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DEVELOPMENT AND EVALUATION OF A NEAR INFRARED REFLECTING AND LOW VISIBILITY PAINT SCHEME FOR RAAF P-3C ORION AIRCRAFT

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Development and Evaluation of a Near Infrared Reflecting and Low Visibility Paint Scheme for RAAF P-3C Orion Aircraft

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Abstract

In this report, the development and trialling of a tactical, low visibility paint scheme (LVPS) for RAAF P-3C Orion aircraft is discussed. The LVPS was formulated in grey colours using solar heat reflecting pigments to reduce overheating problems which had resulted in the abandonment of an earlier camouflage trial. The paint scheme, which is one of several schemes under consideration by RAAF, employs strict countershading principles with pale grey underneath the aircraft, light grey on the fuselage sides and vertical flight control surfaces and mid-grey on top of the fuselage and upper flight control surfaces. Evaluation of the paint scheme was carried out at RAAF Edinburgh under summertime conditions and showed that the increase in heat load by use of the solar heat reflecting paint scheme (SHR)-LVPS on the Environmental Control System (ECS) of the aircraft was 0.53 kW compared with the existing paint scheme. This compares favourably with the reported heat load increase of 1.7 kW for countershaded aircraft using conventionally formulated grey paints. It is concluded that the use of the SHR-LVPS would have essentially no effect on P-3C operational temperatures except under severe environmental conditions where an increase in temperatures of 0.3°C in the cabin and 1.3°C at the flight stations could be expected.

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1. *Introduction*

1.1 *General Background*

At the present time, the paint scheme for RAAF P-3C Orion aircraft has the top half of the fuselage painted white and all other surfaces mid-grey. The contrast of the white paint on the upper surfaces against the dark seascape is of concern to RAAF [1] who wish to make the P-3C less conspicuous, so that its track and position are less evident. An earlier attempt to camouflage a RAAF aircraft in dark colours was abandoned because of excessive internal temperatures resulting from solar heating. The Dakota aircraft in that trial was camouflaged using conventionally pigmented coatings.

1.2 *Operational Considerations*

Air Headquarters [2] (AHQ) have stated that '*the smoke reduction modification to P-3C engines...which is currently being considered, needs to be complemented by a concomitant reduction of the aircraft's visual and infrared (IR) signatures*'. AHQ have also stated that '*while agreeing to the operational requirement for a low visibility and a low IR paint finish on the RAAF P-3 fleet, a technical investigation into the appropriate repainting of the P-3 fleet is warranted. Such an investigation should establish the paint colour(s), texture, pattern and the paint quality which would meet the required solar, IR and other technical properties. Also, the examination would need to address the impact of the surface covering on equipment cooling capabilities of the air conditioning system*'.

Following a detailed study of the visibility of maritime reconnaissance aircraft at operational viewing ranges, Beckwith and Boyd [3] recommended a strict countershading paint scheme based on the US Navy's scheme. This scheme employs a dark colour on top of the aircraft for camouflage against a dark sea background when viewed from above and progressively lighter colours on the side and underneath the aircraft for camouflage at distance or when viewed against the horizon sky. The scheme selected for the P-3C aircraft uses pale grey underneath the fuselage, light grey on the fuselage sides and vertical flight control surfaces and mid-grey on top of the fuselage and upper flying surfaces (Fig. 1). This scheme is one of several under consideration by RAAF and was selected for the first aircraft trial (Fig. 1).

The camouflage scheme was developed using solar heat reflecting paints in view of the marginal heating problem already existing in the P-3C aircraft. These paints have the same visible appearance as standard paints, but reduce solar heating by reflecting the near infrared (NIR) component of solar radiation.

A trial was carried out at RAAF Edinburgh comparing the temperature effects of the SHR-LVPS on a P-3C aircraft against an aircraft painted in conventional RAAF colours. RAAF [4] requested that this be undertaken for evaluation prior to AHQ approval for the adoption of the LVPS for P-3C aircraft. As high ground-temperatures are known to stress the ECS operation of the P-3C, the two aircraft were sited on the Edinburgh Base tarmac, instrumented, and the temperature build-up measured under summertime conditions. The test period was selected so that zero to light cloud cover was present throughout the trial and so that the sun passed through its zenith. The main purpose of the trial was to provide a data base for estimation of the relative solar heat loading properties and the aircraft internal temperatures resulting from the camouflage scheme.

1.3 *Thermal Considerations*

The thermal balance of a static aircraft ultimately depends on the radiation exchange across its surface with the environment and any adjustment to this balance is largely dependent on the absorption and emission characteristics in the relevant spectral regions. Materials which absorb little or no solar radiation and which strongly emit at the temperature of the aircraft are generally preferred. These properties are determined by the ratio of the solar absorptance (α_S) to the emittance (e); the solar absorptance (α_S) is defined as the ratio of solar radiation absorbed by a coating to that incident upon it and the emittance (e) by the ratio of the radiation emitted by the body to that emitted by an ideal black body at the same temperature.

The important region for solar absorption and reflection is the region between the wavelengths 0.3 μ and 2.5 μ as greater than 95% of solar radiation falls in this region. The solar absorptance of paint coatings (α_S) commonly shows spectral variation over this region which can be averaged out, e.g. the averaged solar absorptance of white paints is approximately 0.20 whereas conventional grey paints average around 0.75-0.80. The higher absorptance of darker paints increases the heat flow to the aircraft and the resulting thermal equilibrium temperature. If camouflage can be achieved while minimising any increase in solar absorption, equilibrium temperatures lower than those produced using conventional camouflage paints will be obtained. New paints with these features are the subject of the present trial.

Figure 1: P-3C Orion aircraft in NIR reflecting and current paint schemes.

2. Experimental

The program for painting and evaluation of the temperature build-up in the aircraft involved (i) formulation and application of the solar reflective paints to the aircraft in the Federal Standard colors specified for the tactical paint scheme, and (ii) determination of the level of solar heating of the camouflaged aircraft compared with the aircraft coated in the existing RAAF paint scheme.

2.1 *Paint Formulations*

Aliphatic polyurethane paints based on hexamethylene diisocyanate resins (Bayer N75) were formulated to Federal Standard 595a colors in pale grey, light grey and mid grey FS35237. The colours were formulated from titanium dioxide, an organic perylene black (Helio black, Bayer) and heliogen blue, red and yellow oxide to achieve the three Federal Standard Colors: (i) pale grey FS36495, (ii) light grey FS36375 and (iii) mid-grey FS35237. Color matching was achieved using a Hunter L,a,b Color Difference program attached to the HunterLab Labscan II spectrophotometer. Differences between the gloss of the resulting paint was reduced with microfine silica (Syloid) to a 60° gloss rating of 10-15 when applied to a flat plate in the laboratory by suction operating spray gun. This gloss level was considered sufficient to produce a flat paint under field conditions, however the on-site application by airless spray resulted in much higher gloss levels (*ca* 50).

The juncture between the mid grey and light grey paints around the top of the aircraft was achieved by taping whereas tape was not used along the bottom of the aircraft sides where the pale grey met the light grey paint used on the undersides of the aircraft. In retrospect, the latter technique was preferential as overspray blurred the line where the two colours met blending the two colours. The upper line between the mid grey and light grey, on the other hand, was clearly identifiable and detracted from the camouflage properties.

2.2 *Preparation of the Aircraft for the Solar Heat Trial*

The two aircraft were prepared in the following manner to reduce extraneous causes of differential heating:

(a) Orion A9-665 and Orion A9-659 aircraft each underwent aircraft washing prior to the trial.

(b) Both aircraft were loaded with fuel.

(c) All thermocouples near the window were shielded using a small foil reflector to eliminate the effect of direct sunlight upon a thermocouple junction.

(d) All flight station seats were set in the fully down and aft position.

(e) Flight station sun visors were in the fully up position in front of the high window.

(f) Navigation and Tactical (tacco) station window shutters were fully open.

(g) SS3 polarised window was in the fully light position.

(h) All seats were in the fully down position.

(i) The galley vent was fully closed.

Aircraft number A9-659 was painted in conventional RAAF grey/white and aircraft number A9-665 was painted in the SHR-LVPS. Both aircraft were instrumented and exposed to direct sunlight on 13 February 1992. The aircraft were initially aligned nose South-East side by side during the test procedure. Because of a shift in wind direction, aircraft number A9-665 was rolled directly back to avoid shielding of the wind by the other aircraft. This was achieved without the need to open up the aircraft. This change was carried out within a few minutes of the wind change, and is not considered that aircraft A9-665 suffered any significant additional heating caused by wind-screening. If any had occurred, the result would be to improve the assessment of the new paints.

A data logger was connected to a series of thermocouples in each aircraft. The data logger was positioned outside the sonarbuoy free fall chute, a shield being provided to eliminate noise and provide a common reference. The following parameters [5] were monitored: (a) air temperature, (b) humidity, (c) solar radiation and (d) wind speed and direction.

3. Results

3.1 Infrared Reflectance

The near infrared reflectance of the three colours is shown in Table 1. It can be seen that paints formulated to the specified Federal Standard 595a colours using solar reflecting pigments had near infrared reflectance values which were significantly higher than the standard grey colours. It can also be seen that the difference in NIR reflectance between conventional and solar reflecting paint is greater for the darker coloured paints. As the darker colours are employed on the illuminated upper surfaces, use of NIR reflecting paints would therefore be expected to have a pronounced effect on aircraft temperature increases.

Table 1: *Near Infrared Reflectances* Of Standard And Solar Reflecting Paints For P3-C Orion Aircraft*

Colour	Y	Standard Paint %	NIR Reflecting Paint %
Pale grey	49.5	52	77
Light grey	37.5	43	70
Mid grey	23.5	24	61

* NIR reflectance is defined as the ratio of the NIR radiant energy reflected by a body to the NIR energy incident upon it.

3.2 Environmental Test Conditions

The environmental conditions, including dry-bulb temperature, wind speed, humidity and cloud cover present during the test period were measured to determine their effect on the temperature build-up and are shown in Table 2.

Slight to significant increases in cloud and wind speed are believed to have had a moderating influence on solar heating of the aircraft towards the end of the test period together with the lower sun angle resulting in illumination of the lighter camouflage colours on the side of the aircraft.

***Table 2:** Environmental Test Conditions*

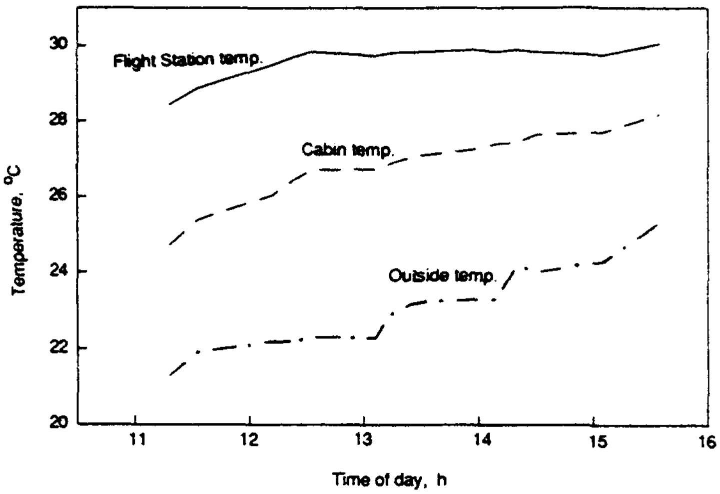
Time	Temp (°C) Dry bulb	Wind Speed	Humidity (kg/kg)	Cloud (eighths)
10:00	18.20	2.00	0.0075	1
10:30	20.00	1.00	0.0075	1
11:00	20.10	0.00	0.0075	clear
11:30	22.00	2.00	0.0078	clear
12:00	21.80	2.00	0.0070	clear
12:30	22.00	11.00	0.0085	clear
13:00	22.00	8.00	0.0078	1
13:30	23.00	8.00	0.0085	1
14:00	23.90	11.00	0.0090	1
14:30	24.00	9.00	0.0080	1
15:00	24.20	13.00	0.0080	3
15:30	26.00	12.00	0.0080	3
16:00	26.00	14.00	0.0080	3
16:30	26.20	12.00	0.0080	3

Table 3 shows the relationship between the temperature changes (a) outside the aircraft, (b) at the flight stations and (c) in the cabin.

***Table 3:** Aircraft Temperature Recordings During Test Period*

Time	Outside Average Temperatures (°C)	Flight Station Averages		Cabin Averages	
		LVPS	Standard	LVPS	Standard
11:30	21.30	29.88	28.42	26.70	24.71
11:55	21.90	31.22	28.86	27.95	25.38
12:20	22.20	31.75	29.49	28.62	26.03
12:38	22.20	32.17	29.69	29.21	26.41
12:55	22.30	32.11	29.84	29.39	26.69
13:11	22.30	32.30	29.73	29.61	26.72
13:27	23.00	32.29	29.80	29.79	26.90
13:45	23.20	32.49	29.82	30.17	27.07
14:00	23.30	32.43	29.88	30.28	27.25
14:15	23.30	32.58	29.82	30.47	27.39
14:33	24.20	32.40	29.88	30.52	27.42
14:50	24.00	32.58	29.82	30.82	27.63
15:08	24.30	32.39	29.74	30.82	27.70
15:58	26.20	32.53	30.05	31.20	28.19

The results of the trial showed that aircraft temperatures generally increased with increasing external temperatures and were significantly higher than the external ambient temperature. The temperature in the camouflaged aircraft was around 2.75-3.15°C higher than in the aircraft painted with conventional RAAF colours (Table 3 and Figure 2).



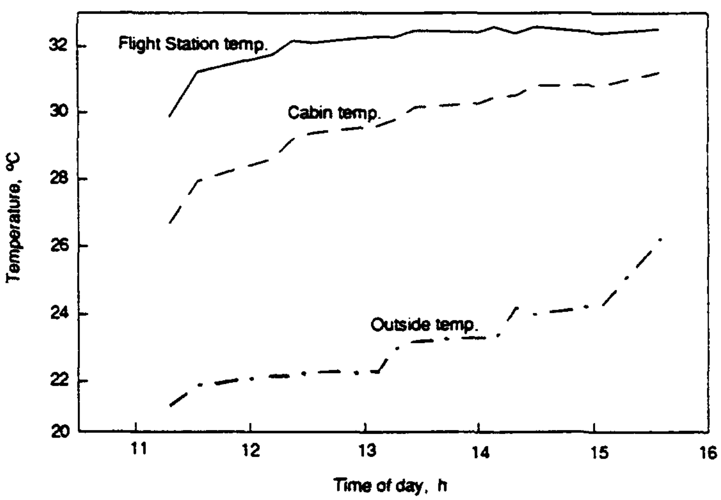


Figure 2: Temperatures in LVPS aircraft and Standard aircraft.

The flight station temperatures were significantly higher than the cabin temperatures in both aircraft although the temperature differential between the flight stations of the two aircraft was less than the cabin temperature differentials. The higher flight station temperatures with reduced temperature differentials are believed to result from the larger proportion of glass at the flight stations.

While the internal aircraft temperatures increased with external temperature, the magnitude of the internal/external temperature differential varied, being highest around 1300 hours when the ambient external temperature was relatively low. As indicated above, the reduced temperature differentials thereafter are believed to be in response to the increasing cloud cover and higher wind speed at those times together with the lower sun angles illuminating the lighter camouflage colours on the side of the aircraft.

4. Discussion

Data from the present trial show that the solar heat reflecting LVPS absorbs a greater proportion of solar radiation than the white paint on a conventionally painted RAAF aircraft. The temperature increase of 2.75-3.15 ^{o}C by the solar heat reflecting LVPS will impose a greater cooling load on the aircraft's ECS.

A P-3C thermal database was generated by Hawker de Havilland Victoria [6] during the AQS-901 ECS development program in conjunction with Lockhead Aeronautical Systems Company. Using information from this database, the in-flight overall exterior/interior conduction heat transfer coefficients in the standard aircraft have been determined to be in the region of [6]:

Flight station	98 watts/^{o}C
Cabin	83 watts/^{o}C

From the stabilised temperature difference in Table 3 of 2.75 ^{o}C at the flight station and 3.15^{o}C in the cabin, the additional heat loads, estimated from the in-flight exterior/interior conduction heat transfer coefficients are [7] :

Cabin heat load increase	=	$3.15 \times 83 = 262$ watts
Flight station heat load increase	=	$2.75 \times 98 = 270$ watts
Total aircraft heat load increase	=	$262 + 270 = 532$ watts

Hawker de Havilland believe that from their knowledge of airflow over the aircraft shell, the aircraft static transfer coefficients would be at least 50% of the subsonic flight values for the type of shell construction/insulation used on the P-3C aircraft [7]. Accordingly, a rough estimate of an upper limit of the additional static heat load for the SHR-LVPS aircraft would lie somewhere between 1/4 kW and 1/2 kW.

The AQS-901 ECS development program established that the critical condition for ECS cooling performance occurs at low altitude in the Orion [8]. The P-3C ECS is powered in flight by Engine Driven Compressors (EDC's) on each inboard engine. Analysis carried out under the Project AIR 5140 contract [8] (electronic countermeasure upgrade) determined that the heat absorbed from the cabin by cooling air from the ECS is 907 watts/°C (flow rate × S.H. (air) × temperature difference) and 206 watts/°C in the flight station and the total heat absorbed 907 + 206 = 1113 watts/°C. Under operating conditions, the flight station temperature rise due to the LVPS is estimated as 270/206 = 1.3°C and that in the cabin as 262/907 = 0.3 °C using the high figure for the additional heat load due to the solar heat reflecting LVPS (i.e. 1/2 kW).

It must be stressed that the interior temperature rises due to the solar heat reflecting LVPS, as portrayed above, can be considered a worst-case scenario. As previously indicated, the actual heat transferred to the aircraft interior is expected to be lower than the 1/2 kW figure used for the analysis.

At present, the aircraft operational requirements do not cause the ECS to use its full cooling capacity (i.e. a situation is rarely encountered where a properly operating ECS cannot control an average compartment temperature below 27°C, as required by the RAAF Project Air 5140 specification [8]). It is therefore probable that the SHR-LVPS would have no effect on the interior environment under any operational condition. The added heat load would simply be absorbed by lower ECS supply air temperatures. It is only in the low altitude, high humidity, tropical environment that the current P-3C ECS capacity limit may be exceeded and hence interior temperatures could rise slightly due to the SHR-LVPS.

It is of interest to determine whether additional heat loads measured in this and other programs are consistent with predictions based on the absorption properties of the conventional and NIR reflecting paint schemes employed in the various studies. US workers [9] determined that the additional thermal load for a P-3 aircraft painted in the grey countershading paint scheme formulated with conventional paints was 1.7 kW more than with the standard maritime paint scheme under daytime conditions of 32°C, dewpoint 21°C. This heat load figure is approximately three times larger than the present heat load obtained with the NIR reflecting paints in this study.

Calculations to determine the heat flow to (and from) an aircraft are obtained from the product of the thermal conductance, the surface area and the temperature differential. Figures for the exterior/interior temperature differential are not available in some reports [9], however surface temperatures are a function of the solar absorptance of the surface paints. The solar absorptance of white paints, such as are currently used on the RAAF P-3C upper surfaces, are approximately 20%. Conventionally pigmented grey paints, as used in the US trial, absorb around 75% of NIR radiation. The NIR reflecting grey, as is used on the upper parts of the trial aircraft, absorbs approximately 40% of NIR radiation. The internal/external temperature differential in the conventional white painted RAAF aircraft cabin at noon was 3.5 °C whereas it was 6.05 °C in the solar heat reflecting LVPS aircraft cabin. These differentials are roughly in proportion to the changed solar absorbance of the NIR reflecting paint scheme (40%/20%). The temperature increase by the LVPS is calculated to increase the cooling load by between 1/4 kW and 1/2 kW. From these calculations, it is predicted that the 75% NIR absorbance by conventionally formulated grey camouflage paints would increase the cooling load by around 1.9 kW (i.e. (75-20/40 - 20) × 1/2 kW) if the present additional heat load figure of 1/2 kW is accepted or 0.9 kW if 1/4 kW figure is correct. This compares closely to the recorded increase of 1.7 kW [9]. The results also suggest that if conventional paints had been used, temperature increases of around 11 °C would have been experienced in the cabin of the static aircraft.

5. Conclusions

1. A low visibility paint scheme (LVPS) based on strict countershading principles was applied to an RAAF P-3C Orion aircraft to improve the aircraft's camouflage characteristics. The LVPS was formulated with solar heat reflecting pigments which limited the summertime solar temperature increase of a static aircraft on the tarmac to 2.75-3.15 °C above that of an aircraft painted with the current white-light grey RAAF P-3C colours.

2. The magnitude of the operational temperature increase under the most severe conditions of low altitude in a hot/humid environment is calculated to be 0.3°C in the cabin and 1.3°C at the flight stations. Under less severe conditions, temperatures in the cabin and the flight station will be controlled to current levels by the ECS.

3. Taping of the aircraft to separate paint colours along the top of the fuselage during paint application resulted in a sharp division between the colours which increases visibility of the aircraft. Paint application around the lower section of the aircraft at the pale grey-light grey interface without the use of tape resulted in overspray and a graded transition between these colours. This transition is considered to be preferable to the sharp colour separation above.

6. Further Work

A second RAAF aircraft is presently (April 1993) being camouflage painted throughout in a simplified SHR camouflage scheme using light grey (FS36375) over the entire aircraft augmented with pale grey (FS36495) markings. The selection of this modified scheme is, in part, to overcome the sharp colour change apparent on the upper areas of the SHR-LVPS aircraft. As such, the second camouflaged aircraft should enjoy even lower solar heating than occurred with the first SHR-LVPS aircraft.

7. Acknowledgements

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