Development of NASA-DeBakey Ventricular Assist Device
Using Numerical Aerospace Simulation Technology

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Outline of Talk

- MOTIVATION
- MECHANICAL HEART ASSIST DEVICES
- VAD
  - Requirements
    - NASA DeBakey VAD
- COMPUTATIONAL APPROACH FOR VAD DEVELOPMENT
  - CFD Technology Developed for Space Shuttle
  - Design Improvements Using CFD: Development Timeline
- FUTURE WORK

Ventricular Assist Device

- Motivation
  - Over 3 million Americans and 20 million people worldwide suffer from some form of heart failure
  - Mechanical heart assist devices are being used as a temporary support to sick ventricle and valves as a "BRIDGE-TO-TRANSPLANT" or "BRIDGE-TO-RECOVERY"
  - Need for assist devices is very high
    - Permanent VAD need: 25,000-60,000 / YR
    - Current valve replacement: 120,000 / YR
    - Donor hearts available: 2,000-2,500 / YR
Mechanical Heart-Assist Device

- Heart Valves
- Ventricular Assist Device (VAD)

**Pulsatile Pump**
- Piston Driven: Low speed, Bulky
- Pneumatically Driven: Need external support equipment

**Rotary Pump**
- Axial Flow Pump: High speed, Small

→ DeBakey VAD is based on this concept

- Total Artificial Heart

Schematic of DeBakey VAD
Issues in Axial flow VAD

- Problems Related to Fluid Dynamics
  - Small size requires high rotational speed
    Highly efficient pump design required
  - High shear regions in the pump may cause excessive blood cell damage
    Minimize high shear regions
  - Local regions of recirculation may cause blood clotting
    Good wall washing necessary

⇒ Small size and delicate operating conditions make it difficult to quantify the flow characteristics experimentally

Ventricular Assist Device

- Requirements
  - Simplicity and Reliability
  - Small size for ease of implantation
  - Supply 5 liter/min of blood against 100 mmHg pressure
  - High pumping efficiency to minimize power requirements
  - Minimum Hemolysis and Thrombus Formation
Computational Methods Developed for Space Shuttle Main Engine Redesign

SSME: High Speed Turbopump

Inlet Guide Vane
Impeller
Diffuser
Validation-SSME Turbopump Flow Analysis

- SSME HPFTP 1:1 Impeller
  Shrouded impeller: 6 full blades, 6 long partials, 12 short partials 6322 rpm, Re=1.81x10^6 per inch
  HUB SURFACE COLORED BY STATIC PRESSURE

COMPARISON WITH EXPERIMENTAL DATA

IMPELLER EXIT PLANE AT 51% BLADE HEIGHT

Pressure

DeBakey VAD Development Timeline

- Baseline Design Design
  1984 - NASA Johnson Space Center's David Sauier begins initial design work on axial pump VAD with Dr. DeBakey
  1988 - NASA/JSC and Baylor College of Medicine signs Memorandum of Understanding to develop the DeBakey VAD
  1992 - NASA/JSC begins funding the project
**NASA/DeBakey Ventricular Assist Device**

*(Baseline Design)*

**NASA/DeBakey Axial Flow VAD Impeller**

- Zone 1: 101 x 39 x 33
- Zone 2: 101 x 39 x 33
- Zone 3: 59 x 21 x 7
- Zone 4: 47 x 21 x 7
- Zone 5: 59 x 21 x 7

*Geometry*

*Computational Grid*

Rotational Speed: 12,600 RPM
Flow Rate: 5 liter/min

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**DeBakey VAD Development Timeline**

- **CFD Assisted Design**
  - 1993 - NASA/ARC is asked to develop CFD procedure to improve design and performance. D. Kwak and C. Kirs visit JSC to study the device.
  - The technology developed for rocket engines such as the Space Shuttle main engine was to be extended to blood flow simulation.
  - 1994 - Kirs and Kwak begin work on design analysis using NAS supercomputers.
  - NEW DESIGN WAS PROPOSED TO INCLUDE AN INDUCER BETWEEN THE FLOW STRAIGHTENER AND THE IMPELLER.

*Particle Traces Colored by Velocity Magnitude*
DeBakey VAD Development Timeline

- CFD Assisted Design
  1994 - Kris and Kwak continued design changes
  ⇒ IMPROVE BEARING, HUB AND Hub EXTENSION DESIGN TO REDUCE BLOOD CLOTTING

**Bearing Optimization**

- Animal Tests

  1995 - Animal implantation: passed two-week requirements

  1996 - Full design rights are granted to MicroMed, Inc. to produce the pump
  Began using bio-compatible titanium replacing polycarbonate

  1997 - Configuration design finalized
**CFD Contributions to VAD Design**

CFD Contributions To Design

- Antithrombogenic Front Hub Area
- Inducer addition
- Bearing cavity design
- Change diffuser inlet angle

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<tr>
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<th>Baseline Design</th>
<th>New Design</th>
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<tr>
<td>Hemolytic Index</td>
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<tr>
<td>Thrombus Formation</td>
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<tr>
<td>Test Run Time</td>
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<td>30+ days</td>
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<tr>
<td>Human Implantation</td>
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**DeBakey VAD Development Timeline**

- **Human Implantation in Europe**
  
  1998 - On November 13, 1998, the first six DeBakey VADs are implanted in European patients by Roland Hetzer and DeBakey at the German Heart Institute of Berlin. One of the patients, fifty-six year old Josef Pristov, is able to return home and spend Christmas with his wife after a month's stay for recovery and monitoring at the clinic.
  
  
  2000 - Over 30 patients have received the device.

  The longest successful trial period to date in human was 123 days.

  US trial is planned during year 2000.
DeBakey VAD Development Timeline

- Human Implantation - November 1969

Future Work: VAD Simulation and Control

- Ultimate Goal
  To make the VAD an alternative to heart transplant

- Long-Term Impact Study
  Unsteady simulation of the entire bloodstream system
Morris in a loud voice, all could hear, said argumentatively,

"So Mr. fancy doctor, look at this work. I also take valves out, grind 'em, put in new parts, and when I finish this baby will purr like a kitten.

So how come you get the BIG BUCKS, when you and me are doing basically the same work?"

DeBakey, very embarrassed, walked away, and said softly, to Morris,

"Try doing your work with the engine running."
Morris was removing some engine valves from a car on the lift when he spotted the famous heart surgeon Dr. Michael DeBakey, who was standing off to the side, waiting for the service manager.

Morris, somewhat of a loud mouth, shouted across the garage, "Hey DeBakey . . . Is dat you? Come over here a minute."

The famous surgeon, a bit surprised, walked over to where Morris was working on the car.