High-Pressure Turbulent Flame Speeds and Chemical Kinetics of Syngas Blends With and Without Impurities

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Project Overview

Project Began in October, 2013

Project Highlights:

1. Duration: **Oct. 1, 2013 – Sept. 30, 2017**
2. DOE NETL Award **DE-FE0011778**
3. Budget: $498,382 DOE + $124,595 Cost Share
4. Principal Investigator: Dr. Eric L. Petersen

Project Overview

This Project Addresses Several Problems for HHC Fuels

1. Improve **NOx kinetics** for High-Hydrogen Fuels at Engine Conditions

2. Effect of **Contaminant Species** on Ignition and Flame Speed

3. Impact of **Diluents** on Ignition Kinetics and Flame Speeds

4. Data on **Turbulent Flame Speeds** at Engine Pressures

Project Overview

There are Five Main Work Tasks for the Project

Work Tasks:

Task 1 – Project Management and Program Planning

Task 2 – Turbulent Flame Speed Measurements at Atmospheric Pressure

Task 3 – Experiments and Kinetics of Syngas Blends with Impurities

Task 4 – Design and Construction of a High-Pressure Turbulent Flame Speed Facility

Task 5 – High-Pressure Turbulent Flame Speed Measurements

Project Publications

5 Journal Publications from Project to Date

Journal Publications

1) O. Mathieu, C. Mulvihill, and E. L. Petersen, "Shock-Tube Water Time-Histories and Ignition Delay Time Measurements for H_2S Near Atmospheric Pressure," *Proceedings of the Combustion Institute*, in press.

2) N. Donohoe, K. A. Heufer, C. J. Aul, E. L. Petersen, G. Bourque, R. Gordon, and H. J. Curran, "Influence of Steam Dilution on the Ignition of Hydrogen, Syngas and Natural Gas Blends at Elevated Pressures," *Combustion and Flame*, Vol. 162, 2015, pp. 1126-1135.

3) O. Mathieu and E. L. Petersen, "Experimental and Modeling Study on the High-Temperature Oxidation of Ammonia and Related NOx Chemistry," *Combustion and Flame*, Vol. 162, 2015, pp. 554-570.

4) S. Ravi, T. G. Sikes, A. Morones, C. L. Keesee, and E. L. Petersen, "Comparative Study on the Laminar Flame Speed Enhancement of Methane with Ethane and Ethylene Addition," *Proceedings of the Combustion Institute*, Vol. 35, Issue 1, 2015, pp. 679-686.

5) O. Mathieu, J. W. Hargis, A. Camou, C. Mulvihill, and E. L. Petersen, "Ignition Delay Time Measurements Behind Reflected Shock Waves for a Representative Coal-Derived Syngas With and Without NH_3 and H_2S Impurities," *Proceedings of the Combustion Institute*, Vol. 35, Issue 3, 2015, pp. 3143-3150.

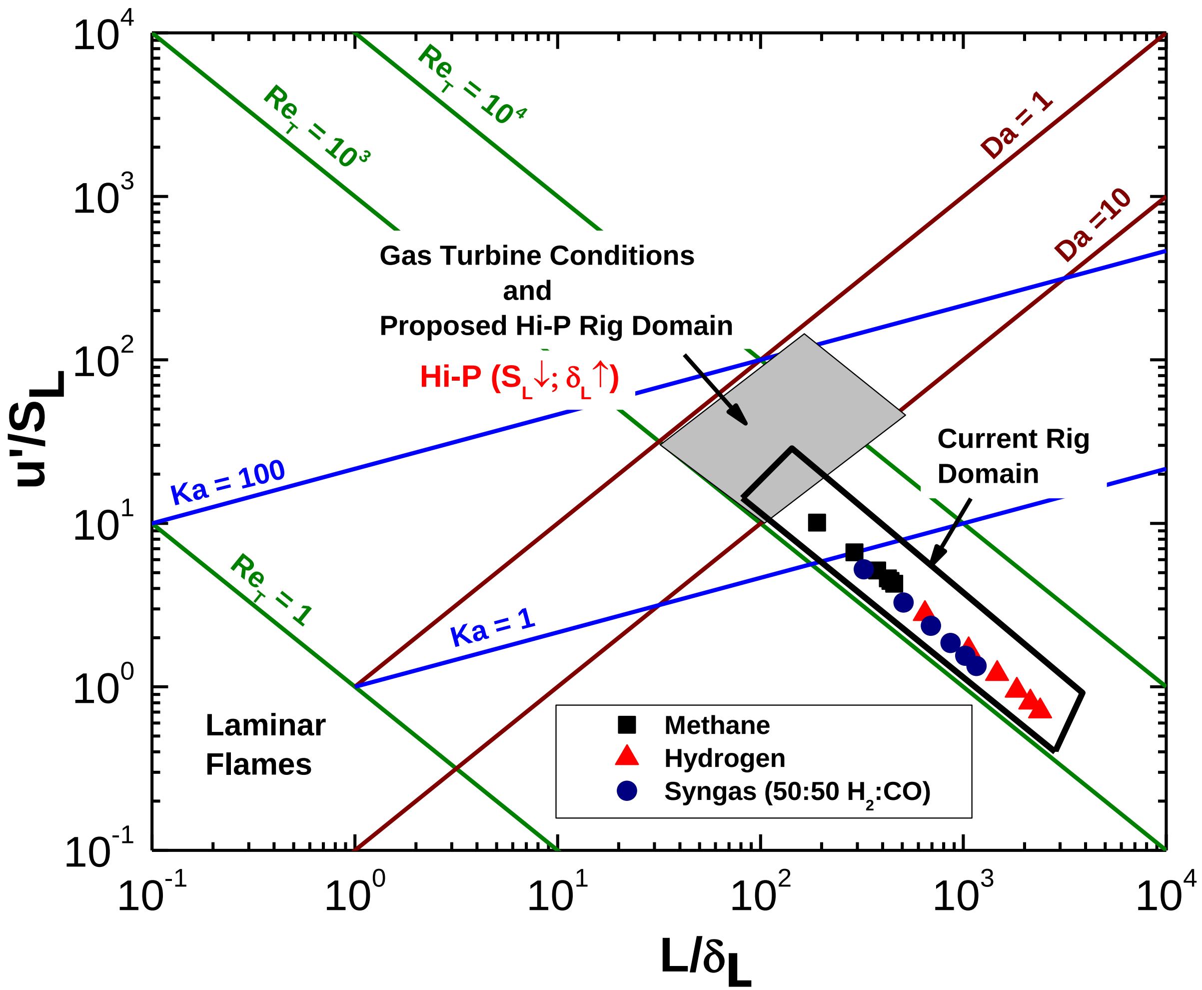
Conference Publications

7 Conference Papers to Date

Task 4 – Design and Construction of a Turbulent Flame Speed Facility

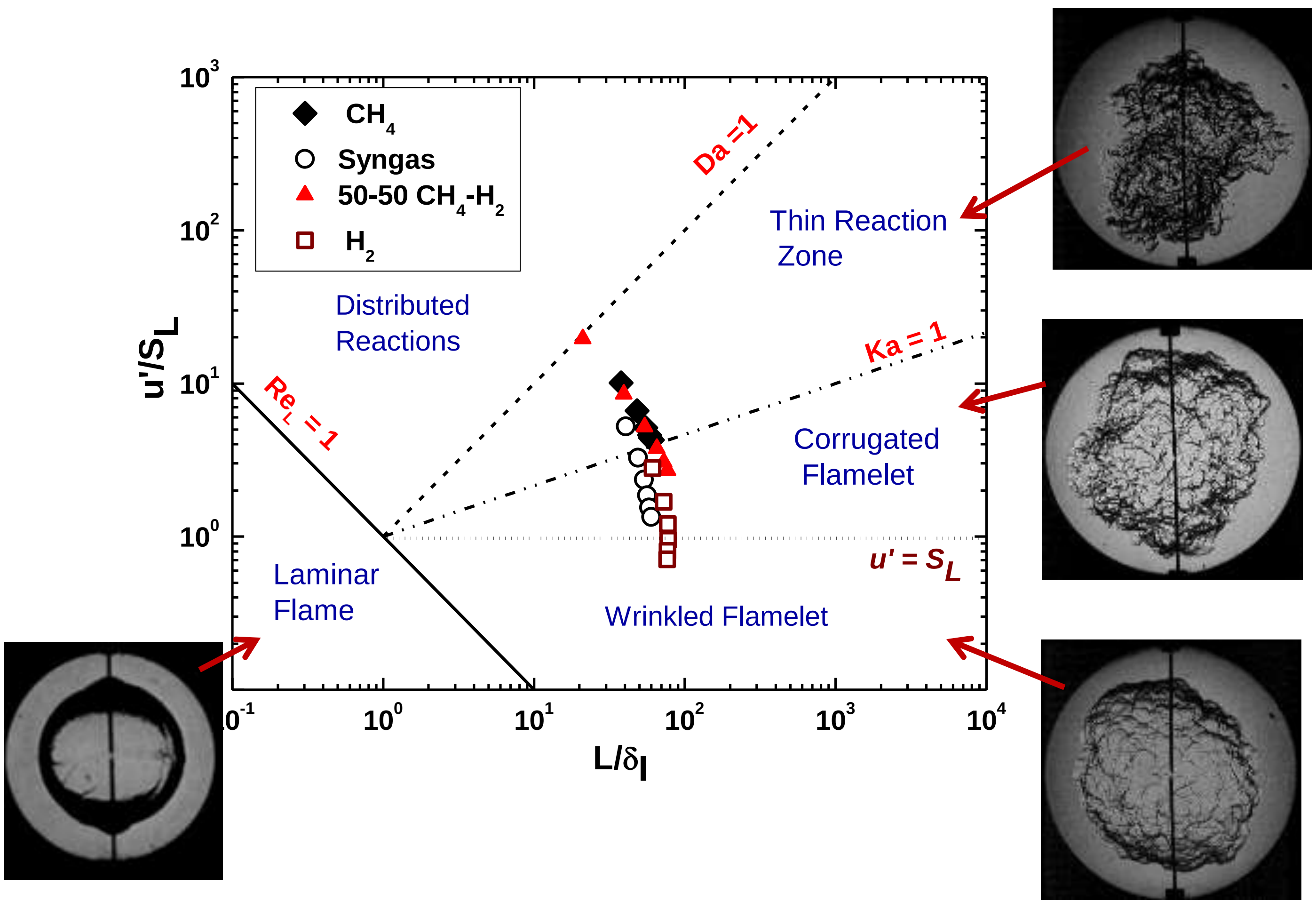
Task 4 – New Facility

Borghi Diagram shows Current and Desired Regions for Turbulent Flame Speeds



Task 2 – Turbulent Speeds

Recent Data Cover a Wide Range of Flamelet Regions



Task 4 – New Facility

New Facility Designed and Built at TAMU

1. Detailed Design and Structural Analysis

2. Fabrication of Vessel Components

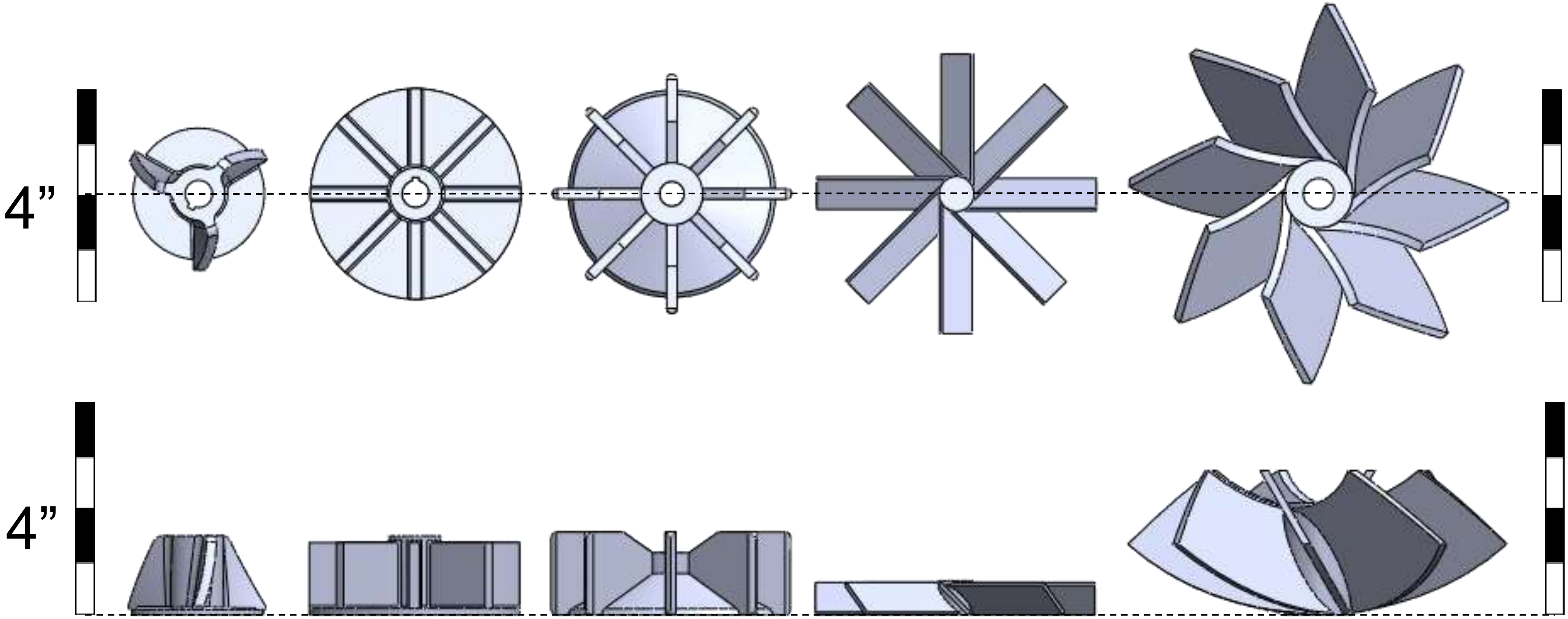
3. Installation of Vessel

4. Characterization of Flow Conditions

Motivation

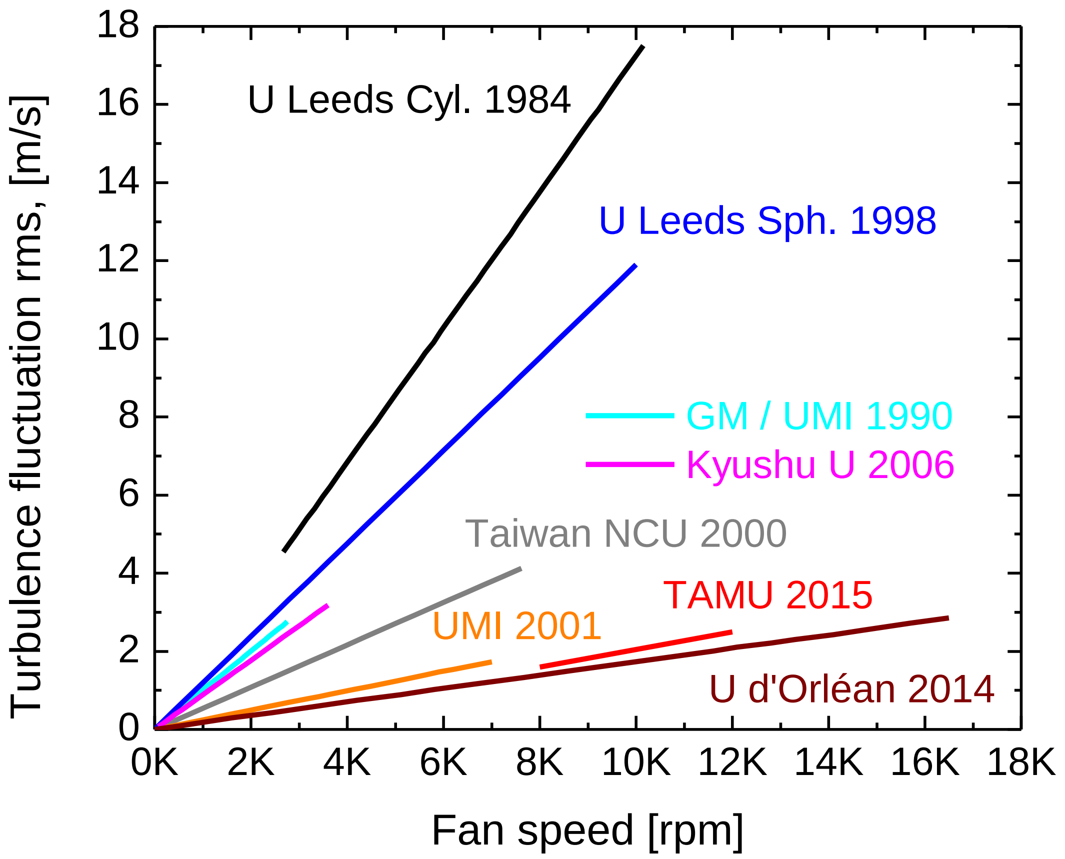
What can we learn from other designs?

- Rich variety of approaches in design of **vessel** and **fans**.
- Marked difference in **effectiveness in turbulence**.
- **Newer** bombs do **not** necessarily perform **better**.



Motivation

Can we replicate the success of The University of Leeds?



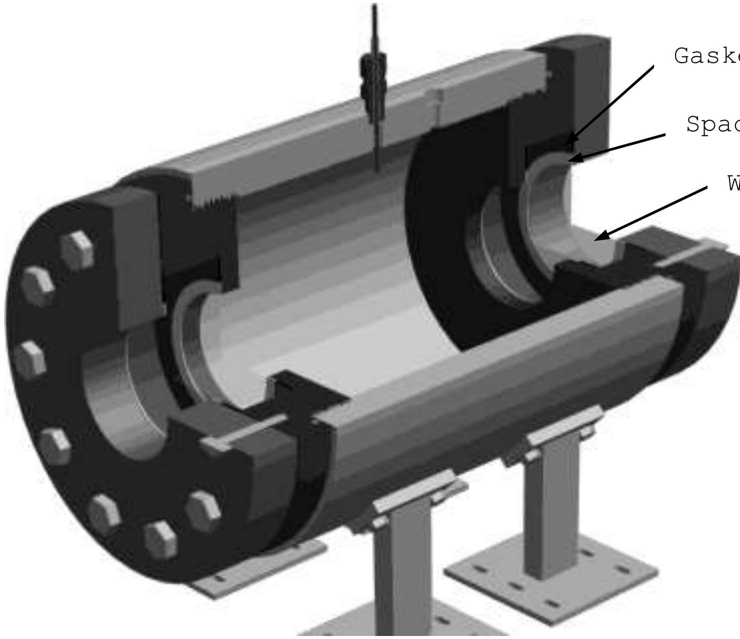
How to get the most intense turbulence with the lowest fan speed?

Objectives

- Complement previous PIV description of the flow field with LDV.
- Try a different impeller geometry.
- Extract guidelines for a new design.

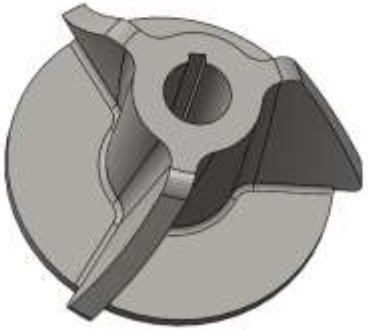
Background

The facility



(De Vries 2009)

- Originally a laminar flame bomb
- Aluminum construction
- Ø 305 mm
- L 356 mm

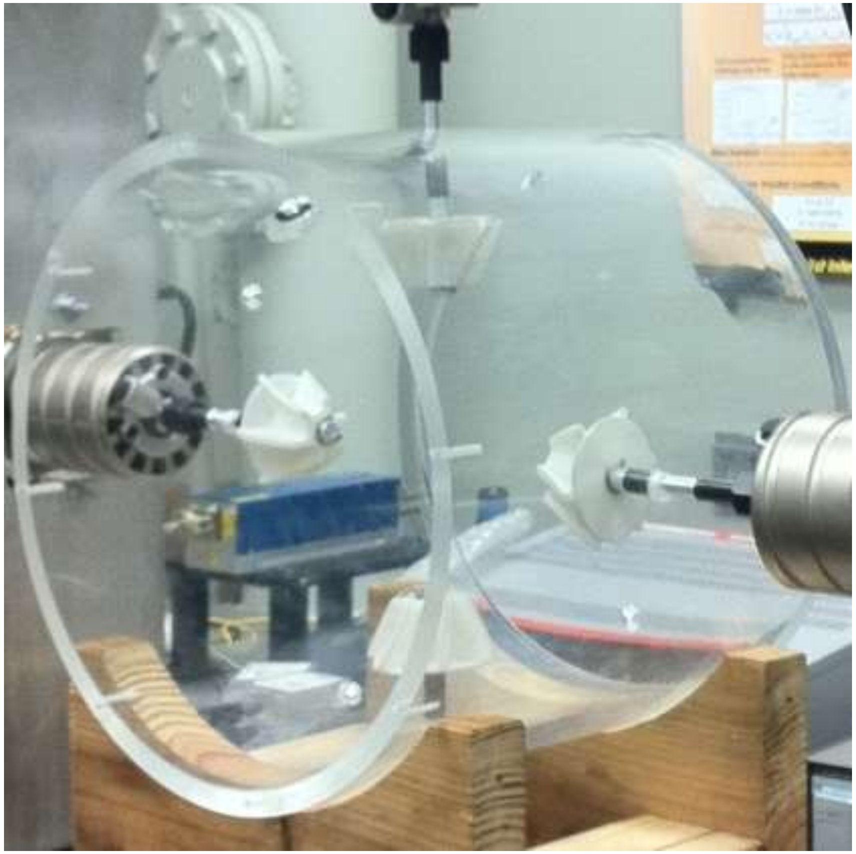


Ø	76mm
L	38mm
Pitch	20°

"Alpha" impeller

Background

PIV measurements



Model scale 1:1

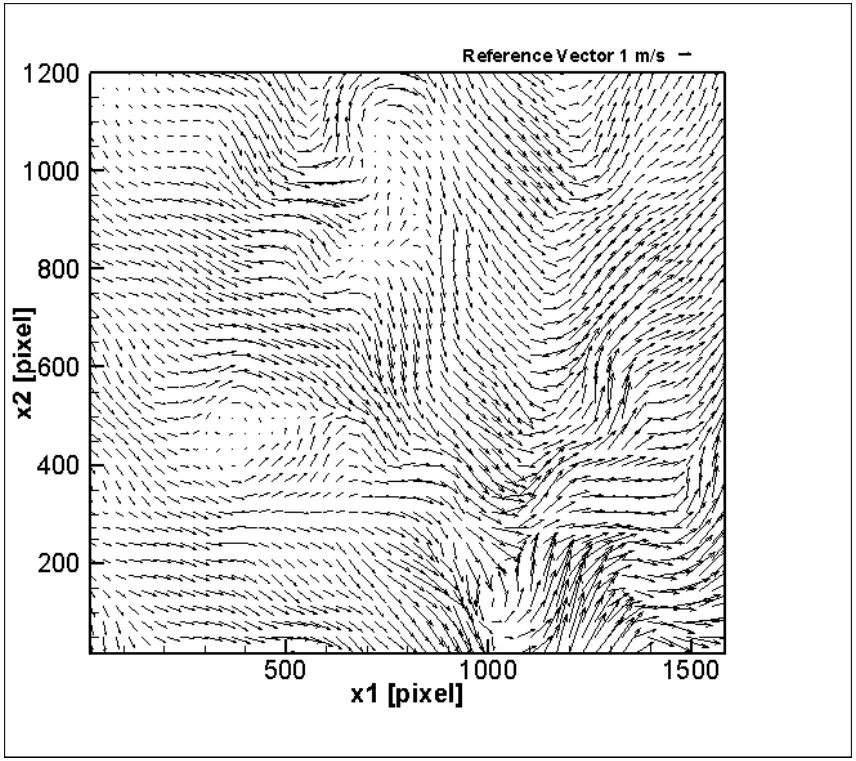
(Ravi, Petersen et al. 2013)

- Fan speed: 8,300 ±100 rpm
- Location: central plane
- FOV: 36 × 26 mm

Background

PIV Results

Instantaneous velocity field ũ



(Ravi, Petersen et al. 2013)

Highlights

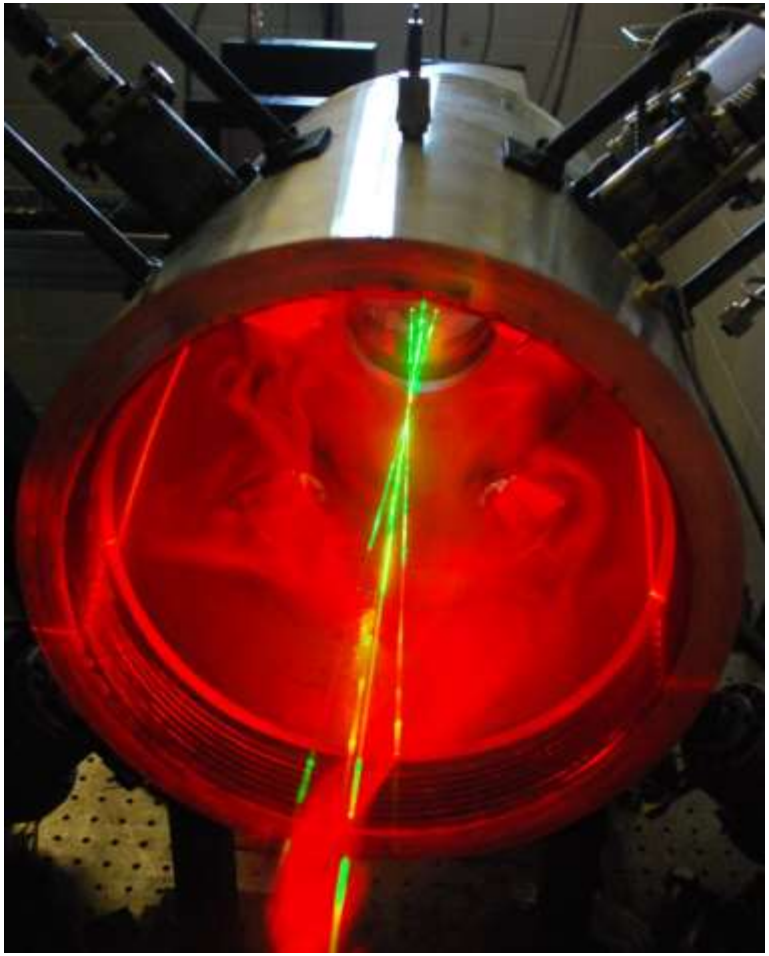
- Nearly HIT flow field
- Vortex pattern
- L_T 54 mm
- τ_ε 55 ms
- U_x 0.03 $u_{x,rms}$ 1.48 m/s
- U_y -0.01 $u_{y,rms}$ 1.49 m/s

$$\tilde{u}(t,\mathbf{x}) = U(\mathbf{x}) + u(t,\mathbf{x})$$

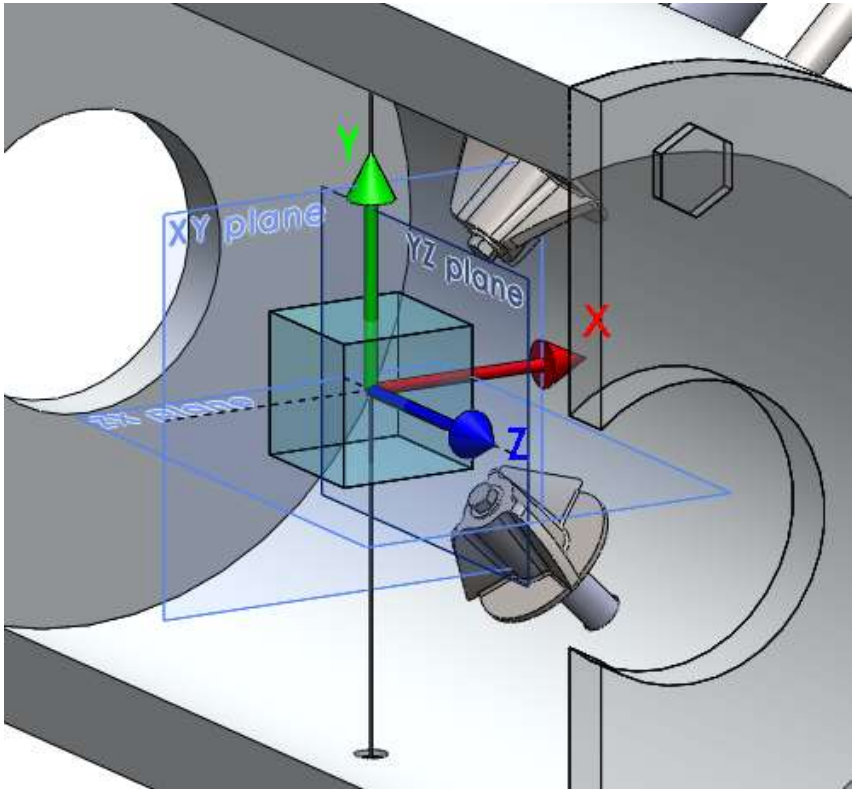
$$U(\mathbf{x}) = \frac{1}{\tau}\int^{\tau} \tilde{u}(t,\mathbf{x})\, dt$$

Experimental setup

2D solid state laser LDV system (TSI)



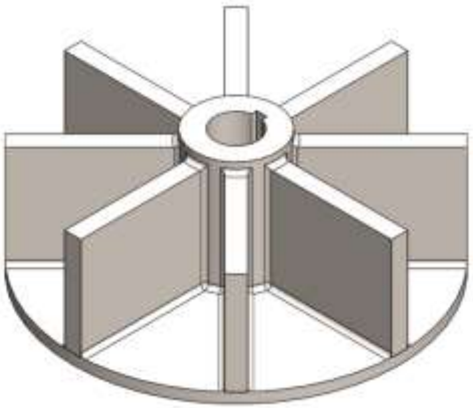
- 60 X 60 X 60 mm test region
- Grid size 10 mm



Experimental setup

Alternative impeller

Impeller "Beta"

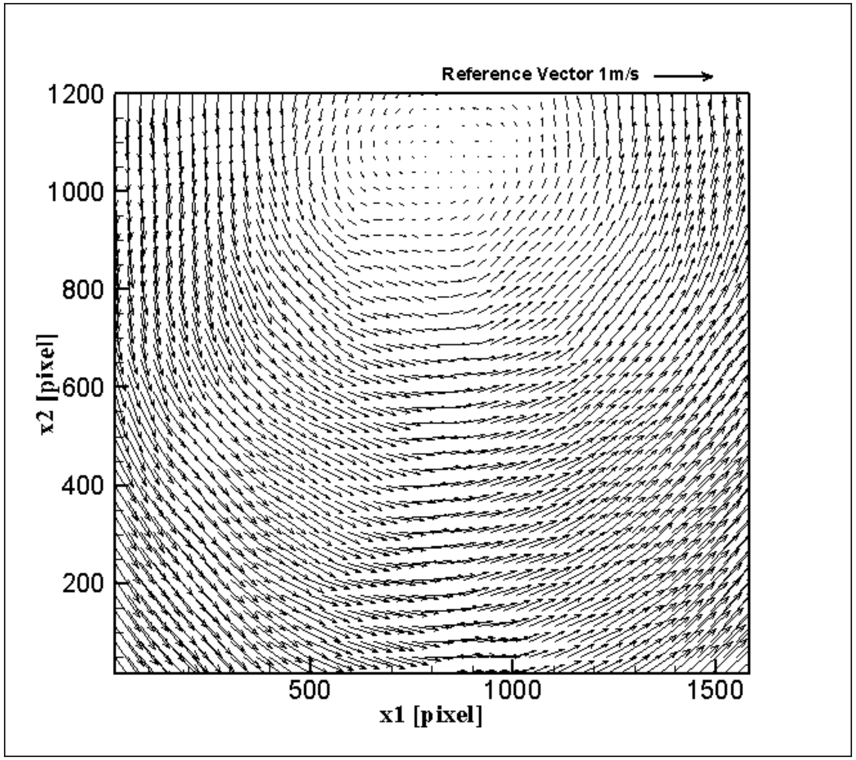


- Radial
- 8 blades
- Ø 102 mm
- L 38 mm

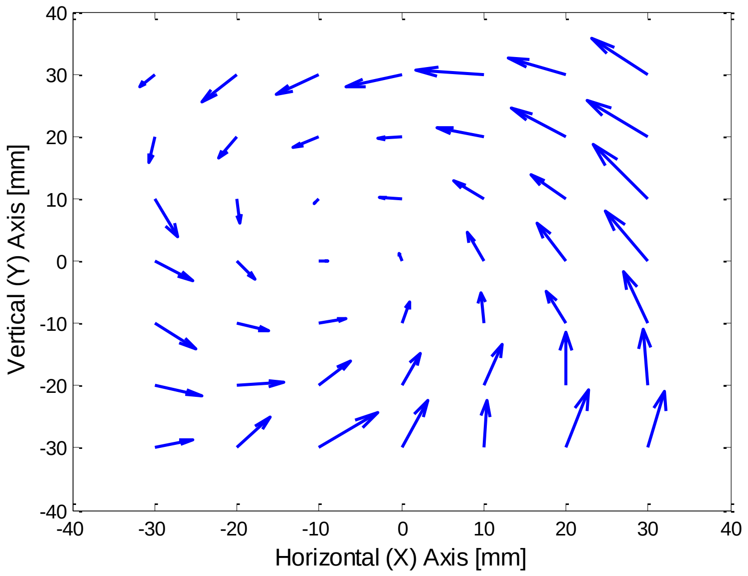
Mean velocity field at central plane

Flow pattern ratified

Alpha, PIV



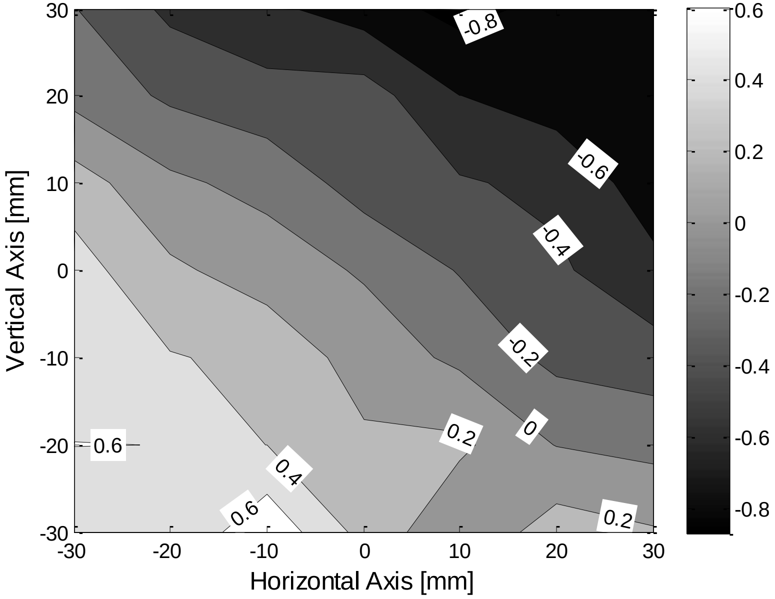
Alpha, LDV



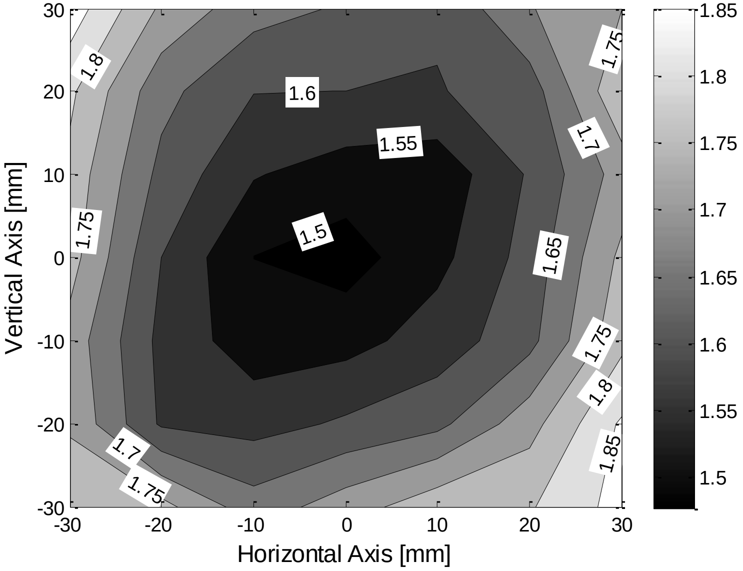
Impeller Alpha

Fairly homogenous and isotropic turbulence fluctuation

Mean velocity, U_x



Turbulence fluctuation, u_x

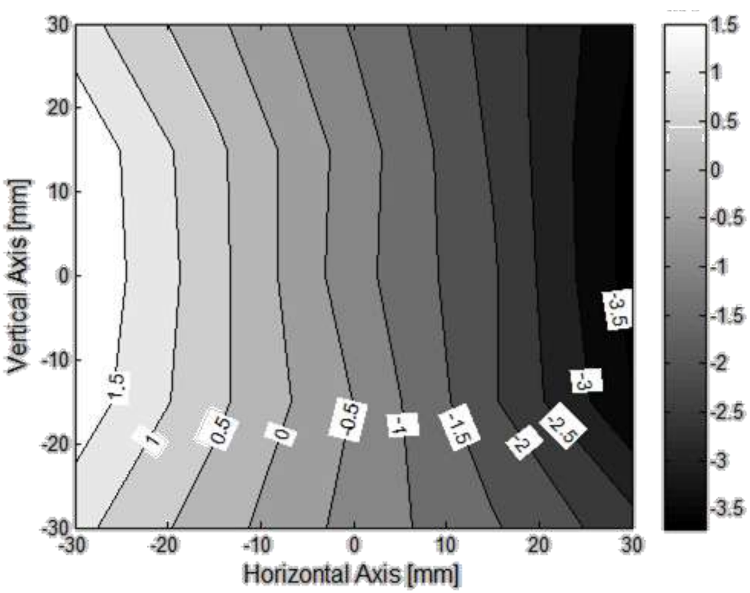


- U_x -0.07 $u_{x,rms}$ 1.60 m/s
- U_y -0.21 $u_{y,rms}$ 1.63 m/s

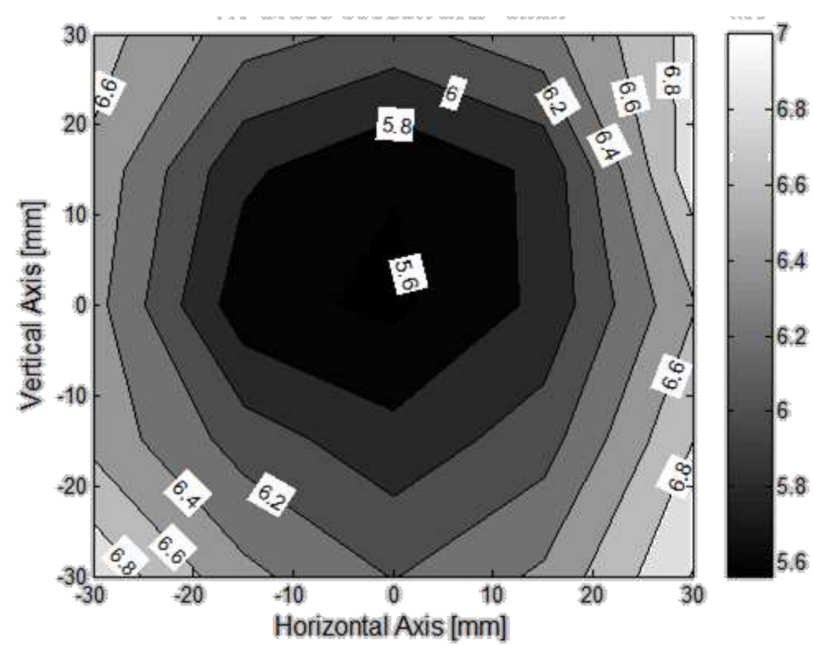
Impeller Beta

Higher magnitudes everywhere

Mean velocity, U_x



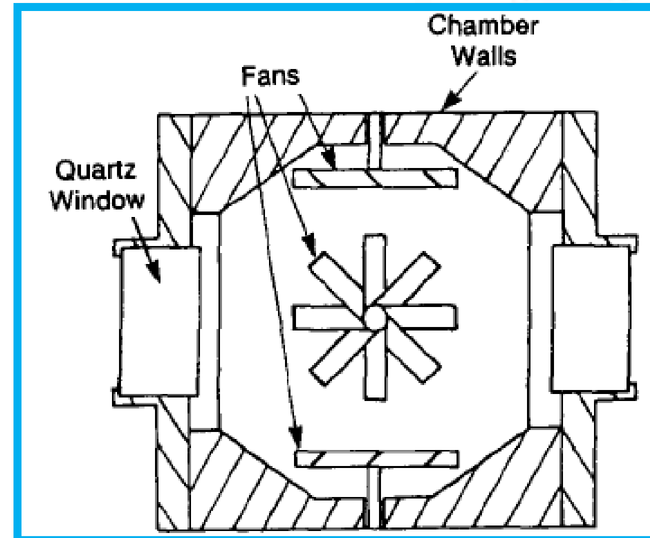
Turbulence fluctuation, u_x

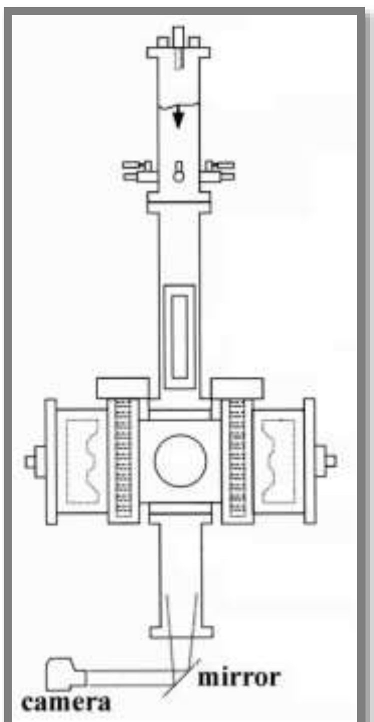


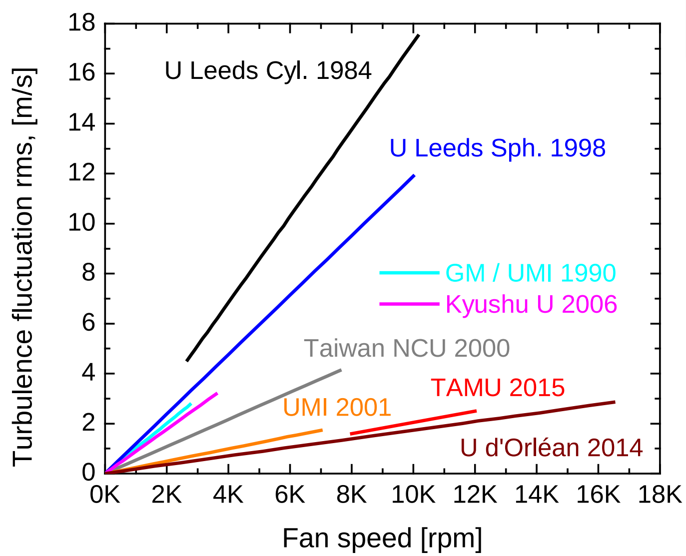
- $U = 1.2$ u_{rms} $= 6.5$ m/s

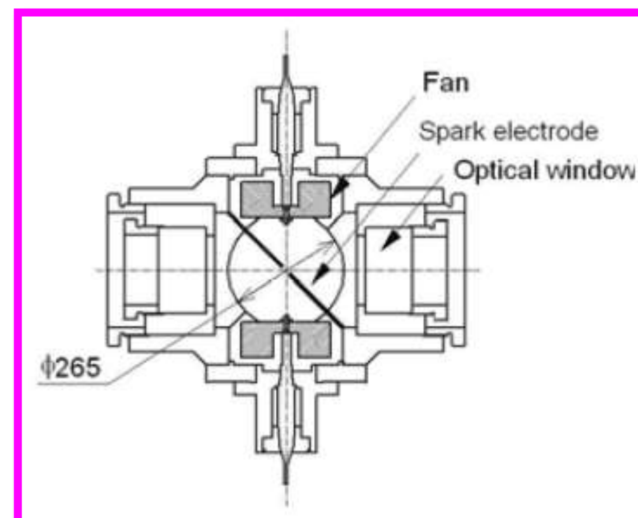
We improved, but can we do better?

Fan-stirred bombs



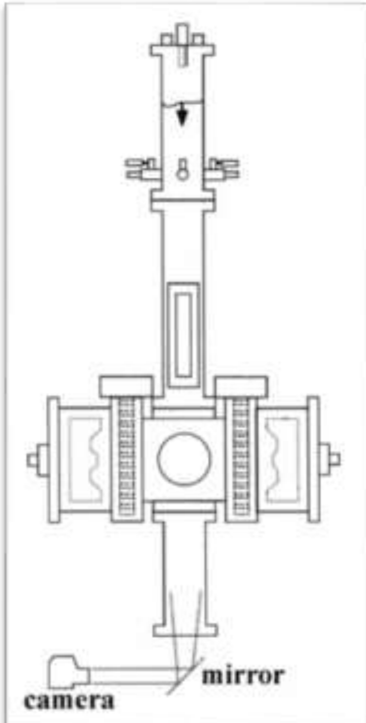




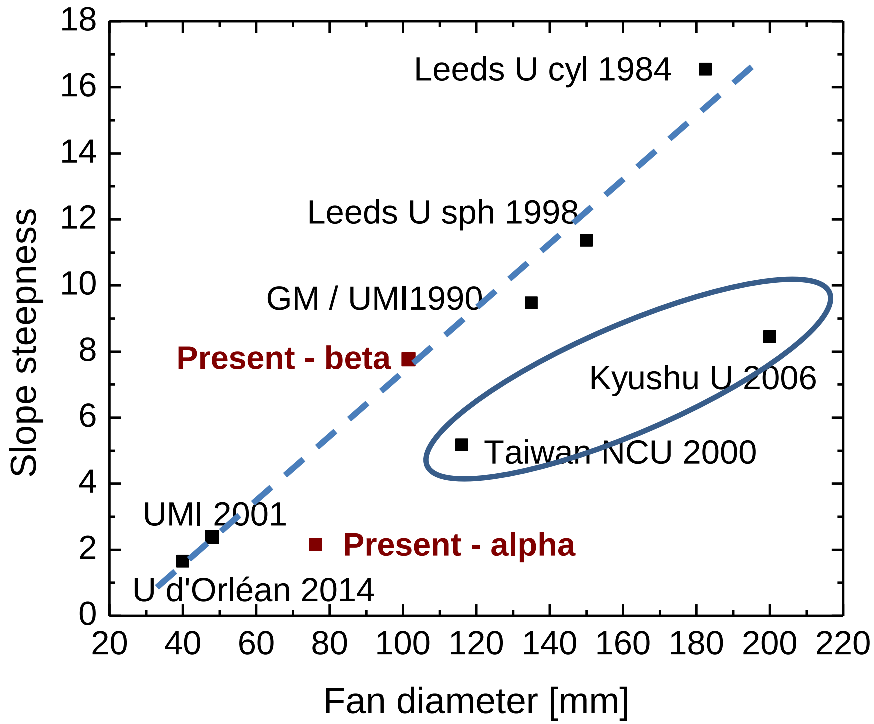


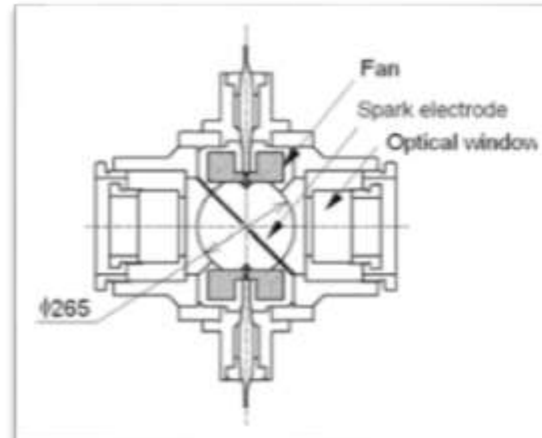
The role of impeller diameter

In general, larger impellers are more effective



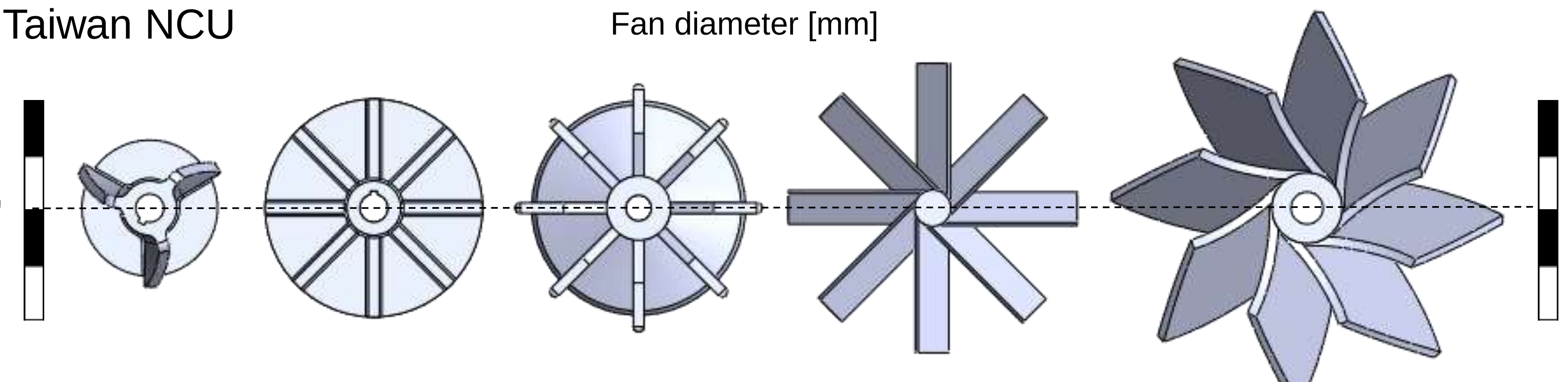
Taiwan NCU





Kyushu U

4”

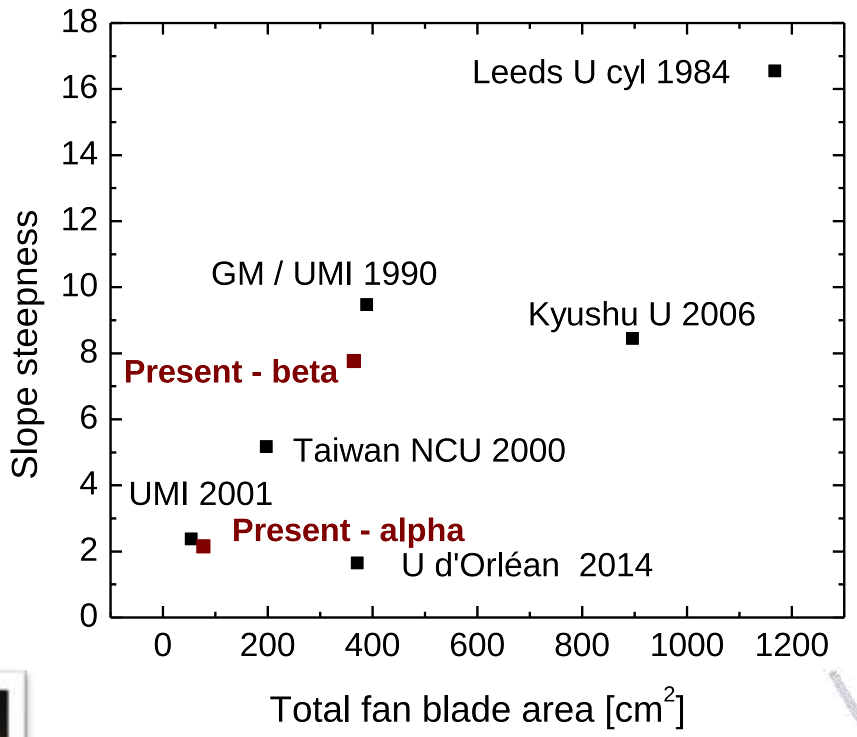


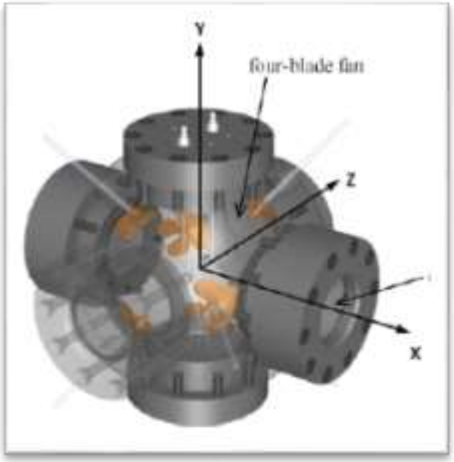
Total fan blade area

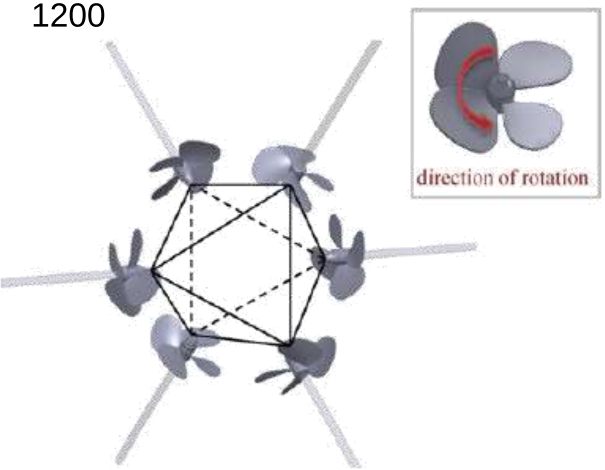
The more, the better

Alpha

Beta







U d'Orleans 2014

Task 4 – New Facility

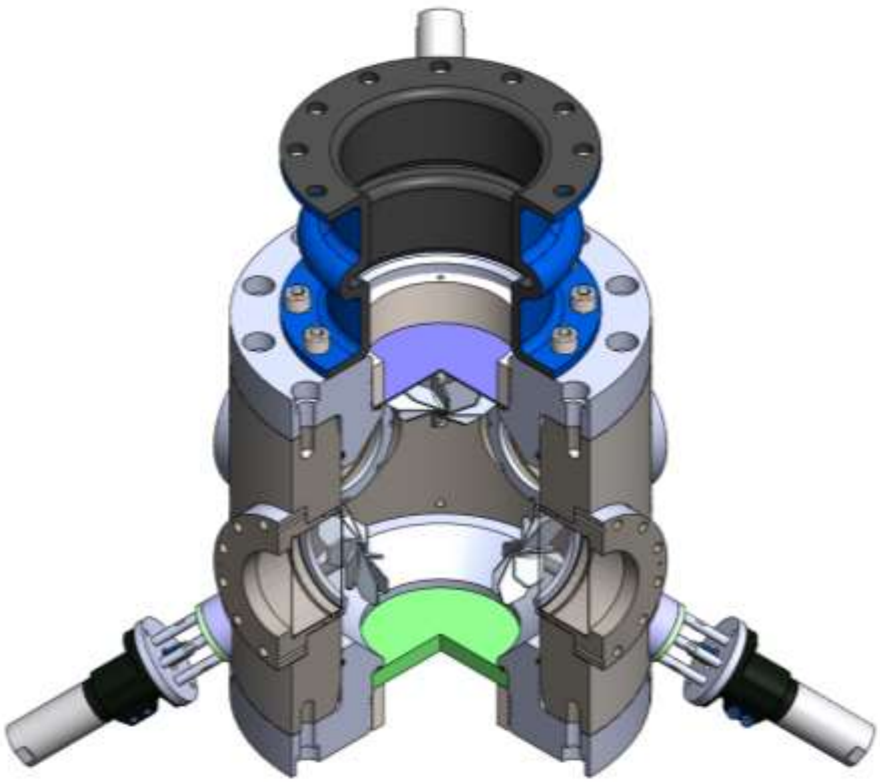
Task 4 Design and Installation is Underway

- Survey of Existing Turbulent Flame Speed Facilities Completed
- Trade-off Study for Final Design Finished
- Critical Aspect is how to Handle or Reduce the Overpressure
- Will Have a Design that Involves a Blowout Disk and Reservoir for Overpressure
- Detail Design is Complete
- Main Fabrication is Complete

Task 4 – New Facility

New Design is Complete

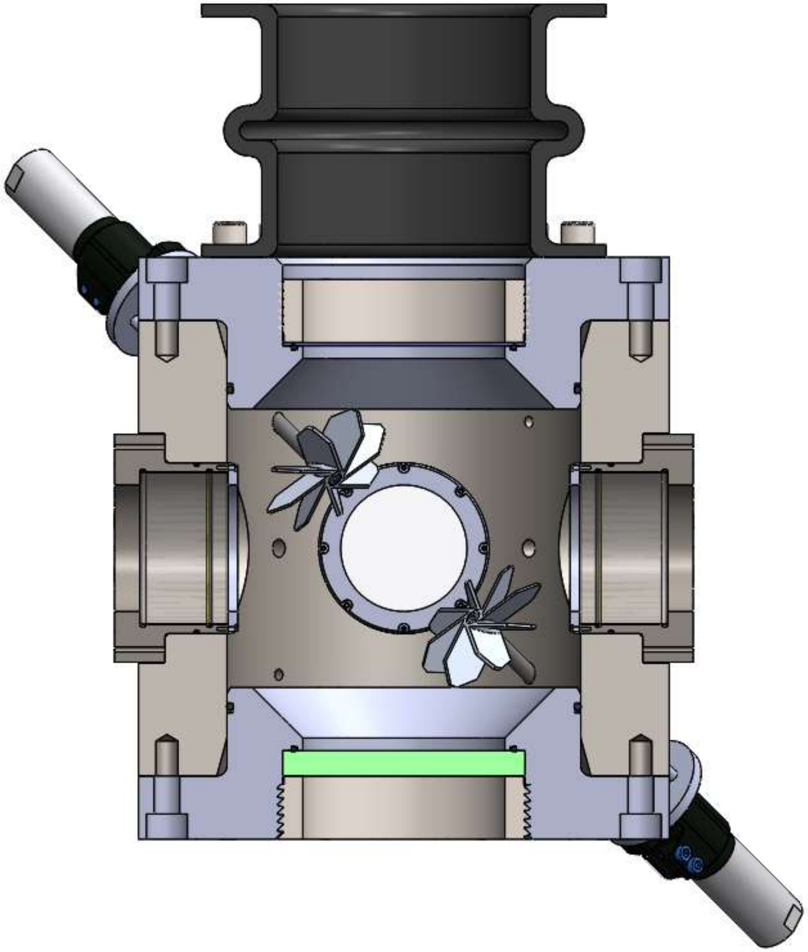
- Built in forged SS
- ID 14”; height 18”
- 4 windows; ∅5” aperture
- 4 stirring fans; ∅5.75”
- Max. allowable pressure: 200 atm



Task 4 – New Facility

Breach and Diaphragm Method Selected for Venting

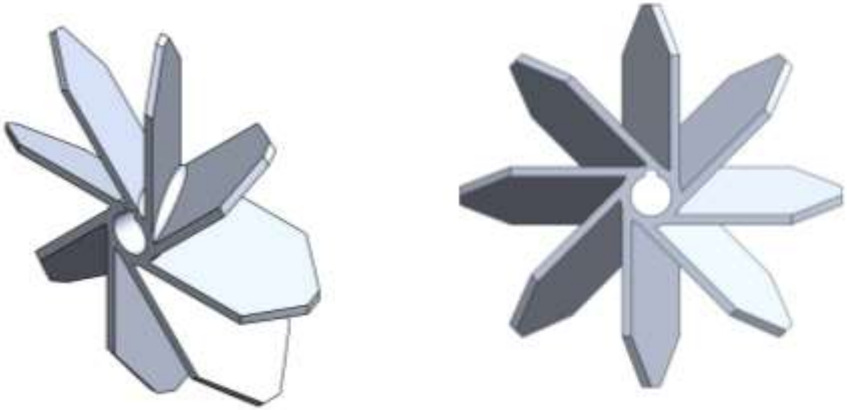
- Breach ∅8”
- Vented deflagration through diaphragm (top)
- Bottom breach is reconfigurable:
  - Heater
  - Injection port
  - Spark plug gland



Task 4 – New Facility

New Fan Design is Being Implemented, Based on LDV Results from Existing Rig

- Arranged in tetrahedral configuration
- Max. speed: 10,000 rpm
- 8-bladed radial impeller with 30° pitch and 1.25″ axial depth.



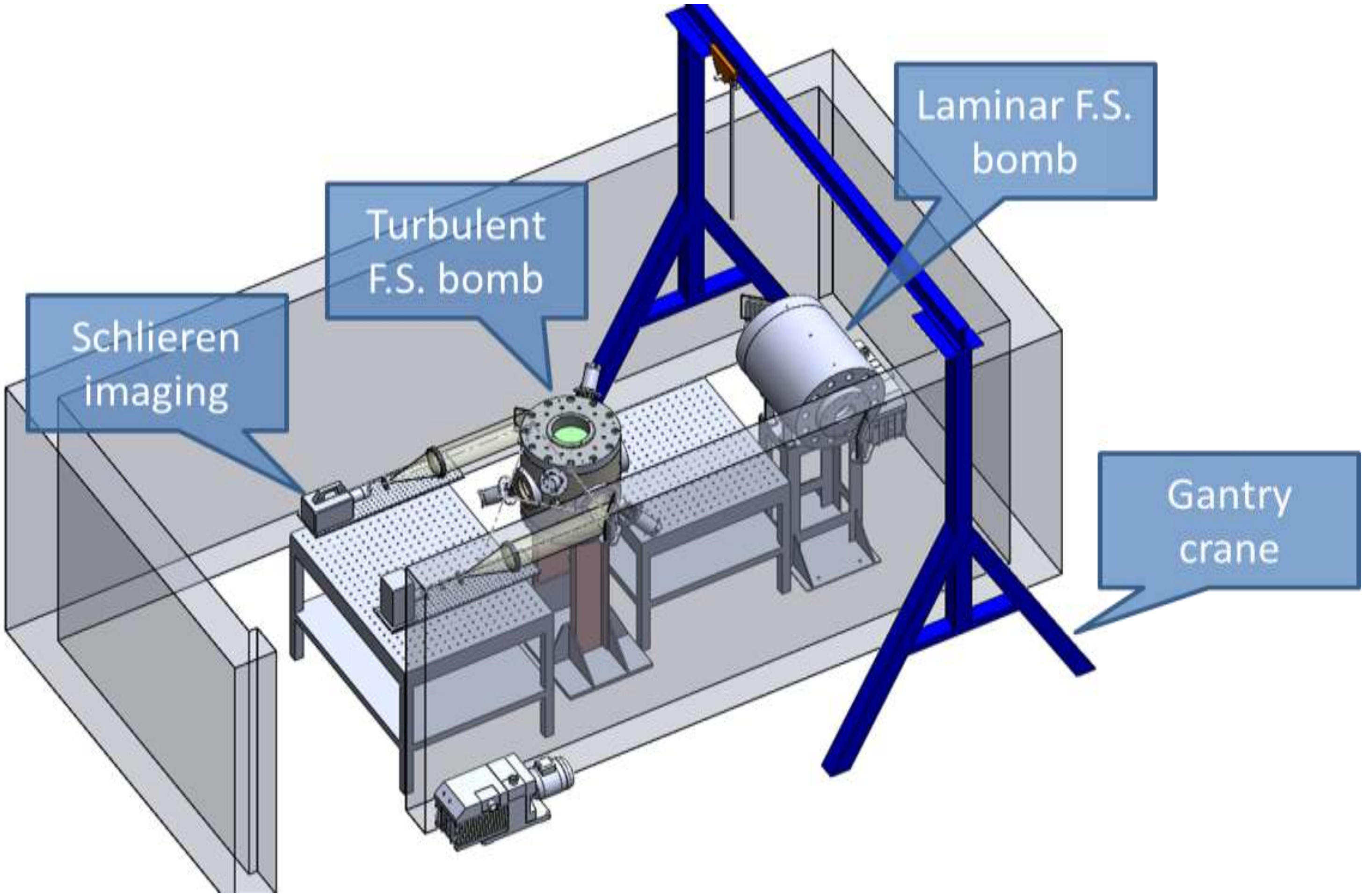
Fabrication of Rig




Fabrication of Rig

Rig Installation

Facility Space Required Modification to Accommodate The New Rig



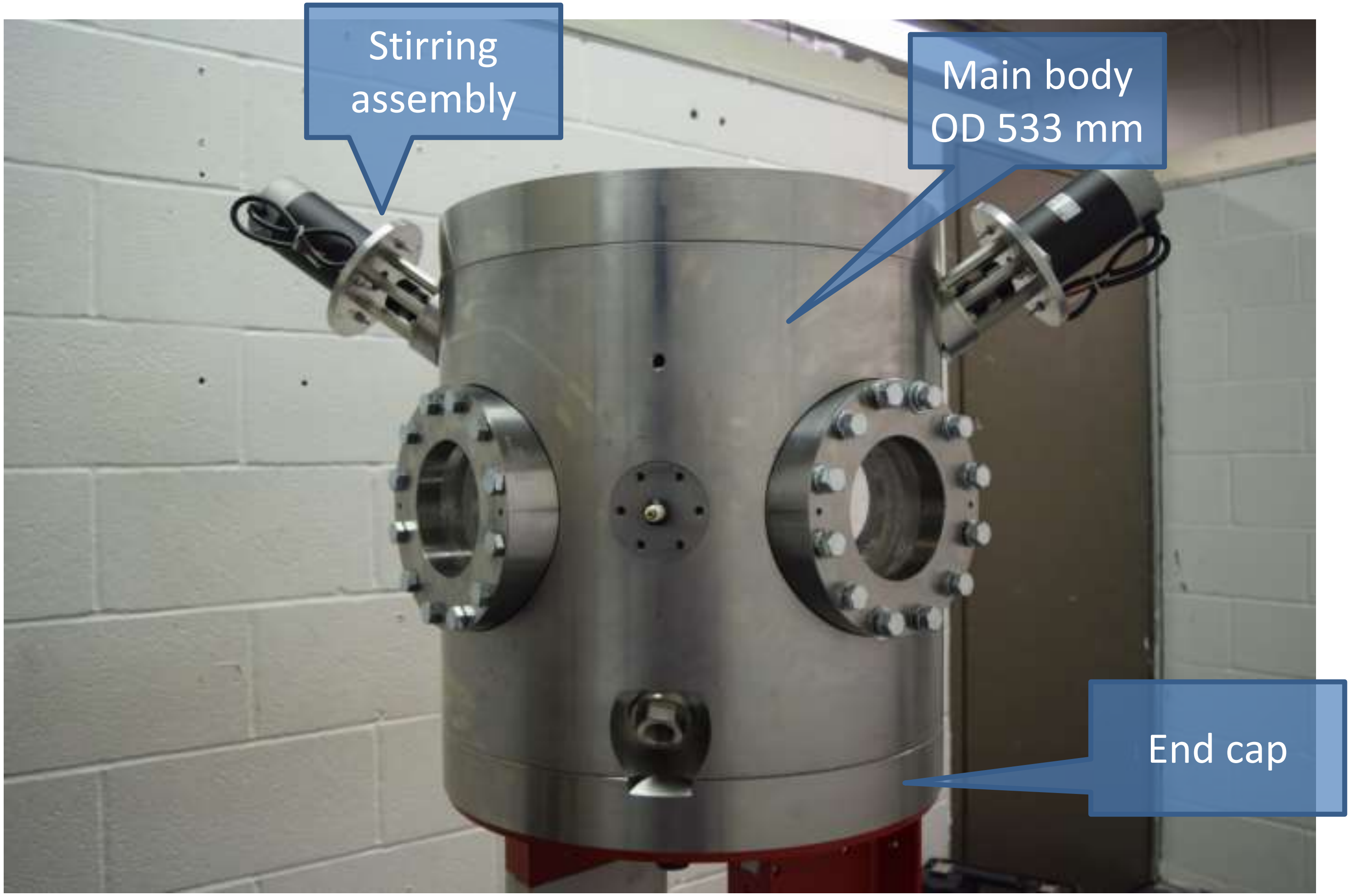
Rig Installation

Initial Assembly and Installation is Complete

Assembly rendering

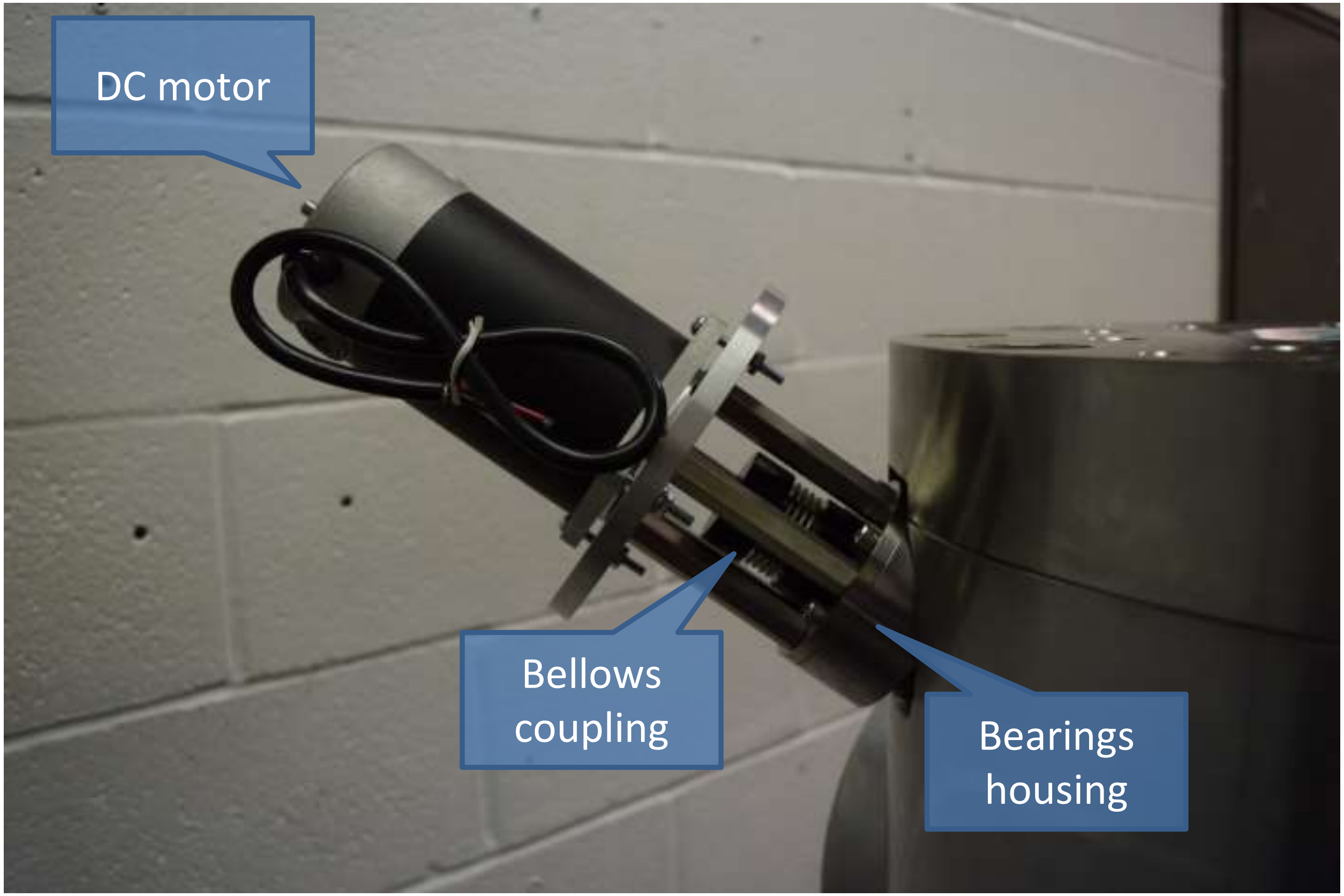
Rig Installation

Front View Showing Motors and Windows



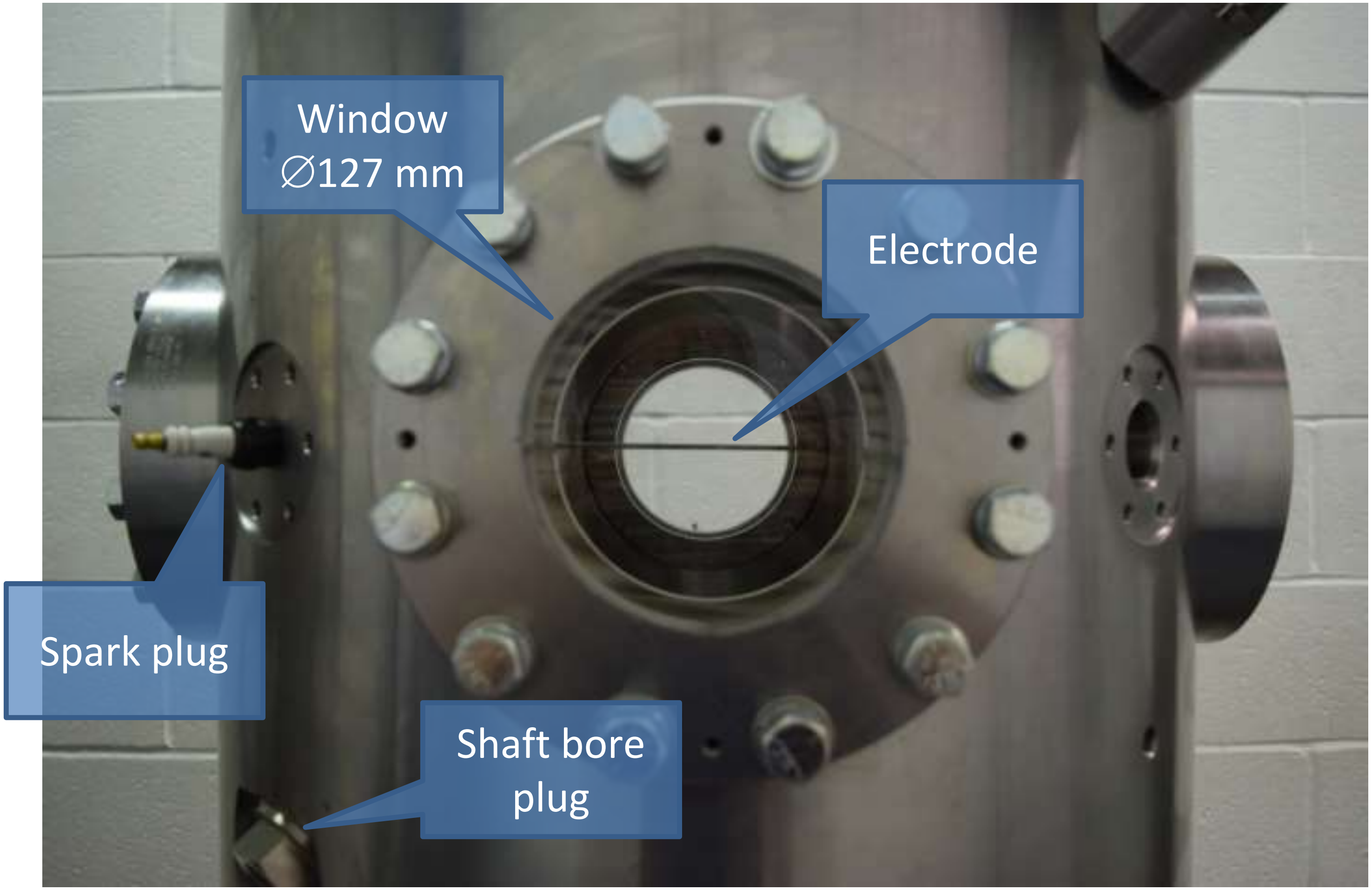
Rig Installation

Detail View of Motor Assembly



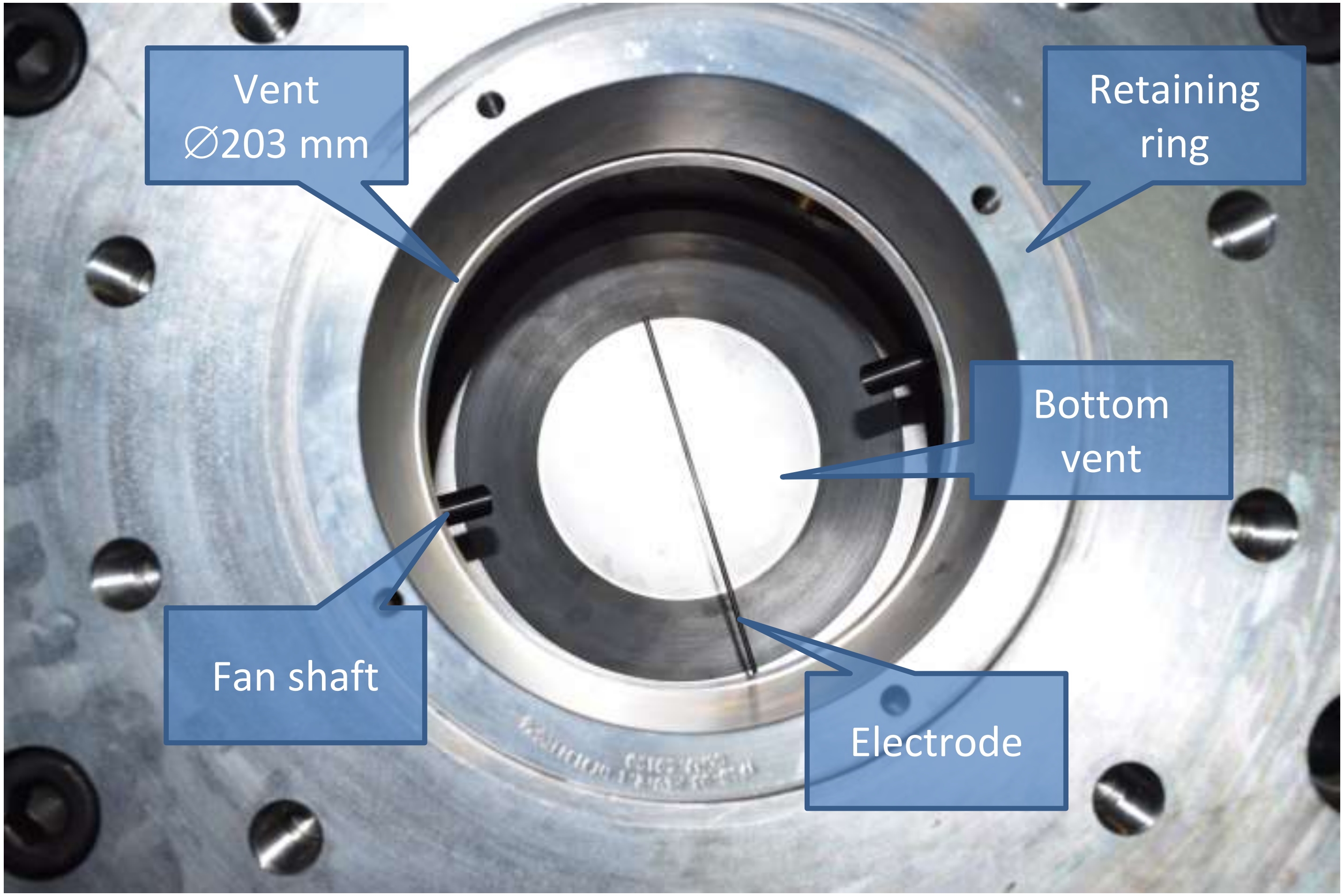
Rig Installation

Detail View of Window and Igniter Assemblies



Rig Installation

View from Top of Rig



Conclusions

- The flow field characterization with LDV agreed with that of PIV and was extended to 3D.
- An alternative impeller design has better performance, (but there is still room for improvement).
- New apparatus has been installed, and characterization has begun.

Task 5 – High-Pressure Turbulent Flame Speed Measurements

Task 5 – High-Pressure Turbulence

High-Pressure Experiments Will be Performed for Selected Syngas Blends

- Identify Two Test Matrices (Fuel Blends) for Study
- Utilize Results from Tasks 2 and 3 for Guidance
- Perform Experiments at Elevated Pressures
- Parallel High-Pressure Laminar Tests Should also be Done

Project Personnel

TAMU Work is a Team Effort of Several People

Dr. Olivier Mathieu

Charles Keesee

Anibal Morones

Clayton Mulvihill

Summary

Progress on the Five Main Work Tasks for the Project Was Presented

Task 1 – Project Management and Program Planning

Task 2 – Turbulent Flame Speed Measurements at Atmospheric Pressure

Task 3 – Experiments and Kinetics of Syngas Blends with Impurities

Task 4 – Design and Construction of a High-Pressure Turbulent Flame Speed Facility

Task 5 – High-Pressure Turbulent Flame Speed Measurements

TEXAS A&M UNIVERSITY

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