Modeling and Simulation Tools for Heavy Lift Airships

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ABSTRACT

For conventional fixed wing and rotary wing aircraft a variety of modeling and simulation tools have been developed to provide designers the means to thoroughly investigate proposed designs and operational concepts. However, lighter-than-air (LTA) airships, hybrid air vehicles, and aerostats have some important aspects that are different from heavier-than-air (HTA) vehicles. In order to account for these differences, modifications are required to the standard design tools to fully characterize the LTA vehicle design and performance parameters.. To address these LTA design and operational factors, LTA development organizations have created unique proprietary modeling tools, often at their own expense.

An expansion of this limited LTA tool set could be accomplished by leveraging existing modeling and simulation capabilities available in the National laboratories and public research centers. Development of an expanded set of publicly available LTA modeling and simulation tools for LTA developers would mitigate the reliance on proprietary LTA design tools in use today. A set of well researched, open source, high fidelity LTA design modeling and simulation tools would advance LTA vehicle development and also provide the analytical basis for accurate LTA operational cost assessments.

This paper will present the modeling and analysis tool capabilities required for LTA vehicle design, analysis of operations, and full life-cycle support. A survey of the tools currently available will be assessed to identify the gaps between their capabilities and the LTA industry's needs. Options for development of new modeling and analysis capabilities to supplement contemporary tools will also be presented.

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INTRODUCTION

In 2015 NASA Ames Research Center (ARC) conducted a study for the US DoD Transport Command (USTRANSCOM) of the airship industry and its enabling technologies. This research effort resulted in a comprehensive insight to date into the design, development, and operational capabilities of the airship industry and its ability to produce modern cargo airships for DoD and civilian missions. Within this study a survey was conducted of the modeling and analysis tools most applicable to LTA vehicle design efforts, their operational developments, and the sources and users of those tools. This survey also identified the capabilities, strengths, and weaknesses of each tool as they apply to LTA vehicles. In addition, a gap analysis was performed to determine what further tool development was necessary to meet the needs of current and future airship design efforts, and the technologies involved in those efforts.

LTA AERODYNAMIC MODELING & FLIGHT SIMULATION REQUIREMENTS AND CHALLENGES

At equilibrium conditions, the net average density of an airship must be equivalent to that of the atmosphere displaced by its volume. Replacing much of that volume with an LTA gas creates the weight surplus required for the heavier airship structure and payload. While every aircraft and watercraft influences, and is influenced by, its surrounding medium, the resultant forces are a strong function of the ratio of the vehicle mass to the displaced mass of the ambient surrounding fluid. For traditional HTA aircraft and rotorcraft, the mass of the displaced atmosphere is typically a very small fraction of the vehicle mass. This allows for simplifications in the equations of motion for HTA vehicles. Many of these simplifications do not apply to LTA vehicles, since whenever the LTA vehicle accelerates, in translation or rotation, the inertial forces from the surrounding air are significant and must be accounted for **(Fossen, 2011) (Imlay, 1961).** Despite over one hundred years since Lamb's mathematical description **(Lamb, 1879)** and the practical calculations and applications demonstrated by famed aerodynamicists like Munk and Jones during the golden age of airships **(Munk, 1924)**, this "apparent"/"added"/"virtual" mass and its inclusion into the equations of motion still remains the source of some confusion. Fortunately, most modern, full potential modeling codes, require only a slight modification to generate the initial apparent mass estimates (k-factors) appropriate for use in preliminary flight simulation **(R. G. Atkinson, 2006)** It is also important to remember that theoretical calculations of the apparent mass factors ignore viscous effects and flow separation. Unlike the situation for HTA flight simulation, the proper formulation (and simplification) of the full LTA equations of motion appears to still be the subject of some debate within the aeronautical community.

Flight simulation for LTA vehicles is especially challenging. During cargo transfer operations, winds can be expected to be variable and gusting, with sometimes fairly rapid changes in direction. The wind has a different impact on LTA vehicles than is experienced by most HTA vehicles (and especially conventional airplanes), where significant sideslip angles during flight are usually limited to ±30 degrees. Due to the universal nature of potential winds, the creation of the aerodynamic database required for a detailed LTA flight simulation can quickly grow to include a large number of potential flight conditions. Turn performance and hover control grows in importance; rivaling and sometimes exceeding the importance of climb performance. Low speed controllability requires an accurate modeling of any vectored thrusters, which can quickly become quite complicated if there are secondary interactions between the thruster-induced flow-field and the envelope or control surfaces. Models must be extended to provide accurate force and moment estimates well outside of the traditional HTA range of aerodynamic onset angles. Finally, there is a general lack of publicly-available aerodynamic and structural test data from near full-scale airship models and flight tests. This dearth of data negatively affects the development of many crucial aspects of

airship modeling and analysis, from the development of appropriate CFD boundary layer turbulence models to structural weight estimates and gust loadings **(ARC, 2015)**.

SURVEY OF LTA MODELING AND SIMULATION TOOLS

The 2015 USTRANSCOM airship tools survey looked at the various modeling and simulation tools developed for airship sizing, design, development, and operations. In addition to the tools described, there are many others that are considered highly proprietary by their owners and consequently no information was made available about their design or capabilities. While Lockheed Martin was unable to provide information on some of the interesting tools they have likely developed in the course of designing their commercial hybrid vehicle, the 2013 book by Carichner and Nicolai does provide some insight into their modeling and simulation resources **(Grant E. Carichner, 2013)**. The 1999 book "Airship Technology" provides some useful references to airship development tools **(Khoury, 1999)** and there are some helpful references to modeling applications in the recently published "Advanced Airship Technologies and Design Approaches" book by Philip Hunt **(Hunt, 2015).** The tools that were discovered in the survey are reported here.

Naval Airship Program for Sizing and Performance (NAPSAP)

In the early 1980's the US Naval Air Development Center (NADC) needed an analytical airship sizing and steady state performance evaluation program that could perform quick evaluations of the technical and operational feasibility of LTA vehicles. This requirement led to the development of the "Naval Airship Program for Sizing and Performance" (NAPSAP) program **(Lancaster & Bailey, 1981).** The NAPSAP program was designed to handle two case types. The "Basic Case" sized a vehicle in terms of a simplified set of input data, with the vehicle's performance being evaluated in terms of payload as a function of range at the input design speed. The second principal application allowed the performance of the "Basic Case" vehicle to consequently be evaluated against multi-segment mission profiles. This sizing tool is rudimentary by today's standards that it would require considerable update for current sizing studies.

LTASIM

In 1991 Systems Technology Incorporated (STI), under the direction of Henry Jex, developed a comprehensive proprietary 6 Degree-Of-Freedom (DOF) simulation model for modern airships (LTASIM) **(H. R. Jex, 1991)**. The model included nonlinear aerodynamics and buoyancy effects, various thruster types, important virtual mass and inertia tensor terms, and non-constant wind effects including turbulence, stability and trim control-system, and airship-to-target relative motions. This tool was developed using the TUTSIM-6 program for use on PC-compatible computers. On a 25 MHz 486-type computer, it could run much faster than the simulated time interval, thereby offering possibilities for use in real-time simulation devices. The LTASIM model was developed out of one that was created to look at the Piasecki Helistat rotary-hybrid airship and other airships employing helicopter rotors. That precursor program was co-developed with ARC in the early 1980s (R. F. Ringland, 1980)**.**

Naval Airship YEZ-2A Simulation

In 1994 the US Navy contracted with ARC to conduct a human-in-the-loop evaluation of the handling qualities of the YEZ-2A Air Early Warning (AEW) concept airship (Fig. 1). ARC investigated the ability of the airship to conduct refueling and resupply operations from a simulated surface ship under visual flight rules (VFR) conditions at a number of airspeeds and static heaviness conditions. This program resulted in the construction of a full 6 DOF non-linear flight dynamics simulation model for the YEZ-2A airship. While the model used wind tunnel data for the aerodynamic database, it did not include wind and turbulence inputs. ARC used this research to obtain a catalogue of vehicle responses to both aerodynamic and power control inputs as well as longitudinal handling qualities. For follow-on studies,ARC took the airship's flight dynamics model (which was based on Remotely Operated Underwater Vehicle dynamics developed by S. B. Gomez **(Gomez, 1990)**, and modified its equations of motion to include wind and turbulence.

Fig. 1. US Navy YEZ-2A Airship Concept in Showing Internal Structures and Surveillance Radar

Airship Mission Simulation (ASPEN)

In the mid-1990's RED Scientific LTD, a British company, developed the "Airship Mission Simulation" (ASPEN) airship mission simulation for the UK Defence Evaluation Research Agency (DERA) **(Privett, 1999).** The function of the model was to calculate the fuel required by a helium filled non-rigid airship to fly a specified mission. ASPEN comprised a Fortran calculation module and a database contained within a Windows graphical user interface. ASPEN consists of several simple windows in which the user can retrieve, edit, print or create the input files that model the mission and point performance of an airship. Each mission is represented in individual segments characterized by a range of environmental and operational parameters. ASPEN requires an input file, which characterizes the airship physical and aerodynamic performance, together with its propulsion unit and propeller. The output provides the mission performance (mass, heaviness, altitude, ground speed, distance traveled, fuel consumption, ballast requirements, etc.) at each point in the mission (Fig. 2). The flight path is input from a hard copy map as a track profile. Future development was planned to include the dynamics of realistic weather patterns.
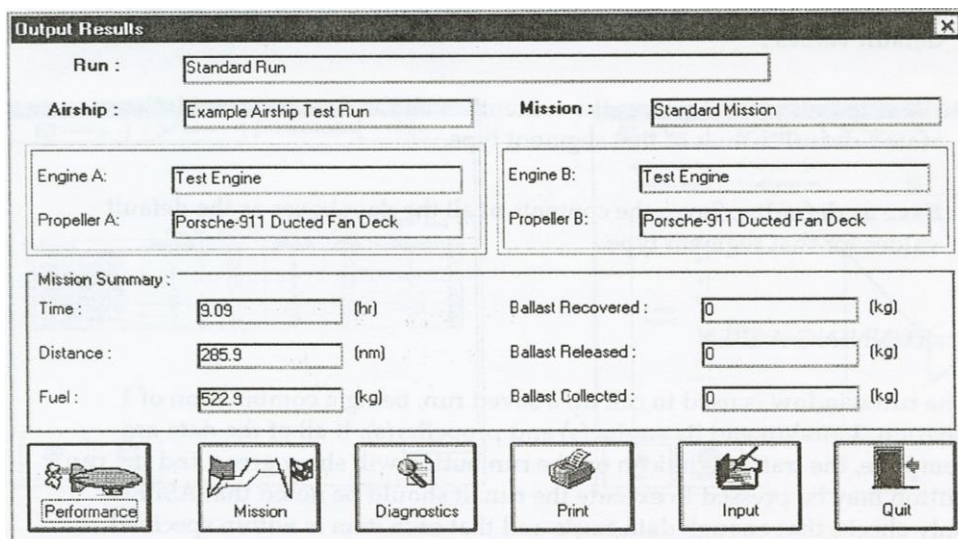

Fig. 2. ASPEN Output Results Window

CargoLifter Sizing and Design Tools

In the late 1990's the CargoLifter airship company was in the early stages of designing their heavy lift cargo airship, the CL-160. At that time the flight sciences department, led by Dr. Bernhard Kaempf, developed a large set of "small tools" (Excel sheets, Matlab programs, etc.) for various sizing and trading studies. A simulation model was also developed for real time simulation and was used by CargoLifter for assessing airship handling qualities and developing the man-machine interface. The tools developed at CargoLifter were validated against a large number of wind tunnel tests, CFD, and flight data tests that were carried out in Germany and Moscow at the TsAGI research facility. **(Kaempf, 2015)** Some examples of the individual CargoLifter analysis modules are presented below.

CargoLifter Flight Mechanical Model

The flight mechanical model defines the core for different applications like the performance model, the simulation model, or the loads computation model. Different levels of abstraction of the model are applied for different needs of fidelity. Figure 3 provides a graphic overview of the model.
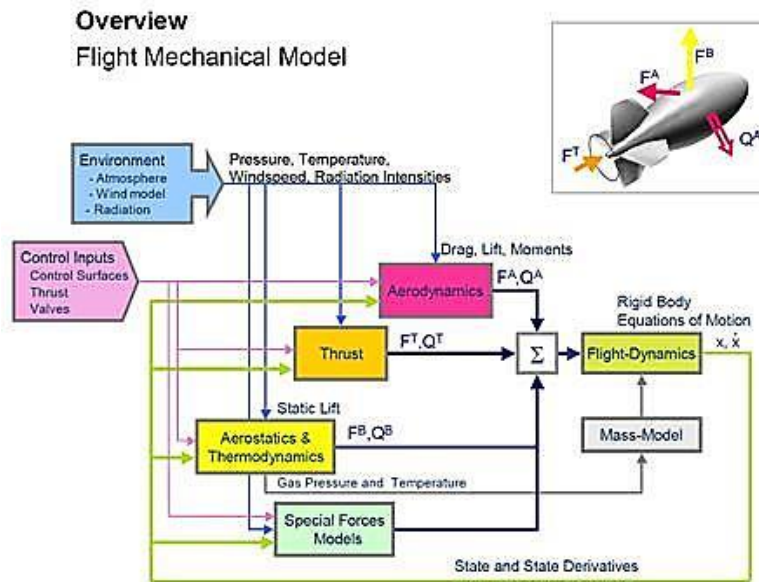

Fig. 3. Flight Mechanical Model

CargoLifter Aerodynamic Model

The aerodynamic model provides hull pressure distribution approximations based on potential flow around an ellipsoid, and correction factors for laminar shapes and off-ellipsoid shapes. The model has been validated with CFD and wind tunnel data, and different fin models and parameterizations are available. Aero forces can be computed from body acceleration, steady aerodynamic flow, accelerated wind, and control surface (or thrust) deflection. The model provides consistent computation of pressure distribution, axially distributed force, and single point aerodynamics for different applications (a+i engineering LTA Flight Mechanical Model 2 of 2©). Figure 4 provides a graphic overview of the aerodynamic model.
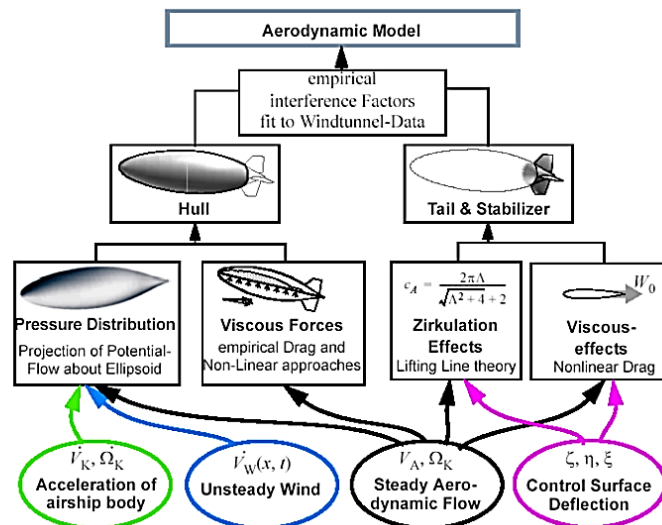
Fig. 4. Aerodynamic Model

CargoLifter Loads Computation

Loads computation is divided into pre, main, and post processing. During preprocessing load cases are being defined and initial states are being computed. During main processing the transient LTA simulation is run through the defined gust or maneuver load case. At each time step all external and internal forces along the airship provided by the simulation models are integrated. Results are shear forces and bending moments both at selected monitoring stations and distributed over the longitudinal airship axis as well as accelerations at arbitrary stations. Data from critical load cases are post processed to compute higher resolution distributions and to export data to finite element tools for more detailed stress analysis. Figures 5 and 6 provide graphic overviews of the model outputs.
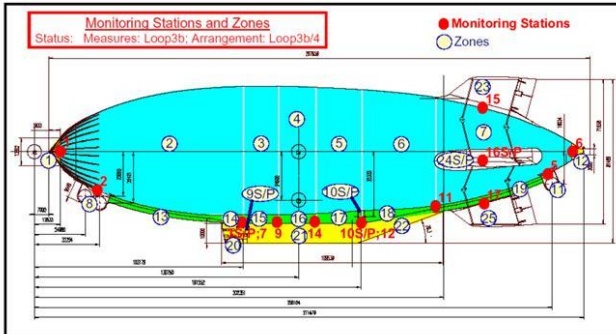
Fig. 5. Loads Monitoring Stations and Zones
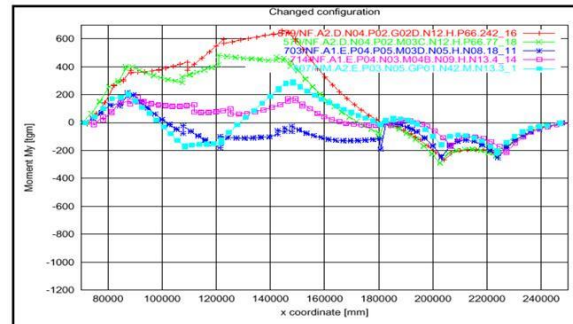
Fig. 6. Load Configuration Changes

CargoLifter Aerostatics/Thermodynamics Model

The aerostatics/thermodynamics model characterizes the state of the inner gases and the exchange of heat between surfaces, gases, air, space, and earth. Inner convection and radiation is modeled as well as convection between outer envelope and air and radiation from/to sun, earth (clouds etc.), and space. View factors are computed to consider different radiation angles. Earth radiation intensity is modeled based on meteorological models and data or satellite measurements. Sun radiation is modeled taking into account distance to Earth. Earth ultraviolet (UV) reflection is modeled either statistically or from satellite measurements.

CargoLifter LTA Simulation

The LTA simulation integrates the different numerical models to enable the simulation of airship flight and airship systems dynamics. The additions to the core flight mechanics model are an interface to subsystems like electric power models, propulsion systems, or flight control systems. An improved aerostatics/thermodynamics and environment model can also be integrated. The Airship-Subsystem interface is utilized to link the model of the envelope pressure control systems. Figures 7 and 8 provide a graphic overview of the model outputs.
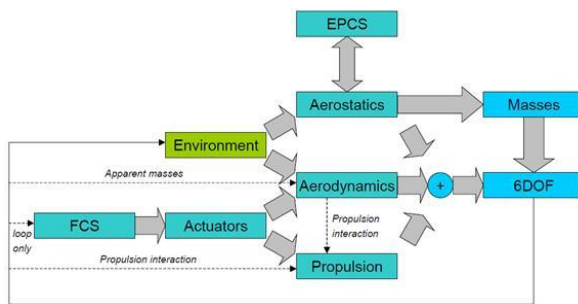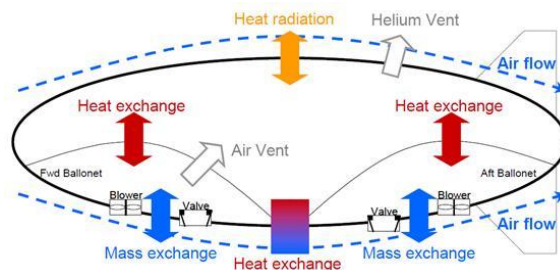

Fig. 7. Airship-Subsystem model

Fig. 8. Airship Environment Model

Burgess-Mayer Parametric Airship Sizing Model

In 2004 BMT Syntek Inc. developed a conceptual design tool to size and estimate the steady state performance of LTA vehicles **(ARC, 2015)**. The tool was created by BMT Syntek for the 2005 "Airship Transport Study". The study was conducted by SAIC for the Center for Army Analysis (CAA) **(SAIC, 2005)**. The resulting "Burgess-Mayer" parametric model (named after two notable airship engineers) provided "real-time" engineering insight into the impact of mission requirements, conceptual design decisions, and technology choices on the size, performance, and complexity of conventional and hybrid airships. The tool follows an analysis sequence to determine an airship's size, power, and weight requirements. Once all the weights are defined the values for all weight elements can be calculated according to the Airship Weight Breakdown Structure (AWBS), such as estimates of the operational empty weight, fuel weight, payload weight, and so forth. The model provides takeoff performance analysis for an airship and takeoff, distance and climb performance according to weight, thrust, drag, dynamic lift, friction, and accelerated mass. A cost model, which includes average procurement cost and direct operating cost of the airship, is developed based on the AWBS and the complexity and performance estimated by the airship sizing and synthesis tools. Figure 9 shows an example of a contour plot output with the shaded area indicating the design space that is unfeasible for a particular airship design concept.
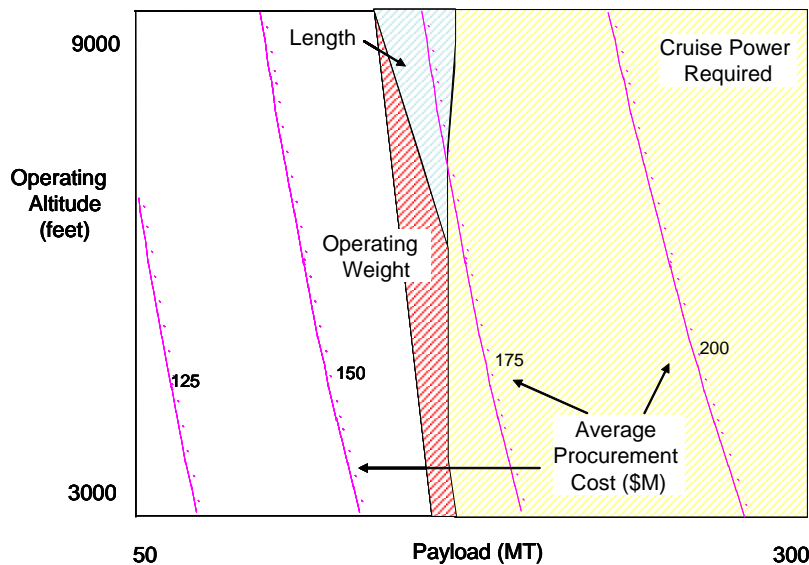

Fig. 9. Sample Burgess-Mayer Model Output

In this example the airship operating weight is limited and is shaded red. Likewise length (aqua) and cruise power required (yellow) are limited and the appropriate part of the design space is shaded. Thus the decision maker can see in real-time the design altitude and payload combinations that meet these constraints for the particular airship concept. The Burgess-Mayer approach is appropriate for very initial sizing studies. It relies on scaling factors to represent technology and design enhancements. The Burgess-Mayer method has the advantage of requiring few inputs (and few computations), and while there is significant uncertainty in the absolute magnitudes of its results, it is very useful for understanding trends and sensitivities to size, shape, and "efficiencies" in design and technology. **(Melton, 2015)**

Airship Operational Model

In 2015 Strongside Technologies LLC Canada modified the Simio LLC aircraft operations model to develop a tool to model and visualize potential operating scenarios for Cargo Airships **(Strongside Technologies Inc., 2015)**. This tool outputs system performance and provides an initial estimate of operating costs and the revenues required to make the scenarios feasible. The airship operations simulation tracks operating costs while accounting for uncertainties within the system (Fig. 10).
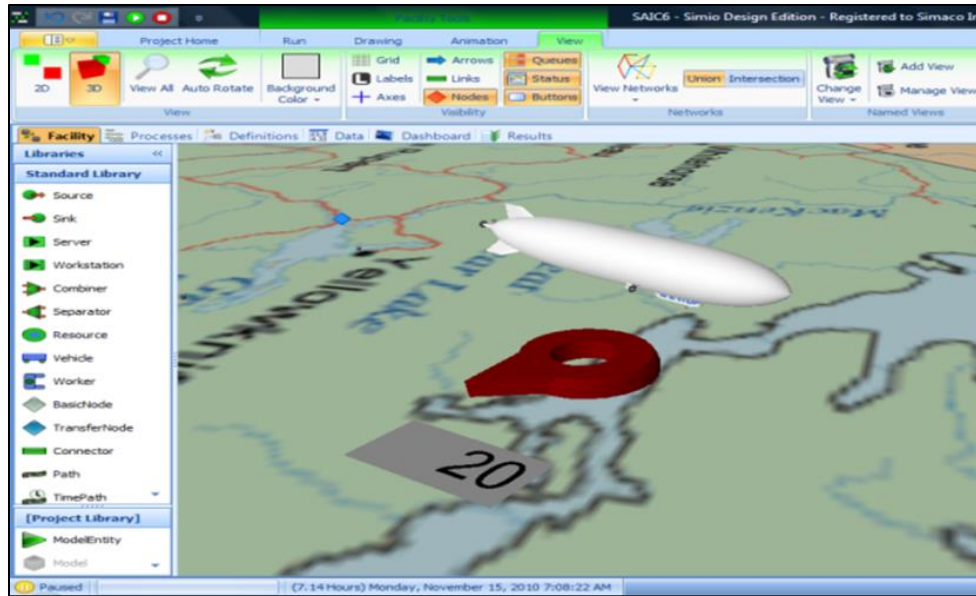
Fig. 10. Sample Screen Shot for Airship Operational Analysis Simulating a Flight

Operational costs include fuel, crew, equipment, maintenance, and supplies. The model handles system variability and risk by using randomized data distributions and running multiple scenarios. Sensitivity analysis is used to assess the impact of severe weather, changes to key performance, cost, or revenue assumptions. The model can also simulate a variable number of operations bases used for such operational support activities as administration, cargo transfer, maintenance, and refueling. This airship operational model is an excellent tool for initial operational concept and airship business concept development efforts. The simplicity and flexibility of the model allows users to easily change any number of factors (number of airships, locations, dispatching, or even airship vehicle performance values) to determine the "sweet spot" for the productivity or profitability of the overall operation.

Weather "Optimized Airship Routing" (OAR) Tool

In 2007 SAIC modified its Operational Multiscale Environmental Model with Grid Adaptivity (OMEGA) weather prediction model to create a weather "Optimized Airship Routing" (OAR) flight routing tool. OMEGA is an atmospheric modeling tool originally designed for predicting atmospheric hazards over complex terrain. It incorporates available weather data with a dynamic adaptive unstructured geographic grid technology to produce high resolution, weather optimized airship route maps. The OAR can analyze up to 1 million possible routes with heading, speed, and altitude variables included. To compensate for prevailing winds the OAR route planner provides the crab angle vector necessary to compensate for crosswinds (Fig. 11).
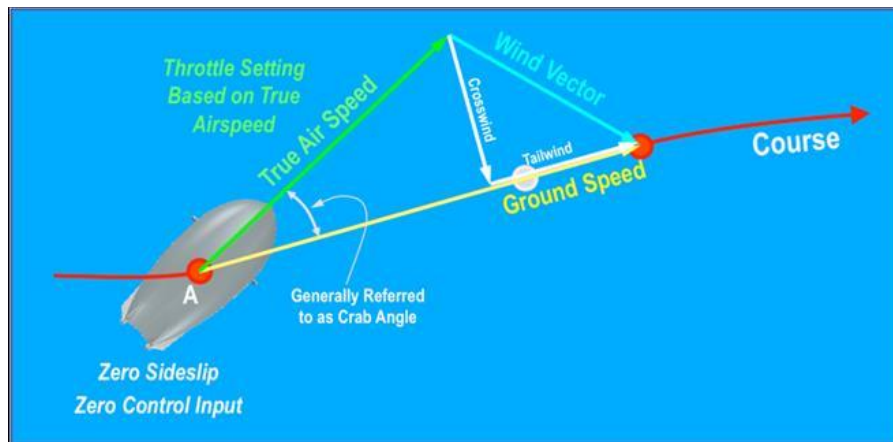

Fig. 11. Depiction of OAR's Calculation for Airship Crab Angle to Compensate for In-flight Crosswinds

With this approach the required airspeed and airship heading can be established throughout the route. The outputs of this predictive tool are route maps for each airship mission that give the flight crew the optimum heading, speed, and altitude necessary to minimize the impact of local weather on each airship flight leg. This weather optimized routing model has yet to be validated through actual flight operations of an airship so a series of validation trials would need to be conducted. In 2013 the OMEGA system and its OAR derivative were transferred from SAIC to Leidos Inc. where it continues to be supported and refined by its original authors. **(David P. Bacon, 2000) (Dr. Ananthakrishna, 2008)**

Advanced Airship Analysis and Design (A3D)

In 2011 the Air Force Research Laboratory (AFRL) contracted with Boeing to develop a conceptual tool for airship design **(Blaine Rawdon, 2014)**. In 2014 Boeing delivered the "Advanced Airship Analysis and Design" (A3D) tool specifically designed to enable evaluation of existing and proposed airships and provide performance comparisons among user specified designs. Technology or mission changes to an existing design can also be explored. The A3D tool considers airship payload; aerodynamic lift and drag; buoyancy; stability and control; structural loads; materials and weight; mass properties including center of buoyancy and mass; and propulsion. Because the A3D can be used to create new airships from scratch it can help to explore the effect of alternative technologies, configurations, and mission requirements on airship sizing or performance. These comparisons include envelope volume vs. length-to-diameter (L/D) ratios, fuel weight vs. L/D, and estimated cost vs. L/D, for the user-specified designs. Figure 12 provides a graphic output from the A3D tool showing the Envelope Volume versus the Length/Equivalent Diameter values for five different airship hull shapes. The A3D however, is not intended for the preliminary design of a specific airship – this requires more detail than is available from this conceptual design tool.
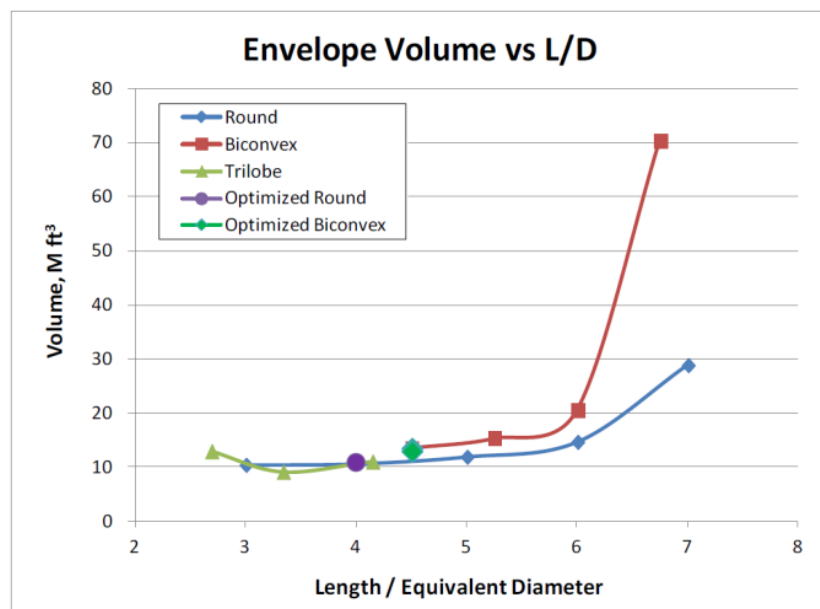

Fig. 12. Envelope Volume versus L/D for Three Envelope Species

GAP ANALYSIS OF MODELING AND SOFTWARE TOOLS FOR AIRSHIP DESIGN

As part of the USTRANSCOM airship study **(ARC, 2015)** a Gap Analysis was conducted of the few known airship applicable modeling and simulation tools to determine their deficiencies. There are a few other airship modeling and simulation tools in existence, but those were unavailable for consideration since they remain under proprietary control. The oldest airship modeling tool surveyed was the NAPSAP developed by the Navy in the early 1980s, and the most recent being the set of tools created for the CargoLifter program in 2000 – 2001.

In Gap Analysis Chart 1 (below) the red cells indicate no capability, the yellow cells indicate marginal capability, and the green cells indicate functional capability.

Chart 1. Gap Analysis of Airship Modeling and Simulation Tool Attributes

The following chart presents a gap analysis across nine modeling and simulation tools. Each tool is color-coded against each attribute per the legend (Functional Capability = green, Marginal Capability = yellow, No Capability = red).

Tools (columns):
- NAPSAP (NADC)
- NASA Ames (YEZ-2A) UNREP Simulation
- Weather Optimized Airship Routing (OAR) Tool
- Airship Mission Simulation (ASPEN)
- CargoLifter Sizing and Design Tools
- Burgess-Mayer Parametric Airship Sizing Model
- LTASIM (STI)
- Airship and Hybrid Concept Assessment Tool (AFRL)
- Airship Operational Model

Airship Modeling and Simulation Tool Attributes (rows):

Concept Studies and Design Trades
- Overall airship and system level
- Airship sizing and weight
- Performance/Mission parameters
- Mission requirements development
- Project schedule
- Business plan and costs
- Concept of operations (CONOP) development

Modeling, Analysis, and Simulations
- Numerical modeling (CFD, FEM)
- Aerodynamics
  - Estimating mass and inertia properties
  - Aerodynamic estimation database
  - Propulsion interactions
  - Pressure distributions
  - Flow field visualization
- Aerostatics and aeroelastics
- Thermodynamics
- Structural mechanics
- Flight mechanics and dynamics
  - Flight performance
  - Man-in-the-loop simulations
- Loads computation and interface loads
  - Structural loads
  - Ground loads, gust loads
  - Flight loads and maneuver loads
  - Cargo load management
- Cargo handling simulation
- Ground handling simulation
- Concept of operations (CONOP) simulation

Design and Specification Development
- Overall airship layout
- Structures (rigid and fabric)
- Propulsion (engines and props)
- Landing gear systems
- Fin and control surface design
- Cargo carriage and handling
- Weights
- Flight control system
  - Auto stabilization system
- Airship sub-systems
  - Pressure control system, blowers, and valves
  - Electrical
  - Pneumatic
  - Fuel storage and management
- Ground handling systems
- Maintenance support

Analysis in Concept, Design, & Certification Phases
- Steady state performance
- Transient, flight, and mission phases
- Stability and controllability
- Mission performance capability
- Manufacturing and assembly process

LEGEND — Tool provides:
- Functional Capability (green)
- Marginal Capability (yellow)
- No Capability (red)

CONCLUSIONS

Airships offer a transportation solution unencumbered by some of the limitations of legacy transport systems. Development of advanced modeling and simulation programs would greatly expand the ability of designers to create heavy lift airships that offer new and, in some cases, unique transport capabilities. Due to the inherent high cost of forming new modeling and simulation tools, it should not come as a surprise that competing LTA manufacturers are motivated to keep their modeling and simulation developments secret from their competitors. This proprietary cloak forces LTA manufacturers to utilize or generate their own suite of expensive modeling tools in order to validate new concepts. This results in manufacturers creating very distinct models that only characterize their particular project in the effort of minimizing cost. This process debilitates future LTA growth, and hampers elaboration of fresh

concepts. A set of industry-accepted standardized tools would mitigate this vindictive cycle, and give future developers a validated starting point upon which to approach new ideas.

The survey found some tools to be more capable than others but none represented fully developed or validated models. Several of the available tools are outdated and of low fidelity, or lacking in depth of analytical insight. The majority of LTA tools reviewed are able to provide first order sizing and high level assessments of design, mission, concept of operations (CONOPS), and overall procurement costs. Only three of the tools (Naval Airship YEZ-2A Simulation, CargoLifter Sizing and Design Tools, and LTASIM) offered any capabilities beyond initial airship sizing. The Weather "Optimized Airship Routing" (OAR) tool is not strictly speaking an aircraft design tool but rather provides designers with a set of airship performance values based on the impact that various weather factors will have on a particular airship point design. Of all the tools reviewed only the CargoLifter modeling set comes closest to broadly addressing airship detailed design analysis or definition in such areas as: Aerodynamics, Structures, Dynamic Loads, or Propulsion, to name just a few of the crucial design parameters. None of the tools represented single-discipline programs specially developed to offer high-fidelity analysis of detailed designs for modern airships.

Cost minimization is the driving factor behind creating simulation tools that are tailored to a given manufacturer's present projects. A manufacturer working within the constraints of their allotted budget has no incentive to craft a robust simulation tool capable of handling large design trade-offs that might prove useful to the LTA community as a whole. From an economic standpoint, the modeling tools ultimately take a back seat to the cost of constructing the actual vehicle. This facilitates the use of as many cost-saving simplifications as can be safely included in the initial modeling and planning phase, resulting in extrapolations from simplistic models which propagates a significant amount of uncertainty into the final model. The tools surveyed demonstrate adequate capability for the specific design trades they were built to handle. However, no one tool is robust enough to characterize the full spectrum of potential LTA projects and future visions.

RECOMMENDATIONS

New tools are needed that are based on a fully researched understanding of the essential properties that define LTA vehicles. A complete and integrated set of LTA modeling and simulation programs is needed to replace the medley of LTA design tools available today. This new foundation of well-researched and high fidelity design and operational models are not only critical to the development of LTA vehicles but will also provide the essential basis for accurate LTA cost models. The following actions are specifically recommended:

Assemble an LTA Knowledge Base and Tool Set
1. Collect all of the relevant LTA design and operations data in one searchable on-line repository.
2. Develop a design process tool set for LTA vehicles.
3. Develop or collect a comprehensive set of LTA modeling and simulation tools accessible by LTA firms.
4. Develop a set of cost assessment tools for LTA design, development, manufacture, training, and operations.

Utilize the Tools and Knowledge Database
5. Conduct investigations of critical LTA design concepts, structures, materials, or sub-systems.
6. Conduct operational analysis of LTA vehicles and CONOPS to identify challenges.
7. Conduct modeling and simulation studies of LTA manufacturing concepts and techniques to reduce labor, assembly cost, and improve maintenance support of airships in the field.

Private-Public Airship program

Critical modeling and simulation investigations are needed to unlock the great potential of the airship industry and its user community. Government bodies such as USTRANSCOM could provide the leadership for a public-private-partnership to leverage available airship platforms for investigations into cargo and UAS carrier missions. Other government entities such as NASA could provide the world class modeling analytical guidance, technical knowledge, and development of engineering tools that will enable the cargo airship industry to provide a viable alternative where traditional transportation systems are challenged. A Private-Public Airship program could engage (by purchase or lease) an available commercial airship as a platform for development of tools and for investigations of enabling technologies applicable to a subsequent larger common airship to be built by the partnership.

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