



Air Cushion Vehicle (ACV) Developments in the U.S

Presented

to the

**Joint SNAME SD-5/HIS
Dinner Meeting**

by

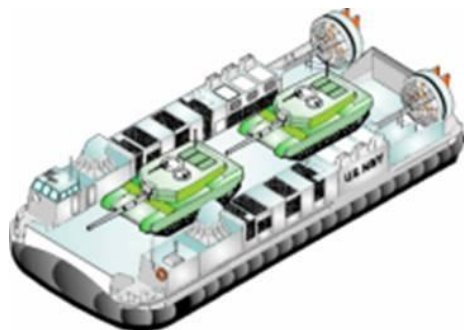
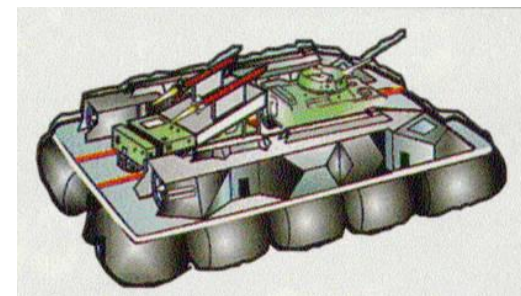
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Director of R&D

CDI Marine Co.

Systems Development Division

9 June 2005





Anatomy of an ACV

- ACVs are truly Amphibious Craft that are capable of traveling over almost any type of surface.
- **Capability comes from ACV unique equipment.**

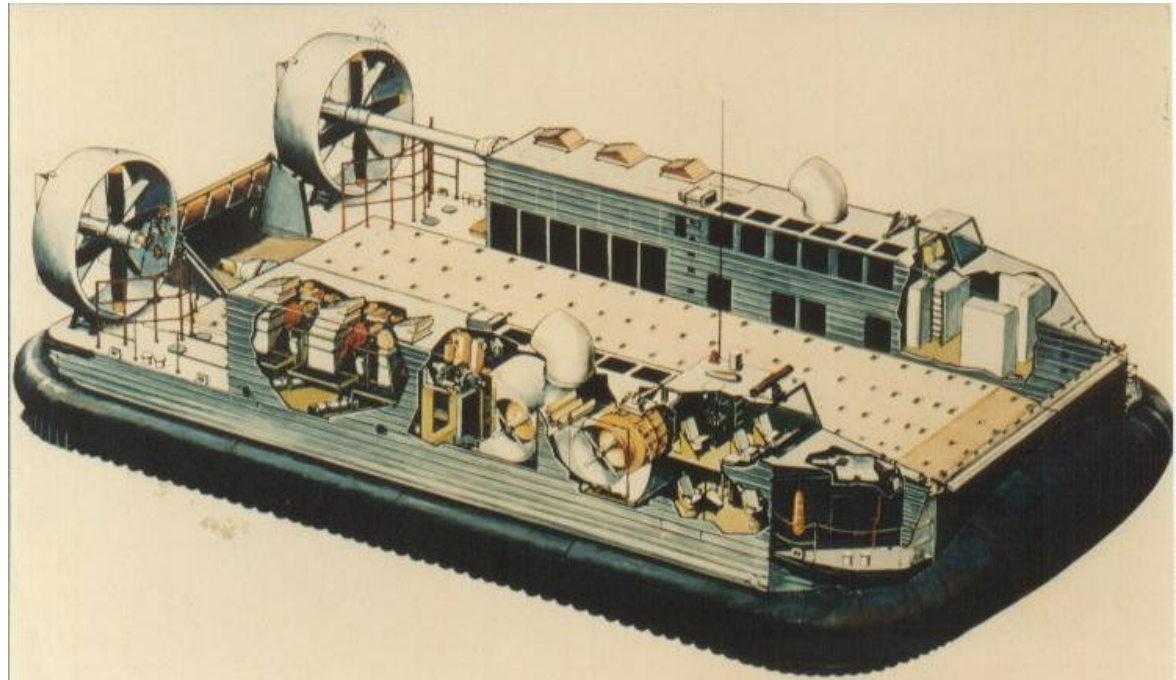




Anatomy of an ACV

**ACV unique
equipment
includes:**

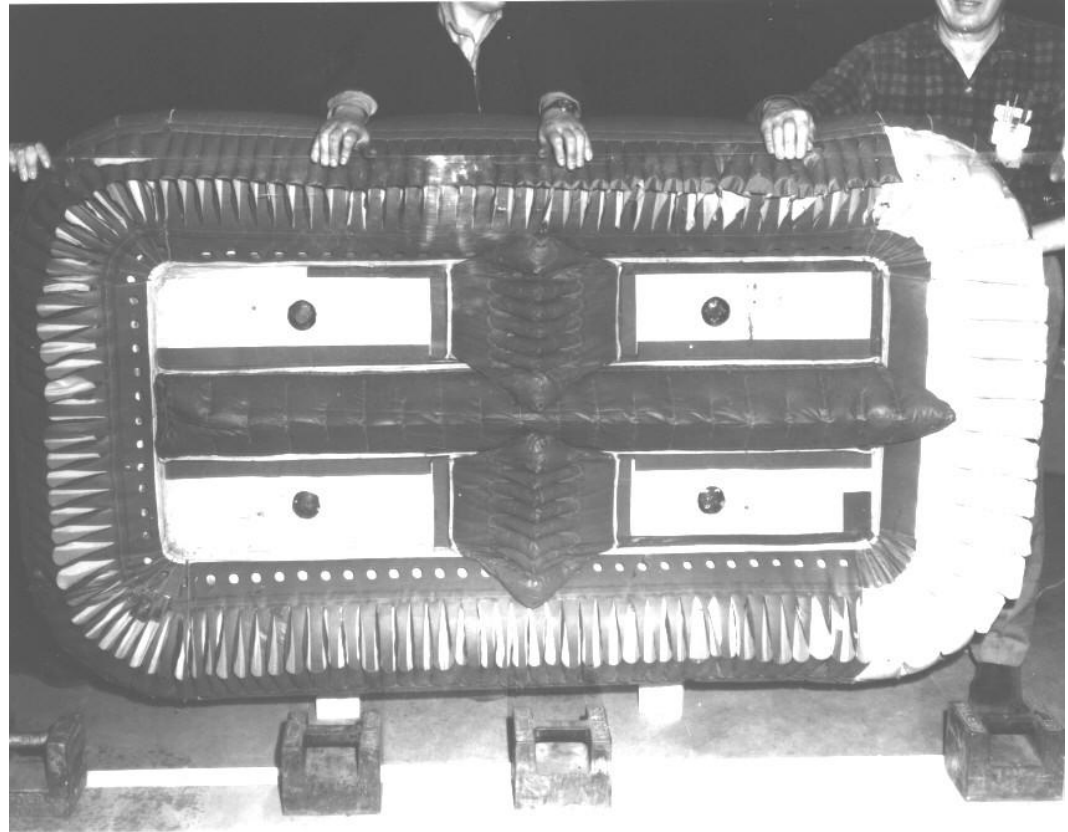
- **Skirt System**
- **Lift System**
- **Air Screw Propulsors**
- **Bow Thrusters**



Skirt Systems



- **Flexible Skirt Systems** were first introduced to **ACVs** in 1961.
- Continued to evolve and mature over the next 20+ years.
- Evolved into the typical **Bag-Finger Skirt**.
 - **Peripheral bag** for air distribution.
 - **Flexible fingers** attached to bag.
 - **Cushion sub-division**.





Deep Skirt Project

- Oct. 1995, CNO N853 directs development of Enhancements for Increasing LCAC Survivability while conducting Shallow Water MCM Mission (SWMCM).
- Jan. 1996, Coastal Systems Station is directed by PEO-CLA, PMS-377 to initiate Deep Skirt Project.

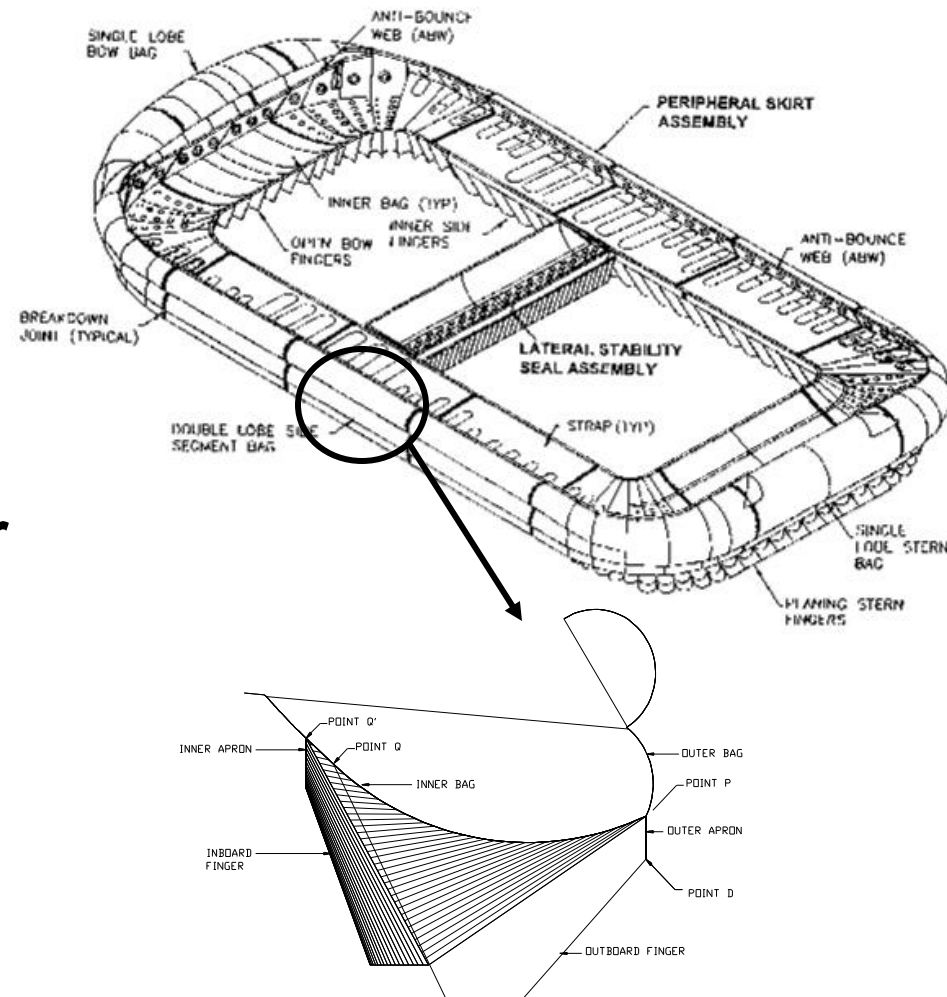


Deep Skirt Design



Principal Characteristics

- 40% Increase in Cushion Height
- Elimination of Longitudinal Cushion Divider
- Double-Bubble Side Seal for Well-Deck Compatibility
- Unique Back-to-Back Side Fingers for enhanced roll static stability



Represented the “First” of a New Generation of Skirt Designs



Deep Skirt Design

Deep Skirt design was subjected to extensive sub-scale test prior to committing to full-scale prototyping



Deep Skirt Design



- SWMCM Mission was **cancelled** after the prototype was built!
- Performance and durability testing of Deep Skirt showed:
 - Improved Ride Quality
 - Improved Payload Carrying Capability
 - Improved Speed/Sea State Performance



Deep Skirt was Retained as a Craft Upgrade and is in Production

Not All Is Good



- **Material Delamination** showed up after 100 operating hours on the prototype skirt.
 - Issue also showed up on the Canadian Coast Guard AP.1-88/200 and the Hoverspeed SR.N4 MKIII.
 - All three craft used the same natural rubber material.

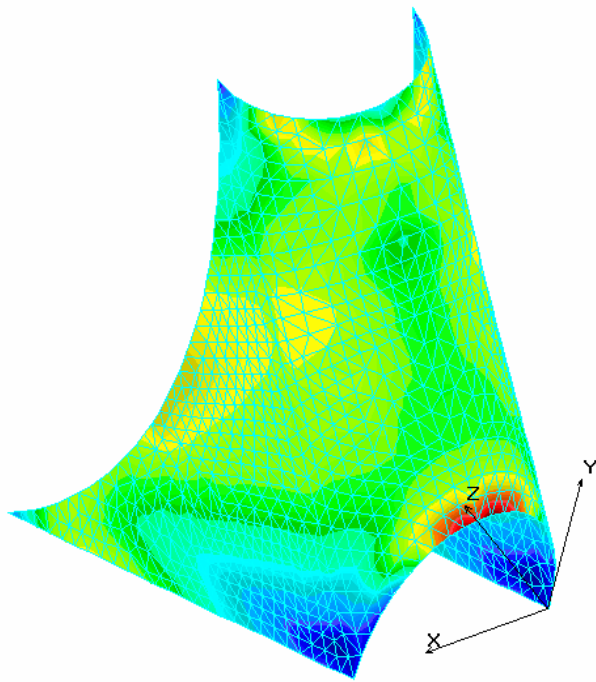


Suspected that Fatigue was the Primary Failure Mode

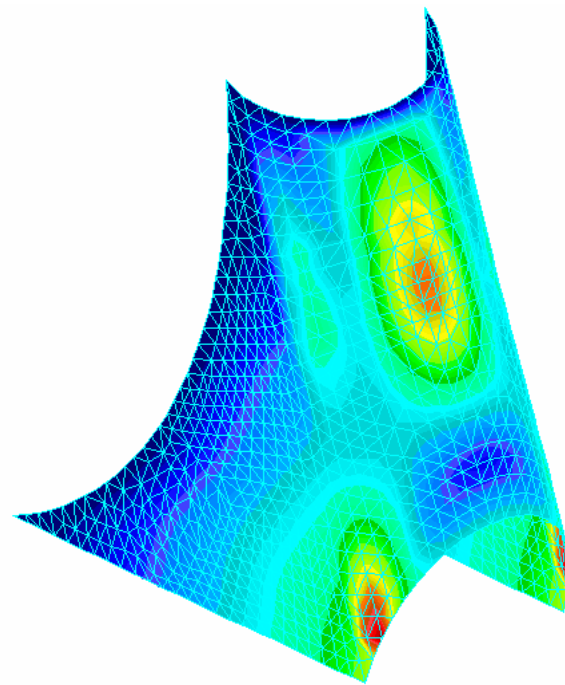


Not All Is Good

- FEA analysis of an inflated finger indicated **Stress Concentrations** and areas of **Large Deformations**.



Stress Map

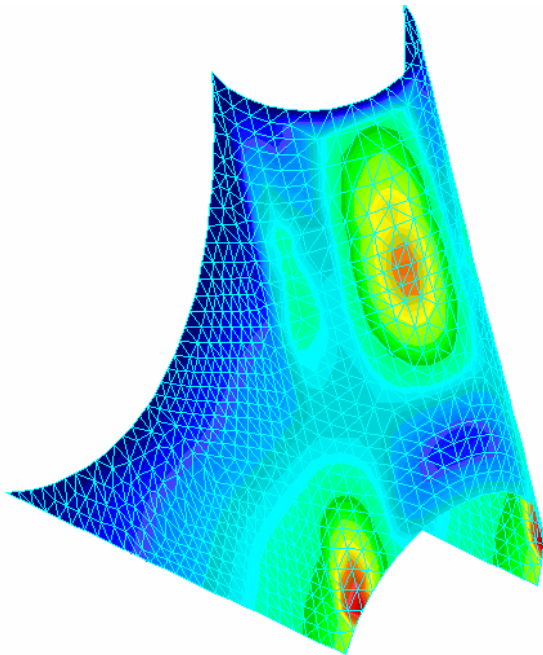


Deflection Map

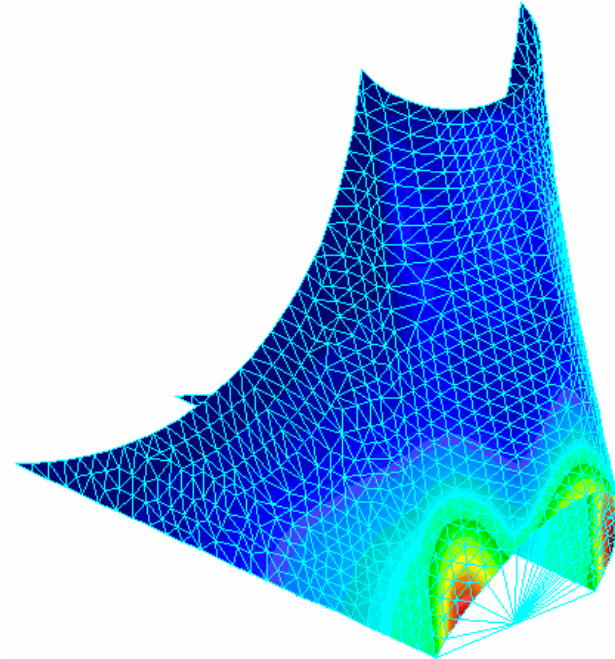


Things Get Better

- FEA analysis indicated that a modification of the Design & Lofting Process would correct this.



Deflection Map
before Modification

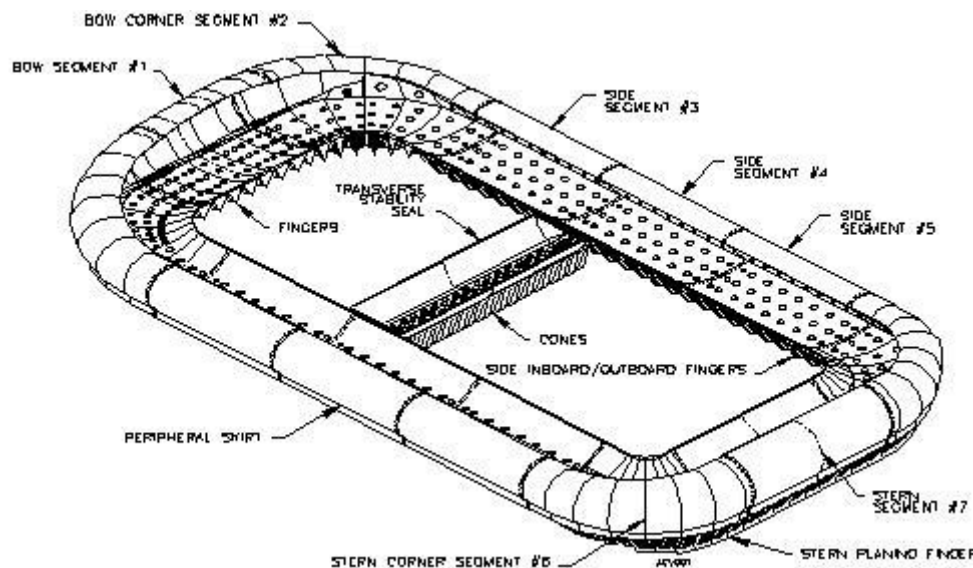


Deflection Map
after Modification



Second & Third Generation Designs

- Lessons Learned were applied to the Finnish T-2000 Combat ACV (2nd Gen).
 - Modified Design/Lofting Process
 - 3-D Design Tools





Second & Third Generation Designs



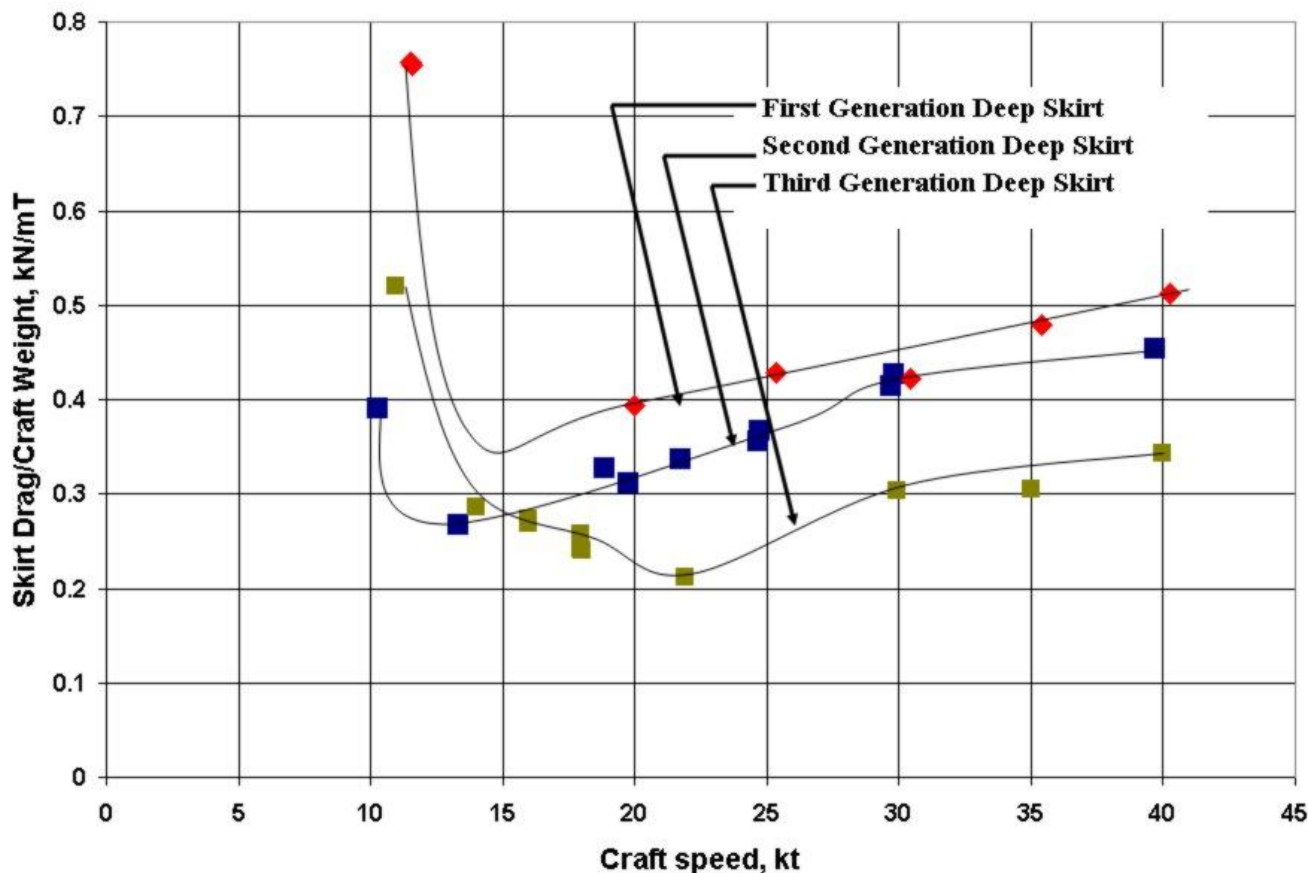
- **2nd Generation T-2000 Skirt has 440+ hours on original bow and side fingers.**
- **Stern corner and stern fingers replaced after approximately 300 hours.**





Second & Third Generation Designs

- 3rd Generation Skirt is being manufactured.
- Model test data results indicate that this will be the best design so far.



Believe that Additional Performance Improvements are Possible



Lift Fan Design



- **Historically, ACVs tended to use commercially available fans or a version of the successful HEBA-A or HEBA-B Fan Series.**
- **Current and future high-density craft are requiring higher pressure, higher air-flow rate and increased efficiency.**
 - **Typically military craft rather than commercial craft.**



Lift Fan Design

- **Systematic series fan tests have not been performed since the mid to late 60's.**
 - Many of these are documented in “Unpublished” Reports.
- **Results have been the primary design guide for:**
 - Fan Aerodynamic Design
 - Volute Design
 - Installation Effects



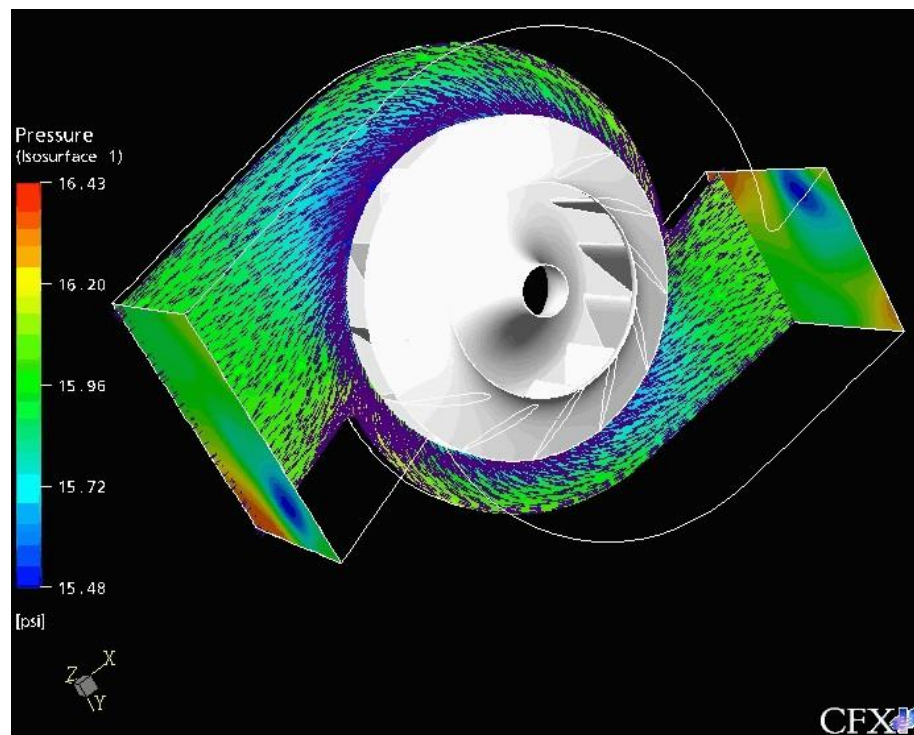
Lift Fan Design

- **CDIM-SDD participated in a Science and Technology (S&T) effort directed at fan design.**
 - **ONR Sponsorship.**
 - **Directed at using Modern CFD Tools to develop lift fans that Improve on Performance and Efficiency achievable with current equipment.**
- **Aerodynamic design drew on prior fan design experience at CDIM-SDD.**

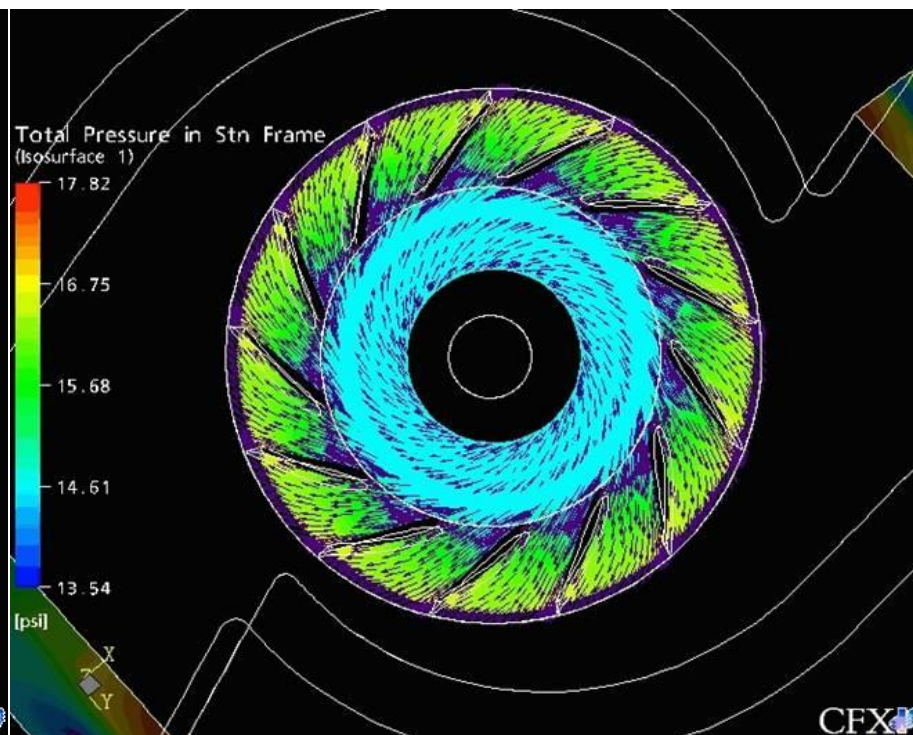


Typical CFD Results

Volute Static Pressure Distribution



Impeller Pressures and Velocity Vectors





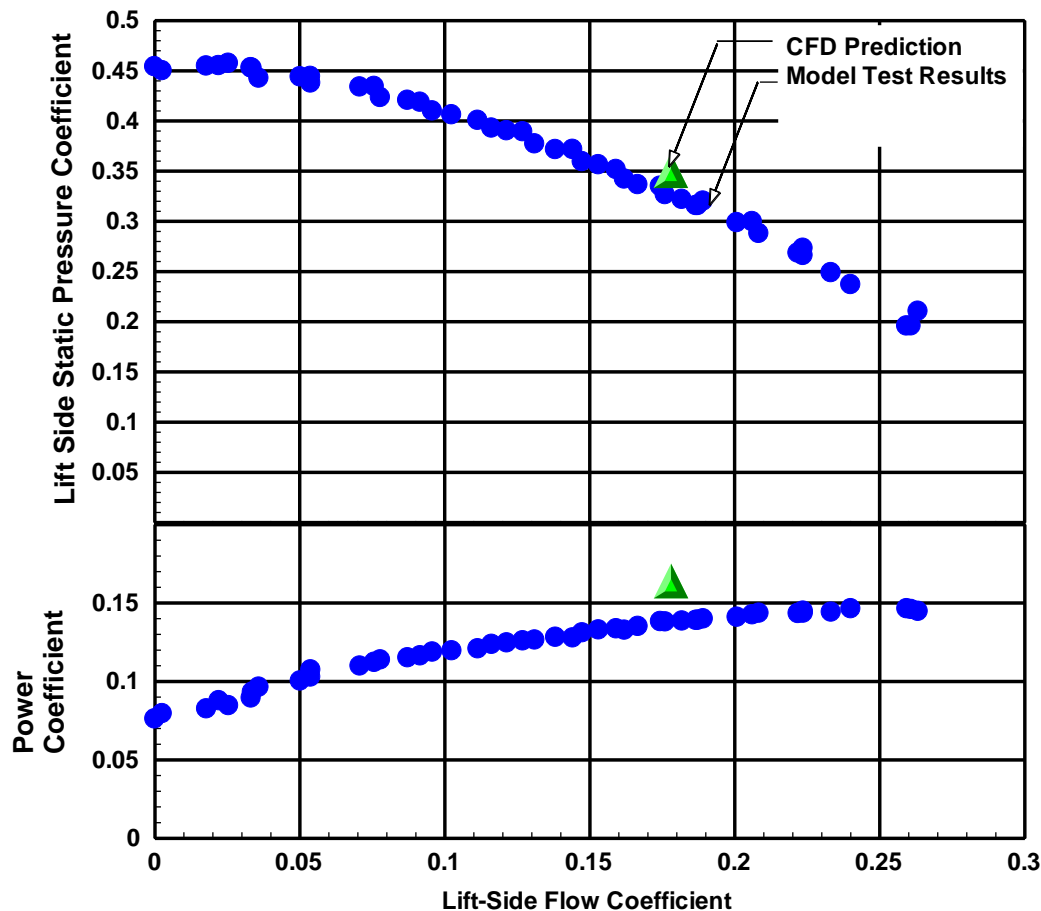
Lift Fan Design

- CFD tools allowed efficient and economical examination of the various fan design parameters.
- Results indicated that:
 - Blade stall is **Very Difficult To Avoid** in heavily loaded fan designs.
 - Good fan performance can be achieved even with some stall present.
 - Volutes can be **Much Smaller** than previously thought without sacrificing fan performance.

Fan Model Test



Sub-Scale Model Tests Conducted in October 2003



Test Results Generally Confirmed CFD Analysis Results

Ducted Propulsors



- Ducted air-screw design has typically relied on Potential Flow Theory, Strip Analysis or, in some cases, Lifting Line Theory.
- Designs are developed for free-stream conditions.
 - Ignores Installation Effects.
- Full-scale trials experience indicates that these designs typically produce **Significantly Less Thrust** than expected.



Ducted Propulsors

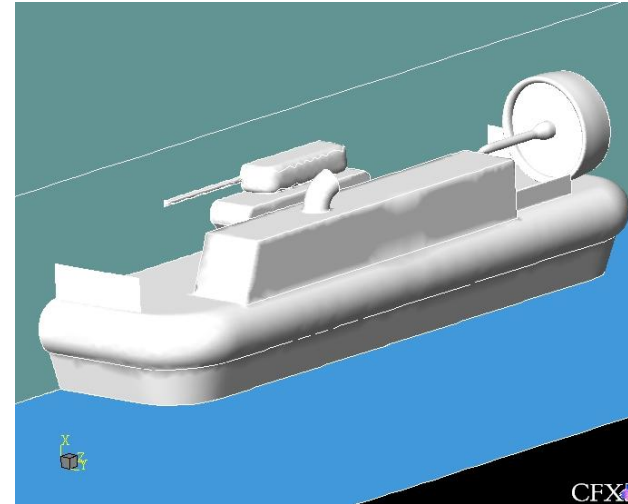
- **CDIM-SDD participated in a Science and Technology (S&T) effort directed at ducted propulsor design.**
 - **ONR Sponsorship.**
 - **Directed at using Modern CFD Tools to develop designs that Improve on Performance and Efficiency achievable with current equipment.**
- **Aerodynamic design considered the actual installed condition.**

Tool Verification

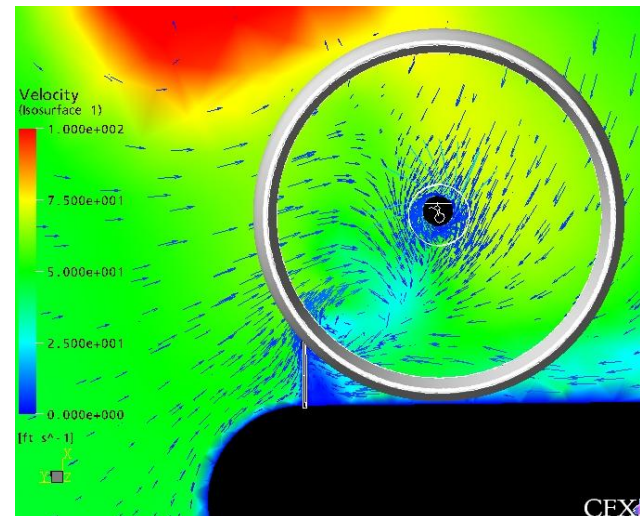


- **LCAC propulsor was analyzed prior to starting the new design.**
- **Checked against known performance.**
- **Results compared favorably.**

LCAC CFX Computational Model

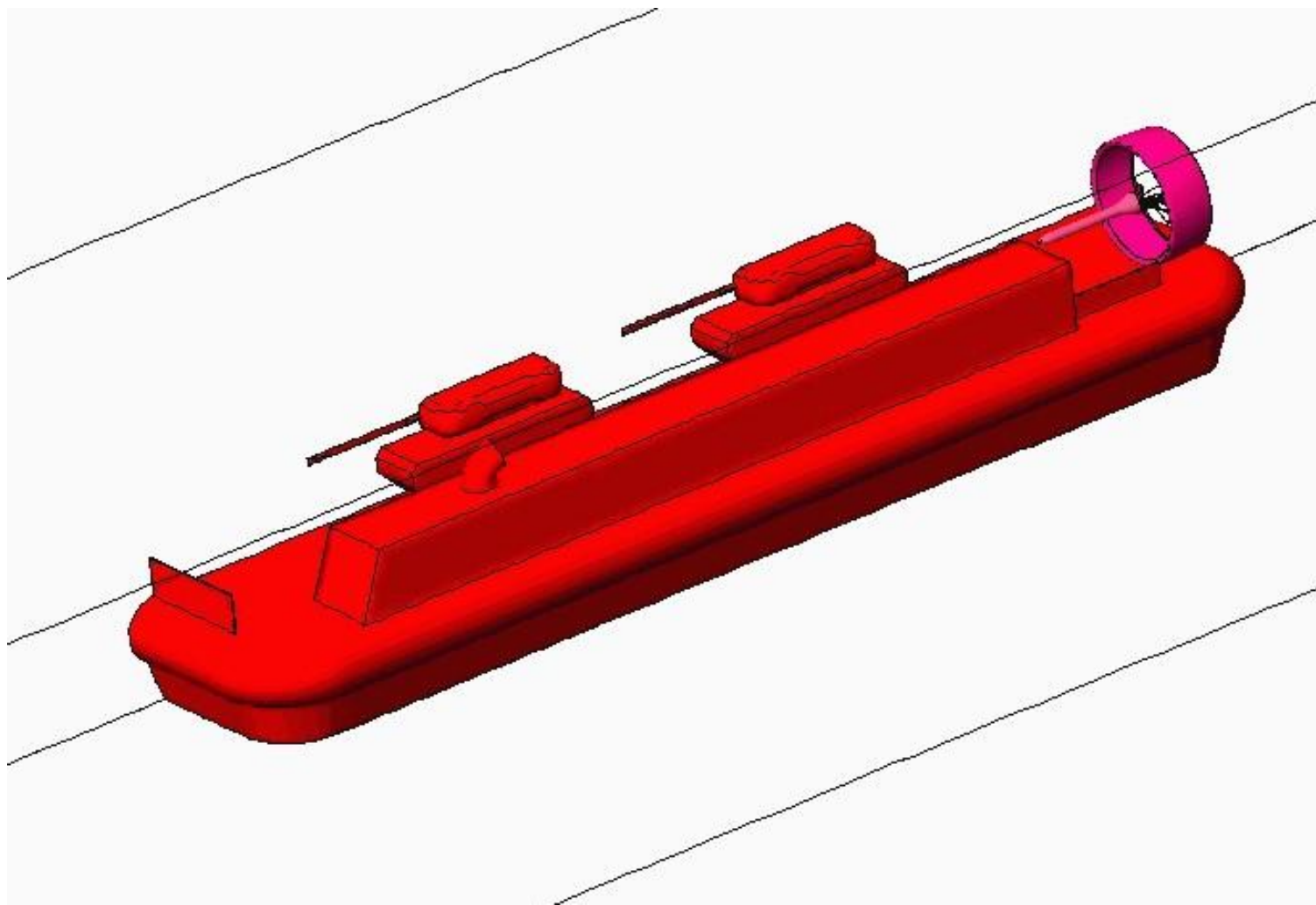


CFX for LCAC at 25 knots (Midway Station 7'6")





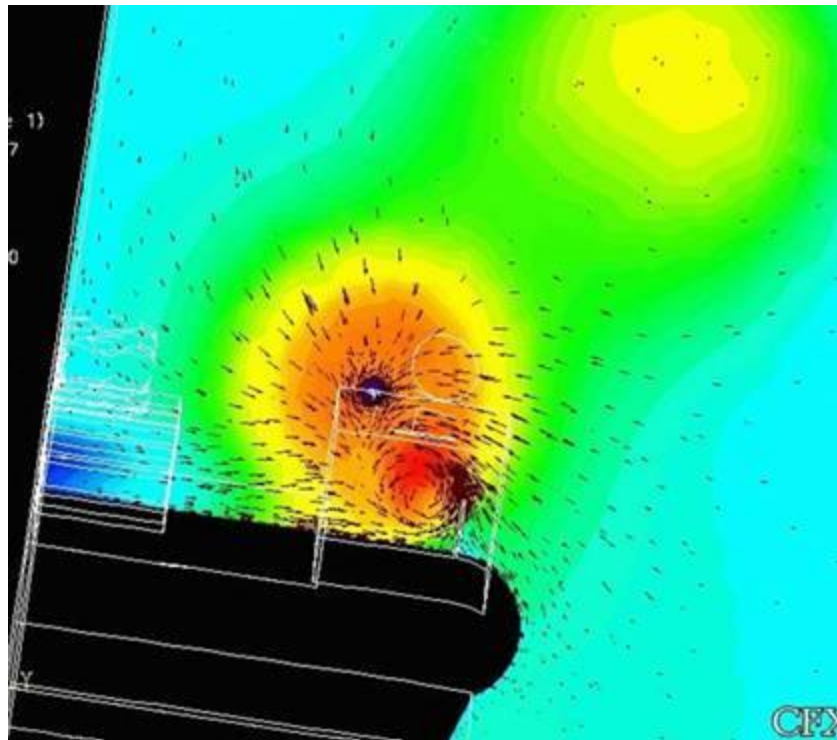
CFX Flow Model of New Design



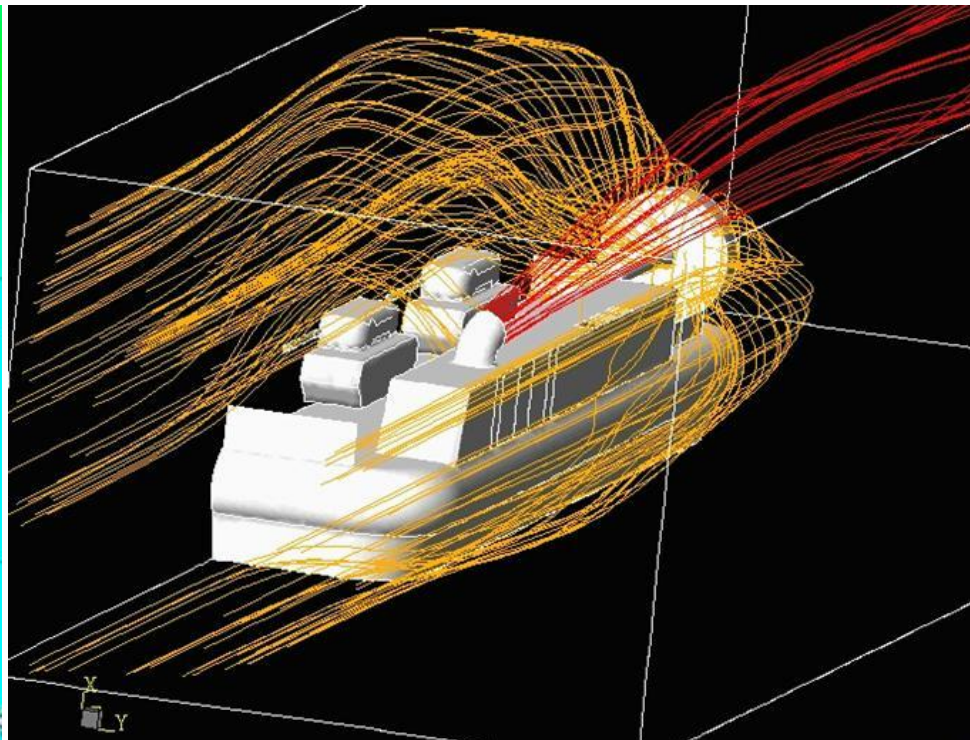


TYPICAL CFD RESULTS

Flow Field in Front of the Prop and Shroud



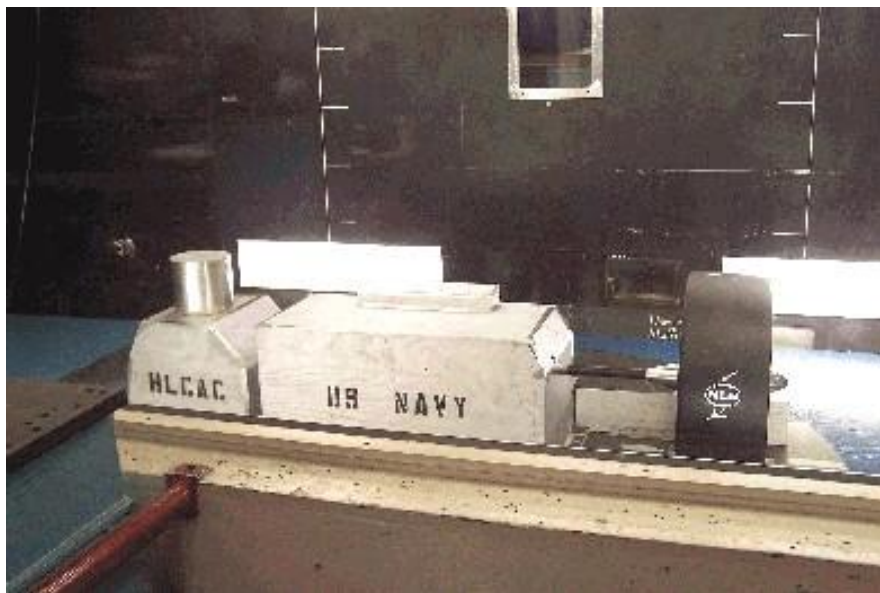
Flow Field in Front of the Prop and Shroud





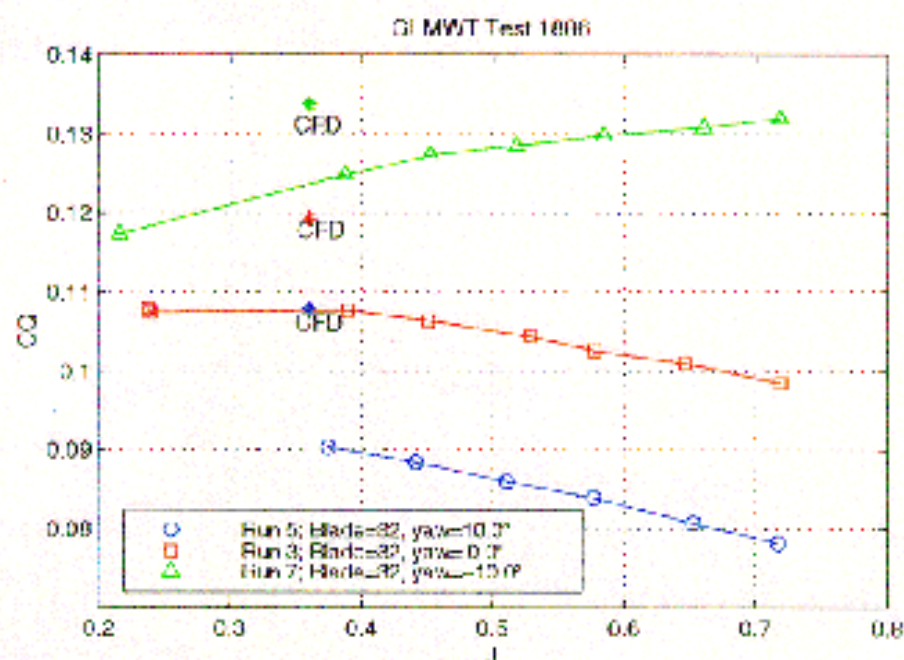
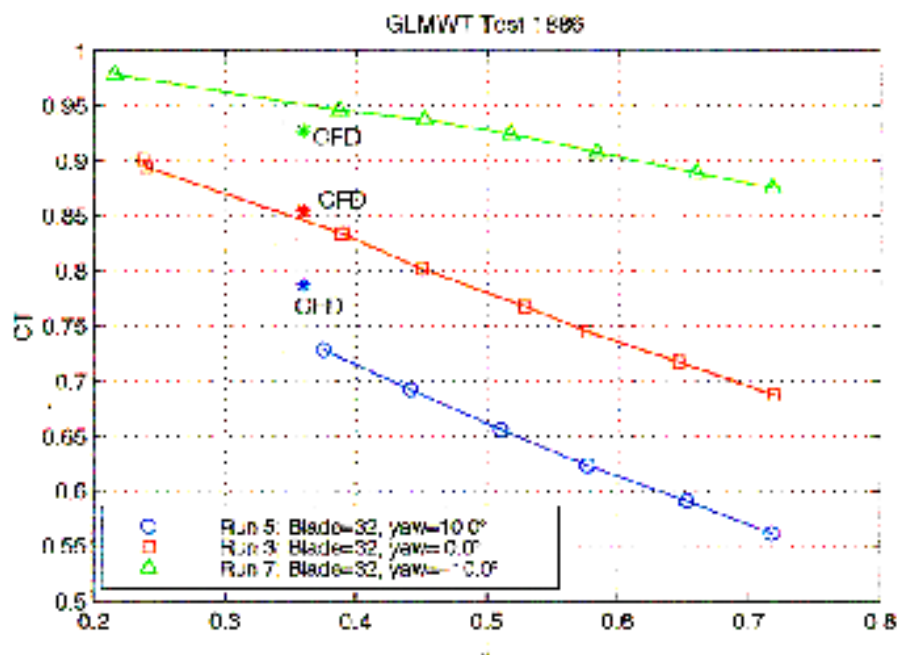
Propulsor Model in Glenn L. Martin Wind Tunnel

- **1/6th Scale Propulsor Tests**
 - **CFD Simulated Wind Tunnel Tests were performed prior to actual physical testing.**





Model Test Results



- Model Generally Performed as Good or Better than CFD Predictions
 - Measured C_t agreed with CFD Predictions $\pm 5\%$
 - Measured $C_q \approx 10\%$ less than CFD Predictions

Results Generally Validated the Design Tool and Approach



Bow Thruster Nozzles

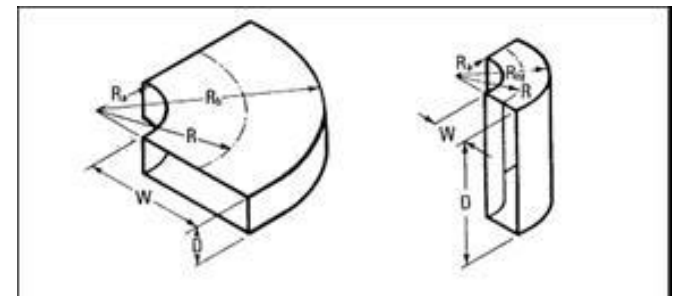
- **Bow Thrusters are used on many modern ACV designs.**
 - **Enhance Maneuverability**
 - **Augment Thrust from Main Propulsors**
 - **Provide Some Redundancy to Main Propulsors**





Bow Thruster Nozzles

- **Typical Bow Thruster Nozzle**
 - Easy to Manufacture
 - Aerodynamically Inefficient
 - Easy Bend versus Hard Bend
 - Large Over-Turning Moment on Bearing





Bow Thruster Nozzles

Low-Profile Bow Thruster

- **Aerodynamically Efficient Cascade**
- **Significant Reduction in “Over-Turning” Moment on Bearing**
- **Reduced Visual & Radar Signature**
- **Complex to Manufacture**



Full-Scale Trials Verified Aerodynamic Efficiency



Questions?

