Tribute to Professor Kunio Kuwahara and Study of Multiphase Flow in a Flat Plate Inducer

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Outline

- **Remarks in honor of Professor Kunio Kuwahara**
- **Simulation of Flow in a Flat-Plate Inducer of a Centrifugal Pump**
- **Closure**

Acknowledgements

- Colleagues
- Funding Agencies
- Students
- Ohio Supercomputer Center

Tribute to Professor Kuwahara

- It has been nearly 25 years since the time I can remember meeting Professor Kuwahara, and here I will reminisce on my association and friendship that grew with the various CFD Nobeyama workshops that he conceived, organized, and ran so efficiently.
- These workshops provided a forum for researchers from all over the world to exchange ideas and methodologies unique to supercomputing of multidisciplinary flows in innovative environments.
- Participation in these workshops was by invitation only, and Professor Kuwahara was able to get some of the leading researchers from around the world to participate in these workshops.
- We have had many interactions during these years, and I will share some that reveal his true personality.

Tribute to Professor Kuwahara (cont'd)

- **Professor Kuwahara and some of us worked on model problems to assess new CFD methodologies.**
- **In particular, our 2-D cavity flow calculations had made a deep impression on him as regards the accuracy of the calculations.**
- **Recognizing that cavity flow does not remain 2D, he had long before carried out full 3D calculations for this flow problem.**
- **He not only strived for accuracy, but he was also keen on seeing that many of these CFD calculations can be done efficiently.**

Tribute to Professor Kuwahara (cont'd)

- On one hand, he was fascinated by supercomputers, to the extent that he gave up his personal fortune to have supercomputers in his estate.
- On the other hand, his love for his notebook never diminished. This allowed him to share his joy with us whenever we met.
- This trait of Professor Kuwahara showed his true passion for CFD research, and that remained with him long after the supercomputers were gone from his estate.
- With an abundance of computational power available to Professor Kuwahara, he made history by providing solutions that were carried out using enormously large number of grid points that can resolve majority of the scales.

Tribute to Professor Kuwahara (cont'd)

- Most of these calculations were done as coarse-grid DNS calculations or as implicit large-eddy simulation (ILES) calculations.
- Often, his results for a specific problem were close to the experiments compared those with any other technique. Some of these contributions to CFD truly deserve recognition.
- There are two other problems on which he contributed a lot. Professor Kuwahara had truly two favorite problems, I will come to them a little later. These problems allowed him to show his creative genius through visualization.
- He loved computer graphics, and used to his fullest advantage to bring clarity to the prevailing physical phenomena.
- He may have had a passion for supercomputers, but at heart he always sought the physics in the flow problems.

Tribute to Professor Kuwahara (cont'd)

- **In 1991, prior to the Fourth Nobeyama workshop, my family and I had spent a month at ICFD.**
- **We became much closer to Professor Kuwahara during this time.**
- **We really got to see Professor Kuwahara's passion to train young Japanese researchers in the art and science of CFD.**
- **He took pride in this noble cause, and today, in many universities and research organizations throughout Japan, there are veteran researchers who have had Professor Kuwahara's mentorship.**

Tribute to Professor Kuwahara (cont'd)

- **We were fortunate that Professor Kuwahara participated in majority of the AIAA and APS meetings. We sought him out at these occasions, and always had lunch or dinner together to catch up on some of his new work beyond what we had seen last.**

- **These social occasions kept us close to him, and through him, to some of our Japanese colleagues in the audience.**

- **He was always very kind to my children, and always took care of them.**

Tribute to Professor Kuwahara (cont'd)

- **We have attended every single Nobeyama workshop except for this one.**
- **We apologize for not being there this time, but with the school in session, we regret that the situation was not favorable to for us to travel to attend the current workshop.**
- **Our final goodbye to a great versatile scientist, a humanitarian and a true friend in Professor Kuwahara.**
- **Our apology to the participants for taking away so much time from the technical presentation.**

Tribute to Professor Kuwahara (cont'd)

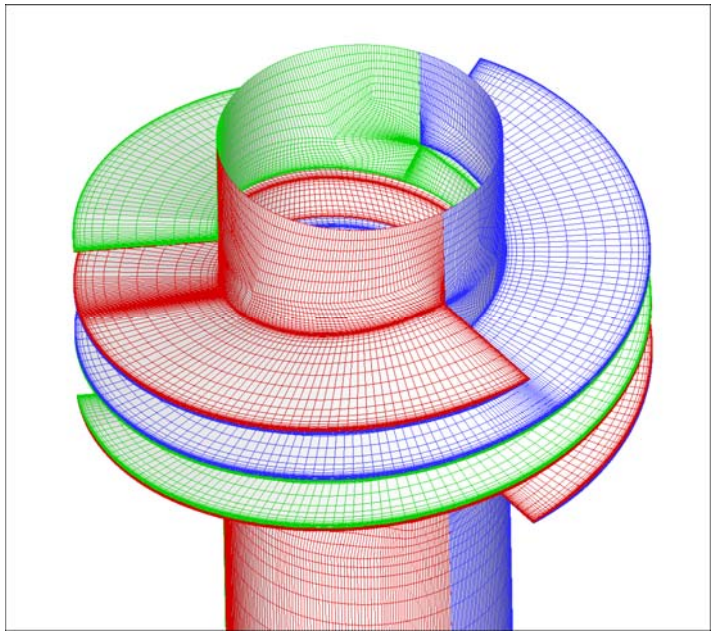
- Two problems that Professor Kuwahara was very fond of are
  - Flow past a circular cylinder, and
  - Flow past a NACA0012 airfoil.
- I wanted to share some of his results for these problems, but currently I do not have time to put his results together here.
- I would mention, that he was able to get results for very high-Re flows, for both of these problems, using coarse-grid DNS simulation or implicit large-eddy simulations. For both of these problems, we have made attempts, but the algorithms we have developed are not able to provide results for the high-Re cases that Professor Kuwahara was able to get.

Technical Presentation:

Multiphase Flow inside the Inducer of a Centrifugal Pump

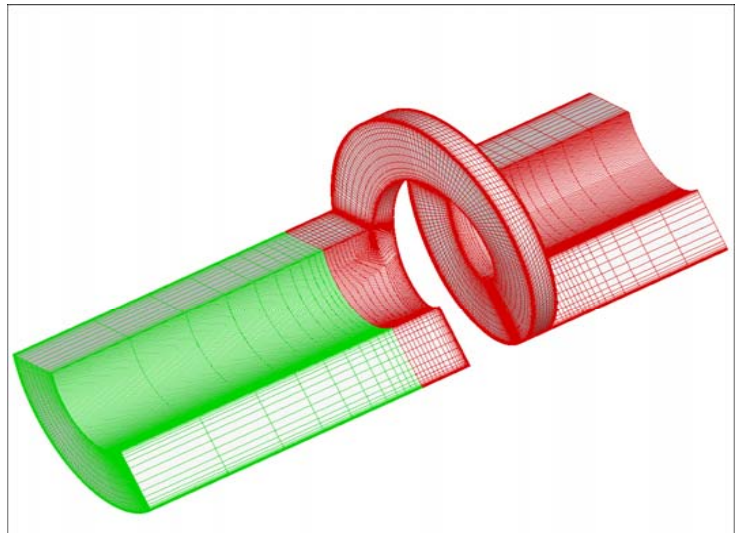
- I will present some of the new results of one of my doctoral students, Zhisong Li, who is embarking on his doctoral research beginning this month.
- This past summer, he worked on the multiphase flow inside the inducer of a centrifugal pump. I will present some preliminary results for this flow problem.
- In the spirit of Professor Kuwahara, I will also be able to share some flow visualizations with you.

3-Bladed Inducer Geometry and Grid

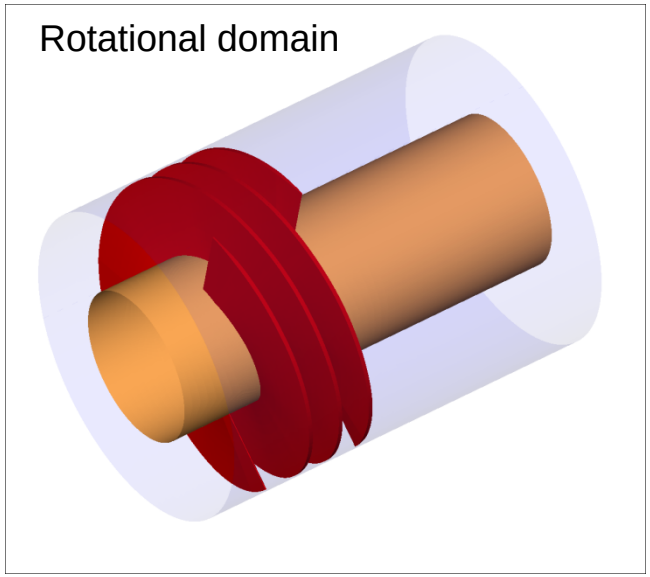


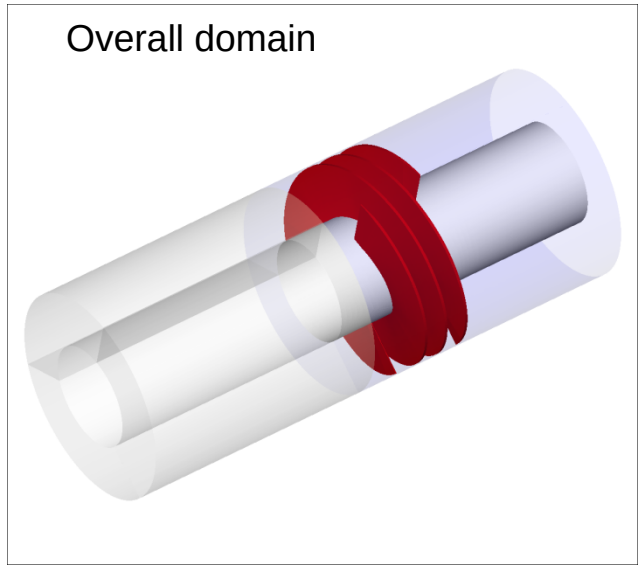
- The full computational mesh is generated by Gridgen software and has approximately 499,000 active cells in 9 blocks.
- Maintained low grid skewness and prevented high mesh nonorthogonality

- The structured mesh is composed of upstream and downstream grids added to a multi-block H grid through the blade passage.
- Rotational periodic connections are defined on the side boundaries with a point-to-point matching.



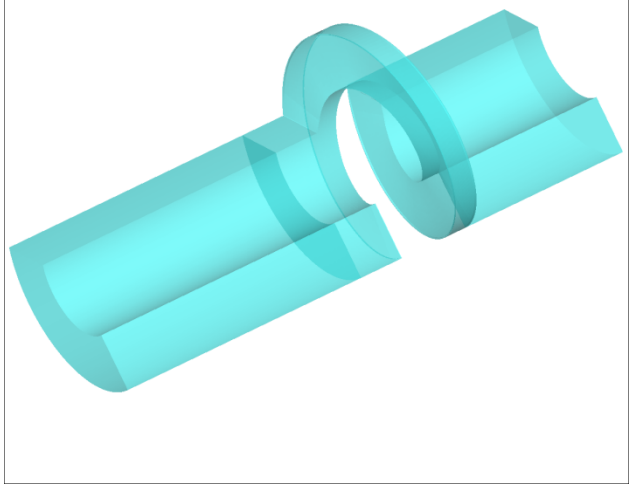
Computation Domain for Flat Plate Helical Inducer Geometry and Parameters





Rotor tip diameter: 4.986 in
Rotor hub diameter: 2.478 in
No. of blades: 3
Tip blade angle (from axial): 84^{o}
Radial clearance: 0.025 in
Peripheral extent of each blade: 360^{o}
Tip thickness: 0.067 in
Hub thickness: 0.1 in
Tip solidity: 3.016
Hub solidity: 3.066
Axial length: 1.637 in
Flow coefficient: 0.072
Rotational speed: 14140 rpm

Single passage in computational domain



The domain consists of a region extending more than about 1.5 diameters upstream of the blade, and a region about 1.0 diameter downstream.

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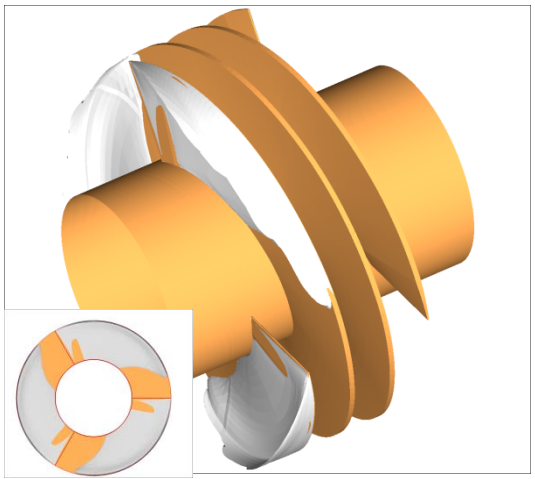
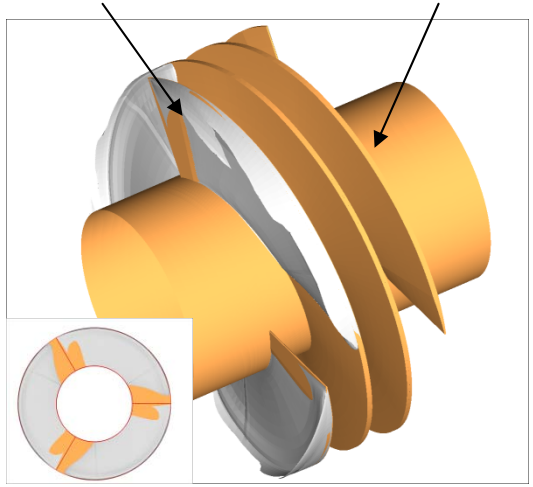
Computational Methodology

- **Boundary Condition: A constant mass flow rate is used at the outlet for cases of different N_{ss} numbers. The blade passage and downstream region are set as in rotational motion around the axis. The shroud, which is stationary for all regions, is configured as counter-spinning wall in the rotational frame. No-slip wall is employed for all solid surfaces.**
- **Turbulence in the flow is handled by applying the standard k-ε model.**
- **The multiphase flow is computed as a homogeneous mixture model of two phases. This model accounts for the nonequilibrium effects during vaporization and condensation.**
- **The inlet static pressure is varied to obtain various N_{ss} numbers in the range of 20000 to 40000.**
- **The Reynolds number based on the axial velocity is 9.897E+05 for a water temperature of 300K.**
- **Commercial solver CFX 11.0 is used for flow calculation involving 3-D Navier-Stokes equation.**

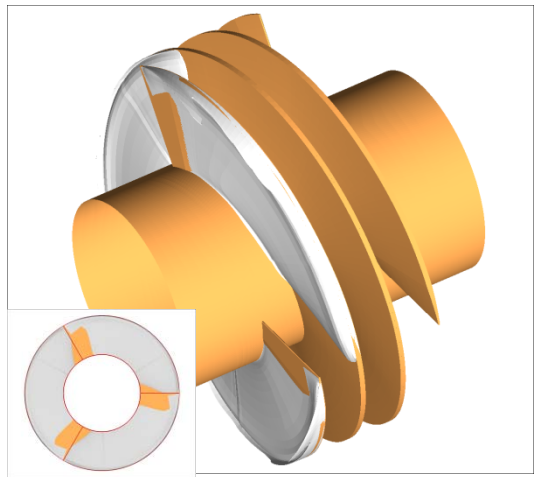
Results: Iso-surfaces of water vapor volume fraction of 0.4



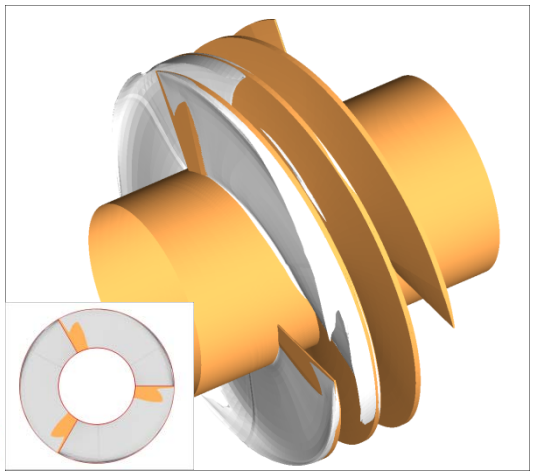
Nss=20k



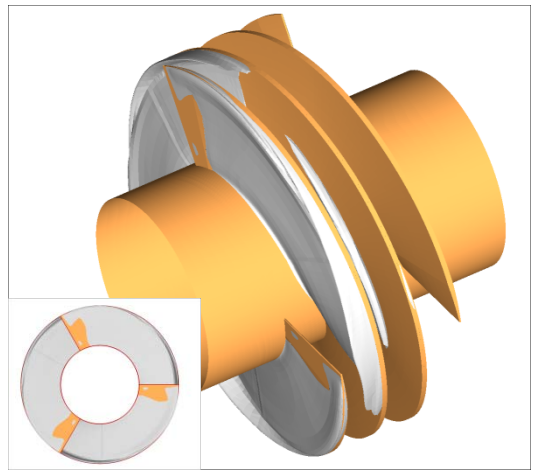
Nss=25k



Nss=30k



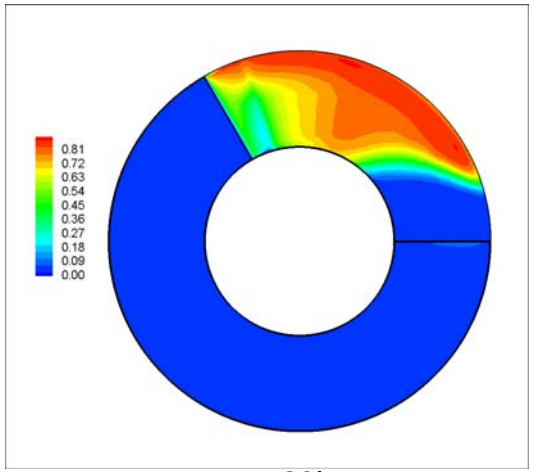
Nss=35k



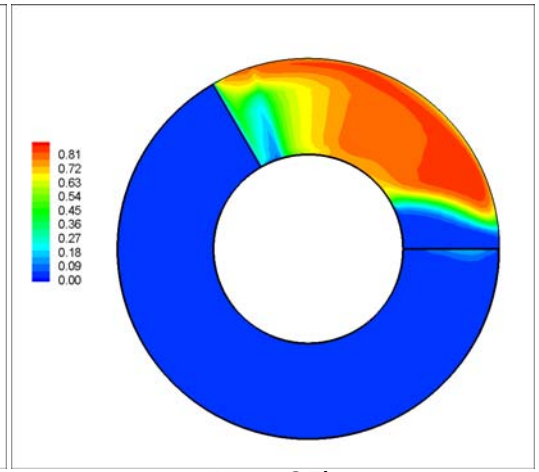
Nss=40k

Nss: suction specific speed

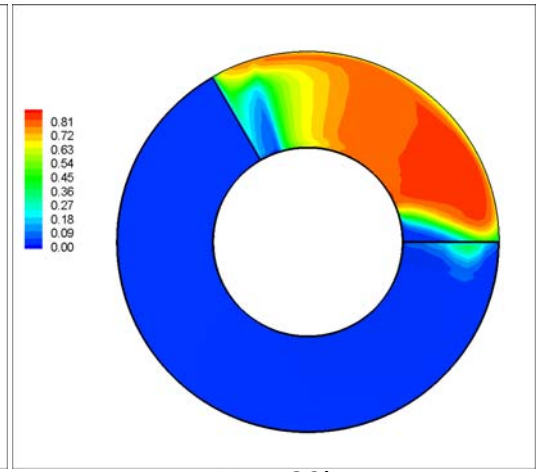
Results (Cont'd) : Water vapor volume fraction contour on blade surface



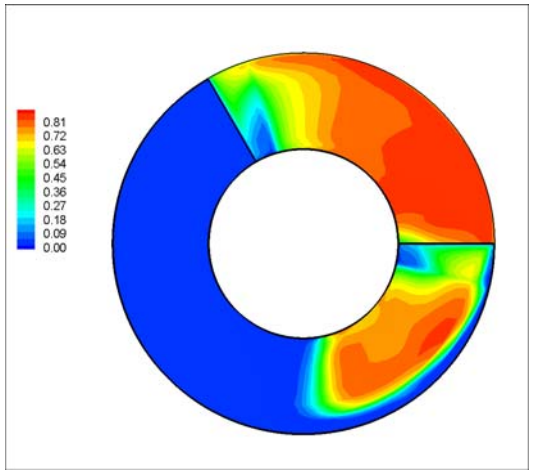
Nss=20k



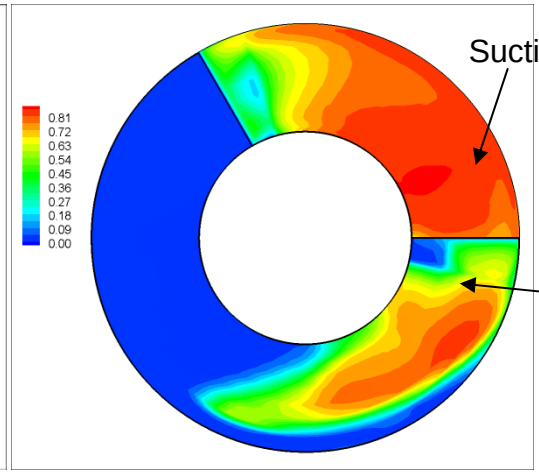
Nss=25k



Nss=30k



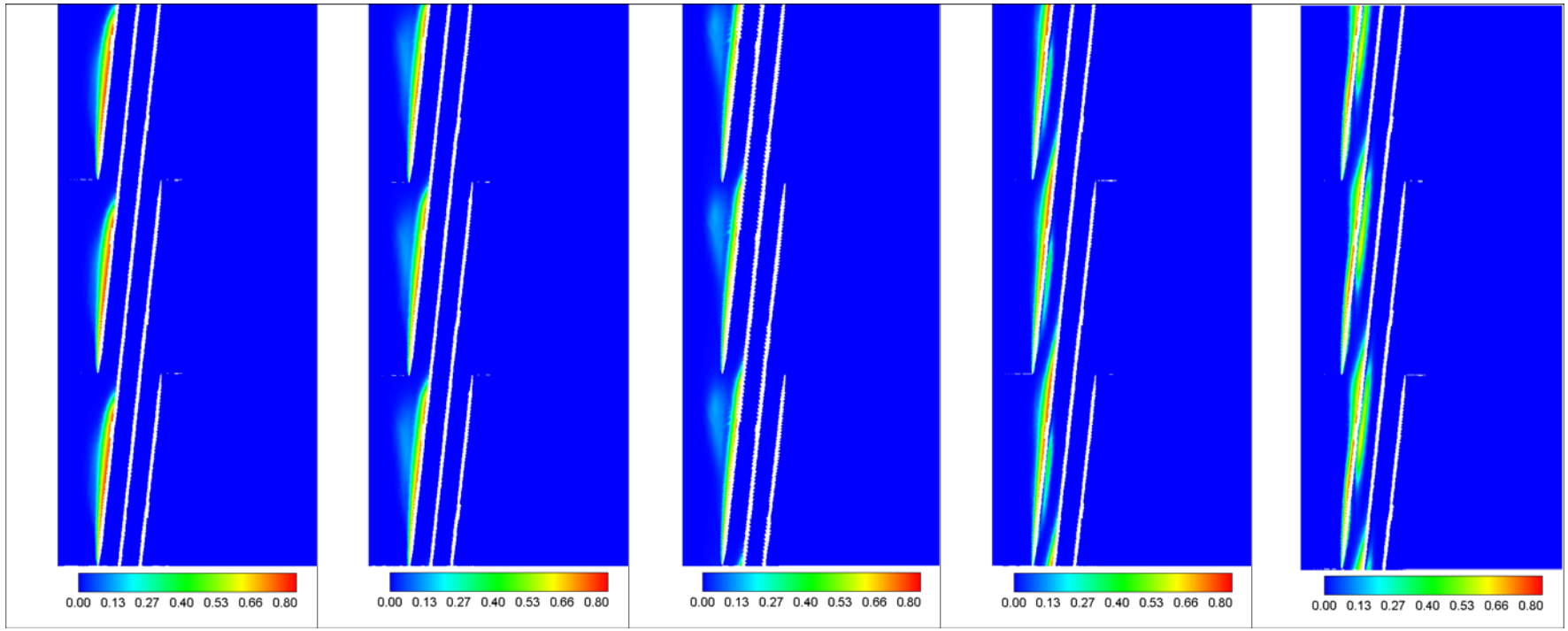
Nss=35k



Nss=40k

Cavitation first appears on the pressure side at 35000, and the inducer breaks at Nss= 40000

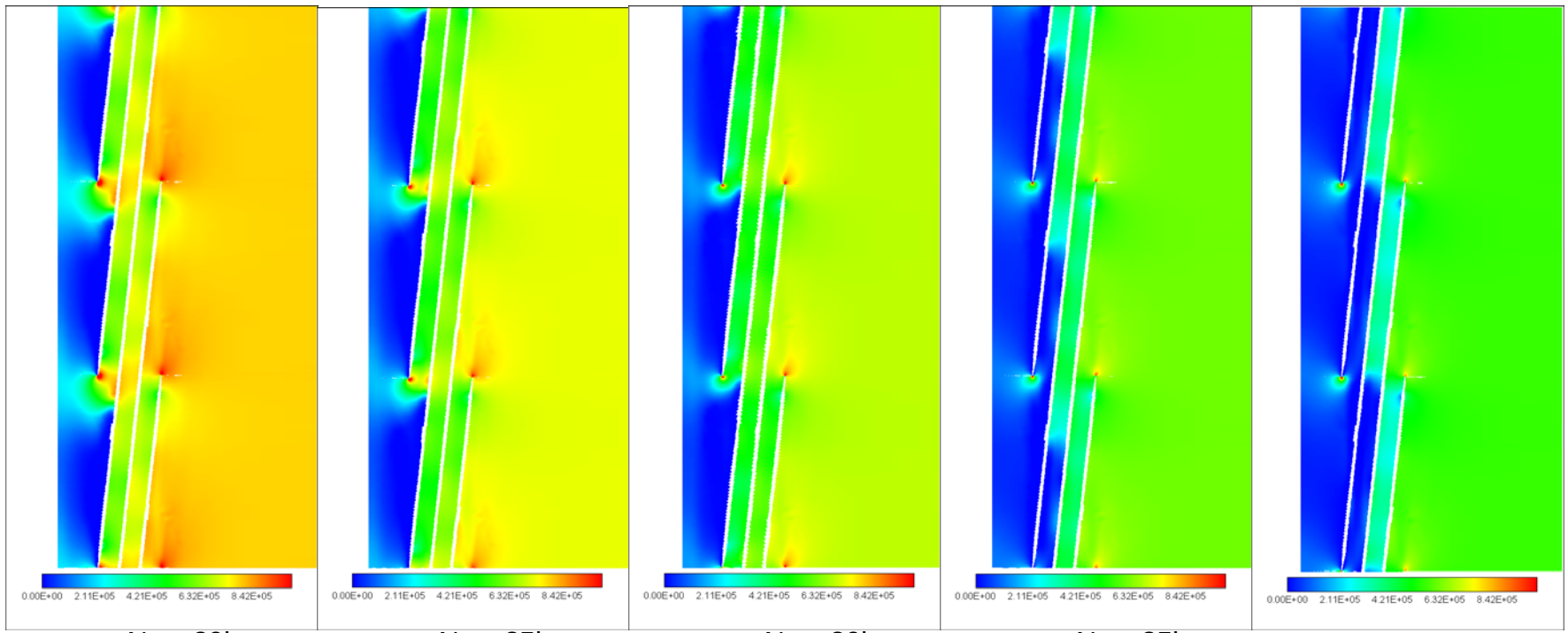
Results (Cont'd): Vapor Volume Fraction Contour on R = 2.4in Plane



Nss=20k Nss=25k Nss=30k Nss=35k Nss=40k

Meridional view: Cavitation blocks the space between the blades and narrows the passage.

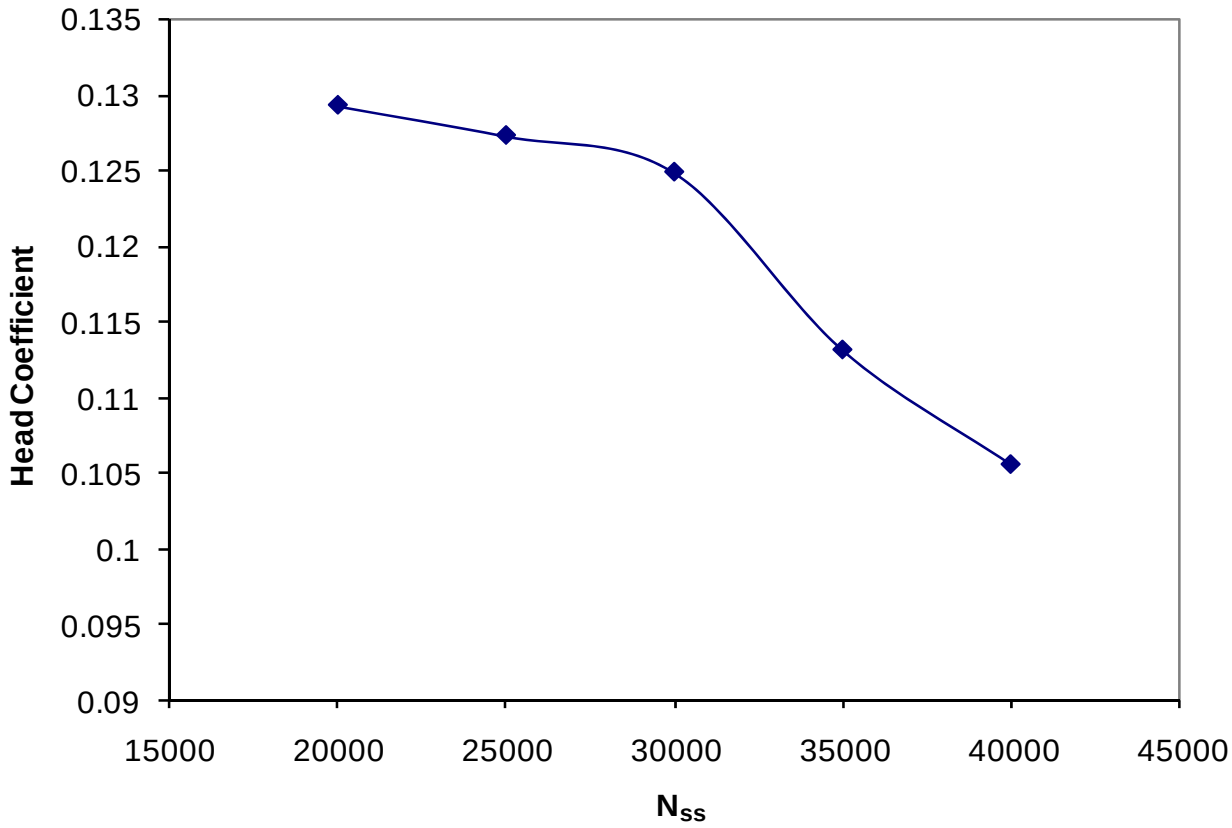
Results (Cont'd) : Static Pressure Contour on R = 2.4in Plane



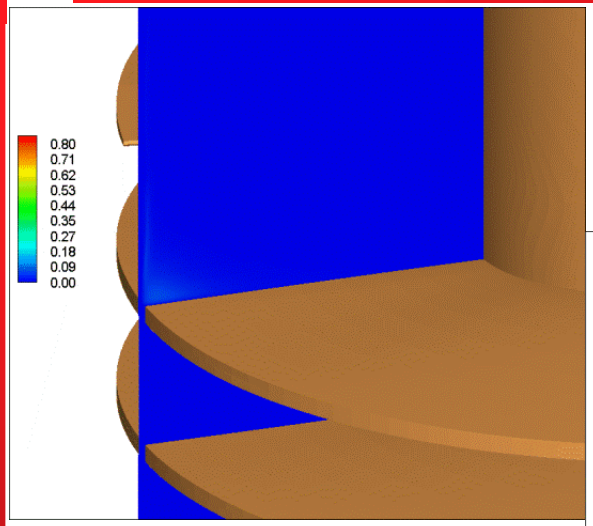
Nss=20k | Nss=25k | Nss=30k | Nss=35k | Nss=40k

Meridional view: Cavitation leads to low pressure in the passage at higher Nss value.

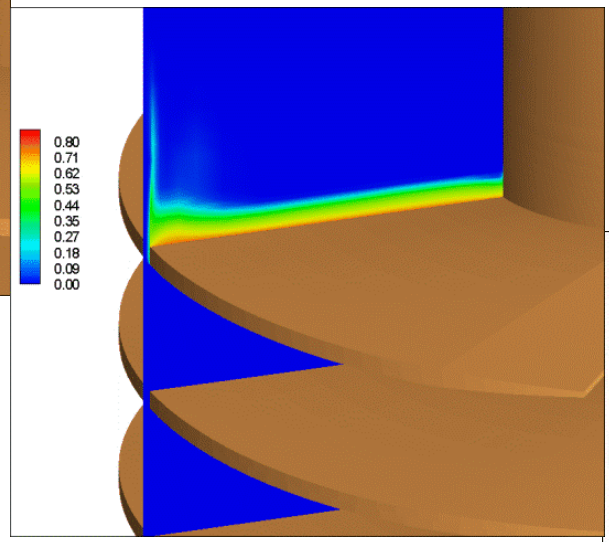
Results (Cont'd) : Head Coefficient as a Function of the Nss Number



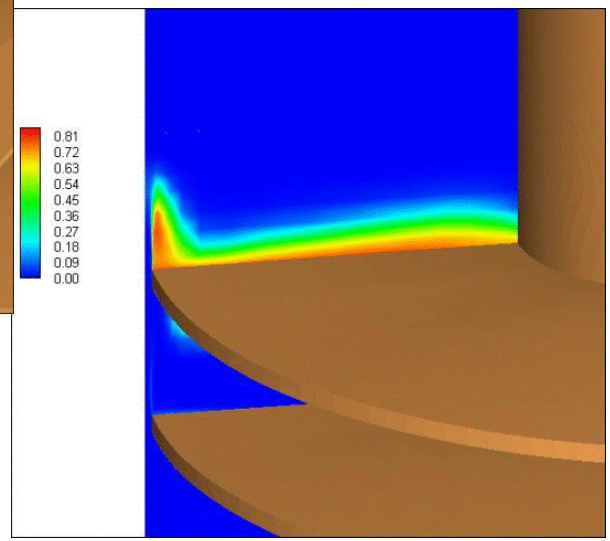
Animations: Vapor Volume Fraction in the Inducer Passage



Nss=20k



Nss=30k



Nss=40k

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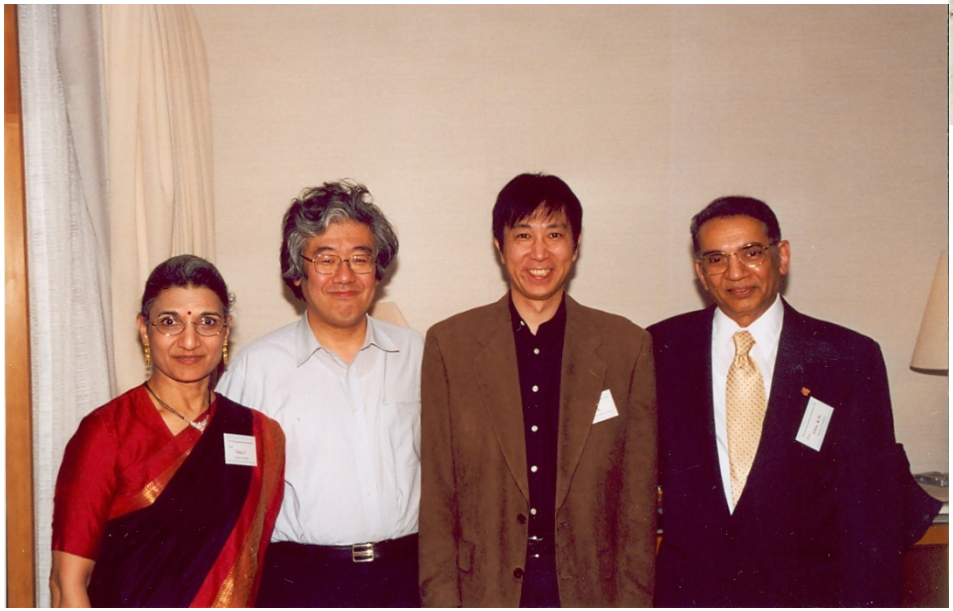
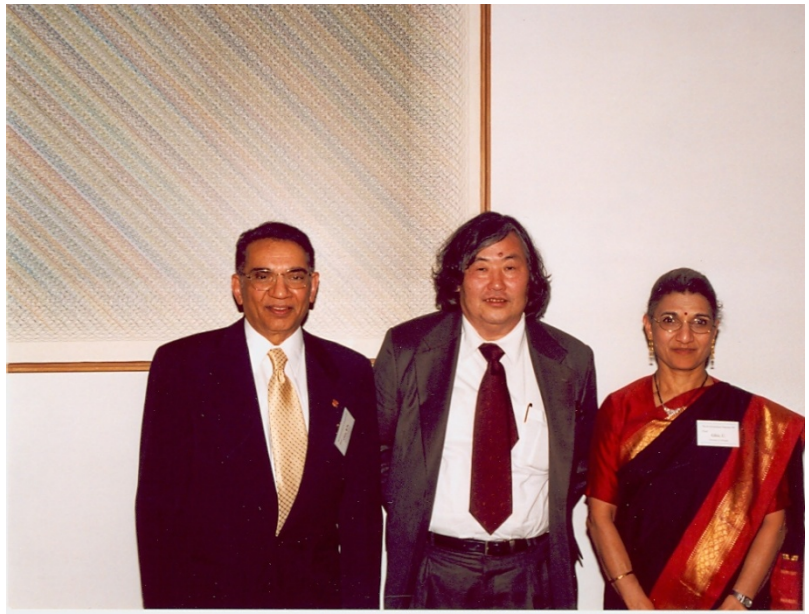


Fourth Nobeyama CFD Conference



Sixth Nobeyama CFD Conference

Seventh Nobeyama CFD Conference

Thank you!