Potential Benefits of Airborne Wind Energy Systems

• Excellent wind resource
• High capacity factors and reduced variability
• Can extract wind energy over instead of on difficult terrain
• Reduced environmental impact
• May eliminate or mitigate land use conflicts
Having a Better Mousetrap is Not Enough!

• Potential benefits must be so compelling that hundreds of millions of dollars can be put at risk
• Technology must be sufficiently mature that it can pass a critical Due Diligence examination
• Technology must be sufficiently mature that insurance can be acquired at acceptable rates
  – Must insure the system against accidental loss
  – Must protect the owners from accident liability
• Increased cost of project financing for immature technologies can be fatal
• Engineering challenge to sufficiently advance Technology Readiness Level so that financial needs are met
Unique Niche for Airborne Wind Systems

Airborne wind needs:

- Low cost of wind turbines
- High reliability of aircraft

$5/lb

$500/lb
Reliability Requirements

• Reliability affects
  – Safety
  – Public perception
  – System development nonrecurring costs
  – Operations and maintenance costs
  – Power production (revenue!)

• Need a comprehensive approach to system reliability to address these diverse needs

• Need clear definition of all reliability requirements

• Reliability is expensive!
Risk Management

• Development, deployment and operation of airborne wind energy systems have unique risks

  Examples:
  – If you exclude certain weather from your design environment, how do you know it’s coming?
  – Who decides to recover?
  – How much time is required to recover the system?

• Must follow a rigorous risk reduction process as these systems are developed

• Different set of issues for system operations, but need for risk management remains
Design and Verification Standards

• Complete set of standards for design, verification, manufacture and operations of aircraft – Title 14 of the Code of Federal Regulations

• Modest set of standards for wind turbines – International Electrotechnical Commission 61400

• Nothing exists for airborne wind energy systems

• No basis for Certification or 3rd party assessment of designs (who is Certifying body?)

• Serious bar to rigorous Due Diligence process

• Must get started defining standards immediately – it takes time!
Resource Assessment

To start, mesoscale models developed for wind turbines can be “queried” at higher elevations

Need much more than average wind speed!
• Wind speed probability distribution
• Turbulence
• Vertical shear
• Extreme winds
• Extreme coherent gusts
• Temperatures
• Probability of thunderstorms, hail, icing, tornados, hurricanes
Design Environment

• Different issue than resource assessment!
• Design environment involves **choices**:
  Will the system be operated in
  – Thunderstorms and lightning
  – Hail
  – Icing
  – Tornados
  – Hurricanes
  – Severe storms (how severe?)
  – High winds (how high?)
• What is the maximum operating wind speed? What is the minimum?
• What is the design envelope for turbulence, gusts, etc?
Design Load Cases

• Definition of comprehensive set of Design Loads Cases is critical

• Must encompass sufficient range of conditions to adequately address entire system lifetime
  – Operational cases, static and dynamic
  – Launch and recovery process
  – Adverse operational environments (e.g. flutter with icing present)
  – Extreme events
  – Partial failure cases
  – Electrical and control system faults

• Must constantly recalculate Design Loads Cases are system configuration evolves
Margins of Safety

- Must establish structural margins of safety
- Aircraft use 1.5. Wind turbines use different factors on loads and on structure
- Must define approach for fatigue analysis
  - Design life
  - Fail safe
  - On condition
  - Damage tolerant
- What is required margin for flutter?
- Want most likely system failures to be handled routinely without loss of entire flight vehicle. Must define these failure cases.
- How much damping is required to be present for normal operational aero-servo-elastic modes?
Simulation and Analysis

• Impossible to test all design conditions
• Must have a complete set of simulation and analysis tools to predict
  – Steady and dynamic loads
  – Aero-servo-elastic stability
  – Stability and control (flight dynamics)
  – Dynamics of launch and recovery process
  – Dynamic response to faults and failures
• These tools must be validated with test data for wide range of conditions for the actual system configuration
• Must validate the tools and the input data
Control Systems

• Control system attributes:
  – Autonomous with ground override
  – Redundant and fault tolerant
  – Must automate launch and recovery
  – Will need to sense operational environment and adapt

• Development of control systems for aircraft has become long expensive process

• Need for autonomy complicates control system development for airborne wind systems

• Having a system that appears to work correctly is only half the battle – must then document, validate, and demonstrate to 3rd party
Aero-servo-elastic Stability

- Systems will inevitably grow in size, and become more flexible
- Aeroelastic stability will eventually become a design driver
- Airborne wind energy systems have relatively low Mach numbers
- Linear potential flow analysis, with Prandtl-Glauert corrections, should be sufficient
- Commercial versions of NASTRAN available with required aerostructural modeling capability
- Still requires lengthy and difficult process to build and verify models for novel configurations
- Little knowledge of modes of instability of novel configurations
Verification and Validation

• No substitute for testing
• Companies that have a robust program of component and field testing are more likely to succeed
• Consider establishment of 1-year and 5-year field tests as important milestones
• Need to complete comprehensive set of component Highly Accelerated Life Tests (HALT)
• Sufficient instrumentation required to validate simulation results, and predict fatigue life
• Should partner with 3rd-party test facilities to provide independence and credibility
Comprehensive Testing Required

Innovation for Our Energy Future
Environmental Impacts

- Environmental impacts cannot be ignored – to produce 1% of US electricity requires 15,000 1MW systems
- Many lessons to be learned from wind industry
- Form and fund direct partnerships with environmental advocacy groups to guide approach (e.g. Audubon Society)
- Be sure to address human impacts as well, such as change in “Viewscape”
- Environmental impact assessments are data driven – go get the needed data!
- Common issues across companies and technologies – should collaborate
Lifecycle Cost Modeling

• With all these details settled, can now assess overall costs
  – Development cost
  – Manufacturing and deployment cost
  – Cost of financing
  – Operations and maintenance cost
  – Replacement cost
  – Decommissioning cost

• Use systems engineering model to optimize
• Use model to inform directions for future R&D investment
Summary and Recommendations

• Must explicitly define all system reliability requirements
• Use an integrated risk management approach to meet these requirements
• Certification Standards urgently needed to
  – Define design environment
  – Define design loads cases
  – Define margins of safety
  – Permit 3rd party assessment and Certification
• Major effort required to develop and validate simulation tools
• Test, test, test, test, test
• Test some more
Thank you!

Questions?

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