Graphene Technology for Design Efficiency of the Solar Hybrid Electrical Cryoplane and Airships

L. Ponyaev¹, M Kuprikov², N Kuprikov³ and R Domjan⁴

¹Prof. Ass. Engineering Graphic Design Department, MAI, Moscow, Russia
²Head of Engineering Graphic Design Department, MAI, Moscow, Russia
³Prof. Ass. Aircraft Design and Certification Department, MAI, Moscow, Russia
⁴President, SolarXplorers SA, Rue Galilee 7, CH-1400 Yverdon-les-Bains, Switzerland

Email: lpt@mai.ru, kuprikov@mai.ru, nkuprikov@yandex.ru, rd@solarstratos.com

Abstract. The problems of introducing graphene technologies into the design studies of complex aviation solutions of minimal weight are relevant for the development of high-strength and lightweight composite structures with surface solar nano film energy storage for hybrid electric cryogenic aircraft (hydrogen cryoplanes LH2) and airships (disk-shaped Thermoplane MAI). The optimal design is directly related to the higher specific characteristics of liquid hydrogen fuel systems together with cryocooling systems, taking into account the use of new graphene-based materials and thin flexible solar cells, which is considered for SOLARSTRATOS and MAI projects or for any projects of hybrid electric aircraft/airships and their engines. A design analysis has been carried out to improve the design capabilities when introducing graphene technologies with their unique strength, electrical superconductivity, gas tightness and low mass in the component modification of a hybrid electric propulsion (HEP) and aero elastic energy-recoverable aircraft structures.

The choice of rational design solutions using combined graphene composites, quartz dampers-vibration accumulators of structures and film solar energy cells allows you to reduce the weight of larger fuel tanks with liquefied hydrogen at high and low internal pressures and at the same time include electric motors in the cryocooling system – generators, power cables and batteries with additional solar energy charging, which increases the efficiency of on-board electrical systems and reduces the initial energy level and allows to increase energy efficiency and reduce weight costs during design studies.

1. Introduction
The development of the Russian program to create "transport latitudinal and meridional corridors for the development of connectivity of vast territories” of Siberia, the Far East and with access to the International Polar Route (IPR) for transnational cross Arctic Transpolar Airlines (TPA) is directly oriented and depends on the introduction and use of innovative design technologies and onboard systems, new environmentally friendly fuels and powerful electric power systems, efficient materials-alloys and composites, integrated digital and robotic systems with artificial intelligence.

New aviation programs and design technologies are associated with the search for effective aerodynamic layouts of aircraft and airships, allowing to compactly place larger fuel tanks with thermal protection for the use of liquefied hydrogen LH2 [1,2] as fuel, and at the same time integrate it into lighter thermal cooling cryo-systems for heating electric power components, including cooling of powerful electric motors of power plants, electric storage generators with recovery, power cables of onboard wiring, electric batteries and solar panels.

2. Breakthrough directions for modern design of aviation hybrid electric air transport
The main priority directions of the development of modern design of hybrid electric air transport are becoming, as new on-board electrical systems using the unique properties of graphene, which has high specific strength and lightness, as well as elasticity and elasticity with high electrical conductivity and
favorable gas permeability for helium and hydrogen. The problems existing today and the high cost of its industrial production are quite surmountable in the near future, which is due to new methods of its wide and cheap production, and its close variations with spatial structures - graphene and borophene. It will be allow to obtain unique new integrated composite structures and integrated multifunctional layouts of aircraft and airships with graphene Li-ion batteries and with nanofilms of solar batteries on the surface of cryoplanes and electric aircraft, taking into account the features of after-sales service and their operation in harsh low-temperature conditions on regional and long-haul geographically advantageous transpolar intercontinental airlines in Russia and abroad.

It should be taken into account that regional hybrid electric passenger aircraft with a low level of toxicity and noise will have a higher commercial demand while providing improved flight performance and economic characteristics with the necessary short (or vertical, like an air taxi drone) take-off and landing eSTOL. At the same time, for mainline hybrid electric passenger aircraft, these requirements are not so acute, but the choice of integrated aerodynamic layouts such as the "BodyCryoPlane integrated circuit", or as a wing with a supporting fuselage, it is easier to solve problems with the internal placement of more voluminous fuel tanks with liquid hydrogen LH2, as well as with a large area of the upper washed surface of the aircraft or a disk-airship under the coating of thin flexible graphene-nanofilm solar panels.

The implementation of the solution of the problem of design optimization of a hybrid electric cryo system, as a problem of mathematical digital modeling software using CATIA5 in the CAD/CAM/CAE system [3] does not always lead to success due to the significant dimension of the vector of design parameters X*, the complexity of the set of constraints U, as well as the long time required to calculate the vector of the objective function. Therefore, the correctness of the decomposition of the vector system of objective functions, project parameters and constraints is very important. This circumstance is due to the fact that the layout of such an aircraft is the result of a compromise solution of phased design tasks and the influence of new technologies through "improvement coefficients", which is characteristic of new versions and patenting of conceptual design with an emphasis on improving the efficiency of maintenance and commercial returns from their operation in the fleet and at the airport hub with minimal maintenance costs for passenger or cargo-passenger aircraft, LH2 refueling and rapid preflight recharge-replacement of rechargeable Li-Ion-Graphene batteries.

3. Features of the selection and synthesis of the optimal design of the hybrid electric passenger aircraft concept

The process of interactive selection and synthesis of a new aircraft design is focused on the integrated integration of the layout appearance (3D projections) of a hybrid electric cryoplane (HEC) of possible aerodynamic schemes or concepts with minimal aerodynamic drag and fuel consumption-electrical energy, and low noise during the entire flight. A feature of the optimal synthesis process is the dominance of certain particular criteria over others and the increase in the significance of the specified particular criteria to the level of general criteria, including the features of liquid hydrogen placement and the use of cryo systems for thermal control and the introduction of graphene composites into power structures and electrical energy components in order to reduce energy and weight costs and increase commercial and environmental efficiency [4].

When performing computational methods of mathematical modeling in solving the "direct" problem of designing an aircraft, multiple iterations are required, which is accompanied by significant time and material costs. Therefore, the computational model of solving the "inverse" problem of designing airplanes or airships, i.e. the situation when the rational values of the parameters correspond to the permissible minimum or maximum value of the main given characteristic, which clearly follows from a set of restrictions affecting the possible concepts of the optimal appearance of the selected aircraft, as shown in Fig. 1. It should be noted that such tasks of this type are often characterized by the frequent absence of optimum points of the function in the interval under consideration and a smooth gradient of its growth, giving preference to compromise solutions where the "positive" sides prevail over the less significant "negative" ones [5].

The desire to use uniquely significant graphene technologies determined by a planar structure in the thickness of one atom, as can be seen in Fig. 2, among which the following properties stand out:
- graphene has high hardness, rigidity and flexibility, and nanotube or "twisted" single-layer graphene allows you to create a wide variety of high-strength and lightweight composite materials with amazing properties and when graphene is added to almost any material (metals, alloys, ceramics, polymers, paints, coatings, glass, etc.) improves its strength properties at times (10 times stronger than steel), elasticity (by 25%), durability and resistance to external influences, while graphene does not pass helium and hydrogen, what is important for covering their gaseous containers in an airplane or airship;
- graphene is characterized by superconductivity, high thermal and electrical conductivity, it has an extremely high electric current density (significantly better than copper) and record mobility of charge carriers, its thermoelectric effect can allow a breakthrough in more compact and lightweight high-capacity batteries and in the use of the most promising and potentially inexhaustible energy industry — solar, increasing the efficiency to 45-54% when using graphene film will allow to "catch" not only most of the solar photons, but also to use, along with the semiconductor thermoelectric effect to convert solar energy.

**Figure 1.** The new optimal design of the aircraft: a - the concept of a Flying Wing, Wing Body and Rombus Wing shape, and b - The Disk Wing Concept for the operation as STOL in urban hubports.

**Figure 2.** Atomic structures of the graphene layer and its visual property of superconductivity

Thus, taking into account the influence of efficient graphene technologies on improving the energy-weight efficiency of HECA, many infrastructure constraints directly or indirectly affect the choice of values of the main layout concepts, parameters and dimensions of the aircraft, as shown in Fig.3. The impact of infrastructure requirements on the dimensions of the aircraft will be considered by the example of factors for which this is crucial. The demographic global factor (DGF) of infrastructure requirements is forecasted for the future and is an objective background that determines the location of aviation infrastructure in each individual continental region with characteristic climatic natural conditions, in particular, both on a large territory in Russia and on the globe. Due to the requirements specified in the ICAO/IATA specification, which a passenger aircraft must comply with, DGF becomes decisive for some types of aircraft.
The choice of layout schemes and innovative efficient graphene technologies to increase the weight and energy efficiency in the design synthesis of HECA is associated with the determination of the main parameters characterizing the trajectory level of flight, the technical equipment of electrical components and their thermal regulation of the components of cryo systems, aerodynamic and fuel efficiency and other priority characteristics. As parameters for the deterministic search for rational values, it is necessary to use the general parameters of the aircraft and functional criteria [6,7].

It can be argued that, all other things being equal, it is necessary to minimize the take-off weight, surface area, thrust and the number of hybrid electric motors, etc. Therefore, the specific load on the wing and the thrust-to-weight ratio of the aircraft can be considered as parameters for optimizing the take-off weight.

4. Minimizing the size and weight of a hybrid aircraft in the new airport infrastructure

In the design analysis and synthesis of a hybrid electric cryoplane (HEC), it is necessary to take into account the impact of infrastructure constraints on the dimension of possible concepts using optimal design methods and digital technologies. In the conditions of increased competition between manufacturers, much attention is paid to the stage of comparative solutions of promising structural and layout schemes and the search for a new design concept and new structural solutions made of graphene composite materials, since we are talking about the design of new types of aircraft that have no analogues or prototypes.

As alternative circuit solutions, along with the traditional normal as a common classical scheme for regional HEC with a given aerodynamic balancing of the aircraft, others are considered that have two promising distinct trends: the desire to increase the number of bearing surfaces - according to the "duck-triplane" scheme or to reduce them - an integral "flying wing" or any variants of the "double hull – rombus – disk" concepts with hybrid electric motors between the fuselages or on the wing surface [8].

The computational studies carried out on the complex algorithmic architecture have shown that for different concepts of the aerodynamic appearance of HEC, the nomenclature of constraints is practically equivalent, and how the layout options are presented in Fig. 4.

However, in absolute terms, the constraints are not always critical. The analysis of constraints allows you to vary the given layouts of the aircraft and their systems with limitations and improvement of specific values from the use of graphene technologies, formalize them in scalar and functional form.

These requirements are formed at the external design stage, and at the internal design stage they are specified in the specification of the main technical requirements. The analysis of the effectiveness of graphene application and the variety of infrastructural constraints-requirements shows that they can be systematized and classified according to its unique properties [9].

Figure 3. Aircraft Design Concepts: a - Canard Integrate Shema and b – Disc Shaped Vision.
The choice of the layout aerodynamic scheme of the HEC with a large passenger capacity is characterized by very significant geometric and mass dimensions, revealing reserves for reducing the weight of the structure of the cryoplane with LH2 and electrical systems with significantly strengthening and electro-efficient new graphene technologies. This feature conflicts with a number of factors of the airport infrastructure that already exists today. The flight operation of the HEC should be carried out in the existing network of airports, which imposes a number of infrastructural restrictions on them, such as: the length and width of the runway, the width and radius of rotation of taxiways, the distance from the wing console to the landing arms of terminals of buildings, the distance between the wing consoles of aircraft on parallel taxiways and runways, the strength of the runway coating, refueling ground safe points for filling LH2 and charging-replacing-testing onboard batteries, etc.

For high-class airports, options and characteristics of basing a carrier with a large passenger capacity are considered based on the use of model computational digital methods at the Aviation Engineering Graphics and Design Department of the MAI. The structural and parametric analysis of high-class hub airports allows us to determine the infrastructure requirements for a carrier and form a vector of constraints \( U = U (u_{ij}) \), which characterizes the problem of conceptual design of aircraft with large passenger capacity:

\[
\begin{align*}
  u_{11} &= u (\text{runway} < 3000 \text{ m}); \\
  u_{12} &= u (L < 60 \text{ m}); \\
  u_{13} &= u (ACN < 65).
\end{align*}
\]

Parametric analysis of the factors of the airfield ground infrastructure shows their influence on the limitations on the dimensions of the aircraft. The main indicators of the dimensions of the aircraft are its take-off weight \( M \) and the placement of larger fuel tanks for LH2. At the stage of determining the dimensions of the aircraft, the classical method is used to determine the weight balance equation, taking into account improvements due to strengthening and lightening of the structure and systems with graphene technologies:

\[
m_{af} + m_{en} + m_{ec} + m_l + m_k + m_{sl} = M,
\]
where \( m_1 \) is the mass of the structure with graphene unloading; \( m_2 \) is the mass of hybrid electric motors; \( m_3 \) is the mass of control system equipment; \( m_4 \) is the mass of fuel; \( m_5 \) is the mass of a given target load; \( m_6 \) is the mass of the service load and electrical equipment with batteries.

Conceptual variants at the stage of synthesis of the aircraft layout using graphene strengthening technologies are associated with three unique tasks of improving the aerodynamic, volume-weight and structural-energy layout. These iterative stages of the synthesis of the layout scheme are aimed at resolving the contradictions of the internal layout with cryogenic systems on hydrogen LH2 and the formation of external streamlined contours of the aircraft. Based on the influence of "strict" infrastructure requirements on the layout of the aircraft, it can be seen that they form a boundary conceptual description of the synthesized appearance of the aircraft. Moreover, its content on the use of graphene technologies and thermal cryo systems depends on the purpose of the aircraft for regional or mainline airlines and, as a consequence, the permissible criticality of the established restrictions. In order to minimize the number of iterations of the layout in digital format, it is necessary to determine the critical factor and build the layout procedures into a single calculation algorithm.

When implementing the task of "reverse" layout, the definition of the permissible layout space and its decomposition are analyzed in accordance with the characteristic features of the domain of existence. At the same time, there are signs that are uniquely determined by infrastructural requirements (dimensions) and more ambiguous signs (balancing scheme, moments of inertia, specific density, etc.). Characteristic signs carry a conceptual components, both for individual decomposition units and systems of hybrid electric aircraft, and for the entire aircraft as a whole. Depending on the implementation of the aircraft layout procedures, taking into account the critical factor, a transition is made to the decomposition of the layout procedures and the determination of the order of their transformation.

5. A promising design concept for a disk solar electric airship using graphene technologies

The desire to improve the aerodynamics of airplanes and disk-shaped airships has not yet been fully appreciated, although several dozen projects are known. A number of projects have used this geometric symmetrical shape – this aerostatic aircraft (ALA) Thermoplane MAI, as shown in Figure 5, is a unique and patented project, as well as very similar subsequent projects "Aerosmena 600" and "Locomosky", or the project of a short take-off and landing aircraft ECIP as elliptical shape with active laminar flow control, while the possibility of placing a surface solar energy system with a thin graphene nano film of photonic electric batteries to ensure long and non-stop flights can be successfully implemented., including mobile rescue anchor points along HEA cross-polar routes as concepts of new air transport systems - modular comfortable hotels with high environmental friendliness for the future development of intercontinental mobility [10].

Hybrid electric solar disk-airships with composite graphene reinforcing and lightening materials with high electrical conductivity are able to provide both high weight return, which is determined by the symmetry of the disk shape with a uniformly distributed load along the contour of the power torus, and the ability of energy-efficient long-term flights with solar energy replenishment not on the ground, but in the air, which simplifies their use without airfield basing in the Arctic regions. The high aerodynamic quality of the disc-shaped geometry and active wind disturbance dumping systems provide the necessary maneuverability and safety of flights near the ground with stable hovering for operational rescue and installation work from the air.

![Figure 5. The patented Disc Shaped LTA: a - THERMOPLANE Project by MAI Design and b - visit President Putin V.V. to the AVIASTAR Plant in Ulyanovsk where produced THERMOPLANE](image-url)
On the Fig. 6 shows the distribution of loads for various geometric shapes - the disk and the supporting fuselage, which are advantageous for HEA, made in accordance with a more efficient integral formation of the power structure and the use of composite graphene technologies. Structural-parametric analysis of the stress-strain state shows a pronounced anomalous zone. To compensate for this, a longitudinal force element is needed that divides the methods of spherical polar geometry into components of the decomposition of the fuselage structure in the form of a disk or a drop into two symmetrical segments [6]. Compared to the basic aircraft of the normal aerodynamic scheme, the low cost of the HEA flight hour is achieved and it is 84%, and compared to the scheme of the aircraft with a diamond-shaped wing - 94%. The advantages of aircraft designed according to the "flying wing" scheme, in comparison with other schemes, increase with increasing dimensions and weight of the aircraft. The greater the value of the target load and flight range, the better the application of this optimal aerodynamic HEA scheme through the North Pole and Russia.

**Figure 6.** The Design Analysis Geometry: a – Disc and b - Drop Shape of the bearing fuselage and the washable surface of the Aircraft made according to c - the Integral Forms of Wing Body Plane.

**6. Conclusion**

The introduction of innovative graphene technologies into the power elements of the design of hybrid electric solar aircraft HEA and disk airships with "passing" cryo systems using liquid hydrogen LH2 with 4 times more volumetric fuel tanks - give increased weight return up to 15-22%, depending on the design optimal solutions with the choice of new alternative integrated aerodynamically elastic volumetric thin-walled layouts with a more favorable uniform distributed load in flight, during takeoff and landing and on the ground.

Despite the high cost of graphene production and the emergence of new simplified methods that reduce the cost of this process, the possibilities of superconductivity of graphene and its elements in on-board electrical power systems provide increased compactness and a reduction in the size of on-board energy components up to 45-50% with a given or greater power and the need for cryo cooling of heating electric motors, generators, recuperators, power wires and fast-charging high-capacity up to 3-5 MGW batteries.

The unique strength ability of graphene nanotubes or thin two-layer nano structure allows for high protection from external influences, such as the bulletproof shell of aircraft, and full gas tightness of
composite elastic-elastic materials with permissible deformations up to 22-25%, which solves acute problems with maximum flight safety of HEA and the need to fill hydrogen or helium leaks in the gas lines of hybrid aircraft or volumetric aerostatic cavities of the disk of Thermoplane MAI type airships.

References

[1] AIRBUS CRYOPLANE: Liquid Hydrogen Fuelled Aircraft-System Analysis. Technical Report, September 2003.
[2] AIRBUS Zero Family Concepts. Internet Online Aviation News, 21 September 2020.
[3] Dolgov O, Kuprikov M, Kuprikov N 2010 Features of detecting the moment-inertial appearance of perspective aircraft, in the early stages of design Bulletin of the Moscow Aviation Institute 2 (17) 1-4
[4] MAI Science R&D Cryogenic Cooling Systems Reports 2018-2019-2020 Conference papers 2018/2019
[5] Javet R, Domjan R 2018 Pionniers et Aventuriers de L’Energie Solare ISBN: 978-2-8289-1719-7 FAVRE SA, Lausanne, Suisse p 136
[6] Ponyaev L 1996-97 Thermoplane ALA-40/ALA-600 Catalog Brassey’s World Aircraft & System Directory p 545
[7] Walter A, Ravikovich Yu, Ponyaev L , Holobtsev D etc. 2020 Thermal Management challenges for HEA – FUTPRINT 50, Conference EASN papers, 2-4 September, Italy
[8] Ponyaev L 2018 Scientific LTA Technologies, S&P Journal PSSN 223-2966: Moscow, Russia, Natural & Technical Science 9 pp 60-65
[9] Dolgov O, Kuprikov M, Kuprikov N 2010 Features of detecting the moment-inertial appearance of perspective aircraft in the early stages of design Bulletin of the Moscow Aviation Institute 2 (17) pp 1-4
[10] Ponyaev L 2018 The Periodical Geometry of Engineering Design Principals by use the Optimal Spherical Transformation to the Disc LTA. ST S&P Journal PSSN 223-2966 pp 1-5