

# EXPERIMENTAL EVALUATION OF PATTERNED REFLECTIVE SURFACES FOR SOLAR GLARE REDUCTION IN SMALL UAV PLATFORMS

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## ABSTRACT

*Small unmanned aerial vehicles (UAVs) increasingly require optical signature control in order to reduce visual detectability during daylight operations. This study investigates the influence of mirror-type polymer surface treatments on solar glare behavior and proposes a patterned reflective configuration as a passive mitigation strategy. A small multirotor UAV platform was partially covered (35–40%) with a PET-based reflective film exhibiting high specular reflectance (approximately 80–85%), and its visual response was evaluated under direct solar illumination.*

*Experimental observations indicated that continuous mirror-like surfaces generate intense specular glints for surface–sun incidence angles between approximately 20° and 45°, with glare visibility durations of 1.5–2.0 seconds. To reduce glare intensity, a segmented surface pattern was introduced, decreasing the estimated effective specular area from 30–35% to 15–20%. The patterned configuration demonstrated a shorter glare duration (0.5–0.8 seconds) and a proportional reduction in glare alignment probability. The results indicate that while reflective polymer coatings may contribute to background blending under diffuse lighting conditions, continuous mirror-like surfaces increase detection risk under direct sunlight. Patterned segmentation represents a low-cost, geometry-based approach for solar glint mitigation and optical camouflage enhancement in small UAV platforms.*

KEYWORDS: UAV, drone, visual signature, reflective film, glare, patterning

## 1. Introduction

Unmanned aerial vehicles (UAVs) have experienced rapid technological development and widespread adoption in civilian, industrial, and security-related applications over the last decade [1-3]. Beyond endurance, payload capacity, and autonomy, operational effectiveness increasingly depends on signature management, particularly visual detectability under varying environmental and illumination conditions [4-5].

The visual detection of small aerial targets is strongly influenced by object size, motion, contrast against the background, illumination geometry, and surface reflectance properties [6-7]. Under daylight conditions, smooth or glossy surfaces may generate

intense specular reflections ("glints"), significantly increasing detection probability at medium and long distances [8-9]. These optical effects are well documented in remote sensing and surface scattering theory [10], as well as in multispectral camouflage research [11].

Recent research in UAV survivability has focused on stealth materials, adaptive coatings, programmable polymer surfaces, and low-observable surface treatments [12-14]. Although effective, these approaches often require advanced materials, complex integration procedures, or increased manufacturing costs. For small UAV platforms, low-cost and geometry-based mitigation strategies remain particularly attractive [15].

From an optical standpoint, reflectance behavior and bidirectional reflectance distribution characteristics play a crucial role in detection probability [16]. In addition, object detection studies confirm that dynamic background interaction and directional reflections may significantly influence visibility when observed by electro-optical systems [17]. Beyond purely optical modeling approaches, recent advancements in computer vision and deep learning have demonstrated improved UAV detection capabilities using image-processing-based frameworks trained to recognize small aerial targets under complex background conditions [18].

Mirror-type polymer films represent a simple and accessible surface modification method. The theoretical assumption is that reflective surfaces may partially mimic environmental background colours by reflecting the surrounding scene. However, while such an approach may reduce contrast under diffuse lighting conditions, the same specular mechanism can lead to concentrated reflections under direct solar illumination that enhance visual detectability.

The balance between background blending and glare-induced detection therefore represents a relevant design challenge.

This paper presents a preliminary experimental evaluation of partial mirror-film coverage applied to a small UAV platform and investigates a patterned reflective surface as a passive mitigation strategy. The proposed approach combines material modification with CAD-supported surface segmentation to reduce the effective specular area and improve optical camouflage performance under direct sunlight.

## 2. Experimental procedure

The experimental study was conducted on a small multirotor UAV platform equipped with a polymer-based external shell. The UAV had an approximate diagonal span of 450 mm and a total mass of 1.2 kg. A commercially available mirror-type polymer film was selected due to its high specular reflectance and low implementation cost. The material was a PET-based reflective film with an estimated visible-spectrum reflectance of approximately 80–85% and a thickness between 50 and 80  $\mu\text{m}$ . Prior to application, the UAV surface was cleaned and degreased to ensure proper adhesion. The reflective film was applied partially to selected fuselage regions, covering approximately 35–40% of the external surface. Partial coverage was intentionally adopted to avoid complete specular dominance and to allow comparative observation between reflective and non-reflective zones. The evaluation was performed under natural outdoor illumination, focusing on clear-sky conditions with direct solar exposure. The UAV was positioned at

varying tilt angles to simulate realistic flight attitudes. The observer distance was maintained between 25 and 35 m to allow consistent visual comparison. Particular attention was given to surface–sun incidence angles between approximately 20° and 45°, representing the most critical interval for specular glare formation. The assessment was qualitative and based on repeated visual observations (five repetitions per configuration). The following parameters were evaluated: presence of high-intensity specular glints, duration of glare visibility, contrast difference between reflective and matte regions, and detectability against the sky background.

Glare duration was defined as the time interval during which the reflected highlight remained clearly distinguishable from background luminance. To mitigate sustained glare formation, a segmented reflective pattern was introduced. The pattern divided large continuous reflective regions into smaller geometrical segments, modifying local surface orientation and reducing coherent specular reflection alignment. This segmentation approach aimed to decrease the effective specular area without completely removing the reflective material, preserving potential background blending effects under diffuse lighting.

According to the law of reflection, the angle of incidence ( $\theta_i$ ) is equal to the angle of reflection ( $\theta_r$ ), both measured relative to the surface normal. This principle explains the concentration of reflected solar energy in a specific direction for smooth mirror-like surfaces:

$$\theta_i = \theta_r \quad (1)$$

where:  $\theta_i$  - angle of incidence,  $\theta_r$  - angle of reflection

It was observed that under direct sunlight the mirror-type surface generated concentrated reflections, increasing the probability of visual detection. This effect confirmed that while reflective materials may reduce contrast in some diffuse lighting conditions, they introduce a significant disadvantage under high solar irradiance.

To mitigate the identified drawback, an intermediate solution was proposed: introducing a patterned geometry on the reflective film. The pattern was designed to: break large continuous reflective surfaces into smaller segments, modify local reflection angles, reduce sustained specular highlight formation. The pattern concept aims to disrupt coherent specular reflection by introducing geometric discontinuities that scatter reflected light over a wider angular range.

### 3. Results and Discussion

The experimental research revealed a clear trade-off between potential background blending and increased detectability due to specular glare. While reflective surfaces may reduce visual contrast in diffuse illumination conditions, their behavior under direct solar radiation represents a critical limitation.

Figure 1 illustrates the initial experimental configuration with partial mirror-film coverage. Based on the observed glare effects, a patterned mitigation concept was developed (Figure 2). The proposed solution was further integrated into CAD-based UAV geometries designed (Figure 3) to enable controlled surface optimization.



**Fig. 1.** The partial coverage of a drone surface with mirror-type plastic film

As shown in Figure 1, the reflective film creates localized high-specular areas on the fuselage. During direct sunlight exposure, these zones generated intense glints visible from significant distance. The concentrated reflection is consistent with specular reflection physics, where smooth surfaces redirect incident light into narrow angular cones. This effect increases instantaneous contrast against the sky

background and therefore enhances visual detectability.

Based on the glare effects observed in the configuration presented in Figure 1, a mitigation concept was developed to reduce sustained specular highlights without completely eliminating the reflective material. To demonstrate this intermediate solution. Figure 2 presents the patterned reflective surface applied to the mirror-type film.



**Fig. 2.** The pattern created on the proposed material surface to reduce visual identification risk due to solar reflection

The patterned geometry divides large continuous reflective areas into smaller segments. This

segmentation modifies local surface orientation and disrupts coherent specular reflection. As a result,

reflected solar radiation is redistributed over a wider angular range, reducing the probability of a strong, sustained glint being observed from a single viewing direction. The pattern therefore functions as a geometric camouflage strategy, combining reflective properties with controlled optical scattering. Following the conceptual validation of the patterned surface approach, the solution was integrated into a digital design workflow in order to enable systematic surface optimization. To support this engineering integration, Figure 3 presents the custom UAV geometry developed in the CAD environment.

The CAD model allows controlled partitioning of reflective and non-reflective zones, parametric

adjustment of pattern dimensions, and visualization of surface orientation relative to the incident solar vector. This digital representation enables repeatable configuration studies and facilitates future quantitative optical simulations.

A comparative summary of glare behavior for the tested configurations is presented in Table 1. Glare duration was estimated through repeated visual observation during controlled angular displacement of the UAV, averaged over five test repetitions. Specular glare was observed for surface–sun incidence angles approximately between 20° and 45°.



*Fig. 3. The custom drone model designed*

The Glint Risk Index (GRI) provides a simplified estimation of glare intensity, indicating that detection risk increases proportionally with the effective specular area and when the observation angle approaches the specular reflection direction. It is defined as:

$$GRI = A_{\text{specular}} \cdot \cos(\theta) \quad (2)$$

The patterned configuration reduced the estimated effective specular area from approximately

30–35% to 15–20%, leading to a proportional decrease in the Glint Risk Index (GRI). Glare duration was defined as the time interval during which the reflected highlight remained clearly distinguishable from background luminance. Assuming a 45% reduction in effective specular area for the patterned configuration, the estimated GRI value decreases proportionally, indicating reduced glare alignment probability. For an identical observation angle, the proportional decrease in

Aspecular leads to an equivalent reduction in the GRI value.

The present study is limited to qualitative outdoor observation without calibrated photometric instrumentation. No BRDF measurements or radiometric sensors were employed. Future work should include controlled illumination measurements, reflectance characterization, and BRDF-based modeling to quantitatively assess glare intensity and detection probability.

In addition to the proportional reduction in the Glint Risk Index, the patterned configuration demonstrated improved temporal instability of specular highlights. Unlike the continuous mirror surface, where glare remained sustained due to coherent reflection alignment, the segmented geometry introduced micro-variations in local surface normals. These variations resulted in rapid angular redistribution of reflected solar energy during UAV motion, thereby decreasing glare persistence.

**Table 1.** Glare performance comparison for tested UAV surface configurations

Configuration	Estimated Specular Area (%)	Glare Duration (s)	Estimated Risk
Continuous mirror	30–35%	1.5–2.0	High
Patterned mirror	15–20%	0.5–0.8	Medium
Matte surface	<5%	<0.3	Low

From an operational perspective, the reduction of glare duration from 1.5–2.0 s to 0.5–0.8 s represents a significant decrease in the visual detection window. In dynamic flight scenarios, even sub-second reductions in high-contrast glint exposure can meaningfully reduce target acquisition probability by human observers or electro-optical tracking systems.

Furthermore, the matte surface configuration confirms that minimal specular contribution (<5%) effectively suppresses glare formation. However, fully matte treatments eliminate potential background blending benefits under diffuse illumination. The patterned reflective approach therefore represents an intermediate optical solution, balancing contrast reduction under cloudy conditions with glare mitigation under direct solar irradiance.

#### 4. Conclusions

This paper evaluated the optical behavior of mirror-type polymer coatings applied to small UAV platforms, focusing on solar glare formation and visual detectability under direct sunlight. Continuous reflective surfaces generated intense specular glints for incidence angles between 20° and 45°, with glare durations of 1.5–2.0 s, increasing the detection risk.

The introduction of a segmented reflective pattern reduced the effective specular area from 30–35% to 15–20%, decreasing glare duration to 0.5–0.8 s and proportionally lowering the Glint Risk Index (GRI). The patterned configuration disrupted coherent reflection alignment and redistributed reflected solar radiation over a wider angular range.

While matte surfaces minimized glare formation, they eliminate potential background blending benefits under diffuse illumination. The patterned reflective approach therefore represents a balanced, low-cost, geometry-based solution for mitigating solar glint while preserving partial camouflage functionality. Future work should include quantitative radiometric measurements, and BRDF-based modeling to further validate and optimize the proposed design strategy.

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