DESIGN AND ANALYSIS OF WATERJET PROPULSION ON PATROLLING VESSEL

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Fulfilment of the Requirements for the Award
of the Degree of

BACHELOR OF ENGINEERING

In

MECHANICAL ENGINEERING

By

G.KRISHNA SRIKANTH	**314126520052**
G.SAHANA	**314126520058**
K. SAI GOWTHAM	**314126520072**
B.MANOHAR	**314126520020**
A.SANTOSH CHANDRA	**314126520002**

Under the esteemed guidance of
K. SATYANARAYANA
-M.TECH, (PhD)
(**Assistant Professor**)

DEPARTMENT OF MECHANICAL ENGINEERING
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES
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ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES
(Affiliated to Andhra University, Approved by AICTE, Accredited by NBA & NAAC with A grade)
SANGIVALASA, VISAKHAPATNAM (District) – 531162

CERTIFICATE

This is to certify that the Project Report entitled "**DESIGN & ANALYSIS OF WATER JET PROPULSION ON ROLLING VESSEL**" being submitted by GAMINI KRISHNA SRIKANTH (314126520052), GOLLAPALLI SAHANA (314126520058), K SAI GOWTHAM (314126520072), BONDI MANOHAR (314126520020), ADIPUDI SANTHOSH CHANDRA (314126520002) in partial fulfillments for the award of degree of **BACHELOR OF TECHNOLOGY** in **MECHANICAL ENGINEERING** of **ANDHRA UNIVERSITY**. It is the work of bona-fide, carried out under the guidance and supervision of **Mr. K.Satyanarayana**, Assistant Professor, Department Of Mechanical Engineering, ANITS during the academic year of 2014-2018.

PROJECT GUIDE

(Mr. K.Satyanarayana)
Assistant Professor
Mechanical Engineering Department
ANITS, Visakhapatnam.

Approved By
HEAD OF THE DEPARTMENT

(Dr. B. Naga Raju)
Head of the Department
Mechanical Engineering Department
ANITS, Visakhapatnam.

PROFESSOR & HEAD
Department of Mechanical Engineering
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES
Sangivalasa-531 162 VISAKHAPATNAM Dist A P

THIS PROJECT IS APPROVED BY THE BOARD OF EXAMINERS

INTERNAL EXAMINER:

Dr. B. Naga Raju
M.Tech,M.E.,Ph.d
Professor & HOD
Dept of Mechanical Engineering
ANITS, Sangivalasa,
Visakhapatnam-531 162.

EXTERNAL EXAMINER:

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Project Members

G. KRISHNA SRIKANTH	- (314126520052)
G. SAHANA	-(314126520058)
K.SAI GOWTHAM	- (314126520072)
B. MANOHAR	-(314126520020)
A.SANTOSH CHANDRA	-(314126520002)

ABSTRACT

The main objective of this Project is to Design and carry out the Analysis of a water jet propulsive patrolling vessel along the coast, in the rivers, in the lakes. Main aim is to define the project with improved propulsive efficiency by working on analysis of cavitation and flow analysis with model of 6 bladed propeller using CFX. This project illustrates the modelling and analysis of a water jet propeller installed in Patrolling vessel in order to achieve improved propulsive efficiency.

The modelling and analysis of water jet propulsion system was performed to provide detail understanding of complicated three-dimensional viscous flow phenomenon including interactions of intake duct, impeller, stator and contracted discharge nozzle. To handle interface boundary between stator and rotor, the complicated viscous flow feature of water jet flow such as the secondary flow inside the intake duct, the recovery of axial flow by the action of stator and tip vortex etc., were well understood by the present simulation. The performance of thrust and torque is predicted.

The hydrodynamic pressure changes, detailed flow analysis, velocity stream flow and cavitation analysis were done with a 6 bladed Impeller using CFX. This work helps in understanding the cavitation and flow with the respective blade and prospects with the change in number of blade can be reviewed. Improved propulsive efficiency with respect to change in blade rake angle can be achieved with this analysis.

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CHAPTER 1

INTRODUCTION

1. INTRODUCTION

1.1 INTRODUCTION OF HINDUSTAN SHIPYARD LIMITED:

Hindustan Shipyard Limited (HSL) the pioneer ship building industry in India is the first ISO 9001-2000 certified shipyard of the nation and currently certified by ISO 9001-2008 strategically located on the East Coast of India in Andhra Pradesh at Visakhapatnam at 83.17’E longitude and 73.41’N latitude. It is the part of the natural harbour of Visakhapatnam.

The harbour provides a direct natural passage into the yard. It is located at a distance of 15 KM from the city at Scindia and is well connected from all the parts of the city. The yard is precisely and compactly laid out of 46.2 Hectors area of land. The organization has outstanding infrastructure, trained workforce, wealthy experience and proficiency in building and repairing ships of all types. By making audacious investments in encouragement talent and raise its technologies and services. HSL is making great strides towards becoming a leader in ship building and ship repairs.

It has an tremendous track record of consistency and value of product. With its full-fledged facilities, the yard is specialized in submarine repairs. The shipyard had built 172 vessels and repaired nearly 1904 ships and can put forward the wide-ranging services beneath the crown in design, erection, renovation and repairs.

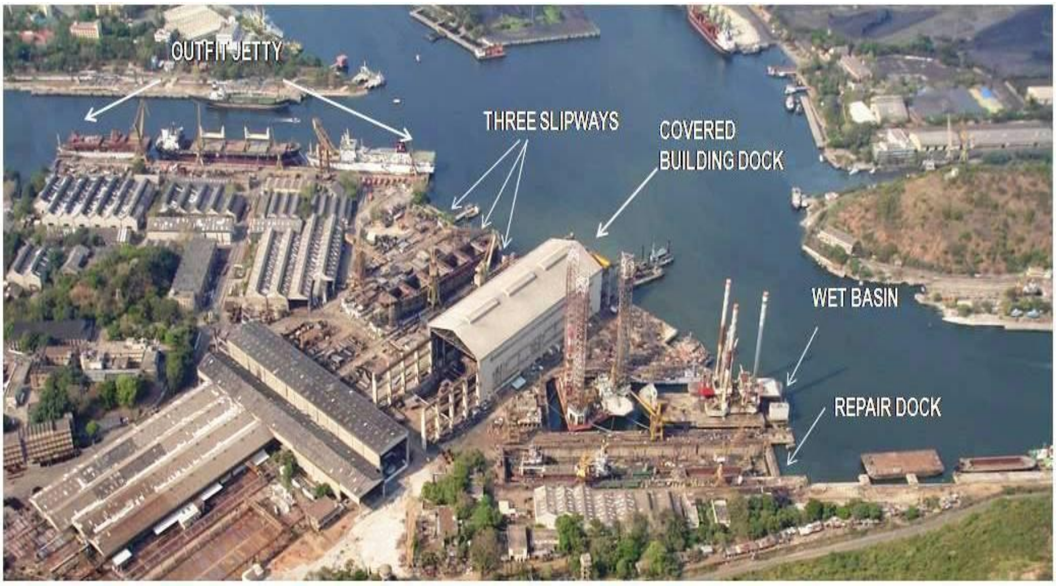


Fig1.1 LAYOUT OF HSL

The yard has three slipways, a covered building dock, a wet basin and a dry dock along with necessary facilities required for shipbuilding, ship repairs and submarine repairs.

Over a period of time the yard has been able to emerge as a one of the major players in the Indian maritime sector. The factors that make HSL stand out are as under:-

- Largest shipyard on the East coast of India.
- Well laid out facilities with steel throughput capacity of 20000 tons/ year.
- Only shipyard with submarine repair capability on the East coast.
- Large covered building dock for un-interrupted work round the year.
- Strategically located at harbour entrance (water depth of about 10 mt).
- Located close to major customers viz. ENC, DCI and VPT.
- Capable of building ships up to 80,000 DWT.
- Excellent Quality of work with low rejection rates.
- 850 m of wharf age with adequate carnage.
- Large dry-dock & wet basin with exclusive workshops to facilitate ship repairs.
- Carnage to handle blocks / loads up to 300 tons.
- Three low bed transporters up to 200 tons capacity.
- ISO 9001 / 2008 certified yard
- Good quality assurance system & test facilities.

1.1.1 HISTORICAL BACKGROUND OF HSL:

Scindia Steam Navigation Company (SSNC) was established at the present place of HSL in 1941. After building 8 ships, the SSNC was unable to finance the organizations, considering the national and strategic importance of the ship industry. The government of India acquired two third of the share in 1952 and the balance of one-third was held by this Scindia Steam Navigation Company. Later in July 1961 the remaining share was also acquired by the government on India and has renamed it as ‘HINDUSTAN SHIPYARD LIMITED’.

Fig1.2 LAYOUT OF SSNC

VARIOUS DEPARTMENTS IN HSL:

The departments in the shipyard are broadly classified into three categories:

- Ship building department
- Ship repair department
- Submarine retrofit department

The departments/divisions in the HSL can broadly be classified into two categories, they are:

I. Technical

  a. Production departments

    - Hull shop department
    - Prefabrication department
    - Erection department
    - Loft department
    - Shipwright department
    - Hull testing department
    - Welding department
    - Black smith department
    - Joiners and Carpentry department
    - Sheet metal department
    - Rigging department

  - Painting department
  - Electrical department
  - Plumbing department
  - Engineering department
  - Galvanizing department

b. Non – production departments

  - Design office
  - Quality assurance and quality check
  - Purchase and material department

II. Non – technical

  - Personal and administration department
  - Finance/accounts department
  - Services

ACTIVITIES AT HSL:

The main activities of the Hindustan Shipyard Limited are as follows:

- Ship Building
- Ship repair
- Submarine Retrofit
- Construction and repair of onshore and offshore structures

1.1.2 SHIP BUILDING:

The yard is outfitted with the plasma cutting machines, steel processing facilities, material handling and transportation equipment, cranes and sizes, logistic and storage conveniences, Quality Check division with testing and measuring services & welding machinery to ensure that the vessels are constructed as per the rules and of excellence standards. The shipyard has division and out-and-out infrastructure and amenities for ship building.

1.1.3 SHIP REPAIR:

The yard has a full-fledged and independent ship repair department with a Graving dock, Wet basin, Outfit jetty and other facilities. Almost 1904 ships including cargos, bulk carriers, petrol vessels, and passenger ships were repaired at the yard till date.

1.1.4 SUBMARINE RETROFITTING:

HSL is specialized in submarine repairs. It has repaired various submarines like F-Class submarine and 877EKM submarine. It has all sort of infrastructure to carry out the submarine retrofitting process.

1.1.5 CONSTRUCTION AND REPAIR OF ONSHORE AND OFFSHORE STRUCTURES:

Type of Ships (Sector)	No. of ships delivered by HSL
Maritime sector	121
Defence Sector	11
Oil sector	22
Total	154

TABLE1: PROJECTS OF HSL

1.2 INTRODUCTION TO SHIPS:

SHIP:

A ship may be regarded as vessel of hollow structures made to float on water and capable of conveying goods from one place to another across the surface of water.

Ship, vessels that is buoyant in the water and used to transport people or cargo from one place to another via rivers, lakes or oceans. Traditionally, ships were distinguished from boats by size any buoyant vessels small enough to fit on board a ship was considered a boat. Based on" Archimedes" principle ships will float.

ARCHIMEDE 'S PRINCIPLE:

- An object is subjected to an upward force when it is immersed in liquid. The force is equal to the weight of the liquid displaced.
- This principle also known as the law of hydrostatics, applies to both floating and submerged bodies to all fluids.

BUOYANCY:

Buoyancy is an upward force exerted by a fluid that opposes the weight of an immersed object. In a column of fluid, pressure increases with depth as a result of the weight of the overlying fluid experiences greater pressure than at the top. This difference in pressure results in a net force that tends to accelerate an object upwards. The magnitude of that force is proportional to the difference in the pressure between the top and the bottom of the column and (as explained by Archimedes principle) is also equivalent to the weight of the fluid that would otherwise occupy the column that is the displaced fluid.

Any object will either float or sink in water depending upon the density. If it is more dense than water it will usually sink. If it is less dense than water it will float.

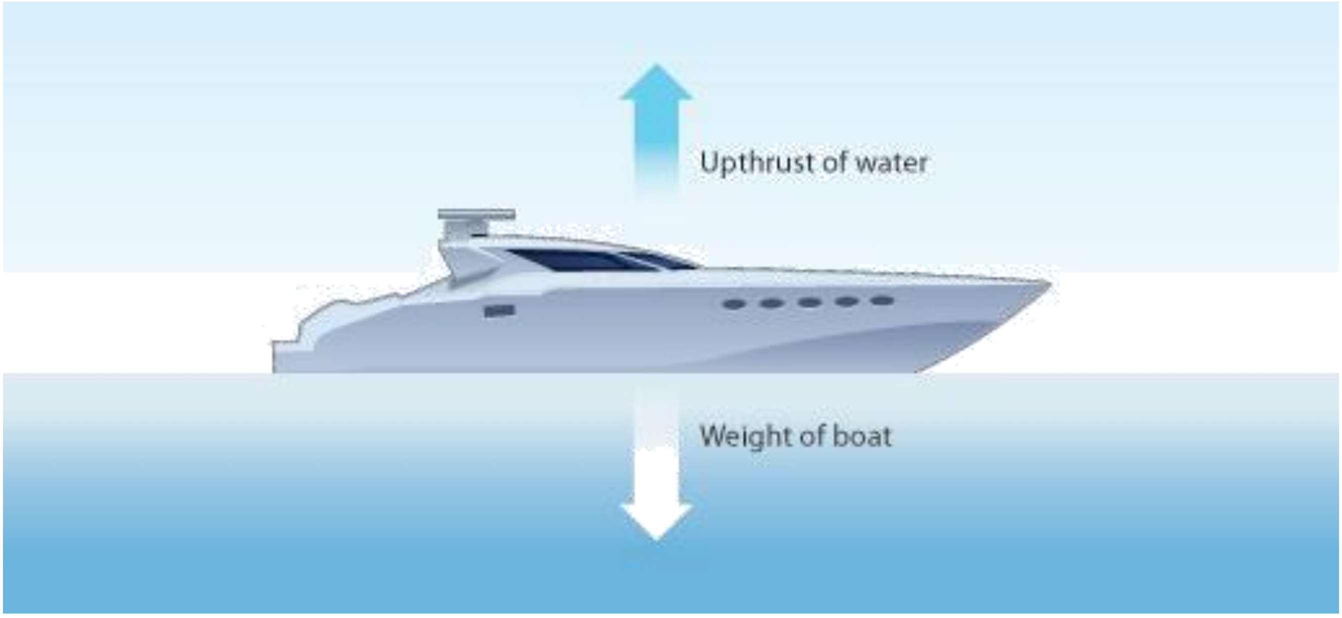


Fig 1.3.1 PRINCIPLE OF BUOYANCY

Fig 1.3.2PATROLLING VESSEL

1.3 TERMINOLOGY OF SHIPS:

Aft/After:

The direction towards the rear of the ship is called aft or after.

Forward/Fore:

The direction towards the front or bow of the ship is called forward –fore.

Mid ship:

The centre of the ship located at the midpoint between the fore and aft perpendicular is called the mid ship.

Forward Body:

The portion of the ship from mid ship to the front or bow of the ship is called forward body.

Port:

The left hand side of the ship, when looking from the fore is called port side.

Fore and Aft:

In the line with length of the ship is called fore and aft.

Arch wart ship:

The part across the ship at right angles to the fore and aft centre line of the ship is called arch wart ship.

In-Board:

The direction towards the centre line of the ship is called in-board.

Out-Board:

The direction away from the centre lone or towards the side of the ship is called out-board.

Stem:

The bow of the ship, the part where the port and starboard meet extending from keel to forecastle deck is called stem of the ship.

Stern:

The aft end of the ship is known as stern.

Bow:

Forward end of the ship is known as bow.

Stern-Frame:

Large casting or forging or built up frame attached to the aft end of the keel to from the ship’s structure is known as stern-frame.

Rudder:

A large heavy fitting hinged to stern frame which is used for steering of the ship is known as rudder.

Keel:

Keel is the back bone of the ship. It is the principal fore-aft member which runs along the bottom and connects the stem and the stern.

Centre Girder:

Centre girders are fore and aft vertical plates fitted at the centre line upon the keel and to which the half floor plates are connected by welding or by vertical angle bars. Sometimes they are also called the ‘vertical-keel’.

Floor:

A floor is a transverse vertical plate running across the bottom of the ship.

Inter-Costal:

An inter-costal plate is a vertical fore and aft plate fitted between the floors, also short length of the plate or bar between frames beams, etc. they are not continuous.

Frames:

One of the ribs forming the skeleton of the ship is known as a frame. They act as stiffeners holding the outside plating in shape and maintain the transverse form of the ship.

Frame-Line:

The fixed position or point of the frame or the frame station fixed to the ship is known as frame-line.

Frame Spacing:

The fore and aft distance between the heels of the frame to heel of the transverse frame measured along the transverse line is called as frame spacing.

Bulk Head:

The vertical portion in ship which divides the interior of the ship into various components is known as bulk head.

Aft-Peak:

The water tight compartment aft of the cast watertight compartment is known as aft-peak.

Fore peak:

A large compartment in the tank at the bow in the lower point of the ship is known as fore peak.

Deck:

Deck is the horizontal platform corresponding to the floor in the building.

Beam:

Beam is the transverse horizontal member supporting a deck o a flat extreme width of the deck.

Deck Girder:

A continuous member running in the fore and aft direction under the deck for the purpose of supporting the deck and beams is known as deck girder.

Stiffener:

A section fastened to the surface to strengthen it and make it rigid is called a stiffener.

Camber:

A transverse curvature or crown given to the decks for the purpose of draining rain or sea water to the sides.

Hatch:

Opening the deck for passage of cargo into the hull is known as hatch.

Coming:

The vertical boundary of the hatch or skylight or for any other opening is known as coming.

Bracket:

A triangular piece of plate used to connect rigidly two or more parts that meet at some angle with ne and other. For example, a deck beam attached to the frame or frame to margin plate.

Butt:

The joint that is formed when two parts are placed edge to edge also end joint between two plates.

Seam:

The fore and aft joint or length wise side joint of the plates is known as steam.

Lap:

A joint in which one part of the plates overlaps the other thus obtaining the use of butt-strap is known as lap joint.

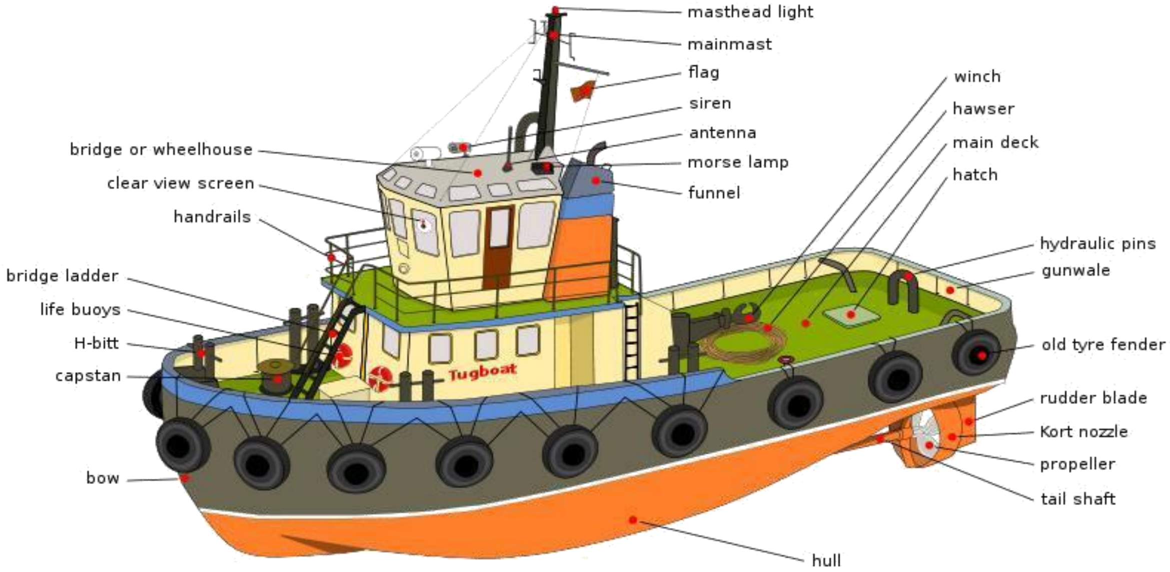


Fig 1.4 BASIC TERMINOLOGY OF A SHIP

1.4 BASIC DISCRIPTION OF SHIPS:

The fore end of the ship is called bow and rear end is known as stern or aft .The left hand and right hand side of the ship when viewed from the stern are called port and star board.

MAIN PARTS OF SHIPS:

1. Smokestack or Funnel
2. Stern
3. Propeller or Rudder
4. Portside
5. Anchor
6. Bulbous bow
7. Bow
8. Deck
9. Superstructure

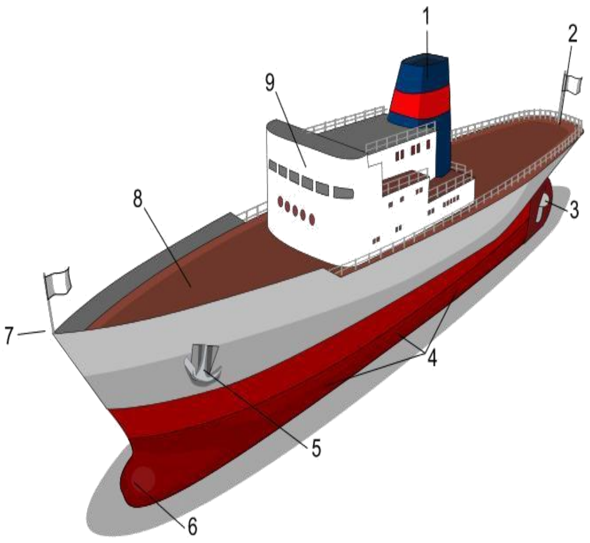


Fig 1.5 PARTS OF THE SHIP

CHAPTER-2

LITERATURE REVIEW

2. LITERATURE REVIEW

Automation was the rage of engineering world. The investigation on the existing Patrolling vessel reviews the following drawbacks such as high investment cost, high usage Of manpower for patrolling, by using these existing patrolling vessels we can travel up to Some extent but by using our innovative patrolling vessel we can travel is wherever the Solar power is available.

This is one of the research projects of HINDUSTAN SHIPYARD LIMITED which is Undergoing to be done in the number name F47 & F48 and we have taken the concept of that research project and the design parameters are taken from the normal patrolling vessel. This is an innovative project where no ship was made by using both the concept of solar power and remote controller.

Marine propellers, although submerged in water aft of the ship, form an integral part of a ship and play a vital role in ship propulsion. Much has been said and published on the development of the marine propeller from the time of antiquity to the present age, but there is more to be done. The movement of a ship through water is achieved by the power so developed in the engine via the propeller shaft to the propeller in water.

The distance or forward motion depends mainly on the propeller pitch which is defined as how far the propeller can travel for one revolution of the shaft. Propeller is a type of a fan that transmits power by converting rotational motion into thrust. A pressure difference is produced between the forward and the rear surfaces of the air foil-shaped blade, and a fluid such as air or water is accelerated behind the blade.Lot of research is going on to minimize the various parameters of the propeller.

Ishiodu Anthony et al. [1] focused on the design procedure of four bladed marine propellers with specific interest on engines with 85Bhp and ship speed of 30 knots. The design and analysis of fixed pitch propeller of a ship is made and a step by step design procedure for a 4-bladed propeller has been outlined in this work.

The result of the work thus shows that for a propeller with Blade area ratio of 0.55, the open water efficiency is 73%. This means that irrespective of the initial cost of design and manufacturing this type of propeller, the development of maximum efficiency should be the pursuit of the designer, the manufacturer and the user.

Ganesh et al. [2] made a modelling and analysis of propeller blade to withstand the static loads for Aluminium alloy and Fibre reinforced composites materials. The present work carries out the structural analysis of a carbon fibre reinforced plastic (CFRP) propeller blade which proposed to replace the aluminium propeller blade and it was observed that maximum displacement for composite propeller is less than the aluminium propeller.

The natural frequencies of aluminium and composite propeller were compared and found that aluminium propeller is 9 % more than the composite propeller. The weight of the composite propeller is 42% less than the aluminium propeller.

BhanuPriya et al. [3] modelled and designed the propeller blade by using CATIA V5 R19and analysis is made by ANSYS12.0 to withstand the static and dynamic load. The study is made for two different materials such as Aluminium and Composite. The deflection for composite propeller blade was found to be around 0.142 mm for all layers which is much less than that of aluminium propeller i.e. 0.181 mm, which shows composite materials is much stiffer than aluminium propeller.

The natural frequency of composite propeller is 150% more than that of aluminium propeller and the max normal stresses of aluminium propeller are 87% higher than the composite propeller. The von- mises stresses are 50% higher in aluminium propeller than that of the composite propeller.

Pavan Kishore et al. [4] investigated that the composite materials are much stiffer than NAB material for propeller blade of an underwater vehicle. Analysis is made by using ANSYS.

The deflection for composite propeller blade was found to be around 0.897 mm for all layers which is more than that of NAB propeller i.e. 0.597 mm,

Suneetha et al. [5] made design by using CATIA and analysis by ABAQUS of a surface propeller using FEM. The geometric shape and its surface finish will decide the efficiency of the propeller. The material used is carbon UD and aluminium.

The von-mises stress for aluminium is 92.642 N /mm^2 and deformation is 0.496mm where as for composite 55.585 N/mm^2 and deformation is 0.297mm.They concluded that carbon UD/epoxy material can give a better performance with respect to the conventional material.

Mohammed Ahmed khan et al. [6] design and dynamic analysis of a propeller of ship made by using FEA. Propeller with conventional isotropic materials creates more vibration and noise in its rotation. In current years the increased need for light weight structural element with acoustic insulation has led to use of fibre reinforced multilayered composite propeller.

The work is to carry out the dynamic analysis of aluminium and composite material, which is a combination of Glass Fibre Reinforced Plastics (GFRP) and Carbon Fibre Reinforced Plastics (CFRP). The deflection for composite propeller blade was found to be around 0.5 mm for all layers which is much less than that of aluminium propeller i.e. 6.883mm, which shows composite materials is much stiffer than aluminium propeller.

Praveen Kumar Surisetti et al. [7] Carried out the structural analysis of a carbon fibre reinforced plastic (CFRP) propeller blade which proposed to replace the Aluminium propeller blade.

The propeller blade is modelled and designed in CATIA to withstand the static loads for both aluminium and carbon fibre reinforced plastic materials and concluded that Composite propellers have more advantages over the conventional metallic propellers.

VidyaSagar et al. [8] made solid model of propeller using CATIA V5 R17. Tetrahedral mesh is generated by using HYPER MESH. Static, Eigen and frequency responses analysis of both aluminium and composite propeller are carried out in ANSYS.

The deflection for composite propeller (combination of GFRP-Glass Fibre Reinforced Plastics and CFRP-Carbon Fibre Reinforced Plastics materials) blade was found to be around 0.5mm for all layers which is much less than that of aluminium propeller i.e. 6.883mm, which shows composite materials is much stiffer than aluminium propeller.

SCOPE OF THE LITERATURE

The investigation on the existing Patrolling vessel reviews the following drawbacks such as high investment cost, high usage of manpower for patrolling. Marine propellers, although submerged in water aft of the ship, form an integral part of a ship and play a vital role in ship propulsion. Much has been said and published on the development of the marine propeller from the time of antiquity to the present age, but there is more to be done. The movement of a ship through water is achieved by the power so developed in the engine via the propeller shaft to the propeller in water.

OBJECTIVE OF LITERATURE

To understand the modelling and analysis of water jet propulsion system to provide detail understanding of complicated three-dimensional viscous flow phenomenon including interactions of intake duct, impeller, stator and contracted discharge nozzle.

CHAPTER-3
DESIGN OF THE SHIP

3. DESIGN OF THE SHIP

3.1 DESIGN THEORY

3.1.1 DESIGN PROCESS

There are three stages in the design procedure of the prototype to be made which constitute the following:

Concept design

- Requirement of the ship
- Load carrying capacity of the ship
- Dimension parameter of the ship ex: Length, Breadth and Draft In concept design, based on the customer requirement use are arriving at length, breadth and depth of ship.

General Arrangement of ship

-Profile view (Longitudinal view)

-Plan view (Lateral view)

-Sectional view (Transverse view)

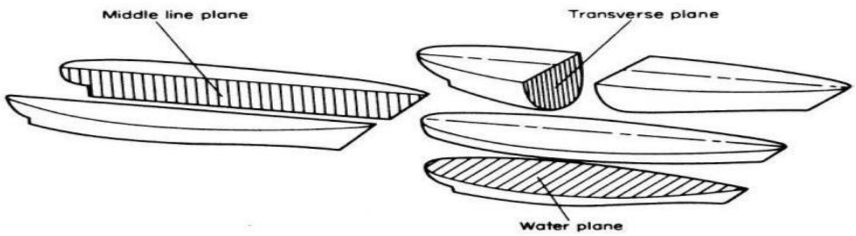


Fig 3.1: DIFFERENT VIEWS OF SHIP

- **Functionality Design**

  Calculations to be done to design a ship

  -Tank capacity calculations

  -structural calculation

  -stability calculation

  -thrust calculation

  -flow calculation

  -powering calculation

  -water jet calculation

  -Efficiency calculation

- **Detailed Design**

  Internal structure of the ship of manufacturing

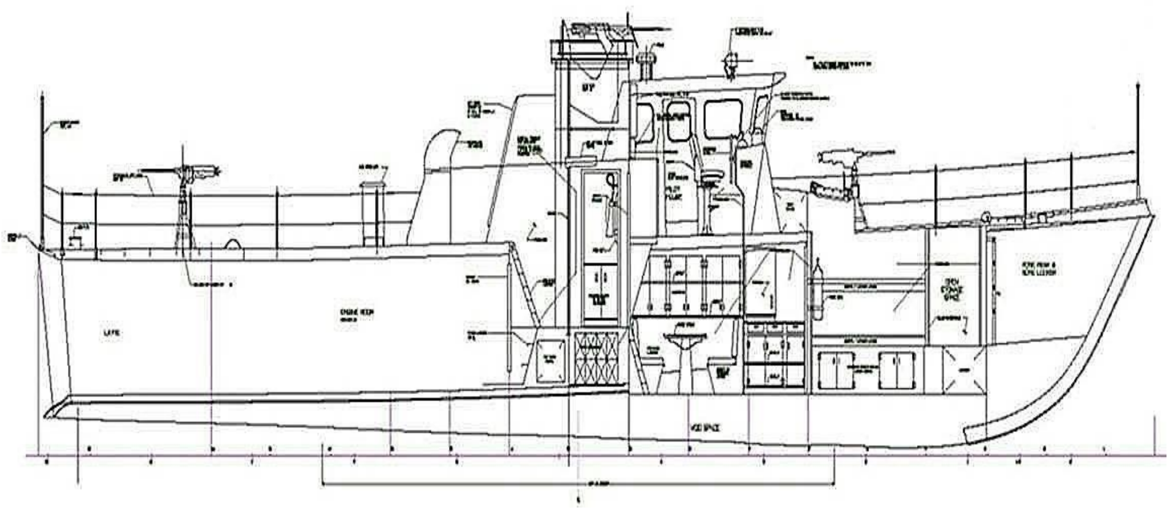


Fig 3.2: DETAILED DESIGN OF BOAT

3.1.2 CONDITIONS OF SEA

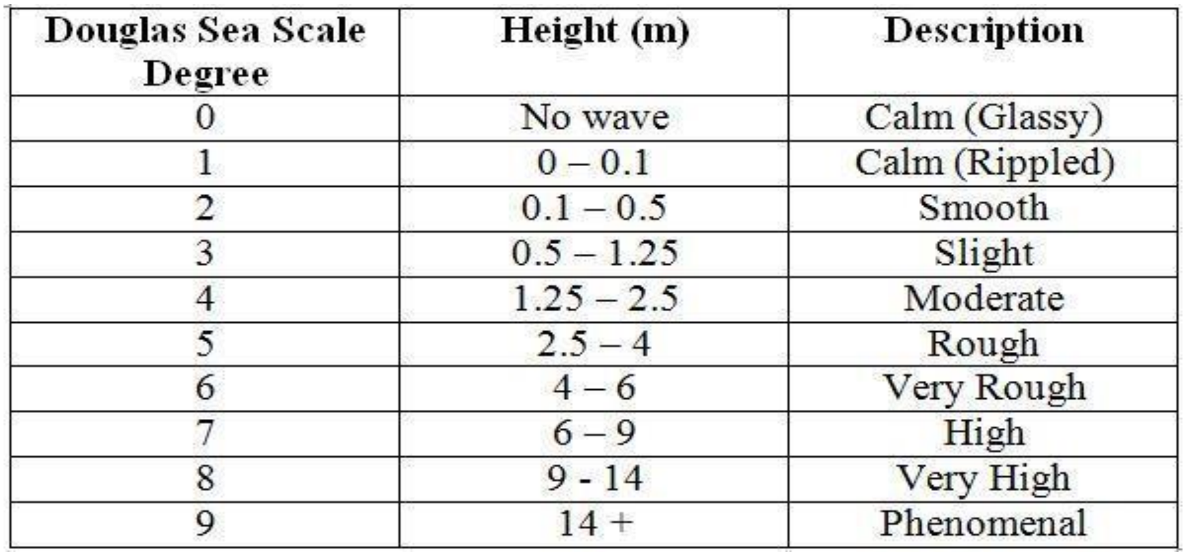
Manoeuvring: Motion of a ship when in the absence of sea excitations (motions results from control surface deflections).

Fig 3.3: MANEUVERING

Sea keeping: Motion response of ships results from excitation Forces in the sea such as waves. The ability of a vessel to withstand rough conditions at sea.

Fig 3.4: SEA KEEPING

SEA SCALE CHART:



Douglas Sea Scale Degree	Height (m)	Description
0	No wave	Calm (Glassy)
1	0 – 0.1	Calm (Rippled)
2	0.1 – 0.5	Smooth
3	0.5 – 1.25	Slight
4	1.25 – 2.5	Moderate
5	2.5 – 4	Rough
6	4 – 6	Very Rough
7	6 – 9	High
8	9 - 14	Very High
9	14 +	Phenomenal

TABLE2: SEA STATE CHART

3.1.3 STABILITY OF THE SHIP

- **Stability:**

A floating body reaches to an equilibrium state, if

1) Its weight = the buoyancy
2) The line of action of these two forces becomes collinear.

The equilibrium: **stable, or unstable or neutrally stable**.

- ✓ **Stable equilibrium**: if it is slightly displaced from its equilibrium position and will return to that position.
- ✓ **Unstable equilibrium**: if it is slightly displaced from its equilibrium position and tends to move farther away from this position.
- ✓ **Neutral equilibrium**: if it is displaced slightly from this position and will remain in the new position.

- **Motion of a Ship:**

6 degrees of freedom

- Surge
- Sway
- Heave
- Roll
- Pitch
- Yaw

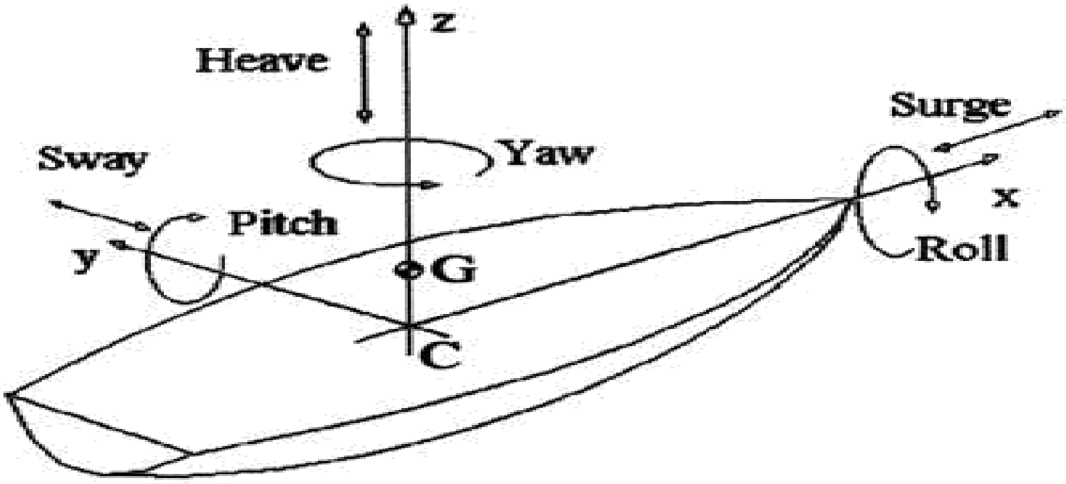


Fig 3.5: GYROSCOPIC COUPLE FORCES ON SHIP

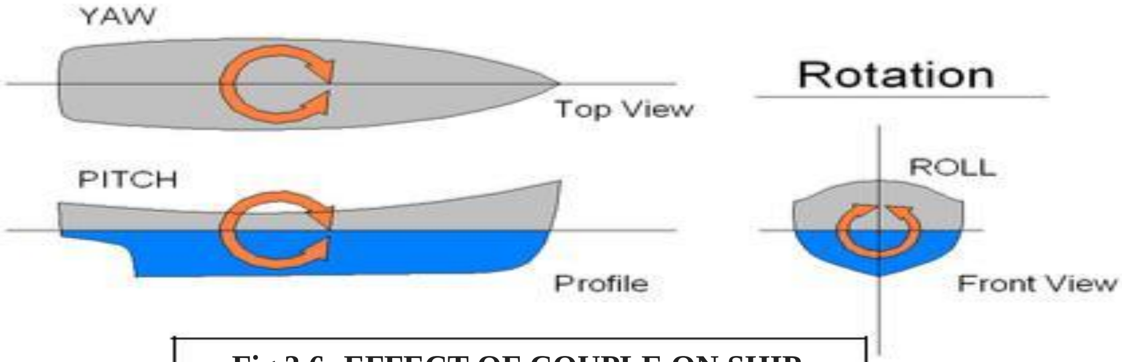


Fig 3.6: EFFECT OF COUPLE ON SHIP

Table 3: GYROSCOPIC MOMENTS

Axis	Translation	Rotation
X Longitudinal	Surge Neutral S.	Roll S. NS. US
Y Transverse	Sway Neutral S.	Pitch S.
Z Vertical	Heave S. (for sub, N.S.)	Yaw NS

3.2 DESIGN SPECIFICATIONS OF THE PROTOTYPE

3.2.1 DEFINITION (TERMINOLOGY):

- Principal Dimensions (length, breadth, depth etc) -Length.

- **FP** –Forward perpendicular (vertical line through intersection of stem and waterline).
- **AP** –Backward perpendicular (vertical line through the centre of rudderpintle)

  LOA – Overall Length

  LWL – Waterline Length (calculation length)

3.2.2 PRINCIPAL DIMENSIONS:

-Breadth, depth & draft.

- Breadth (molded) (inside of plate on one side to another side)
- Breadth maximum
- Depth (measured at midship)
- Camber – the rise of the deck at the centreline. 2% of breadth
- Bilge radius
- Rise of Floor
- Flat of keel (thicker plate)

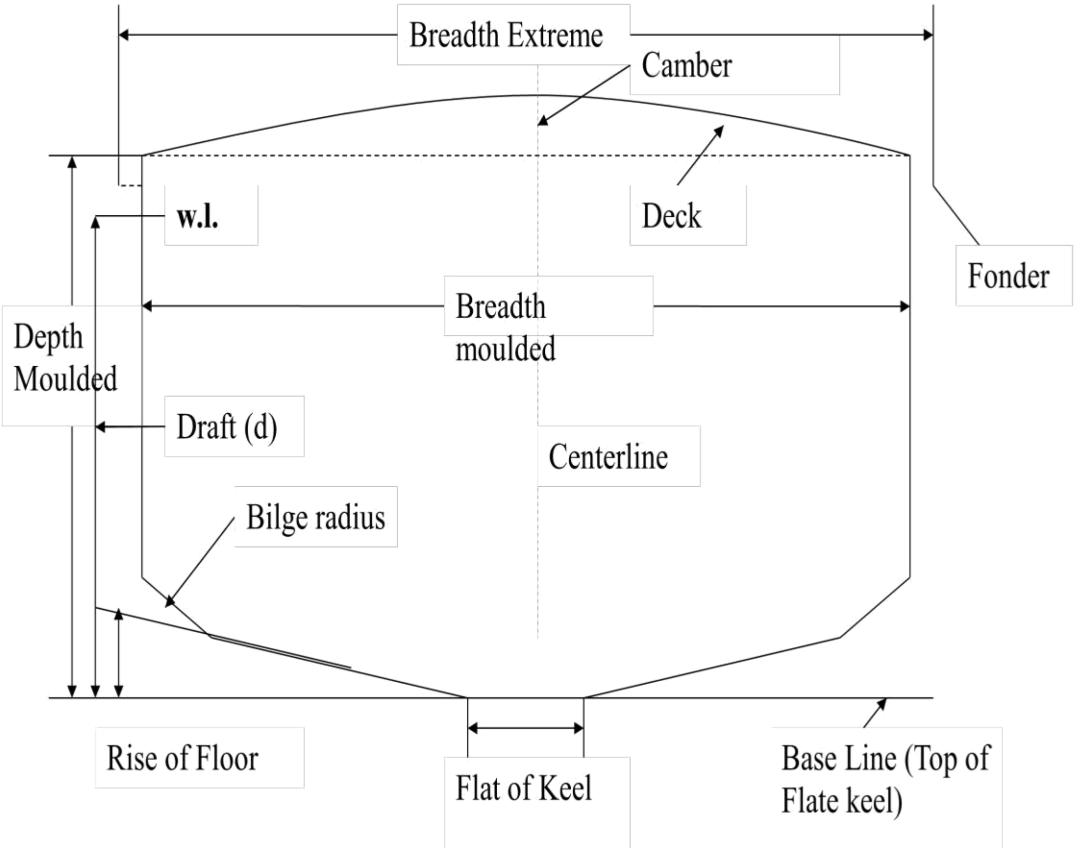


Fig3.7: AFT SECTIONAL VIEW

- If W.L. is parallel to the baseline (keel line), the ship is floating evenly.
- If not parallel, the ship has a trim.

- Free board (F.B) is the distance measured downwards from the deck to the L.W.L.
- Usually F.B. is minimum at mid ship
- Minimum F.B is required by International Law.

3.2.3 DIMENSIONAL SPECIFICATIONS OF THE VESSEL

- The Principal Dimensions of the Vessel are as follows:

Length Overall	51.15 m
Length Hull	48.0 m
Length Waterline	44.0 m
Chine Beam	7.91 m
Displacement tested	275 tones

The Fast Speed Craft Prototype considered for the project is scaled to model of 1:20.

- The Principal Dimensions of the prototype are as follows:

Length Overall	7 feet 2 inches (2.2 m)
Length Hull	1 foot 8 inches (55 cm)
Length Waterline	7 feet 1 inch (2.16 m)
Draft height	20 cm
Chine Beam	1 feet 1inch (35 cm)

- Parameters of the Prototype / Prototype Plan

Speed - 34 knots scaled down to 6.81 knots ~12 km/h

Turning Radius -3* L = 3 * 8 feet = 7 meters approx

Thrust Required -275 KN

Endurance – 4hours @ 85% discharging efficiency

RC max Range - 1 Km to 2km

Solar Cell - 400*300mm size -10 W solar panel

Battery Capacity - 7.0A/H 1battery

Power of the motor – 0.3 HP

CHAPTER-4

PROPELLER AND ENCLOSURE DETAILS

4. PROPELLER

The propeller is 6 blade contra rotating propeller with diameter 690mm and skew angle of 30 deg seated in enclosure.

Propeller clearance: - 30mm from enclosure.

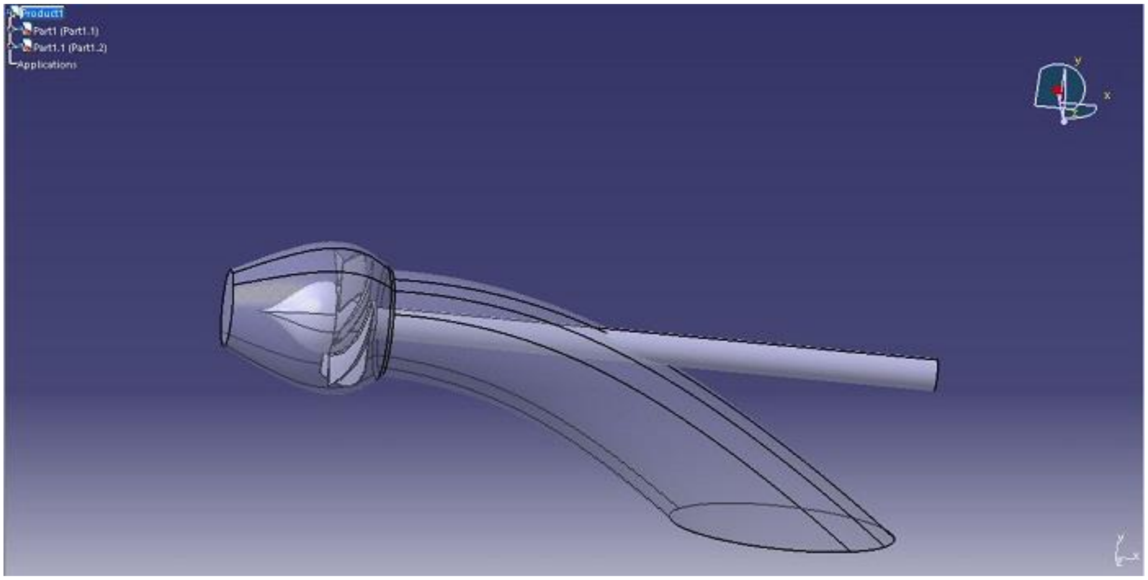


Fig 4.1: PROPELLER

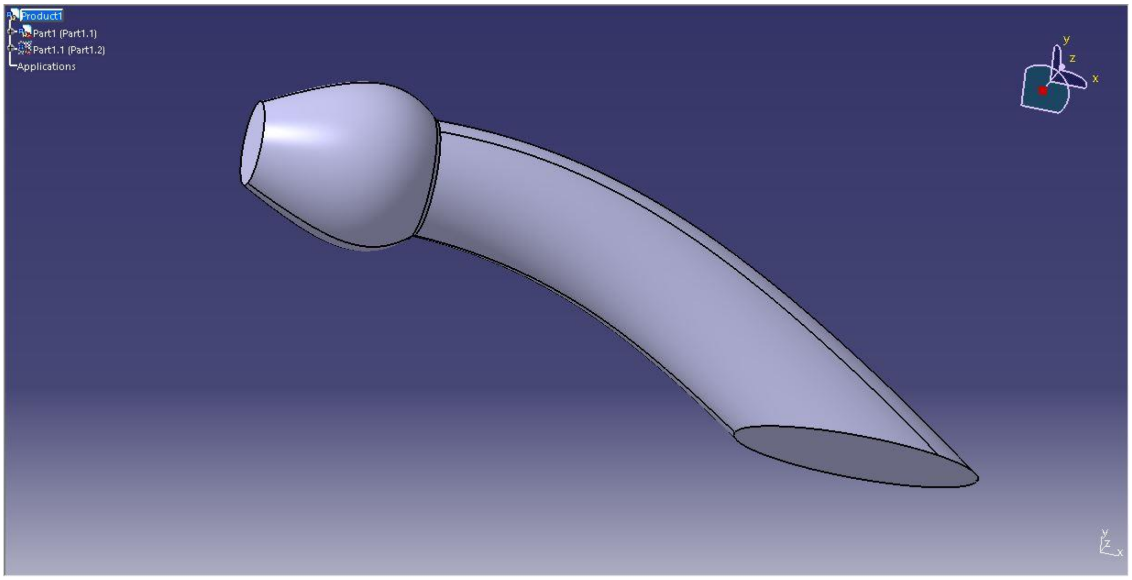


Fig 4.2: ELBOW

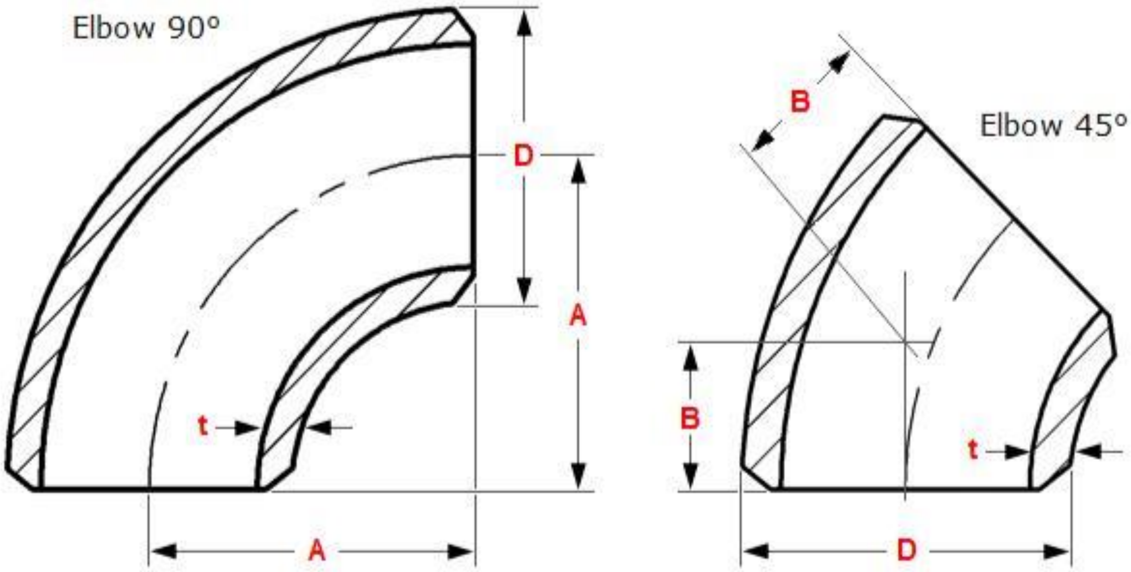


Fig 4.3: ELBOW NOMENCLATURE

NPS	O D D	90 deg Long Rad Centre to End A	45 deg Long Rad Centre to End B	90 deg 3D Centre to End A	45 deg 3D Centre to End B
1/2	21.3	38	16	--	--
3/4	26.7	38	19	57	24
1	33.4	38	22	76	31
1.25	42.2	48	25	95	39
1.5	48.3	57	29	114	47
2	60.3	76	35	152	63
2.5	73	95	44	190	79
3	88.9	114	51	229	95
3.5	101.6	133	57	267	111
4	114.3	152	64	305	127
5	141.3	190	79	381	157
6	168.3	229	95	457	189
8	219.1	305	127	610	252
10	273	381	159	762	316
12	323.8	457	190	914	378
14	355.6	533	222	1067	441

TABLE 4: UNIVERSAL ELBOW DIMENSIONS

❖ O-RING SEAL

This is enclosed with washer which is used for the manufacturing of the seal which is made in the stepped shaft & which seals the elbow & shaft assembly.

It is an alternative for stern tube in marine propulsion system.

4. PROPELLER

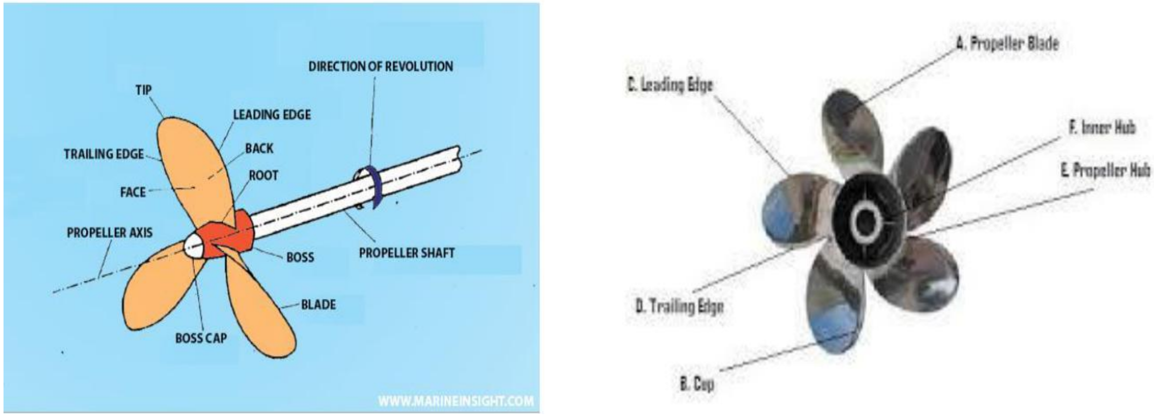


Fig 4.4: PROPELLER AND PROPELLER SHAFT

4.1 TYPES OF PROPELLERS:

The ship propellers are basically two types

- ✓ Screw Propeller
- ✓ Contra-rotating Propeller

Screw propeller:

The concept of screw propeller dates back to the 950 BC to the mid-17th century, the raising of steam engines contributed to valuable use of screw propellers and transform to marine propeller.

Nevertheless, the screw propeller is still considered as a second mover to the paddle wheel at this time. The acknowledgment for the invention of the modern style propeller goes to Smith and Eriksson who acquired patents in 1836 for screw propellers.

The final step to what is now recognizable as a screw propeller is made by George Renee’s combined the ideas of increased pitch, multiple blades, and minimum convolutions called as Conidial propeller, patented in 1840 (Taggart,1969).

Screw propellers installed in the late of the 19th century lacked sophistication, but their performance exceeded all other devices conceived up to that time. During 1880 to 1970 Basic shape of propellers remained unchanged. Ever since, marine propeller technology has made some advancements toward greater efficiency, more reliable design, better performance, improved materials, and cavitations resistance.

Fig.4.5 SCREW PROPELLER

Marine engineers are still looking for new developments of unconventional propellers to improve the propeller efficiency and consequently the total ship fuel consumption. Among these new developments count up the

- Controllable pitch propeller (CPP)
- Skewback propeller
- ducted propeller
- Cycloidal propellers
- water jet propulsion, and
- podded and Azimuth podded propulsion systems.

Contra-rotating propeller:

The concept of having two consecutive propellers behind each other, rotating in different directions is not new. In fact, this concept is as old as the screw propeller itself, as John Ericsson's patent of 1836 included single, twin, as well as contra-rotating propellers (John Ericson RINA affairs, 2004). Although the high efficiency obtained with contra-rotating propellers has long been known, until fairly recently material technology and the need for long concentric shafts running in different directions made the concept both technically and economically unfeasible.

However, in the mid 1980's contra-rotating propellers were successfully introduced in azimuth thrusters for, utilizing the short propeller shaft and bevel gear. In the late 1980’s, a distinct concept has made its way into the marine world. This new concept is referred to as podded propulsion and is distinguished from the original thruster in that its prime mover is an electric motor, situated in hub, directly driving propeller.

FIG 4.6: CONTRA-ROTATING PROPELLER

In the new millennium, efforts have been concentrated on development of a novel propulsion plant using the pod unit; it has been found that the "CRP-POD propulsion

System," combining the conventional propeller propulsion system with pod propulsion, is sufficiently economic and competitive in general merchant ships. The combined high efficiency of CRP and the excellent manoeuvrability of podded propulsions make the hybrid CRP system extremely attractive.

The concept of contra-rotating propellers can be found also in aeronautics industry, Contra rotating aircraft propellers came into service at the end of WW II. This configuration offered a number of advantages including lower asymmetrical torque, higher efficiency, and smaller propeller disk (allowing shorter landing gear), (Carlton, 2008). But the complexity caused by the gearing mechanisms and the expensive maintenance costs resulted in the delay of contra-rotating propeller entering into service. Other fields the contra-rotating propellers are used are in the wind turbine field and in tide turbine for ocean energy utilization.

4.2 GROUPS OF PROPELLERS:

Propellers may be divided into the following two main groups, see also Fig. 7:

- Fixed pitch propeller (FP-propeller)
- Controllable pitch propeller (CP-propeller)

Fixed pitch propeller:

Propellers of the FP-type are cast in one block and normally made of a copper alloy. The position of the blades, and thereby the propeller pitch, is once and for all fixed, with a given pitch that cannot be changed in operation. This means that when operating in, for example, heavy weather conditions, the propeller performance curves, i.e. the combination of power and speed (r/min) points will change according to the physical laws, and the actual propeller curve cannot be changed by the crew. Most ships which do not need a particularly good manoeuvrability are equipped with an FP-propeller.

Controllable pitch propeller:

Propellers of the CP-type have a relatively larger hub compared with the FP-propellers because the hub has to have space for a hydraulically activated mechanism for control of the pitch (angle) of the blades. The CP-propeller is relatively expensive, maybe up to 2-3 times as expensive as a corresponding FP-propeller. Furthermore, because of the relatively larger hub, the propeller efficiency is slightly lower.

CP-propellers are mostly used for Ro-Ro ships, shuttle tankers, ferries and similar ships that require a high degree of manoeuvrability. For ordinary ships like container ships, bulk carriers and crude oil tankers sailing for a long time in normal sea service at a given ship speed, it will, in general, be a waste of money to install an expensive CP-propeller instead of an FP-propeller. Furthermore, a CP-propeller is more complicated, involving a higher risk of problems in service.

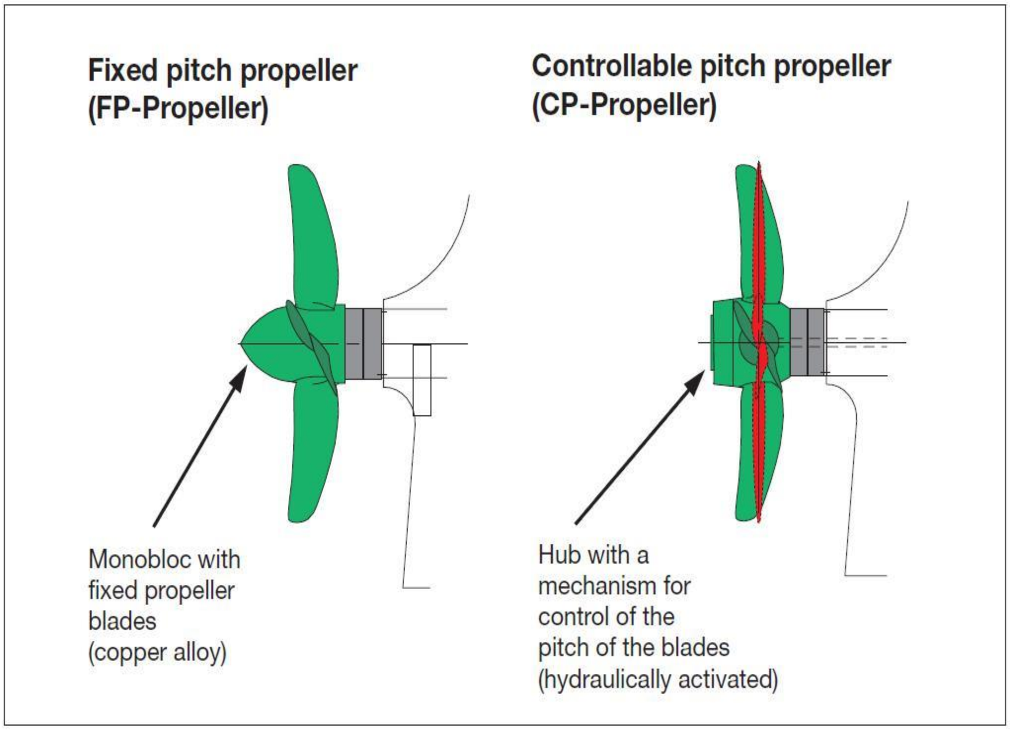


Fig 4.7: FIXED PITCH PROPELLERS AND CONTROLLABLE PITCH PROPELLERS

4.3 CLASSIFICATION OF PROPELLERS:

Propeller blades are classified into 3 blade propellers to 4 blade propellers and 5 blade propellers, the used propeller are 3 blades and 4 blade propellers.

3 blade propeller:

- The manufacturing cost is less than other types.
- Normally are of aluminium alloy.
- Gives a high speed performance.
- The acceleration is healthier than other types.
- Low speed handling is not resourceful.

4 blade propeller:

- The manufacturing cost is higher than 3 blade propellers.
- Have better strength and durability.
- Gives a good low speed handling and performance.
- Has a better holding power in rough seas.
- 4 blade propellers provide a better fuel economy than all the other types.

5 blade propeller:

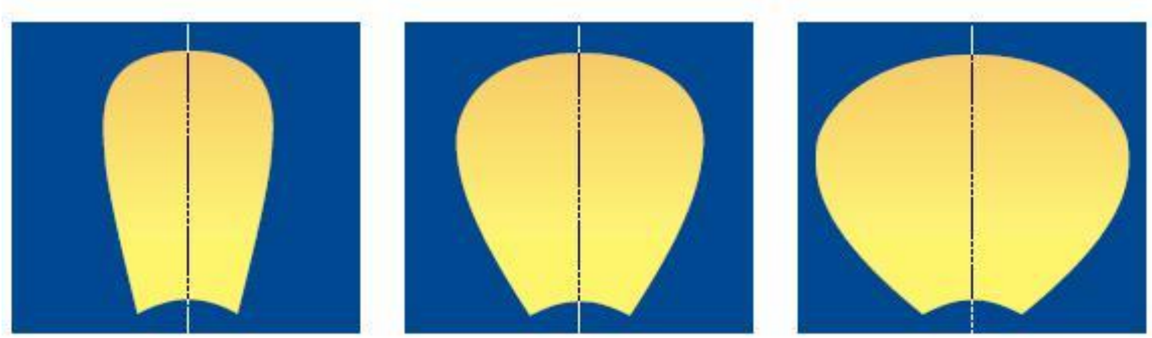
- Manufacturing cost is higher of all.
- Vibration is minimal from all the other types.
- 5 blade propellers have better holding power in rough seas.

4.4 BLADE DESIGN:

It is a common belief among propeller designers that the two design objectives are in contradiction to each other and consequently must be balanced to get a compromised design. But today some design features are available which can be applied to reduce the cavitation without sacrificing the efficiency. To build up a propeller blade, the complicated 3-dimensional form is usually reduced into 2-dimensional elements which are then adjusted during the design process.

A. BLADE AREA:

The blade area should be kept as small as possible in order to reduce the friction losses when turning in the water, but to suppress the cavitations extension a certain area is needed. A measure of the blade area is the so-called “blade area ratio” (A_e/A_o) which is the ratio of all the blades compared to the area of the circle circumscribed by the propeller diameter.



A_e/A_o =0.40

A_e/A_o =0.55

A_e/A_o =0.70

Fig 4.8: DIFFERENT BLADE AREA RATIOS

B. BLADE SHAPE:

The blade shape can be varied to even out the cavitation along radius and in the case of a nozzle propeller; it is advantageous to have wide-chord length at the tip (Kaplan shape).

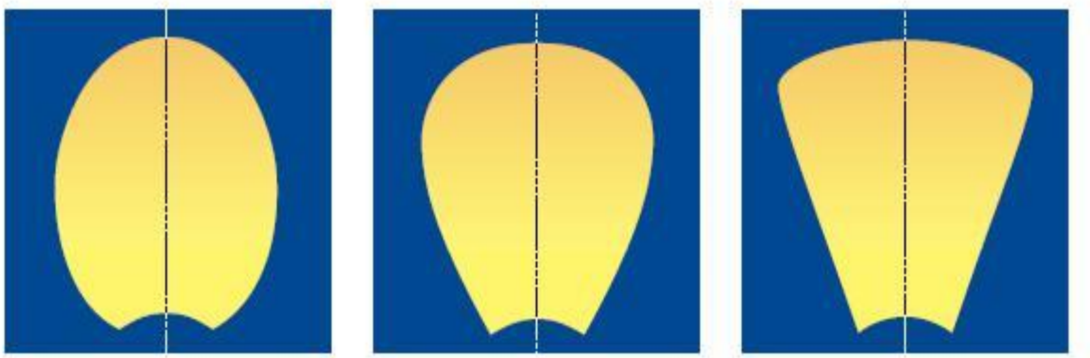
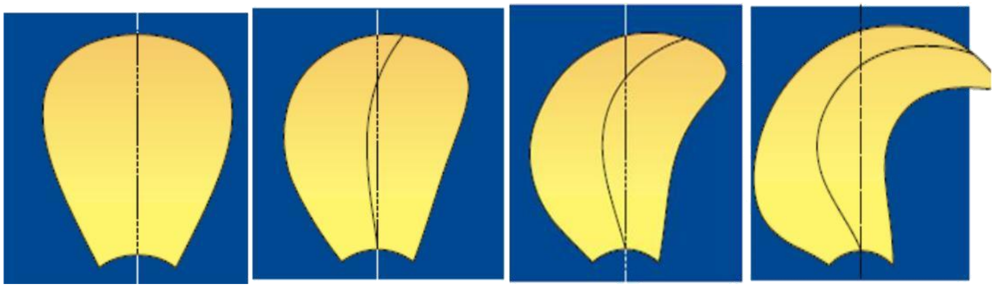


Fig 4.9: DIFFERENT SHAPES

C. SKEW ANGLE:

A powerful tool to suppress propeller induced noise and vibration is the application of skew. For modern CP propellers, the skew distribution is of the balanced type, which means that the blade chords at the inner radii are skewed (moved) forward, while at the outer radii the chords are skewed aft. By applying this type of skew it is possible to control the forces (spindle torque) needed for pitch settings. In most cases the blades will be balanced in such a way that the forces in the design pitch setting will be zero. Skew has the advantage of reducing the pressure impulses emitted from propeller to the hull surface to as much as one third of an un-skewed design without sacrificing the efficiency, which will remain unchanged.



No Skew

Low Skew

Medium

High Skew

Fig 4.10: DIFFERENT SKEW ANGLES

D. **RAKE:**

The noise and vibration level in the aft ship depends on the distance between the propeller tip and hull surface - in particular exactly above and in front of the propeller. A way of increasing the distance is to rake (incline) the blade towards aft. As with skew the efficiency remains unchanged. However, the blade is exposed to higher stresses originating from an increase in the centrifugal forces which must be counteracted by an increase in blade thickness.

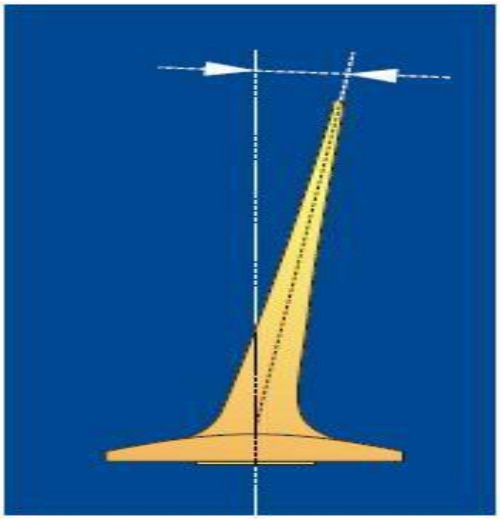
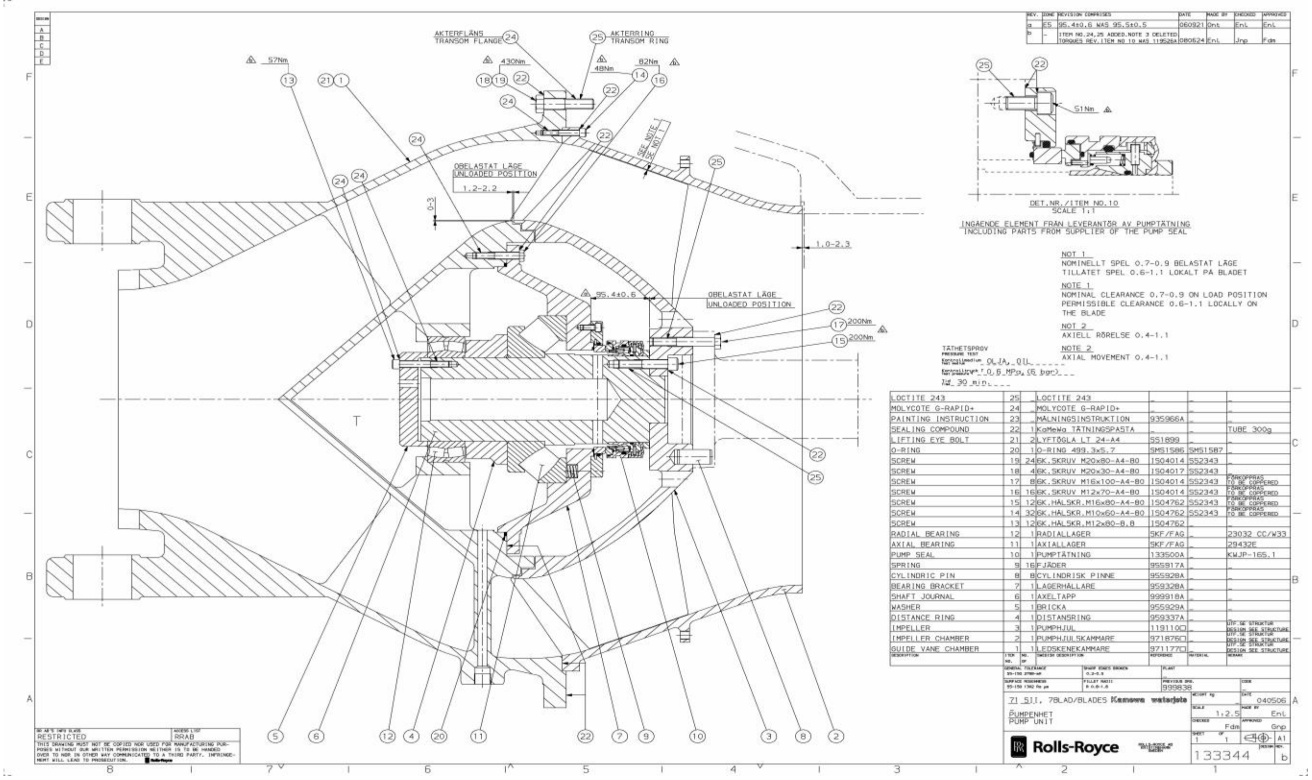


Fig 4.11: RAKE ANGLE



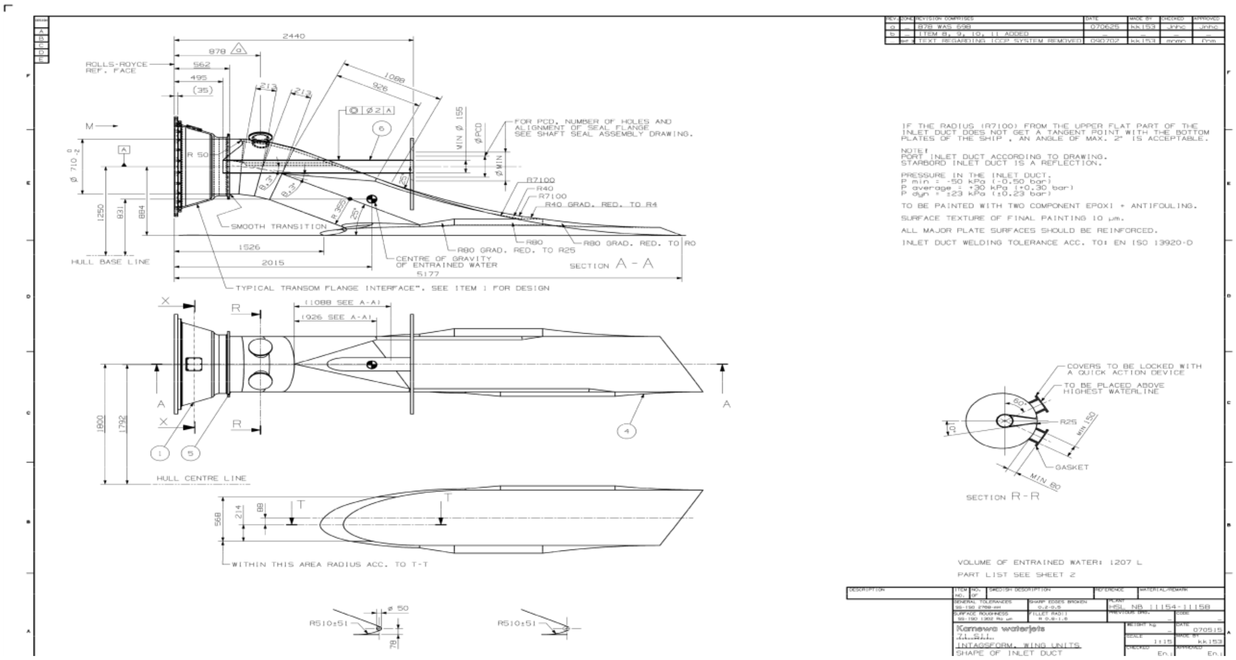
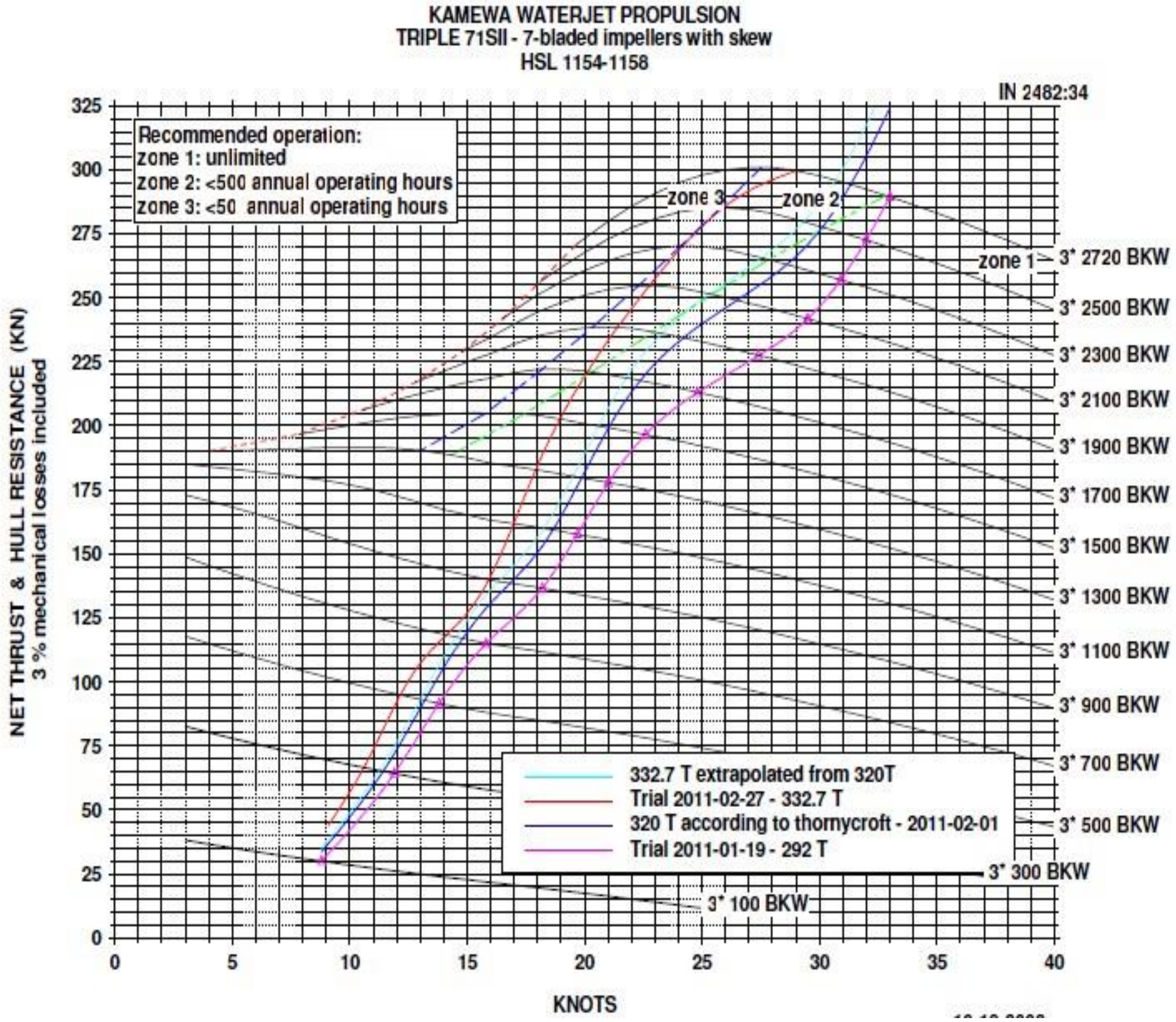


FIGURE SHOWING THE ENCLOSURE



Performance Curve of blade impeller

4.5 WATERJET PROPULSION ASSEMBLY

A water jet generates propulsive thrust from the reaction created when water is forced in a rearward direction. It works in relation to Newton's Third Law of Motion - "every action has an equal and opposite reaction".

The original development of this principle can be traced back to 1661, when Too good and Hayes produced a description of a ship having a central water channel in which either a plunger or centrifugal pump was installed to provide the propulsion.

In a boat hull the jet unit is mounted inboard in the aft section. Water enters the jet unit intake on the bottom of the boat, at boat speed, and is accelerated through the jet unit and discharged through the transom at a high velocity. The unit's thrust is mainly generated by momentum increase given in the water.

Fig 4.12: WATER JET SYSTEM

The picture below shows where water enters the jet unit via the Intake (A). The pumping unit, which includes the Impeller (B) and Stator (C), increases the pressure, or "head", of the flow. This high pressure flow is discharged at the nozzle (D) as a high velocity jet stream. The drive shaft attaches at the coupling (F) to turn the impeller.

Fig 4.13: WATER JET UNIT

Steering is achieved by changing the direction of the stream of water as it leaves the jet unit. Pointing the jet stream one way forces the stern of the boat in the opposite direction which puts the vessel into a turn.

Fig 4.14 WATER JET NOZZLE

Reverse is achieved by lowering an astern deflector (E) into the jet stream after it leaves the nozzle. This reverses the direction of the force generated by the jet stream, forward and down, to keep the boat stationary or propel it in the astern direction. This means that the impeller is never reversed, so no reversible gearbox is needed for this system.

Advantages

a. Very good manoeuvring
b. Easy installation. No engine alignment.
c. Quick braking and reversing mechanism

CHAPTER 5
RESULTS AND DISCUSSIONS

5.1 DESIGN CALCULATIONS

5.1.1 FLUID DYNANIMCS & STABILITY CALCULATIONS

Buoyancy & Metacentric height calculations:

Buoyancy:-

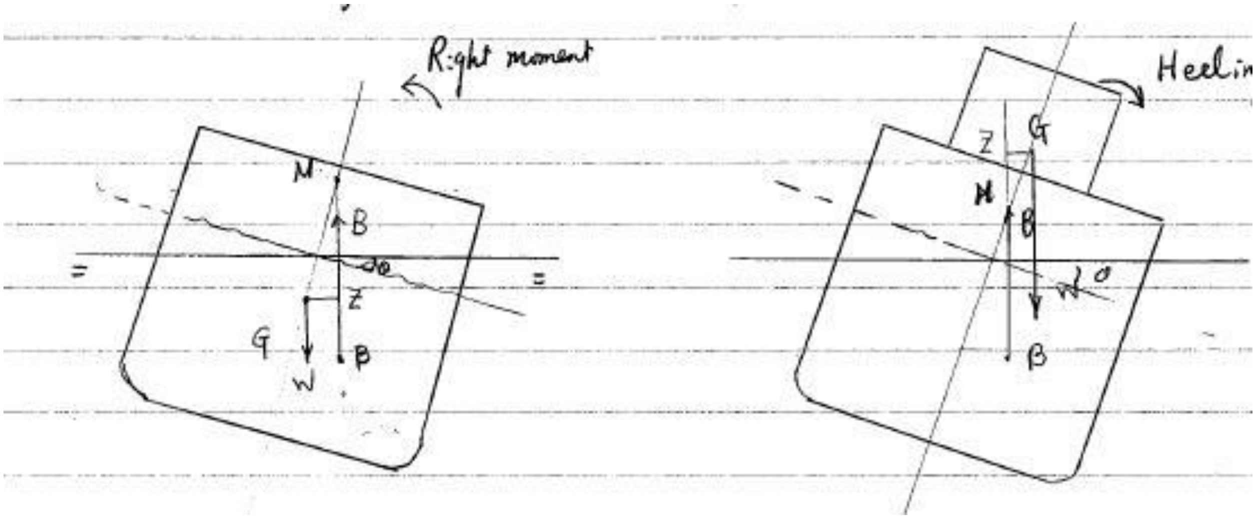


Fig 5.1: METACENTRIC HEIGHT

G---Centre of Gravity,   B---Centre of Buoyancy

M--- Transverse Meta centre,

If M is above G, we will have a righting moment, and

If M is below G, then we have a heeling moment.

Static Stability & Dynamical Stability

Static Stability: Studying the magnitude of the righting moment given the inclination (angle) of the ship. (That is, the rolling velocity and energy are not considered.)

Dynamic Stability: Calculating the amount of work done by the righting moment given the inclination of the ship.

- **Static Stability:**
    1. The initial stability (stability at small inclination)
    2. The stability at large inclinations.

- **The initial stability:** studies the right moments or right arm at small inclination angles (< 5 degree).

The stability at large inclination (angle): computes the right moments (or right arms) as function of the inclination angle, up to a limit angle at which the ship may lose its stability.

Initial stability

- **Righting Arm:** A symmetric ship is inclined at a small angle dΦ. C.B has moved off the ship's centreline as the result of the inclination. The distance between the action of buoyancy and weight, ***GZ***, is called righting arm.
- **Transverse Meta centre:** A vertical line through the C.B intersects the original vertical centreline at point, ***M***.

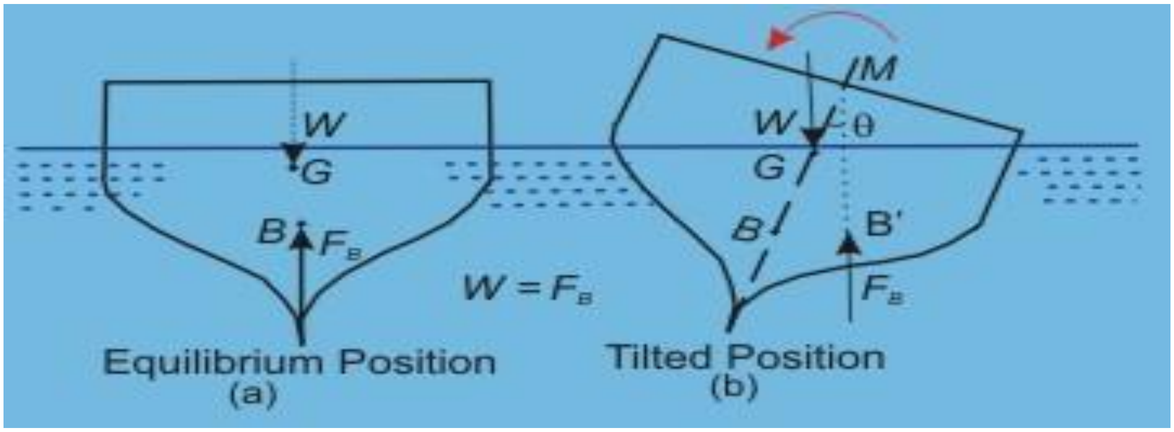
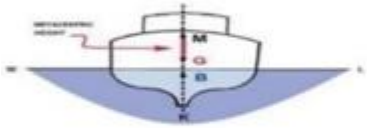


Fig 5.2: STABILITY CONDITION

META-CENTRE

- It is defined as the point about which a body starts oscillating when the body is tilted by a small angle.
- It is the point at which the line of action of force of buoyancy will meet the normal axis of the body when the body is given small angular displacement.



META-CENTRIC HEIGHT

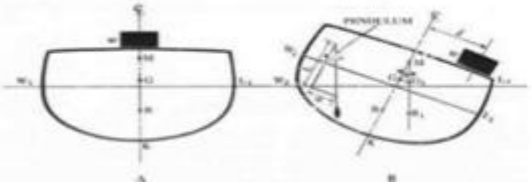
- It is the distance between the meta-centre of floating body and centre of gravity.
- We can find this height by following methods:-

  Analytical Method

$$GM = \frac{I}{\forall} - BG$$

Here I=M.O.I m^4

$\forall$ =Volume of sub-merged body



5.1.2 WATERJET CALCULATION:

CALCULATIONS OF WATERJET PROPULSION SYSTEM:

Water jet propulsion system has three main components: Inlet, Pump and Nozzle. Sea water Enters the system with the velocity V_{in} and leaves it with a different velocity V_{jet} . The mass flow rate of the water through the water jet is given by

$$\dot{m} = \rho A_{jet} V_{jet},$$

$= 1000 * (\pi/4) * 0.71^2 * 13.1$

$= 5186054$ kg/s.

Where A_{jet} and ρ are the area of nozzle outlet and density of water, respectively.

The thrust produced by the system is equal to the rate of change of momentum:

$$T = \rho A_{jet} V_{jet} \left(V_{jet} - V_{in}\right).$$

$=1000 *(\pi/4) * 0.71^2 * 13.1(13.1-6.5)$

$= 34231.17$ N.

The effective propulsion power delivered by the system is given by

$$P_E = TV_S = \dot{m} V_S \left(V_{jet} - V_{in}\right).$$

$= 34231.17 * 17.5$

$= 599.0$ kW

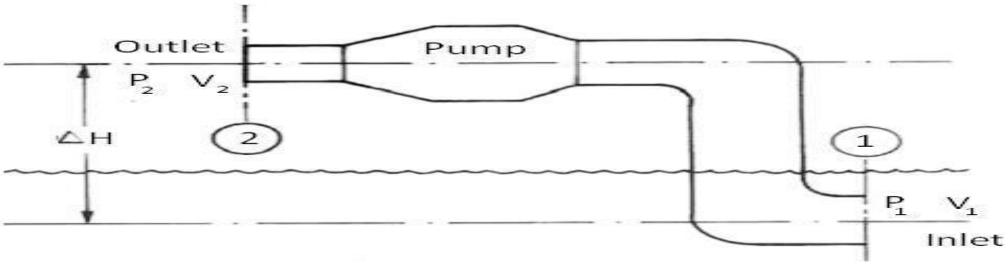


Fig 5.3: PRESSURE HEAD IN WATERJET

The energy equation between points 1 and 2 can be written as

$$\frac{P_1}{\rho g}+\frac{V_1^2}{2g}+H_P=\frac{P_2}{\rho g}+\frac{V_2^2}{2g}+\Delta H+h_{loss},$$

Where

H_P : Pump head

ΔH : Vertical distance between inlet and outlet

: Total head loss.

$(0.15/1000*9.81) + (6.5^2/2*9.81) +710= (0.5/1000*9.81) + (13.1/2*9.81)$

$+1000+h_{loss}$

$h_{loss}= -296.5.$

The jet efficiency is defined as

$$\eta_{jet}=\frac{P_E}{P_E+Losses}.$$

$=599/599+296.5$

$= 81.46\%$

This indicates that the jet efficiency is equal to the ratio of useful power to the total power absorbed by the system.

Because of the effect of hull and geometry of the inlet duct, the inlet velocity is different from ship velocity. Hence, the inlet velocity ratio is defined as follows:

$$IVR=\frac{V_{in}}{V_S}.$$

$=6.5/17.5$

$IVR =0.371$

Head losses in the duct inlet and outlet are functions of squared velocity

$h_{Inlet} = \xi V_{in}^{2}/2g$,

$=(0.25*6.5^{2})/(2*9.81)$

$h_{inlet}=0.53$ m

$h_{Outlet} = \psi V_{jet}^{2}/2g$,

$= (2.8*17.5^{2})/$
$(2*9.81)$ h = 24.49 m

Power input to the system (received by the pump) is given by

$$P_{pump} = \dot{m}\left[\frac{1}{2}\left(V_{jet}^{2} - V_{in}^{2}\right) + g\left(h_{j} + h_{loss}\right)\right],$$

$= 5186.54[0.5(13.1^{2} – 6.5^{2})$
$+9.81(986+296.5)$ $P_{pump} = 88091.32$ kW.

Where h_j is the vertical distance between the outlet nozzle and the water line? By separating system losses and applying loss coefficients, we obtain

$$P_{pump} = \frac{\dot{m}}{2}[V_{jet}^{2}(1+\psi) - (1-\xi)(1-\omega)^{2} V_{s}^{2} + 2gh_{j}].$$

$= (5186.54/2)\ [13.1(1+2.8)-(1-0.25)\ (1-0.5)^{2}*\ 17.5 + 2*9.81*986$

$= 69078$ kW.

Assuming the velocity ratio as

$\mu = V_S / V_{jet}$

$= 17.5/13.1$

$\mu = 1.33$

Now the jet efficiency can be written as

$$\eta_j = \frac{2\mu(1-(1-\omega)\mu)}{1+\psi-(1-\xi)(1-\omega)^2\mu^2+\frac{2gh_1}{V_s^2}\mu^2}.$$

$$= \frac{2(1.33)[1-(1-0.5)1.33]}{1+2.8-(1-0.25)(1-0.5)^2*1.33^2+(2*9.81*986*1.33^2/17.5^2)}$$

= 77.34%

The **efficiency** of hull is given by

$$\eta_{Hull} = \frac{1-t}{1-\omega},$$

$= (1-0.6)/(1-0.5)$

= 80%

The total efficiency is defined by the following equation:

$$\eta_{OA} = \eta_{Pump} \cdot \eta_{Hull} \cdot \eta_{jet},$$

$= 0.8 * 0.7734 * 0.81$

=49%

The total efficiency that we get finally = 49%

Hence the total efficiency = 49% and Efficiency of the hull= 80%.

5.2 3-D MODELLING OF THE SHIP

5.2.1 ABOUT SOFTWARE

CATIA - which stands for **C**omputer **A**ided **T**hree-dimensional **I**nteractive **A**pplication is the most powerful and widely used CAD (computer aided design) software of its kind in the world. CATIA is owned/developed by Dassault Systems of France and until 2010, was marketed worldwide by IBM.

CATIA plays a major role in the design process. Architects are now using CATIA. The great Guggenheim Museum in Spain, considered an architectural masterpiece, was designed using CATIA.

CATIA is used by the automotive and aerospace industries for automobile and aircraft product and tooling design. There are thousands of companies the world over using CATIA. For every company that uses CATIA for product design, there are hundreds of suppliers to those companies that also use CATIA.

CATIA is found in a variety of industries throughout the world. Some of these industries include; Aerospace, Appliances, Architecture, Automotive, Construction, Consumer Goods, Electronics, Medical, Furniture, Machinery, Mould and Die, and Shipbuilding.

CATIA has played a major role in NASA's design of the Space Shuttle. The military - working with private industry - - uses CATIA for the design of "jet-fighter" aircraft, aircraft carriers, helicopters, tanks and various other forms of weaponry.

5.2.2 CATIA MODELLING

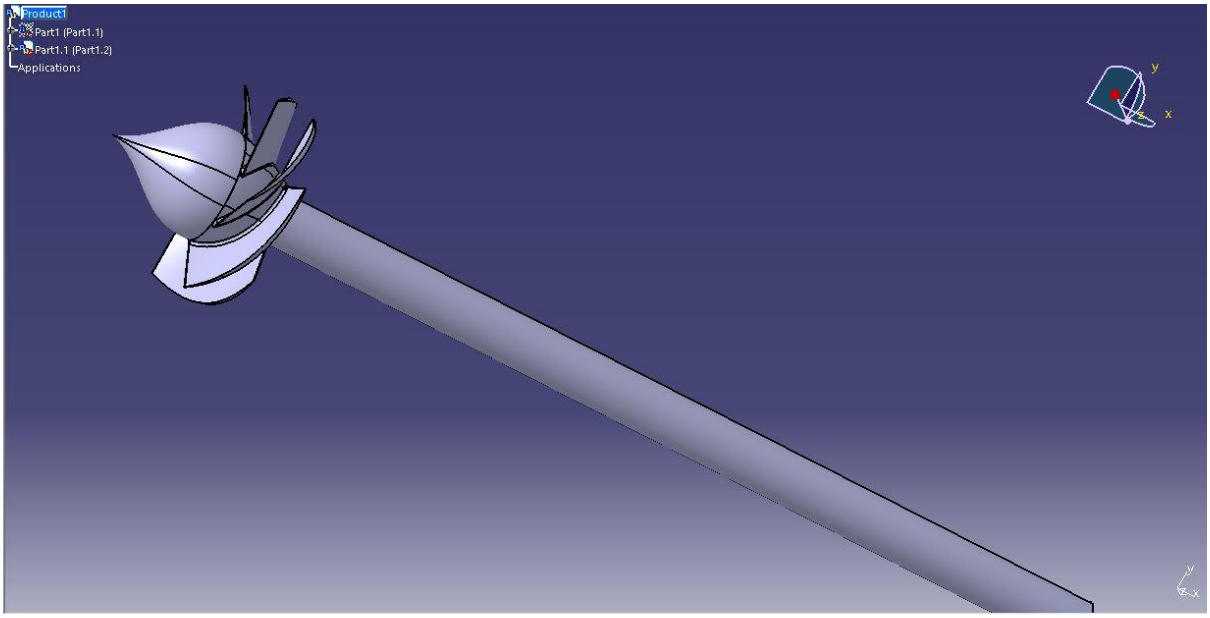


Fig 5.4: IMPELLER (3D Figure)

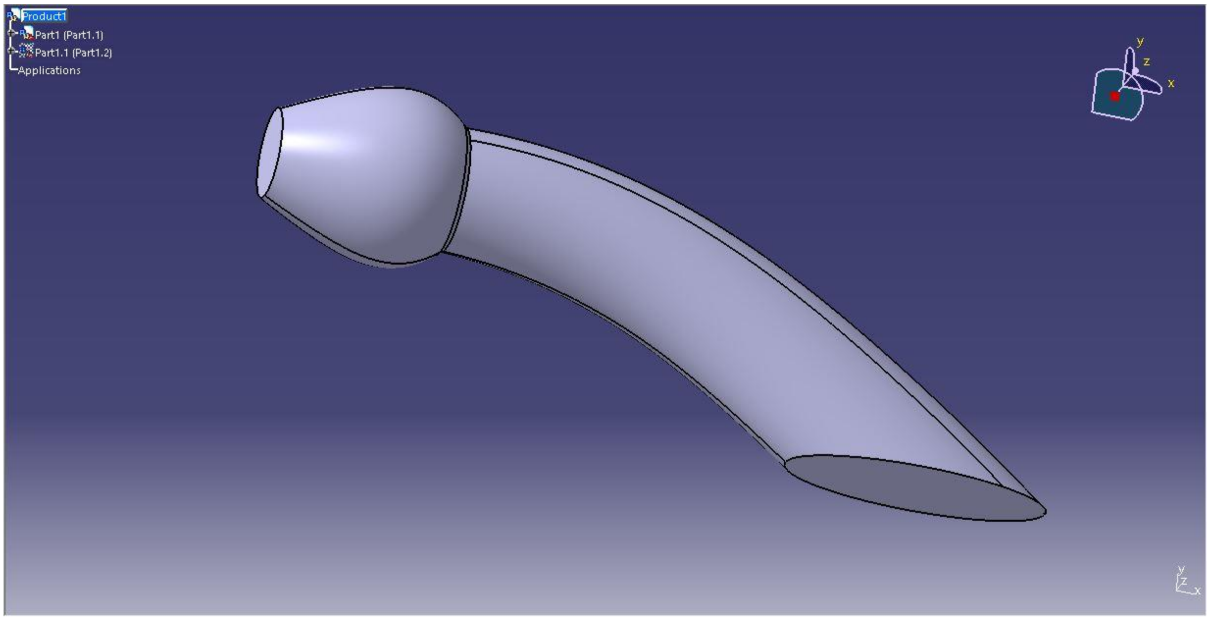


Fig 5.5: WATERJET CASING (3D Figure)

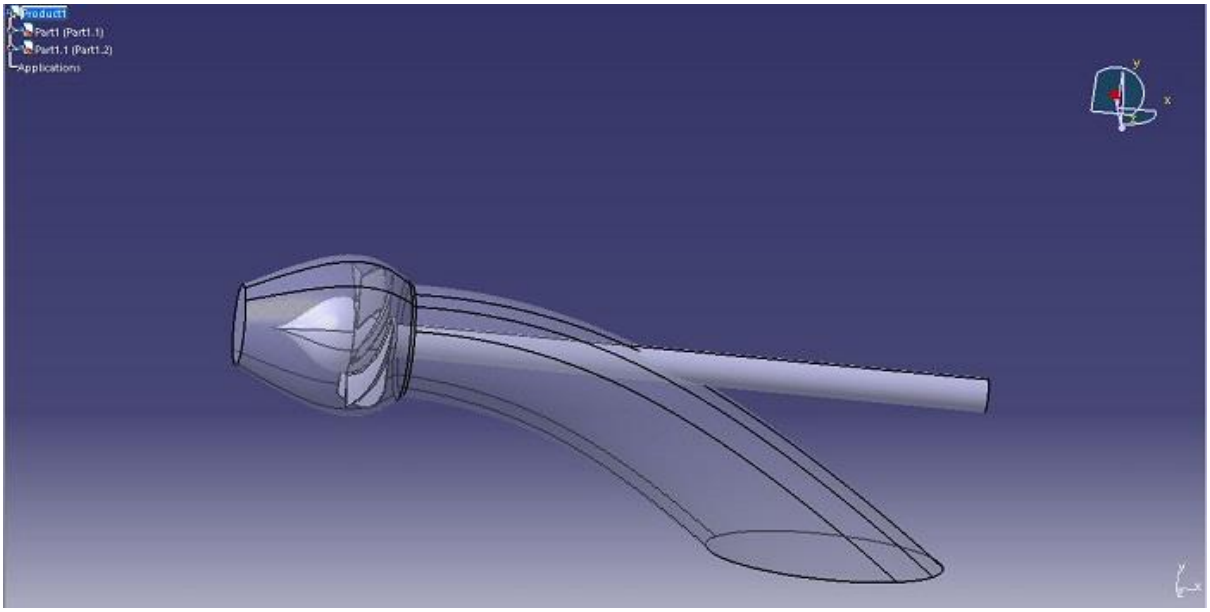


Fig 5.6: FINAL CATIA ASSEMBLY .Cat Product

Steps involved:

1. Click on all programs>click on CATIA V5 R20. Then a new issue means window is opened titled CATIA V5 R20.
2. Click on start>go to mechanical design>click on part design. Then a dialog box appears where a name is given to the part.
3. Click on XY plane & then click in sketch tool.
4. Draw each part (Gear, motor, shaft, pillow block (UCP 205), bush and propeller) by using various tools, profile etc.
5. Save the models as files.CATPart in specified location.
6. Go to Start > Mechanical design > Click on Assembly design. Assembly Workbench will be opened.
7. In the Product Structure Tools > Select Existing Component and click on Products > Select the saved files.CATPart file and click on Open. Components will get imported to Assembly module.

8. Go to Constraints toolbar > Click on Coincidence constraint > Select axis of shaft and gear > Click on Update.
9. Go to Constraints toolbar > Click on Contact constraint > Select the contact surfaces of models and click on Update.
10. If required move or rotate the parts along the axis using move tool.

Result:

11. The Modelling and Assembly of the propulsion system is successfully done.

5.3 ANALYSIS OF THE SHIP PROPELLER WITH ENCLOSURE

ANSYS INTRODUCTION

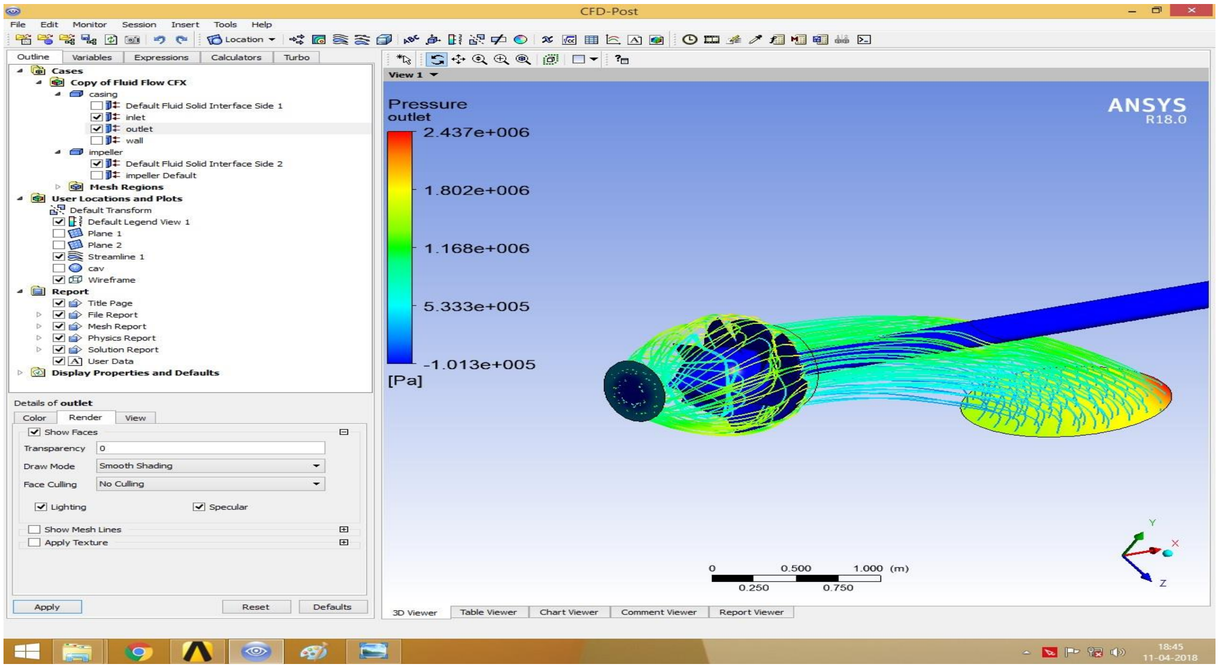
Ansys, Inc. is a public company based in Canonsburg, Pennsylvania. It develops and markets engineering simulation software. Ansys software is used to design products and semiconductors, as well as to create simulations that test a product's durability, temperature distribution, fluid movements, and electromagnetic properties.

Ansys develops and markets finite element analysis software used to simulate engineering problems .The software creates simulated computer models of structures, electronics, or machine components to simulate strength, toughness, elasticity, temperature distribution, electromagnetism, fluid flow, and other attributes Ansys is used to determine how a product will function with different specifications, without building test products or conducting crash tests.] For example, Ansys software may simulate how a bridge will hold up after years of traffic, how to best process salmon in a cannery to reduce waste, or how to design a slide that uses less material without sacrificing safety.

ANSYS CFX is a computational fluid dynamics software that is used by engineers for design and analysis of CAD models. It can simulate fluid flows in a virtual environment and is frequently used in the aerospace, automotive, and oil and energy fields.

ANSYS CFX is especially attuned to solving problems in turbo machinery and conjugate heat transfer, but it can solve any CFD problem, covering compressible and incompressible flow; ideal and real gas equations of steady and unsteady flow; subsonic, transonic, and supersonic flow; coupled convection; and conduction.

5.3.1 FLOW ANALYSIS



☑ Show Faces

Transparency 0

Draw Mode Smooth Shading

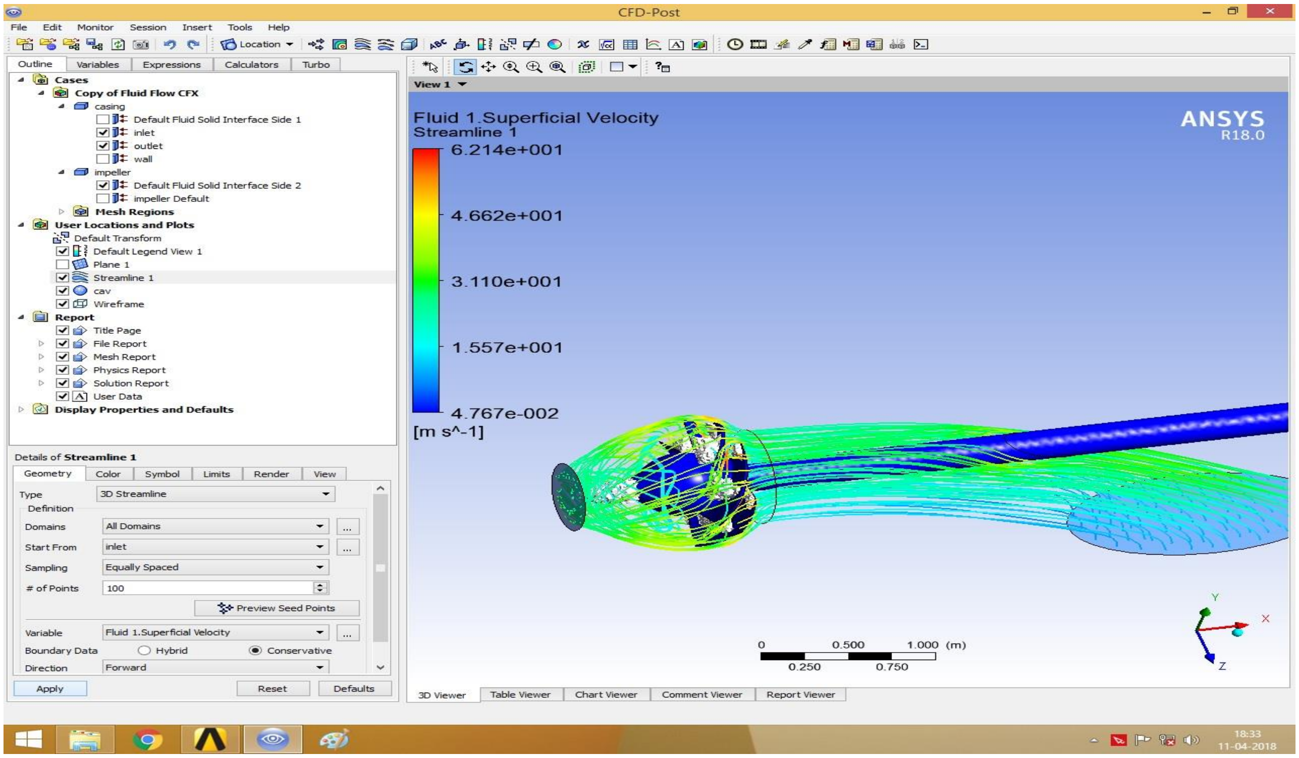
Face Culling No Culling

☑ Lighting ☑ Specular

☐ Show Mesh Lines

☐ Apply Texture

Fig 5.7 PRESSURE OUTLET VARIATION



Type 3D Streamline

Definition

Domains All Domains

Start From inlet

Sampling Equally Spaced

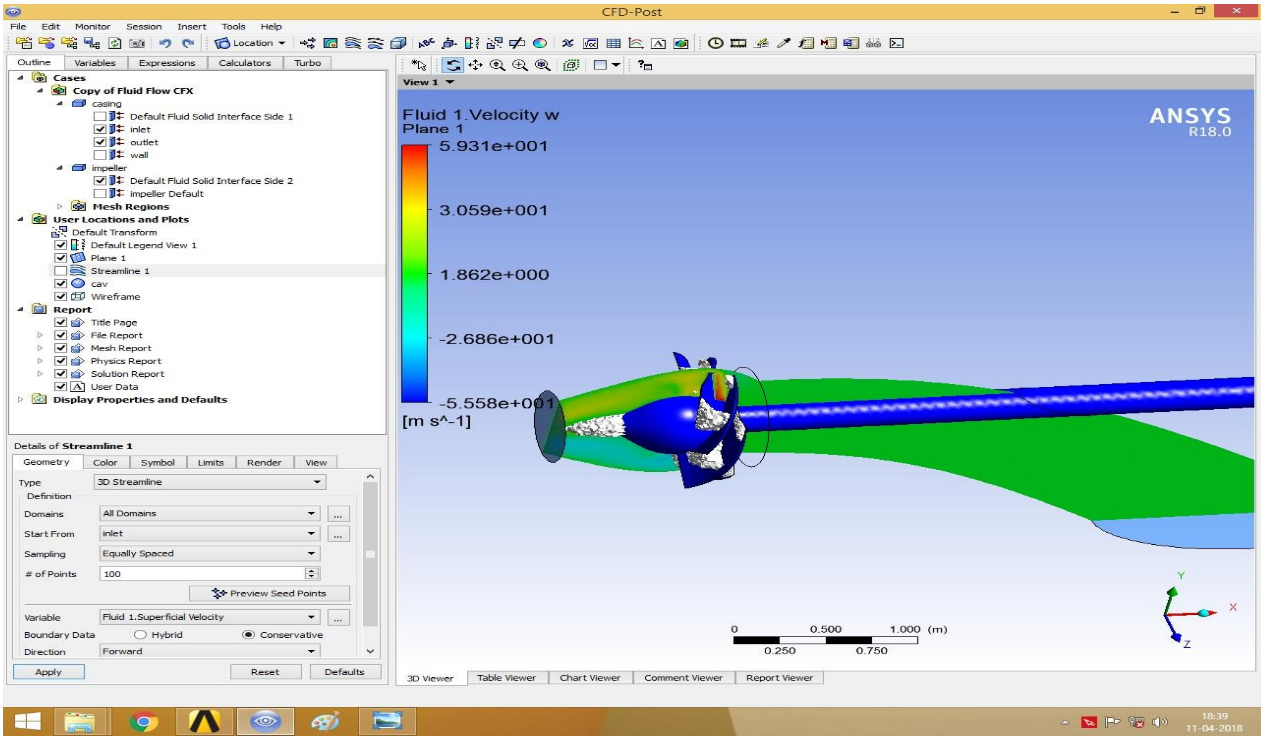
# of Points 100

Variable Fluid 1.Superficial Velocity

Boundary Data ○ Hybrid ● Conservative

Direction Forward

Fig 5.8 SUPERFICIAL VELOCITY STREAM LINE



Details of Streamline 1

Geometry | Color | Symbol | Limits | Render | View

Type: 3D Streamline

Definition

Domains: All Domains

Start From: inlet

Sampling: Equally Spaced

\# of Points: 100

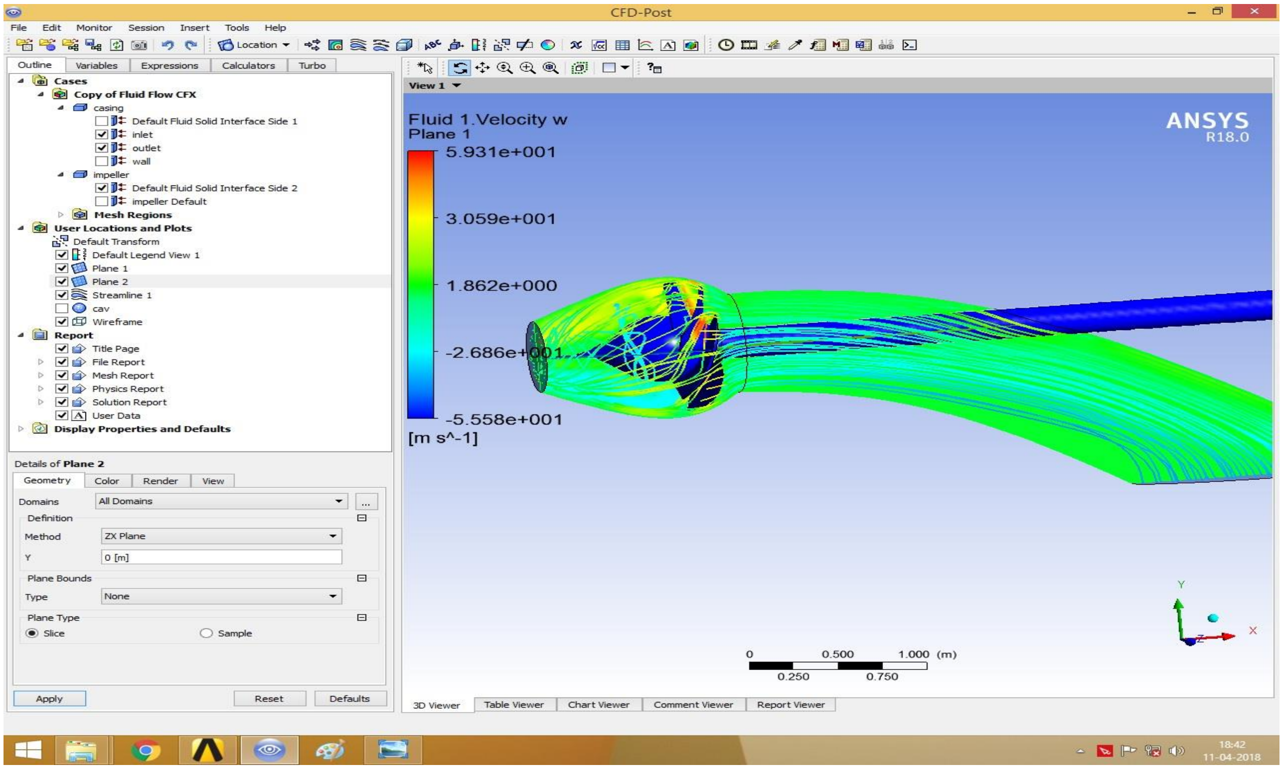
Preview Seed Points

Variable: Fluid 1.Superficial Velocity

Boundary Data: ○ Hybrid ● Conservative

Direction: Forward

Fig 5.9 VELOCITY VARIATION ALONG A PLANE



Details of Plane 2

Geometry | Color | Render | View

Domains: All Domains

Definition

Method: ZX Plane

Y: 0 [m]

Plane Bounds

Type: None

Plane Type

● Slice ○ Sample

Fig 5.10 VELOCITY VARIATION

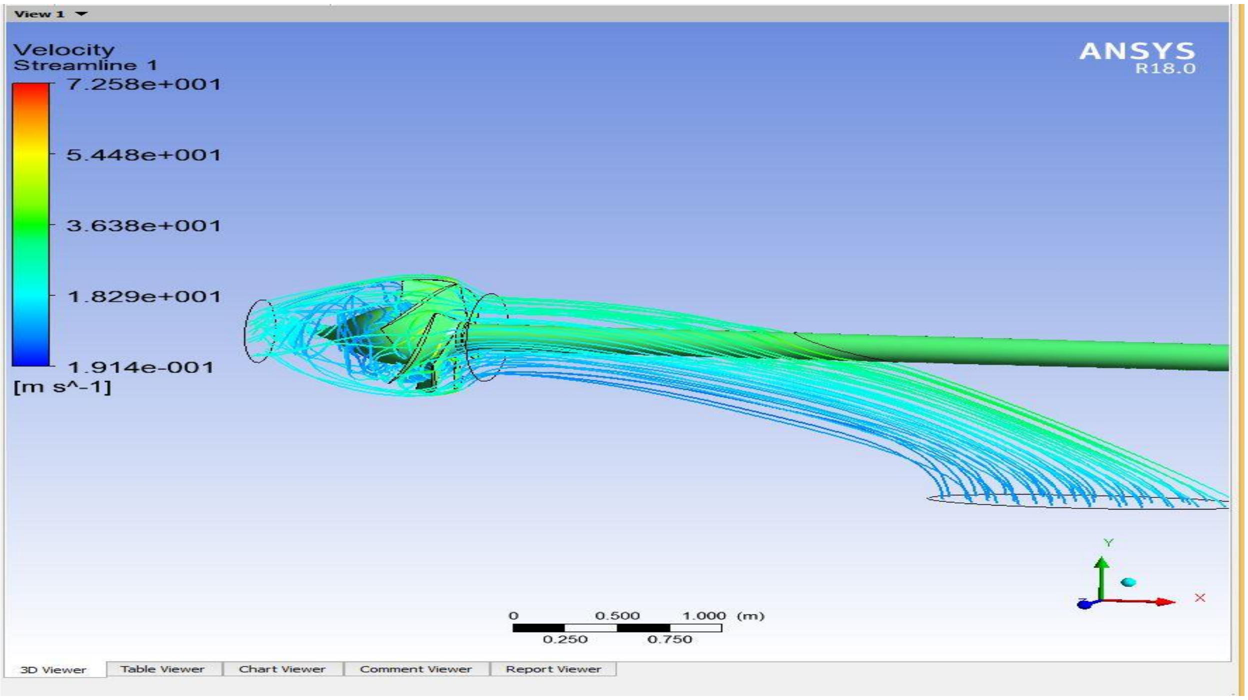
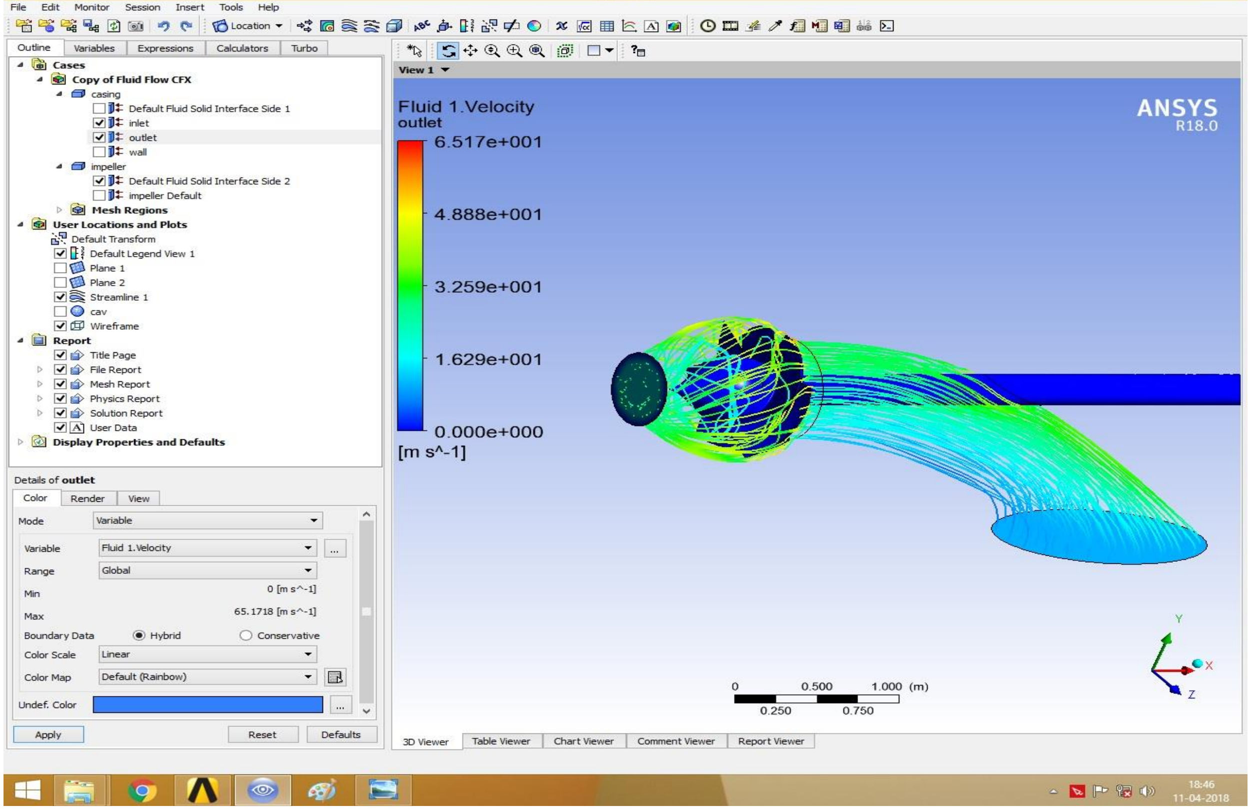


Fig 5.11 VELOCITY STREAM LINE



Details of outlet

Color | Render | View

Mode: Variable

Variable: Fluid 1.Velocity

Range: Global

Min: 0 [m s^-1]

Max: 65.1718 [m s^-1]

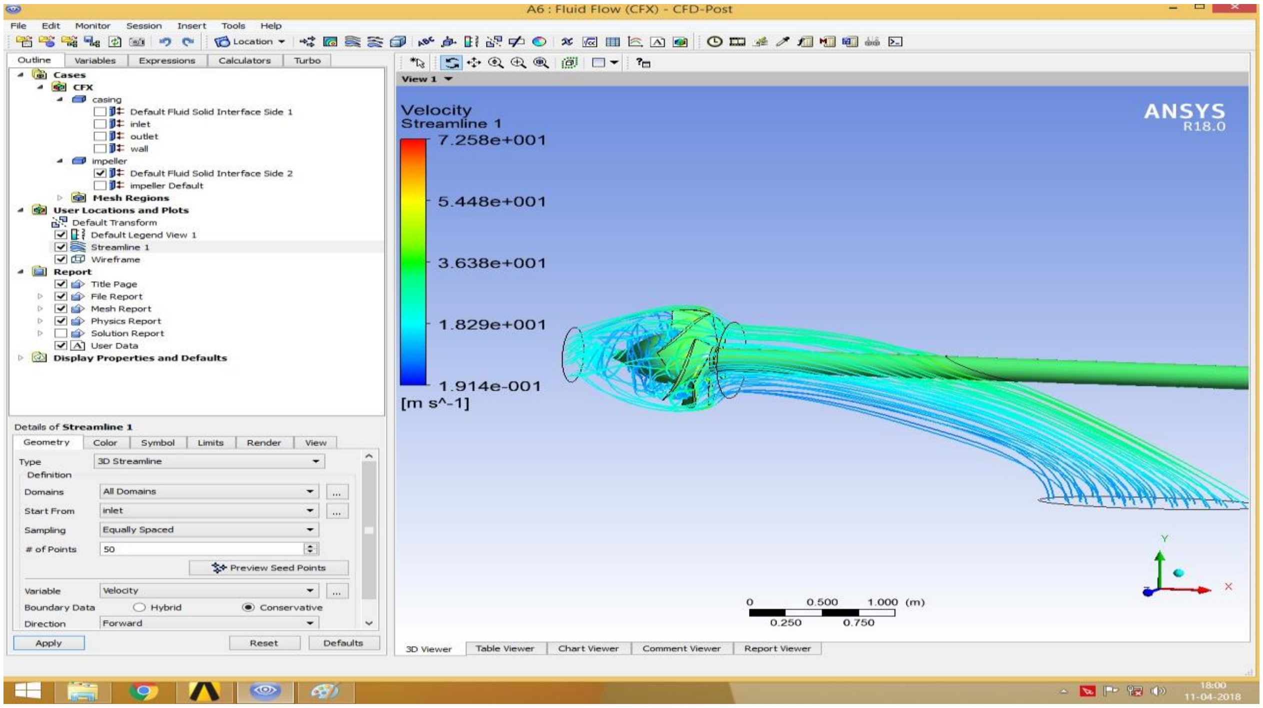
Boundary Data: ● Hybrid ○ Conservative

Color Scale: Linear

Color Map: Default (Rainbow)

Undef. Color

Fig 5.12VARIATION OF VELOCITY FROM INLET TO OUTLET



Details of **Streamline 1**

Type: 3D Streamline

Definition

Domains: All Domains

Start From: inlet

Sampling: Equally Spaced

# of Points: 50

Variable: Velocity

Boundary Data: ○ Hybrid ● Conservative

Direction: Forward

Fig 5.13 VELOCITY STREAM LINE

5.3.2 CAVITATIONS ANALYSIS

Water will boil at room temperature if the pressure is low enough. In fact, the pressure has to be very low, about 2% of standard atmospheric pressure at sea level.

Just like a wing generating lift, marine propellers use pressure differences across their blades to generate thrust. The pressure distribution on a propeller blade depends on its shape and how that shape influences the speed of the water flowing around the blade. As the flow speeds up, the pressure drops and conversely when the flow slows down, the pressure rises.

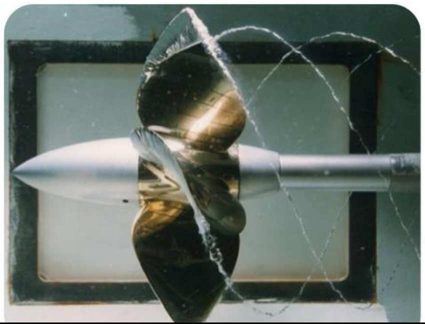


Fig 5.14: SCREW PROPELLER

Thus the blade is shaped to promote higher speed on the forward or suction side and lower speed on the aft or pressure side. If the blade shape is too aggressive, very low pressure can result. Indeed, this pressure can be low enough to reach the boiling point of water which then leads to cavitations.

.

The pressure plots show a problem with this propeller near the leading edge of the blades. There is a narrow band of high pressure (red area, left) on the suction side and a narrow band of low pressure (blue area, right) on the pressure side. This is undesirable since it means that the leading part of each blade is generating thrust in the wrong direction!

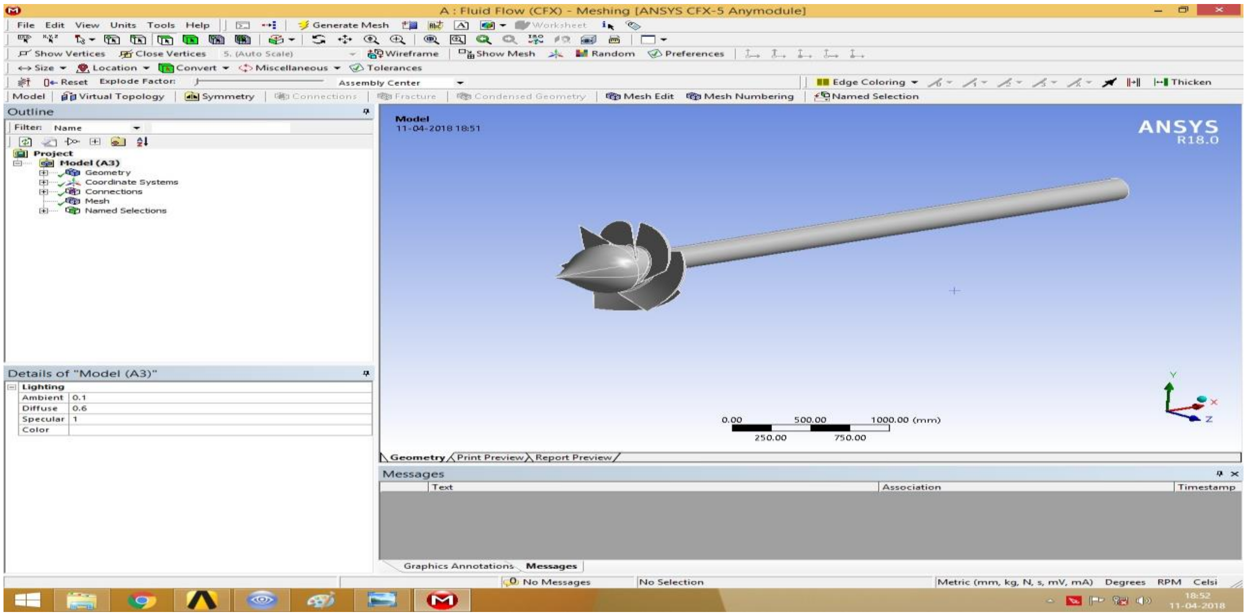
There is one catch though: these pressure plots do not include the effect of cavitation. The dark blue areas show pressure below the vapour pressure of water which means cavitation should occur in those areas. By turning on the cavitation model, the phase change from water to water vapour can be captured. This is shown in the figure at the right where the pink area represents the interface between water and water vapour. The remarkable accuracy of this cavitations prediction can be seen by comparing the areas of erosion on the actual propeller (left) with CFD results (right).

The model shows that sheet cavitations are occurring near the leading edge on the pressure side of the blades. This indicates that effective angle of attack near the leading edge must be negative, resulting in an area of very low pressure on the aft side of the blade.

STEPS INVOLVED IN CAVITATION ANALYSIS:

- ### Geometry

1. Open ANSYS Workbench 18.0 > Drag and Drop Static Fluid CFX into the project schematic.
2. Right click on Geometry > Import Geometry > Select the file “propeller of VIGT-18.igs” in the saved location > Click on Update.
3. Now Double click on geometry, and then design modeller window will open. Go to Tools > Enclosure > In the details toolbar, select uniform cushion > select preference as cylinder enclosure and give the value as 30mm front and 25 mm back > Click on Generate > Update the geometry and exit design modeller window.



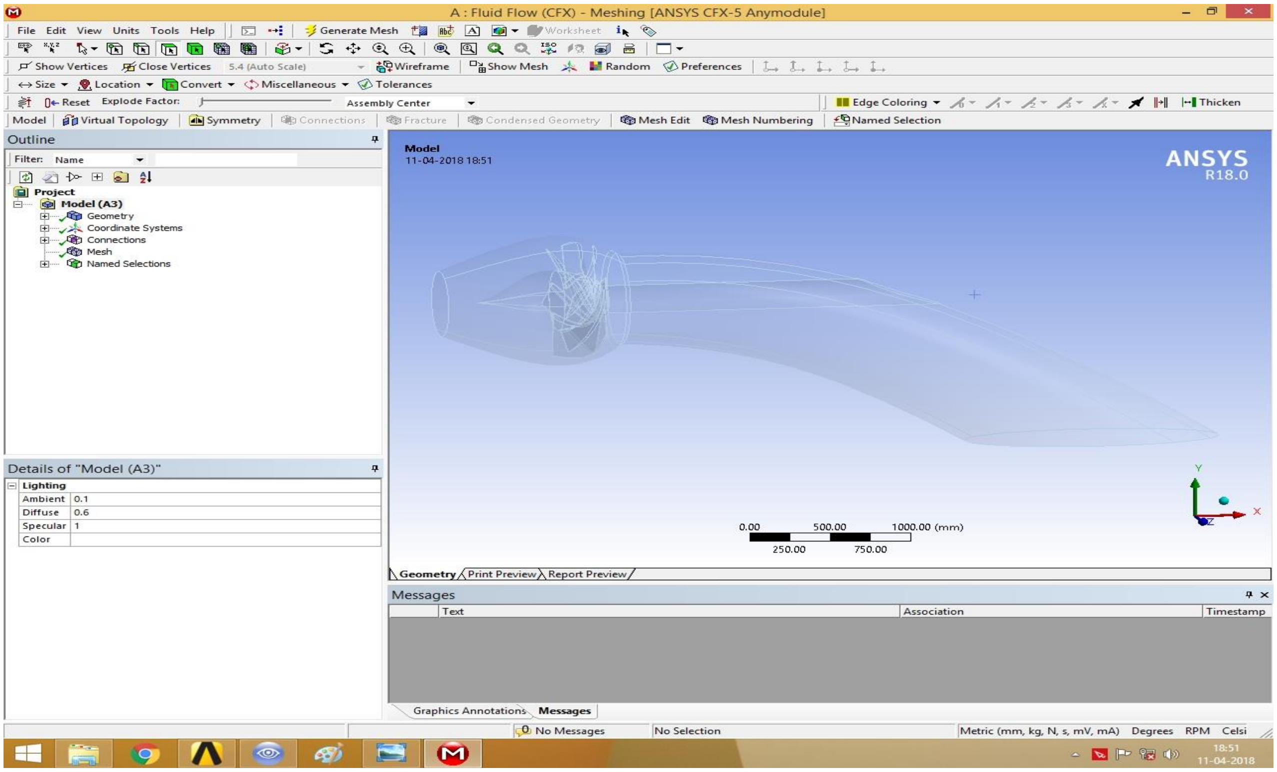
Details of "Model (A3)"

Lighting	
Ambient	0.1
Diffuse	0.6
Specular	1
Color	

No Messages

No Selection

Fig 5.15: IMPORTED IMPELLER IN ANSYS WORKBENCH



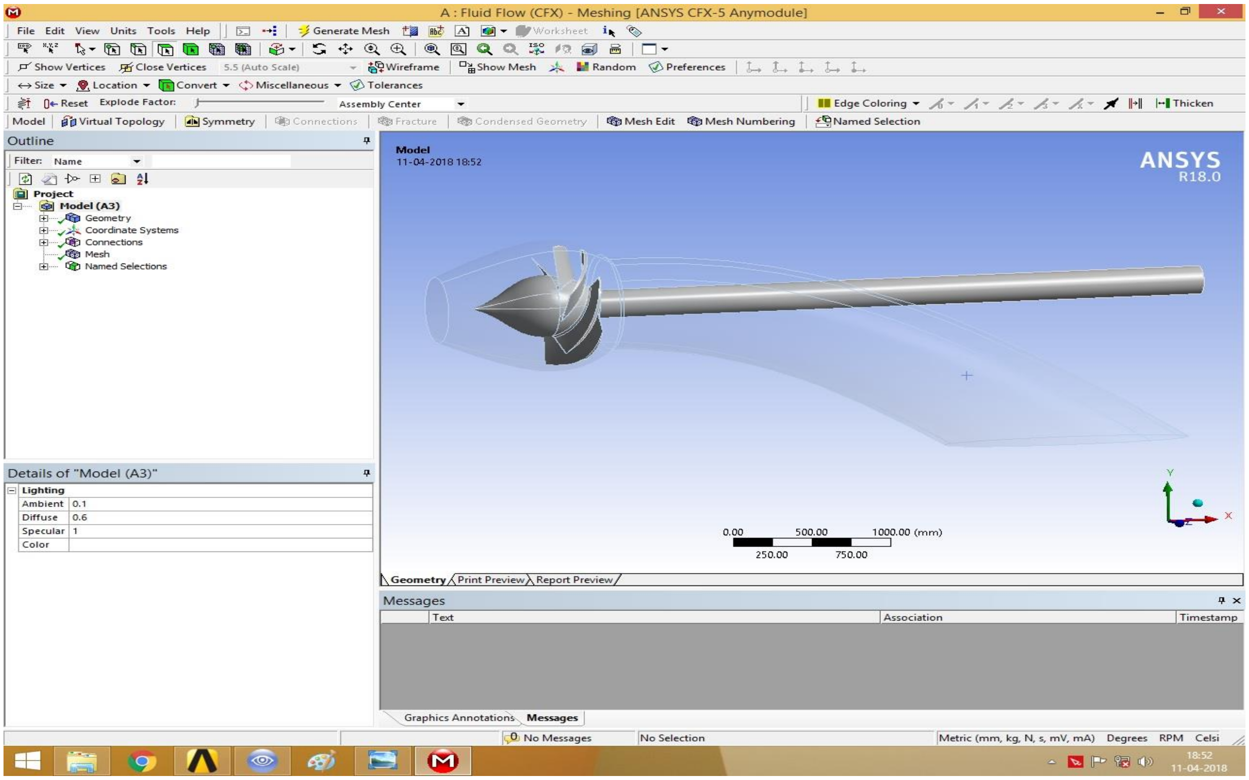
Details of "Model (A3)"

Lighting	
Ambient	0.1
Diffuse	0.6
Specular	1
Color	

No Messages

No Selection

Fig 5.16: IMPORTED ASSEMBLY MODEL OF IMPELLER AND ENCLOSURE WITH TRANSPARENCY IN ANSYS WORKBENCH



Details of "Model (A3)"

Lighting	
Ambient	0.1
Diffuse	0.6
Specular	1
Color	

Fig 5.17 IMPORTED GEOMETRY OF PROPELLER MODEL WITH ENCLOSURE IN ANSYS WORKBENCH

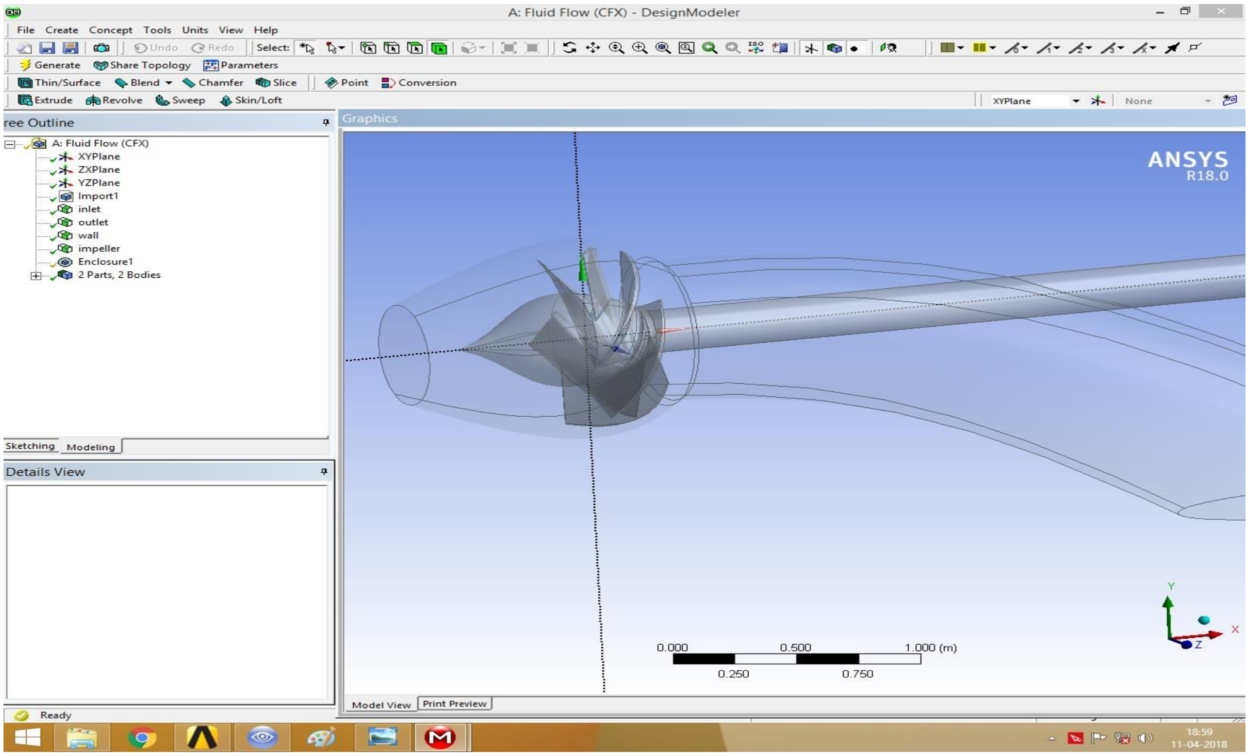


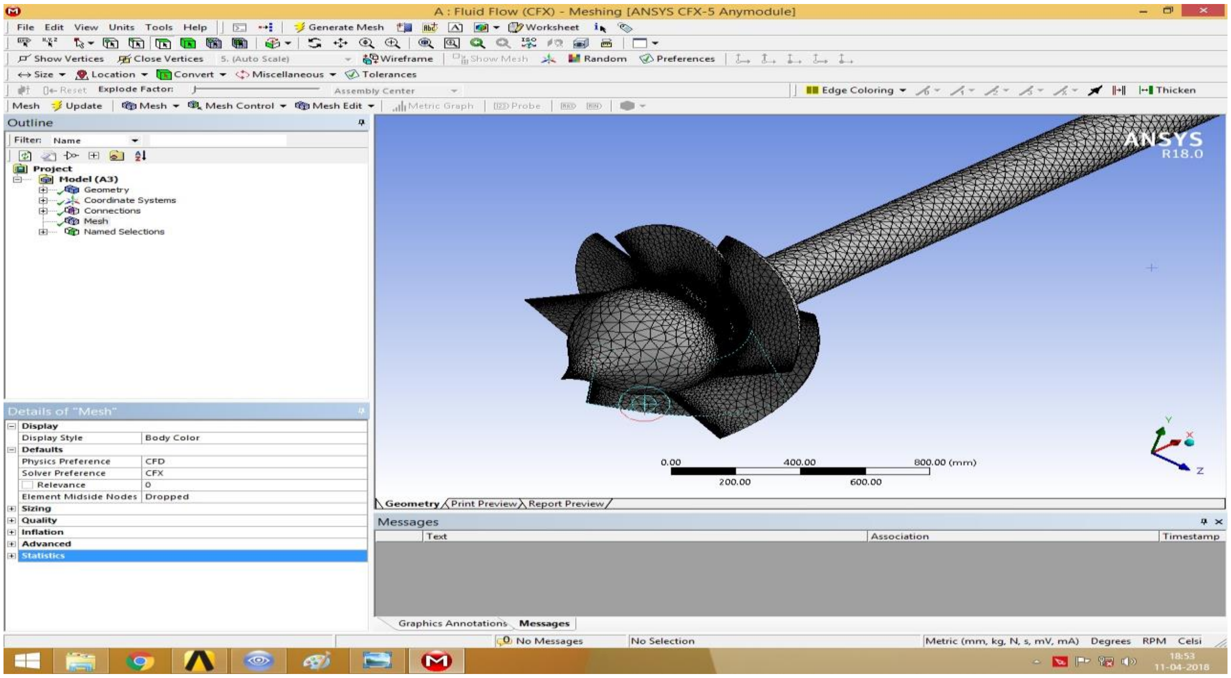
Fig 5.18 IMPORTED GEOMETRY OF PROPELLER MODEL IN ANSYS WORKBENCH

- ## Meshing

4. Right click on mesh > Click on Edit. The meshing window will open.
5. Right Click on Mesh in the specification tree > in the details toolbar, give the following inputs and click on Generate Mesh.

Physics Preference	- CFD
Solver Preference	- Fluent
Relevance Centre	- Fine
Advanced Size function	- Proximity and Curvature
Smoothing	- High

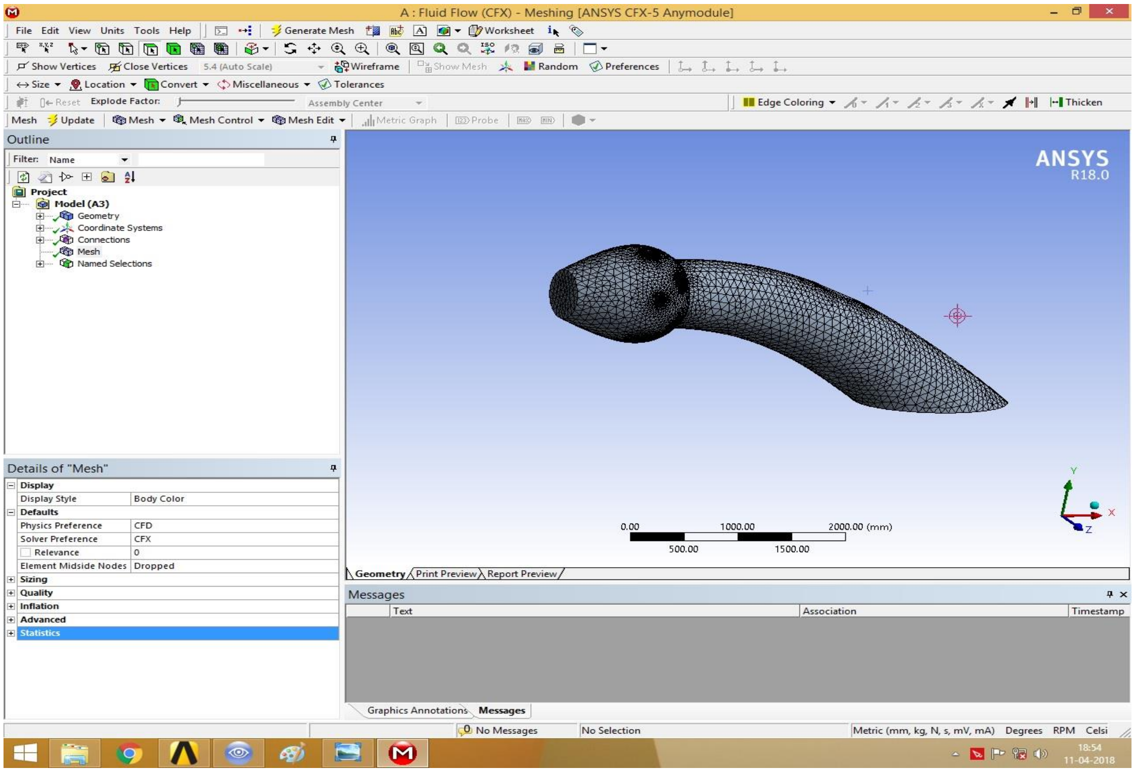
6.Now Select the individual faces of the enclosure, right click on the face > Click on Create Named Selection > select the face and give the names as inlet, outlet and wall > Click on Update Mesh.



Details of "Mesh"

Display	
Display Style	Body Color
Defaults	
Physics Preference	CFD
Solver Preference	CFX
☐ Relevance	0
Element Midside Nodes	Dropped
Sizing	
Quality	
Inflation	
Advanced	
Statistics	

Fig 5.19 IMPELLER MESHING

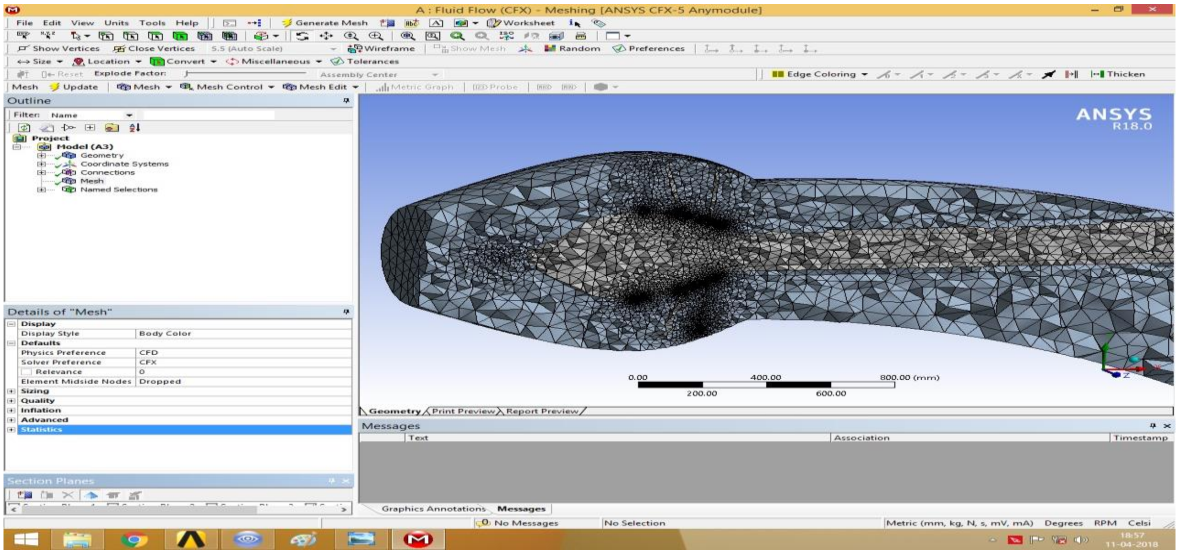


Details of "Mesh"

Display	
Display Style	Body Color
Defaults	
Physics Preference	CFD
Solver Preference	CFX
Relevance	0
Element Midside Nodes	Dropped
Sizing	
Quality	
Inflation	
Advanced	
Statistics	

No Messages | No Selection | Metric (mm, kg, N, s, mV, mA) Degrees RPM Celsi

Fig 5.20 ENCLOSURE MESHING

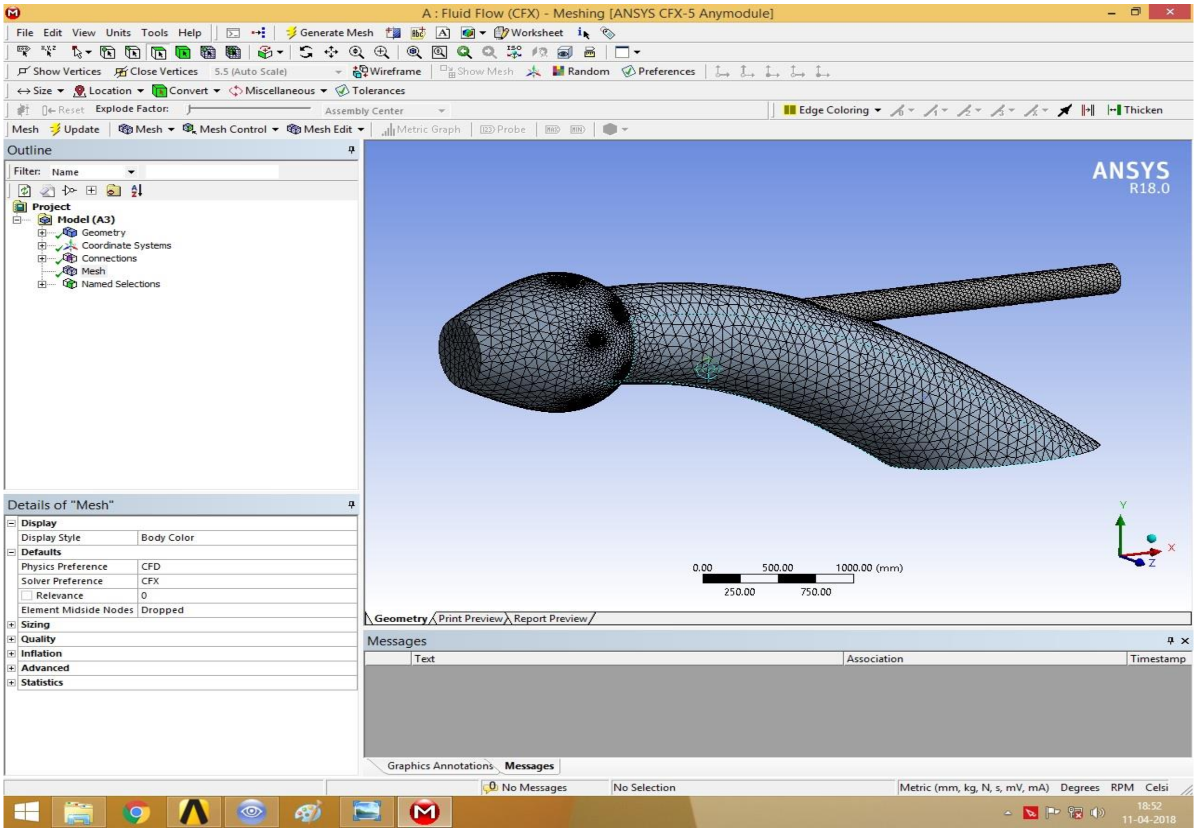


Details of "Mesh"

Display	
Display Style	Body Color
Defaults	
Physics Preference	CFD
Solver Preference	CFX
Relevance	0
Element Midside Nodes	Dropped
Sizing	
Quality	
Inflation	
Advanced	
Statistics	

No Messages | No Selection | Metric (mm, kg, N, s, mV, mA) Degrees RPM Celsi

Fig 5.21 SECTIONAL VIEW OF MESHED WATERJET ASSEMBLY



Details of "Mesh"

Display	
Display Style	Body Color
Defaults	
Physics Preference	CFD
Solver Preference	CFX
Relevance	0
Element Midside Nodes	Dropped
Sizing	
Quality	
Inflation	
Advanced	
Statistics	

No Messages

No Selection

Metric (mm, kg, N, s, mV, mA) Degrees RPM Celsi

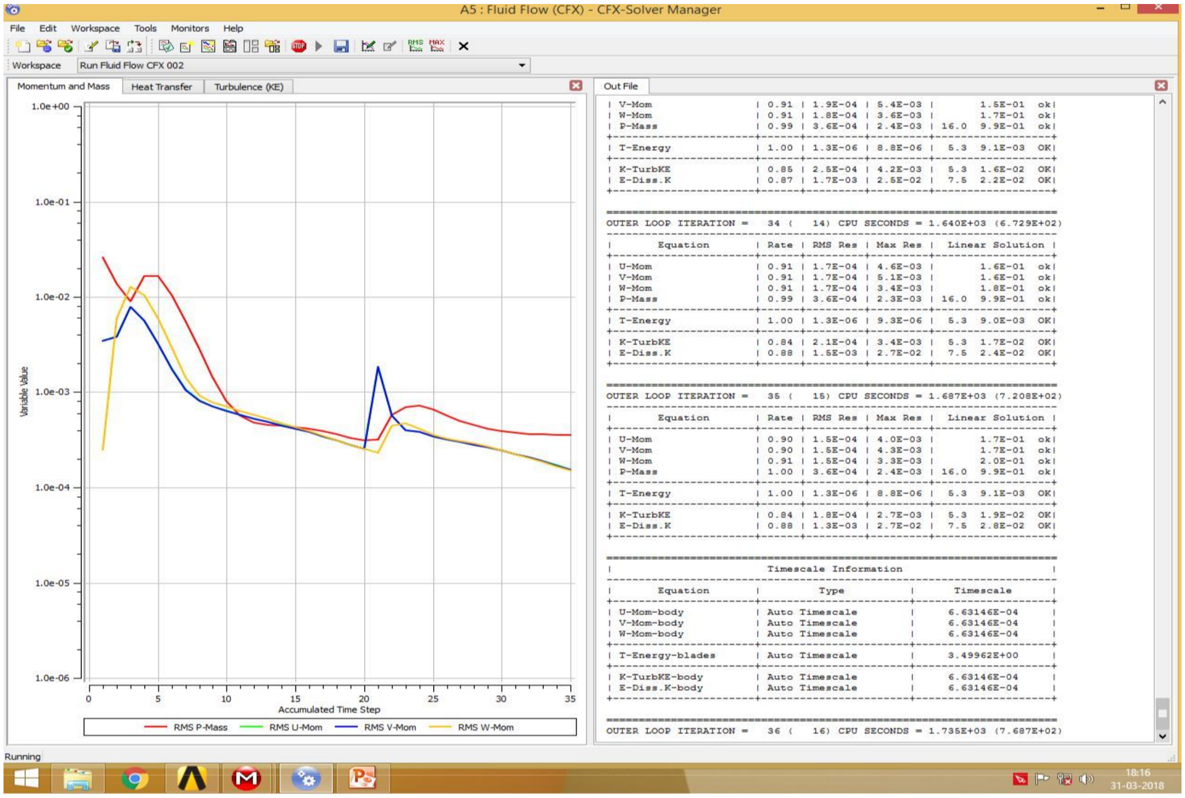
Fig 5.22 MESHED WATERJET ASSEMBLY

- **Setup**

7. Double Click on Setup > Select Double Precision in Options > Serial in processing Options > Click on OK.
8. Create domain structure & generate the domains as per named sections> select the solid component as blade > and liquid profile as inlet , wall,etc
9. Select the blade profile and give the required rpm> 1440 rpm clockwise > then click on the equation method> use Rayleigh Placket equation > click OK.

- **SOLUTION**

10. Wait until the geometry is loaded and in the Solution Setup > Go to General > Click on Check and Report Quality.
11. Go to Materials > Select water > Click on Edit > Verify the default inputs and click OK.
12. Go to Boundary Conditions > Select inlet zone > Set type as velocity-inlet and click on Edit > Give Velocity Magnitude as 6m/s >Go to outlet zone >set velocity –outlet > magnitude as 8m/s> Click on OK.
13. Go to Solution Initialization > Select Standard Initialization > Compute from inlet > Click on Initialize.
14. Go to Run Calculation > Give the number of Iterations as 20 > Profile update and reporting interval as 1 > Click on Calculate.
15. Wait until a information is displayed saying calculation complete. Click on OK and terminate the solution workbench.



```
| V-Mom                | 0.91 | 1.9E-04 | 5.4E-03 |       1.5E-01  ok|
| W-Mom                | 0.91 | 1.8E-04 | 3.6E-03 |       1.7E-01  ok|
| P-Mass               | 0.99 | 3.6E-04 | 2.4E-03 | 16.0  9.9E-01  ok|
+----------------------+------+---------+---------+------------------+
| T-Energy             | 1.00 | 1.3E-06 | 8.8E-06 |  5.3  9.1E-03  OK|
+----------------------+------+---------+---------+------------------+
| K-TurbKE             | 0.85 | 2.5E-04 | 4.2E-03 |  5.3  1.6E-02  OK|
| E-Diss.K             | 0.87 | 1.7E-03 | 2.5E-02 |  7.5  2.2E-02  OK|
+----------------------+------+---------+---------+------------------+

======================================================================
OUTER LOOP ITERATION =   34 (   14) CPU SECONDS = 1.640E+03 (6.729E+02)
----------------------------------------------------------------------
|       Equation       | Rate | RMS Res | Max Res |  Linear Solution |
+----------------------+------+---------+---------+------------------+
| U-Mom                | 0.91 | 1.7E-04 | 4.6E-03 |       1.6E-01  ok|
| V-Mom                | 0.91 | 1.7E-04 | 5.1E-03 |       1.6E-01  ok|
| W-Mom                | 0.91 | 1.7E-04 | 3.4E-03 |       1.8E-01  ok|
| P-Mass               | 0.99 | 3.6E-04 | 2.3E-03 | 16.0  9.9E-01  ok|
+----------------------+------+---------+---------+------------------+
| T-Energy             | 1.00 | 1.3E-06 | 9.3E-06 |  5.3  9.0E-03  OK|
+----------------------+------+---------+---------+------------------+
| K-TurbKE             | 0.84 | 2.1E-04 | 3.4E-03 |  5.3  1.7E-02  OK|
| E-Diss.K             | 0.88 | 1.5E-03 | 2.7E-02 |  7.5  2.4E-02  OK|
+----------------------+------+---------+---------+------------------+

======================================================================
OUTER LOOP ITERATION =   35 (   15) CPU SECONDS = 1.687E+03 (7.208E+02)
----------------------------------------------------------------------
|       Equation       | Rate | RMS Res | Max Res |  Linear Solution |
+----------------------+------+---------+---------+------------------+
| U-Mom                | 0.90 | 1.5E-04 | 4.0E-03 |       1.7E-01  ok|
| V-Mom                | 0.90 | 1.5E-04 | 4.3E-03 |       1.7E-01  ok|
| W-Mom                | 0.91 | 1.5E-04 | 3.3E-03 |       2.0E-01  ok|
| P-Mass               | 1.00 | 3.6E-04 | 2.4E-03 | 16.0  9.9E-01  ok|
+----------------------+------+---------+---------+------------------+
| T-Energy             | 1.00 | 1.3E-06 | 8.8E-06 |  5.3  9.1E-03  OK|
+----------------------+------+---------+---------+------------------+
| K-TurbKE             | 0.84 | 1.8E-04 | 2.7E-03 |  5.3  1.9E-02  OK|
| E-Diss.K             | 0.88 | 1.3E-03 | 2.7E-02 |  7.5  2.8E-02  OK|
+----------------------+------+---------+---------+------------------+

======================================================================
|                        Timescale Information                       |
----------------------------------------------------------------------
|       Equation       |           Type           |     Timescale    |
+----------------------+--------------------------+------------------+
| U-Mom-body           | Auto Timescale           |    6.63146E-04   |
| V-Mom-body           | Auto Timescale           |    6.63146E-04   |
| W-Mom-body           | Auto Timescale           |    6.63146E-04   |
+----------------------+--------------------------+------------------+
| T-Energy-blades      | Auto Timescale           |    3.49962E+00   |
+----------------------+--------------------------+------------------+
| K-TurbKE-body        | Auto Timescale           |    6.63146E-04   |
| E-Diss.K-body        | Auto Timescale           |    6.63146E-04   |
+----------------------+--------------------------+------------------+

======================================================================
OUTER LOOP ITERATION =   36 (   16) CPU SECONDS = 1.735E+03 (7.687E+02)
```

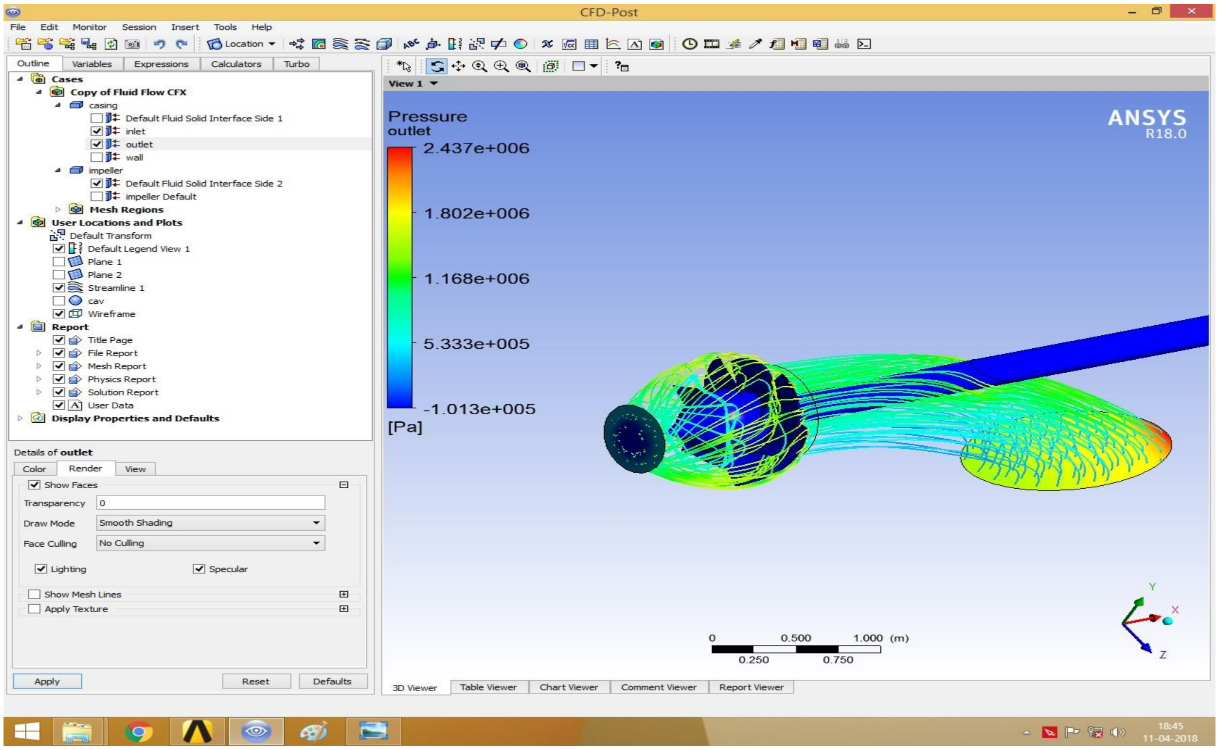
Fig 5.23: SOLUTION ITERATION

5.3.3 PLOT RESULTS

16. Open Results Window > Enable contact region, disable Wireframe > Click on Insert Streamline > give name as streamline 1 > Click on OK.
17. In the details toolbar, give the following inputs and click on OK.

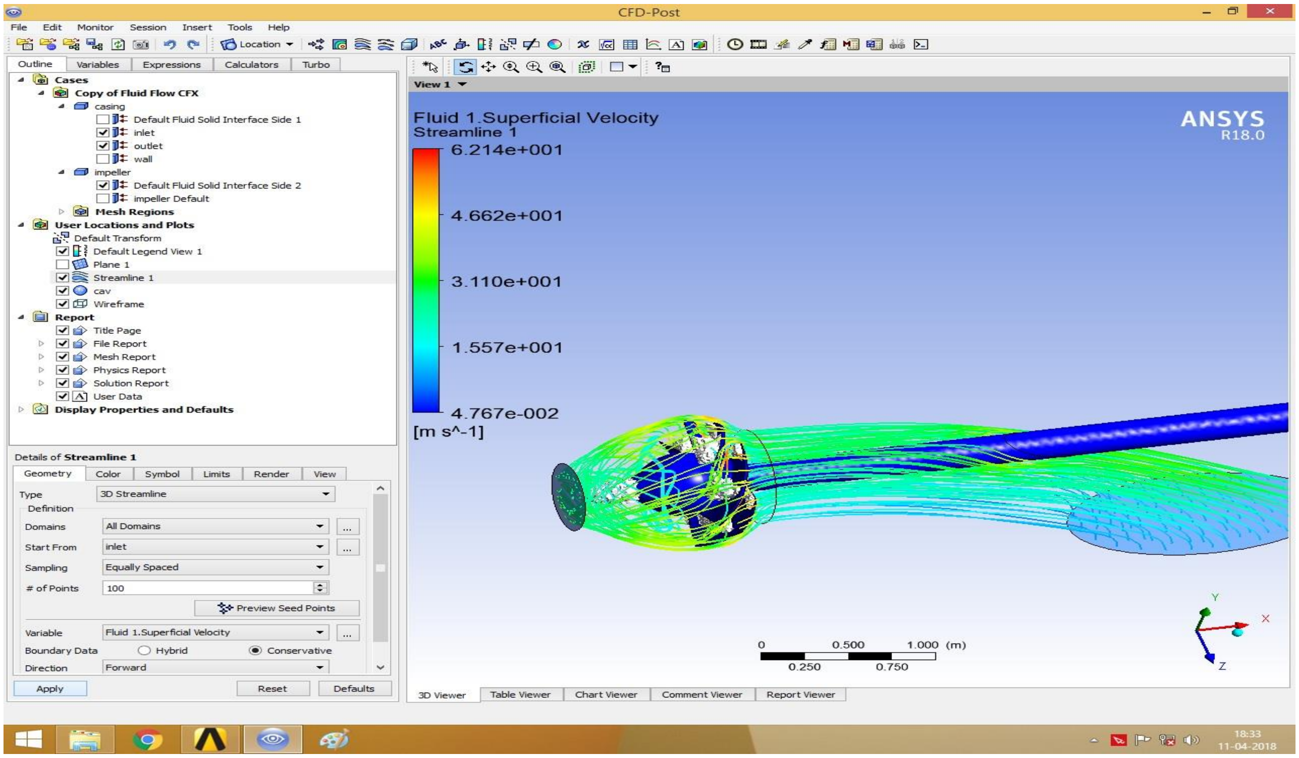
Domains - All Domains
Start from - Inlet
Sampling - Equally spaced
No of points - 150
Variable - Velocity
Direction - Forward and Backward

18. We can visualize the streamlines showing varying velocities over the propeller body from inlet to outlet as shown in the figures. Similarly, other parameters like pressure and temperature variations can also be studied.



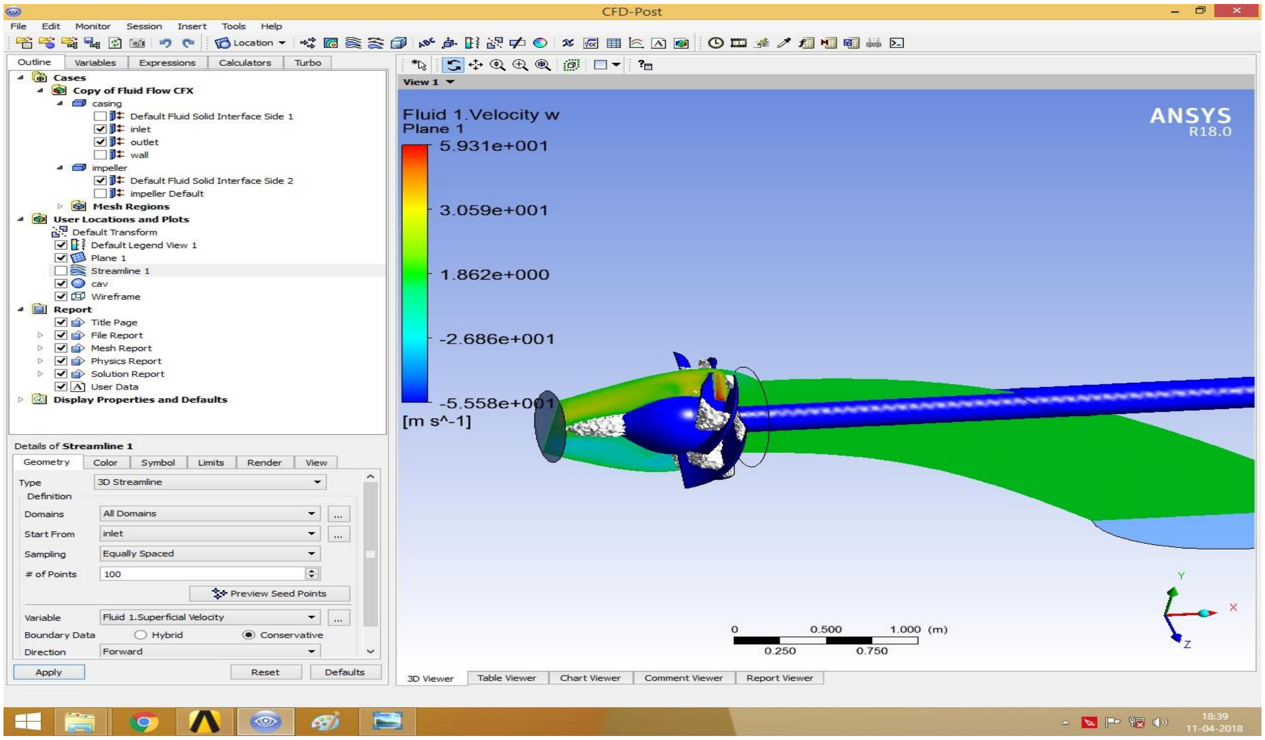
Transparency 0
Draw Mode Smooth Shading
Face Culling No Culling

Fig 5.24 PRESSURE OUTLET VARIATION



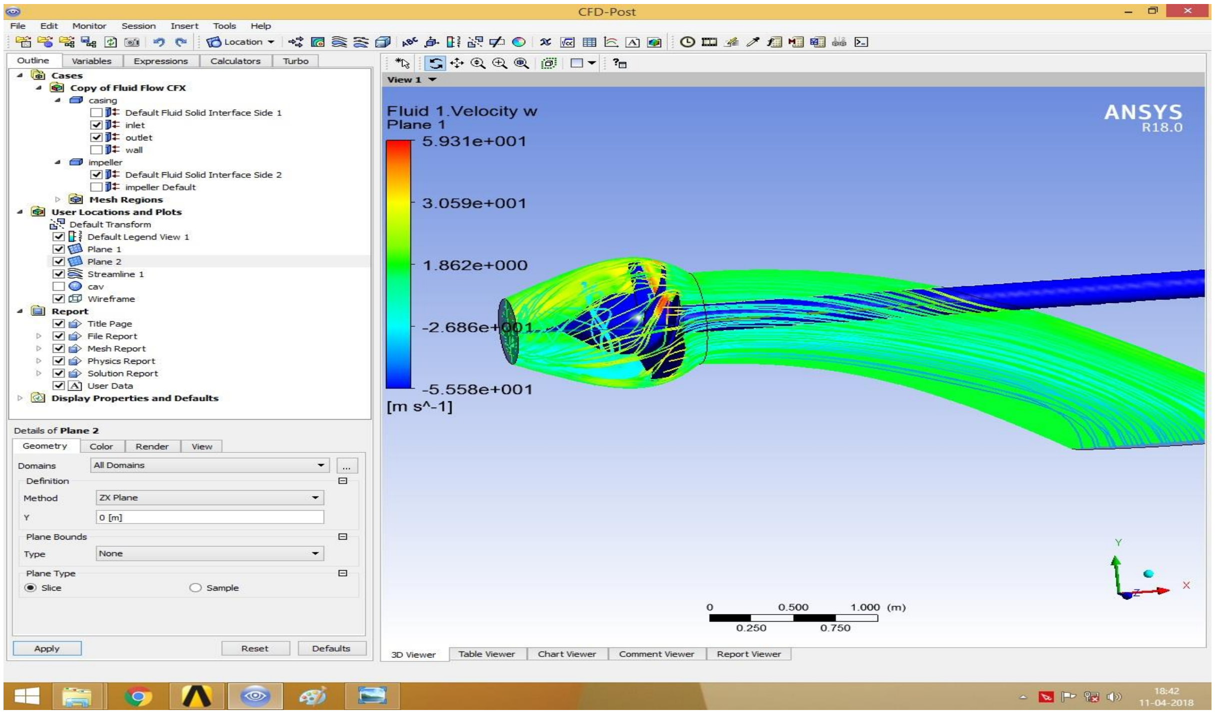
Type: 3D Streamline
Definition
Domains: All Domains
Start From: inlet
Sampling: Equally Spaced
# of Points: 100
Variable: Fluid 1.Superficial Velocity
Boundary Data: ○ Hybrid ● Conservative
Direction: Forward

Fig 5.25 SUPERFICIAL VELOCITY STREAM LINE



Type: 3D Streamline
Definition
Domains: All Domains
Start From: inlet
Sampling: Equally Spaced
# of Points: 100
Variable: Fluid 1.Superficial Velocity
Boundary Data: ○ Hybrid ● Conservative
Direction: Forward

Fig 5.26 VELOCITY VARIATION ALONG A PLANE



Details of **Plane 2**

Geometry Color Render View

Domains: All Domains

Definition

Method: ZX Plane

Y: 0 [m]

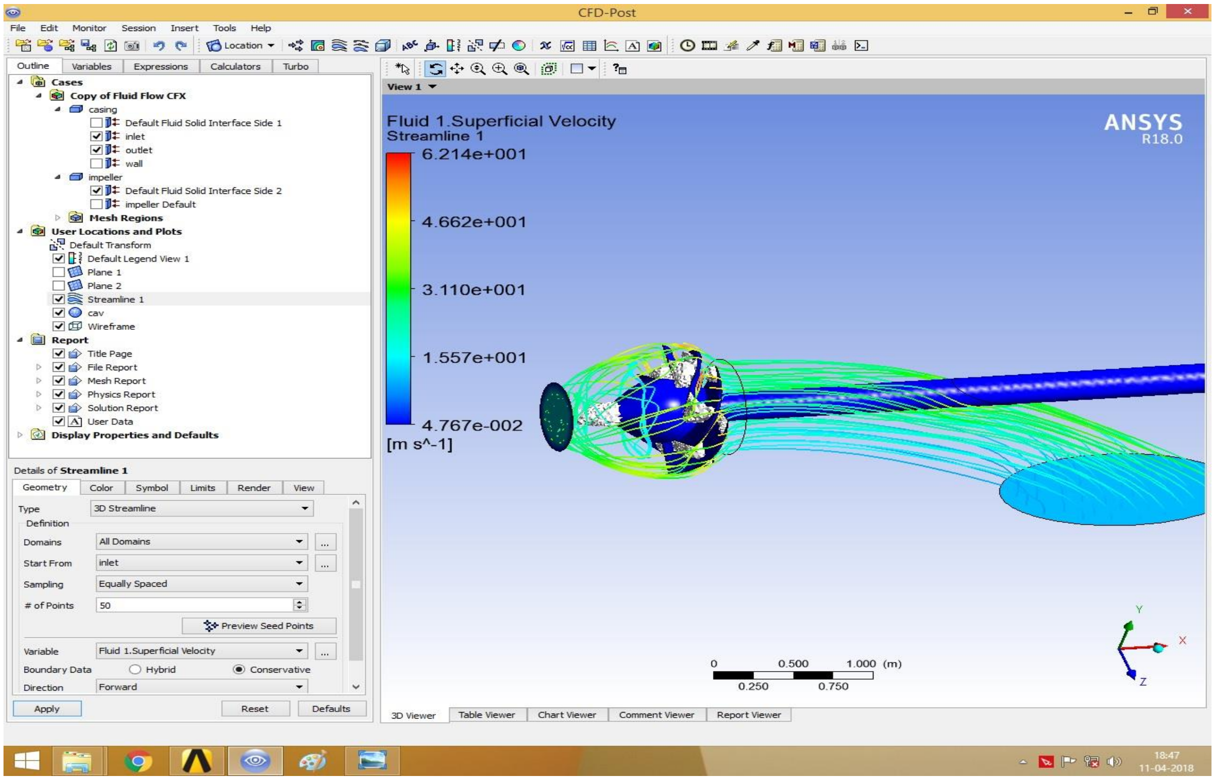
Plane Bounds

Type: None

Plane Type

● Slice ○ Sample

Fig 5.27 VELOCITY VARIATION



Details of **Streamline 1**

Geometry Color Symbol Limits Render View

Type: 3D Streamline

Definition

Domains: All Domains

Start From: inlet

Sampling: Equally Spaced

# of Points: 50

Variable: Fluid 1.Superficial Velocity

Boundary Data: ○ Hybrid ● Conservative

Direction: Forward

Fig 5.28 DEPECTING CAVITATION EFFECTS ALONG WITH STREAM LINES

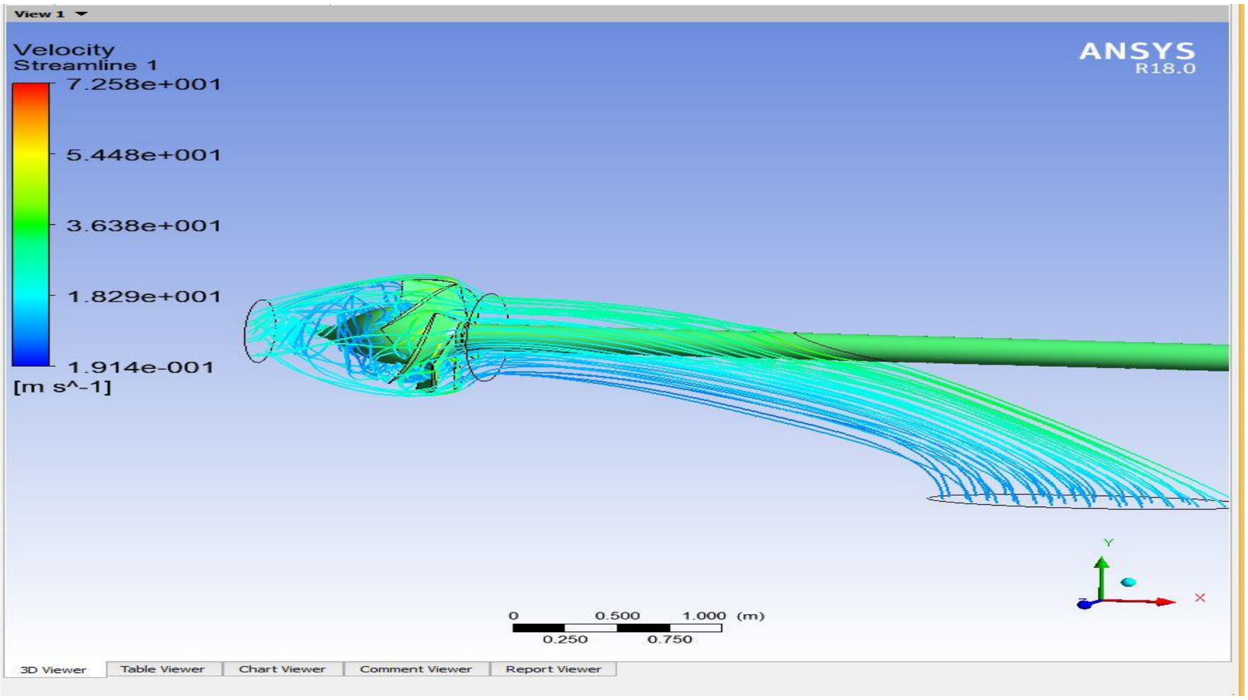
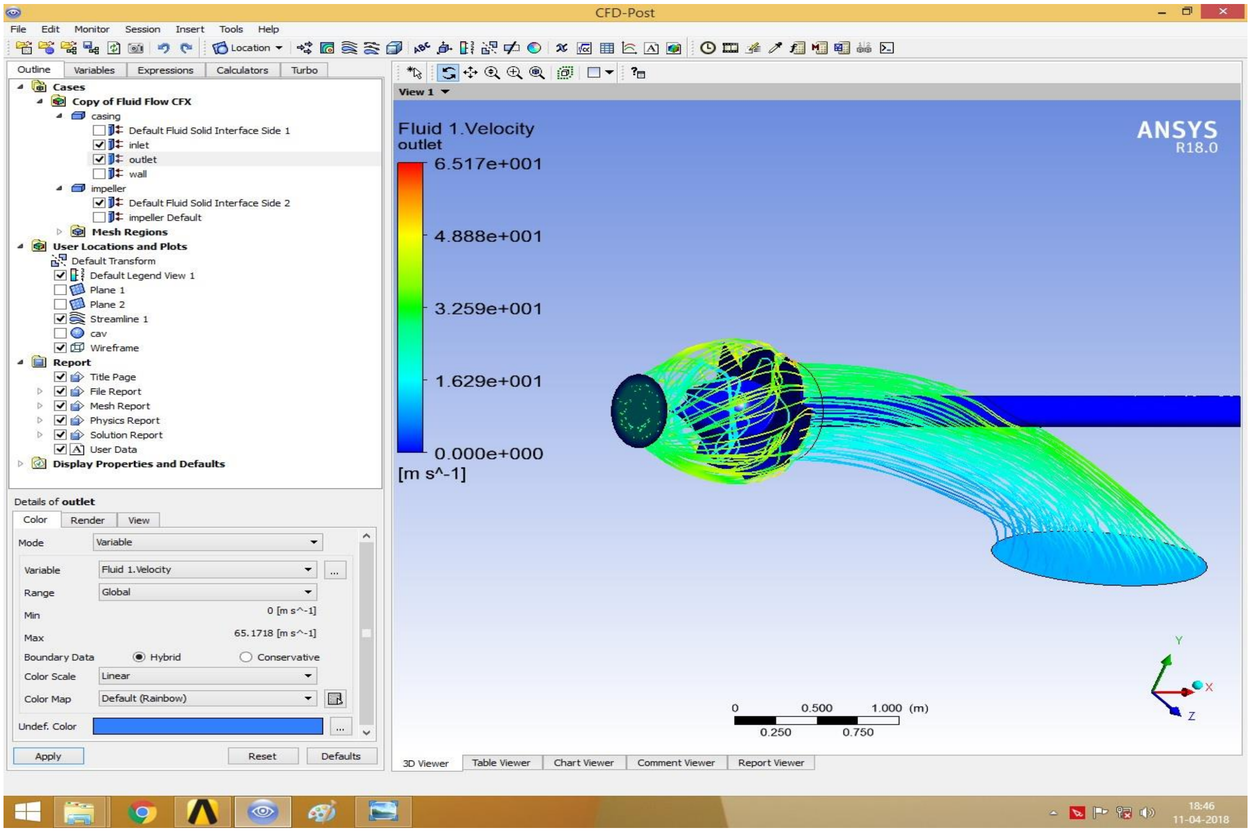


Fig 5.29VELOCITY STREAM LINE



- **Cases**
  - **Copy of Fluid Flow CFX**
    - casing
      - ☐ Default Fluid Solid Interface Side 1
      - ☑ inlet
      - ☑ outlet
      - ☐ wall
    - impeller
      - ☑ Default Fluid Solid Interface Side 2
      - ☐ impeller Default
    - **Mesh Regions**
- **User Locations and Plots**
  - Default Transform
  - ☑ Default Legend View 1
  - ☐ Plane 1
  - ☐ Plane 2
  - ☑ Streamline 1
  - ☐ cav
  - ☑ Wireframe
- **Report**
  - ☑ Title Page
  - ☑ File Report
  - ☑ Mesh Report
  - ☑ Physics Report
  - ☑ Solution Report
  - ☑ User Data
- **Display Properties and Defaults**

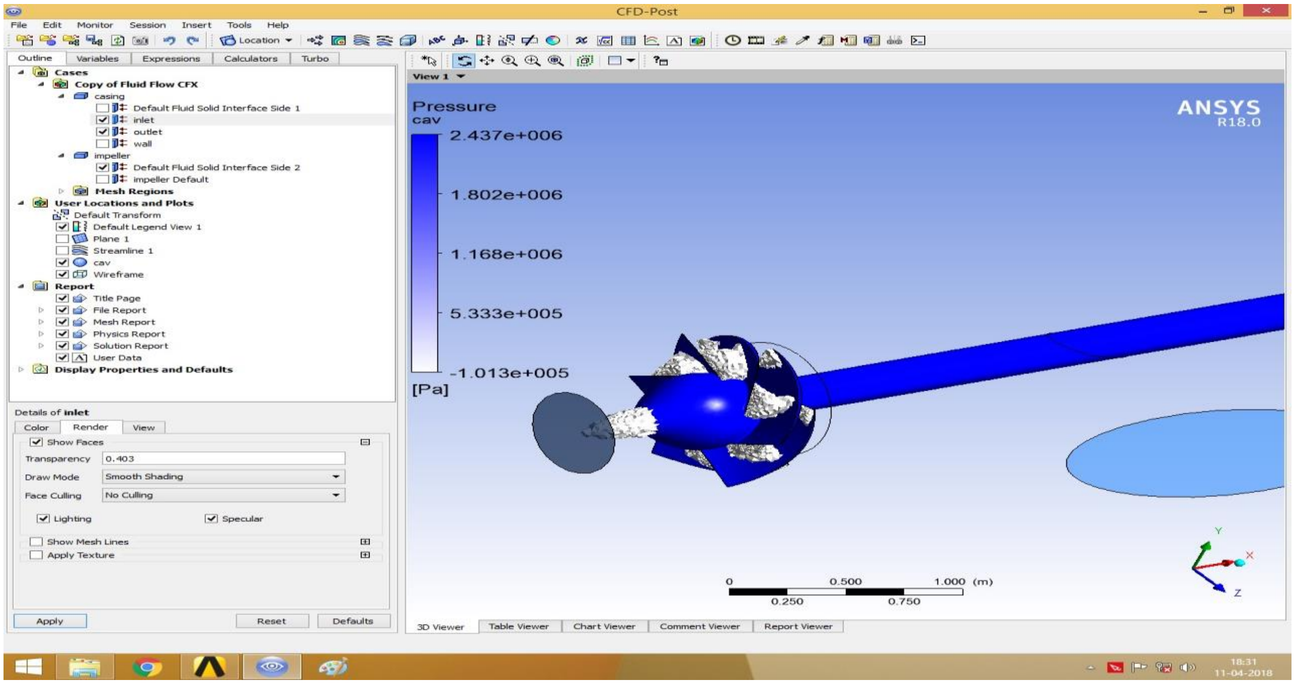
Details of **outlet**

Color | Render | View

Mode: Variable
Variable: Fluid 1.Velocity
Range: Global
Min: 0 [m s^-1]
Max: 65.1718 [m s^-1]
Boundary Data: ● Hybrid ○ Conservative
Color Scale: Linear
Color Map: Default (Rainbow)
Undef. Color:

Apply Reset Defaults

Fig 5.30 VARIATION OF VELOCITY FROM INLET TO OUTLET



Details of inlet

Color | Render | View

☑ Show Faces

Transparency 0.403

Draw Mode Smooth Shading

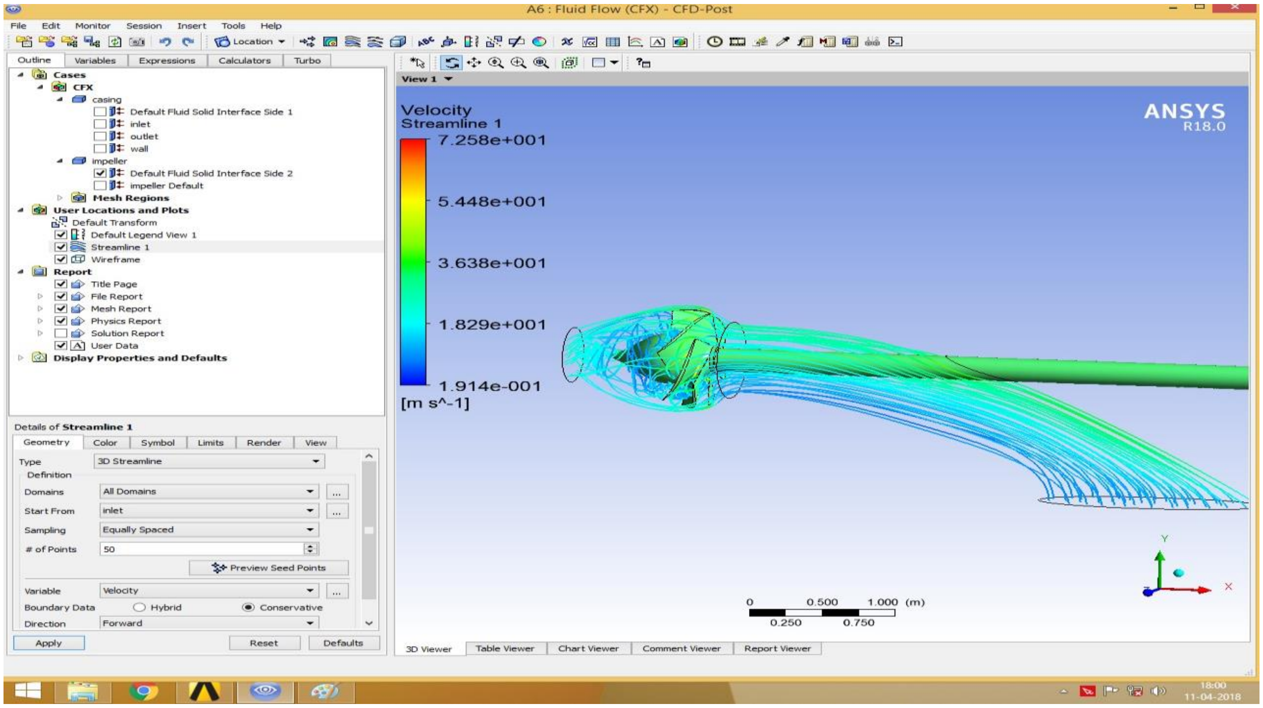
Face Culling No Culling

☑ Lighting ☑ Specular

☐ Show Mesh Lines

☐ Apply Texture

Fig 5.33 CAVITATION ANALYSIS



Details of Streamline 1

Geometry | Color | Symbol | Limits | Render | View

Type 3D Streamline

Definition

Domains All Domains

Start From inlet

Sampling Equally Spaced

# of Points 50

Variable Velocity

Boundary Data ○ Hybrid ● Conservative

Direction Forward

Fig 5.32 VELOCITY STREAM LINE

Cavitation and Flow analysis reports are given in appendix I and appendix II

CONCLUSIONS

1) Design and Analysis of a water jet propulsive patrolling vessel made with six bladed propellers with optimum rake angle and geometry in Order to obtain maximum performance out of the blade design and to minimise cavitation

2) Effect on blades, cavitation decreases with varying blade area. It is observed that the Ship is not proving the speed due to increased displacement and cavitating impeller.

3) To produce the required thrust with the existing ship conditions. Improved blade has the capability to work at maximum thrust with minimised cavitation effect.

4) The hydrodynamic pressure changes, detailed flow analysis, velocity stream flow and cavitation analysis were done with a 6 bladed Impeller using CFX.

5) Improved propulsive efficiency with respect to change in blade rake angle can be achieved with this analysis.

6) From calculations 80% Hull Efficiency and 49% Overall efficiency is proved.

7) Pressure variation, velocity variation with cavitation effects of six numbered blades with improved efficiency is achieved.

`

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APPENDIX I

FLOW ANALYSIS REPORT

Date

2018/04/11 18:00:02

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1. File Report
    Table 1 File Information for CFX
2. Mesh Report
    Table 2 Mesh Information for CFX
3. Physics Report
    Table 3 Domain Physics for CFX
    Table 4 Boundary Physics for CFX
4. User Data

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1. File Report

Table 1. File Information for CFX

Case	CFX
File Path	C:\Users\CADD\Desktop\waterjet anits_files\dp0\CFX\CFX\Fluid Flow CFX_002.res
File Date	08 April 2018
File Time	09:01:10 PM
File Type	CFX5
File Version	18.0

2. Mesh Report

Table 2. Mesh Information for CFX

Domain	Nodes	Elements
casing	803212	4425557
impeller	338216	1646149
All Domains	1141428	6071706

3. Physics Report

Table 3. Domain Physics for CFX

Domain - casing	
Type	Fluid
Location	B1243
Materials	
Water	
Fluid Definition	Material Library
Morphology	Continuous Fluid
Settings	
Buoyancy Model	Non Buoyant
Domain Motion	Stationary
Reference Pressure	1.0000e+00 [atm]
Heat Transfer Model	Isothermal
Fluid Temperature	2.5000e+01 [C]
Turbulence Model	k epsilon
Turbulent Wall Functions	Scalable
Domain - impeller	
Type	Solid
Location	impeller
Settings	
Domain Motion	Rotating
Angular Velocity	9.3400e+02 [rev min^-1]
Axis Definition	Coordinate Axis
Rotation Axis	Coord 0.1
Domain Interface - Default Fluid Solid Interface	
Boundary List1	Default Fluid Solid Interface Side 1
Boundary List2	Default Fluid Solid Interface Side 2
Interface Type	Fluid Solid
Settings	
Interface Models	General Connection
Mesh Connection	Automatic

Table 4. Boundary Physics for CFX

Domain	**Boundaries**

casing	**Boundary - inlet**	
	Type	INLET
	Location	inlet
	Settings	
	Flow Regime	Subsonic
	Mass And Momentum	Normal Speed
	Normal Speed	9.0000e+00 [m s^-1]
	Turbulence	Medium Intensity and Eddy Viscosity Ratio
	Boundary - Default Fluid Solid Interface Side 1	
	Type	INTERFACE
	Location	F1188.1243, F1189.1243, F1190.1243, F1191.1243, F1192.1243, F1193.1243, F1194.1243, F1195.1243, F1196.1243, F1197.1243, F1198.1243, F1199.1243, F1200.1243, F1201.1243, F1202.1243, F1203.1243, F1204.1243, F1205.1243, F1207.1243, F1208.1243, F1210.1243, F1211.1243, F1212.1243, F1213.1243, F1214.1243, F1215.1243, F1216.1243, F1217.1243, F1218.1243, F1219.1243, F1220.1243, F1221.1243, F1222.1243, F1223.1243, F1224.1243, F1225.1243, F1226.1243, F1227.1243, F1228.1243, F1229.1243, F1230.1243, F1232.1243, F1233.1243, F1234.1243, F1235.1243, F1236.1243, F1237.1243, F1238.1243, F1239.1243, F1240.1243, F1241.1243, F1242.1243, F1255.1243, F1256.1243, F1257.1243, F1258.1243, F1259.1243, F1260.1243, F1261.1243, F1262.1243, F1263.1243, F1265.1243, F1266.1243, F1267.1243, F1268.1243, F1269.1243, F1270.1243, F1271.1243, F1272.1243, F1273.1243, F1274.1243, F1275.1243, F1276.1243, F1277.1243, F1278.1243, F1279.1243, F1280.1243, F1281.1243, F1282.1243, F1283.1243, F1284.1243, F1285.1243, F1286.1243, F1287.1243, F1288.1243, F1289.1243, F1290.1243, F1291.1243, F1292.1243, F1294.1243, F1295.1243, F1296.1243, F1297.1243, F1298.1243, F1299.1243, F1301.1243, F1302.1243, F1303.1243, F1304.1243, F1305.1243, F1306.1243, F1307.1243, F1308.1243, F1309.1243, F1310.1243, F1311.1243, F1312.1243, F1313.1243, F1314.1243, F1315.1243, F1316.1243, F1317.1243, F1318.1243, F1319.1243, F1320.1243, F1321.1243, F1322.1243, F1323.1243, F1324.1243, F1325.1243, F1326.1243, F1327.1243, F1328.1243, F1329.1243, F1330.1243, F1331.1243, F1332.1243, F1333.1243, F1334.1243, F1335.1243, F1336.1243, F1337.1243, F1338.1243, F1339.1243, F1340.1243, F1341.1243, F1342.1243, F1343.1243, F1344.1243, F1345.1243, F1346.1243, F1347.1243, F1348.1243, F1349.1243, F1350.1243, F1351.1243, F1352.1243, F1353.1243

	Settings	
	Mass And Momentum	No Slip Wall
	Wall Roughness	Smooth Wall
	Boundary - outlet	
	Type	OUTLET
	Location	outlet
	Settings	
	Flow Regime	Subsonic
	Mass And Momentum	Normal Speed
	Normal Speed	1.5000e+01 [m s^-1]
	Boundary - wall	
	Type	WALL
	Location	wall
	Settings	
	Mass And Momentum	No Slip Wall
	Wall Roughness	Smooth Wall
impeller	**Boundary - Default Fluid Solid Interface Side 2**	
	Type	INTERFACE
	Location	F391.499, F392.499, F393.499, F394.499, F395.499, F396.499, F397.499, F398.499, F399.499, F400.499, F401.499, F402.499, F403.499, F404.499, F405.499, F406.499, F407.499, F408.499, F409.499, F410.499, F411.499, F412.499, F413.499, F414.499, F415.499, F416.499, F417.499, F418.499, F419.499, F420.499, F421.499, F422.499, F423.499, F424.499, F425.499, F426.499, F427.499, F428.499, F429.499, F430.499, F431.499, F432.499, F433.499, F434.499, F435.499, F436.499, F437.499, F438.499, F439.499, F440.499, F441.499, F442.499, F443.499, F444.499, F445.499, F446.499, F447.499, F448.499, F449.499, F450.499, F451.499, F452.499, F453.499, F454.499, F455.499, F456.499, F457.499, F458.499, F459.499, F460.499, F461.499, F463.499, F464.499, F466.499, F467.499, F468.499, F469.499, F470.499, F471.499, F472.499, F473.499, F474.499, F475.499, F476.499, F477.499, F478.499, F479.499, F480.499, F481.499, F482.499, F483.499, F484.499, F485.499, F486.499, F488.499, F489.499, F490.499, F491.499, F492.499, F493.499, F494.499, F495.499, F496.499, F497.499, F498.499, F500.499, F501.499, F502.499, F503.499, F504.499,

		F505.499, F506.499, F507.499, F508.499, F510.499, F511.499, F512.499, F513.499, F514.499, F515.499, F516.499, F517.499, F518.499, F519.499, F520.499, F521.499, F522.499, F523.499, F524.499, F525.499, F526.499, F527.499, F528.499, F529.499, F530.499, F531.499, F532.499, F533.499, F534.499, F535.499, F536.499, F537.499, F539.499, F540.499, F541.499, F542.499, F543.499, F545.499
	Settings	
	Heat Transfer	Adiabatic
	Boundary - impeller Default	
	Type	WALL
	Location	F544.499
	Settings	
	Heat Transfer	Adiabatic

APPENDIX II

CAVITATION ANALYSIS REPORT

Date

2018/04/11 18:49:52

Contents

1. File Report
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    - Table 4 Boundary Physics for Copy of Fluid Flow CFX
4. Solution Report
    - Table 5 Boundary Flows for Copy of Fluid Flow CFX
5. User Data

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1. File Report

Table 1. File Information for Copy of Fluid Flow CFX

Case	Copy of Fluid Flow CFX
File Path	C:\Users\CADD\Desktop\waterjet anits_files\dp0\CFX-1\CFX\Fluid Flow CFX_001.res
File Date	10 April 2018
File Time	05:44:58 PM
File Type	CFX5
File Version	18.0

2. Mesh Report

Table 2. Mesh Information for Copy of Fluid Flow CFX

Domain	Nodes	Elements
casing	309844	1657171
impeller	205477	1040227
All Domains	515321	2697398

3. Physics Report

Table 3. Domain Physics for Copy of Fluid Flow CFX

Domain - casing	
Type	Fluid
Location	B1243
Materials	
Water	
Fluid Definition	Material Library
Morphology	Continuous Fluid
Water Vapour at 25 C	
Fluid Definition	Material Library
Morphology	Continuous Fluid
Settings	
Buoyancy Model	Non Buoyant

Domain Motion	Stationary
Reference Pressure	1.0000e+00 [atm]
Heat Transfer Model	Isothermal
Fluid Temperature	2.5000e+01 [C]
Homogeneous Model	True
Turbulence Model	k epsilon
Turbulent Wall Functions	Scalable
Domain - impeller	
Type	Solid
Location	impeller
Settings	
Domain Motion	Rotating
Angular Velocity	9.3400e+02 [rev min^-1]
Axis Definition	Coordinate Axis
Rotation Axis	Coord 0.1
Domain Interface - Default Fluid Solid Interface	
Boundary List1	Default Fluid Solid Interface Side 1
Boundary List2	Default Fluid Solid Interface Side 2
Interface Type	Fluid Solid
Settings	
Interface Models	General Connection
Mesh Connection	Automatic

Table 4. Boundary Physics for Copy of Fluid Flow CFX

Domain	**Boundaries**	
casing	**Boundary - inlet**	
	Type	INLET
	Location	inlet
	Settings	
	Flow Regime	Subsonic
	Mass And Momentum	Normal Speed
	Normal Speed	9.0000e+00 [m s^-1]
	Turbulence	Medium Intensity and Eddy Viscosity Ratio
	Fluid	Fluid 1
	Volume Fraction	Value
	Volume	1.0000e+00

	Fraction	
	Fluid	vapour
	Volume Fraction	Value
	Volume Fraction	0.0000e+00
	Boundary - Default Fluid Solid Interface Side 1	
	Type	INTERFACE
	Location	F1188.1243, F1189.1243, F1191.1243, F1192.1243, F1193.1243, F1194.1243, F1195.1243, F1196.1243, F1197.1243, F1198.1243, F1199.1243, F1200.1243, F1201.1243, F1202.1243, F1203.1243, F1204.1243, F1205.1243, F1207.1243, F1208.1243, F1210.1243, F1211.1243, F1212.1243, F1213.1243, F1214.1243, F1215.1243, F1219.1243, F1220.1243, F1221.1243, F1222.1243, F1223.1243, F1224.1243, F1225.1243, F1226.1243, F1227.1243, F1228.1243, F1229.1243, F1230.1243, F1232.1243, F1233.1243, F1234.1243, F1235.1243, F1236.1243, F1237.1243, F1238.1243, F1239.1243, F1240.1243, F1241.1243, F1242.1243, F1255.1243, F1256.1243, F1257.1243, F1258.1243, F1259.1243, F1260.1243, F1261.1243, F1262.1243, F1266.1243, F1267.1243, F1268.1243, F1269.1243, F1270.1243, F1271.1243, F1272.1243, F1273.1243, F1274.1243, F1275.1243, F1276.1243, F1277.1243, F1278.1243, F1279.1243, F1280.1243, F1281.1243, F1282.1243, F1283.1243, F1284.1243, F1285.1243, F1286.1243, F1287.1243, F1288.1243, F1289.1243, F1290.1243, F1291.1243, F1292.1243, F1294.1243, F1296.1243, F1297.1243, F1298.1243, F1299.1243, F1301.1243, F1302.1243, F1303.1243, F1305.1243, F1306.1243, F1307.1243, F1308.1243, F1309.1243, F1310.1243, F1311.1243, F1312.1243, F1313.1243, F1314.1243, F1315.1243, F1316.1243, F1317.1243, F1318.1243, F1319.1243, F1320.1243, F1321.1243, F1322.1243, F1323.1243, F1324.1243, F1325.1243, F1326.1243, F1327.1243, F1329.1243, F1330.1243, F1331.1243, F1332.1243, F1333.1243, F1334.1243, F1335.1243, F1336.1243, F1337.1243, F1338.1243, F1339.1243, F1340.1243, F1341.1243, F1342.1243, F1343.1243, F1345.1243, F1346.1243, F1347.1243, F1348.1243, F1349.1243, F1350.1243, F1351.1243, F1352.1243, F1353.1243
	Settings	
	Mass And Momentum	No Slip Wall
	Wall Roughness	Smooth Wall
	Boundary - outlet	

	Type	OUTLET
	Location	outlet
	Settings	
	Flow Regime	Subsonic
	Mass And Momentum	Normal Speed
	Normal Speed	1.5000e+01 [m s^-1]
	Boundary - wall	
	Type	WALL
	Location	wall
	Settings	
	Mass And Momentum	No Slip Wall
	Wall Roughness	Smooth Wall
impeller	**Boundary - Default Fluid Solid Interface Side 2**	
	Type	INTERFACE
	Location	F391.499, F392.499, F393.499, F395.499, F396.499, F397.499, F398.499, F399.499, F400.499, F401.499, F402.499, F403.499, F404.499, F405.499, F406.499, F407.499, F408.499, F409.499, F410.499, F411.499, F412.499, F413.499, F414.499, F415.499, F416.499, F417.499, F419.499, F420.499, F421.499, F422.499, F423.499, F424.499, F425.499, F426.499, F427.499, F428.499, F429.499, F430.499, F431.499, F432.499, F433.499, F435.499, F436.499, F437.499, F438.499, F439.499, F440.499, F441.499, F442.499, F443.499, F444.499, F445.499, F447.499, F448.499, F449.499, F450.499, F451.499, F452.499, F453.499, F454.499, F455.499, F456.499, F457.499, F458.499, F459.499, F460.499, F461.499, F463.499, F464.499, F466.499, F467.499, F468.499, F469.499, F470.499, F471.499, F475.499, F476.499, F477.499, F478.499, F479.499, F480.499, F481.499, F482.499, F483.499, F484.499, F485.499, F486.499, F488.499, F489.499, F490.499, F491.499, F492.499, F493.499, F494.499, F495.499, F496.499, F497.499, F498.499, F500.499, F501.499, F502.499, F503.499, F504.499, F505.499, F506.499, F507.499, F511.499, F512.499, F513.499, F514.499, F515.499, F516.499, F517.499, F518.499, F519.499, F520.499, F521.499, F522.499, F523.499, F524.499, F525.499, F526.499, F527.499, F528.499, F529.499, F530.499, F531.499, F532.499, F533.499, F534.499, F535.499, F536.499, F537.499, F539.499, F541.499, F542.499, F543.499, F545.499
	Settings	

	Heat Transfer	Adiabatic
	Boundary - impeller Default	
	Type	WALL
	Location	F544.499
	Settings	
	Heat Transfer	Adiabatic

4. Solution Report

Table 5. Boundary Flows for Copy of Fluid Flow CFX

Location	Type	Mass	Momentum		
			X	Y	Z
Default Fluid Solid Interface Side 1 (Bulk-casing)	Boundary		8.2193e+05	-1.1159e+05	3.2650e+03
Default Fluid Solid Interface Side 1 (casing)	Boundary	0.0000e+00			
inlet (Bulk-casing)	Boundary		6.1355e-02	1.6581e+06	-4.8153e-05
inlet (casing)	Boundary	8.4054e+03			
outlet (Bulk-casing)	Boundary		1.0165e+05	1.0941e+04	3.8683e+02
outlet (casing)	Boundary	-3.2584e+03			
wall (Bulk-casing)	Boundary		-9.8964e+05	-1.5692e+06	-3.5136e+04
wall (casing)	Boundary	0.0000e+00			