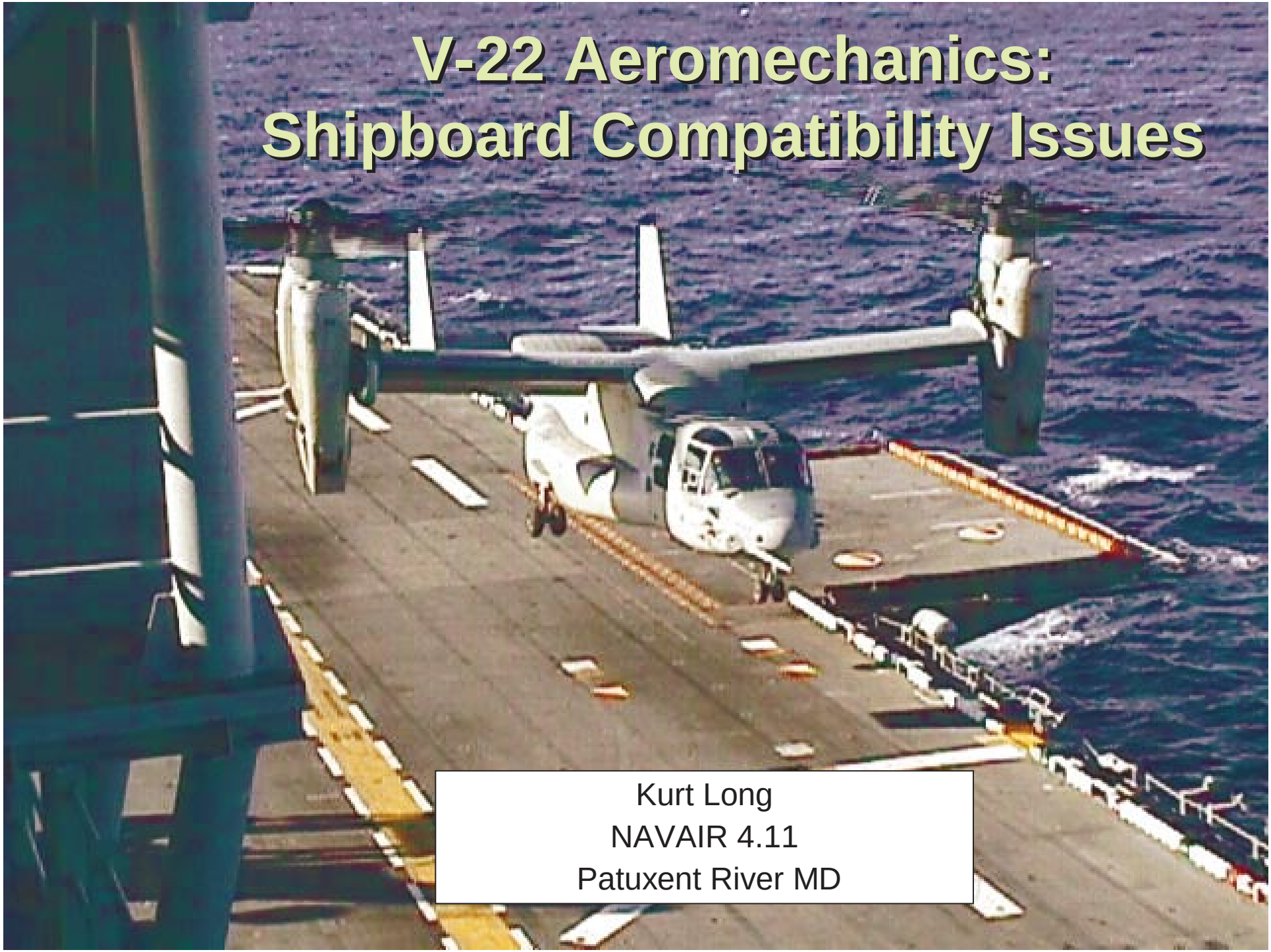
V-22 Aeromechanics: Shipboard Compatibility Issues



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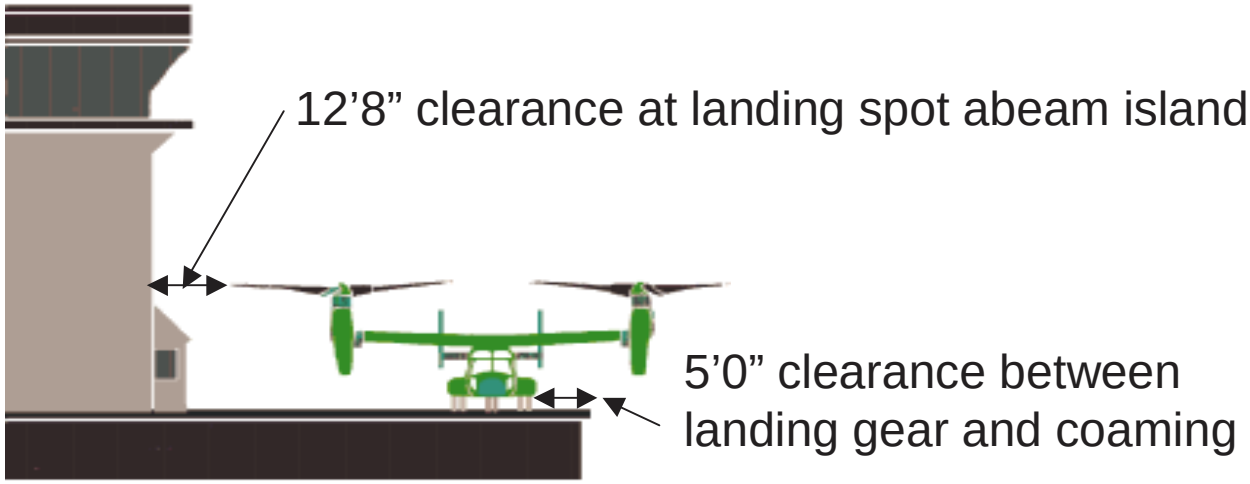
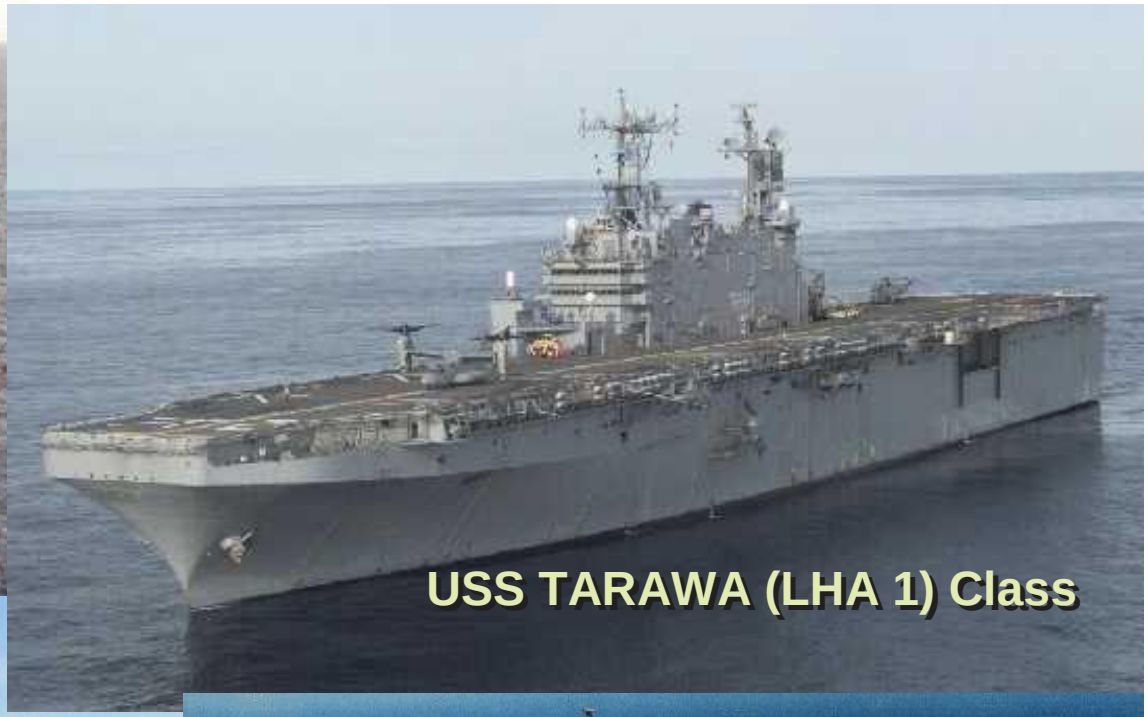
Background:
V-22 Shipboard Operations

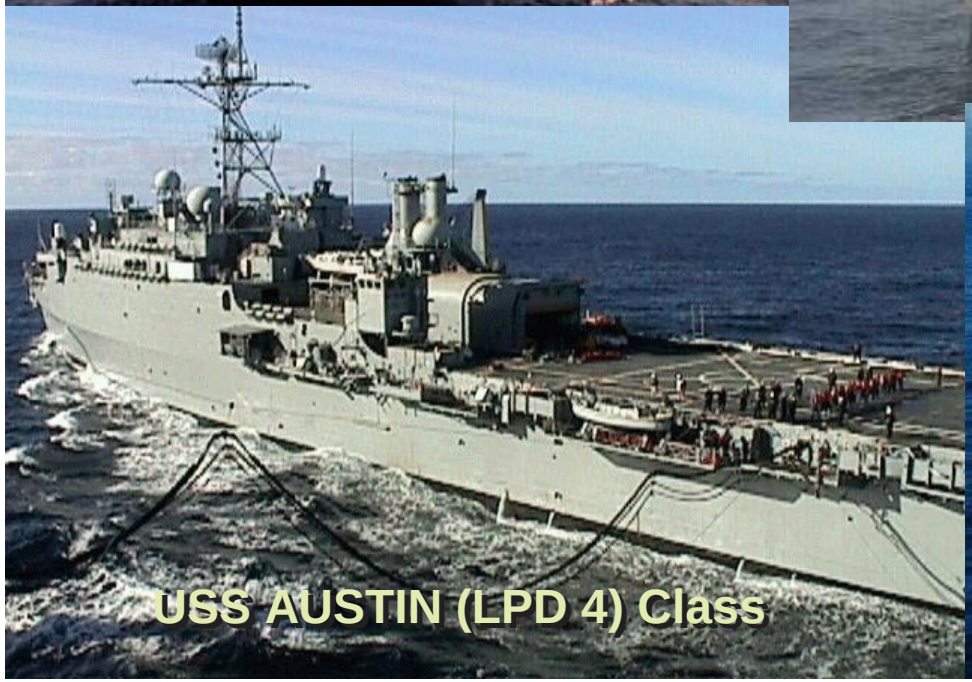
- **Mandated by Operational Requirements Document (ORD)**
  - Operate from air capable ships without reconfiguration or modification.
  - Embark and operate 24-30 aircraft from an LHA or LHD class ship.
  - Stow below deck on LHA, LHD, and CVN class ships.
  - Launch/recover in conditions of up to ±3 deg ship pitch, ±8 deg ship roll.
  - Sustain winds of up to 60 kts without damage when folded/stowed/tied.
  - Engage/disengage proprotors in speeds up to 45 kts from any direction.
  - Blade fold/wing stow in winds up to 45 kts from any direction.
- **Shipboard Ops Requirement Drove Rotor Radius**

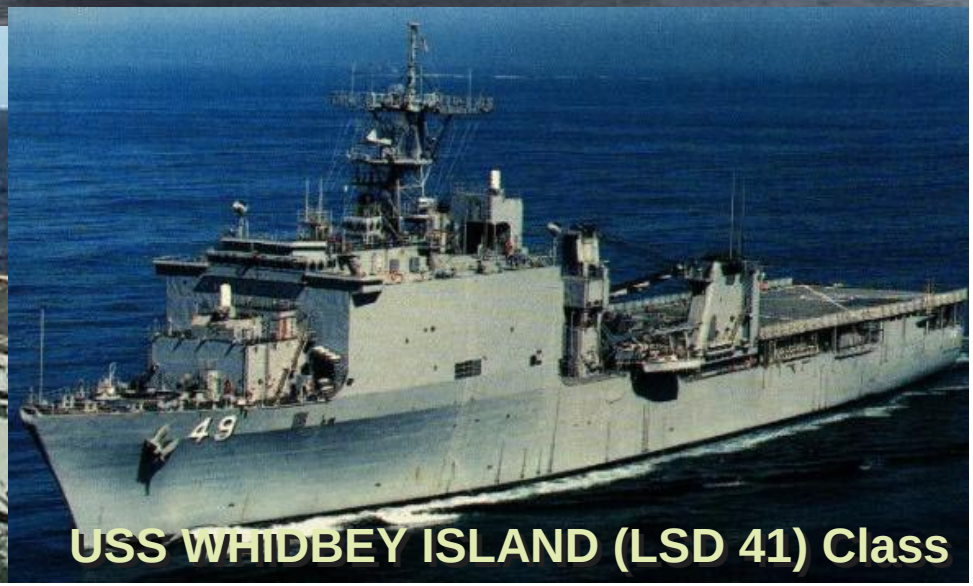


Background:
Ship Classes That V-22s Will Operate From

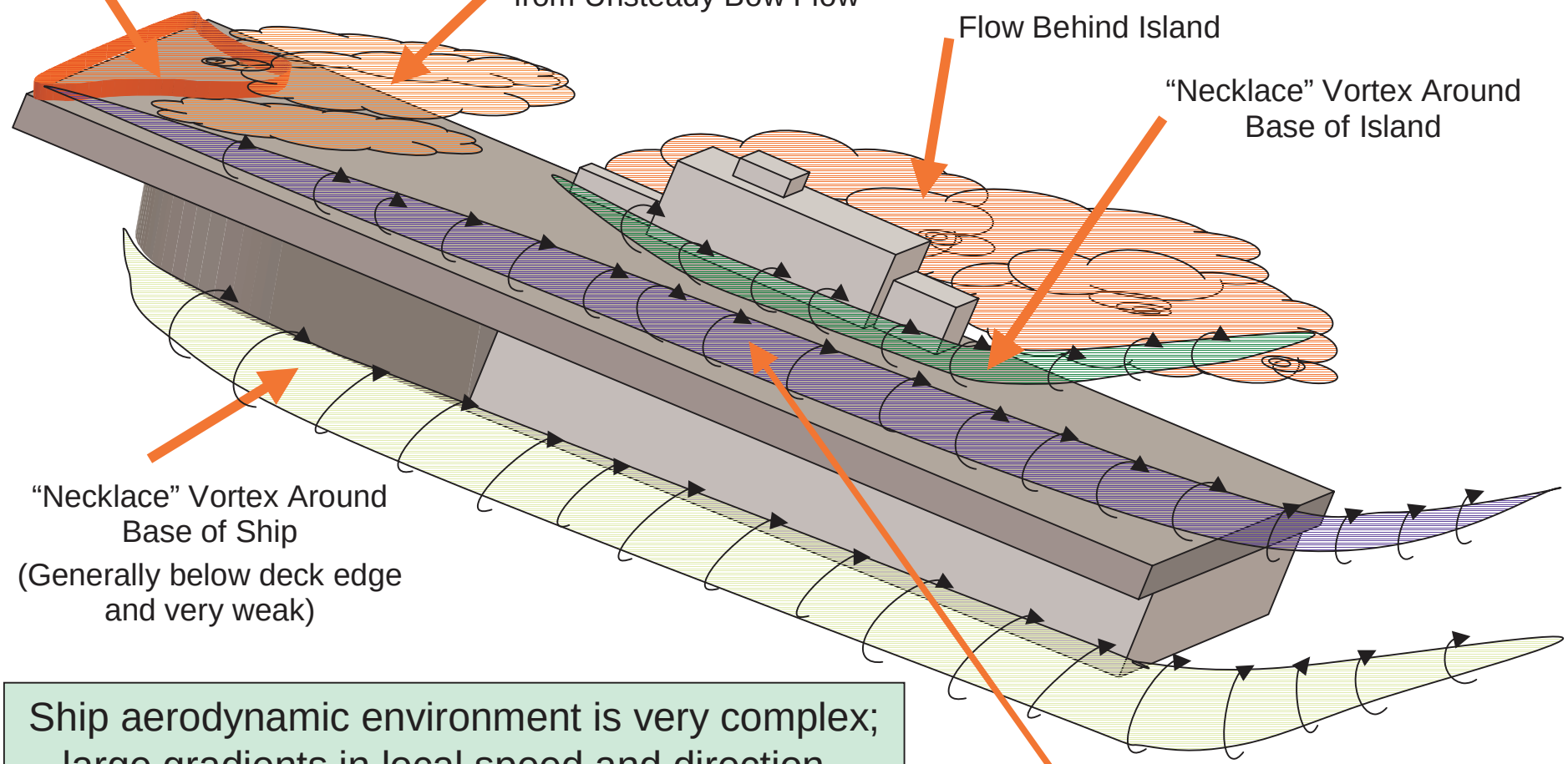

USS WASP (LHD 1) Class


USS TARAWA (LHA 1) Class


USS AUSTIN (LPD 4) Class


USS WHIDBEY ISLAND (LSD 41) Class

Background:
Basic Flow Structures, USN Amphibious Assault Ships

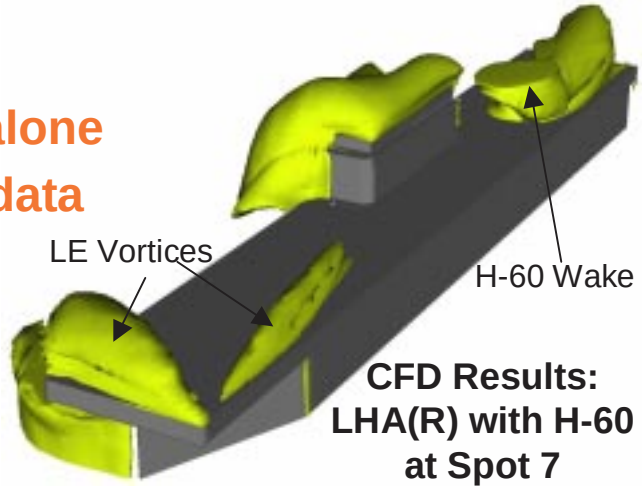


Ship aerodynamic environment is very complex; large gradients in local speed and direction, which vary with relative wind speed and direction (and presence of other aircraft).

Background:
Rotorcraft/Ship Airwake Knowledge

- **Wind Tunnel Efforts**
  - Many (40+) efforts and accurate results for ships alone
  - Few (<10) efforts to investigate ship + rotorcraft data
  - Difficult to include controls, FCS, etc...
  - Good short term technique for limited conditions
- **Computational Fluid Dynamics (CFD) Efforts**
  - Few (<10) efforts, but accurate results for ships alone
  - Few (<10) efforts to investigate ship + rotorcraft data
  - Limited capability to model structural detail
  - More validation of techniques is required
  - Probably best prospects in long term
- **Flight Test Efforts (Dynamic Interface Tests)**
  - At sea, underway, shipboard tests; actual aircraft
  - Operating envelope development technique
  - Safe, but time consuming and expensive
    - (>20 hrs/spot, $M per test)
- **<u>Overall, capabilities to predict ship/rotorcraft interactional aerodynamics are less than desirable!</u>**

LPD 17
Wind Tunnel Model



CFD Results:
LHA(R) with H-60
at Spot 7

V-22 Shipboard Operational Summary

Developmental Tests (~ Envelope Development)

FSD Aircraft (12 flight hrs; 30 takeoffs/landings)

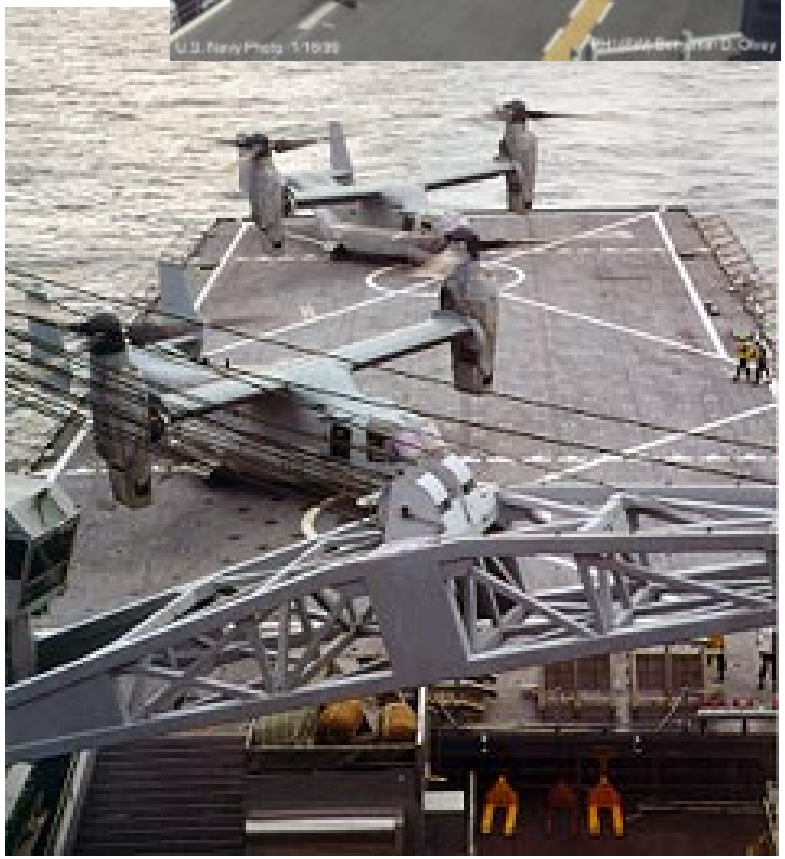
- Dec ‘90, USS WASP (LHD 1)

EMD Aircraft (98 flight hrs; 650 takeoffs/landings)

- 14 Jan-08 Feb ‘99, USS SAIPAN (LHA 2)
- 16-27 Aug ‘99, USS SAIPAN (LHA 2)
- 7-11 Sep ‘99, USS TORTUGA (LSD 46)

Operational Tests (~Tactics/Procedures)

EMD Aircraft, USS Essex (LHD 2) + others



Accomplishments

- Static Compatibility
- Day, night launch/recovery envelopes
- Rolling short takeoffs
- External loads operations
- Night Vision Device (NVD) operations
- Blade Fold/Wing Stow
- Rotor Engage/Disengage
- Maintenance/Supportability
- Limited multi-aircraft operations

V-22 Shipboard Operations: Summary of Aeromechanic Phenomena

- **Pitch Up with Sideslip**
  - Port and starboard quartering relative winds
  - Proprotor wake impinges on horizontal stab
  - Momentary pitch-up, degrades Field of View, potential for deck contact
- **Longitudinal Control During STO**
  - Proper long. cyclic control required to minimize yoke loads on Takeoff
- **Lateral Control Nonlinearities**
  - Slight roll unsteadiness, low over spot
  - "USS SAIPAN Incident" - ~37 deg AoB, ~ 8 ft wheel height
  - Potential for deck contact (damage and/or injury)
- **On-Deck Uncommanded Roll Oscillations**
  - V-22 on deck, rotors turning @ "flat pitch", aircraft chained to deck
  - Variety of landing spots, ship motion, relative wind speed/direction (no correl)
  - Up to ± 10 deg roll oscillations
  - Potential for excessive structural loads, deck contact or worse (damage, injury)
- **Excessive On-Deck Roll Response to Upwind Aircraft**
  - V-22 on deck, rotors turning, "flat pitch"
  - H-46 approaching location 3 spots ahead (upwind) of V-22
  - H-46 wake caused >10 deg left wing down roll
  - Potential for excessive structural loads, deck contact or worse (damage, injury)

Investigations into V-22 Shipboard Aeromechanic Phenomena, I

- **Pitch Up with Sideslip**
  - Shipboard tests produced mitigating procedures
    - **Landing: Trim out nacelle compensation, and align heading with relative winds**
    - **Takeoff: Slow, controlled TCL application**
  - Procedures recommended for routine use

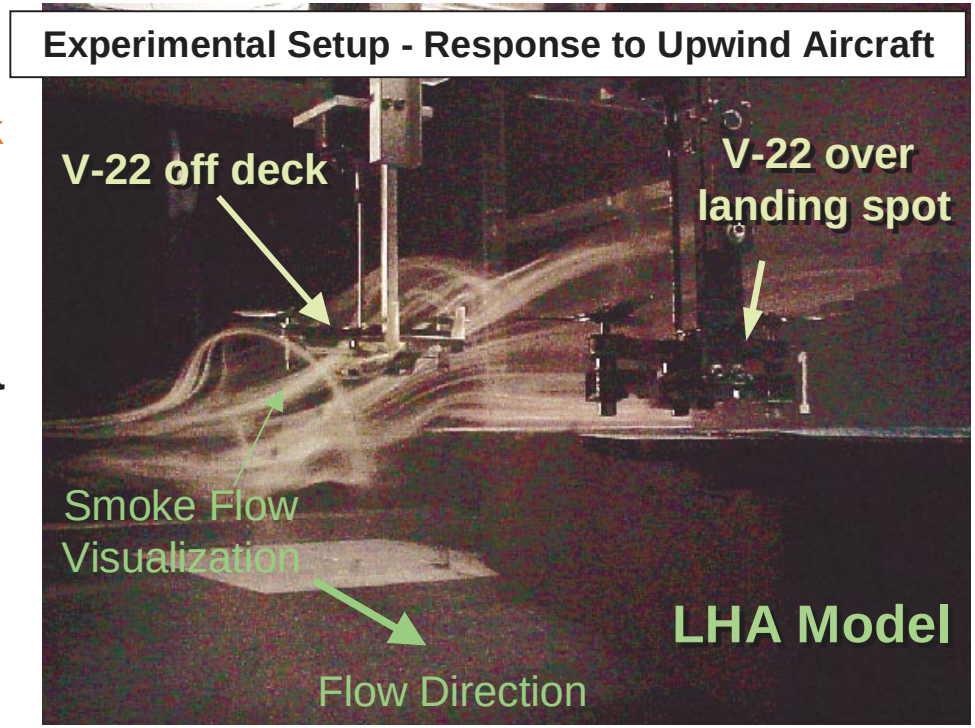
- **Longitudinal Control During STO**
  - Shipboard tests produced mitigating procedures
    - **Select proper longitudinal stick position for given CG, prior to adding power**
  - Procedures recommended for routine use

Investigations into
V-22 Shipboard Aeromechanic Phenomena, II

- **Lateral Control Nonlinearities**
  - Extensive post-test investigation program (ITT/Bell/Boeing)
    - **FCS analysis, piloted simulator efforts, landbased flight tests, wind tunnel tests**
  - Incident attributed to lateral control axis saturation
    - **Left lateral trim bias, limited AFCS lateral port authority, high freq control inputs**
  - Aircraft solution: improve the lateral phase margin
    - **Modify AFCS port logic to avoid saturation during high frequency inputs**
    - **Optimize swashplate actuator authority allocation (Differential Collective Pitch (DCP) vs Lateral Swashplate Gearing (LSG))**
    - **Modify roll rate gain**
  - Wind tunnel revealed on-deck vortex as probable source of left lateral bias
  - Subsequent at-sea tests >> improved performance, limited set of conditions

Investigations into V-22 Shipboard Aeromechanic Phenomena, III

- **On-Deck Uncommanded Roll Oscillations (URO)**
  - Initial wind tunnel tunnel tests in Fall, 2001
  - Proposed large scale tests (NRTC RITA/Boeing)
  - Currently, the possibility of tightening tiedown chains is being investigated
  - Next shipboard tests will include investigation of phenomena
- **Excessive On-Deck Roll Response to Upwind Aircraft**
  - Initial wind tunnel tests in 2000; subsequent in Fall, 2001
    - **Large (overturning?) roll moments can occur for a variety of conditions:**
      - **Relative wind speed, direction**
      - **Upwind helo gross weight**
      - **Upwind helo proximity (3D)**
    - **Moments largest when helo on deck**
  - Large scale tests (NRTC/Boeing)
  - Next shipboard tests will investigate
- **Summary: Both phenomena could be VERY significant!**
  - Until well understood, they could prohibit ALL shipboard ops!
  - More investigation needed!



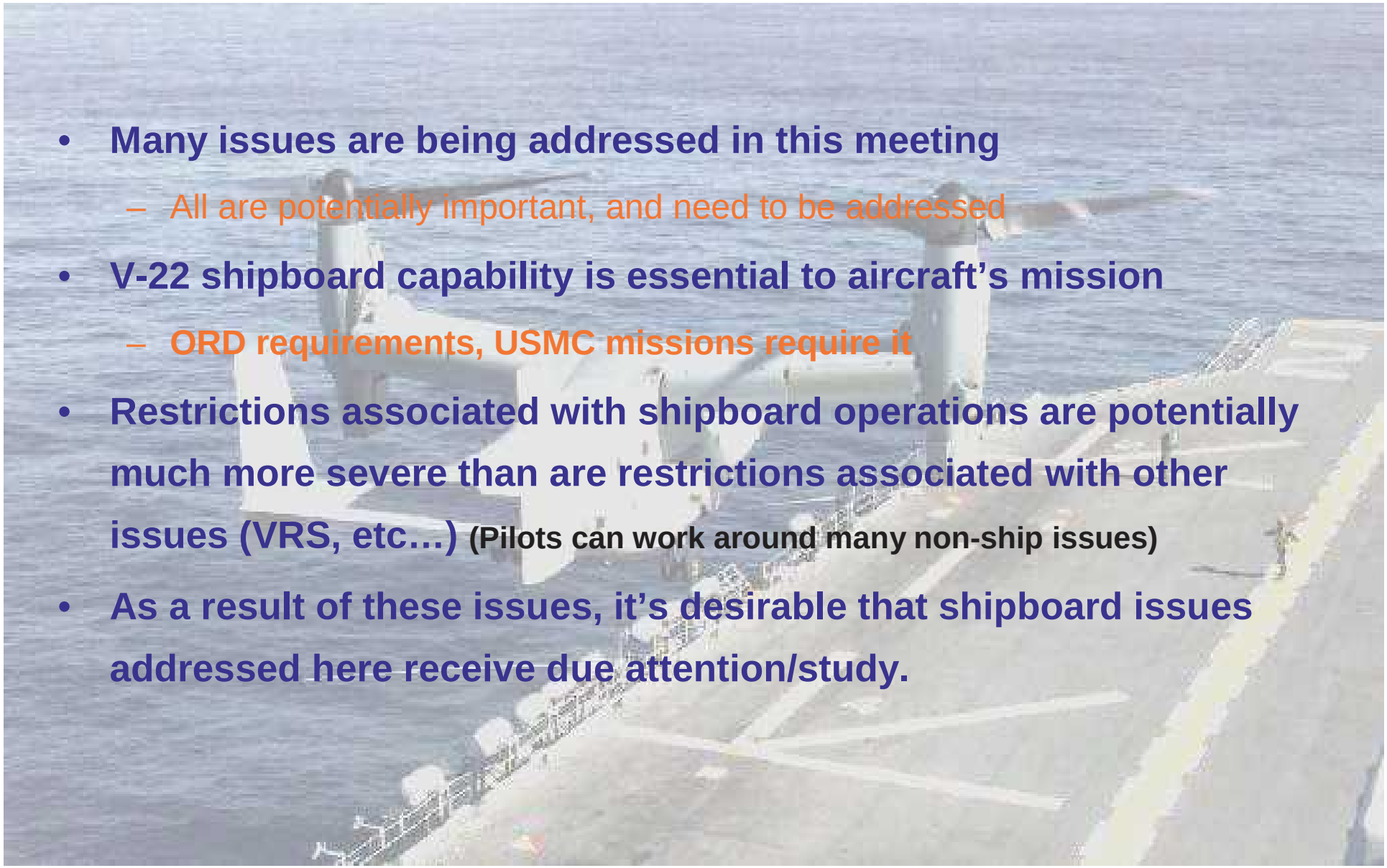
V-22 Shipboard Aeromechanic Phenomena Unresolved Issues

- **Lateral Control Nonlinearities**
  - Is Flight Control System (with fixes) valid for all untested conditions?
    - **Relative wind speed, direction**
    - **Gross weight/density altitude**
    - **Ship motion**
    - **Aircraft location on deck**
  - (Do we really understand the causal factors?)
- **On-Deck Uncommanded Roll Oscillations**
  - Is tiedown tightening a valid solution?
  - What conditions contribute to the oscillations?
  - Are there any aerodynamic/landing gear/flight controls interactions?
  - How do we mitigate the condition?
- **Excessive On-Deck Roll Response to Upwind Aircraft**
  - What conditions contribute to the roll response?
  - Are there any aerodynamic/landing gear/flight controls interactions?
  - How do we mitigate the condition?
- ***Summary: We just don't know enough about complicated shipboard rotorcraft interactional aerodynamics - expedite all efforts (wind tunnel, CFD, analytic, etc…) to investigate!***

V-22 Shipboard Aeromechanic Phenomena Recommendations

- **Lateral Control Nonlinearities**
  - Conduct sea trials!
  - Continue wind tunnel/analytic studies to evaluate conditions
    - **Large scale NRTC/Boeing effort**
  - Continue development of high fidelity ship/rotorcraft CFD techniques
- **On-Deck Uncommanded Roll Oscillations**
  - Conduct sea trials!
  - Continue wind tunnel/analytic studies to evaluate the causal conditions
  - Continue development of high fidelity ship/rotorcraft CFD techniques
- **Excessive On-Deck Roll Response to Upwind Aircraft**
  - Conduct sea trials!
  - Continue wind tunnel/analytic studies to evaluate causal conditions
  - Continue development of high fidelity ship/rotorcraft CFD techniques
- **One Extra Recommendation**
  - Optimal landbased buildup requires provision of good low airspeed sensor!

Significance of V-22 Shipboard Aeromechanic Phenomena



- **Many issues are being addressed in this meeting**
  - All are potentially important, and need to be addressed
- **V-22 shipboard capability is essential to aircraft's mission**
  - **ORD requirements, USMC missions require it**
- **Restrictions associated with shipboard operations are potentially much more severe than are restrictions associated with other issues (VRS, etc…)** **(Pilots can work around many non-ship issues)**
- **As a result of these issues, it's desirable that shipboard issues addressed here receive due attention/study.**

V-22 Shipboard Aeromechanic Phenomena ReCap

1a) What are the aeromechanic phenomena?

- **Lateral Control Nonlinearities (LCN)**
- **On-Deck Uncommanded Roll Oscillations (URO)**
- **Excessive On-Deck Roll Response to Upwind Aircraft (ERR)**

1b) How well do we understand them?

- **LCN - Probably, pretty well - aerodynamics+ pilot excitation combined to saturate the old FCS design**
- **URO - Not very well - probably aero interaction, but no strongly correlated cause**
- **ERR - Not very well - aero interaction, we cannot predict conditions that lead to it**

2) What are the operational implications?

- **All - If uncorrected, any/all could lead to damage or injury; at minimum, until we understand them more, they have already resulted in tactically undesirable reductions in shipboard operating envelope size.**

3) State of testing and analysis?

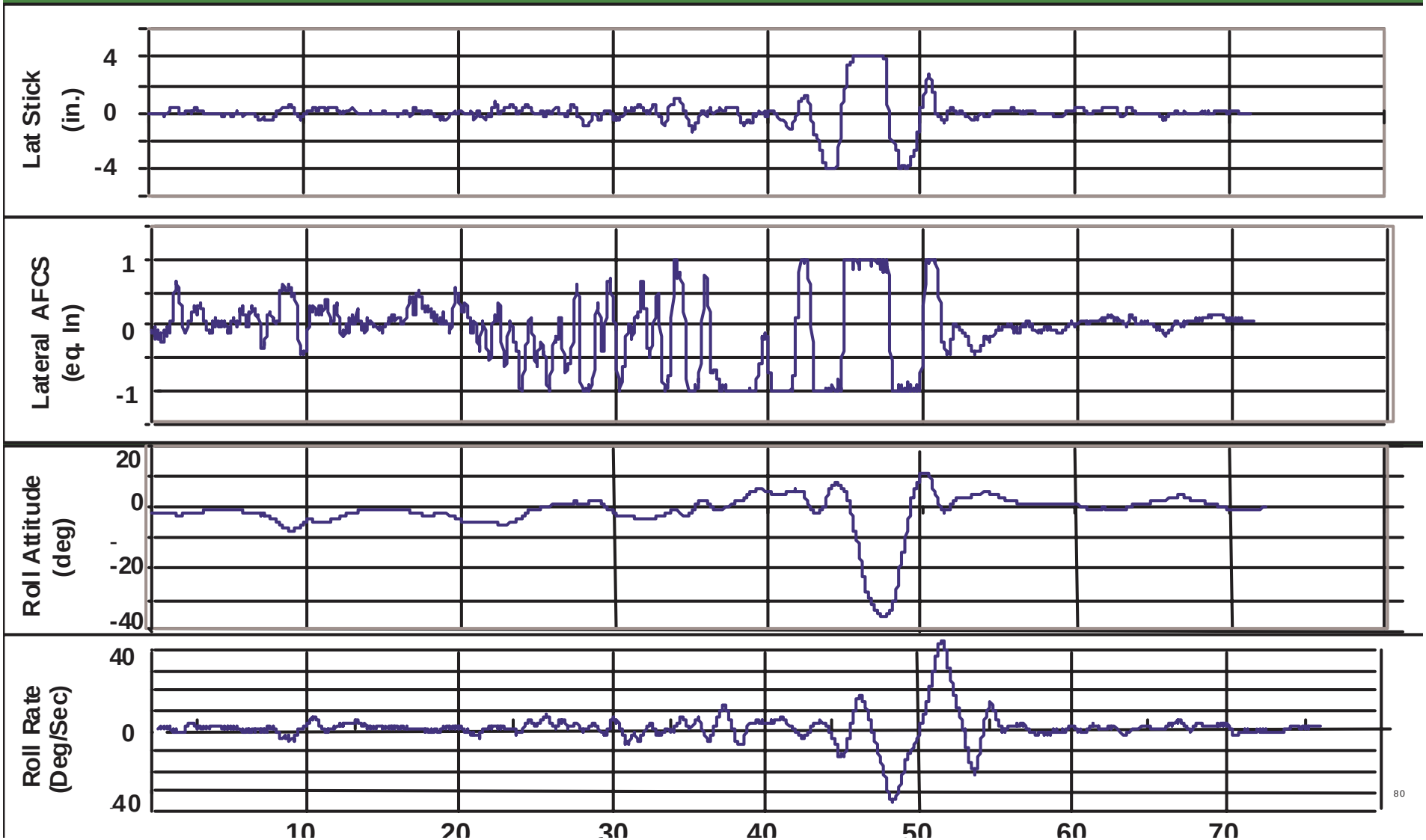
- **LCN - Probably pretty good - initial "fixed" results are duplicatable to some extent in simulator and aboard ship, but insufficient conditions have been investigated**
- **URO - Not very good - few wind tunnel/analytic efforts, no CFD efforts; inadequate understanding of phenomena to date**
- **ERR - Not very good - few wind tunnel/analytic efforts, no CFD efforts; inadequate understanding of phenomena to date**
- **All- Landbased buildup tests are hampered by lack of good/accurate low airspeed sensor**

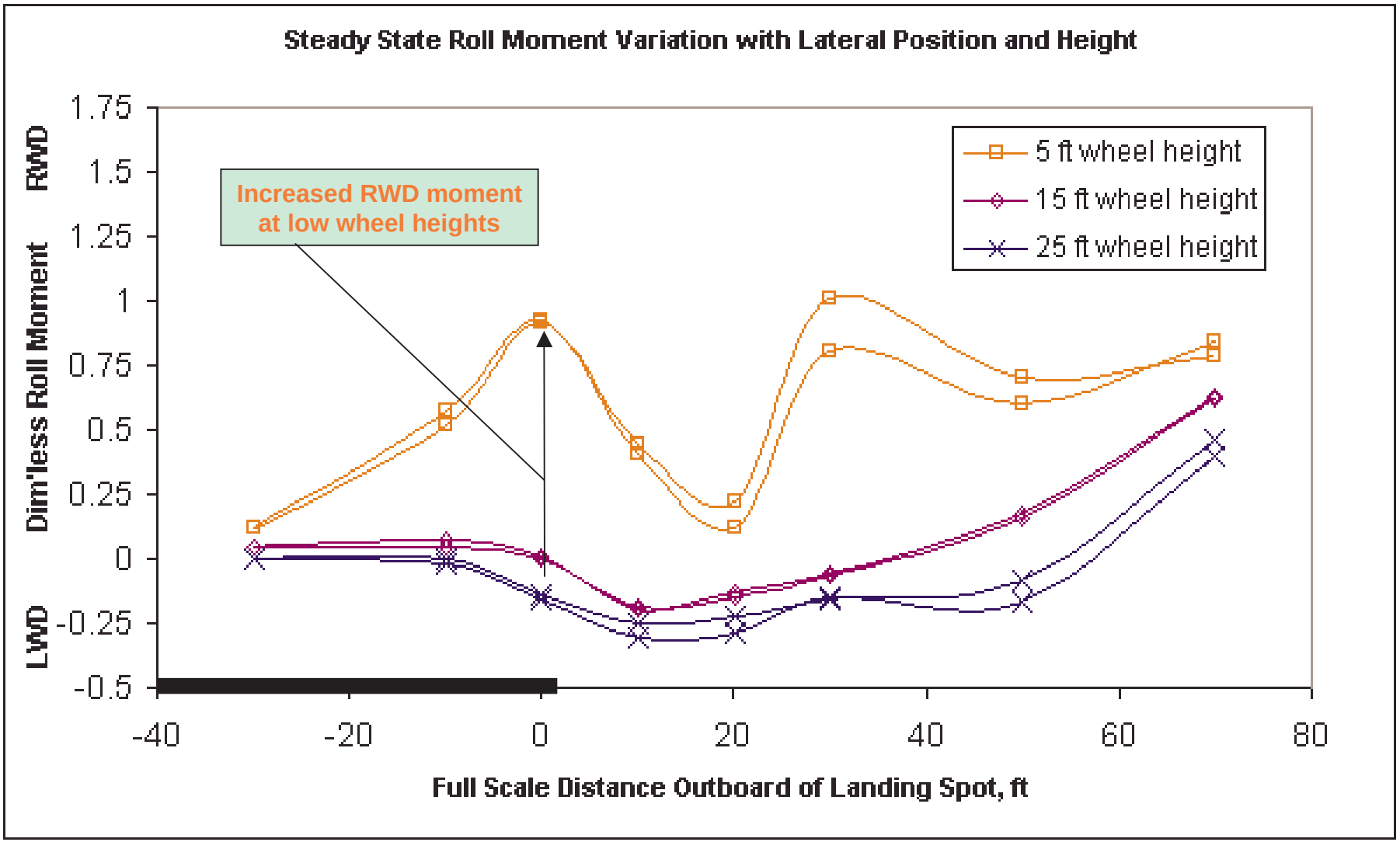
4) What do we need to know?

- **LCN - At-sea results for more parameters (effect of spot, wind, ship motion, lateral CG)**
- **URO, ERR - Basic causal effects and parameters (effect of wind, ship motion, gross weight, spot); overall, we need a capability to predict shipboard rotorcraft interactional aero effects**

Backup Slides

USS SAIPAN Incident Data Trace





Wind Tunnel Test Results - SAIPAN Incident