EXPERIMENTAL MODELLING WITH THEORETICAL VALIDATION OF LIQUID CRYSTAL DISPLAY ELEMENTS FOR UAV OPTIMAL (OPTICAL) STEALTH

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INTRODUCTION

Advanced optical stealth technologies are now important in operational aircraft roles whether: manned (e.g. F35B), or unmanned (e.g. X47B Pegasus), with active / passive display methods. This poster presents some thoughts around practical user issues regarding minimising power requirements, namely with passive adaptive methods to achieve platform stealth. Passive reflectivity reduction is based upon Liquid Crystal (LC) parameters obtained from prism-coupling. Prism-coupling is a method to probe LC layers, providing key optical parameters, and is one route to achieve large switchable displays. LC cells are fabricated with: glass/ITO/alignment-layer/LC/alignment-layer/ITO/glass multi-layers. Optical reflectivity as a function of incident angle and applied voltage is compared with reflectivity theory generated from a Fresnel matrix formalism. Real reflectivity changes are used to simulate contrast across an aircraft model with 60000+ pixel elements, to evaluate this method for minimising power consumption.

History of Optical Stealth

Stealth, or more generally **L**ow **O**bservable **T**echnology (LOT), is concerned with making *any* platform: manned or unmanned, much *less* visible to Radar, Infra-Red or other detection methods. During WW1, Britain lost 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. Vessels would 'blur' into a complex background of sea, sky & coastline. Normal Wilkinson CBE, primarily a marine painter, was first credited to use such disruptive naval camouflage patterns. Dazzle camouflage was used widely at the end of WW1 and to a degree in WW2, see **fig. 1**.

Fig. 1. The Normandy landings 6 June 1944 with 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

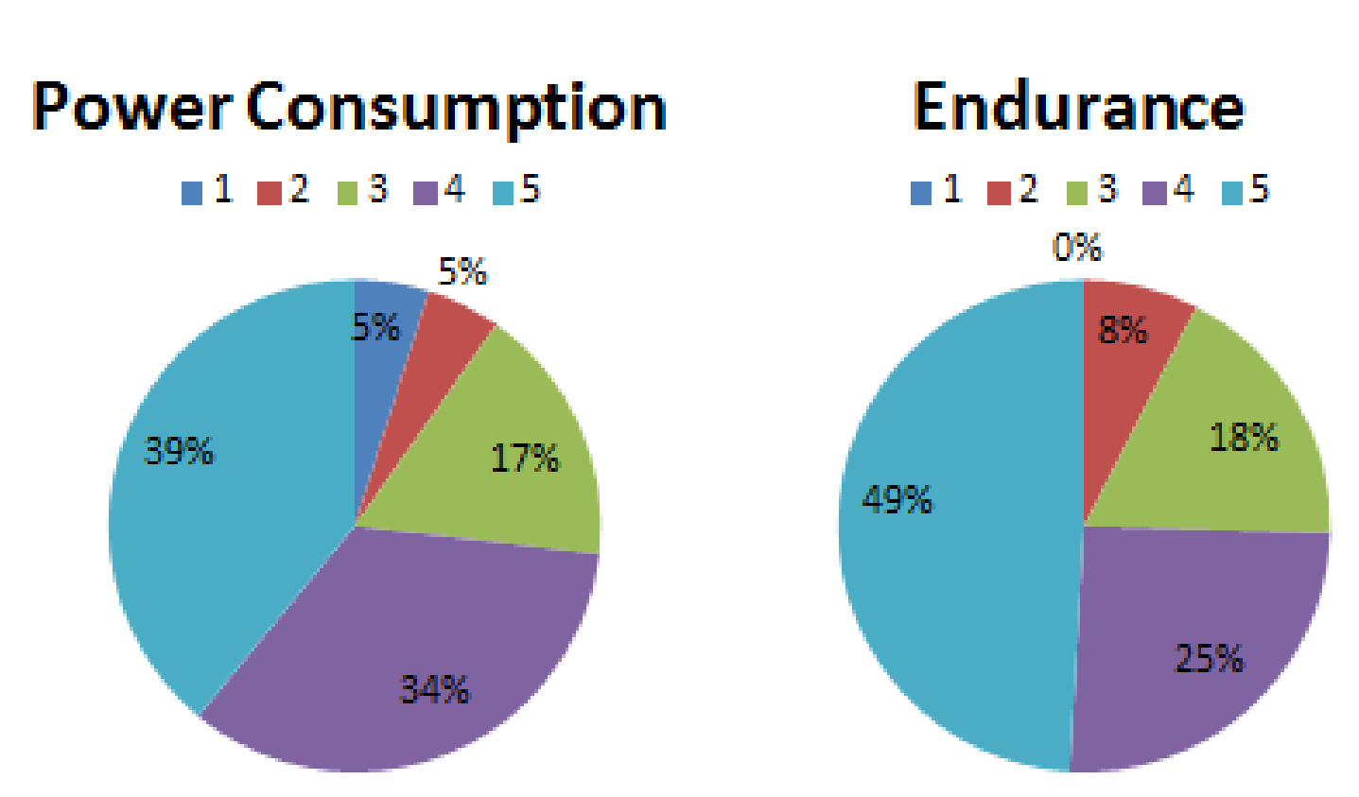
Fig. 2. X47B Pegasus

Detection, visual or by radar, is largely about contrast. Clothing, airframes, ships or vehicles matching the background forms the basis of concealment. Addition of optical 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 and make aircraft invisible with a transparent monoplane of light colours, just detectable at a height of 900ft. Such invisibly cloaked stealth aircraft might fly over enemies, safely undetected.

Dazzle camouflage is passive, and is changed only by painting, but active methods alter appearance in near-real time to confuse enemies. Active or adaptive camouflage uses emerging technologies to 'blend' objects into the surroundings, with panels or coatings to alter colour, luminance or reflectivity. Active camouflage provides concealment from visual detection. An example during WW2 were Allied efforts to defeat the U-boat menace. Aircraft struggled to target surfaced submarines because German lookouts could spot the dark silhouettes of incoming aircraft a long way off, diving to the safety of deeper water. By 1940 US researchers made aircraft effectively 'invisible', by adjusting the brightness of lights on leading wing edges to hide them. Project Yehudi's Avenger bombers reduced detection to about 2 miles. Likewise prototype F-117A used distributed optical fibre lighting on wing surfaces to minimise contrast against background skies [1], now optimised by 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 the UAV military and civilian community, is seen from our upstream/downstream UAV sensors research: **fig. 3**, on a scale from 1 - 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 in simulated 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 the structure is modelled this permits optimised LC cell fabrication **[3]**. Real data obtained from reflectivity monitoring is compared with theoretical modelling, permitting LC cell design optimization. such LC cell reflectivity data, as a function of voltage provides an estimate of achievable real contrast variation for a UAV skin covered with pixelated LC cells.



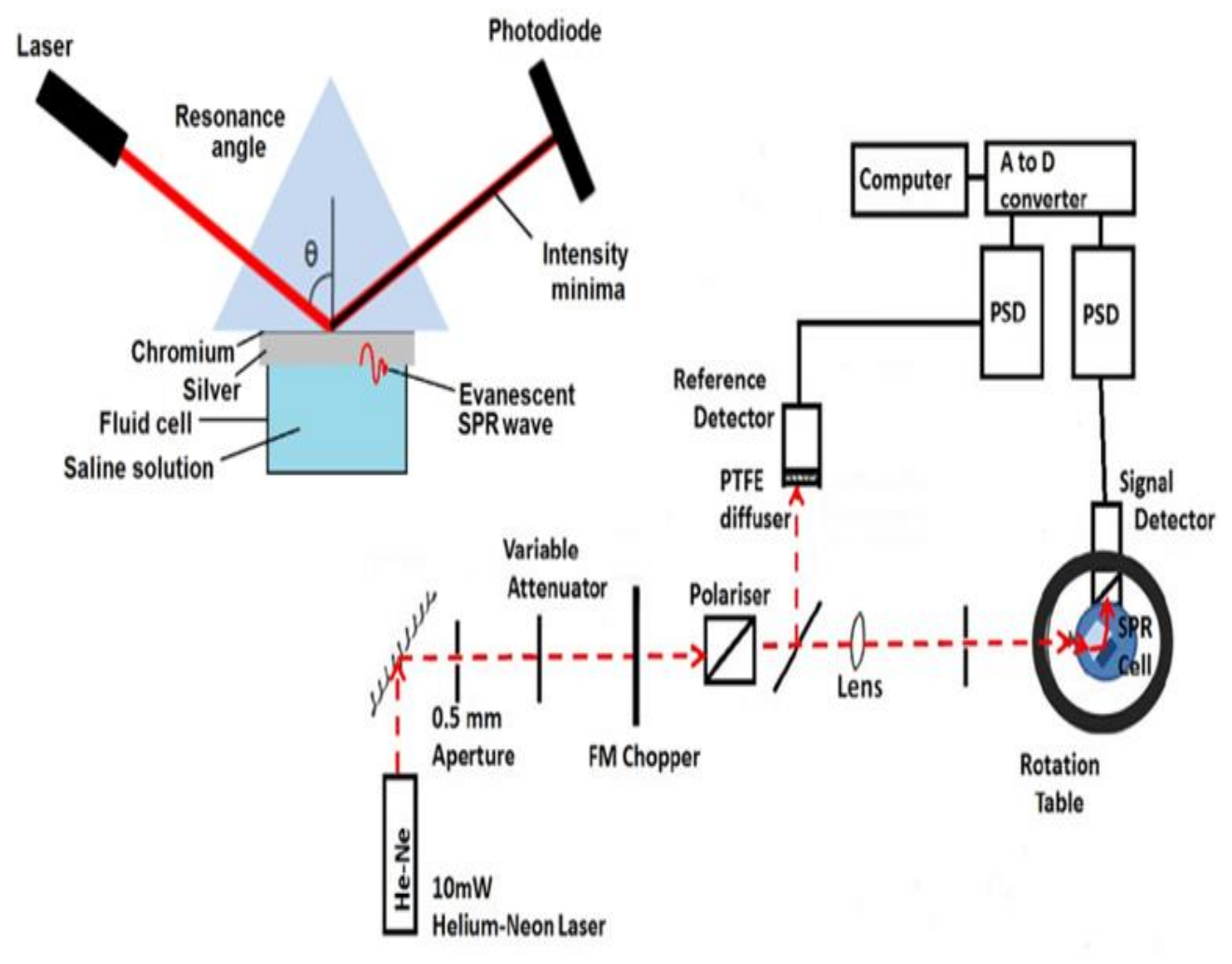


Fig. 3 UAV platform responses Fig 4. Optical reflectivity arrangement

EXPERIMENTAL RESULTS

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

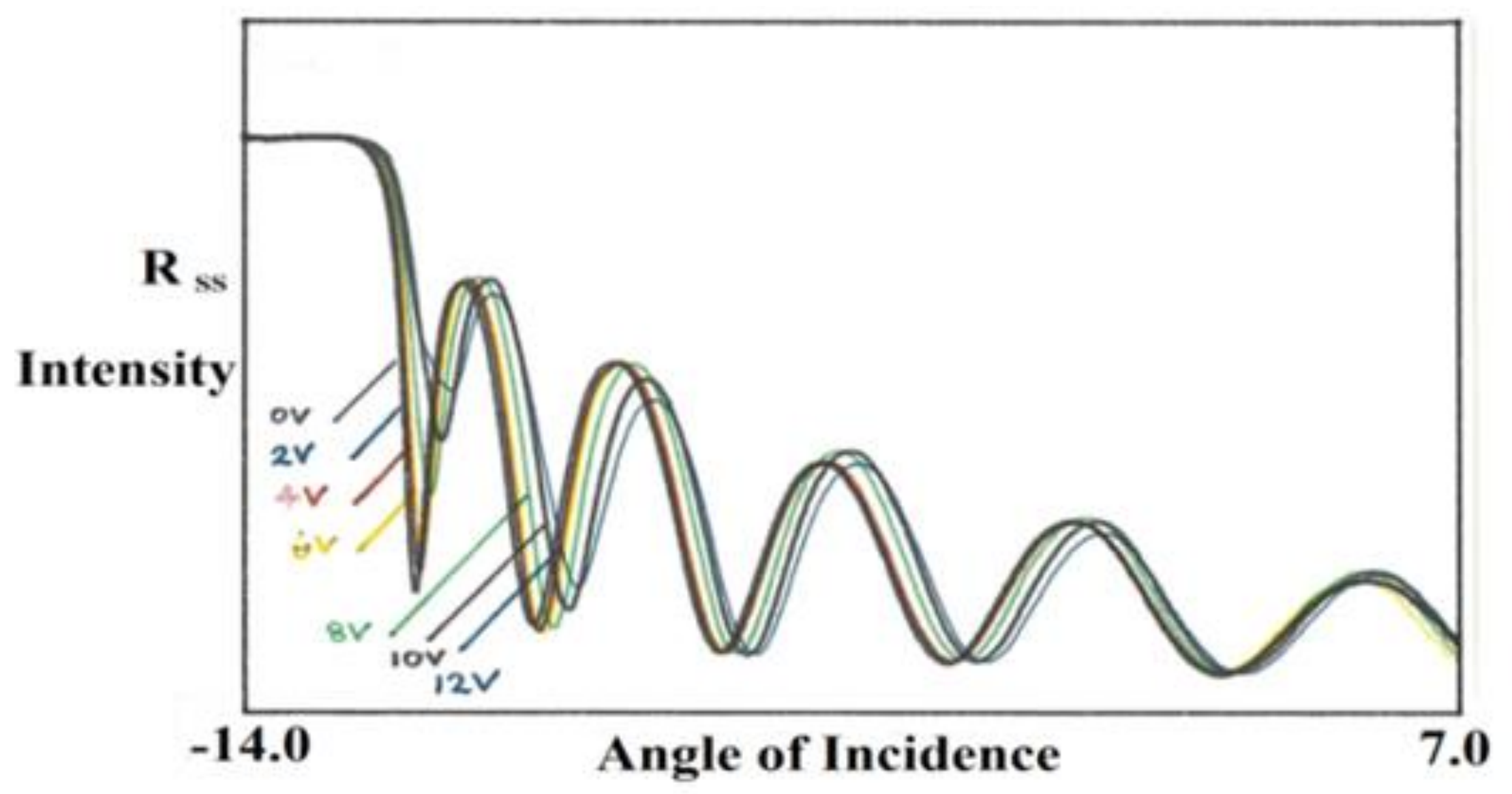


Fig. 5. Experimentally recorded Rss reflectivities as a function of applied DC voltage for the Ferroelectric LC SCE8 at room temperature

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 (**fig. 6**).

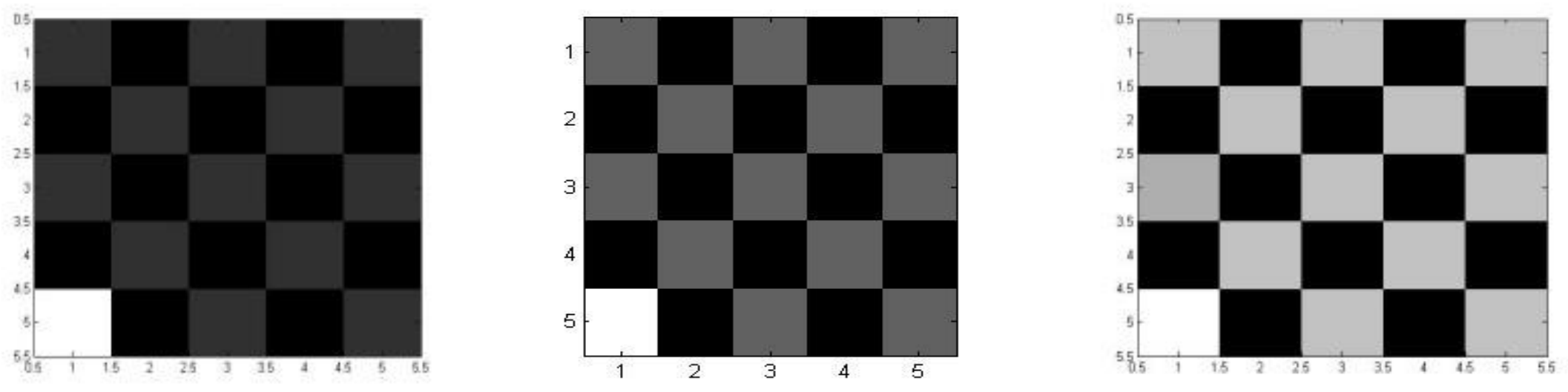


Fig. 6. Applied Voltage: 0 V 6 V 12 V
Max White and Min Black chequers, with alternative LC square values

The maximum silhouette contrast of a F117A was entered into Matlab with 120 000 pixel elements, with 64 brightness levels (0 to 63) as shown in **fig. 7a**. The silhouette is at 0 level and the background at brightness level 1. Normalised contrast may be calculated for target Intensity It against background Ib with the equation :

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

Simulated platform reflectivity elements at 632.8nm show approximate maximum silhouette contrast for 0V applied, and 12V applied, given in **fig. 7b,** and **fig. 7c** respectively. **Fig. 7b** closely matches **fig. 7a**, whilst **fig. 7c** has 12V applied, simulating a much reduced contrast against background.

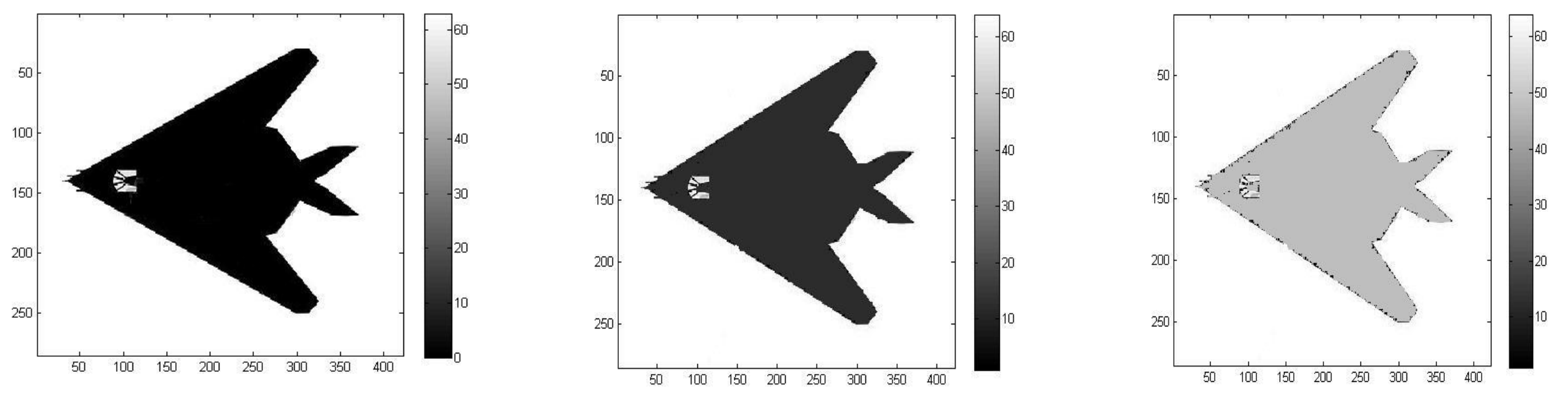


fig. 7a F117A silhouette 7b. 0V applied 7c. 12V applied

CONCLUSIONS

1. **Modelling and visualisation of a platform coated with Liquid Crystal cells shows large potential change in visual contrast with adaptive low power UAV LC camouflage.**
2. **Liquid Crystal cells with 0-12V applied provide large contrast change, approaching max/min conditions. The electric field strength across the elements is typically 4-5 MV per m.**

Future optical modelling research will look at emerging new technologies, w.r.t. the potential afforded by new LCs and synthetic electro-optical materials with temperature, angle, voltage and wavelength dependent effects, which may provide disruptive contrast applications in low observable UAV platforms, built of cellulose materials, e.g. cardboard or wood. 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 upon the changing character of modern aerial warfare.

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3. Ko, D.Y.K., and Sambles, J.R., *J. Opt., Am.,* 5, 1863, (1988).

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