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PERKIN-ELMER
BOLLER & CHIVENS DIVISION

DESIGN STUDY
of the
DEEPSKY ULTRAVIOLET SURVEY TELESCOPE
(Rev. A)

SPO 59170

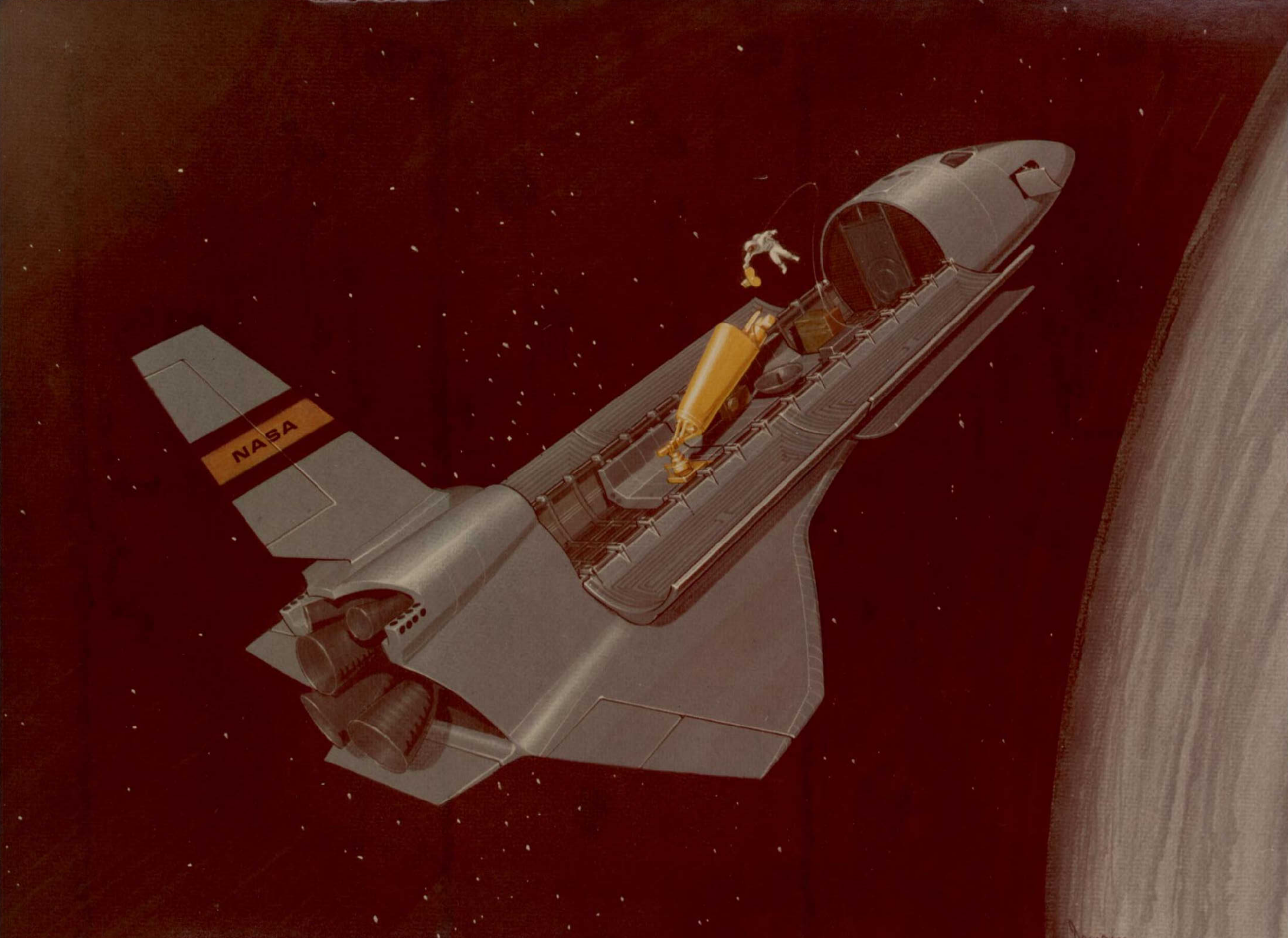
FINAL REPORT

August 1977

Contract NAS 9-14684
~~Mod. 2A~~

Contract Value - $15,000

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lyndon B. Johnson Space Center
Houston, Texas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FOREWORD

This final report on the design study of the Deepsky Ultraviolet Survey Telescope (DUVS) was prepared by the Boller & Chivens Division of the Perkin-Elmer Corporation, South Pasadena, California for the NASA Johnson Space Center (JSC), under contract number NAS 9-14684/Mod. 2S.

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INTRODUCTION

This study is an extension of NASA contract NAS 9-14684. Its purpose is to provide a preliminary mechanical design and specifications for a wide field ultraviolet telescope based on an optical design and a detector configuration supplied by Johnson Space Center.

LIST OF FIGURES

1.0 DESCRIPTION OF THE DEEPSKY ULTRAVIOLET SURVEY TELESCOPE

1.1 GENERAL ARRANGEMENT

The general arrangement of the telescope is shown in Figure 1. The optical design was performed by Dr. Dan Schroeder of Beloit College who considered several systems, namely an all reflecting Schmidt system, a Ritchey-Cretien system, a Schwartzschild system, and a Baker-Schmidt flat field system. The Baker-Schmidt flat field system having a reflective corrector was accepted by NASA as the one most suitable for the purpose, mainly because of its accessible focal plane and its large flat field. Figure 2 shows the optical design and relevant parameters. (Refer to Table 1.)

TABLE 1

SUMMARY OF MECHANICAL, THERMAL AND POWER PARAMETERS

Overall Mechanical Dimensions: 106" x 50" x 170"
(2.7 m x 1.25 m x 4.3 m)

Subassembly	Weights (Lb.)	Weights (Kg.)
Truss	230	105
Mirror Cell	300	136

TABLE 1 (continued)

Subassembly	Weights (Lb.)	Weights (Kg.)
Primary Mirror	381	173
Corrector	190	86
Secondary Mirror	33	15
Solenoid + Magazine	350	159
Shell	100	46
Corrector Cell	50	23
Secondary Mirror Support	80	36
Mounting Member	150	68
	1864	847

Distance to C.G. (Telescope)

From I.P.S. Interface: 121" (3.03 m)
From I.P.S. Cross Axis: 18" (0.45 m)

Moment of Inertia of Telescope

About I.P.S. Interface: 6251 Lb.Ft.Sec.^{2} (8416 Kg.m^2)
About I.P.S. Cross Axis: 268 Lb.Ft.Sec.^{2} (337.5 Kg.m^2)
About I.P.S. Azimuth Axis: 8886 Lb.Ft.Sec.^{2} (11,984 Kg.m^2)

Power Requirements

600 watts during operation
20 watts during launch and re-entry

One of the major problems involved in the design study was the configuration of a support structure with adequate stiffness that would maintain the optical components in their positions relative to each other. The feature that makes this particular telescope different from the normal Baker-Schmidt telescopes is the fact that the incoming light is not on the same axis as the telescope optical axis but is at an angle of 164° to the telescope optical axis. Because of this, a thin-walled tube considered as a structure to mount the optical elements would be severely weakened by the opening that would be required to allow the light to enter. A structure of the Serrurier truss type would also have a similar weakness (especially in torsion) because no adequate bracing on the side that accepts the incoming light could be conceived. The weaknesses of such structures would result in quite low natural frequencies in both torsion and bending so both methods were rejected as inadequate.

In order to arrive at a solution having adequate rigidity in both bending and torsion, a triangular sectioned, trussed structure was designed consisting of three longerons of thin-walled circular tubing. Diagonal bracings and spacers made from thin-walled circular tubing are attached at major stress points along its length. Both ends of the structure have circular pads attached to accommodate the primary mirror cell and the IPS/Payload Integration Ring mounting member. Two box-section members are attached to the upper longerons to support the secondary mirror assembly. The material used for this structure is discussed elsewhere in this report.

Let us consider an invar structure and find the maximum temperature change of the structure that will maintain the image plane within its focal range, eliminating the need for active focus control by mechanical means.

Depth of Focus = 4λ (Focal Ratio)^2

For λ = .5μm

Depth of Focus = $4 x .5 x 3.5^2$

= 24.5μm (.00096")

Magnification of Secondary = 1.69

Movement of Secondary to Move Focal Plane by 24.5μm =

$$\frac{\text{Depth of Focus}}{(\text{Magnification of Secondary})^2} = \frac{24.5\mu m}{1.69^2} = \underline{\underline{8.6\mu m}} = (.000337")$$

Primary/Secondary Separation = 92.05cm (36.24")

Coefficient of Linear Expansion of Invar (αt) = $12.5 x 10^{-7}/°C$

$(12.5 x 10^{-7} x\ 92.05cm)\ \Delta t = (8.6\mu m x 10^{-4})cm$ Where Δt = temperature difference

$$\Delta t = \frac{(8.6\mu m x 10^{-4})cm}{12.5\ x\ 10^{-7}\ x\ 92.05cm}$$

$$\Delta t = \underline{\underline{7.5°C}}$$

Assuming that the thermal control will be required to hold the focus within 1/2 the acceptable depth of focus, the 1/2 temperature range will be 3.75°C or ±1.87°C. Such a temperature variation could easily be accomplished using simple on-off controllers.

Other materials considered were aluminum and steel, which were rejected (in this preliminary design phase at least) due in part to the allowable temperature variation being small. For instance, if the structure was made of aluminum the allowable temperature variation would be:

$$3.75°\text{C} \times \frac{\text{(coefficient of linear expansion invar)}}{\text{(coefficient of linear expansion aluminum)}}$$

$$= 3.75°\text{C} \times \frac{12.5\text{x}10^{-7}}{23.4\text{x}10^{-6}}$$

$$= 0.2°\text{C}$$

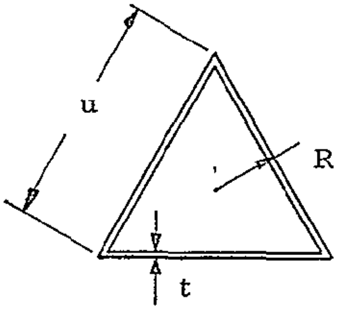
If the structure was made of steel, the allowable temperature variation would be:

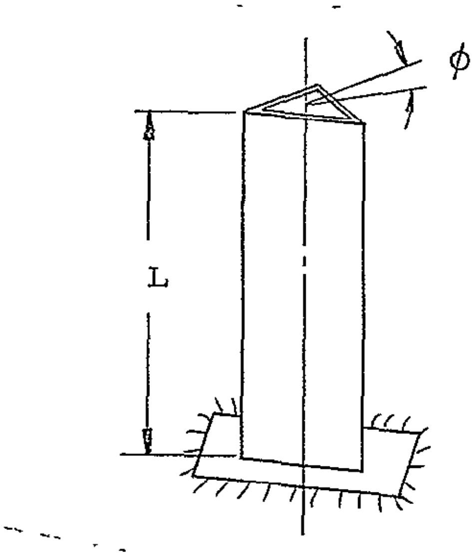
$$3.75°\text{C} \times \frac{\text{(coefficient of linear expansion of invar)}}{\text{(coefficient of linear expansion of steel)}}$$

$$= 3.75°\text{C} \times \frac{12.5\text{x}10^{-7}}{11.7\text{x}10^{-6}}$$

$$= 0.4°\text{C}$$

STIFFNESS OF SUPPORT STRUCTURE (TORSIONAL)





u = 35 inches

L = 180 inches

t = Thickness

$R = \frac{\mu}{2} \tan 30°$

G = Mod. of Rigidity

$= 8.1\text{x}10^{6} \text{ lb/in}^{2}$

M_T = Moment(Torsion)

Calculation of Constants

$$u = \frac{3R}{\cos \frac{x}{2}} = 3.46R$$

$$Ix = Iy = \frac{2u^3 t \sin^2 120°}{12} + \frac{2t^3 u \cos^2 120°}{12} + 2uR^2 t \sin^2 \frac{x}{2} + u\,tR^2$$

$$= 2\,\frac{27R^3 t \sin^2 60°}{12 \cos^3 30°} + 2\,\frac{t^3 3R \cos^2 60°}{12 \cos 30°} + 2\,\frac{3R^3 t \sin^2 30°}{\cos 30°} + \frac{3\,R^3 t}{\cos 30°}$$

$$= 10.4R^3 t$$

Torsional Moment

$$\phi = \frac{M_T L\,(R_1 + R_o)}{4Gt\,10.4\,R_1^{\,2}\,R_o^{\,2}}$$

$R_1 = R_o = R$

$$\phi = \frac{M_T\, L2R}{4Gt10.4R^4}$$

$$= \frac{M_T\, L2}{4Gt\ 10.4R^3}$$

$$\frac{M_T}{\phi t} = \frac{4x8.1x10^6x10.4x\left(\frac{\mu}{2} \tan 30^\circ\right)^3}{180x2} \qquad \frac{(\text{LB.IN})}{(\text{RAD})\ (\text{IN})}$$

$$= 9.65x10^8\ \frac{(\text{LB.IN.})}{(\text{RAD})\ (\text{IN})}$$

Let u't be the area of shear members.

$$u't = \frac{\pi}{4}(2^2 - 1.75^2) = .7363$$

If $u' = (u - 5) = (35 - 5) = 30''$

then, $t = \frac{.7363}{u'} = \frac{.7363}{30} = \underline{\underline{.025''}}$

$$\frac{M_T}{\phi} = (9.65 \times 10^8)\, t = 2.413 \times 10^7 \ \frac{\text{Lb. In.}}{\text{Rad.}}$$

Spring Constant $K = \frac{2.413 \times 10^7}{12}$

$$\underline{\underline{K = 2.01 \times 10^6 \ \frac{\text{Lb. Ft.}}{\text{Rad.}}}}$$

Moment of Inertia and Weight Calculations for Primary Mirror System Plus Detector

ELEMENT	WEIGHT	$I_{(xx)}$	$I_{(\text{about n. a. of truss})}$
Primary Mirror	381	93,440	320,421
Solenoid	250	22,562	210,250
Film Transport	100	2,466	84,100
Mirror Cell	300	90,000	252,300

Total $I_{(xx)} = 208,468$ Lb. In.^{2}

Total $I_{(n.a.)} = 867,071$ Lb. In.^{2}

Sum $I_{(xx)} + I_{(n.a.)} = 1,075,539$ Lb. In.^{2}

$I_{(\text{primary mirror})} = 232$ Lb. Ft. Sec.^{2}

Moment of Inertia and Weights for Corrector Mirror Assembly

ELEMENT	WEIGHT	$I_{(xx)}$	$I_{(\text{about n. a. of truss})}$
Corrector	190	148	638
Cell	50	50	168
Mounting Member	150	600	---

Total $I_{(xx)} = 798$ Lb. Ft.^{2}

Total $I_{(n.a.)} = 806$ Lb. Ft.^{2}

Sum $I_{(xx)} + I_{(n.a.)} = 1,604$ Lb. Ft.^{2}

$I_{(\text{corrector})} = 49.8$ Lb. Ft. Sec.^{2}

Moment of Inertia and Weights for Secondary Mirror Assembly

ELEMENT	WEIGHT	$I_{(xx)}$	$I_{(\text{about n. a. of truss})}$
Mirror	33	9	111
Support System	80	418	269

Total $I_{(xx)} = 427$ Lb. Ft.^{2}

Total $I_{(n.a.)} = 380$ Lb. Ft.^{2}

Sum $I_{(xx)} + I_{(n.a.)} = 807$ Lb. Ft.^{2}

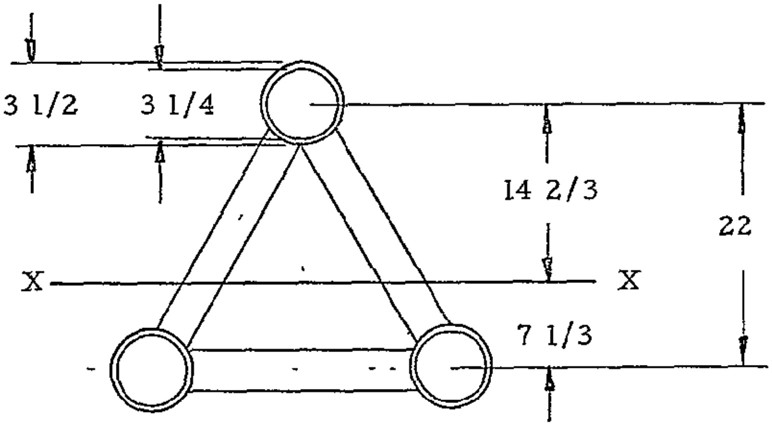
$I_{(\text{secondary mirror})} = 25$ Lb. Ft. Sec.^{2}

Resonant Frequency (Torsional) $(f_n) = \frac{1}{2\pi}\sqrt{\frac{K}{I_{pm}}}$

$$f_n = \frac{1}{2\pi}\sqrt{\frac{2.01 \times 10^6}{232}}$$

f_n (torsional) = 15 Hz.

Stiffness of Support Structure (Bending)



$I = \Sigma I_o + \Sigma Ad^2$

Where, $A = \frac{\pi}{4}(3\ 1/2^2 - 3\ 1/4^2)$

$I_o = \frac{\pi}{64}(3\ 1/2^4 - 3\ 1/4^4)$

d = 7 1/3" and 14 2/3"

$$I = \frac{3\pi}{64}(3\ 1/2^4 - 3\ 1/4^4) + \frac{\pi}{4}(3\ 1/2^2 - 3\ 1/4^2)(7\ 1/3^2 + 14\ 2/3^2)$$

$$= 5.67 + 356.3 = \underline{362\ \text{In}^4}$$

Consider support structure as a cantilevered beam with gravity acting on primary mirror assembly plus detector.

Deflection $\delta = \frac{Wl^3}{3\ EI}$

$E_{inv} = 21 \times 10^6$

$W = 1000$ Lb.

$l = 150$ In.

$I = 362$ In.^{4}

$$\delta = \frac{1031 \times 150^3}{3 \times 21 \times 10^6 \times 362}$$

$$\delta = \underline{\underline{.152''}}$$

Resonant Frequency $f_n = \frac{3.13}{\sqrt{\delta}}$

f_n (bending) = 8 Hz.

This frequency is rather low. Although it can be improved somewhat in the final design, its characteristics are inherent in the cantilevered end mounting. The alternate possibility of a mounting at the instrument center of gravity will be considered.

Moment of Corrector Mirror Assembly about C.G. of Telescope

	Weight (lb)	Distance to C.G. (in.)	Moment (lb.in.)
Corrector	190	109	20710
Corrector Cell	50	111	5550
Mounting Member	150	118	17700
	390	112.7	43960

Deflection $\delta = \frac{Wl^3}{3\ EI}$

$$\delta = \frac{390 \times 112.7^3}{3 \times 21 \times 10^6 \times 362}$$

$$\delta = .024''$$

Resonant Frequency $f_n = \frac{3.13}{\sqrt{\delta}}$

f_n (bending) = 20 Hz. (C.G. Mount)

Moment of Primary Mirror Assembly about C.G. of Telescope

	Weight (lb.)	Distance to C.G. (in.)	Moment (lb. in.)
Cell	300	32.75	9825
Primary Mirror	381	30.25	11525.25
Solenoid + Magazine	350	37.75	13212.5
	1031	33.5	34562.75

Deflection $\delta = \frac{Wl^3}{3\ EI}$

$$\delta = \frac{1031 \times 33.5^3}{3 \times 21 \times 10^6 \times 362}$$

$$\delta = .0017''$$

Resonant Frequency $f_n = \frac{3.13}{\sqrt{\delta}}$

f_n (bending) = 76 Hz. (For C.G. Mount)

These calculations for C.G. mounting have assumed the same structure as considered for the cantilevered end mounting. A final design for the C.G. mounting could yield even further improvement in the natural frequency.

The IPS/Payload Integration Ring mounting member is a hollow cored "D" shaped structure having a circular central hole. Its purpose is to provide an efficient means of coupling the telescope to the IPS during orbital missions and de-coupling same during launch, re-entry and landing. This is done by the use of three spherical mounting points that accurately mate with and lock to the kinematic mounts as shown on pages 4.9-4 and -5 of Spacelab Payload Accommodation Handbook dated May 1976. Another function of the mounting member is to establish support and alignment means for the corrector mirror system.

The Schmidt corrector system consists essentially of a perforated corrector mirror, a central supporting ring that is clamped to mirror, and a mirror cell. The central supporting ring will be made from invar which closely matches the coefficient of thermal expansion of Cer-Vit (the material of the Schmidt corrector). The mirror cell material can be aluminum. Its function being to protect the mirror during handling and to support an elliptical aperture.

The secondary mirror is made of Cer-Vit and is perforated. It is supported from its central hole by a spool which has a cupped flange having mounting screws and collimating adjustments. This is attached with the mounting screws to the focussing mechanism. The assembly is held firmly in place to the support structure by two diagonal fins having sufficient stiffness to give a high resonant frequency.

The primary mirror, like the Schmidt corrector and the secondary mirror is made of Cer-Vit and has a central perforation. It is housed in an invar cell to closely match the coefficient of linear expansion of Cer-Vit. The ultimate method of support of the primary mirror in its cell has not at this time been deduced. The tentative choice is the method suggested by Ball Brothers in their Feasibility Study of the Spacelab Ultraviolet Optical Telescope Facility, dated October 1975, Figures 3 - 7. The mirror cell also supports and positions the detector which will be an electrographic camera (not part of this study) designed by Dr. George Carruthers. The mirror cell is mounted securely to the upper longerons of the support structure and braced by two diagonal members.

1.2 THERMAL CONTROL DESIGN

The purpose of the thermal control design is to maintain the telescope close to its calibration temperature of 70°F (21°C). This stems from the fact that large variations of temperature of the optical elements from the calibration temperature will cause distortions that would possibly exceed optical tolerance. Excessive variations in temperature will vary the optical conjugates requiring an active focus control system.

1.3 PASSIVE THERMAL CONTROL

To cancel the effects of solar radiation and also radiation exchange from the spacecraft, a passive multilayer insulation shield surrounds the entire telescope. The insulation shield is composed of thirty (30) layers of one quarter mil thick, doubly aluminized Mylar with outer and inner layers of one half mil thick black Kapton. The heat leak through the insulation shield was calculated to be approximately 20 watts (see page 16). The outer black Kapton layer provides an absorptivity to emissivity ratio of one thus limiting the maximum exterior surface temperature to 250°F (121°C) (see page 17) when exposed to direct solar radiation. This is an acceptable exposure temperature for Mylar or Kapton.

1.4 ACTIVE THERMAL CONTROL

Heat loss through the aperture and insulation shield was calculated to be approximately 366 watts maximum (see page 17). A hinged aperture door is provided as a part of the passive thermal control. When closed during periods of non-operation, this will eliminate the direct heat loss through the aperture and reduce the average power consumption to approximately 20 watts.

It is proposed that Kapton encapsulated film type heaters be bonded to each member of the trussed support structure. Because the optical elements are not surrounded by the support structure as in a conventional telescope, the radiating coupling between the structure and the optical elements is low. This means that heaters will be needed at the rear faces and edges of the corrector and the primary mirror to maintain them at the calibration temperature of 70°F ± 3°F. The secondary mirror being smaller can withstand a wider temperature range without excessive distortion so it may be possible to eliminate any secondary mirror direct heating. Because of the large thermal mass of the primary mirror and the corrector, the time required to change the mean temperature of these elements after a hot or cold soak would be long. (The thermal time constant for the primary mirror is approximately 6 1/2 hours.) For this reason it is essential that the telescope be kept near its calibration temperature during pre-launch, launch, and orbit.

1.5 THERMAL COMPUTATIONS (Heat Loss)

Aperture $Q_A = \epsilon A \sigma T^4$

$\epsilon = 1$ (view from aperture to space)

$$A = \frac{\pi}{4} D^2 = \frac{\pi}{4} \left(\frac{40}{12}\right)^2 = 8.72 \text{ Ft.}^2$$

$$\sigma = \frac{.1714 \times 10^{-8} \text{ BTU}}{\text{Hr. Ft.}^2 \, {}^\circ\text{R}^4} \quad \left(\begin{matrix}\text{Stefan-Boltzmann} \\ \text{Constant}\end{matrix}\right)$$

T = telescope interior temperature

$= 70°F = 530°R$

$$Q_A = (1)\ 8.72 \times .1714 \times 10^{-8} \times 530^4$$

$= 1180$ BTU/Hr.

$= 1180 \times .293$

$= \underline{\underline{346 \text{ watts}}}$

Insulation $Q_I = AF\sigma T^4$

$$F = \frac{1}{1171.5} \quad \left(\begin{array}{l}\text{Ball Brothers Shuttle}\\ \text{Final Report p. F72-09}\end{array}\right)$$

$\sigma = .1714 \times 10^{-8}$

$T = 530°R$

$$= \frac{187 \times .1714 \times 10^{-8} \times 530^4}{1171.5}$$

$= 21.58$ BTU/Hr.

$= \underline{\underline{6.3 \text{ watts}}}$

If insulation factor is degraded by a factor of 3 to account for compression, etc.

$Q_I = \underline{\underline{20 \text{ watts}}}$

Total Heat Loss $Q_T = Q_A + Q_I$

$= 346 + 20$

$= \underline{\underline{366 \text{ watts}}}$

Maximum Insulation Outer Layer Temperature

$$\alpha q = A\mathcal{E}\sigma T^4 \quad \text{or} \quad T = \sqrt[4]{\frac{\alpha q}{A\mathcal{E}\sigma}}$$

$\alpha = 0.8$ Black Kapton

$q = 443$ BTU/Hr. Ft.^{2} (Solar Flux)

$A = 1$ Ft.^{2}

$\mathcal{E} = 0.8$ Black Kapton

$\sigma = .1714 \times 10^{-8}$ BTU/Hr. Ft.^{2} °R^4

$$T = \sqrt[4]{\frac{.8(443)}{1(.8)(.1714 \times 10^{-8})}} = 713°\text{R} \quad \text{or } 253°\text{F} \quad (122.8°\text{C})$$

Maximum insulation outer layer temperature is 122.8°C which is within the allowable temperature limits for Kapton of +176.7°C (+350°F).

Thermal Time Constant (Primary Mirror)

$$\theta = \frac{WC_p}{h_r A}$$

Weight $(W) = 381$

Thermal Capacity $(C_p) = 0.2$ BTU/Lb. °F

Area $$(A) = \frac{\frac{\pi}{\boxed{4}}(39^2 - 21^2)2 + 5\pi(39 + 21)}{144}$$

$$= 18.3 \text{ Ft.}^2$$

$$h_r = \sigma(T_m^3 + T_s T_m^2 + T_s^2 T_m + T_s^3)F$$

$$F = (1)(.8)(.8) = 0.64$$

where $T_m \approx T_s \approx 530°\text{R}$

and $\sigma(4T^3) \approx 1$

$$h_r = 0.64$$

$$\theta = \frac{381(.2)}{(0.64)18.3}$$

$\theta' = 6.5$ Hrs. (Time Constant - Primary Mirror)

'Time required to change the temperature of the primary mirror from 60°F to 70°F in an 80°F temperature.

$$\theta = \frac{WC_p}{2T_E^3 \ FA\sigma} \left\{ \frac{1}{2} \left[\ln \left(\frac{T_E + T_M}{T_E - T_M} \cdot \frac{T_E - T_o}{T_E + T_o} \right) \right] + \left[\tan^{-1} \frac{T_M}{T_E} - \tan^{-1} \frac{T_o}{T_E} \right] \right\}$$

Where T_E = 80°F =540°R (Environment Temp)

T_M = 70°F =530°R (Final Temp. of Mirror)

T_o = 60°F = 520°R (Initial Temp. of Mirror)

W = 381 lb

C_p = 0.2BTU/lb. °F

F = 0.8(0.8) = .64

A = 18.3ft^2

σ = .1714x10^{-8} BTU/Hr.Ft.^{2} °R^4

$$\theta = \frac{381\ (.2)}{2(640)^3\ (.64)\ (18.3)\ (.1714\text{x}10^{-8})} \ \frac{1}{2} \left[\ln \left(\frac{540+530}{540-530} \cdot \frac{540-520}{540+520} \right) \right] +$$

$$+ \left[\tan^{-1} \frac{530}{540} - \tan^{-1} \frac{520}{540} \right]$$

= 10.8 Hours.

Thermal Time Constant (Corrector)

$$W = \frac{\pi}{4} 30^2 \times 3 \times .09 = 190\#$$

$$C_p = 0.2$$

$$A = \frac{(\frac{\pi}{2} 30^2) + (\pi 30 \times 3)}{144} = 12 \text{ Sq. Ft.}$$

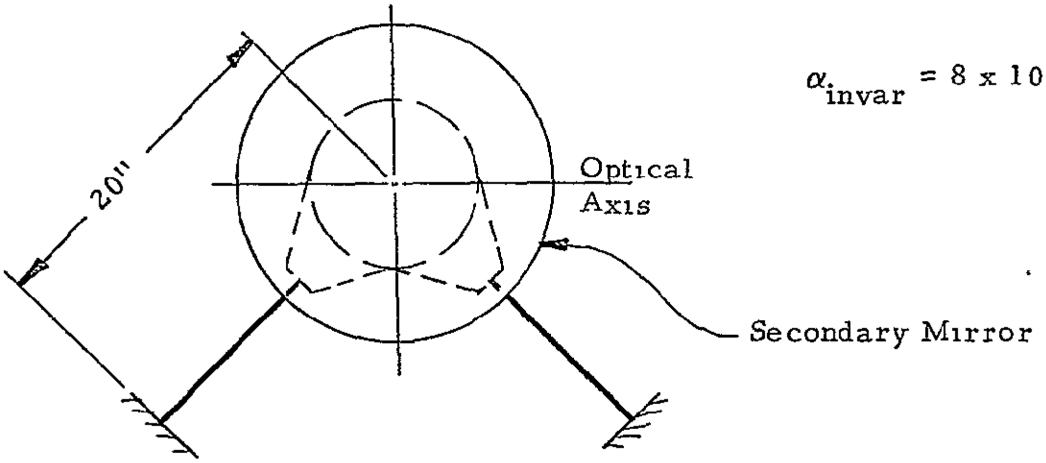
$$h_r = 0.64$$

$$\theta = \frac{190 \times 0.2}{0.64 \times 12}$$

θ = 5 Hrs. (Time Constant - Corrector)

1.6 OPTICAL ALIGNMENT OF SECONDARY MIRROR

Let us calculate "on-axis" coma due to temperature difference between secondary mirror support vanes and structure.



$$\alpha_{invar} = 8 \times 10^{-7}/°F$$

$$\text{Off-Axis Shift}/°F = 8 \times 10^{-7} \times 20 \text{ sec. } 45°$$

$$= \underline{\underline{2.26 \times 10^{-5} \text{ Inches}/°F}} \quad (5.747 \times 10^{-4} \text{ mm})$$

Axial Coma (Expressed as Wavefront Error)("Applied Optics", Dec'72 p. 2824)

σ_d = misalignment coefficient

$\lambda = .0005$ mm

$F_p = 2.07$ (focal length of primary)

$$\beta = \frac{\text{Back Focus}}{f_p} = \frac{15.0}{155.45} = .0965$$

$m = 1.69$ (magnification of secondary)

$$W_c = \sigma_d \, \Delta Y_{wo}$$

$$\sigma_d = \frac{0.0037}{\lambda \, F_p^{\,3}} \left[1 + \frac{(1+\beta)}{m^2 \, (m-\beta)} \right]$$

$$\sigma_d = \frac{0.0037}{.0005 \times 2.07^3} \left[1 + \frac{1.0965}{1.69^2 \, (1.5935)} \right]$$

$$\sigma_d = .83429 \, (1.2409)$$

$$\sigma_d = \underline{\underline{1.035}}$$

ΔY_{wo} = lateral misalignment

$= 5.747 \times 10^{-4}$ mm

$$W_c = \sigma_d \, \Delta Y_{wo}$$

$$W_c = 1.035 \times 5.747 \times 10^{-4}$$

$$W_c = \underline{\underline{5.95 \times 10^{-4}/°F}} \text{ (wavefront error per °F)}$$

1/20 λ RMS wavefront error (.05) would result in 90% of normalized intensity being contained in central diffraction disc.

Temperature difference between truss and support fins results in this amount:

$$\Delta t = \frac{.05}{5.95 \times 10^{-4}}\ ^{\circ}F$$

$$\Delta t = \underline{\underline{84^{\circ}F}}\ \ (46.5^{\circ}C)$$

Decentering (1/20 λ RMS) would be:

$$(5.747 \times 10^{-4}\ mm) \times 84^{\circ}F = .048\ mm$$

Allowable decentering of secondary mirror resulting in one arc second image degradation due to coma (from Dr. Dan Schroeder's optical study) is 1.7 mm.

1.7 ATTACHMENT TO IPS

The method of clamping the telescope to the pallets is shown on page 4.9-5 of Spacelab Payload Accommodation Handbook dated May 1976. Moment of inertia of 3000 kg payload 3 m diameter whose C.G. is offset 5 cm (as described in paragraph 4.9.2.1 of the aforementioned handbook):

$$I = m\left(\frac{R^2}{2} + x^2\right)$$

$$= \frac{3000 \times 2.2}{32.2}\left(\frac{5^2}{2} + .164^2\right)$$

$$= \underline{\underline{2568 \text{ Lb. Ft. Sec.}^2}}$$

where $R = 1.5$ m (5 Ft.)

$$m = \frac{3000 \times 2.2}{32.2}\left(\frac{\text{Lb. Sec.}^2}{\text{Ft.}}\right)$$

$x = 5$ cm (.164 Ft.)

Moment of inertia of telescope about IPS cross-elevation axis:

$$I_{(c.e.a.)} = 268 \text{ Lb. Ft. Sec.}^2$$

which is within limits by a factor of ten.

The same paragraph also dictates that the C.G. of the payload shall not be greater than a distance of 3 m (120 In.) from the IPS/Payload interface.

The C.G. of the telescope calculates to be at a distance of 3.28 m (131.5 In.). The tolerance given is ±10cm per 3000 kg payload weight, which is equivalent to:

$$\frac{3000 \times 2.2 \times 10}{1714} = \pm\underline{\underline{38 \text{ cm } (15 \text{ In.})}}$$

Thus the C.G. is marginally within tolerance. In the final design, improvements will be made to bring the C.G. within the nominal tolerance figure.

Moment of inertia about the IPS elevation axis and azimuth axis:

$$I_{(\text{elevation axis})} = \underline{\underline{8886 \text{ Lb. Ft. Sec.}^2}}$$

1.8 OPTICAL BAFFLING

It is desired to baffle the system so that no light ray from outside the field of observation may reach the focal plane in less than two diffuse reflections. This requirement is necessary to maximize the potential use of the telescope in the solar-illuminated portions of the orbit.

This requirement has been achieved by the system illustrated in Figure 1. Shown are baffles placed parallel to the incoming on-axis light to prevent unwanted light from striking the secondary mirror directly and being reflected (both directly and diffusely) to the focal plane. The addition of these baffles will result in a graduated loss of aperture from zero for on-axis images to 5% for 2° off-axis images.

Other baffles are placed between the secondary mirror and the corrector mirror with overlapping circular apertures to accommodate the light bundles that fall on and are reflected by the corrector mirror. These are spaced such as to absorb scattered light that would otherwise reach the focal plane. All baffles will have an optically absorbing matte black finish.

1.9 DETECTOR MOUNTING

The detector (an electrographic camera designed by Dr. George Carruthers) is mounted to the rear of the primary mirror cell.

A ring, that is adjustable both axially and in tilt, will be part of the mirror cell. Two pins having tapered ends will serve to locate the camera radially and rotationally. To securely position the camera axially it will be manually clamped to the ring with clamps that will be designed to be operated by an astronaut in EVA mode.

A roll film camera interchangeable with the electrographic camera will be supplied. Four filter positions will be available, which can be selectively flipped into place ahead of the focal plane. The camera will be positioned and clamped in a manner identical to that of the electrograph by an astronaut during EVA if an interchange with the electrograph is planned during orbital operation.

1.10 CONTROLS AND DISPLAYS

The monitors and controls required for DUVS are listed in Table 2. Their specific purposes are:

1. To sense and control the thermal environment

2. To adjust focus for filter insertion

3. To open or close the instrument cover/shutter

4. To control several detector operations.

The means of acquiring and guiding on a star field are controlled by the IPS and are totally external to the DUVS instrument which has no internal image compensation. Acquisition and guidance, then, is considered out of the scope of this study.

The required spacings between optics can be maintained as long as the main structure and optical elements are kept within the limits of 70 ±3°F. This would be accomplished with proper thermal insulation, and distributed heating strips and thermistors. Each mirror will have a heating strip with thermistor monitor and appropriate units will be placed along the main frame and secondary mirror supports.

The secondary mirror can be moved to change focus when filters are inserted before the focal plane.

One of the four filter positions can be used as a shutter. This is desirable because of the low mass of the shutter at this location. The aperture cover also could be used as a shutter.

The detector modules house several controls and monitors which would be used depending upon the detector. The filter insert controls would move each filter in front of the focal plane and rotate it out to a 90° position to the side of the photocathode. Film advance with frame number would be used with all modules as all use film cannisters. When an image intensifier or electrograph is used, a high voltage control and monitor would be used.

TABLE 2

MONITORS AND CONTROLS
REQUIRED FOR DUVS

	Function	Readout	Increment
1 -	Temperature Monitor and Control for Corrector Mirror	°C	1°C
1 -	Temperature Monitor and Control for Primary Mirror	°C	1°C
1 -	Temperature Monitor and Control for Secondary Mirror	°C	1°C
1 -	Temperature Monitor and Control for Secondary Mirror Support Fins	°C	1°C
4 -	Temperature Monitor and Control for Main Structure	°C	1°C
1 -	Secondary Mirror Focus Control and Encoder	Microns	5 Microns
1 -	Aperture Cover (Shutter) Control, Position	Open/Closed	
1 -	High Voltage, Control and Encoder	0 to 30 KeV	10 V
1 -	Frame Advance and Encoder	0 to 500 Frames	1 Frame
4 -	Filter Insert Controls (one may be exposure shutter)	Filter 1 In/Out Filter 2 In/Out Filter 3 In/Out Shutter 4 In/Out	

1.11 POWER REQUIREMENTS

The estimated average power requirement for the active thermal control is 366 watts. If the heaters are sized to allow a duty cycle of about 65%, then the maximum heater wattage requirement would be approximately 500 watts. An estimate of the power to operate the film transport is 100 watts. The power requirement to open the aperture door is about 50 watts but this should never occur when the film is being transported. The maximum power allowance of 600 watts need not be exceeded.

2.0 ACCEPTANCE AND QUALIFICATION TEST PLAN

2.1 PURPOSE

The purpose of this section of the report is to outline and identify the equipment and tests necessary to verify the acceptance and qualification of the DUVS for flight on shuttle. The tests are outlined in two sections: environmental tests and acceptance tests. The testing of this instrument will follow the "protoflight" concept in which only one model will be constructed. After a preliminary functional verification test, the instrument will be subjected to environmental tests. Following this the instrument will be modified or refurbished as necessary, then subjected to final acceptance tests.

2.2 APPLICABLE DOCUMENTS

Levels and other applicable data for the above outlined tests were determined by use of "Spacelab Payload Accommodation Handbook" marked "Preliminary" and dated May 1976 (SLP/2104). Much of the required data is in very preliminary form or TBD. Levels and other data included in this document are best estimates based on Skylab experience.

2.3 TEST CONFIGURATION AND INTERFACE FIXTURE

Some of the tests require the complete experiment to be assembled in an operational configuration. This will require a test fixture which simulates the IPS and IPS/Payload Clamp Assembly mounted onto pallets. The test fixture should be designed to duplicate all required interfaces and be compatible with the requirements of all environmental tests.

2.4 ENVIRONMENTAL TESTS

The following tests are considered required or desirable for the DUVS hardware. Actual requirements could vary depending on future definition and completion of shuttle payload environmental tests requirements documentation.

1. Vibration

   The DUVS hardware shall be subjected to vibration tests in an assembled non-operating configuration. That means the telescope will be locked into its launch and re-entry support structure. The environmental levels are defined by SLP/2104 Paragraph 5.1.

2. Shock

Mounted in the configuration described above (1. Vibration), the experiment hardware shall be subjected to shock tests as outlined in Section 5.1.3 of SLP/2104. This includes pyro shock TBD, landing shock as detailed in Table 5-3 of SLP/2104, and crash safety shock. Crash safety shock will be covered by static stress analysis only. This last requirement is for equipment survival only in a non-operating condition with no loose parts.

3. Thermal Vacuum

The telescope shall be mounted in a suitable thermal vacuum chamber in an unstowed operational configuration. All control heaters shall be operational during tests. The pressure shall be reduced to 1×10^{-6} torr with a non-contaminating pumping system. The thermal environment is defined by Tables 5-15 and 5-17 of SPL/2104. Test -- operation of all mechanical parts; functioning of detectors; and changes in optical alignments.

4. EMI

To insure compatibility with the shuttle spacecraft and its sub-systems, the DUVS hardware in the operational mode shall be qualified in accordance with the Space Shuttle Amendment to MIL-STD-461A.

2.5 ACCEPTANCE TESTS

1. Verify operation of all mechanical parts.
2. Verify operation of all thermal controls.
3. Verify detector operation and modular interchange.
4. Optical Performance Tests

   Using a full aperture collimator, the following optical parameters shall be verified:

   a) Collimation

   b) Resolution as a function of field position.

3.0 COST AND SCHEDULE

Table 3 gives an analysis of the estimated cost of building the telescope described in this report. It lists both the cost of building a single "protoflight" unit and also the cost of building a second unit in parallel with the first. It should be noted that this costing is based on the concept that NASA-required documentation and quality assurance will be reduced to a minimum and that the good judgment and technical experience of the PI and the manufacturer will generally prevail in these matters. It must also be noted that the estimate includes only the costs of telescope design and manufacture and does not include costs of integration, mission support and PI activities. However, the estimate does include all the contractor's overhead costs as well as a 10% fee. The items shown are for a combined engineering and manufacturing price.

Table 4 gives the proposed production schedule for a single protoflight unit, while Table 5 gives the schedule for manufacturing the protoflight unit plus a second unit.

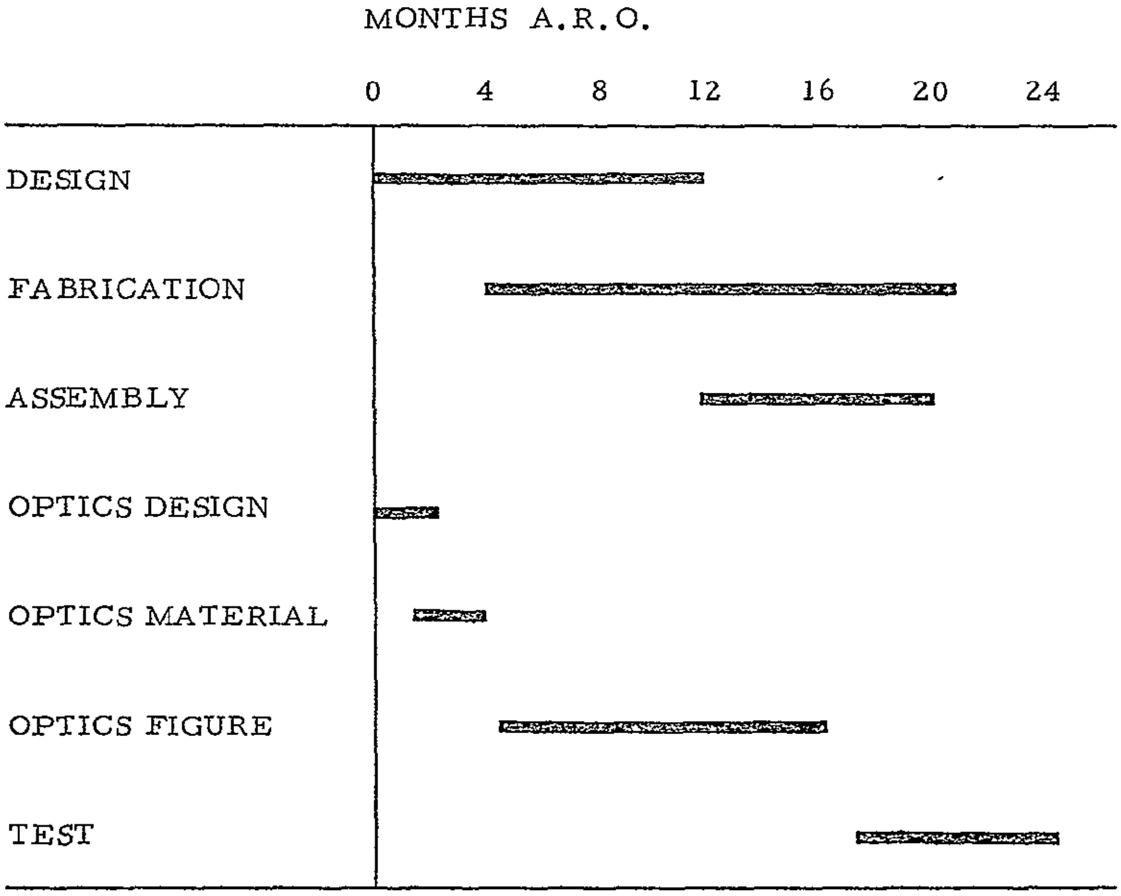
TABLE 3

DUVS COST ANALYSIS

Task Number	Item	Protoflight ($1,000)	Second Unit ($1,000)
100	General Assembly, Program Manager, Project Engineer	310	130
110	Mount Adapter	65	30
120	Frame, Including Launch Caging	280	120
130	Corrector Mirror Mount	50	30
140	Primary Mirror Cell	125	65
150	Secondary Support	85	50
160	Covers	115	60
170	Heater, Insulation, Wiring	100	60
180	Test Equipment & Fixtures	150	10
190	Testing, Reports, QA Services	400	70
195	Interface, PDR, CDR, Reports	150	50
200	Shipping Fixture, Crates	30	15
205	Optics	200	150
	TOTAL	2060	840

TABLE 4

DUVS SCHEDULE (PROTOFLIGHT UNIT)



NASA
FORMAL
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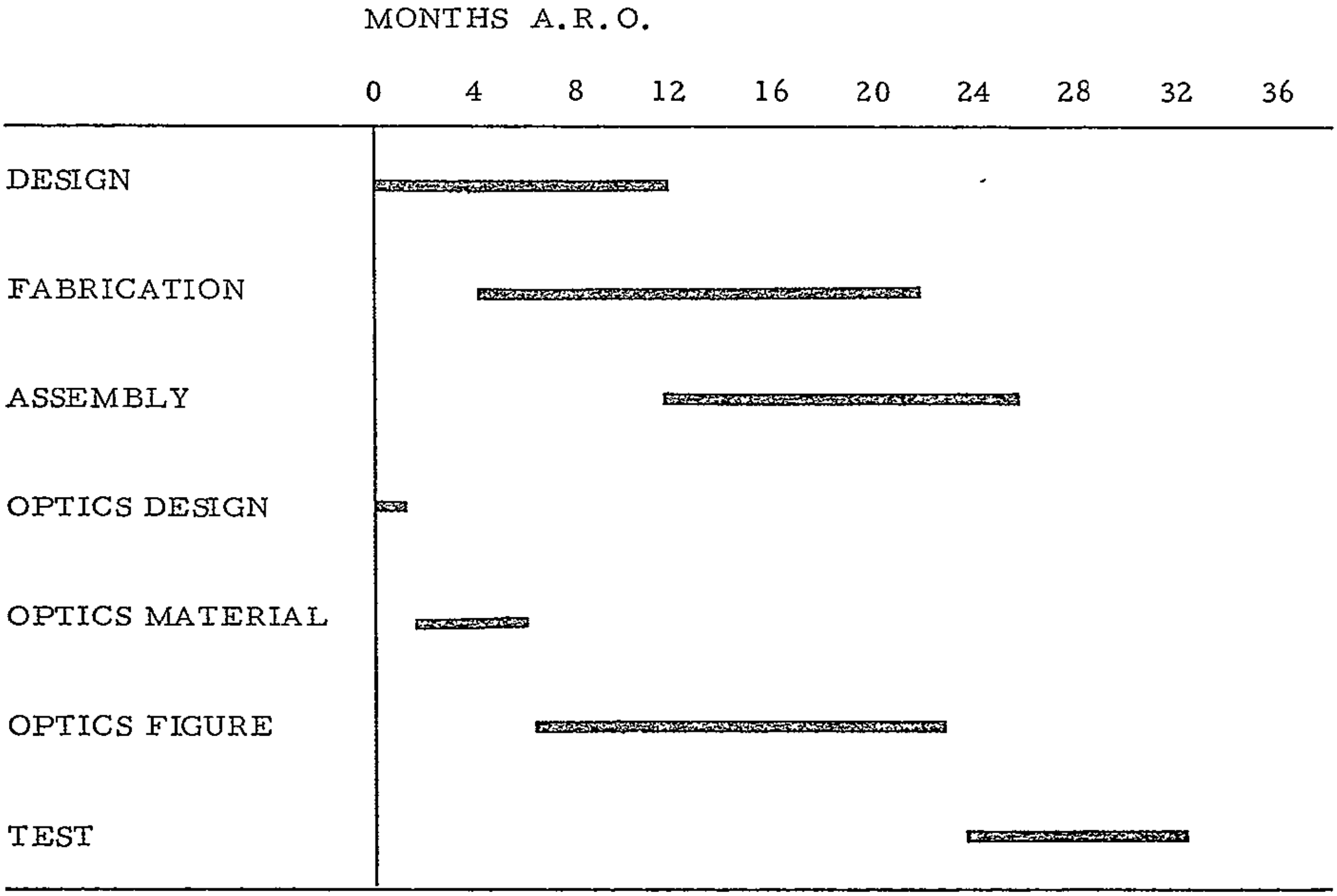
TABLE 5

DUVS SCHEDULE (PROTOFLIGHT PLUS SECOND UNIT)



REFERENCES

1. SPACELAB PAYLOAD ACCOMMODATION HANDBOOK. May 1976. NASA & ESRO.

2. OPTICAL DESIGN STUDY. Dr. Dan Schreoder, Beloit College.

3. FINAL REPORT, JAN. 1973. Ball Brothers Research Corp. CONTRACT NAS9-13094.

4. FINAL REPORT, OCT. 1975. Ball Brothers Research Corp. CONTRACT NAS 5-24048.

5. APPLIED OPTICS. Dec. 1972. page 2824.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

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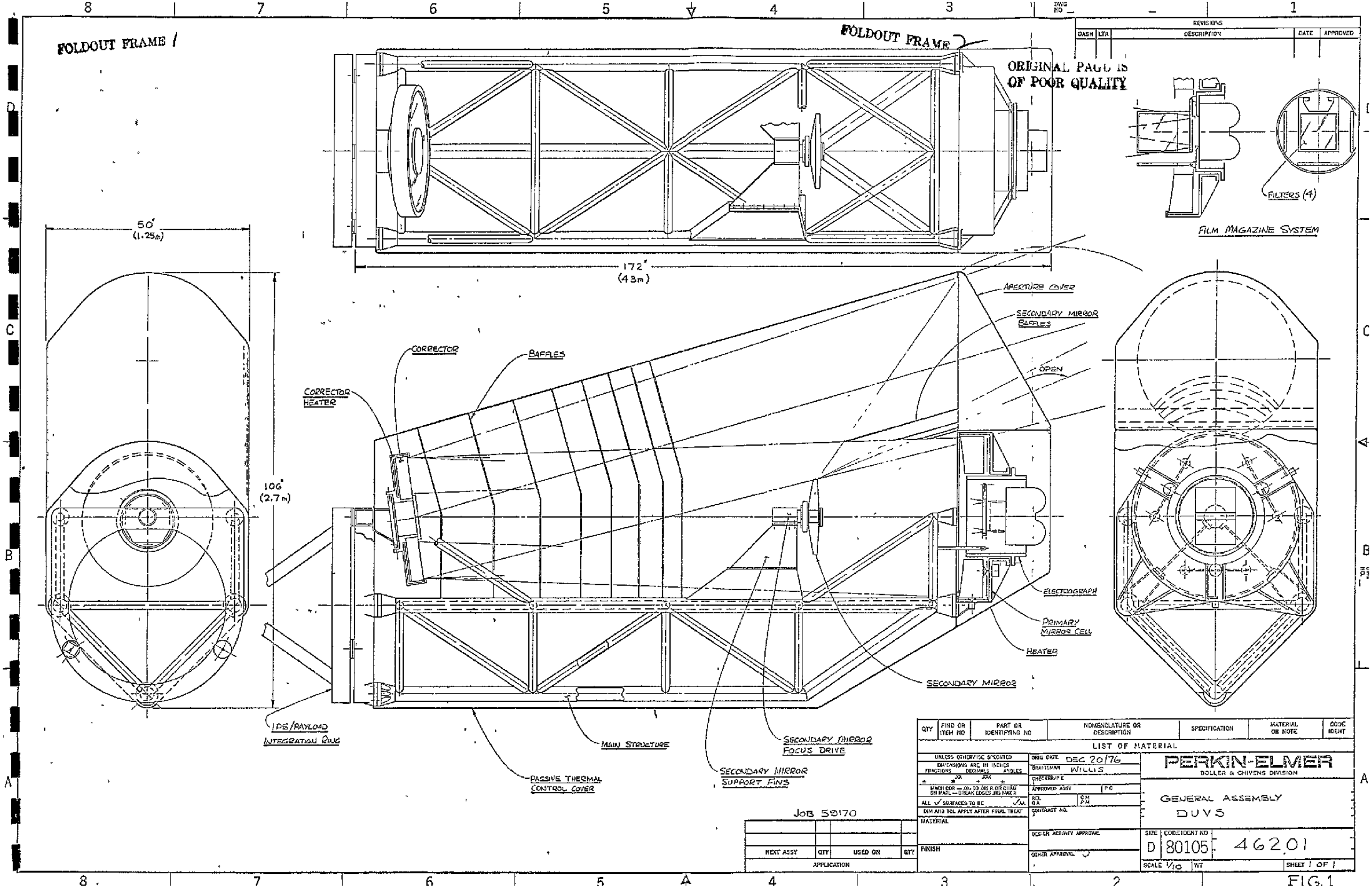


QTY	FIND OR ITEM NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	SPECIFICATION	MATERIAL OR NOTE	CODE IDENT

LIST OF MATERIAL

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
FRACTIONS DECIMALS ANGLES
± .XX ± .XXX ± ±
MACH COR — .005 TO .015 R OR CHAM
SH MATL — BREAK EDGES .005 MAX R
ALL ✓ SURFACES TO BE ✓
DIM AND TOL APPLY AFTER FINAL TREAT
MATERIAL
FINISH

ORIG DATE DEC 20/76
DRAFTSMAN WILLIS
CHECKER/P E
APPROVED ASSY
P C
REL
Q A
C M
P M
CONTRACT NO.
DESIGN ACTIVITY APPROVAL
OTHER APPROVAL

PERKIN-ELMER
BOLLER & CHIVENS DIVISION

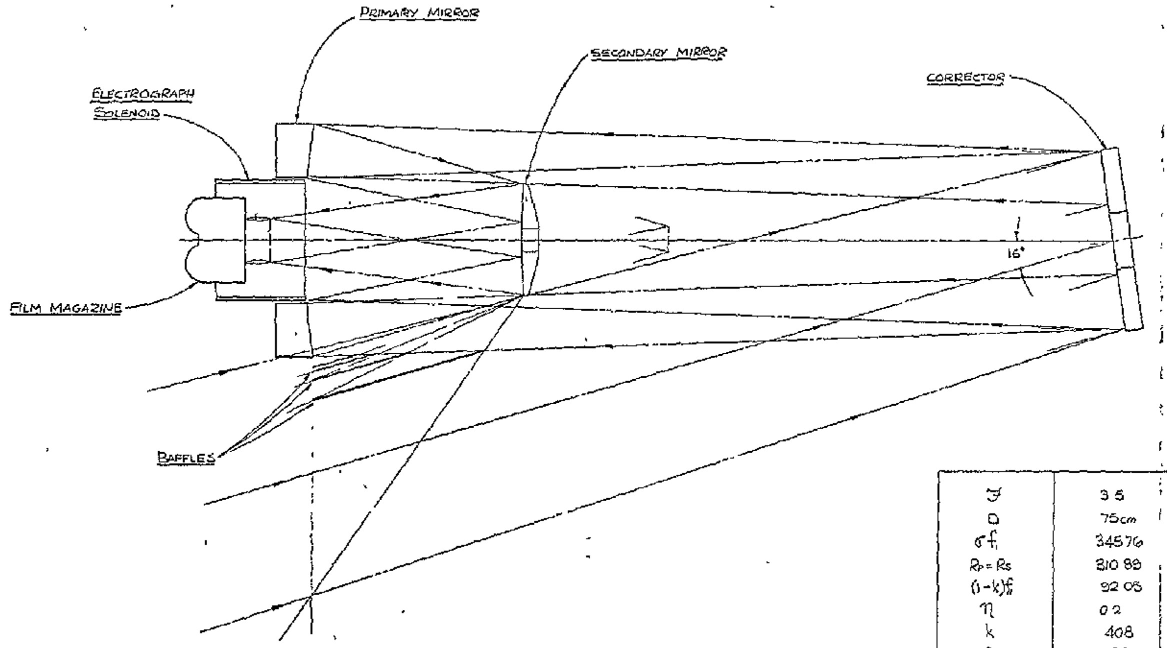
GENERAL ASSEMBLY
DUVS

SIZE D
CODE IDENT NO 80105
46201
SCALE 1/10
WT
SHEET 1 OF 1

FIG. 1

FOLDOUT FRAME 1

FOLDOUT FRAME 2



$\mathfrak{F}$	3 5	TELESCOPE FOCAL RATIO
D	75cm	STOP DIAMETER
σf_1	345 76	STOP TO PRIMARY DISTANCE
$R_P = R_S$	310 89	RADIUS OF BOTH MIRRORS
$(1-k)f_1$	92 05	MIRROR SEPARATION
η	0 2	BACK FOCAL DISTANCE IN TERMS OF D
k	408	MIN OBSCURATION RATIO
θ	4° (07RAD)	FIELD ANGLE
f_1	155 45	PRIMARY FOCAL LENGTH
m	1 69	MAGNIFICATION
$\mathfrak{F}_P$	2.07	PRIMARY FOCAL RATIO
σ	2 224	STOP TO PRIMARY DIST IN TERMS OF f_1
D_1	99 17cm	PRIMARY MIRROR DIAMETER
D_2	46 89cm	SECONDARY MIRROR DIAMETER

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JOB 59170

QTY	FIND OR ITEM NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	SPECIFICATION	MATERIAL OR NOTE	CODE IDENT

LIST OF MATERIAL

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
FRACTIONS DECIMALS ANGLES
MACH COR — .005 TO .015 R OR CHAM
SH MATL — BREAK EDGES .005 MAX R
ALL ✓ SURFACES TO BE ✓
DIM AND TOL APPLY AFTER FINAL TREAT
MATERIAL
FINISH

NEXT ASSY | QTY | USED ON | QTY
APPLICATION

ORIG DATE DEC 24/76
DRAFTSMAN WILLIS
CHECKED/P E
APPROVED ASSY
P O
REL
O A
C M
P M
CONTRACT NO.
DESIGN ACTIVITY APPROVAL
OTHER APPROVAL

PERKIN-ELMER
BOLLER & CHIVENS DIVISION

OPTICAL DIAGRAM
$\mathfrak{F}$=3.5, D=75cm, η=0.2
DUVS

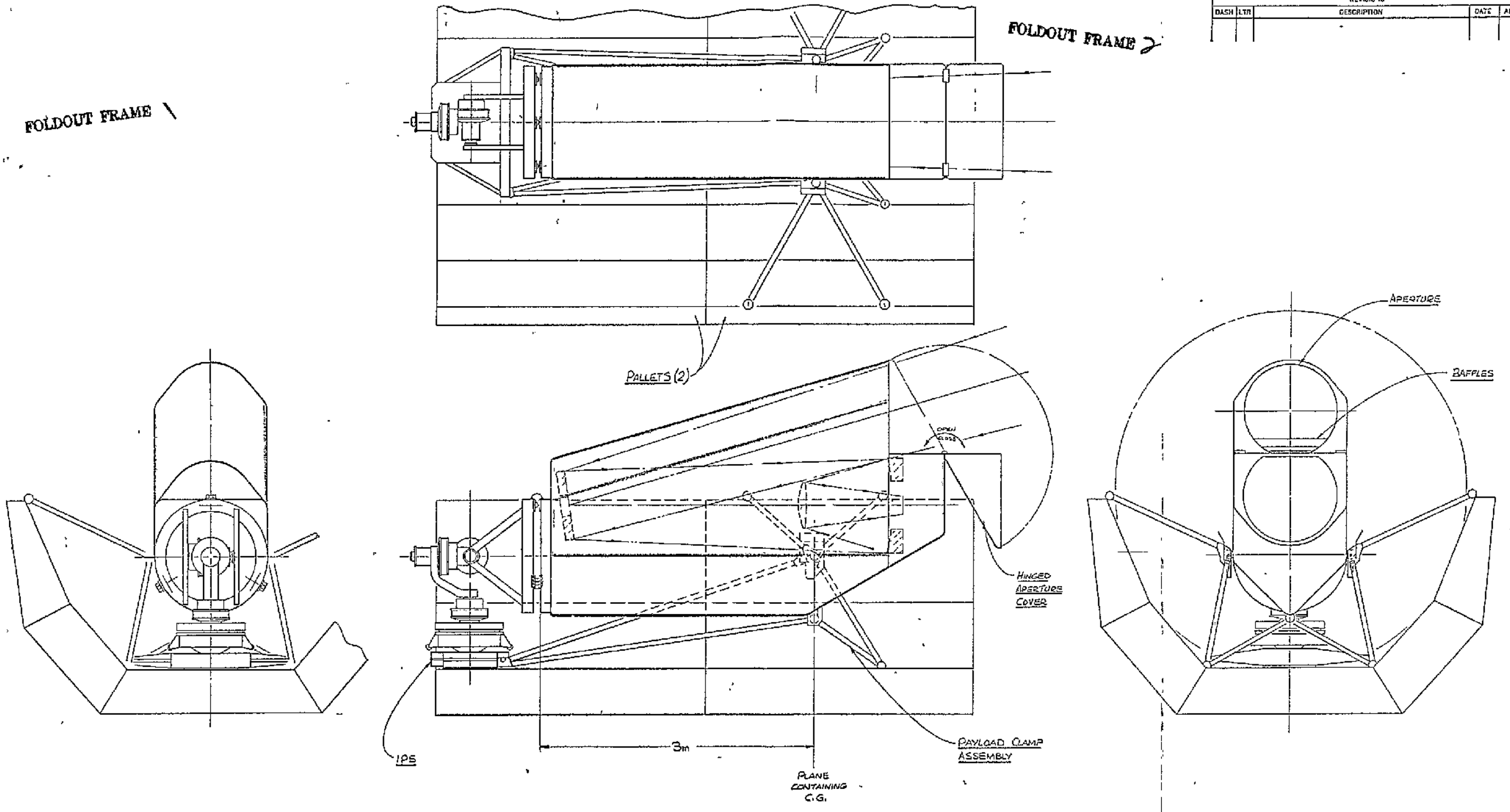
SIZE D
CODE IDENT NO 80105
46202
SCALE 1/10
WT
SHEET 1 OF 1

FIG. 2

FOLDOUT FRAME 1

FOLDOUT FRAME 2

DASH	LTR	REVISIONS DESCRIPTION	DATE	APPROVED



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JOB 59170

QTY	FIND OR ITEM NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	SPECIFICATION	MATERIAL OR NOTE	CODE IDENT

LIST OF MATERIAL

NEXT ASSY	QTY	USED ON	QTY

APPLICATION

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
FRACTIONS DECIMALS ANGLES
± .XX ± .XXX ± ±
MACH COR — .005 TO .015 R OR CHAM
SH MATL — BREAK EDGES .005 MAX R
ALL ✓ SURFACES TO BE ✓
DIM AND TOL APPLY AFTER FINAL TREAT
MATERIAL
FINISH

ORIG DATE JAN 5/77
DRAFTSMAN WILLIS
CHECKER/P E
APPROVED ASSY
P C
REL Q A
C M P M
CONTRACT NO.
DESIGN ACTIVITY APPROVAL
OTHER APPROVAL

PERKIN-ELMER
BOLLER & CHIVENS DIVISION

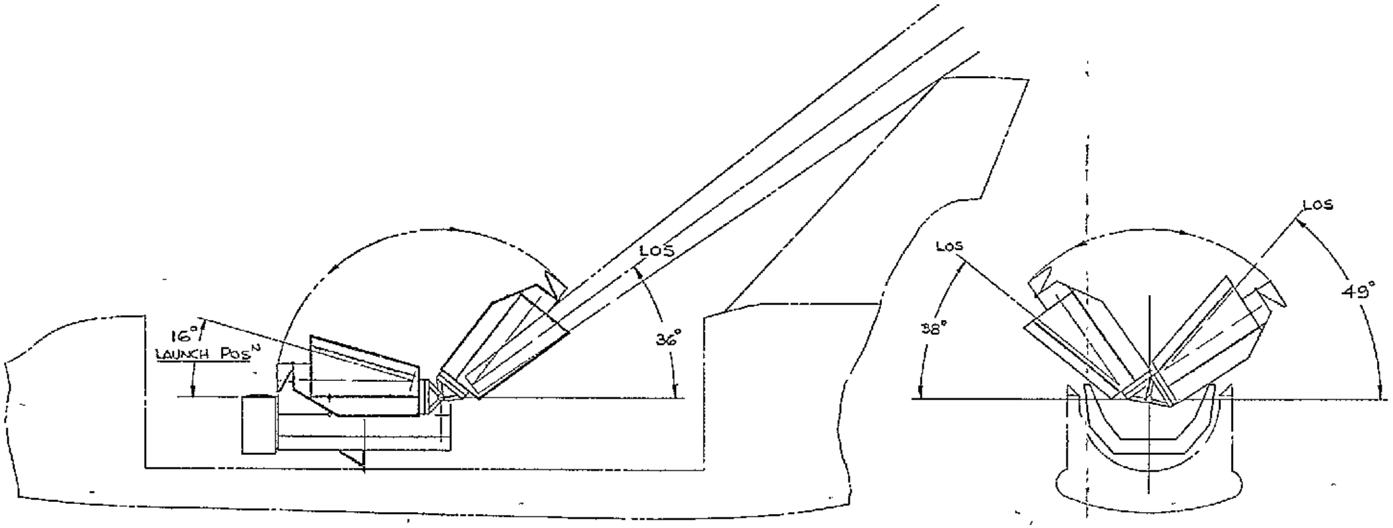
IPS & PAYLOAD CLAMP ARRANGEMENT
DUVS

SIZE D
CODE IDENT NO 80105
46203
SCALE 1/20
WT
SHEET 1 OF 1

FIG. 3

REVISIONS

DASH	LTR	DESCRIPTION	DATE	APPROVED



QTY	FIND OR ITEM NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	SPECIFICATION	MATERIAL OR NOTE	CODE IDENT

LIST OF MATERIAL

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
FRACTIONS ± DECIMALS .XX ± .XXX ± ANGLES ±
MACH COR — .005 TO .015 R OR CHAM
SH MATL — BREAK EDGES .005 MAX R
ALL ✓ SURFACES TO BE ✓AA
DIM AND TOL APPLY AFTER FINAL TREAT
MATERIAL
FINISH

ORIG DATE JAN 7/77
DRAFTSMAN WILLIS
CHECKER/P E
APPROVED ASSY
P C
REL Q A
C M P M
CONTRACT NO
DESIGN ACTIVITY APPROVAL
OTHER APPROVAL

PERKIN-ELMER
BOLLER & CHIVENS DIVISION

FIELD OF VIEW
DUVS

SIZE C
CODE IDENT NO 80105
46204
SCALE 1/100
WT
SHEET 1 OF 1

JOB 59170

NEXT ASSY	QTY	USED ON	QTY

APPLICATION

FIG. 4