Underwater Express

Proposers' Day

16 December 2005

Khine Latt
Program Manager/ATO

NOTES:

(1) TECHNOLOGY DEVELOPMENT AND TESTING APPROACHES ARE PRESENTED FOR INFORMATION ONLY AND SHOULD NOT BE REGARDED AS REQUIREMENTS FOR THE PROPOSAL UNLESS STATED IN THE PROPOSER INFORMATION PAMPHLET.

(2) GRAPHICS OF THE NOTIONAL SST CRAFT IS FOR ILLUSTRATIVE PURPOSES ONLY AND HAVE NO TECHNICAL DESIGN BASIS.

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Program Objective

Demonstrate stable and controllable supercavitation at speeds up to 100 knots to enable a new class of high-speed underwater craft (manned or unmanned) for future littoral missions.

PRODUCTS

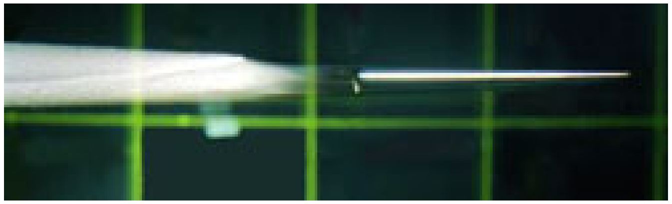
- Credible demonstration of stable and controllable supercavitation, applicable to an operationally-significant scale
  - 10 minutes at full speed
  - Body accelerations <0.3 g RMS
  - 10-ft depth change +/- 1 foot
  - 30-deg turn at 10 deg/sec with <10% speed loss
- NOTIONAL concept for a future 8-ft diameter craft

***from www.deepangel.com**

Background

- 1960s - Supercavitation theory developed by Dr. Marshall Tulin of US
- 1980s - Soviets field Shkval underwater rocket with a top speed of over 170 knots
- 1990s - NUWC develops Mach 1 (1500 m/sec) underwater bullet under DARPA and ONR sponsorship
- 2000s - ONR & Germans continue development of torpedo concepts
- 2009 - ??

SHKVAL TORPEDO



SUPERSONIC PROJECTILE

TECHNOLOGICAL SIGNIFICANCE

• Supercavitation technology is important to understanding future military paradigms for high speed underwater.

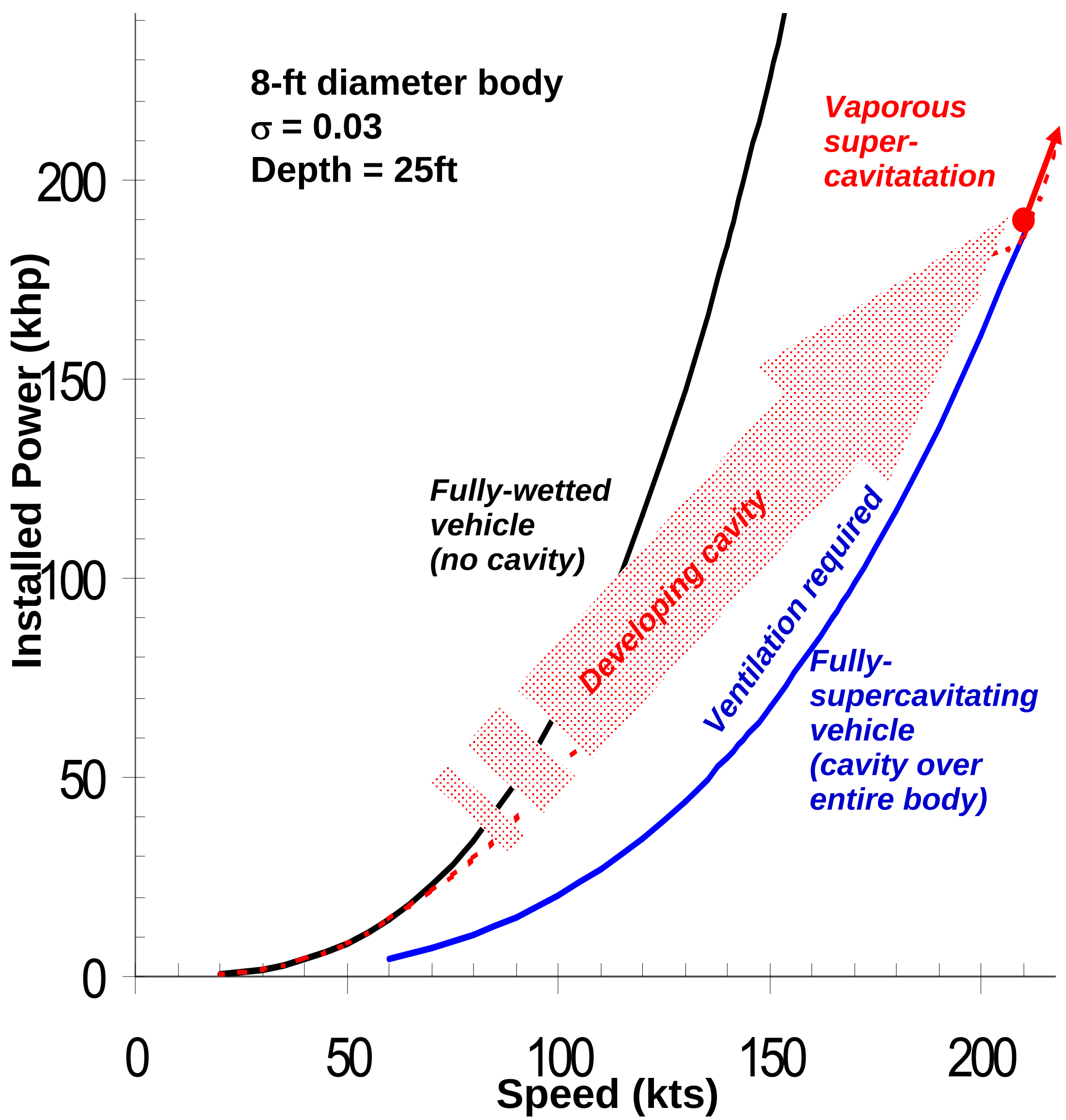
• TECHNOLOGICAL SURPRISE is a logical eventuality from rapid proliferation of high speed underwater technology.

Program Motivations

- **High underwater speed – an untapped tactical opportunity?**
  - **Prevailing mindset of Power ~ $(Speed)^3$**
  - **Advances further restrained with other technological limitations under water: sensing, nav, comms**
- **Control is key to utility**
- **In addition… … a potential alternative to current ops**

CURRENT LIMITATIONS FOR SMALL HIGH-SPEED CRAFT	*UNDERWATER EXPRESS*
High-speed surface ships and boats: • Must slow down in waves − Calm water speed means very little in open ocean role − High waves can abort missions • Cargoes and personnel are seriously degraded during rough transits • Can be targeted by radar Underwater alternatives: covert, but very slow	HIGH-SPEED UNDERWATER TRANSIT • Provides first level of covertness • Avoids surface wave “slamming” injuries • Obtain high-speed with supercavitation, while keeping power requirement low by running as shallow as possible

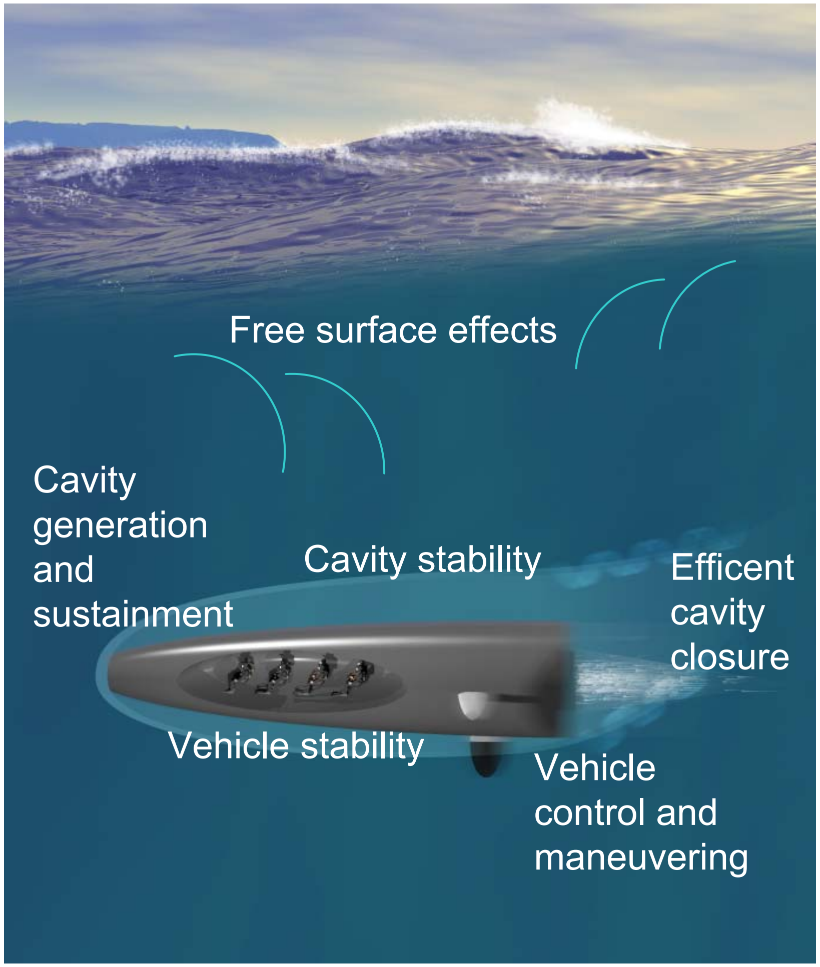
Supercavitation



- *Supercavitation shifts the curve that governs speed and power on or in the water by removing the frictional drag → Order of magnitude more effective than other drag reduction approaches*
- *Ventilation can induce supercavitation at lower vehicle speeds*
- *It is a validated physics approach that has never been used for transport of personnel or cargo*

Technical Approach

- Develop understanding of supercavitation physics for large-body operating at shallower depths
  - Supercavitation inception at low cavitation number
  - Shallow depth vs. free surface interactions
  - Proper analysis of ventilated cavity
- Predict supercavity and body behavior
- Design cavitator, demonstrator and SST vehicle concept to handle operating envelope for high and low speed; cavity generation, sustainment and stability; and control considerations
  - Eventual consideration is man-rated high-speed underwater operation (stable/controllable/maneuverable)
- Build a demonstrator vehicle to validate speed, stability, and controllability
  - Full speed goal
  - Required 10-minute run with maneuvers to be specified



End-of-Phase Testing and Go/No-Go Criteria

Phase I	Phase II	Phase III
<u>STABLE CAVITY GENERATION AND SUSTAINMENT</u> ▪ Small-scale representative of vehicle concept ▪ Multiple 1 minute runs **<u>Measurements/Observations</u>** ▪ Measure gas expenditures ▪ Pressure fluctuations ▪ Cavity stability and closure	**<u>STABLE CAVITY AND VEHICLE DYNAMICS</u>** ▪ Appropriate scale ▪ Free running or wire-guided ▪ Multiple runs ▪ Mild manuever (depth excursion) **<u>Measurements/Observations</u>** ▪ Body forces and accelerations ▪ Gas expenditures ▪ Thrust ▪ Failure modes testing	**<u>FINAL SPEED AND MANEUVER DEMO</u>** ▪ ¼ - ½ scale ▪ Free running ▪ 10 minute runs ▪ Controlled maneuvers at speed **<u>Measurements/Observations</u>** ▪ Maneuvering Trajectory ▪ Speed ▪ Power ▪ Body Forces & Acceleration
<u>Go/No Go</u> ▪ No portion of the hull wet at full speed ▪ Steady or decaying oscillations <25% of run time ▪ Concept design propulsion and gas generation system takes no more than half the volume of the nominal 8 foot vehicle	**<u>Go/No Go</u>** ▪ Body motion control •Maintain depth +/- 1 ft •Conduct depth excursion of 10 ft, +/- 1 ft ▪ Body Accel < 0.3g RMS at steady transit speed ▪ Preliminary design propulsion and gas generation system takes no more than half the volume of the nominal 8 foot vehicle	**<u>Goals</u>** ▪ Stable cavity ▪ Controlled maneuvers •10-ft depth change +/- 1 ft •30-deg turns at 10 deg/s with <10% speed loss ▪ 10 minutes at full speed

Underwater Express Technical Issues

Jim Fein

Technical Approach

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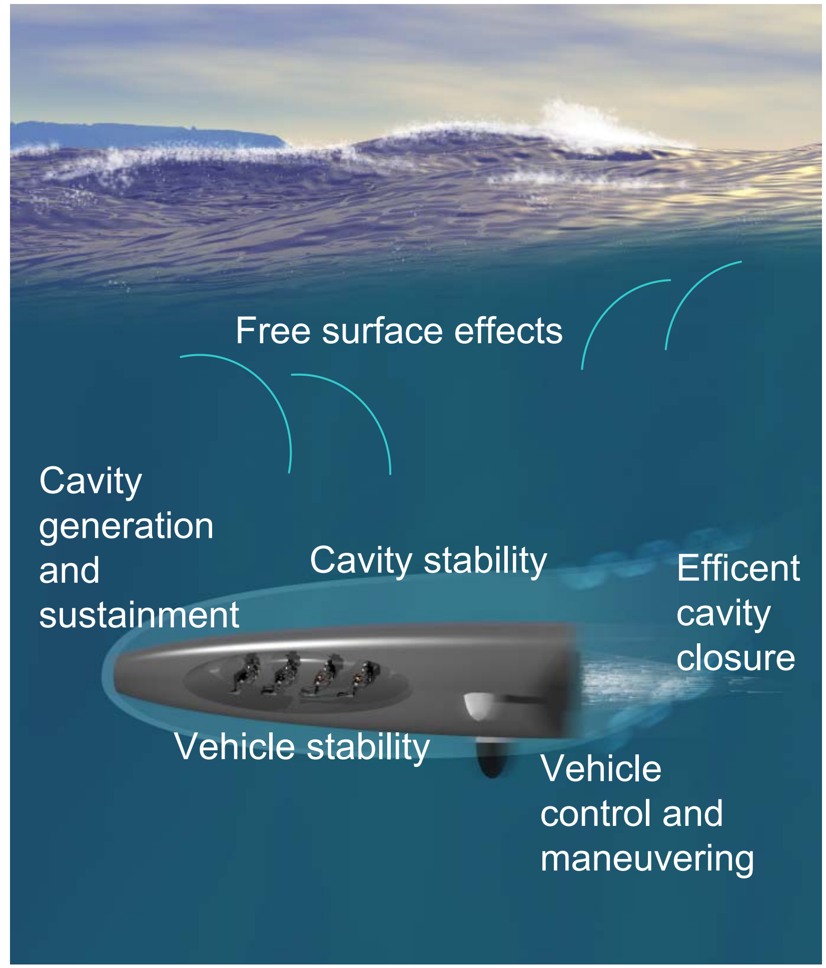
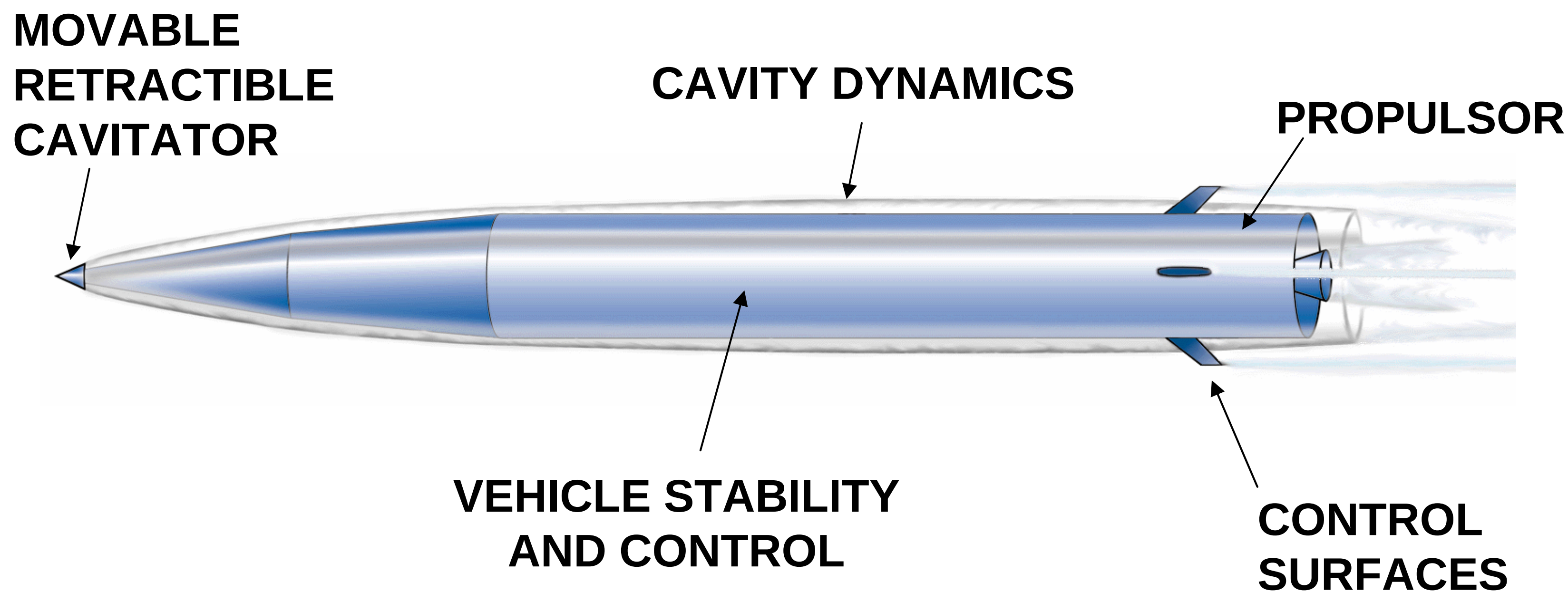


Components of
High-Speed Supercavitating Vehicles

THE VEHICLE IS CONTAINED INSIDE A CAVITY OF VAPOR & GASES



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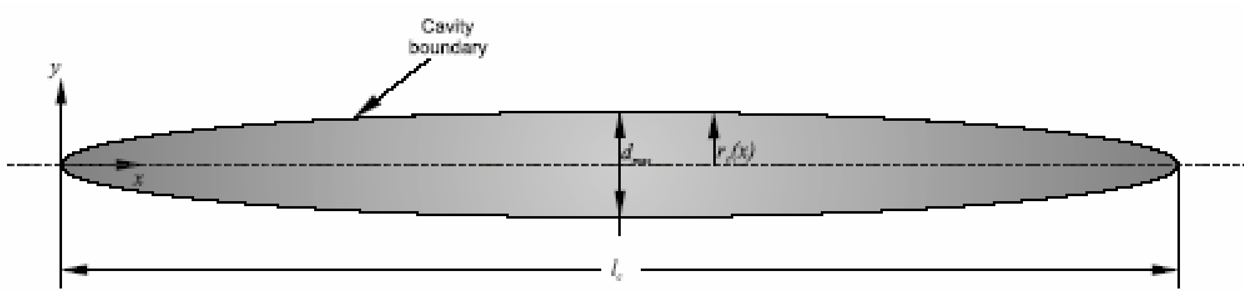
Program Emphasis

- Physical understanding of cavity formation, ventilation, stability, and control
- Cavitator designs that generate stable, robust, and controllable cavities
- Prediction of cavity dynamics and vehicle behavior, over the range of speeds
- Control system technologies that enable maneuverability when supercavitating
- A system concept, preliminary design, and requirements documentation for the notional SST craft

Cavity Stability and Control



- Cavity/Body Analytical Predictions
- Cavitator design for low speed, cavity generation and cavity stability
  - Must support most of the weight of the body
  - Should be hinged for maneuvering , stability and depth control
  - Vents for gas injection into the cavity
  - Retractible for smooth nose at up to cavitation speeds
- Shallow Depth Lowers Cavitation Number for Supercavitation Inception

Cavitators

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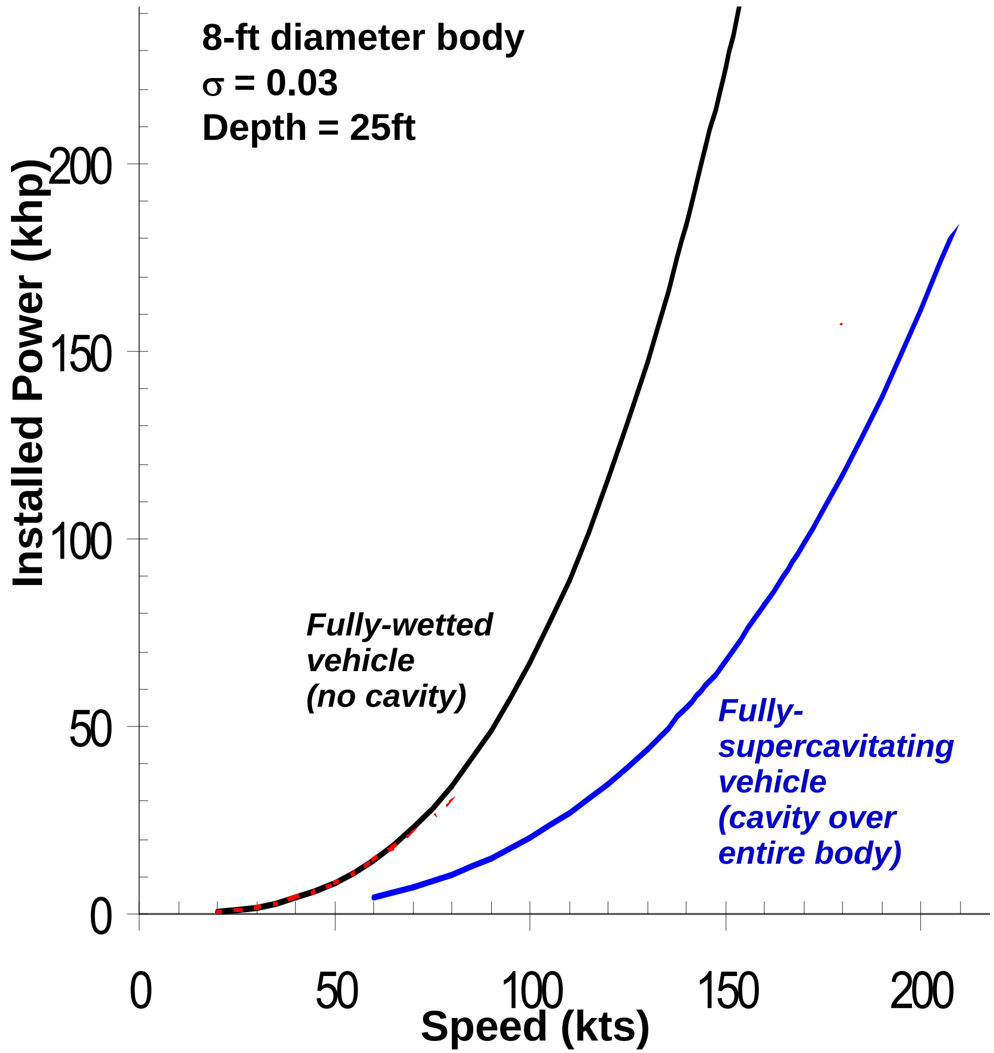
Technology Development Considerations

- Drag reduction – speed/power over the speed range
- Free surface interaction effects
- Cavity buoyancy effects as they vary with speed
- Scaling of physical phenomena

Supercavitation



Drag Reduction Approaches	Speed +	Mechanism
Shaping	10%	Reduces form and wave drag
Polymers	20%	Reduces boundary layer frictional drag
Microbubbles	12%	Reduces boundary layer frictional drag
Coatings	4%	Modifies frictional drag of boundary layer
Supercavitation	**65%**	**Eliminates most frictional drag**

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Vehicle System Issues

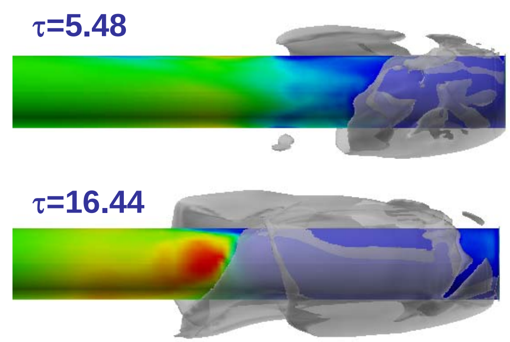
- Cost effective scale for demonstrator
- Test plan for demonstrator
- Arrangements for system concept
  - Weights
  - Volumes
  - Propulsion
  - Gas Generator

Key Technical Challenges

- **Achieving sustainable stable cavity**
  - **Stable cavity with shape and pressure as predicted**
  - **Manageable interaction with free surface**
  - **Buoyancy**

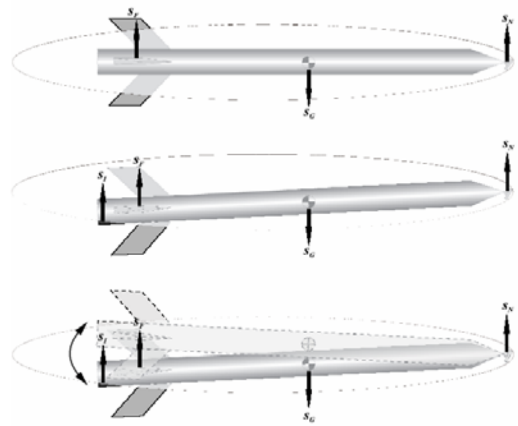
STABLE CAVITY UNSTABLE CAVITY

- **Controlling cavity and vehicle interactions**
  - **Proper design of moveable cavitator and control surfaces**
  - **Cavitator movement with motions as predicted**
  - **Maneuvering performance in turns**
  - **Failure modes**



MULTIPHASE CFD MODELING OF DEVELOPING CAVITY

- **Managing and optimizing energy expenditure**
  - **Cavity ventilation/propulsion integration**
  - **Propulsion plant arrangement**



DYNAMICS OF VEHICLE BODY IN CAVITY

Operational Drivers
(considerations for this program, but not the focus)

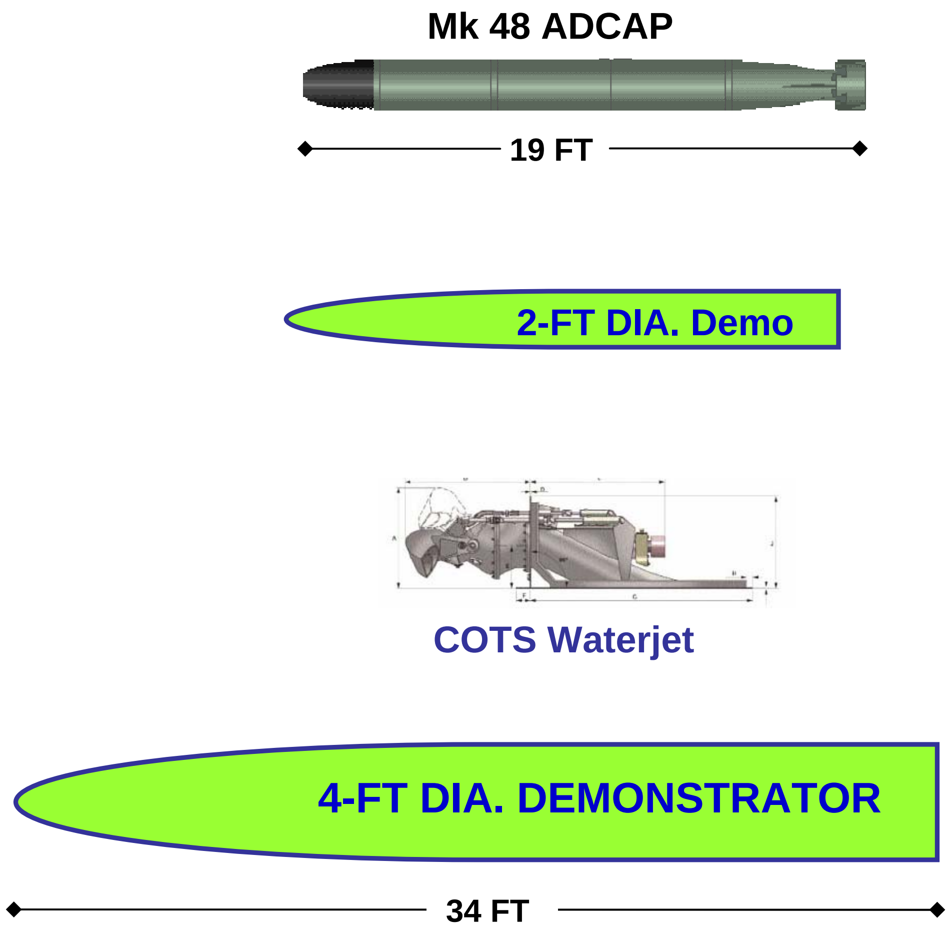
- **Sensing, Obstacle Avoidance and Navigation**
- **Signatures**
  - **Surface**
  - **Acoustic**
  - **Other**
- **Safety**

The SST concept proposed will have to be characterized with respect to its operational performance and limitations

The demonstrator design proposed will have to represent the proposed SST concept in its control and maneuvering behavior

Demonstration Scales

- **Physical similitude: Froude and cavitation numbers can be matched at smaller scales with reduced speed**
- **Maneuvering dynamics: Vehicles should be modeled at least at ¼ scale based on sufficient Reynolds number**
- **Not necessarily cheaper to go smaller**
  - **COTS waterjets are available down to approximately 3ft diameter**
- **Larger scale vehicle demonstrates a greater military capacity to the Navy.**



Phase 1 Products

- Report on cavity interaction with the free surface at the concept design depth chosen by the bidder
- Report on the scaled cavity size and shape for an 8-ft diameter vehicle at goal speed
- Control strategy for stability, maneuvering and safe operating
- Experimentation plan for Phase 1
- Draft test plan for Phase 2
- System concept report for the SST, including volume and weight estimates for major subsystems, and speed and power prediction

Phase 2 Products

- Control system design document including control forces and expected trajectories
- Maneuvering predictions and empirical validation of the predictions
- Updated speed/power, free surface effects, and cavity size and shape predictions
- Test plan for Phase 2
- Draft test plan for Phase 3 and preliminary design of the DSST, the demonstrator to be used in Phase 3
- Detailed system design for the 8-ft diameter notional concept SST

Phase 3 Products

- **Final report on experimental field test results and a comparison of those results with the prior prediction of analytic tools will be produced. The report should provide an assessment of the range of validity of the analytic tools and provide prediction of full- scale operating performance**
- **Updated and final system specifications for SST**

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Wrap-up

Notes on Proposal Approach

- Propose innovative technology concepts, but they must be translatable to a future realizable craft concept
- Provide clear technical rationale behind any claims of potential benefits of technology choices
- Identify/discuss trade-offs that may have to be made
- Substantiate validity of experimental and demonstration approaches
- Focus on program phase go/no-go metrics; determine/suggest interim technical metrics to measure progress
- Emphasize industrial partnerships

Programmatics

- Acquisition strategy
  - Phased programs (note BAA mod for duration of phases)
    - Phase 1 is the base program; subsequent phases are options
    - Each phase will have metrics ('go/no-go criteria') to determine potential for continuation to the next phase
  - Likely to have only one team go forward to Phase 2
- Contracting Officer: Patty Matyskiela, DARPA CMO
- Teaming is strongly encouraged: combine expertise to provide good value to Government and cross-pollination of ideas
- Use or participation of Government labs
  - Nature of partnering arrangement must be described
  - Government labs cannot be exclusive; firewalls needed

Security

- **Security Classification Guide for Underwater Express: DARPA-CG-367**

Tentative Solicitation Schedule

BAA Release	**November 2, 2005**
Proposers' Conference	**December 16, 2005**
Proposals Due	**February 1, 2006**
Source Selection Completed	**March 7, 2005**
Contract(s) Awarded	**April 2005**