Estimation of main parameters for solar-powered long endurance airplane at the preliminary design stage

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For the present state of the art the design of the solar-powered airplane for multi-day mission is a serious problem because of the moderate value of the solar radiation intensity, rather low efficiency and high density of the solar cells, insufficient energy density of the onboard energy storage and some other factors.
Optimal design of airplane can improve its performance. It is also well known that the stage of preliminary design gives the results which significantly affect on the aircraft performance. So, the designer must have a set of recommendations and necessary conditions for this stage of design.
Analytical investigation was made for the optimal mass definition of solar-powered airplane. Masses of spar, photovoltaic cells, wing skin, powerplant, energy storage and payload as functions of aircraft performance parameters (aspect ratio, wing area, gross weight etc.) and flight conditions (altitude, velocity, intensity of solar radiation etc.) were taken into account. The problem of airplane gross weight minimization was analyzed.
The model of spar investigated corresponds to the condition of equal mechanical tension along the spar.
Expressions for the main flight conditions and aircraft parameters including the masses of aircraft parts (spar, cells, drive etc.) as functions of altitude, sun radiation intensity, aircraft construction material properties has been obtained.
From these expressions it was found that some definite maximal mass of payload as a part of gross weight exists for which the sun-powered airplane can be designed. It was shown that the numerical value of this part depends on the models of aircraft parts. For example, for the equal tension model of spar the payload can not exceed 1/8 of gross weight.
Another fact that has been derived from the expressions obtained is that the photovoltaic cells must cover the whole wing area only if the intensity of sun radiation is lower than some value defined only by the properties of photovoltaic cells and wing skin properties and powerplant characteristics. For the higher intensities the area of photovoltaic cells is lower than wing area. For the lower intensities it can also be recommended to use some extra surfaces (tail, fuselage etc.) for the photovoltaic cells.
The results obtained were compared with the performance of existing and desined solar powered airplanes (Pathfinder, Helios, Zephyr, SoLong, Solar Impulse etc.)
The results of investigation can be applied not only to the aircrafts that can fly above the Earth but also for those that can fly above the other planets with atmosphere and light from star (such as Mars, Venus etc.)