for CFAI

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

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Presented at
Samsung Medical Center
July 27, 2000

Acknowledgement

Much of the material presented in this talk is contributed
by
Dr. Cetin Kiris of NASA Ames research Center and
Robert Benkowski of MicroMed Technologies, Inc.

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
- FUTURRRE 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)

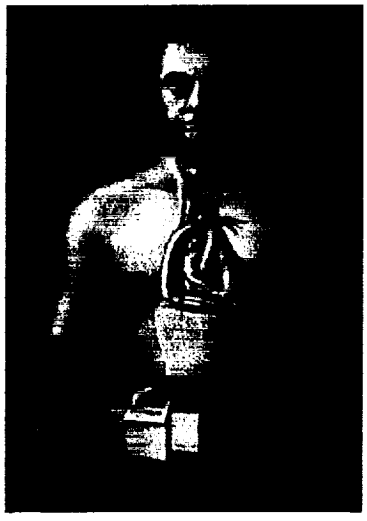
Pulsatile Pump
- Piston Driven : Low speed, Bulky
- Pneumatically Driven : Need external support equipment

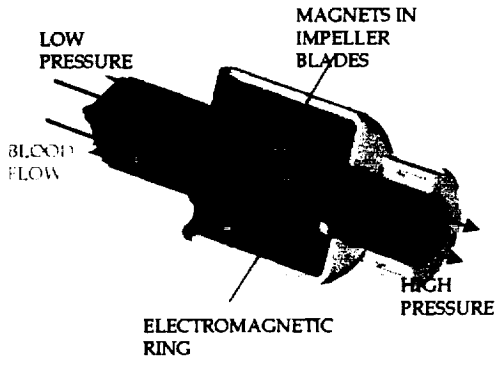
Rotary Pump
- Axial Flow Pump : High speed, Small

⇒ **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

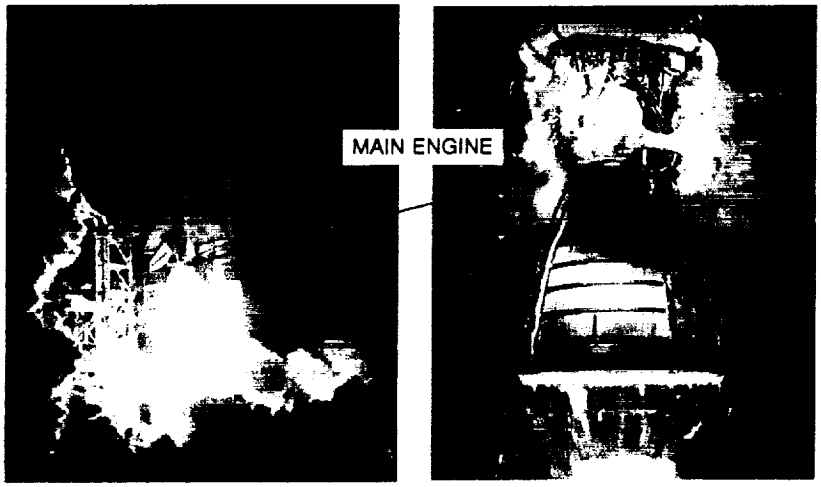
  -Local regions of recirculation may cause blood clotting
    Good wall washing necessary

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

Ventricular Assist Device

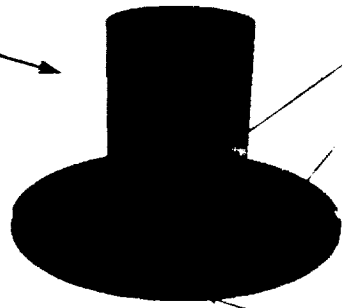
- Requirements
  - Simplicity and Reliability
  - Small size for ease of implantation
  - Supply 5 liter/min of blood against 100 mmHg pressure
  - High pumping efficiency to minimize power requirements
  - Minimum Hemolysis and Thrombus Formation

Computational Methods Developed for Space Shuttle Main Engine Redesign



SSME : High Speed Turbopump

TURBOPUMP IN SSME POWERHEAD

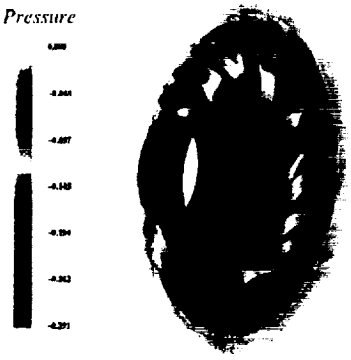


Validation-SSME Turbopump Flow Analysis

- SSME HPFTP 11" Impeller

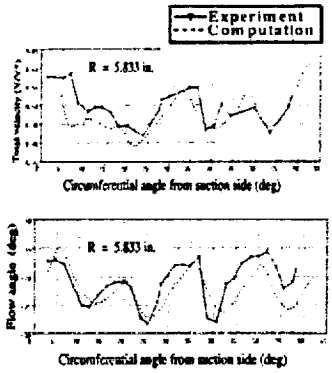
  Shrouded impeller: 6 full blades, 6 long partials, 12 short partials 6322 rpm, Re=1.81x10^5 per inch

HUB SURFACE COLORED BY STATIC PRESSURE



COMPARISON WITH EXPERIMENTAL DATA

IMPELLER EXIT PLANE AT 51% BLADE HEIGHT



DeBakey VAD Development Timeline

- Baseline Design Design

  1984 - NASA Johnson Space Center's David Saucier 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

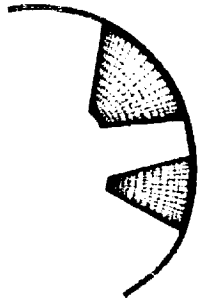
NASA/DeBakey Ventricular Assist Device (Baseline Design)

NASA / DeBakey Axial Flow VAD Impeller

Geometry

Computational Grid

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



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

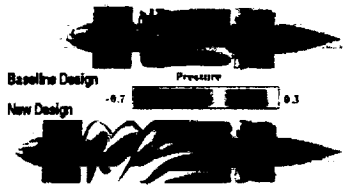
DeBakey VAD Development Timeline

- CFD Assisted Design

1993 - NASA/ARC is asked to develop CFD procedure to improve design and performance. D. Kwak and C. Kiris visit JSC to study the device
The technology developed for rocket engine such as the Space Shuttle main engine was to be extended to blood flow simulation

1994 - · Kiris and Kwak begin work on design analysis using NAS supercomputers

⇒ NEW DESIGN WAS PROPOSED TO INCLUDE AN INDUCER BETWEEN THE FLOW STRAIGHTNER AND THE IMPELLER



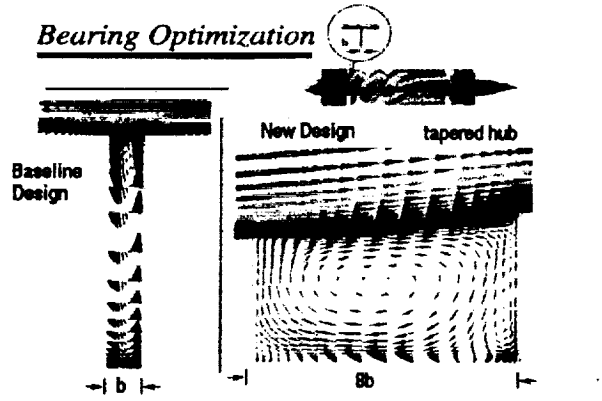
Particle Traces Colored by Velocity Magnitude

DeBakey VAD Development Timeline

- CFD Assisted Design

  1994 -Kiris and Kwak continued design changes

  ⇒ IMPROVE BEARING, HUB AND HUB EXTENSION DESIGN TO REDUCE BLOOD CLOTTING



DeBakey VAD Development Timeline

- Animal Tests

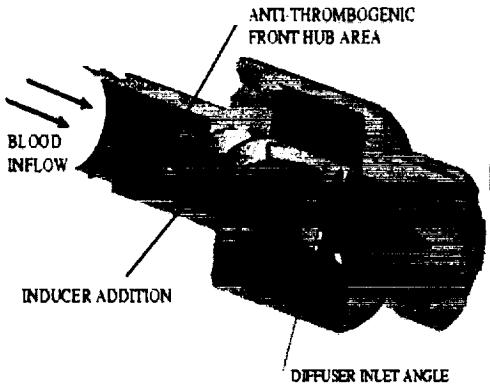
  1995 - Animal implantation: passed two-week requirements

  1996 - Fulll 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



	Baseline Design	New Design
Hemolysis Index	0.02	0.002
Thrombus Formation	Yes	no
Test Run Time	2 days	30+ days
Human Implantation		120+ days

- ***Inducer addition***
- ***Bearing cavity design***
- ***Change diffuser inlet angle***

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

1999 - US Patent is granted for the device on September 9, 1999

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

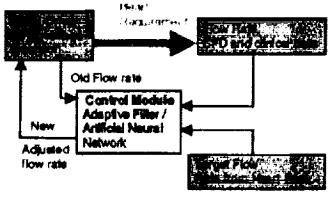
DeBakey VAD Development Timeline

- Human Implantation - November 1998

Future Work : VAD Simulation and Control

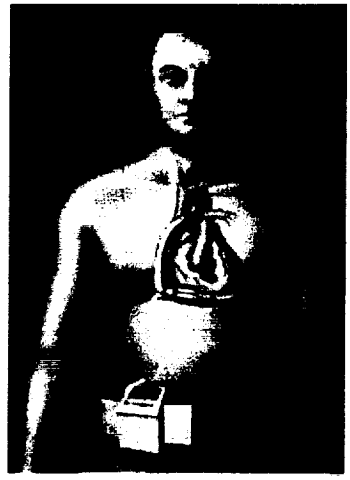
- Ultimate Goal

  To make the VAD an alternative to heart transplant



- Long-Term Impact Study

  Unsteady simulation of the entire circulatory 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."

NASA/DeBakey Ventricular Assist Device

April 1999 - Inducted into "Space Technology Hall of Fame"

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.