VIRTUAL DESIGN OF QUIET UNDERWATER SHELLS

W. Akl and A. Baz

University of Maryland
Mechanical Engineering Department
College Park, MD 20742
Tel: 301-405-5216
e-mail: baz@eng.umd.edu

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OUTLINE OF PRESENTATION

- ☑Introduction
- ☑Structural Acoustics of Underwater Stiffened Shells
- ☑Virtual Reality Design of The Shells
- ☑Performance of the Shells
- ☑Conclusions
- ☑Future Directions

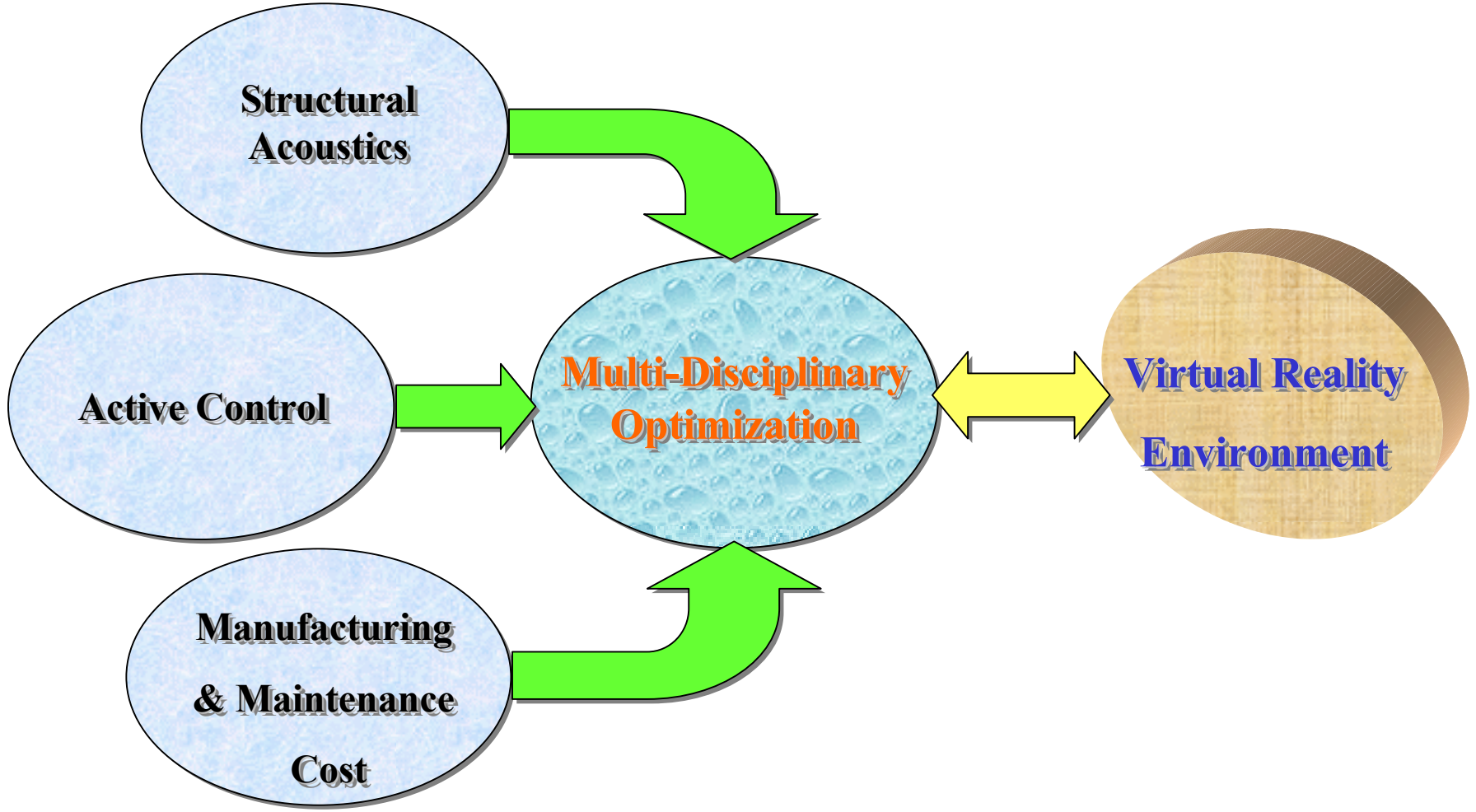
OBJECTIVES

Design of Quiet Underwater Shells with Passive Stiffeners using:

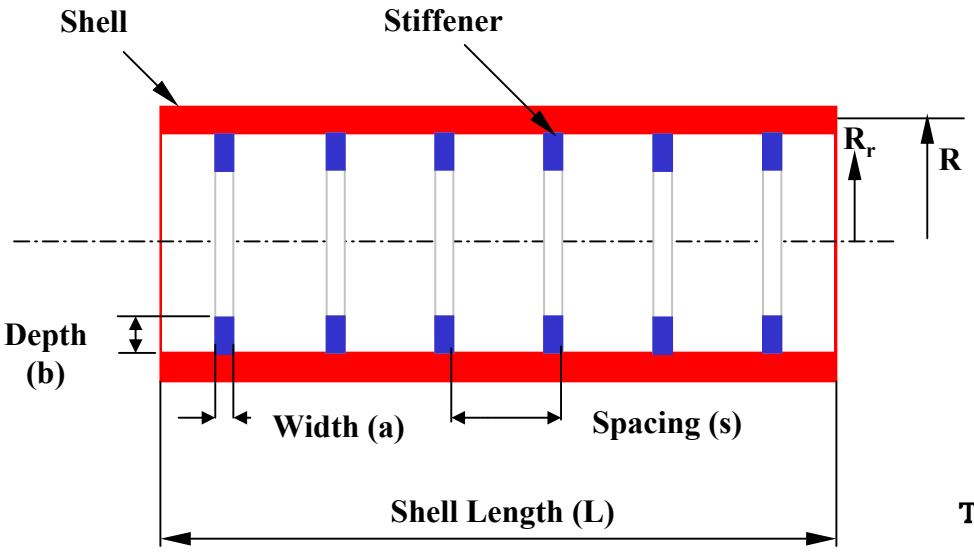
☑Multi-Disciplinary Design Optimization Strategies

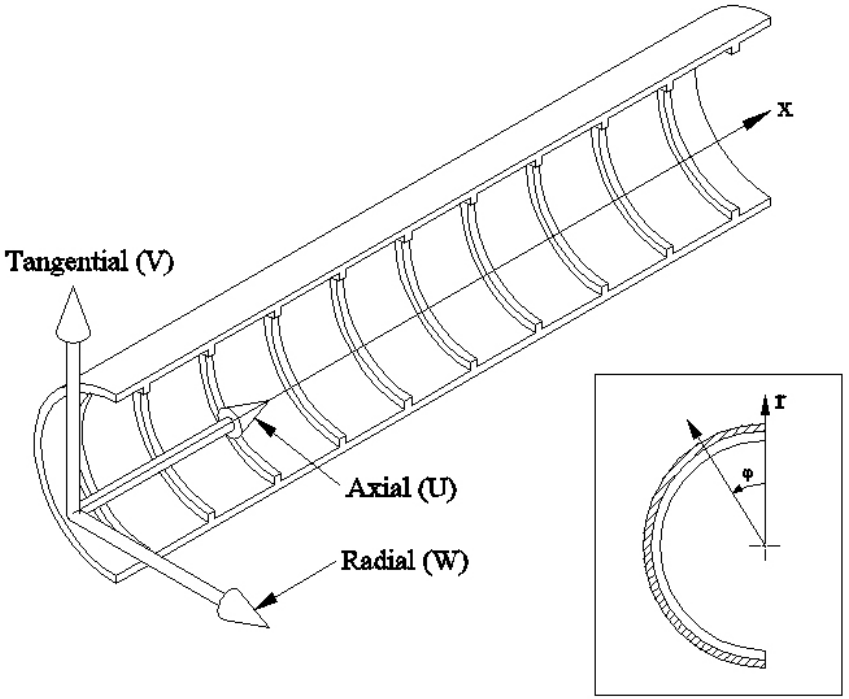
☑Virtual Reality Environment

DESIGN OF UNDERWATER SHELLS

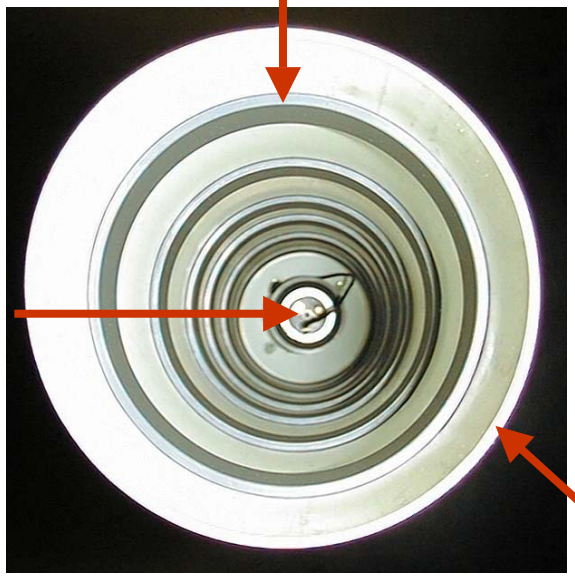


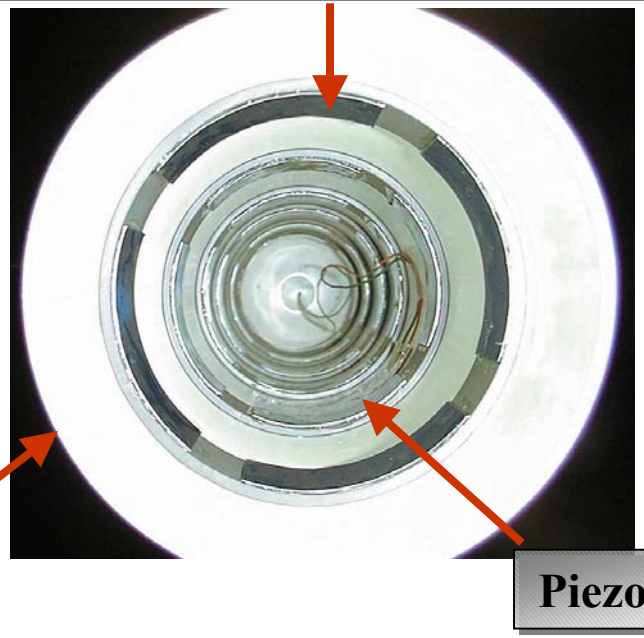
Stiffened shell configuration & geometrical parameters



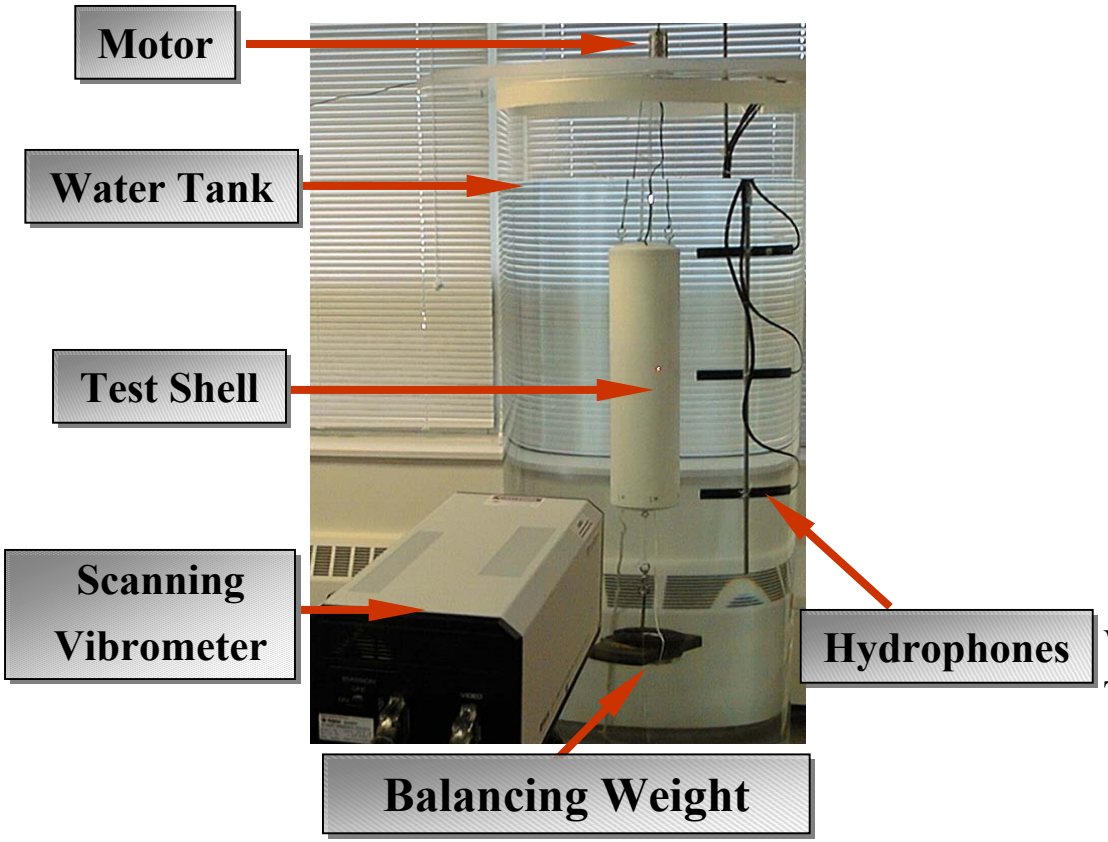


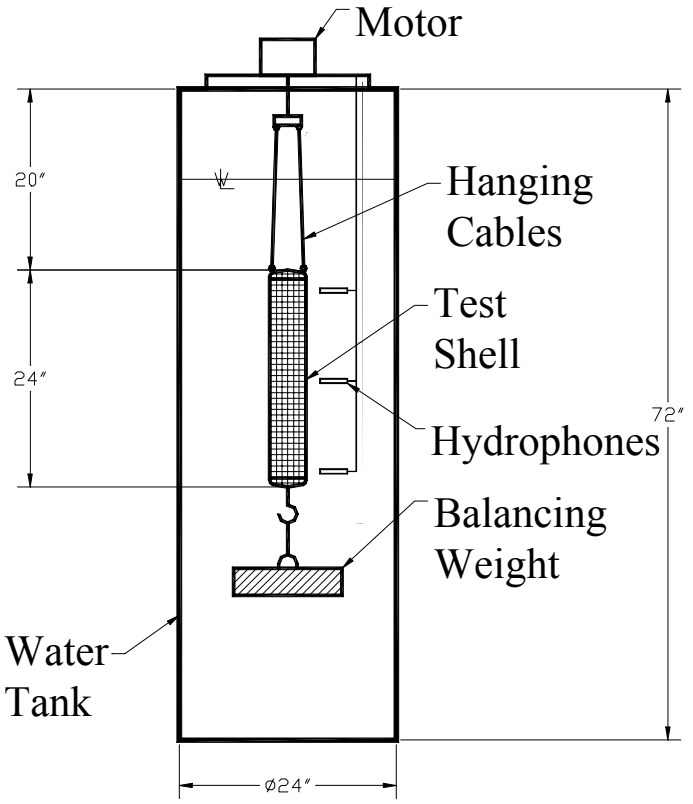
STIFFENED, DAMPED & ACTIVE SHELLS



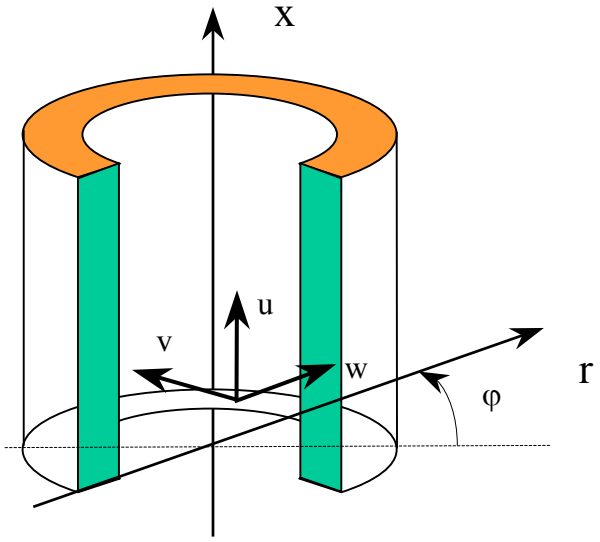


TESTING OF STIFFENED, DAMPED & ACTIVE SHELLS



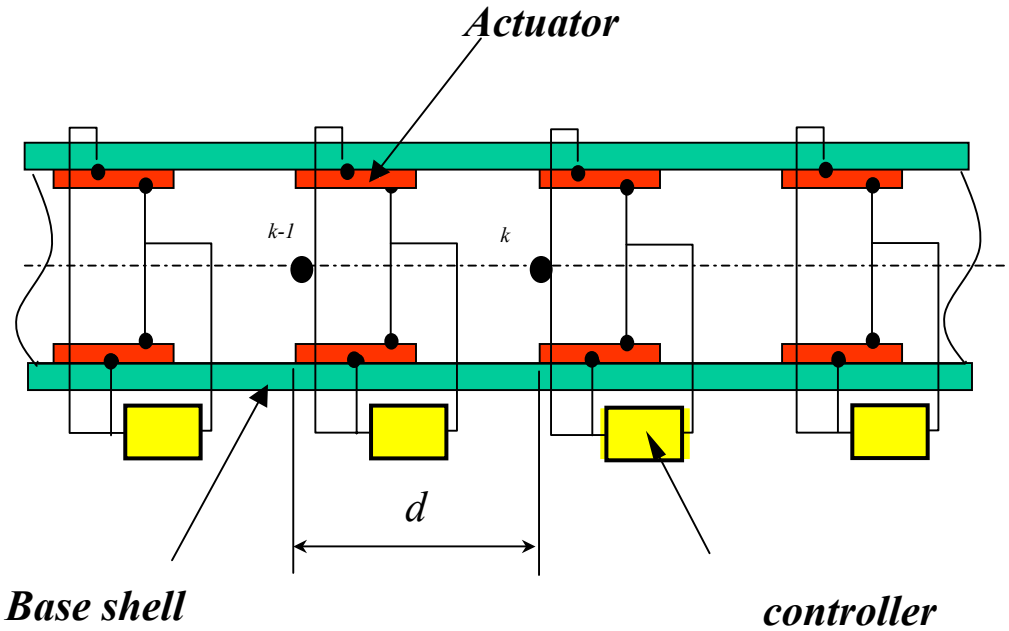


ACTIVE PERIODIC SHELL

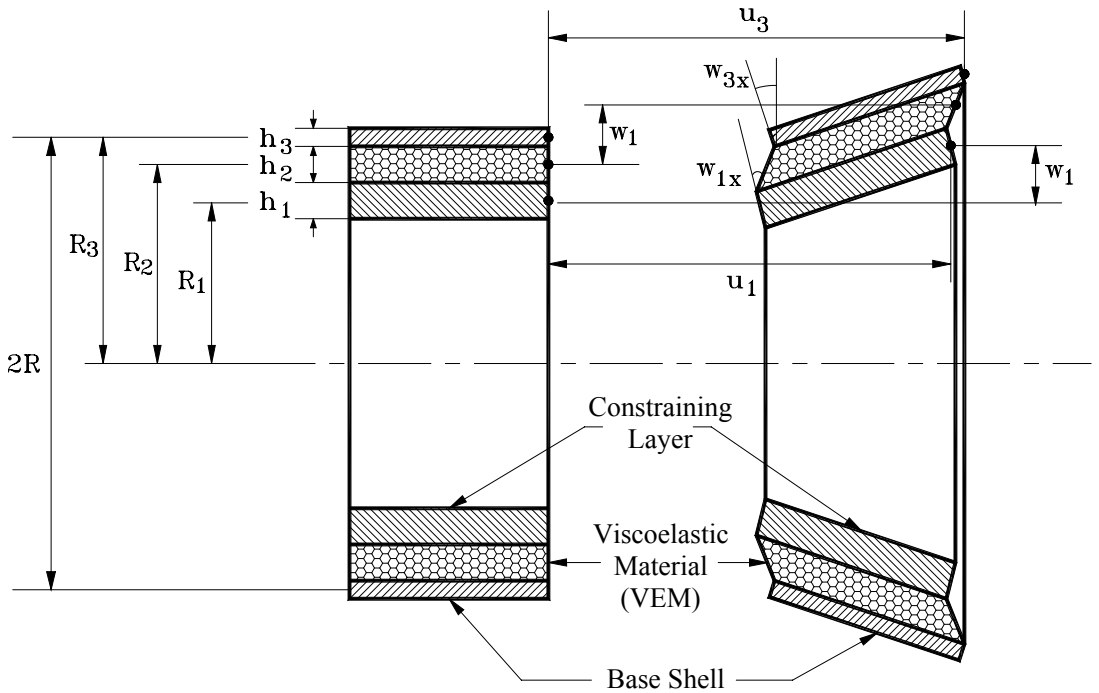


Coordinate System

Active Periodic Shell Assembly



GEOMETRICAL AND KINEMATICAL PARAMETERS OF THE SHELL SYSTEM



FINITE ELEMENT MODELING

The nodal deflection vector is:

$$\{\delta(n,x)\} = \{u, v, w, w_x\}^T \cdot \cos(n\varphi)$$

where n = order of lobar mode, and φ = Circumferential angle

Equations of Harmonic Motion of Fluid-Loaded Shell:

Structural Stiff. Control Stiff. Structural Mass Coupling Matrix Structural Defl. Loads

$$\begin{bmatrix} [K(n)] + [K_C(n)] - \omega^2 \cdot [M(n)] & -[\Omega(n)] \\ -\rho_f \cdot \omega^2 \cdot [\Omega(n)] & [K_f(n)] - \omega^2 \cdot [M_f(n)] \end{bmatrix} \cdot \begin{Bmatrix} \delta^{(e)}(n) \\ p^{(e)}(n) \end{Bmatrix} = \begin{Bmatrix} F(n) \\ 0 \end{Bmatrix}$$

Fluid Stiff. Fluid Mass Fluid Pressure

Finite Element of Fluid-Loaded Stiffened Shells (cont.)

☑For harmonic motion at frequency "ω"

$$([M(n)]+[M_a(n)])\cdot\left\{\ddot{\delta}^{(e)}(n)\right\}+[K(n)]\cdot\left\{\delta^{(e)}(n)\right\}=\{F(n)\}$$

where $$[M_a(n)]=\rho_f\cdot[\Omega(n)]\cdot[K_f(n)]^{-1}\cdot[\Omega(n)]^T$$ **Added Mass**

☑Pressure distribution

$$\left\{p^{(e)}(n)\right\}=\rho_f\cdot\omega^2\cdot[K_f(n)]^{-1}\cdot[\Omega(n)]^T\cdot\left\{\delta^{(e)}(n)\right\}$$

Finite Element of Fluid-Loaded Stiffened Shells (cont.)

☑ **External Loads (F)**

$$F = \underbrace{F_e}_{\text{External Loads}} + \underbrace{F_c}_{\text{Control Forces}}$$

where $F_c = - K_d S \dot{\delta}$

S = Actuator / Sensor Placement Matrix

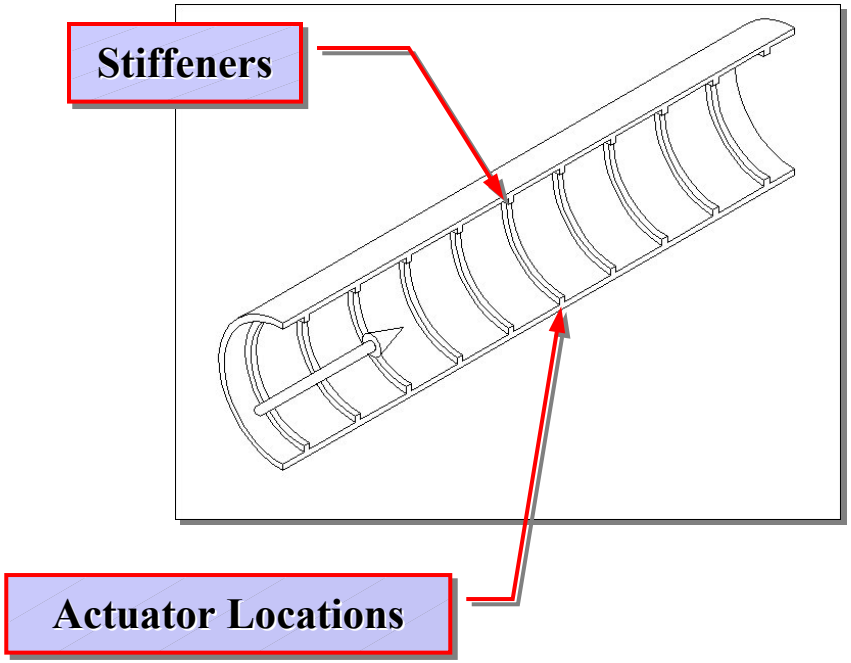
☑ **Sound Intensity (I)**

$$I(x, r, \varphi) = \frac{p^2(x, r, \varphi)}{2 \cdot \rho_f \cdot c}$$

Multi-Criterion Optimization (cont.)

Objective Functions (Minimize)

- Maximum Sound Intensity
- Maximum Radial Vibration Level
- Maximum Tangential Vibration Level
- Maximum Axial Vibration Level
- Cost of Passive Stiffeners
- Weight of Passive Stiffeners
- Cost of Added Actuators/Sensors
- Weight of Actuator/Sensor Mass
- Control Effort
- - Controllability
- - Observability

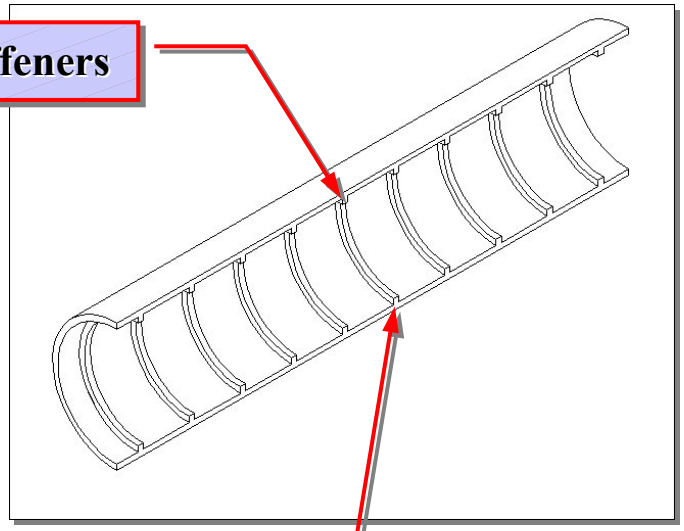


Multi-Criterion Optimization (cont.)

Constraints

No. of Stiffeners

- No. of Actuators/sensors (N_a) $0 < N_a \leq N_s$
- Control Gain (K_d) $0 \leq K \leq 2\times10^5$

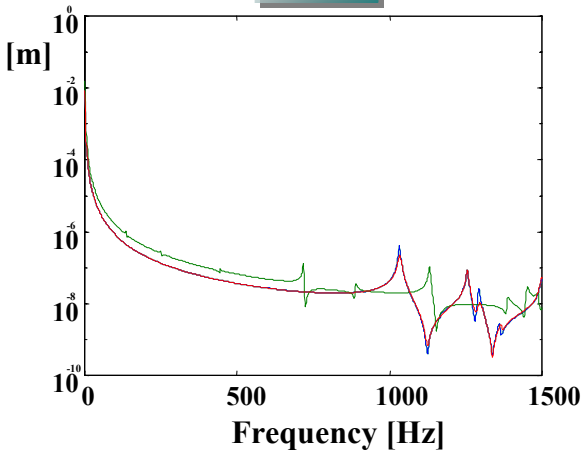


Design Variables

- Number of Actuators
- Actuator/Sensor Locations
- Control Gain

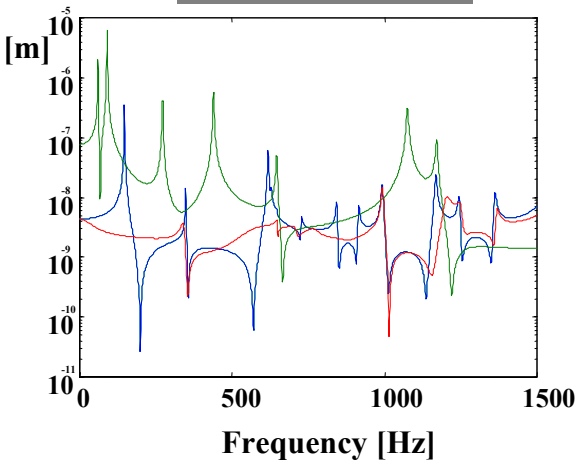
Configuration 3: 3 Actuators on Ribs 1-3-7, Kd=3,100 (All design Objectives)

Axial

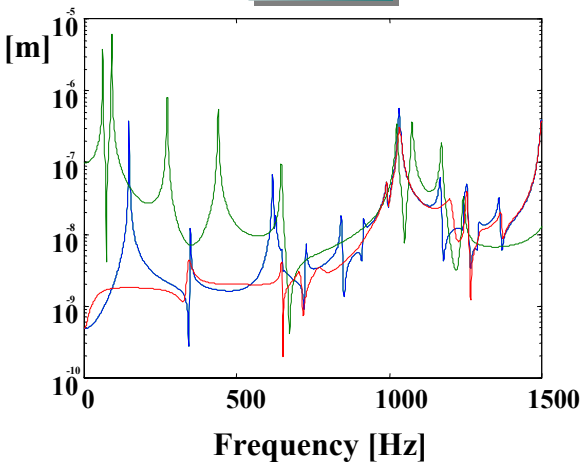


Vibration FRF

Circumferential



Radial

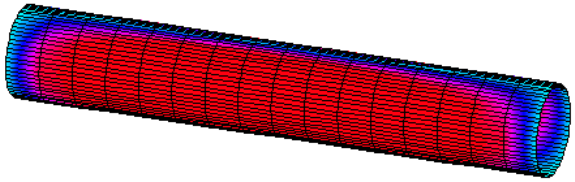


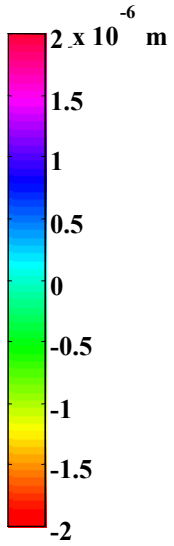
Plain Shell
7 stiffeners - Uncontrolled
7 stiffeners - Controlled

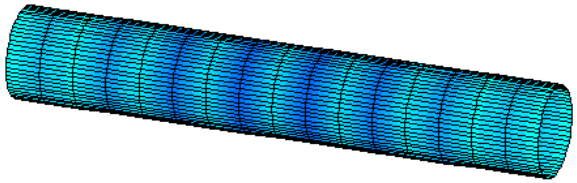
Configuration 3: 3 Actuators on Ribs 1-3-7, Kd=3,100 (All design Objectives)

Shell Vibration

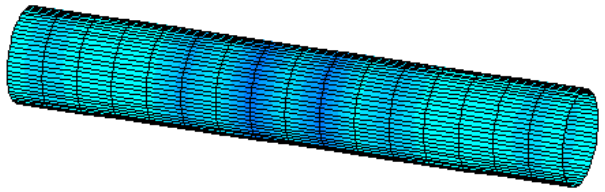
Plain







7 Stiffeners - Uncontrolled

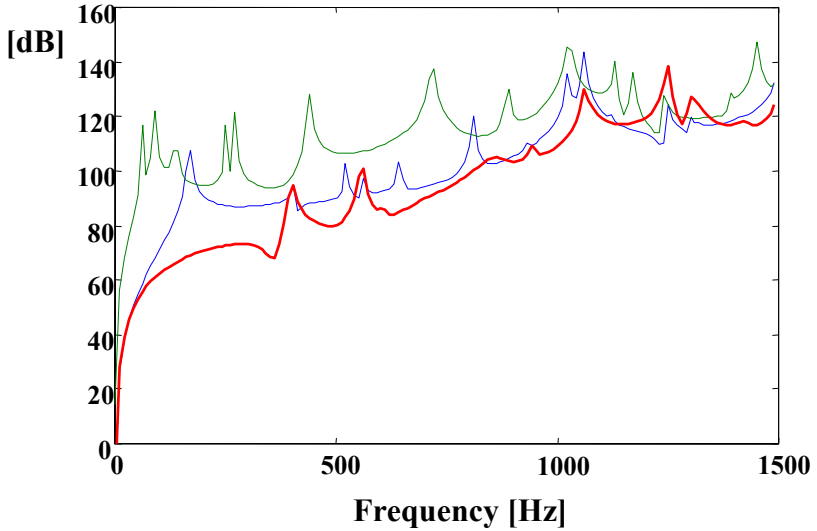


7 Stiffeners - Controlled

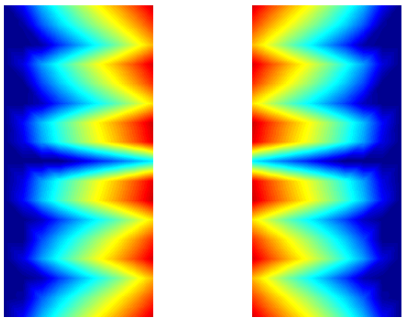
Configuration 3: 3 Actuators on Ribs 1-3-7, Kd=3,100 (All design Objectives)

Sound Intensity

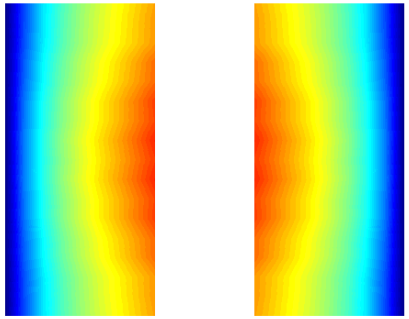
Plain Shell
7 stiffeners - Uncontrolled
7 stiffeners - Controlled



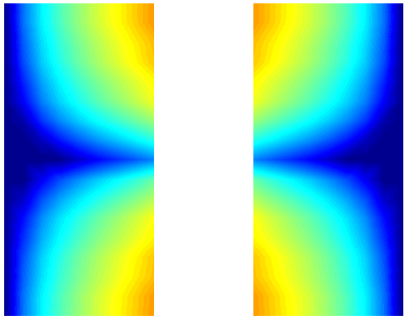
Plain

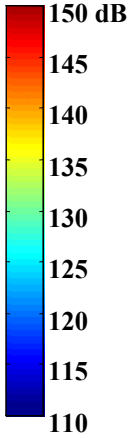


7 Stiffeners - Uncontrolled



7 Stiffeners - Controlled





VIRTUAL REALITY DESIGN OF A TORPEDO SHELL

WHY VIRTUAL REALITY ENVIRONMENT ?

•Today's interfaces (keyboard, mouse, monitor, etc.) force us to working within tight, unnatural, two-dimensional constraints.

•In **Virtual Reality (VR),** *human-computer interface technology* leverages the *natural human capabilities*.

•**VR** provides engineers with real-time 3D audio, visual & sensory perception in a more intuitive & natural manner.

•In VR, engineers can look and move around/inside a virtual model or environment, drive through it, lift items, hear things & feel things.

MISSION OF VIRTUAL REALITY LABORATORY

Interactive & Collaborative Design of SMART Structures in:

- **Real time**
- **Environment with:**

virtual reality audio,

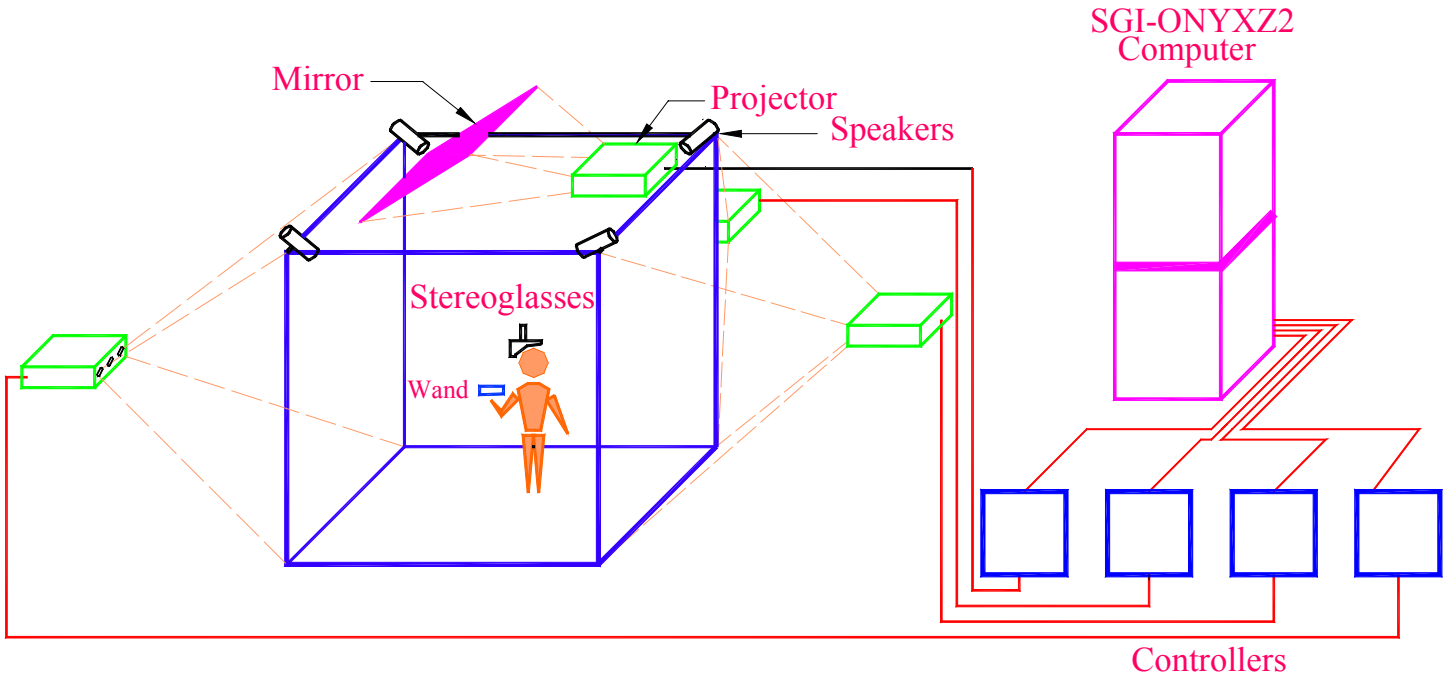
visual, and

sensory capabilities.

DESIGN IN VIRTUAL REALITY ENVIRONMENT

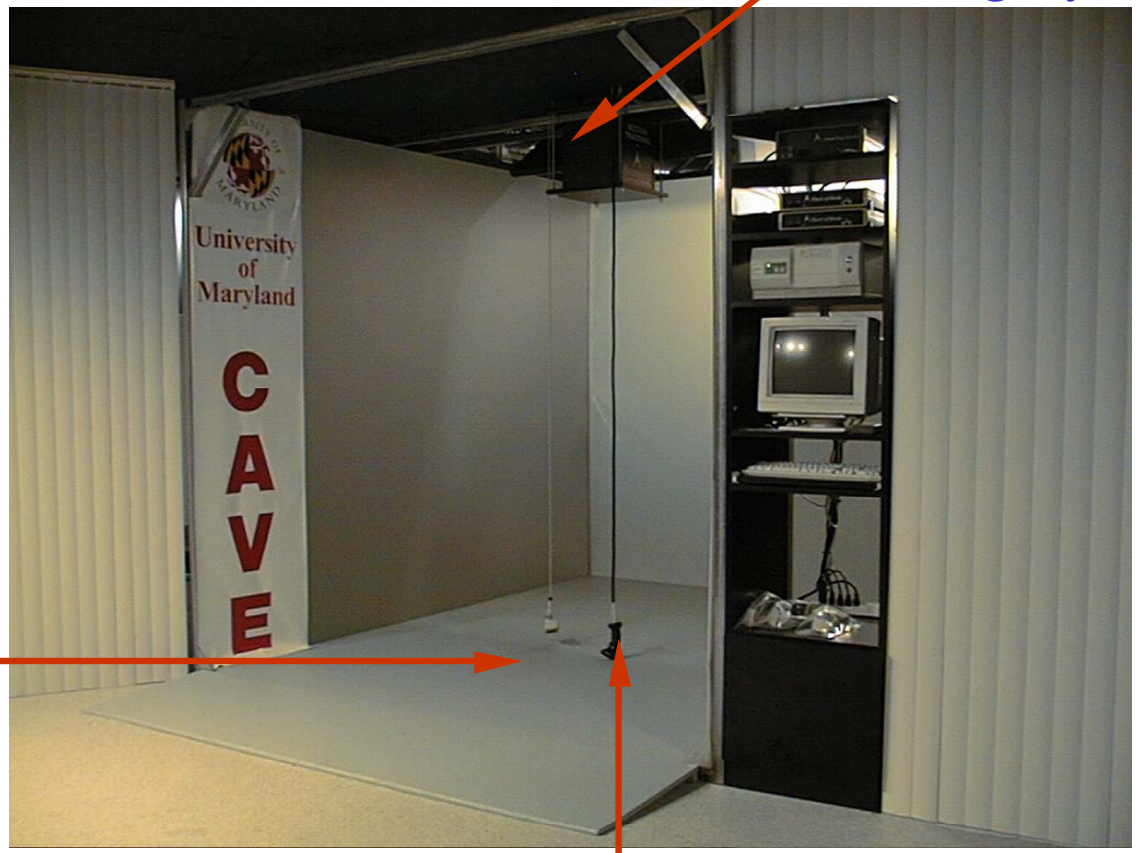
- **Design is Interactive with Designer in the Loop**
- **Vary design parameters & monitor response in real-time**
- **Collaborative Design with other design sites**

COMPUTER-AUTOMATED VIRTUAL ENVIRONMENT



UMCP VIRTUAL REALITY LAB

Tracking System



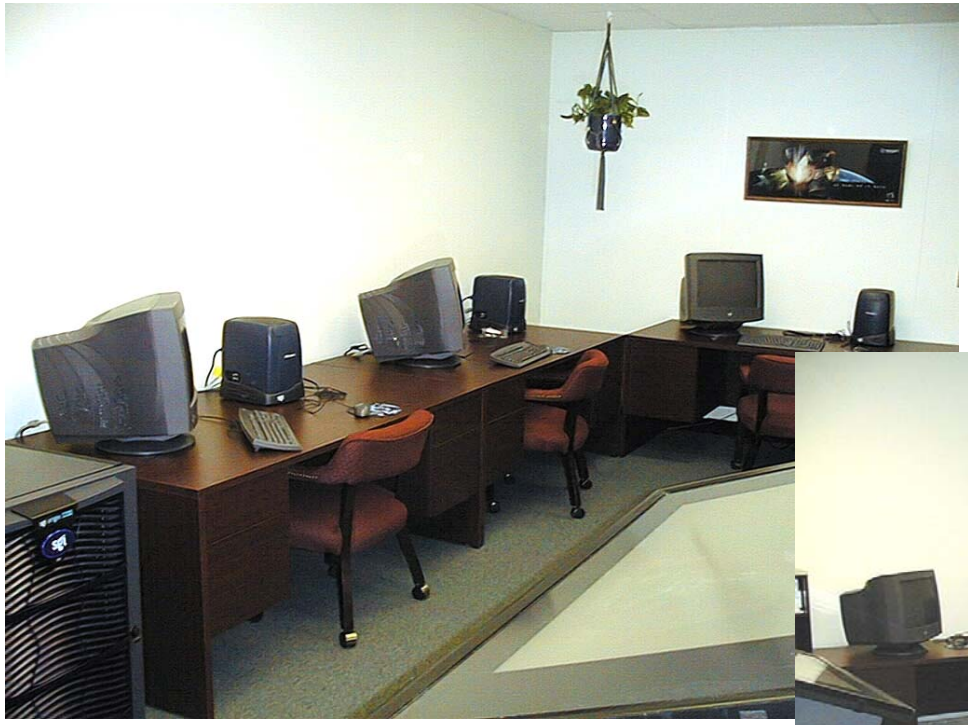
Goggles

Wand

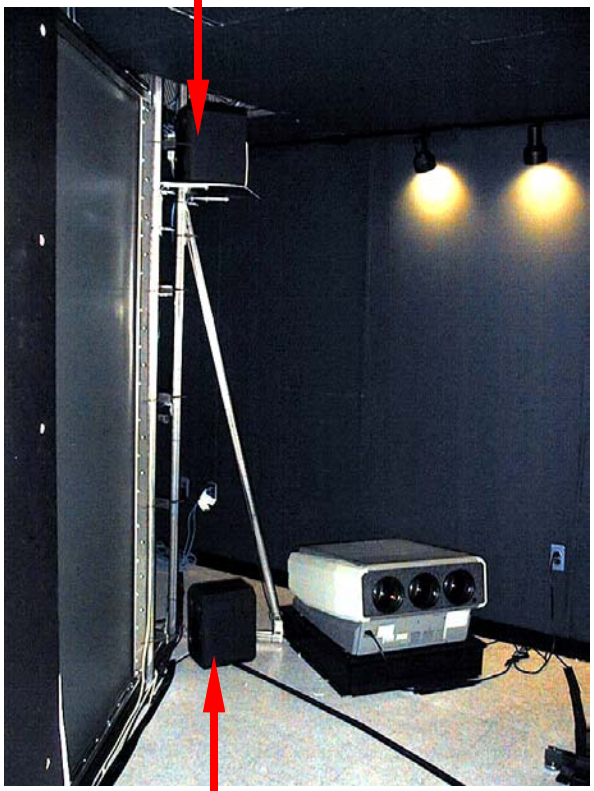
COMPUTER SYSTEM OF VIRTUAL REALITY LAB

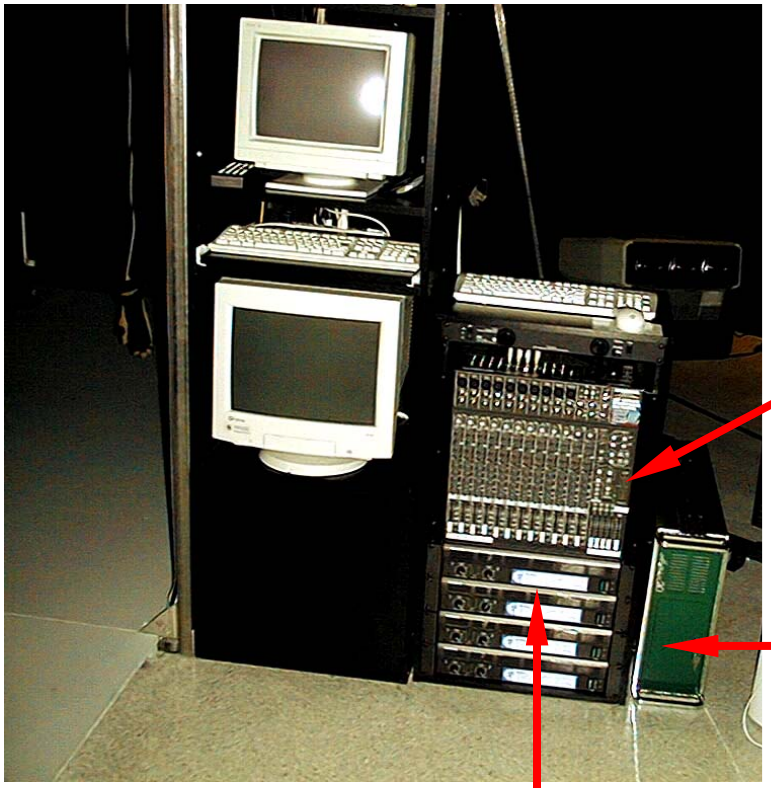
SGI/ONYX2
COMPUTER

VIRTUAL REALITY LAB – USERS ROOM

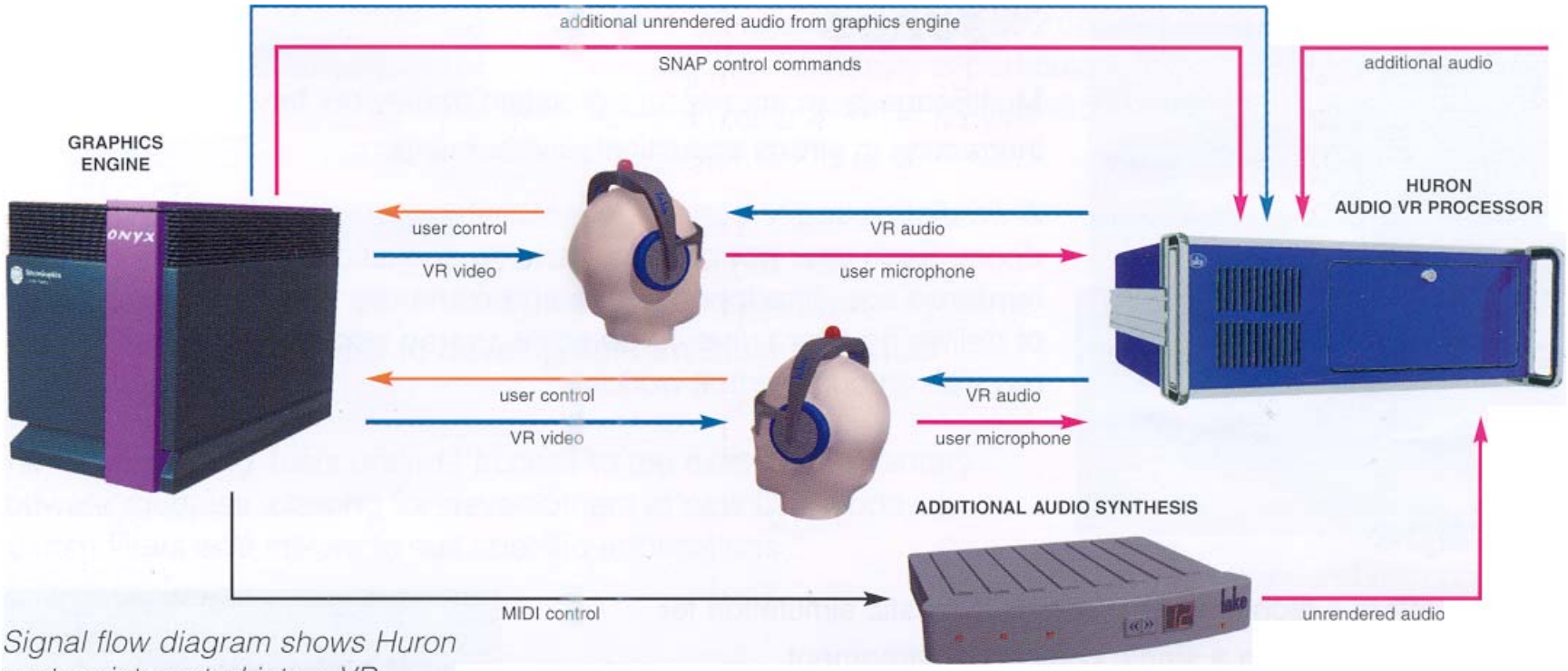


VIRTUAL REALITY LAB - ACOUSTICS





COMPUTER-AUTOMATED VIRTUAL ENVIRONMENT



Signal flow diagram shows Huron system integrated into a VR simulation environment.

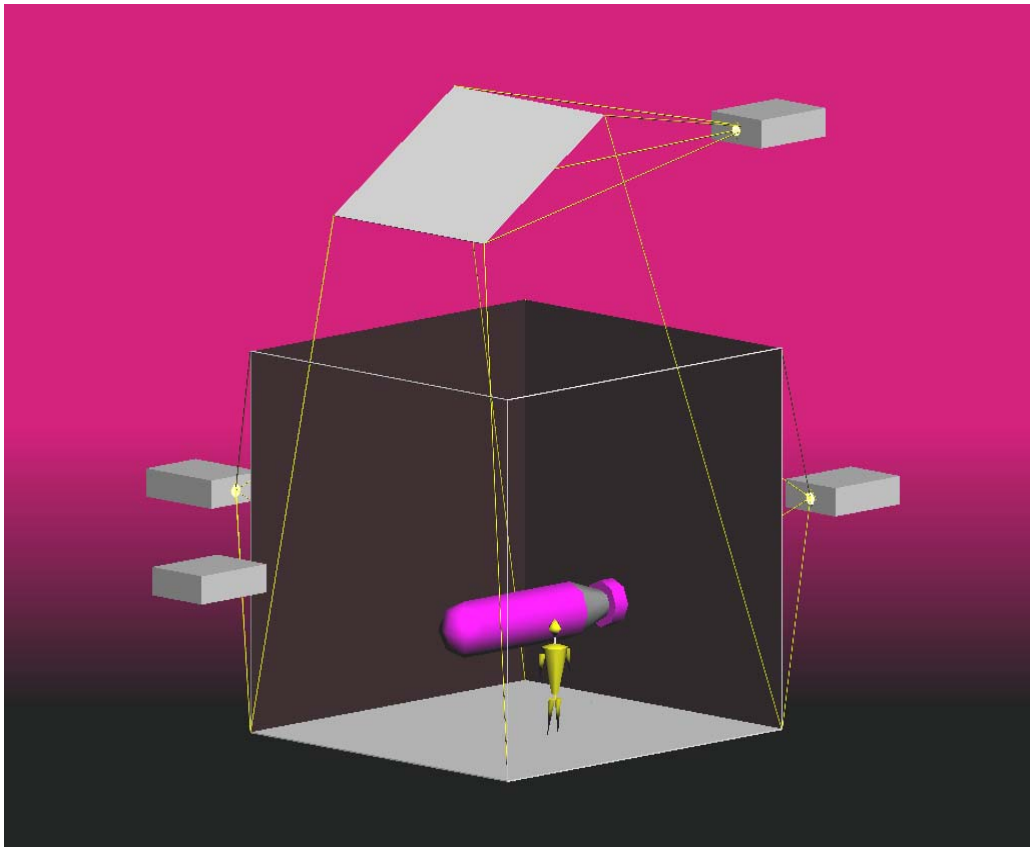
CYBER TOUCH GLOVES

The Glove has six small vibro-tactile stimulators on the fingers and the palm.

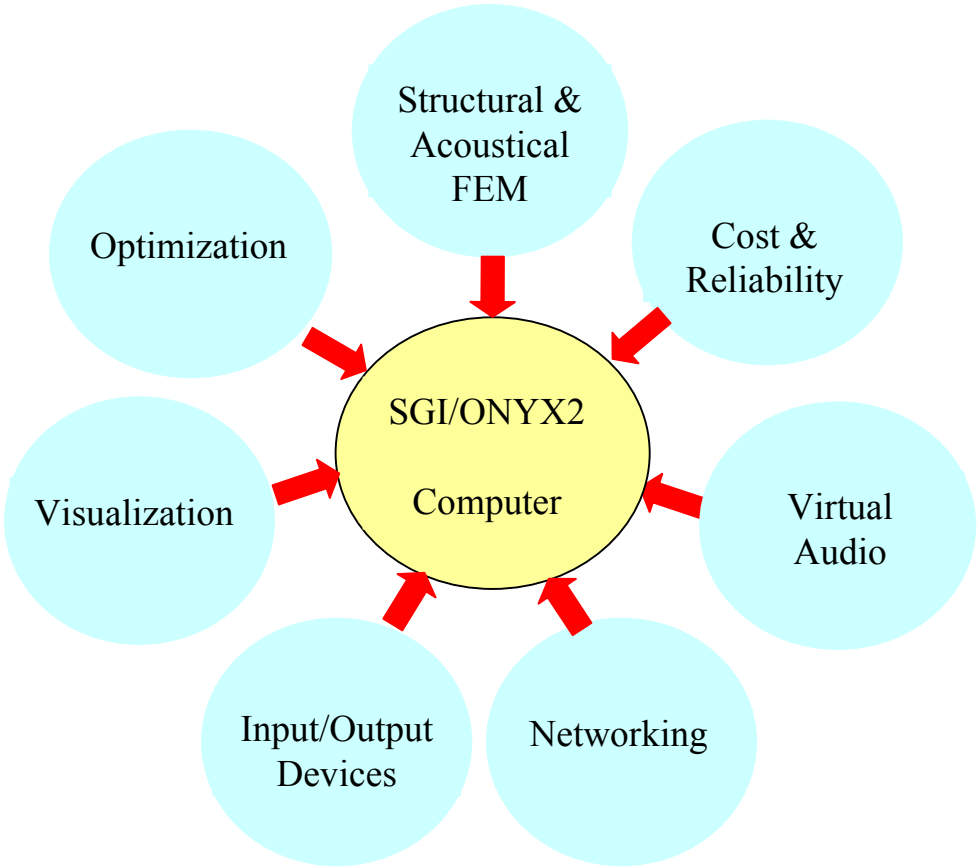
Each stimulator can be individually programmed to vary the strength of touch sensation.

VIRTUAL DESIGN OF ACTIVE STRUCTURES

Torpedo

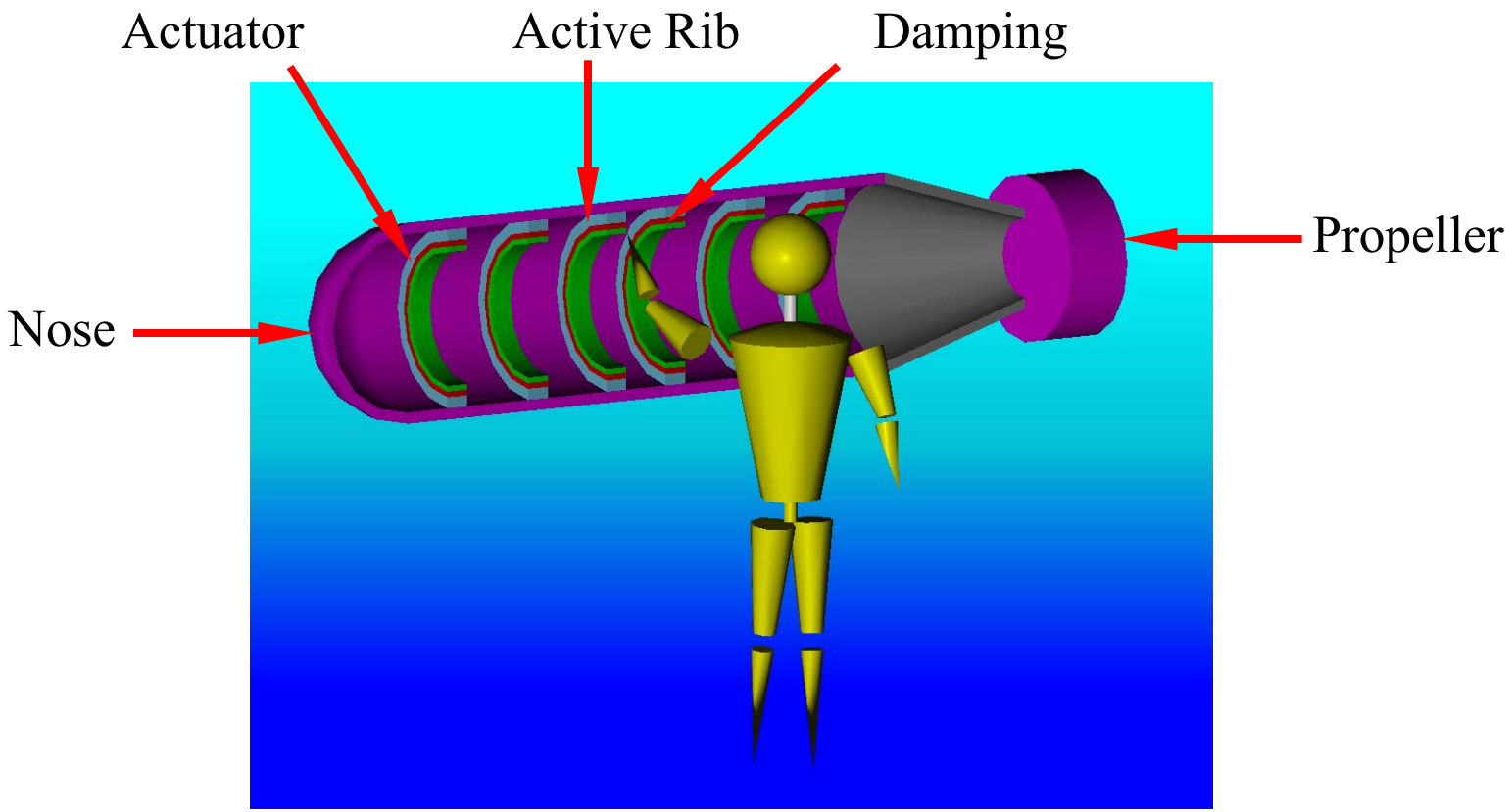


VIRTUAL DESIGN OF A TORPEDOE SHELL



Implementation of virtual reality on SGI/ONYX2 Computer

VIRTUAL DESIGN OF ACTIVE TORPEDOES



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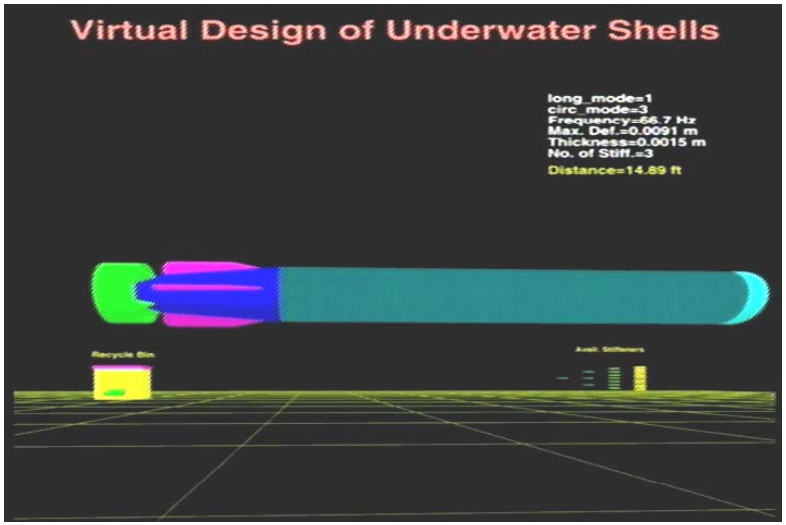

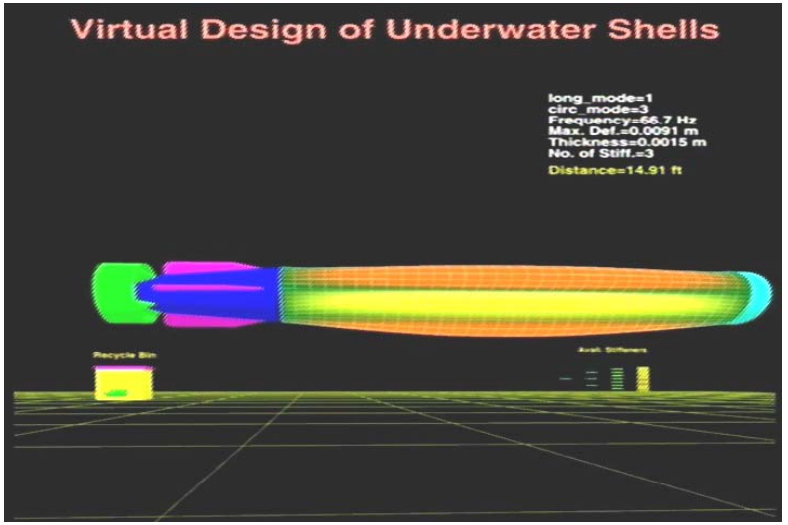

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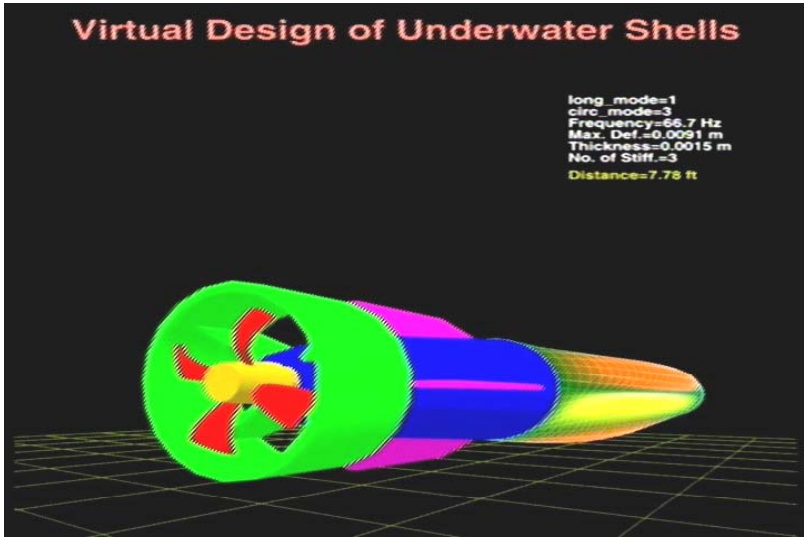

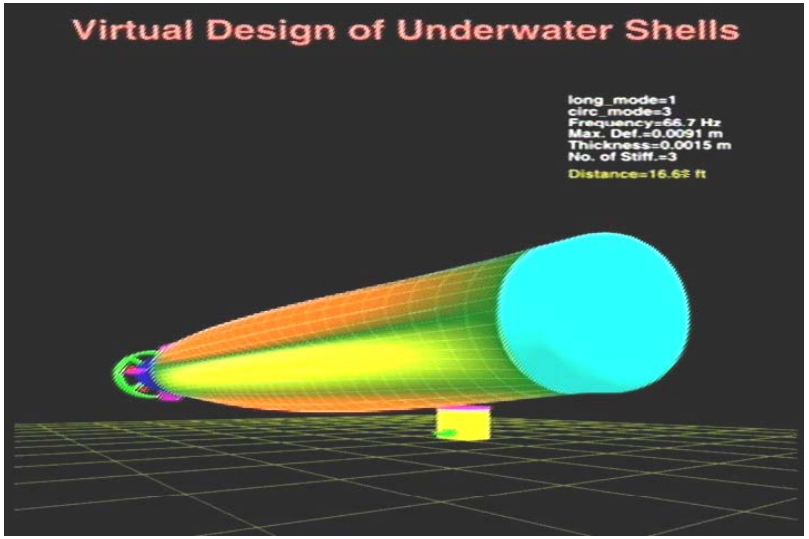

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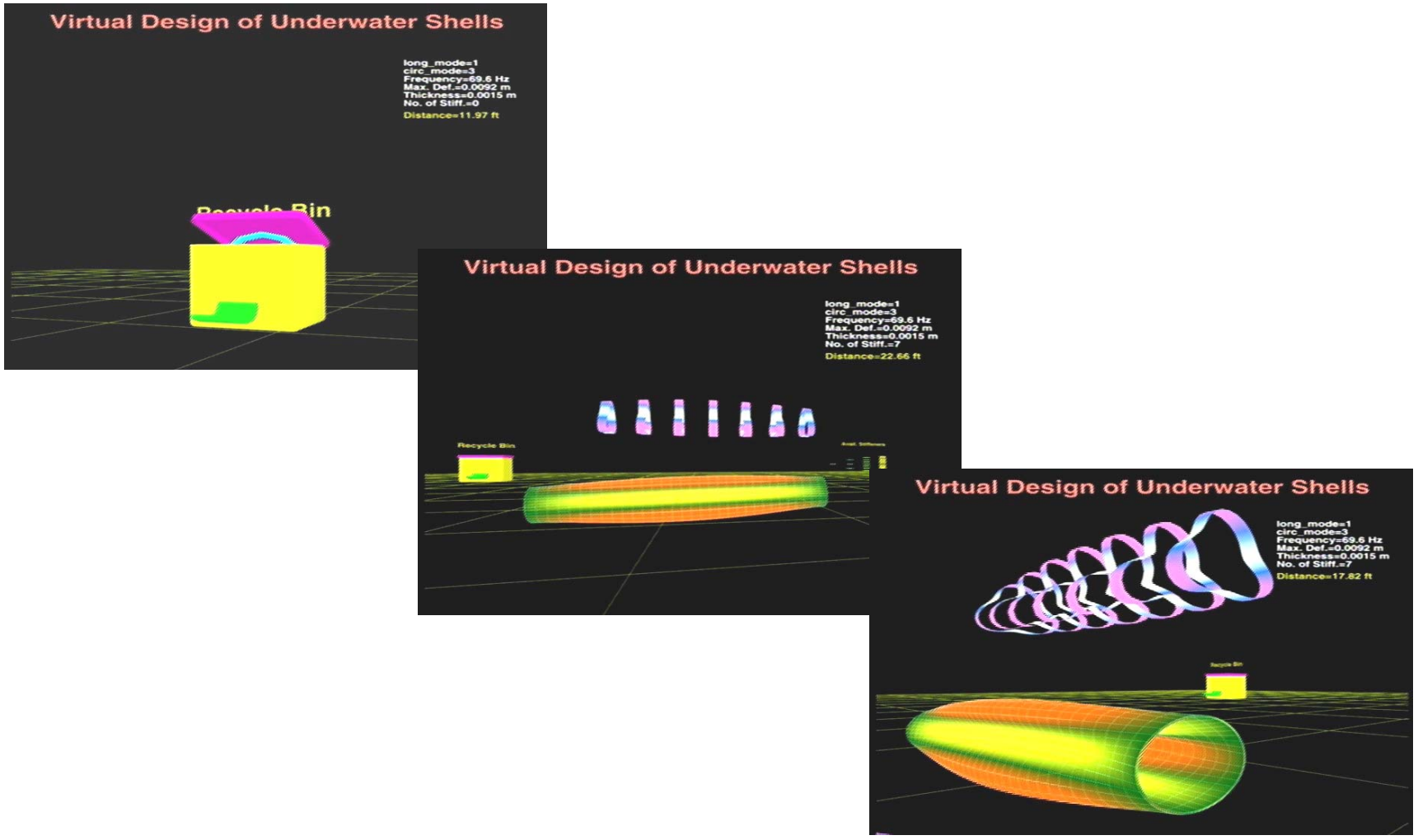

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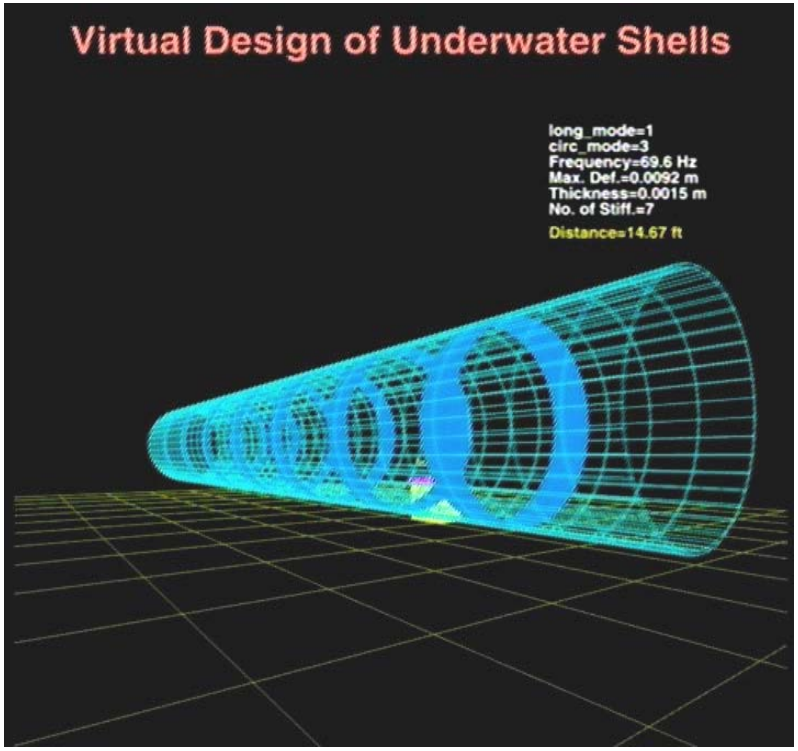
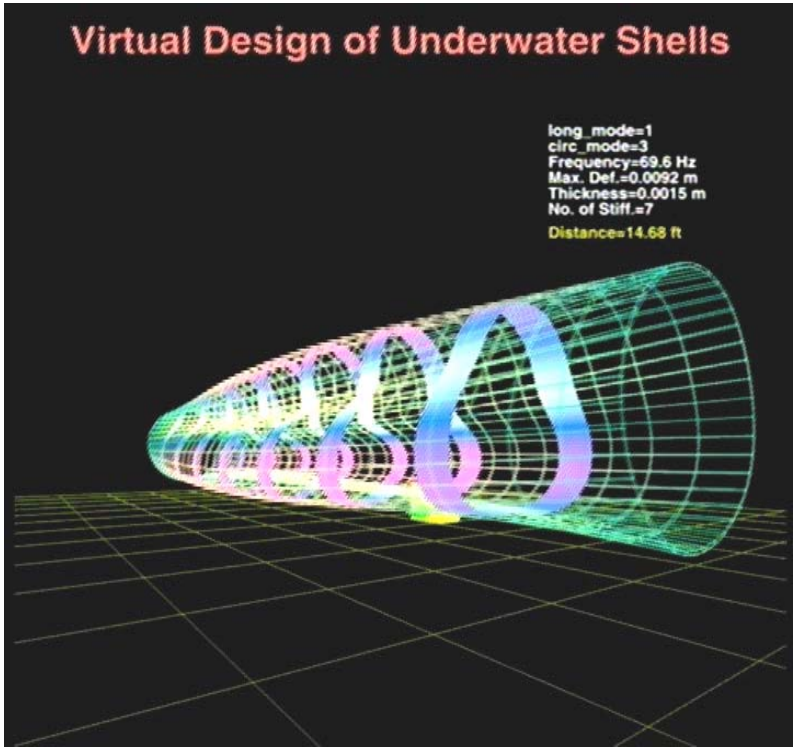
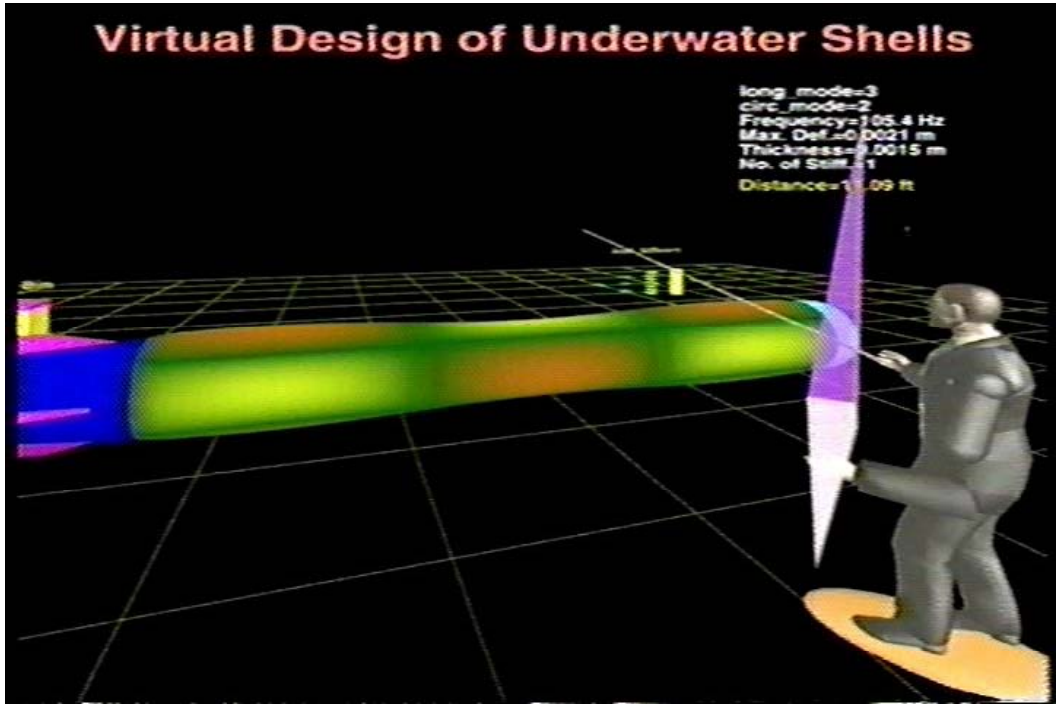
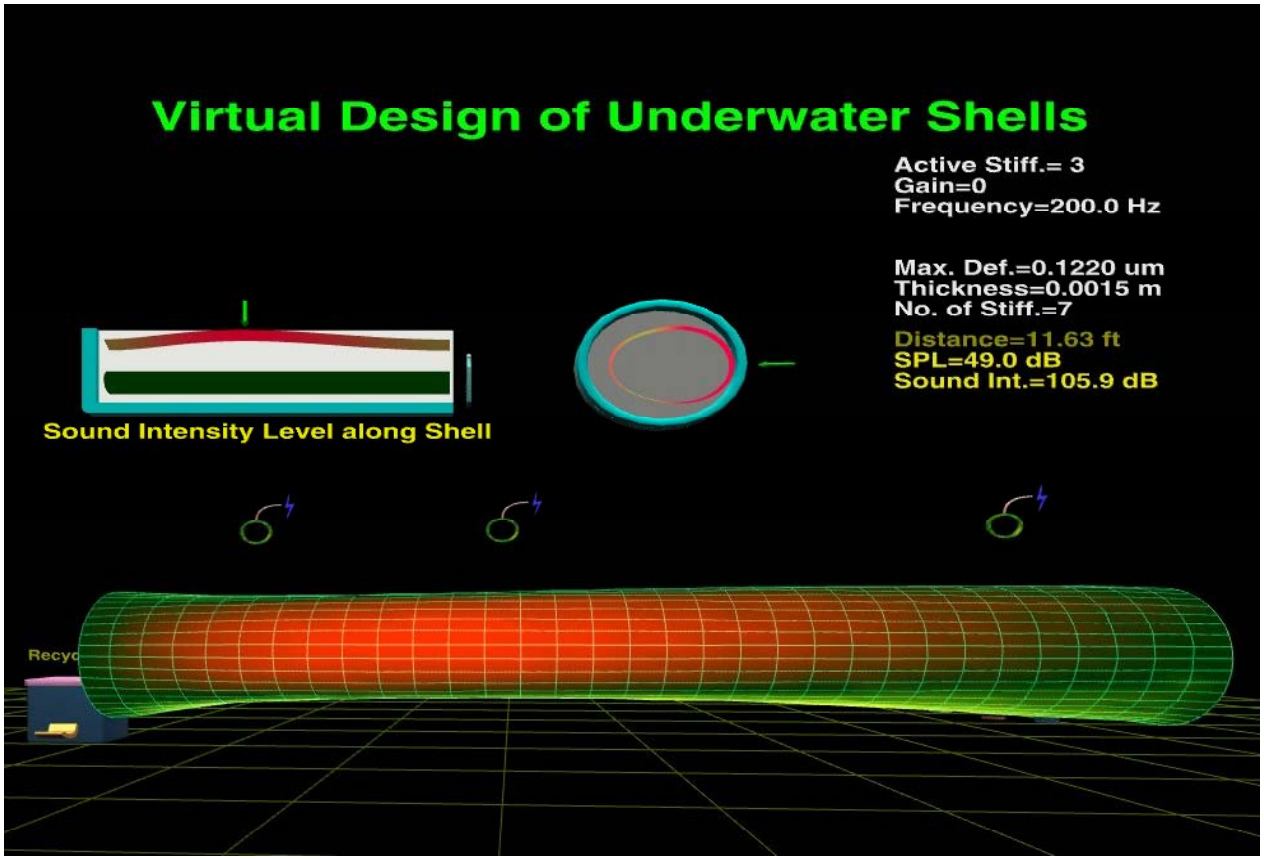




COLLABORATIVE DESIGN OF A TORPEDO SHELL

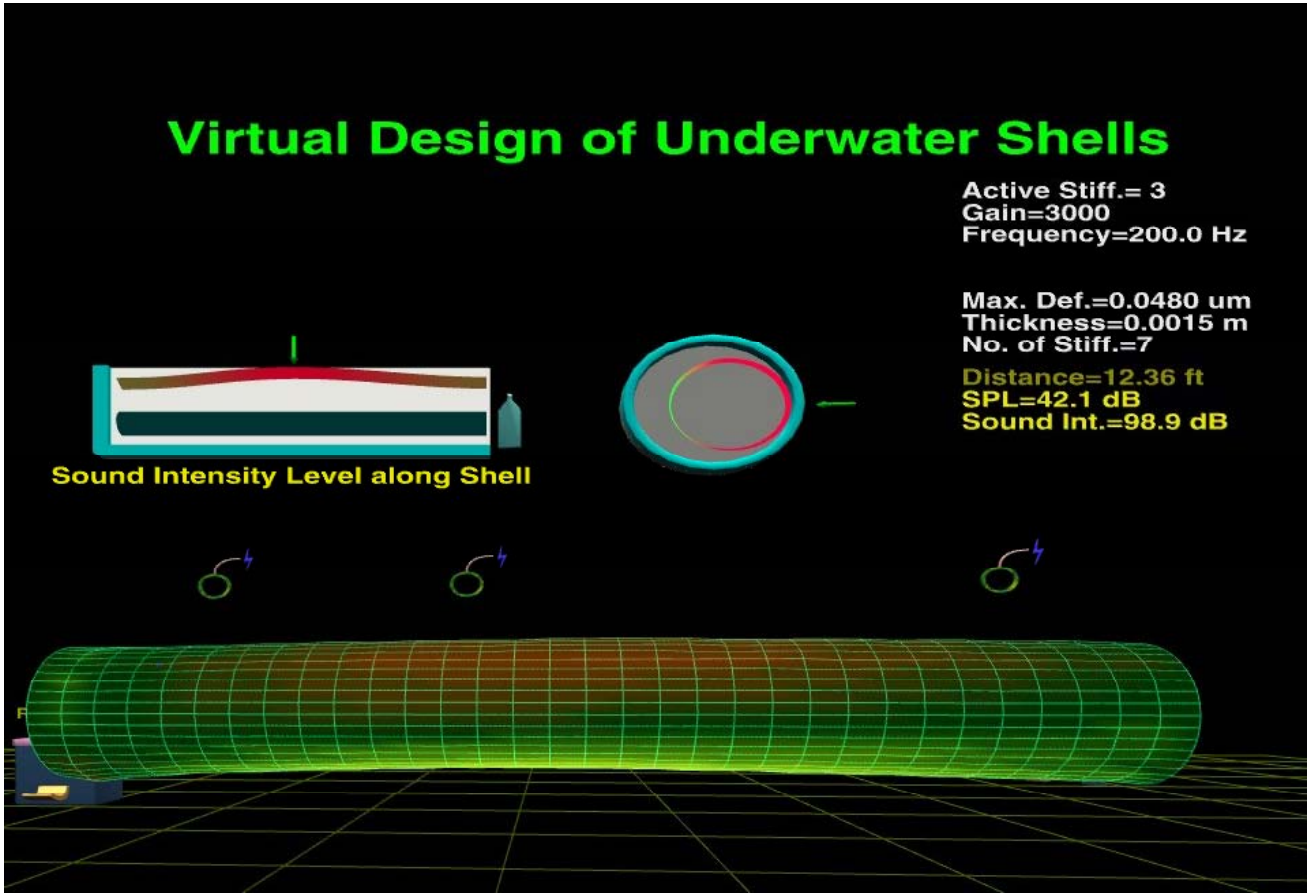


No. of stiffeners = 7, Active Stiffeners: 1,3, 7, Frequency 200 Hz



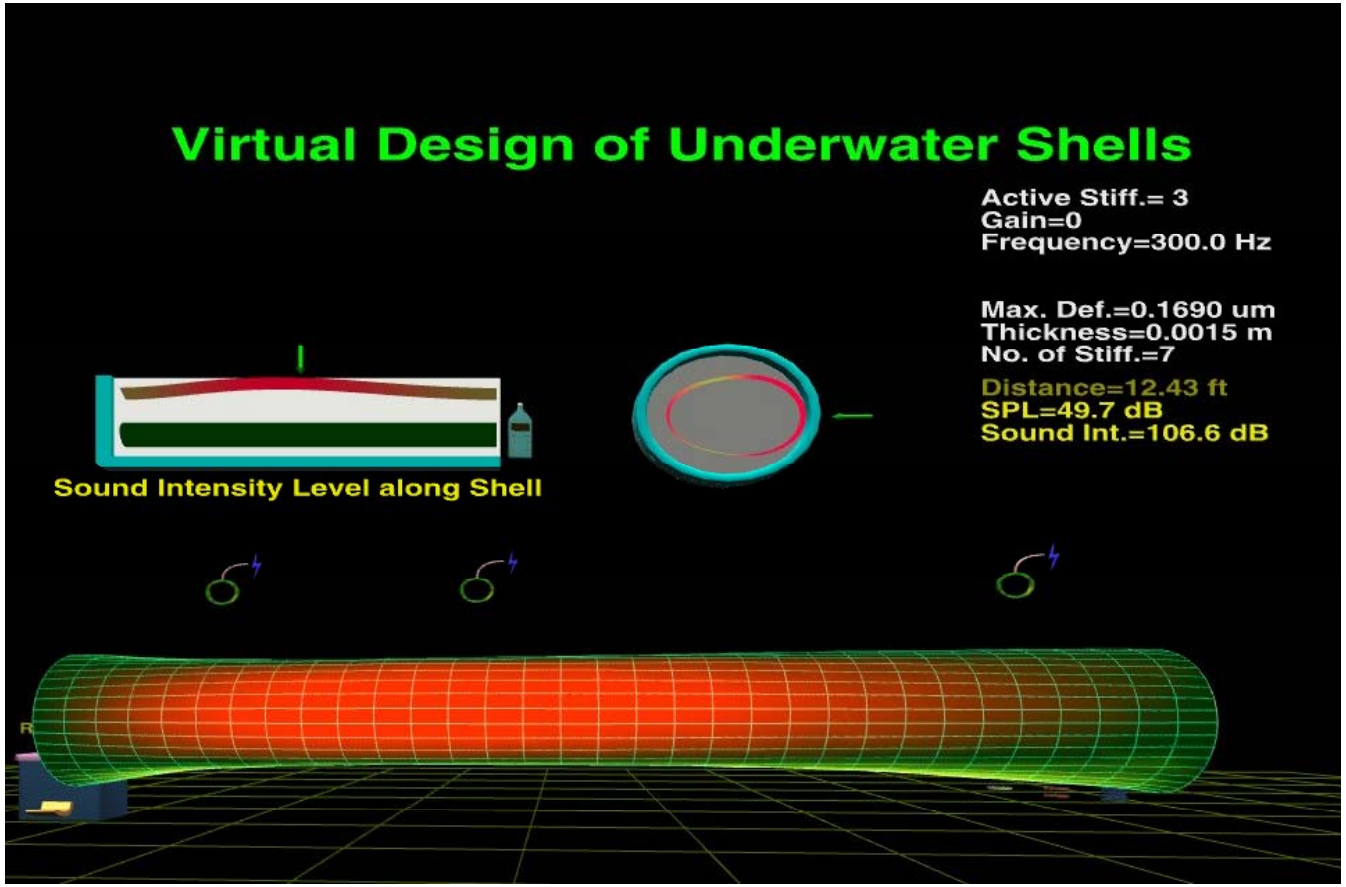
Gain =0

No. of stiffeners = 7, Active Stiffeners: 1,3, 7, Frequency 200 Hz



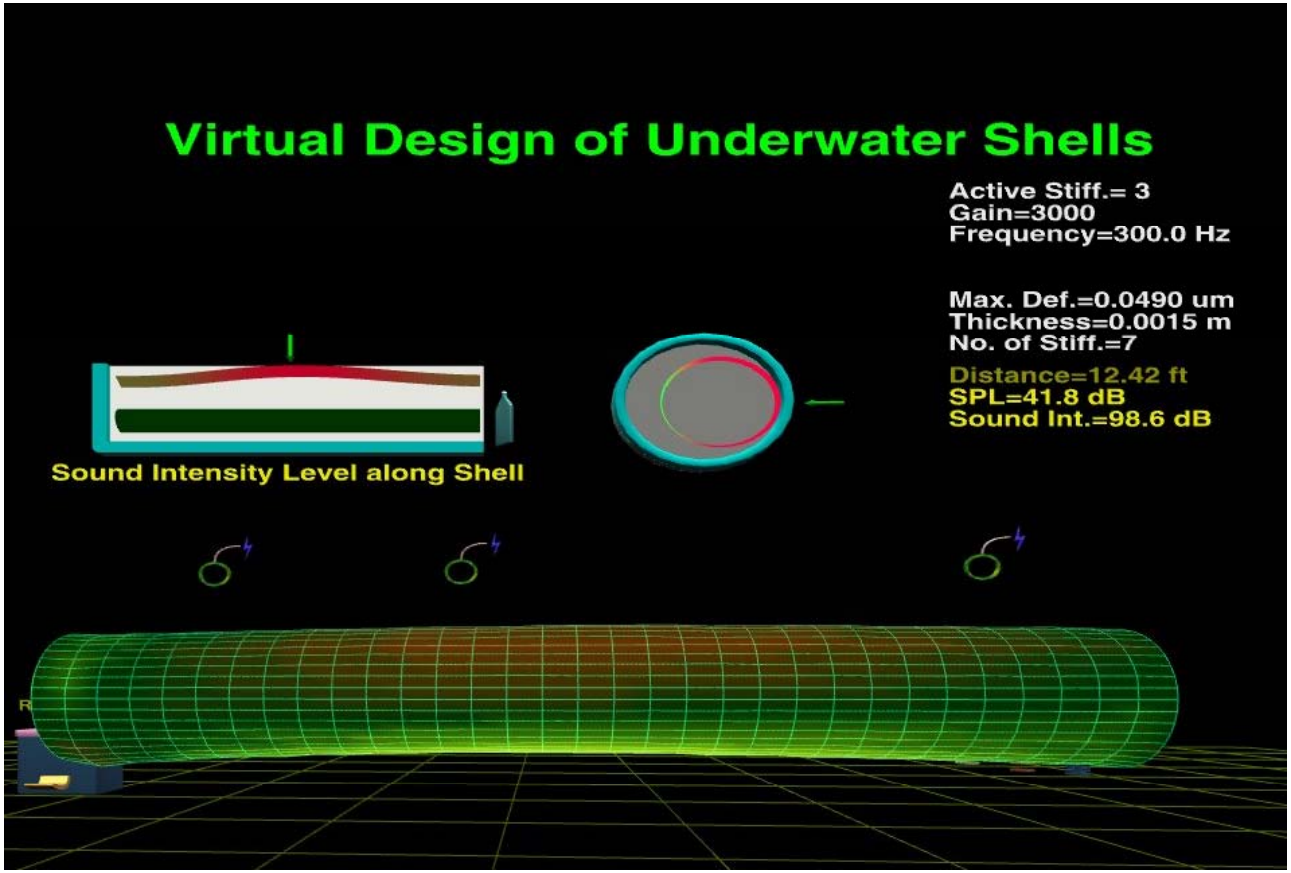
Gain =3000

No. of stiffeners = 7, Active Stiffeners: 1,3, 7, Frequency 300 Hz



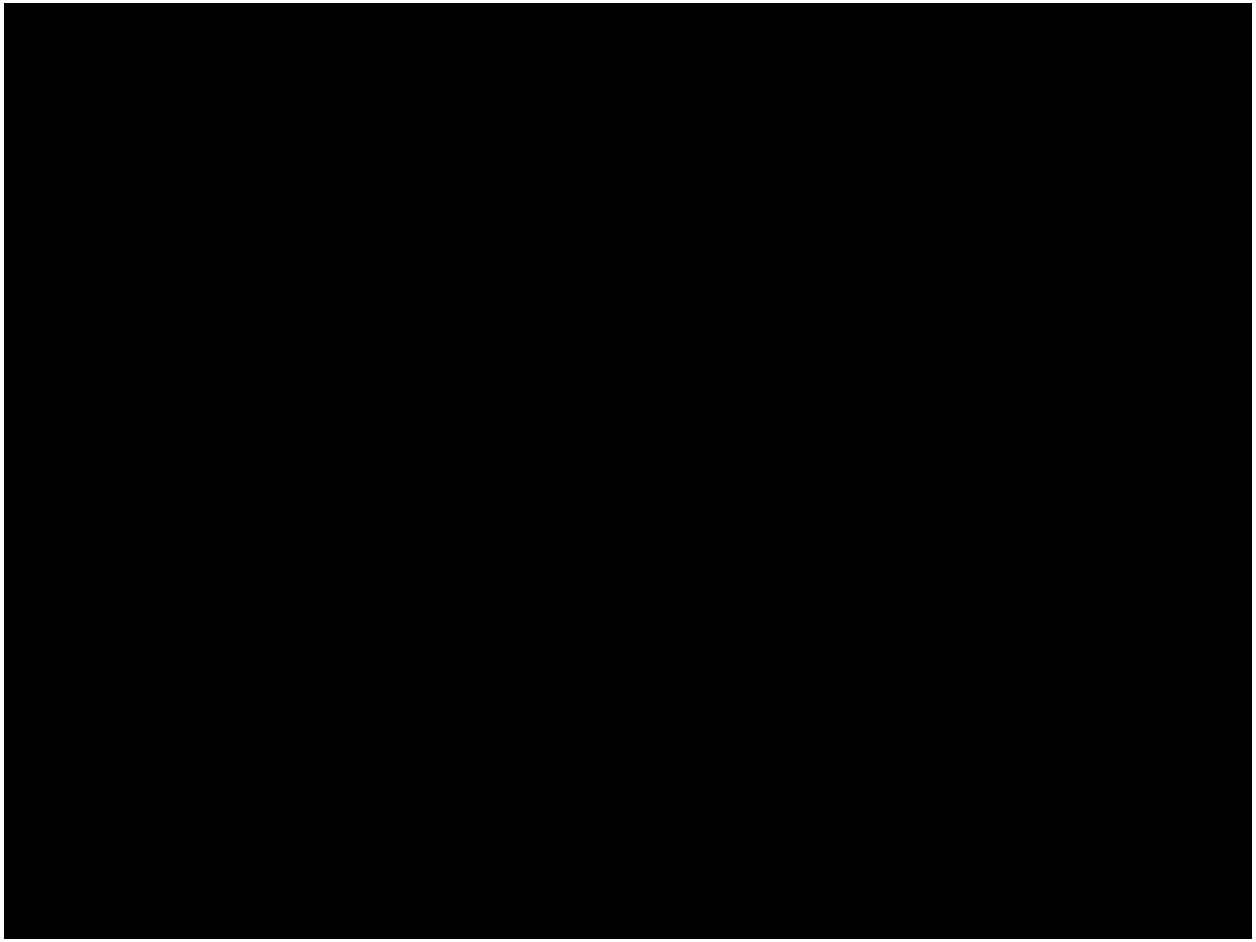
Gain =0

No. of stiffeners = 7, Active Stiffeners: 1,3, 7, Frequency 300 Hz

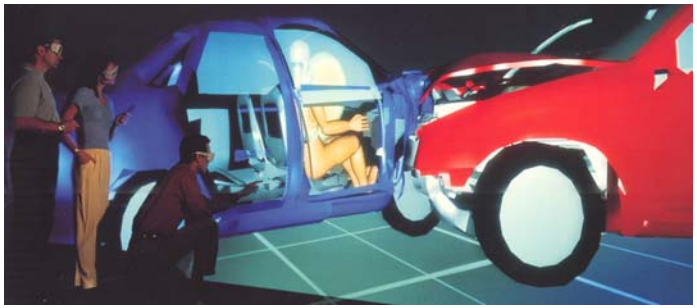


Gain =3000

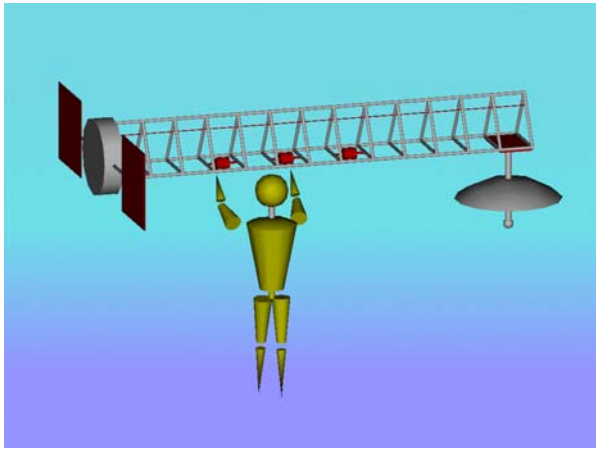
VIRTUAL DESIGN OF A TORPEDO SHELL



FUTURE APPLICATIONS



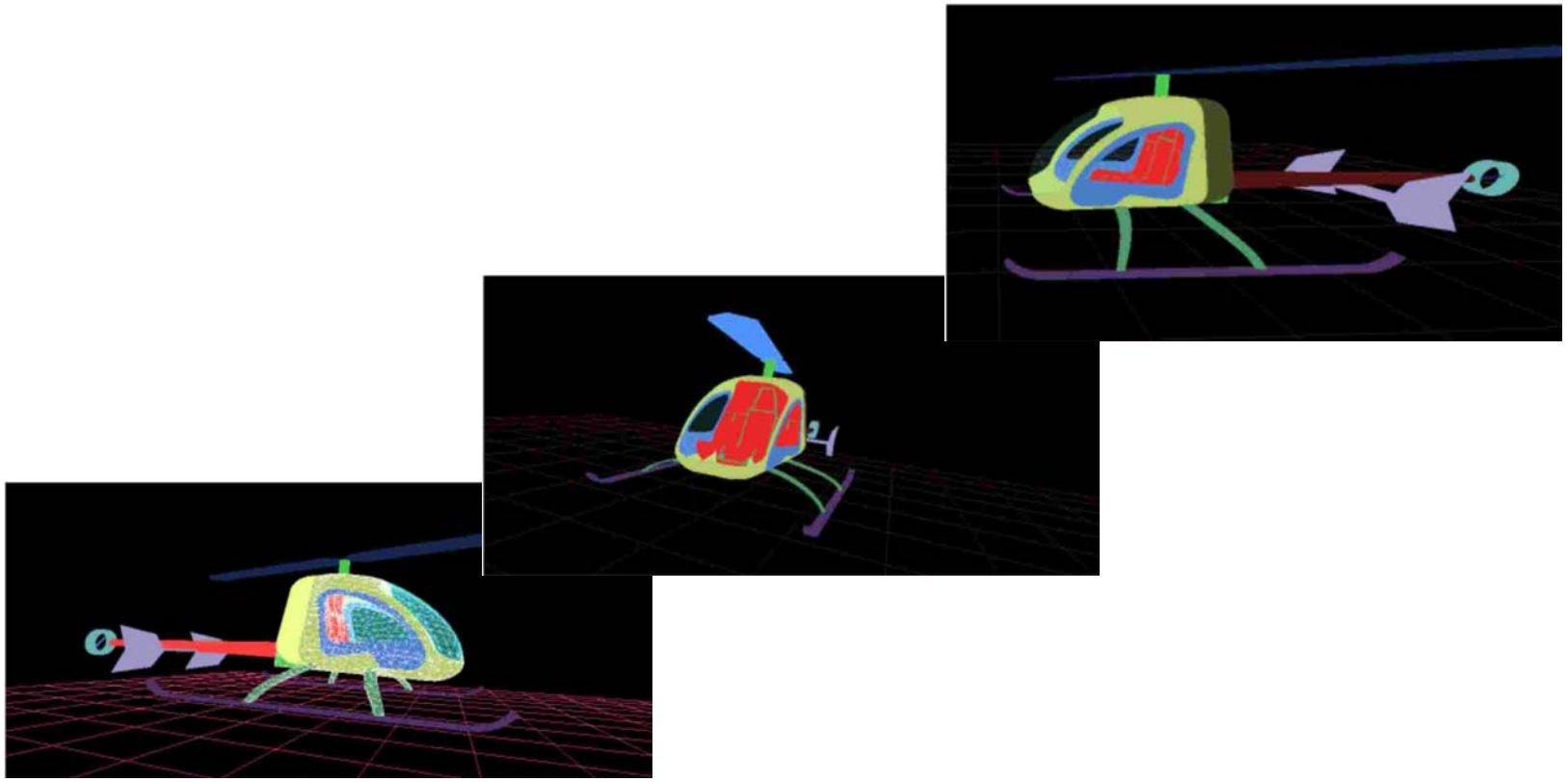
Car Crash



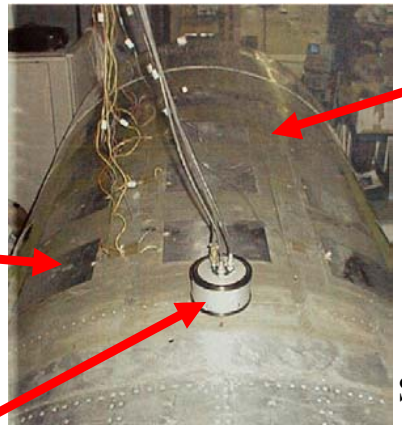
Space Structures

Vehicle Dynamics & Acoustics

Virtual Reality Design of Helicopter Noise & Vibration Controls



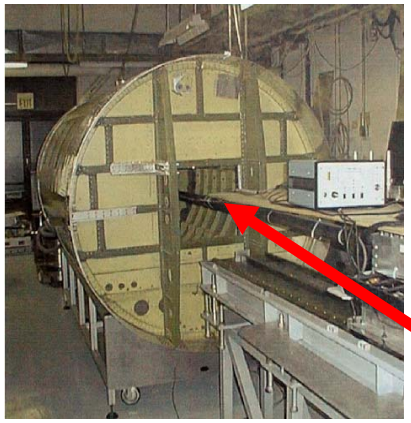
Cessna Citation II Fuselage



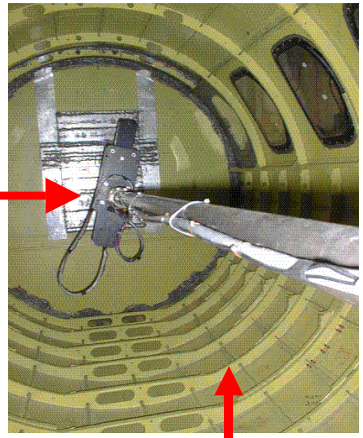
Fuselage

Active Patches

Shaker



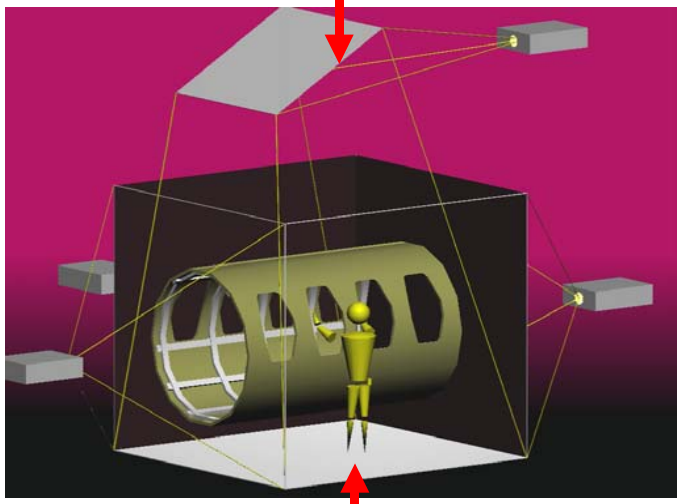
Scanning arm



Scanning Laser

Stiffeners

CAVE



Engineer

Conclusions

1. Underwater Shells with Active stiffeners are designed using Multi-Disciplinary Optimization (MDO).

2. The optimal design parameters of the Actuator/sensor pairs (**Number, Location & Control Gain**) are determined in order to minimize the sound radiation, the structural vibration, weight, production & life cycle cost, control effort & maximize controllability & observability.

END