High performance and reconfigurable design at moderate cost

A design has been made for a high-end telescope system aimed at the amateur astronomer market. The design goal was to achieve high optical performance, while keeping the telescope structure light-weight and dividable so that the system is portable. Special attention was paid to the mechanical performance of the telescope structure, making the system robust and extremely reliable. Finally, the telescope was given a modular setup, making the optical characteristics adjustable for specific applications.

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Backyard astronomy

Amateur astronomy is a hobby, whose participants enjoy watching the night sky and the wide variety of objects found in it, mainly using telescopes or binoculars. In some cases, amateur astronomy is focused on day sky as well, e.g. for viewing solar eclipses, sunspots, etc. Amateur astronomy is sometimes referred to as “backyard astronomy”, after the most common viewing location.

Amateur astronomers observe the sky from a variety of locations, ranging from a person’s backyard to special public areas where light pollution is limited. The latter category comprises open spots in forests, mountain tops, or

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desert locations. For this reason, amateur astronomers like their optical system to be portable, robust and low-maintenance.

Common targets of amateur astronomers include the moon, planets, stars, comets, meteor showers as well as deep-sky objects, such as nebulae, galaxies and star clusters. Many amateur astronomers like to specialize in observing particular (types of) objects or interesting astronomic events. One of the branches of amateur astronomy is astrophotography, and involves taking photos of the night sky. This has become especially popular since high-quality CCD cameras have become affordable.

Furthermore, amateur astronomers are highly dependent on atmospheric conditions for the performance of their optical system. It is essential that the night sky is clear and the weather is calm. Atmospheric turbulence is a common cause of optical aberrations. These effects, combined with the fact that most optical systems owned by amateur astronomers are relatively low-tech (compared to the giants in scientific astronomy), allow the amateur to make high-quality observations only a few times a year.

Amateur astronomers pay high regards to reliable and easy-to-use telescope systems, which do not require frequent calibration. Most amateur astronomers consider astronomy as a mere hobby, which is why they are particularly interested in low price-to-quality ratios. Following the above requirements, a design has been made for a high-end telescope system aimed at the amateur astronomer market.

High performance versus low cost

Among amateurs, Cassegrain systems are appreciated for their relatively short length compared to the focal ratio. The short length makes it easy to move the telescope to different viewing locations, as opposed to refractor systems which are generally long and slender. The Dall-Kirkham variant has an elliptical primary mirror surface and a spherical secondary mirror, which makes the mirrors easier to grind than in the "classic" system, greatly reducing the costs [1]. An unfavorable side effect is that the image quality quickly degrades off-axis. Since this is less noticeable at longer focal ratios, a Dall-Kirkham design is particularly suitable for planetary and deep-space applications.

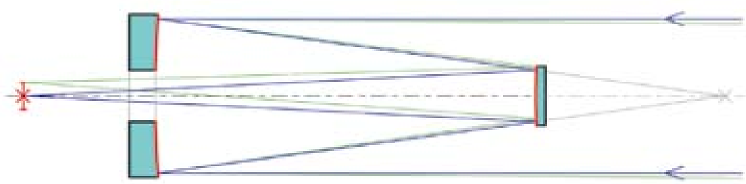

Figure 1. Cassegrain light path.

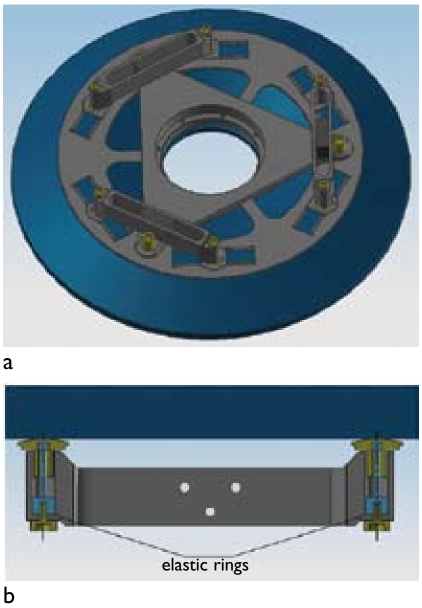

Figure 2. Primary mirror suspension.
(a) Overview.
(b) Section view of a linked pair of rods.

The primary mirror in a Cassegrain telescope system is one of the most important components, as it directly defines the light-gathering power and the resolution for the entire system. The proposed design contains a Ø300 mm primary mirror made of Pyrex 7740, with a silver reflective coating on the front surface, as well as a secondary coating to protect the mirror against detrimental external influences.

All individual light rays reflecting through the system ideally have an equal length, creating a perfect image on the focal plane; see Figure 1. Any misalignment of optical components or deflection of mirror surfaces will result in an aberrated image. A commonly used telescope specification [2] defining the maximum allowable variation in light-path lengths is set to

$$E_g \leq \lambda / 20$$

where λ is the wavelength of light. A system suitable for applications in the near UV spectrum is therefore limited to maximum geometrical deviations of around 18 nm. To be able to meet this demand, static deflection of the mirror surfaces under various viewing angles is a vital issue.

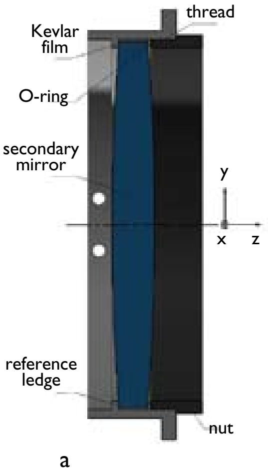

Figure 3. Secondary mirror mount
(a) Section view.
(b) Mounting on a series of elastic line hinges, crossing at the mirror apex, with two differential screws used to set the rotation angles.

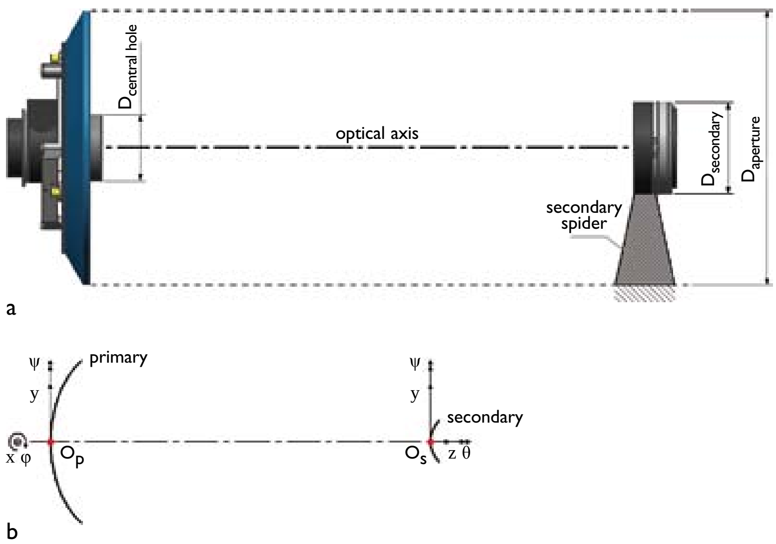

Figure 5. Simplified representations of the optical components and their mounts.

Thermal stability versus simple design

Mirror mounts should provide a stable and controlled environment for an optical component, regarding its position, static and dynamic behavior, and any thermal influences [3]. Inevitably, any mounting system will have a negative effect on the optical performance. Yet a well-thought-out suspension can reduce this to a minimum. A stress-free and statically determined design can avoid internal forces. Using a whiffle-tree offers a suspension for the primary mirror, where axially orientated rods offer support in z, φ and ψ, pairwise linked to a rigid base; see Figure 2. The remaining degrees of freedom are independently defined by a sheet-metal ring containing tangentially orientated rods, again connected to the base of the whiffle-tree. Radial expansion of the mirror is left free, which means that the suspension has no influence on system performance due to slow homogeneous thermal effects.

Considering the relatively small dimensions of the secondary mirror, a simpler mount can suffice; see Figure 3. The secondary mirror is suspended above the primary mirror by a C-shaped frame, supporting the mount in x, y, z and θ. Rotations φ and ψ around the apex of the mirror can be adjusted by manipulating two differential screws on the backside of the mount. The hollow CFRE (Carbon Fibre Reinforced Epoxy) frame runs along the bottom of the telescope and can be connected to any regular commercially available tripod. The result is an open structure (Figure 4), allowing air to flow through the system, hence thermally balancing all optical components with ambient conditions. When viewing in breezy weather, forced convection reduces thermal boundary layers or dew formation on the mirror surfaces.

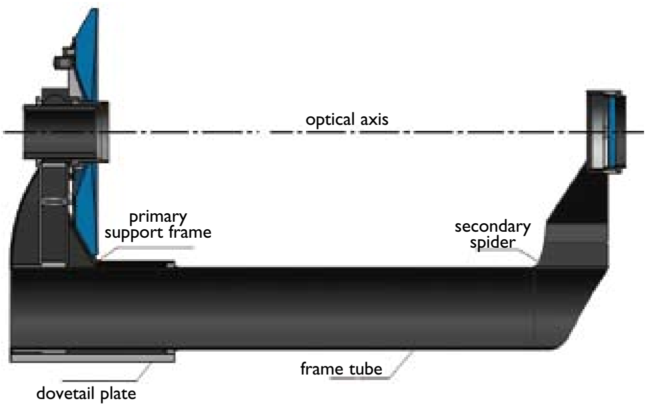

Figure 4. Section view of the CFRE C-frame

Accurate alignment versus reconfigurable setup

Using Zemax [4], all optical components have been modeled with parametrized variables. With the primary mirror rigidly fixed, the effects of deviations in the secondary mirror position and orientation (Figure 5) have been analyzed and qualified in terms of image aberration type. Referring to the geometrical aberration limit E_g, the numerical results have been used to define the relative positioning tolerances of all optical components. Accordingly, throughout the design process these values have been used as a benchmark; see Table 1.

Table 1. Relative positioning tolerances between primary and secondary mirror.

Defocus (z-translation)	1	µm
Decenter (*xy*-translation)	30	µm
Tilt ($\phi\psi$-rotation)	100	µrad

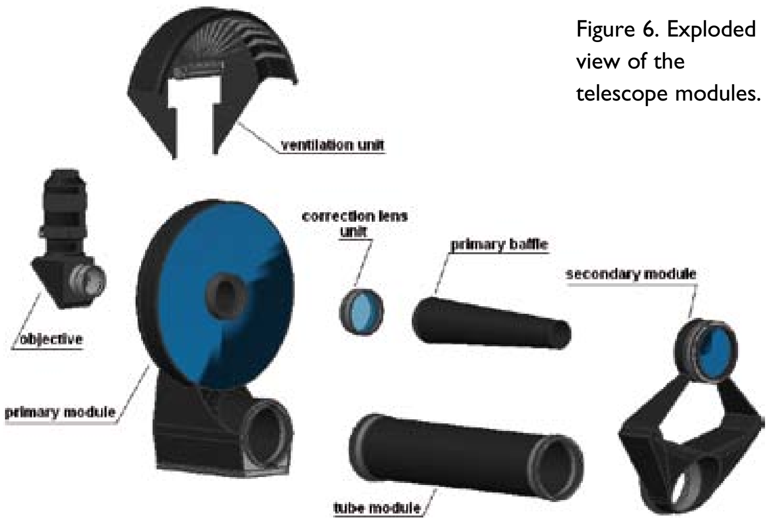

Figure 6. Exploded view of the telescope modules.

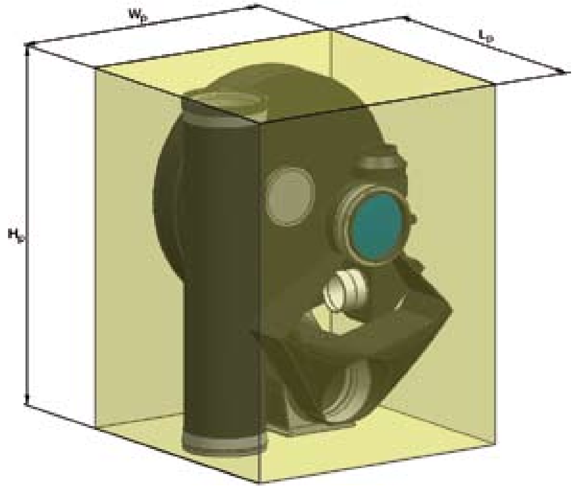

Figure 7. Packaged telescope.

Dynamic response versus portability

The structural frame can be disassembled into several modules (Figure 6), being the primary and secondary support frame, and the frame tube. The connection between the modules and the tube is made by frame connectors. To enhance packaging, the frame connector has a universal design for each module. Apart from this, there are several other demands; see Table 2.

Table 2. Additional demands.

Accuracy	Upon assembly, the structural frame needs to position the optical components within the calculated tolerance limits.
Reproducibility	When assembled, the system components should not need recalibration.
Rigidity	The frame needs to provide adequate stiffness to maintain system dynamic performance.
Controllability	All joints must be free of play.
Durability	A connector can be used numerous times before losing performance or requiring maintenance.
Stability	The relative position of the modules imposed by the connectors has to stay constant at least for the duration of use.
Ease of use	Attaching/detaching modules should be quick and easy for non-technical users.

The proposed connector design is based on a male-female interface, with insertion along the frame tube centerline. Consequently, the connector consists of two parts, either of which is rigidly fixed to one of the opposing modules. The circular frame tube calls for an axisymmetrical design, with material concentrated along the edges as much as possible. An elastic centering mechanism between the connector halves, compressed by a union nut, provides the required pre-loading force to ensure adequate stiffness and correct radial and axial positions.

The secondary mirror unit is suspended from the frame tube by a two-legged straight spider, specifically designed to weaken the effect of spider diffraction, reducing the obstructed area while maintaining proper stiffness. This causes the first eigenmode (frame tube flexure) of the entire system to be at 180 Hz.

Another demand is portability, such that it is allowed in an airplane as carry-on luggage. This implies the telescope should be packaged according to airline restrictions, i.e. regarding weight and overall dimensions; see Figure 7 and Table 3.

Table 3. Casing properties (as in Figure 7).

Dimensions			
	Length	350	mm
	Width	350	mm
	Height	450	mm
Volume		55	l
Mass		11	kg

State of affairs

A proposal has been made for the design of a 300mm Dall-Kirkham Cassegrain, incorporating basic essentials for high performance and features desired by most amateur astronomers as much as possible. The modular setup allows changing the optical configuration while using the same primary mirror, greatly reducing the costs.

Moreover, this creates a universal telescope system suitable for a wide variety of applications, dependent on the modules used. During the design process, all variables have been made parametric, allowing easy recalculation of dimensions and relative positions of components for different configurations.

Dedicated accessory components such as primary and secondary baffles, correction lenses and a ventilation unit have been designed to further enhance optical performance. Current prospects are that a full-scale model and an extensive series of experiments will ultimately provide a valuable product for the amateur astronomy market.

References

[1] H. Rutten and M. van Venrooy, 2002. Telescope Optics, A Comprehensive Manual for Amateur Astronomers, fifth printing. Willman-Bell Inc, Virginia.
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[3] P. R. Yoder, Jr., 2006. Opto-Mechanical Systems Design, third ed. Taylor & Francis Group, Boca Raton.
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