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Placement of broad beam beacon antennas within wing of HALE UAV

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1. Introduction

The wind speeds at the bottom of the stratosphere (≈20km altitude) are relatively low. Consequently, for several decades there has been interest in placing aircraft at those altitudes which would loiter and thus be suitable as platforms for earth observation and communications systems. This would add a layer between terrestrial and satellite systems, that had all the advantages of geo-stationary satellites without the disadvantages of propagation delay, high launch costs and the inability to retrieve the platform for servicing [1]. Solar powered flying wing Unmanned Aerial Vehicles (UAVs) offer the promise of "eternal flight" where the UAV would remain airborne for years without landing. NASA's Environmental Research Aircraft and Sensor Technology (ERAST) program aimed to develop such UAVs, but this work was terminated with the loss of the 70m wingspan Helios in 2003. This accident also brought an end to the various radio communications and localisation systems for stratospheric UAVs that were under development at NICT. After a furlough of almost a decade, the promise of low operating cost airborne platforms for earth observation and communications systems has sparked a revival of interest in the US, with public funds been committed for the development of a single 140m wingspan prototype to fly in 2014 that is capable of supplying 5kW of power to a 450kg payload [1]. With a potential revival in the wind, this paper considers placement of UHF antennas within a generic solar powered UAV wing for a Direction of Arrival (DOA) system.

The asymptotic maximum aperture dimension for a DOA operating at 1.5GHz beyond which the resolution will not improve substantially on 0.007º (2.5m for an altitude of 20km) is about 90m [2], which fits comfortably with the 140m wingspan of the new UAV. The structure of the new UAV wing is expected to be the same as the ERAST UAVs [3], irrespective of whether the UAV has a tail or not. The shape of the reflexed aerofoil will be held by Carbon Fibre Reinforced Plastic (CFRP) ribs over which a skin of thin UV-tolerant plastic is stretched, with the ribs held in position by a cylindrical CFRP spar, while photovoltaic (PV) cells would be draped over the upper surface of the wing [3], Figures 1 and 2. This very unusual wing structure allows for antennas to be installed within the wing itself in the spaces between the ribs. Prior work showed that the rib struts will resonate and likely enhance coupling between 1.5GHz antennas in adjacent inter-rib spaces [4]. With that in mind, 4 circularly polarised 1.5GHz antennas, which were designed as sensors for a DOA, were placed within a wing model in FEKO™.

2. Solar powered UAV structure and modelling

In developing an electromagnetic model of the UAV wing for 1.5GHz, only the conductive components of the airframe need be retained [4]: the spar and ribs as are composed of medium conductivity CFRP [3], and the PV-cells as are composed of high conductivity DC-lines and low conductivity semi-conductor. For this initial study, all conductive parts were set to Perfect Electric Conductor (PEC). This simplification is likely unsound for the PV-cells, so the simulations were run both with and without the PEC sheet representing the PV-cells on the upper surface of the wing, Figure 2. It is not yet known if the new UAV will be made of rigid wing sections connected by mechanical joints or will be aeroelastic, as NASA's ERAST UAVs were. For this initial study, it was assumed that the wing section modelled is rigid. The inter-rib spacing was 0.52m, allowing a 13 rib model (half wing section [3]) to be simulated in FEKO™ on a modest desktop PC.

3. Behaviour of antennas installed in the UAV wing model

Three of the 4 circularly polarised 1.5GHz antennas considered as candidates for DOA sensors had broad beamwidths to give flat gain below the UAV irrespective of roll or wing flex during flight, Table 1. Broad beamwidth was achieved by a different method in each case to enable investigation of near field interaction with the UAV structure; higher order mode microstrip patch [6], ground plane shaping [7] and an integrated volute helix [8], Figure 3. All the antennas were designed to be built at minimal weight from metal foil and expanded polystyrene foam.

Table 1: Free antenna characteristics at 1.5GHz, from FEKO™.

Antenna	Peak directivity (dBi)	Beamwidths (°)		Minimum across track spacing (m)
		-3dB	-10dB	
TM_{101} microstrip patch [5]	9.53	68	113	0.4
TM_{301} microstrip patch [6]	7.98	89	130	0.4
trifilar antenna [7]	2.85	170	256	0.15
volute helix [8]	3.73	166	235	0.10

As in the original study using dipole antennas [4], the 4 different antennas were trialled at 8 different positions on a plane at the centre of an inter-rib space, Figure 4; giving a total of 64 across track radiation patterns. Gross deviations from the “free” antenna radiation patterns were found at some positions, Figure 5(A), while at others the wing structure had relatively little effect, Figure 5(B). The -3dB and -10dB beamwidths were extracted for the 64 across track radiation patterns. In general, the broader the beamwidth the more the radiation pattern was affected by the wing, and the solar panels did not add greatly to the effect of the spar and ribs on the -3dB beamwidths, Figure 6. Position A immediately below the spar narrowed the beamwidths the most, indicating that the spar acted as a reflector and that this position should be avoided. The -3dB beamwidths of the trifilar antenna and the volute helix were close to equal when free, but the former was more adversely affected by the wing structure, indicating that beamwidth broadening by ground plane shaping should not be used in antennas for this application. Overall, Positions C to E were the least detrimental to the across track beamwidths, and as these positions are directly below the position of the centre of gravity of the new UAV, whether tailed or tailless, should be considered in future work on wing flex and modelling of the full DOA system.

Acknowledgments

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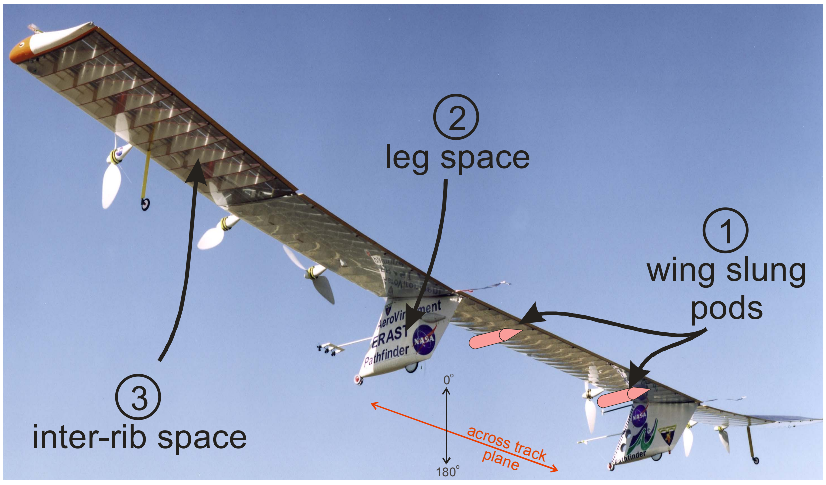

Figure 1: The ERAST Pathfinder Plus UAV with potential antenna installation locations marked; photograph courtesy of NASA. The inter-rib space was considered here.

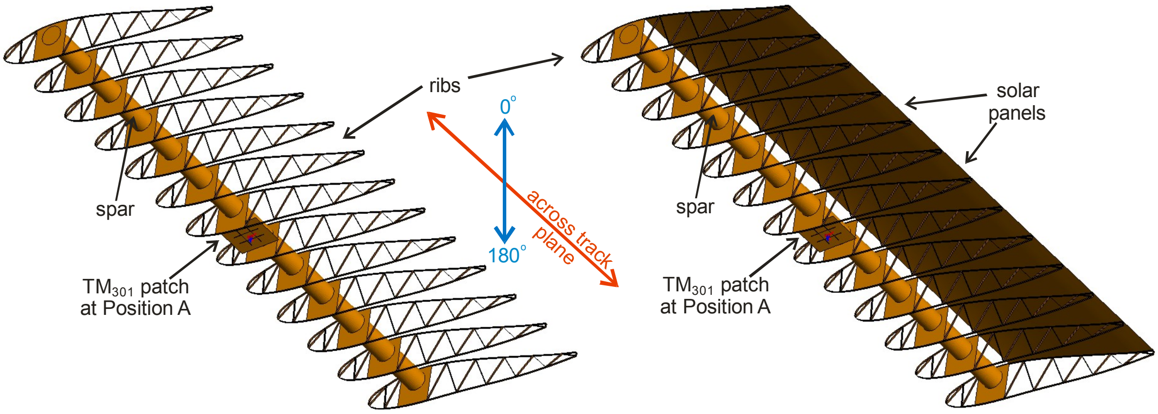

Figure 2: Rigid 6.24m 13-rib wing section model with and without solar panels.

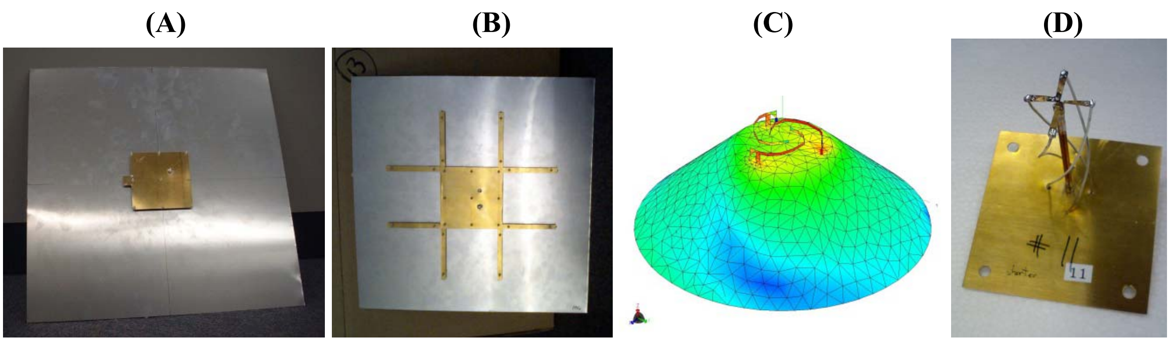

Figure 3: Antenna pictures; **(A)** TM_{101} microstrip patch [5], **(B)** TM_{301} microstrip patch [6], **(C)** trifilar antenna [7], **(D)** volute helix [8].

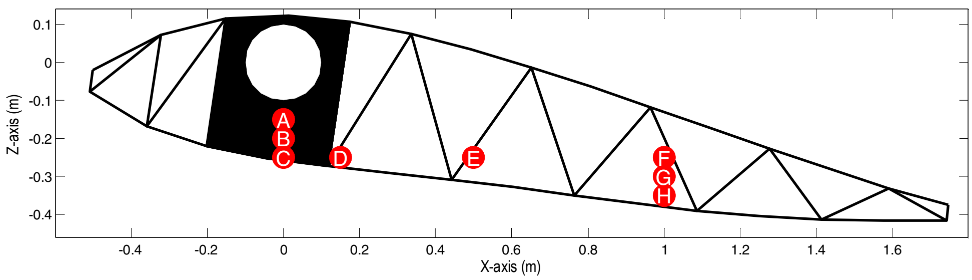

Figure 4: Rib geometry from [2], with antenna positions marked [4].

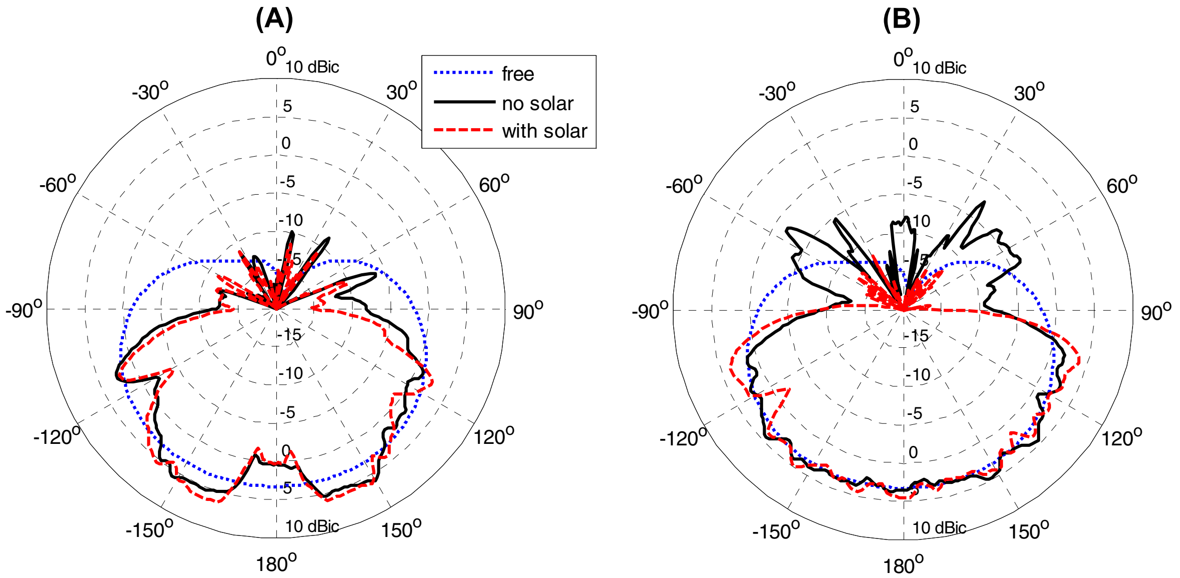

Figure 5: Across track radiation patterns of the volute helix antenna [8]; **(A)** at position A and **(B)** at position G as per Figure 4, from FEKO™.

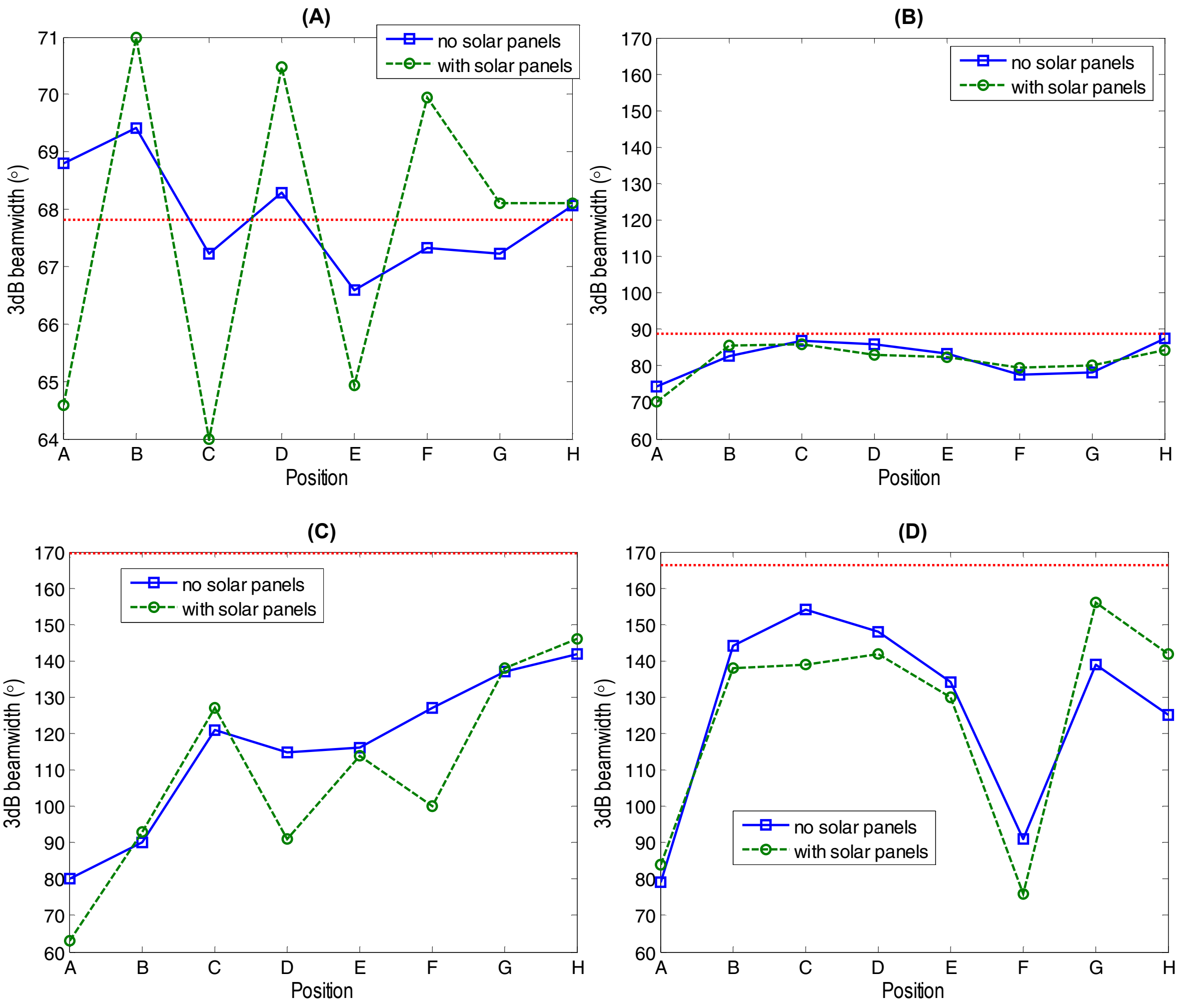

Figure 6: Across track -3dB beamwidths of antennas installed in UAV wing models, derived from FEKO™ radiation patterns, free antenna beamwidths from Table 1 plotted as red dotted lines; **(A)** TM_{101} microstrip patch [5], **(B)** TM_{301} microstrip patch [6], **(C)** trifilar antenna[7], **(D)** volute helix [8].