Small UAV Antenna Development

White Paper
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Small unmanned airborne vehicles (UAV) have a strong tactical value with their range and longevity of flight for close-in support. However, an airframe with a 6-foot wingspan, or smaller, presents real design challenges to the development of antennas to cover a wide frequency bandwidth. We strive to cover the 30 MHz to 3 GHz frequency band, with non-protruding antennas and omnidirectional patterns in the horizontal plane. Ultra-wideband (UWB) antenna concepts are applied to present a complete antenna solution in limited space and tuning and switching complexity. Unfortunately, the size and weight requirements point towards using embedded wire antennas, while the bandwidth requirements argue otherwise.

A design methodology is developed to reduce the whole aircraft design to tractable sub-bands. Embedded antennas on a small UAV require careful knowledge and management of payload and structural elements. Antenna feed placement, payload contents and placement, and internal wires are considered parametrically to develop guidance for similarly sized UAV's. This approach is meant to build sufficient expert knowledge on the antenna design factors, so that their associated space can be allocated into the aircraft form at an early stage. The general design process is as follows:

1. Find real estate on UAV
2. Investigate region in view of fundamental limits of antennas
3. Divide full bandwidth into sub-bands
4. Select antenna candidates that fit within form factor and provide desired pattern
5. Simulate antenna candidates in simplified environment
6. If successful, simulate in a more complex environment

Antennas are evaluated for each aircraft section and their design limitations considered. These include pattern, field polarization, antenna size, access to non-antenna systems, surrounding structures and their materials, and antenna input impedance. Material effects and aircraft loading are analyzed qualitatively or parametrically to gain insight into future designs.

Fundamental limits theory states that the antenna's performance is a trade-off between bandwidth, size, and gain, as expressed through its radiation efficiency. Equation (1) defines an antenna's minimum Q_{rad} (the inverse of the antenna's 3-dB bandwidth) for a sphere enclosing the antenna [1]. This is the lowest order spherical mode (TM_{01}) for omnidirectional patterns. Most antennas on a SUAV occupy volumetrically little of such a sphere, however.

$$Q_{rad} = e_r \frac{1+2(ka)^2}{(ka)^3[1+(ka)^2]} \approx e_r \frac{VSWR-1}{BW_{VSWR}\sqrt{VSWR}} \tag{1}$$

Where

e_r	radiation efficiency
k	wave number ($2\pi/\lambda$)
a	radius of sphere enclosing the antenna structure

$$BW = \frac{f_h - f_l}{f_c} = \frac{f_h - f_l}{\sqrt{f_h f_l}}$$

Using FL theory, the engineer can determine realistic sub-bands for the SUAV. Our approach then is to fix *a* for each aircraft section, the upper or lower frequency desired, and VSWR (e.g., 2:1), and to vary the opposite frequency to set a realistic bandwidth. For a generic SUAV, we consider the tail as perhaps the most optimal location on the SUAV for an omnidirectional antenna, as shown in Figure 1. The need for a ground plane here argues for horizontal stabilizers constructed from, or covered by, a conducting material. Likewise, the vertical stabilizer must be either entirely metallic, for the development of a slot antenna, or non-metallic, so that an antenna may be embedded. We repeat the application of FL in other antenna locations, but they are more challenging, as a note, because of the SUAV's small electrical size and its mainly horizontal orientation.

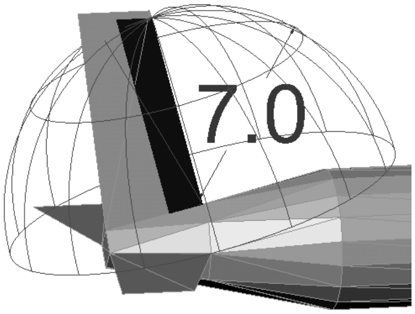

Figure 1 – Radian Sphere around Tail Section

Using (1), we see the likely bandwidth that this SUAV's region provides. The lowest frequency considered is 470 MHz, but the limited volumetric use of radian sphere argues against approaching the limit. Achieving a lower frequency of at least 806 MHz, just to the left of the *legacy curve*, would be advantageous since it is the lower end of the cellular/public safety band.

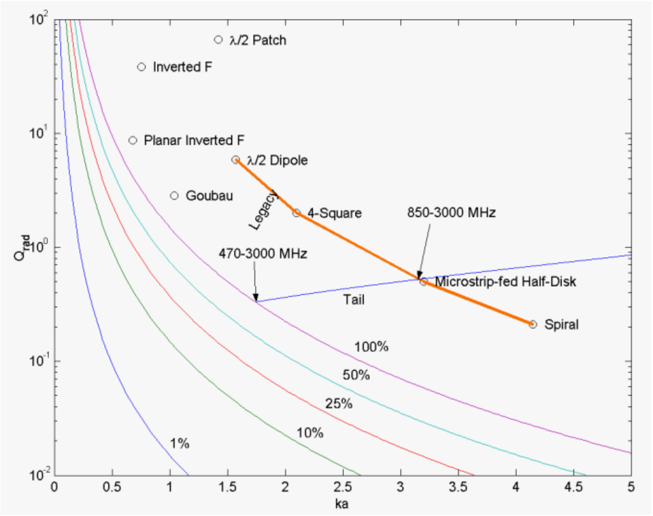

Figure 2 – Fundamental Limits of Tail Section

This example provides little width in which to develop a wideband antenna. The pattern and impedance results of the antenna shown in Figure 3 prove this limitation. A low VSWR is achieved for a 50-Ω reference impedance at resonance (459 MHz), but the wide impedance bandwidth of antenna is lost. A $Z_o = 150\ \Omega$ yields VSWR < 2:1 over 1.2 GHz – 3.0 GHz and VSWR < 2.5:1 over 725 MHz – 3.0 GHz, but the antenna pattern exhibits higher order modes about 1200 MHz.

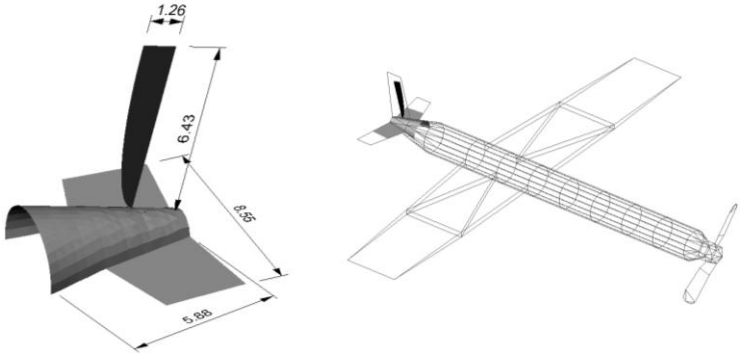

Figure 3 – Tapered Monopole as Modeled on SUAV Tail

This simulation is restricted to a simplified structure for a first-order analysis. Outside of the ground plane region, the SUAV was treated as air. We know that the remainder of the SUAV will be conducting or have conducting elements embedded within dielectric sheets and cavities. These details will affect the antenna’s pattern and may affect the input impedance, if closely coupled. For instance, the materials in the remainder of the tail will impact the antenna’s pattern and input impedance most. Simulations with the inclusion of a metallic rudder show the development of a between the feed and the metallic rudder. At certain frequencies, the rudder acts as either a reflector or director and distorts the omnidirectional pattern.

To support a physically wider antenna and achieve a wider impedance and pattern bandwidth, an expanded tail is needed. Improvements in the pattern shapes can be achieved at higher frequencies through alterations of the ground plane. However, before extensive time is committed to such an optimization, thorough details on the tail’s form and material construction are required. This antenna could then cover a substantial portion of the SUAV’s frequency range without a tuning network. However, a controlled tuner could allow for the antenna’s use at lower frequencies, down to ~λ/8 or 225 MHz.

Changes in the SUAV shape may yield a more promising pattern performance. For example, a drop tail could also eliminate the potential shadowing problems near the horizon. Alternate vertical real estate could be developed on the SUAV to host additional antennas for lower frequencies. These observations argue for the synthesis of antennas with the aerodynamic design so that such locations or forms are advocated and intentionally included in early structural designs.

Once a promising simplified antenna design is found, the designer must consider the more complex environment found on a SUAV. And, like with the allocation of antenna space at an early stage, the antenna engineer must provide design guidance for internal structures. We show some basic effects for wires and objects with a fat dipole on the fuselage. A cargo box of 3” in length was considered in three locations as shown in Figure 4. No significant changes are noted in the input impedance, although the cargo box located within the tapered gap has the most impact. Similarly, five wires positions of 24” each in length were considered inside the fuselage, as in Figure 5. The wires’ impact on the VSWR is shown in Figure 6. Spikes correspond almost entirely to the length of the wire which has $n\lambda/2$ resonances at 246n MHz, and the amplitude of each wire’s effect on VSWR is controlled by the location of the wire from the feed. The wire with the least impact is found opposite the feed.

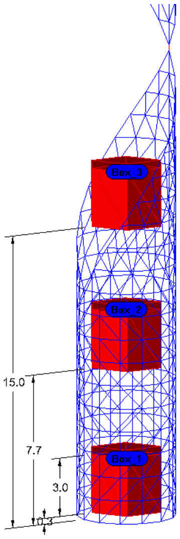

Figure 4 – Cargo Locations

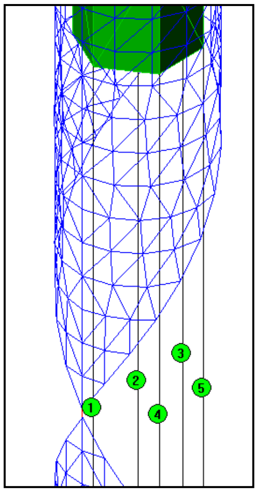

Figure 5 – Internal Wire Test Positions

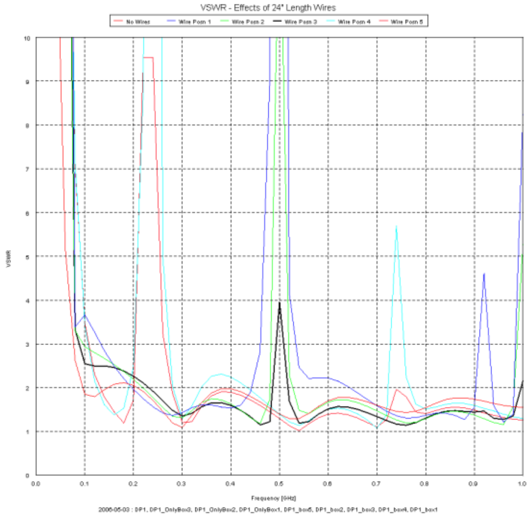

Figure 6 – Impact of Internal Wires of VSWR

We have shown how the fundamental limit of antennas illuminates space requirements, the division of required frequency range, and antenna efficiency. We know how pattern and polarization are related to antenna orientation, but we understand the true complexity of this problem. Antenna and aeronautical designs must work together to: *avoid resonant sizes in* *internal components at critical frequencies, select appropriate UAV materials, and build qualified antenna regions into the UAV airframe design.*