With this newsletter we would like to inform you about the progress of the EU-funded project “MAAT – Multibody Advanced Airship for Transport”. Several concepts of airships have been presented in the literature. The most different shapes can be identified, from classic Parsifal ball and disc-shaped forms. In all cases the aim has always been thought of as transport. It is then presented with the conceptual path that allowed defining the future of new aircraft ecological systems.

The first concept is PSYCHE (Photovoltaic stratospheric Isle for Conversion Hydrogen as Energy-vector). It aims producing hydrogen by photovoltaic solar energy. Hydrogen is liquefied and transported on the ground by a feeder airship that lift up the necessary water for Hydrolysis and lift down hydrogen and oxygen. This concept has been then modified to produce novel air vehicle concepts more suitable for transport operations. The concept of PSYCHE has been evolved in the MAAT (Multibody Advanced Airship for Transport) cruiser feeder airship concept. This project is becoming an effective platform for studies related to future green aeronautics and for ensuring the future European leadership in green aeronautics.

On the following pages we would like to provide you with an overview over the work packages (WP) we are currently working on. We hope you enjoy your reading!
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NEW DESIGN METHODS BASED ON THERMODYNAMIC RESEARCH

The MAAT project has allowed the definition of radically new design methods based on Modular Design (which is widely used at industrial level), which has been coupled constructive law, intended as a formulation of first principle of thermodynamics. This design method allows an effective definition of evolving design concepts, such as the one actuated during the project.

![Diagram of Modular Schematization of an Airship](image)

Figure 1. Modular schematization of an airship representing internal fluxes.

Adrian Bejan has defined constructive principle as follows: “For a finite-size system to persist in time (to live), it must evolve in such a way that it provides easier access to the imposed currents that flow through it.” This controversial principle of thermodynamics allows producing an effective design of a system by considering a modular schematization of the system in terms of modules. It could be possible to couple the fluxes of different physical magnitudes through it (Figure 1).

The analysis of fluxes at different level of detail allows the individuation of the components that presents higher resistance, which can be substituted by existing ones or substituted by ones that removes the criticalities. After optimization another component becomes the critical one. Then the optimization of the component can be performed removing the criticality.

Constructal Design for Efficiency aims to produce an effective and applicable design method for industrial products based on the constructive law defined by Adrian Bejan. After an effective analysis of existing design methods adopted at industrial or scientific level, this paper gives a more accurate definition of the Constructal Design for Efficiency method.

Considering the advancement of the results towards an ideal theoretical solution of the problem, it allows a precise evaluation on how the system is far from the ideal solution and how a modification could affect the final results. In particular, those differences could be evaluated and allows programming possible product evolution strategies in future.

The derived method has been defined by UNIMORE as CDE (Constructal Design for Efficiency. It can be formulated as: “A complex system can meet optimal performances (according to existing technology) if it has been optimized as a whole, defining the ideal performance required by the system considered as a whole and the requirements of its subsystems for optimal performances”.

In particular, it has been compared to the Modular Design method, which is actually utilized in the transport vehicle industry,
showing how the fundamentals of this method are adopted also in CDE method. It could be an effective improvement because it aims to the definition of an industrial ready industrial product through the preliminary design of an optimized ideal system which is used a term of comparison to define the possible future evolution of different components of the full product. This comparison, which is a necessary part of CDE method, allows defining reasonable lines for future implementation and for future development and the direction of research, to respond to the technological needs which are necessary to realize an effective and appreciable advancement.

The proposed method has performed very good results in terms of product innovation because it generates a schema that allows on an effective design process which can fit industrial Modular Design, introducing also breakthrough innovations inside an effective standardized modular schema, it allows predicting the evolution of the performances according to expected technological evolution, coupled with interesting results.

University of Modena and Reggio Emilia

NEW MULTIDISCIPLINARY OPTIMIZATION METHODOLOGIES AND TOOLS FOR AIRSHIP DESIGN

The MAAT project has given to the University of Bologna team the opportunity to develop some new methodologies for the non-conventional airships design and a realistic case study to test the effect of the modern techniques on the design of complex systems. Indeed, on the web there are a lot of more or less futuristic sketches of airships, often realized by architects, designers and artists; during the MAAT project it has been developed an easy methodology for the preliminary design and for an initial sizing of these air vehicles, so as to provide to everyone, not engineers included, a tool to evaluate the feasibility, the performances and the dimensions of the airship sketched by them.

Concerning the application of the innovative tools of design for the airships project, evolutionary algorithms have been successfully applied to find the best optimization point in case of complex case studies: both the configurations’ design and the trajectories can take
advantage by the application of these methodologies.

The airships’ design is in fact a complex and multidisciplinary task, in which it can sometimes happen that the improvement connected to a change of a given parameter leads to the worsening of other important aspects. As far as new technologies are concerned, some new methodologies related to the Rapid Prototyping have been used to evaluate new airships’ geometries and to produce in short time models to be used in wind tunnel tests. Some numerical methodologies have been developed for the calculation of the Added Masses coefficients once the CAD model of a generic object is available. This evaluation is essential for airships where a precise modelling of the dynamics of the airships requires a correct consideration of the effects related to the displacement of the fluid by an immersed body. Beyond the mere technical aspect, the MAAT project has been a good opportunity to meet and work with European partners and to collaborate together in a complex design case study, both for the UniBo faculty staff and the young research fellows that have been involved in the project.

University of Bologna, Italy

**TENSAIRITY USES IN AERONAUTIC DOMAIN**

Heavy payload airships and non-conventional shape airships require a rigid keel to maintain its shape under loading. The keel increases the structural weight, which in turn decreases its payload capacity. In this context, Tensairity appears as a promising solution to reduce the structural weight in those cases where a keel is required. Tensairity is an inflatable beam reinforced with stiff elements: cables for traction forces and struts for compression forces. Tensairity beams are able to withstand identical loads to conventional rigid structures at a weight factors lower. Figure 33 shows a Tensairity prototype.

Figure 3: Tensairity is a structure which can carry similar weights to conventional beams at a weight factors lower

Tensairity is a new concept which is still under rigorous scientific investigations. This paper is an attempt to explore its possible application on airship’s structural components. More specifically, a Tensairity frame has been investigated. The first objective has been to validate the definition of Tensairity frame within the context of the beam theory. The validation of such analogy will enable one to obtain an analytical expression that can be used for preliminary sizing of Tensairity frames, minimizing the number of Finite Element Analysis (FEA)
needed. The conclusions from such study have been extracted and applied for design of a large large scale Tensairity frame within the constraints traits of a static loading scenario. The weight of the Tensairity frame has been compared to the the weight of a similarly sized I-profile beam and and to a non-reinforced inflatable beam inflated with same pressure, to understand weight-weight-reduction potential of Tensairity – if any.

Figure 44 shows the studied frame.

![Sized Tensairity frame](image)

Figure 4: the considered Tensairity frame is the horizontal upper frame on the Cruiser.

In order to assess the validity of applying beam theory in Tensairity frames, a small-scale circular frame with a distributed load has been considered. The tension and compression areas have been identified through analysis of the stress distribution, which will allow the determination of the positioning of cables and struts. Utilizing the obtained stress distribution, a baseline Tensairity beam has been modelled in a commercial software package - Abaqus. The stress distribution obtained numerically has then been compared to the one predicted by the beam theory, to evaluate the validity of defining Tensairity as a composite beam. Different loading conditions and design parameters values have been modeled, aiming to identify the limitations of the developed expressions. For a circular frame, the design parameters include the major radius, the minor radius, the internal overpressure, the stiff elements cross-section and the influence of a direct connection between the two stiff elements.

The implementation of the above process resulted in reasonable agreement between analytical and computational results under certain conditions, which validates the FEA model. In general, for slender geometries (slenderness larger than 10, defined as major radius divided by minor radius) the Tensairity frame can be explained by the beam theory as long as the small displacements theory is fulfilled. In other cases, significant differences between analytical and computational are found, which establishes the limits of the beam theory on Tensairity frames.

An important conclusion obtained is that for the studied geometry and loading conditions, it appears compression and tension stresses both along the inner and outer torus faces. For low slenderness Tensairity frames, the stiff elements are only loaded in compression. As a consequence, the stiff elements must be able to withstand compression in both inner and outer faces, making less evident the position where cables can be employed compared to Tensairity beams. The solution analyzed in the performed research is the use of struts on both the inner and the outer faces of the torus.

The obtained conclusions have been taken into account to size a Tensairity frame for a Cruiser keel. The Tensairity frame was sized to withstand drag force, and the obtained mass has been compared to an I-beam frame of similar dimensions and loading conditions. In addition, the Tensairity frame was compared to a non-reinforced air beam inflated with identical overpressure. The analysis showed that, if similar deformation is targeted, the Tensairity frame is more than 4 times lighter than the I-beam. Compared to a non-reinforced inflatable beam, the applied over-
pressure is not sufficient to avoid compression stress on the entire membrane, hence, leading to failure. Thus, if an air beam must withstand the same loading conditions, higher overpressure must be applied. This would lead to a challenging research on fabrics that will be able to withstand sufficiently high breaking stress.

Taking into account the detailed findings, the use of the developed equations are a useful tool to preliminary assess the design of a Tensairity frame, as well as to validate a numerical simulation. Future work will be focused on buckling, three dimensional loading, torsional rigidity and connection of different Tensairity beams and frames to create a Tensairity keel.

Vrije Universiteit Brussel, Belgium

EVALUATION OF THE AERODYNAMIC INTERACTION BETWEEN AIRSHIPS

In spite of the acceptable performance of both airships analyzed individually, the aerodynamic interference between them involves significant aerodynamic effects, which might significantly reduce the aerodynamic performance of the airships system. In this line, the two airships interaction has been assessed through the evaluation of the aerodynamic performance of the airships as a system, aiming to shed light on the feasibility of a frontal docking operation and of a physically connected system of airships at stratospheric altitudes. The airship geometry has been redesign according to the obtained results, targeting to reduce the global drag and minimizing the aerodynamic interference.

The first airships system tested has been composed by an ellipsoidal airship with a longitudinal tunnel on the center to position the two other airships. A large aerodynamic interaction has been founded. The main conclusions to extract from the obtained results have been:

- The presence of the cruiser provokes a blockage effect on the flow impinging on the Feeder, increasing the aerodynamic forces.
- The high speed in the gap between feeder and cruiser creates a suction force, affecting significantly the lift force and pitch moment of both Feeder and Cruiser.
- The suction force created by the gap will induce high internal stress and high loads to be absorbed by the fixation system. This will results in heavy aircraft structures.

Figure 5: The baseline geometry (figure a) has been modified to an updated geometry (figure b) according to the CFD results
- The pitch moment range appearing at the different scenarios is excessively wide to be efficiently controlled.

- The two smaller airships increase the value of the system drag coefficient to the double, compared to the larger airship drag coefficient.

Figure 6: The presence of the Feeder increases twice the system drag coefficient

Figure 7: The presence and position of the Feeder excessively affects the pitch moment, which implies a challenging design of the control surfaces

Summarizing the conclusions to the obtained results, the present geometry is found to be not feasible in terms of controllability and propulsion. Due to the results obtained, the geometry ellipsoidal airship has been modified, closing the central tunnel in the frontal part. The main conclusions to extract from the second geometry have been:

- The system drag coefficient is decreased approximately a 40%

- The large velocities in the gap have been avoided, decreasing the aerodynamic interference

- The system pitch moment remains severely affected, which implies a challenging design of the control surfaces.

- The higher velocities in the smaller airships surroundings induce suction force in the vertical direction, tending to separate both airships.

Figure 8: The aerodynamic interaction is less severe; although still significant for the pitch moment.

The presented results evidence a large improvement compared to the baseline geometry, with a system drag force 40% lower and a narrower pitch moment range. Consequently, and although requiring further modifications (specifically aiming to reduce the Feeder aerodynamic forces), there is a significant improvement in drag force and airships interaction.

The presented results have been computed with the commercial software package FlowVision, which includes the moving body capability, a useful capability to simulate the docking. Figure 9 shows the velocity field computed with such software. The simulated scenarios will be validated experimentally.

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with wind tunnel testing. Figure 10 shows the 3D model printed by the Moscow Aviation Institute (MAI) for such purpose.

Figure 9: Velocity field computed with the commercial software FlowVision

Figure 10: 3D printing prototype for wind tunnel testing, crated by MAI

APPLICATION OF COMPUTATIONAL FLUID DYNAMICS (CFD) AND MULTI-DISCIPLINARY OPTIMISATION (MDO)

ENGYS (www.engys.com) is a medium sized engineering company that develops, supports and delivers best-in-class CAE software solutions based on proven open-source technologies, offering a variety of expert CFD and MDO products and services to industrial customers around the world. The company operates globally through a network of offices in the UK, Germany, Italy, USA and Australia, and local distributors in Japan, Korea, Benelux and China.

ENGYS contributions to the MAAT project were mainly focused on the application of Computational Fluid Dynamics (CFD) and Multi-disciplinary Optimisation (MDO) techniques to aid on the aerodynamic design of the airship cruiser and feeders.

State-of-the-art CFD simulation techniques were employed to predict and assess the aerodynamic performance and stability of every proposed airship design operating in a wide range of conditions, cruising speeds and altitudes, as an essential requirement to complete the design of the control and propulsion systems. The application of CFD in the engineering design process offers a highly cost-effective way of verifying the aerodynamic performance of the proposed shapes without having to rely solely on more expensive and lengthy wind tunnel experiments.

In an effort to define the best aerodynamic airship envelop, CFD was combined with widely used MDO methods – such and Response Surface Methods (RSM), Design of Experiments (DoE) and genetic type optimisation algorithms – to develop a fully-automated parametric design process for the neutrally buoyant apparatus aimed at minimising aero-
dynamic drag resistance (for minimum power consumption) and maximising stability (for maximum safety and comfort). The automatic process is enabled by morphing the shape of the external envelop using advanced CAD techniques; the aerodynamic characteristics of each new envelop shape generated by morphing are verified using CFD; the same process is repeated several times in a close loop to drive the shape towards optimal performance.

Baseline Cruiser Design | Optimised Cruiser Design

<table>
<thead>
<tr>
<th>$F_d = 572 \text{ kN}$</th>
<th>$F_d = 503 \text{ kN}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_m \alpha = 32740 \text{ kN-m/deg}$</td>
<td>$C_m \alpha = 28085 \text{ kN-m/deg}$</td>
</tr>
<tr>
<td>$C_l \beta = 803 \text{ kN-m/deg}$</td>
<td>$C_l \beta = 629 \text{ kN-m/deg}$</td>
</tr>
<tr>
<td>$C_n \beta = 2374 \text{ kN-m/deg}$</td>
<td>$C_n \beta = 2784 \text{ kN-m/deg}$</td>
</tr>
</tbody>
</table>

Figure 11

The CFD optimisation process proposed by ENGYS as part of the MAAT project was successfully applied to both the cruiser airship and the feeder balloons, thus confirming the validity of this approach as a potential design tool for similar applications. Figure 12 shows typical results for an intermediate cruiser airship design before and after MDO has been applied.

ENGYS also applied advanced CFD techniques to simulate the docking and undocking procedures between feeder and cruiser during flight. For this purpose a new dynamic mesh library was developed and implemented by ENGYS as part of the project efforts, using the open-source based CFD software HELYX®. The new technique combines mesh deformation with automatic remeshing to enable the complete simulation of the feeder approaching the cruiser to complete docking, and vice versa. The new dynamic mesh method was extensively tested to ensure the validity of the aerodynamics results subject to relative motion of the feeder with respect to the cruiser.

Understanding the dynamic response of each body in proximity during flight is fundamental to ensure the aerodynamic forces acting on both the cruiser and feeder stay within acceptable limits for the purpose of stability and control, structural soundness and propulsion.

Several docking/undocking scenarios, including different approaching speeds and angles, were analysed for the final design of both cruiser and feeder to establish the best docking approach and provide insightful data to all designers.
Figure 13 shows the air velocities calculated by the CFD simulations when the feeder is performing a docking operation at different relative approaching speeds.

![Air Velocities Diagram](image)

EVALUATION OF SOLAR ENERGY CAPTION AND PV PRODUCTIVITY

UNIMORE team energy vocation has allowed the definition of solar energy models. They have been defined by a former model which has been produced inside PSICHE Project. Starting from this preliminary model an effective improvement has been produced.

Theoretical solar radiation is calculated by MIDC SOLPOS algorithm by NREL. It has been integrated on annual basis by 10 min step to calculate daily average irradiation on annual basis. By verifying that the maximum of solar radiation is 12221.26 Wh/m² day it can be easily defined a daily coefficient of solar energy, which will permit to take into account the day of the year and the latitude.

A further advantage is the fact that the low temperature at high altitude allows to raise the nominal yield of photovoltaic panels. It has been considered that the energy exchange schema presented in Fig. 14. The equilibrium temperature has been evaluated by calculating the temperature of equilibrium through the heat balance of the PV module:

![Daily Irradiance Diagram](image)
The heat exchange has been evaluated in terms of power per unit of area of PV module, due to conductive, convective, radiant and electrical power, providing the equilibrium temperature of the cell. The conductive term is negligible, if compared to other exchange mechanisms. It has a significant value only in the case of a thermal difference between different modules, due, for example, to shadowing effects, which do not apply to high altitude applications.

![Diagram of the energy exchanges of a photovoltaic panel](image)

**Fig. 15 - Diagram of the energy exchanges of a photovoltaic panel**

It is possible to define the following model of energy production by the two defined coefficients $s_d$ and $c_{ds}$:

$$m_{h}(h, H) = c_{ds} \cdot m_d(H) = c_{ds} \cdot s_d \cdot \frac{m_{H}(H)}{365}$$

By this equation it is possible to evaluate the energy productivity during the mission. If the top photovoltaic roof surface can be considered a plain surface, the Hydrogen production of the entire photovoltaic ceiling $S_{PV}$ can be evaluated. Energetic evaluation have performed during operations.

![Compressed Hydrogen productivity as a function of altitude with interpolating functions](image)

**Figure 17. Compressed Hydrogen productivity as a function of altitude with interpolating functions**

The daily production in terms of Hydrogen and oxygen can be calculated. It can be also assigned a daily solar coefficient assumed on the basis of the hour (Figure 16). This coefficient takes into account the daily solar phase. It is defined for simplicity on the basis of a day of 24 hours and is defined as a semi-sinusoid.
The need to store sufficient energy during the day to maintain operational performance during the night has provided many challenges. The picture above describes the challenge.

As the length of the day varies throughout the season varying amounts of energy are stored by using a unitized regenerative fuel cell. This converts surplus electrical power from the PV arrays into hydrogen which can be used during the night in fuel cells to maintain the crafts operation. This process is closed cycle as water is split into hydrogen and oxygen and then reformed back to water releasing the stored energy. Previous studies into stratospheric airship systems are for unmanned small drones used for reconnaissance and communication. MAAT is the first study of passenger and freight operations where the impact of day and night operation is not as demanding.

In addition to the reversible fuel cell a low temperature stirling engine has been considered in order to harvest rejected heat. This was chosen over technologies such as TEG as they can be constructed using lightweight composite materials and utilise hydrogen as the working gas.
Figure 19. Modular energy system schematization

This allows easy scalability of the systems and segregation of the electrical systems providing a high degree of reliability and intrinsic safety. The current system utilises around 70 propulsion pods mounted around the perimeter of the airship along with the cabin and docking systems.

It is important that the energy transport systems meet current and future safety requirements and as such the study has considered the safety implications and how the systems architecture will be designed in order to meet or exceed the current design assurance levels of aircraft. Of specific interest will be the need to certify the system for passenger operation at 15000m. Future consideration will need to be given to atmospheric radiation at this level and its potential effect of power electronic reliability.

University of Lincoln, United Kingdom
HIGH ALTITUDE PROPELLERS: NEWLY DEVELOPED JBLADE CODE

New analysis software for propeller design was elaborated. JBLADE software is developed from QBLADE and XFLR5 and it uses an improved version of Blade Element Momentum (BEM) theory that embeds a new model for the 3D flow equilibrium. The software allows the introduction of the blade geometry as an arbitrary number of sections characterized by their radial position, chord, twist, length, airfoil and associated complete angle of attack range airfoil polar. The code provides a 3D graphical view of blade to the user, helping the user to detect inconsistencies. JBLADE also allows a direct visualization of simulation results through a graphical user interface making the software accessible and easy to understand by willing users. The software is developed as an open-source tool for the simulation of propellers and it has the capability to estimate the performance of a given propeller geometry in design and off-design operating conditions.

New 3D flow equilibrium formulation was performed. This 3D flow equilibrium model accounts for the radial movement of the flow, improving the performance prediction of the software. The development of a new method for the prediction of the airfoil drag coefficient at a 90 degrees angle of attack for a better post-stall modelling is also presented. The analysis of the results shows that the propeller performance prediction can be improved using these implemented post-stall methods. An inverse design methodology based on minimum induced losses was implemented in JBLADE software in order to obtain optimized geometries for a given operating point, fig.20. In addition a structural sub-module was also integrated in the software allowing the estimation of blade weight as well as tip displacement and twist angle changes due to the thrust generation. The inverse design and structural sub-module were also validated against other numerical results.

To verify the reliability of XFOIL, the XFOIL Code, the Shear Stress Transport k-ω turbulence model and a refurbished version of k-kl-ω transition model were used to estimate the airfoil aerodynamic performance. It has been shown that XFOIL code gives the closest prediction when compared with experimental data and can be used in JBLADE Software as airfoil’s performance estimation tool.

In addition, a new test rig was developed and used to adequately validate numerical design tools for the low Reynolds number propellers. The measurements of the new test rig were validated against reference data and additional performance data can be obtained for propellers that are not characterized in the existing literature. Thus it is possible to conclude that JBLADE can be used to design and calculate the performance of different propellers, with a wide range of applications, including the MAAT airships.

Figure 20. Flowchart of inverse design procedure in JBLADE.

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EFFECTS ON TRANSITION FLOW IN HIGH ALTITUDE PROPULSION SYSTEM COMPONENTS.

Turbulence transition modelling is still an active research area of interest for various industry sectors. Its modelling can range from RANS based closures to full DNS computations. The former approach is of course the most feasible simulation methodology. Therefore, RANS based transition models have been developed for industry use. These range from empirically correlated transition models to physics based phenomenological transition closures. Implementation and validation of these models resulted in a deeper understanding of the processes by which RANS based closures are able to predict turbulence transition onset. Further, the research on the specific type of physics based transition models resulted in an improvement of an existing turbulence transition closure, the k-kl-ω. Additionally, upon gaining a deeper understanding on the role of the pre-transitional flow region, a new turbulence transition model was devised. This is based on a never before applied concept of pre-transitional turbulent vortex deformation due to mean flow shear. This will induce the appearance of a small pre-transitional turbulent viscosity on the upper reaches of the laminar boundary layer. The latter viscosity is a result from the predicted small negative pre-transitional u'v' values. Although experimentally verified, up until now, no model has ever been able to predict this turbulent feature based on a mechanical analogy. The transition V-model was then coupled to a turbulence model, the Spalart-Allmaras closure, resulting in the V-SA transition model. This was validated for a wide range of flow conditions and multiple geometries as wings, fig. 22. It is concluded that the mechanical analogy based closure is a feasible concept with a promising future. However, there is still work to do on this new transition model.

Figure 21. Fig. 3. Onera-M6 wing skin-friction coefficient contour plot with flow field streamlines.

Figure 22. Prolate Spheroid 6:1 – model validation against other specific turbulence models for transition modeling

For the three-dimensional prolate spheroid case, the γ-Re • turbulence model predicts late transition. Transition onset is calculated too early by the SA model. Our corrected turbulence transitional model behaves accordingly, correctly predicting transition in agreement with the experimental results, fig. 23.

The corrected model behaves more accurately than its original formulation. Comparisons between the commercial and corrected versions of the laminar kinetic energy transition model are in agreement. The effects of three-dimensional flows in transition are captured by the corrected model.
NUMERICAL RESEARCH ON POSSIBILITIES FOR EFFICIENCY INCREASE USING PLASMA ACTUATORS

A solver for both plasma and gas dynamics, based on the transport equations of charged particles and the Navier–Stokes equations, is developed in the OpenFoam environment for modeling nanosecond plasma actuators, fig. 24. Based on the results of the plasma discharge model, an energy deposition model was also developed for the simulation of the effects of DBD actuators. The accuracy of the solver was tested through comparison with the available results in the literature. It was shown that fast energy transfer, from plasma to fluid, leads to the formation of micro-shock waves responsible for modifying the flow. Also, a nanosecond plasma actuator for transonic flow over an airfoil was tested and verified.

A model for plasma discharge and its effect on the flow was developed based on scaling the thrust generated by DBD plasma actuators. The scaled thrust model correctly predicts the nonlinear dependency of the thrust produced and the applied voltage. These scales were then introduced into a phenomenological model to estimate and simulate the body force distribution generated by the plasma actuator. Although the model includes some experimental correlations, it does not need any fitting parameter. The model was validated with experimental results and showed better accuracy compared to previous plasma models. Moreover, the generality of the model was confirmed through validation with three different experiments. Finally, the model was tested for predicting the thrust for cases in which the altitude (pressure) is changing.

Universidade da Beira Interior, Portugal

Figure 24. Schematic illustration of a single–dielectric barrier discharge plasma actuator.
GREEN AND EFFICIENT PROPULSION SYSTEM BASED ON AIR-JETS. NEW METHOD FOR FULLY NUMERICAL IDENTIFICATION OF HIGH-ALTITUDE AIRSHIP AERODYNAMIC STABILITY AND CONTROL

Based on a developed code, and research approach for a classical airship design shape, the optimum value for fineness ratio is obtained. However, the computations for the bending stresses and deformations of the airship have shown that the classic shape is not acceptable for the MAAT requirements, being these stated beforehand.

In order to overcome the mentioned problems, and meet the project requirements, an innovative airship shape was implemented, which provides: vertical climbing as a stratospheric balloon and vertical control by the buoyancy force. This shape can also get over the problems related to the excessive bending moments and stresses; it is also resistant to strong winds with an ability to drift.

The geometric characteristics of the feeder airship shape introduced new challenges into the propulsion system. In this case an innovative propulsion system based on air-jets was assessed. This innovative design is appropriate for VTOL and horizontal cruise flight, having also the capability to vectorized thrust.

The air-jets system is environmentally friendly, being based on solar collected electric power, and can operate with a reduced air density, at low-Re with good efficiency, being also capable of fast changing the thrust direction. Also, the present approach for the propulsion system leads to a weight reduction for the airship. This is very important, since it also contributes for the decrease in gross power needed for propulsion.

Also, fully numerical dynamic model of high-altitude airship with innovative design shape and propulsion system is developed. Approaches used to attain the objectives of our study are application of dynamic mesh with spring-based smoothing, performed for every time step, and activated 6 DoF model with implemented equations of motion. An option to read forces and moments acting on the airship’s hull in order to obtain new CG position and implement it in the calculations for next time step was used.

Unsteady computations have shown that the stability and related to the propulsive system problems (due to inertia, added masses, pressure forces on the vehicle’s body, etc) lead to CG additional movement different from the envelope trajectory, development of vortex structures and to increase in propulsive requirements.

It is also observed that were introduced strong changes in both the drag coefficients and required power budget.

The change of vorticity during the disturbing movements of the CG lead to irregularity in pressure distribution around the hull and will

Figure 165. Figure 6. Changes in CG position in 3D aspect
introduce stability problems. Also, a change in vorticity means that there is additional force acting on the body under study.

The additional vortex structures provoke less aerodynamic performance and stability problems. The results obtained for this research are applicable as very important and strong basis for a study on the frequency of vortex shedding, stability problems and how they exert the propulsion system performance.

The numerical code developed in FLUENT, presents the aerodynamic behavior of the innovative design shape and its propulsion system during flight. The code simulates the interaction effects between the shape and the air-jets as part of the propulsion system. As a result of the performed research works were obtained - position and change of CG coordinates during flight; value of forces and moments acting on the hull’s structure; specific features in vehicle’s aerodynamics due to the observed instabilities. The results attained so far were applied to improve significantly the current state-of-the-art of the aerodynamics and stability determination, to obtain the restoring moment in order to control the airship and were implemented in control codes [53, 54]. The obtained simulation results are very encouraging in terms of predicting the airship’s dynamics and stability and how they are affected by the complicated flow around airship in flight. The numerical approach provides a certain level of confidence in its use to design efficient procedures for instabilities detection and next to perform control procedures for various flight applications.

Figure 176. Vortex shedding at three control section at the air-vehicle’s rear part. The colour map presents the velocity flow field realized around and after the airship.

Universidade da Beira Interior, Portugal
CONTROL SYSTEM DEVELOPMENT

SFEDU has provided work on detailed development of control system for MAAT system compatible with requirements of high reliability, energy efficiency. Functionality of control system includes cruising flight of cruiser, feeder, and docking control.

![Figure 187 – SFEDU personnel implementing control system on the consortium demonstrator at AEROSEKUR](image)

For this purposes general structure of control system was developed. It provides control of cruiser and feeder in autonomous, automatic and manual modes. The main units of this scheme are intellectual planner, controller and pilot. Intellectual planner generates trajectory of energy efficient flight in format and depending on mode submits this data to controller or to the pilot. Controller is active in automatic and autonomous mode calculating cruiser or feeder whole flight (autonomous mode) or flight to certain global point, defined
by pilot (automatic mode). Pilot controls actuators in bypass of controller in manual mode. Pilot control devices interaction with cruiser and feeder actuators is considered.

Software and hardware architecture, implementing this structure and algorithms, were developed. Developed software is a set of interacting processes. Data exchange between them is organized with named data channels in the stream and in one direction. Structure of software modules, implementing referent hardware and algorithmic modules was developed. It includes modules variables and methods development.

Hardware architecture considers issues of computers and sensors selection and connection. Recommendations for devices location were provided.

Researches are confirmed by simulation results, showing appropriate quality of control.
DEVELOPMENT OF DOCKING DEMONSTRATOR

The aim of the WP8 is the realization of the reduced scale demonstrators in order to evaluate the proposed technical solutions about docking, control systems and materials.

The demonstrators foreseen for the MAAT program are of three different type.

Each of them has been specifically designed to investigate one or more technological aspects, identifying possible criticalities in the technologies to be implemented on the full scale airships.

For this reason, no demonstrator has the aim to reproduce the whole complexity of the MAAT project, neither the equipment or the exactly shape of the full scale airships. They are representative of those aspects involved in the test activities for which they have been thought.

The three demonstrators and relative topics are:

- control demonstrator, designed to test the systems dedicated to the airship’s flight control;
- docking demonstrator, designed to test the capacity of two airships to move towards and join together;
- cruiser demonstrator, designed to test the use of Hydrogen as buoyancy gas.

Aero Sekur had the responsibility for the docking demonstrator.

Figure 198. Docking demonstrator

The docking demonstrator wants to investigate the critical aspects concerning the flight, the approach and the docking of two airships of different shape and dimensions. This demonstrator is composed of two different airships, the Feeder (Figure 28) and the Cruiser (Figure 29).

The docking configuration will happen as reported in Figure 30.

Figure 209 - Cruiser demonstrator

www.eumaat.info
Figure 30. Final docking configuration

The structures are designed as a compromise between light weight and good stability, because they shall support the propulsion systems and the equipment, keeping good stability and control performance to the airship.

Materials

The materials used for the envelope construction are desirable to have the following properties:

- **High resistance** - The resistance of the fabric determines the maximum dimension (volume) achieved by the envelope and the maximum height reachable.
- **High strength / weight ratio** to minimize weight.
- **Resistance to external environment** - Moisture, ultraviolet rays and variations temperature resistance, allow a longer duration of envelope and reduced maintenance costs (defined as the ratio hour flight / maintenance hours, and as maintenance specifications).
- **Low permeability** to minimize the leakage of gas.
- **High tearing and laceration resistance** to ensure behavior "damage tolerance".
- Joining techniques likely to realize persistent connections, durable and reliable.
- Low creep to guarantee that the shape of the envelope will be maintained in the time.

Since these airships will be used as indoor prototype, some aspects like the resistance to external environment or the low creep can be overlooked.

Moreover, since the filling gas will be Helium instead of Hydrogen, it is not necessary that the material has an antistatic coating.

The candidate material have been selected in function of three key parameters:

- weight;
- Helium permeability;
- mechanical properties.

For the envelopes, several material have been evaluated, in order to find the most suitable material to best withstand both weight and permeability requirements. The most promising materials have been tested, especially tensile tests and Helium permeability tests have been performed.

Among the considered and tested materials, have been selected the Tuftane TF310, a polyester thermoplastic Polyurethane film (Figure 31).

Figure 31 - Cruiser demonstrator
In Table 1 are summarized the properties of the candidate material.

<table>
<thead>
<tr>
<th>Table 1 - Material properties</th>
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<tbody>
<tr>
<td>Tuftane TF310 - 50µm</td>
</tr>
<tr>
<td>Weight</td>
</tr>
<tr>
<td>Thickness</td>
</tr>
<tr>
<td>Permeability</td>
</tr>
<tr>
<td>Tensile Strength</td>
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<tr>
<td>Elongation</td>
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</table>

The joining technology has been evaluated. Ultrasonic welding has proven to be the best choice. Ultrasonic welding is an industrial technique whereby high-frequency ultrasonic acoustic vibrations are locally applied to workpieces being held together under pressure to create a solid-state weld.

For the structures and the docking system, different light materials have been used:
- carbon fiber (tube)
- polycarbonate (rings and main plates)
- aluminum alloy (rigid frame of docking system)
- ABS plastic (some parts of docking system)

The problem to solve was to made an attraction system between the feeder and the cruiser, allowing the locking of the feeder during the descent phase and the detaching of the two units at the take-off phase, with the minimum needing of power supply and the minimum weight.

For this purpose it has been selected the properties of permanent magnets, and of Shape Memory Alloy material. It was designed...
and manufactured an aluminum frame, fixed on the cruiser, making the base for the docking system. The magnetic force is realized with permanent magnets located on the cruiser structure; the detaching force is done by a Shape Memory Actuator.

The selected magnets will be Mounting Magnets type, strong neodymium magnets that are set inside a steel cup or channel, as shown on the following picture (Figure 36):

![Figure 36. Figure 1 - Mounting Neodymium Magnet](image)

A Mounting Magnet offers much more strength than the magnet alone. The magnet out of a Mounting Magnet, will give half the pull force that the fully assembled.

Their construction consists of a disc or ring magnet sitting inside a steel cup. With a plain disc magnet sticking to a steel surface, the magnetic field looks as shown in the top part of the magnetic field picture at left. You get a strong attraction where the magnet touches the steel, but the magnetic field on the opposite side of the magnet isn't doing much to provide pull force.

With the steel cup of a mounting magnet, the steel structure redirects the magnetic field from the back-side of the magnet, turning it into more useful holding strength. A Mounting Magnet gets a lot of its strength by the steel cup attracting to the surface, because the steel cup is magnetized by the magnet. In the magnetic field picture, the steel cup looks purple on the colour scale because the steel is magnetically saturated -- as full of magnetic flux as it can get.

About the Shape Memory Alloy (SMA), it is a technology which can provide the same mechanical movement and required forces of an electromagnetic actuator but in a more compact form, while removing the need for motors, gearing or springs.

Shape memory alloys (SMAs) are metals that “remember” their original shapes. The large force generated upon returning to its original shape is a very useful property.

The characteristics of SMA material Direct Electrical Heating Nitinol wire can be activated using a low voltage DC (12volts) power supply. When activating a Nitinol wire wire using DC current it is important not to overheat the wire by keeping the current on too long. Overheating the Nitinol wire will degrade its properties. DC current doesn't heat the wire evenly. An electrical circuit that uses Pulse Width Modulation (PWM), heats the wire more evenly and is better for activating Nitinol wire. When you switch on the current to the nitinol wire, the wire heats up quickly, contracts his length of 3,5% with a force variable with the wire diameter. When power is removed the wire cools, allowing the Bias spring to elongate the nitinol wire and return to its initial position.
Nitinol wire usually has a counter-force applied to it in the opposite direction of its contraction. The counter force resets, or stretches the wire back to its original length when in the low temperature phase. This is called the bias force. If the nitinol wire is brought to its transition temperature without a bias force it will contract, however, when it cools it will not return to its original length.

The maintaining of the contracted position is realized with a modulation (PWM) circuit. Activating nitinol wire using pulse width modulation has distinct advantages. Pulse Width Modulation turns the current on and off to the nitinol wire very quickly. The oscillating on-off of the power allows the heat to flow to cold spots making for more even heating of the wire (reduces hot spots). The duty cycle of the square wave output can be varied from fully on 100% to fully off 0%. The duty cycle of the square wave can be varied to generate a degree of proportional control over the contraction. These factors allow us to activate the Nitinol wire with better control for longer periods of time without causing heat damage to the crystalline structure of the Nitinol alloy.

The chart on the left shows the heat response of Nitinol wire. You can gauge from the chart as the Nitinol wire is heated it contracts and as it cools it can expand again. This is the same information that's been provided before. What is new is the "H" area in the chart, this represent the hysteresis. There is a hysteresis curve for every Nitinol alloy. Hysteresis is a retardation of movement when there are thermal changes acting upon the Nitinol (as if from viscosity or internal friction).

The Nitinol wire utilized for this project is a 0,4 mm diameter. The characteristics of this wire are depicted in Figure 40:

The brackets are moved by an actuator, acted by a Shape Memory Wires.

The mechanical device to allow the movement away of the Feeder iron plate and the permanent magnets is described in the following paragraphs.

The locking device on the feeder is made by two iron plate, shaped to allow a maximum positioning tolerance during the docking phases between cruiser and feeder.

In OFF position the plates of the Feeder are on the upper level of the frame, so they are in contact with the magnets: in this way the attraction strength is activated.

When the actuator is turned ON, by a small electrical current, the brackets rotate on their axis and the permanent magnet plate will move away of some millimeters, interrupting the contact with the iron plate and increasing the distance between the plates.

In this way the attraction force is removed.
Figure 228. Electrical Heating (PWM)

Figure 39. SMA Wire technical characteristics

Permanent magnets

Figure 40. Docking device and SMA actuator
Figure 41. Docking device

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AIRSHIP PROJECTS AND COMPANIES WORLDWIDE

Airship research has increased during the last decade. Find below a useful collection of links to interesting projects, companies and activities related to modern airships:

- Aerosurve
- The Airship Association
- Airship Solutions
- American Blimp
- Airship Ventures
- ARL - Airship Research Lab
- Dynalifter
- Flying Yachts
- Hybrid Air Vehicles
- Lindstrand Technologies
- Isopolar
- Pegasus
- Skylifter
- United States Naval Research Lab.
- Vertical Airships
IMPRINT

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