A major drawback to employing very small, remotely piloted aircraft in certain scenarios in urban operations is that they may not have sufficient range or endurance to be recovered. Clearly, this may not be an issue if there are sanctuaries controlled by friendlies within the city, or not too far outside. The question we address in this appendix is whether it is feasible to reuse mini–unmanned aerial vehicles (mini-UAVs) or micro–aerial vehicles (MAVs) by recharging them, using either solar energy or microwave beams directed downward by high-altitude UAVs.

The assumed characteristics of the UAVs are listed in Table B.1.\textsuperscript{1,2} The average power calculation assumes a mix of 80 percent level flight and 20 percent maneuver flight.

The approximate ratio of the weights of the two aircraft featured in the table is nearly 100, yet, surprisingly, the average electrical power expended per unit area of wing surface is only 20 percent lower in the micro-UAV. For both platforms, interestingly, the power density is somewhat less than the maximum irradiance of the sun, i.e., 0.137 W/cm\textsuperscript{2}. If solar panels were able to transform solar photons to electricity with at least 60-percent efficiency, the aircraft could fly on

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
Vehicle & Power Density (W/cm\textsuperscript{2}) \\
\hline
Mini-UAV & 0.12 \textsuperscript{1} \\
Micro-UAV & 0.10 \textsuperscript{2} \\
\hline
\end{tabular}
\caption{Assumed Power Densities for UAVs}
\end{table}


Table B.1
Sample Characteristics of Mini-UAVs and MAVs

<table>
<thead>
<tr>
<th></th>
<th>Mini-UAV</th>
<th>MAV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (g)</td>
<td>4540</td>
<td>49</td>
</tr>
<tr>
<td>Wingspan (cm)</td>
<td>121</td>
<td>15</td>
</tr>
<tr>
<td>Aspect Ratio</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Wing Area (cm²)</td>
<td>2096</td>
<td>76</td>
</tr>
<tr>
<td>CL</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>CL/CD</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Propeller Efficiency</td>
<td>0.8</td>
<td>0.5</td>
</tr>
<tr>
<td>Electrical Efficiency</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Average Power (W)</td>
<td>178</td>
<td>5.1</td>
</tr>
<tr>
<td>Average Power/Wing Area (W/cm²)</td>
<td>.085</td>
<td>.068</td>
</tr>
</tbody>
</table>

NOTE: CD = aerodynamic drag coefficient; CL = aerodynamic lift coefficient.

solar power with the sun directly overhead. For cases when the sun is
not directly overhead, we explore alternatives.

It seems unlikely that the mini-UAV can land in hostile areas for
recharging, survive, then take off for another mission. If it can reach
sanctuary, simple refueling of an internal combustion engine is the
most efficient approach.

The MAV is designed to perch on buildings, with some chance for
covertness. Recharging in this instance is practical. Assuming that
the solar panels recharge the MAV’s battery with an overall efficiency
of 20 percent, 2.5 hr of sunlight would be required for the MAV to fly
for 1 hr. A critical issue is whether the solar panels can be made light
enough for the MAV to carry them.

Another alternative means of recharging the MAV is by beaming
down microwaves from a Global Hawk–class or larger UAV at 60,000
ft altitude. The power per unit surface area obtained as a function of
radiated power is shown in Figure B.1. MAV P(avg) is the average
power required for the MAV to fly. There are separate curves for
radar frequencies of X-band (10 GHz), Ku-band (18 GHz), and the
millimeter-wave frequencies of 35 GHz and 95 GHz. With the size of
the antenna assumed fixed at 24 ft², the antenna gain and effective
radiated power increase as the square of the frequency. Therefore,
the power densities depend on frequency.
Supposing the conversion efficiency for microwaves to electricity is higher than for solar power, around 90 percent, a 100-kW radiator beaming down through all the daylight hours at 95 GHz would be required to recharge a MAV for 1 hr of flight. The radiated power is a factor of several times what Global Hawk can deliver in prime power, and the efficiency of antennas at 95 GHz is much worse than at X-band. Moreover, at this high frequency, the beam is very focused, and the MAVs undergoing recharging would be confined to the area of a city block (<2000 m²).

In summary, whereas recharging mini-UAVs is not practical, refueling them may be, under some circumstances. Solar recharging of MAVs is practical, provided that flight can be restricted to roughly 1 hr out of every 3.5 hr and that solar panels that are very light, yet efficient, become available.

![Figure B.1—Irradiance from a 24-ft² Antenna at 60,000 ft](image)