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Conceptual Design Considerations for Microwave- and Solar-Powered Fuel-Less Aircraft

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Unmanned aerial vehicles typically have limited flight duration, particularly at smaller scales. A microwave-/solar-powered flight vehicle, on the other hand, can remain in theater continuously by harvesting electromagnetic radiation using onboard antennas and solar panels. Moreover, these seemingly disparate power sources are complementary in that they are both heavily dependent on the wing area. Rectifying antennas are used to harvest power and convert it into electrical energy usable by the onboard motors and other electronics. To supplement this energy source, photovoltaic cells are used to harness incoming solar radiation. Discussed herein are design features of fuel-less air vehicles and their sensitivity to several key performance metrics for this class of aircraft. In this study, aircraft with wingspans in the range 3–5 m and cruise $Re = 5 \times 10^5$–5×10^6 are considered. New metrics are presented that are unique to a microwave-powered aircraft and are useful in the development of its missions. These metrics relate the design of the aircraft and the energy transmitter to the duration and range of the vehicle's missions. The addition of solar power harvesting to a microwave-powered aircraft is examined. Furthermore, an examination of the strong coupling among the aircraft's flight performance, power harvesting abilities, and its mission capabilities is given. Traditional and nontraditional wing shapes are presented to motivate a discussion of this coupling. In particular, tradeoffs between flight performance and power harvesting performance are discussed.

Nomenclature

A = actual patch area
A_{eff} = effective patch area
A_{tr} = transmitter dish area
AR = aspect ratio
b = wing span
C_{D_0} = parasite drag coefficient
C_f = flat-plate skin friction drag coefficient
$\bar{c}$ = mean aerodynamic chord
D = drag force magnitude
d = fuselage diameter
E = stored energy
E_{cap} = energy storage capacity
E_{solar} = incident solar irradiance
FF = component form factor
f = microwave frequency
G_{dir} = microwave transmitter directivity loss
G_{tr} = microwave transmitter gain
h = altitude
L = lift force magnitude
l = fuselage length
l_t = distance between wing and tail quarter-chord lines
P_{patch} = received microwave power at a patch
P_{req} = power required for flight
P_{solar} = received solar power
P_{tr} = microwave transmitter power
$P_{\mu w}$ = received microwave power
Q_{int} = component interference factor
R = flight range
r = distance from microwave transmitter to aircraft
r_{eq} = equilibrium power radius
r_{nr} = no-return radius
r_{tr} = microwave transmitter dish radius
S = wing planform/reference area
S_{wet} = wetted area
T = thrust magnitude
t/c = thickness-to-chord ratio
t_{loiter} = loiter time at a given distance
V = cruise velocity
W_{pay} = payload weight
W_{struct} = aircraft structural weight
W_0 = aircraft gross weight
α = angle of attack
$\eta_{airfoil}$ = wing airfoil efficiency
η_{m+p} = motor/propeller efficiency
η_{pv} = photovoltaic cell efficiency
η_r = rectenna efficiency
η_{tr} = microwave transmitter efficiency
θ = angle between patch normal and microwave beam direction
Λ = sweep angle
λ = microwave wavelength
ϕ = angle from transmitter boresight

I. Introduction

WIRELESS power transmission through electromagnetic wave propagation began with the pioneering work of Heinrich Hertz and was made famous by the spectacular demonstrations of Nicola Tesla; however, practical methods of focusing and directing high-power electromagnetic energy have only existed since the 1930s. Furthermore, efficient means for converting this energy into usable direct current at appreciable power densities did not exist before the development of the rectenna (or rectifying antenna) in the 1960s. The development of this invention and the desire to communicate by line of sight over large distances subsequently spurred research in the area of fuel-less aircraft [1].

An aircraft that harvests energy from solar and microwave sources has the potential for extremely long persistence in its theater of operation. Aircraft powered by solar energy alone have garnered a significant amount of research since the 1980s for use in extremely long-duration missions, including several successful aircraft developed by AeroVironment. (See [2] for an extensive list of

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