UNIVERSITY OF CALIFORNIA

LICK OBSERVATORY TECHNICAL REPORTS

NO. 39

OPTIMIZING CASSEGRAIN SHIELDS

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Santa Cruz, California
November 1984

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ABSTRACT:

It is possible to optimize a pair of light baffles for a two-mirror Cassegrain system. There are a number of pairs of shields which will eliminate sky rays from the selected focal plane field, but there is one unique set which will maximize the photon throughput (% illumination). This paper documents how this is done.

HISTORY:

The technique for optimizing the shields for a Cassegrain system is simple and straight-forward. It has been done a number of times by me. Each time takes about a week and the next time, I have completely forgotten the technique and have to re-derive it. This time it is being documented in a general form. If I am the only person to ever use this report and I use it twice, then the present effort of documentation will not have been wasted.

The current project which needs shields is the 10-Meter Telescope. It has a number of complications. The major one is that the optics are not round; they are not even hexagonal. This is easy to handle with non-round shields. A second complication is that the shields must be removable in 10 minutes. This could imply that they will be less rigid than permanent shields and therefore more "overlap" must be provided so that flexure doesn't let any sky light sneak past the flexed shields.

DEFINITIONS:

PRIMARY SHIELD. This is the shield that is closest to the primary mirror.

SECONDARY SHIELD. This is the shield that is closest to the secondary mirror.

FIELD. This is the area in the focal plane that must not "see" sky directly.

SKY RAY. This is the ray that passes just outside the secondary shield and fits inside the primary shield and hits at the edge of the field.

% ILLUMINATION. This is what we optimize. You want % illumination to be a maximum. Each shield will cast a shadow and thus make part of the primary mirror unusable. When each shield casts the same shadow, you are optimized.

OVERLAP. It is prudent to make the shields slightly larger than ideal so that flexure and location accuracy won't let sky light get to the field. (You are essentially shielding a slightly larger field at the expense of photons.)

MERIDIONAL RAY. This is a ray that is contained in a plane containing the optical centerline of the telescope. It is not a SKEW RAY.

SKEW RAY. All other rays that are not meridional.

METHOD:

One begins with the desired mirrors and spacing and back focal distance and desired field size. Of these, the desired field size is the most arbitrary. In the case of the 40-inch telescope, the shields were designed so that 6 inch diameter photomultiplier tubes could some day be used should they become available. This constraint has caused the % illumination to be smaller for the common 3 inch diameter fields used to date. These are being revised.

The TMT Cassegrain requirement for shielded field is 20 arc-minutes (diameter). These optimized shields will throw away 3% of the primary mirror for a smaller field instrument (3% is 1.5 square meters!). Since the engineering becomes extremely complicated for adjustable shields, let alone quickly retractable ones, it is important to justify a 20 minute field. (That's 0.88 meters or 35 inches in diameter.) Unless 3% loss is livable.

At any rate, we now have the optics defined and the field size. One then draws the elements. See Figure 1 for the F/15 Cassegrain system. See also Figure 2 for the actual primary mirror (the secondary mirror will be round).

The next step is to draw in the extreme off axis ray (10 arc minutes in this case) that hits the outer edge of the primary mirror. It traces to the secondary mirror and then to the edge of the shielded field. (Dashed line in Figure 3. Note that in Figure 3 we compress the horizontal scale. This makes things easier to see.)

Now, create a sky ray to the opposite edge of the field. It will cross our first off axis ray in two places. This is the solid line in Figure 3. This arbitrarily-drawn sky ray can be shielded by choosing points A1 and B1 for primary and secondary shields. Now, all other sky rays are excluded from our field and we are happy. EXCEPT, we may not have found the optimum set of shields and so this is where we look at shadows and % illumination.

Now we go to Figure 4. Points A1* and B1* are drawn to complete the shields on the other side of the optical centerline. By constructing the inner 10 minute ray, that just misses the primary shield at A1*, one can see that now the primary has been vignetted or shadowed by the primary shield. The secondary shield point, B1*, causes no further vignetting. This set of shields has a certain % illumination.

We pick a second sky ray and hopefully bracket the optimized shielding. (The secondary shield will cause shadowing.) This is shown in Figure 5 with points A2 and B2, as before. Then points A2* and B2* are located. Again, one constructs the inner 10 minute ray and we see that the secondary shield causes vignetting this time.

For the optimum set of shields, the primary shield and secondary shield form shadows at the same place on the primary mirror (Figure 6). I haven't been able to derive an analytic relationship for this unique set of shields, so I developed a ray-tracing computer program which does the graphical optimizing until the change in shield diameter gets to be less than some tolerance, say 1 mm. Figure 6 shows an optimized set of shields. No overlap is provided.

The program runs on a Commodore 64 with a C-Link, and is included here for the reader's amusement. Sample output is included.

Note: If meridional rays are shielded, then so are skew rays.

APPLICATIONS FOR THE 10-METER TELESCOPE

The major and minor "diameters" for the TMT primary are not the same. Thus, two shield sets were obtained. Six sets of shield points are arranged for shielding in the planes of the major diameters and six sets are arranged for shielding the minor diameters (flats). By connecting these 12 points, the secondary shield takes on an unusual configuration. It is not round and it is not hexagonal. It is shown in Figure 6 by Nelson (1980). It may be prudent to use round shields since the bundle of serrated hexagon beams is not easily definable (Conversation with Harland Epps.)

REAL NUMBERS:

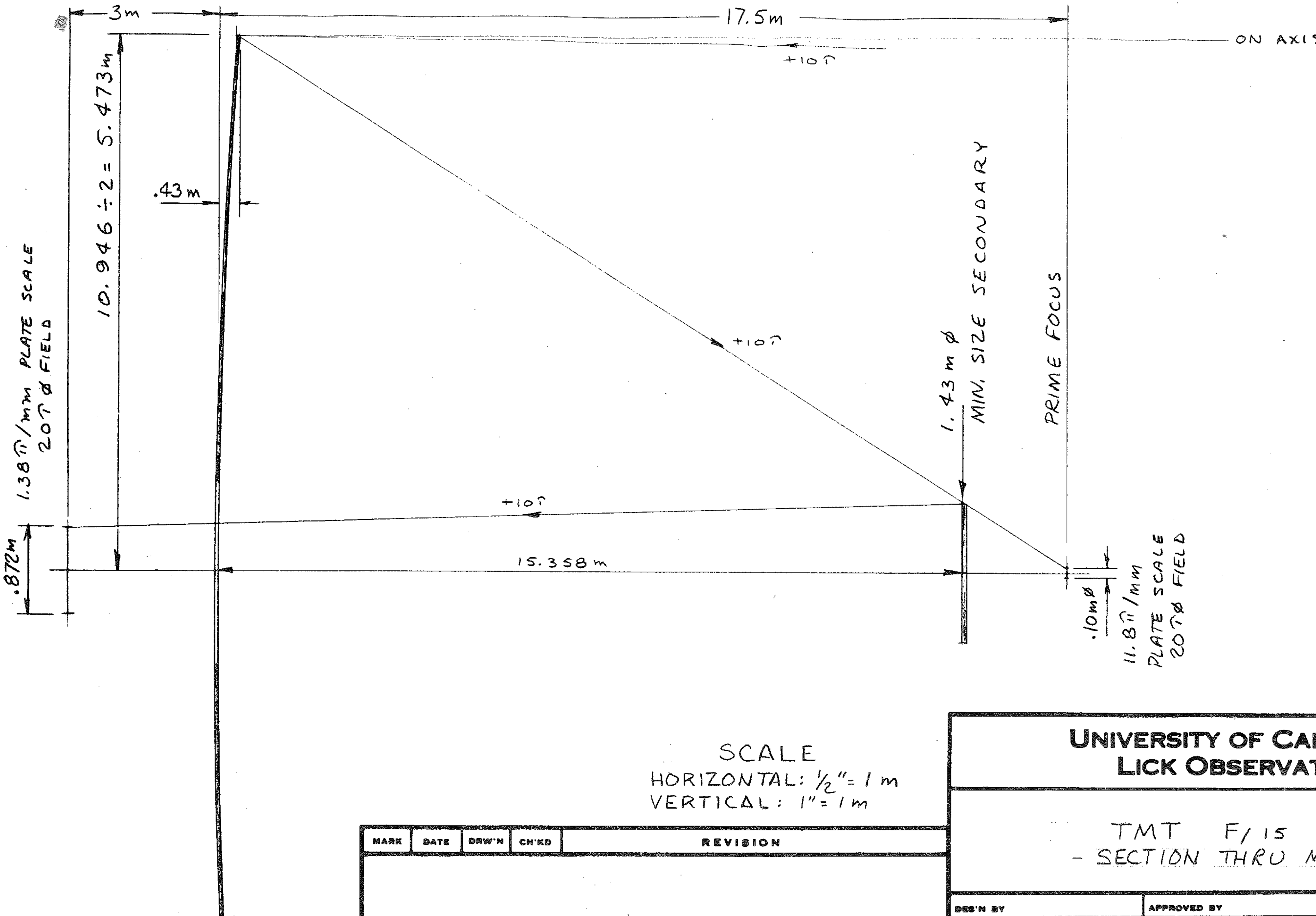
The primary mirror shown in Figure 2 has a major dimension of 10.946 m, a minor dimension of 9.897 m, and a radius of curvature of 35 m. The conic constant is -1.0038 (hyperbolic). The secondary for F/15 is 1.43 m in diameter and has a radius (convex) of 4.848 m. The conic constant is -1.6431. The nominal spacing is 15.36 m and the back focal length is 3 m. These are all of the parameters needed for the ray trace. The curve for a mirror is given by $Z = R^2/(2K) + (1+B)R^4/(8K^3)$, where K is the radius of curvature, B (or A2) is the conic constant, R is the radial distance from the mirror centerline and Z is the distance from the vertex along the centerline.

FURTHER COMMENTS ON THE F/15 SYSTEM:

1. This set of shields is valid for an F/15 Cassegrain configuration. There are minor changes when using a folded Cassegrain or "Nasmyth" system. Epps' preprint #163 shows a set of baffles for a Nasmyth system. There is a large round baffle as part of the primary shield that shields the focal plane from stray dome light. This also obstructs light going to the secondary, and a further refinement on the shielding might be used to consider this. (At this stage in the design, we should use Harland's shields.)

2. The optimized shields presented here have no overlap. The

amount of overlap depends on several factors. The shields may be stored in a place where they might be damaged and lose their correct size and shape. The alignment must be considered. If the shields fold into and out of position, then re-alignment tolerances will affect the overlap. Also, shield flexure must be considered. In Epps' shield system, the overlap produces a shielded field that is 15 inches in diameter larger than the desired 20 arc-minute diameter field. The secondary baffle is 4.5 inches larger on the radius for outer rays and the primary baffle is 1.8 inches larger on the radius. The inner rays, however, just clear both shields.



SCALE
HORIZONTAL: ½″ = 1 m
VERTICAL: 1″ = 1 m

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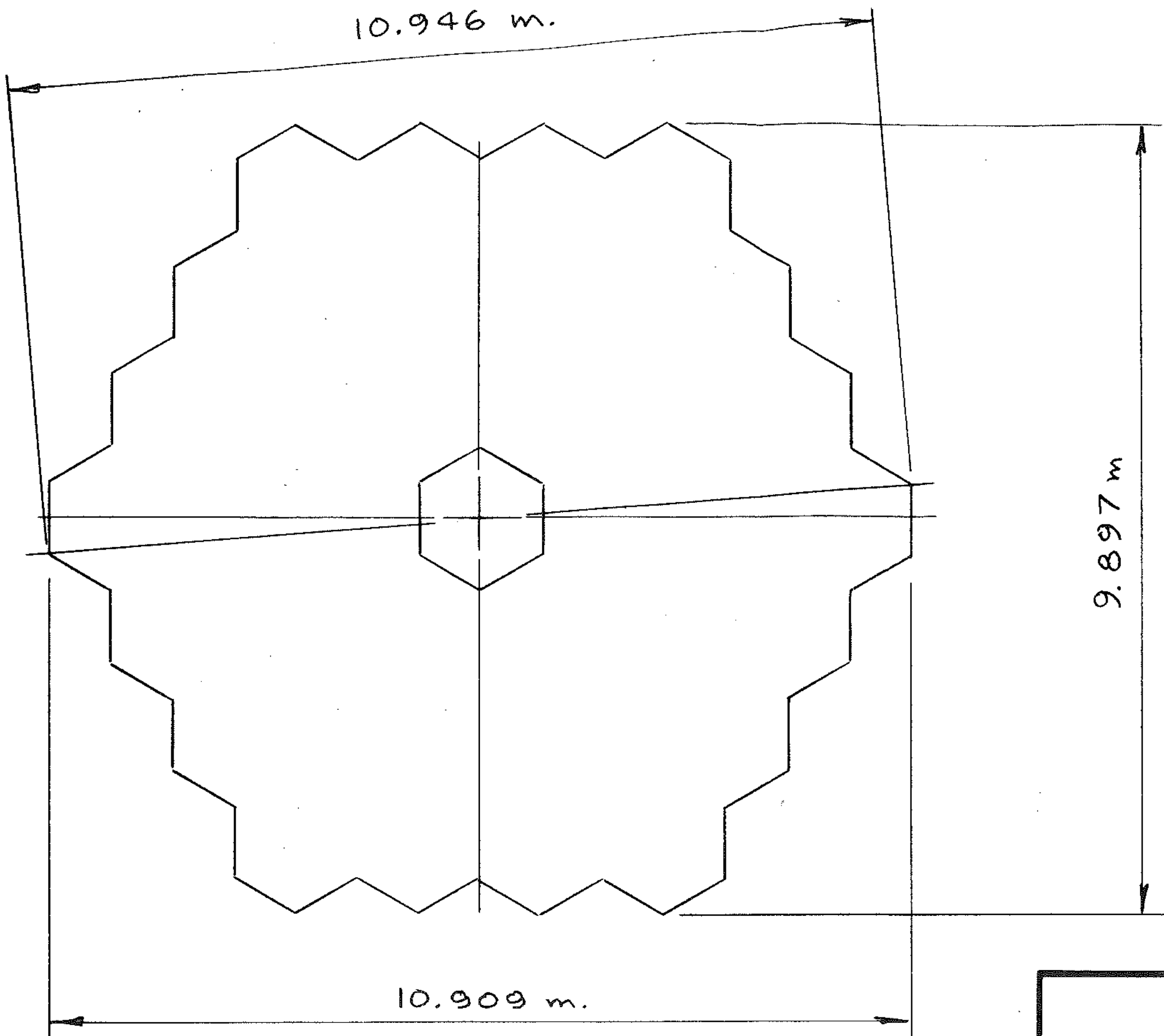
TMT F/15 CASS
- SECTION THRU MAJOR AXIS

DES'N BY	APPROVED BY	DWG. NO.
DRW'N BY JO		FIG 1
CHK'D BY	DATE 11-6-84	



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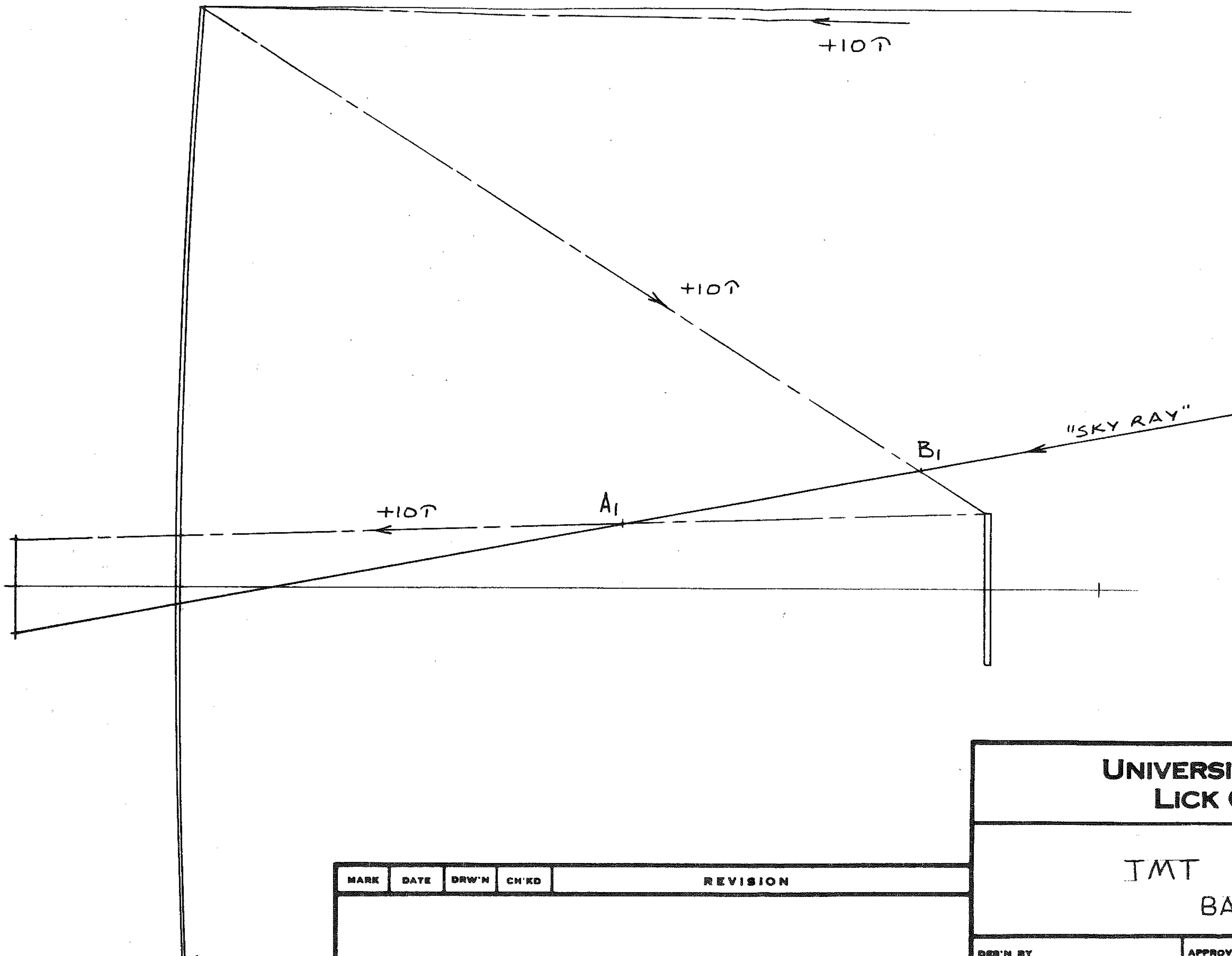
TMT F/15 CASS
PRIMARY

DES'N BY	APPROVED BY	DWG. NO. FIG. 2
DRW'N BY JO		
CHK'D BY	DATE 11-6-84	



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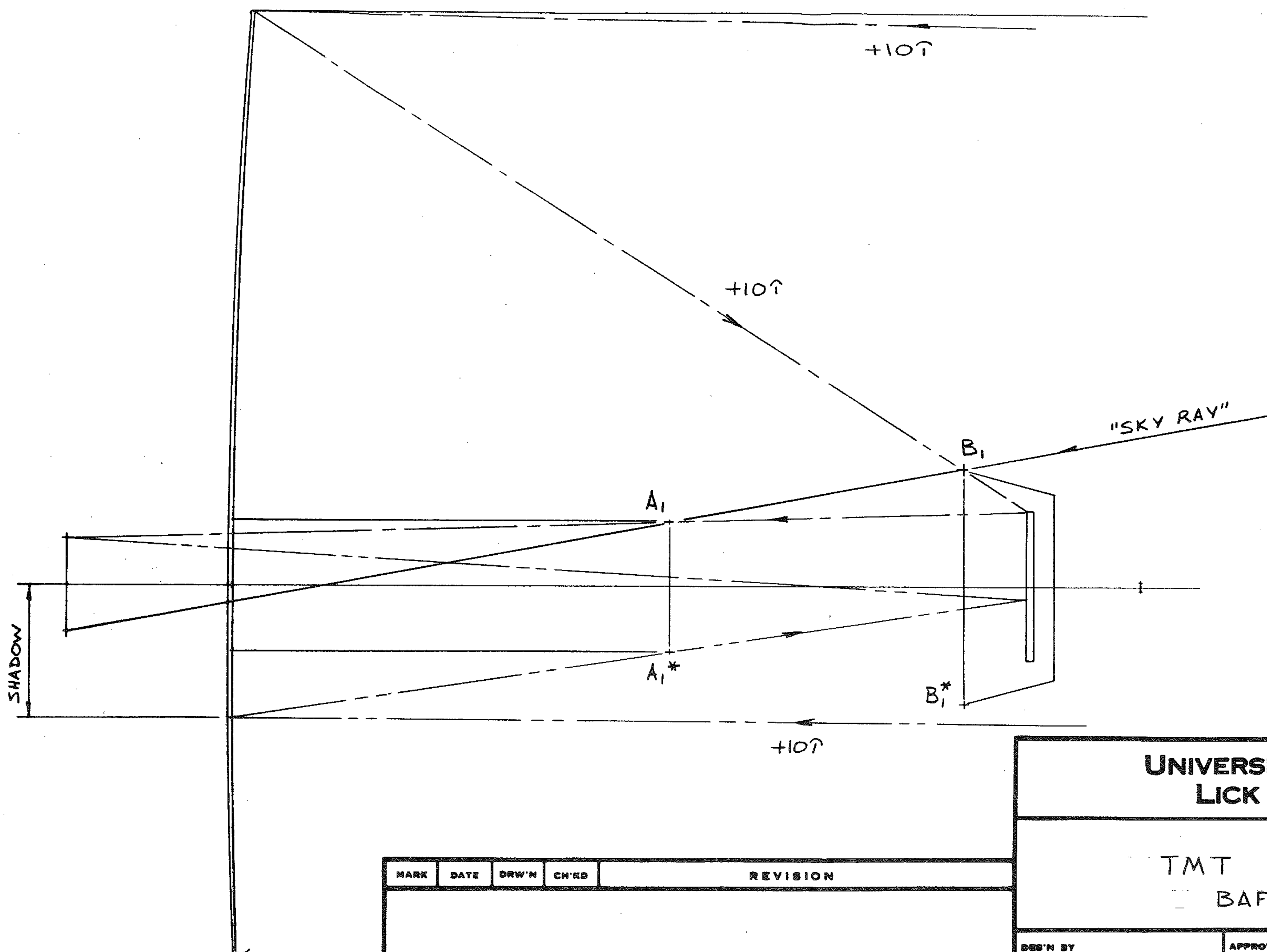
TMT F/15 CASS
BAFFLES

DES'N BY	APPROVED BY	DWG. NO.
DRW'N BY JO		FIG. 3
CHK'D BY	DATE 11-6-84	



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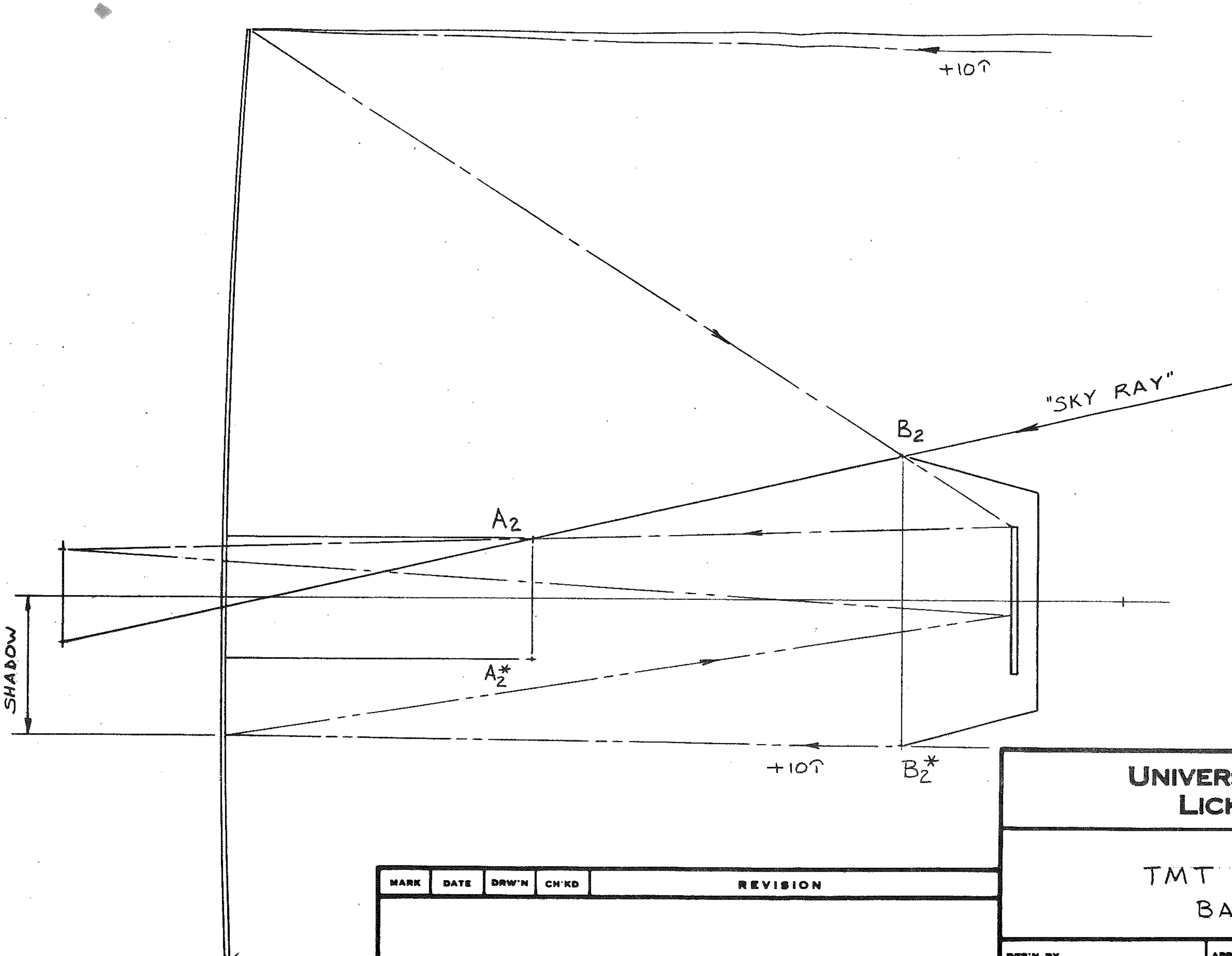
TMT F/15 CASS
BAFFLES

DES'N BY	APPROVED BY	DWG. NO.
DRW'N BY JO		FIG. 4
CHK'D BY	DATE 11-6-84	



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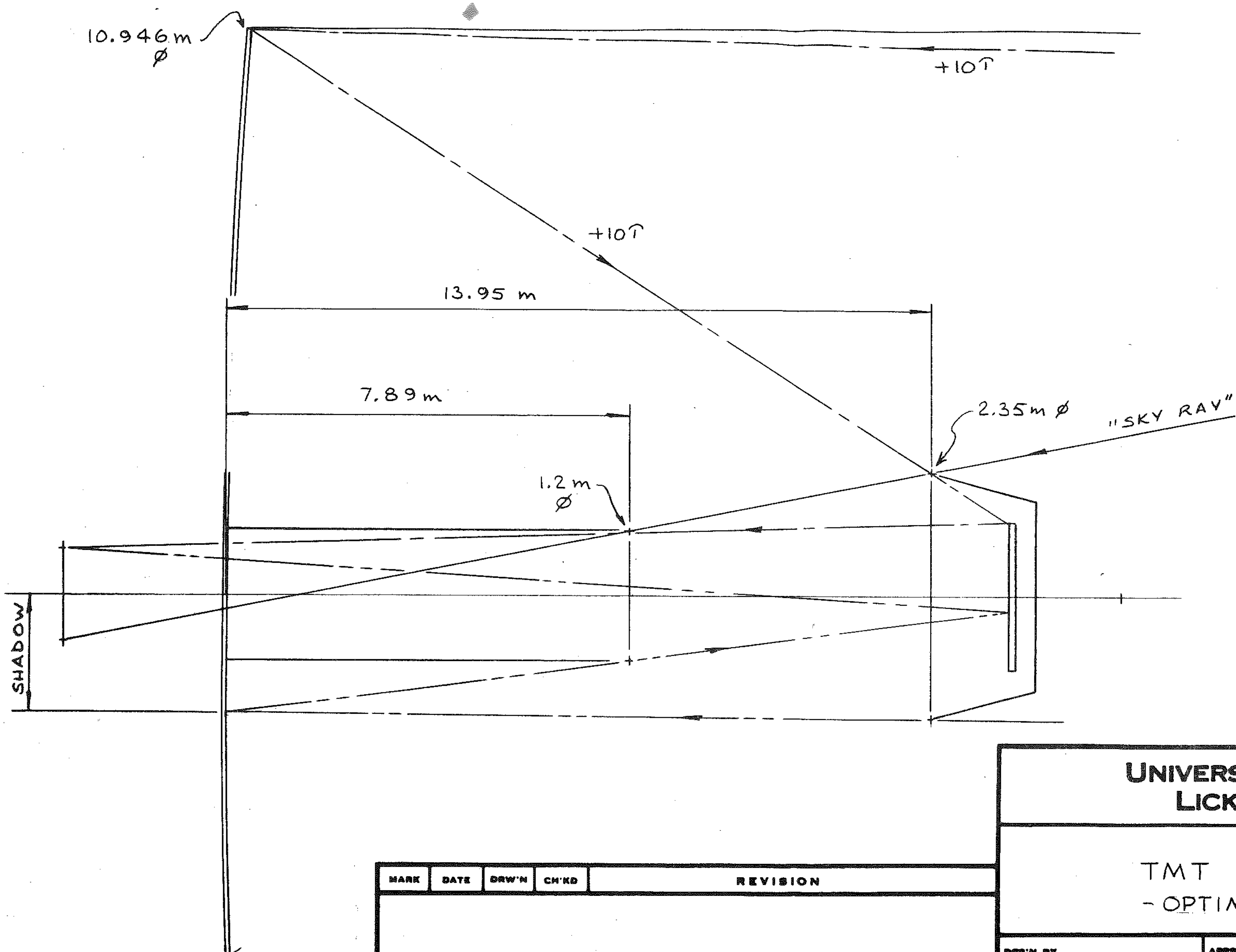
TMT F/15 CASS
BAFFLES

DES'N BY	APPROVED BY	DWG. NO.
DRW'N BY JO		FIG. 5
CHK'D BY	DATE 11-6-84	



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TMT F/15 CASS
- OPTIMIZED BAFFLES -

DES'N BY	APPROVED BY	DWG. NO.
DRW'N BY JO		FIG. 6
CHK'D BY	DATE 11-6-84	

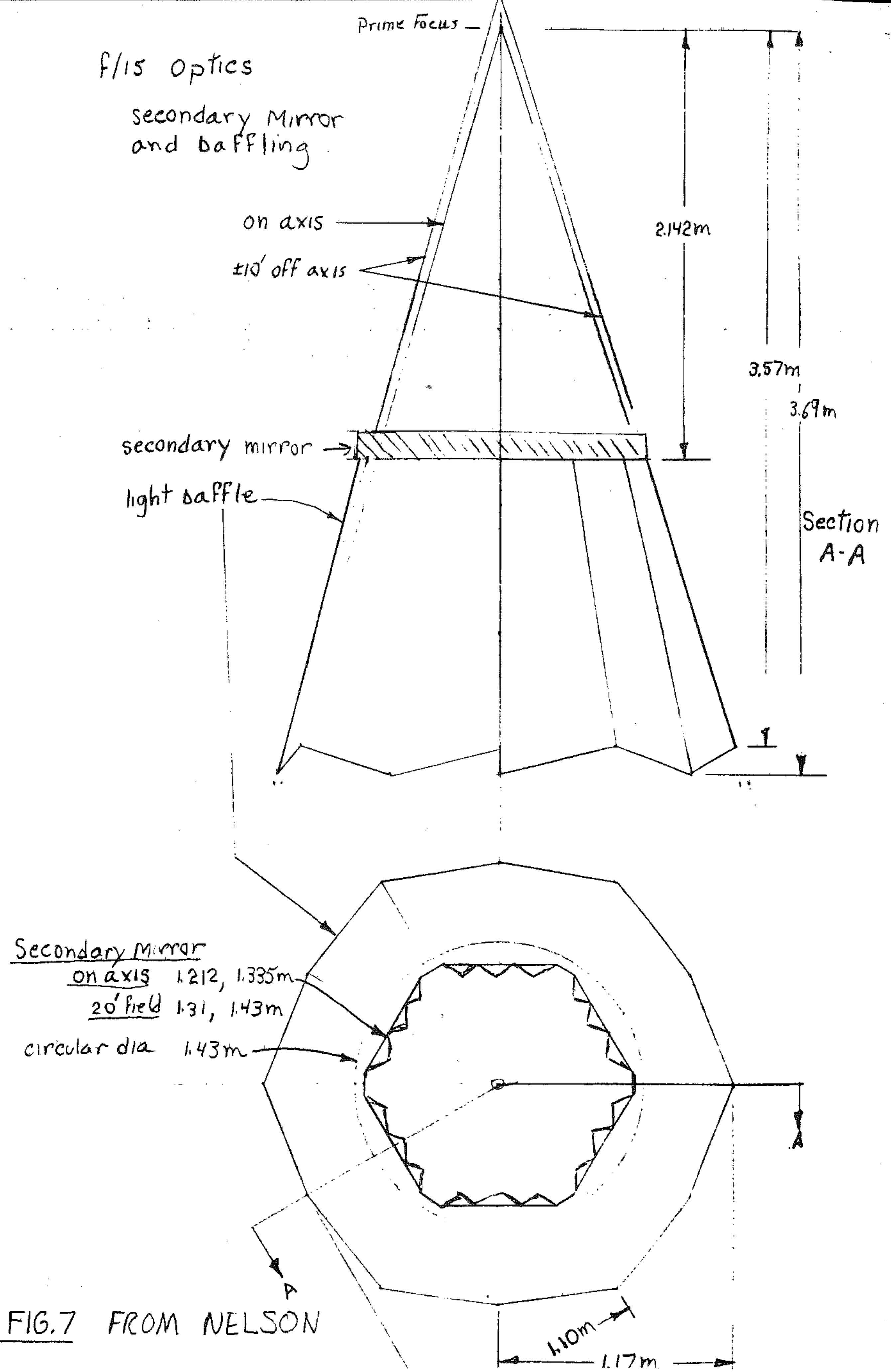

FIG. 7 FROM NELSON

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-
PROGRAM RAYOPT4, 12/19/80, J.OSBORNE; MODIFIED 11/6/84
CURVATURE,CONIC CONSTANT
 35           -1.0139 PRIMARY
-4.84           -1.7634 SECONDARY
SPACING IS  15.36
BACK FOCUS IS  3


...
OFF AXIS RAY = -10  ARC-MIN
RAY HITS PRIMARY AT  4.949  METERS FROM OPTICAL AXIS
CASS FOCAL PLANE DISTANCE FROM  CL=  .438313058  METERS
(MERIDIONAL RAYTRACE)


OPTIMIZED CASS SHIELDING
(RC,ZC)= ( .565  M, 7.887 M)

(R4,Z4)= ( 1.109  M, 13.798 M)

 9 ITERATIONS 1E-03 M,TOLERANCE ON PRIMARY SHIELD RADIUS
ENTRY RAY AT  4.949  METERS
```

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-
PROGRAM RAYOPT4, 12/19/80, J.OSBORNE; MODIFIED 11/6/84
CURVATURE,CONIC CONSTANT
 35           -1.0139 PRIMARY
-4.84           -1.7634 SECONDARY
SPACING IS  15.36
BACK FOCUS IS  3


...
OFF AXIS RAY = -10  ARC-MIN
RAY HITS PRIMARY AT  5.473  METERS FROM OPTICAL AXIS
CASS FOCAL PLANE DISTANCE FROM  CL=  .438099124  METERS
(MERIDIONAL RAYTRACE)


OPTIMIZED CASS SHIELDING
(RC,ZC)= ( .604  M, 7.899 M)

(R4,Z4)= ( 1.181  M, 13.948 M)

 9 ITERATIONS 1E-03 M,TOLERANCE ON PRIMARY SHIELD RADIUS
ENTRY RAY AT  5.473  METERS
```

```
10 PI=3.141592654
90 PRINT"PROGRAM RAYOPT4, DEC. 18, 1980  MODIFIED NOVEMBER 1984."
100 GOSUB9100:REM SET UP OPTICAL PARAMETERS.
348 INPUT"OFF AXIS RAY,(ARC-MIN)= ";OFF
349 AX=OFF:OFRAD=(OFF/60)*PI/180
500 INPUT "R= ";R:IF R=0 GOTO0348
510 Q=R:F=0
600 GOSUB 7500:REM GET (R,Z) AND M, P FOR FIRST BOUNCE.
1250 GOSUB8000:REM FIND POINT AT SECONDARY MIRROR (R2,Z2).
2000 PRINT"RAY HITS SECONDARY = ";R2,Z2
2100 GOSUB 7700:REM FIND (R3,Z3) IN FOCAL PLANE AND M3, P3 FOR SECOND BOUNCE..
3300 GOSUB 9500:REM PRINT STUFF
4000 REM:OPTIMIZING SHIELDING..........
4001 INPUT "TOLERANCE= ";T
4002 IF T=0 GOTO0348
4003 I=1
4004 IF F=1 GOTO4030
4005 P6=P:M6=M:REM SAVE FIRST BOUNCE RAY AS M6, P6.
4020 R4=R2:REM START AT (R2,Z2) AT SECONDARY MIRROR
4025 F=1
4027 PRINT"OPTIMIZING"
4030 REM:POINT A
4100 Z4=M6*R4+P6:REM Z4 IS ALWAYS ON FIRST BOUNCE RAY
4110 M4=(Z4-Z3)/(R4-(-R3)):P4=Z4-M4*R4:REM SKY RAY SLOPE M4, INTERCEPT P4
4160 REM:POINT C IS SKY RAY + INNER RAY (-OFF) SECOND BOUNCE.
4180 OFRAD=(-AX/60)*PI/180
4183 R=R4-Z4*TAN(OFRAD)
4186 PRINT R4
4190 GOSUB 7500:REM GET (R,Z) AND M,P.
4195 GOSUB 8000:REM GET (R2,Z2).
5000 RC=(P4-P)/(M-M4)
5100 ZC=M*RC+P
5200 REM:POINT D IS SKY RAY + OUTER RAY (+OFF) SECOND BOUNCE
5210 REM:LET ZD=ZC
5220 RD=(ZC-P3)/M3
5222 PP=(INT(1000*RD))/1000:PQ=(INT(1000*RC))/1000
5330 R4=R4*RD/RC
5335 I=I+1
5338 REM:NOW TEST/POINT D=POINT C?
5340 IF ABS(RD-RC)>T GOTO4030
5345 GOSUB6000:REM PRINT RESULTS.
5400 GOTO4001
6000 PP=(INT(1000*RC))/1000:REM OUTPUT FOR FINAL SHIELDS TO GIVEN TOLERANCE....
6005 PQ=(INT(1000*ZC))/1000
6030 OPEN 4,4
6032 CMD 4
6040 PRINT"OPTIMIZED CASS SHIELDING  "
6050 PRINT"(RC,ZC)= (";PP;" M,";PQ;"M)"
6075 PP=(INT(1000*R4))/1000
6080 PQ=(INT(1000*Z4))/1000
6100 PRINT:PRINT"(R4,Z4)= (";PP;" M,";PQ;"M)":PRINT
6120 PRINTI;"ITERATIONS";T;"M,TOLERANCE ON PRIMARY SHIELD RADIUS"
6130 PRINT"ENTRY RAY AT ";Q;" METERS"
6140 PRINT#4,CHR$(13)
6142 CLOSE4
6200 RETURN:REM...........................................................

READY.
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```
7500 Z=R^2/(2*K1)+(1+B1)*R^4/(8*K1^3):REM.................................
7510 SLOPE = R/K1+ (1+B1)*R^3/(2*K1^3)
7520 THETA=ATN(SLOPE)
7530 M=-TAN(PI/2-2*THETA-OFRAD):REM M IS SLOPE OF RAY HEADING FOR SECONDARY.
7540 P = -M*R+Z:REM P IS OPTICAL AXIS INTERCEPT.
7550 RETURN:REM WITH (R,Z) AND M, P FOR FIRST BOUNCE.........................
7700 REM:SLOPE2 AT INTERSECTION OF RAY AND SECOND SURFACE:................
7710 SLOPE2=R2/K2+(1+B2)*R2^3/(2*K2^3)
7720 BETA=ATN(-1/SLOPE2)
7730 GAMMA=ATN(M)
7740 M3=TAN(2*BETA-GAMMA):REM M3 IS SLOPE OF RAY HEADING FOR FOCAL PLANE.
7750 P3=Z2-M3*R2:REM P3 IS OPTIC AXIS INTERCEPT.
7760 Z3=-E
7770 R3=(Z3-P3)/M3
7780 PRINT"FOCAL PLANE  = ";R3,Z3
7790 RETURN:REM (R3,Z3)FOCAL PLANE AND M3,P3 FOR SECOND BOUNCE RAY.........
8000 REM: FIND R2,Z2 AT SECONDARY MIRROR BY ITERATION.....
8010 REM: COME IN WITH Y=MX+P FORM OF RAY. (Z=MR+P)
8020 REM: CURRENT M, CURRENT P. RETURN WITH R2,Z2.
8050 R1=.1
8060 Z1=M*R1+P
8070 Z2=R1^2/(2*K2)+(1+B2)*R1^4/(8*K2^3)+D
8080 DZ=Z1-Z2
8090 IF ABS(DZ)<.0000001 GOTO 8115
8100 R1=R1-DZ/M
8110 GOTO 8060
8115 R2=R1
8200 RETURN:REM.........................................
9100 INPUT "K1,CURVATURE, M = ";K1:REM............................
9101 IF K1=0 THEN K1=35
9102 PRINT"K1= ";K1
9105 REM:K1=35 (2*17.5)
9225 INPUT"SPACING, M= ";D
9226 IF D=0 THEN D=15.36
9227 PRINT"SPACING = ";D
9230 REM:SPACING=15.36 (NASMYTH)
9240 INPUT"BACK FOCUS = ";E
9242 IF E=0 THEN E=3
9295 REM:B IS CONIC CONSTANT
9300 INPUT"B1= ";B1
9301 IF B1=0 THEN B1=-1.0139
9302 PRINT"B1 = ";B1
9305 REM:B1=-1.0139
9310 INPUT"B2 = ";B2
9311 IF B2=0 THEN B2=-1.7634
9312 PRINT"B2 = ";B2
9315 REM:B2=-1.7634 (NASMYTH)
9317 INPUT "K2 = ";K2
9318 IF K2=0 THEN K2=4.84
9319 REM:K2=4.84 (NASMYTH) =2*2.42
9330 OPEN 4,4
9331 CMD 4
9332 PRINT"-"
9333 PRINT"PROGRAM RAYOPT4, 12/19/80, J.OSBORNE; MODIFIED 11/6/84"
9334 PRINT"CURVATURE,CONIC CONSTANT"
9335 PRINT K1,B1;"PRIMARY"
9336 PRINT-K2,B2;"SECONDARY"
9338 PRINT"SPACING IS ";D
9339 PRINT"BACK FOCUS IS ";E
9341 PRINT#4,CHR$(13)
9342 CLOSE4
9346 RETURN:REM........................................
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```
9500 OPEN 4,4:CMD 4:REM.................................................................
9520 PRINT"..."
9530 PRINT"OFF AXIS RAY = ";AX;" ARC-MIN"
9540 PRINT"RAY HITS PRIMARY AT ";R;" METERS FROM OPTICAL AXIS"
9550 PRINT"CASS FOCAL PLANE DISTANCE FROM  CL= ";R3;" METERS"
9560 PRINT"(MERIDIONAL RAYTRACE)"
9570 PRINT:PRINT
9580 PRINT#4,CHR$(13)
9590 CLOSE4
9595 RETURN:REM.........................................................................

READY.


1 THIS FILE IS ON I04 DISK AS RAY84-3

READY.
```