THE DESIGN AND DESCRIPTION OF A 300-1200 Å

STELLAR SPECTROGRAPH

Neil A. Hochgraf and Roman Kucil

Final report, supervised by Dr. Robert E. Hopkins, performed for the National Aeronautics and Space Administration under Contract NASr-14

Institute of Optics

University of Rochester

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ABSTRACT

This report is a feature and performance presentation of a superior single surface concave grating stellar spectrograph for the vacuum ultraviolet region having 1 Å resolution, f/5.5 optical speed and being an experimentally complete self-contained instrument except for a 24 v dc power supply. The 11 inch high x fifteen inch diameter spectrograph is described in a report containing lucid and capsule discussion of the Optics (brief), Mechanics, Electronics, Optical Alignment, Processing-Handling of the film. The design strategies, physical form, and the operation and performance of the individual features are given together. The optical and mechanical form of the described instrument should be considered standards and worthy of scaling or copying. The optical and mechanical designs are highly developed and residual errors are also cited along with appropriate corrections. This rocket spectrograph design is capable of operating very satisfactorily in different spectral regions, with different grating apertures and radii, different grating film plane-order formats as well as with vastly different exposure times or multiples of nine stellar exposures. These features are available with minor change while the optical performance can

be substantially improved by the built-in grating warping feature. This rugged 24# magnesium flight package has convenient adjustment, dependable alignment and ease of service with attention given to foolproof design so as to give first quality data everytime.

The stellar spectrograph project was supported by Contract NASr-14 from the National Aeronautics and Space Administration and was carried out under the direction of Robert E. Hopkins.

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HISTORY of the U. of R. no. 2, 300-1200Å Stellar Spectrograph for a NASA Aerobee Rocket.

The project at least the optical part of it, was started by Dr. Murty who suggested the use of the minus one order objective type optical arrangement for the spectrograph as one fast in optical speed and possible of having high wavelength resolution by minimizing astigmatism. The original specifications were for better than 50Å resolution and better than f/8. The experiment was to be piggybacked and look out of the side of an Aerobee rocket. These specifications and initial impetus for the project came from Mr. T. Stecker of Goddard Space Flight Center. Spryt Ray tracing by R. Mostrum of a -1 order system using a standard grating revealed that 5-7Å resolution was possible. Mechanical conceptual design was by N. Hochgraf and R. Kucil. Mr. Kucil did, also, all the rigorous detailing and trigonometric checking that included the cassette's eccentric conical geometry. Mechanically Hochgraf and Kucil found that certain constructional constants prevented mechanical realization of a system using -1 order and $8^{\circ}17'$ incident angle and a standard grating that was wider than tall (50 mm x 30 mm).

The mechanical design group deduced that the best improvement to the mechanical problems could be by keeping the same f/5.5 f-number and make the grating tall and narrow. The new aperture format gave sufficient mechanical room between the entrance angle baffle and the wall of the film cassette. Checking with H. Beutler's "The Theory of the Concave Grating" paper in JOSA revealed that in fact this tall narrow grating optical arrangement incurred much less optical aberration. Mostrum ray traced this system for $\pm 1^{\circ}$ field and showed that about 1 Å resolution was to be expected. Such a grating was ordered from the Bausch & Lomb Co. through the efforts of the late Dr. D. Richardson. The grating was successfully delivered after only one ruling attempt despite the nominal 2° blaze angle and the large sag. of the 500 mm radius in the f/3.3 direction. To speed delivery of the replica gratings thin rectangular master and replica blanks were rapidly fabricated by Mr. Graf and Mr. Klinkert of the U. of R. Optical Shop.

Some construction of the instrument was done in the U. of R. with the cassette and its eccentric conical structure by P. Borrelli while the cassette cover and shutter gearing-cam structure were fabricated by J. Moore and the baffle drive by W. Johnson.

Outside vendors were used for the larger machining and

for special welding skills. The Genesee Tool and Die Corp. jigged and welded the entrance angle baffle from .004" stainless steel stock.

The A.J. Ketter Machine Corp. made the outer case casting that became the rocket extension including the tricky hardened curved door spring-hinges.

All the prototype's rather extensive photographic vacuum ultraviolet work, including focusing, was done by D. Baumgardner. His patience and persistance while the mechanics were being optically tested is appreciated. In particular, the spectra he obtained gave final incentive to complete the project and use the instrument. Mr. Baumgardner also fabricated and double checked on the electrical control package.

Though we have noted the many people and their special and significant contributions to this project this has not been a committee design. Each person and vendor had responsibility for his part which used his special skills to complete the total package. The judicially picked concept, allowing modification, that is methodically and skillfully instrumented and is realistically tested and debugged, gives the substantial foundation for an experiment

that works the first time and has many lives in reuse. Such instruments are pace setting in that they efficiently collect data and do not allow the scientist to think that engineering is a substitute for his original experiment in physics.

I INTRODUCTION

The University of Rochester Spectrograph is designed to be a rugged Aerobee flight package having convenient adjustment, dependability of alignment and ease of service. The Spectrograph is made mainly of magnesium and weighs about 24 lbs. It is composed of four basic constructional parts. These are: (1) the outer case and sturdy rocket extension (Aerobee 15" dia.), (2) the inner case or instrument cover including door and grating end castings, (3) the baffle and screw door drive-baffle extender, and finally (4) the grating holder and conical film cassette sub-assembly with grating to film spacing arms and built-in focal plane shutter. The most important film cassette sub-assembly (4) is mounted within the instrument cover. The instrument may be summarized as being of two gross units: outer case or rocket extension and the inner unit, the actual optical instrument.

II BRIEF OPTICAL DISCUSSION

The spectrograph optics were specially designed to give performance under the condition of stellar vacuum violet operation. The optics are of the objective type, being 1/2 of a Wadsworth mount. The tall and narrow grating aperture with the grating lines running in the tall direction gives the unusually good optical performance. The new (Fig. 1) grating aperture, as introduced by the mechanical design group, lessened construction clearance problems and improved optical performances of the instrument. The aperture of the grating (tall 75 mm x 20 mm wide) results from the fact that this grating aperture is better for an aberration limited spectrograph design than the standard grating formats. The unusual aperture gives rise to a focusing beam f/10 wide and f/3.33 high with an effective aperture of f/5.5 for a focal length of 250 mm. From the single concave spherical, 1200 ℓ/mm grating, giving 33Å/mm dispersion, with its effective f-number 5.5 resolution of 1Å is obtained over the spectral range of 200Å to 900Å while the images are still good at 300Å. The field of this instrument is plus and minus 1° vertically and horizontally. The optical layout is illustrated in $4118\text{-}A_1$

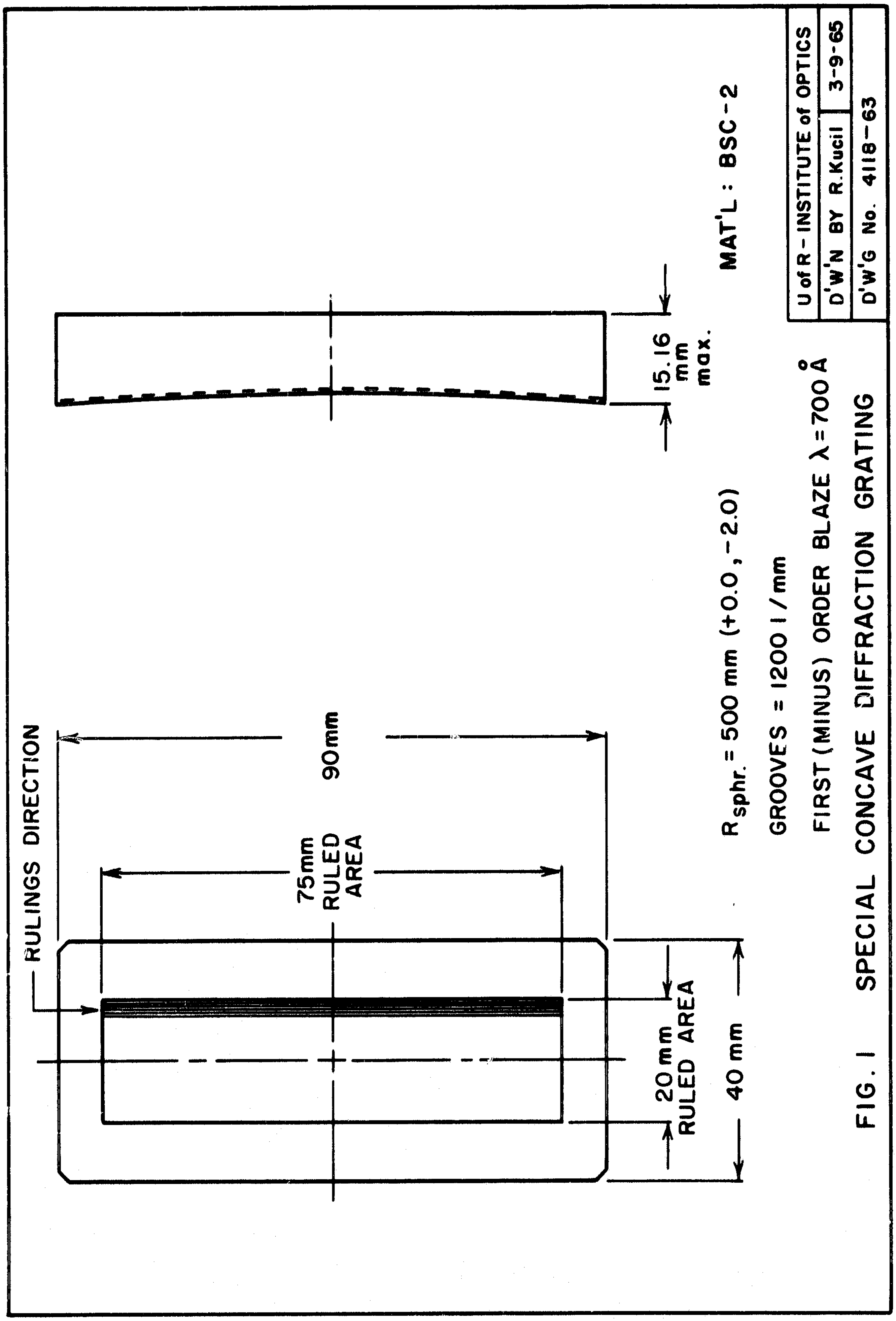
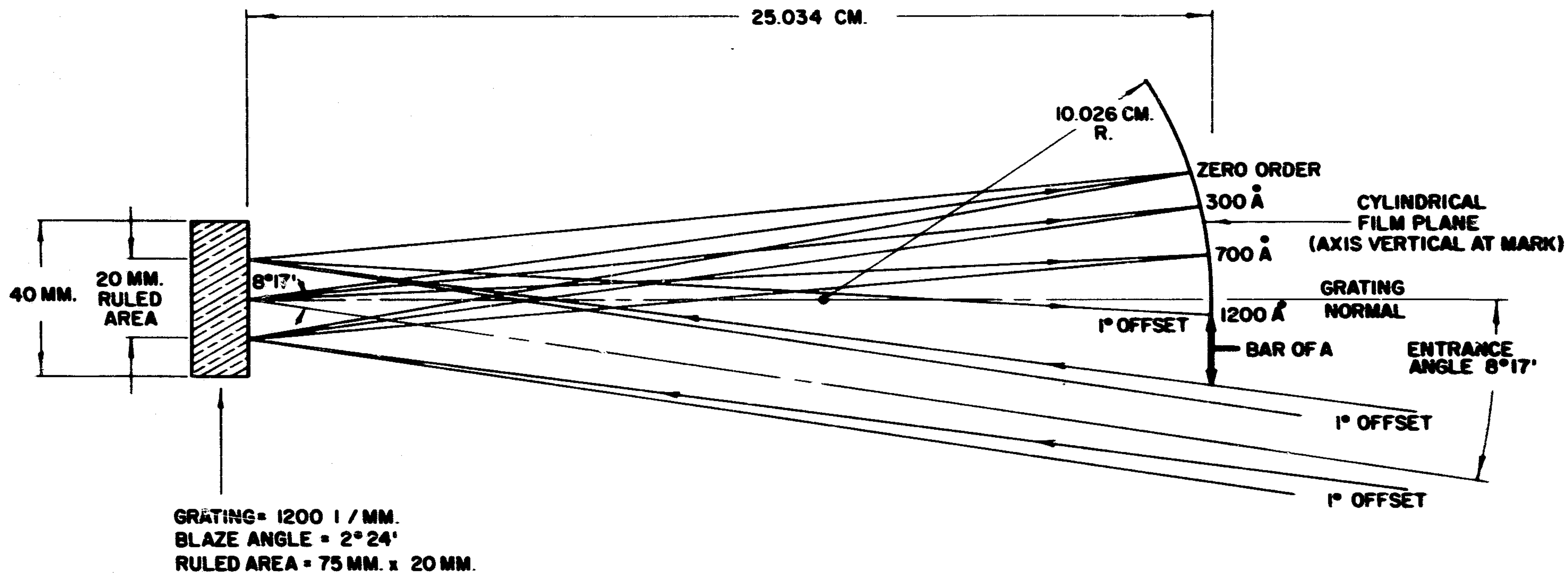


FIG. 1 SPECIAL CONCAVE DIFFRACTION GRATING

Fig. 1 while the formate difficulty and test spectra are shown in the photograph that composes Fig. 2. One may get a general view of the instrument from Fig. 3. The optical design of the instrument was done by Richard N. Mostrum for his master's thesis[1]. This work describes the basic optics and the optical potential still left in the optics, along with some rather early experimental results. Special attention should also be given to sections D and F of the thesis for implications on the improvement of the optical performance. There is a tall narrow arc shaped aperture which is even better for improved resolution and there is much that has been said on this and the problem of focusing for resolution or image intensity in the quarterly reports on this contract.

The baffle is a necessary device with the objective type instrument to limit the entrance field angles, especially in the direction of dispersion. The rectangular grating, and hence baffle aperture being narrow in this direction cuts down the chance of having two spectra overlaping and sheared in the wavelength direction. The diagram of the baffle used in this instrument is presented and is noted for its sharp cut-off brought about by the center baffle plate which is



TOP VIEW

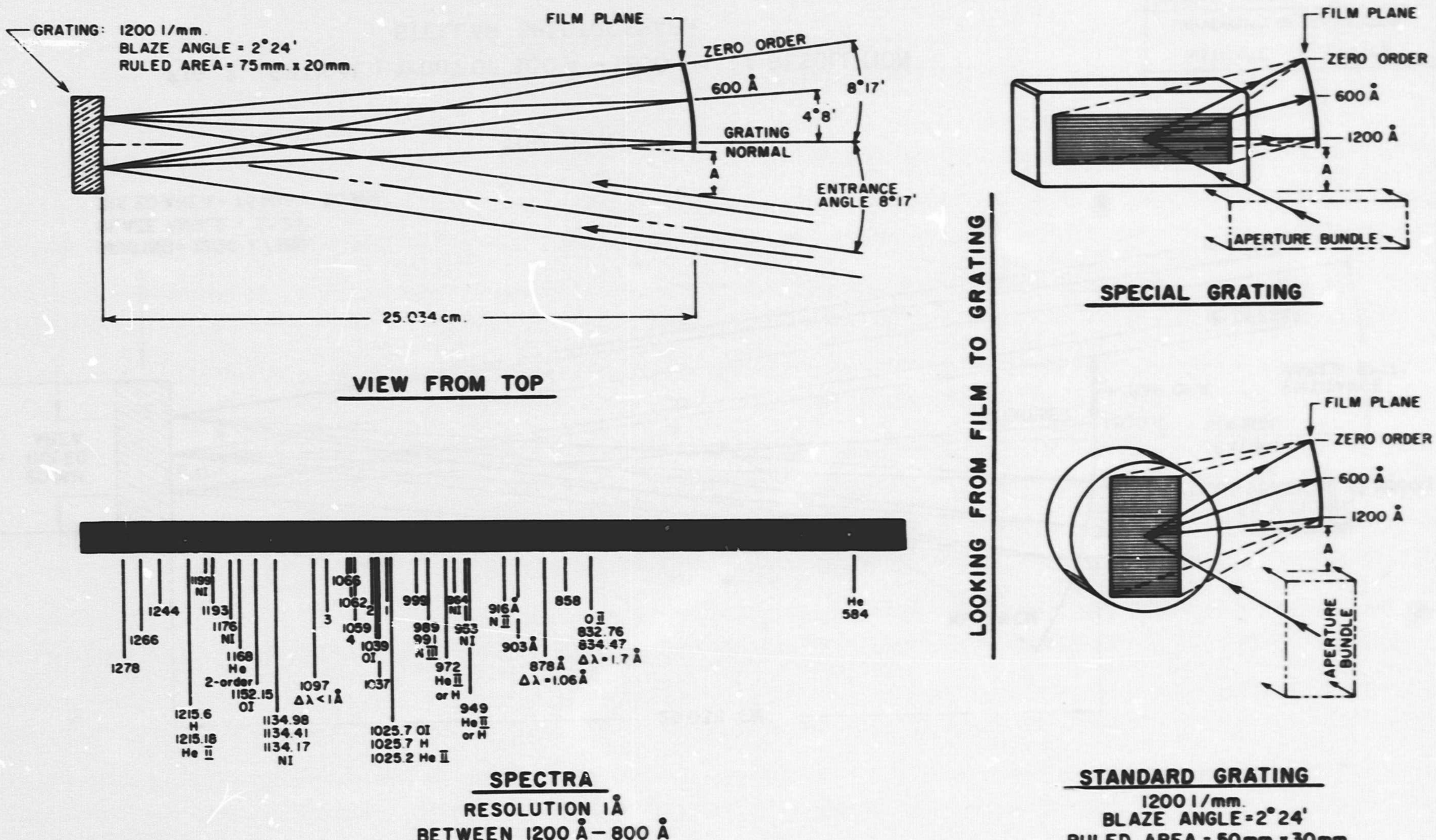
FIG. 2 OPTICAL LAYOUT OF 300 Å – 1200 Å ~ 1 Å RESOLUTION STELLAR SPECTROGRAPH

INSTITUTE OF OPTICS UNIVERSITY OF ROCHESTER	
OPTICAL LAYOUT	
DRAWN BY R. KUCIL	
DATE 10 - 28 - 65	SCALE FULL
DWG. NO. 4118 – A_1	

0-1200Å STELLAR SPECTROGRAPH

WADSWORTH TYPE, USING -1 ORDER

DESIGNED & CONSTRUCTED AT THE INSTITUTE OF OPTICS - U. of R.



N. HOCHGRAF & R. KUCIL

FIGURE 3

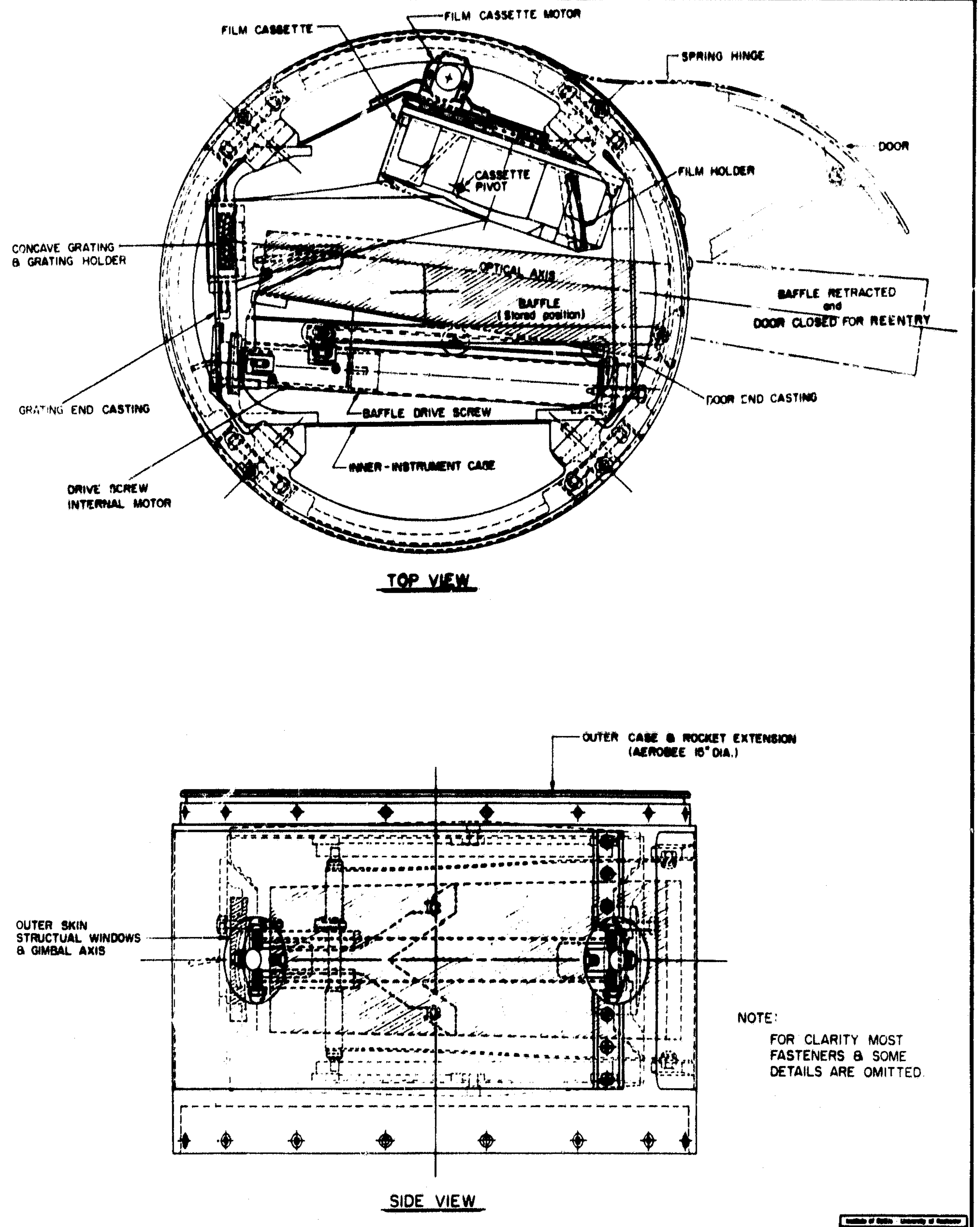
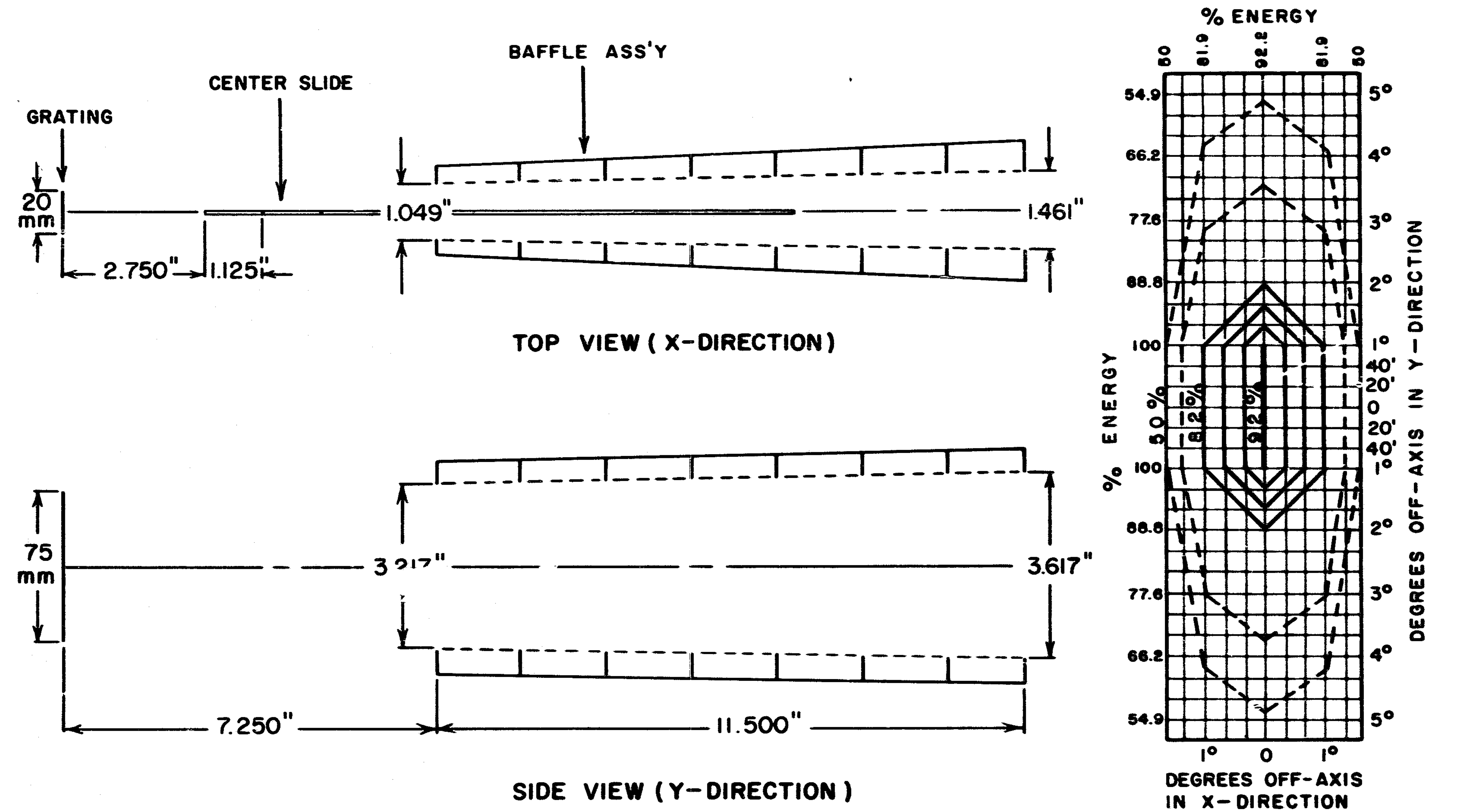


FIG. 4 300 Å-1200 Å STELLAR SPECTROGRAPH — OVERALL ASS'Y

retained as the outer baffle is extended. At about 1/4 power cut-off angles the off axis parallel light incident on the grating aperture is vignetted by this center venetian blind type baffle plate. The cut off function for this and 11 other baffles were found graphically and the integrated area intensity function versus angle were plotted and used in several revealing merit functions. These will not be discussed here but are mentioned to illustrate the importance and the stage of development that good baffle design entails. (See Fig. 5) Normally the outer most baffle aperture is larger than required so that its illuminated edges can not be seen by the grating. The second plate's edges protected by the first plate actually define the entrance angle field. On the second instrument reduced aperture plates for the outside and inside end of the baffle tube were supplied so as to reduce the field from $\pm 1^{o}$ to ± 20 min that the new tracking system could easily find and hold within. It is important to remember that off-axis light illuminates interior baffle edges and since their reflectivity or scattering reflectivity can not really be reduced, they must be made very thin so that the scattered off-axis optical noise light will be low. The aperture plates



VIGNETTING FUNCTION PLOT
VECTOR PRODUCT OF X·Y

FIG. 5 BAFFLE DESIGN (STYLE 12, WITH CENTER SLIDE, FOR ±1° OFF-AXIS ANGLE) were .004" thick stainless and of course the structure was blackened (but not by paint which would have increased the edge radius substantially).

This design as far as instrument aspect (ie. looking sideways from the 15" dia. rocket) has been out-dated by the operation of the new NASA STRAP semi TV pointing system which is potentially accurate to ±15 sec. of arc and requires an axial looking instrument. The optics may now be scaled up profitably, optical field format rearranged and the baffle replaced by a longer, more restricting one to reduce sky glow-optical fog.

Your attention is turned to the following sections, which describe the myriad of sound individual features realized from the cited instrument development strategies.

III MECHANICAL INFORMATION

1. Outer Case or Rocket Extension Description. See Fig. 6

The outer case or rocket extension is a sturdy cast unit composed of male and female Aerobee mounting rings with four spacing columns containing the gimbal windows. The short shaft gimbal axes support the instrument unit in three dimensions completely and nearly kinematically. The pair of screws Gimbal Push-lock Assemblies (vertical and horizontal) in the four windows allows translation of the instrument unit in three directions (useful only to give clearance to the instrument in the rocket casing) and allows the optical axis to be easily tilted $\pm 3.5^{\circ}$ from a sideways looking aspect. With some shortening of the adjusting screws, $\pm 5^{\circ}$ can be achieved. There is some support redundancy, especially in the axial support and rotation about the rocket axis. Positioning difficulties and Gimbal damage can be avoided by checking all screws, making a cyclic adjustment of all screws, and then tightening all screws. The screw assemblies are usually adjusted in pairs for the rotations which are the only meaningful motions for distant objects. The screw assemblies are composed of two cap nuts and a suitable length of screw stock threaded through the gimbal axis. Final adjustment should require and insure that all screws are equally loaded. Such loading is

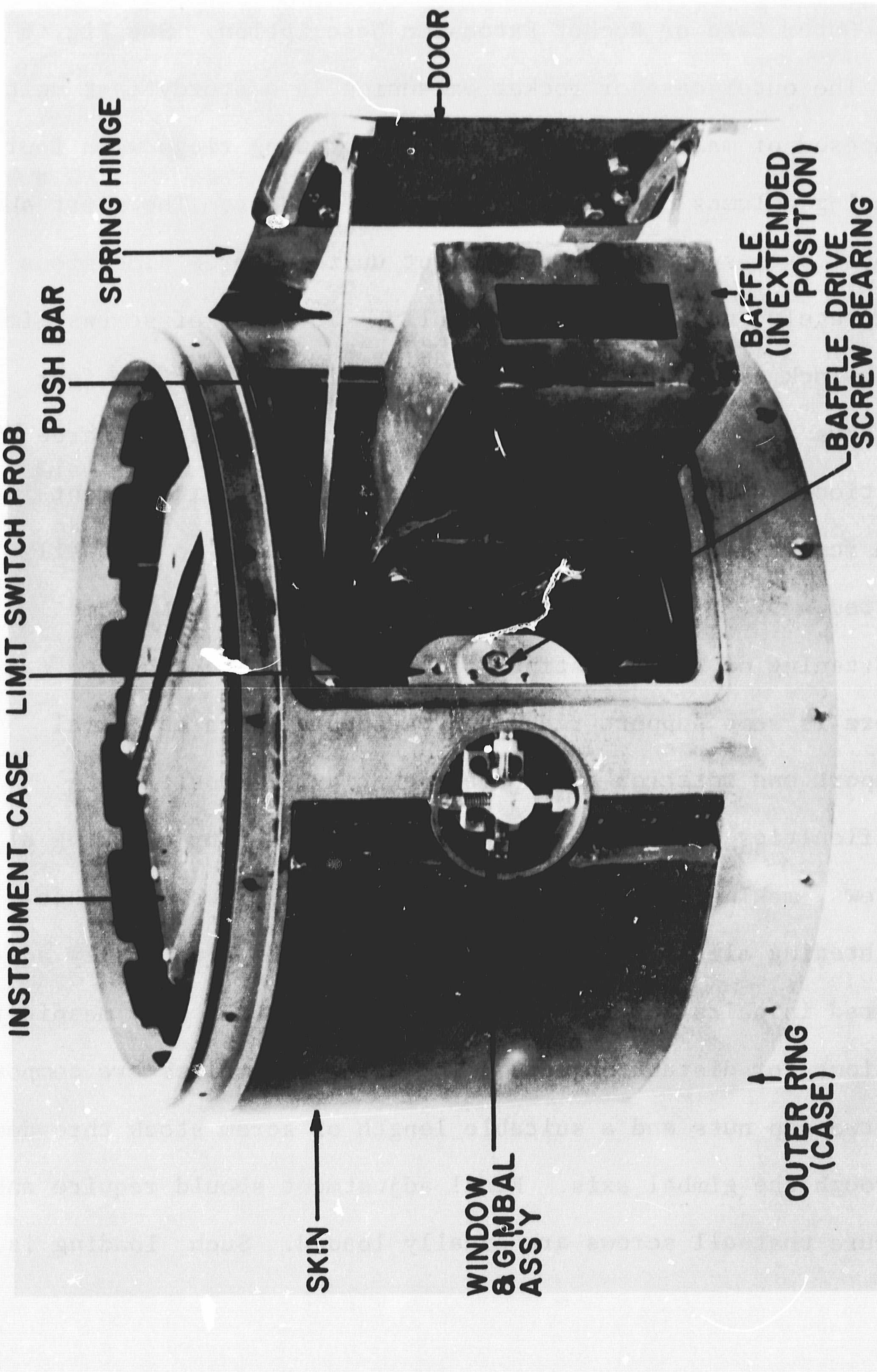


FIGURE 6 OUTER CASE OR ROCKET EXTENSION

accomplished by jamming the screw assemblies (expanded by unscrewing the cap) within the hardened cylindrical windows. All nuts should be turned off the gimbal screws an equal number of threads (≈ 2 turns each). For flight, the window may be covered by a disc using an appropriate eccentric central mounting hole in the gimbal end. The rocket extension has another feature which will be very useful to the experimenter . A non-structural skin covering 3/4ths of the circumference of the extension is removable even when the instrument is mounted in the rocket. The removal of the skin exposes almost all of the adjustments of the instrument package. (See next section.)

2. Service Access to Various Instrument Adjustments with the Skin Removed

Our convention for describing the instrument will be to refer all directions relative to looking back into the instrument through the door with the instrument's top towards the rocket nose.

To the left side of the door is the baffle drive screw and its front bearing block. This front bearing takes all thrust and most of the transverse loads. The front bearing block also carries the baffle outward limit switch probe. The baffle is positioned centrally in the door opening and can be extended some 9". See Fig. 7.

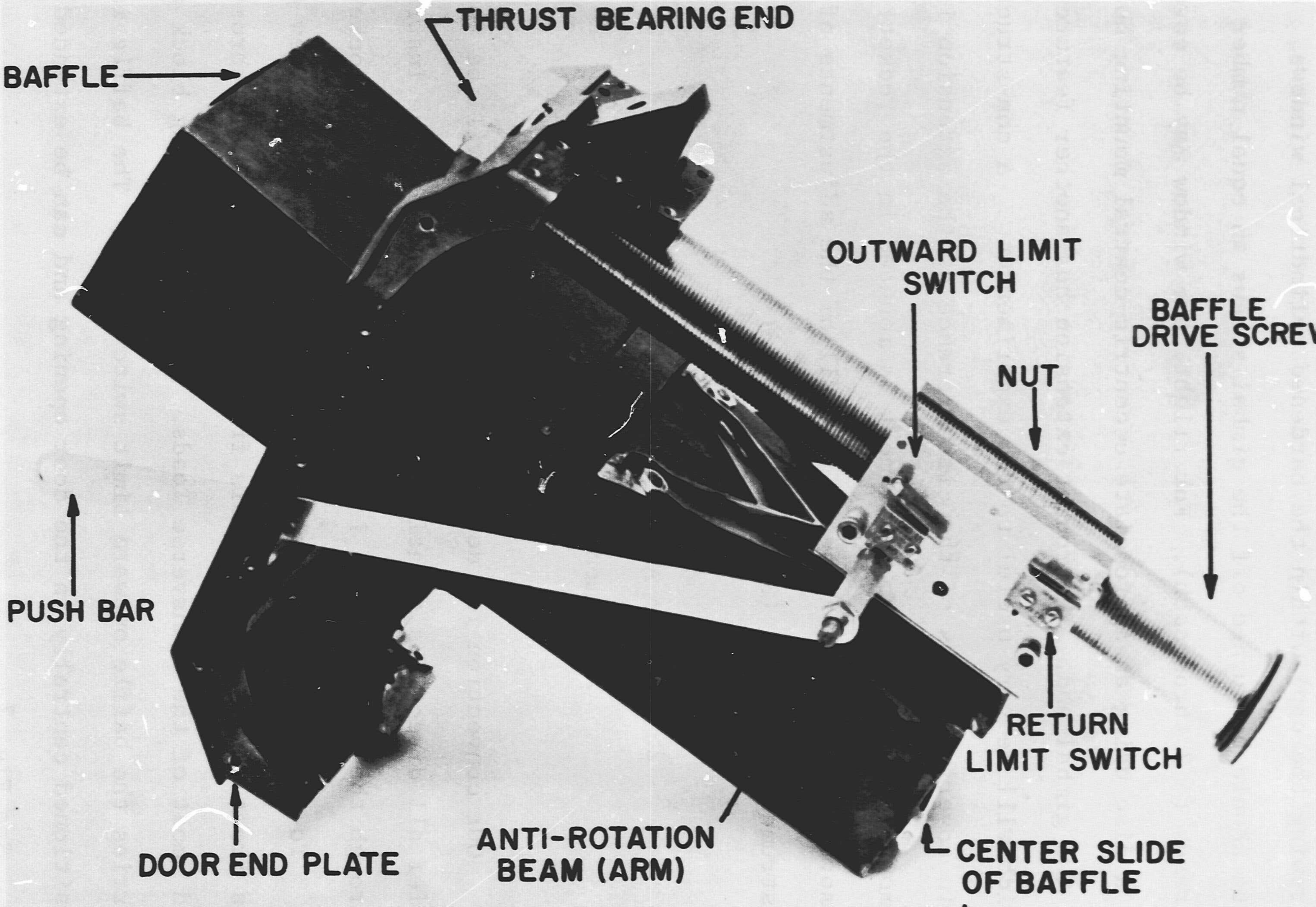


FIGURE 7 BAFFLE AND BAFFLE DRIVE ASS'Y

Baffle installation and removal can be accomplished in the 1/4 extended position (3/4 retracted position) by loosening the two nuts on its middle left side (when extended). The baffle must be retracted some 7" and then the center baffle slide retainer's (See Fig. 8) screws (only those nearest the grating) must be removed and the center baffle slide retainers must be spread apart from the rear. This releases the center baffle slides' pins. By pushing rearward on the baffle to the right 3/4", thereby releasing its rear slip mount, one may translate the baffle to the right 3/8" and bring it out. This center baffle plate is an optically valuable component and must be handled carefully (come lateral bending occurs on retraction).

With the baffle removed the anti-rotation arms and the door push-pull bars are easily examined. The anti-rotation tube arm is positioned in the nut, so as to load the nut centrally when the baffle is extended. The metal arm tube should clear the anti-rotation arm guide at all times by about 1/16", and even the plastic feet or inserts should clear the bottom of the guide by 1/16". Blind mounting holes in the guide track prevent it from being jammed by a long screw. The type of failure in which a loose or long object must be sheared has been given great attention in the design of all assemblies. Shear jaming or scraping is unfortunately possible in closed compact types of instruments.

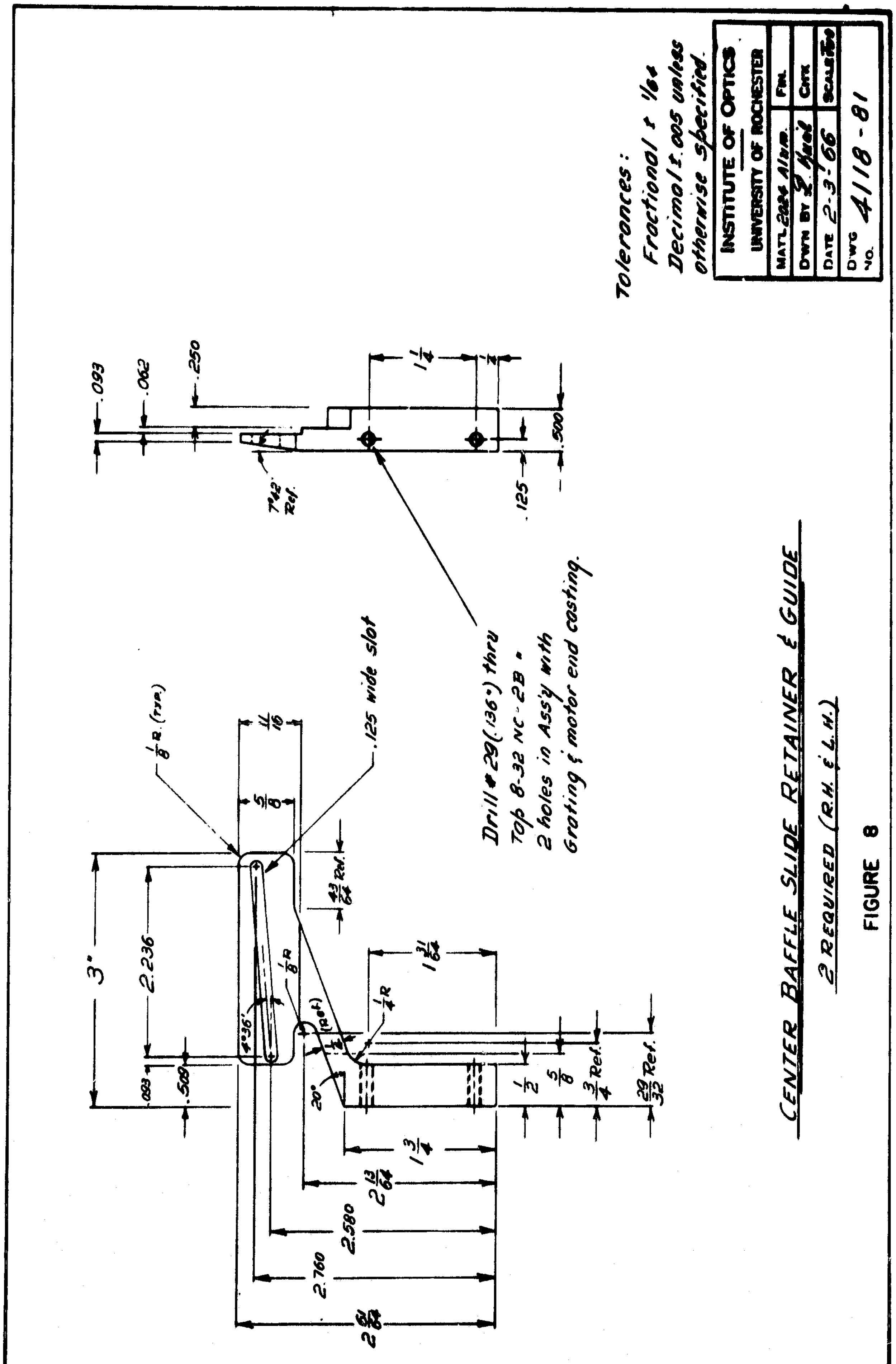

Tolerances:
Fractional ± 1/64
Decimal ±.005 unless otherwise specified.
INSTITUTE OF OPTICS
UNIVERSITY OF ROCHESTER
MAT'L 2024 Alum.
DRWN BY
DATE 2-3-66
DWG NO. 4118-81
Drill #29(.136") thru
Tap 8-32 NC-2B
2 holes in Ass'y with
Grating & motor end casting.
.125 wide slot
CENTER BAFFLE SLIDE RETAINER & GUIDE
2 REQUIRED (R.H. & L.H.)

FIGURE 8

3. Service Access, Grating End-Rear Side

On the grating end casting is the mount and wiring of the baffle lead screw motor, and next to it is the grating mount. The grating mount is removable from the back (four far corner screws). It may be adjusted in tilt $\pm 1^{o}$ about a vertical axis by two screw and spring return pairs (near its outer corners). The grating is held in from the back by eight filister screws and a front bracket or retainer mask.

4. Warping the Spherical Grating
See Fig. 9

A special feature of this grating mount (which has been unused to date) is a set of 12 screws[1] and spring plunger[2] pairs which allow bending or warping of the grating. These should result in straightening the cresent shaped images and then vertically compressing these images to effectively give at least twice the exposure presently available. This improved image intensity cannot be achieved so easily by varying any other instrument - optical parameter. The stress on the grating is well within the glass' elastic limits, and the use of these screws requires only that several more exposure runs be taken to bring about this new type of lateral focusing phenomena. (It should be noted

1 in grating back
2 in grating front cover

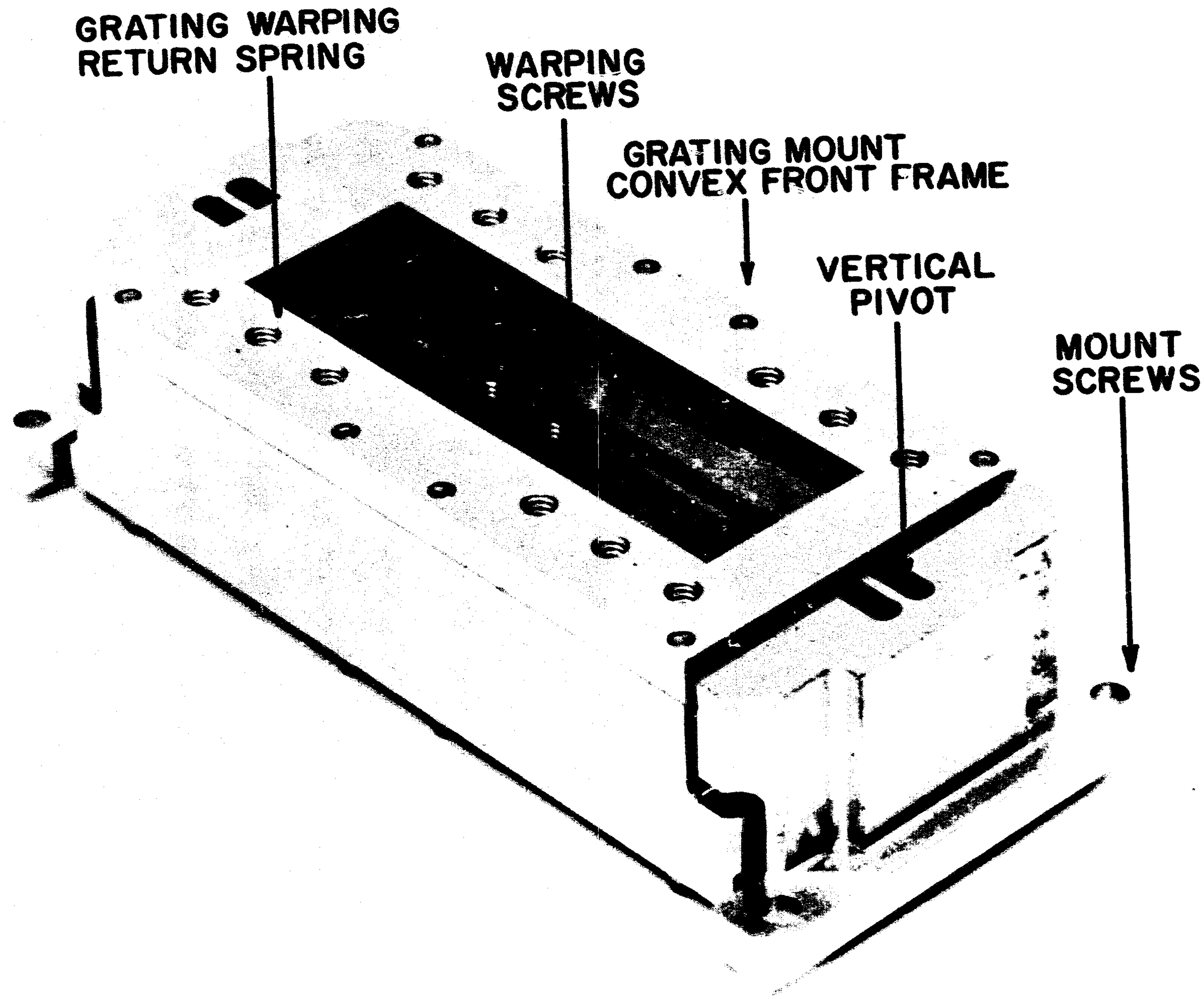


FIGURE 9 GRATING MOUNT

that the special grating fits loosely in its holder so that its side may be packed with oil free gasket paper, (gotten by oven drying)). There are also available around the grating holder frame, six screws (including two spring plungers), which are used to center the grating in its end casting and to carry the weight of the grating. These screws really adjust the nominal incidence and diffraction angles of the grating between the relatively fixed position of the film's curved surface and aperture of the extended baffle (slightly adjustable though with difficulty).

5. Access on the Cassette Side of the Instrument (right side when looking back into the instrument aperture) See Fig. 10

On the right side of the instrument cover (which is accessible with the skin removed) are the cassette motor (shutter and film drive motor), the access to the film loading cover (arch shaped), and the timing cam switches cover (square). For subdued light lab conditions these covers need not be in place. The motor mount, which lies to the right of the cassette openings, should always be used; for it conducts* out the substantial amount of heat generated in a five minute running cycle and keeps the motor centered on its soft vibration isolation

*Clean and seat surfaces for good thermal contact

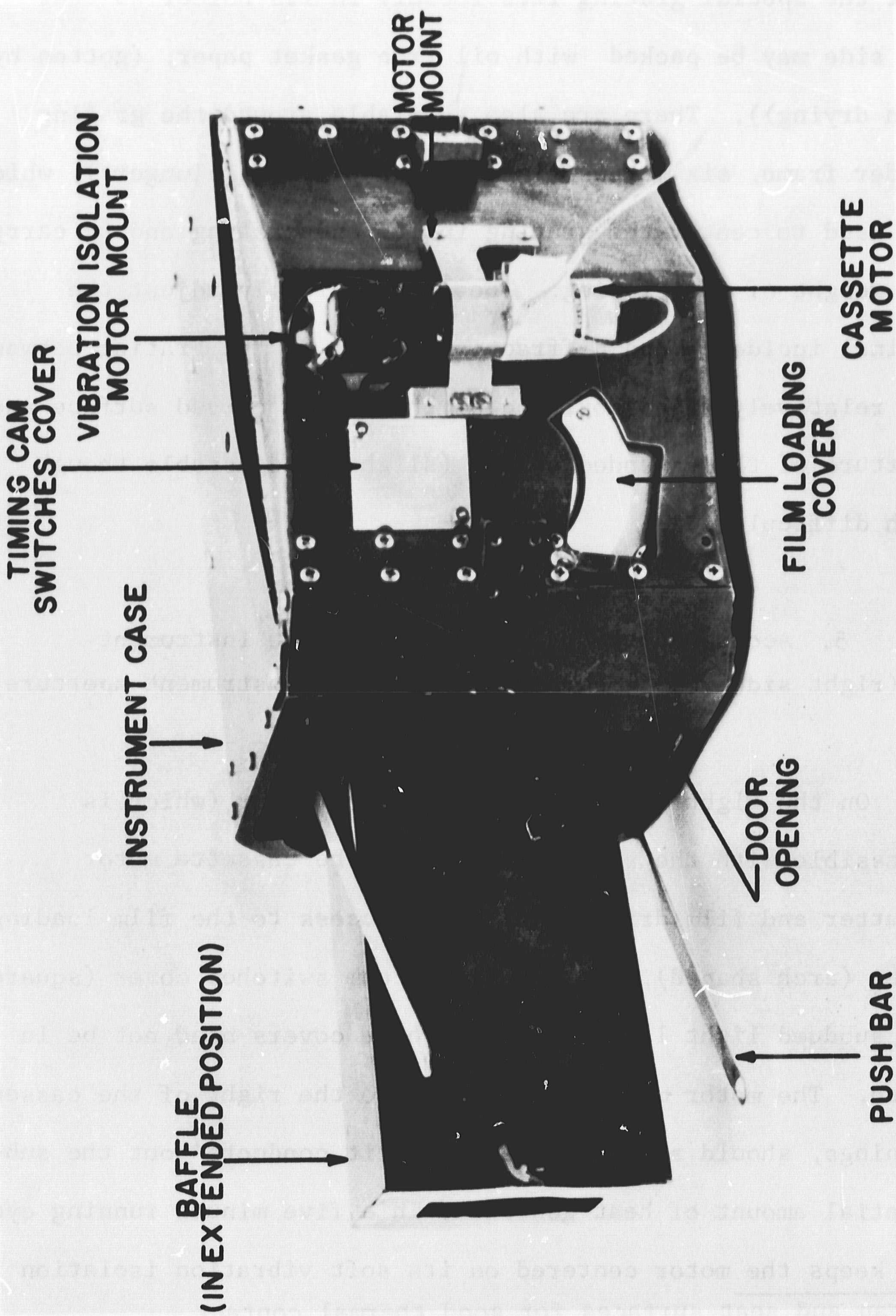


FIGURE 10 RIGHT SIDE OF THE INSTRUMENT CASE AND DOOR END

mount. Without this motor mount the motor initially runs true, but may slowly and progressively start to gyrate, eventually damaging the inner bellows of the spring isolator. High and near the motor is located the access hole to the spring ratchet to prevent the shutter from running backwards when the film is advanced. More than a few teeth back rotation will cause false shuttering (very short cycle which moves the film essentially continuously past the field stop).

Special cams (precipice type) and cam riders have been designed to MINIMIZE the false cycling, which is accentuated by a small amount of back lash of the cams. At this time these cams cannot be easily removed from the cassette when the cassette is mounted in the instrument case. But the cassette can be removed from the instrument without affecting the optical alignment by removing the non-critical door end casting.

6. Door End and Left Service Side

From the door end the baffle front limit switch probe and bearing may be adjusted. From the left skin service area the two screws holding the baffle's front bearing block may be removed and then the baffle, nut, limit switches, and drive screw can be pulled out and rotated to a diagonal position so that the anti-rotation arms clear the door end casting. Holes could be drilled in the left side of the instrument cover to facilitate release of the baffle at 70% of retraction. A large hole on the left rear side of the instrument case would allow observation of the film field and shutter positions.

7. Motor, Baffle and Door Drive Mechanism
See Fig. 7 & Fig.11

Early in the design of this instrument, we expected to have an external motor geared to the baffle drive-screw. This baffle drive solution was found to have too great an uncertainty in useful drive torque by reason of the torque losses in the external gears and their bearing at high loads. A special Globe motor was procured to allow the coaxial mounting of the screw over either one or two of these motors. The 1" diameter Globe motor acts both as a driver and rear bearing support for the baffle lead screw-nut assembly. A single motor is normally mounted in the lead screw at the grating end casting with access from the outside of the instrument case.

This nominally 30 in-oz. motor is first mounted to the grating end casting and then to the baffle and baffle drive nut assembly. The front bearing assembly is slid over the motor into place through the door end casting with a very slow

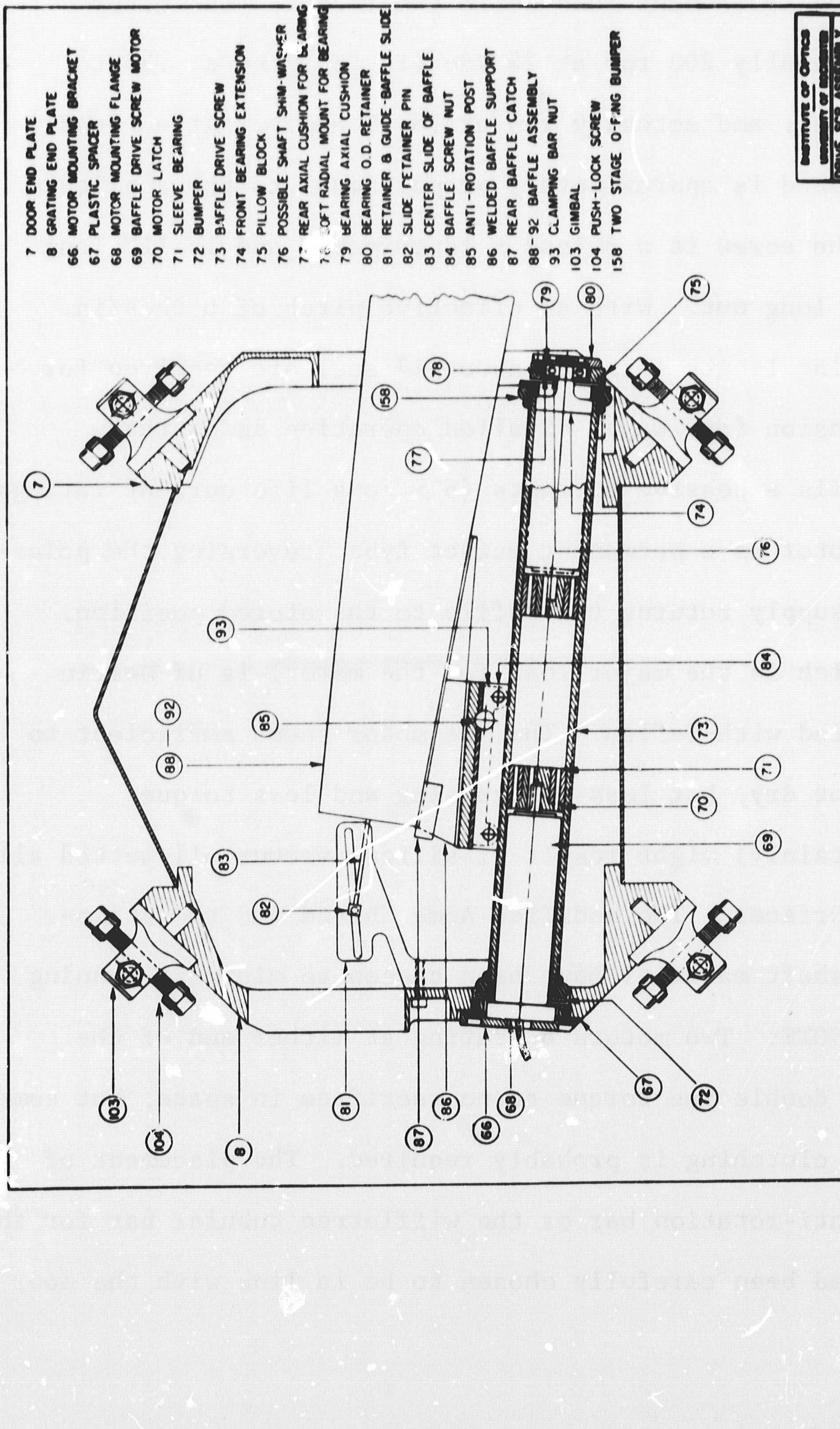


FIG. 11 BAFFLE DRIVE SCREW ASSEMBLY

SECTIONAL TOP VIEW

rotation to align the torque pin. This assembly may be made even with the instrument mounted in the rocket. The motor speed is nominally 200 rpm at 24 Vdc (it is rated at .30 to .575 amp. max., and actually run at .8-.9 amp.). At no load the motor speed is approximately proportional to the applied voltage. The screw is a 3 lead x 18 threads, and is 11" long moving a 3" long nut. With an effective pitch of 6 thds/in. and 9" working length turns or about 17 sec. are required for baffle extension (one way). Stalled operation as at the bumper entails excessive currents (6 x long life current ratings). Since the motor is a permanent magnet type, reversing the polarity of the supply returns the baffle to the stored position. The nut (which is the major load for the motor) is of Delrin plastic filled with Teflon. The one motor seems sufficient to drive the nut dry, but less out-gassing and less torque (less uncertainly) might result if silicon vacuum oil wetted all the nut's surfaces. The Modified Acme Thread and the stainless steel shaft material have been chosen to minimize running friction. NOTE: Two motors operating at either end of the shaft would double the torque at no sacrifice in space, but some anti-damage clutching is probably required. The placement of the nut's anti-rotation bar or the wiffletree tubular bar for the door arms had been carefully chosen to be in line with the door mount and the nut's compression centroid. In this way the door's load will not cock the drive nut creating artificial or induced loads by a door opening linkage of unfavorable mechanical advantage. With the .030"thick spring steel hinge on the door at maximum opening, a force of 10# is exerted on the nut (at max. extension) causing the motor current to rise 25%.

Reversing switches have been provided to return the door. "O" ring bumpers prevent dangerously high loading when over-running the limit switches when the baffle is either improperly powered or coasting. These bumpers stop the motor without damage, but cause high currents which must be turned off within seconds. The fusing in our proposed circuit not only protects but is used sometimes in the electrical logic; and, therefore, the circuit description should be carefully referred to. In several trials the motor was allowed to run into the bumper; and on reversing the motor leads, the motor always could move promptly away from the bumper. The baffle motor current always seems to increase about 20% during the first several seconds of running. This might be caused by the apparent viscous effects of the nut's Teflon filler or by friction induced thermal swelling of the plastic nut. In any case, the nut should be clamped <u>very</u> lightly. See Fig.12.

Care should be taken in running the motor, for it is not rated at these overload currents for continuous operation , nor

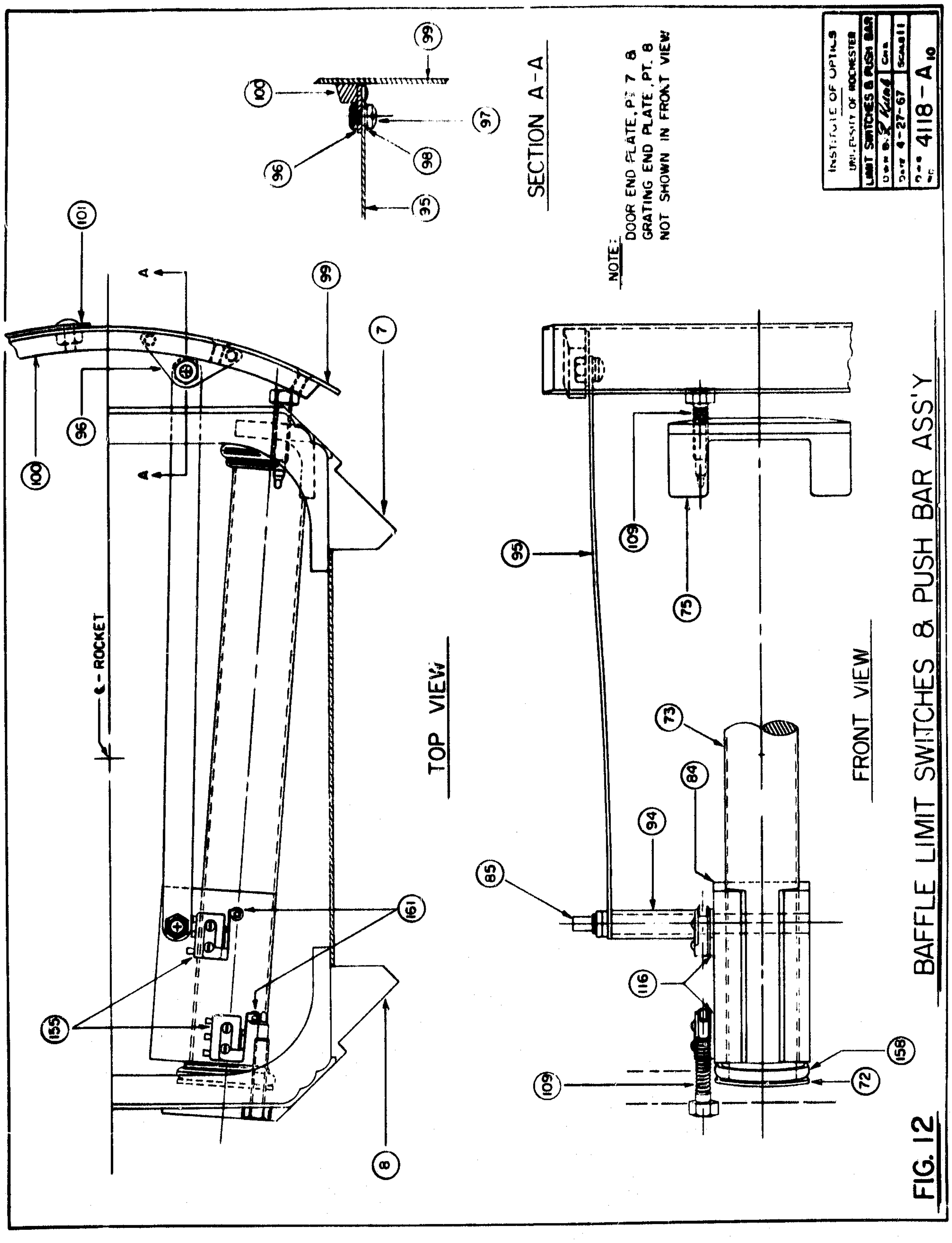


FIG. 12 BAFFLE LIMIT SWITCHES & PUSH BAR ASS'Y

can its winding temperature be sensed through the tubular stainless baffle screw. Since brush life on these motors is limited, only one motor was used for testing. Reduced voltage operation, fusing, and current monitoring are the best procedures to protect these expensive specially manufactured motors from needless damage. See section on electrical considerations.

8. Unique Motor Drive for Isolating the Film Cassette from Unfavorable Forces and Moments

See Fig. 13 & Fig. 14

The U of R Stellar Spectrograph's film cassette -- as all photographic instuments -- needs some rotary power to move the film and work the shutter. Problems arise in that these motors have the practical side effects of substantial volume, mass, heat, and usually, a fixed shape. The concept here-in used is to isolate the cassette conveniently from the side effects while receiving the desired quantities of torque and/or angular motion. In most space applications "conveniently" means that side effect isolation must be reliable; of low weight; and in this case, inexpensive to design, construtt, and install. This moment and heat -- but not torque -- isolator needs no adjustment. Bellows shaft part 4118-151, and motor spring part 4118-33 perform the isolation.

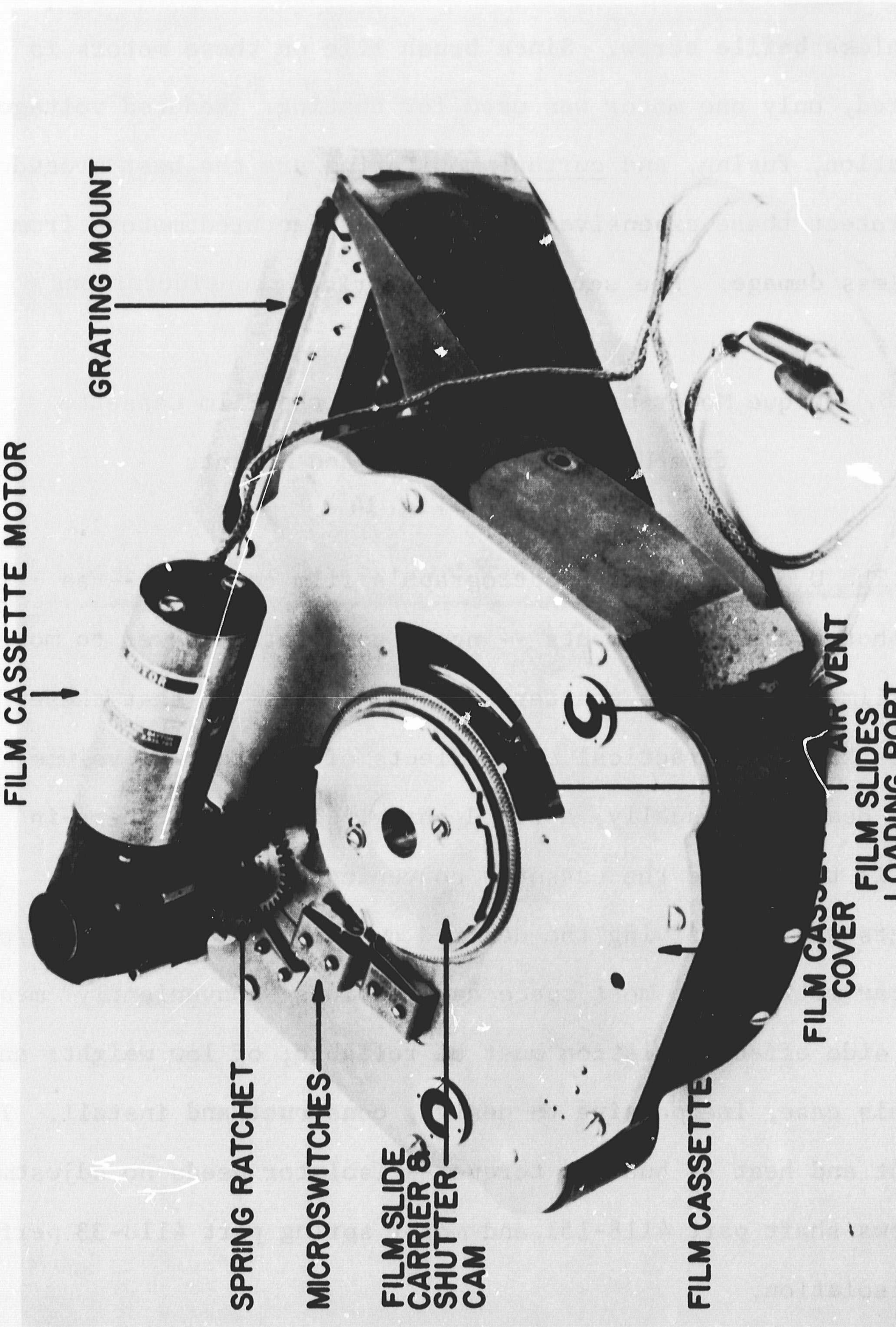


FIGURE 13 FILM CASSETTE ASS'Y

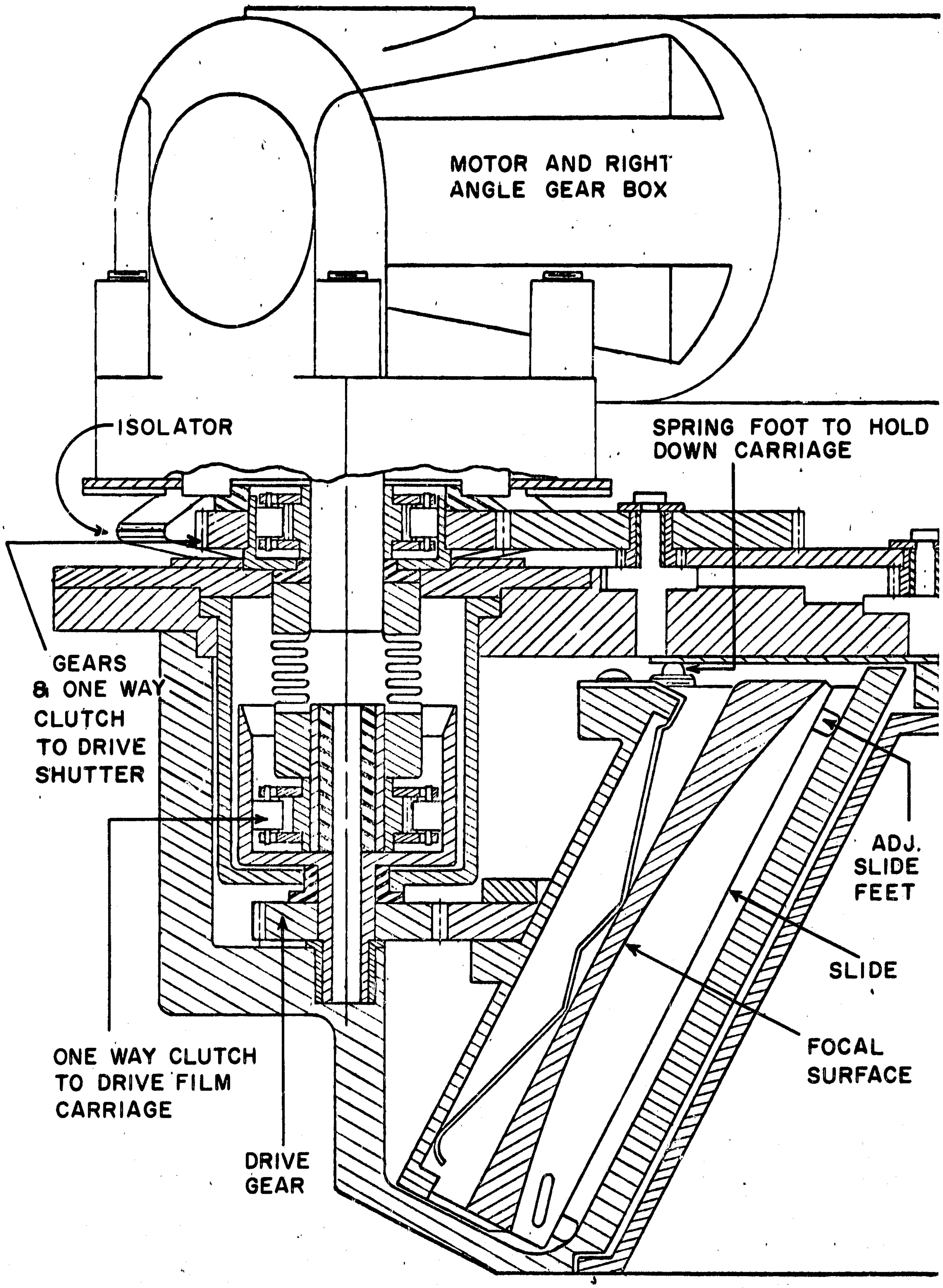


FIG. 14 FILM CASSETTE MOTOR DRIVE (SECTION)

We recommend our vibration and heat solution to others in that it delivers 100 in-oz. (at 30 rpm) with 15 min. of arc backlash across an isolator that takes approximately 1-1/2 cubic inches of volume and only 3 oz. of weight. This isolator we consider to be very efficient, for it protects the film cassette by soft connection from moderate amounts of 2 tilts ($\approx \pm 4^{\circ}$ each) and 2 translations ($\approx \pm$ .040" each) and by a coaxial path from motor torque reaction. Both the motor's reaction torque and shaft torque are delivered through the isolator to the corresponding parts of the film cassette in order to balance each other. These torques are therfore contained within -- not across -- the boundaries of the film cassette system. Motor vibration, heat and positional errors are essentially outside the cassette's critical force system boundaries. Such a contrived isolator with the motor bracket makes the cassette center of gravity independent of the motor's shape, weight and density distribution. In our case, added advantages were obtained by passing the instrument case between motor and film cassette. This increases the serviceability of the motor while lessening the chance of distilling optically absorbing motor vapors on the grating or film.

9. FILM CASSETTE

To give alignment ease and reliable maintenance of optical adjustment the film cassette has been stiffly constructed so that there are the fewest possible interfaces between the surface of the grating and the surface of the film. The film cassette, shown in whole, in the assembly drawing of the rocket Fig. 4, is supported through its center of mass by two shoulder pins which make up the pivot which sets the grating incident angle. The grating box is also supported by the screws that set the grating incident angle. It should be noted that every attempt was made to use structural bodies for two if not three similar functions so as to have an efficient instrument without excessive redundancy. The grating tilting mount box is held to the cassette by four corner screws. These may be removed any time to protect the grating while the rest of the cassette is undergoing a fix. A pin top and bottom of the box should be put into the cassette frame so that the lateral optical position of the grating alignment is not lost on removal. The axial positioning can not be easily lost. The grating box frame is cast to the cassette by tapered angular spacer bars which should not resonate in a vibrational environment and certainly be stiff enough to maintain the optical spacing. The film cassette working body is of a conical nature. This is so for as the grating light may skim over one of the open edges and incident normal on the other side which is near the film plane. Nested inside the cone of the cassette can be a conical shutter which was used in the final instrument. The converging grating light skims over the lip of the conical shutter and strikes normally through the cone's surface to the film slide within the cassette. The film slide has four corner adjusting feet (for focusing and tilts) which rest on a rather generous reference plane machined into the back of the cassette cone*. The conical carrier with slides partially and fully inserted is shown in Fig. 16. The carrier crude-positions the slide radially and angularly but accurately perpendicular to the cone's surface element. A flat circular spring washer which covers the slide's loading port presses the slide against the carrier's accurate conical surface in the direction of its stop. A spring on the carrier presses on the back of the loosely held slide and forces it firmly against the focus reference plane. It is important

*The inside of the cassette cone is so machined that a slide is carried in any of nine pockets of a conical carrier. The carrier rides upon a conical shaped seat positioning the film slides within 1^{o} tolerance on the field reference plane. After exposure the carrier rotates and the slide returns to a stowed position.

that the slide forces and frictions be so arranged that the slide is pushed along the conical element toward the large end and its stop. If this is not done the cylindrical focal plane that holds the film will be displaced and all but one point will be out of focus on a spectrum record. film. Only slides coming to and leaving of the focus reference plane drag their feet over the carrier surface. This cuts the load on the film carrier which is driven and positioned by one active trunion driving gear out of four such gears.

The cover of the cassette is complicated for it carries the motor and the special one way clutches which allow one directional rotation of the motor to change the film, ie. drive the film cassette one pocket and then to reverse the motor electrically so that only the shutter gearing of the back of the cassette cover is turned until it's cam says that the shuttering is done. (See Fig. 15,16,17.)

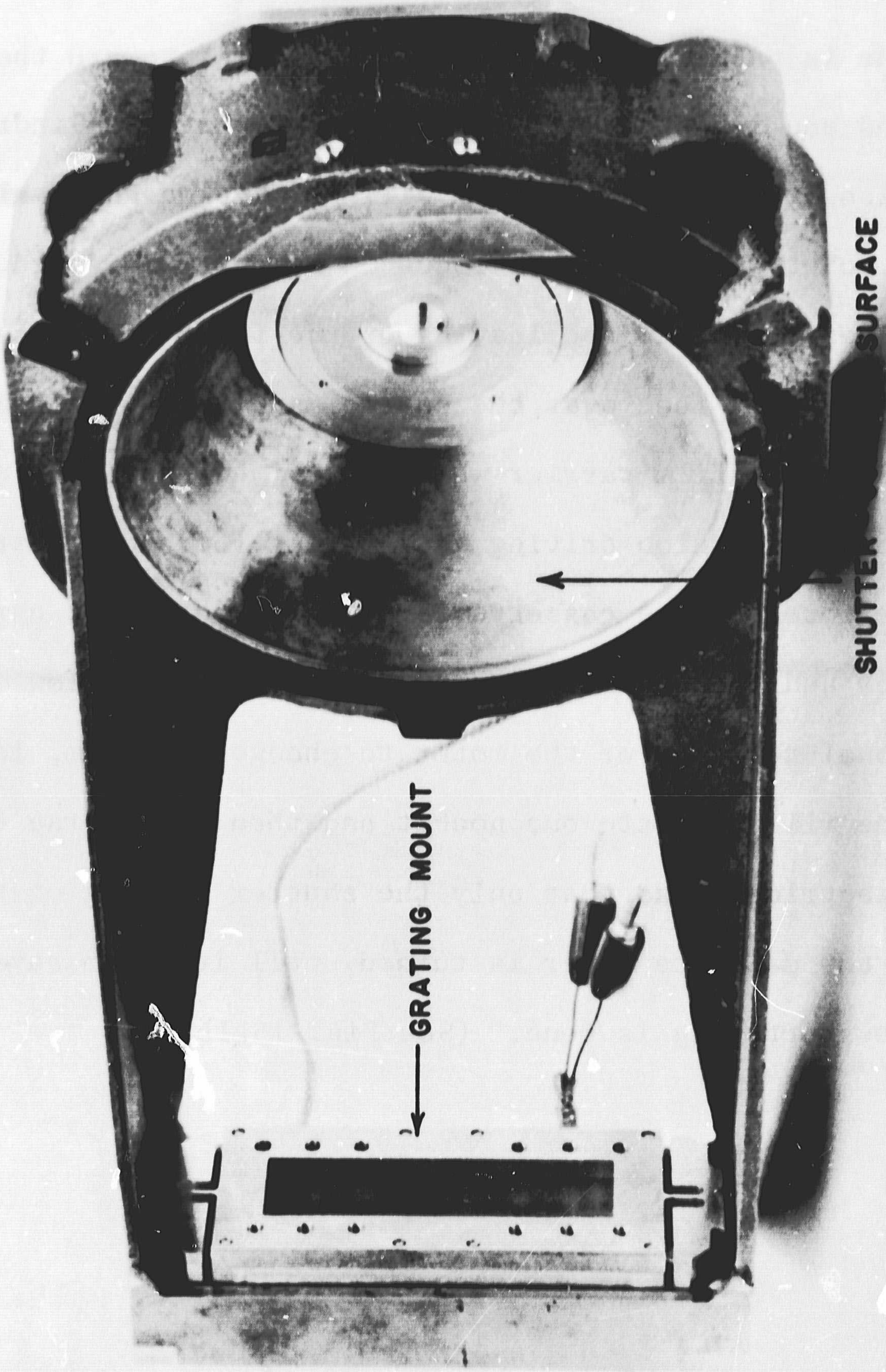
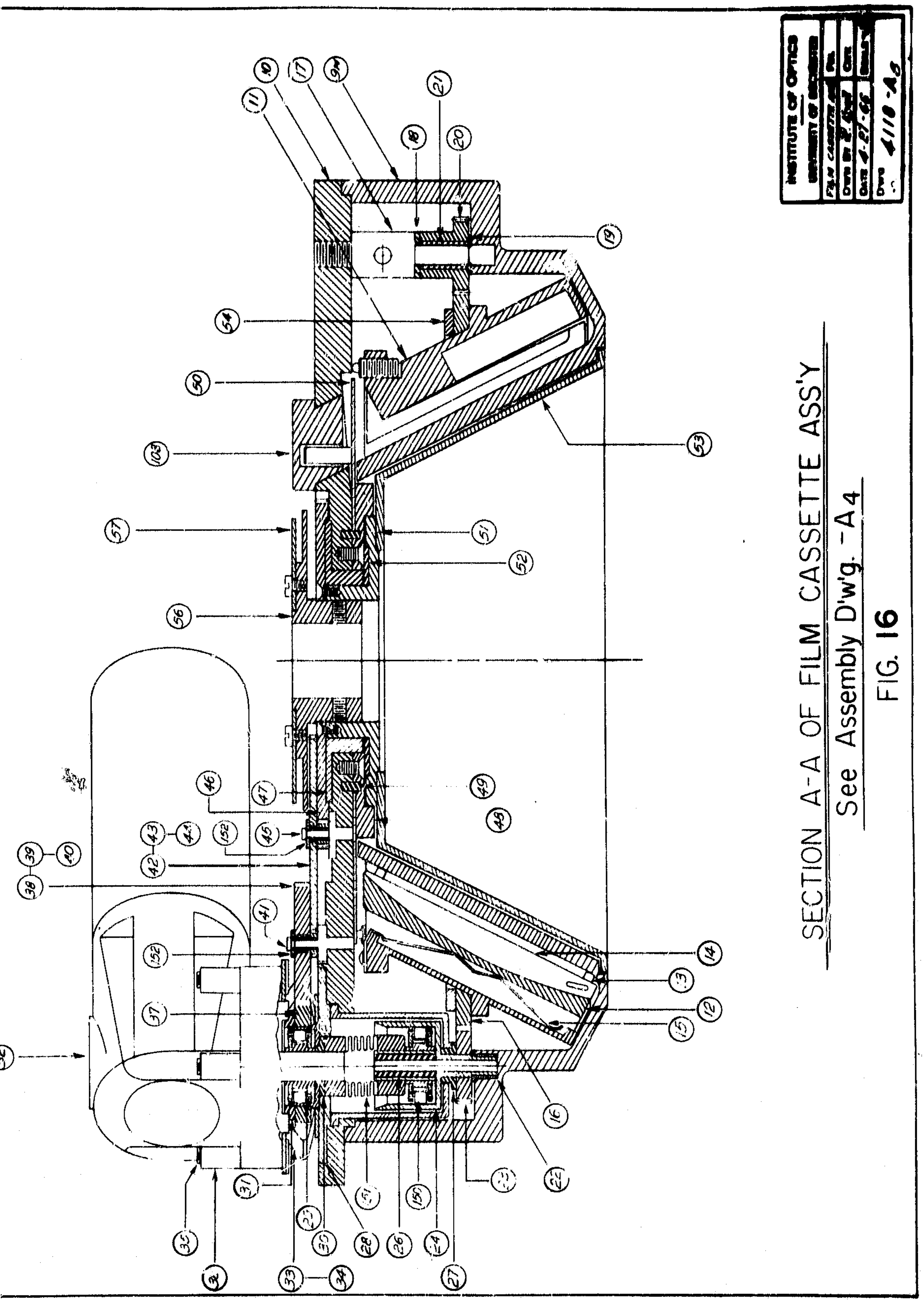


FIGURE 15 FILM CASSETTE & GRATING MOUNT ASS'Y



SECTION A-A OF FILM CASSETTE ASS'Y

See Assembly D'w'g. -A4

FIG. 16

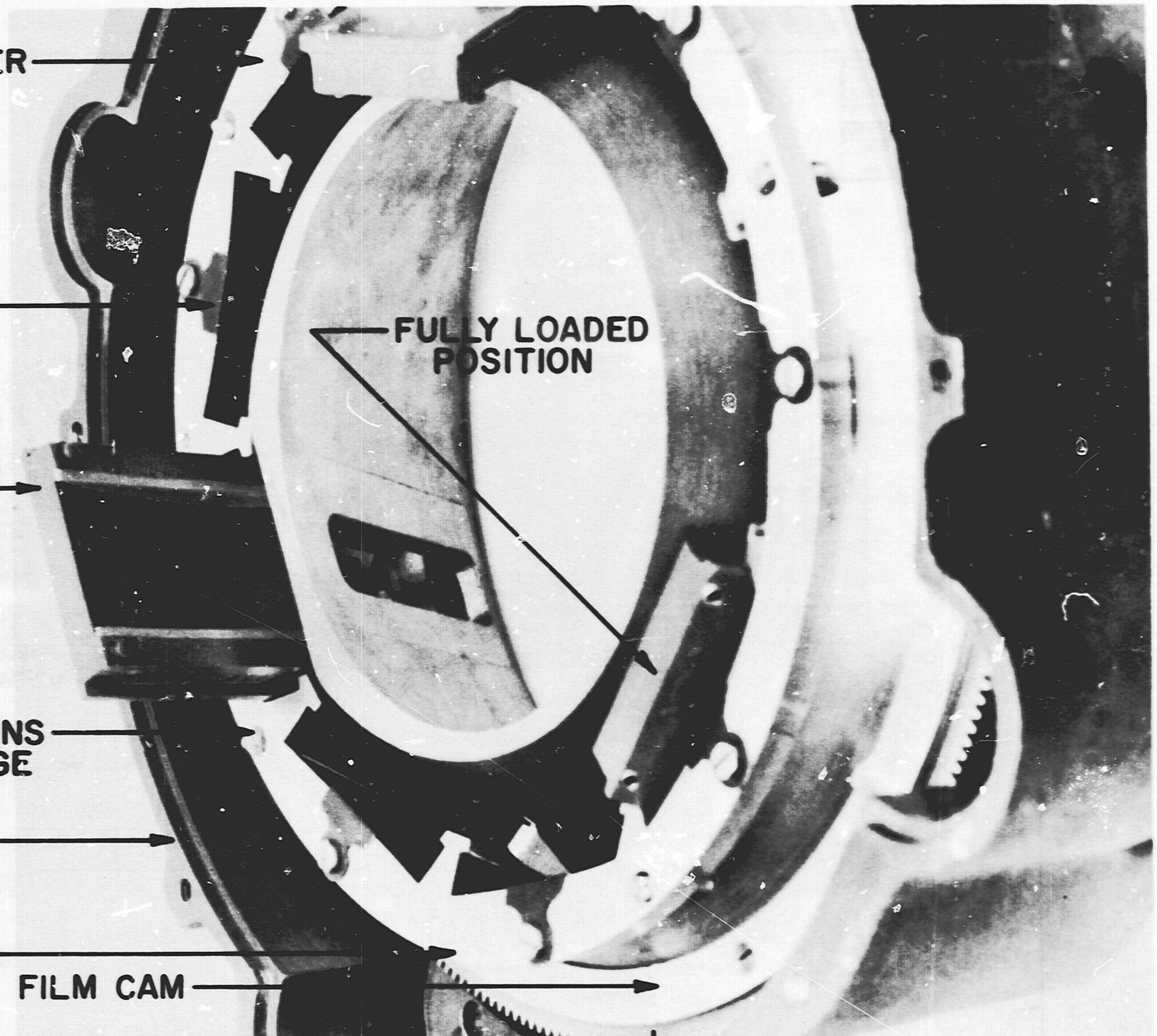


FIGURE 17 FILM SLIDE CARRIER ASS'Y

10. Installing the Instument in the Rocket Casing

With the present rocket casing or rocket extension cylinder there is only one way of mounting-gimbaling the optical instrument. This is accomplished by removing the gimbal axis and door push arms with baffle removed or retracted and pushing the instrument up to position from the bottom of the rocket extension.[1] The gimbal axes are then put on with adjustment screws in place but with the lock nuts retracted about one turn each. The cassette motor can be in place during this installation. Care should be taken that the instrument is centered (as seen in plan view) in the rocket extension cylinder. With the flight instrument mounted in the rocket, the optical instrument case and interior parts cannot be removed as a unit[2]; and for that reason almost total service (about (270°) was designed in. Service can be conveniently effected with the covering skin removed.

11. Helical Light Traps

In the left side of the cassette cover are installed two spiral staircase type light traps. These traps seem very effective in allowing the interior of the cassette to be

---

[1] We actually prop the instrument to the right height and lower the rocket extension or outer case over the instrument.

[2] By redesigning the door end casting to the outside of the instrument cover, the film cassette could be removed without having to disassemble the instrument case.

expeditiously pumped out without the leakage inward of light. Two complete turns are used with a cross-section of 1/4" x 1/4". These light tight vents open into the area behind the film carriage, and several more reflections would then be required for light to reach the photo-sensitive surface of the film. The traps are screwed into place and upon removal, use of a small mirror allows the inspection of the film positioning switch and its cam.

12. Screw Fasteners

Unfortunately this instrument uses a significant number of screws and also, somewhat more seriously, a wide range of sizes, head types, lengths and materials for screws. Failure by shearing or jamming of screws and loose parts has largely been avoided. The use of too long a screw and the loosening and dropping out of screws are serious and very destructive forms of failure in compact closed form instruments, where access is limited both mechanically and visually.

In general, all screws (especially in magnesium) must have smooth non-galling thread surfaces and be engaged over as many threads as possible to prevent damage to the threads in the mating part. In this instrument there are very few screws that must be tightened up to or even near their torque or elastic limit. This applies either for stiffness reasons and/or vibration locking; since the latter is usually provided by a nylon inset, friction, or a locking compound.

Head types are better if they are the pan head type (especially where there is any hint of close fitting), since some clearences are not as generous as we would have liked. Pan head screws are recommended providing greater resistance to wear and chip generation caused by improper driver fit and use.

The screws are usually of aluminum (as in the instrument cover) to save weight, especially when they are infrequently turned, may easily be replaced, and are used in a large number. Aluminum screws should always be replaced at the slightest sign of wear. For all applications an anti-galling surface on the screw threads is required. In some areas of dense packing and close clearances, special screws of low head height and diameter have been manufactured from hardened steel. Unfortunately, these are required (could be designed-out in the next redesign) and are found only in clutching area of the shutter-film drive. There is little extra durability in these screws to allow for careless abuse, but they should not cause the careful user any trouble.

In the mounting of the cassette motor, large pan head screws made of brass have been purposely selected to aid in conducting motor heat from the motor clamp-bracket to the motor mount and instrument cover. Special care should be taken to see that these coated screws (chromed) are used here and all mating surfaces are clean of oxide. These surfaces may be coated with a silicon thermal coupling grease (like that used for transistors). This thermal assist is necessary in a vacuum when long and heavy usage occurs, since heat transfer by convection can not obviously occur.

Allen socket hex screws are acceptable where head height and steel material are acceptable. They are good in that head damage from driving is usually impossible.

IV. ELECTRONICS

1. Electronics for Laboratory Testing the U or R Rocket Spectrograph

This section describes an electrical circuit designed to certify that at least the minimum limit switching was provided for in the instrument. It has been highly developed and warrants careful consideration for actual use. The circuits operate over a wide range of voltages, include careful consideration to coast and creep of the mechanical components they control. These special circuits must be rewired and specially housed for flight use.

The circuit flexibility as it aids the experimenter is carefully noted.

Included in this section is the operational sequence, wiring diagrams, and front and rear view of the electronics package.

Nominal operation of the spectrograph package and electronics package is: turn on power, this opens the door and starts extending the baffle. At the same time the focal plane shutter begins operation and the film slides begin changing. The chosen alternation of shuttering and film changing then continue for the duration of the data taking period.

2. The Electrical System

Both the baffle and film cassette electrical systems, as proposed, are comparatively reliable, foolproof, and with the exception of one situation -- that in which the final cassette power is to be turned off -- is logically complete. These circuits will trigger properly at 15 volts or more but the baffle motor will drive from 24-30v power supply.* Reducing the cassette motor's general voltage supply slows both film changing and shuttering. Insertion of a resistor at "B" slows the changing of the film with 4 seconds suggested as a good nominal value. A resistor at point "C" slows the focal plane shutter but does not change the ratio of the built-in exposure times. These resistors together with the voltage-rpm characteristics of DC motors allow a useful flexibility of experimental timings with the same mechnaical components; i.e., shutter and cams. See Figs. 18, 19, 20, and 21.

Operation of the cassette motor with a dropping resistor[1] in the film changing circuit ("B") reduces the change for any

[1] A dropping resistor with thermal delay and positive characteristics would be best. It would allow the motor to start at full voltage for about a second and then slow down to the desired speed.

* Figs. 19 and 20 are schematics of the two switching circuits. Fig. 22 is a drawing of the motor for the film cassette with its complete specifications.

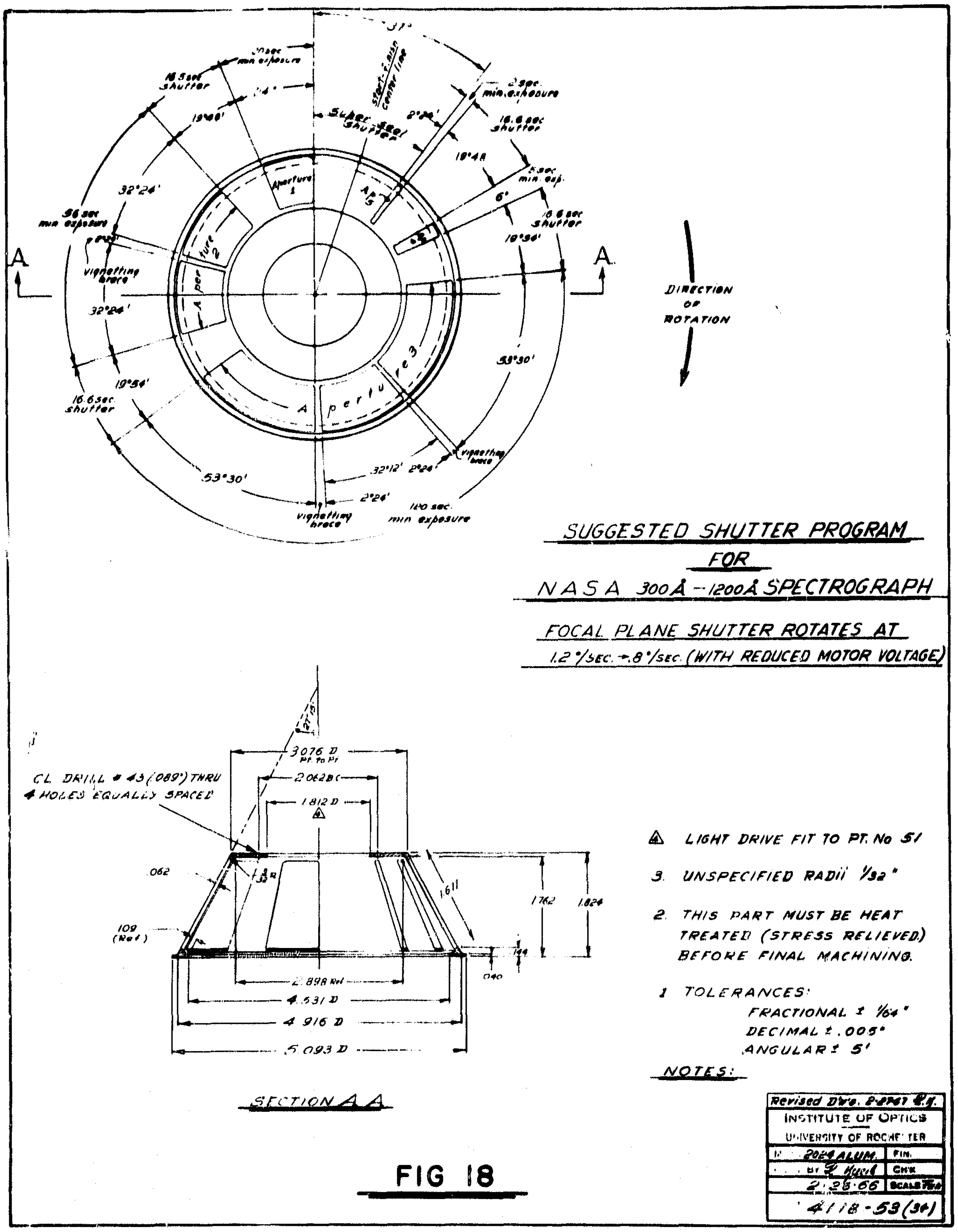
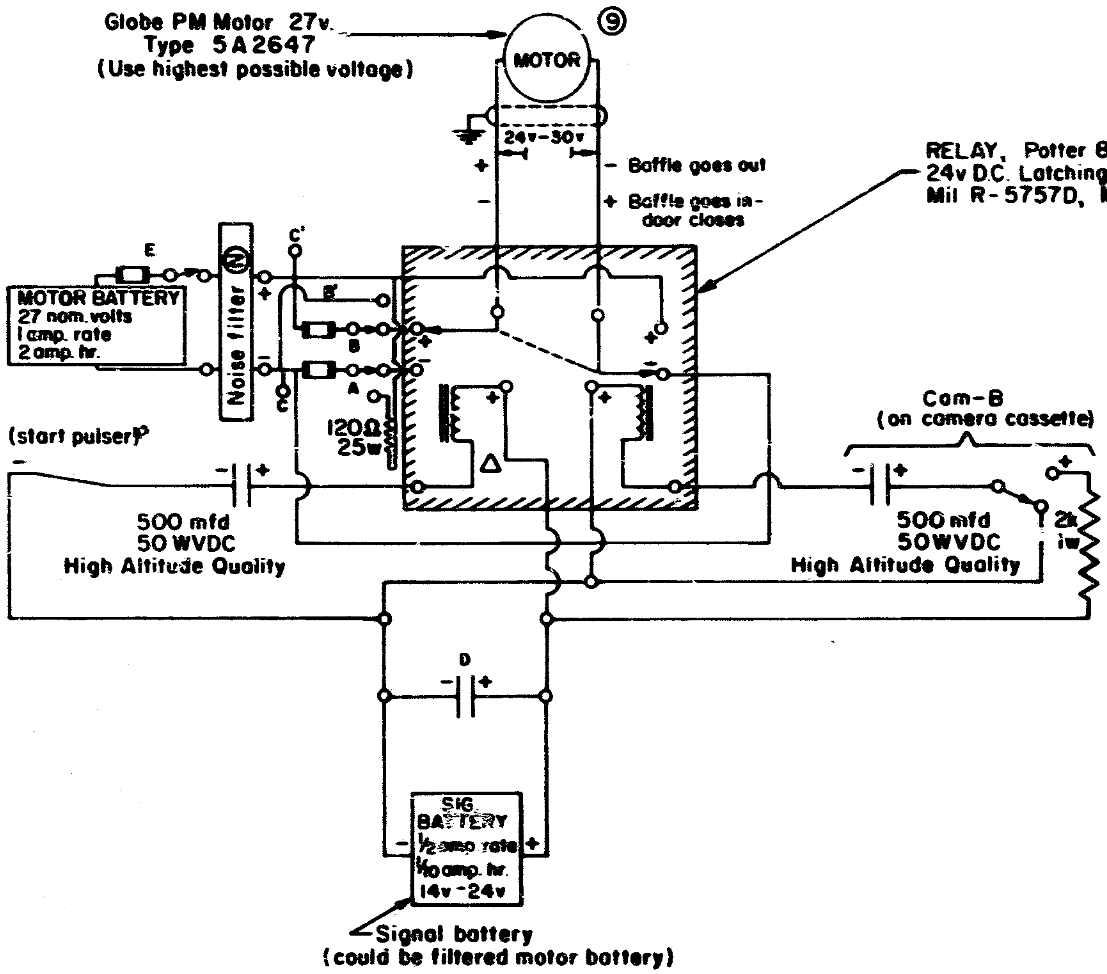

SUGGESTED SHUTTER PROGRAM
FOR
NASA 300Å – 1200Å SPECTROGRAPH
FOCAL PLANE SHUTTER ROTATES AT
1.2°/SEC. – .8°/SEC. (WITH REDUCED MOTOR VOLTAGE)
DIRECTION OF ROTATION
A
A
Super Seal Shutter
Aperture 1
Aperture 2
Aperture 3
16.6 sec shutter
56 sec min exposure
vignetting brace
120 sec. min exposure
53°30'
32°24'
19°54'
19°48'
2°24'
6°
32°12'
CL DRILL # 43 (.089") THRU
4 HOLES EQUALLY SPACED
3.076 D Pt. to Pt
2.062 B C
1.812 D
.062
.109 (Ref)
1.611
1.762
1.824
.144
.040
2.898 Ref
4.531 D
4.916 D
5.093 D
SECTION A-A
LIGHT DRIVE FIT TO PT. No 51
3. UNSPECIFIED RADII 1/32"
2. THIS PART MUST BE HEAT TREATED (STRESS RELIEVED) BEFORE FINAL MACHINING.
1. TOLERANCES:
FRACTIONAL ± 1/64"
DECIMAL ± .005"
ANGULAR ± 5'
NOTES:
INSTITUTE OF OPTICS
UNIVERSITY OF ROCHESTER
2024 ALUM.
2-28-66
4118-53(34)

FIG 18

FIGURE 19

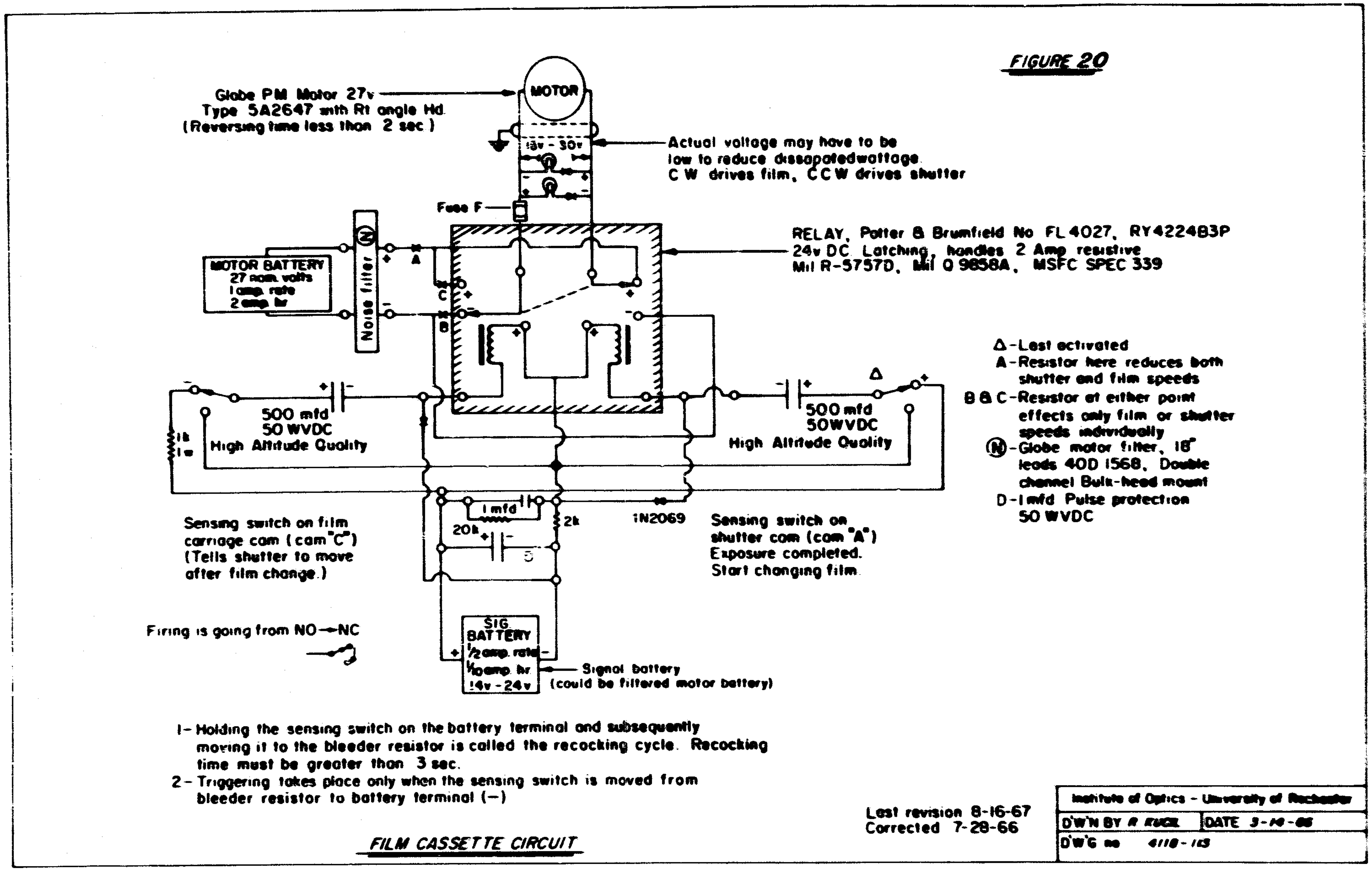


BAFFLE DRIVE CIRCUIT
(Self starting and one cycle only)

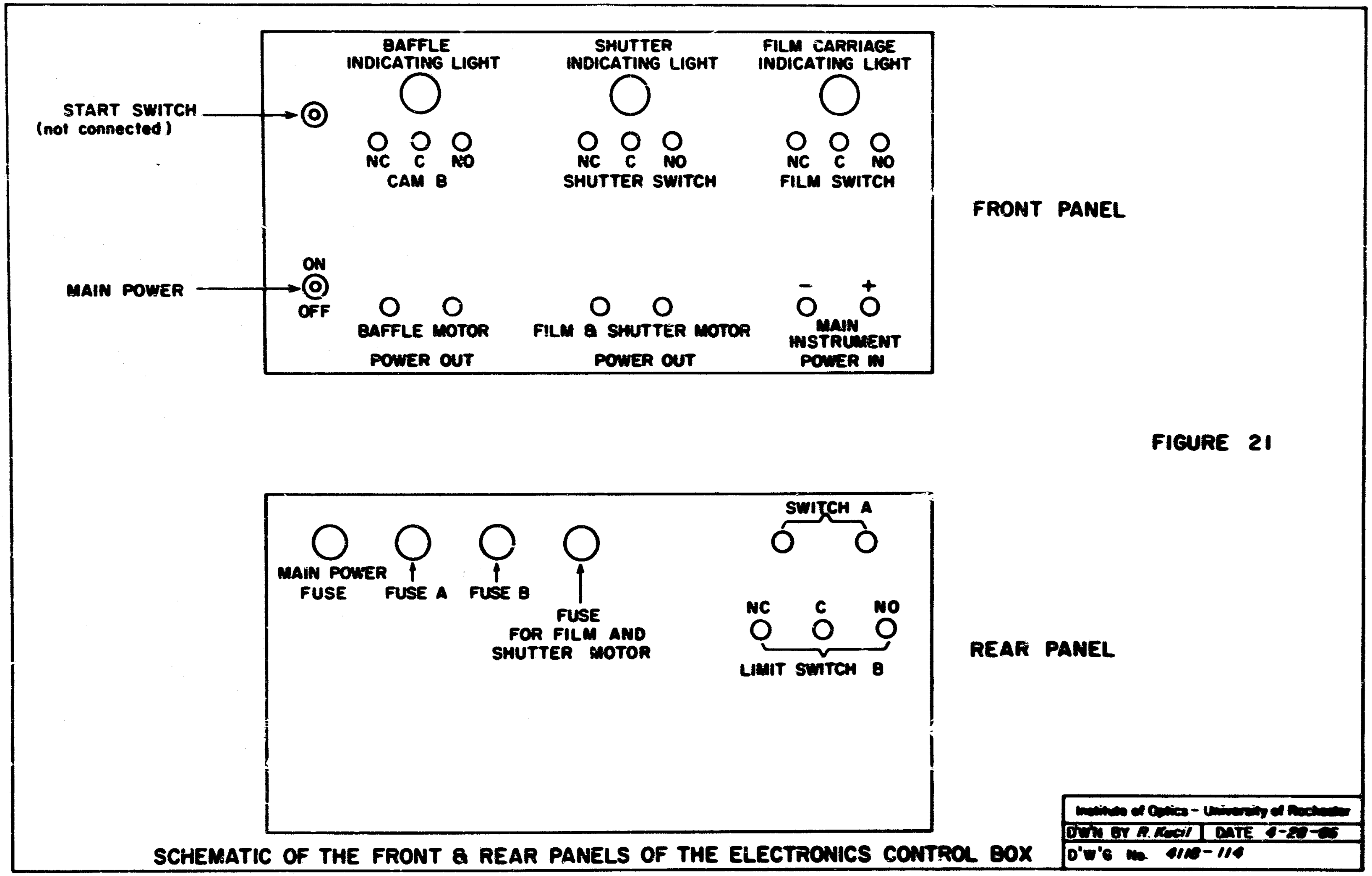
1 - Start instrument by turning Power ON
   Left switch automatically fires - +
   makes baffle go out.
2 - Normally closed switch at B opens when baffle is out. (series slow-blow fuse for 4x normal running current is in series with limit switch) - "out" limit switch.
3 - Cam-B at end of last exposure pulses its switch and drives + - baffle back.
4 - Return limit switch at A breaks "in" power on return and is backed up by slow-blow fuse to prevent motor burnout.
5 - C-C' is power to film-shutter drives.
6 - D ~1 mfd pulse protection 50 WVDC.
7 - E is position of overall instrument start switch.
8 - (N) - Globe motor filter, 18" leads 4DD 1568, double channel bulk-head mount.
9 - Stall not over 4 seconds.
10 - Disconnect at B' for recycling in trials
11 - Firing is going from NO→NC
Δ - Last activated

Last revision 8-16-67
Corrected 7-28-66

Institute of Optics - University of Rochester	
DWN BY R. Koch	DATE 4-29-66
DWG no. 4118-112	

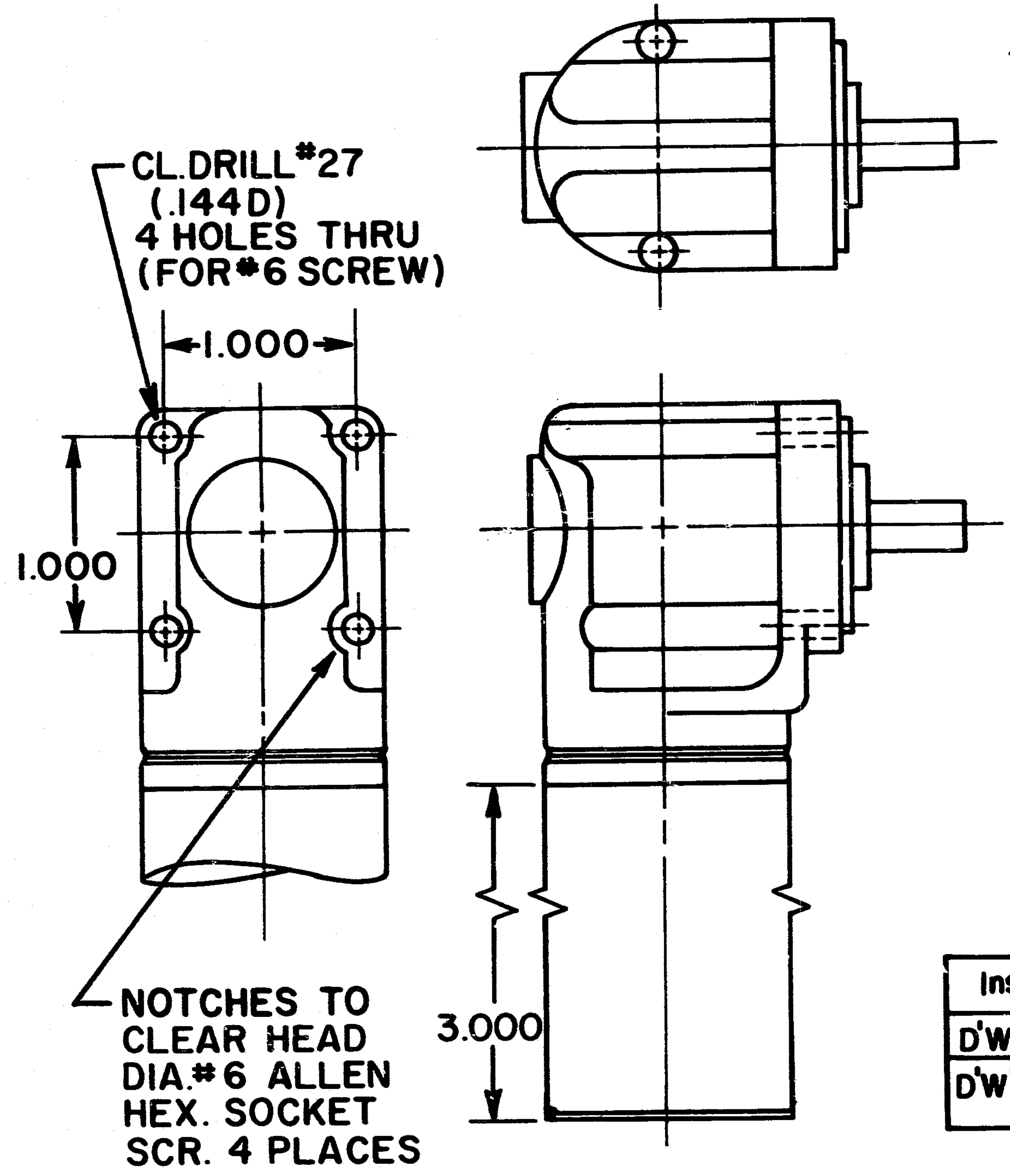


FILM CASSETTE CIRCUIT



SCHEMATIC OF THE FRONT & REAR PANELS OF THE ELECTRONICS CONTROL BOX

FIGURE 21



MOTOR FOR FILM CASSETTE

TYPE MM No. 5A2647 - WITH PLANETARY GEARBOX and RIGHT ANGLE HEAD-VACUUM TREATED* No. 7 Armature. 2 x 36" lead length with shield. Speed: 20,000 r.p.m. at 24 v. Speed reduction ratio 780:1 List size of resistor to drop motor speed from 30 r.p.m. to required 20 r.p.m. - using 780:1 gearbox. Specify torque at this speed. Duty cycle is 3 sec. on, 3 sec. off - 20 times at rate load, 250 gross cycles. Minimize and specify backlash (should be less than ±1° if possible).

* - Less than 1/100 liter per sec. out-gassing at ambient pressure of 1×10^{-6} mm. Hg. Power 22 watts at 24 v.

FIGURE 22

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D'W'N BY *R. KUCIL*	DATE *9-17-65*
D'W'G no. *4118-32 (21)*	SCALE *FULL*

damage when slides are improperly loaded and also reduces the coast of the film carriage and slides. Friction between the film cassette and slides is desirable to reduce coast and/or after-run creep. The slides fit loosely in the film carriage so as to be free of driven creep, and the film slide's focal reference plane is about $\pm 1^{o}$ over-size along the focal plane cylinder to reduce the induced difficulties of carriage coast. Current monitoring is extremely important to avoid internal cassette damage since torques of 1000 in. oz. are available on the film carriage which could shear or crush any slide. Since the motor will drive incorrectly made components (usually slides too long), the friction sensitive loading door shutter operation should be tested for stiffness as a test for an internal jam or potential jam.

Single pulse circuits, finite recocking times, and precipice cams are special precautionary features intended to prevent false shuttering. "False" shuttering or "false" film changing is the situation in which a switch foot rides-up a cam projection, stops, and then creeps back down so that the next drive pulse just rides up the same cam projection. A false shuttering defect is caused by back-lash but triggered by creep and vibration. Coasting and precipice type cams provide good protection against "false" shuttering. The relay is triggered only when the switch foot falls from the precipice to the lower cam level. The switch foot is prevented mechanically from re-ascending to the top of the cam.

Single pulse triggering and recocking delays allow the latching relay to remain in the desired position and prevents switch bounce and cam roughness from causing multiple triggering.

3. Sequence of Operations

Pre-start configuration:

1) Limit Switch A, (baffle return limit) switch position open (soon closes).
2) Limit Switch B, (baffle extension limit)position NC.
3) Switch E, (main power) open.
4) Cam A, (shutter timing cam) switch position NC. The switch trigger in this position will be fully extended and ready to move film onto reference-focal plane.
5) Cam B, (baffle timing cam) switch position NC. The switch foot in this position will be completely depressed.
6) Cam C, (film cassette positioning cam) switch position NC. The switch foot in this position will be depressed. The first film carriage is blank and before the super shutter[1] is removed a film is moved into place.

[1] Start and finish shutter area of shutter is extra wide to reduce light leakage, hence super shutter.

Start Experiment:- Electrical Circuit Operation:

Switch E (total power) is closed, this will have two results: (1) the baffle relay will be started outward (as described previously) and put under the control of out space limit switch (b) circuit; (2) the cassette relay will be activated by a pseudo film pulse, so that the super shutter will start out of the way. The super shutter opening time plus positioning of the first film will be slightly longer than the time required by the baffle to become completely extended.

When the baffle is fully extended, it will actuate limit switch B to its N.O. position. Switch B in N.O. is a short circuit which will "blow" limit fuse B and thereby render it impossible for the baffle to ever extend again.

The baffle is now in its out position with the film and shutter operating in their cammed sequence.

At the end of the last exposure, baffle cam B will actuate its switch to the N.O. position, thereby charging the capacitor and on dropping to N.C. trips the baffle relay to commence retracting the baffle. This will pulse the relay and baffle return switch A to the normally open position. In this position, the baffle drive power will be discontinued or a small amount of power can be supplied to the baffle motor to hold the door shut without depending on passive friction.

In conclusion the described circuit is protected against most faults and is extremely flexible allowing convenient changes in the flight program. This circuit was developed primarily to make sure that sufficient and correct positioning of the mechanical switches was designed so that a logically complete switching circuit could be installed. The circuit was designed, fabricated, and used extensively to test the mechanical components of the first delivered flight instrument. It proved invaluable for the mechanical testing and did receive rough electrical treatment with oscilloscope testing and monitoring of motor reversing current and time. With current overloads exceeding twice rated motor current no change in required relay tripping power (just about 130 mw) was noticed and never was a relay replace. Under the above conditions relay life exceeded 200 reversals.

Figure 8 is a schematic of the front and rear panels of the electronics control box and should be consulted when connecting the instrument for test. Some important items to note are: 1) if the N.C. and N.O. wires are reversed when connections are made to the box, the system will still operate but the relay triggering will now be taking place when the switch foot rides up on a cam. This means that the circuit will be cocked for longer periods of time and will increase the possibility of erroneaous shuttering; 2) care must be take to see that the right polarity voltage is applied to the switching circuits; 3) if the N. C. and N.O. wires are reversed for the switch B, fuse B will blow and the baffle will only extend $\sim$ 1". For this reversed condition, start-up is followed by immediate shut-down of the baffle circuit.

V. Optical Focusing and Alignment of the Rocket Stellar Spectrograph

1. General Set-up

The optical alignment of the rocket spectrograph was performed in a specially built vacuum system equiped with a helium discharge source, a single mirror collimating system, and ionization and thermocouple pressure monitoring gauges. The windowless Tropel discharge source was purposefully supplied unpurified commercial grade helium. The collimating system consisted of a .0005" diameter pinhole at the focus of a f/10 f = 30" spherical platinum coated mirror. A perfect image of the pinhole would give a spectrograph image 1/4 of the expected spectrograph's image abberations. See Fig. 23.

2. Focusing and Image Shapes for Maximum Resolution and Maximum Intensity

Focusing of the instrument may be rapidly accomplished because the film slides may be individually adjusted for tilt and translation, and the instrument has the capability of 9 exposures with each test run. A rapid survey for best focus can be made by recording the image height of the 584A and 1216A lines obtained by

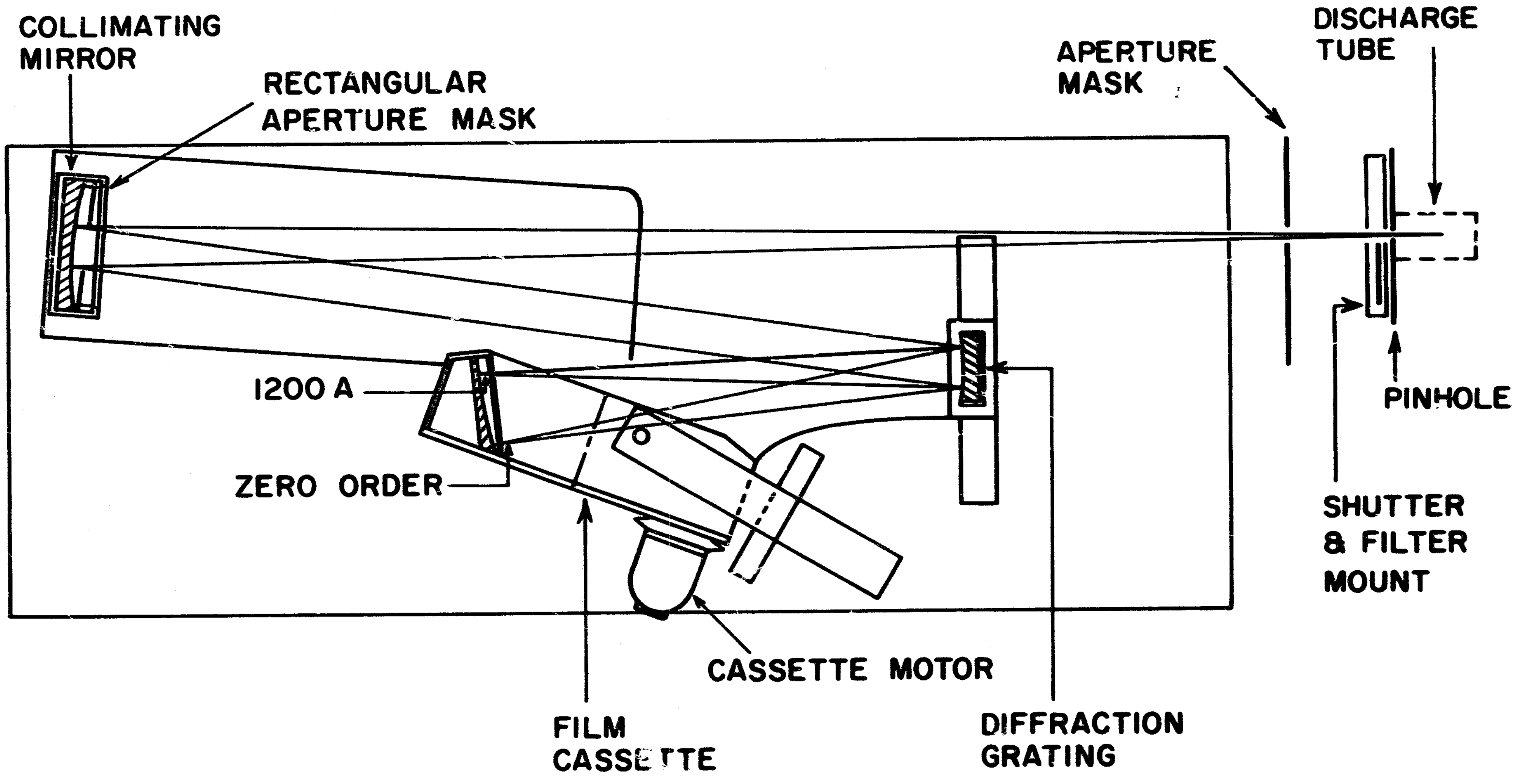


FIGURE 23 TEST APPARATUS (VACUUM)

adjusting each film slide to have a translation differing from the theoretical focal curve. Figure 24 is a graph representing a typical calibration curve. The image heights have been plotted versus dial guage translation position. From this graph it can be seen that these test slides actually need to be tilted to yield best focus at both the 584A and 1216A positions. The position of best focus at the 1216A line lies somewhere between a +.015 to .020 inch translation from the theoretical focal curve, while the position of best focus at the 584A line lies in the region of -.010 inch (measured at center of slide) displacement from the true curvature. A +.015 inch translation is a movement of the film plane .015 inch toward the grating and vice versa for a -.015 inch translation. Since astigmatism becomes fairly pronounced at the 585A line, one has to decide whether one wants an image giving energy concentration or resolution or a compromise in choosing the position of best focus. Five typical spectra were obtained while attempting to fine focus the instrument. Out-of-focus images always appeared as tall rectangles. The 584A line began to curl over for maximum energy concentration as this position was moved farther away (further from grating) from the theoretical focal curve. Figure 25 - spectrum from test set-up (584A - 1278A) is considered to be very close to a perfect maximum resolution focus.(having most prominent

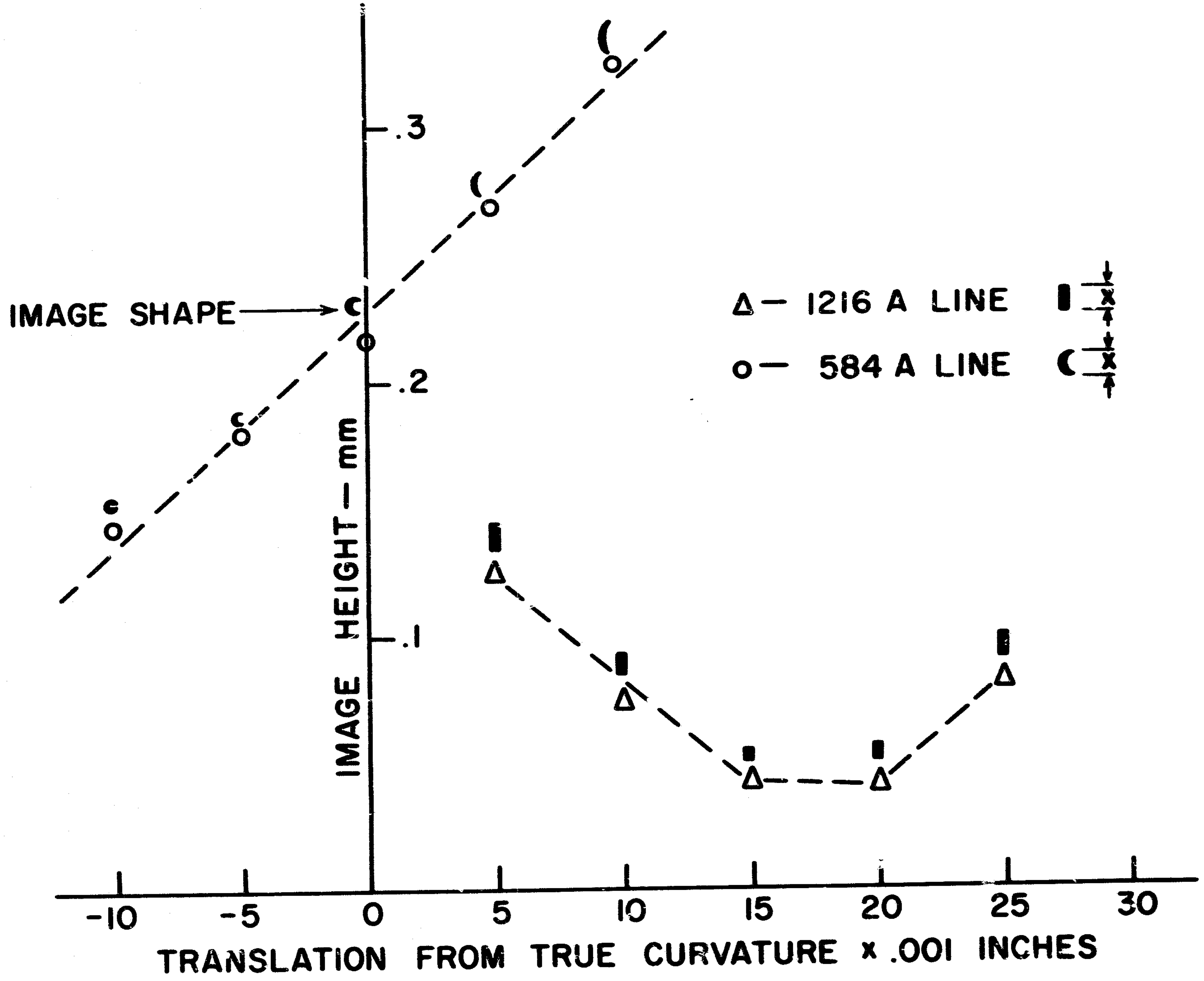
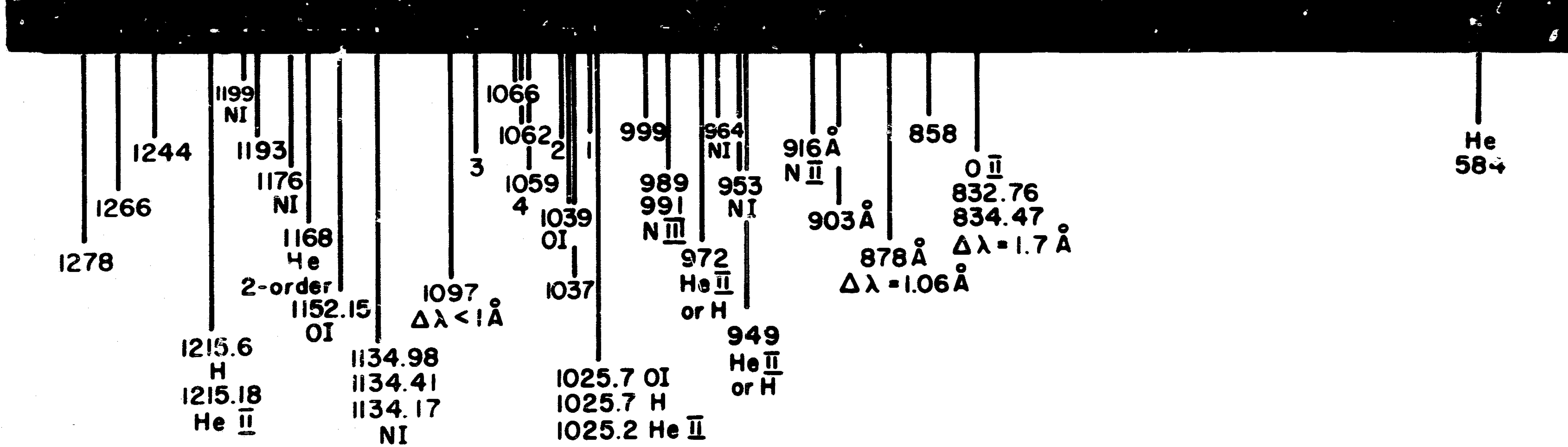


FIGURE 24 TYPICAL CALIBRATION CURVE



DISPERSION ON FILM = 33 Å/mm. SCALE: 10x

1. THESE TWO FAINT LINES ARE THE OI SERIES 1027.43 & 1028.16
2. THIS IS PROBABLY THE OI DOUBLET 1040.44 & 1041.69
3. SERIES OF N II LINES 1083.99, 1084.56, 1084.58, 1085.55, 1085.7: THE 1084.58 & 1085.7 ARE THE STRONGEST AND IT APPEARS THAT THEY ARE JUST RESOLVED.
4. WEAK COPPER SERIES.

FIGURE 25. SPECTRUM FROM TEST SET-UP (584Å-1278Å)

lines identified.) The most useful impurity lines (usually nitrogen) can be attributed to the boron nitride discharge tube and impure commercial grade helium gas. From this spectrum it is seen that the instrument is capable of resolving a 1A separation of two lines, (1200-800A), when inspecting an enlarged print of the original spectra.

Focusing Details

The adjustment of the film slides for tilt and translation is facilitated by using a special dial guage jug (supplied to NASA). Figure 25 is a picture of this jig. This jig expects the film slide to have a radius of R = 3.947 inches. A brass post whose surface is this selected radial distance from the dial guage pivot is provided for zeroing the dial gauage. The radius is not centered over the slide but is off-set .244 inches from the center of the slide. This off-set is built into the block of this jig. When the flat end of a good slide is against the end stop of the block, and the dial guage has swept across, the surface should be within $\pm$ .0005 inch of zero[1]. The slides screw feet should be adjusted from the back of the slide to bring this about. When the slide is in position for adjusting,

---

[1]Usually when adjusted the slide's legs are .015" different in height (which is probably a result of tolerance build-up and grating mount errors).

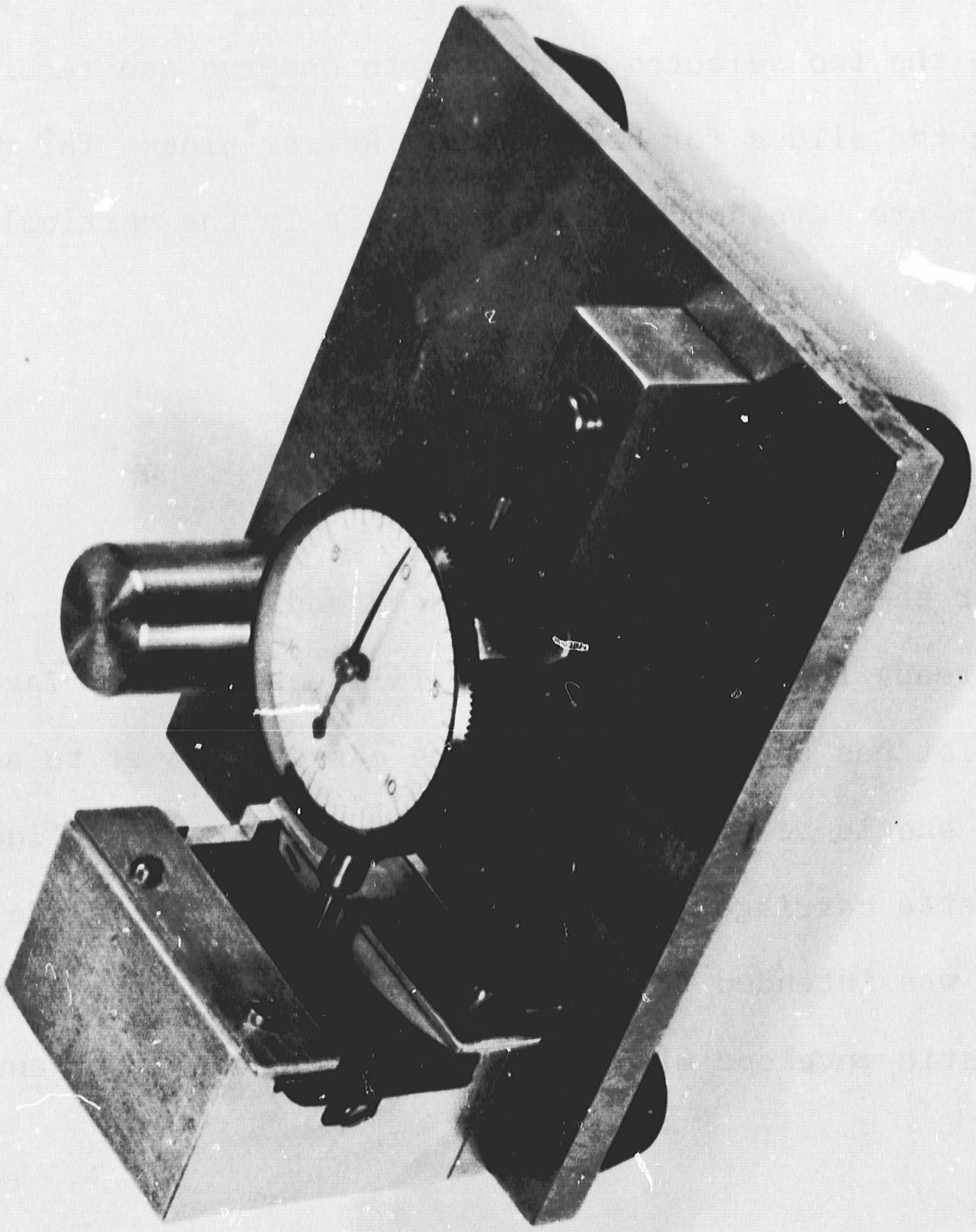


FIG. 26 SLIDE FOCUSING JIG

the 1216A position corresponds to the side closest to the brass post and lies approximately .25 inch in from this end.[2] The 584A position lies almost exactly in the center of the slide.[3] These are the two selected positions to observe and record when adjusting the slides for best focus. Raiser blocks for the radius arm are furnished so that the tilt in the vertical direction can also be adjusted.

Loading

After the film slides are adjusted and loaded with film they are then ready for loading into the film cassette carriage. A special slot has been provided in the cassette cover to accomplish this. It should be noted that when loading the film slides in the film cassette carriage, the beveled-flat end of the slide goes in last. It was intended to load each slide singly from a small black plastic envelope within at least a subdued light environment.

[2]Drop pin in right hand hole.

[3]Drop pin in center hole.

VI. HANDLING AND PROCESSING PROCEDURES

SC-5 AND SC-7 FILMS

by D. Baumgardner

This section contains notes on the handling; i.e., cutting, loading into film cassette, etc. of SC-5 and SC-7 films and a summary of the processing techniques used with each type film.

SC type films are obtained from Kodak-Pathe in 35 mm x 180 mm strips on a .20 mm triacetate base. General information concerning handling and processing is furnished with each batch of film. This information will be summarized here including a few notes concerning methods which I have found helpful in the handling and processing of the film.

1. Cutting Procedures

Since the film cassette in the rocket spectrograph requires film that is 22 mm wide x 53 mm long, it is necessary that a cutting operation be performed on the film as it is received from Kodak or Kodak-Pathe. It has been found that a standard paper cutter slightly modified for the correct width (22 mm) is completely satisfactory for this operation. The film can then be cut to the correct length using the paper cutter or by sliding the film into the cassette and trimming with a razor blade.

2. Handling Under Safelight

All handling operations are facilitated by using a safelight equipped with a #6B Wratten filter. Once the eye is dark adapted, this safelight yields a sufficient amount of illumination for the performance of all operations. A study was made in which both types of film were exposed to the safelight at a distance of 4 feet for periods ranging up to 1 hour. In both cases, no noticeable amount of fog was observed upon subsequent processing.

3. Unusual Handling Problems Characteristic of SC Type Films

Since the sensitized surface of the film has no gelatin protection, it is absolutely necessary that no contact of any kind be made with this surface. If contact is made with the sensitized surface, a darkened area will appear after development. In addition, sliding contact of the triacetate base with other surfaces should be minimized. This base has a tendency to accumulate a static electric charge and in certain instances the discharges can be seen with the eye. These discharges will, in effect, expose moderate areas of the film and will produce false images after processing.

4. Processing Techniques

The times and temperatures required for developing, rinsing, and fixing are indicated for each batch of film and will only be summarized here. Both SC-5 and -7 films are developed in D19.B at 20°C for a time ranging from 2 to 8 minutes (the optimum time is given for each batch). D19.B, as reported by Fowler, et al. utilizes maximum emulsion speed but does produce a coarse grain negative. The films are then rinsed for 10-20 seconds in running water, fixed in Kodak F-5 fixer for 2 minutes, washed 2 minutes in running water, and dried at room temperature. It was found that the single most important factor in controlling fog during the processing was maintaining the temperature of the developer accurately at 20°C. A variation by just + 1°C gave a noticeable fog level, especially with the SC-7 type film. It is also important to maintain the temperature of the other baths at 20°C to prevent a partial stripping of the emulsion edges. Our SC-5 negatives are fog-free by any but the most rigorous standards. Our SC-7 negatives showed block fogging of about 1/3 area of the film, about .8 of the time. This is thought to be a static problem since the usually single fog patch showed no detail or structure but amazing smoothness of the spatial density functions.