

# Design of CASSEGRAIN telescope baffles with honeycomb entrance

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The stray radiation suppression in Cassegrain family optical system is presented. The design method for ultra-short outer baffle with honeycomb structure is proposed. Meanwhile the constraint formulas for designing the geometries of primary baffle and secondary baffle are deduced when basing the characteristic and taking vignette into account. According to the ray trace simulated data, the point source transmittance values of the baffle are less than  $10^{-10}$  when incident angles are larger than the rejection angle. The honeycomb-look front baffle guarantees a comparable performance of stray light suppression with traditional tube baffle, while reducing the size greatly.

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Telescopes are usually designed in accordance with the requirements set by the resolution, sensor specifications, total weight, occupied space volume, and construction budget<sup>[1]</sup>. The cassegrain type which is widely used in classic telescope design is composed of a two-mirror-system, namely the primary mirror and secondary mirror<sup>[2]</sup>. It can also be modified into other branches. Correction lenses are often included in order to increase the viewing angle or to balance the off-axis aberrations. Because all the elements are symmetric about the optical axis, the cassegrain type can be manufactured and aligned much more easily compared with other off-axis telescopes. Because the cassegrain design has a central hole on the primary mirror, stray light has opportunities to enter through the central hole, to reach the focal plane, and to result in image corruption. Stray light could be regarded as optical noises. Sometimes it could damage system performance seriously. Thus the optimal baffle design is one of the important steps in the telescope system<sup>[3]</sup>.

For a Cassegrain telescope, the main tube supports, aligns and positions the primary mirror, secondary mirror, correction lenses, sensors, and other components<sup>[4]</sup>. As a matter of fact, the main tube provides the appropriate shielding to prevent the components from direct light exposure. However, some stray light may still pass through the central hole of the primary mirror if there is no baffle in the telescope. Because of the high energy intensity, this stray light reduces image quality. Although the energy intensity of multi-reflection light attenuates by absorption and is much lower than that of direct-hit light, it leads to ghosts and scattering stray light. In order to block the stray light, the designed system is regularly equipped with both outer and inner baffles<sup>[5]</sup>.

The outer baffle is usually composed of a long tube with ring vanes on the inside wall. The inner baffle consists of a the primary baffle around the central hole of the primary mirror and a secondary baffle around the secondary mirror. The secondary baffle will always be conical in shape, opening outward from the secondary position. The primary baffle may be conical or cylindrical.

The basic rule of baffle design is that the baffle should give a maximum blocking performance while never interrupting the imaging ray in the optical path. Meanwhile, the central obscuration, size and weight should be kept to a minimum<sup>[6]</sup>.

Conventionally, the outer baffle is designed in a graphical procedure. The size is always rather large. For some volume-critical configurations to volume, it seems too cumbersome. The same situation as outer baffle, there are also a number of methods in the professional literature describing graphical procedures for the layout of inner baffles<sup>[7,8]</sup>. However, there are few papers giving quantitative procedures<sup>[9,10]</sup>. Young described a programmable iterative procedure that needed a starting guess to guarantee the convergence<sup>[9]</sup>. Hales took a similar basic approach to Young, but by manipulating the equations describing the baffle positions he derived a quartic equation for one of the baffle coordinates, from which the remaining coordinates were solved in a sequence of substitutions<sup>[10]</sup>. A couple of practical difficulties should be noticed in the method mentioned by Hales. First, he attempted to derive an "exact" solution using an exact raytrace, and it made the analysis considerably complicated. Second, there were some undefined parameters in the paper, which made the procedure problematic. Finally, vignetting was observed in the method he proposed.

This work takes an analytical approach based on Hales' work, but makes an appropriate simplification by using a paraxial approximation, which has proved to be entirely adequate in practice, especially for amateur projects. Besides, the vignetting is considered. Treating the mirrors as effective planes eliminates the second order terms from Young's equations, and turns the analysis into solving a quadratic equation. Consequently, a quantitative procedure during the baffle design could be used to fix the final baffle positions. Moreover, a new type of honeycomb outer baffle design variation is also introduced.

The conventional outer baffle is always rather big. The fundamental principle is utilizing a long tube with ring vanes on the inside wall to produce multi-reflection. Each

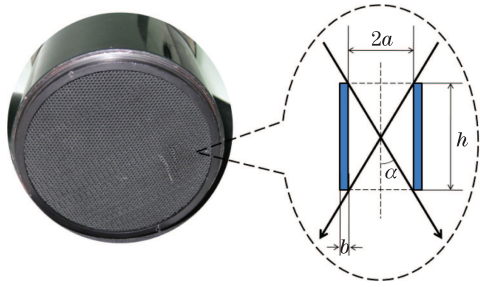


Fig. 1. Honeycomb-look outer baffle.

time the incident light hit on the baffle, the energy intensity is greatly attenuated. Consequently, after several reflections, the stray light is exhausted. Therewith the image corruption becomes neglectable. Although the performance of conventional outer baffle is convinced up-standing, the big size makes it cumbersome for some special occasion. Here we refer to a new honeycomb outer baffle design variation, as shown in Fig. 1. It is composed of a hexagon tubes array. The back-scattering of hexagon tube was proved to be tremendous by Chen *et al.*<sup>[11]</sup>. Light with incident angle smaller than rejection angle ( $\alpha$ ) could pass through directly, where as that with incident angle larger than  $\alpha$  is blocked and absorbed by black paint coating on the hexagon tube surface<sup>[12]</sup>. The main parameters of honeycomb outer baffle design should be semi-diameter ( $a$ ), honeycomb wall thickness ( $b$ ) and length ( $h$ ). The rejection angle ( $\alpha$ ) is decided by both semi-diameter ( $a$ ) and length ( $h$ ):

$$\alpha = \arctan\left(\frac{2a}{h}\right), \quad (1)$$

The honeycomb wall thickness ( $b$ ) is related to obscuration ( $\Phi$ ). Thicker  $b$  leads to larger  $\Phi$ .

$$\Phi = \frac{b}{\frac{\sqrt{3}}{2}a}, \quad (2)$$

The signs and symbols commonly used in geometric optics are not universally agreed on conventions. Thus we decided to use the notational conventions adopted by Wilson<sup>[2]</sup>, because the book was likely to remain the standard reference for telescope design. In particular we follow Wilson in using a “strict Cartesian” sign convention—this is consistent with the practice of most modern lens design software. Also following the modern lens design conventions the optical axis of the system is coincident with the  $z$ -axis, with the optical elements parallel to the  $x - y$  plane. Since we only need to trace “meridional” rays, we define the vertical axis to be the  $y$ -axis; the  $x$ -axis is unneeded. The vertex of the primary mirror is taken to be the origin.

In the following, the parameters necessary for the analysis is defined. For the primary mirror, the semi-diameter is defined as  $y_1(+)$  and the focal length is defined as  $f'_1(-)$ . For the secondary mirror, the semi-diameter is defined as  $y_2(+)$  and the magnification is defined as  $m_2(-)$ . The separation between the primary mirror and the focal plane is defined as  $b(+)$ , and that between the primary mirror and the secondary mirror is defined as  $d(-)$ . Angular field semi-diameter (in radians) is defined as  $u_{pr}(+)$ . According to the above-mentioned parameters,

the system effective focal length ( $f$ ) could be calculated by  $f = m_2 \cdot f'_1$ . Besides, the fully illuminated field size at the focal plane ( $y_F$ ) could be got by  $y_F = u_{pr} \cdot f$ . In addition, we also define  $y_S$  as the fully shielded field size at the focal plane field. Those were chosen from the paraxial solution for a cassegrain system and could be easily got during telescope design. The signs are indicated as “+” or “-”, where “+” means “>0”.

The conceptual idea behind the following analysis is quite simple. According to Hales there are three conditions for an “optimum” baffle system<sup>[10]</sup>: (I) direct rays of stray light must be eliminated for an image area; (II) the field of view must be uniformly illuminated; (III) the baffles must introduce minimal obstruction consistent with (I) and (II). In practice only three rays need to be traced to determine the baffle, including two full field rays and one stray light ray through the system.

As shown in Fig. 2, in order to guarantee all rays in the field of view pass through both baffle openings, the minimum bounds on secondary and primary baffle should be defined by the line segments  $L_1$  and  $L_2$ , respectively. The line segment  $L_4$  represents a stray light ray. The points where it intersects the line segments  $L_1$  and  $L_2$  define the endpoints of the secondary and primary baffle, respectively. It should be obvious from the drawing that for position with  $y \leq |y_S|$ , no stray light could reach the focal plane. Finally, the minimum vignetting condition is met as follows: consider the full field ray represented by the line segment  $L'_3$  that just clears the secondary baffle and reflects off the primary mirror at position  $y_4$ . That ray must clear the primary baffle on its way to the secondary (represented by  $L_3$ ), and that in turn implies that all three line segments  $L_2$ ,  $L_3$ , and  $L_4$  must intersect at the position ( $z_P$ ,  $y_P$ ), which defines the endpoint of the primary baffle.

Hales has shown linear equations representing the five ray segments that need to be traced. As a matter of fact, it turns out that there are only four independent variables here. They are the coordinates ( $z_B$ ,  $y_B$ ) and ( $z_P$ ,  $y_P$ ) which represent the endpoints of the secondary and primary baffles respectively. Accordingly, only four equations are needed to define the relations between them. If the ray equation is expressed as  $y = a + z \cdot b$ , where  $a$  and  $b$  represent the slope and intercept, respectively. The expression for the line segment  $L_i$  ( $i=1,2,3,4$ ) can be easily got as

$$L_1 : y = y_1 \left( \frac{y_2 + y_1}{d} \right) z, \quad (3)$$

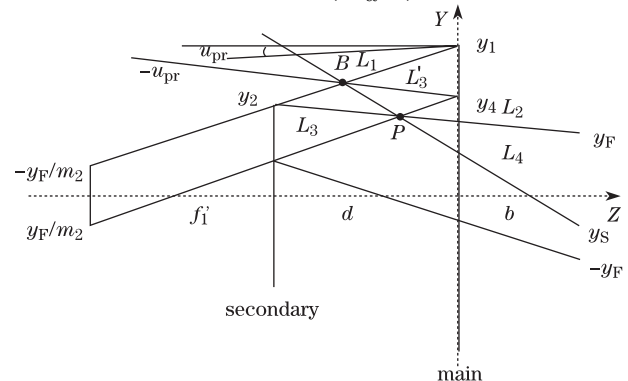


Fig. 2. Sketch map of primary and secondary baffle design.

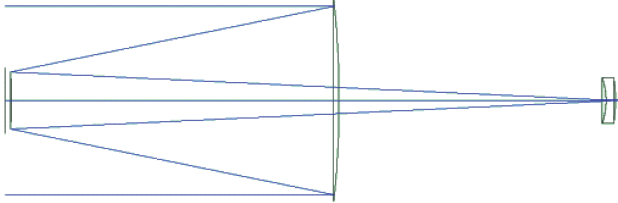


Fig. 3. Ray traced Cassegrain-type Ritchie Cretien telescope.

$$L_2 : y = \left( \frac{y_2 b + y_F}{b - d} \right) + \left( \frac{y_F - y_2}{b - d} \right) z, \quad (4)$$

$$L_3 : y = y_4 \left( \frac{y_F / m_2 - y_4}{f'_1} \right) z \\ = y_4 + (y_F / f'_1 - y_4 / f'_1) z, \quad (5)$$

$$L_4 : y = \left( \frac{y_P b - y_S z_P}{b - z_P} \right) + \left( \frac{y_S - y_P}{b - z_P} \right) z. \quad (6)$$

In order to simplify the expressions we substitute the symbols  $b_1$ ,  $a_2$ , and  $b_2$  for the known slopes and intercepts in Eqs. (1) and (2). Since point  $B$  is the intersection of the line segments  $L_1$  and  $L_4$ , the coordinates  $(z_B, y_B)$  fulfill Eqs. (3) and (6). With a bit of rearrangement of terms we get

$$z_B = \frac{y_1(b - z_P) - (y_P b - y_S z_P)}{y_S - y_P - b_1(b - z_P)}, \quad (7)$$

$$y_B = \frac{y_1(y_S - y_P) - b_1(y_P b - y_S z_P)}{y_S - y_P - b_1(b - z_P)}. \quad (8)$$

Similarly, point  $P$  is the intersection of the line segments  $L_2$  and  $L_3$ , the coordinates  $(z_P, y_P)$  fulfill Eqs. (4) and (5). With a bit of rearrangement of terms we get

$$z_P = \frac{a_2 - y_4}{y_F / f'_1 - y_4 / f'_1 - b_2}, \quad (9)$$

$$y_P = \frac{a_2(y_F / f'_1 - y_4 / f'_1) - b_2 y_4}{y_F / f'_1 - y_4 / f'_1 - b_2}. \quad (10)$$

As shown in Fig. 2, we could easily get  $y_4 = y_B + u_{pr} \cdot z_B$ . Now substitute Eqs. (7) and (8) into this equation, and then an expression for  $y_4$  is obtained:

$$y_4 = [y_1(y_S - y_P) - (b_1 + u_{pr})(y_P b - y_S z_P) \\ + u_{pr} y_1(b - z_P)] / [y_S - y_P - b_1(b - z_P)]. \quad (11)$$

Note that Eq. (11) is an expression for  $y_4$  in terms of the unknowns  $z_P$  and  $y_P$ , while Eqs. (9) and (10) give expressions for  $z_P$  and  $y_P$  in terms of  $y_4$ . Thus, substituting Eqs. (9) and (10) into Eq. (11) we get a quadratic equation in  $y_4$ :

$$A y_4^2 + B y_4 + C = 0, \quad (12)$$

where

$$A = -y_F / f'_1 + a_2 / f'_1 + b_2 + b_1 b / f'_1 - b_1, \quad (13)$$

$$B = (y_F / f'_1 - b_2)(y_F - b_1 b) + a_2(b_1 y_F / f'_1 - y_1 / f'_1) \\ + y_1 y_S / f'_1 - b_2 y_1 + (b_1 + u_{pr})(y_S - b a_2 / f'_1 - b b_2) \\ + u_{pr} y_1(b_1 / f'_1 - 1), \quad (14)$$

$$C = -y_1 y_S (y_F / f'_1 - b_2) \\ + a_2 y_1 y_F / f'_1 + a_2(b_1 + u_{pr})(b y_F / f'_1 y_S) \\ + u_{pr} y_1 [a_2 - b(y_F / f'_1 - b_2)]. \quad (15)$$

Now the problem becomes easy and clear.  $y_4$  could be extracted using the parameters given by Eqs. (13)–(15). Then substitute  $y_4$  into Eqs. (9) and (10) to get  $z_P$  and  $y_P$ . Eventually substitute  $z_P$  and  $y_P$  in Eqs. (6) and (7) to get the

secondary baffle position  $(z_B, y_B)$ .

In order to verify the method, we take a Cassegrain-type Ritchie Cretien system for example, as shown in Fig. 3. The parameters for baffle design are listed as follows: primary mirror diameter is 150 mm; secondary mirror diameter is 150 mm; secondary mirror magnification is  $-4.717$ ; separation between primary mirror and focal plane is 282.35; separation between primary mirror and secondary mirror is  $-257.08$ ; angular field semi-diameter is  $0.116^\circ$ . If the vertex of the primary mirror is taken to be the origin, accordingly,  $y_4$  equals 27.35236, and coordinates of point  $B$  and  $P$  are  $(-231.33, 27.82)$  and  $(-124.83, 17.91)$ , respectively. For comparison, both the honeycomb outer baffle and the conventional outer baffle are discussed. The rejection angle is set  $30^\circ$ .

As shown in Fig. 4, the conventional outer baffle is designed in a graphical procedure as mentioned by Moore *et al.*<sup>[13]</sup>. The parameters of honeycomb outer baffle are calculated as the above method, and listed as follows: semi-diameter is 3 mm; honeycomb wall thickness is 0.25 mm; length is 3 mm. Although the light loss of the baffle is 38%, which is 8% larger than that of the conventional design, the volume and weight of the new baffle are greatly reduced. Besides, the honeycomb baffle fabricated with Nomex, which has low cost and good mechanical stability, is inexpensive compared to the conventional design. Additionally, to optimize the performance of the baffle, some variations have been made as shown in Fig. 5. Firstly, in order to produce more multi-reflection, several ring vanes have been added on the inside wall of the primary mirror baffle. Moreover, the edges of vanes are sharpened at  $30^\circ$  to enhance front scattering<sup>[14]</sup>. The layout of the total baffle is shown in Fig. 6.

Stray light can never be totally eliminated. However, it can often be reduced to a tolerable level. The point source transmittance (PST) will be used to evaluate the baffle-blocking

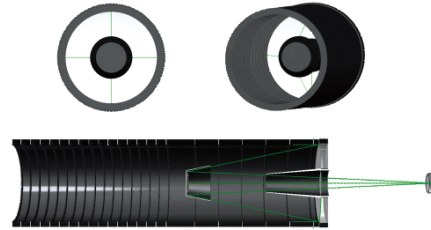


Fig. 4. Layouts of conventional baffle.

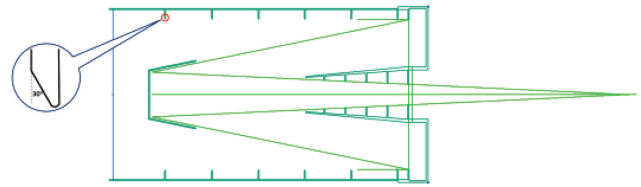


Fig. 5. Layouts of optimization.

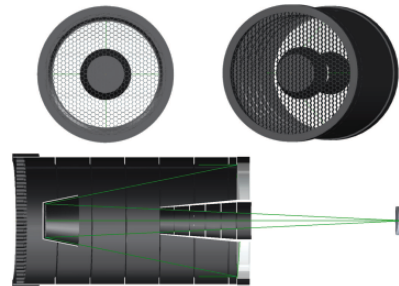


Fig. 6. Layouts of baffle with a honeycomb front.

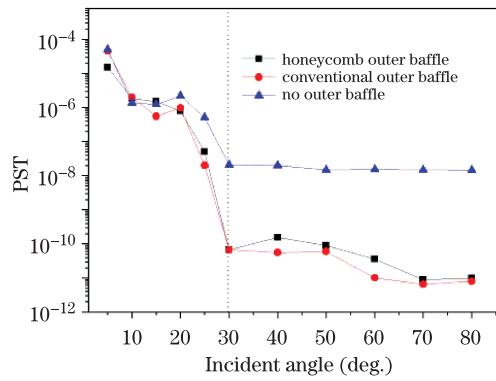


Fig. 7. PST curves of the stray light analysis.

efficiency. The PST is one of common ways to define the merit function of stray light in an optical system<sup>[15]</sup>. The PST formula is expressed as the ratio of the focal plane irradiance  $E_d(\theta, \lambda)$  to the entrance aperture irradiance  $E_i(\theta, \lambda)$ .

$$\text{PST}(\theta, \lambda) = \frac{E_d(\theta, \lambda)}{E_i(\theta, \lambda)}. \quad (16)$$

PST is generally obtained by Monte-Carlo analysis on computer. In this paper, the simulation is executed by TracePro a stray light tracking software<sup>[16]</sup>. 26991001 rays have been traced. The flux per ray is 1 W. The threshold is set to be  $10^{-9}$ . All the baffle surfaces are considered to be painted black paint. The scatter parameters of the black paint is  $A=0.07$ ,  $B=1$ ,  $g=0$ , and the absorption is 0.9. Figure 7 presents the level of stray light at different incident angles.

By comparing the data obtained with and without outer baffle, it could be concluded that the outer baffle is significant for incident angle that larger than the rejection angle. On the contrary, for incident angle that smaller than the rejection angle, the difference of PST seems not great. As shown in Fig. 7, the novel baffle with a honeycomb front discussed in this letter shows almost equivalent performance to traditional design, however, the size is much more compact. Moreover, according to the simulated datum, there is no significant difference between the point spread functions of the two designs, and the curve shows that PST values are less than  $10^{-10}$  when incident angles are larger than the rejection angle which satisfies common requirement.

In conclusion, we present a simple, analytical method for the design of compact Cassegrain family telescopes baffle with honeycomb-look front that can easily be calculated in computer based program. The baffles are

determined by the geometric calculation and finalized by the computer software-assisted ray-tracing. Compared with traditional tube baffle, the honeycomb structure is used on the outer baffle design, and several ring vanes are added on the inside wall of primary mirror baffle in order to produce more multi-reflection. These optimum designs guarantee a comparable performance of stray light suppression with traditional tube baffle, while reducing the size greatly. The result shows that the honeycomb-look front baffle can be a good solution for stray radiation suppression in cassegrain family telescopes. It has broad application prospects as an alternative to traditional tube baffle. The procedure given in this letter only works for a Cassegrain family telescope. However, it can be used for other style optics telescope with modifications, which will be researched in the follow-up works.

## References

1. B. Mu, H. Liu, H. Jin, X. Yang, F. Wang, W. Li, H. Chen, and Z. Wang, *Chin. Opt. Lett.* **10**, 103401 (2012).
2. R. N. Wilson, *Reflecting Telescope Optics I* (Springer, Berlin, 1996).
3. H. Ye, Z. Gao, Z. Qin, and Q. Wang, *Chin. Opt. Lett.* **11**, 031702 (2013).
4. R. N. Wilson, *Reflecting Telescope Optics II* (Springer, Berlin, 1999).
5. V. Y. Terebizh, *Exp. Astron.* **11**, 171 (2001).
6. N. Song, Z. Yin, and F. Hu, *Opt. Eng.* **41**, 2353 (2002).
7. H. G. J. Rutten and M. A. M. van Venrooij, *Telescope Optics-Evaluation and Design* (Willmann-Bell, Richmond, 1988).
8. R. Prescott, *Appl. Opt.* **7**, 479 (1968).
9. A. T. Young, *Appl. Opt.* **6**, 1063 (1967).
10. W. L. Hales, *Appl. Opt.* **31**, 5341 (1992).
11. X. Chen, C. Sun, and X. L. Xia, *Acta Photon. Sin.* (in Chinese) **41**, 353 (2012).
12. B. Outram, *OPTI 521-Optomechanical Engineering* (2009).
13. K. E. Moore and T. Valente, in *Proceedings of 33rd Annual Technical Symposium* 228 (1989).
14. G. C. Kung, *Proc. SPIE* **0511**, 44 (1984).
15. C. F. Ho and S. T. Chang, in *Proceedings of International Conference on Optical Instrumentation and Technology* 75061S (2009).
16. M. A. Gauvin and E. R. Freniere, "Reducing stray light in Opto-Mechanical Systems", [http://boojum.as.arizona.edu/~jill/MAESTRO/References/stray\\_light\\_paper.Pdf](http://boojum.as.arizona.edu/~jill/MAESTRO/References/stray_light_paper.Pdf).