)^2 \leq 1.0$$

Moment Calculation:

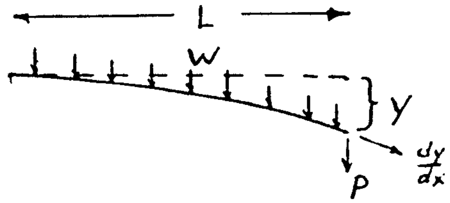
$$M = \int Vdx$$

Beam Deflection:

$$\frac{d^2y}{dx^2} = \frac{-M}{EI}$$

$$\frac{dy}{dx} = \int \frac{-M}{EI}\, dx$$

$$y = \iint \frac{-M}{EI}\, dx^2$$



$$\frac{dy}{dx} = \frac{L^2}{EI}\left[\frac{WL}{6} + \frac{P}{2}\right]$$

$$y = \frac{L^3}{EI}\left[\frac{WL}{8} + \frac{P}{3}\right]$$

$$y = \frac{PL^3}{3EI}$$

Slenderness Ratio:

$$\frac{2L}{R}$$

3. UPPER BEAM:

Aluminum Rectangular Tube
2" x 5" x .125"
6063-T52

$W = 2.00\ lb_m/ft.$

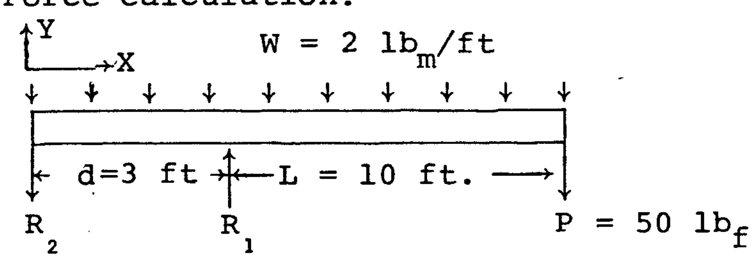
$A = 1.69\ in^2$

$I_{xx} = 5.20\ in^4$

$I_{yy} = 1.21\ in^4$

$R = 1.76\ in$

(1) Force Calculation:



$$\frac{WL^2}{2} + PL = \frac{Wd^2}{2} + R_2 d$$

$$R_2 = \frac{1}{d}\left[\frac{W}{2}(L^2 - d^2) + PL\right]$$

$R_2 = 197\ lb_f \approx 200\ lb_f$ maximum R_2

$$R_1 = WL + P + R_2$$

$$R_1 = 276\ lb_f \approx 280\ lb_f \quad \text{maximum } R_1$$

$$V_{max} = R_2 + Wd \quad \text{by inspection}$$

$$V_{max} = 206\ lb_f \approx 210\ lb_f$$

$$M_{max} = \frac{Wd^2}{2} + R_2 d$$

$$M_{max} = 609\ lb_f\text{-ft} \approx 610\ lb_f\text{-ft}$$

$$N_{max} = W(L+d) + P \quad \text{if the beam is vertical on end}$$

$$N_{max} = 76\ lb_f$$

(2) Deflection Calculation:

$$\frac{dy}{dx} = \frac{L^2}{EI}\left(\frac{WL}{6} + \frac{P}{2}\right)$$

$$\frac{dy}{dx} = .0078$$

$$y = \frac{L^3}{EI}\left(\frac{WL}{8} + \frac{P}{3}\right)$$

$$y = .637 \text{ inches}$$

Summary of Upper Beam Forces and Stresses

V_{max}	210 lb_f
M_{max}	610 lb_f-ft
N_{max}	76 lb_f
f_s	124 psi
F_s	$4.9 \cdot 10^3$ psi
f_b	3519 psi
F_b	$8.5 \cdot 10^3$ psi
f_a	45 psi
f_A	1432 psi
Stress Limit Factor	.203
Max $\frac{dy}{dx}$	.0078 (.450°)
Max Y	.637 inches

4. LOWER BEAM:

Aluminum Pipe
Size 5 Schedule 40
6061-T6

OD = 5.563 in.

ID = 5.047 in.

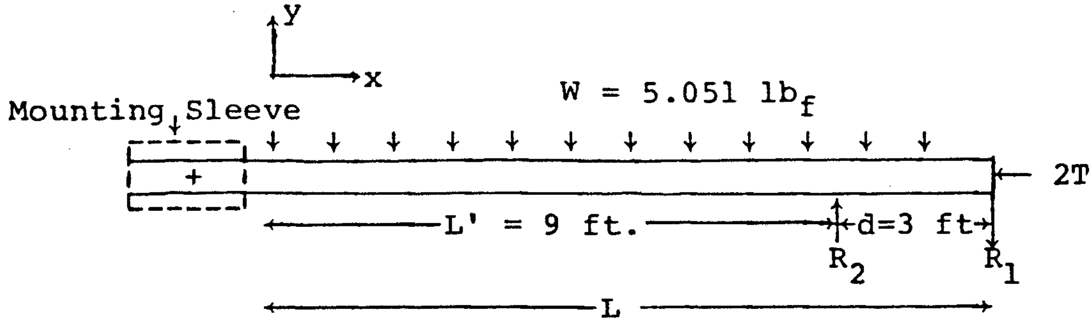
W = 5.051 lb_m/ft.

A = 4.30 in^2

I = 15.16 in^4

R = 1.88 in.

(1) Force Calculation:



$T_{max} = N_{max}$ of upper beam

$N_{max} = WL + 2T_{max}$

$N_{max} = 213\ lb_f$

$V_{max} = R_1 + Wd$ by inspection

$V_{max} = 295\ lb_f \approx 300\ lb_f$

$M_{max} = \frac{WL^2}{2} + R_1L - R_2L'$

$M_{max} = 1924\ lb_f\text{-}ft$

(2) Deflection Calculation:

Shear Forces:

$0 \leq x \leq L'$ $\quad V = W(L-X)\cos\theta + (R_1 - R_2)$

$L' \leq x \leq L$ $\quad V = W(L-X)\cos\theta + R_1$

where: θ = angle of inclination of boom.

Moment:

Boundary Conditions: $X = 0,\ M = \frac{-WL^2}{2} - R_1L + R_2L'$

$X = L,\ M = 0$

$0 \leq x \leq L'$ $\quad M = \frac{-W(L-X)^2}{2}\cos\theta + (R_1-R_2)\,x - R_1L + R_2L'$

$L' \leq x \leq L$ $\quad M = \frac{-W(L-X)^2}{2}\cos\theta + R_1\,x - R_1L$

Beam Slope and Deflection:

$0 \le x \le L'$:

Boundary Conditions: $x = 0, \quad y = 0$

$x = 0, \quad \frac{dy}{dx} = 0$

$$M = -EI\frac{d^2y}{dx^2} = \frac{-W(L-X)^2}{2}\cos + (R - R_2)\ x - R_1L + R_2L'$$

Integrate and apply boundary condition

$$-EI\frac{dy}{dx} = \frac{W(L-X)^3}{6}\cos + \frac{R_1-R_2}{2}X^2 + (R_2L' - R_1L)X + \frac{WL^3}{6}\cos\theta$$

Integrate again and apply boundary condition

$$-EIY = \frac{-W(L-X)^4}{24}\cos\theta + \frac{R_1-R_2}{6}X^3 + \frac{R_2L'-R_1L}{2}X^2 - \frac{WL^3}{6}\cos\theta X + \frac{WL^4}{24}\cos\theta$$

$L' \le X \le L$:

Boundary Conditions: $X = L'$ $\quad \frac{dy}{dx}_{0\le X\le L'} = \frac{dy}{dx}_{L'\le X\le L}$

$y_{0\le X\le L'} = y_{L'\le X\le L}$

$$M = -EI\frac{d^2y}{dx^2} = \frac{-W(L-X)^2}{2}\cos\theta + R_1X - R_1L$$

Integrate and apply boundary condition

$$-EI\frac{dy}{dx} = \frac{W(L-X)^3}{6}\cos\theta + \frac{R_1}{2}X^2 - R_1LX + \frac{R_2L}{2} - \frac{WL^3}{6}\cos\theta$$

Integrate again and apply boundary condition

$$-EIY = \frac{-W(L-X)^4}{24}\cos\theta - \frac{R_1}{6}X^3 - \frac{R_1LX^2}{2} + \left[\frac{R_2L'^2}{2} - \frac{WL^3}{6}\cos\theta\right]X + \frac{WL^4}{24}\cos\theta - \frac{R_2L'^3}{6}$$

At $X = L, \quad \theta = 0°$

$$\frac{dy}{dx} = \frac{-1}{EI}\left[\frac{-R_1 L^2}{2} + \frac{R_2 L'^2}{2} - \frac{WL^3}{6}\right]$$

$$y = \frac{-1}{EI}\left[\frac{-R_1 L^3}{3} + \frac{R_2 L'^2 L}{2} - \frac{R_2 L'^3}{6} + \frac{WL^4}{8}\right]$$

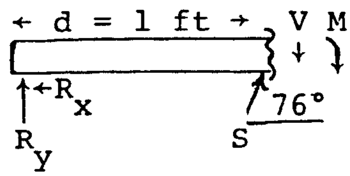
Summary of Lower Beam Forces and Stresses

V_{max}	300 lb_f
M_{max}	1924 lb_f-ft
N_{max}	213 lb_f
f_s	70 psi
F_s	$10.84 \cdot 10^3$ psi
f_b	4234 psi
F_b	$22 \cdot 10^3$ psi
f_a	50 psi
F_a	1918 psi
Stress Limit Factor	.0631
Max $\frac{dy}{dx}$	.013 (.735°)
Max Y	1.157 in.

5. MOUNTING SPINDLE

(1) Force Calculation:

Mounting Sleeve



$V = WL + R_1 - R_2$ lower beam sheer force equation at X=0

$V = 141\ lb_f$

$M \approx 2000\ lb_f\text{-}ft$ lower beam M_{max}

$\sum F_x : S \cos 76° - R_x = 0$

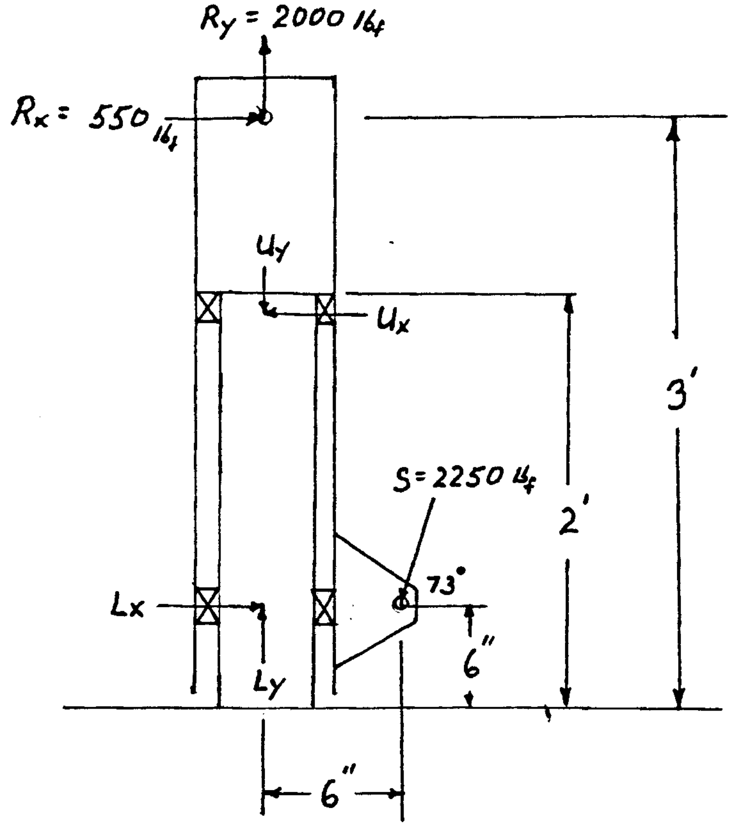
$\sum F_y : S \sin 76° + R_y - V = 0$

$\sum M : R_y d + M = 0$

$$R_y = \frac{-M}{d} = -2000\ lb_f$$

$$S = \frac{V - R_y}{\sin 76°} = 2207\ lb_f$$

$$R_x = S \cos 76^{\circ} = 534\ lb_f$$



$$\sum M_{\text{about } L} : -2.5\ R_x - 1/2\ S \sin 73° + 1.5\ U_x = 0$$

$$U_x = \frac{5}{3} R_x + \frac{1}{3} S \sin 73°$$

$$U_x = 1634\ lb_f$$

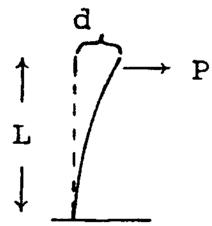
$$\sum M_{\text{about } U} : -R_x + 1.5 L_x - 1/2\ S \sin 73° - 1.5\ S \cos 73° = 0$$

$$L_x = \frac{2}{3}\left(R_x + \frac{1}{2} S \sin 73° + 1.5\ S \cos 73°\right)$$

$$L_x = 1742\ lb_f$$

$$\sum F_y : L_y - U_y = 2000 - 2250 \sin 73° = 152\ lb_f$$

(2) Spindle Sizing:



$$d = \frac{PL^3}{3EI}$$

$$I = \frac{PL^3}{3Ed}$$

Assume $P = 2000\ lb_f$

$L = 24$ inches

$d \leq .10$ inch

$E = 30 \cdot 10^6$ psi (steel)

$I = 3.07\ in^4$

King Post 3" x 1/2" cold drawn steel pipe $I = 3.19\ in^4$

Assume $P = 2000\ lb_f$

$L = 36$ inches

$d \leq .20$ inch

$E = 10 \cdot 10^6$ psi (aluminum)

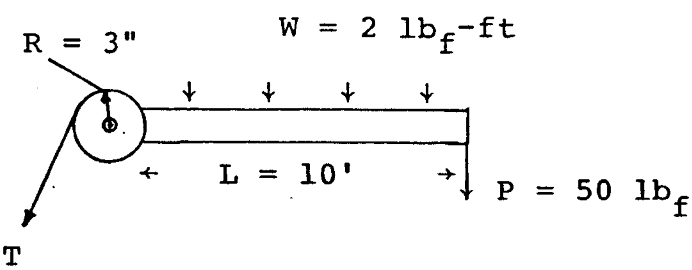
$I = 15.55\ in^4$

Yoke Aluminum Plate, 1" x 5" $I = 20.83\ in^4$

(6) FOLDING BOOM CABLE TENSION TO SUPPORT UPPER ARM

Assume: (1) The upper arm of the folding boom has the same dimensions of the telescoping boom upper arm.

(2) The moment of the upper arm is countered by a wire cable wrapped around a 6 inch diameter pulley.



$M_{max} = \frac{WL^2}{2} + PL$

$M_{max} = 609\ lb_f\text{-}ft \approx 610\ lb_f\text{-}ft$

$RT_{max} = M_{max}$

$T_{max} = M_{max}/R$

$T_{max} = 2440\ lb_f$

C. REFERENCES

Aluminum Construction Manual, Section 1, Specifications for Aluminum Structures; Second Edition, November, 1971; The Aluminum Association, New York.