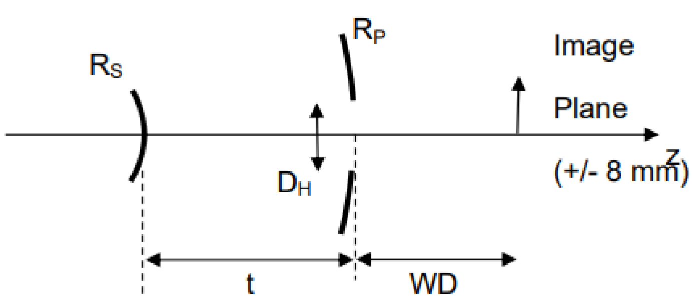
1. Cassegrain Objective Raytrace (Legacy HW 11)

A Cassegrain Objective consists of a concave primary mirror and a convex secondary mirror. The system stop is located at the primary mirror. The working distance is defined from the vertex of the primary mirror to the image plane. For the purposes of this problem, assume that the mirrors have zero thickness.

The object is at infinity. The maximum image size is $\pm 8mm$. The system operates at an f-number of $f/4$.

The system specification is (only the magnitudes of the quantities are provided):

$R_P = 500$ mm $\qquad R_S = 125$ mm $\qquad t = 200$ mm



Determine the following:

- System focal length and the working distance
- Diameter of the Primary Mirror D_P
- The location and diameter of the Exit Pupil

- The required diameter of the Secondary Mirror D_S and required diameter of the Hole in the Primary Mirror D_H the system to be unvignetted over the specified Image Size
- The angular Field of View of the system in Object Space

Note: This problem is to be worked using raytrace methods only.

System: $R_1 = -500mm,\ t = -200mm,\ R_2 = -125mm$

System focal length: $f = 1250mm$

Working distance: $WD = 50.00mm$

Exit Pupil: $246.62mm$ to the left of the primary mirror with diameter $D_{XP} = 74.40mm$

Secondary mirror: $D_S = 65.06mm$

Primary mirror hole: $D_H = 25.81mm$

Angular object space FOV: $\pm 0.367^o$

See uploaded spreadsheet for raytrace solution.

2. Eyepieces (Legacy HW 11)

Design three different eyepieces for an optical system. All three eyepieces have a Magnifying Power of 10, and are used with a relaxed eye (the image presented to the eye is at infinity). The system objective presents an intermediate image to the eyepiece, and the intermediate pupil of the system is 200mm to the left of this intermediate image plane. This intermediate pupil is the image of the stop through any optical elements between the stop and the eyepiece.

a. A simple eyepiece consisting of just an eye lens. Determine the focal length and the eye relief.
b. A compound eyepiece with a field lens located at the intermediate image plane. The field lens has a focal length of 40mm. Determine the eye relief.
c. A Ramsden-style eyepiece with the same eye relief as found with compound eyepiece of part (b). The field lens is located 12mm to the right of the intermediate image plane. Determine the focal lengths of the two lenses and their separation. Hint: Three conditions must be met by the design—the eyepiece must have the proper magnifying power, the final image presented to the eye must be at infinity, and the required eye relief must be obtained.

$$MP = 10 = \frac{250mm}{f_{EP}} \rightarrow f_{EP} = 25mm$$

To be used with a relaxed eye, the intermediate image must be at the front focal plane f_{EP} of the eyepiece.

The intermediate pupil is 200mm to the left of the intermediate image plane or the front focal plane F_{EP} of the eyepiece.

a. Simple Eyepiece

$f_{EYE} = f_{EP} = 25mm$

The eye lens is 25mm to the right of the intermediate plane.

Image the pupil through the eye lens for the XP and the ER:

$Eyerelief = ER = z'$

$z = -200 - f_{EYE} = -225mm$

$$\frac{1}{ER} = \frac{1}{z} + \frac{1}{f_{EYE}}$$

$$ER = \frac{1}{\frac{1}{z} + \frac{1}{f_{EYE}}} = 28.125mm$$

b. Compound Eyepiece

$f_F = 40mm$

$t = 25mm$

Because the field lens is located at F_{EYE}, only the rear principle plane and the ER change from the simple eyepiece.

$f_{EP} = f_{EYE} = 25mm$

The front focal point of the eyepiece is coincident with the front focal point of the eye lens (and intermediate image plane).

The focal principal plane of the eyepiece is coincident with the front principal plane of the eye lens (and is the eye lens).

Rear principal plane of the eyepiece is shifted:

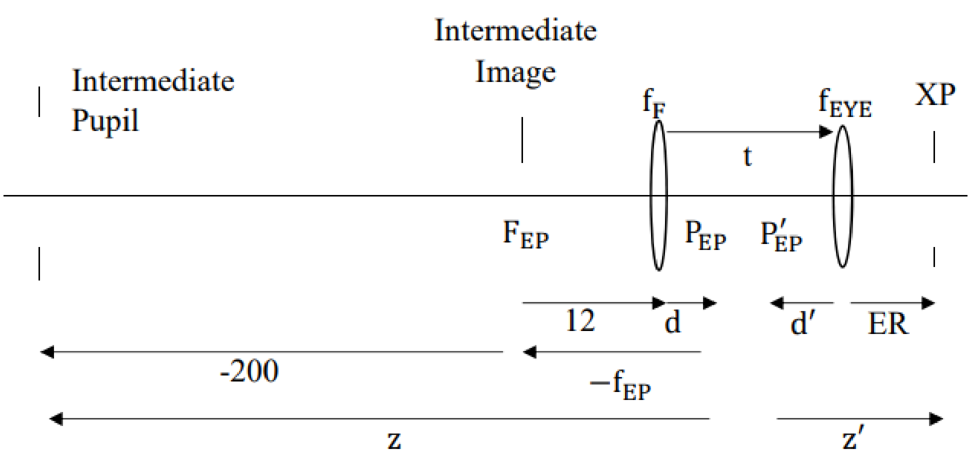
$$d' = -\frac{\varphi_F}{\varphi_{EP}}t = -\frac{\varphi_F}{\varphi_{EP}}t = -\frac{f_{EYE}}{f_F}f_{EYE} = -15.625mm$$

This shift reduces the eye relief of the simple eyepiece to that of the compound eyepiece:

$$ER = 28.125mm - 15.625mm = 12.5mm$$

c. Ramsden Eyepiece

Design to have the same ER as the compound eyepiece. The field lens is located 12mm to the right of the intermediate image.



Three conditions must be met:

1. $f_{EP} = 25mm$

$$\varphi_{EP} = \varphi_F + \varphi_{EYE} - \varphi_F \varphi_{EYE} t$$

$$d = \frac{\varphi_{EYE}}{\varphi_{EP}} t, \qquad d' = -\frac{\varphi_F}{\varphi_{EP}} t$$

2. F_{EP} located at the intermediate image

$$f_{EP} = 12mm + d = 25mm$$

3. The intermediate pupil is imaged to the proper $ER = 12.5mm$

$$\frac{1}{z'} = \frac{1}{z} + \frac{1}{f_{EP}}$$

$z' = ER - d' = 12.5mm - d'$ (XP distance)

$z = -200mm - 12mm - d$ (Pupil distance)

Solving for these conditions.

$$f_{EP} = 12mm + d = 25mm \rightarrow d = 13mm$$

$$d = \frac{\varphi_{EYE}}{\varphi_{EP}} t = 13mm \rightarrow \varphi_{EYE} t = d\varphi_{EP} = \frac{d}{f_{EP}} = \frac{13mm}{25mm} = 0.52$$

$$z = -200mm - 12mm - d = -225mm$$

$$\frac{1}{z'} = \frac{1}{z} + \frac{1}{f_{EP}}$$

$$z' = 28.215mm = ER - d' = 12.5mm - d' \rightarrow d' = -15.625mm$$

$$d' = -\frac{\varphi_F}{\varphi_{EP}} t \to \varphi_F t = -d'\varphi_{EP} = -\frac{d'}{f_{EP}} = 0.625$$

Now we know that:

$$\varphi_{EYE} t = 0.52$$

$$\varphi_F t = 0.625$$

$$\varphi_{EP} = \varphi_F + \varphi_{EYE} - \varphi_F \varphi_{EP} t$$

$$\varphi_{EP} t = \varphi_F t + \varphi_{EYE} t - \varphi_F \varphi_{EP} t^2 = 0.625 + 0.52 - 0.625 \cdot 0.52 = 0.82$$

$$t = \frac{0.82}{\varphi_{EP}} = 0.82\, f_{EP} \to f_{EP} = 25mm$$

$$t = 20.5mm$$

$$\varphi_{EYE} = \frac{0.52}{t} = 0.02536 \to f_{EYE} = 39.42mm$$

$$\varphi_F = \frac{0.625}{t} = 0.03049 \to f_F = 32.8m$$