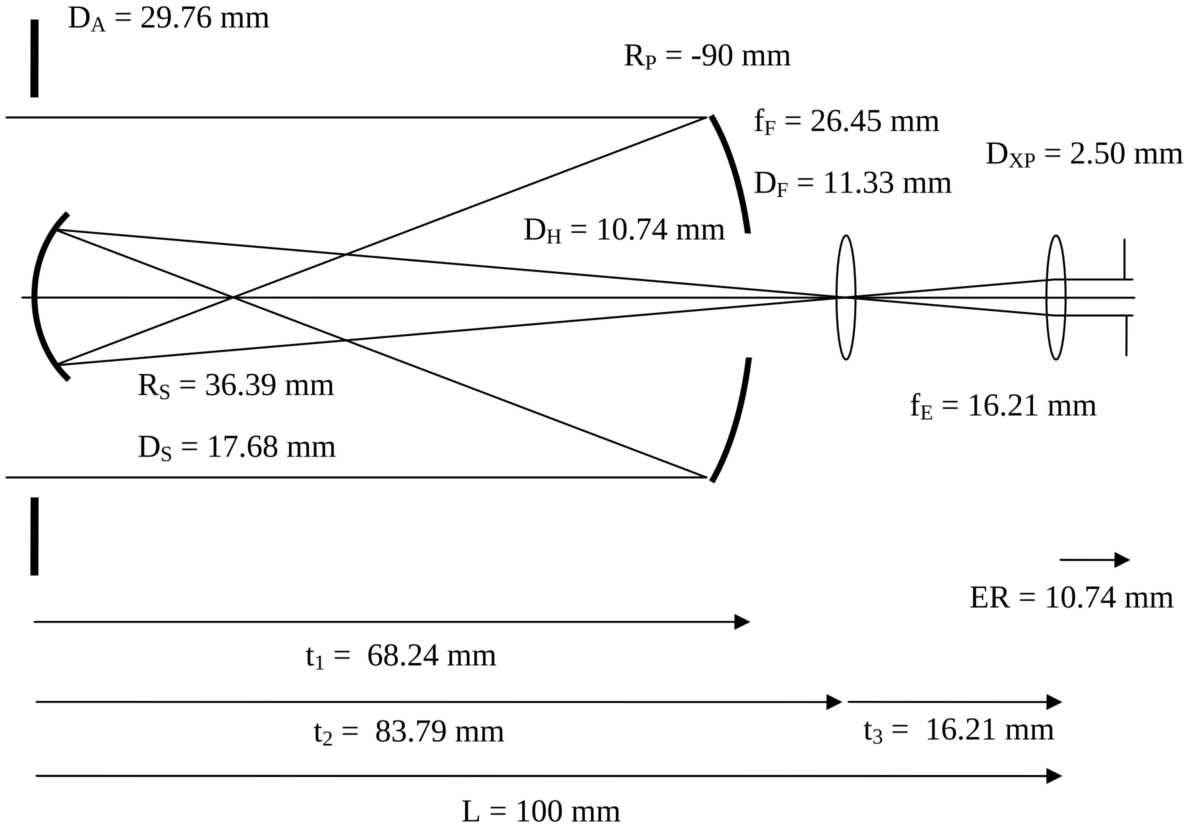
Compact Gregorian Telescope

Section A



Section B – Summary of Discussion

The Maksutov shell used to form the secondary mirror introduces a small amount of power into the optical system. For the configuration given, the focal length of the shell is 4400 mm. This additional power will change MP of the telescope by changing the focal length of the telescope objective (the combination of the shell and the primary mirror). In addition, the locations of both intermediate images will shift, so that the telescope will no longer be in focus.

Two changes to the eyepiece must occur:

- modify the focal length of the eyepiece to get the desired MP.
- shift the eyepiece to place its front focal point at the second intermediate image to present an image ay infinity to the eye.

Design a compact 10X25 Gregorian telescope.

Specifications:

Magnifying Power	MP	10X
Field of View	FOV	+/- 2 deg
Primary Mirror		
Focal Length	f_P	45 mm
Diameter	D_P	25 mm
Stop is located at the primary mirror		
Obscuration Ratio		50%
Eye Lens Diameter	D_E	10 mm
Overall System Length	L	100 mm
(from the secondary mirror or mounting aperture to the eye lens)		
Unvignetted		
Object at Infinity		

$$\text{Obscuration Ratio} = \frac{\text{Area of the Secondary Mirror}}{\text{Area of the EP Ignoring the Obscuration}}$$

Starting with the specifications and the layout:

$$R_P < 0 \qquad R_P = -2f_P = -90\text{mm}$$

$$R_S > 0$$

$$\bar{u} = \tan\theta_{1/2} = \tan 2° = 0.03492$$

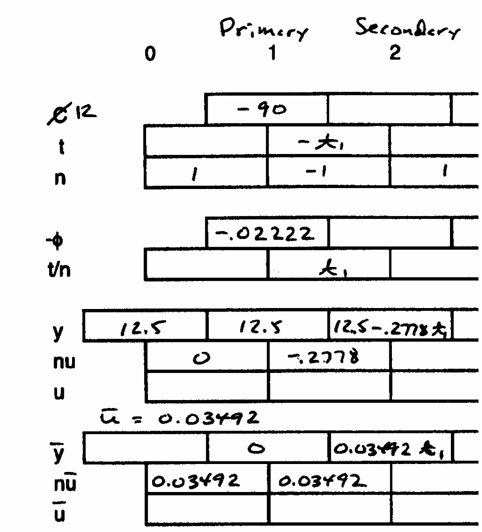
The obscuration ration gives the diameter of the secondary mirror:

$$\text{Obscuration Ratio} = \frac{\text{Area}_S}{\text{Area}_{EP}} = \frac{\text{Area}_S}{\text{Area}_P} = \frac{\pi D_S^2/4}{\pi D_P^2/4} = \frac{D_S^2}{D_P^2} = 0.5$$

$$D_S = 0.707 D_P = 0.707(25\text{mm}) = 17.68\text{mm}$$

$$a_S = 8.84\text{mm}$$

The separation between the primary and the secondary is determined by the vignetting condition at the secondary. Trace marginal and chief rays from the primary to an arbitrary secondary location (transfer distance = $-t_1$).



			Primary		Secondary	
	0		1		2	
~~C~~ 12			-90			
t				$-t_1$		
n		1		-1		1
$-\phi$			-.02222			
t/n				t_1		
y	12.5		12.5		$12.5-.2778t_1$	
nu		0		-.2778		
u						
$\bar{u} = 0.03492$						
$\bar{y}$			0		$0.03492\,t_1$	
$n\bar{u}$		0.03492		0.03492		
$\bar{u}$						

At the secondary mirror:

$$y_S = 12.5 - 0.2778t_1 < 0$$

$$\bar{y}_S = 0.03492t_1 > 0$$

For no vignetting (and solving for the minimum secondary size):

$$a_S \geq |y_S| + |\bar{y}_S|$$

$$a_S = -12.5 + 0.2778t_1 + 0.03492t_1 = 8.84\text{mm}$$

$$t_1 = 68.24\text{mm}$$

The next step is to obtain the proper MP for the telescope and solve for the focal lengths of the secondary mirror and the eye lens. No field lens is needed at this time. Note that a Gregorian telescope is a mirror version of a relayed Keplerian telescope, where the secondary mirror is the relay lens. The total magnifying power is

$$MP = -\frac{f_P}{f_E} m_R = -\frac{f_P}{f_E} m_S \qquad m_S = \frac{z'_S/1}{z_S/-1} = -\frac{z'_S}{z_S}$$

Remember that z_S is in the reflected space of the primary and has an index of -1.

On the top of the next page, the system is shown with various distances.

As an aside, it may be easier to design the system as the equivalent refracting relayed Keplerian telescope, and convert it back into the mirror based system. This works because a raytrace unfolds the mirror system into an air equivalent refractive system.

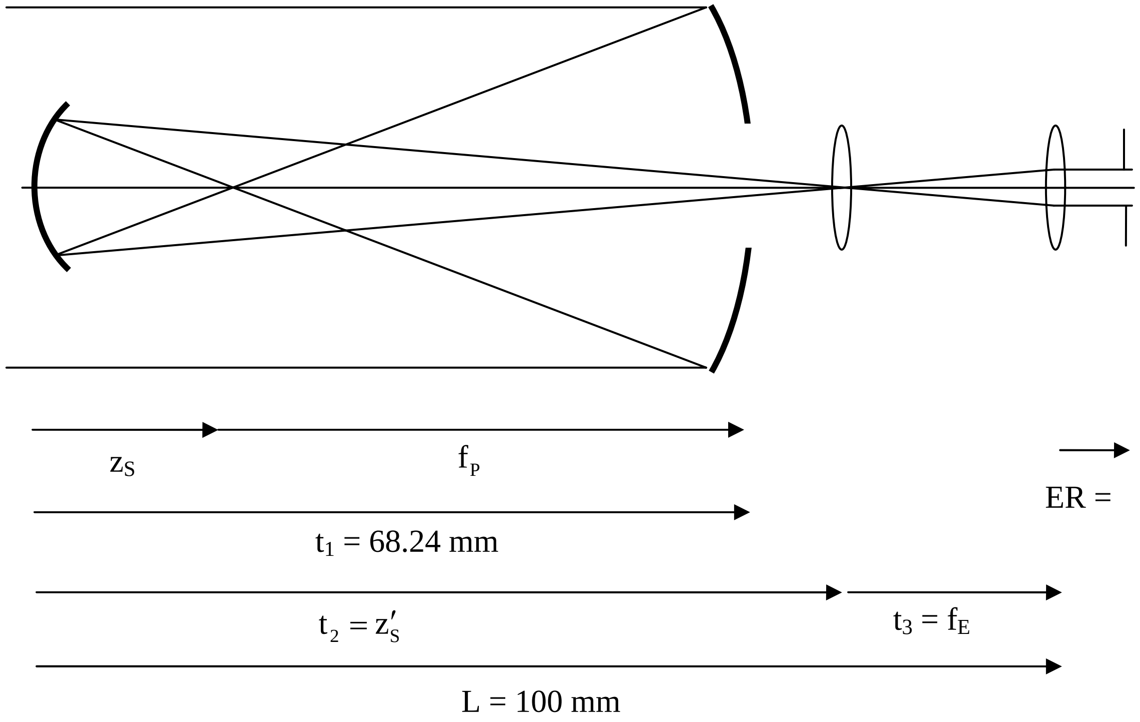
$$z_S = t_1 - f_P \qquad f_P = 45\text{mm} \qquad L = z'_S + f_E = 100\text{mm}$$

$$z_S = 23.24\text{mm} \qquad z'_S = 100\text{mm} - f_E$$

$$MP = \frac{f_P}{f_E}\frac{z'_S}{z_S} = \frac{45\text{mm}}{f_E}\frac{(100\text{mm} - f_E)}{23.24\text{mm}} = 10 \qquad f_E = 16.21\text{mm}$$

$$z'_S = 83.79\text{mm} \qquad \frac{1}{z'_S} = \frac{-1}{z_S} + \frac{1}{f_S} \qquad \frac{1}{83.79\text{mm}} = \frac{-1}{23.24} + \frac{1}{f_S}$$

$$f_S = 18.194\text{mm} \qquad R_S = 2f_S = 36.39\text{mm}$$



The spacings of all the elements are now specified, and the field lens is added at the front focal point of the eye lens. The focal length of this lens is determined by the condition of no vignetting at the eye lens (D_E = 10 mm). A system raytrace to the eye lens is attached as Raytrace 1. Note that the marginal ray raytrace confirms that the system MP = 10 ($y_E = y_P/10$) and that D_{XP} = 2.5 mm.

At the eye lens:

$$y_E = 1.25\text{mm}$$

$$\bar{y}_E = 16.21(5.665\phi_F - 0.09605) - 5.665$$

$$\bar{y}_E = 91.83\phi_F - 7.222 < 0$$

For no vignetting at the eye lens (using the equality to utilize the entire aperture of the eye lens):

$$a_E \le |y_E| + |\bar{y}_E| = 5.0\text{mm}$$

$$1.25\text{mm} - 91.83\phi_F + 7.222\text{mm} = 5.0\text{mm}$$

$$\phi_F = 0.03781/\text{mm} \qquad f_F = 26.45\text{mm}$$

The diameter of the filed lens is given by the chief ray at the field lens (the location of the second intermediate image):

$$a_F = |\bar{y}_F| = 5.665\text{mm} \qquad D_F = 11.33\text{mm}$$

Now that all of the optical components are specified, a final raytrace can determine the ER and the sizes of the two other apertures. The entrance aperture is located t_1 in front of the primary mirror and the hole in the primary mirror is optically located t_1 behind the secondary mirror. From the perspective of the secondary mirror, the hole looks just like an aperture that must pass all of the light. As a result, the minimum hole size in the primary mirror can be found by applying the condition for no vignetting at this location. Of course, the XP is located where the system chief ray goes to zero.

Raytrace 2 is attached.

ER = 10.74 mm

Aperture:

$$y_A = 12.5\text{mm} \qquad a_A \ge |y_A| + |\bar{y}_A| = 14.88\text{mm}$$

$$\bar{y}_A = -2.383\text{mm} \qquad D_A = 29.76\text{mm}$$

Hole:

$$y_H = -1.203\text{mm} \qquad a_H \ge |y_H| + |\bar{y}_H| = 5.37\text{mm}$$

$$\bar{y}_H = -4.171\text{mm} \qquad D_H = 10.74\text{mm}$$

Summary of the results:

Primary Mirror:	Radius of Curvature	R_P = -90 mm
	Minimum Hole Size	D_H = 10.74 mm
Secondary Mirror	Radius of Curvature	R_S = 36.39 mm
	Diameter	D_S = 17.68 mm
Field Lens	Focal Length	f_F = 26.45 mm
	Diameter	D_F = 11.33 mm
Eye Lens	Focal Length	f_E = 16.21 mm
Aperture	Diameter	D_A = 29.76 mm
Exit Pupil	Diameter	D_{XP} = 2.50 mm
Eye Relief	(Eye Lens to XP)	ER = 10.74 mm
Primary-Secondary Spacing		t_1 = 68.24 mm
Secondary-Field Lens Spacing		t_2 = 83.79 mm
Field Lens-Eye Lens Spacing		t_3 = 16.21 mm

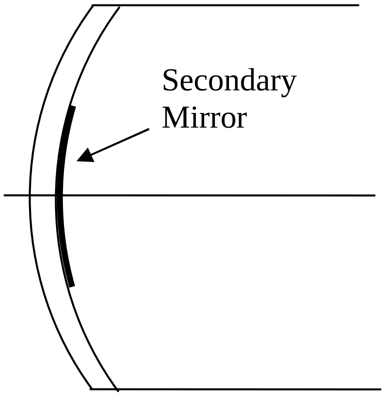
Section B

The Maksutov shell used to form the secondary mirror introduces a small amount of power into the optical system. For the configuration given:

$$\phi_1 = \frac{(1.517 - 1.0)}{R_S} = \frac{0.517}{36.39\text{mm}} = 0.0142/\text{mm}$$

$$\phi = -\phi_1 \phi_2 \frac{t}{n} = \phi_1^2 \frac{t}{n} \qquad \phi_2 = -\phi_1 \qquad t = 2.0\text{mm}$$

$$\phi = 0.000266/\text{mm} \qquad f = 3760\text{mm}$$



This additional power will change MP of the telescope by changing the focal length of the telescope objective (the combination of the shell and the primary mirror). In addition, the locations of both intermediate images will shift, so that the telescope will no longer be in focus.

Two changes to the eyepiece must occur:

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In practice, the MP error is small enough that it might be ignored, and the focusing mechanism in the telescope can be used to adjust for the focus error. Note also that a concentric shell introduces a negative power, and that a zero power shell can be designed.

Raytrace 1

YNU Method

			Primary		Secondary		Field		Eye										
	0		1		2		3		4		5		6		7		8		9
C R, f			-90		36.39		f_F		16.21										
t		∞		$-t_1 = -68.24$		$z_3' = 83.79$		$f_E = 16.21$											
n		1		-1		1		1											
-φ			-.02222		-.05496		$-\phi_F$												
t/n				68.24		83.79		16.21											
y	12.5		12.5		-6.454		0		1.25										
nu		0		-.2778		.07689		.07689											
u																			
$\bar{y}$			0		2.383		-5.665												
$n\bar{u}$		.03492		.03492		-.09605													
$\bar{u}$																			
y																			
nu																			
u																			

$16.21(5.665\,\phi_F - .09605) - 5.665$

$5.665\,\phi_F - .09605$

Raytrace 2

YNU Method

	0		Aperture 1		Primary 2		Secondary 3		Hole 4		Field 5		Eye 6		XP 7		8		9
ø R, f			—		-90		36.39		—		26.45		16.21		—				
t		→		68.24		-68.24		68.24		15.55		16.21		ER					
n		1		1		-1		1		1		1		1					
-φ			—		-.02222		-.05496		—		-.03781		-.06169		—				
t/n		→		68.24		68.24		68.24		15.55		16.21		10.74					
y	12.5		12.5		12.5		-6.454		-1.203		0		1.25		1.25				
nu		0		0		-.2778		.07689		.07689		.07689		0					
u																			
$\bar{y}$			-2.383		0		2.383		-4,171		-5.665		-3.75		0				
$\overline{nu}$		.03492		.03492		.03492		-.09605		-.09605		.1181		.3492					
$\bar{u}$																			
y																			
nu																			
u																			