Modeling and Simulation for Airship Design and Operations

Bimal Aponso
John Melton

NASA Ames Research Center
Moffett Field, CA

July 10, 2013

3rd Cargo Airships for Northern Operations Workshop, Anchorage, AK
The Role of Modeling in the Design Process

**Aerodynamics & Buoyancy**
- Fluid Flow Models (*CFD, wind tunnel*)
- Forces (F)
- Moments (M)

**Structure**
- Structural Dynamic Model (*NASTRAN, lab test*)
- Mass (M)
- Flexible dynamics

**Stability & Control**
- Dynamic Model (Airship body + propulsion + flight control)
  - $F = M\ddot{\nu}$
  - $\dot{M} = I\dot{\omega}$

**Performance**
- Speed/Altitude envelope
- Range
- Wind/gust limits
- Economics

3rd Cargo Airships for Northern Operations Workshop, Anchorage, AK
Sources for Aerodynamics Data

- Vast international literature, including online sources
  http://ntrs.nasa.gov/search.jsp (NACA and NASA airship research)

- Several comprehensive, MODERN overview texts
  - “Airship Technology” by Khoury and Gillett, 1999
  - “Fundamentals of Aircraft and Airship Design” by Carichner and Nicolai, 2013

The LTA aerodynamicist is challenged to develop timely data with an appropriate balance of geometric fidelity and physics accuracy for the current design stage.
Experimental Aerodynamics Data Sources

- **Experimental Data Sources**
  - **Historical Databases**
    - Books, reports, online sources
    - Inexpensive
    - “Occasionally” conflicting data
  - **Wind / Water Tunnels**
    - “Low cost” design exploration
    - Flowfield visualization
    - Low Reynolds number
  - **Subscale Models**
    - Larger in/outdoor models, unmanned
    - Unsteady and propulsive flows
    - Maneuvering with dynamic similitude
  - **Flight Testing**
    - Expensive, optionally piloted
    - Large ground facility

Increasing Cost, Risk, Fidelity
Ames Large Wind Tunnels (40x80 and 80x120)
Computational Aerodynamics Data Sources

Computational Data Sources

- **Historical Databases**
  - http://ntrs.nasa.gov/search.jsp, AIAA papers
  - Airship and aerodynamics books (Hoerner, Burgess, et al.)
  - Important markers for LTA language and approach

- **Analytic Expressions**
  - Geometry approximated with ellipsoids
  - Spreadsheet design exploration on a laptop
  - Limited assessment of component interactions
  - Estimates for added mass coefficients (Lamb, Munk)

- **Inviscid (No B-Layer)**
  - “Panel” methods (VS-Aero, QUADPAN, PMARC, etc.)
  - Laptop-class computer: minutes per CPU
  - Corrections can be applied for boundary layers
  - Complicated by wake specifications, propulsive flows

- **Viscous (with B-Layer)**
  - Navier-Stokes methods (FLUENT, STAR-CCM+, etc.)
  - Multi-core cluster computer: hours per CPU (>>32)
  - 6-DOF motion, “exact” geometry representations
  - Boundary layers via turbulence modeling
  - Require dedicated CAE and CAD specialists

Increasing Cost, Complexity, Fidelity

Limited availability in open literature

Code Validation
Outputs of Modern Aerodynamics Software

- Time histories of forces, moments, flowfield, and surface quantities
- Complex geometries with control surfaces and props/rotors can be analyzed
- Understand motions, accelerations (added mass), gust effects, propulsive flows

**Compared to HTA, LTA computational aerodynamics is still hampered by the lack of widely-accessible large-scale validation datasets**
STATIC EQUILIBRIUM - HOVER

$V_{GUST}$

$B$

$W$

$N_T$

$M_T$

$L_T$
Controlling an Airship - Dynamic Modes

- Surge – variation in speed, aperiodic.
- Heave – vertical motion, aperiodic.
- Coupled surge/heave oscillation – phugoid-like with speed and pitch attitude variations.
- Pitch oscillation – variation in angle-of-attack and pitch attitude, speed “fixed.”
- Yaw/sway – dutch roll-like with variations in sideslip, heading, and roll.
- Roll oscillation – pendulum mode.
- *Pitch oscillation becomes more unstable with speed.*
Control for Station Keeping

• At very low-speed:
  • Aerodynamic surfaces have no effect
  • Response to gusts is quick (apparent mass effect)
  • Response to controls is slow (mass, inertia, and apparent mass)

• Station keeping precision will depend on installed power
  • Need to create large forces and moments to oppose drift due to wind
  • The larger the applied forces, the smaller the deviations in position
  • Ability to anticipate gusts will allow counter forces to be applied proactively to reduce deviation
Thrust Required to Balance Lateral Drag at Zero Forward Speed
- precise slung load delivery with no rotation or transverse motion

Drag (and Thrust) = $0.5 \rho_\infty S C_D V_\infty^2$; Power = $TV_{\text{prop}} = T (V_\infty + w)$

$w = [(V_\infty^2 + 2T/(\rho_\infty A_{\text{prop}}))^{1/2} - V_\infty] / 2$

Steady hover in moderate winds may determine installed power

Lots of trend insight from “simple” physics, but detailed design requires fidelity

GIGO…

Inspired by “Aerodynamics and Hovering Control of LTA Vehicles”, Putnam, Maughmer, Curtiss, and Traybar; Princeton University, 1977

3rd Cargo Airships for Northern Operations Workshop, Anchorage, AK
Airship Modeling at SimLabs

- Developed Airship modeling framework
  - adaptable to varying Airship types/configurations
  - validated against published Airship data
  - simulate flight operations (Nominal & Off-Nominal), Airborne and ground handling (Masting)
  - includes basic wind and weather effects
- Model integrated with VMS cab
- Network to interact with ATC and ground station crew
- PC based version under development
  - Mission performance assessment
  - Flight control development
  - Dynamic loads analysis
The Vertical Motion Simulator (VMS)

• Reduce risk through realistic simulation
• Model development
  ➢ Evaluate Airship Dynamics
• Cab/cockpit integration
  ➢ Evaluate Pilot/Vehicle Interface
• Operational scenarios
  ➢ Nominal and off nominal conditions
Airship Simulations at SimLabs

• YEZ-2A (1994)
  - Evaluated handling qualities of an airship during refueling and resupply from a surface ship under VFR conditions at a number of airspeeds and static heaviness.

• Recent Airship design and deployment support
  - Two airship simulations conducted in last two years
  - Conducted Simulations for: handling qualities evaluations, design load analysis, flight operations and training procedures development.
Modeling and Analysis Capabilities at NASA Ames

**Structures**
- Design and Analysis
- Testing and Instrumentation
- Materials

**Aerodynamics**
- Steady Loads Estimation
- Performance
- Gust and Fin loads

**Flight Simulation**
- Handling Qualities
- Controls Development
- Mooring
- Buoyancy Management
- Vectored thrust

**Mission Analysis**
- Airspace Operations
- Cargo Handling
- Risk Analysis
Questions?