
TEST

National Aeronautics and Space Administration

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	Structure	Stability & Control	Performance
Fluid Flow Models *(CFD, wind tunnel)*	Structural Dynamic Model *(NASTRAN, lab test)*	Dynamic Model (Airship body + propulsion + flight control)	Speed/Altitude envelope Range Wind/gust limits Economics
Forces (F) Moments (M)	Mass (M) Flexible dynamics	$F = M\dot{\underline{v}}$ $M = I\dot{\underline{\omega}}$	

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

Experimental

- Historical Databases
- Wind and Water Tunnels
- Subscale Models
- Flight Testing

Computational

- Historical Databases
- Analytic Expressions
- Inviscid (no Boundary Layer)
- Viscous (with Boundary Layer)

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

Increasing Cost, Risk, Fidelity

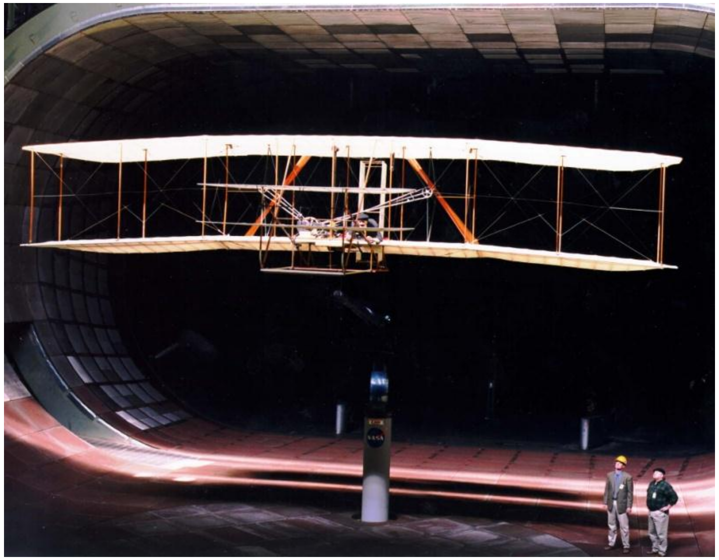
Historical Databases
- Books, reports, online sources
- Inexpensive
- "Occasionally" conflicting data

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
- Moderate ground facility

Flight Testing
- Expensive, optionally piloted
- Large ground facility

Ames Large Wind Tunnels (40x80 and 80x120)



Computational Aerodynamics Data Sources

Computational Data Sources

Increasing Cost, Complexity, Fidelity

Limited availability in open literature

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

"Classic" methods

Analytic Expressions

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

Code Validation

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

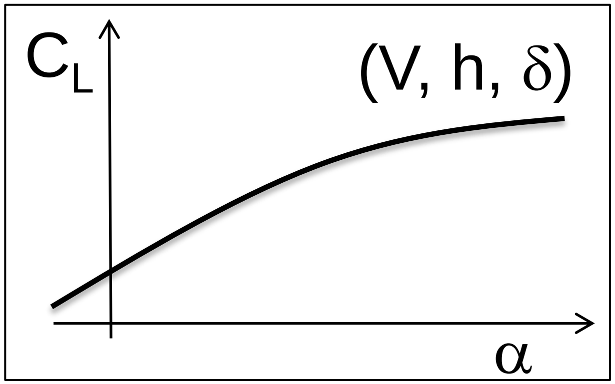
"Modern" methods

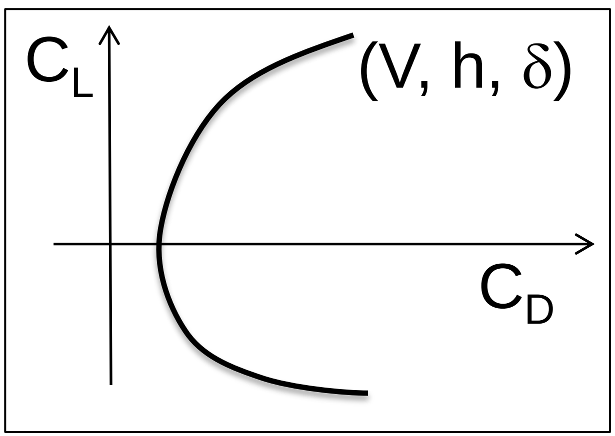
Viscous (with B-Layer)

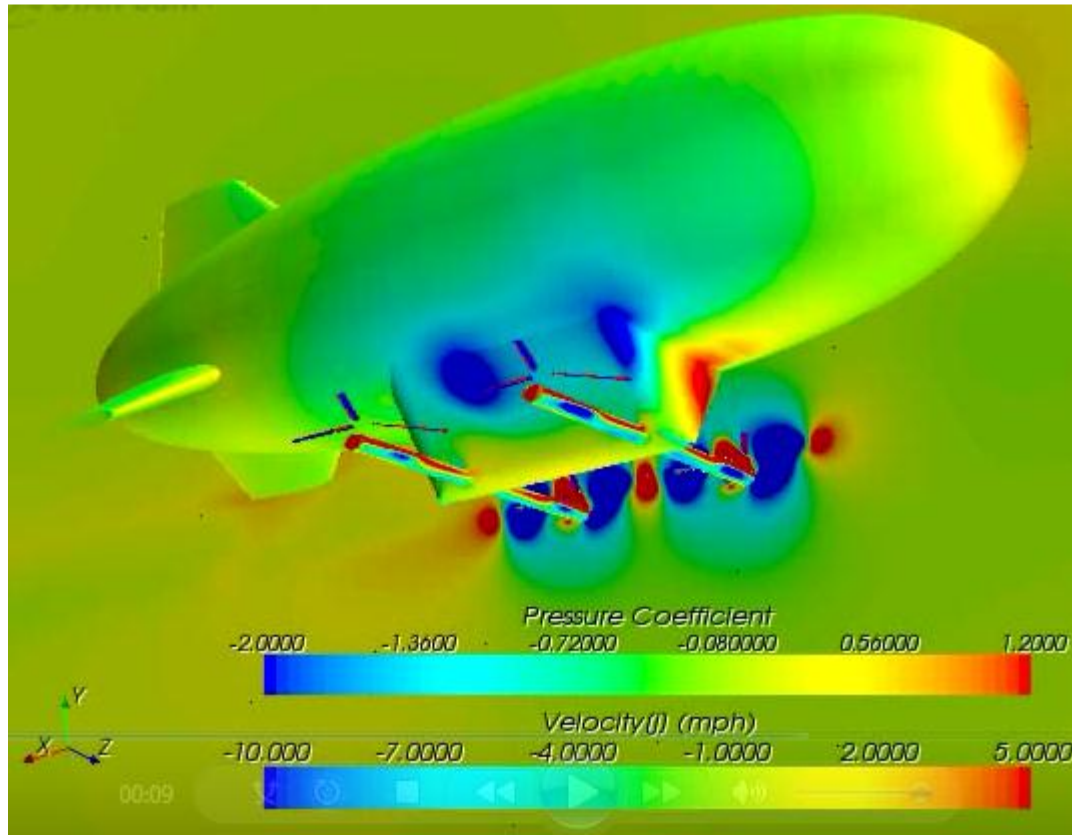
Navier-Stokes methods (FLUENT, STAR-CCM+, etc.)
Multi-core cluster computer: hours per CPU (>>32)
6-DOF motion, "exact" geometry representations
Boundary layers via turbulence modeling
Require dedicated CAE and CAD specialists

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

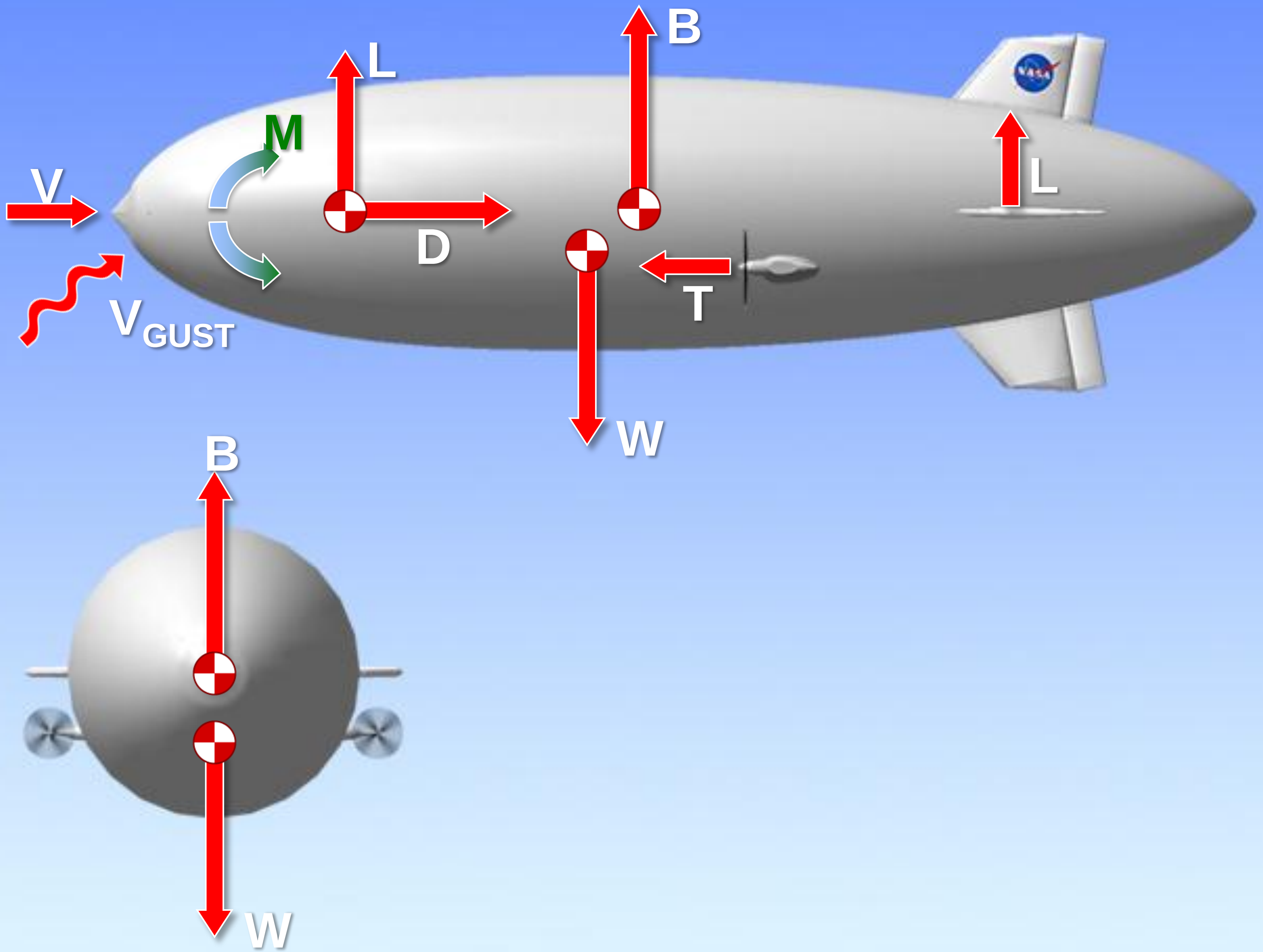




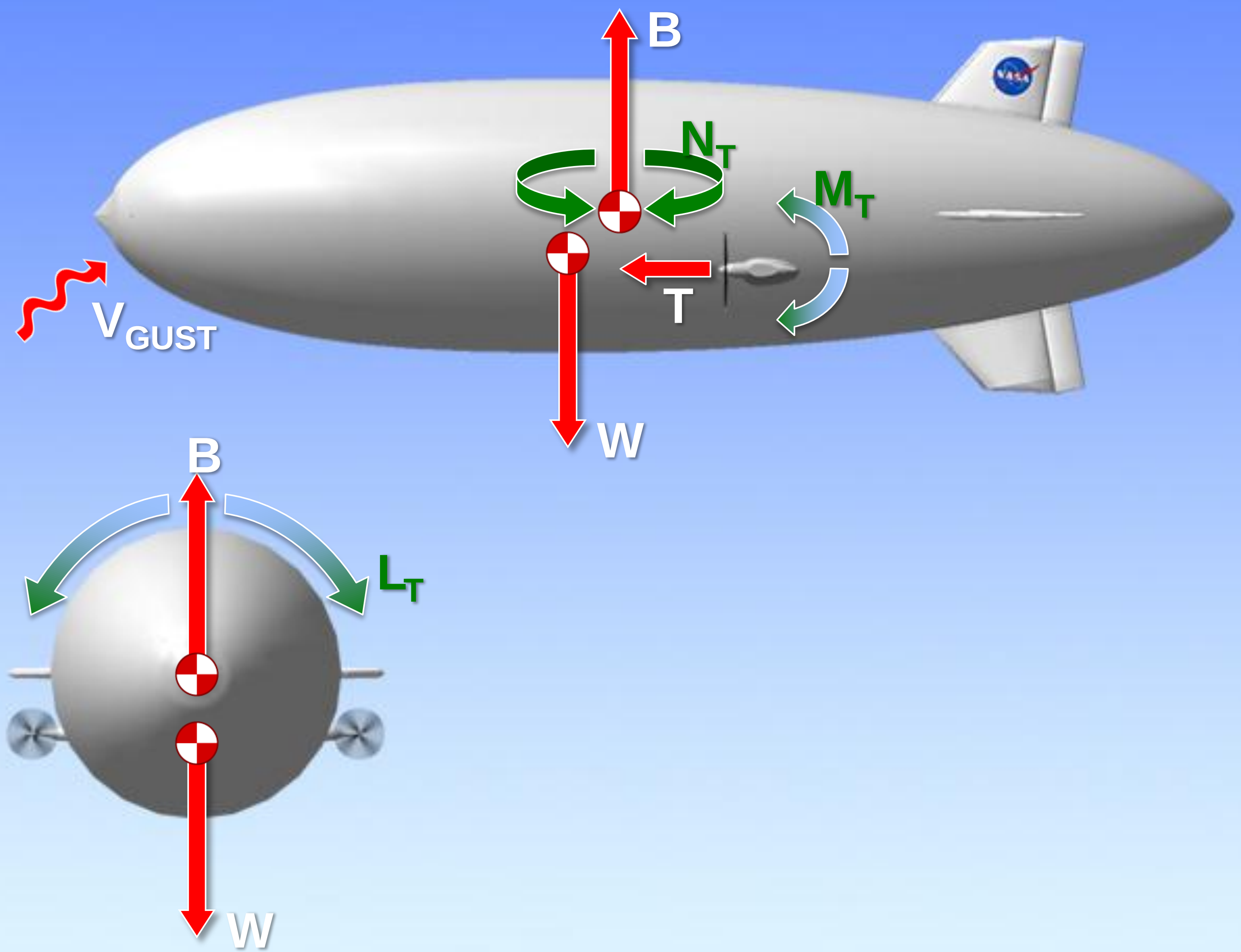


Compared to HTA, LTA computational aerodynamics is still hampered by the lack of widely-accessible large-scale validation datasets

STATIC EQUILIBRIUM - CRUISE



STATIC EQUILIBRIUM - HOVER



Controlling an Airship - Dynamic Modes

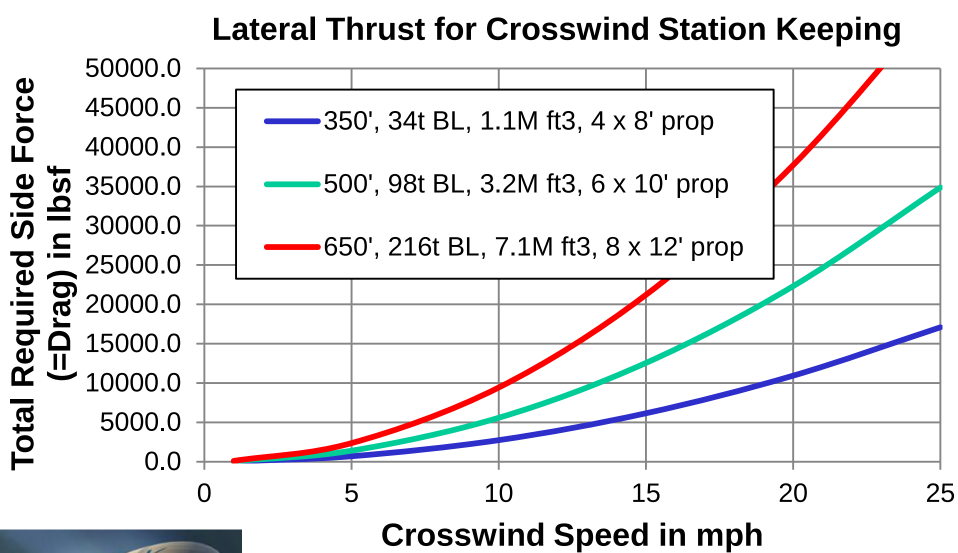
- **Surge – variation in speed, aperiodic.**
- **Heave – vertical motion, aperiodic.**
- **Coupled surge/heave oscillation – phugoid-like with speed and pitch attitude variations.**
- **Pitch oscillation – variation in angle-of-attack and pitch attitude, speed "fixed."**
- **Yaw/sway – dutch roll-like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

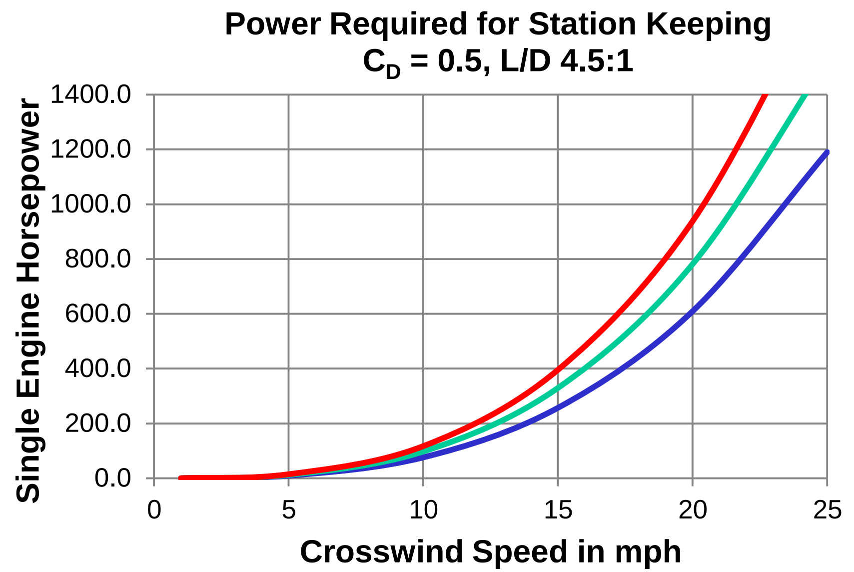
Control for Station Keeping

- **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

Aero Fidelity: Station-Keeping with Steady Lateral Wind





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 = $TV_{prop} = T\ (V_\infty + w)$

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

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

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

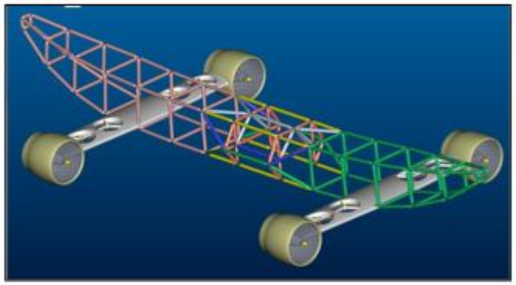
The Vertical Motion Simulator (VMS)

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

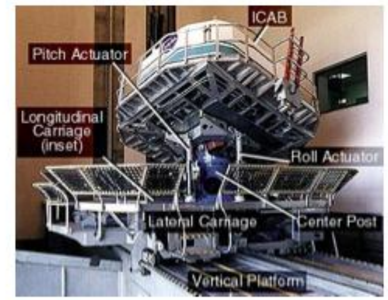
Airship Simulations at SimLabs

- **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

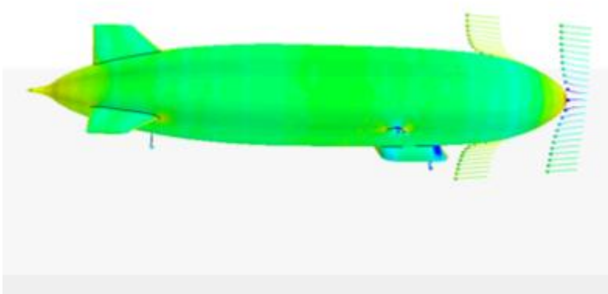


Structures
- Design and Analysis
- Testing and Instrumentation
- Materials

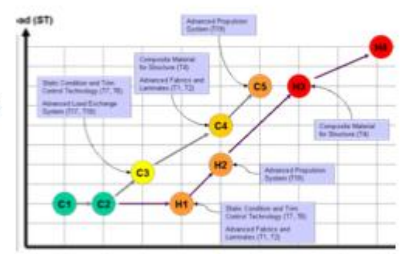


Aerodynamics
- Steady Loads Estimation
- Performance
-Gust and Fin loads

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



Mission Analysis
- Airspace Operations
- Cargo Handling
- Risk Analysis



Questions?