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Experimental modelling with theoretical validation of liquid crystal display elements for UAV optimal (optical) stealth

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2nd LOGO

INTRODUCTION

Advanced optical stealth technology is increasingly important in the role of aircraft: manned (e.g. F117A) or unmanned (e.g., X47B Pegasus), with active projection or passive reflective display elements. This paper presents practical user consideration towards minimal power requirements with passive adaptive methods for stealth platform protection. Prism-coupling as a means of probing Liquid Crystal (LC) layers provides information on optical parameters provides a possible route to large display area. Leaky LC cells fabricated from: glass /ITO / alignment layer/ LC /alignment layer/ ITO / glass multi-layer structures support guided modes. Optical reflectivity as a function of incident angle and applied voltage are compared with theory generated from a Fresnel matrix formalism. Real achievable reflectivities may then be used to simulate contrast across an aircraft platform with 120,000 pixel elements, to evaluate methods for minimising passive power consumption.

History of Optical Stealth

Stealth, or **L**ow **O**bservable **T**echnology (LOT), is concerned with making *any* platform: UAV, aircraft, ship, vehicle, *less* visible to Radar, Infra-Red or other detection methods. During WW1, Britain was losing many warships, so the Royal Navy, desperate for a solution, attempted to hide them though bizarre dazzle camouflage paints schemes of colourful and abstract cubist blocks and stripes, so vessels would 'blur' into a complex background of sea, sky and coastline. Normal Wilkinson CBE, primarily marine painter, was the first credited to use disruptive naval camouflage patterns. Dazzle camouflage was used widely at the end of WW1 and to a lesser extent WW2, **fig. 1**. shows HMS Uranus and HMS Jervis.

Fig. 1. The Normandy landings 6 June 1944 HMS Uranus and HMS Jervis, in the early morning with landing craft waiting to go in, painting by Norman Wilkinson, held at Britannia Royal Naval College © CR Lavers.

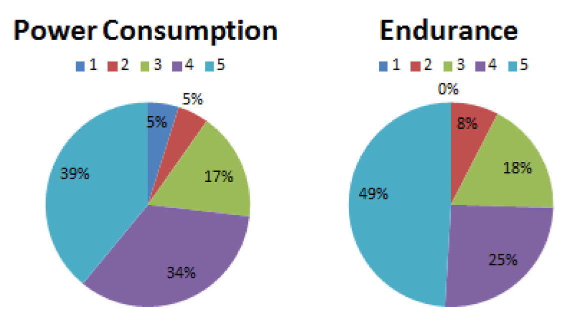
Fig. 2. X47B Pegasus.

Detection be it visual or radar is largely about contrast. Clothing, airframes, ships or vehicles matching the background forms the basis of concealment. Addition of coloured patterns makes it less likely to be detected in a complex environmental and forms the basis of disruptive camouflage. The German Air Force (1913) was the first to try to make aircraft invisible with a transparent monoplane of light colours, detectable at a height of 900ft. Cloaked with visible such stealth aircraft may fly over enemies to drop ordnance.

Dazzle camouflage is entirely passive, and can only be changed by painting. Active methods alter appearance near-real time to confuse enemies. Active or adaptive camouflage uses emerging technologies which blend objects into their surroundings with panels or coatings to alter colour, luminance and reflectivity. Active camouflage provides concealment from visual detection. One proven example was during WW2 in efforts to defeat the U-boat menace. Aircraft trying to target surfaced submarines had a problem because German lookouts could spot the dark silhouettes of incoming aircraft a large distance away, diving to the safety of deep water. By 1940 US researchers made aircraft effectively 'invisible', adjusting the brightness of lights on leading wing edges to hide them. Project Yehudi's Avenger bombers reduced detection to about 2 miles. Prototype F-117A used distributed optical fibre lighting on wing surfaces to minimise contrast against background skies [**1**], now optimised with the X47B Pegasus UAV (**fig. 2**), recording sky and using lights below to blur outline, reducing contrast. However, projection requires high power levels, and consumption reduces endurance and other factors. The importance of endurance (106 responses) and power consumption (41 responses) to both the UAV military and civilian community, is seen from our upstream downstream UAV sensors research: **fig. 3**, on a scale from 1 to 5 where 1 is not at all important, to 5 very important. The reduced number of responses regarding power is indicative of the freedom to discuss power related issues.

THEORETICAL APPROACH

Conformable optical reflectivity element design uses Fresnel theory for multi-layer modelling of liquid crystals. LC cell model design allows optimal cell reflectivity changes to simulated real reflectivity across proposed UAV platforms. A Fortran scattering matrix method **[2]** accounts for reflection / transmission coefficients at media interfaces, coupling incoming fields with a stable matrix for data fitting (**fig. 4**). Our method calculates reflectivity as a function of incident angle for multi-layer media as a series of isotropic slabs of thickness below a wavelength**.** Once a LC structure is modelled this permits optimised LC cell fabrication **[3]**. Data obtained from reflectivity monitoring is compared with theoretical modelling, permitting LC cell design optimisation. Optimised LC cell reflectivity data as a function of voltage provides an estimate of real contrast variation for a UAV skin covered with pixelated LC cells.



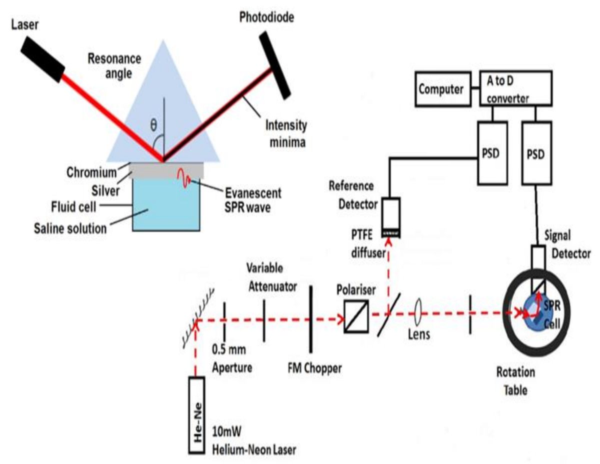


Fig. 3 UAV platform responses Fig 4. Optical reflectivity arrangement.

EXPERIMENTAL RESULTS

The Kretschmann experimental configuration (**fig. 4**) records reflectivity from fabricated LC cells. A He-Ne laser (632.8nm) provided coupling to the LC cell guided modes, stepped in angle under computer control. A FM chopper permits signal and reference PSD with lock-in amplifiers to minimise noise. Data acquisition takes place with a National Instruments USB 6210. A LabView program controls a motorised rotation stage, recording diode reflectivities from sample / reference beams. A θ prism movement gives a 2θ diode turn, ensuring reflected beams strike a diode. As the stage rotates we record reflectivity data against steps. Cells are examined with the Krestchmann configuration. MIX 783 LC cell data under applied voltage, 0 - 12V, recorded at 632.8nm, is shown (**fig. 5**).

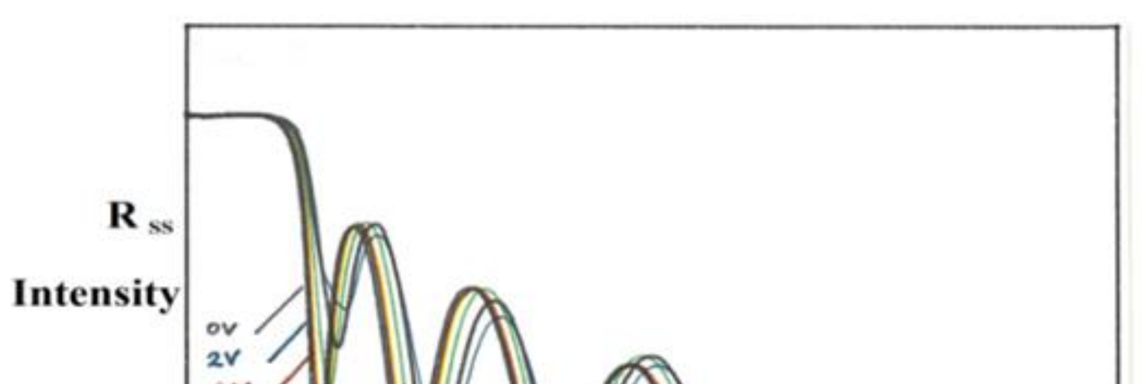


Fig. 5. Experimentally recorded Rss reflectivities as a function of applied DC voltage for the Ferroelectric LC SCE8 at room temperature.

OPTICS PREDICTION AND DISCUSSION

Fig. 5 shows reflectivity changes as a function of applied voltage. Such reflectivity values allow us to predict likely adaptive contrast variation with a pixel grid showing minimum / maximum contrast and variation for 0V, 6V and 12V applied in Matlab respectively (**fig. 6**).

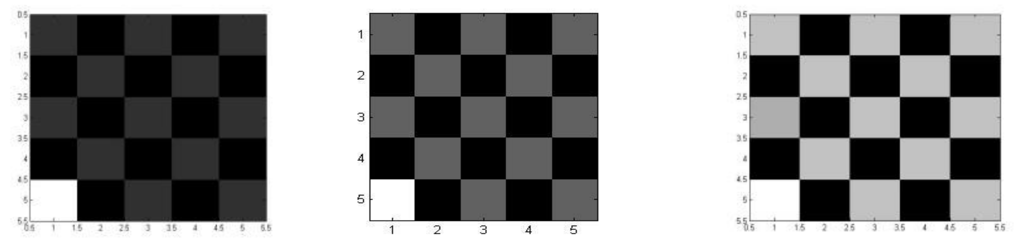


Fig. 6. Applied Voltage: 0 V 6 V 12 V

Max White and Min Black chequers, alternative squares LC values.

The maximum silhouette contrast of a F117A was entered into Matlab having 120 000 pixel elements, with 64 levels of brightness (0 to 63) is shown in **fig. 7a**. Normalised contrast may be calculated for target Intensity It against background Ib using the equation :

$$C = \frac{I_T - I_B}{I_T + I_B}$$

Simulated platform reflectivity elements at 632.8nm show approximate maximum silhouette contrast conditions for 0 V applied, and 12 V applied, are given in fig. **7b,** closely matching 7a. and fig. **7c** respectively with much reduced contrast.

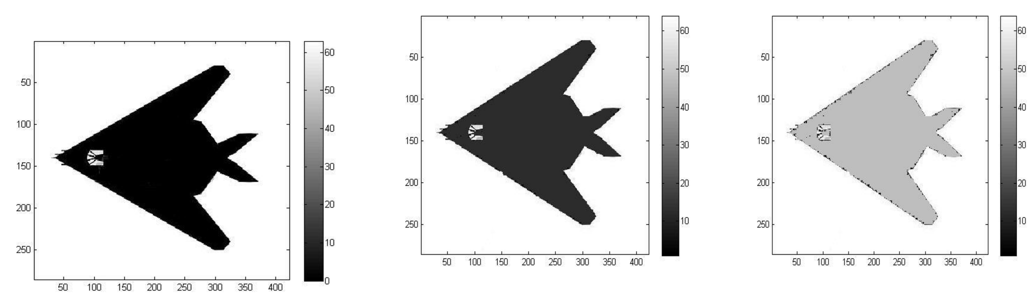


fig. 7a F117A silhouette 7b. 0V applied 7c. 12V applied

CONCLUSIONS

1. **Modelling and visualisation of a platform coated with Liquid Crystal Cells show large changes in visual contrast for adaptive low power UAV camouflage.**
2. **Liquid Crystal Cells in the range 0-12V applied voltage provide significant contrast changes closely approaching max/min contrast conditions.**

Future Changing Character of Warfare research will look at such emerging new technologies, w.r.t. the potential afforded by a range of synthetic electro-optical materials with temperature, angle, voltage and wavelength dependent effects, which when combined with disruptive contrast 'patch' applications in UAV platforms will enable transformational capabilities. We will look at how this will influence interactions and dynamics between human actors, the spatial and time domain, and any ethical and moral limitations such approaches may impose.

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