

**NASA TECHNICAL
MEMORANDUM**

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LEAR JET TELESCOPE SYSTEM

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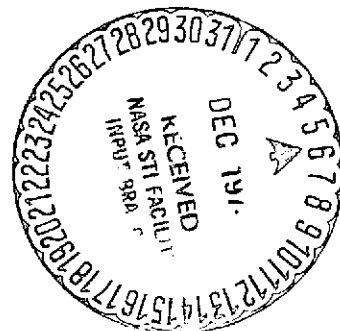


TABLE OF CONTENTS

	Page
I. Description of Telescope	1
A. Introduction	1
B. Telescope Guidance System	2
C. Instrument Compatibility	6
D. Auxiliary Equipment	8
II. Telescope System Installation	9
A. Mounting the Telescope	9
B. Installation of the Electronics	9
C. Installing the Primary Mirrors	13
D. Balancing the Telescope	14
E. Completing the Installation	16
III. Telescope Setup and Adjustment Procedure	17
A. Selecting the Secondary	18
B. Installation of Secondary	20
C. Checking Chopper Alignment	27
D. Setting the Chopper Throw and Alignment	28
E. Focusing the Telescope	28
IV. Guidance System Operation	32
A. Telescope Stabilization Electronics	32
B. Joystick Assembly	33
C. Gyro Orientation	33
D. Telescope Attitude Indication	35
E. Test Box	35
F. Trouble Shooting	36
V. Airborne Operation	37
A. Remarks	37
B. Check List	38

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PREFACE

The telescope described in this document was patterned after the original "Flying Infrared Telescope" developed by F. J. Low, H. H. Aumann, and C. M. Gillespie. The present instrument was designed as a multi-user facility for observations of celestial objects at infrared wavelengths, where ground-based observations are difficult or impossible due to effects of telluric atmospheric absorption. The telescope is mounted in a Lear Jet model 24B which permits typically 70 min. of observing per flight at altitudes in excess of 13 km (45,000 ft, figure 1). The facility is managed by the Airborne Science Office at the National Aeronautics and Space Administration's Ames Research Center, Moffett Field, California.

The telescope was developed at Ames by personnel of the Astrophysics Branch with assistance of personnel from the Research Facilities and Instrumentation Division and the Technical Services Division. The cooperation of Prof. Low, Mr. Gillespie, and Dr. D. A. Harper who used the original telescope, is gratefully acknowledged.

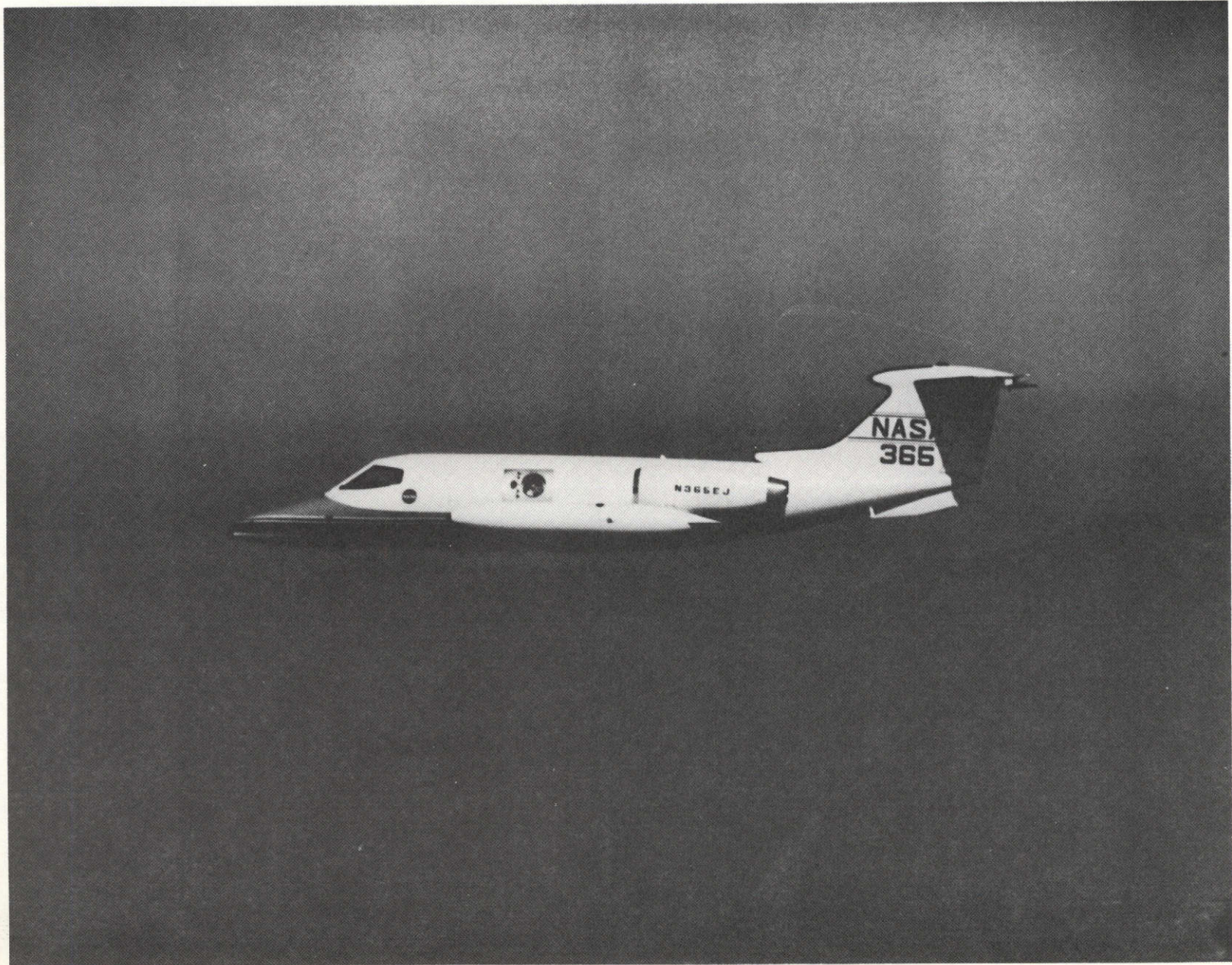


Figure 1.—The Lear Jet in flight.

I. Description of the Telescope

A. Introduction

This telescope is a Dall-Kirkham Cassegrain configuration. As such the primary is an ellipsoidal mirror and the secondary is a spherical mirror. The primary mirror is made from Cervit and coated with aluminum plus an overcoating of silicon monoxide. There are several secondary mirrors made of Silicon, Cervit, and Aluminum. The maximum useful diameter of the primary is 30 cm (12 in.).

The secondary mirror can be made to oscillate about the vertical axis of the telescope. An on-axis detector then observes two adjacent parts of the sky called right beam and left beam. The secondary mirror, driven by a pair of solenoids, oscillates back and forth from right beam to left beam at frequencies up to about 100 Hz. A chopper-driver circuit is available, providing frequencies of about 15, 30, 48, 70, and 95 Hz. A separate input connector allows one to set the chopping frequency by an external oscillator. The throw on the oscillating secondary can be adjusted manually up to about 15 arc min on either side of the vertical axis of the telescope.

The telescope is mounted in the Lear jet at a mean elevation of 20° above the horizon. A variable angle adapter permits operation of the telescope from 13° to 28° in elevation. The telescope has $\pm 3^\circ$ of gimballed, gyro-stabilized motion both in the roll direction (elevation) and the yaw direction (azimuth). An additional motion of up to 2° can be obtained in roll by flying with the wing up or down. In the yaw direction additional motion can be obtained by turning the plane right or left. An air seal near the front of the telescope leaks cabin air when the aircraft is pressurized

to permit free motion of the telescope in the gimbals. A schematic view of the telescope is shown in figure 2 and a photograph of the telescope in the cabin is shown in figure 3.

In a typical flight pattern the object appears at the beginning of an observation either high in roll (for a setting object) or low in roll (for a rising object). The pilot then flies the jet in a predetermined flight plan keeping the yaw axis in its midrange while the object traverses the roll direction from $(20 \pm 8)^\circ$ to $(20 \mp 8)^\circ$. Thereafter the object is out of the field of view of the telescope terminating the observation.

Sighting is done with an auxiliary telescope designated as the guide scope. This telescope has a reticle to assist in guiding the telescope. The two available reticle patterns are shown in figure 4. The total field of view as seen in the guide scope is about 5° . The guide scope has two optical adjustments, one to position the reticle at the focus of the objective, the other to focus the eyepiece on the reticle. The alignment of the guide scope relative to the main telescope can be varied mechanically to provide a convenient "boresight", i.e., correlation between the detector and guide-scope image fields.

B. Telescope Guidance System

The telescope is held fixed in inertial space in two axes by two torque motors. The two controlled axes of the telescope correspond to roll and yaw of the airplane. The attitude of the telescope in inertial space is sensed by two gyroscopes. An electronics stabilization system senses the gyro outputs and drives the torque motors. The telescope may be pointed in any direction perpendicular to the plane defined by the roll and yaw axes.

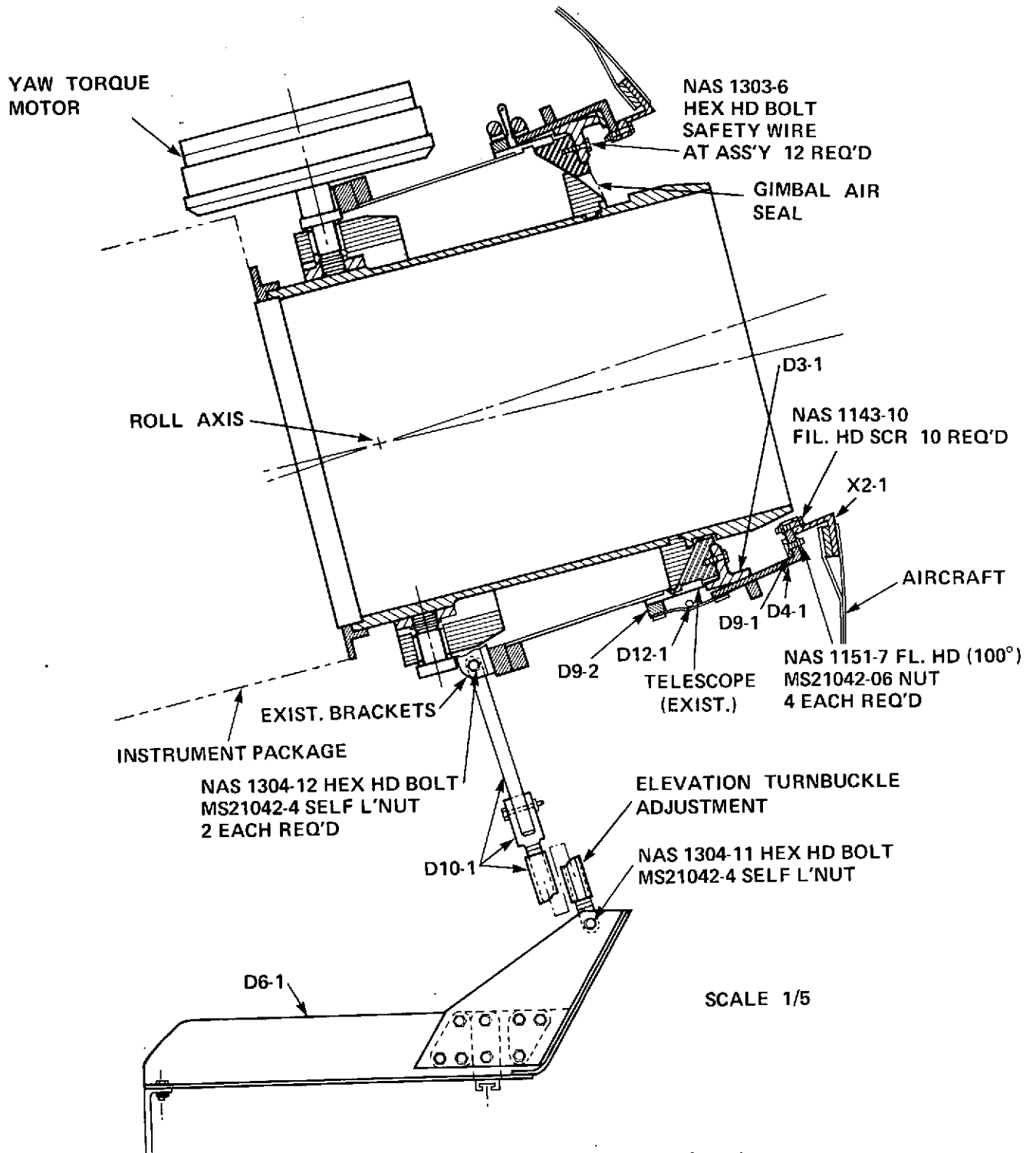


Figure 2.- Schematic drawing of telescope in place.

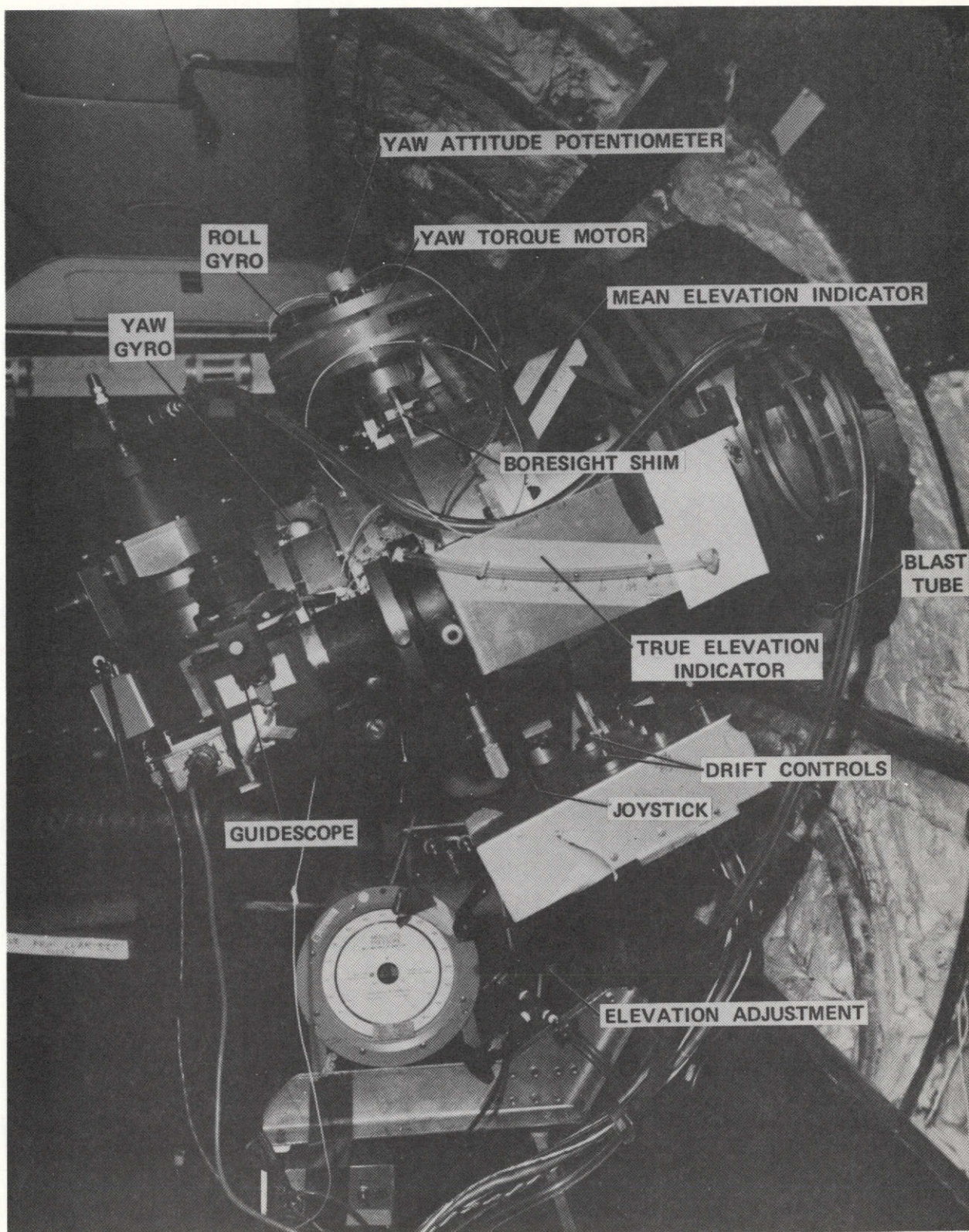
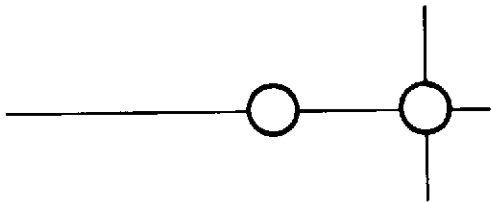
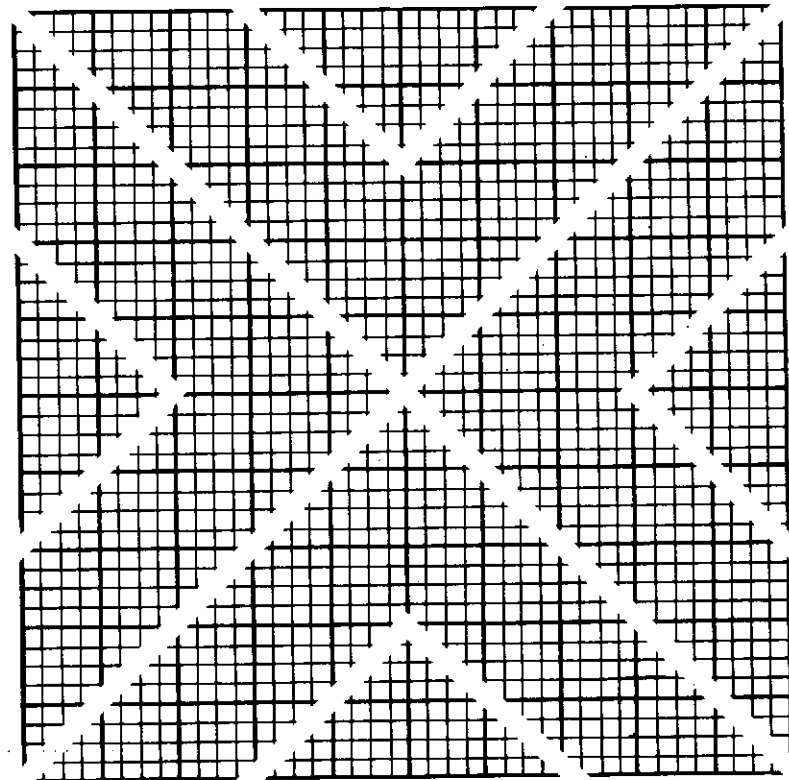


Figure 3.- Lear Jet telescope: interior view of aircraft looking aft on left side.



EACH CIRCLE HAS A 5 arcminute
DIAMETER AND THE SEPARATION
BETWEEN CIRCLE CENTERS IS
10 arcminutes.

(A)



→ | | ←
4 arcminutes

(B)

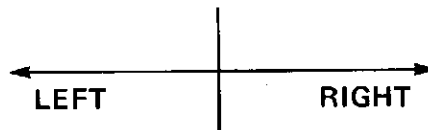


Figure 4.— Available recticle patterns.

The mechanism for controlling the motion of the telescope manually is a "joy stick" which electronically overrides the gyroscope signals. The joy stick responds to the pressure applied, the greater the pressure the faster the telescope moves. This pressure-sensitive joy stick does not move when pressure is applied.

On the front panel of the gyroscope telescope-stabilization electronics package are two controls for each axis - the phase and gain for adjusting the servo-system parameters. Drift controls on the joy stick box may be used to null out any large drift and one can obtain drift rates as low as one arcminute per minute with a pointing stability of ± 1 arcmin.

C. Instrument Compatibility

There is a 6.35 cm (2.5 in.) diameter hole in the primary mirror permitting the radiation to be coupled to a measuring device. The measuring instrument that can be used on the back of the telescope can be almost of any variety. However, the following physical dimensions should be kept in mind.

The telescope has a 38.1 cm (15 in.) diameter back plate. In this plate are two sets of 1/4-28 NF blind-tapped holes for securing an instrument package. The first set of holes consists of 12 holes on a 29.21 cm (11.5 in.) BCD. The second set of holes consists of 6 holes on a 10.16 cm (4 in.) BCD. The back plate and all pertinent dimensions are shown in figure 5. Care in instrument design is required to avoid the three screws on a 30.48 cm (12 in.) BCD on the back plate which retain the primary mirror. The instrument must also clear the yaw torque motor, (see figures 2 and 3) and permit mounting the yaw gyro on the back plate.

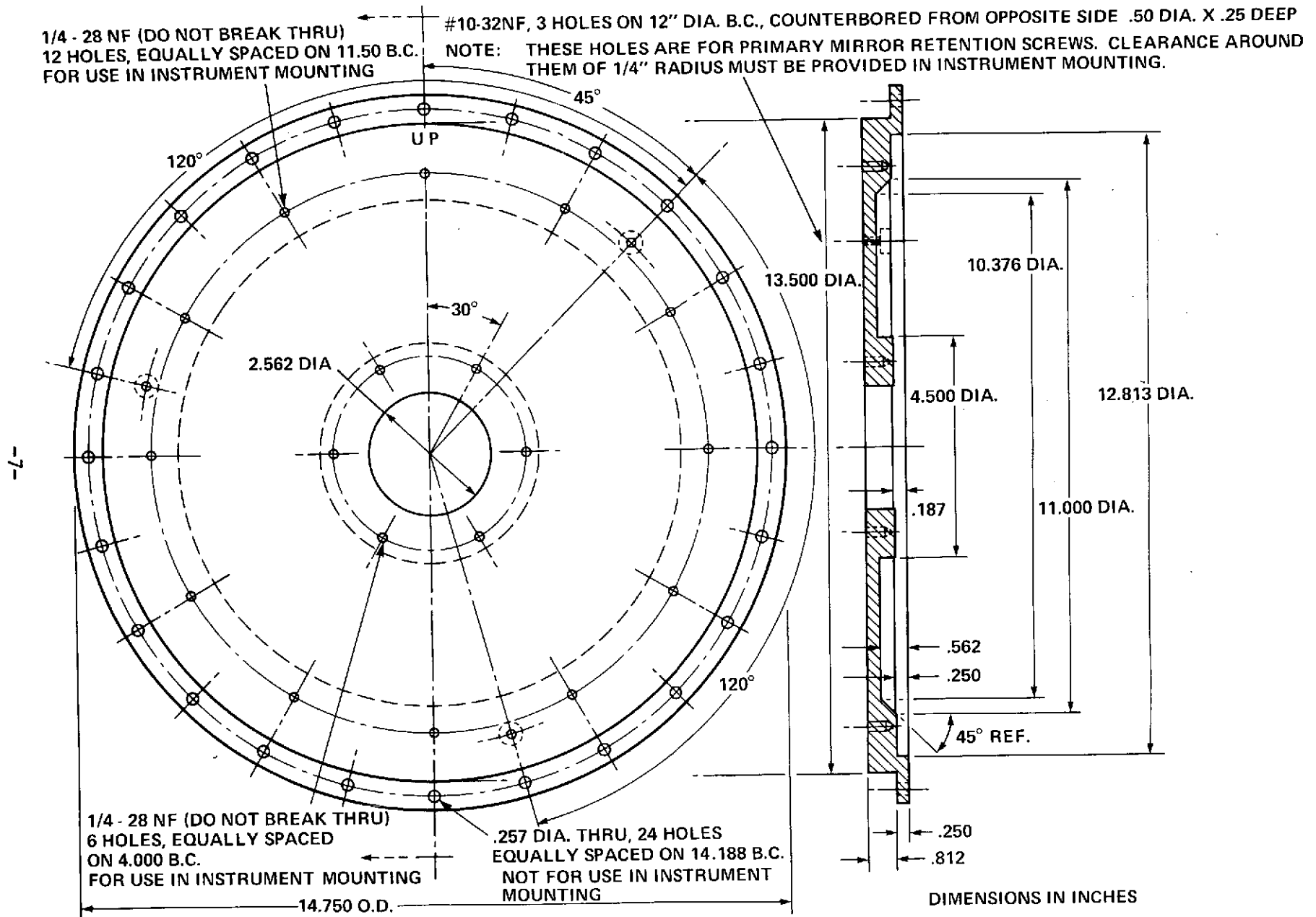


Figure 5.- Telescope backplate.

The maximum torque relative to the roll axis allowed for an instrument package is about 6.8×10^8 dyne-cm (600 in.-lb). The weight of the instrument package must be offset by counterweights leaving the telescope balanced.

D. Auxiliary Equipment

There is a wheeled cart for testing the telescope out of the aircraft.

A collimated light source for testing the instrument can be mounted in the telescope barrel. The lamp used is a T-1 subminiature incandescent lamp 715 manufactured by Chicago Miniature Lamp Works. The electrical characteristics of this lamp are: $V = 5$ volts, $I = 0.115$ amperes, approximate temperature = 2100° K.

A 35.56 cm x 45.72 cm (14 in. x 18 in.) mirror mounted on a tripod is available. This permits looking at ground-bound objects for focusing and boresighting when the telescope is mounted in the aircraft.

A circuit for driving the oscillating secondary mirror is available. This is shown in figure 6. This chassis contains two voltage-to-frequency converters for use in recording DC signals on an FM tape recorder, in addition to the chopper driver circuit.

An eyepiece adapter is also available. This adapter fits into the 6.35 cm (2.5 in.) diameter hole in the backplate. The adapter can be adjusted to position the reticle of the eyepiece at the desired focal plane. The adapter may also be used to focus the telescope. This procedure is described in section III. E.

CHOPPER DRIVER MAY "LOCK UP" WHEN TURNED ON. CHOPPER IS OSCILLATING IF REFERENCE SIGNAL EXISTS WHEN CHOPPER ON/OFF SWITCH IS ON. THE REMEDY IS TO FLIP THE ON/OFF SWITCH.

THIS HALF OF THE INSTRUMENT CONTAINS TWO VCO'S. ONE VCO IS FOR AUDIO OUTPUT, THE OTHER IS FOR RECORDING.

THIS HALF OF THE INSTRUMENT CONTAINS THE CHOPPER DRIVER.

HIGH/LOW POWER SWITCH; THIS PUTS MORE CURRENT ON THE CHOPPER SOLENOIDS IN THE "HIGH" POSITION. USE "LOW" POWER EXCEPT WHEN FLYING.

-9-

5 INCHES

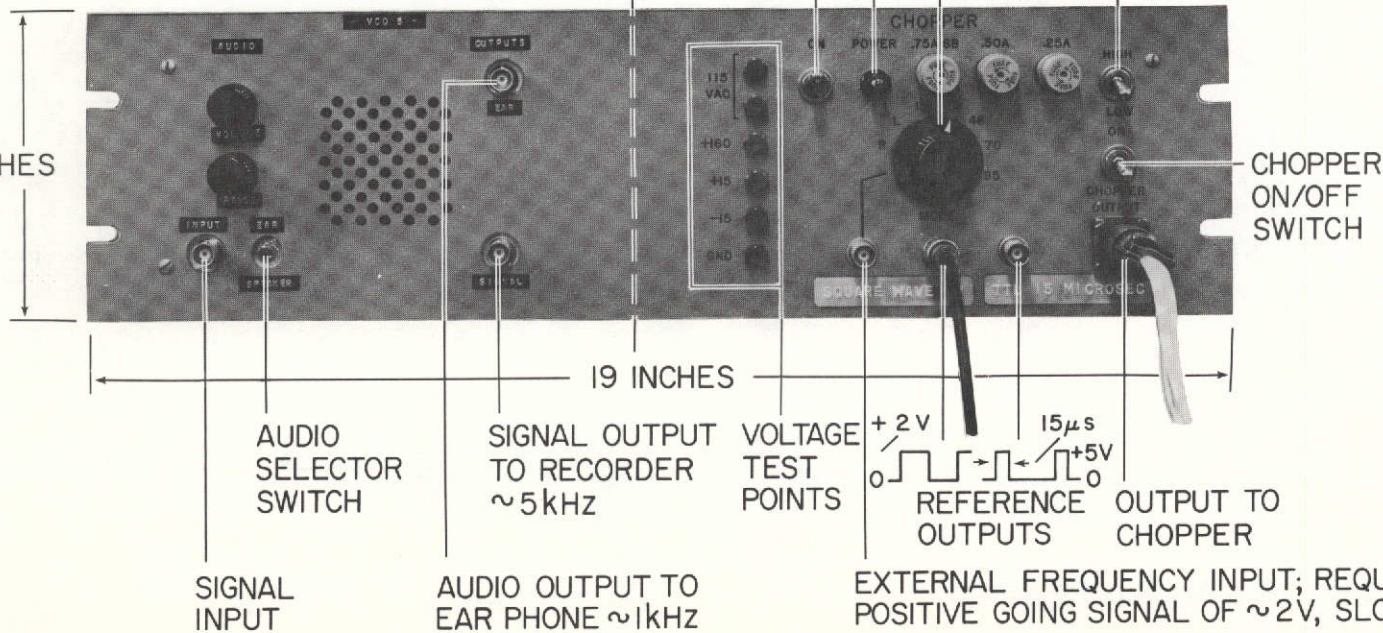


Figure 6.— Available chopper driver and voltage-to-frequency converter electronics.

II. Telescope Guidance Installation

A. Mounting the Telescope

The telescope attaches to the Lear Jet fuselage just aft of the entrance. A bolt mounting circle on the telescope mates with a similar hole pattern in an adapter plate on the fuselage. The elevation turnbuckle adjustment mounted between the floor of the cabin and the rear of the telescope provides further support for the telescope.

Mounting procedure for the telescope:

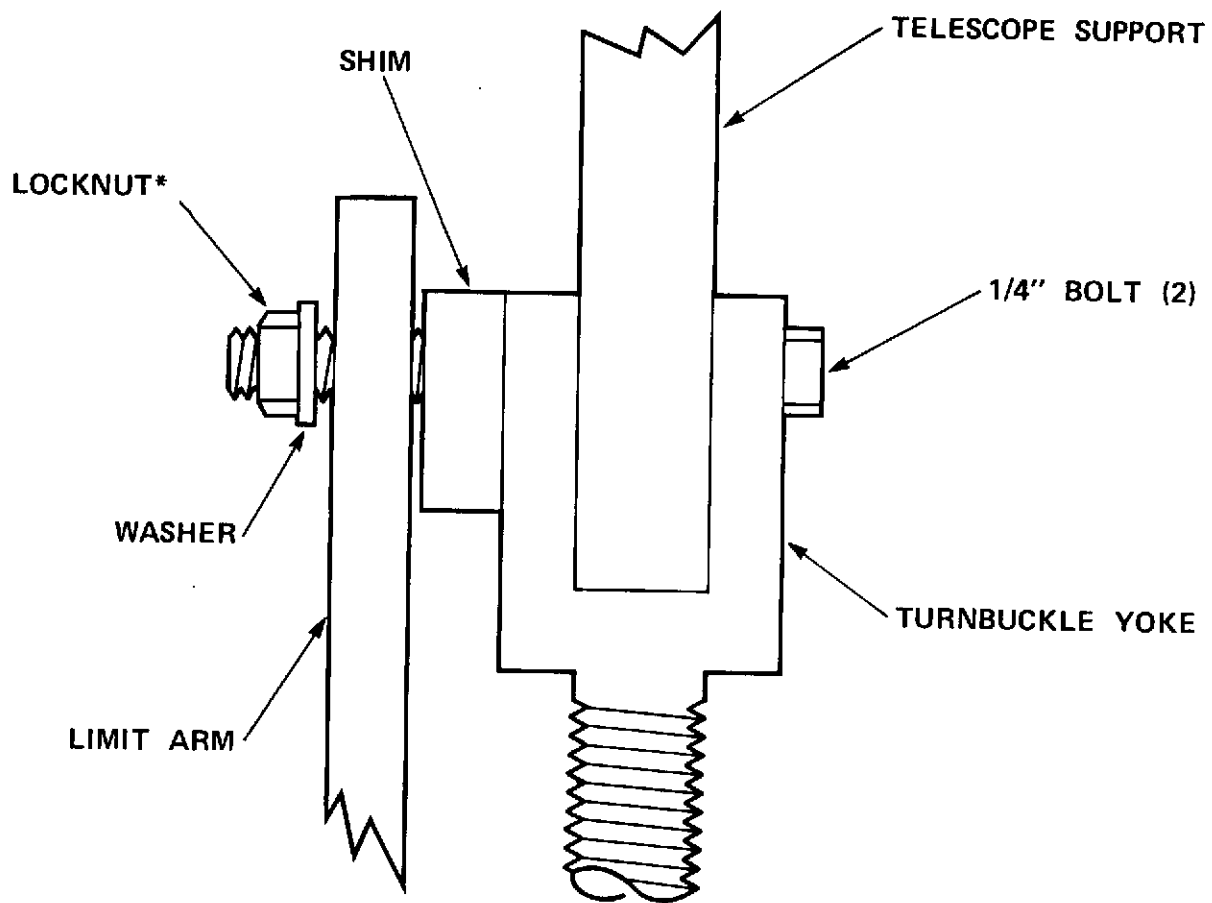
1. Engage two guide bolts on telescope with mounting plate.*
2. Attach elevation turnbuckle support bracket between cabin floor and telescope.
3. Using NAS 1143-10 screws complete mounting plate assembly.*
4. Complete assembly of turnbuckle support (see figure 7).
5. Mount the joy stick box on its bracket (optional).
6. Operate the turnbuckle and gimbals to verify that the telescope has an unrestricted total elevation range from 13° to 28°.

B. Installation of the Electronics

The telescope Guidance Unit, figure 8, mounts in the bottom of a rack just opposite the entrance, or on the floor between the door and the telescope, or in the baggage compartment.

1. Connect 28 volt power to rear of Guidance unit (Power Switch OFF).

*The telescope must be supported manually from the rear during steps 1-3.



***DO NOT TIGHTEN LOCKNUT COMPLETELY TO AVOID BINDING TELESCOPE LIMIT ARM AT LOW ELEVATION ANGLES.**

Figure 7.— Assembly of Lear Jet telescope turnbuckle support.

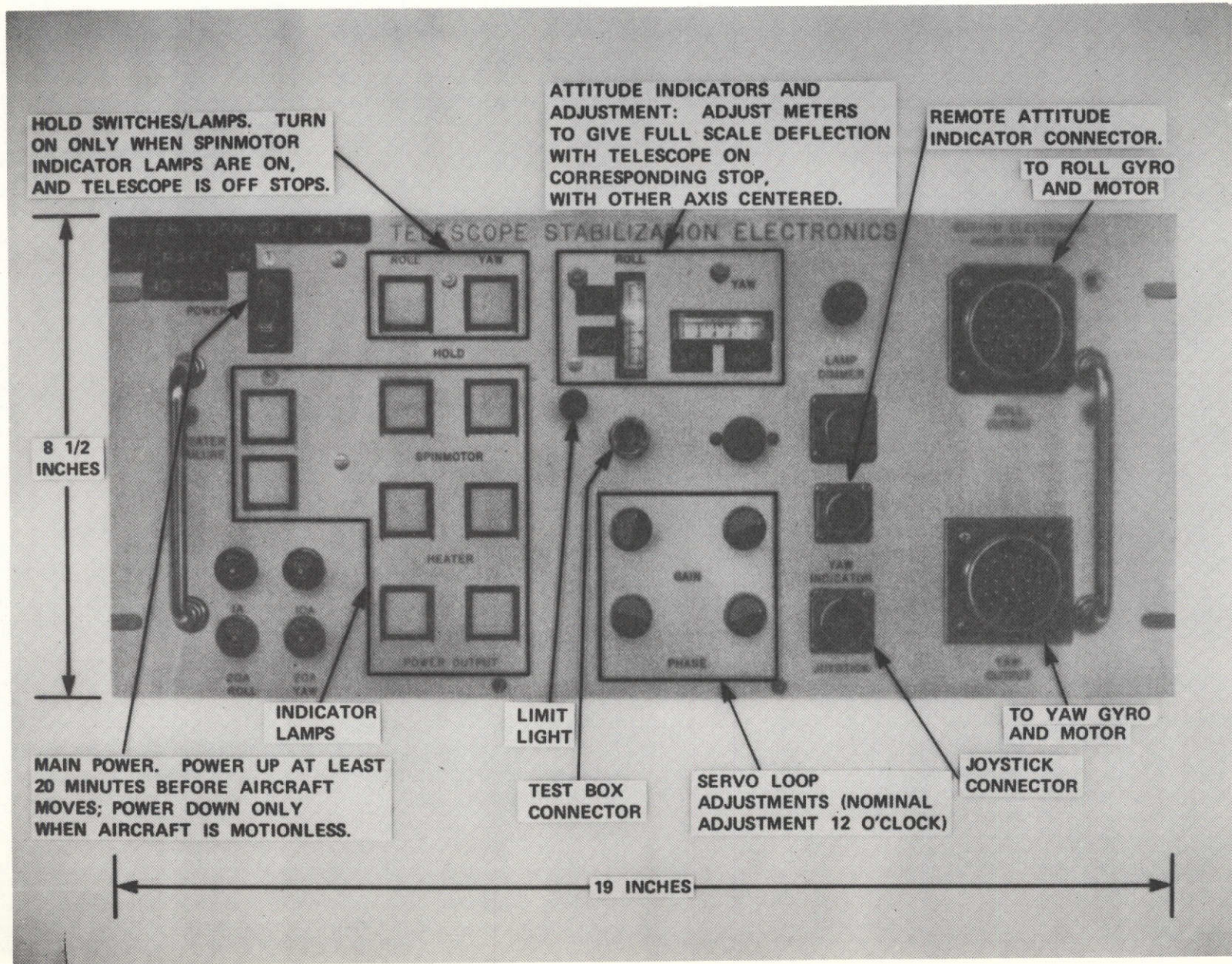


Figure 8.— Telescope stabilization electronics.

2. Mount Guidance Unit in rack or appropriate bracket with four 10-32 binding head screws, with washers under the heads.
3. Connect telescope cables to Telescope Stabilization Electronics. The roll and yaw outputs on the Guidance Unit are labelled on front panel, and color coded.
4. Connect Joy stick Box to Guidance Unit at connector labelled "Joy Stick."
5. Connect Pilot Indicator to connector labelled "Yaw Indicator."

C. Installing the Primary Mirror

Install the primary mirror from the rear of the telescope with the backplate removed. The front outside edge of the primary should rest against three 1-mm thick polyethylene pads glued to the shoulder in the telescope tube. It is essential that the pads be located at the same angular position as the tapped holes for the Primary Mirror Retention Screws (see figure 5). The telescope tube should be warmer than about 65° F to allow the primary mirror to be mounted without binding. Once the mirror is in place, the backplate can be installed; the Primary Mirror Retention Screws should be in the appropriate holes in the backplate. These screws (1) should have Nylon feet on the ends which bear on the mirror, (2) should turn freely in the threaded holes in the backplate, (3) should have lock nuts on the instrument side of the backplate, and (4) should be backed out of the backplate as far as possible so as not to bear on the mirror while the backplate is being bolted onto the telescope tube. Once the backplate is bolted in place, the Primary Mirror Retention Screws can be tightened to hold the mirror firmly against the pads which are between the front edge of the mirror and the shoulder in the telescope tube.

Since the pads are located opposite the screws, the forces exerted on the mirror tend only to compress the mirror at the edge and not to bend it. Care must be exercised to avoid damage to the mirror by tightening the screws too far. After the screws have been tightened, the lock nuts must be tightened against the backplate to prevent the screws from backing out.

D. Balancing the Telescope (see figure 9).

Ideally the telescope should be balanced so that it will remain in any orientation in which it is placed. The telescope structure is unbalanced in roll due to the yaw torque motor mounted on the top of the gimbal ring, and in yaw due to the guide scope mounted on the right side of the tube. Counterbalances for these effects are supplied: weights on the bottom of the gimbal ring counterbalance the yaw torque motor, and weights on the telescope tube and backplate counterbalance the guide telescope. To complete the balancing job, the secondary mirror should be installed (as described in section III B), the instrument must be installed on the back plate, and weights added until the telescope balances: this will be possible for instruments weighing up to about 20 kg (45 lb) depending on the distance of the center of mass from the backplate. The maximum torque relative to the roll axis which can be balanced is about 6.78×10^8 dyne-cm (600 in.-lb).

In general the "balanced" telescope will correspond to one of the following configurations:

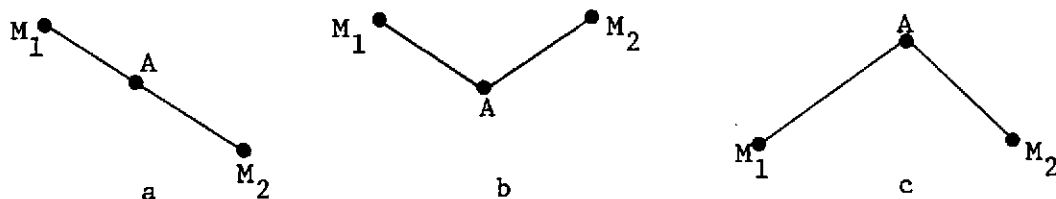


Figure 9.— Balance configurations.

Here M_1 and M_2 are unequal weights supported on unequal but rigid arms pivoted at an axis A. In configuration (a) the instrument is perfectly balanced, the arms being colinear; in configuration (b) one has unstable equilibrium, and configuration (c) corresponds to stable equilibrium. The counterweights should be distributed to approximate configuration (a) as nearly as possible. There is a 6.35 kg (14 lb) weight located on the bottom of the telescope tube 19 cm (7 1/2 in.) forward of the gimbal ring, which will help compensate the load of a heavy instrument (dewar) extending above the telescope axis. For light instruments this weight can be removed. The telescope/instrument combination is difficult to balance perfectly, but stable equilibrium is probably more desirable than unstable equilibrium. The torque motors can compensate an imbalance $\sim 3.38 \times 10^6$ dyne-cm (1/4 ft-lb) without serious reduction in tracking capability when the aircraft is flying through "smooth" air.

In flight it may be noticed that the telescope becomes unbalanced in roll and yaw. In roll, the usual effect is such that less weight (a pound or so) is required on the back plate to maintain balance. The balancing arrangement should permit easy removal of up to ~ 1.5 kg (3 lb) of weight from the backplate to compensate for this effect. In yaw, the front end of the telescope may tend to go forward, and if so, a forward force can be applied to the rear fo the telescope with a bunje cord.

E. Completing the Installation

All cables must be secured and routed to avoid interference with the observers. A metal channel is supplied which allows cables to be routed across the cabin floor. All Cables should be securely mounted and attached

to their respective connectors. Signal cables from the detector should not be routed near the telescope cables or the chopper drive cable.

Signal channel noise may, at times, be reduced by grounding the detector assembly to the airplane structure since a low resistance path may not exist through the telescope gimbals.

A flexible heating duct called the "blast tube" blows warm air on the guide scope window to prevent it from frosting. Be sure the blast tube is installed.

III. Telescope Setup and Adjustment Procedure

The procedure for setup and adjustment of the telescope for the desired optical characteristics is:

- A. Select a secondary mirror.
- B. Install the secondary mirror.
- C. Check chopper alignment.
- D. Set the chopper throw and alignment.
- E. Focus the telescope.
- F. Boresight.

III.A. Selecting the Secondary - see figure 10

Several secondary mirrors are available for use with the telescope. The choice of which secondary to use depends primarily on the back focal distance of the instrument. Let f be the distance of the detector aperture behind the backplate mounting surface. Then

$$Z_L = f + d \approx f + 31 \text{ mm} \quad (1)$$

is the distance from the image plane to the primary vertex.

If D_s is the secondary mirror diameter and Z_s the distance between the vertices of the primary and secondary mirrors, then the equivalent f-number of the telescope is

$$f_e = \frac{Z_s + Z_L}{D_s}, \quad (2)$$

and the underfilled primary diameter is

$$D_{pu} = \frac{F_p D_s}{F_p - Z_s}, \quad (3)$$

where F_p is the focal length of the primary mirror. The equation for focus is

$$\frac{1}{F_p - Z_s} - \frac{1}{Z_s + Z_L} = \frac{2}{r_s}, \quad (4)$$

where r_s is the radius of curvature of the secondary mirror. Solving (4)

for Z_s , one obtains

$$Z_s = \frac{1}{2} \left\{ F_p - Z_L - r_s + \left[r_s^2 + (F_p + Z_L)^2 \right]^{1/2} \right\} \quad (5)$$

If the primary is to be underfilled, then for each secondary mirror there is a maximum value of Z_s, Z_s^{MAX} , determined by (3), a corresponding minimum value of f_e, f_e^{MIN} , is determined by (2), and a minimum value of Z_L, Z_L^{MIN} , determined by (4). The values of Z_s^{MAX} , f_e^{MIN} , and Z_L^{MIN} , assuming $D_{\text{pu}} = 300$ mm are shown for the various secondaries in figure 10. Actually these values are somewhat extreme, since the effects of chopping and finite detector aperture will increase the telescope aperture used over that predicted by (2). The effect of an on-axis detector aperture of diameter a will be to increase D_{pu} by

$$\delta_1 \approx \frac{a Z_s}{Z_s + Z_L} \quad (6)$$

A chopper throw of angle γ relative to the beam axis (total symmetric throw 2γ) will increase D_{pu} by

$$\delta_2 \lesssim \frac{Z_s F_p 2\gamma}{F_p - Z_s}$$

Typically $\delta_1 + \delta_2 \lesssim 5$ mm.

To choose a secondary, one must first determine Z_L for his instrument from (1). Then from the list in figure 10 select a secondary such that $Z_L \gtrsim Z_L^{\text{MIN}}$. Where two or more secondaries can do the job, select the one which gives the f-number nearest the desired value. Using the parameters r_s and D_s for the selected secondary, find Z_s from (5). Use this to obtain f_e , D_{pu} , δ_1 , and δ_2 from (2), (3), (6), and (7), respectively. The quantity $D_{pu} + \delta_1 + \delta_2$ should be less than about 300 mm, assuming the primary must be underfilled.

Image quality will depend on the chopper throw, the secondary used, and the back focal distance. Typically images are less than one millimeter in diameter and the best images are obtained for $Z_L \sim 80$ mm. A computer program for calculating the image quality for a given configuration is available.

III.B Installation of Secondary

The first step in installing the Secondary is to position the spider. The distance L between the spider and the end of the telescope barrel is calculated from $Z = Z_s - 314$ (mm) (see figs. 11 and 12). Once the distance L is calculated, the optimum spacer as shown in figure 13 is then chosen.

Once the spider has been mounted, the selected secondary should be mounted on the chopper. Two types of secondaries are used, aluminum type and silicon or cervit type.

The aluminum secondary is held on the Mirror Support by the special retainer Screw, as shown in figure 14. The Teflon Washer prevents the Secondary from distorting when the Screw is tightened. Do not tighten too much! About

5 ft-lb is adequate. After the Screw is tight, secure it with the Lock Nut, using the special long-shank nut driver.

The silicon and cervit secondaries are permanently bonded to chopper mirror support. The special retainer screw is still used as an additional precaution.

F_p = PRIMARY FOCAL LENGTH = 460
 r_s = SECONDARY RADIUS OF CURVATURE

SECONDARIES

MATERIAL	t_s	r_s	D_s	Z_s^{max}	Z_L^{min}	f_e^{min}
ALUMINUM	4.0	369	78	340	5	4.4
SILICON	7.3	325	78	340	118	5.9
SILICON	6.5	360	84	331	124	5.4
CERVIT	4.4	435	99	308	196	5.1
CERVIT	4.3	298	78	340	276	7.9
CERVIT	4.9	324	84	331	302	7.5

EQUIVALENT F-NUMBER $f_e = \frac{Z_L + Z_s}{D_s}$

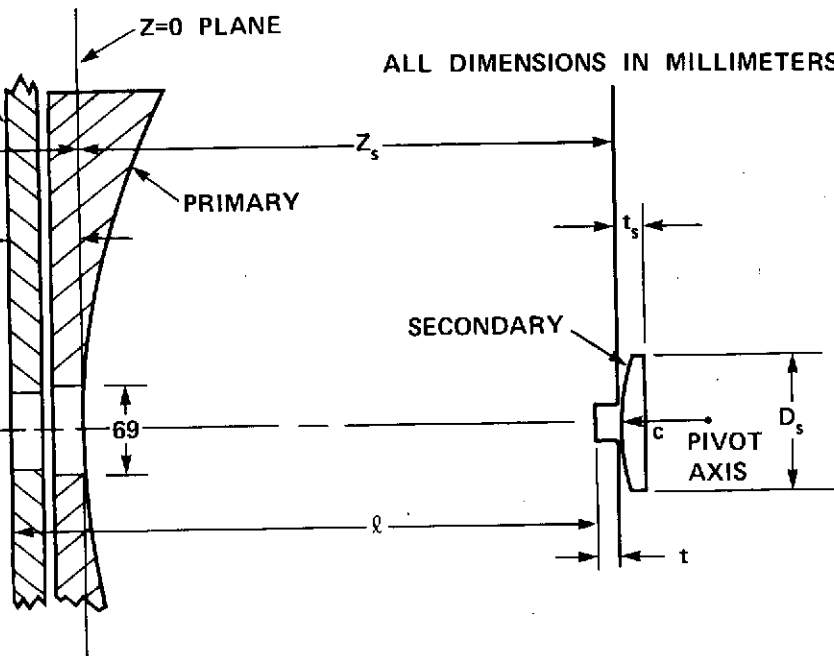
EQUATIONS FOR FOCUS

$$\frac{1}{F_p - Z_s} - \frac{1}{Z_s + Z_L} = \frac{2}{r_s}$$

OR,

$$Z_s = \frac{1}{2} \left\{ F_p - Z_L - r_s + \left[r_s^2 + (F_p + Z_L)^2 \right]^{1/2} \right\}$$

$$\frac{dZ_L}{dZ_s} = 1 + \left(\frac{Z_s + Z_L}{F_p - Z_s} \right)^2$$



ALL DIMENSIONS IN MILLIMETERS

PHYSICAL LIMITATION: $290 \lesssim Z_s \lesssim 390$

$Z_s = \ell + t - d, d \cong 31, t \cong 7, c \cong 20$

RELATION BETWEEN CHOPPER THROW θ AND BEAM THROW γ :

$$\theta = \left(\frac{r_s}{r_s - c} \frac{D_p}{2 D_s} \right) \gamma$$

c = SECONDARY PIVOT RADIUS

$$D_{pu} = \frac{F_p}{F_p - Z_s} \times D_s = \text{UNDERFILLED PRIMARY DIAMETER}$$

Figure 10.— Lear Jet telescope optics information sheet.

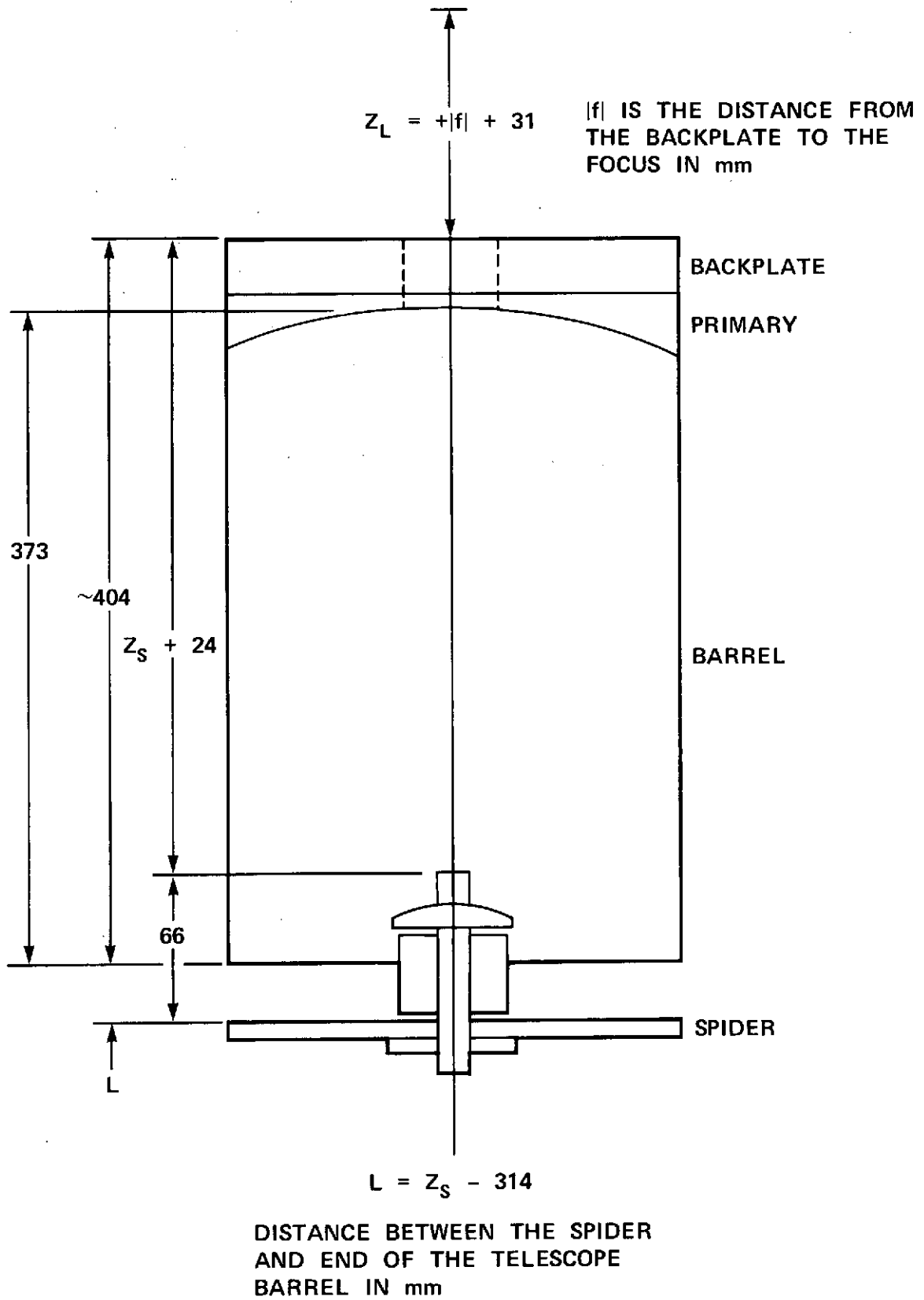


Figure 11.— Determination of spacer for Lear Jet telescope.

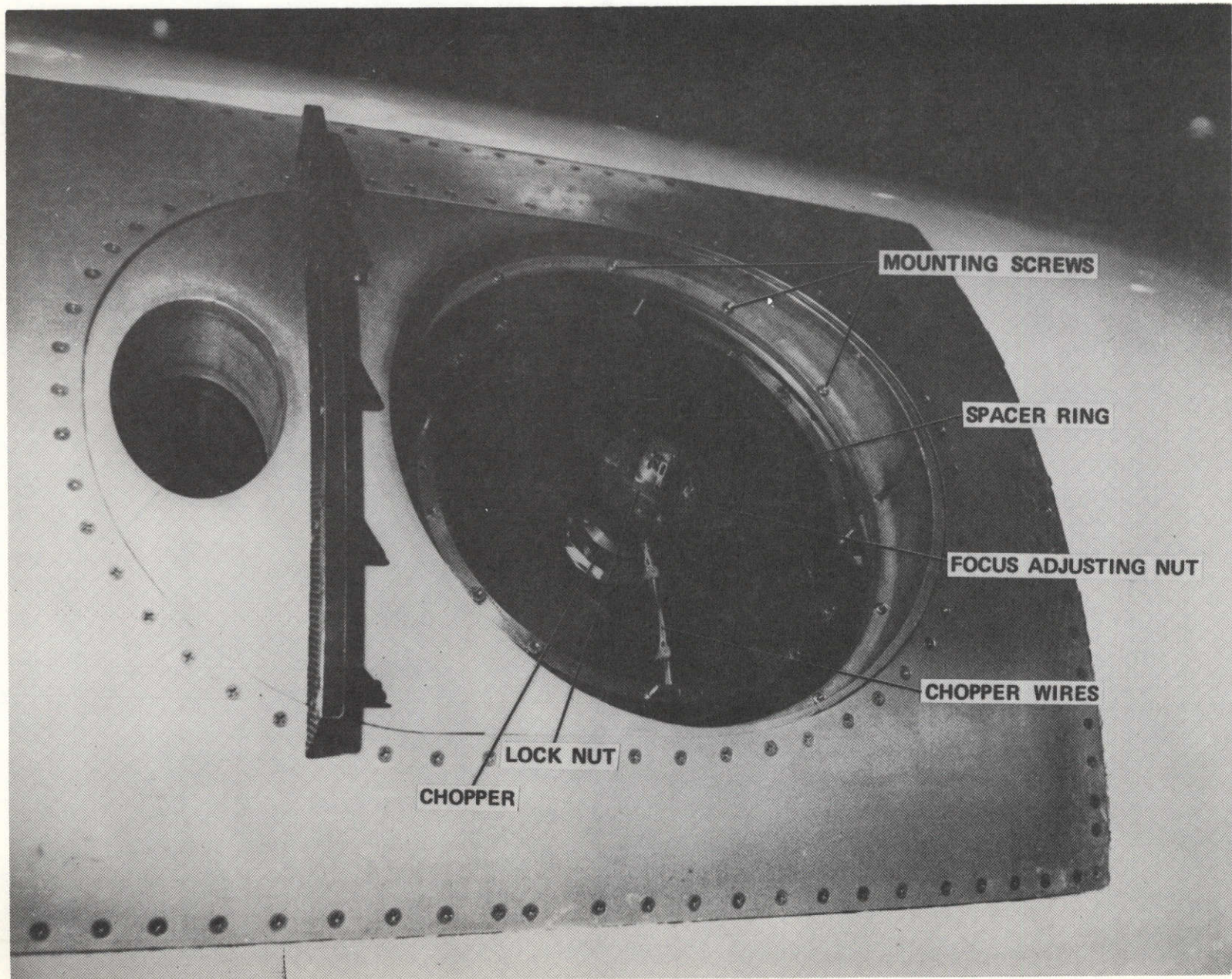
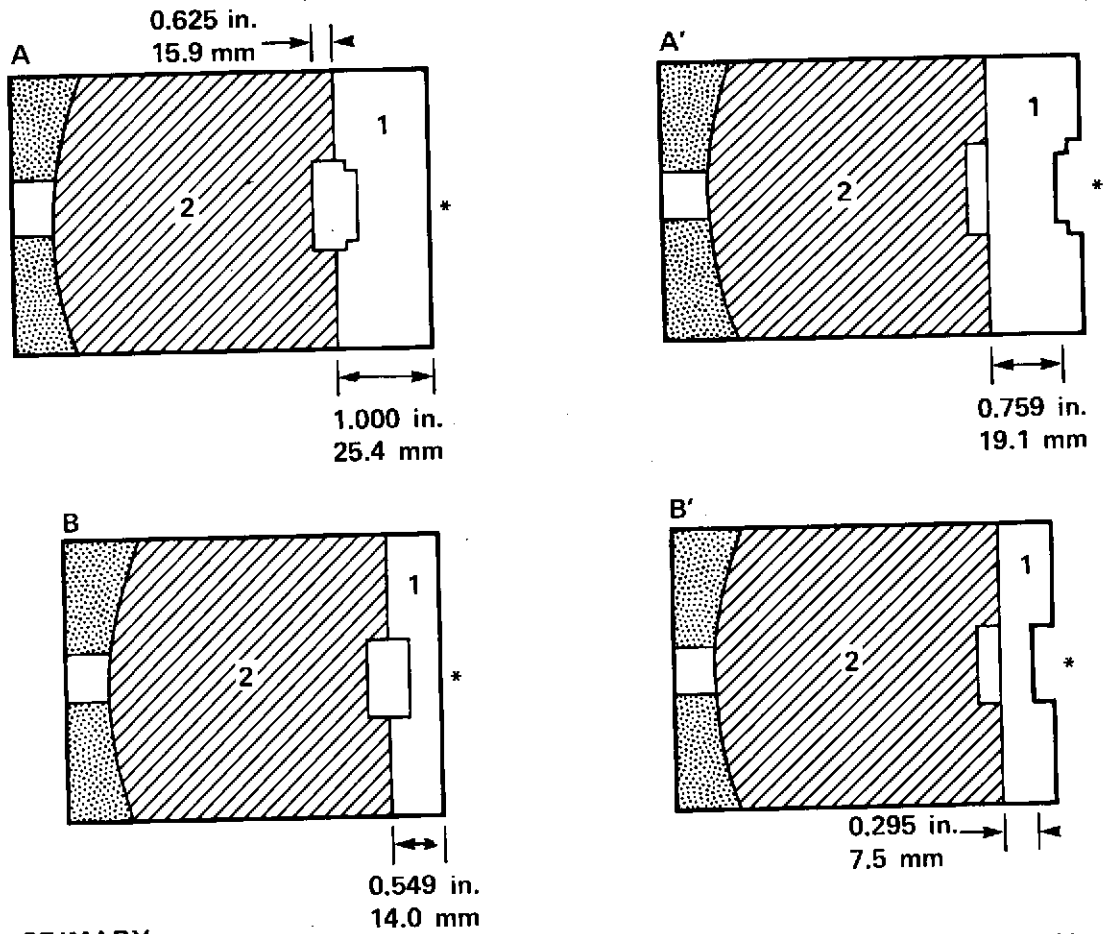


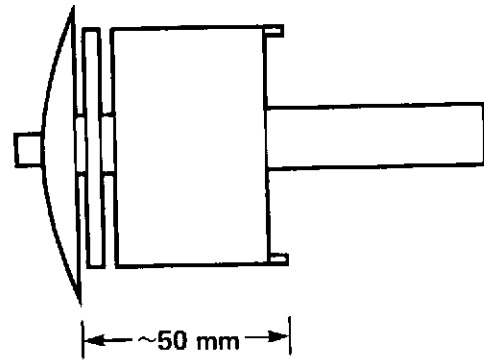
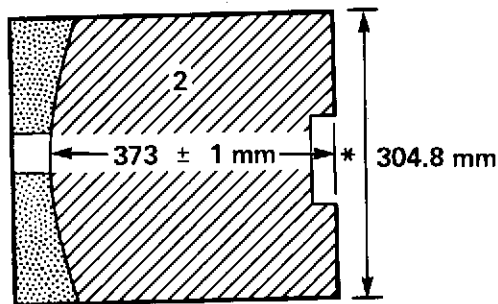
Figure 12.— Lear Jet telescope: exterior view showing oscillating secondary mechanism.

AVAILABLE SPACERS



PRIMARY

CHOPPER ASSEMBLY



* SPIDER MOUNTS HERE
 1 SPACER
 2 TELESCOPE BARREL

THE DISTANCE BETWEEN THE SPIDER AND THE TELESCOPE BARREL MAY BE VARIED BY SELECTING ONE OF THE FIVE SPACER CONFIGURATIONS AS SHOWN IN THIS FIGURE.
 THE SPACERS A,A' AND B,B' ARE THE SAME BUT INVERTED

Figure 13.— Available spacers.

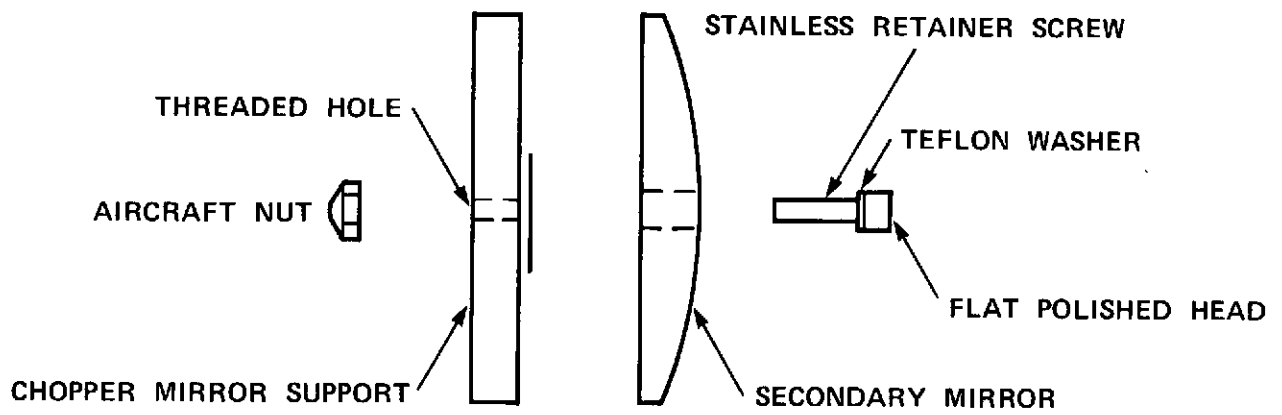


Figure 14.— Secondary mirror support.

III.C Checking Chopper Alignment

Viewed from about four feet behind the back plate, the secondary has the following appearance:

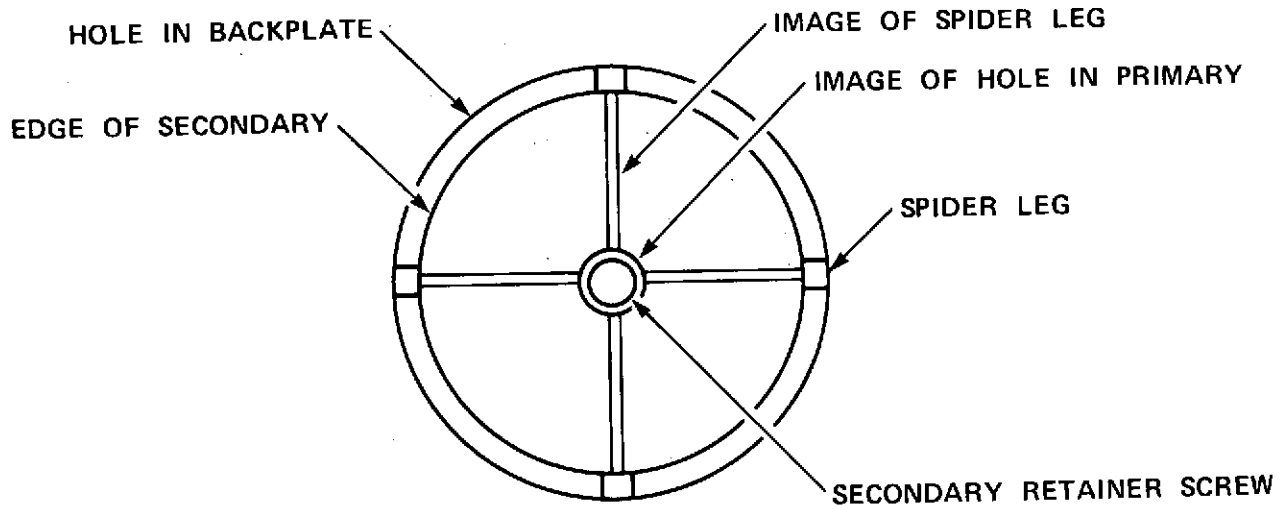


Figure 15.— View of secondary during optical adjustments.

Place your eye in such a position that the hole in the back plate and the edge of the secondary are concentric. When the assembly is aligned and when the chopper is in the middle of its throw the secondary retainer screw head and the image of the primary hole are also concentric. Moving the chopper from one beam to the other then moves the image of the hole in the primary symmetrically back and forth with respect to the screw head and moves the image of the vertical spider leg back and forth relative to the vertical spider leg. The chopper-driver circuit can be used to hold the mirror in either position for extended periods in the "LOW" current drive position. Sensitivity of this method is about $\pm 1/2$ arc min. Misalignments on the order of 1 arc min have not been found to affect offset signals appreciably in the 27-120 μ range. Adjustment of the Chopper Alignment is achieved by resetting the Chopper Throw Adjustment.

III.D Setting the Chopper Throw and Alignment

A gap in the chopper throw adjustment of X in thousandths of an inch results in a total chopper throw angle of 2θ , where

$$2\theta \approx 2.5 X \text{ arc min}$$

The relation between the chopper throw θ and γ = beam throw in the sky (relative to the telescope axis) is given in the Optics Information Sheet (figure 10). There are several models of chopper presently used. The chopper adjustment procedure, figure 16, shows the mechanical details for adjusting the throw and alignment.

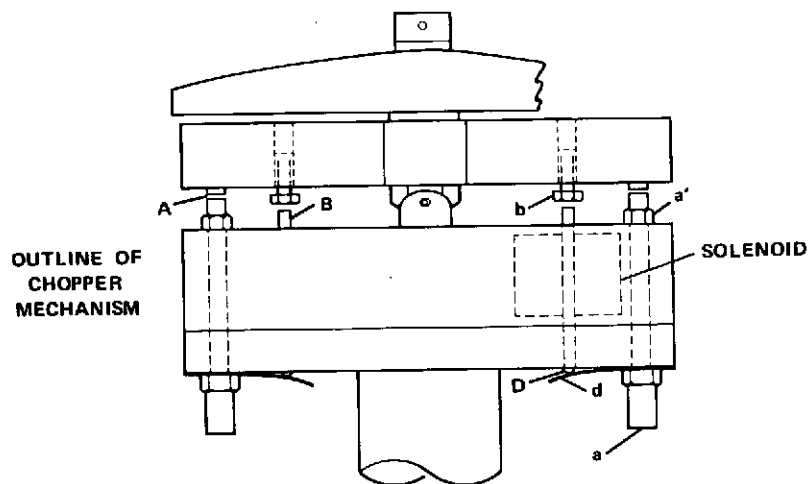
III.E Focusing the Telescope

The focal plane of the telescope can be moved by manually moving the secondary mirror in and out. The position for the secondary, Z_s , may be calculated as indicated on the Optics Information sheet and in Section III A, equation 5. A measuring device can be used to obtain an approximate value for the primary-secondary distance. An adapter holding an eyepiece identical to the eyepiece of the spotting scope can be mounted on the back plate of the primary mirror. With the reticle at the desired position of the focal plane, the secondary mirror is moved in and out until the image of an object at infinity is in focus. The depth of focus is about ± 4 mm.

The focusing mechanism is depicted in figure 17. To focus the telescope, the Guide Screw and Lock Nut should be loosened, the four Locking Screws removed, and the Adjusting Nut rotated. When correct focus has been obtained, the Guide Screw, Locking Screws, and Lock Nut must be tightened and safety wired.

CHOPPER ADJUSTMENT PROCEDURE

TOOLS: LONG SHANK 7/16 in (NUT DRIVER)
7/32 & 1/4 in OPEN END WRENCHES



There are two adjustments on each side, A: chopper-throw, and B: solenoid stop. After the desired throw is obtained, the solenoid stops must be adjusted so that the solenoid push-rods almost (but not quite) "bottom out". Some models of chopper do not have solenoid stop adjustments.

A. Chopper throw and alignment adjustment

1. Adjust the chopper throw to give the desired value and alignment using the adjustment screw a and lock-nut a'. The choppers which do not have a lock-nut a', have permanent nylon screw locking the adjustment screw a.

B. Solenoid push rod adjustment (some choppers do not have push rod adjustments)

1. Actuate one of the solenoid push-rods D by turning the chopper driver on "LOW" so as to close the gap A on the opposite side. Hold the mirror support to keep the gap A shut.
2. Loosen the stop-screw b until there is a gap B between the end of the stop screw and the end of the solenoid push-rod.
3. Keeping the throw-gap A closed and the opposite solenoid push-rod D depressed, advance the stop-screw b until it is $\approx 1/4$ turn beyond the position at which it contacts the end of the push-rod at B. This ensures that the push-rod is not "bottomed out".
4. Repeat B1-B3 on the other side
5. If chopper sounds erratic after this procedure, it is usually because one of the stop screws b needs to be advanced so as to further decrease the gap B.

Figure 16.— Chopper adjustment procedure.

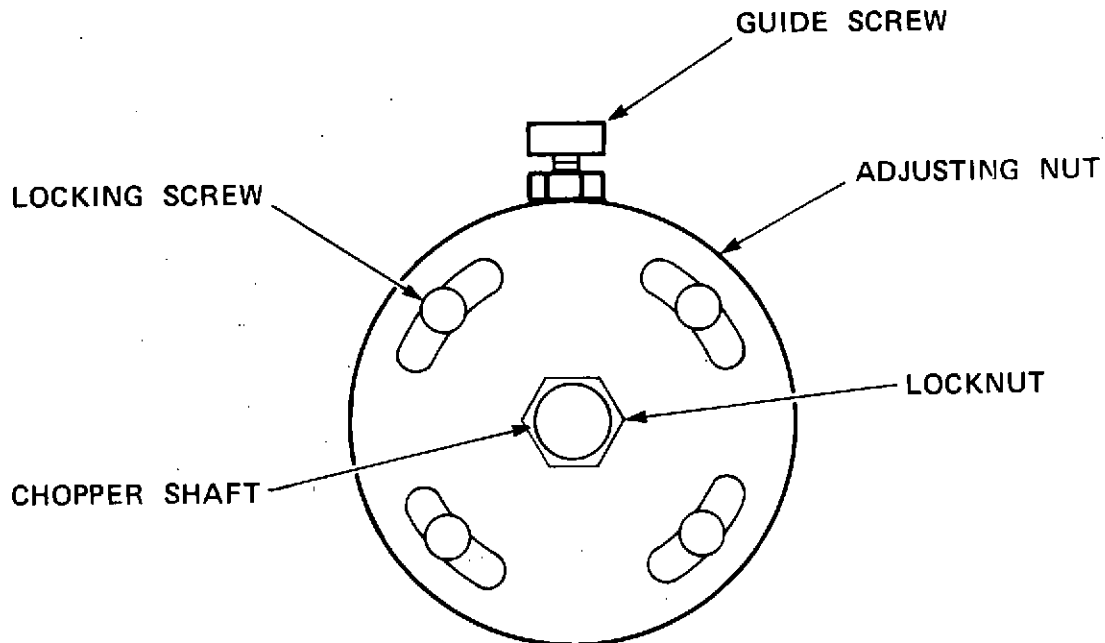


Figure 17.— Focusing mechanism seen from the rear.

The best object to focus on is a star. Alternatively, one can install a focusing adapter in the desired image plane. This adapter consists of a small light and screen which is mounted in the eyepiece adapter. By pointing the telescope at a first surface plane mirror, the image of the small light will be in focus on the screen when the telescope is properly focused.

III.F Boresighting the Guide Scope

This is best done using a distant point object (star) which can be detected with the detector and seen in the guide scope. Regrettably this often is not possible from the ground, so one arranges to view an optical image at a position corresponding to that of the detector. The eyepiece adapter which mounts on the back plate can be used, but it is usually more satisfactory to have a reticle which mounts at the detector position for the instrument being used. A distant light can be used as an object, but one should estimate the resulting parallax error. A boresight target is available in the hangar for use in inclement weather; to use this target,

the main telescope is aimed at the light and the guide scope aimed at the cross. The separation between the axes of the guide scope and the main telescope is 32.4 cm (12 3/4 in.).

The boresight procedure consists of establishing a convenient correlation between the detector and guide-scope image fields. If a fixed object is used, the variable boresight shims on the telescope can be used to clamp the telescope in position. The guide scope Lock Adjustment is then loosened and the Roll and Yaw Adjustments turned until the image is located at the desired position on the guide-scope reticle. The image should be checked for both right and left beams. Nominally, the image for each beam is located near a convenient fiducial mark on the reticle.

IV. Guidance System Operation

A. Telescope Stabilization Electronics (see figure 8).

The guidance system will perform properly only when the telescope is balanced. The balancing procedure may be found under the section II.E Telescope Balance. Normally for sensor assemblies between 9 and 18 kg (20 and 40 lb), the "Gain" and "Phase" controls will be set to 12 o'clock. If the telescope response is either underdamped or overdamped, adjustment of the phase and gain controls is necessary.

The phase and gain controls vary the coefficients of the damping and restoring force terms for the second order differential equation describing the motion of the telescope. However, these controls are not independent of one another and one must vary them in an iterative process to find the settings for critical damping.

The gain control should be increased (clockwise) for a heavier instrumental package or decreased (counterclockwise) for a lighter instrumental package. Then the phase control should be varied until the telescope response is critically damped. It may be necessary to repeat this process several times.

1. Verify telescope balance.
2. Check that all cables are connected.
3. Check that the motion of the telescope is unrestricted.
4. Turn power on using "Power" switch. Both heater lights are on continuously.
5. Wait approximately 20 min until both "SPIN MOTORS" indicators are lit (Heater lights cycling).

6. Hand guide telescope to desired object.
7. Press Roll and Yaw "HOLD" buttons. The "HOLD" switches are interlocked off unless the "SPINMOTOR" lights are on.
8. The telescope will hold until the object is beyond the limits of the telescope travel (LIMIT light on continuously, "POWER OUTPUT" lights on bright).
9. Press "HOLD" buttons turning off servo system (HOLD switch lights off).

The "POWER OUTPUT" lights monitor the torque motor amplifier outputs and should not be on bright continuously.

B. Joystick Assembly

The joystick assembly consists of a pressure sensitive rod for telescope pointing, roll and yaw drift controls, four switches controlling joystick and drift control sense, and remote "HOLD" and "CAGE" switches for the servo system.

The drift controls are set by observing an object while the telescope is in "HOLD". The controls are set to give no motion in the field-of-view. Once set, locking pins on the controls are set.

The Joystick, with no pressure applied, should cause no movement in the field-of-view. If motion is observed the drift controls require readjustment. With light pressure on the control stick the field-of-view will move slowly. The rate of movement is proportional to the pressure applied to the control stick.

C. Gyro Orientation

Each guidance gyroscope provides a voltage output to the servo system error amplifier proportional to the angular deflection about that gyroscope's sensitive axis. Angular deflections on the axes orthogonal to the sensitive

axis produce no output. The definition of the sensitive axis of the gyroscope is shown in the figure 18. Note the two notches in the brass ring on the gyro. The notch located 90° from the cable defines one point on the sensitive axis. The second notch, opposite the cable, defines the normal to the sensitive axis. When the gyro is mounted on a gimballed surface the sensitive axis must be parallel to the axis of rotation of that gimbal. The gyro mounted on the back surface of the telescope is the yaw gyro. The roll gyro is mounted to the gimbal ring.

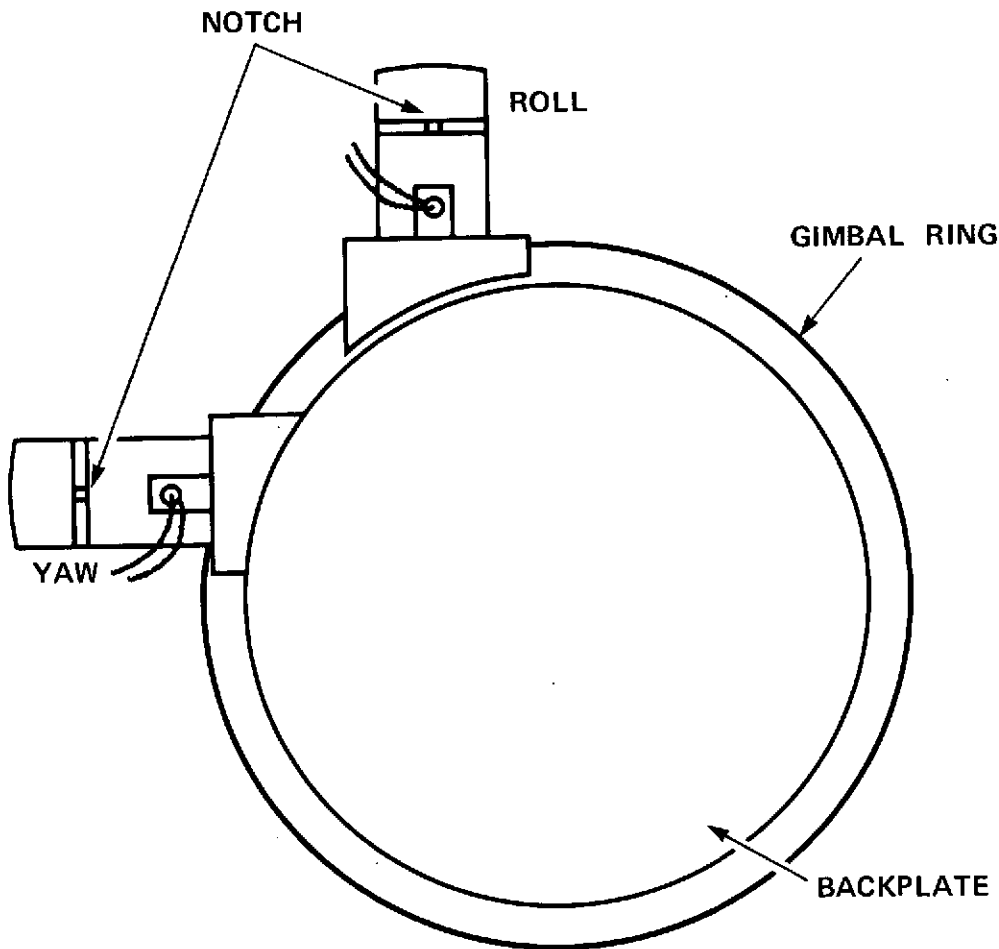


Figure 18.- Schematic of the sensitive gyro axes.

If cross-coupling (i.e., aircraft roll causing telescope yaw or conversely) occurs then the gimbal axes are not parallel to the gyroscope sensitive axes.

D. Telescope Attitude Indication

Potentiometers on the Torque Motors sense the attitude of the telescope relative to the roll and yaw limit positions. The attitude is indicated by meters on the front of the telescope stabilization package and remote meters on the umbilical, and can be calibrated by swinging the telescope from stop to stop using adjustments on the front panel. A limit light indicates when the telescope is near limiting positions.

The true and mean telescope elevations are given by indicators mounted on the telescope as shown in figure 3.

E. Test Box

The test box can be connected to the front of the Telescope Stabilization Electronics (see figure 8) to bring out the voltages from the Roll and Yaw power amplifiers and the error amplifier signals. A selection switch allows the various signals to be presented across a two terminal type GR connector. An oscilloscope or voltmeter can be used to monitor the voltages at the terminal posts. Due to the nature of the signals being monitored the measuring instrument must be floating. DO NOT GROUND EITHER TEST BOX OUTPUT.

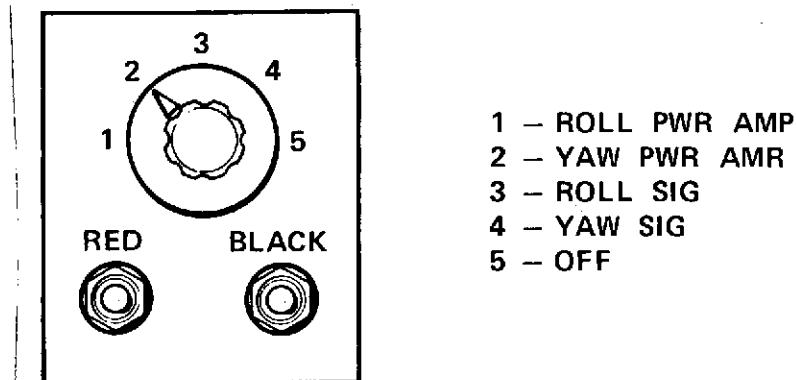


Figure 19.— Test box for the telescope stabilization electronics.

When the selection switch is in the PWR AMP position the voltage across the torque motor is monitored. If the telescope is balanced, and in HOLD, the voltage will be less than 0.5 volt. When a force is applied to the telescope this voltage will increase to approximately 24 volts with a polarity dependent on the direction of the force. The voltage may be used as an indication of balance. Weights should be adjusted to prevent the voltage from exceeding 2 to 3 volts in HOLD when the telescope is static. For proper operation the voltage should not contain ripple exceeding 2 to 3 volts nor should it show evidence of oscillation.

When the selection switch is in the SIG position the error amplifier output is monitored. This voltage, in either the HOLD or CAGE mode should be less than 0.5 volt when the telescope is static. For proper operation the output of the error amplifier should show no oscillations nor excessive DC offset (less than 0.05 volt). The voltage output from the error amplifier should not change when the gain control or phase control on the front panel of the Guidance Unit is changed.

F. Trouble Shooting

A Telescope Guidance Servo System Manual with a detailed description of the electronics is available for finding and repairing electronics malfunctions.

V. Airborne Operation

A. Remarks

A checklist for a typical infrared astronomy mission aboard the Lear Jet is given here as an example of the procedure which, with minor modifications, should be followed by most investigators. Many of the items on the list are related to safety and operation of the experimenters' equipment. However the sequence shown indicates how the operation of the telescope is integrated into a normal investigation.

In addition, a trouble-shooting list which covers the most common problems encountered during a flight is included. Again, many of the items do not concern the telescope. Experience has shown that such a list is often helpful in sorting out problems which arise during a Lear Jet observation.

These lists are presented as guidelines only. Experimenters often generate check lists appropriate to their particular investigation. However, the items on the lists presented here which are associated with the telescope and safety should be included in any such list.

B. Check List

- T - 6 hours
1. Fuel aircraft, fill oxygen tanks
 2. Check inventory: tools, strip chart paper & ink, magnetic tape, finding chart, flight plan
 3. Get personnel to check out oxygen masks
- T - 3 hours
- Final fill with liquid He, start pump-down in airplane
- T - 1 hour
1. Check tape and strip chart calibration
 2. Check chopper and turn off
 3. Check intercom to tape recorder, using headsets
 4. Turn on telescope electronics to start gyro warmup
 5. Check adjustment of attitude meters
 6. Check preamp gain, batteries
 7. Record D.C. voltage on detector
- T - 1/2 hour
1. Turn on system except chopper
 2. Check stabilization on "HOLD", and adjust drift if ≥ 10 arc min/min
 3. Cage gyros (turn off HOLD lights)
 4. Record noise out of preamp and phase-lock amplifier with chopper off and on
 5. Check hand signal
 6. Check phase, set gain to measure noise
 7. Spectrometer on starting position
 8. Check safety wires on chopper, spider, and telescope
 9. Check that racks are secure

10. Adjust Elevation Angle Adapter to position telescope for initial observing elevation angle
 11. Check that there is no loose equipment or tools
 12. Check availability of spare masks
- T - 1/4 hour
1. Start strip chart on slow speed
 2. Chopper on "Low"
 3. Put on and test oxygen masks and head sets. (Observer install ear phone)
 4. Fasten seat belts
 5. Review emergency procedures list provided by pilots
- Takeoff
1. Gyros on and caged
 2. Electronics on
 3. Strip chart running, slow speed
 4. Hang on to telescope to prevent bumping
- T + 5 min Ascent
1. Request pilot permission to take off seat belts
 2. Check proper operation of masks periodically
 3. Avoid pointing telescope at sun
 4. Turn chopper on "high"
 5. Adjust telescope balance (remove typically ~ 1 kg or 2 lb)
 6. Check blast tube output on guidescope window
 7. Record temperature, altitude, Mach No. and detector noise periodically, say every km or 3000 ft.
 8. Check and record cabin pressure differential (~4 psi) detector pressure, D.C. voltage on detector

9. Check drift in telescope by guiding on a star
10. Check yaw and roll meter calibration for pilots

T + 30 min

On course

1. Request pilot turn off beacon
2. Start recorder
3. Acquire source in finder telescope
4. Request pilot to orient aircraft to zero yaw meter
5. Center object in yaw and tell pilots to follow yaw meter
6. Put gyros on hold
7. Reacquire source and check boresight (left and right)
8. Adjust gain and offset, check phase
9. Hold on object in right beam and left beam to check pointing and stability for duration of a scan
10. Adjust mean telescope elevation to keep object centered in roll
11. Cage gyros when telescope has been on stops more than 10 sec

Between objects/end of observations

1. Put gyros on cage
2. Watch sun position
3. Record altitude, temperature, Mach No., cabin pressure
4. Record detector pressure, noise, & D.C. voltage
5. Turn off recorder
6. Turn system power off except GYROS
7. Valve off detector

8. Watch detector pressure
9. Secure all loose equipment
10. Fasten seat belts
11. Write summary note describing flight

Landing

1. Hold telescope to prevent BUMPING!
2. Turn off gyro power only after aircraft has stopped moving

Post flight

1. Stay with dewar until up to atmosphere
2. Complete flight summary note
3. Cover telescope

Trouble shooting

1. Object not in guidescope field-of-view (FOV)
 - a. Focus guidescope. (If daytime, bank aircraft and focus on ground.)
 - b. Scan guidescope FOV with gimbals (1) centered, (2) full right, (3) full left, (4) full up, (5) full down
 - c. Request pilot verification of adherence to flight plan
 - d. After 5 minutes on published heading, request 3° right turn, repeat b; then 6° left turn, repeat b
2. No signal from object
 - a. Thump bias box or dewar to produce microphonics

- b. Ground preamp input to see if noise changes
 - c. Check preamp settings
 - d. Check detector pressure
 - e. Measure detector bias voltage
 - f. Check phase lock: gain, phase, time constant
 - g. Verify chopper is operating
 - h. Search vicinity of nominal boresight
3. Excessive noise:
- a. Check noise with preamp input shorted
 - b. Check noise with detector bias off
 - c. Check noise with chopper off
 - d. Check noise with gyros off
 - e. Try another chopper speed
 - f. Check for correct phase, time constant on phase lock
 - g. Try damping telescope vibrations with hand
 - h. Try grounding preamp, phase-lock input, etc. with clip lead
4. Telescope sticks in gimbals:
- a. Check cabin pressure differential is 4 psi
 - b. Look for mechanical restrictions near underside of telescope
5. Telescope elevation adapter sticks
- a. DO NOT FORCE TURNBUCKLE!
 - b. Check boot; if stuck in air seal, back off turnbuckle and try to remove boot from air seal manually