NORTHERN ILLINOIS UNIVERSITY

Hamilton Sundstrand Deaerator Project

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Engineering and Engineering Technology

Mechanical Engineering

By

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Abstract

The deaerator is a mechanical device that is used to separate air from oil. The deaerator is a component of the Integrated Drive Generator (IDG). The Integrated Drive Generator is used in aircrafts as the main power generator. Oil is used in the IDG as a lubricant and coolant. Air is trapped in the oil due to high suction forces of the oil pumps. The entrained air adversely affects the lubricative and thermal properties of oil. Centrifugal forces inside the deaerator are used to remove this entrained air from the oil.

Hamilton Sundstrand has several different deaerator models, but has been unable to evaluate the efficiency of oil separation for different designs. Our goal is to evaluate the efficiency of two deaerator models. The evaluation will be based on experimental and theoretical data. The experimental data will be collected using an actual deaerator setup. The theoretical data will be collected using computational fluid dynamic (CFD) software models. ANSYS CFX software will be used for CFD models. The experimental results will then be compared to the theoretical results. An analysis of both results will lead to a better understanding of flow separation.

University Honors Program

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Finally, I would like to acknowledge all of the previous senior design groups who have allowed the project to develop to its current phase.

Note: The Honors Capstone project is part of my Mechanical Engineering Senior Design project. This project has been a group effort due to the size and scope of research work being carried out. I have included the complete senior design report .I realize that specific individual work is necessary for fulfillment of the Capstone requirement. The specific area that I have chosen to concentrate on is the CFX ANSYS analysis of deaerator.

Abstract

The deaerator is a mechanical device that is used to separate air from oil. The deaerator is a component of the Integrated Drive Generator (IDG). The Integrated Drive Generator is used in aircrafts as the main power generator. Oil is used in the IDG as a lubricant and coolant. Air is trapped in the oil due to high suction forces of the oil pumps. The entrained air adversely affects the lubricative and thermal properties of oil. Centrifugal forces inside the deaerator are used to remove this entrained air from the oil.

Hamilton Sundstrand has several different deaerator models, but has been unable to evaluate the efficiency of oil separation for different designs. Our goal is to evaluate the efficiency of two deaerator models. The evaluation will be based on experimental and theoretical data. The experimental data will be collected using an actual deaerator setup. The theoretical data will be collected using computational fluid dynamic (CFD) software models. ANSYS CFX software will be used for CFD models. The experimental results will then be compared to the theoretical results. An analysis of both results will lead to a better understanding of flow separation.

Chapter 1: Introduction

1.1 Industry Background

The Integrated Drive Generator (IDG) is a major component in airplane engines. It generates electric power used in airplane components and instrumentation. Jet engine oil is used in the system to act as a coolant, and a lubricant. The oil is circulated through oil pumps. The high suction of these pumps can cause air to be introduced into the system. The flow of oil in the pipes is turbulent and causes air to be mixed with oil. The types of mixture vary throughout the system. This entrained air leads to problems in the system. The thermal and lubricative efficiency of the oil is reduced. Air bubbles can also cause blocks in the system and force oil pumps to run dry and eventually burn up. These problems are dangerous as they affect critical components on an aircraft. It is very important to have a good separation of oil and air. A deaerator is used to accomplish this task.

The deaerator is a mechanical component used in the Integrated Drive Generator. The deaerator consists of three components; inlet casing, outlet casing and deaerator [Figure 1.1.1]. The deaerator is a hollow cylinder with one inlet and two outlets. Oil and air mixture enter the inlet [Figure 1.1.2]. The deaerator is rotated to create a centrifugal force. This centrifugal force pushes the denser oil to the outer walls, and the lighter air bubbles to the center of the deaerator [Figure 1.1.4]. The deaerator has two outlets, the oil outlet and the air outlet. The oil outlet lies on the exit walls, while the air outlet lies perpendicular to the fluid flow [Figure 1.1.3].

1.2 Industry Problem

The aerospace industry is faced with the problem of efficiency and performance measurements. Hamilton Sundstrand currently has eleven models of deaerators [Figure 1.2.1]. All models of deaerators have experimentally shown positive results. All deaerators are capable of separating oil from air. The problem is largely associated with efficiency measurements. Experimental procedures are time consuming and costly, and theoretical models are difficult to design.

1.3 NIU Background

Hamilton Sundstrand donated an experimental deaerator setup to Northern Illinois University, to help with data collection [Figure 1.3.1]. The experimental setup has been used to collect data by previous groups. Data was collected for 75/90 model deaerator. No data was collected for other deaerator models. To our knowledge no theoretical computational fluid dynamic (CFD) models have been designed.

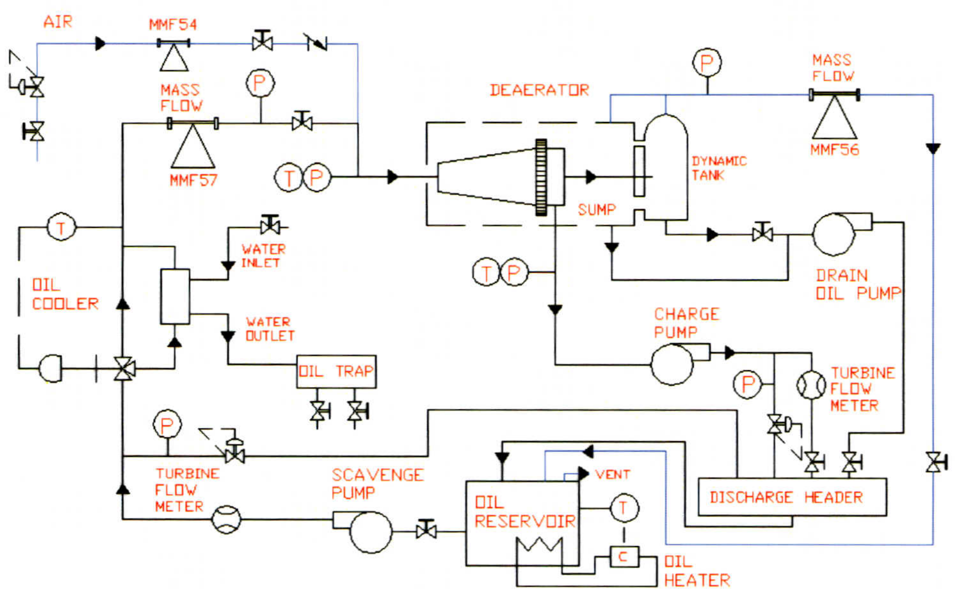
1.4 Deaerator Experimental Setup

The setup consists of the following major components.

- Oil reservoir and Heater- The reservoir holds oil that is circulated through the system. The heater can be used to change temperature for high temperature measurements.
- Motor and Gear box - Consists of a 9,000 rpm variable speed prime motor with controls and a 2:1 gearbox

- Oil – Mobile Jet 2
- Air – Consists of high pressure air line to introduce air into the system
- Scavenger Pump – Pumps oil through deaerator
- Charge Pump – Removes oil from charge casing
- Drain Pump - Removes oil from dynamic tank
- Deaerator and Dynamic Tank – The deaerator is mounted inside a controlled tank, known as a dynamic tank
- Sensors, Thermocouples and Pressure Transducer – Used to collect data
- ODAC system – Main electronic control for entire system and for Other Data Acquisition (ODAC) [Figure 1.4.1]
- LabVIEW Setup – Consists of a computer running LabVIEW software. A direct current supply to power sensors. A national instrument box to convert electric signal from sensors to quantitative data. [Figure1.4.2]

A flow diagram is shown for the deaerator setup



NIU Flow Diagram [1]

1.5. Initial Thoughts and Goals

The team's first goal was to study and understand the most current layout of the apparatus. This includes retesting the most currently tested deaerator design. Through re-testing we will be allowed to learn the system operation. Another key benefit of re-testing is the ability to compare our data analysis with the previously obtained data. This will allow for reinsurance of system performance and system accuracy. Once we have determined proper system operation and knowledge of the testing procedure we can test more of the actual deaerators used in industry.

The team's second goal was to test one more model of the deaerator (A320). This knowledge will lead us into the design phase, in which we will take advantage of industry standard software, such as ANSYS CFX, to create a theoretical model.

1.6 Professional Components

1.6a. Economics

The goal of the deaerator is to improve the efficiency of air removal. Oil exhibits better lubrication and heat transfer properties when there is a minimum amount of air entrained. Understanding the influence of air in the system is economically important since it could possibly degrade the oil, resulting in an increase in frequency for oil changes.

1.6b. Environmental

The environmental aspects are somewhat limited for the deaerator. The deaerator should not consume an excessive amount of power. Another important consideration is how much oil is escaping with the air in the form of vapor. It is important to limit the amount of escaped oil as much as possible.

1.6c. Sustainability

Maintenance will be considered, since simple routine maintenance could effectively improve performance of the apparatus, while keeping cost low. Maintenance will also affect the life cycle, so it should be evaluated properly to ensure that proper maintenance techniques are developed.

1.6d. Manufacturability

There are not many manufacturability aspects in this project as it is based on research and design. Any manufacturing that does take place will be to insure safety and reliability.

1.6e. Ethical

The ethical aspects include confidentiality, impeccability with results and data and an overall concern for the environment and society. All the work to be done for Hamilton Sundstrand should be kept strictly confidential. It is important to always remember that all work and data from this project is strictly the property of Hamilton Sundstrand. We will have an accurate and conclusive analysis of all information regarding the project with the proper supporting information.

1.6f. Health and Safety

Health and safety aspects include testing procedure, manufacturing procedure, and other various hazards. The testing procedure should be standardized and followed to ensure that no injury or health risk could occur. If at all possible all testing should always be completed when the minimum amount of students are around to reduce the injury. The highest safety precautions should be taken at all time and most importantly when heated oil is to be used in testing. All health and safety hazards should be found and known by the users, in order for the users to avoid any negative effect.

1.6g. Social

The social aspects include any negative influence the design could have on the society. This includes society's opinion on the manufacturing technique, the function of the deaerator, and others.

1.6h. Individual Contributions

The group consisted of four members. All members contributed equally towards the project. The first half of this project dealt with understanding the experimental setup and maintenance. All members contributed towards understanding the setup and maintenance.

The group was later divided into two groups for data collection and theoretical analysis. Luke Fisher and Edward Goy were responsible for collecting and analyzing data for the A320 deaerator model. This included new LabVIEW and computer setup, collection of data, analysis of data and final conclusions and recommendations.

Mike Matusky and Sohrab Sethna were responsible for the theoretical analysis. This included modeling of three deaerators in Pro E, meshing in ANSYS, and ANSYS CFX simulation of flow. They were also responsible for final conclusions and recommendations.

It was essential that all members contributed equally and understood all aspects of the project. Overall it can be said that all members contributed equally.

Chapter 2: Project Planning

Project Definition and Planning

2.1 Develop Tasks

The first stage of planning is to develop tasks for the project. There were 3 main tasks.

- Testing of old deaerator
- ANSYS CFX Modeling
- Comparison of data

These 3 objectives were further divided into sub-objectives. These objectives are outlined in the Gant chart [Figure 2.1.1]. The tasks were then divided between the members as personnel assignments. The entire team will be involved with testing of the old deaerator. This would insure that all members of the team know how to operate the system safely. Luke Fisher and Edward Goy would be responsible for data analysis. Sohrab Sethna and Mike Matusky would be responsible for the ANSYS CFX model. The project was divided to maximize time and still insure that all members knew the project well.

2.2 Estimate Schedule

The schedule was divided over a seven month period. The schedule is outlined in the Gant chart of Figure 2.1.1.

The first month would be spent on familiarizing with the system, to insure safety. The team will be running tests on old Deaerator design and collecting data.

The next few months would be spent on learning ANSYS CFX Software. The deaerator would be modeled in ANSYS CFX and data compared to the experimental data. This would help us compare our theoretical and experimental design as well as give us a platform to carry out design changes. The experimental and theoretical data is then compared and analyzed.

Chapter 3: Design Specifications

Quality Function Development was applied to the project. The engineering specification phase for planning are divided into main parameters. The parameters are highlighted below.

3.1 Identify Customers

The main customer for this product will be Hamilton Sundstrand. The project is funded and supported by Hamilton Sundstrand and any resulting work will be the property of Hamilton Sundstrand. It would be unethical to develop this product for other companies or use.

This deaerator will be used in military and commercial aircrafts. It is used in the Integrated Drive Generator (IDG).

Deaerators are used in a wide number of applications, such as Thermal Power Stations and Air Pre-heaters. The finished product may be redesigned for use in these areas, with permission.

3.2 Generating Customer Requirements

The main requirements of the customer and design are as follows. They are shown in the House of Quality [Figure 3.2.1].

1. Separation of oil from air - This is the main requirement. The deaerator should be efficient in separating mixed oil and air.

2. Integration with IDG - The deaerator should integrate well with existing IDG. This would ensure that no other components would have to be redesigned. This is cost effective.
3. Reliable: - The deaerator is used in commercial aircrafts and should comply with all safety specifications. The material should be of aircraft grade and the overall design should be reliable and have a long life.
4. Collection of Data: - This is an aspect of our design. Data will be collected and analyzed to give us a clearer picture of deaerator function and efficiency.

3.3 Evaluate Competition

The competition in this project will be existing deaerators manufactured by Hamilton Sundstrand. We will be testing existing designs to evaluate efficiency of performance. There will be no outside competition.

3.4 Generate Engineering Specifications

The engineering specifications will help us evaluate our final design. They are as follows.

1. Air and oil flow rate
2. Oil density after process
3. Speed of Deaerator
4. Oil Temperature and lubrication

3.5 Cost

There are no major costs associated with this project. The test rig and all required components have been donated by Hamilton Sundstrand.

The theoretical models will be run on ANSYS CFX which is available in the Engineering computer labs.

3.6 Patents

Market research discovered many different oil deaerators [Figure 3.6.1]. The majority of what was found was for use inside an oil tank to eliminate air from the oil going into the tank. Most deaerators use a centrifugal motion to force the separation of oil and air. The majority of the deaerators found were solid cast metal spun at high speeds. The deaerators vary in their geometry from inlet to outlet; some have a conical shape compared to the current deaerator in the test stand, which has a cylindrical shape.

Chapter 4: Testing of Deaerator

4.1 Learning Equipment

The first step carried out for testing of deaerator was to familiarize ourselves with the entire system. The test setup consisted of many components that required attention. The team went through individual components to understand their importance and use in the system. Technical drawings of internal parts, provided by Hamilton Sundstrand, were also analyzed.

4.2 Calibration of Sensors

Sensors were recalibrated prior to running of the system and collection of data. The entire deaerator setup was five years old and the sensors had not been recalibrated. Recalibration of sensors was done to ensure better accuracy in measurements. The two phase flow sensor, thermocouple and pressure transducers were removed and sent to Hamilton Sundstrand for recalibration.

Hamilton Sundstrand returned the sensors, along with data sheets for calibration numbers. All sensors were attached to the setup. The ODAC system was then used to enter the new calibration numbers. This process was documented in the provided ODAC manual [2].

4.3 Safety Issues

There were several safety related issues that were addressed during the collection of data. The first issue was general clean up. Over the years, oil was spilled on the floor and had collected in the oil pans. The entire setup was cleaned and arranged to ensure safety of operators.

I was in charge of fixing air leaks and loose joints. I replaced the worn-out Teflon tape on all critical joints. This was done to insure that we did not have any leaks or bursts. All other joints were checked for air leaks and changed.

Another cause of concern was oil vapor mist coming through the air outlet. The air outlet was open to the atmosphere and oil mist was filling the room. This was a cause for concern due to health issues associated with Jet Oil. I was in charge of fixing this problem. My first step was to research oil vapor filters. I contacted suppliers and manufacturers to help solve this problem. My research led me to the conclusion that 3 filters would be needed in series. The 3 filters would be a particulate filter, coalescing filter and an oil vapor filter. These 3 filter were expensive and not within the project budget. I was required to then come up with another alternative.

In order to fix the oil vapor issue, I design and manufacture an oil vapor condenser. I generated the initial idea and sketches. A 3 inch PVC pipe was used to act as the condenser. The pipe was sealed at one end and open to the atmosphere on the other. The pipe was then stuffed with steel wool to help trap oil vapor. The condenser was then connected to the air outlet through tubing. The entire condenser was designed and manufactured by me using parts available at the hardware store [Figure 4.3.1]. The condenser was effective but was not able to completely remove the oil vapor.

4.4 LabVIEW Setup

On collection of data, the group noticed that the LabVIEW software that was being used was old and on an antiquated machine. We requested a new computer and had all the required hardware and software installed by the department. The new computer was then connected in place of the old LabVIEW Computer. A new National Instrument's cable was ordered to fit the system. The old LabVIEW program was also rewritten and updated to improve accuracy [Figure 4.4.1, 4.4.2].

4.5 Testing Method

Data was collected in two sets. First we collected air only data. This was done to examine correct operation of sensors as well as overall efficiency measurements. The air only data also helped in examining trends with different flow rates of air.

The second step was to collect data for both air and oil flow for the A320 deaerator model. This data was the primary data used for examination and analysis.

The data collection procedure is explained below.

- Power on main switch
- Power on PSI control board with switch and button
- Power on drain pump panel
- Begin Pumping with Scavenger Pump by sliding the scavenger pumping bar to the right slightly and pressing the start button on the ODACS computer
    - Start at a slow speed and fill all lines with oil

    Note: output line to charge pump will be empty until deaerator is running
- Power on the Drain Pump by flipping the power on switch at the lower left end of the deaerator/drain pump control cart which should be adjacent to the ODACS system
- Power on the control for the drain pump's generator by pressing the "Control Power On" button
- Power on the pump motor by pressing the "Pump Motor On" button

- Begin Pumping with the drain pump by turning the drain pump dial being sure to keep the oil in the dynamic tank and level indicator low but not empty
- Start up the deaerator by pressing the "On/Off" button on the deaerator control cart and adjust the speed with the dial on the upper right end of the cart
- Once oil has filled the charge pump's site tube start the charge pump keeping the ratio of charge to scavenger pumping speeds around 70% (just until operating conditions are reached)
- Gradually increase Scavenger and charge pumps (and drain pump as needed) to operating conditions of 15 gpm for the scavenger pump and the appropriate charge pump flow rate as dictated by the ratio being tested
- While increasing flow rates gradually increase deaerator RPM's to the required testing speed. (typically 4 to 7 thousand RPM)
- Allow the system to run for a short period of time (3-5 min) after reaching 15gpm Scavenger pump rate and begin introducing air.
    - Air will have a breakout point where it may require pressure around 30-50psi to introduce air into the system depending on the deaerator
- Allow the system to run for 15min. at steady state
- Begin ODACS and LabVIEW data collection simultaneously (It is important to start both at precisely the same time to correlate data collected via both mediums)

  ODACS
    - Begin ODACS collection by pressing the "Start Auto Snapshots" button

  LabVIEW
    - Begin LabVIEW by pressing the white arrow indicating start. This brings up a save dialogue. Input the pumping ratio and date for the name and test number
    - Select "Save" at precisely the same time as the ODACS operator begins collections to ensure matching times
    - Stop the data collection at the same time
- Stop the data collection at the same time
- Shut down the system between data collections
    - Shut down by turning down the pumping speeds and deaerator rpm's. Be sure to shut down the deaerator prior to reaching very low oil pumping speeds.
- The filtration system should be examined and cleaned between collections

Chapter 5: Experimental Results

5.1 Results for Air Only Data

Air data was collected by testing the rig with the inlet pump, outlet pump and drain pump closed via valves, leaving only the air exit open. Air was then pumped through the rig at different volume flow rates. The flow rates of the inlet and exit were measured in Standard Cubic Feet per Minute (SCFM). Mass ratio was defined as the percentage of mass flow rate out over mass flow rate in. Lower SCFM's pumped into the rig yielded lower mass flow ratios. Figure 14 shows the results for 5 different methods of air data collection. The data was first collected by increasing air flow, then by decreasing air flow. Random order was also used as a control. The random order was selected by using a random number generator program. Two more sets of data were also collected, data set 1, and data set 2. These sets were collected earlier prior to the setup of a standardized testing. They are shown on the graph and were used to verify data collected through different methods.

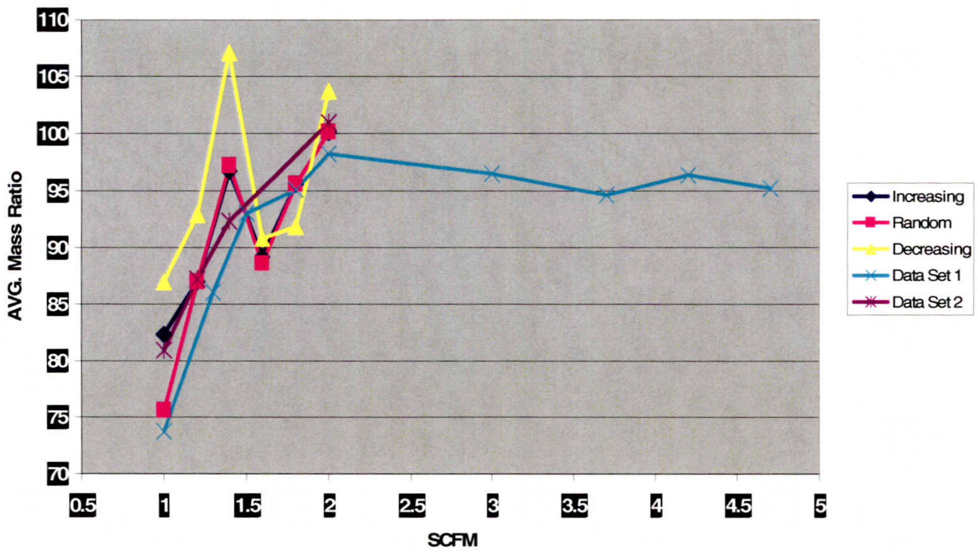


Figure 5.1.1
Average Mass Ratio for three testing methods and two prior to establishing set testing methods

Percentage differences between different methods were also analyzed for different mass flow rates of air. A graph was generated for these percent differences as is shown below [Figure 15].

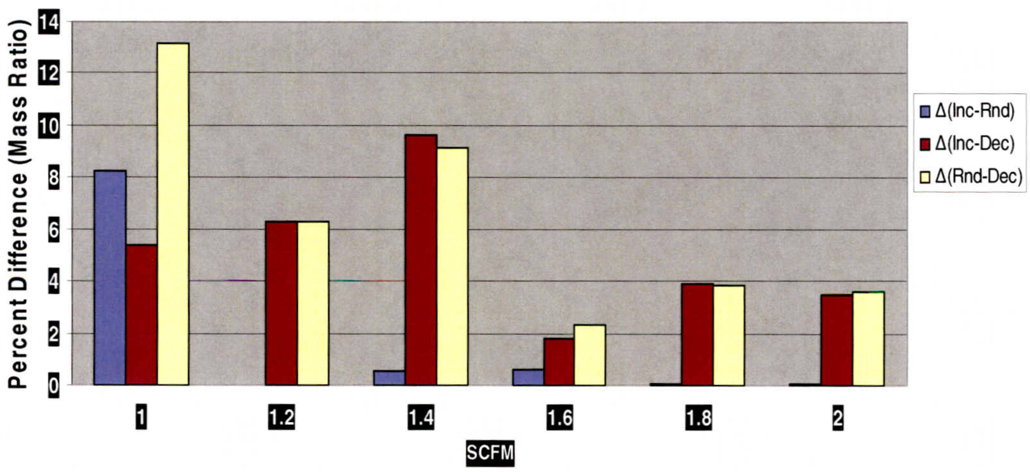


Figure 5.1.2
Percent Difference between air input methods

Data was also collected for SCFM values over the standard operating conditions. This was done to see the effects of large SCFM values on the overall data collection. A graph was generated for SCFM values 1 SCFM to 4.7 SCFM showing averages and standard deviations between values [Figure 16].

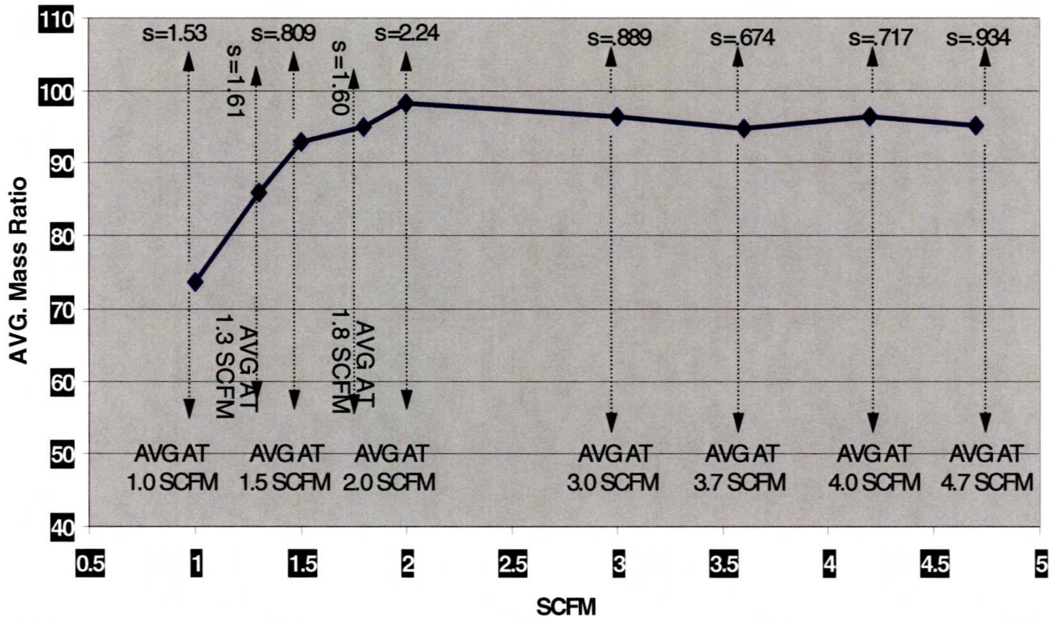


Figure 5.1.3
Air inputs above standard operating range

The data suggest that at higher SCFM values the mass ratio or efficiency stabilizes between 95% to 100 %. This is the efficiency that is expected. SCFM values lower than 2 SCFM do not accurately represent efficiency.

5.2 Results for Air and Oil Data

Hours of testing were run with different oil pumping ratios and different methods of air introduction. The data collected for the A320 deaerator showed mass ratios above 100%. Oil vapors consistently emitted from the air outlet when the rig was running. More oil vapor flowed when the rig was run at lower pumping ratios. These oil vapors corrupted our output data which lead to the high efficiency. The air out contained oil vapor which is denser than air. This increase in density also increased our mass flow rate out [Figure 17]. At times oil liquid would bubble out of the air exit.

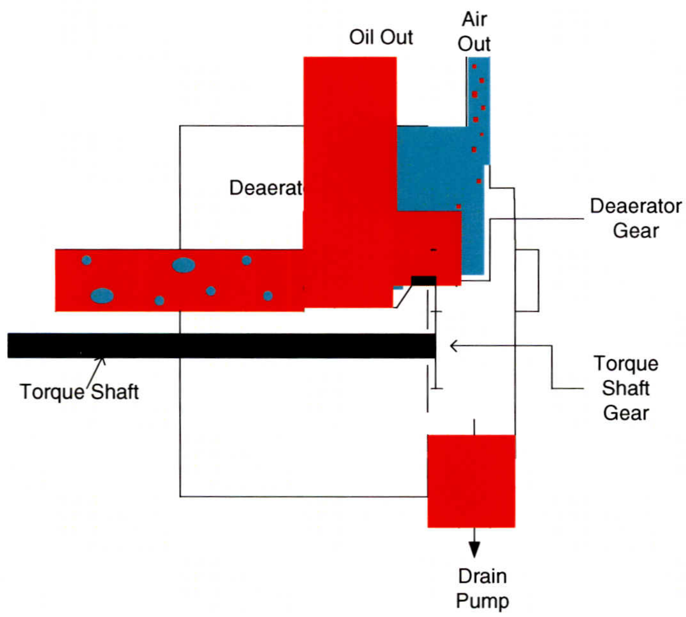


Figure 5.2.1

Schematic of the deaerator rig running the A320 deaerator

The group also noticed that the level indicator sometimes filled rapidly for no apparent reason. Also, the charge pump would at times not increase the flow rate out of the deaerator after the pump's rotation rates were increased.

Data was collected for oil and air flow using 3 different methods. The methods used were increasing the air, decreasing the air and random air flows. Graphs for average mass ratio and percentage difference are shown below [Figure 5.2.2, 5.2.3].

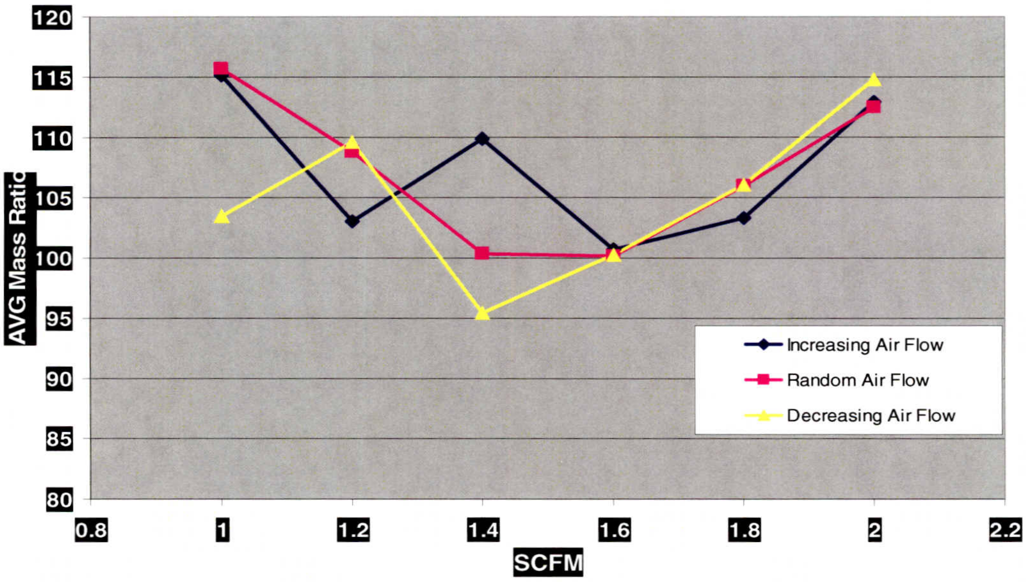


Figure 5.2.2
Average mass ratios for different air inlet methods

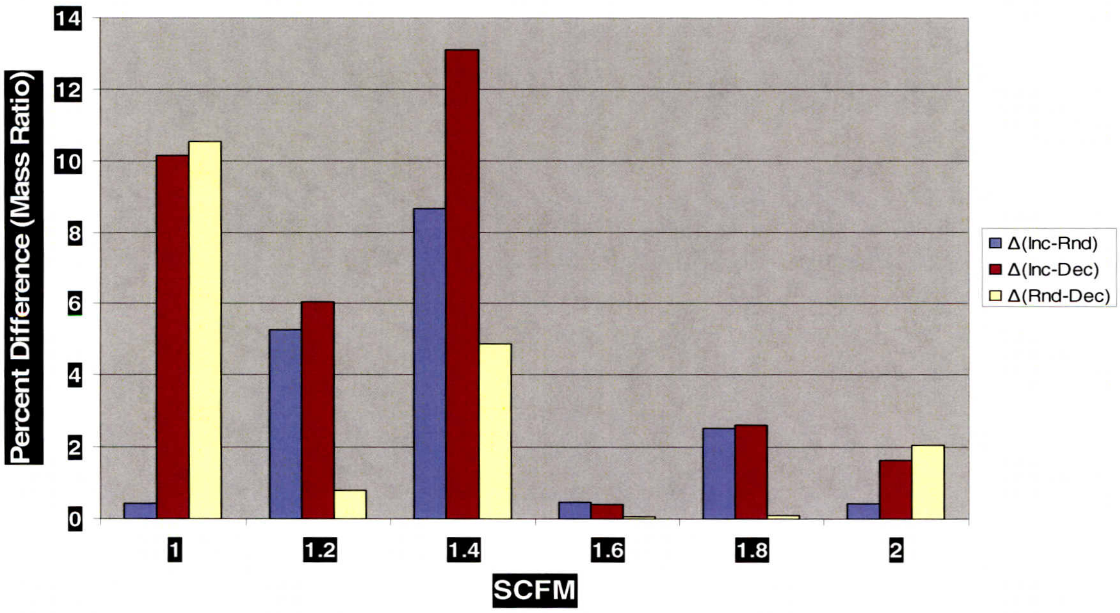


Figure 5.2.3
Percent difference between different air introduction methods

The graphs above show a definite trend in mass flow ratios. The percentage difference also decreases at higher SCFM values. This is related to our findings from air only data.

Data was also collected for different pump ratios [Figure 5.2.4]. The pump ratios are defined as the ratio of the mass flow rate of the Scavenger pump to the mass flow rate of the charge pump. Data was collected for pump ratios of 70% and 65 %. The data was collected using the same three methods of air introduction explained above.

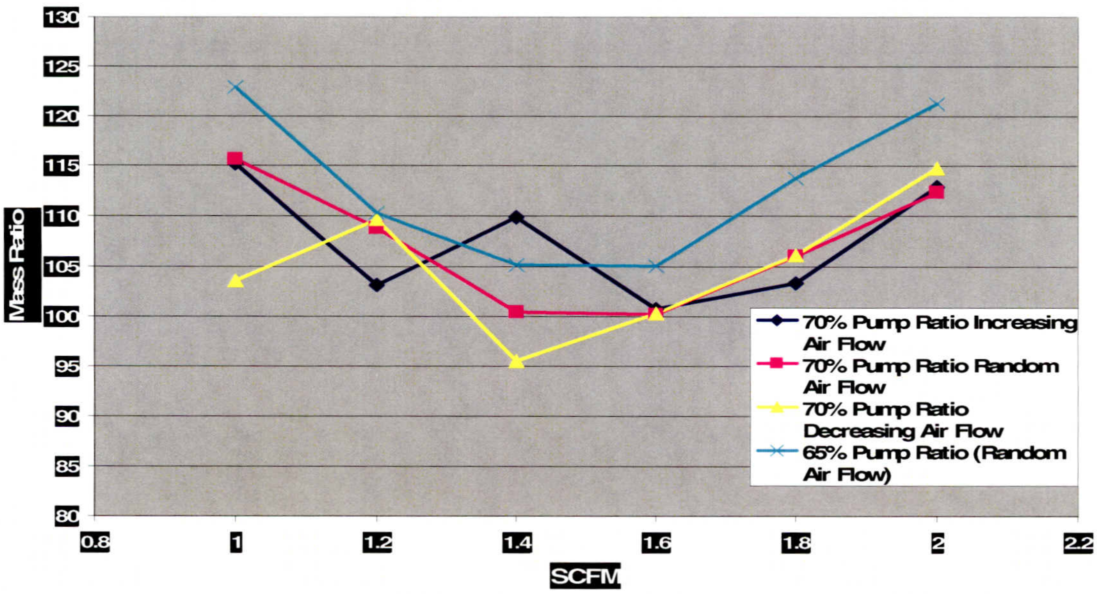


Figure 5.2.4
Mass Ratio for three testing methods and two pumping ratios

Graphs were also generated for each pump ratio using different methods of air input. The graphs show averages and standard deviations [Figure 5.2.5, 5.2.6, 5.2.7, 5.2.8].

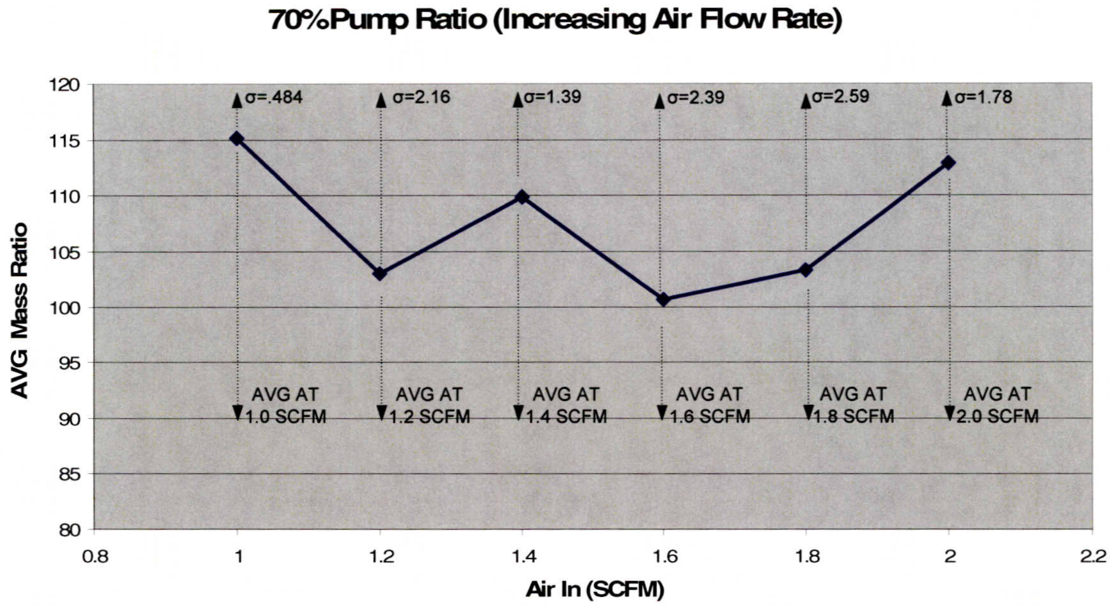


Figure 5.2.5
Average Mass Flow Vs. Average SCFM for 70% pump ratio with decreasing flow rates.

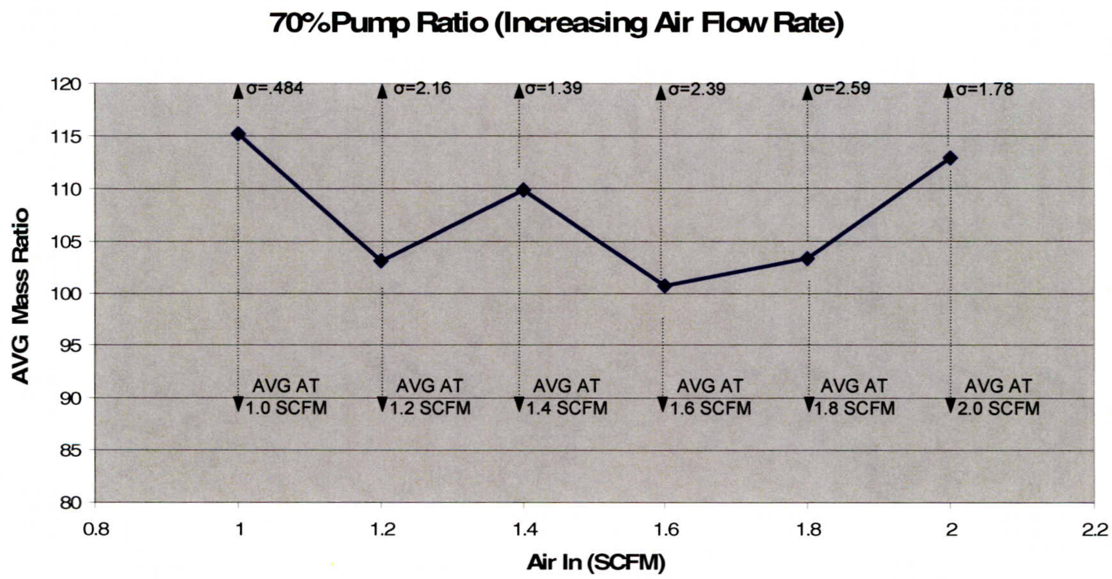


Figure 5.2.6
Average Mass Flow Vs. Average SCFM for 70% pump ratio with increasing flow rates.

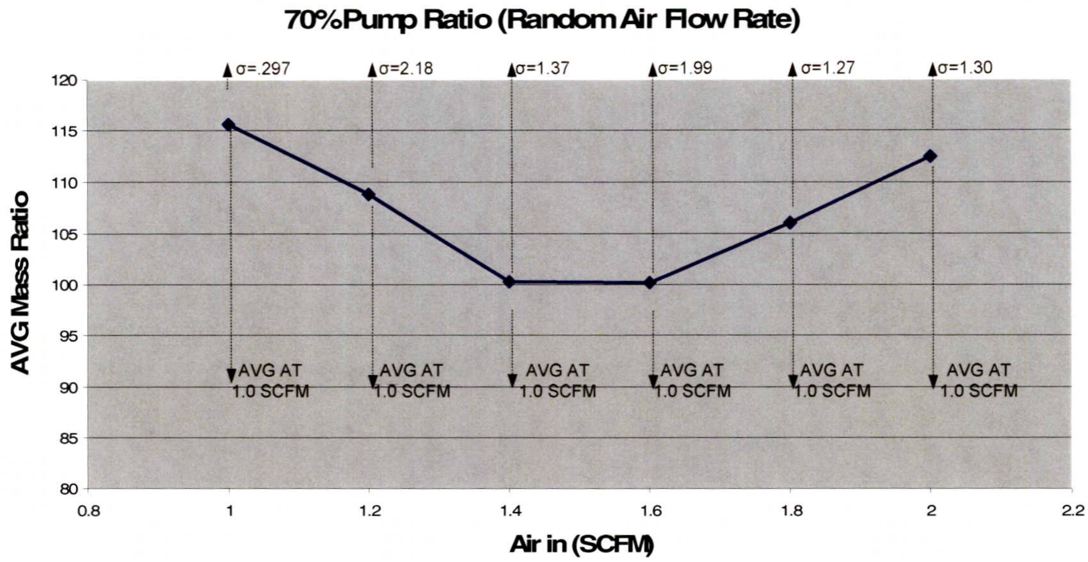


Figure 5.2.7
Average Mass Flow Vs Average SCFM for 70% pump ratio with random flow

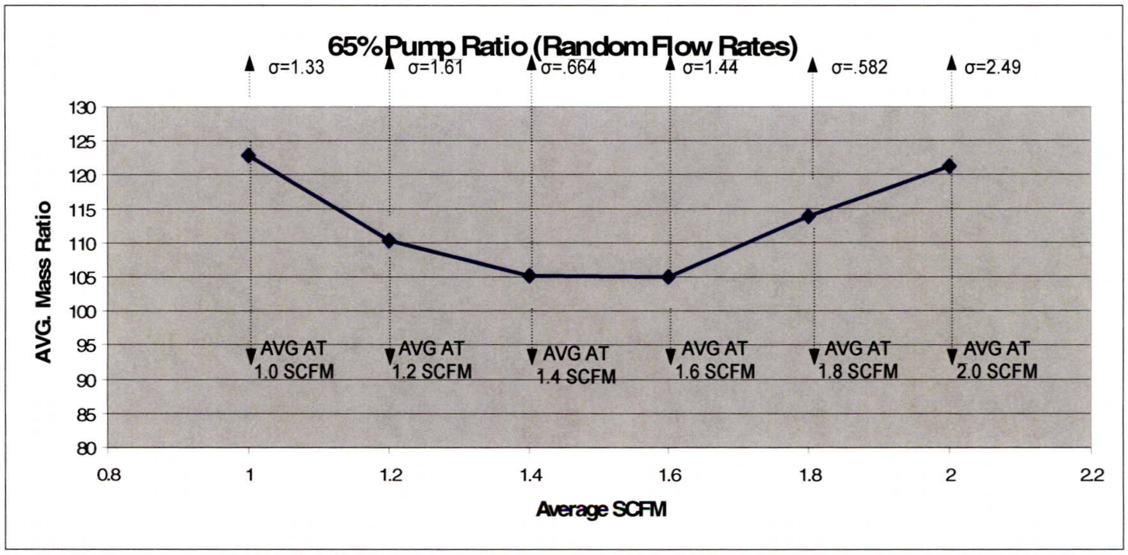


Figure 5.2.8
Average Mass Flow Vs Average SCFM for 65% pump ratio with random flow rates.

Data for 65% pump ratios was difficult to obtain as oil would leave through air outlets. We were only able to collect data for random flow rates at 65 % pump ratio.

All the above data was collected for the A320 model of deaerator. The data for the 75/90 model had been previously collected by Narender Ambati. The 75/90 data was used to compare with our data. The 75/90 data is attached in the appendix [Figure 5.2.9].

Chapter 6: Experimental Conclusions and Recommendations

6.1 Conclusions for Air only data

The air only data show a definite trend. The graphs suggest that the volumetric flow meters used at the air inlets and air outlets work best at higher flow rates. . It appears that at low air flow rates the rig responds in a very sporadic manner. Figure 5.1.1 and figure 5.1.3 show that value of SCFM above 2 SCFM gives us an efficiency of 95% to 100 %. This is the efficiency that is expected. The low SCFM values have low efficiency values which tend to increase as the SCFM is increased. This could indicate a problem with the flow meters. The three different methods used for air only data which were increasing air flow, decreasing air flow and random air flow, and they all show a similar trend. The different methods do not show the same values, but the values do correlate and show similar trends.

6.2 Conclusions for Air and Oil data

The graphs for oil and air data also show a trend. The data from figure 18 to 24 show mass ratio values of over 100 %. This can be expected due to the increased density of oil vapor flowing through the air outlet. Figure 5.2.4 indicates that the mass ratio for 65% pump ratio is higher than the 70% pump ratio. This does not however indicate a higher efficiency. More oil vapor leaving the air outlet at this ratio was observed and this added density could explain the increased efficiency or mass ratio.

The 70 % pump ratio with different methods of air introduction also showed similar trends. At 1.4 SCFM the data varied the most based on the path. The current rig is unable to collect good data for the A320 deaerator because of the oil vapor flow out of the air exit. It is believed that there are some modifications that could be made to the rig that would enable more data to be collected.

6.3 Recommendations

It is suggested that future tests are run from the range 1.6 to 2.2 SCFM for air and data is collected and analyzed to ensure reproducibility. Random flow rates are suggested as the method of air introduction.

In addition to the particulate filter attached to the air outlet, it is suggested that a coalescing filter and desiccant dryer are added in series to the particulate filter before the Omega flow meter. With these additions the flow meter should be reading only air after the three stage filter collects the majority of the oil. If this method does not work it is suggested to add a baffle to the inside of the dynamic tank before the air exit to force the air through a more intricate path to exit and collect some of the oil. Another method of collecting data for the air exit is to attach a two phase density meter at that end and calculate the volume fraction. This last method is expensive and may not be within the budget of the project.

Chapter 7: Modeling of Flow

I have chosen to concentrate on the ANSYS CFX model for fulfillment of this honors thesis. Mike Matusky and I have been responsible for the CFX model, and as such I have received valuable help from him.

There are three major components of modeling flow. They are modeling in Pro Engineer, ANSYS Workbench Mesh, and ANSYS CFX.

7.1 Pro E Model

The first step in analysis was to create a 3-dimensional model of the deaerator as it appears. Pro E software was used to create a computer models for the two different deaerators. The existing paper drawings, provided by Hamilton Sundstrand, were used to create these models. The models hold dimensionally accurate representation [Figure 7.1.1].

A fluid flow regime model was then required for ANSYS CFX. The fluid flow model is different from the deaerator model, as it represents the fluid regime inside the deaerator. To accurately represent the fluid flow a solid representation of the fluid regime is needed in CFX. This model was created by utilizing the "merge inheritance" feature of Pro E. The modeled deaerator is required to be placed into a solid cylinder and subtracted. This allowed for all solid protrusions to be inverted into hollow regions. Therefore, we are left with a solid model representing the flow regime of the deaerator, including internal obstructions as hollow regions to obstruct flow [Figure 7.1.2].

7.2 Meshing

With the flow regime now a solid part in Pro E, meshing is required for analysis. Meshing is completed in ANSYS Workbench which imports the cad geometry from Pro E. Before meshing it is required to first define regions of interest. These regions are the 2-dimensional surfaces which we want to develop boundary conditions for. All deaerators call for a single inlet and two outlet regions, air and oil. With these three regions defined the remaining portions of the domain are group together.

With the regions defined we utilize the comprehensive meshing capabilities of Workbench. Since we are concerned with CFD analysis we adjust the Body and Face spacing for fine meshing and tight Angular Resolution to develop a coarse mesh. Aside from the body and face spacing an Inflation Boundary was introduced for the Default Domain, all regions expect inlets and outlets. Due to the complexity of meshing and the limited availability of computing power we utilized automatic generation for the volume mesh. We were then allowed to later refine the mesh for more accurate analysis. The process of meshing is very specialized and has to be done carefully. A surface mesh was first produced followed by the volume mesh [Figure 7.2.1].

7.3 CFX ANSYS Simulation

The meshed model was then imported into ANSYS CFX. The CFX software is divided into 3 components.

- CFX Pre – The CFX module allows the boundary conditions to be inserted.
- CFX Solver – This module is used to compute equations of flow.
- CFX Post – This module is used to analyze and document flow.

Chapter 8: CFX ANSYS Boundary Conditions

8.1 Types of Flow

The first problem to address was to consider the type of 2-phase flow we were dealing with. These are several different types of flow that can be created through the flow of oil and air. The types of flow are slug, bubbly, churn and annular flow.

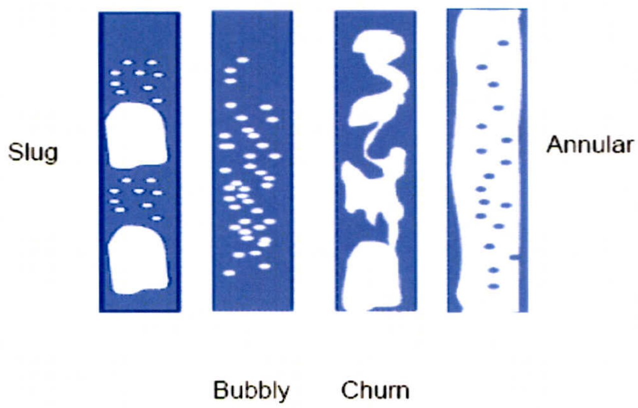


Figure 8.1.1 Types of Flow [4]

The initial flow in the pipes can be considered as churn flow. This churn flow carries on until it enters the deaerator. On discussion with our advisor Dr. Majumdar, we assumed that the flow would change to bubbly flow upon entering the deaerator and striking the stagnation wall. This assumption was used to simplify the model and create a more realistic condition for the theoretical model

The experimental setup, however, should be considered as churn flow. This is because air is forced into the oil line. The pipe then leads to the deaerator. The length of the pipe does not allow for a proper mixing of the fluids. This problem was reduced by attaching the air line further back on the oil line.

8.2 Two Phase Flow

The fluid flowing through the deaerator is a mixture of air and oil. These two different material phases have to be modeled as two phase flow. There are two models in CFX that allow for two phase flow. They are Eulerian-Eulerian model and Lagrangian model. Both models can be used to predict dispersion and distribution of two-phase flows [5].

- Eulerian Model – The air and oil are considered as interpenetrating and interacting continua. Navier-Stokes equations are used to govern flow. A separate set of mass, momentum, and energy conservation equations are solved for each phase [6]. Eulerian model is able to account for turbulence modeling. This model is also easier to parallel process [5]. This model assumes independent particles with the possibility of coalescence and dispersion
- Lagrangian Model - k–ε turbulence model is available. The Lagrangian model incorporates particle tracking which allows for a multiple particles to be tracked through the flow. This method integrates 3 dimensional trajectories based on forces acting on them [5]. It is used in cases where interaction of particles can be neglected.

The model chosen for simulation was the Eulerian-Eulerian model, as it better suited our application. This model allowed for coalescence and dispersion of particles, which we would see in air flow.

8.3 ANSYS CFX Boundary Conditions

There are several different boundary conditions used in ASYS CFX. A detailed list of all boundary conditions have been created and shown. This list was primarily created for design groups to build on our work. The list provides a framework and detailed explanations of boundary conditions. The boundary conditions used in the CFX model were derived from experimental data and research. The boundary conditions were kept as close to the experimental model. The boundary condition included.

ANSYS Module	Compone nt	Feature	Detail	Explanations
ANSYS CFX Pre	**Material** Mobile Jet Oil 2	Fluid Type	Pure Substance	Material is a single pure species. The properties of density, molar mass and viscosity are known
		Thermodynam ic State	Liquid	This parameter sets the state of a substance to solid, liquid
		Molar Mass	560 kg / kmol	Obtained from Exxon Mobile technical support engineer
		Density	982.9 kg / m^3	
		Specific Heat Capacity	0.46 BTU lb^ -1 F^ -1	
		Specific Heat Type	Constant Pressure	The amount of energy required to raise the temperature of a fixed mass of the fluid by 1K.
		Reference Temperature	37.8 C	Used as reference for oil properties by Exxon

		Reference Pressure	1 atm	Mobile
	Material Air at 25 C	Fluid Type	Pure Substance	Material is a single pure species. The properties of density, molar mass and viscosity are known
		Thermodynamic State	Gas	This parameter sets the state of a substance to gas
		Molar Mass	28.96 kg / kmol	Obtained from ANSYS material data
		Density	1.185 kg / m^3	
		Specific Heat Capacity	1004.4 J kg^1 K^1	
		Specific Heat Type	Constant Pressure	
		Reference Temperature	25 C	
ANSYS CFX Pre		Reference Pressure	1 atm	
	Default Domain	Heat Transfer Model	Isothermal	Heat transfer is not considered as a defining characteristic in this project
		Turbulence Model	K - Epsilon	K-Epsilon is used as an industry standard as it offers good compromise between accuracy and robustness.
		Domain Motion	Rotating	Models the rotations of deaerator

ANSYS CFX Pre		Buoyancy	Buoyant (our models were non-buoyant due to computing problems)	It is almost always important to set buoyancy in multiphase flow. We choose density of lighter fluid as it gives intuitive interpretation of pressure. This simplifies pressure initial, pressure, boundary and force conditions
		Morphology	Continuous Fluid Dispersed Fluid Polydisperse d Fluid	Morphology chosen according to type of two-phase model
		Surface Tension Coefficient	29.3 dyne cm^-1	
ANSYS CFX Pre	Inlet	Boundary Type	Inlet	Region of inflow
		Frame type	Rotating	Rotation of deaerator
		Flow Regime	Subsonic	Flow is below mach number unity (supersonic)
		Bulk Mass Flow Rate	1.5 kg/s	Condition Specified by Hamilton Sundstrand
		Flow Direction	Normal to Boundary Condition	
		Turbulence	Medium Intensity 5%	Recommended for regions where information on turbulence is absent
		Volume Fraction Air	0.34	Calculated by condition of bulk mass Flow rate specified by Hamilton Sundstrand
		Volume Fraction Oil	0.66	

ANSYS CFX Pre	**Air Outlet**	Boundary Type	Outlet	Region of outflow. Direction and pressure of flow is known
		Frame type	Rotating	Rotation of deaerator
		Flow Regime	Subsonic	Flow is below mach number unity (supersonic)
		Static Pressure	Variable Range:20-50 kpa	Different values are modeled to simulate different pump ratio pressure
	Oil Opening	Boundary Type	Opening	Region of outflow. Direction and pressure of flow is not known
		Frame type	Rotating	Rotation of deaerator
		Flow Regime	Subsonic	Flow is below mach number unity (supersonic)
		Static Pressure Entrained	Variable Range:20-50 kpa	Has stability when flow direction is unknown. Useful when flow tends to be pulled through boundary.
ANSYS CFX Solver	**Solver Control**	Advective Scheme	High Resolution	High resolution is used for results
		Max Iterations	100-200+	Iterations are set to 100 but due to mesh refinement solution can run to 200+ iterations
		Residual Type	RMS	
		Residual Target	0.0001-0.00001	Convergence Criteria
ANSYS CFX Post	**Tools**	Contours	Variable	These tools are available in CFX and are used primarily for analysis of simulation
		Vectors	Velocity	
		Stream Lines	Velocity	
		Function Calculator	Mass Flow	

Chapter 9: CFX ANSYS Model Simulation

Simulation was run for three deaerator models, the 75/90 model, the A320 without inducer, and A320 with inducer. All three types of deaerator had different internal geometry. Working fluids consists of Air and Mobile Jet Oil II (MJOII) and the properties of air are standard with the software, while MJOII properties were obtained from Exxon Mobile.

9.1 Single Phase Flow.

All models of deaerator were first run with single phase. Simulations were run for oil only and air only. This was important to gain a better understanding of flow through complex geometry. There were several types of simulations run for results and comparison. Single phase most importantly allowed us to gain insight on the effect of the internal geometry and verification of our modeling with simplified flow. Also, multiple simulations were run starting with the rotation as stationary and then increasing to 1000, 2000, and 3600 rpm. The A320 calls for higher rotation reaching just over 7000 rpm.

9.2 Two Phase Flow.

The next step was to run simulations of two phase flow. Air and MJOII were simulated flowing through the deaerator as stationary and rotating. Much investigation was required into running multiple simulations to determine the proper conditions to closely simulate the deaerators in actual operation.

9.3 MUSIG Two Phase Model

The Multiple Size Group (MUSIG) model was also simulated. The MUSIG model is a specialized model that is used for polydispersed multiphase flow which has large variations in size. Different size phases are allowed to interact with each other through the mechanism of breakup and coalescence. Multiple size particles can be established through population balance [7].

The MUSIG model allows for random generation of size groups. Simulations were run for 5 groups. ANSYS generates random diameter bubbles for every group according to user specified minimum and maximum expected air diameters (0.0015m to 0.020 m).

It is inaccurate to model the simulation for only a single diameter value of air bubbles. This would not be an inaccurate representation for the experimental and theoretical model. In bubbly flow we can assume many different particle sizes for air bubbles. MUSIG allows for multiple diameter sizes and is a more realistic model.

The MUSIG model also allows for breakup and coalescence of fluid phases. This is important as inside the deaerator we see that large bubbles are broken up and small bubbles can meet and join. The MUSIG model allows us to study not only the volume fraction of air inside the deaerator, but also the behavior of air bubbles. Currently, we were only able to gain minimal useable results from the MUSIG model and a further investigation is required and recommended as our mass balance yields unusual results.

Chapter 10: CFX ANSYS Model Results

10.1 Single Phase Flow 75/90 Deaerator

Single phase simulations allowed for validation of modeling and initial boundary conditions. Each deaerator was simulated with only oil and only air. The results from single phase also aid in helping understand the internal geometry and its effect on the flow.

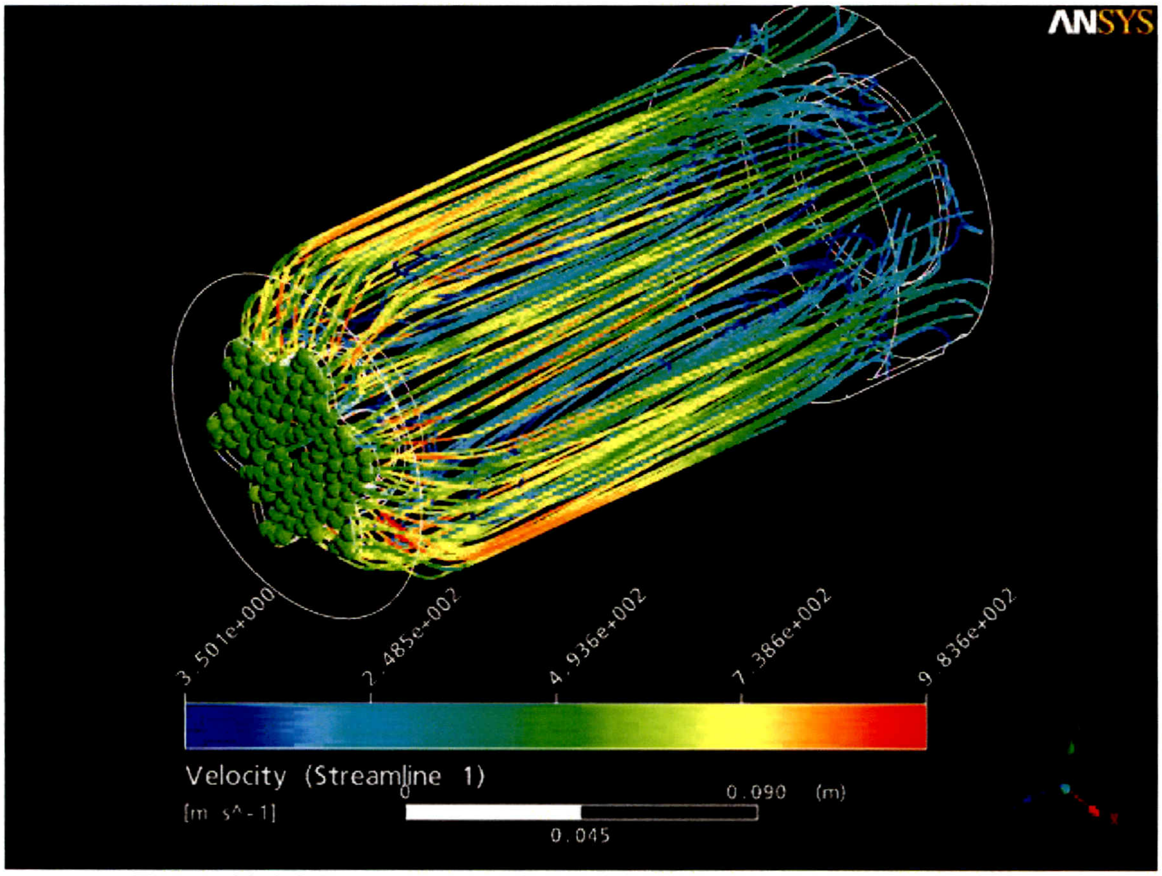
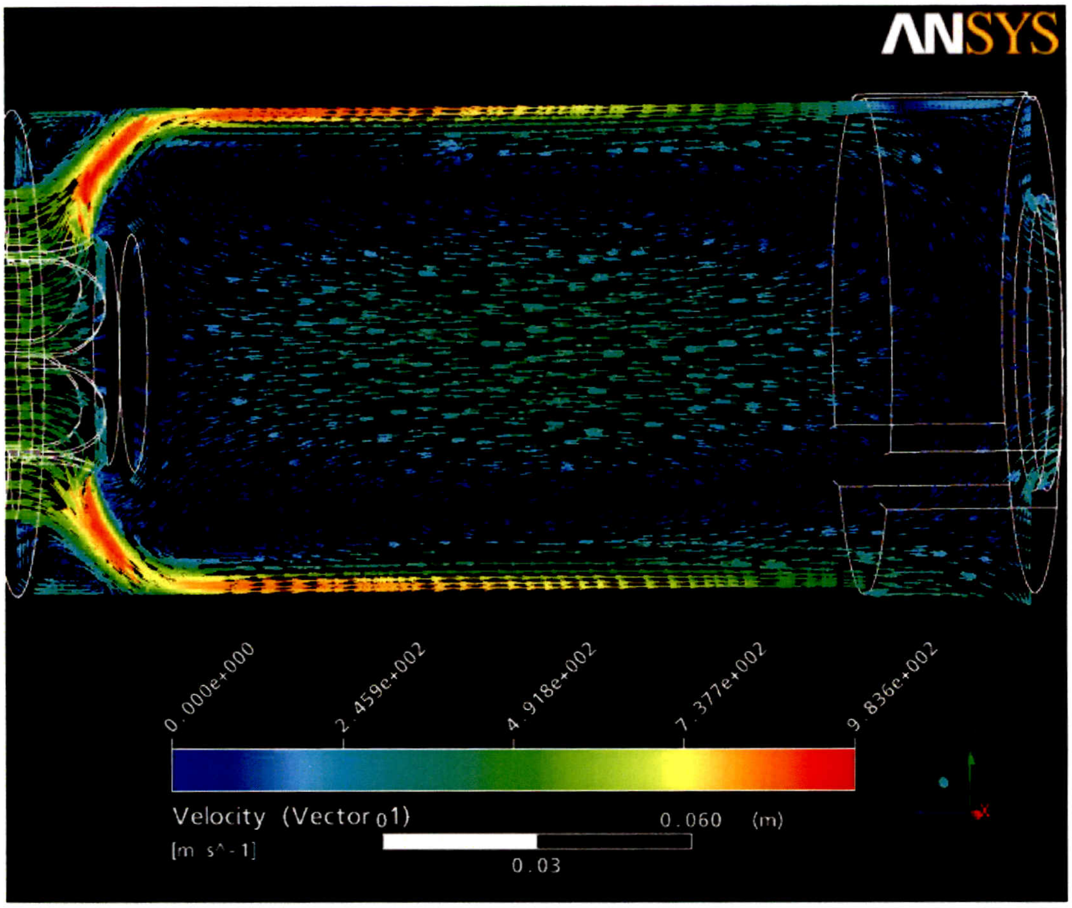
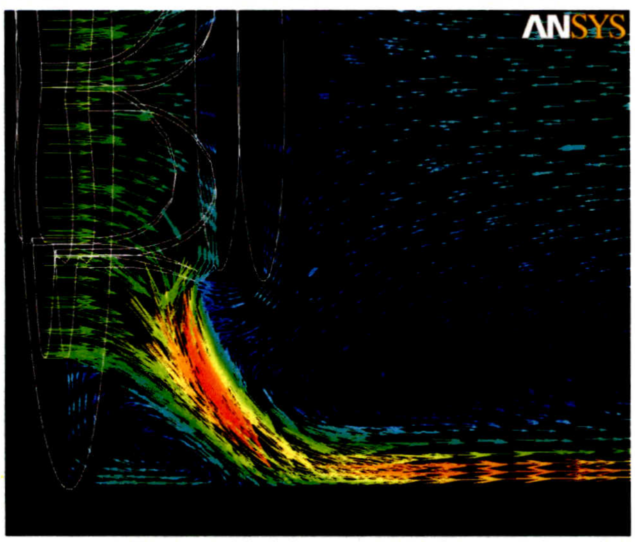


Figure 10.1.1 Stream Line of the 75/90 Single Phase Air @ 3600 RPM





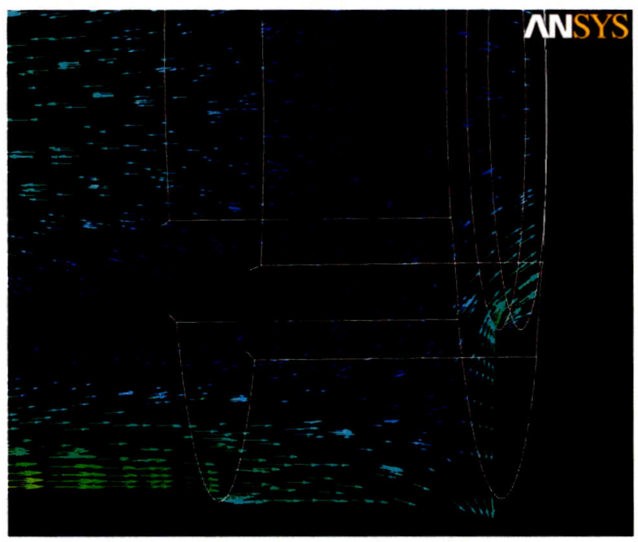


Figure 10.1.2 Vector Velocity Plot of Air Only @ 3600 RPM 75/90 Model (Above)

Figure 10.1.2a Inlet of Figure 10.1.2 (Left) Figure 10.1.2b Outlet Figure 10.1.2 (Right)

The results for MJOII as single phase are presented below. These results can be compared to the single phase results for air. As seen in the air results there is multiple areas of recirculation, which is the results one would expect from the properties of air. In comparison which the images below, we see much different flow through the 75/90 deaerator. Here the properties of the oil and the rotation of the deaerator are causing the fluid to pull against the walls due to the centrifugal forces along with the surface tension coefficient. It is most important to note the area in the center of the deaerator as there is zero velocity and no oil. This is the area where the two-phase air is expected to exist.

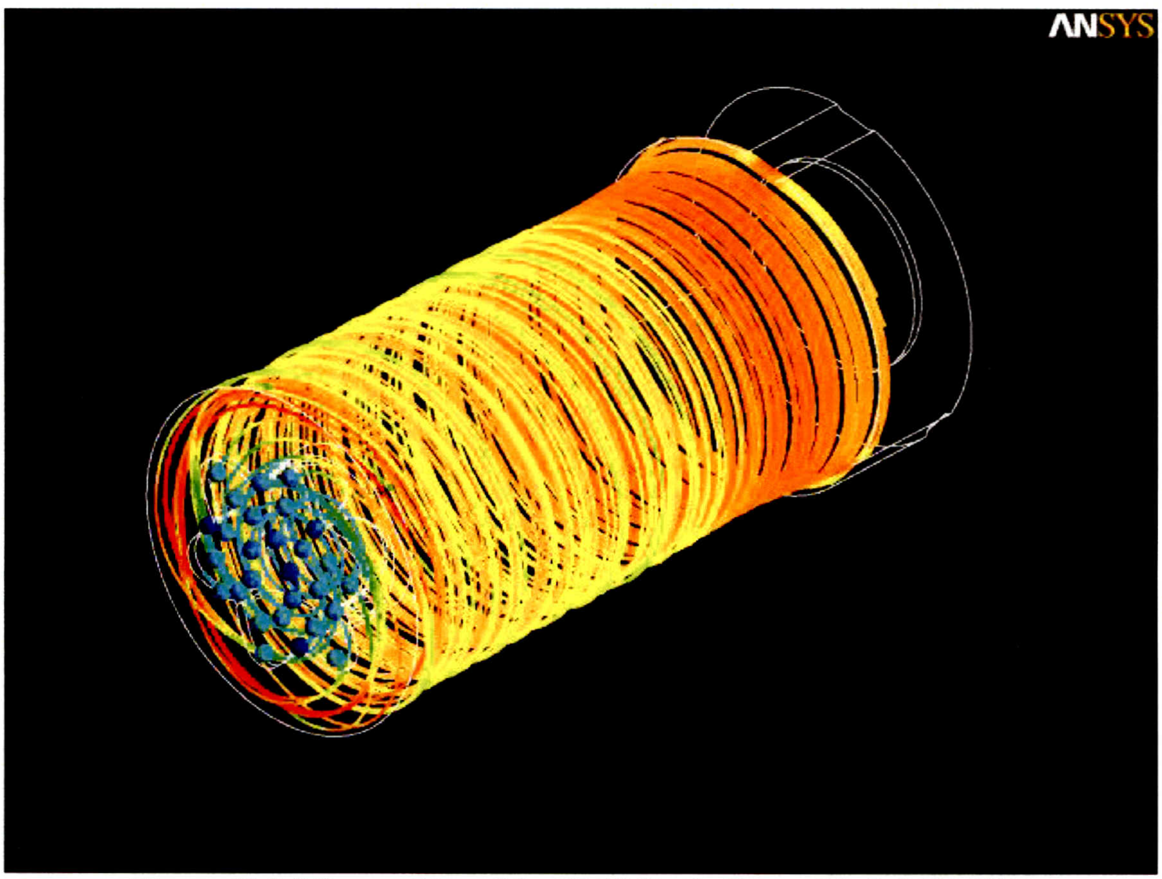
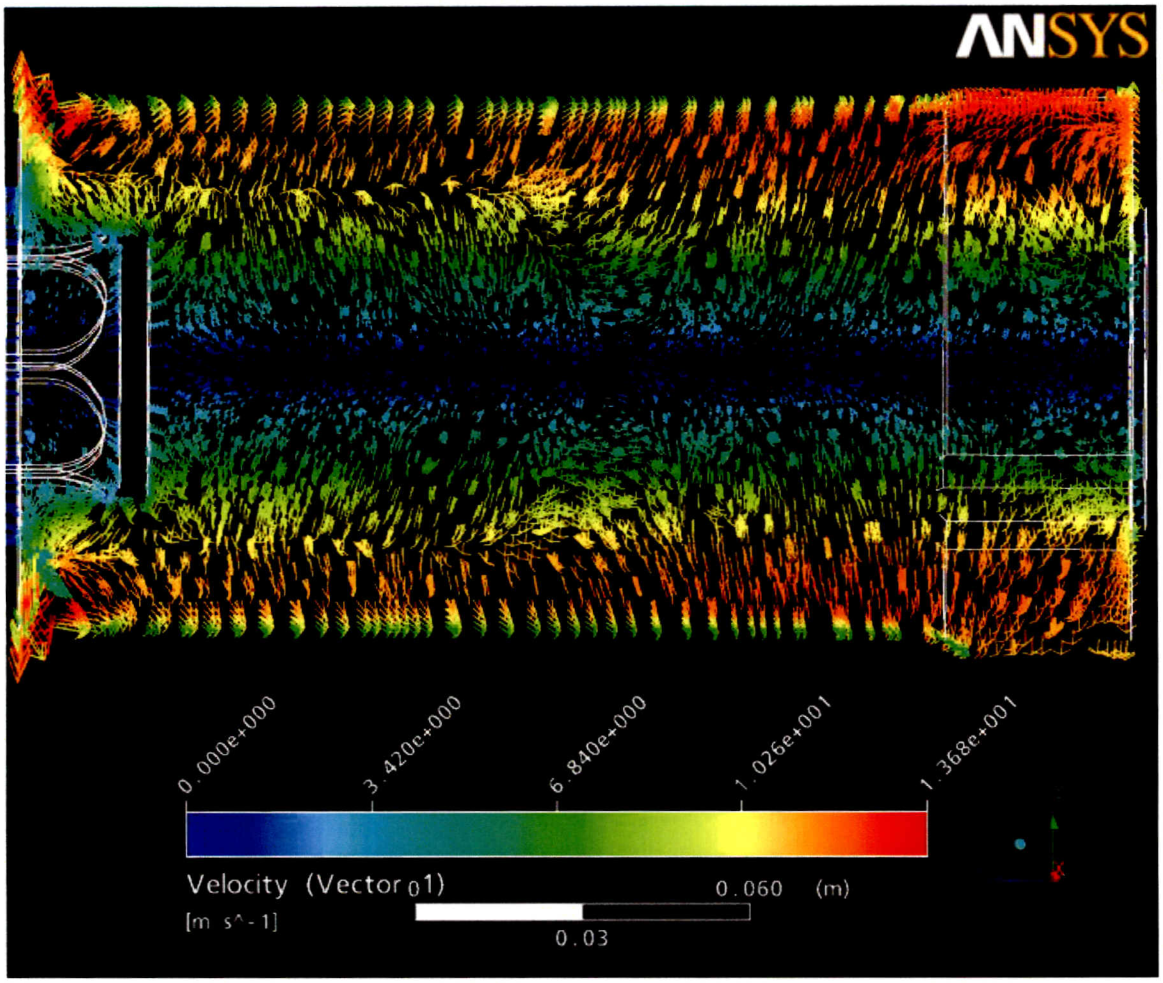
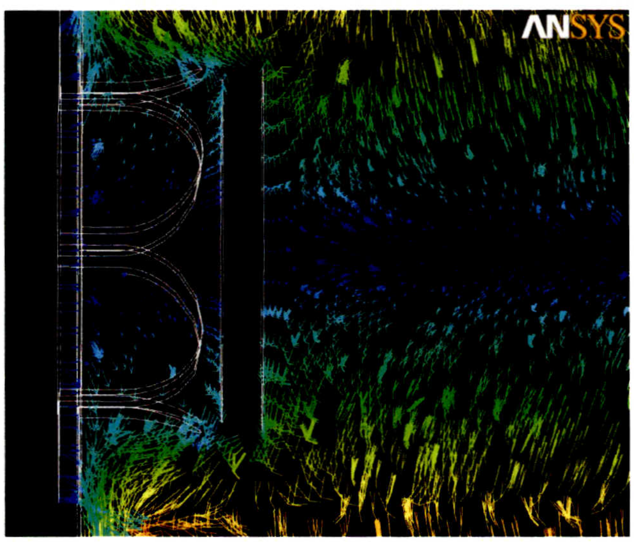


Figure 10.1.3 Stream Line of the 75/90 Single Phase Oil @ 3600 RPM





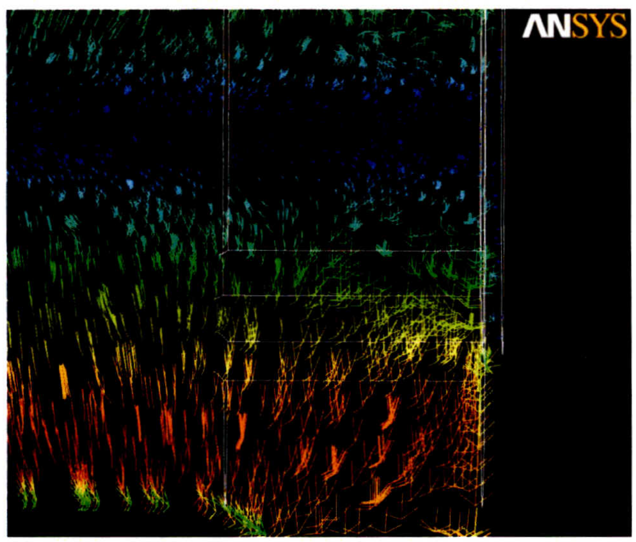


Figure 10.1.4 Vector Velocity Plot of Oil Only @ 3600 RPM 75/90 Model (Above)

Figure 10.1.4a Inlet of Figure 10.1.4 (Left) Figure 10.1.4b Outlet Figure 10.1.4 (Right)

10.2 Two Phase Flow 75/90 Deaerator

With the model verified through the use of single phase simulations, the model is ready for two-phase flow simulation. The boundary conditions for the two-phase flow models can be found previously in section 8.3. The two-phase results are best examined using volume fraction contour plots. The normal operating condition of the 75/90 deaerator is at 3600 RPM. In order to examine the development of the separation of phases, results were necessary at multiple rotational speeds. Below the separation of flow is seen sequentially through the 1000, 2000, and 3600 RPMs.

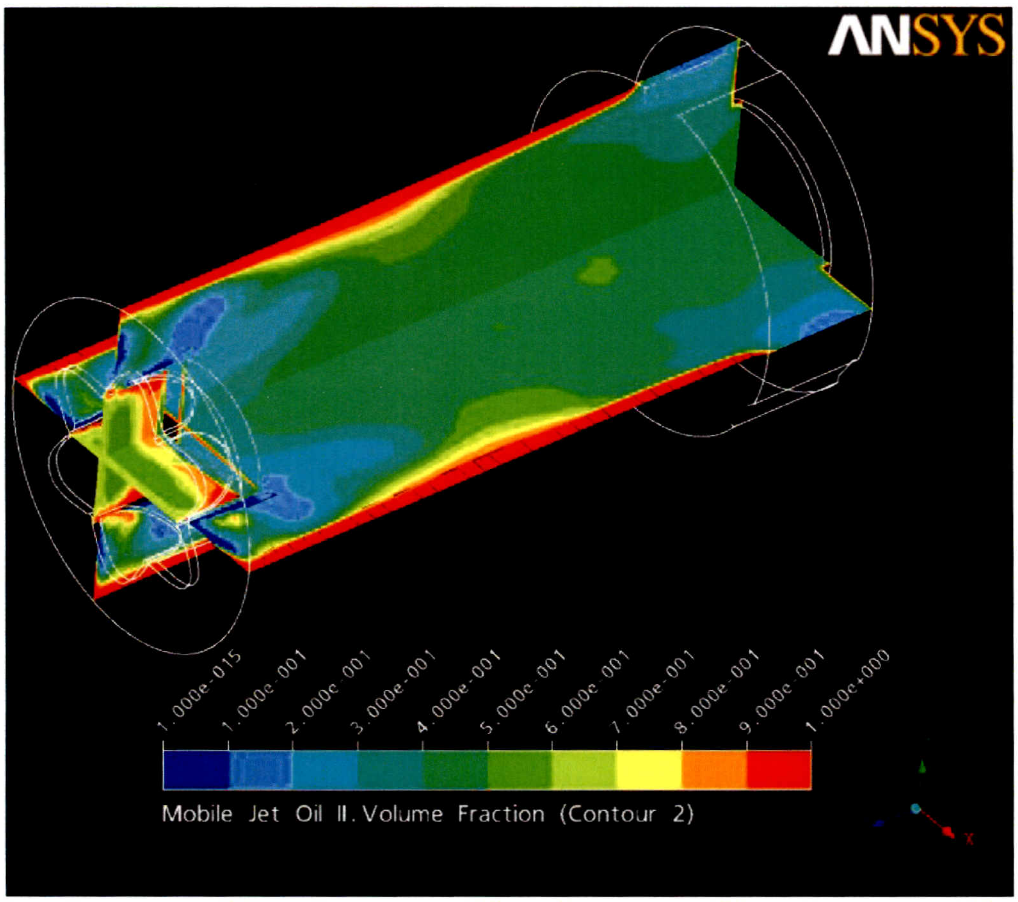


Figure 10.2.1 MJOII Volume Fraction @ 1000 RPM 75/90 Model

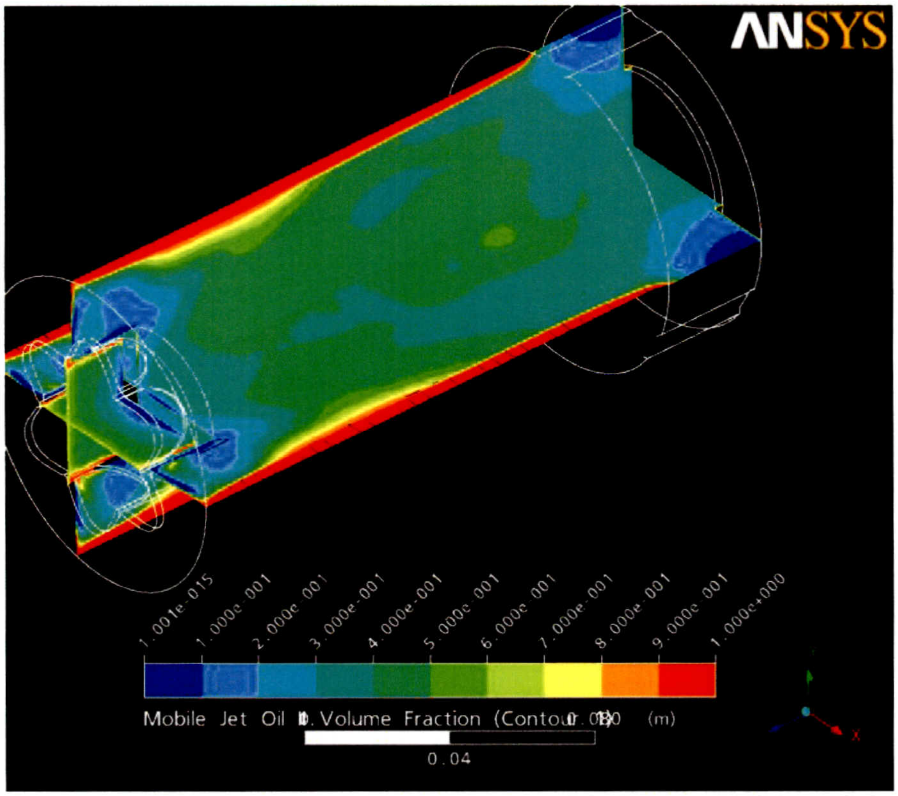


Figure 10.2.2 MJOII Volume Fraction @ 2000 RPM 75/90 Model

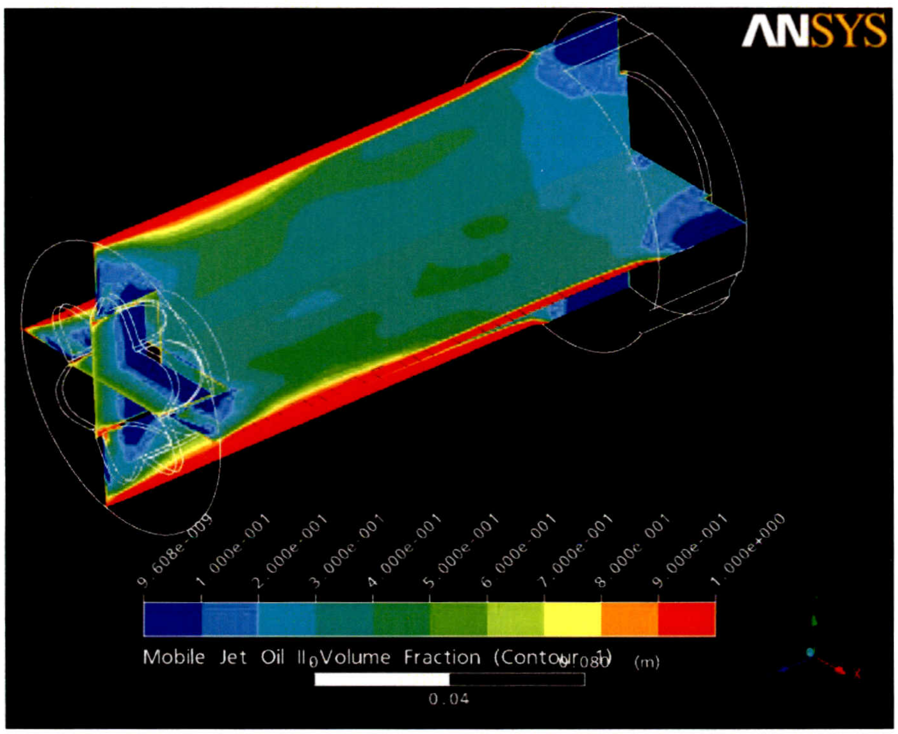


Figure 10.2.3 MJOII Volume Fraction @ 3600 RPM 75/90 Model

10.3 MUSIG Model 75/90 Deaerator

The MUSIG model yielded only initial results for this project. Utilizing the MUSIG model allows for two-phase results demonstrating the effect of random generation of size groups. This, in turn, creates different size air bubbles in two-phase flow. Also, it allows for breakup and coalescence of fluid phases. These are important results for future investigation of this project, as we have only studied the volume fraction of air inside the deaerator. Currently, we were only able to gain minimal useable results from the MUSIG model and a further investigation is required and recommended as our mass balance yields unusual results.

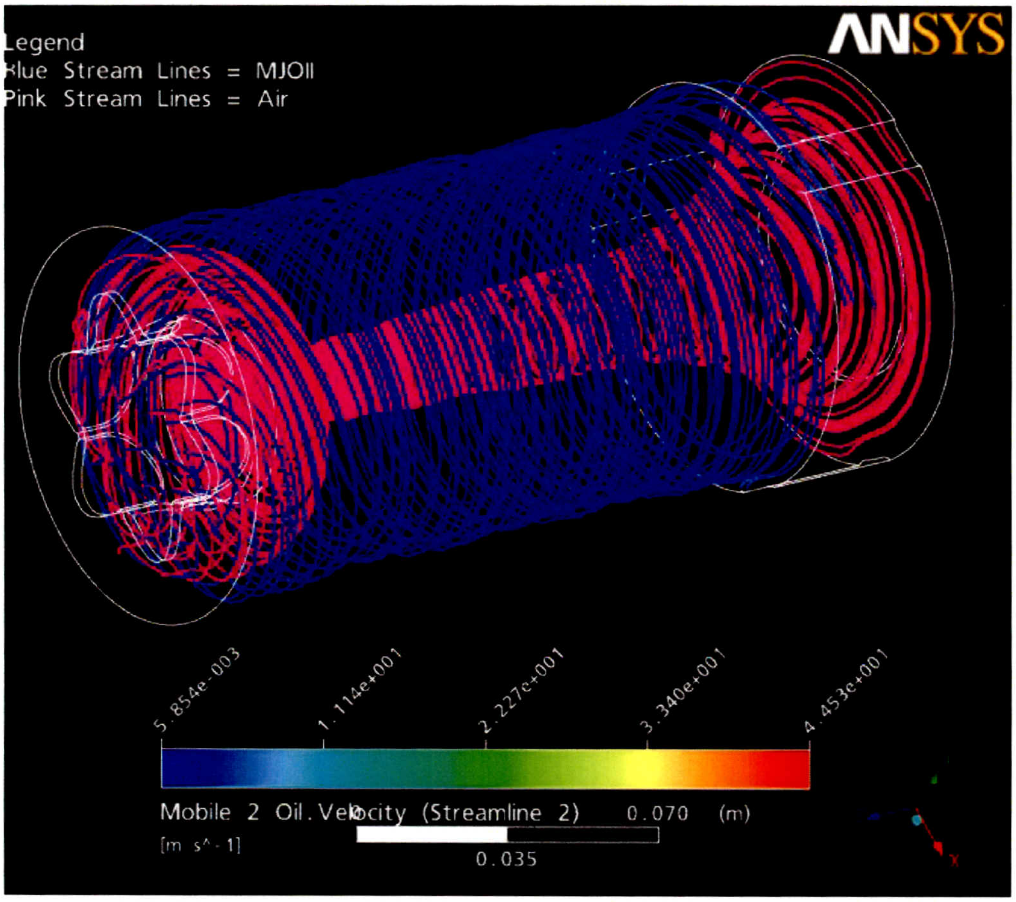


Figure 10.3.1 MUSIG Model Separation of Phases @ 3600 RPM 75/90 Model

10.4 Single Phase A320 without Inducer

Currently, as this report is written future plans of Hamilton Sundstrand is to test the A320 deaerator without the inducer next in the test rig. Therefore, with the success of the 75/90 models and the current A320 deaerator in testing with the inducer, we modeled the A320 without the inducer. The same boundary conditions exist in the simulation, except for the operating condition near 7000 RPM. The results of the A320 without the inducer have the main intention of eliminating actual testing of the deaerator in the rig. This can be accomplished with successful modeling of both with and without the inducer and demonstrating the effect of the inducer.

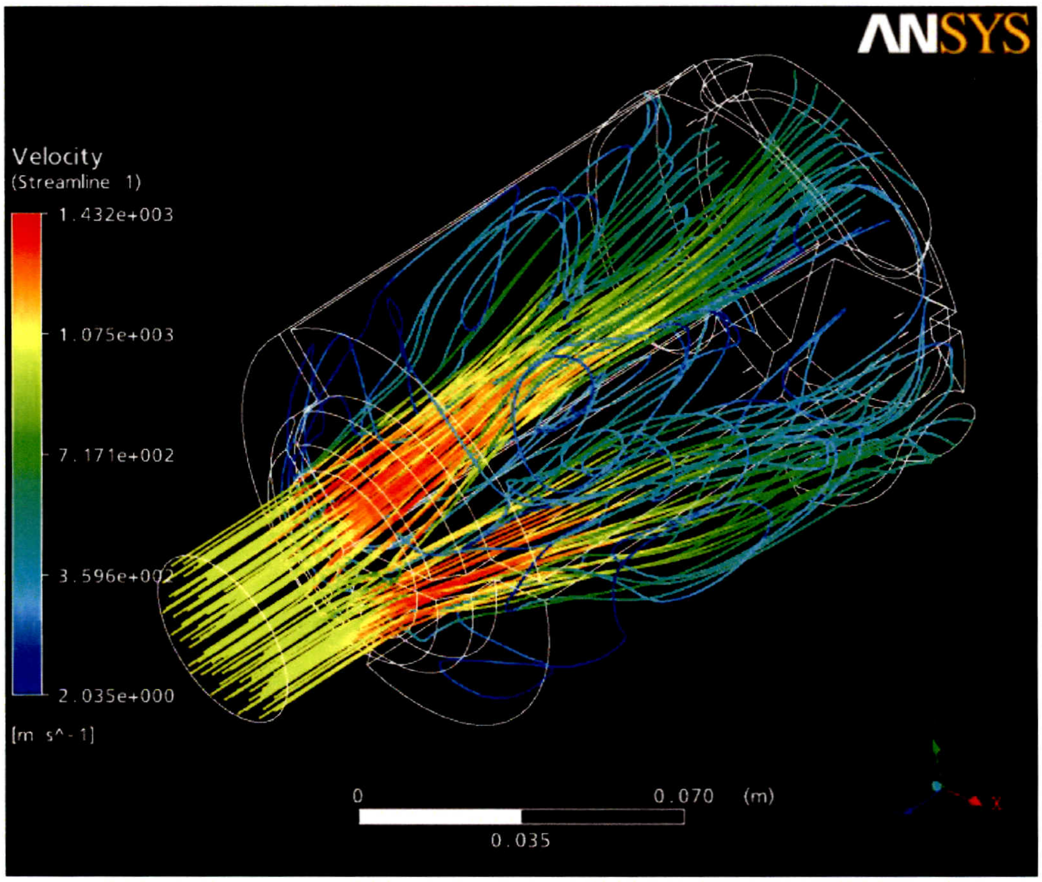


Figure 10.4.1 Stream Lines of the A320 (No Inducer) Air Only @ 0 RPM

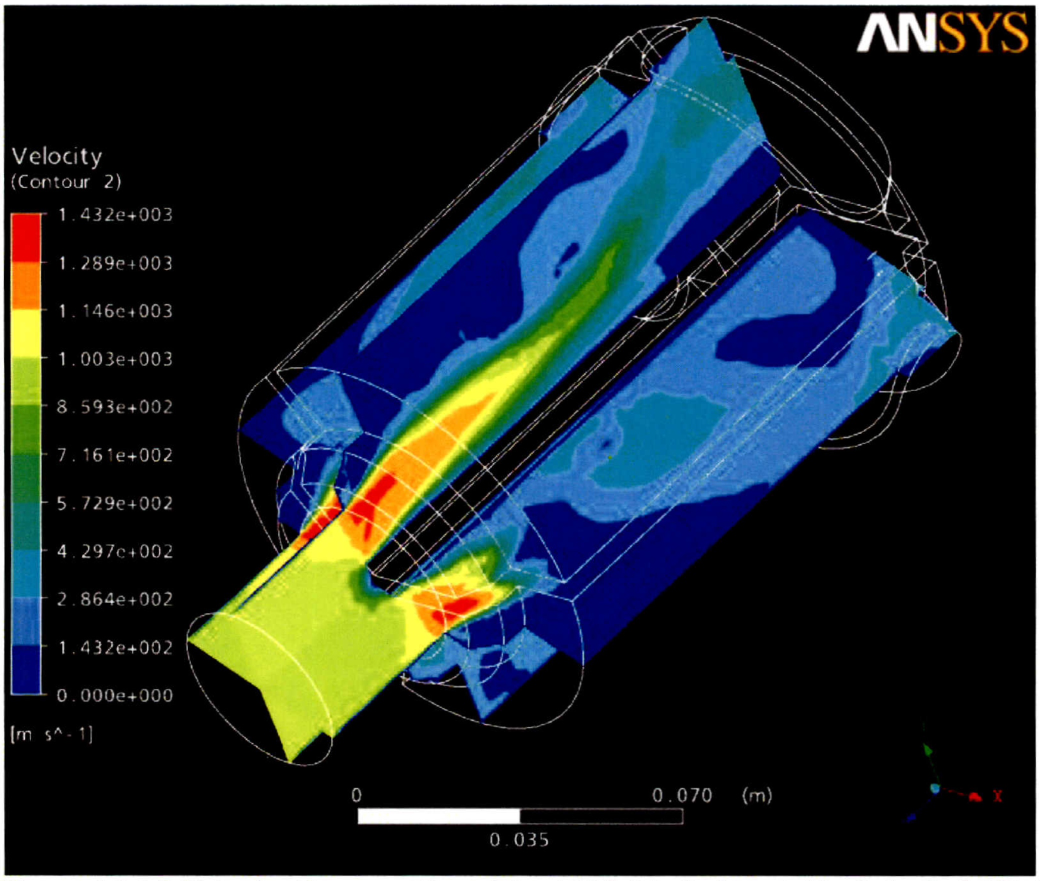


Figure 10.4.2 Velocity Contour Plot of the A320 (No Inducer) Air Only @ 0 RPM

The above results for air only in the A320 (no inducer) illustrates the velocity in stream lines and contour plots for one of the three cavities, or regions of flow seen in figure 10.4.5. As in the 75/90 air has areas of recirculation inside of each cavity. Also, the results for oil as single phase (below) demonstrate the same difference in flow due to the oil properties. At operation rotational speed of 7000 RPM, similar zero velocity areas in the center of oil flow can be seen in each cavity. It can be concluded from these results that the model is valid and ready for two-phase flow.

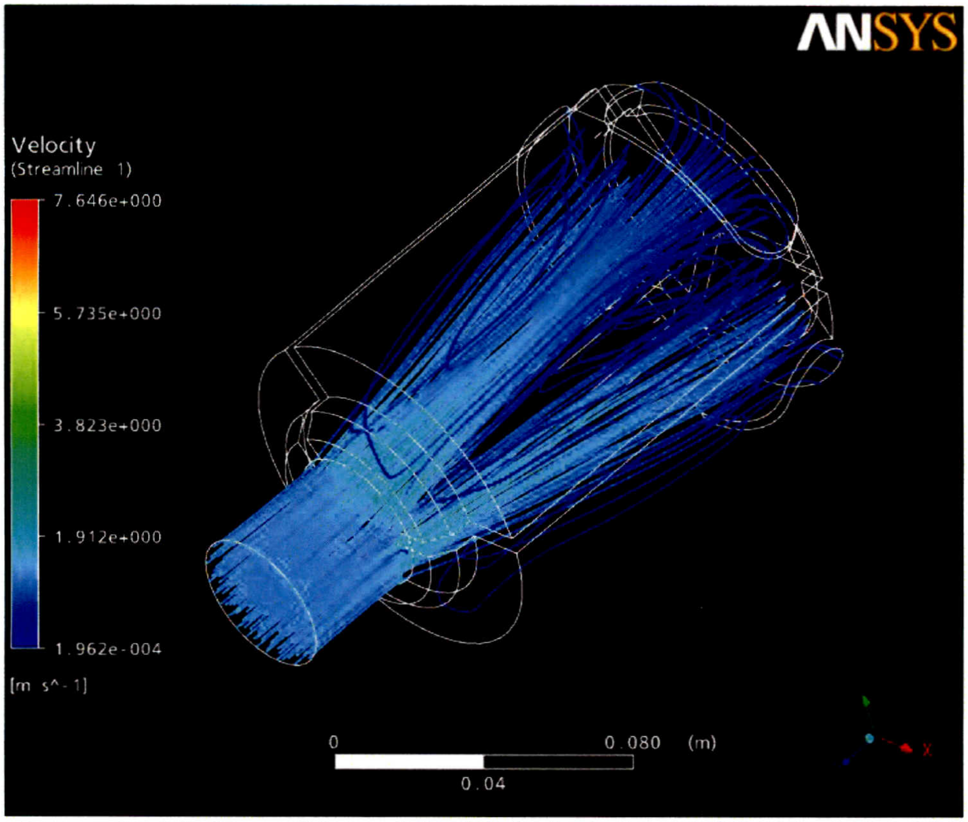


Figure 10.4.3 Stream Lines of the A320 (No Inducer) Oil Only @ 0 RPM

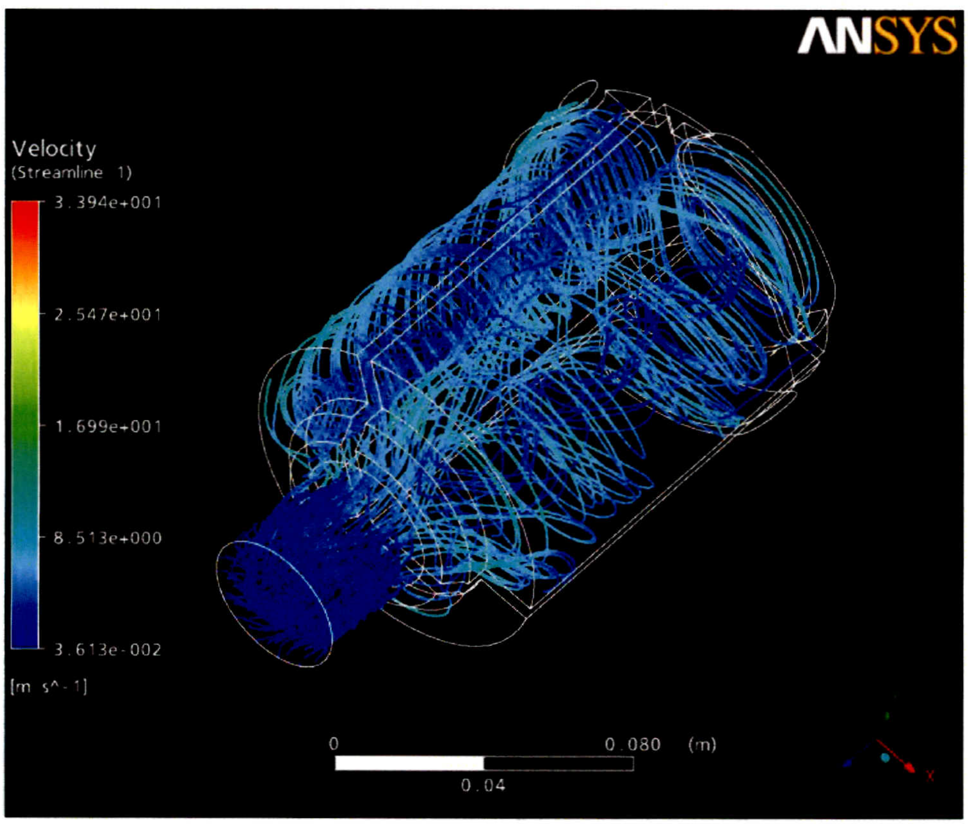


Figure 10.4.4 Stream Lines of the A320 (No Inducer) Oil Only @ 7000 RPM

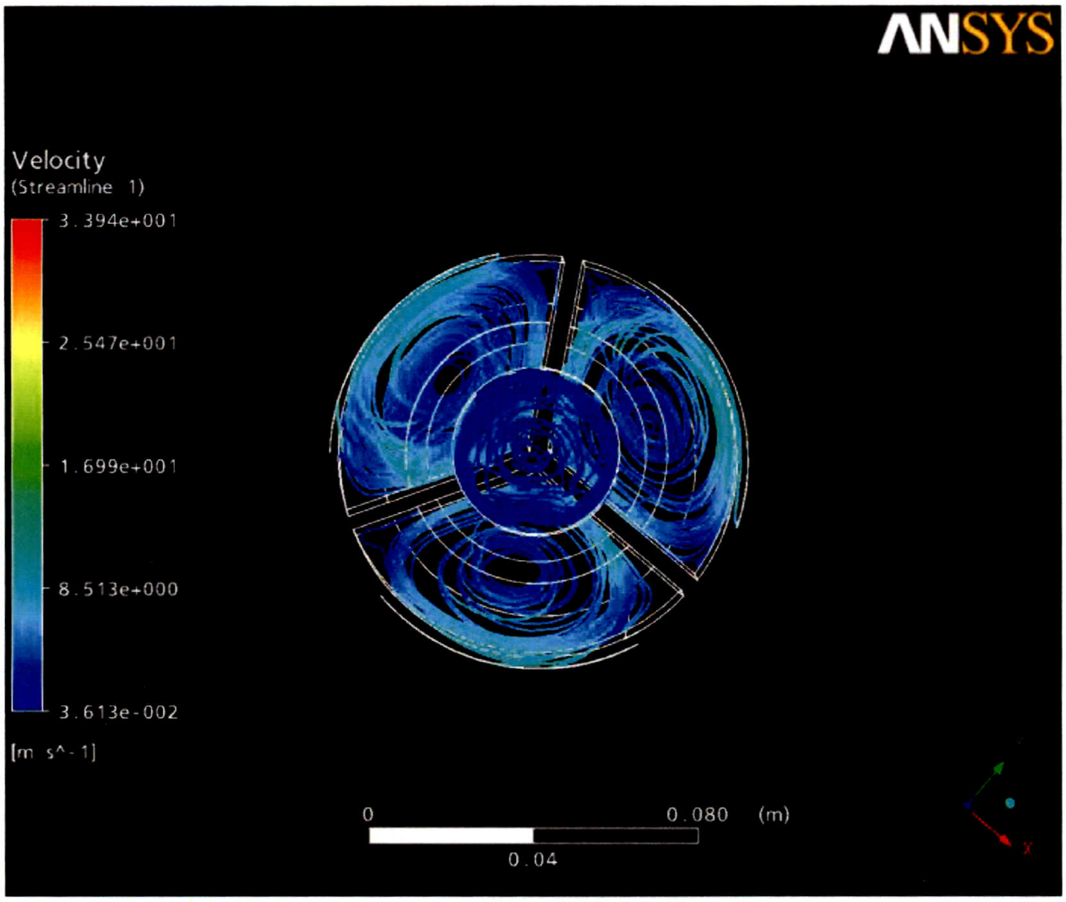


Figure 10.4.5 Stream Lines of the A320 Cavities (No Inducer) Oil Only @ 7000 RPM

10.5 Two Phase Flow A320 (No Inducer)

The results of two-phase flow in the A320 deaerator yielded the best separation of phases thus far in our simulations. In each cavity a very well defined thickness very high volume fraction of oil can be seen against the walls. These results yield a large defined area for air to separate from the oil and proceed to exit the deaerator through the air outlet. This would indicate a better design and future improvement of the CFX model is needed to confirm with absolute certainty.

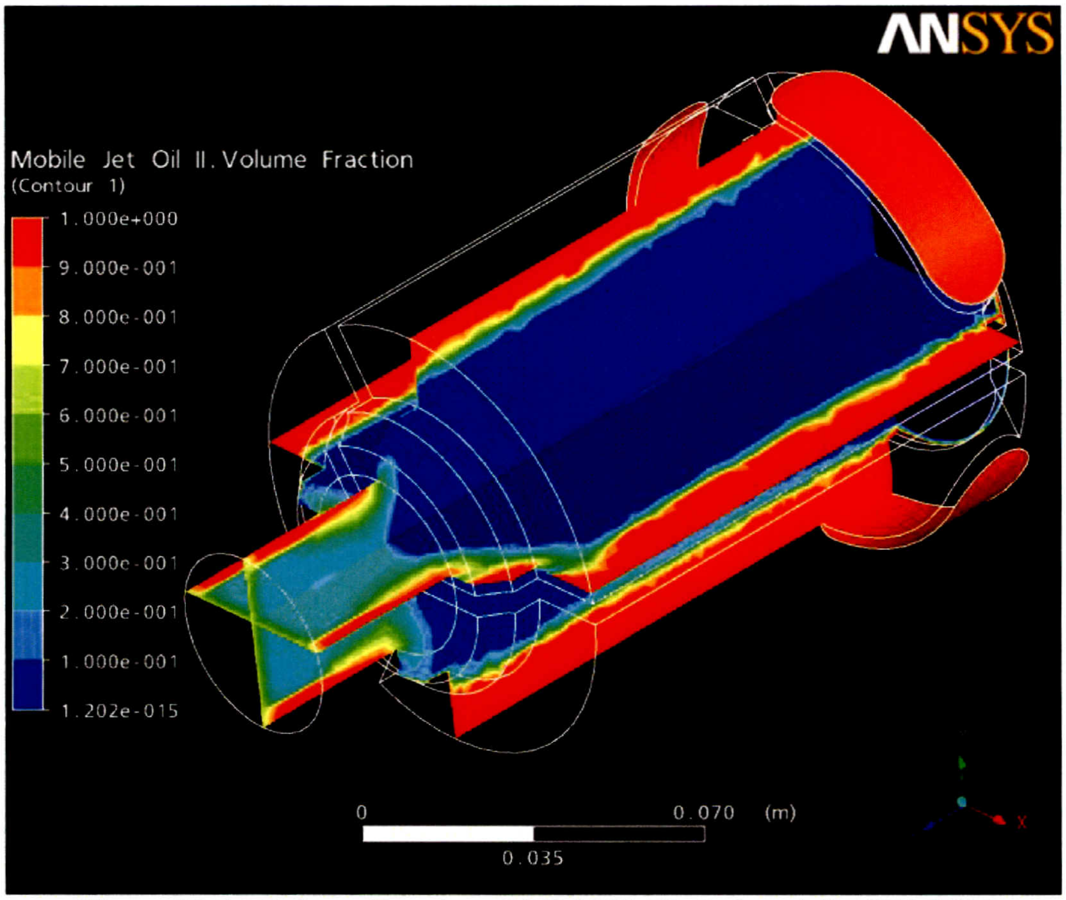


Figure 10.5.1 Volume Fraction of Oil A320 (No Inducer) @ 7000 RPM

10.6 Single Phase Flow A320 with Inducer

All current test results in this paper preceding the simulation chapter were conducted using the A320 deaerator with the inducer (A320I). Simulations of the A320I were run using the exact same boundary conditions of the previous deaerator without the inducer. Single phase results were very comparable to the previous results with added rotation and thus only illustrated below.

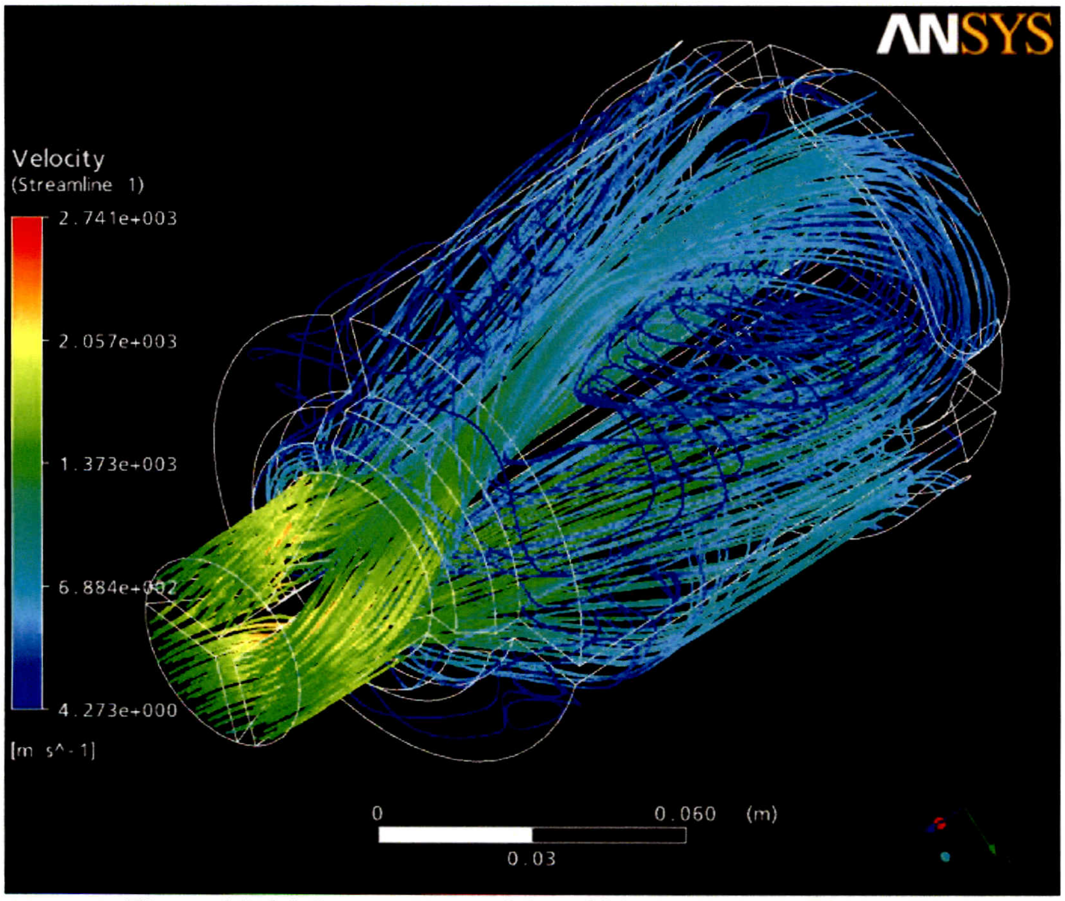


Figure 10.6.1 Stream Lines of the A320I Air Only @ 7000 RPM

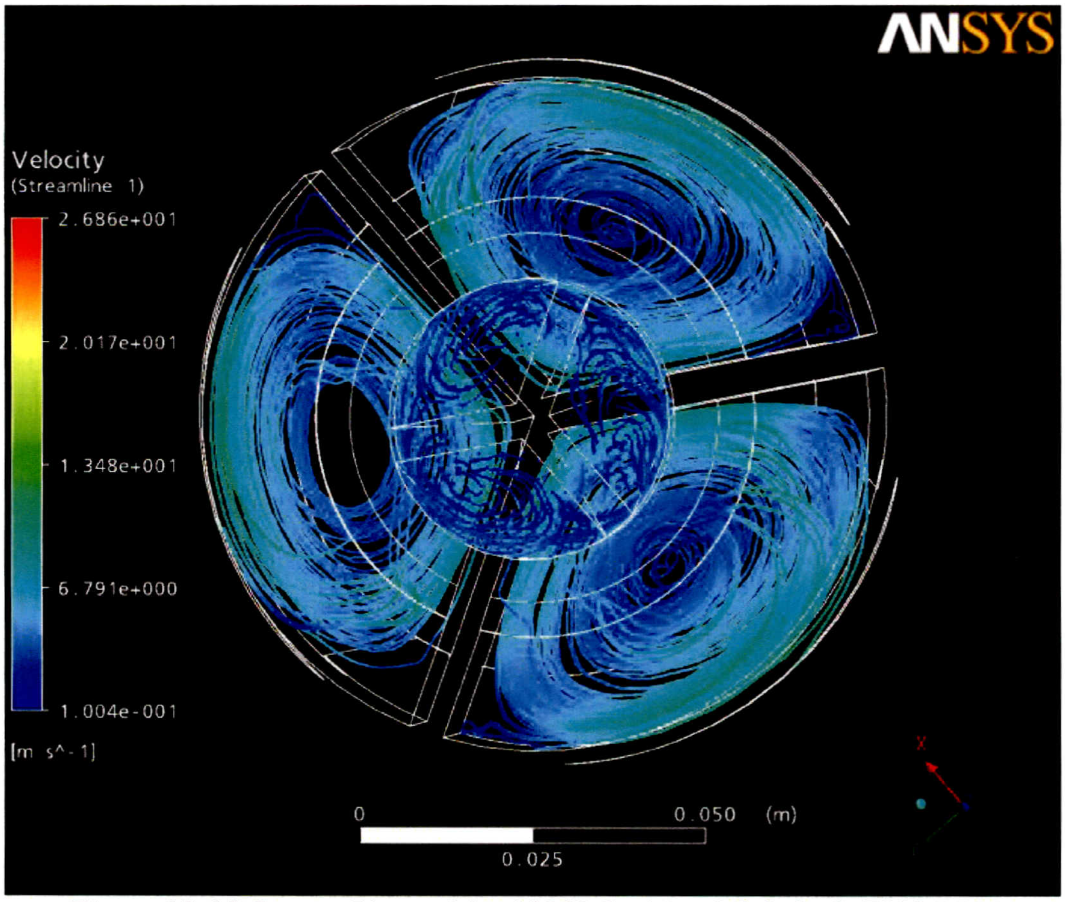


Figure 10.6.2 Stream Lines of the A320I Cavities Oil Only @ 7000 RPM

10.7 Two Phase Flow A320 with Inducer

The two phase flow results of the A320I indicate quicker and better separation of oil the walls of the deaerator. The effect of the inducer from this initial model demonstrates quicker separation, but it is unclear if this has any effect on the phases leaving the deaerator. Improvement on the two A320 models in CFX is required to investigate this difference. The results of the A320I support the idea that the internal geometry is much better than that of the 75/90.

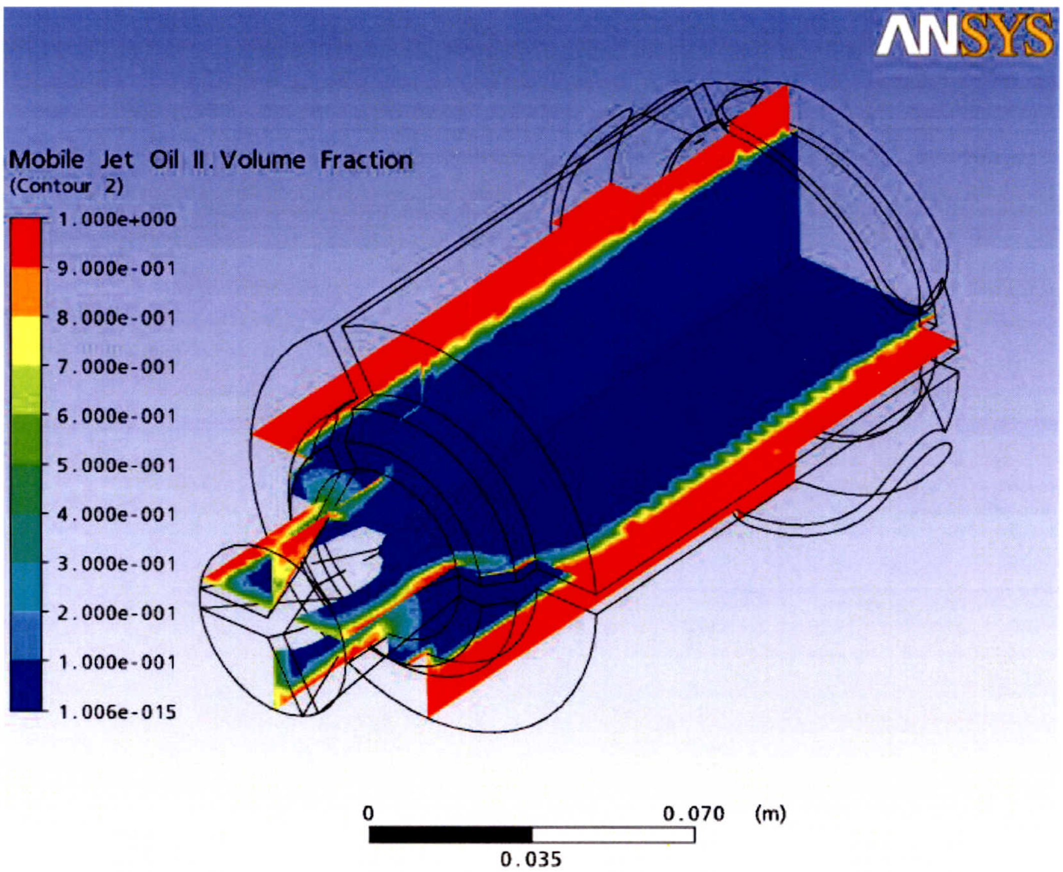


Figure 10.7.1 Volume Fraction of Oil A320I @ 7000 RPM

10.8 Two Phase Flow Comparison of A320 Models

The extensive work completed thus far on the simulation side of the deaerator has lead to the first time two different deaerators can be compared. Although these two models are very similar, we have set the foundation to compare deaerators with the possibility of not running the rig for the A320 without the inducer. In order for these results, below, to have the most accuracy we still need further investigation into the models and solutions for areas of improvement.

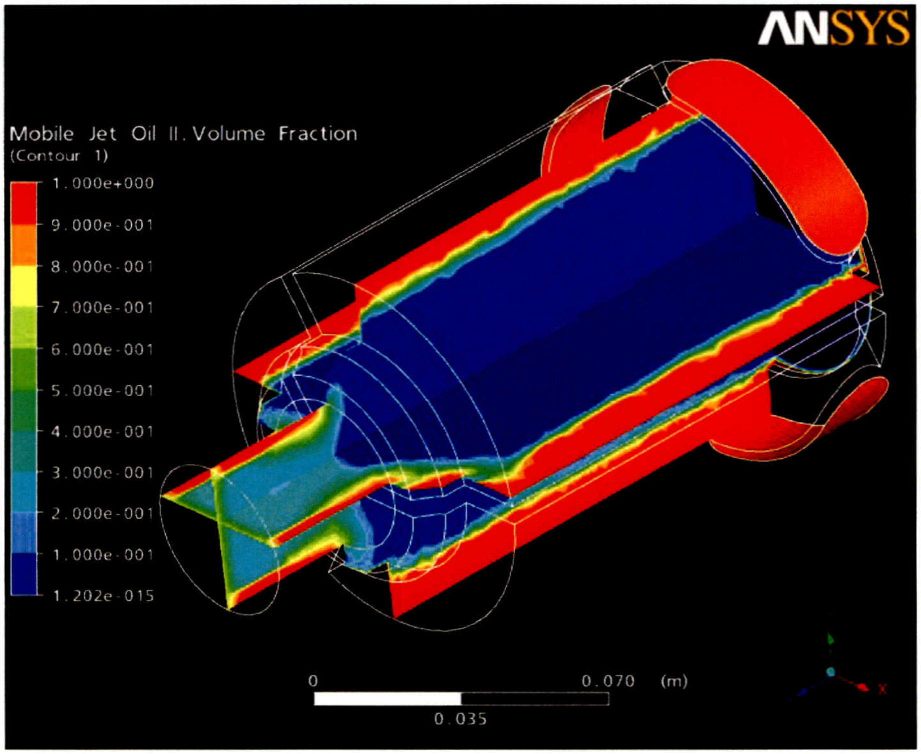


Figure 10.8.1 Volume Fraction of Oil A320 (No Inducer) @ 7000 RPM

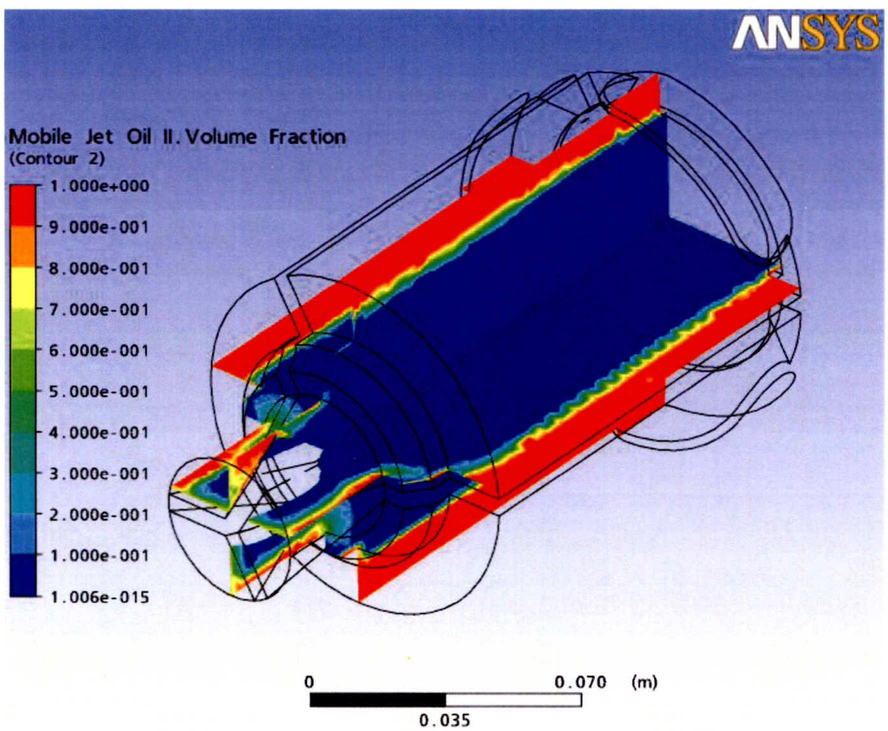


Figure 10.8.2 Volume Fraction of Oil A320I @ 7000 RPM

Chapter 11: Final Conclusion

The first task completed in this project was the collection of data for the A320 model deaerator. After validation of all testing equipment and installation of new deaerator, we were able to collect data using our new LabVIEW system. The data that we collected yielded useful and insightful results. We were able to develop useful trends relating mass ratio to pump ratios and air input values. We also noticed problems in the experimental system, especially with the A320 deaerator. Further investigation is required in testing the 1.6 to 2.0 SCFM range for air input. Also, investigation is required into the increased oil vapor at the air outlet. Therefore, validation of current data results with new operating conditions will yield final results for A320 deaerator.

Our team developed the foundation for all present and future deaerator simulations utilizing ANSYS CFX. We successfully modeled and simulated three deaerators, illustrating the effects of internal geometry on the separation of flow. These simulations are the first of its kind and have opened the door for insight into the actual operation of deaerators. Our results yielded the very first comparison of two similar deaerator models, the A320 with inducer and A320 without inducer, via simulation.

Although not yet perfect, this foundation eases the transition of the next team in the simulation aspect. Investigation into improved meshing and solution convergence will further the simulation progress to experimental and theoretical comparison. This is an important development in adding a new layer to deaerator evaluation and development. With completion of the next stage a new project goal of simulating deaerators, new and old, with minimum use of testing rig will be possible.

References

[1] Delgado N, Mbende E, Reddy N, Thomas S. (2004). *MEE 482- Project Report.*

[2] Hamilton Sundstrand. (2003). *ODAC Manual.* Hamilton Sundstrand.

[3] CFD-Online. (2008). *Meshing.* Retrieved October 11, 2008, from

http://www.cfd-online.com/Wiki/Meshing.

[4] University of California Berkeley. (2008). *Two Phase Flow.* Retrieved September 15,

2008, from http://iron.nuc.berkeley.edu/~bdwirth/Public/NE104B/documents/Expt1.pdf

[5] Justin J. Nijdam, Baoyu Guo, David F. Fletcher, Tim A.G. Langrish. (2006). *Lagrangian and Eulerian Models for Simulating Turbulent Dispersion and Coalescence of Droplets within a Spray.* University of Sydney.

[6] Yunus A. Cengel, and John Cimbala. (2005). *Fluid Mechanics.* McGraw Hill Inc.

[7] ANSYS CFX. (2006). *ANSYS CFX Manual.* ANSYS.

Appendix

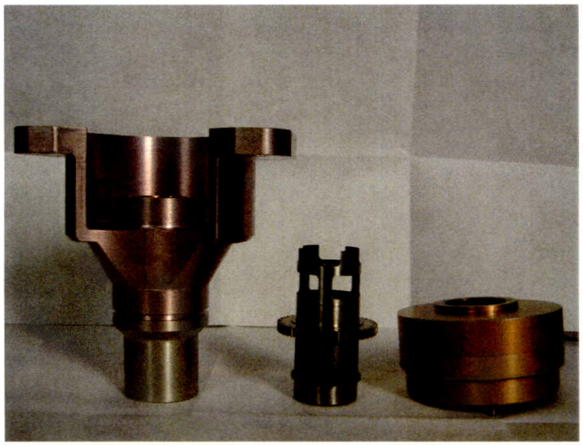


Figure 1.1.1 – Deaerator and Casing
(Left - Inlet casing, Center – Deaerator
Right - outlet casing)

Figure 1.1.2 – Deaerator 75/90
(Inlet Geometry)

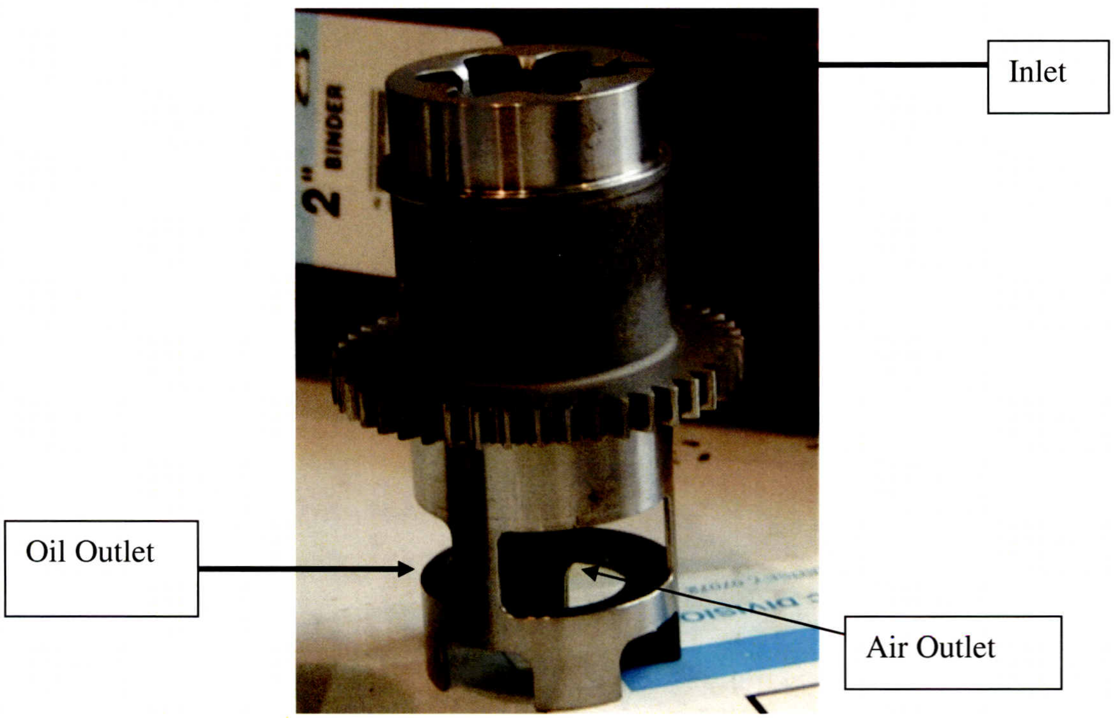


Figure 1.1.3- Deaerator 75/90
(Inlet, Oil Outlet, Air Outlet)

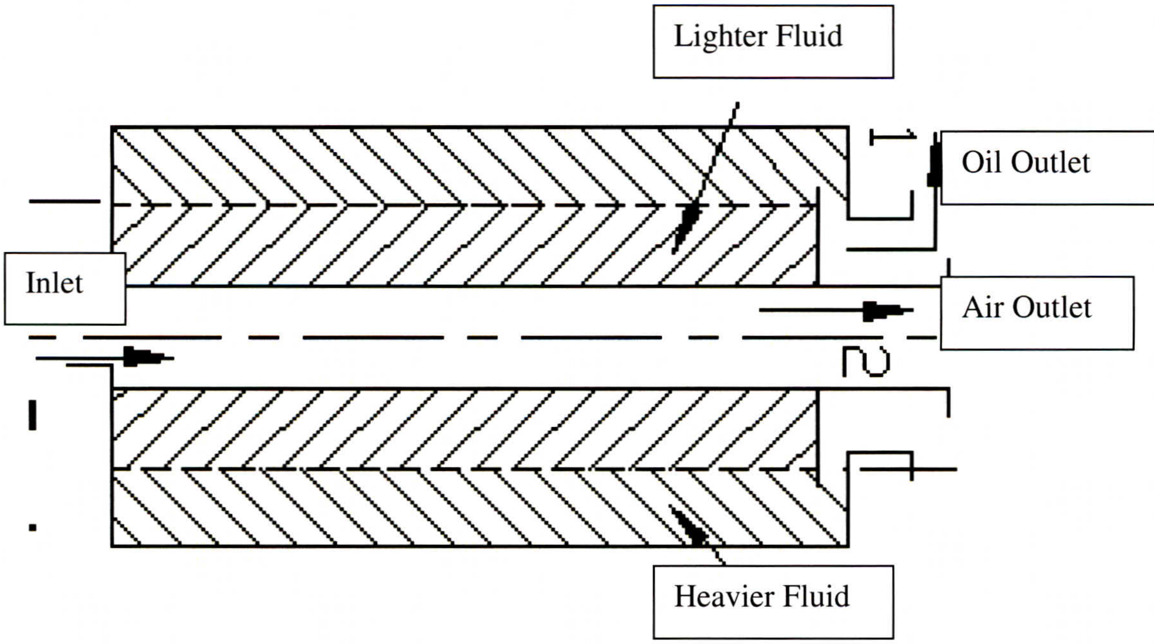


Figure 1.1.4 – Separation of Flow [5]
(Schematic for flow separation in simple deaerator)

Figure 1.2.1 – Deaerator 75/90 and A320
(Top-75/90 Deaerator Bottom – A320 Deaerator)

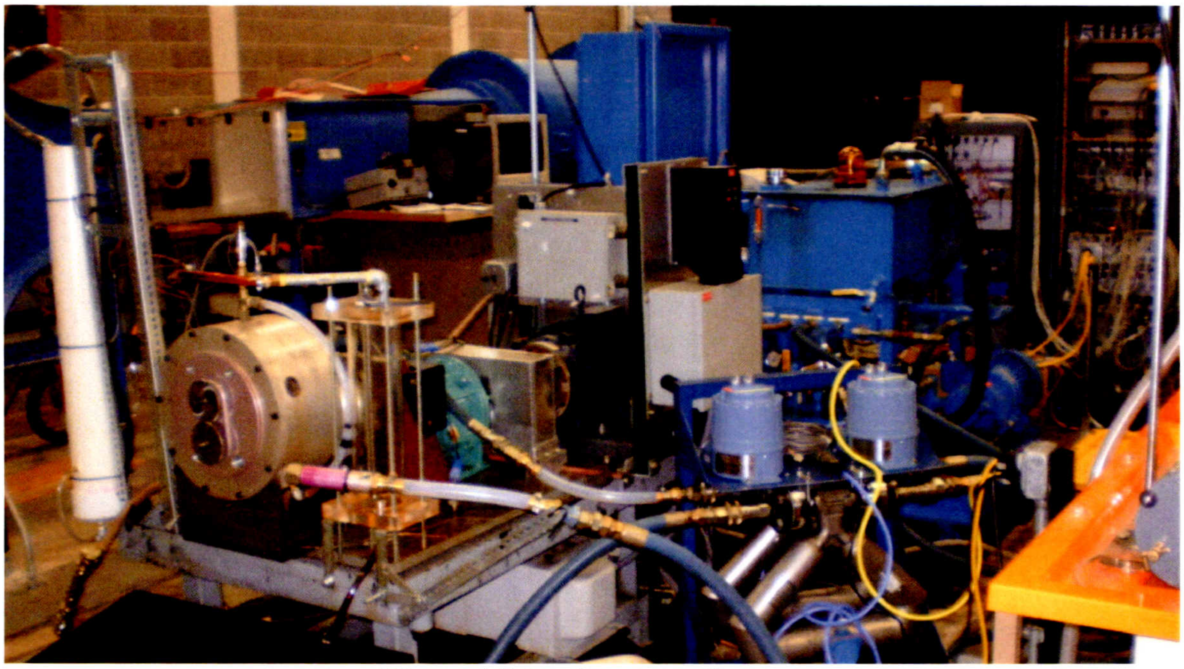


Figure 1.3.1 – Deaerator Setup
(Entire Deaerator Setup-Front View)

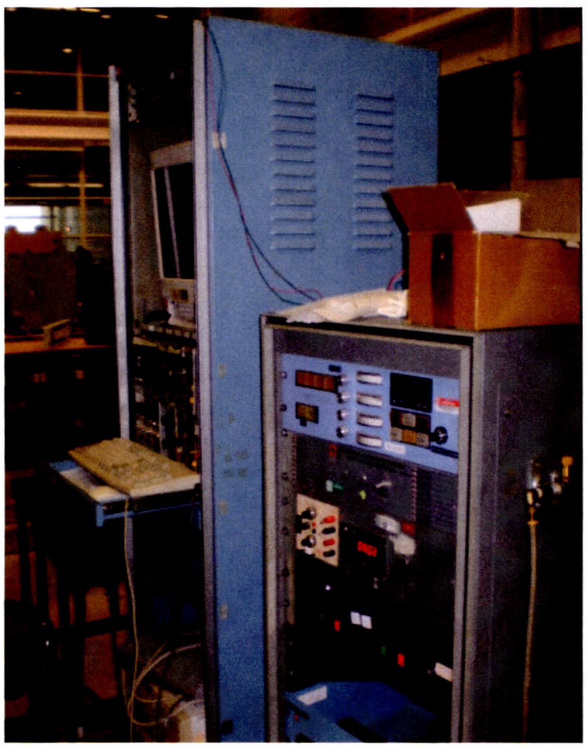


Figure 1.4.1 – Deaerator Setup
(ODAC System)

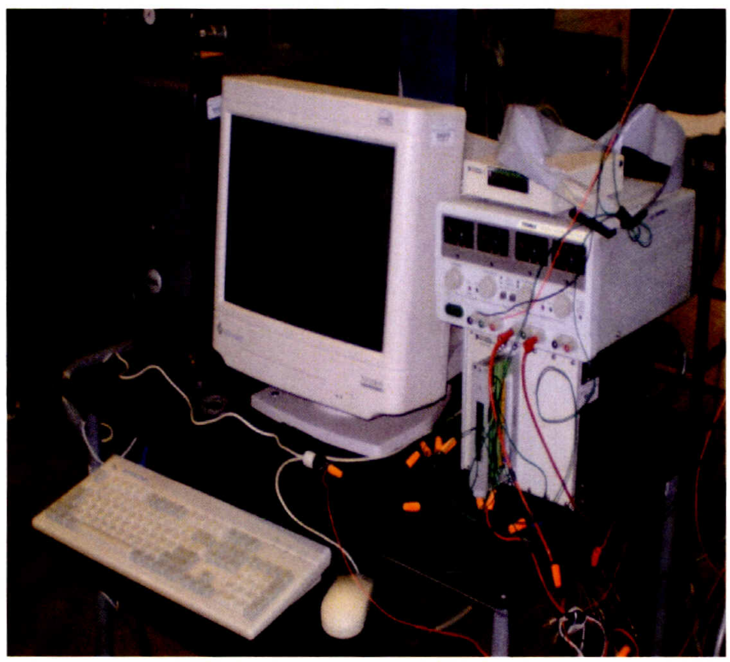


Figure 1.4.2 – Deaerator Setup
(LabVIEW System)

Hamilton Sundstrand

Project Lead: Group 1

Today's Date: 4/21/2008 (vertical red line)

Start Date: 4/21/2008 (Mon)

WBS	Tasks	Task Lead	Start	End	Duration (Days)	Working Days
1	**Testing of Deaerators**		4/21/08	10/16/08	179	129
1.1	Learning Equipment		4/21/08	4/30/08	10	8
1.2	Calibration of Sensors		6/20/08	7/04/08	15	5
1.3	Learning CFX Modeling		9/14/08	10/13/08	30	26
1.4	Fixing Gyser Saftey Issue		9/14/08	9/20/08	7	7
1.5	LabVIEW System Update		9/14/08	9/20/08	7	7
1.6	Run Test on Deaerators		10/01/08	10/14/08	14	14
1.7	Compare Results		10/15/08	10/16/08	2	2
2	**CFX/Fluent Model**		10/20/08	11/18/08	30	22
2.1	Model Existing Deaerator		10/20/08	10/26/08	7	5
2.2	Compare Results		10/27/08	11/02/08	7	5
2.3	Improve Model		11/03/08	11/18/08	16	12
3	**Final Analysis**		11/18/08	12/07/08	20	14
3.1	Validation of Results		11/18/08	11/22/08	5	4
3.2	Theoretical vs. Acutal		11/23/08	11/27/08	5	4
3.3	Efficiency Calculation		11/28/08	12/07/08	10	6

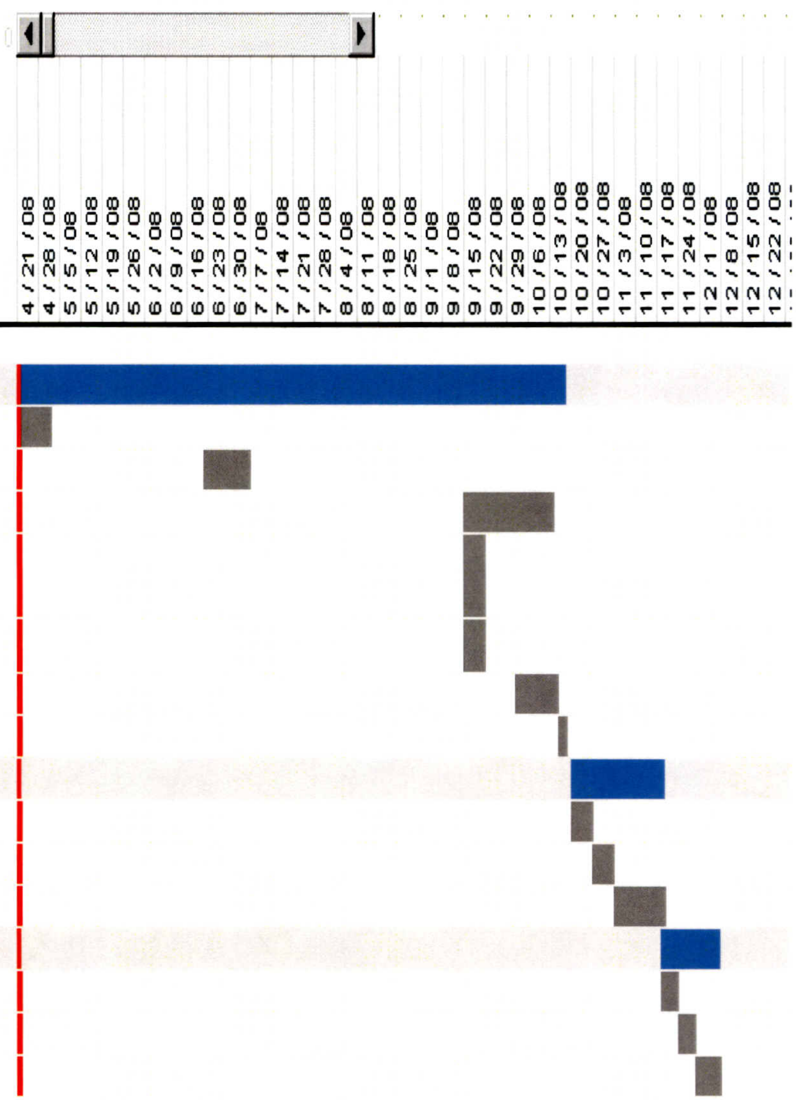


Figure 2.1.1- Time Line
(Gant Chart)

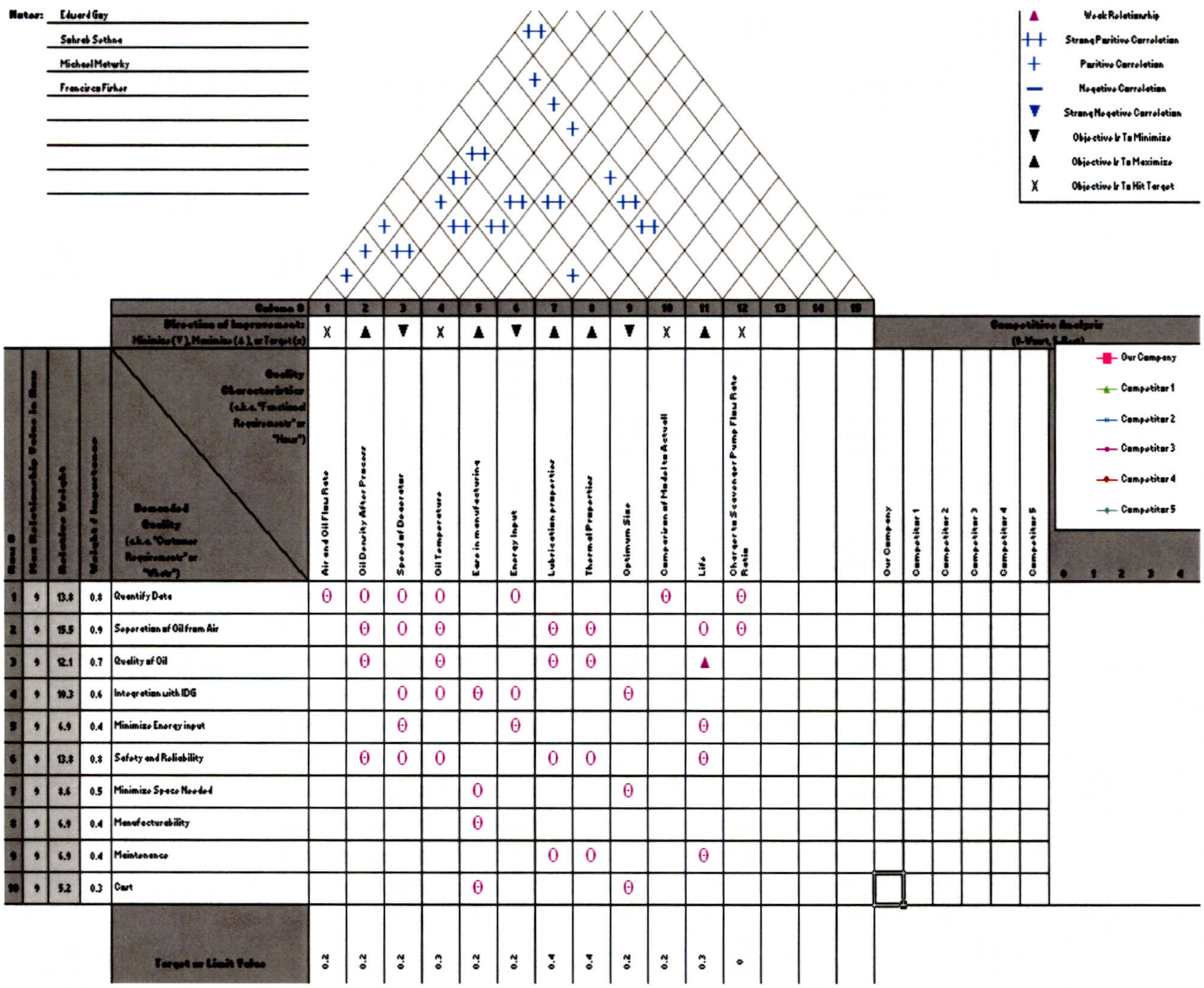


Figure 3.2.1- Process Development
(House of Quality)

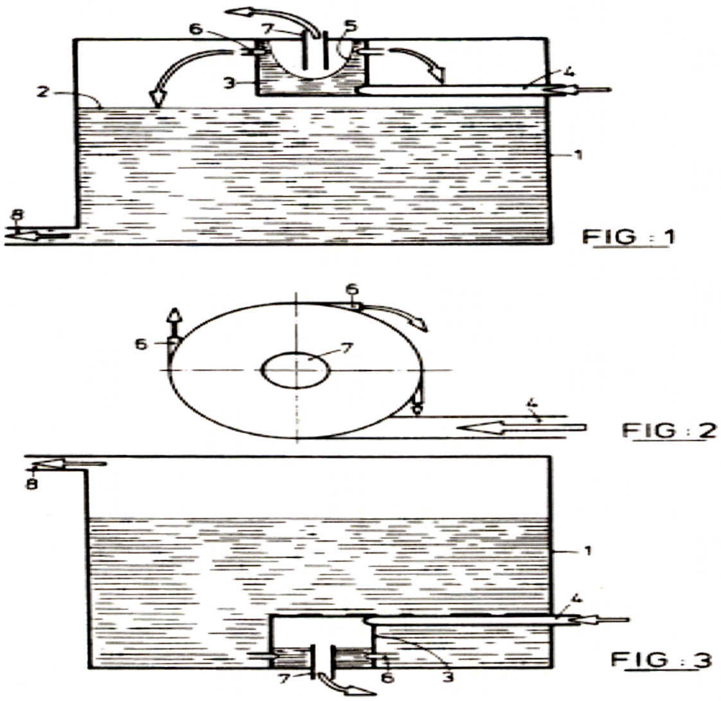


Figure3.6.1
Deaerator Patent

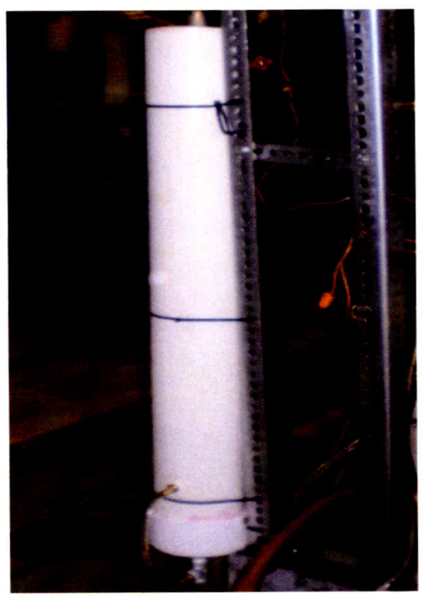


Figure 4.3.1
Oil Vapor Condenser

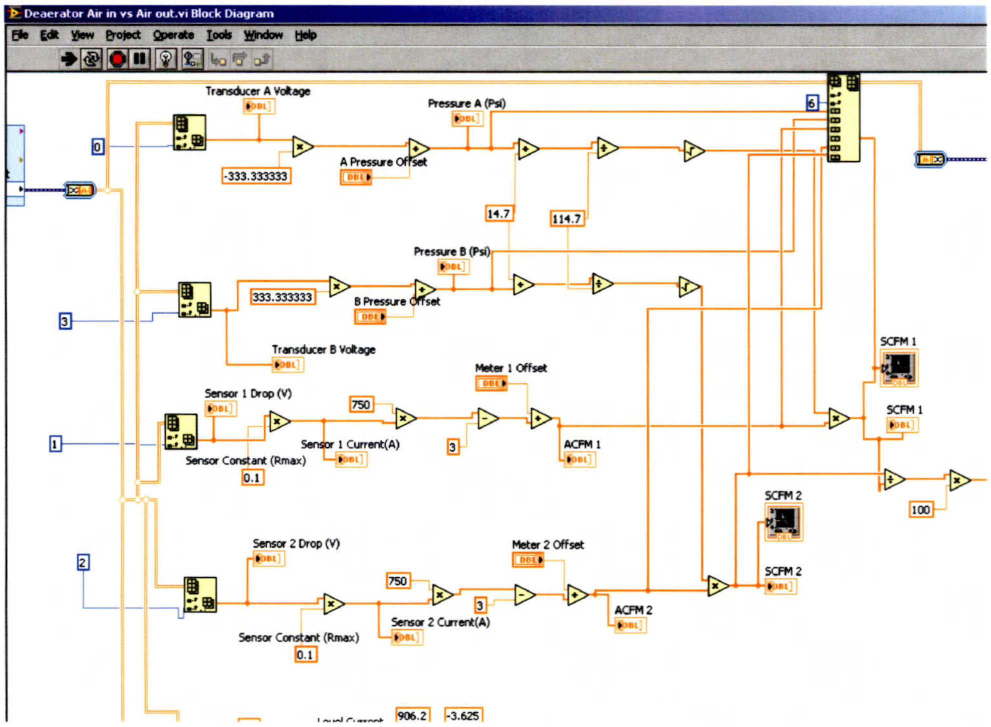


Figure 4.4.1
LabVIEW Code

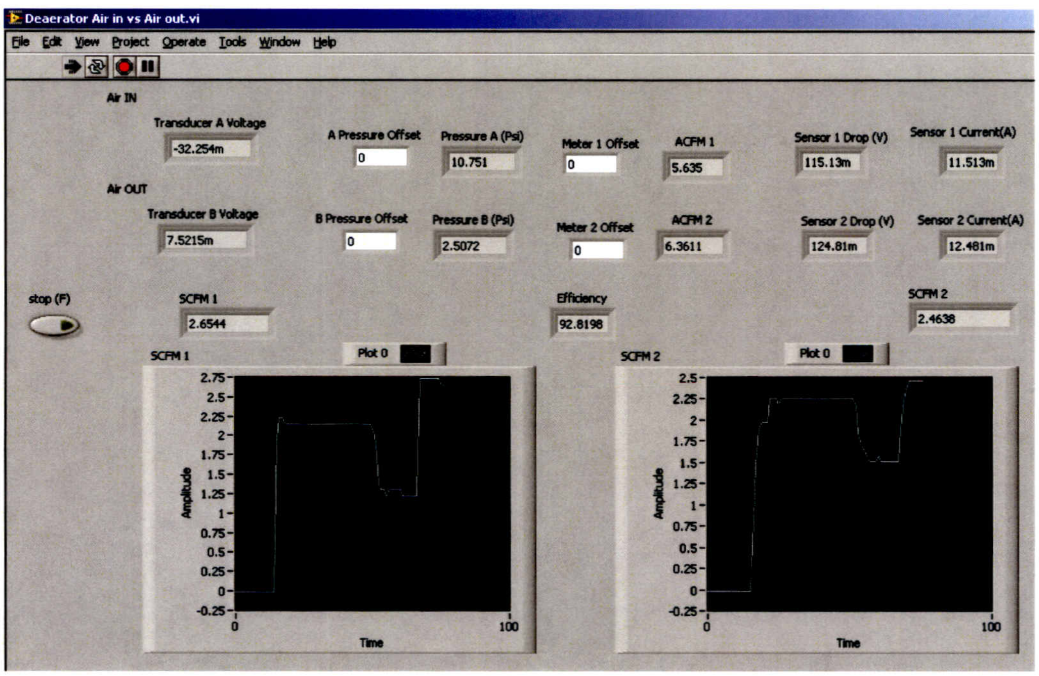


Figure 4.4.2

LabVIEW Graphical Output

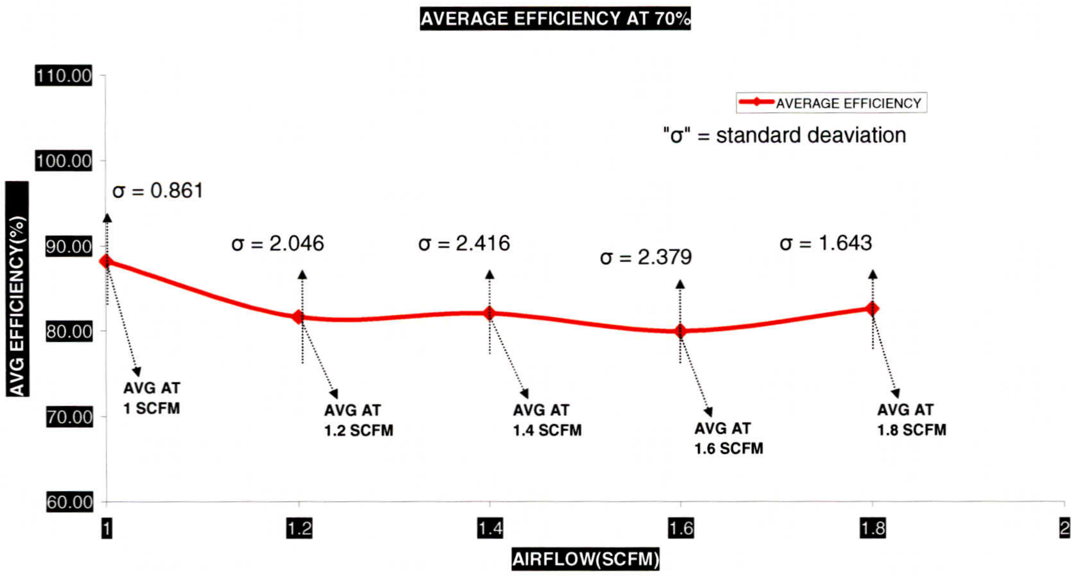


Figure 5.2.9
75/90 Deaerator efficiency at 70% pumping ratio (collected by Navakanth)

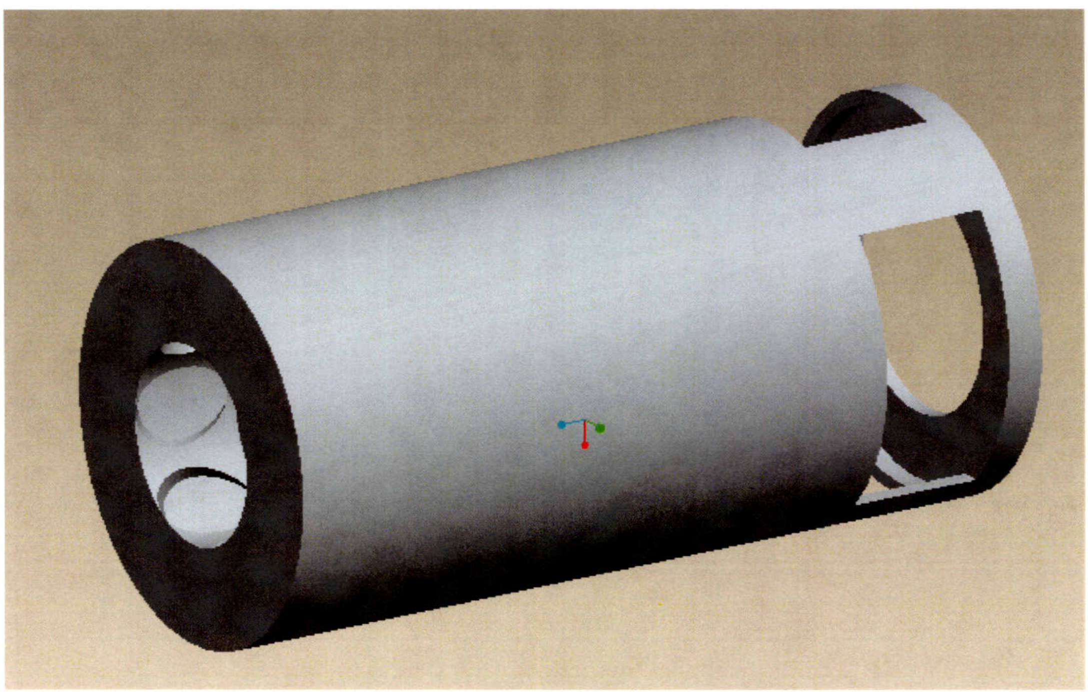


Figure 7.1.1
Pro E Deaerator Model

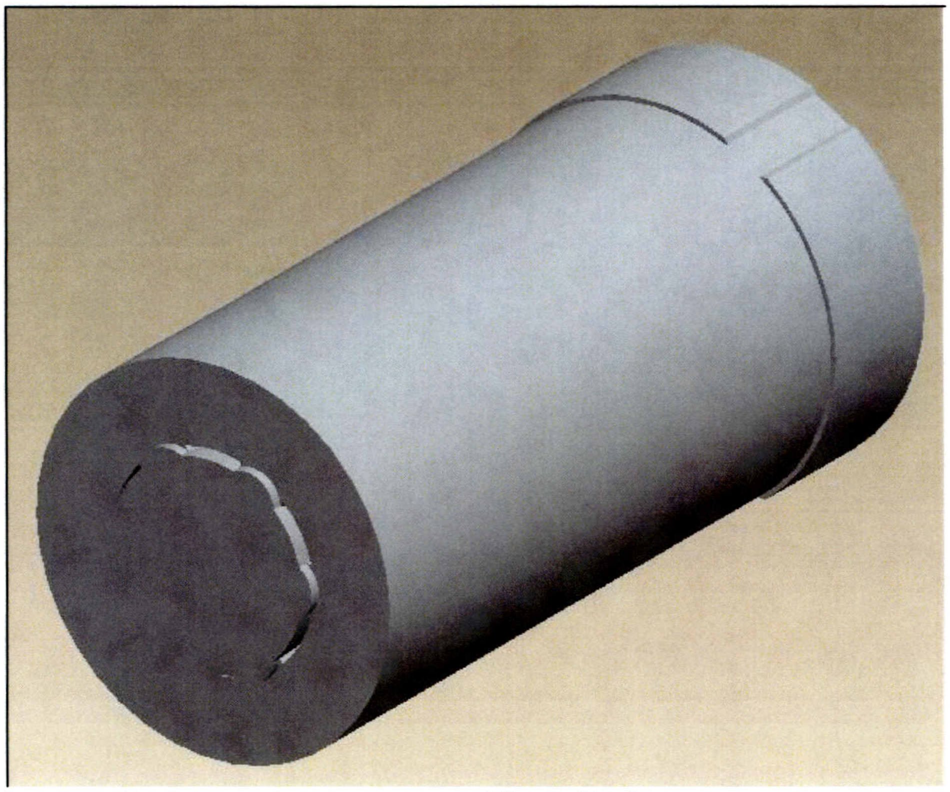


Figure 7.1.2
Pro E Flow Domain Model

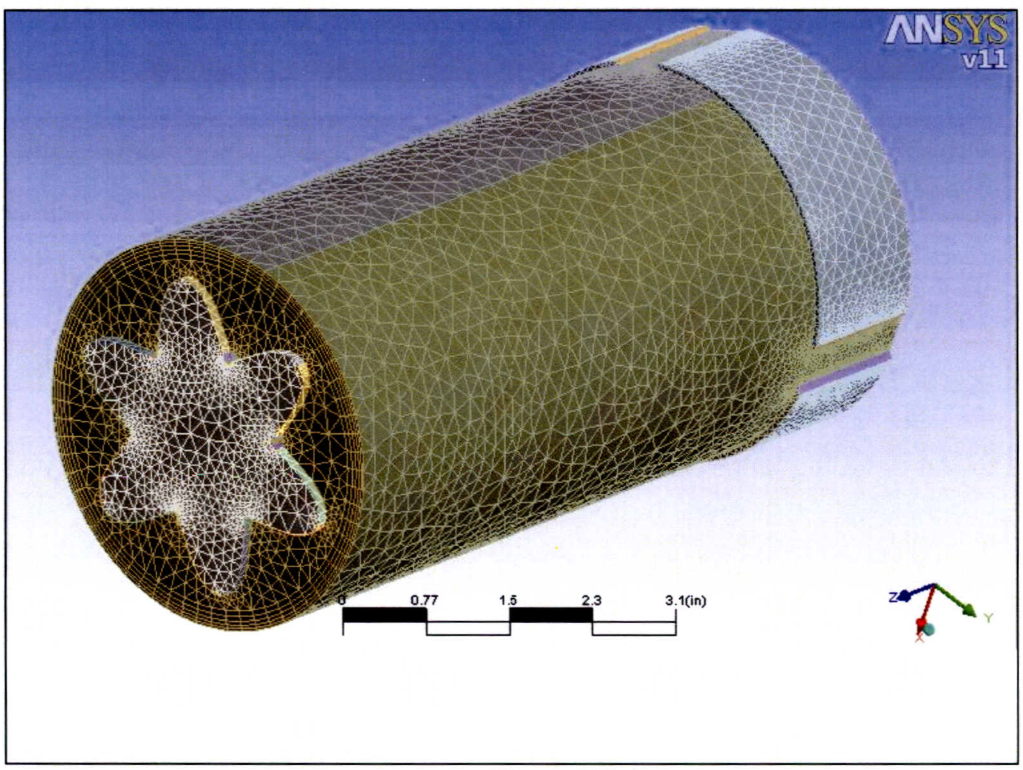


Figure 7.2.1
ANSYS Mesh