A Prospective Solution for Consistent Aerostatic Lift for a Hybrid Buoyant Aircraft

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Abstract— Concept of aerostatic lift from the long ignored buoyant aerial vehicles has now a day been applied for partial fulfilment of the lift requirement for hybrid buoyant aircraft. This diffused lift technology seems to have eradicated the separate requirement of the heating mechanism for the lifting gas. In comparison with conventional aircraft, such aircraft have big surface area available on the voluminous fuselage which is made up of thin shells and transverse frames. Depending on the power requirement and the power available through the irradiance modeling, partial surface area of fuselage can be utilized to provide power to the miniaturized avionics, specially the electrically driven heating elements; a prospective solution to provide heat to the lifting gas on as and when required basis. Potential issues related to the heat generated by the solar cells, bulky batteries and fuel powered plasmatrons are also discussed. A methodology for system design for the said issue is proposed. Based on the irradiance model of Malaysia, solar energy available throughout the day has been calculated. A detailed analysis is required for accurate estimation of energy and power budget along with a fine balance between the heat available and the one required.

***Keywords*—**buffer battery, system engineering, modeling of solar system, hybrid buoyant aircraft, aerostatic lift.

I. Introduction

Similar to the aerodynamic lift, aerostatic lift varies with altitude if the temperature of the lifting gas does not remain consistent [1]. This issue is of prime importance for a type of aircraft in which partial takeoff weight is balanced by the aerostatic lift and which can only fly till pressure altitude [2]–[4]. Such type of aircraft is recently labelled as hybrid buoyant *(HB)* aircraft and sizing of the same is dependent on the requirement of consistent aerostatic lift. This is due to the fact that the volume of the helium gases changes significantly with temperature [5]. Similar to any gas, when helium gas is heated, it expands; when it is cooled, it shrinks [6]. Such properties of lifting gas cause a change in aerostatic lift due to change in volume, which is perhaps many times greater than for liquids or solids. This concept of gas expansion, when heated has advantage which has been used earlier for other engineering applications like lifting a rocket into space, ballooning etc [7]. However, in the case of hybrid buoyant aircraft, this expansion is somehow similar to popping corn. To cater for such a natural phenomenon, there is a requirement to keep additional volume during the sizing of the hull [8] as it can swell the outer contour of the hull body. This increase in the aerostatic lift and volume is not essential when designing the heating gas balloons [9] that incorporate advanced technology for heating the lifting gas. But for the case of *HB* aircraft with fuselage made up of material like veteran [10] and have no ballonets, it can change the aerodynamics of the outer contour of fuselage.

It is natural that during the flight, the *HB* aircraft will become unduly light, due to the consumption of fuel. In early ages, for an airship which has no ballonets, the pilot has to vent the lifting gas for reducing the aerostatic lift [11]. An alternative option was to reuse the hot gases coming out from the engine in such a way that by maintaining the pressure differential, the steam air from the engines can be pumped into the envelope [12]. This issue becomes more critical during the descend phase for which the aerostatic lift has to decrease. However, in both cases the envelop of airships should be sufficiently elastic [13], specially in the longitudinal direction as compared with the circumferential direction. But, the vehicle gets heavier as some mass has been added to it [14], which affects the performance and stability. Therefore, there is a need to look at the alternative options with no add on mass during flight to keep the temperature of the lifting gas as per design specifications. One of the prospective solutions of this is to employ the electric heating elements, powered either by the batteries or directly from the green energy technologies like solar cell, fuel cells and electrolyzes. Fuel cells require additional tank for liquid hydrogen and will have additional weight to be added in gross takeoff mass. But the Array of photovoltaic cells can be used on the fuselage by removing the existing partial skin. Moreover, it is the best practice to incorporate some battery capacity as a buffer/accumulator in order to moderate the power coming from the solar system [15]. But, in absolute terms the amount of power required by the avionics and other ancillary systems is small as compared to the propulsive motor power, normally used in family of solar-electric hybrid aircraft [16]. So even on a relatively cloudy day, a buffer battery is sufficient for this purpose and should be able to be charged by the solar systems even while pre-flight checks are taking place outside the hanger. For the design of a solar system, there is a requirement of the estimation of the available energy for the defined area of the solar module [17]. At the same time, the required

input details for analysis need to be known before conducting any numerical modeling and suitability of the defined subsystems of the proposed concept.

An effort is done in the present work to rearrange the existing knowledge of solar energy for its earlier defined application for *HB* aircraft. First, the available analytical relationships are utilized for calculating the coefficient of buoyant/aerostatic lift, followed by the estimation of heating of the lifting gas during flight. Brief detail of the proposed concept is outlined alongwith the methodology for optimizing the heat sources i.e. multiple heating elements for the defined design limits. All the factors involved in such system design are highlighted and special emphasis is given to the flow of the work. Limitations of the existing batteries are also provided in the tabulated form for quick reference. Keeping in view these pros and cons, the lithium polymer batteries have been selected for use in the propulsion system of aircraft. Nonetheless, the exact number and weight of the batteries can only be finalized after detailed analyses. Due to the constraint of the pressure height, an HB aircraft has to fly at altitude equal to or less than the pressure height. Under these circumstances the pilot has to decrease the aerodynamic lift. Although, this sulphurous aerodynamic lift can be utilized to balance the decrease in aerostatic lift due to decrease in temperature of the lifting gas, if there is leakage of the lifting gas. But the situation will be vice versa when preheated lifting gas is filled in gas bags and environmental conditions are hot.

II. Basics Of Aerostatic Lift

The concept of aerostatic lift is derived from the Archimedes' principle, according to which the aerostatic lift i.e. P_L , in kg is produced due to the difference of densities of the air ρ_A and lifting gas ρ_G as [18]:

$$P_L = V(\rho_A - \rho_G) = V\Delta\rho \tag{1}$$

In Eq. 1, V is the volume of the lifting gas, m^3 and ρ_A , ρ_G are air and gas densities, kg/m^3. Where $\Delta\rho$ is the specific buoyancy, kg/m^3. The densities of the air and gas can be defined by using the fundamental relationships, derived from the Clapeyron gas law [19]:

$$pv = RT; v = \frac{RT}{p} = \frac{1}{\rho}; \rho = \frac{p}{RT} \tag{2}$$

Where, p, R, T and P are specific density (m^3/kg), gas constant ($m/kg°C$), absolute temperature (°K) and atmospheric pressure (kg/m^2), respectively. According to the above relationship, as an *HB* aircraft will rise from the ground, the pressure of the lifting gas decreases uniformly but the lifting gas itself will expand and hence its volume will increase. As a result, the density of the lifting gas will decrease but the buoyant force can be maintained constant, if there is no change in the temperature of the lifting gas. For example, due to the superheating, there will be a change in aerostatic lift ΔL_{buoy} and according to ideal gas law, change in volume can be represented as Eq. (3) [1]:

$$\Delta L_{buoy} = \frac{G_a P V_{ol} \Delta T_g}{T_g^2} \tag{3}$$

Where value of G_a for helium gas at 32° F is 0.1832 and T_g is the temperature of gas [1]. Moreover, the pressure and density can be estimated by using Eq. 4 [19] and Eq. 5 [19], respectively. These are valid till altitude of 11 km:

$$\frac{p}{p_o} = \left(1 - \frac{H}{44300}\right)^{5.256} \tag{4}$$

$$\frac{\rho_H}{\rho_o} = \Delta = \left(1 - \frac{H}{44300}\right)^{4.256} \tag{5}$$

The buoyant lift coefficient can be defined by Eq. 6, where L_{buoy} is buoyant lift and V is the volume:

$$C_{Lbuoy} = \frac{L_{buoy}}{\rho\, g\, V} \tag{6}$$

If we include the effect of change of temperature, described by Eq. 3, then for a fixed initial volume of the lifting gas, a continuous increase in the T_g can double the aerostatic force, while flying from sea level to an altitude of 7 km, Fig. 1:

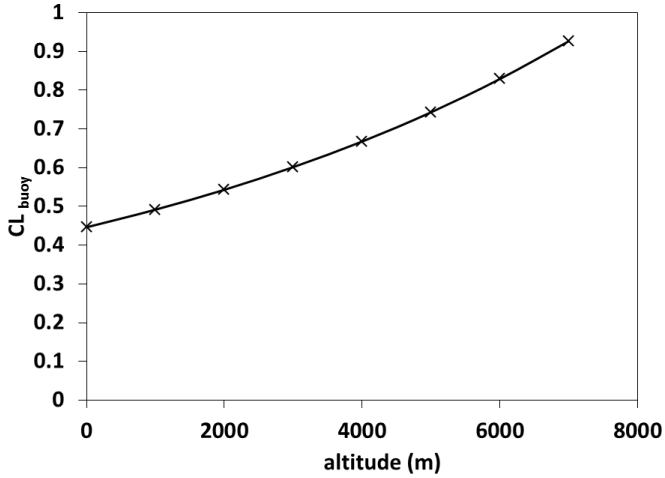


Fig. 1 Increase in the Aerostatic Lift due to temperature rise

III. Proposed Concept And Its Methodology

The proposed concept is quite simple in terms of design and development. It consists of the multiple heating rods attached to a center beam with is a load bearing member for the structure of hybrid lifting fuselage *(HLF)*. These multiple heating rods can be heated on requirement basis for the cogeneration of heat. Each of these elements will have a uniform operating temperature and is well adjustable to capture the waste heat for the lifting gas.

The methodology for the above mentioned design starts with the calculation for the required limits of heat generated by the electric heating elements as well as the power requirement for the electronics and control system. First the heat sources are to be selected for the heat exchange system, Fig. 3. It has perhaps direct impact on the selection of the solar panel/array and for the battery to provide power. Similar to any aircraft the battery has to provide power to the thermal insulation system for the batteries [20], electrically driven heating element and reserve power during flight.

The required energy for heating the elements depends on the long calculations, involving the heat conduction and convection terms [21]. Thus, providing an initial estimation of the pessimistic extremes for the system design as per the required increase in lift, alongwith the calculations for the weight that has to be added in the gross takeoff mass. This does not include the mass of the central beam of the structure as it is one of the parts of the main airframe. The heat generated by the heating element is a variable for the system modeling and one of the major control parameters for the heat modeling. Also, the power required for such a system needs calculations for the sizing of the solar array to generate the power by the solar system as a backup system. Indeed, it depends on the available irradiance model of the operating area, which will provide the power available from the solar panels. The geometry of the solar array involves an optimization between power output, aerodynamic resistance and vehicle mass, as well as practical considerations

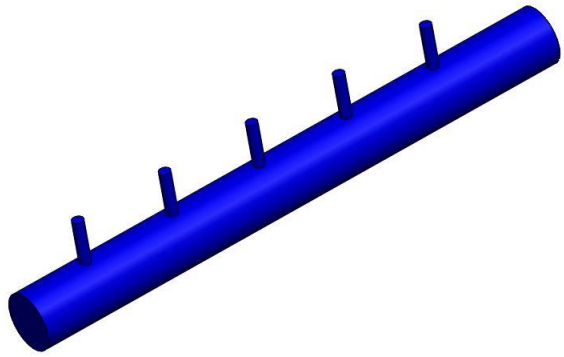


Fig. 2. Heating elements attached with the central rod

The methodology presented in Fig. 3 is just an overview of the major parameters involved for the question in research and the flow of the parameters.

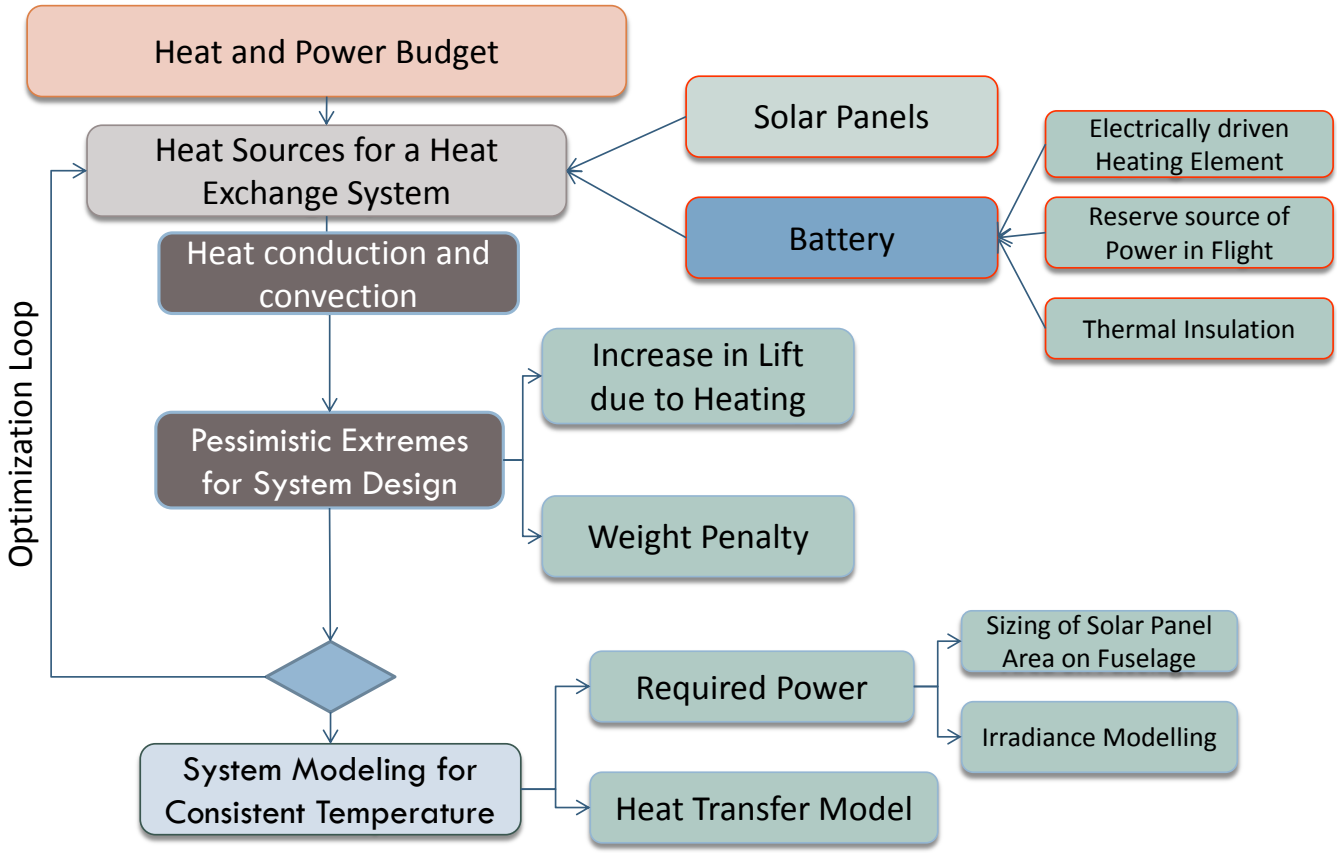


Fig. 3. Flow chart of the proposed methodology

A detailed analysis is required for accurate estimation of heat required, which will include accurate estimation of heat convection and conduction. In order to determine these important parameters, one has to build up a model and conduct tests on a laboratory scale. After making appropriate model development, the data can be scaled up to predict the heat required and dissipated for the full scale prototype. The ability to test a small model and to develop a mathematical model will enable to test a small model and to implement the design much more quickly and cheaply than would be possible if full size aircraft had to be built for testing. However, it also needs the selection of suitable sub systems. For example, the battery is the heart of the solar system. A comparison study has shown that *LiPo* (Lithium Polymer) batteries have added advantages over the others, Tab. 1. In this table, a lithium-sulfur rechargeable battery has not been considered. Although the power density of such a battery is maximum but it currently exhibits a cycle life of around only 100 cycles. A *LiPo* battery is relatively fragile and it costs more than Lithium Ion battery. Also it lower energy density is lower than that of the lithium Ion batteries. But its added advantages over other type of batteries are obvious from Tab. 1, specially the constant output power, which is discussed in detail with the help of test example of *LiPo* battery in the following section.

TABLE 1. COMPARISON OF FEW GOOD FEATURES OF DIFFERENT BATTERIES

Nickel-Metal Hydride	**Nickel Cadmium**	**Lithium Ion**	**Lithium Polymer**
It has more charging capacity and it is less toxic than Nickel Cadmium batteries.	It is inexpensive, fast and simple charging and has higher number of charging/discharging cycles. It has good performance in low temperature and is available in wide range of sizes and performance.	It is having more energy density than NiCd with more voltage operating range and a lower self-discharge rate, when it is compared with the other types of batteries.	It is lighter in weight and flexible in design with any arrangement of cells for the specified power. Less Lithium Sulphur, this type of battery has high power to weight ratio. It has more resistance to overcharging with inflammable structural anatomy and delivers almost constant power and current output. In comparison with other batteries, it can retain charge for longer period of time

IV. Potential Issues

Similar to a buoyant vehicle i.e. airship [1], the cruise segment of a HB aircraft will be a combination of constant velocity and constant height. The later one is to keep the aircraft flying at or less than the specified pressure height. Under such condition, $C_{L_{aero_{cruise}}}$ must have to reduce as fuel is burned off, Fig. 4.This phenomenon is independent of the cruise strategy adopted by the pilot. This decrease follows a linear trend but it cannot balance the reduction in aerostatic lift. Although due to the increase in altitude, the effect of the change in density of air and the lifting gas cancel each other. But the lifting gas itself changes its volume due to the atmospheric conditions. Under such condition, there is a requirement to define a subsystem which can keep the temperature of the lifting gas as consistent.

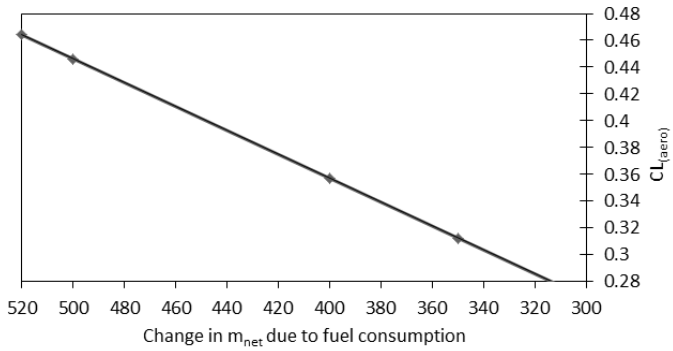


Fig. 4 Variation in $C_{L_{aero_{cruise}}}$ due to burning of fuel

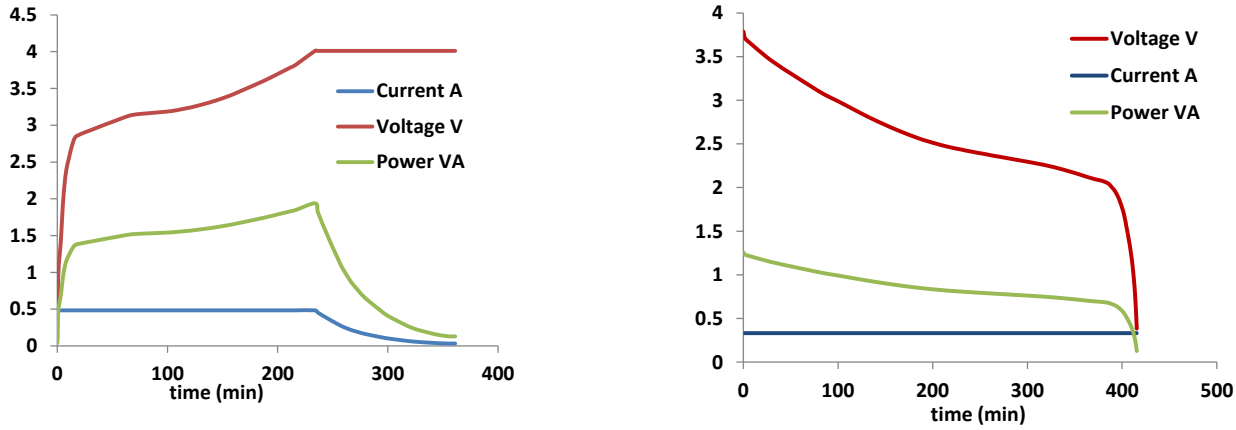
It is important to highlight that the option of heating the lifting gas due to the heat dissipated by the batteries cannot be utilized for the solution of the problem in research. This is because that the heat dissipation rate by the batteries is not following a uniform pattern during the charging as well in the discharge process. Moreover, unlike volume and pressure, according to Charles law [22], for a fixed number of moles of the gas, the volume and temperature change always has a linear trend. The increase in load of battery causes an increase in the current and thus the temperature. As a result, the resistance and the voltage of the battery drops [23]. Hence, during the discharge, there will always be a drop in the voltage and the power will also decrease [24]. This phenomenon has been explained with the help of an example of a small Lithium Polymer *(Li Po)* battery usually used in a *R/C* aircraft, tested under standard atmospheric condition, Fig. 5. Trend plots of voltage, power and current during charge and discharge process are obtained for a time period of about 350 min and 420 min, respectively. It can be observed that the charging time is less than the discharge time. Moreover, the current remains almost constant till 350 min during charging. A slight decrease in the value of power is observed during discharge and a sudden drop in it is observed, when the battery goes down. It takes about 250 min to fully charge the battery after which there is no change in the value of power. A slight increase in the magnitude of the current is also observed.

From the operational point of view, any increase in the temperature can cause undesirable chemical reactions inside the battery. It may cause temporary cell-to-cell imbalances and as a result, the discharge rate will be higher [24]. High temperature of the battery can even cause a catastrophic failure [25]. That is perhaps the reason that the environmental control unit is always required as a thermal management strategy to improve the efficiency of a battery, either it is the case of an automotive car or an aircraft.

In lieu of the facts discussed about the battery, it can be concluded that the use of battery as a heat exchange source for the lifting gas (inside the gas bags) is perhaps not practicable. Moreover, option of fuel powered plasmatrons [26] is not explored as additional wait penalty will be there for the required fuel system. Moreover, the hydrogen generated by these plasmatrons will add mass to the *HLF* and thus make it heavier during flight. Furthermore, the solar cells also dissipate heat but this little heat can keep the temperature of the outer contour hot with heavy weight penalty due to the additional weight of the solar array installed all around the fuselage. But, an electrically powered heating device can be a potential solution of the question in research. Also, such a system should have power backup system for the condition of any electrical failure. A solar system is perhaps one of the prospective solutions of the said problem and it has been elaborated in details with the help of a design example of an *HB* aircraft.

V. Power Augmentation by Employing Solar Array on a Hybrid Buoyant Aircraft

The electric solar power system will provide the required power which can be utilized to charge the batteries in day time. In this way, alternative power will not affect the fundamental process of generating power for the avionics. Now a day, the solar technology is quite matured and the solar arrays/panels can provide clean energy for avionics of aircraft under discussion.



(a) Charging

(b) Discharging

Fig. 5 General trends of current (Ampere), voltage (Volt) and power (Watt) of a small *LiPo* battery during charging as well as during the discharge process

A. Details of the Configuration:

The configuration considered for the present case is taken from reference [2], [3], [27], [28]; the pictorial view of the same is shown in Fig. 6. It is a short takeoff and landing (*STOL)* hybrid buoyant aircraft whose fuselage's design was conceived from the unconventional hull of hybrid airship, whose wing is similar to a sailplane wing. The hybrid lift concept for this configuration gives additional benefit during takeoff and ground handling with penalty of less wetted area per unit volume when compared with the hull of conventional airship. A part of its surface area can be utilized for the solar array to give power to the avionics and heat generating source.

The structure of the voluminous fuselage is quite dirigible with thin wings attached to it. These thin wings are subject to high loading condition during flight and may deflect due to high loading on it. Therefore, as compared with the wing, the *HLF* gives more flexibility in the design and mounting on the solar modules containing fragile solar cells.

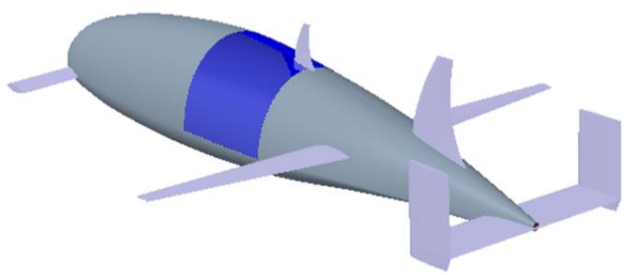


Fig. 6 A pictorial view of a HB aircraft with solar arrays installed on the partial surface area of voluminous fuselage

B. Wing Deflection-An Aberrant Issue for Solar Array:

The structure of an aircraft has to support ground as well as air loads experienced during the flight [29]. The second one is perhaps more critical for which a details analysis is required for the specified input load [30]. The requirement of structural analysis is to estimate the maximum deflection expected to occur at the wing tips [29]. The structural analysis is performed by modeling half wing in *ANSYS®*. The semi span wing section has been modeled such that the direct-stress is carried by the spars and shear-stress is carried by the skin. Symmetry boundary condition is applied at the plain of symmetry while *ADOF* constraint is applied at the location of the pod. A preliminary structural analysis of the complete *HB* aircraft is performed by applying constraint of fixed node at the end of the wing attached to the *HLH*. The maximum displacement of the tip is 520 mm. The directional stresses (for fibrous material) and equivalent stress (for isotropic material) are shown in Fig. 7, which are well within the failure range. The presented results are just to get first-hand knowledge about the deflection of the wing, where detailed analysis is out of the scope of the present work.

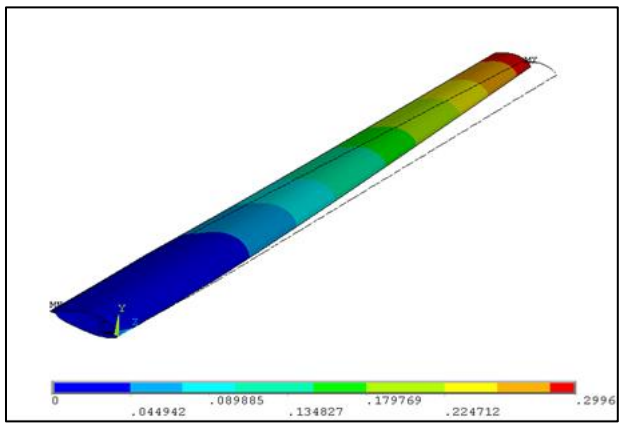


Fig. 7 Stress distribution (kg/m^2) over the semi-span wing of *HB* aircraft

C. Available Irradiance Model:

The calculations were performed based on the available irradiance data of Bangi-Malaysia for the defined span of the day (from morning till evening), throughout the year 2011-2012, Fig. 8 [31]. Two important parameters for irradiance model are always the maximum irradiance, I_{max} and the duration of the day time T_{day}. These parameters may also change with the latitude and longitude. Therefore, they may be taken at different locations so that the considerations of earth observation can also be incorporated in the calculations for available power, accordingly.

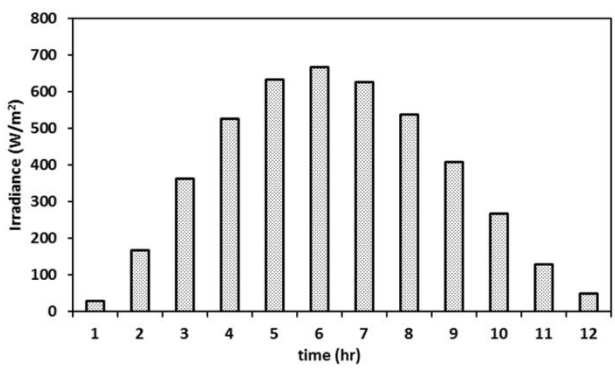


Fig. 8 Mean daily global horizontal irradiance data in Bangi for June 2011-May 2012, reproduced from data provided in ref [31]

D. Calculation of the Daily Solar Energy:

Weather conditions do affect the irradiance modeling. For example, in the winter, the duration of the day and the maximum irradiance decreases due to the low sun's elevation. In order to simplify the calculation, we will consider it as instantaneous, introducing the day period T_{day} during which we charge the battery and use it in evening, Eq. 7 [32]. In this equation, the two important parameters are I_{max} and T_{day}, which depend on the location and the date of the year. The total electric energy is obtained by multiplying irradiance equation with the surface of solar cells and their efficiency [32].

$$E_{elect\_tot} = \frac{I_{max} T_{day}}{\pi/2} A_{sc} \eta \tag{7}$$

In the above relationship, A_{sc} and η are the available surface area and the overall efficiency of the system. The results are plotted in Fig. 9 for A_{sc} to be equal to 50 m^2 and η is assumed to be equal to 1.0. The duration of the day time is taken equal to 12 hours. It can be observed from this figure that maximum available solar energy is available at around 2 *PM* and after that it decreases linearly till evening. The corresponding maximum power is 5000 Watt. Since the complete breakdown of the power requirement are still unknown. Therefore, the results presented here are not for a complete design solution of the problem.

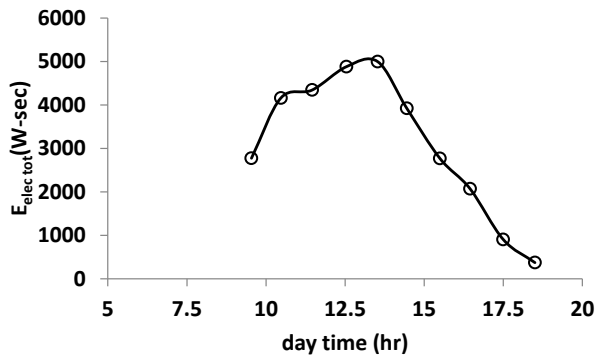


Fig. 9 Electrical energy available from the solar module

E. Lamination of Solar Modules for vulnerability to Contamination and Environmental Impacts

There are different types of solar cells and processes for preparing the laminate structure for the high power to weight ratio flexile solar arrays [33]–[35]. One of the options [36] is to prepare a sandwich structure containing thin layers of silicone as an adhesive. Such a structure is labelled as sandwich because the upper and the lower surfaces are bounded by the silicone adhesive layers of micro meter thickness, Fig. 10.

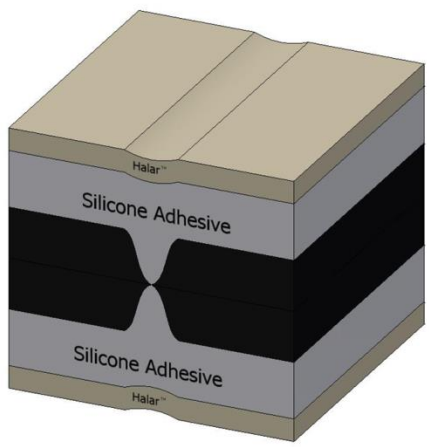


Fig. 10 Module structure of a solar array, redrawn from ref [36]

Halar® ECTFE is normally used as a coating material for anti-corrosion applications and it also protects the formation of silicon dioxide. The process of making such a corrosion proof structure is quite interesting and is somewhat similar to making a composite sheet. Laminating rollers are used to laminate the top and the bottom layers of *Halar*® at a temperature of about 140° C, Fig. 11.

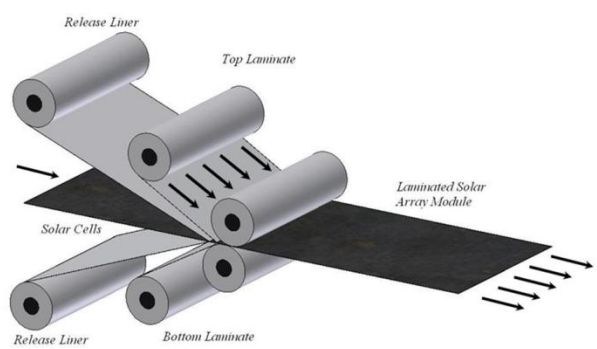


Fig. 11 A schematic view of lamination process of a solar array, redrawn from ref [36]

Lamination of the solar module is perhaps one of the knowledge that can be applied for *HB* aircraft. In addition to it, there are many other existing technological experiences [37- 44] of the solar powered aircraft that can be utilized for the *HB* aircraft technology as well. For example, ref [38] provides the structural anatomy of solar aircraft and the breakdown of the analytical relationship to be used for the calculation of the mass of the solar panel. Reference [44] gives guidelines for estimating the efficiency of subsystems for the calculation of the power required. Furthermore, a heat transfer model was formulated by for heated helium airship to augment and/or the heated helium [45].

F. Implication of the Solar Modules on Aerodynamics

Solar modules create skin roughness and irregularity of the contour at the mating point with the voluminous fuselage. Hence its location on the hull is quite critical. This is due to the fact that the minute geometric imperfections can trigger the boundary layer to separate and can be a cause of asymmetric vortical pattern, specially when the body is at some high angle of attack. This argument is well supported by the experimental work performed in low speed wind tunnel by Degani [46] in which the boundary layer was triggered by a small surface jet blowing normal to the surface as a small perturbation. It was observed that an asymmetric pattern is quite little till angle of attack equal to 12 degree but two vortices were generated from the nose and side force of moderate value was observed. The wind tunnel will therefore be an important tool to estimate the effect of the said irregularities on the subscale model. This issue is quite critical for the estimation of the drag count as it is directly related with the cost of the fuel burnt and also for the operating cost.

VI. CONCLUSION

The proposed methodology will give a future road map for the system design for consistent aerostatic lift till pressure altitude for a hybrid buoyant aircraft. Out of the available options for heating the lifting gas, heating elements is found to be a prospective solution for a hybrid buoyant aircraft in which there are no ballonets. By utilizing 11.3% of the surface area of the Hybrid lifting fuselage, about 5000 Watt of the power can be generated. Furthermore, accurate power budget is required for the sizing of arrays of solar cells. Due to the deflection of wings, placement of arrays of solar cells on the wings is not recommended.

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REFERENCES

[1] G. E Carichner and L. M Nicolai, Fundamentals of Aircraft and Airship Design: Volume II, Airship Design. American Institute of Aeronautics and Astronautics,AIAA, 2013.
[2] A. U. Haque, W. Asrar, A. A. Omar, E. Sulaeman, and J. S. M. Ali,"Aerostatic and Aerodynamic Modules of A Hybrid Buoyant Aircraft: An Analytical Approach." IIUM Engineering Journal, Vol. 16, No.1, 2015.
[3] A. U. Haque, W. Asrar, A. A. Omar, E. Sulaeman, and J. S. M. Ali "Pugh Analysis for Configuration Selection of a Hybrid Buoyant Aircraft," No. 2015-01-2446. SAE Technical Paper, 2015.
[4] A. U. Haque, W. Asrar, A. A. Omar, E. Sulaeman, and J. S. M. Ali, "Stability and Takeoff Ground Roll Issues of Hybrid Buoyant Aircraft," In Applied Mechanics and Materials, Vol. 660, pp. 503-507
[5] L. C. Gerken, Airship History and Technology. CA: American Scientific Corp, 1990.
[6] J. D. Khoury, G. A., and Gillett, Airship Technology. New York, NY: Cambridge Univ. Press, 1999.
[7] M. Ardema, "Vehicle concepts and technology requirements for buoyant heavy-lift systems," NACA Report, 1981.
[8] A. U. Haque, W. Asrar, A. A. Omar, E. Sulaeman, and J. S. M. Ali "Conceptual Design of a Winged Hybrid Airship," 2^{1st} AIAA Light. Syst. Technol. Conf., pp. AIAA–2014–2710, 2014.
[9] N. J. Mayer and R. H. Krida, "A review of lighter-than-air progress in the United States and its technological significance," Acta Astronaut., vol. 5, no. 10, pp. 917–934, 1978.
[10] A. U. Haque, W. Asrar, A. A. Omar, E. Sulaeman, and J. S. M. Ali, "Hybrid Buoyant Aircrafts : a Potential Greener Solution for Inter Connectivity of Malaysian's Islands," AIAC-2015, Canada, 2105
[11] A. Landewers, "Rigid Airship Design - Rise and fall of a Dutch airship manufacturer," 2001.
[12] M. B. Tischler, R. F. Ringland, and H. R. Jexj, "Heavy-Lift Airship Dynamics," vol. 20, no. 5, pp. 425–434, 1983.
[13] L. Liao and I. Pasternak, "A review of airship structural research and development," Prog. Aerosp. Sci., vol. 45, no. 4–5, pp. 83–96, May 2009.
[14] A. U. Haque, W. Asrar, A. A. Omar, E. Sulaeman, and M. J. S. Ali, "Aerodynamics and Static Stability Characteristics of a Hybrid Buoyant Aerial Vehicle at Low Speed," AERO-15, Canada, 2015.
[15] O. R. Alvi, "Development of Solar-Powered Aircraft for Multipurpose Application," 51st Structuctural Dynamics and Material Conference. 2010.
[16] C. Friedrich and P. Robertson, "Hybrid-Electric Propulsion for Aircraft," Journal of Aircraft, Vol. 52, No.1, pp. 176-189, 2014.
[17] M. Hajianmaleki, "Conceptual Design Method for Solar Powered Aircrafts," In 49th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition pp. 2011-165, 2011.
[18] T. Abe, T. Imamura, N. Izutsu, and N. Yajima, Scientific Ballooning. New York, NY: Springer New York, 2009.
[19] L. Konstantinov, "The Theory of Gas and Airships Theory," Tech. Sci. J. Mod. Aerostatic Probl., pp. 1–21, 2003.
[20] G. Romeo, F. Borello, and E. Cestino, "Design of inter-city transport aircraft powered by fuel cell & flight test of zero emission 2-seater aircraft powered by fuel cells," in Electrical Systems for Aircraft, Railway and Ship Propulsion, ESARS, 2012.

[21] G. S. Seth, R. Sharma, and S. Sarkar, "Natural Convection Heat and Mass Transfer Flow with Hall Current , Rotation , Radiation and Heat Absorption Past an Accelerated Moving Vertical Plate with Ramped Temperature," Vol. 8, No. 1, pp. 7–20, 2015.
[22] A. K. Kundu, Aircraft Design. Cambridge University Press, 2010.
[23] S. Goutam, J. Timmermans, N. Omar, P. Van Den Bossche, J. Van Mierlo, L. Rodriguez, N. Nieto, and M. Swierczynski, "Surface temperature evolution and the location of maximum and average surface temperature of a lithium-ion pouch cell under variable load profiles .," EEVC 2014 - European Electric Vehicle Congress, December, 2014.
[24] Y. Ji,, Y. Zhang,, & C. Y. Wang, "Li-Ion Cell Operation at Low Temperatures service Li-Ion Cell Operation at Low Temperatures," Journal of The Electrochemical Society, Vol. 160, No. 4, pp. A636-A649, 2013.
[25] T. M. Bandhauer, S. Garimella, and T. F. Fuller, "A Critical Review of Thermal Issues in Lithium-Ion Batteries," Journal of the Electrochemical Society, Vol.158, No. 33,pp. R1-R25, 2011.
[26] W. Østreng, K. M. Eger, B. Fløistad, A., L. Jørgensen-Dahl, Lothe, M., Mejlænder-Larsen, & T. Wergeland, Shipping in Arctic waters: a comparison of the Northeast, Northwest and trans polar passages. Springer Science & Business Media, 2013
[27] A. U. Haque, W. Asrar, A. A. Omar, E. Sulaeman, and J. S. M. Ali, "Hydrodynamic Contour of Steller sea lion-An Inspiration for future Hybrid Buoyant Aircrafts", 4th International Scientific conference on Applied Sciences and Engineering, Langkawi Lagoon Resort, Malaysia, 3-4 October, 2015 .
[28] A. U. Haque, W. Asrar, A. A. Omar, E. Sulaeman, and J. S. M. Ali, "Estimation of Neutral Point for a Biologically Inspired Hybrid Buoyant Aircraft", FluidsChe,Langkawi Island, 25th to 27th November 2015
[29] E. Rodrigues and M. Kamiyama, "Computation of Dynamic Loads on Aircraft Structure due to Continuous Gust using MSC/NASTRAN," MacNeal-Schwendler Co, 1997.
[30] A. Design, "Aircraft Design : Synthesis and Analysis Aircraft Design : Synthesis and Analysis."
[31] C. W. Azlan, M. H., Badrol, A., Roslin, M. S., Mohd Razwan, R., Mohd Azwan, A., Jasman, H., & Mohd Zamri, "A Preliminary Analysis of Solar Irradiance Measurements at TNB Solar Research Centre for Optimal Orientation of Fixed Solar Panels installed in Selangor Malaysia," in 4th International conference on energy and environment, 2012.
[32] A. Noth, R. Siegwart, and W. Engel, "Design of Solar Powered Airplanes for Continuous Flight," Environ. Res., no. December, p. 18, 2007.
[33] C. Stockbridge, A. Ceruti, and P. Marzocca, "Airship research and development in the areas of design, structures, dynamics and energy systems," Int. J. Aeronaut. Sp. Sci., vol. 13, no. 2, pp. 170–187, 2012.
[34] A. S. Gohardani, G. Doulgeris, R. Singh, and A. S. G. Ã, "Challenges of future aircraft propulsion: A review of distributed propulsion technology and its potential application for the all electric commercial aircraft," Prog. Aerosp. Sci., vol. 47, no. 5, pp. 369–391, Jul. 2011.
[35] Kaltenbrunner, M., White, M. S., Głowacki, E. D., Sekitani, T., Someya, T., Sariciftci, N. S., & Bauer, S. (2012). Ultrathin and lightweight organic solar cells with high flexibility. Nature communications, Vol. 3, No. 770, 2012.
[36] P. G. Carey, R. C. Aceves, N. J. Colella, K. A. Williams, R. A. Sinton, and G. S. Glenn, "A solar module fabrication process for HALE solar electric UAVs," Conference Record of the Twenty Fourth. IEEE Photovoltaic Specialists Conference, Vol. 2, pp. 1963-1969, IEEE. 1994.
[37] D. W. Hall, "Mission analysis of solar powered aircraft", NASA Report CR-172583, 1985.
[38] D. W. Hall, and S. A Hall, Structural sizing of a solar powered aircraft. NASA Report CR-172313, 1984.
[39] J. W., Youngblood, T. A. Talay, and R. J. Pegg, Design of long endurance unmanned airplanes incorporating solar and fuel cell propulsion. AIAA Paper 84-1430, June 1984.
[40] G. Romeo, and G. Frulla, "Analysis of an advanced composite wing structure for a solar powered airplane" In XIII AIDAA Congress, Roma, Sett, 1995, Vol. II, pp. 965-976 (Italian Association of Aeronautics and Astronautics).
[41] G. Romeo, "Design proposal and wing box manufacturing of a self-launching solar-powered sailplane", Tech. Soaring, Vol. 21, No. 4, 106-115, 1997.
[42] G. Romeo, "Numerical analysis, manufacturing and testing of advanced composite structures for a solar powered airplane",. In XV AIDAA Congress, Torino, Italy, November 1999, Vol. II, pp. 1001-1012.
[43] M. D. Bailey and M. V. Bower. "High-Altitude Solar Power Platform". Technical Report, NASA-TM-103578, George C. Marshall Space Flight Center Huntsville, AL, USA, April 1992.
[44] D. W. Hall, C. D. Fortenbach, E. V. Dimiceli, and R. W. Parks. "A Preliminary Study of Solar Powered Aircraft and Associated Power Trains". Technical Report, NASA CR 3699, December 1983.
[45] Rapert, R. M. A heat transfer model for a heated helium airship. Naval Postgraduate School Monterey CA, 1987.
[46] D. Degani, "Effect of geometrical disturbance on vortex asymmetry." AIAA Journal Vol. 29, No. 4, pp. 560-566, 1991.

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