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VIDEO MODEL DEFORMATION SYSTEM FOR THE NATIONAL TRANSONIC FACILITY

A. W. Burner, W. L. Snow, and W. K. Goad

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National Aeronautics and
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Langley Research Center
Hampton, Virginia 23665

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ABS: A photogrammetric closed circuit television system to measure model deformation at the National Transonic Faci

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A photogrammetric closed circuit television system to measure model deformation at the National Transonic Facility is described. The photogrammetric approach was chosen because of its inherent rapid data recording of the entire object field. Video cameras are used to acquire data instead of film cameras due to the inaccessibility of cameras which must be housed within the cryogenic, high pressure plenum of this facility. A rudimentary theory section is followed by a description of the video-based system and control measures required to protect cameras from the hostile environment. Preliminary results obtained with the same camera placement as planned for NTF are presented and plans for facility testing with a specially designed test wing are discussed.

INTRODUCTION

Experimental testing of cryogenic wind tunnels at the Langley Research Center began in the 1970's using a pilot facility (ref. 1) and will come to full fruition with the operational start up of the National Transonic Facility (NTF) in the fall of 1983 (ref. 2). The combination of high pressure and low temperature will greatly expand existing wind tunnel testing capabilities as shown in figure 1. Judicious use of both temperature and pressure allows two of the aerodynamic parameters such as Reynolds number, Mach number, or dynamic pressure to be held constant, while one of the other parameters can be varied to truly separate Reynolds number, Mach number and dynamic pressure effects. Due to the increased dynamic pressure capability of this facility, some of the higher aspect ratio models may experience wing tip deflections of several inches. A method is thus required to measure static model deformation (wing deflections) to an accuracy of between 4 and 40 mils.

Nonintrusive schemes to ascertain model deformation are complicated by the lack of optical penetrations in the outer pressure shell of the NTF which has a thermos bottle configuration as suggested in figure 2. The test section has a limited number of usable 6-inch-diameter access ports, but equipment placed inside the outer pressure shell (plenum) must be protected from the high-pressure cryogenic environment and may be inaccessible for long periods of time.

A number of techniques have been considered for measuring model deformation including moiré contouring, scanning heterodyne interferometry, holographic contouring, and stereo-electro-optical tracking using image dissector cameras (refs. 3, 4, 5). This report describes a stereo photogrammetric approach which was chosen because of its inherent rapid data recording of the entire object field (i.e., scanning is not required as for single point techniques) and is based on earlier wind tunnel work at Langley Research Center with film cameras (ref. 6). The inaccessibility for long periods of time of cameras which must be housed within the facility prompted the selection of video instead of film cameras (with an attendant loss of resolution) to acquire data.

MEASUREMENT CONCEPT

The basic measurement concept can be described with plane geometry. Up to the resolution limit of the system the potential accuracy is usually compromised only by the inability to provide distortion free imagery. If a point in space (X, Y, Z) is imaged to (x', y') on the film plane by projection through the camera perspective center, the mapping is not unique since any point along the line would project to the same image coordinates as (X, Y, Z). If the distance from the perspective center to the image plane and the orientation of the cameras are known, then the measured image coordinates of the point are functions of X, Y, Z only

$$
\begin{aligned}
x' &= x'(X, Y, Z) \\
y' &= y'(X, Y, Z)
\end{aligned}
\tag{1}
$$

providing only two equations in three unknowns. The ambiguity is removed by adding another view and, therefore, two more equations. These four equations in three unknowns admit a solution with one degree of freedom. The two-camera solution is portrayed in figure 3 where for ease in interpretation the unknown object point is placed in the XZ plane. The cameras are forward looking, identical, and parallel, with image plane to perspective center length c (so-called camera constant), and are displaced from one another by base separation B. By similar triangles

$$Z = cB/p \tag{2}$$

p is the parallax of the imaged point defined as $p \equiv x' - x''$ where x' and x'' are the x image coordinates of the point for the two cameras. The equally simple relations which apply for X and Y are included in figure 3.

Equation (2) captures the essence and simplicity of the approach. The recovery of spatial information Z depends on elements of interior orientation c, exterior orientation B, and measurements p taken on the recording plane. Since these variables are independent and linear the relative errors add so that

$$\left|\frac{dZ}{Z}\right| = \left|\frac{dc}{c}\right| + \left|\frac{dB}{B}\right| + \left|\frac{dp}{p}\right| \tag{3}$$

Equation (3) can be used to estimate the limiting accuracy of the technique in the absence of orientation uncertainty (i.e., when dc and dB = 0), giving $|dZ| = Z|dp|/p$. Note from figure 3 that $x' = |m|X$ and that $x'' = |m|(X-B)$ where $|m|$ is the lateral magnification (or scale) equal to the image-to-object ratio, c/Z, thus $p = |m|B$. The above expression for $|dZ|$ then becomes

$$|dZ| = \frac{Z}{B} \left|\frac{dp}{m}\right| \tag{4}$$

Equation (4) shows that under ideal conditions (i.e., exactly placed, distortion free cameras) the accuracy is bounded by the product of range-to-base ratio and readup error divided by the magnification. For close range applications Z/B is on the order of 1. Using expensive, large format, highly corrected metric cameras it is possible to determine Z to better than one part in 50,000. In practice the cameras are converged to improve coverage with usually (ref. 7) some increase in accuracy and the data are reduced using least squares techniques.

VMD System

The configuration of the NTF essentially precludes the use of film recording due to equipment inaccessibility. Among the measurement options considered, closed circuit television (CCTV) was chosen as a suitable approach for acquiring baseline experience with model deformation in the new environment. A considerable penalty in attainable resolution over film cameras was accepted in exchange for ease in transferring data from the test section to the control room. Photogrammetric data have been acquired using TV imagery from satellites (ref. 8) for many years, but close range applications seemingly have not been exploited despite the excellent theoretical study by Wong (ref. 9) in the late 1960's. The VMD system for the NTF will use high resolution (~ 1000 TV lines horizontal) 875 scan rate cameras which incorporate reseau marks on the image tube faceplate to assess distortion. By comparing the positions of the reseau marks on the hard copy with their known placement on the vidicon faceplate the electronic distortion of the TV system can be determined (ref. 10). Scene to faceplate distortion due to the lens aberrations can similarly be determined by using scene grids.

The test section walls have a limited number of 6-inch-diameter penetrations which are acceptable for lighting or viewports as shown in the exploded view of figure 4. Windows 17 and 18 on the far side wall were chosen for the current system. (The near sidewall is shown in the down configuration on figure 2.) The ports are not clearly accessible as might be suggested by the schematic but are recessed. Figure 5 shows some of the reinforcement surrounding the sidewall ports. Floor and ceiling stations, which are even more limited in space, were too small to accommodate existing cameras in their protective enclosures. The cameras slide into protective housings as shown in figure 6 where the end cap has been removed and the camera partially retracted. Figure 7 shows an exploded view of the enclosure to emphasize its complexity. The compound angle on the front end is necessary to provide oblique viewing through the sidewall porthole. Insulation blankets the interior upon which are laminated surface heaters to counteract the cryogenic temperatures. Temperature, pressure, and vibrations can be monitored during a tunnel run. A purge line of dry N_2 is used to maintain the camera at ambient pressure and provide some circulation for temperature distribution as well as to prevent frost formation on the glass windows of the enclosures.

An assembled housing is shown connected to the control racks by its umbilical cord in figure 8. The left rack contains pressure, temperature, and accelerometer readouts, a spare TV monitor, signal monitoring equipment, and the power supplies for the enclosure heaters. The two monitors in the middle of the central rack provide live views from the data cameras with provision for a third station for future expansion. The right-hand rack contains switching patch-panels, signal generators, two monitors for viewing facility operations, and a video disc recorder which will allow storing up to 150 image pairs for later readup. The right-hand rack also contains a video graphics recorder (hardcopy unit) which can output video images on page size dry-silver paper with a resolution of 150 lines/mm.

Figure 9 shows the control racks next to a full-scale wooden mock-up of the top half of the NTF test section which contains a wooden facimile of the Pathfinder model used for initial tests. The 6-inch-diameter viewports can be seen on the far wall. The VMD cameras which face slightly upstream and look over the fuselage at the far wing are in the ports directly across from the two upper left viewports. In the left and right views, shown respectively in figures 10a and 10b, the vidicon reseau marks are clearly visible on each of the frames. The targets in this case are provided by fluorescent paint. Note that the fuselage blocks from view the root of the wing and that it may be necessary to run some models upside down to prevent the fuselage or tail fin from blocking the view of the far wing. Several targets will be placed on the fuselage to provide points whose relative positions are invariant under load. Control targets will be placed on the far wall to monitor the exterior orientation of the cameras.

The target images are measured using the mono-comparator in figure 11 and the xy coordinates logged into the adjacent desktop computer. Acquired xy coordinate data files can be reduced on-line using the desktop computer or transferred to the Langley central computer if necessary. The Direct Linear Transformation (DLT) program described and listed in reference 11 will be used to reduce data.

Results and Current Status

In practice the camera orientations are determined by solving the collinearity equations (ref. 11) with known targets. The so determined constants can then be used in the same equations to locate unknown points in the field. A calibration jig (fig. 12) was constructed of parallel rods upon which were inscribed 40 targets whose positions were measured to several mil using a stylus machine. The calibration jig was placed in the scene and used to determine unknown constants. The locations of the points were predicted and compared with the known data. A 70-mm reflex nonmetric camera was used to establish a reference against which to judge the CCTV results. Negatives from film cameras placed in the approximate positions of the television counterparts were read with the mono-comparator. Two methods were used to acquire video data. In one case a camera was used to photograph the video monitor screen and the negative used for data (which were obviously distorted by the curved CRT screen). In another test the hardcopy unit was used to output the pertinent frames in a 7 in. by 9 in. format from which measurements were made. The results comparing the three techniques are shown in table I.

TABLE I.- OBJECT SPACE COMPARISON TO KNOWN LOCATIONS (MILS)

	X	Y	Z
70 mm Reflex	7	18	8
875 Scanline CCTV-photograph CRT	41	79	68
875 Scanline CCTV-hardcopy	17	29	25

In conventional wind tunnel work the X axis is alined with the flow with Z up, therefore the camera axis is roughly along the span direction (Y), making Y the least accurate coordinate. None of these data have been corrected for distortion which was manifest in the photographed CRT and is reflected in the degraded accuracy. Note that the hardcopy results are surprisingly close to the film camera results. A cursory analysis suggests that the hardcopy process essentially introduces an independent scale change in x and y which is accommodated by the DLT program. Z/B is on the order of 80"/24" and the scale is approximately one-third for the hardcopy. The targets can only be located repeatedly to about 0.001" on the hardcopy due in part to image breakup from raster scanning. Equation (4) would suggest a lower error bound of $|dZ| \sim (80/24)\ (3)\ (0.001)$ or ~ 10 mils which is within a factor of 2 to 3 of the observations for the CCTV/hardcopy combination. It is unlikely that the accuracy of this system will exceed 10 mils over the 2-3-foot wing span even under best viewing conditions. Furthermore, aerodynamic and flow field effects which may have adverse effects on seeing as described in reference 12 could undermine potential accuracy considerably.

Proposed Facility Testing

The need for crisp identifiable targets for the photogrammetric approaches poses a non-trivial problem for cryogenic wind tunnel models. Boundary layer thicknesses are diminished at high Reynolds numbers and effects of roughness on skin friction, transition, boundary layer separation, etc., must be guarded against. Since more information exists on skin friction than in other areas, figure 13 has become the current criterion for admissible roughness. As noted in reference 13 this data applies to zero-pressure-gradient turbulent boundary layers and is interpreted such that any roughness height falling below the admissible roughness curve will incur no skin friction penalty. Future testing may relax this standard but at present models are expensive to prepare and preclude the use of targets which alter the surface finish.

Part of the benchmark testing for the VMD will include different targetting schemes. For this purpose a special "target wing" has been constructed (fig. 14) which has the planform of the conventional Pathfinder wing (Pathfinder is the designation of the model series which will be used for initial shakedown testing at NTF) and will mate to the existing fuselage. The wing is a 1" thick slab with rounded leading edge and is purposely made to be rigid. The rationale is to provide a set of targets relatively unaffected by flow conditions to uncover artifacts in the VMD measurement system wrought by poor visibility, temperature induced orientation changes, vibration, etc. This wing will include some drill and fill targets using suitable fillers (perhaps impregnated with fluorescent materials). Conventional machinist dyes will provide other less contrasty targets since such methods, if acceptable optically, may be acceptable from an aerodynamic standpoint. The wing has been machined with a number of 20 mil i.d. pressure tubes which will be used as conduits for optical fibers. Since many wings are already configured with pressure ports, the fibers could be snaked through for later deformation tests without further impacting the model design. The fibers would be coupled to conventional or laser light sources which would allow "freezing" vibratory motion faster than the 60 Hz field rate of the video cameras if the fiber bundles were illuminated with short duration flash. Also included in the target options will be a number of light emitting diodes which are being considered for the model deformation system described in reference 5. The wing will be liberally arrayed with various optical targets such as grids and resolution charts to investigate flow and gas inhomogeneity induced visibility problems. The VMD system will be installed and tested within 6 months of the operational startup of the NTF currently scheduled for fall 1983.

CONCLUDING REMARKS

Large loads on the model within the testing capabilities of the National Transonic Facility have prompted the need for a nonintrusive model deformation system. One approach based on standard photogrammetric principles has been described in this report. The video model deformation system substitutes video for photographic cameras with attendant loss in resolution to facilitate data acquisition from the harsh (cryogenic, $\leq$ 9 atm) plenum environment. The system hardware has been described which insures the integrity of the cameras. The current system will view one wing with a demonstrated accuracy (using a full scale lab mockup) across the field of view of about 1 part in 1000 (24 mils in 24"). Distortion corrections could conceivably increase the accuracy by a factor or 2 or 3 while anticipated operational problems associated with flow field effects, thermal induced shifting of camera stations, vibration, etc., would work to degrade the accuracy. The proposed facility tests will include a target wing to accommodate targetting options such as drill and (fluorescent) fill, laser illuminated fibers, machinist dyes, and light emitting diodes.

REFERENCES

1. Kilgore, Robert A.; Adcock, Jerry B.; and Ray, Edward J.: Simulation of Flight Test Conditions in the Langley Transonic Cryogenic Tunnel. NASA TN D-7811, 1974.

2. Howell, Robert R.: The National Transonic Facility: Status and Operational Planning. A Collection of Technical Papers--AIAA 11th Aerodynamic Testing Conference, Mar. 1980, pp. 1-9. (Available as AIAA-80-0415.)

3. Hildebrand, B. P.; and Doty, J. L.: A Study of Model Deformation Measurement Techniques Applicable Within the National Transonic Facility. Spectron Development Laboratories, Inc., Costa Mesa, CA. Available as NASA CR 165853, Feb. 1982.

4. Harding, K.; and Harris, J.: Evaluation of Moiré Technique for Wind Tunnel Metrology. University of Dayton Research Institute, Dayton, OH. Available as UDR-TR-81-111.

5. Hertel, Richard J.: Stereo-Electro-Optical Tracker System for the Measurement of Model Deformations at the National Transonic Facility. Oct. 1979. Available as NASA CR 159146.

6. Brooks, Joseph D.; and Beamish, Jerry K.: Measurement of Model Aeroelastic Deformations in the Wind Tunnel at Transonic Speeds Using Stereophotogrammetry. NASA TP 1010, Oct. 1977.

7. Abdel-Aziz, Youssef, I.: Expected Accuracy of Convergent Photos, Photogrammetric Engineering, pp. 1341-1346, 1974.

8. Slama, Chester C., editor: Manual of Photogrammetry, Fourth ed. Chapter XVII entitled Satellite Photogrammetry. Published by the American Society of Photogrammetry, Falls Church, VA.

9. Wong, K. W.: Photogrammetric Quality of Television Pictures, Civil Engineering Studies Photogrammetry Series No. 17. University of Illinois, Urbana, IL, Feb. 1968.

10. Sieffert, James A.: CRT Image Distortion Determination Experiment. Rome Air Development Center Air Force Systems Command RADC-TR-82-239 In-House Report, Sept. 1982.

11. Marzan, G. T.; and Karara, H. M.: A Computer Program for Direct Linear Transformation Solution of the Collinearity Condition, and Some Applications of It. Proceedings of the Symposium on Close-Range Photogrammetric Systems, July 28-Aug. 1, 1975, Champaign, IL, pp. 420-476.

12. Snow, W. L.; Burner, A. W.; and Goad, W. K.: Image Degradation in Langley 0.3-Meter Transonic Cryogenic Tunnel. NASA TM 84550, Nov. 1982

13. McKinney, L. W.: Overview of National Transonic Facility Model Technology Program. NASA CP 2262, pp. 1-9, Proceedings of Workshop on Cryogenic Wind Tunnel Model held at LaRC, Hampton, VA, May 5-9, 1982.

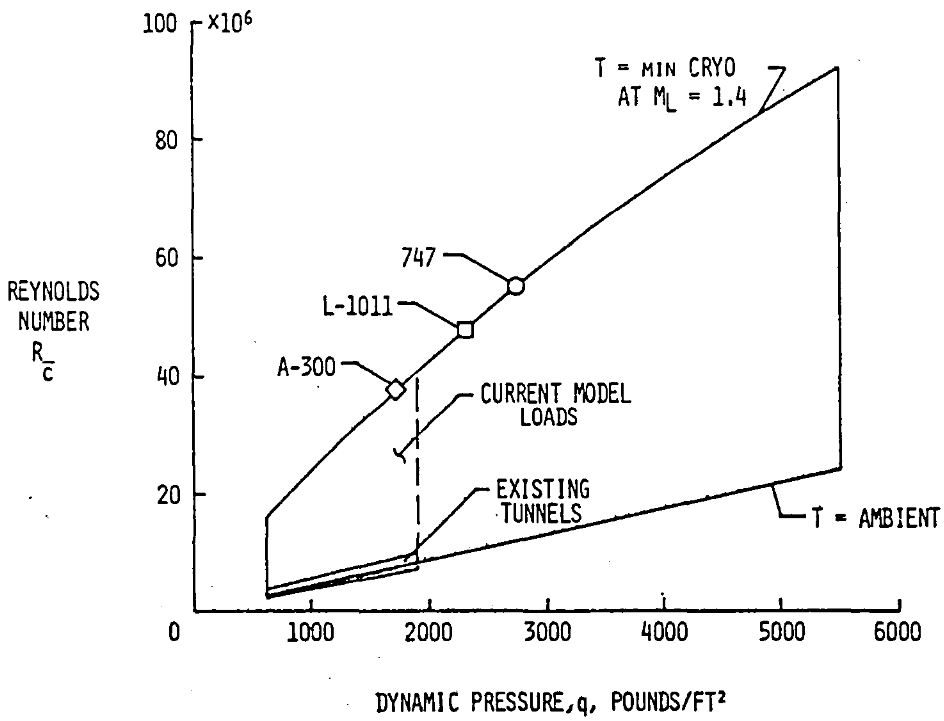


Figure 1. NTF operating envelope at M - 0.8. Model span = 1.50 m.

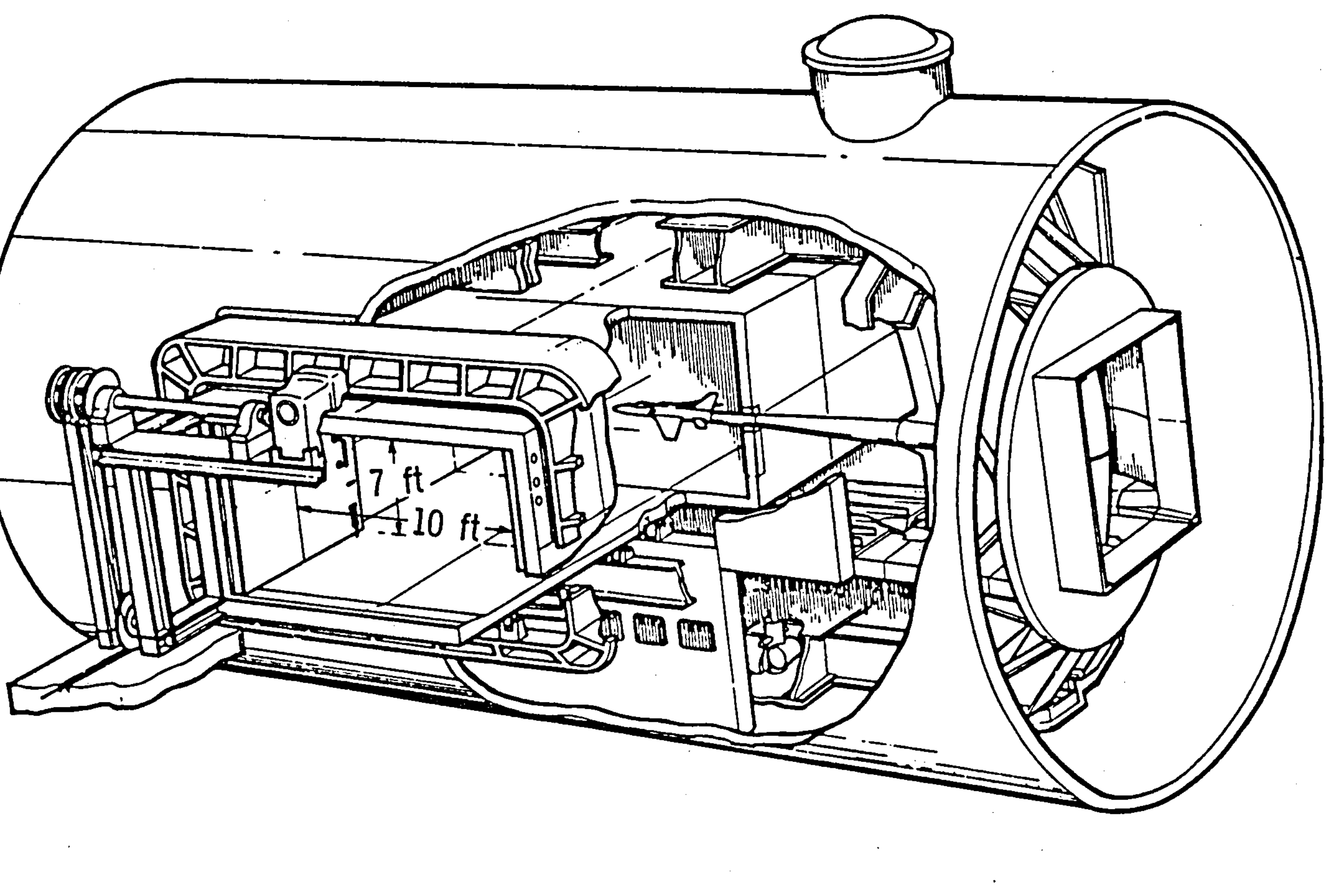
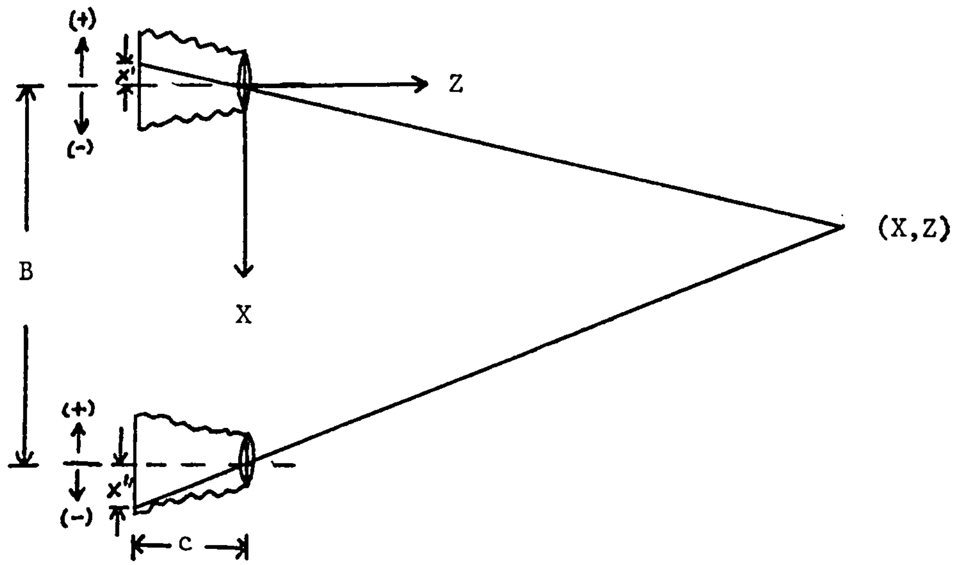


Figure 2. Sketch of test section and plenum showing the side door in the lowered position. VMD cameras will be mounted in the sidewall.



$$p = \text{parallax} = x' - x''$$

$$X = x'B/p \qquad Y = y'B/p \qquad Z = cB/p$$

Figure 3. Sketch to indicate photogrammetric principles.

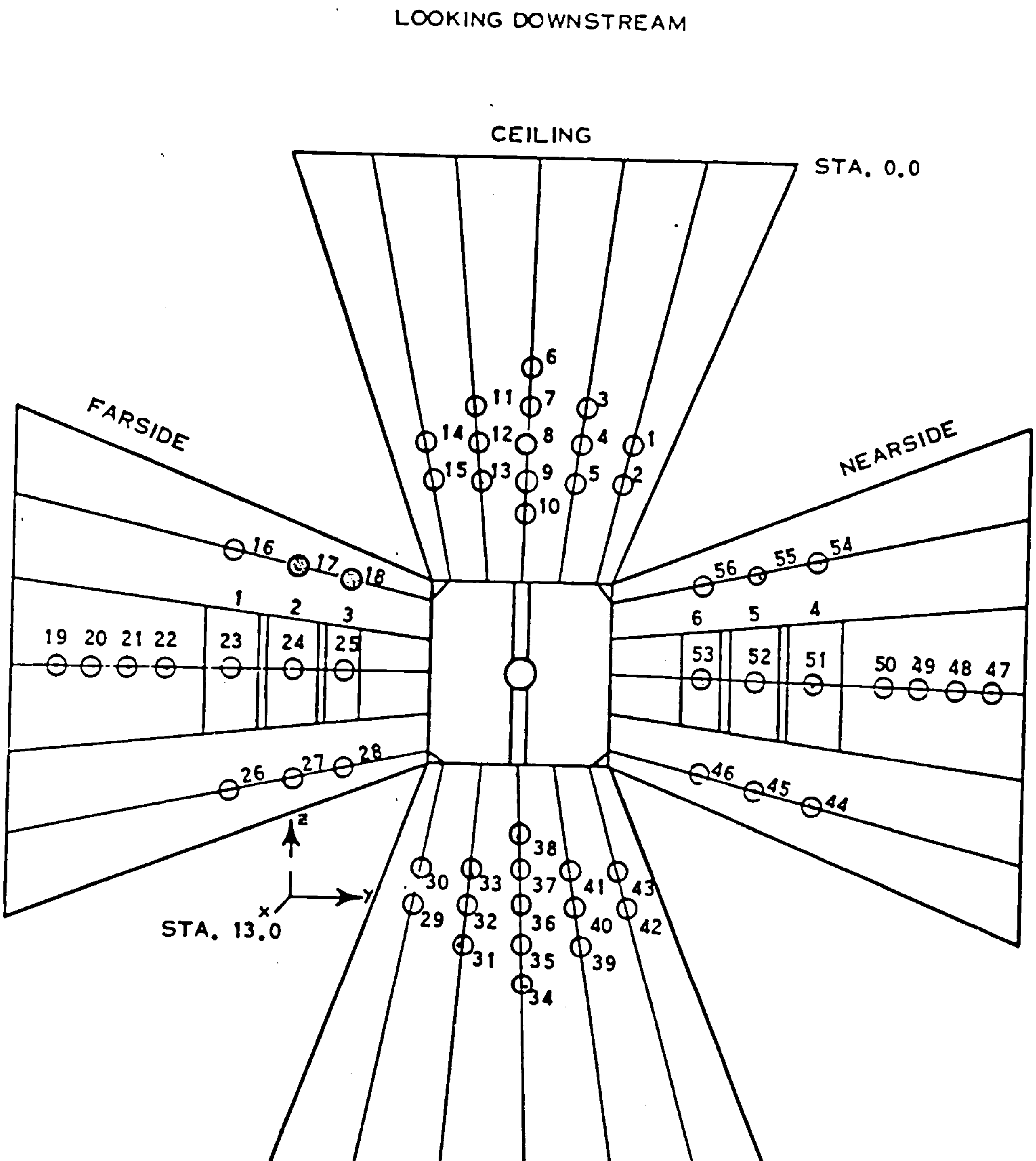


Figure 4. Exploded view of test section to indicate potential lighting and/or viewing ports. VMD cameras will be installed in ports 17 and 18.

NTF SIDEWALL

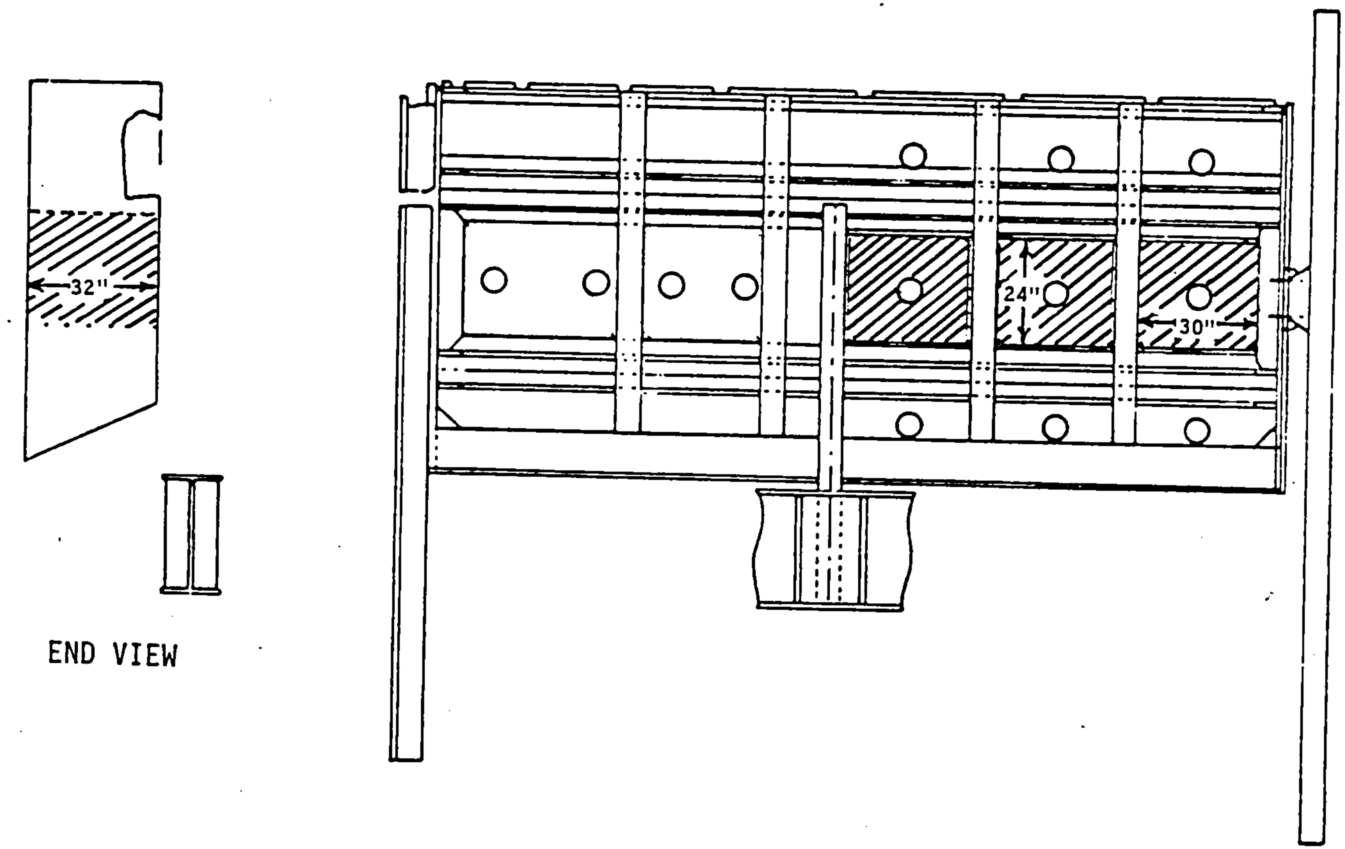


Figure 5. Typical sidewall construction within which are housed video equipment. VMD equipment will be in enclosures above those shown shaded.

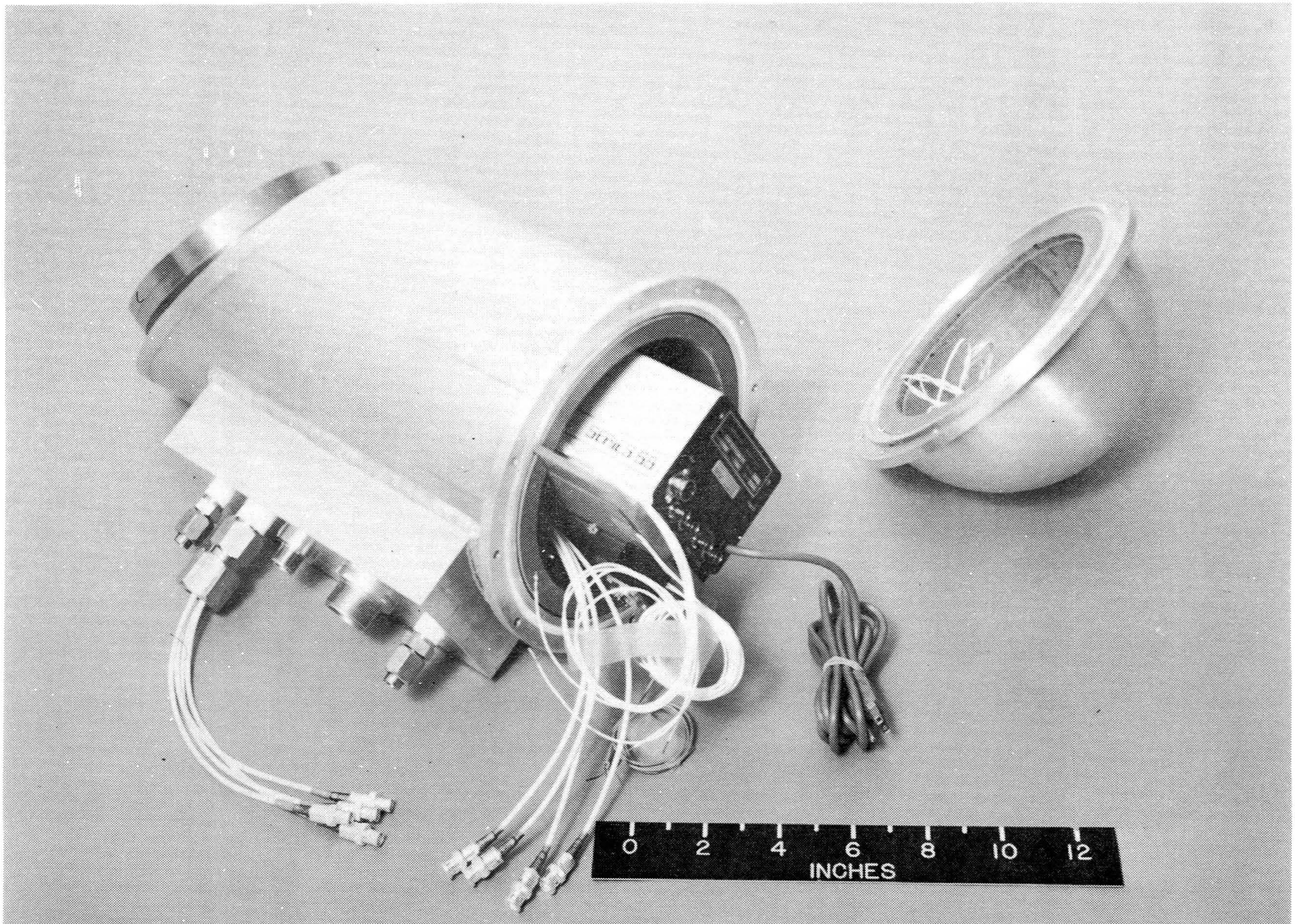


Figure 6. Video camera shown partially inserted in protective housing.

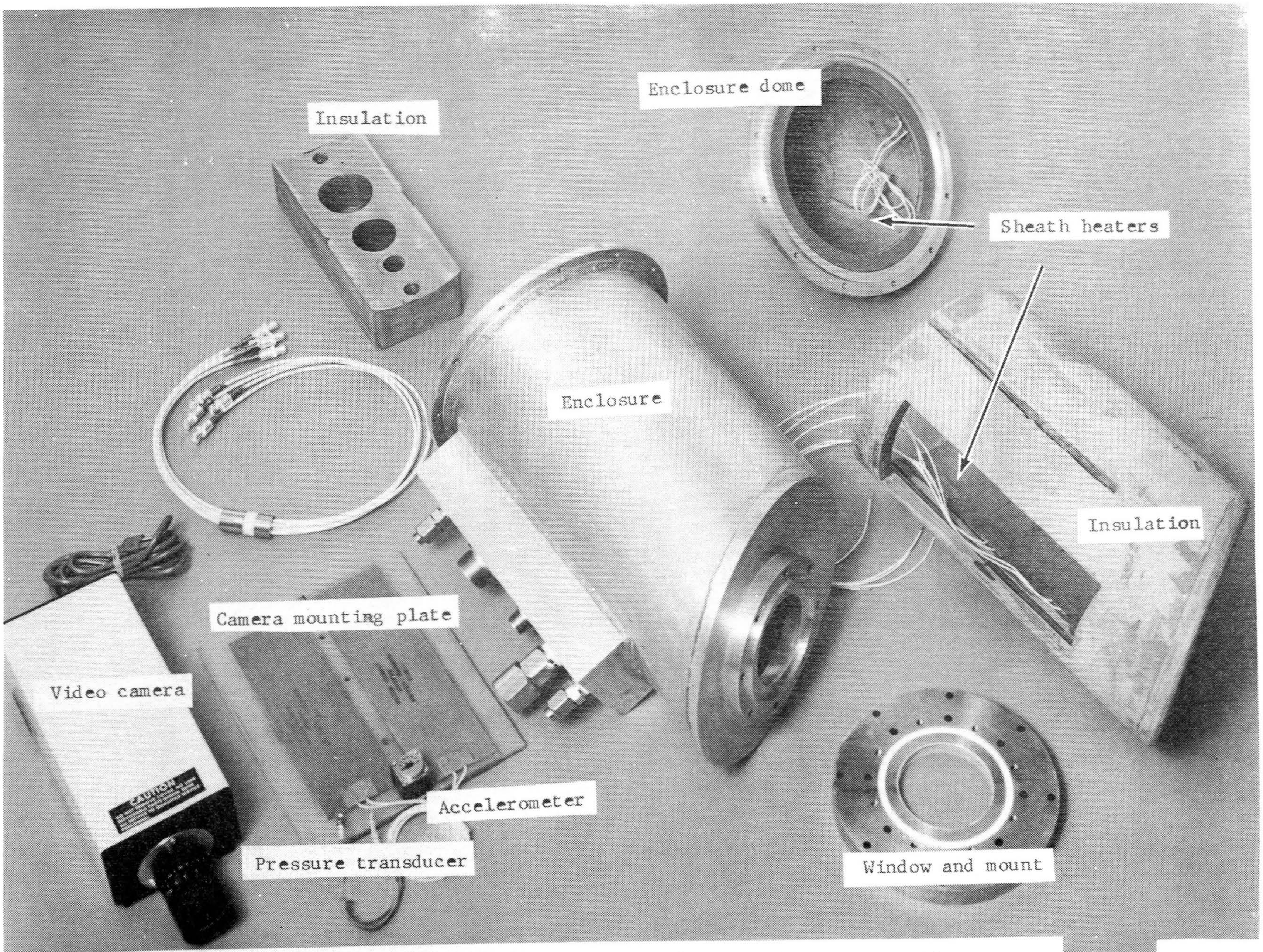


Figure 7. Exploded view of camera housing to show insulation and heating pads.

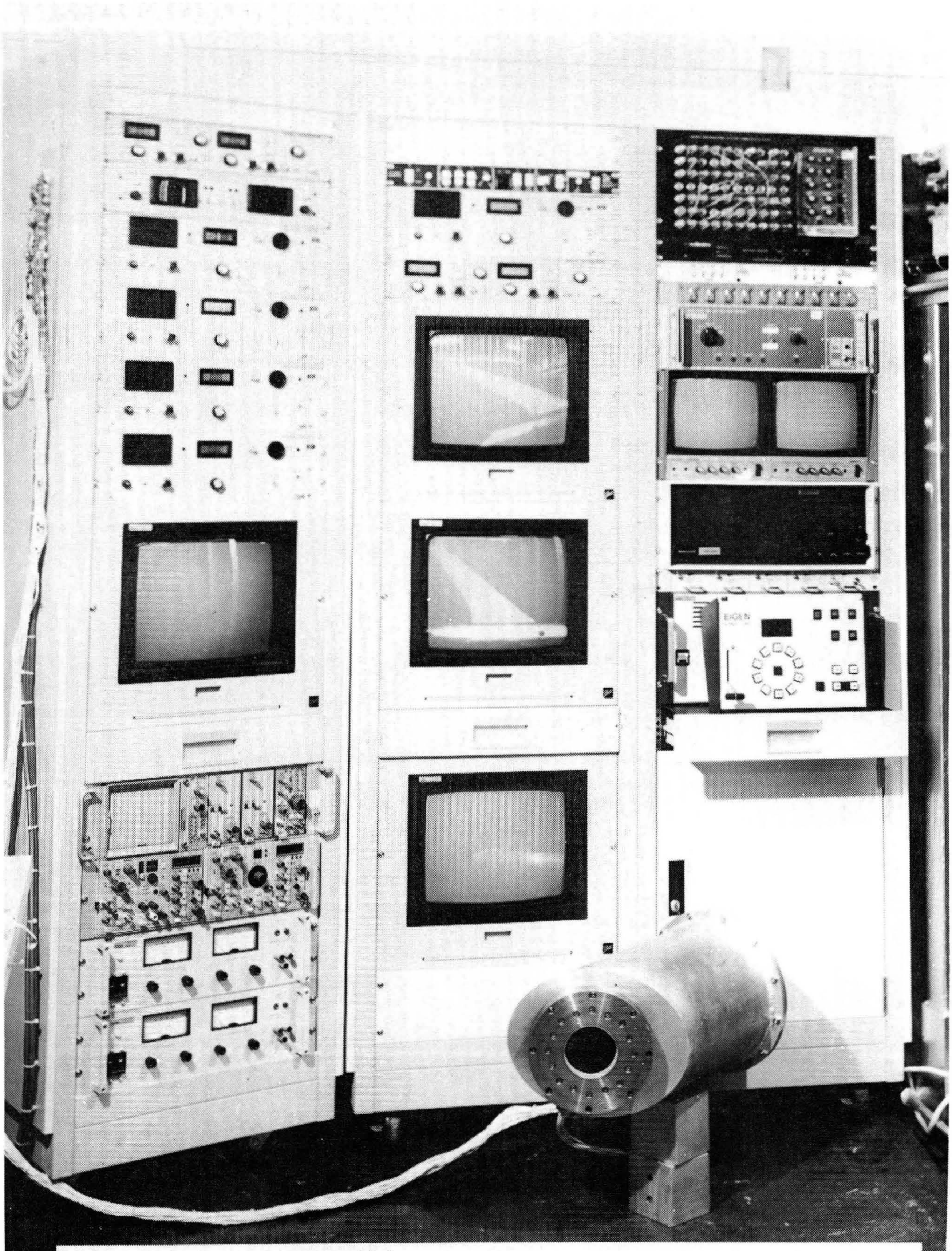


Figure 8. Camera enclosure shown coupled via umbilical cord to the support racks.

Figure 9. Full scale mock up of NTF test section (top half) showing wooden model of Pathfinder. Support racks for the VMD system are shown.

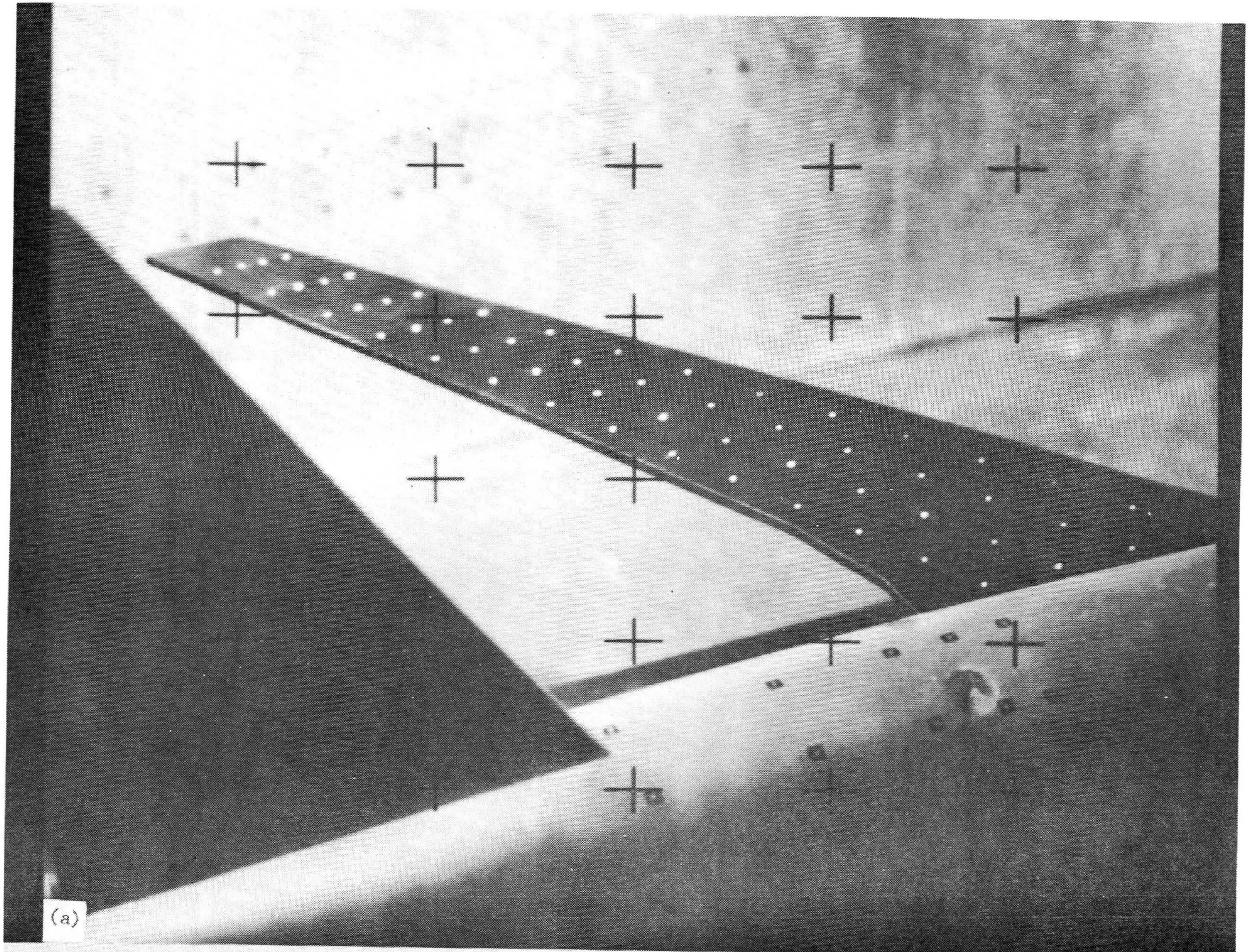


Figure 10. Left (a) and right (b) views of the far wing as seen with the VMD cameras. (continued)

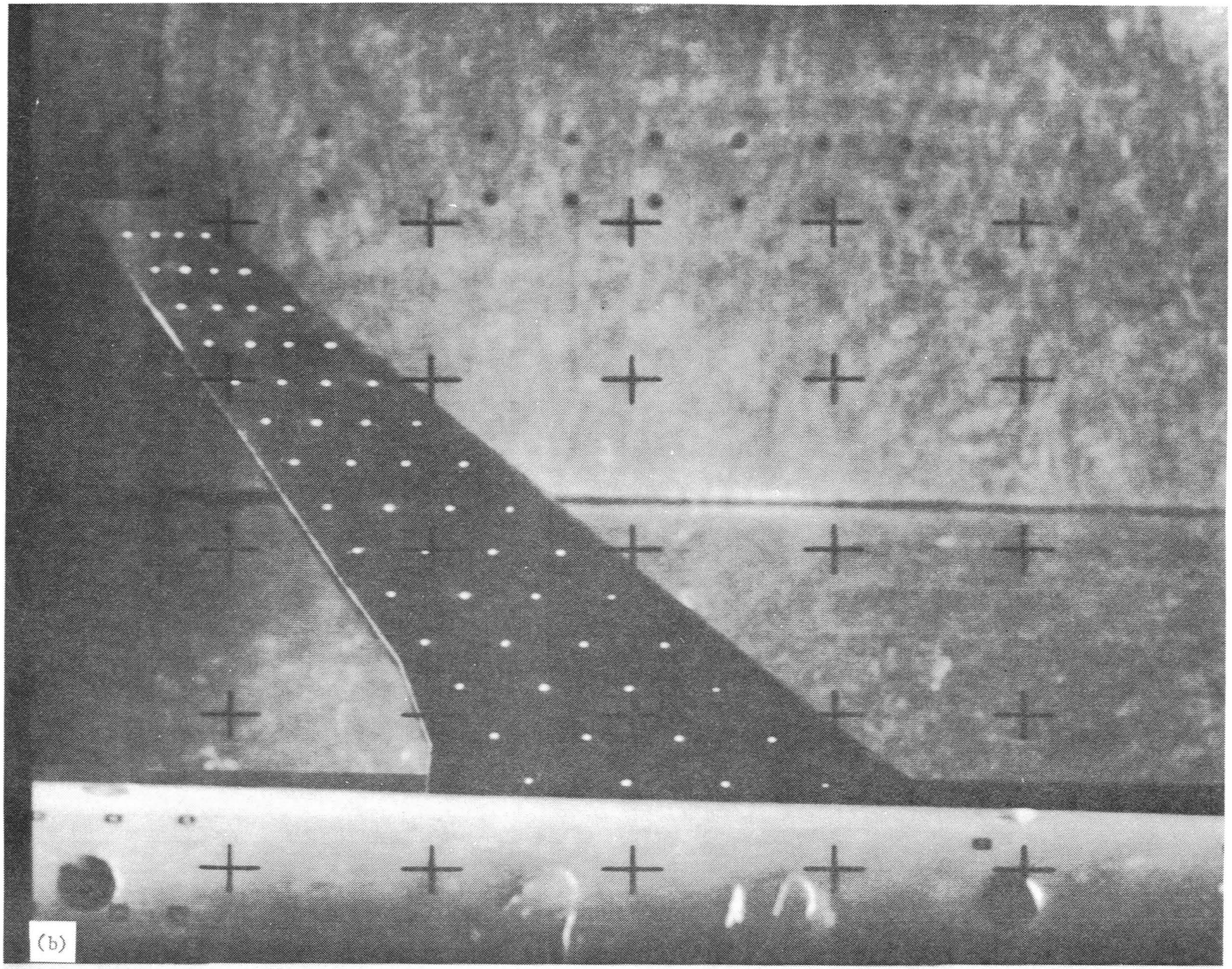


Figure 10 b. (concluded)

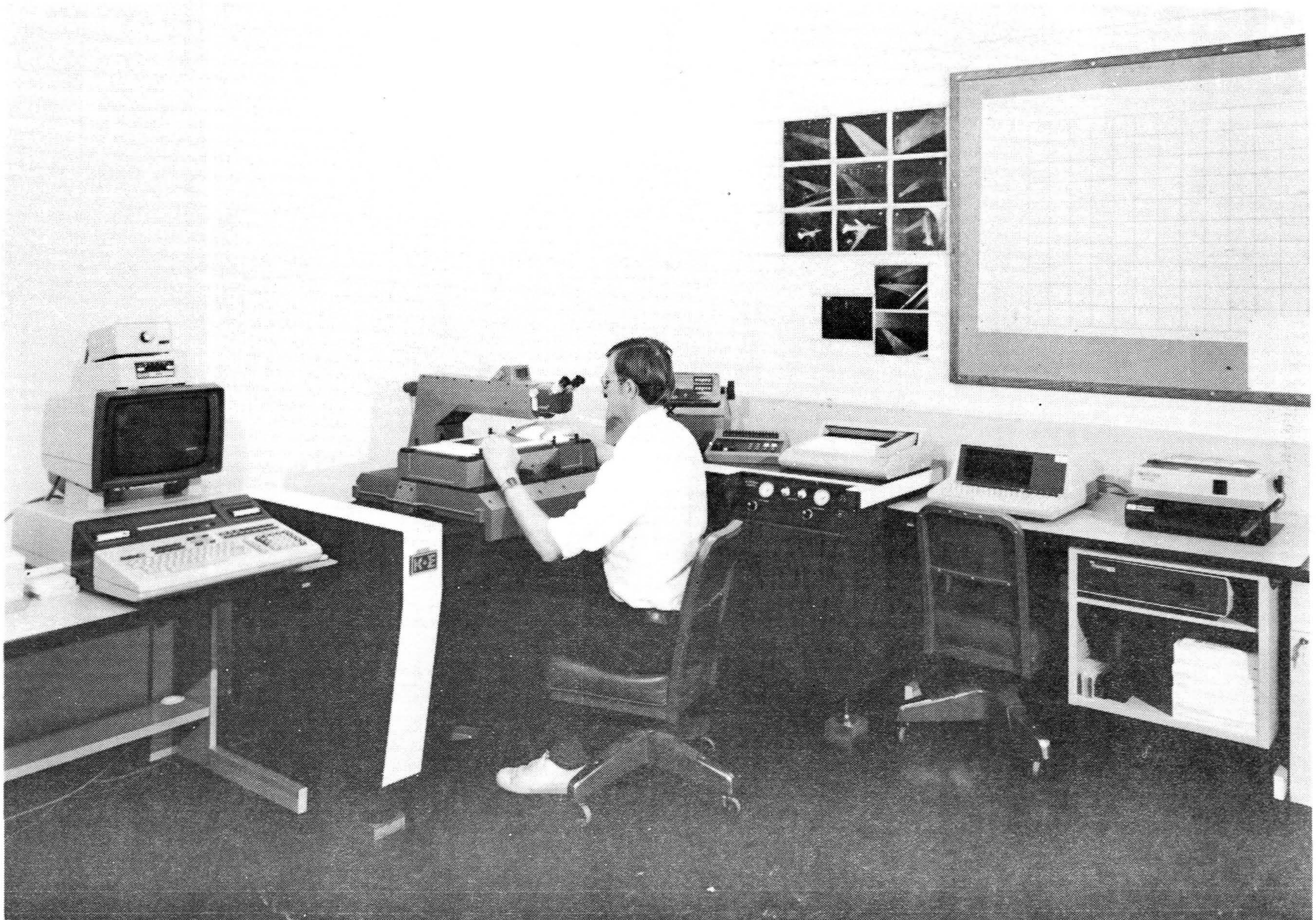


Figure 11. Data readup station. Operator is shown at mono-comparator sending xy plate coordinates to data-logging desktop computer.

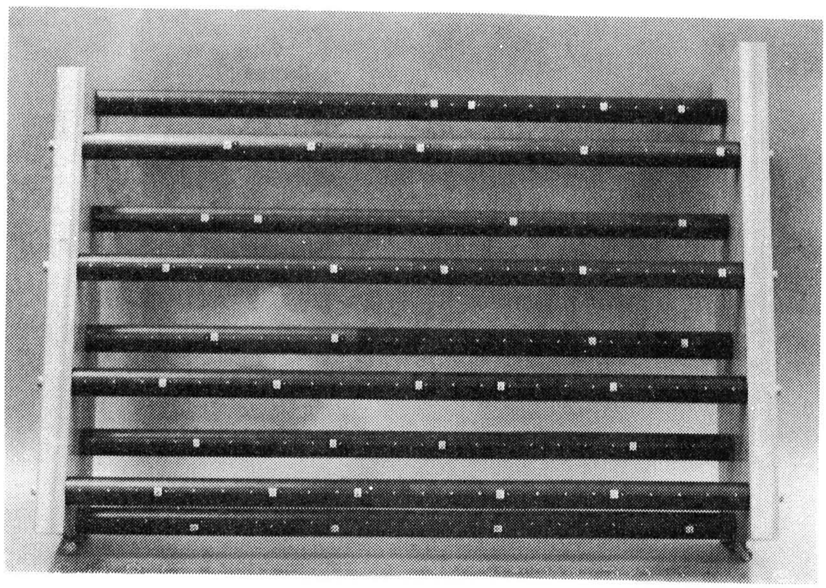


Figure 12. Calibration jig.

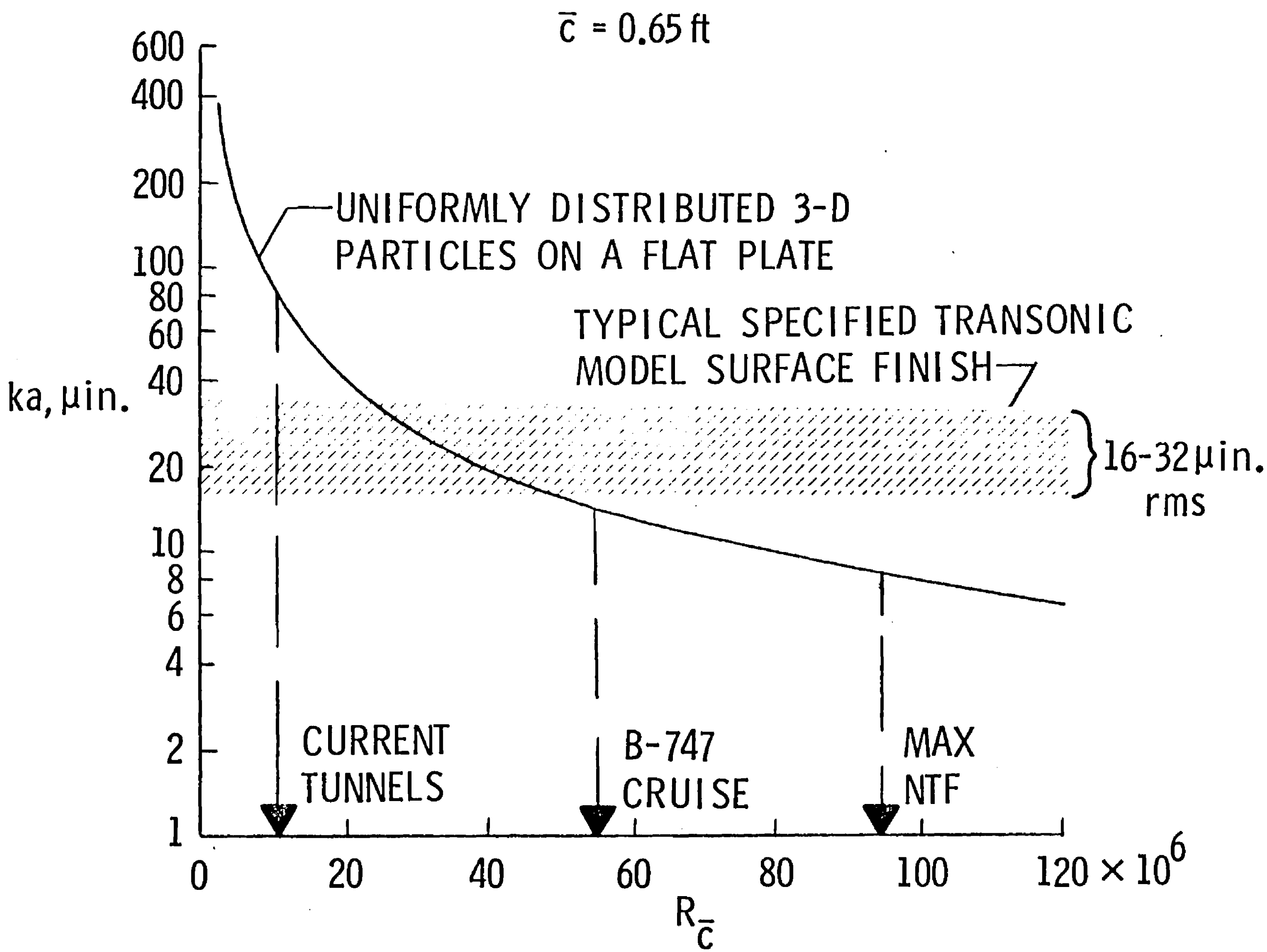


Figure 13. Admissible surface roughness for typical NTF sized models.

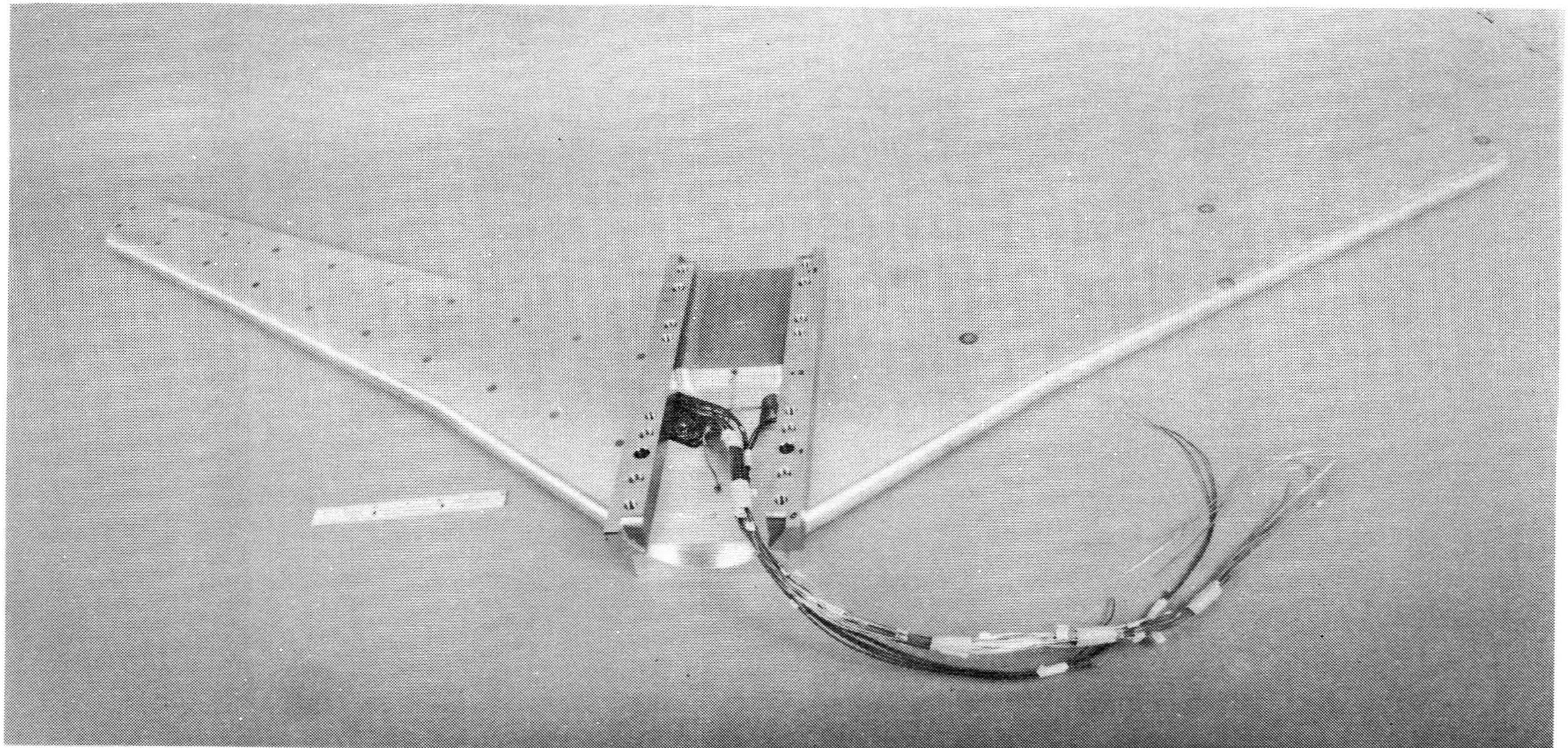


Figure 14. Target wing to be used for checkout of VMD at NTF.

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15. Supplementary Notes

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16. Abstract

A photogrammetric closed circuit television system to measure model deformation at the National Transonic Facility is described. The photogrammetric approach was chosen because of its inherent rapid data recording of the entire object field. Video cameras are used to acquire data instead of film cameras due to the inaccessibility of cameras which must be housed within the cryogenic, high pressure plenum of this facility. A rudimentary theory section is followed by a description of the video-based system and control measures required to protect cameras from the hostile environment. Preliminary results obtained with the same camera placement as planned for NTF are presented and plans for facility testing with a specially designed test wing are discussed.

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