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MAAT Cruiser/Feeder Project: Criticalities and Solution Guidelines

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ABSTRACT

MAAT project is a large airship project presented to the last European 7 Framework Program Transport including Aeronautics 2011 deadline. MAAT project is an airship based cruiser-feeder transport system. This paper analyzes the criticalities of the project and the way to upfront these problems which have different natures and possible solutions. Most important criticalities are analyzed both on a methodological point of view and on a direct point of view. Enhanced design methodologies are analyzed in depth to analyze problems, upgrade the project design status continuously and to examine different design options and solutions. An innovative design method has been defined to avoid that problems can produce show stoppers and minimize time delays during project definition.

INTRODUCTION

The aim of the MAAT (Multibody Advanced Airship for Transport) project is to finalize the definition and the design of a new global transport system based on the cruiser/feeder concept [1, 2]. It applies to middle and long range continental and intercontinental transport service based on a new generation of air vehicles. The project of an innovative idea according to principles of basic research and the development of organizational principles follows a precise methodology and an organizational form.

The MAAT project aims to produce a feasibility study and a general design implementation of a modular system composed of three main subsystems:

- the cruiser core PTAH (Photovoltaic Transport Airship for High-altitude);
- the feeder element ATEN (Aerial Transport Elevator Network Feeder);
- the urban airport hub AHA (Airship Hub Airport).

The main directive relating to system design is related to harmonize functional modules using well known technologies and subsystems, if possible. This general design directive aims to reduce the possibility of system faults by the use of well tested solutions, and reducing the innovation to the parts of the project strictly related to the new functions provided.

The project is related to a long term feasibility study based on the cruiser feeder/concept and needs to be analyzed in depth as a complex but unitary vision. The work organization is deeply inspired need to study the system and its components in a structured and systemic approach conditions. This necessary systematic approach needs a highly interdisciplinary work. The organization is conceived to encourage the continued dialogue between the different partners and promote the dissemination of information among the project participants.

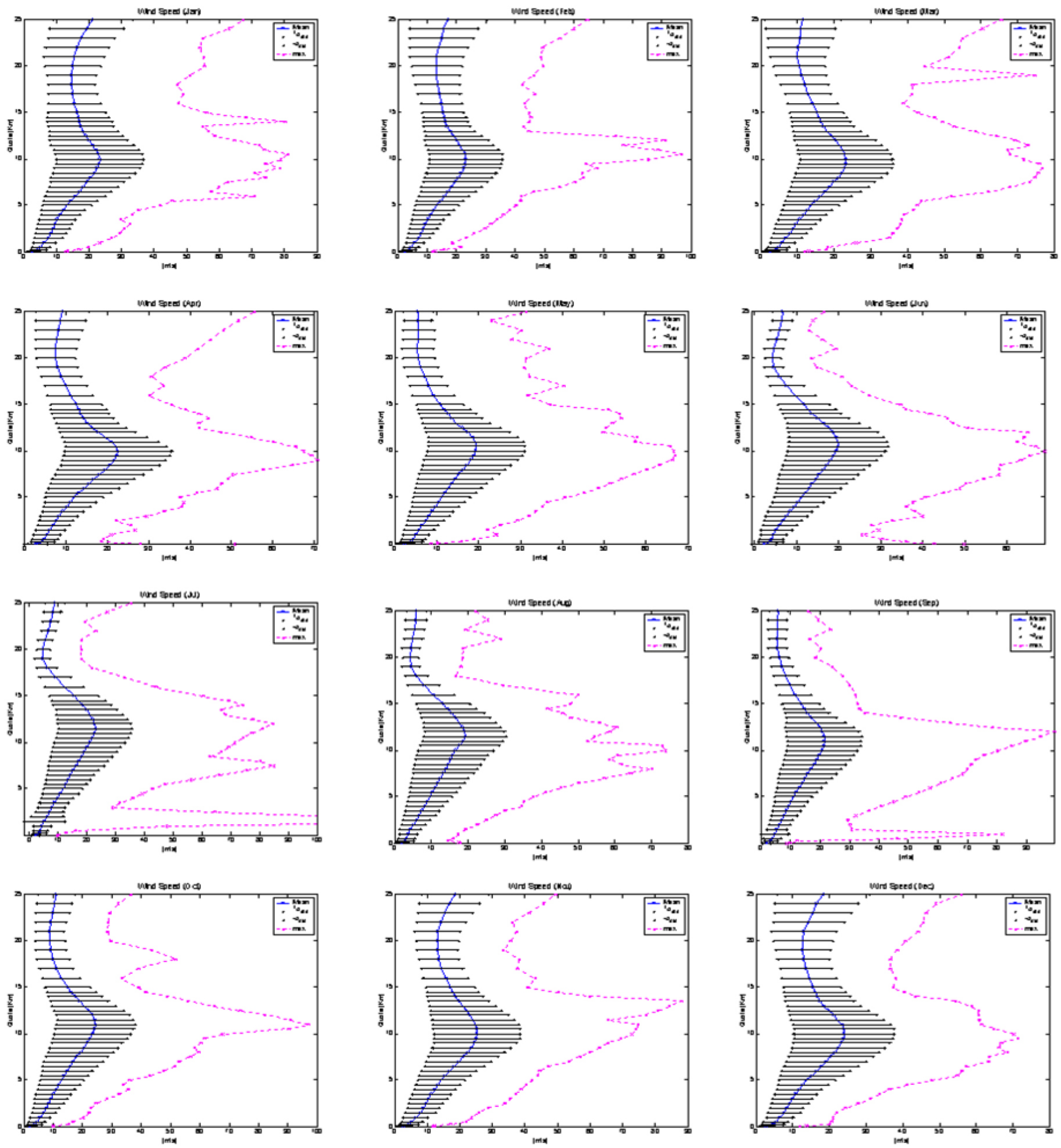

Figure 1. Wind speed monthly tables (near Bologna - Italy latitude 44.5 N); blue line indicates average values and pink one indicates the maximum value.

The specific call in which the project is inserted needs to study the system and its components in a structured approach, because of the complexity of the argument. The project needs an organizations for thematic It is organized to maximize the internal possibilities of a continue control of the obtained results and will contain 9 Work Packages, of which 7 are technical work packages, with different functions to achieve the project aims.

This structured and systemic approach is guaranteed by organization, which is characterized by a strong coordination by WP0 Project Management and Coordination (which guarantees the project and by the introduction of a strong technical coordination by WP1 System Design and Engineering. The effective organization of the system is oriented to a matrix organization because it permits the best interaction between participating subjects.

MAAT PROJECT CRITICALITIES

The MAAT project has been presented more in depth into another paper presented at SAE AEROTECH 2011 [1] and in the project presentation realized for European Commission [2].

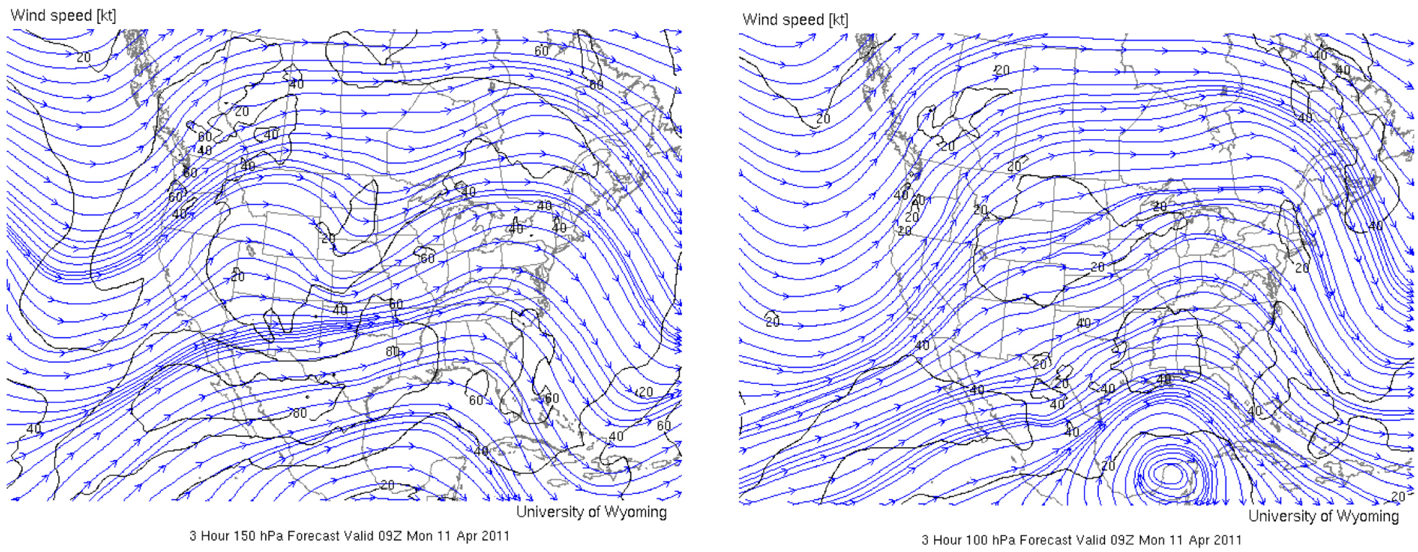

Figure 2. Jet stream Forecast Maps at various altitudes (University of Wyoming - http://weather.uwyo.edu***)***

The MAAT project is a modular integrated airship cruiser based on a cruiser core (PTAH) with remains airborne for long times and can be connected by more feeders (ATEN), to create a complete cruiser. Feeder connects the cruiser core to the airport hubs (AHA). This innovative architecture is conceived to enhance the system effectiveness and intrinsic safety during operations. This design concept is defined for enhancing the safety of the system and to permit feeder approach, engagement and joint in hovering conditions, reducing to the minimum the hovering waste of time because the passengers and/or freight transfer can be safely realized with the cruiser on the move. In particular feeder engagement operations both with cruiser and feeder are deeply analyzed both in terms of safety and connected hybrid systems that can permit a safe joint also in presence of high wind speeds (30 knots or more). Both cruiser and feeders presents a good scalability, and aerodynamic performances can be evaluated varying overall system dimensions [12].

EFFECTS OF CLIMATIC CONDITIONS ON OPERATIONS

The system needs to be dimensioned with a maximum service ceiling much higher than common operating conditions. This exigency is directly connected with the typical wind profiles.

Other important physical parameters are plotted on Figure 9. These parameters permit an effective determination of main aerodynamic parameters such as Reynolds and Mach number. These data permit also to study the system in terms of aerodynamic similitude and volumetric scalability of the system.

Wind profiles are plotted for example for the location of Bologna, Italy. Wind altimetry profiles permit to define the optimal altitudes for travelling and for cruiser feeder rendez vous. Such graphs can be plotted for any location and using them the optimal altitude for any kind of operation can be defined. In particular rendez vous altitude can be considered much higher than cruising one, because it needs to be in correspondence of the minimum wind speed. Common operative range of the cruiser can vary between 13 and 17 km, even if a supplementary over altitude can be necessary. The maximum gas volume of the system is then calculated considering a higher operative ceiling.

It is also possible to define precise forecasts about jet stream positions at various altitudes such as the ones produced by University of Wyoming (in figure 2 is represented the maps at different altitudes over the northern hemisphere related to a particular day of the year). Mixing results from historical wind profiles (Figure 2) and jet streams forecasts (Figure 3) optimal operative conditions can be determined both for rendez vous and travel.

Jet streams allow also defining optimal routes and optimal cruise altitudes which can guarantee the best compromise between speed, comfort and safety.

As figure 9-d indicates this altitude is also higher than clouds and so is higher than most meteorological phenomena. Cruise altitude can be reduced in order to use (if structural design and analysis will give adequate results) higher speed winds such as upper regions of jet streams to enhance cruiser performances.

By these considerations daily routes and optimal positions for rendez vous operations can be determined.

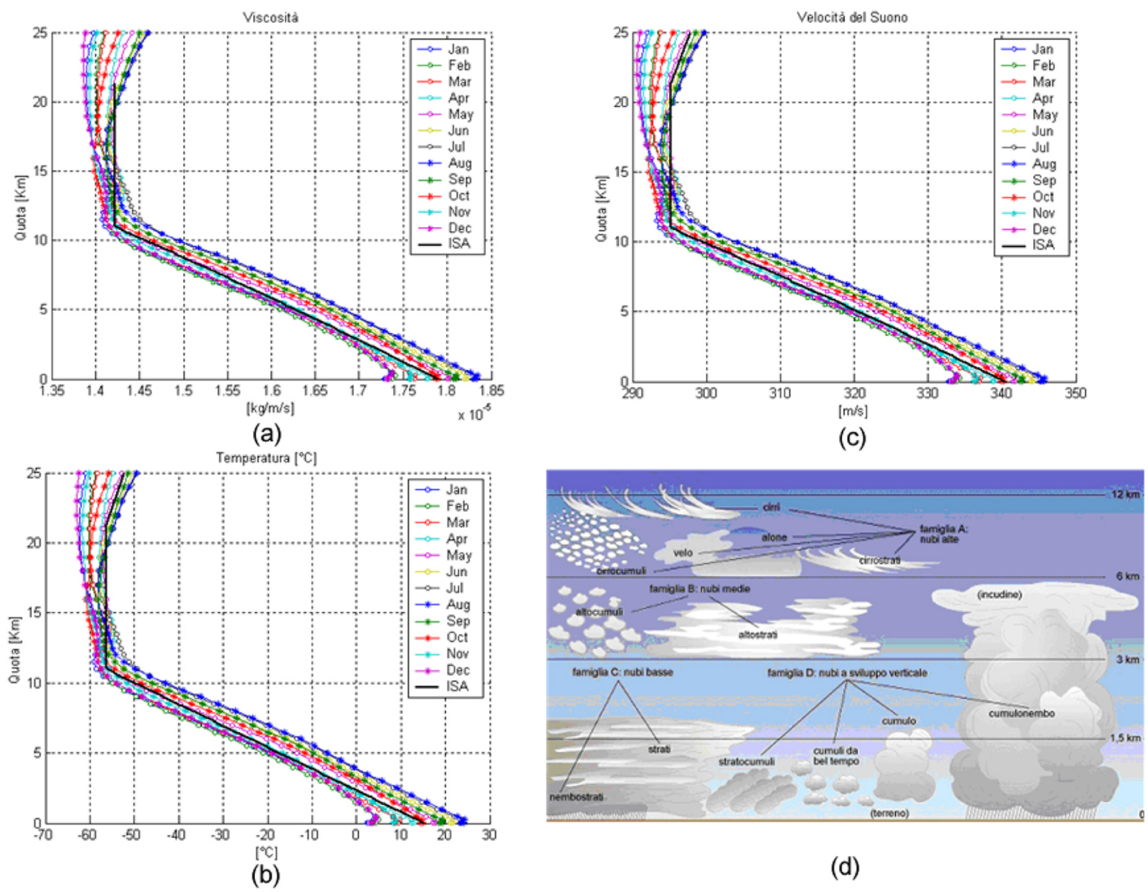

Figure 3. Main atmospheric properties (a) Viscosity, (b) Temperature, (c) Sound Speed and (d) Clouds altimetry (Bologna, Italy).

TIME FOR TRAVELS

In order to evaluate the time for travelling it has been evaluated the time necessary for flight operations.

In particular, times connected to the system have been evaluated both in terms of parasite time and I term of total time for a flight. The graph in figure 11 shows times including parasite times for a travel with different lengths. In particular it can be verified that the MAAT cruiser feeder system can be competitive also in terms of journey times for movements rather short (on the order of 1000 km).

Table 1. Time estimations for ground based operations

	Airplane [h]	MAAT [h]
Time for airport operations	2.50	1.00
Time for ground travels	1.00	0.00
Time for takeoff and landing	0.50	1.00
Total Dead Times	4.00	2.00

Parasitic times involved to ground operations and movements are evaluated in Table 2.

AERIAL OPERATIONS GUIDELINES

The autonomy of flight of cruisers is enormously superior to any airplane but logistical fluxes of people and goods from one cruiser to another will be defined in order to define by the MAAT concept a worldwide connection networks which can open new frontiers to worldwide logistic network system.

This system is much slower than any actual jet airplane. There is a similar situation comparing high velocity trains and the buses. Both satisfy needs of the costumers having different missions. Cruiser speed can be evaluated between 100 and 300 km/h, depending on wind intensity and direction. It is expected that it can be also faster if the system if the designed system will result able to flight using the currents of the jet streams as extra boost.

COMFORT GUIDELINES

The system is conceived to be a complete and comfortable transport system. Cabin and cargo architecture will be studied together with transferring systems both for crew, passengers and goods from the feeder to the cruiser and vice-versa. One of the most important strongpoint of the MAAT project is

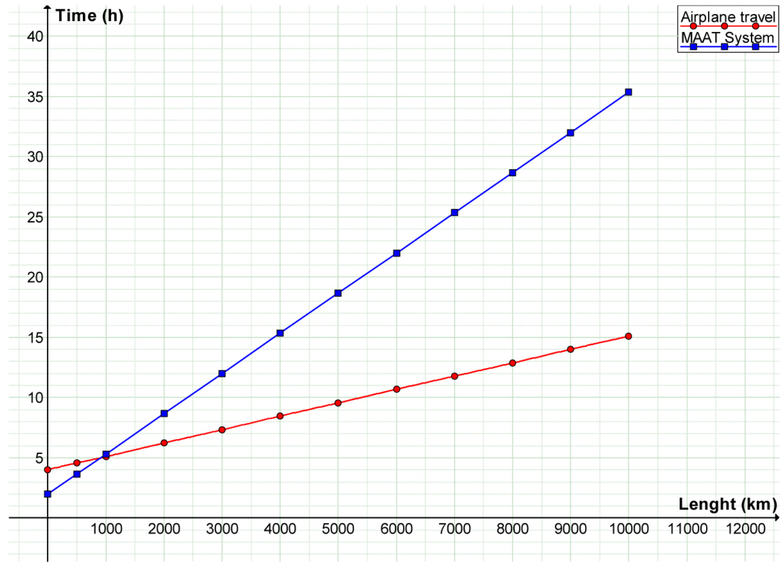

Figure 4. Times for a nonstop flight of different lengths.

related to a superior flight comfort which is guaranteed both by almost 10 times increased space for passenger if compared to the traditional aircrafts and more comfortable travel conditions more similar to sea ships granting possibilities of movement and a on board stay which is similar to ground living conditions. These comfort related aspects will produce a novel transport concept slower than traditional airline operations but actually on a human scale.

The better internal and living conditions will mitigate longer travel durations and possible delays which can be due to meteorological conditions during flight.

GROUND BASED OPERATIONS GUIDELINES

The unique architecture of cruiser and feeder is a completely VTOL vehicle. The vertical thrust will generate a new concept of innovative airport hub which can be installed in correspondence to intermodal connections of public transport will be designed to ensure the best possible system usability even inside urban environment:

• the acoustic impact of the air transport on the towns and human communities will be drastically reduced by the use of the buoyancy and the electric propulsive system of the feeder;

• the innovative concept of airport hub AHA can be easily deployed in urban environments in correspondence with intermodal transport nodes.

This novel vehicle philosophy will permit to the air transport to break the traditional access barrier constituted by noise and the necessity of long runaways. This new environmental friendly system will produce a reduced consumption of soil due to air transport together with the possibility of being completely integrated with urban transport existing infrastructures.

CLIMATIC CONDITIONS AND THEIR EFFECTS

The weather is claimed to be the most relevant problem related to airship operations. This assertion requires some additional considerations. An airship is not a free balloon. Its propulsive system gives a handling and steerage capability. Its structural resilience, riding quality, control responsiveness and other attributes provide altogether excellent weather handling qualities. In short, today airships can and do fly in all weather conditions in which fixed-wing aircraft can fly. The only restriction which applies to contemporary airships in severe weather is the ability to take-off and land in winds exceeding 30 knots. This project aims to overcome this traditional limitation enhancing it to 50 knots.

In particular airships are not negatively affected by icing and snows, which can be catastrophic for transport based on traditional airplanes. The cruiser shape propulsion and movements must be designed to minimize the problems related to weather conditions, even if some delays remains possible, especially in presence of violent storms and high speed winds. On the other hand the MAAT system is not affected by severe temperatures, minimizing the potential discomforts due to one of the most important delay causes related to traditional aerial transport.

It can be concluded that retards cannot be avoided, but their causes are different. Their dependence on wind velocity creates a different distribution during the year of these delays and forces to reduce their seasonal impact. Two elements of

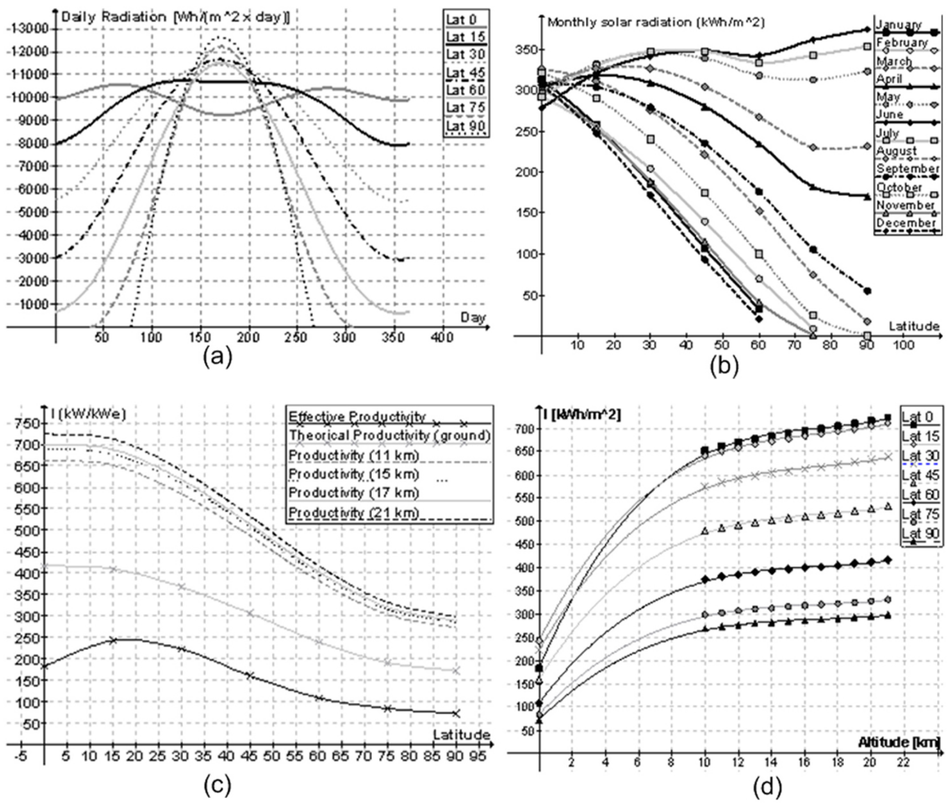

Figure 5. Solar radiation and photovoltaic electric production for square meter of PV horizontal flat plane: (a) Daily solar radiation calculated by Solpos code; (b) Montly solar radiation at different latitudes; Productivity at various altitude calculated as a function of latitude; PV productivity at various latitudes as a function of altitude.

the system can reduce their impact and consequent distress conditions:

• the position of the novel airport hub, placed inside the town and closer to transport interchange nodes allows to avoid long stays in isolated structures, such as the current airports, which are not always easy to reach and often too distant from population centers;

• the increased internal comfort and the increased space for passenger permit a more comfortable travel, also in presence of possible in case of possible delays due to bad weather.

ENERGY PRODUCTION SYSTEM DESIGN GUIDELINES

One of the most important criticalities related with the use of a photovoltaic propelled air-vehicle is related to difference in solar irradiation due to latitude and altitude. These problems have been deeply analyzed in recent papers [78, 79]. A paper [79] also includes an evaluation of hydrogen productivity in terms of compressed hydrogen (200.00 bar) or liquefied. In particular solar irradiation and produced energy has been defined as productivity for 1 m^2 of a PV horizontal flat plane. High altitude results are calculated by using NIST SOLPOS Code.

By this analysis it is possible to make a parametric analysis of photovoltaic electric production for different location at various altitudes and it is also possible to define the optimal PV field dimension to be mounted on top of feeders and cruiser systems.

The methodology used for this parametric study is also important to be applied, using real meteorological data to define the photovoltaic field if problems that can arise will force a lowering of operative altitudes at values lower than 11 km. These values are not optimal as we can see by wind speed graphics. These altitudes present more turbulence problem an increased aerodynamic resistance and an increased variability in winds directions.

The energy production system is designed to ensure an optimal electric production, which must ensure an adequate production at optimal operative altitudes.

ENERGY STORAGE SYSTEM

The energy storage system must be dimensioned correctly both with an important protection to prevent fire accidents and their propagation to hydrogen balloons. This system will be constituted by a mix of two different technologies.

Table 2. Comparison of some aircrafts with MAAT concept

	B747-8	B777-300	A340	A380	Average considered planes	MAAT	Units
Price	317.5	284.1	275.4000	375.3000	294.9600	600	millions USD
Passengers (3 classes configuration)	467	365	380	525	406	510	
Empty weight, operating	185980	167800	245800	276800	200176	500000	kg
Maximum range, fully loaded	14815	14690	14360	15200	13979	100000	km
Service Ceiling	13746	13140	12530	13130	13015	18000	m
Maximum fuel capacity	64225	47890	43090	85472	53287	0	US gal
Maximum fuel capacity	243	181	163	324	202	0	m3
Kerosene Average Price	4	4	4	4	4	4	USD/US gal
Maximum Fuel Cost	256900	191560	172360	341888	213150	0	USD
Average consumption	15.5897	11.7236	10.7909	20.2217	12.9869	0	l/km
Average cost for km	16.4735	12.3882	11.4026	21.3680	14.4855	0	USD/km
Average cost/passenger/km	0.0371	0.0357	0.0316	0.0428	0.0359	0	USD/passenger/km
Other costs	0.0350	0.0350	0.0350	0.0350	0.0350	0	USD/passenger/km
Total Costs	0.0721	0.0707	0.0666	0.0778	0.0709	0.0400	USD/passenger/km
Lifetime	50000	50000	50000	50000	50000	100000	ours
Annual cost	74.2519	56.9316	55.8897	89.9185	64.1604	30.6000	millions USD
Financial leasing (20years, 4%)	21.2302	18.9968	18.4151	25.0951	19.7230	40.1200	millions USD
Total Annual Costs	95.4	75.9	74.3	115.0	83.9	70.7200	millions USD

Table 3. Maximum volume evaluation

	Cruiser/feeder	Feeder only	Cruiser only	
Freight Weight	76550	12758	50000	Kg
Fuselage weight	125000	5000	95000	Kg
Other structural weights	298450	29845	119380	Kg
Balloon Volume	5000000	476033	2143800	m^3

The first technology is constituted by electrolysis and fuel cells. Electrolytic hydrogen and oxygen is a good energy storage method for any energetic use with a nearly constant demand. In particular fuel cells can also assume the important role of heat generators for many onboard uses, including thermal regulation of buoyant gasses necessary to maintain the correct altitude during night time. On board production of electrolytic hydrogen is also important for the replacement of buoyant gas dispersed by the unavoidable permeability of the balloons. The water consumption can be integrated by feeders.

The second technology is constituted by traditional batteries. In particular high capacity and lifetime battery can be used for any transient electric consumption, including emergencies.

The definition of the optimal mix of storage technologies will be one of the key elements of the project.

PRELIMINARY MAAT SYSTEM ASSESSMENT

This paragraph is dedicated to present a preliminary analysis of advantages and disadvantages of the MAAT cruiser feeder system if compared with traditional aircrafts. Different evaluations are produced: economic, payload and volumes.

In terms of costs for MAAT system it has been evaluated a configuration with six hubs and 12 feeders six on the ground and six on the MAAT cruiser/feeder Platform.

The main financial advantage related to the MAAT cruiser feeder platform is that it is not sensible to energy prices variation and so can guarantee a better economic and financial planning for the future activities.

Other considerations can be effectuated on the necessary volume of hydrogen at the service ceiling. It can be evaluated in Table 4. In particular data in Table 4 are defined assuming a maximum operative ceiling of about around 18 km. A little over volume is guaranteed to allow supplementary emergency maneuvers. Density of air and volume of hydrogen necessary to maintain the system at different altitudes has been evaluated and plotted (Figure 6).

By the graphics plotted in Figure 12 it can be also verified that the hydrogen balloons volume to be guaranteed for avoiding crashes and maintain the system at about 4 km can be evaluated about 0.7 10^6 St m^3.

Similar evaluations can be performed both on Cruiser alone and on the feeders.

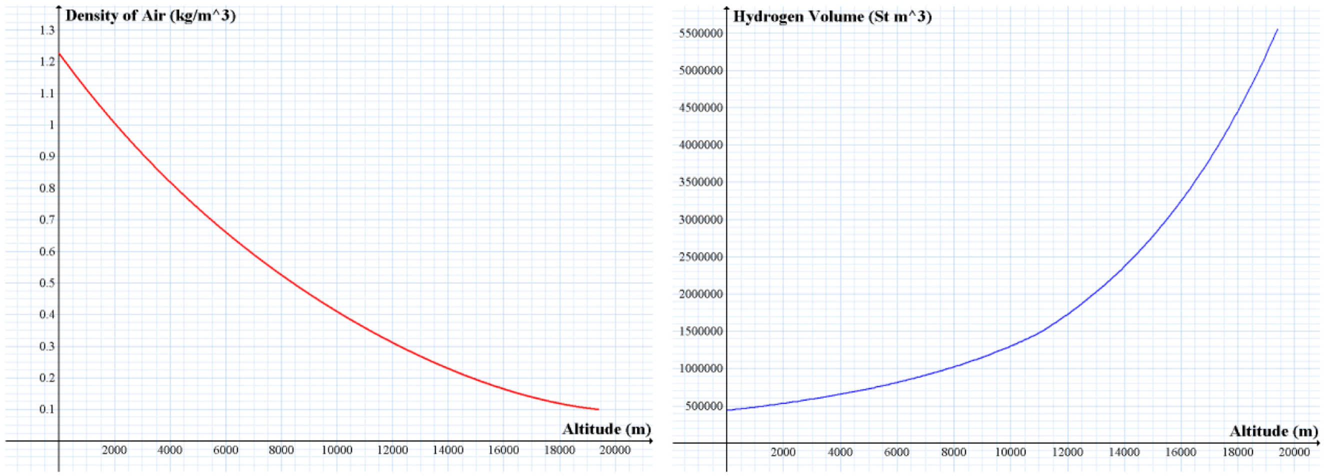

Figure 6. Atmospheric density and hydrogen required volume for about 500 tons mass of the MAAT system as a function of altitude.

SAFETY DESIGN OVERVIEW

SAFETY DESIGN GUIDELINES

The intrinsic safety of the system is success key of the system because the capability to prevent by design deadly events such crashes on the ground is guaranteed by design. In particular both an accurate Fault Three Analysis and an innovative design characterized by redundancy of safety systems and protections will ensure the definition of an airship transport system with the intrinsic ability to overcome the traditional perception of low security levels connected with airship transport. Other on board safety systems which can permit to the MAAT modular airship to become the most effective and safe air transport system will be defined during the project evolution.

PREVENTION OF CRASHES

MAAT system is defined to ensure the maximum level of safety, being capable of crash prevention. Buoyancy system design is conceived as a multi-balloon system. The presence of an emergency balloon can ensure minimum buoyancy in the case of catastrophic events. This novel safety concept will be designed to guarantee safety levels higher than any other flying system. It can guarantee that the system will not crash even in case of dangerous failures. Only 15% of the maximum volume of balloons can prevent crashes on the ground both for cruiser and feeder sustaining them at 4 km altitude.

EMERGENCY LANDING AND ENERGY REQUIREMENTS

The decrease of operative height is related to a system problem or to a system general failure. In this case the energetic needs are guaranteed to move the system to a safe position for emergency landing operation, which will be defined during the project.

FIRE PROTECTION

The electrostatic and fire protection of the system can be ensured by passive and active systems. Passive systems include in particular the choice of materials which can guarantee a good level of fire protection for cabins and cargos and low flammability especially for ballonets and external shape envelopes. Active systems are related to cabin and cargo protection, including fire extinguishing plants and the possibility of detachment in case of extreme emergency conditions.

ELECTROSTATIC PROTECTION

MAAT system is exposed to the atmospheric electrical environment, which includes electric fields, electrostatic charges, and lightning. Protection from hazards presented by these environments is necessary. The consequent risks can be avoided using both antistatic materials, and electrostatic diverters strategically placed on the system shape, according to Transport Airworthiness Requirement (TAR) developed by German and Dutch authorities for certification purposes. Due to its large physical size MAAT, both ATEN feeder and Cruiser core structure PTAH, would require a network of lightning diverters spaced strategically around the envelope to reduce the electric fields within the envelope to non-ionizing levels.

PROTECTION OF ONBOARD ELECTRONICS

Due to the extremely low humidity in high atmosphere, very large static charges can accumulate, causing also a major hazard for the complex electronics. Airships Additional

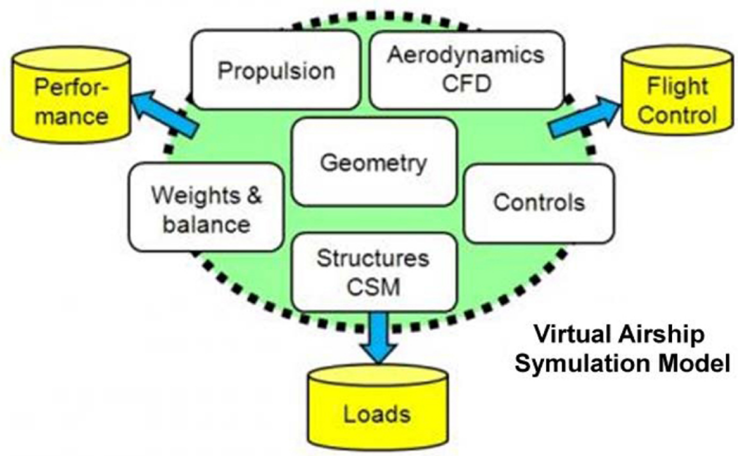

Figure 7. Design parameters and their influence

protection was required for electronic control systems and avionics since the airship was to be fully "fly by wire" and can necessitate some long electrical circuits whose exposure to onboard and external electromagnetic environments would be higher than the usual aircraft EMI environments.

DESIGN METHODOLOGIES

Problems may arise during the project. They must be addressed on a methodological point of view to avoid that they materialize as show stoppers. In particular two different methodological approaches:
• Integrated Testing Methods (ITM) to verify different design alternatives both stand alone and integrated into the project by steps of advancement;
• Collaborative engineering environment (CEE) to allow a more effective cooperation of all partners to the project analysis and development.

ACCELERATE TESTING METHOD

MAAT Project is a typical system that interacts with the physical world. It should be designed with a high degree of safety. To reduce risks it is helpful to introduce methodologies that favorite a continuous verification process of MAAT subsystems by formal methods and according to system requirements, based on a partition of the system into the objects from which it is built.

To accelerate the evaluations of different possible technological and technical choices computational models can be used. Different subsystems can be tested standalone or integrated.

This methodology is specifically designed for MAAT project, but can apply to any complex system which is safety critical, such as any other transport system. This method requires a description of the system from the beginning of the design activity with decreasing levels of abstraction.

This approach is necessary to test different technical solutions relating to a large complex system described by many physical laws. This approach is conceived to build and improve a formal mathematical model of the system. By this model based on different levels of abstraction it is possible to define an innovative modeling and verification method divided into stages, with a loop methodology, as described in the figure above.

This partitioning method is specifically defined to allow corrections and implementations into complex system design allowing them to be built from the start and avoids problems which otherwise would only be found after the initial design is complete. The main effect of this operative methodology is focused on describing the system requirements by examples of their usage in operative cases, and on allowing verification of the gathered requirements and represents a starting point for the analysis. The analysis of the different subsystems hierarchically decomposes them according to the abstraction levels that build the system model, with respect to the abstraction level boundaries.

This stage of the methodology design system model has all the features described in the requirements and is a backbone of the model used in the system verification process. All the necessary information is gathered during the design of the system model. The final verification of the system and the possible parameters of the system are done by hybrid automaton and by the final realization of a prototype. This approach builds and verifies the system model by steps of advancement and simulates the effects on the overall system design and model of different subsystem architectures. This makes it possible to compare the effects of different design solutions, minimizing the risks of bottlenecks and showstoppers.

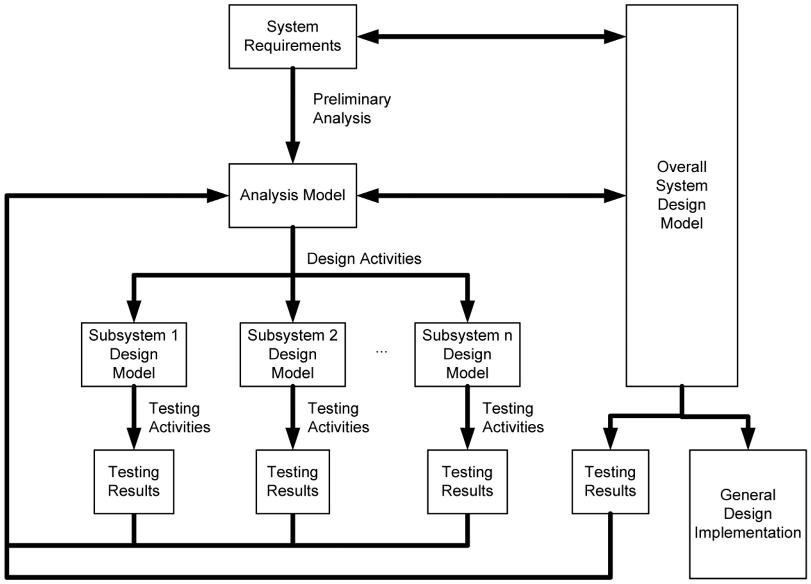

Figure 8. Design Method to reduce bottlenecks and showstoppers.

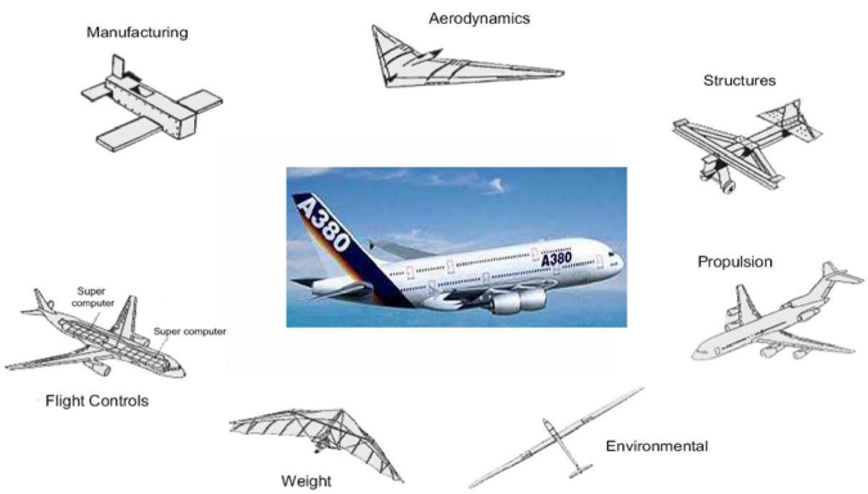

Figure 9. Multidisciplinary domains in the aircraft design process

COLLABORATIVE ENGINEERING ENVIRONMENT

The use of ITM methods and the MAAT project nature of complex multidisciplinary engineering problem require that all the human, experimental and computing assets are used efficiently.

Thus, as an overall approach for working together, it is needed to establish a collaborative engineering environment (CEE), in order that all the MAAT team members can bring their results quickly in evidence to the entire MAAT consortium. Thus the virtual prototyping and coming fast to the 3D/4D model of the MAAT cruiser is an essential step to have a virtual experience of it behaviour and related analysis.

Within such collaborative engineering environment equipped with large display hardware, it is possible to create a central virtual design office, a main control room for shaping our engineering activities of all the team members, enabling their remote presence to perform “Data exploration” and “Design decisions” based on the M&S results, from all our resources, at the one or more places, in time and space.

The provided ITM method and CEE infrastructure are the best way to manage possible problems and different design alternatives by a methodological point of view avoiding that they degenerate into dangerous show stoppers. In particular these technologies can improve design effectiveness and advance the chances to deliver on time our work.

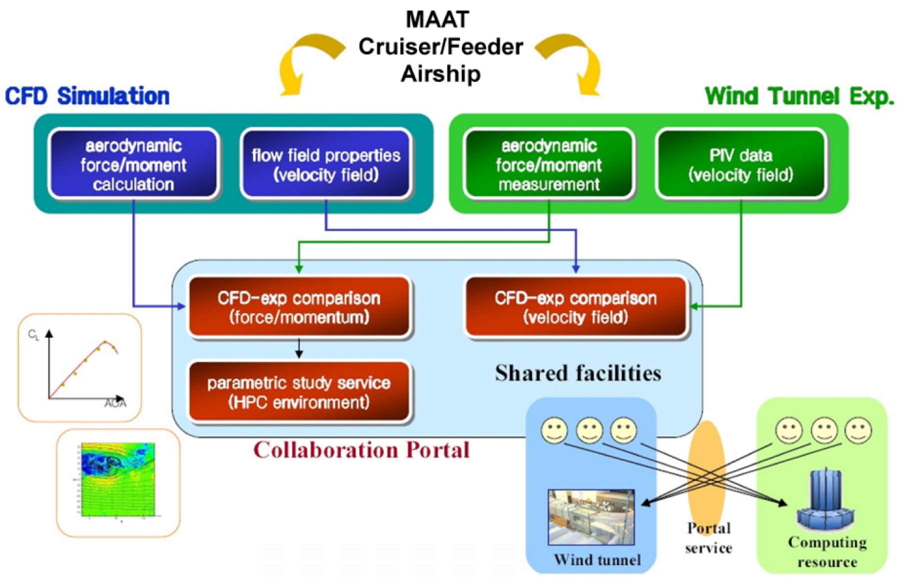

Figure 10. Integrated M&S Environment

Table 4. MAAT Project participant list

Participant N°	Participant organisation name	Organisation short name	Country
1	Università di Modena e Reggio Emilia	Unimore	Italy
2	Universidade da Beira Interior	UBI	Portugal
3	LogisticNetwork Consultants GmbH	LNC	Germany
4	The University of Hertfordshire Higher Education Corp.	UH	United Kingdom
5	Southern Federal University,	SFEDU	Russsia
6	Engys Ltd.	ENGYS	United Kingdom
7	University Of Lincoln	UOL	United Kingdom
8	Università di Bologna	Unibo	Italy
9	Esponential design Lab. S.A.	eDL	Uruguay
10	Aero Sekr S.p.A.	ASKR	Italy
11	Vrije Universiteit Brussel	VUB	Belgium
12	Università di Torino	Polito	Italy

CONCLUSIONS

MAAT Project is starting, financed by European Commission, and will lead to a novel transport system design model. This project will take 3 years to materialize in form of a working prototype and will lead to a novel concept of cruiser feeder system.

The team involved is constituted by different subjects reported in the below table.

MAAT team auspicate in particular the possibility to work in cooperation with SAE and Standardization Committees inside SAE to develop adequate technical standards because a novel transport concept, such as MAAT needs the development of new standards which must define design guidelines for unconventional aspects of cruiser feeder platforms and for hydrogen based airships.

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DEFINITIONS/ABBREVIATIONS

MAAT
Multibody Advanced Airship for Transport

EU
European Union

EC
European Commission

7 FP 7
7th Framework Program 7

ATM
Accelerated Testing Method

CEE
Collaborative Engineering Environment

ITM
Information Technology Management

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