Haptic visualization of computational fluid dynamics data using reactive forces

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Computational Fluid Dynamics

- Evaluate aircraft design
  - Find dangerous vortices, shock waves
- Complex data
  - Multivariate
  - Multifield
  - Turbulent

Scientific Visualization

- 3D visualization
  - Pressure rendering
    - Opacity from pressure or curl
  - Stream-ribbons
    - Show flow
    - Color from speed
    - Color from pressure
User Interface

- Reachin Desktop Display
  - PHANToM haptic device
  - Personal VR workstation

User Interface

- Virtual Reality
  - direct interaction
- Integrated GUI
  - no context switch needed
- Stream Ribbons
  - visualize flow
  - place and drag

Haptic Force Feedback

- Guide the user
  - physical support
  - pathway to features
- Present information from data
  - complement to visual feedback
  - sometimes more intuitive through touch
  - ex: flow strength and pressure
Haptic Force Feedback

- **Force Functions**
  - Been around since early 90's
  - Vector valued functions
    - etc: viscosity, pressure
- **Proxy-based Methods**
  - Common in surface interaction
  - Recently also for volume haptics
  - Passive representation of features
    - feedback answers to our actions -
      does not actively push

Proxy-based Methods

- Proxy is controllable representation of probe
  1) Determine local data properties
    - scalar value interpolation, gradient estimation, etc.
  2) Move proxy to simulate constraints from data
    \[
    x_{\text{proxy}} = \begin{cases} 
    x_{\text{proxy}} + \dot{x}(x_{\text{proxy}} - x_{\text{probe}}), & \text{if } \dot{s} \leq k(\ddot{x} - \ddot{q}) \\
    x_{\text{proxy}}, & \text{otherwise}
    \end{cases}
    \]
  3) Calculate force feedback from coupling
    \[
    \mathbf{f}_{\text{feedback}} = -k(x_{\text{probe}} - \mathbf{v}_{\text{probe}}) - D(\mathbf{v}_{\text{probe}} - \mathbf{v}_{\text{probe}})
    \]

Proxy Balance Equation

**Move a proxy to minimize residual force**

\[
\mathbf{f}_{\text{residual}} = -k(x_{\text{proxy}} - x_{\text{probe}}) + \sum_{n \in \text{forces}} n_i q_i + \sum_{n \in \text{forces}} \begin{cases} 
0, & \text{if } |n| = 0 \\
\frac{1}{2} |n|^2, & \text{if } |n| < \frac{1}{2} |n| \\
\frac{1}{2} |n|, & \text{if } |n| \geq \frac{1}{2} |n|
\end{cases}
\]

\[
+ \sum_{n \in \text{forces}} \begin{cases} 
0, & \text{if } \dot{q} \leq 0 \\
\frac{1}{2} \dot{q}^2, & \text{if } \dot{q} > 0
\end{cases}
\]
Direct Volume Haptics

Haptic Modes

- Follow Mode
  - feedback restricting movement across the vector field
  - encourages the instrument to follow the field
  - convey air flow orientation
  - guides the user to find where flow originates
  - also presents air speed by strength

- Surface Mode

- Viscosity Mode

Haptic Modes represent different features
- ex: flow orientation, vorticity, pressure gradient
- does not necessarily mimic flow

Choose right mode for right task
- find shock waves
- search for dangerous vortices

QuickTime™ and a decompressor are needed to see this picture.
Conclusions

- Take advantage of human perception
  - immersion – direct navigation
  - natural and intuitive interaction
  - present data and guide actions
- Need training
  - learn to understand local cues for global features
  - learn to take advantage of given feedback
  - hard to teach – need experience

Haptic exploration of heart flow

- Interactive exploration
- Clip planes placed with pen
- Stream ribbons interactively placed in the flow
- Structural feedback from heart walls
- All flow modes implemented
- Clinical evaluation shows promising results
**Sneak Preview**

- Time resolved data
- Beating heart
- Force feedback generated
- Optical flow in between frames
- General method – can deal with data from simulators and sensors

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**The Future of Volume Haptics**

- New methods for volume haptics
  - more intuitive abstraction layer for programming
  - a more versatile palette of available modes
  - No constraints on how to use the haptic modes
- General visualization platforms with haptics
  - Cheaper haptic equipment
  - Increased availability from new methods