DESIGN, CONSTRUCTION AND TESTING OF AN AIR CUSHION VEHICLE (ACV)

Guide: Sandeep Dasgupta

Co-guide: Ruchi Shinde

GROUP MEMBERS

- **JOEL RHINE**
- **MARTIN CHARLES**
- **JESVIN JOSE**
- **GARETH PEREIRA**
- **SIBI MATTATHIL**
- **MELVIN NADAR**
- **DION PEREIRA**
- **ALEX SALVE**
- **ROHAN MAHADIK**
- **PRATIK KOLI**

PROBLEM STATEMENT

To study and research all the design parameters of an ACV and implement all these while constructing the same.

CONTENTS

OBJECTIVES

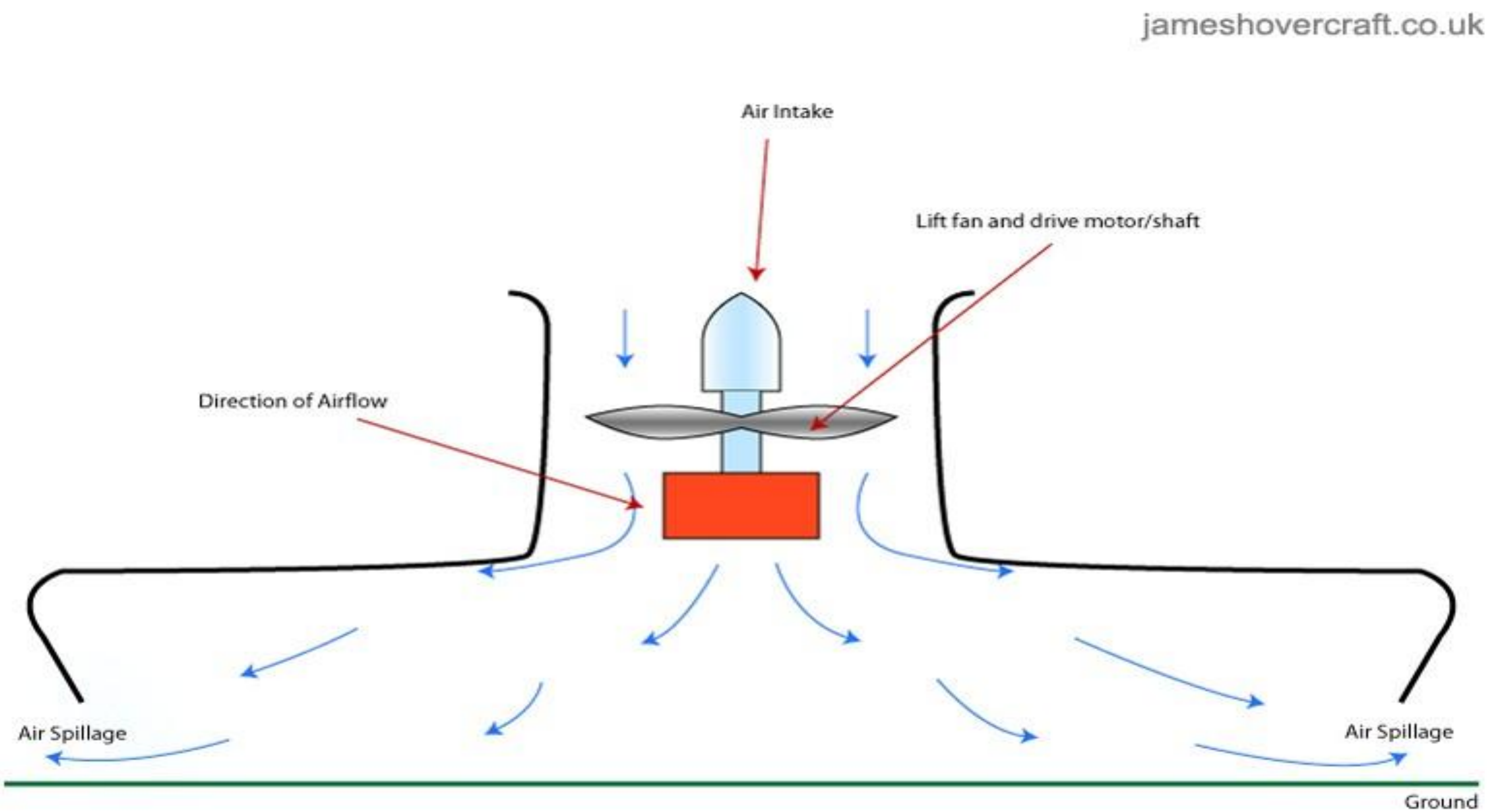
- To analyze the potential capabilities of designing and building hovercrafts locally.
- To identify potential research areas related to hovercraft technology and implement upon completion of the project.
- To introduce an energy-efficient way of travelling and search for other utilities of implementing this technology.
- To understand the applications of basic engineering principles learnt as a mechanical engineering student and to improve professional and teamwork skills.
- To get hands on experience with various manufacturing methods and engineering tools.

Principle behind Working of a Hovercraft

- A hovercraft comes under the category of amphibian vehicles, which means that it can, not only travel on land, but also over water, sand or any surface that is not very uniform.
- The hovercraft works on the principle of lift due to the thrust produced by an impeller.
- This impeller is mounted on an engine and pulls air perpendicular to the travelling surface.
- The engine is fixed on the hull of the vehicle.
- The air is sucked in from the top and thrown in to the bottom.

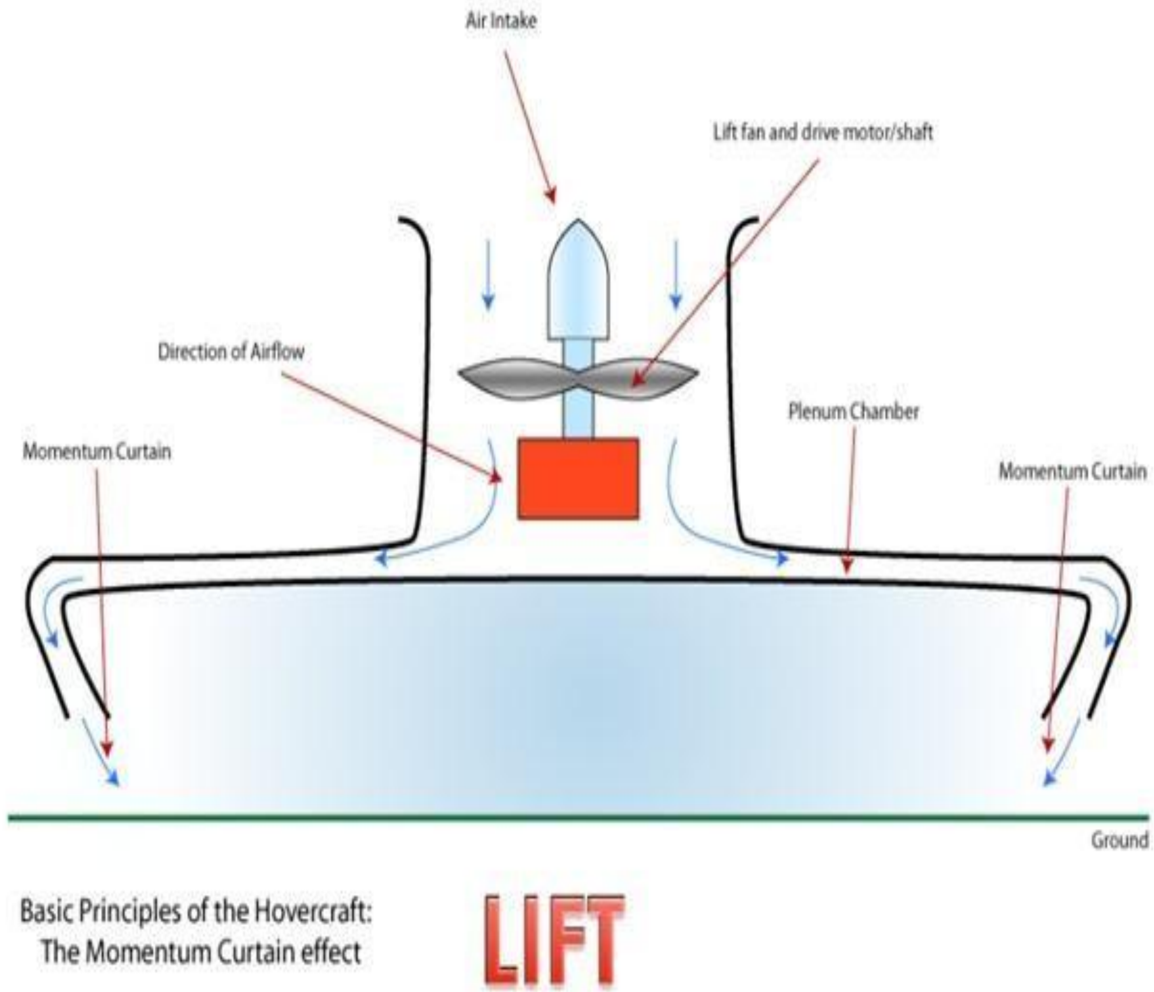
- The skirt is fixed all around the perimeter of the hull, which does not allow the leakage of the air to the sides and pushes it to the bottom, towards the ground.
- The high pressurized air then hits the surface, which generates a reactive force, which in turn is the reason of the force that lifts the vehicle.
- Now, basically hovercraft deigns differ on the grounds on the lift theory they follow
- The open plenum theory
- The closed plenum or momentum curtain theory

THE OPEN PLENUM THEORY



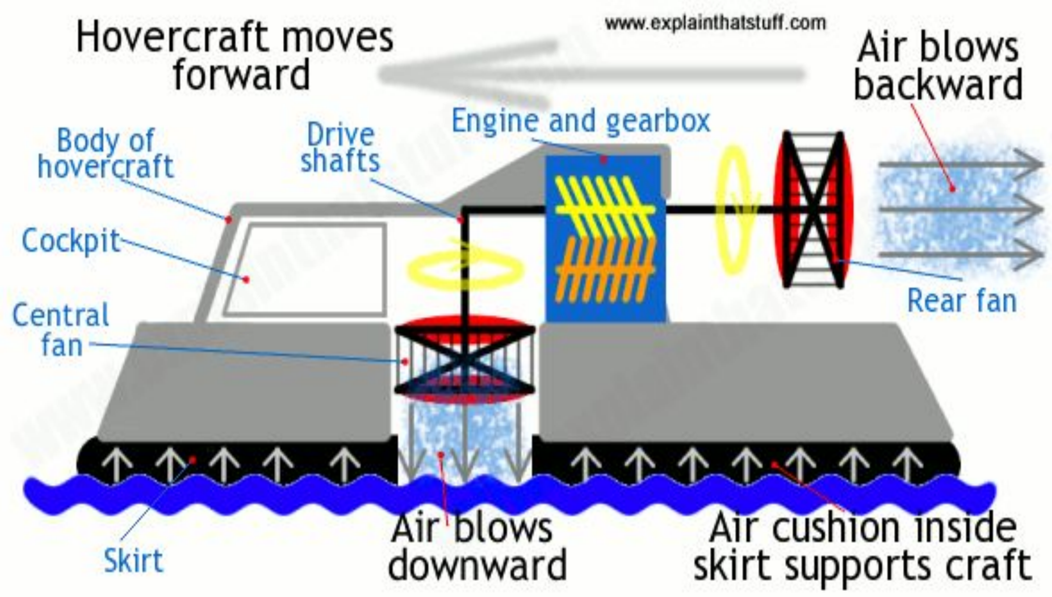
Basic Principles of the Hovercraft:
Open plenum, no Momentum Curtain effect

CLOSED PLENUM THEORY



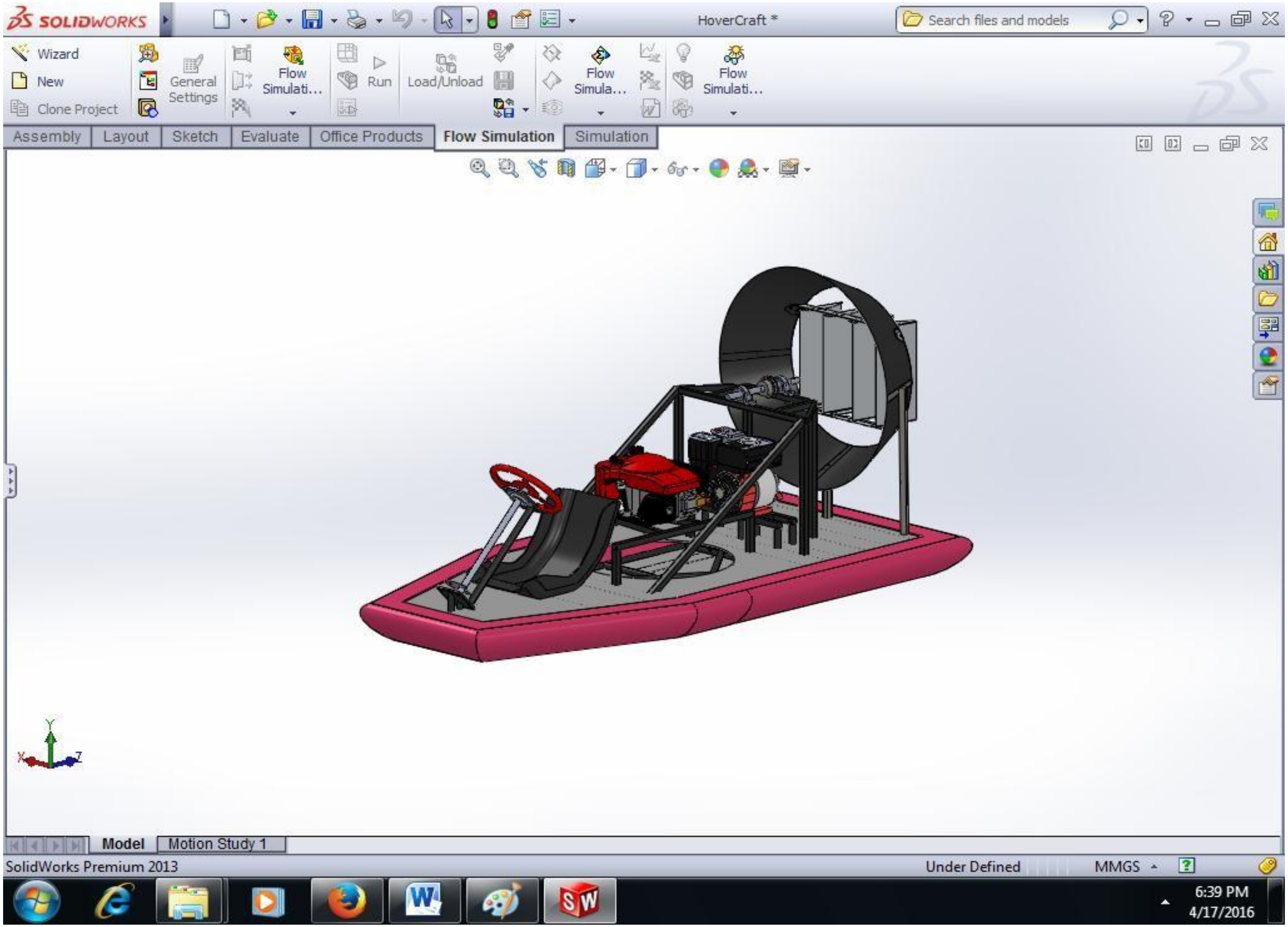
Working of a Hovercraft

- As we can observe from the figure a minimum of two fans are required for the functioning of the hovercraft vehicle, an impeller to lift the craft and a propeller to move it forward.



- Considering that a single internal combustion engine is used for both the processes, then the propeller is connected to a shaft which is connected the shaft of the engine via a reduction gear.
- The propeller shaft is also connected to the impeller. Both the propeller and the impeller are connected to the shaft through a clutching mechanism, which can engage or disengage the power transmission whenever required.
- First the impeller is engaged which causes the vehicle to lift. Then the propeller is engaged and movement is acquired. The control of the vehicle like tuning is done with the help of rudders. They are connected mechanically to the steering mechanism

Analysis and Study of Components



- HOVERCRAFT DESIGN ON SOLIDWORKS

WORKING MODEL OF A HOVERCRAFT

List of Components

Item	Description	Quantity
1	The hull base	1
2	Lift duct	1
3	Seat assembly	1
4	Thrust duct assembly	1
5	Thrust engine and fan Assembly	1
6	The skirt	1
7	Stand	1
8	Rudder	4
9	Steering Mechanism	1
10	Lift engine mount	1
11	Thrust engine mount	1
12	Lift engine and fan assembly	1
13	Plenum chamber	1

The Hull Base

- The hull of the ACV is made up of an Aluminum base on a metal frame

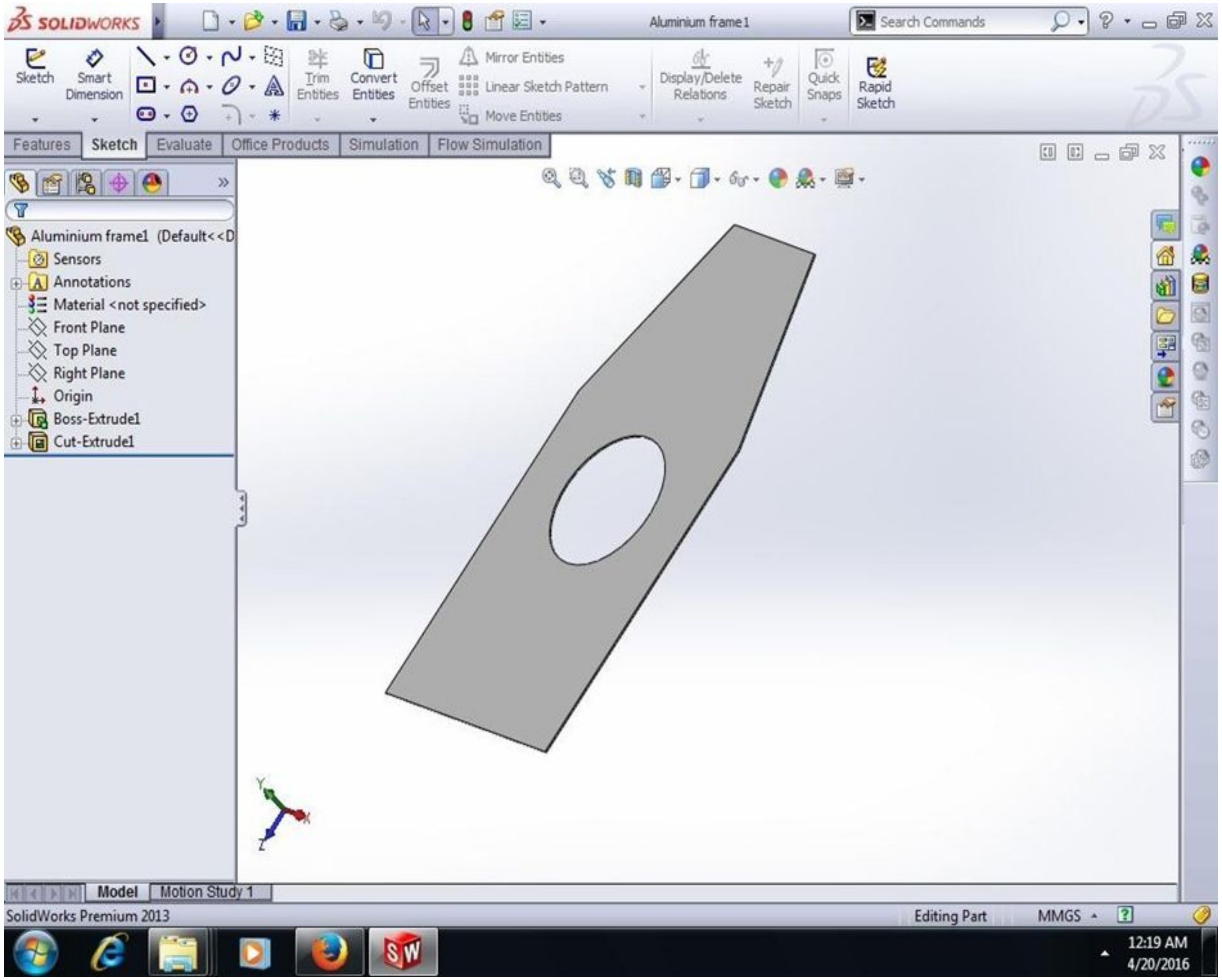
- The dimensions are

Width = 4ft

length = 8ft

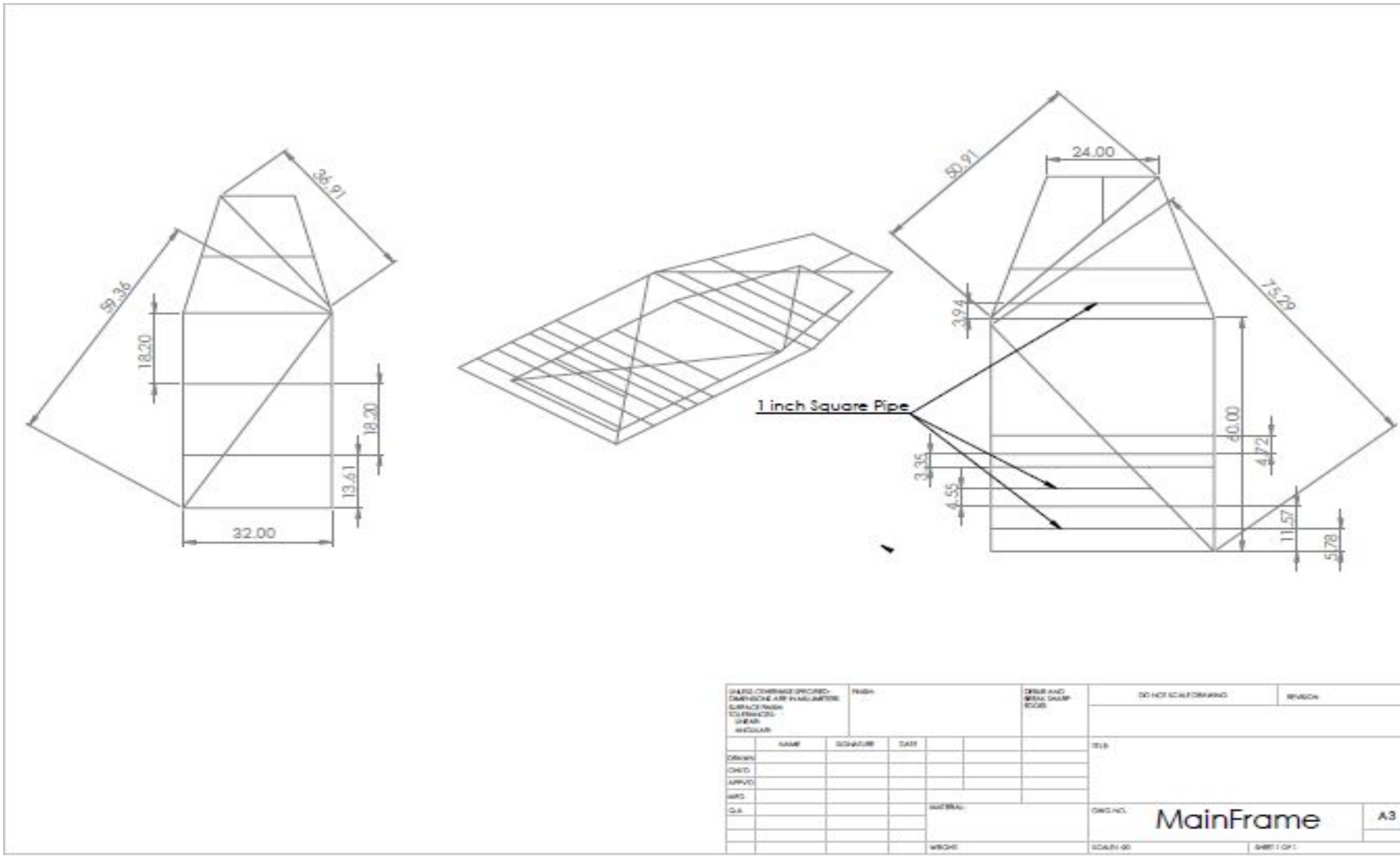
Slant length = 2.83ft

Total area of base = 2.492m2



ALUMINIUM BASE ORIGINAL

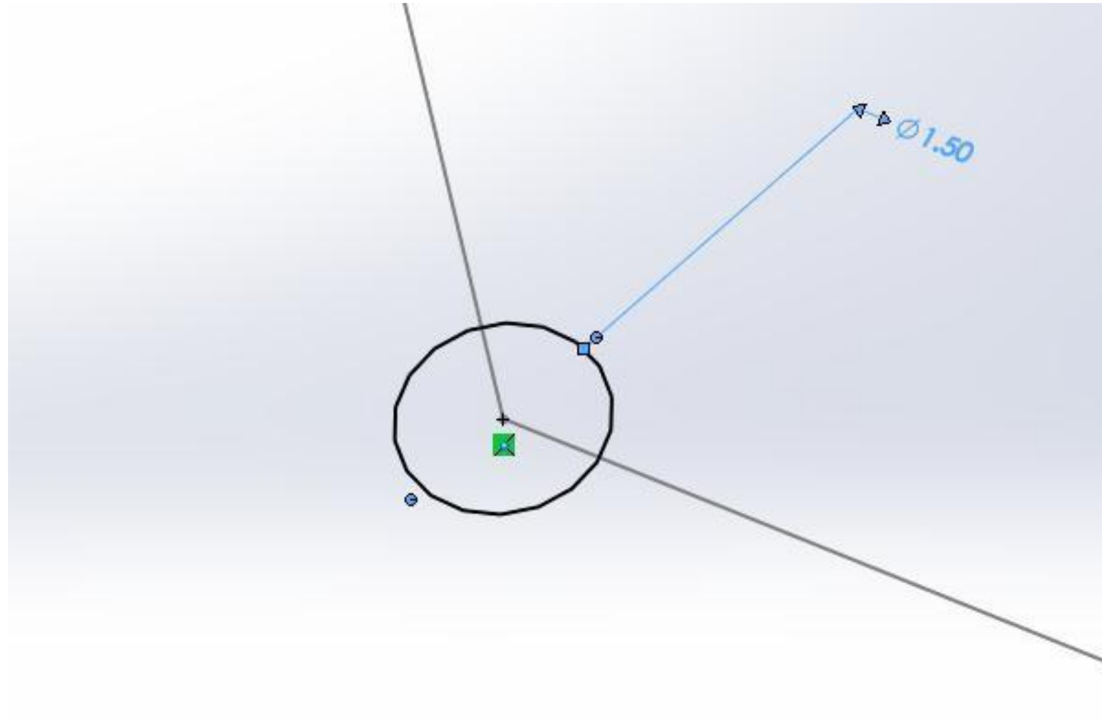
2D MODEL OF THE MAIN FRAME



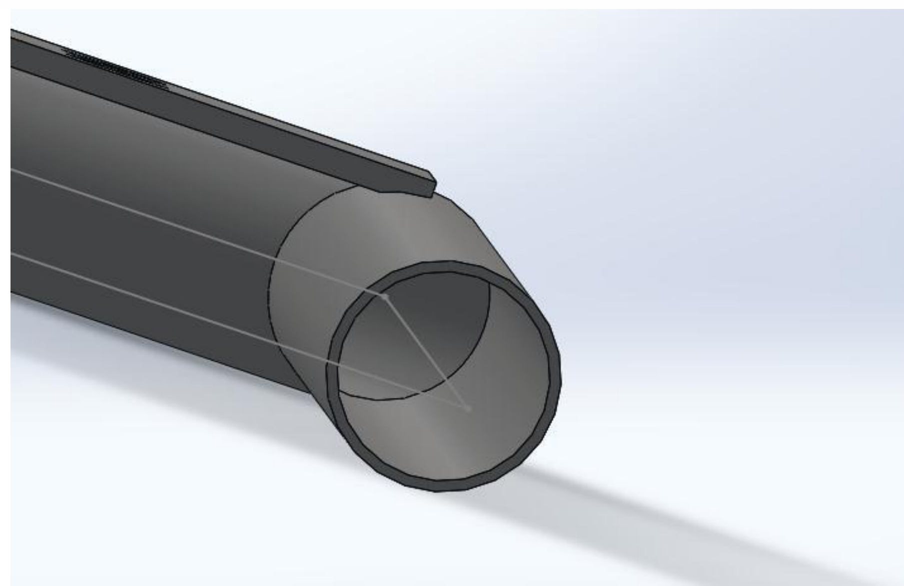
- The Base frame is of the same dimensions but constructed using welded pipes. Material AISI 4130 steel annealed at 865^{o}C
- The mechanical properties of AISI 4130 alloy steel are outlined in the following table

Properties	Metric	Imperial
Tensile strength, ultimate	560 MPa	81200 psi
Tensile strength, yield	460 MPa	66700 psi
Modulus of elasticity	190-210 GPa	27557-30458 ksi
Bulk modulus (Typical for steel)	140 GPa	20300 ksi
Shear modulus (Typical for steel)	80 GPa	11600 ksi
Poissons ratio	0.27-0.30	0.27-0.30
Elongation at break (in 50 mm)	21.50%	21.50%
Reduction of area	59.6	59.60%
Hardness, Brinell	217	217
Hardness, Knoop (Converted from Brinell hardness)	240	240
Hardness, Rockwell B (Converted from Brinell hardness)	95	95
Hardness, Rockwell C (Converted from Brinell hardness, value below normal HRC range, for comparison purposes only.)	17	17
Hardness, Vickers (Converted from Brinell hardness)	228	228

Outer diameter 1.5mm



Thickness 2mm



Thrust Engine and Fan Selection

- The ACV comprises of two separate systems for its lift and thrust respectively. The thrust system imparts the thrust to the vehicle for it to move forward. Many hovercrafts usually use a single system for both thrust and lift.
- This is achieved by providing a splitter in the thrust duct. This construction uses about 1/3rd of the thrust air to the bag skirt for lift generation, there in reducing the net thrust of the vehicle.
- This in turn reduces the maximum available speed that the ACV can achieve But here, we have used a separate system for thrust as well as lift It was agreed upon that that the maximum speed of the craft would be 50km/hr which means 14m/s.

Now,

- Thrust Tg= V_d x Q_d x ρ

Where,

V_d is the velocity of discharge

Q_d is the discharge is the density of air.

- Momentum drag, Dm = Qd x x (Vd-Vo)

Where,

Vo is the velocity with which the craft is moving.

More the velocity Vo less will be the thrust imparted to the craft. At Vo=Vd,

thrust imparted = 0.

- It was agreed upon that max velocity of craft to be 50km/hr (14m/s). Therefore,
- Vd = 14m/s.
- Thus Thrust Tg = 14^2 x A x 1.1455

  = 14^2 x 0.3848 x 1.1455

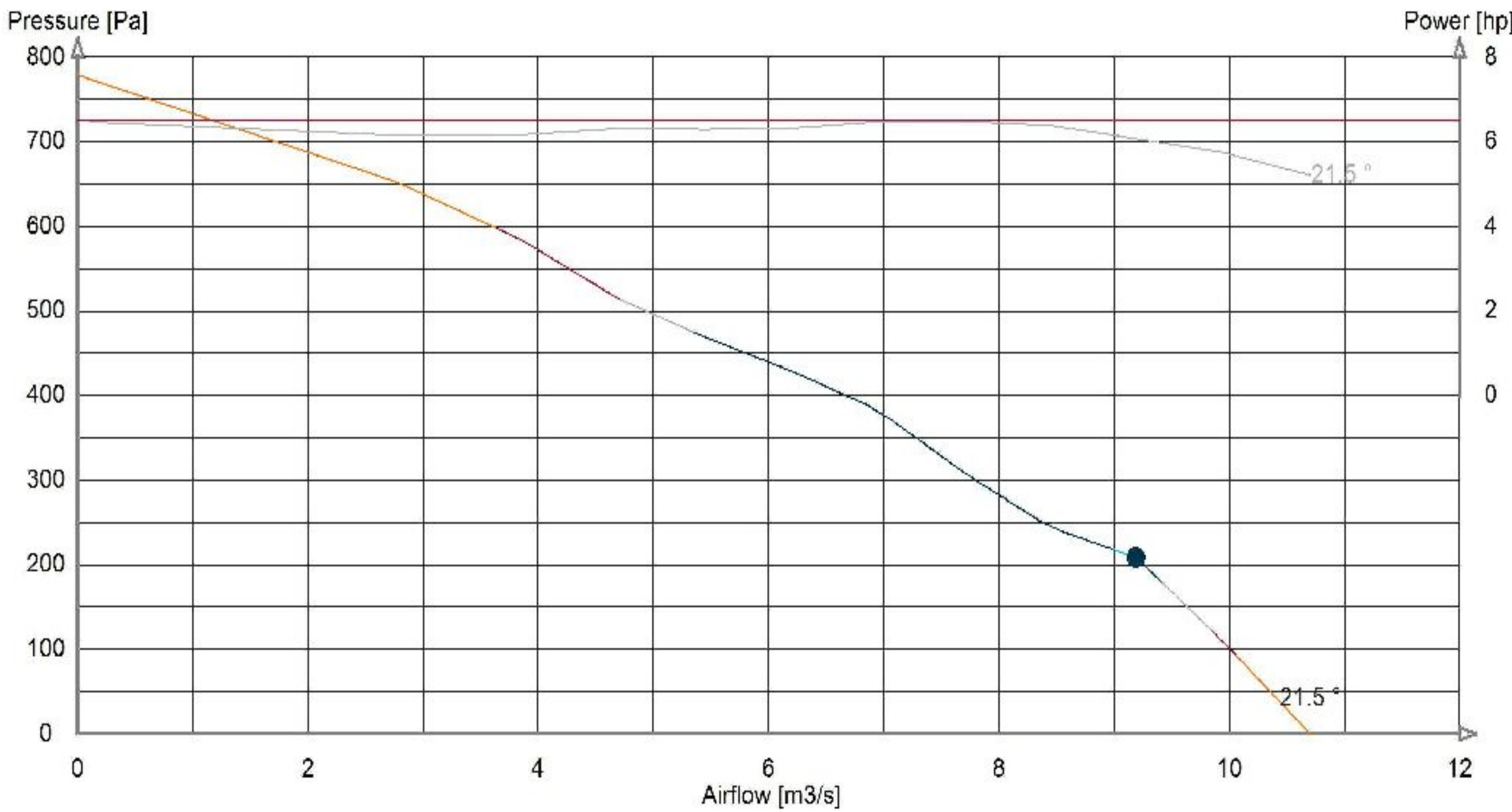
  Tg = 86.394 N. is the amount of thrust that is to be generated.
- Which is equal to 19.42 pounds of force

- Thus the thrust engine power should be 5.5 Hp or greater @3600 rpm. To achieve the fore said parameters a Briggs & Stratton Horizontal Shaft Engine with the following specifications was selected which gives power output of 6.5Hp @ 3600 rpm

Brand Name	Briggs & Stratton
Material Type	Sleeve: Cast Iron
Speed	3600 rpm
Item Weight	14 kg
Series	550
Model	83100
Number of Items in Pack	1
Key Features	Fuel Tank and Muffler Straight Keyway Shaft Recoil Start Petrol Engine

Thrust Propeller

- According to the above calculations, the design was finalized.
- Using a propeller development software ie. Optimizer 9, the following data was obtained.



Impeller Diameter:	36 in
No of blades:	3
Pitch:	21.5 °
Blade Material:	PAG
Blade Type:	5Z
Impeller Rotation:	L

Tests are carried out according to methods described in ANSI / AMCA 210-99 (ISO 5801, DIN 24163)

Sound data is calculated and should be used as guideline only

Speed:	2400 RPM
Tip Clearance:	0.5 %
Temperature	40 °C
Altitude:	0 m
Density:	1.127 kg/m3

Disclaimer

Load factors in Optimiser are based on static operation.

Current Working Point

Airflow	9.19 m3/s	Total Pres	319 Pa	Propagation	
Static Pres	209 Pa	Power	6.07 hp		
Dynamic Pressure	110 Pa	Efficiency	65 %	Sound Power	105 LW dB

OPERATIONAL DATA:

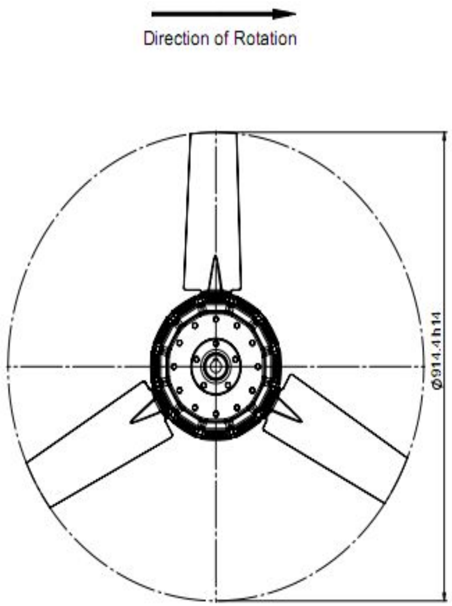
Tip Speed:	115 m/s
Temperature:	40 °C
Air Velocity:	14 m/s
Torque:	18 Nm
Axial Force:	210 N

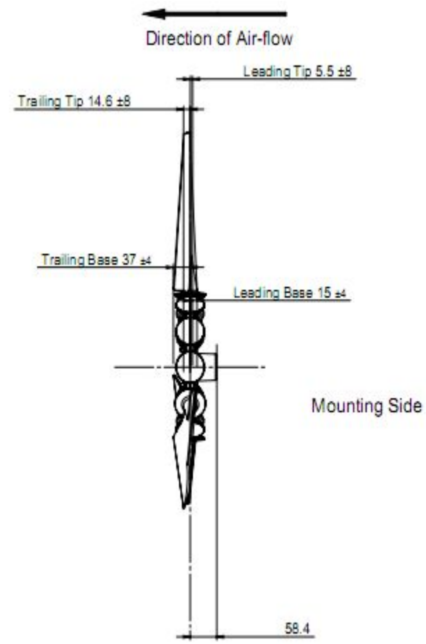
OPERATIONAL IMPELLER LIMITS:

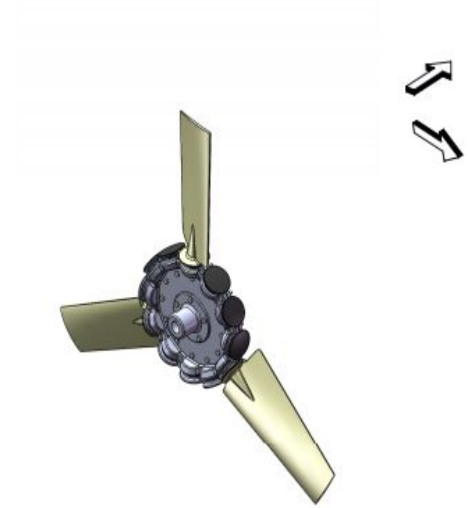
Tip Speed:	133 m/s (2778 RPM)
Temperature:	-40°C - 76 °C
Diameter range:	22.2 - 45.91 in
Blade, load factor:	74.6 %
Hub, load factor:	39.7 %
Power, load factor:	N.A. %

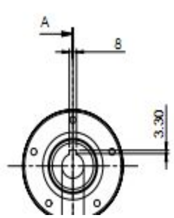
Static impeller data:

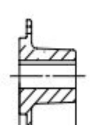
Moment of Inertia:	0.0937 kgm2
Blade Centrifugal force:	5000 N
Solidity factor:	0.11
Mass with std. boss:	3.26 kg











Bolt guide:

5 Bolts @ M8x25 DIN 933 BCD 90
12 Bolts @ M8x20 DIN 933 BCD 185
12 Bolts @ M8x30 DIN 933 BCD 265.5

Impeller weight guide:

3.82 kg

Part number:	Part description:	Quantity:	Material:
1510020001 8	5ZL/PAG Fan Blade	3	PAG
2112070810 3	Z-Retaining plate/12/000075	2	EN AC-47100
2400070820 0	Boss/825 12 2/7 5	1	EN AC-47100
1019050007 2	Z-Spacer/PAGII	9	PAGII
5100000000 2	Z-Pitch Setting Pin/PAGII	3	PAGII

THRUST PROPELLER DETAILS

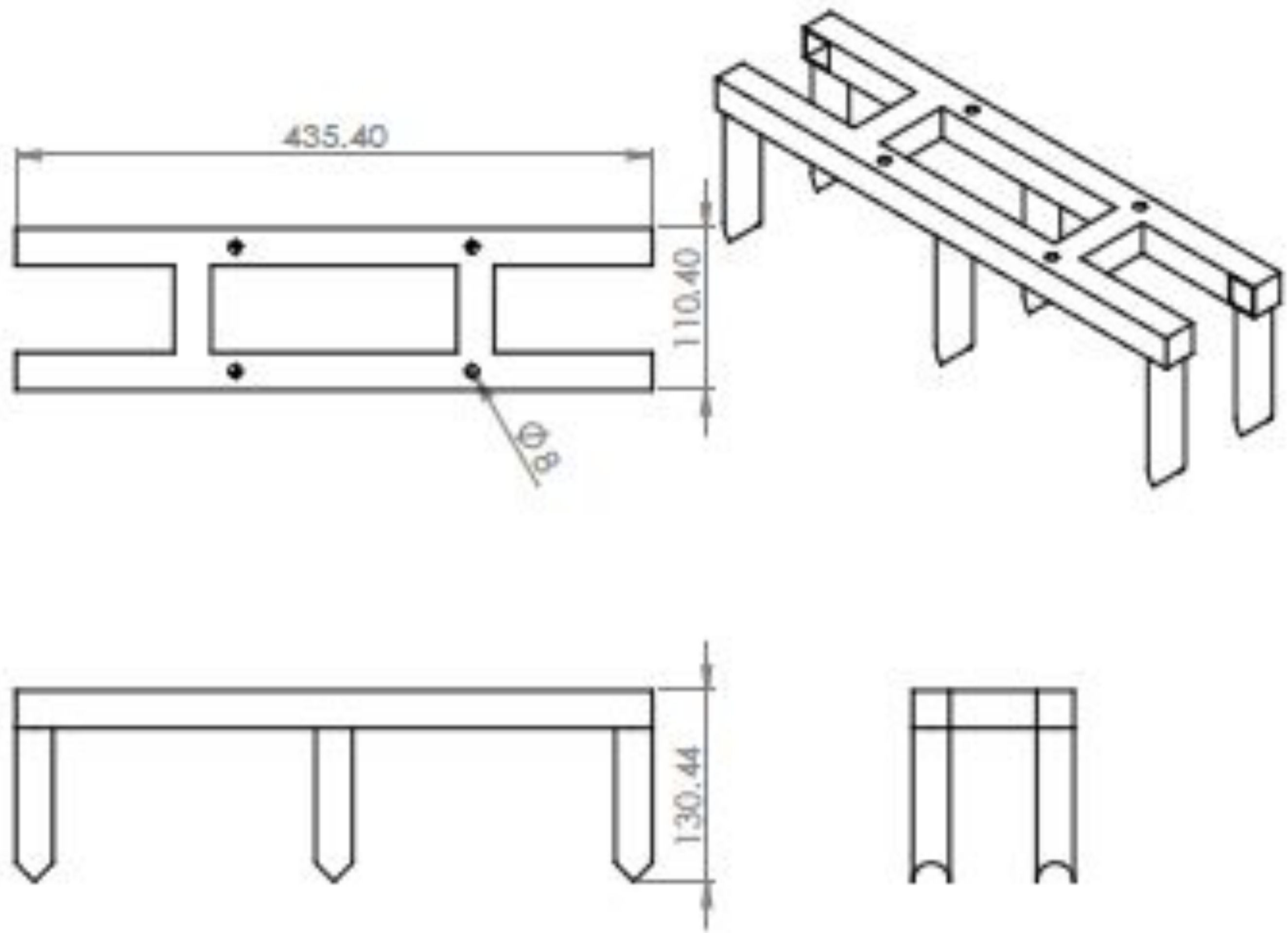
Glass Reinforced Polyamide (PAG)	
Temperature range: -40ºC to +120ºC Please observe penalty factors for temperatures above 40ºC	
Mechanical properties (Dry as moulded):	
Tensile strength:	165 Mpa
Izod impact strength notched (at 23°C):	11.0 kJ/m^2
Izod impact strength notched (at -30°C):	9.0 kJ/m^2
Tensile modulus:	8.2 Gpa
Mechanical properties (50% relative humidity):	
Tensile strength:	100 Mpa
Izod impact strength notched (at 23°C):	17.0 kJ/m^2
Izod impact strength notched (at -30°C):	9.0 kJ/m^2
Tensile modulus:	5.6 Gpa

Parameter	DIMENSIONS
Diameter	36‘”
Pitch	21.5 degrees
No of blades	3
Blade Material	Glass reinforced polymide
Speed	2400 rpm
Airflow	$9.25m^3/s$
Power	6.07HP
Efficiency	65%

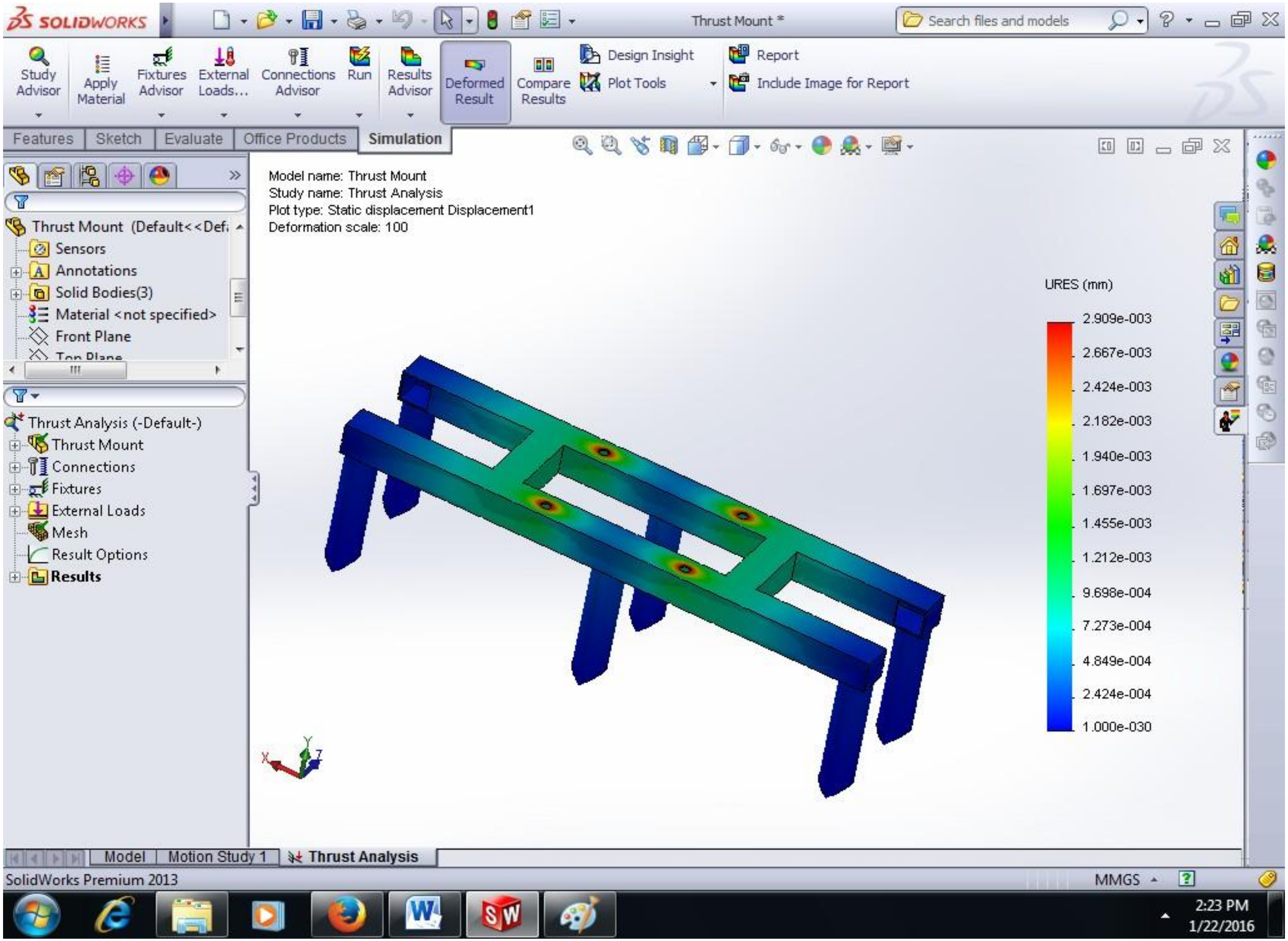
Thrust Engine Supports

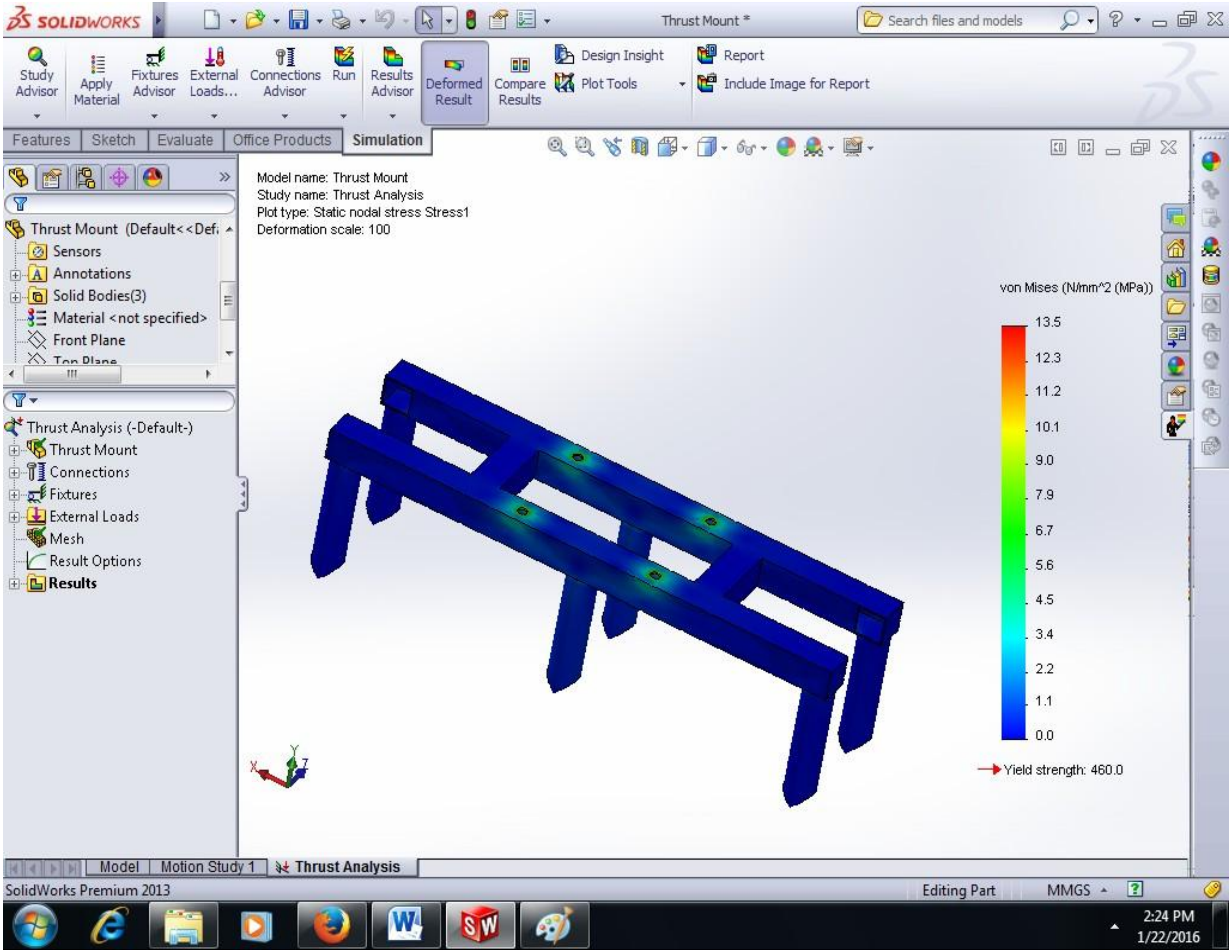
- Due to the belt assembly which is used to transmit the motion to the thrust propeller by the engine, the thrust engine must be stable and balanced. The frame used to mount the thrust engine had to be structurally accessed and designed.

2D MODEL OF THE THRUST MOUNT



Thrust engine support SW analysis

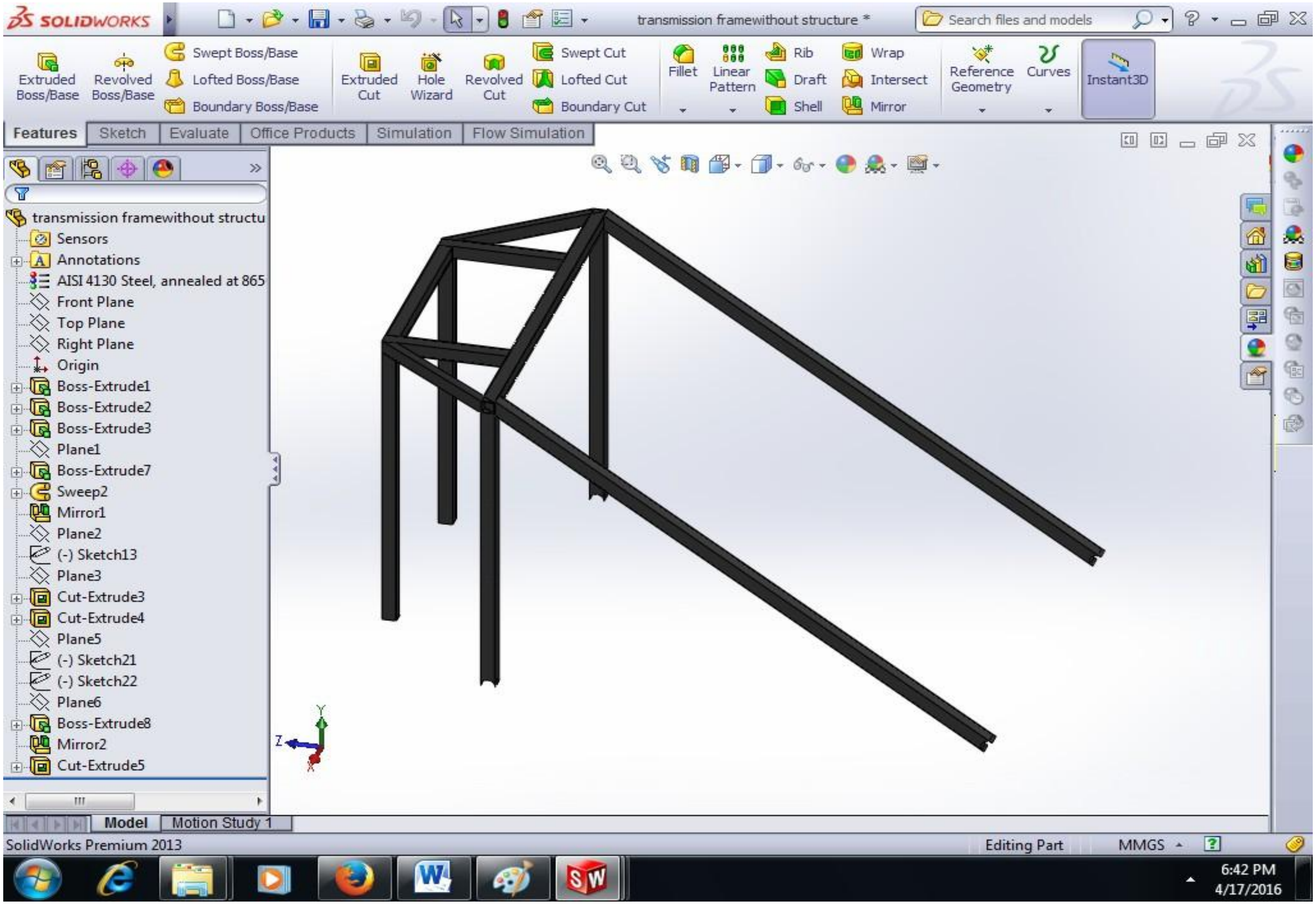




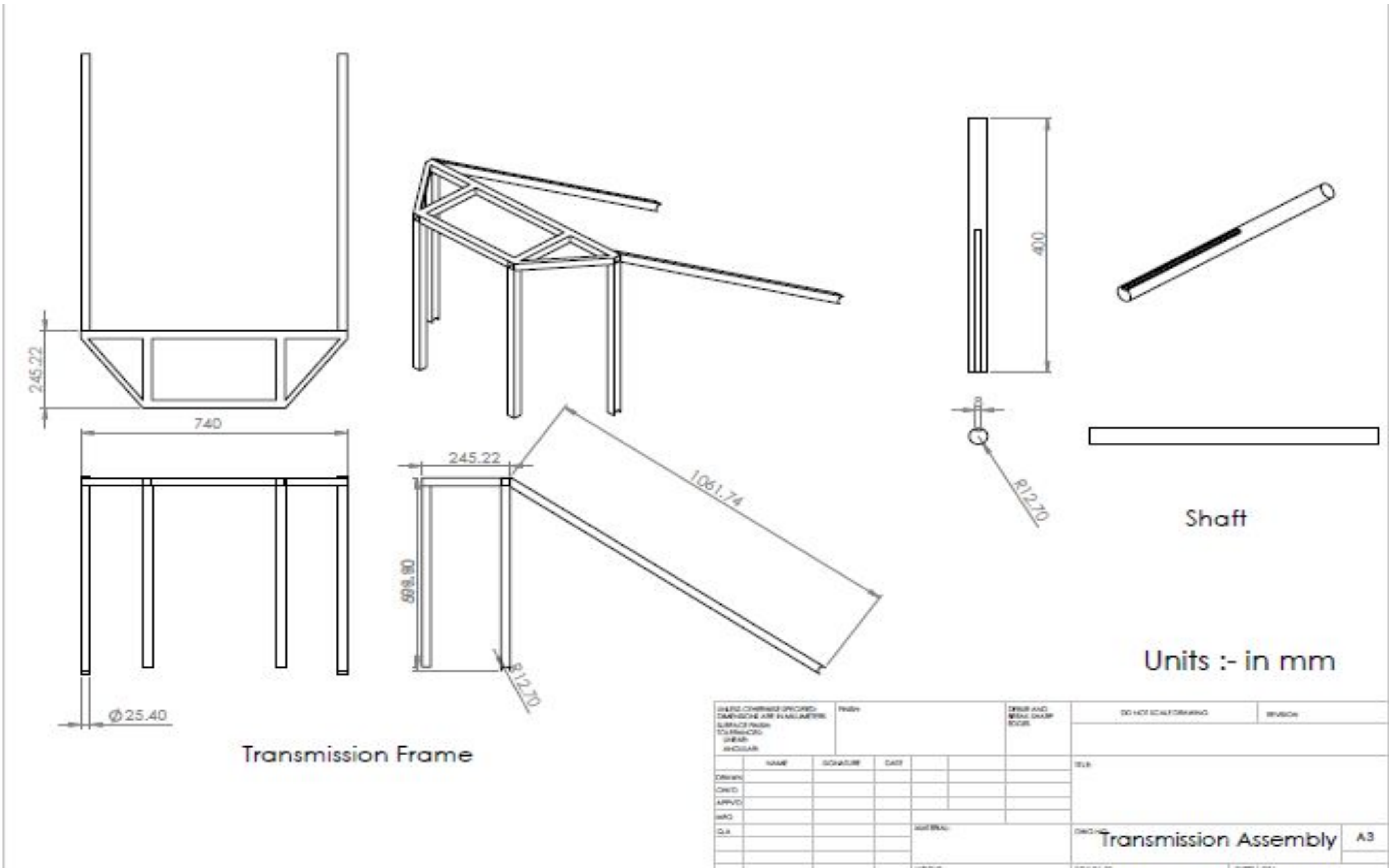
Thrust Mount *
Study Advisor
Apply Material
Fixtures Advisor
External Loads...
Connections Advisor
Run
Results Advisor
Deformed Result
Compare Results
Design Insight
Plot Tools
Report
Include Image for Report
Features
Sketch
Evaluate
Office Products
Simulation
Thrust Mount (Default<<Def
Sensors
Annotations
Solid Bodies(3)
Material <not specified>
Front Plane
Thrust Analysis (-Default-)
Thrust Mount
Connections
Fixtures
External Loads
Mesh
Result Options
Results
Model name: Thrust Mount
Study name: Thrust Analysis
Plot type: Static nodal stress Stress1
Deformation scale: 100
von Mises (N/mm^2 (MPa))
13.5
12.3
11.2
10.1
9.0
7.9
6.7
5.6
4.5
3.4
2.2
1.1
0.0
Yield strength: 460.0
Model
Motion Study 1
Thrust Analysis
SolidWorks Premium 2013
Editing Part
MMGS
2:24 PM
1/22/2016

Thrust engine mount original

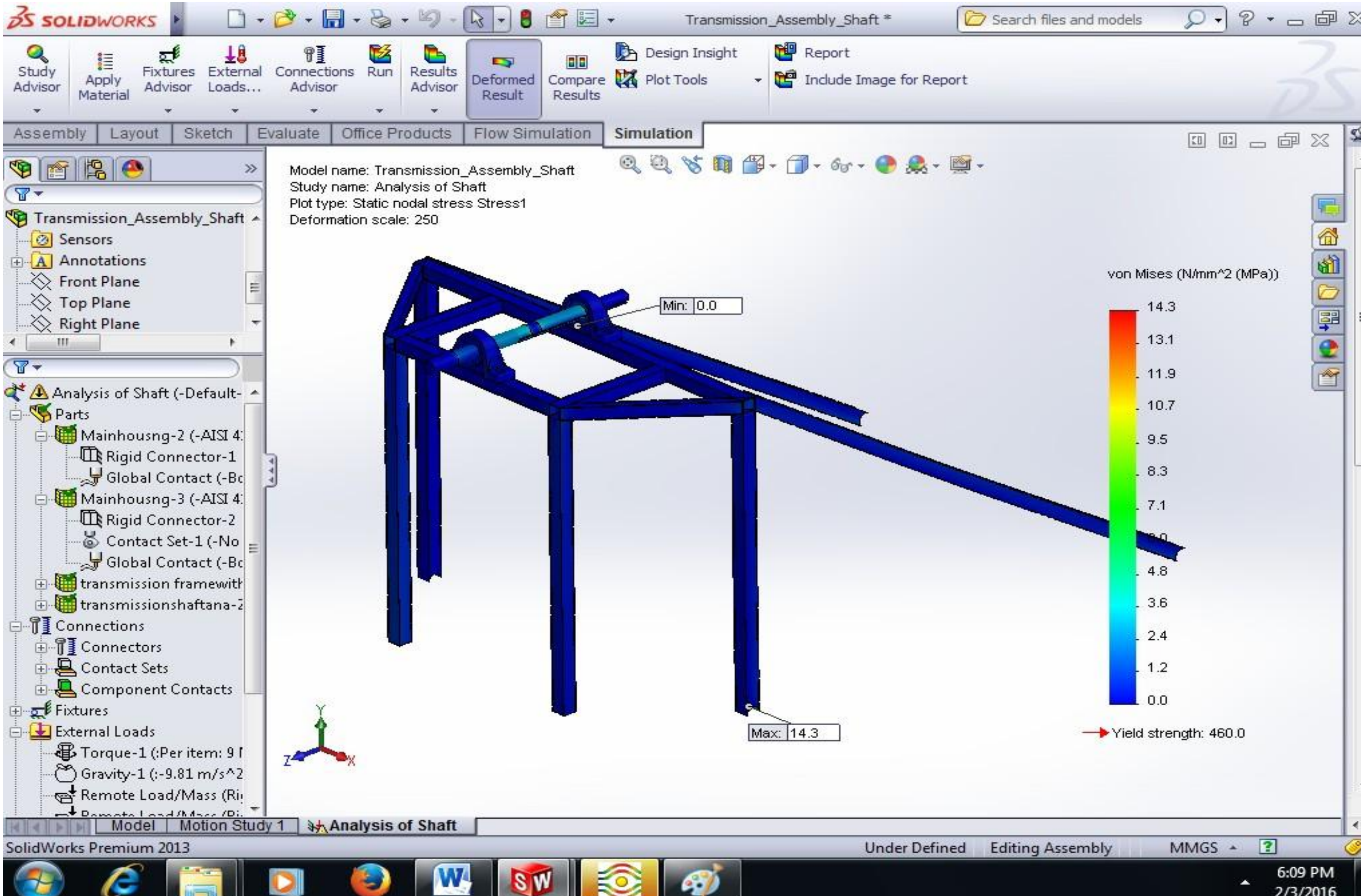
Transmission mount



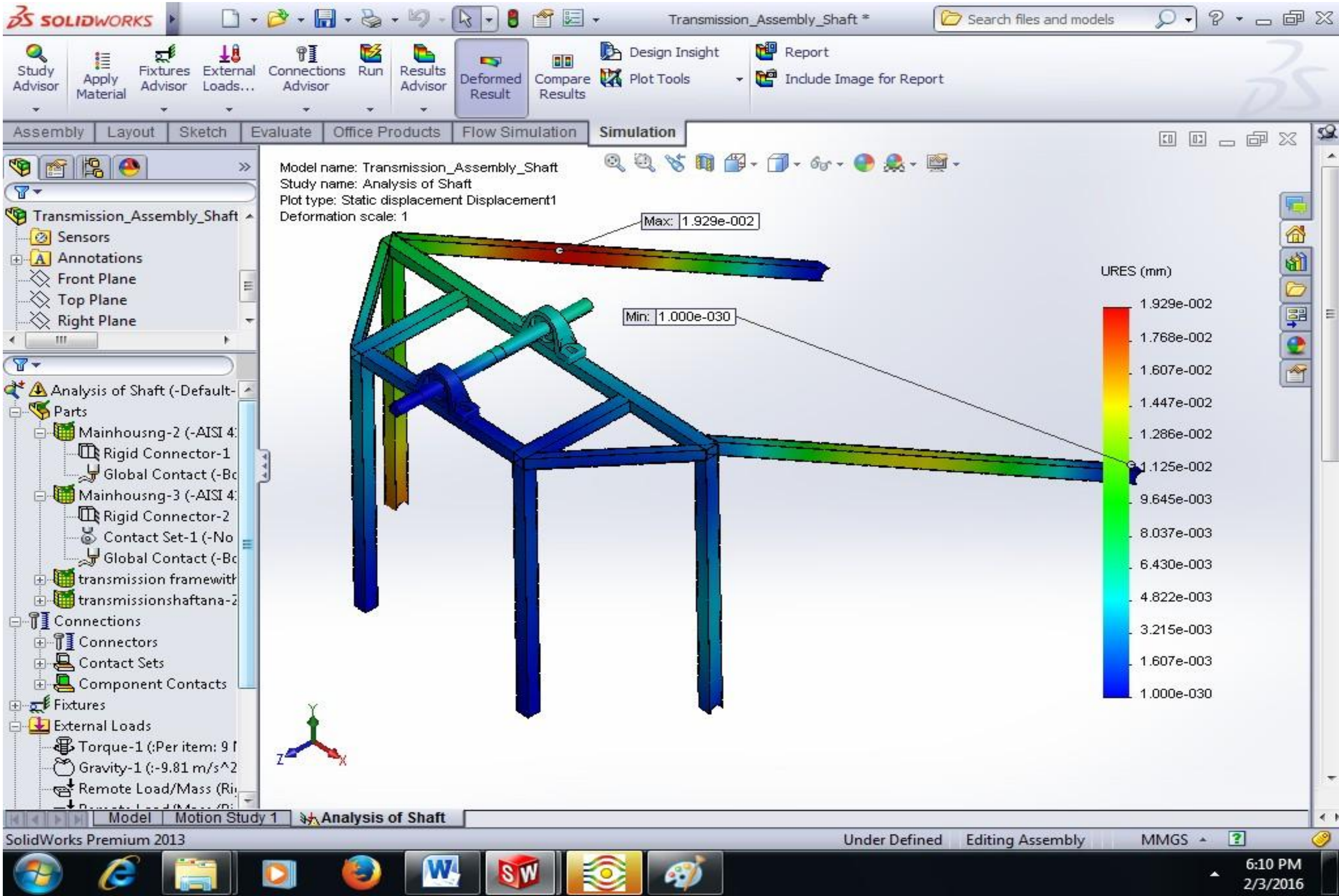
TRANSMISSION ASSEMBLY 2D MODEL



Static nodal stress analysis on the shaft and transmission assembly



Static displacement analysis on the shaft



Lift Engine Selection

- In response to modifying the hull and skirt size, it was decided to reexamine the fluid dynamics of the lift system. This involved calculating the cushion pressure, volumetric flow rate and the pressure inside of the hull. The estimated weight of the hovercraft is 180 kg and the craft footprint is 8ft x 4ft. Based on these characteristics, the pressure required inside the air cushion to negate the craft's weight can be found from:

- Pressure = F/A
- Pcu = 180 x 9.81/2.4982 Pcu =

595.54 Pa

- Exit velocity coming out through the hover gap Ve

Lift Engine Calculation

- Pressure = F/A

Pcu = 300 x 9.81/2.703

Pcu = 1088 Pa

- Exit velocity coming out through the hover gap Ve
- Ve = $\sqrt{\frac{2\ Pcu}{\rho}}$ Ve = $\sqrt{\frac{2\ x\ 1088}{1.2041}}$

  Ve = 42.51 x Dc

  Ve = 42.51 x 0.53

  Ve = 22.53m/s

- Area of lift = lift perimeter x hover height

  Al = 6.766 x 0.0127

  Al = 0.0859m^2

- $Q = Al \times Ve$

  $Q = 0.0859 \times 22.53$

  $Q = 1.93 m^3/s$ ………………………………………………………………………………(1)

- For proper lift to be achieved the bag pressure should be at least 20% greater than the cushion pressure
- $Pb = 1.3\ Pcu$……………………………………………………………………………………(2)

Thus $Pb = 1.3 \times 1088$

- $Pb = 1414.4\ Pa$
- Now, For flow from bag to cushion area
- $Q = 0.5 \times Anet \times \sqrt{\frac{2(Pb-Pcu)}{1.2041}}$

$1.935 = 0.5 \times Anet \times \sqrt{\frac{2\ x\ 0.3\ Pcu}{1.2041}}$ ……………………………………………(**from 1, 2)**

- Anet = 0.0.166 m^2

= $257.3005 in^2$

Now,

- Flow from hull to the bag,
- Pb = 1.3 Pcu
- Pb = 1.3 x 1088
- Pb = 1414.4 Pa

- Considering diameter is 2”
- Thus area of one hole = $\frac{\pi D^2}{4}$

= 3.141 in^2

- Thus number of holes = $\frac{A_{net}}{A_{hole}}$

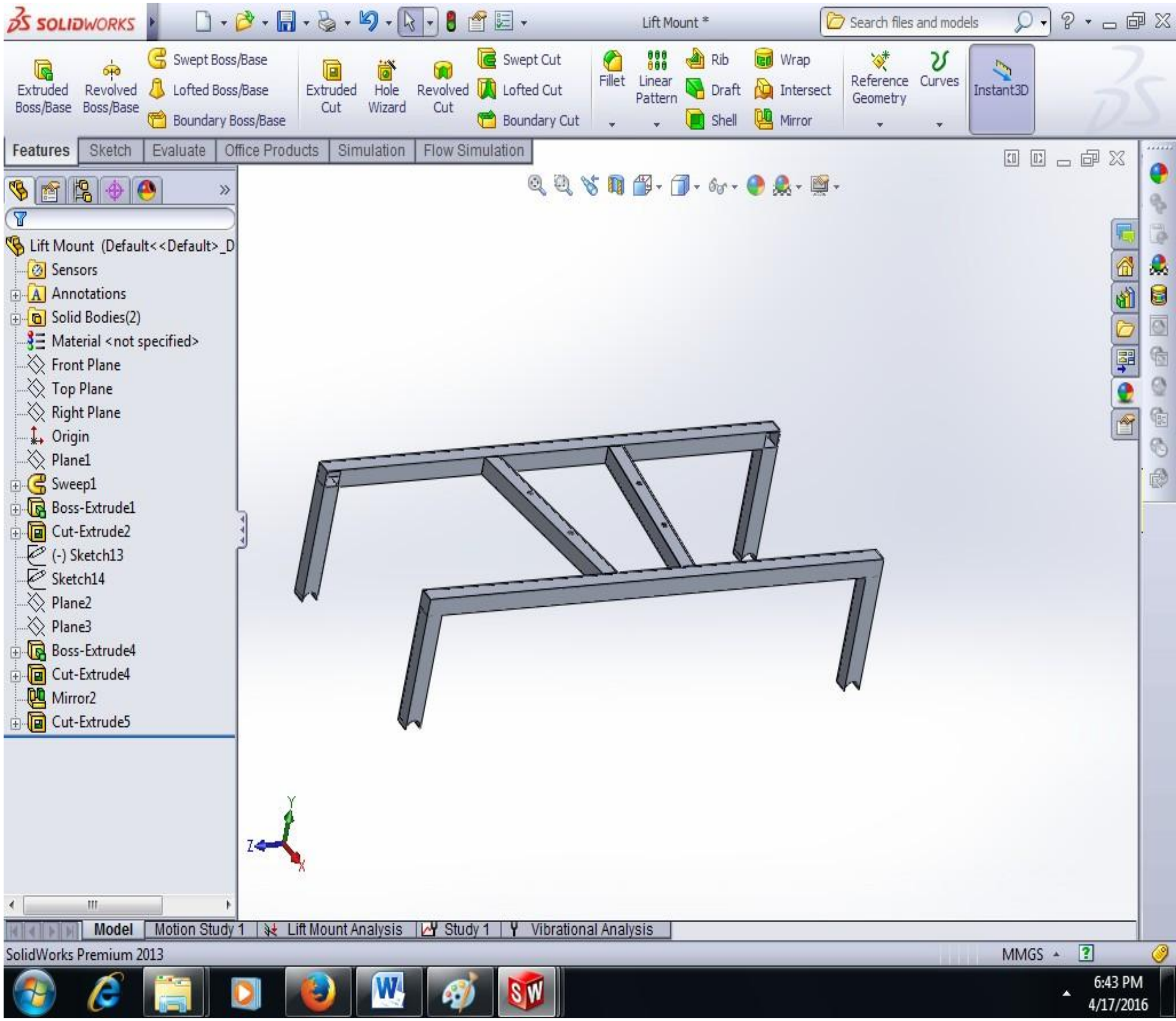
=$\frac{257.3005}{3.141}$ = 81.91 holes.

LIFT ENGINE

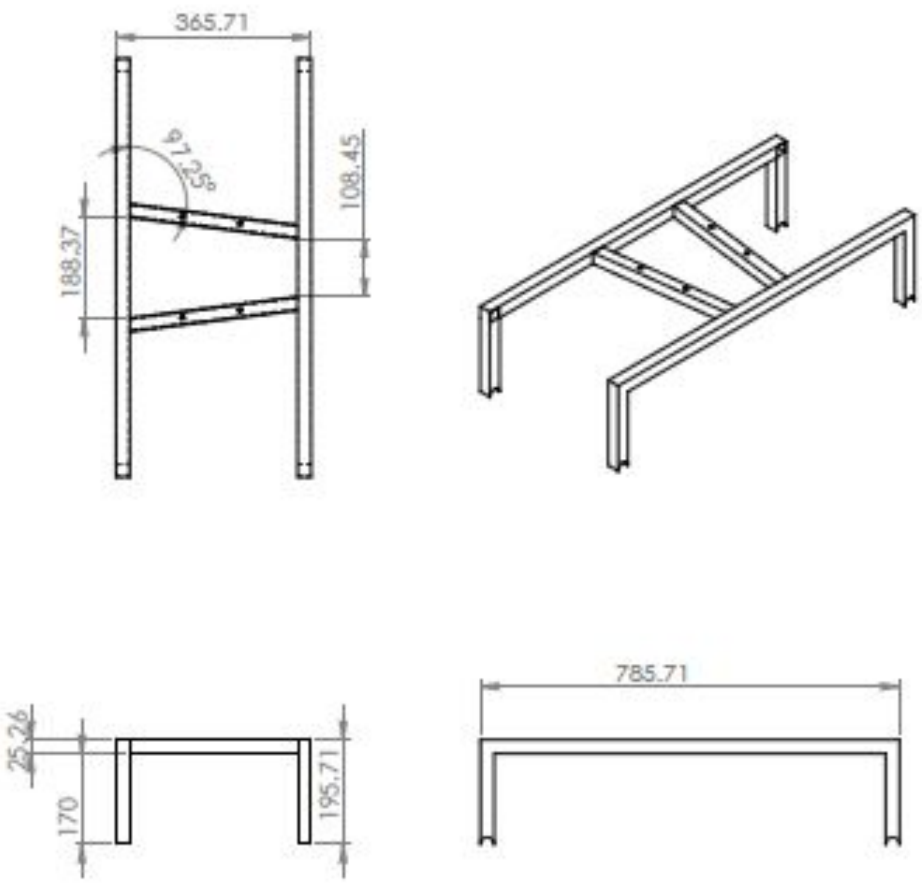
Briggs & Stratton
Vertical Shaft
Single cylinder, 4-stroke, air cooled, OHV (Overhead Valve)
21R5
20,78*
10.5Hp@3600rpm
344
Cast Iron Sleeve
87,3
57,5
2,6
1,4
26,8
452
393
327

Lift Engine Support

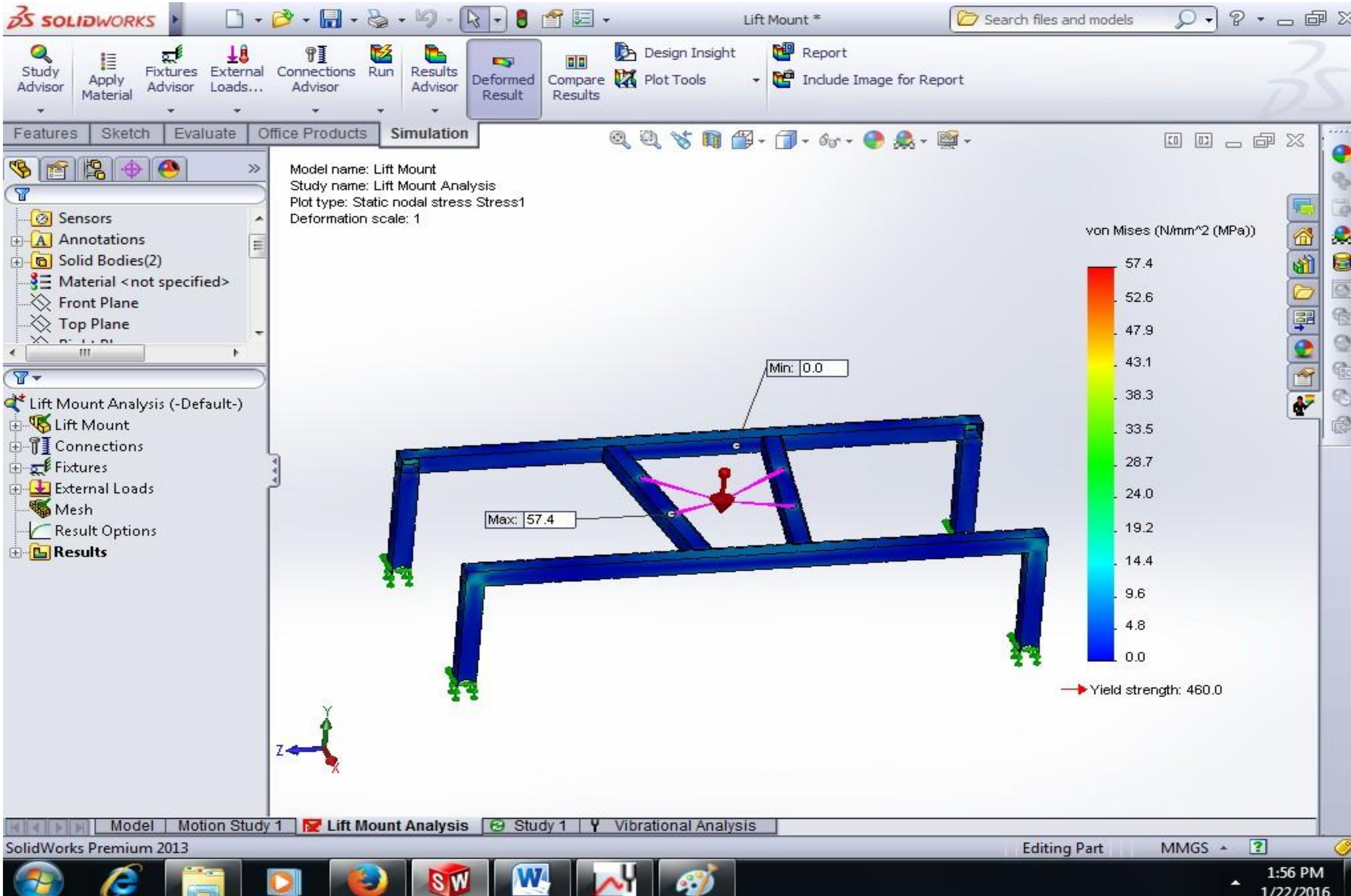
- The Lift engine used is of high power output. The chances of unnecessary vibrations are too high. To compromise the unnecessary effects, the support mounted for the engine should be highly stable and balanced.



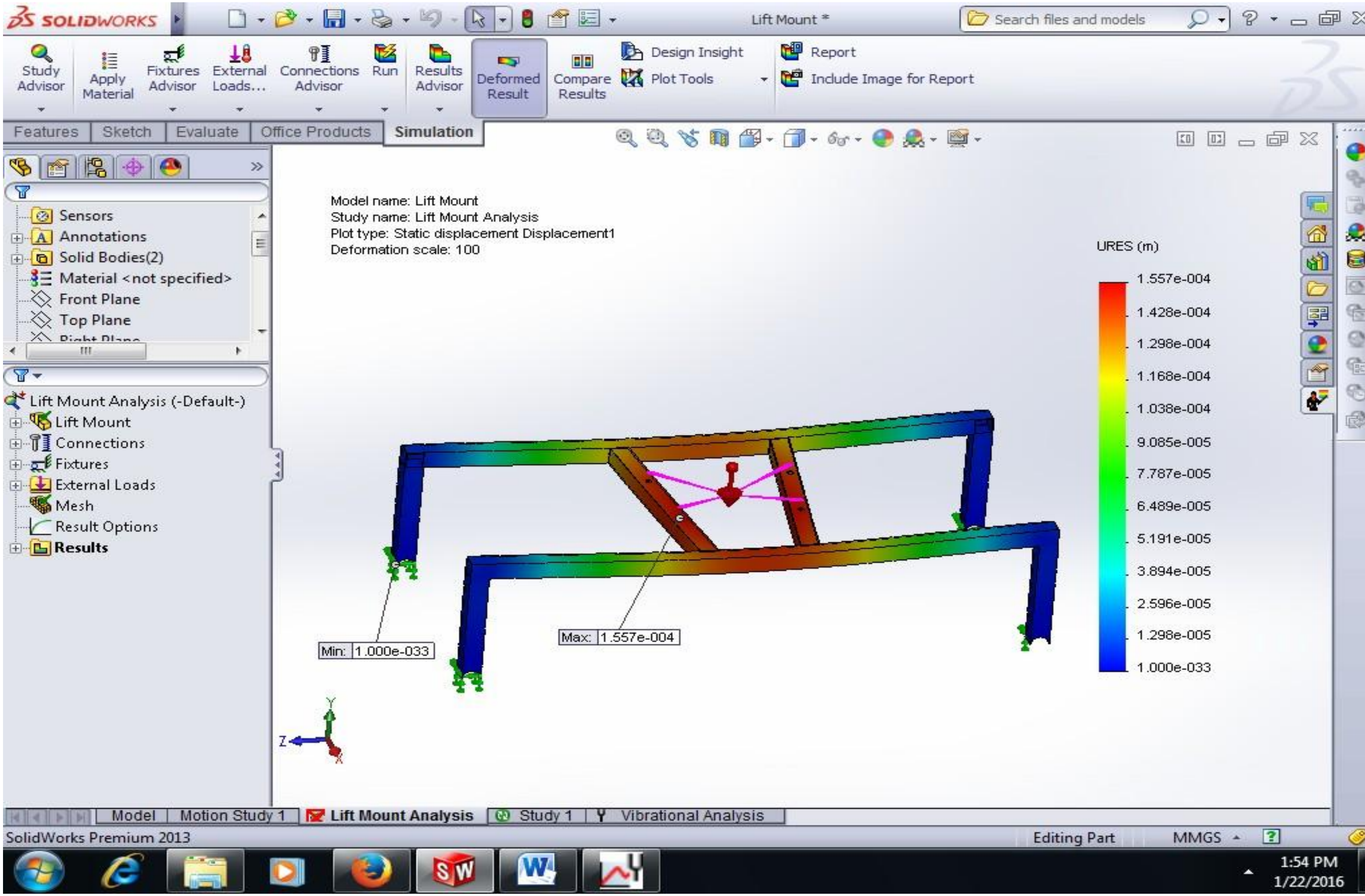
2D MODEL OF THE LIFT MOUNT



Static nodal analysis on the lift mount

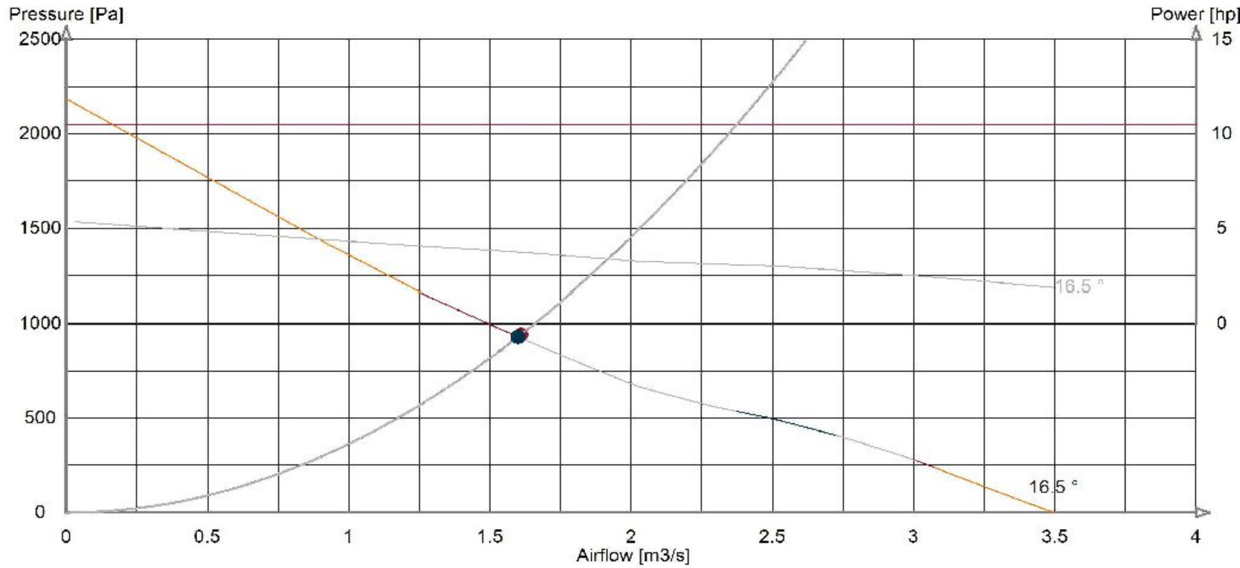


Static displacement analysis on the lift mount



Lift Propeller

- The Software which was used for the thrust propeller design was used to design the lift Propeller. The details are as follows:



Current Working Point

Airflow	1.6 m3/s	Total Pres	949 Pa	Propagation	
Static Pres	932 Pa	Power	3.74 hp		
Dynamic Pressure	17 Pa	Efficiency	54 %	Sound Power	111 LW dB

OPERATIONAL DATA:

Tip Speed:	83 m/s
Temperature:	40 °C
Air Velocity:	5.48 m/s
Torque:	10.2 Nm
Axial Force:	277 N

OPERATIONAL IMPELLER LIMITS:

Tip Speed:	124 m/s (3885 RPM)
Temperature:	-40°C - 120 °C
Diameter range:	19.6 - 31.5 in
Blade, load factor:	44.7 %
Hub, load factor:	N.A. %
Power, load factor:	N.A. %

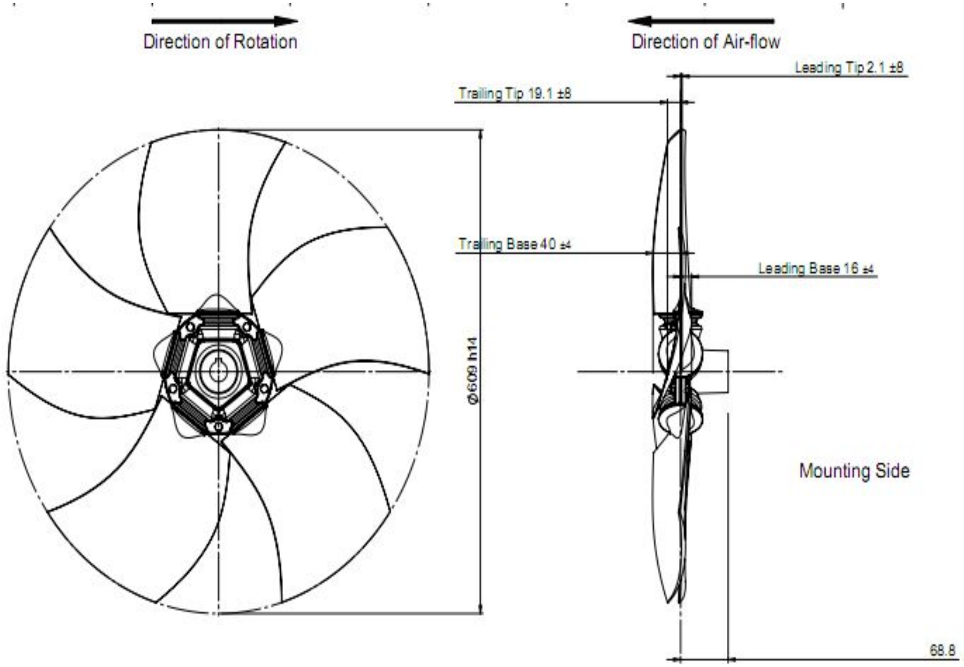
Static impeller data:

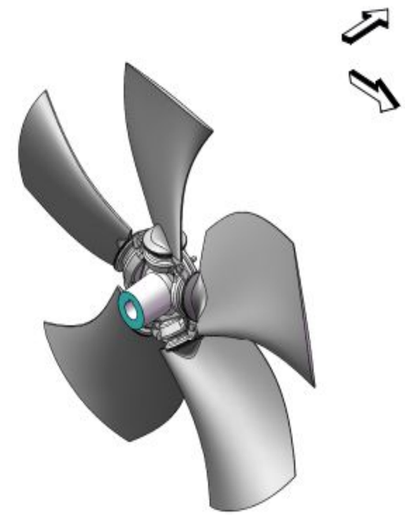
Moment of Inertia:	0.0518 kgm2
Blade Centrifugal force:	3490 N
Solidity factor:	0.47
Mass with std. boss:	2.21 kg

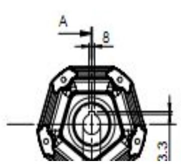
PARAMETRES FOR LIFT FAN

Glass Reinforced Polyamide (PAG)	
Temperature range: -40ºC to +120ºC Please observe penalty factors for temperatures above 40ºC	
Mechanical properties (Dry as moulded):	
Tensile strength:	165 Mpa
Izod impact strength notched (at 23°C):	11.0 kJ/m^2
Izod impact strength notched (at -30°C):	9.0 kJ/m^2
Tensile modulus:	8.2 Gpa
Mechanical properties (50% relative humidity):	
Tensile strength:	100 Mpa
Izod impact strength notched (at 23°C):	17.0 kJ/m^2
Izod impact strength notched (at -30°C):	9.0 kJ/m^2
Tensile modulus:	5.6 Gpa

Diameter	24”
No of blades	5
Pitch	
Speed	4160 rpm
Airflow	2.07m^3/s
Static Pressure	1088pa
Power	10.5HP
Efficiency	54%







*Not indicated tolerances and balancing grade are applied unless otherwise specified in the customer request field

Bolt guide:

5 Bolts @ M8x30 DIN 933 BCD 139

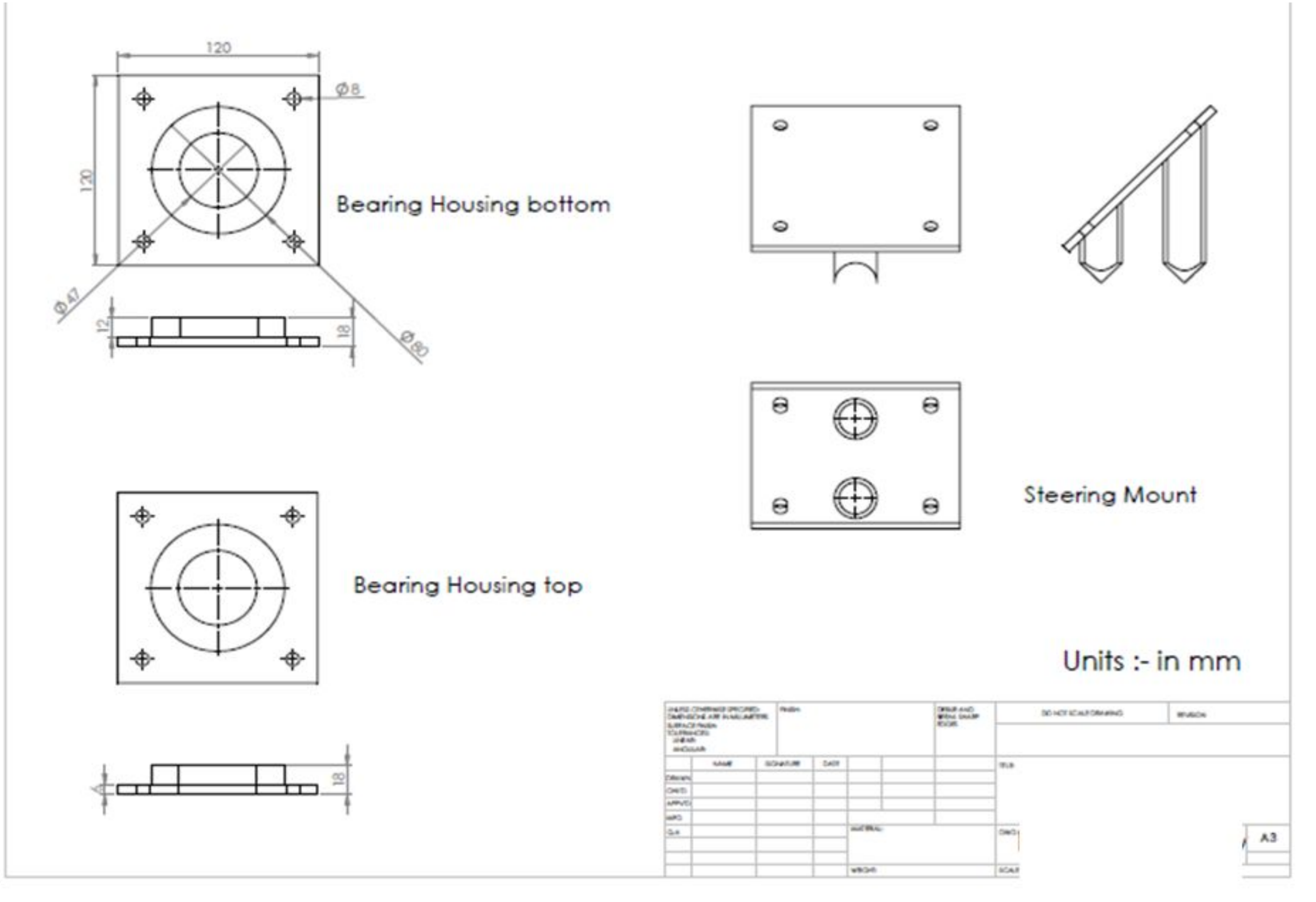
Impeller weight guide:

2.5 kg

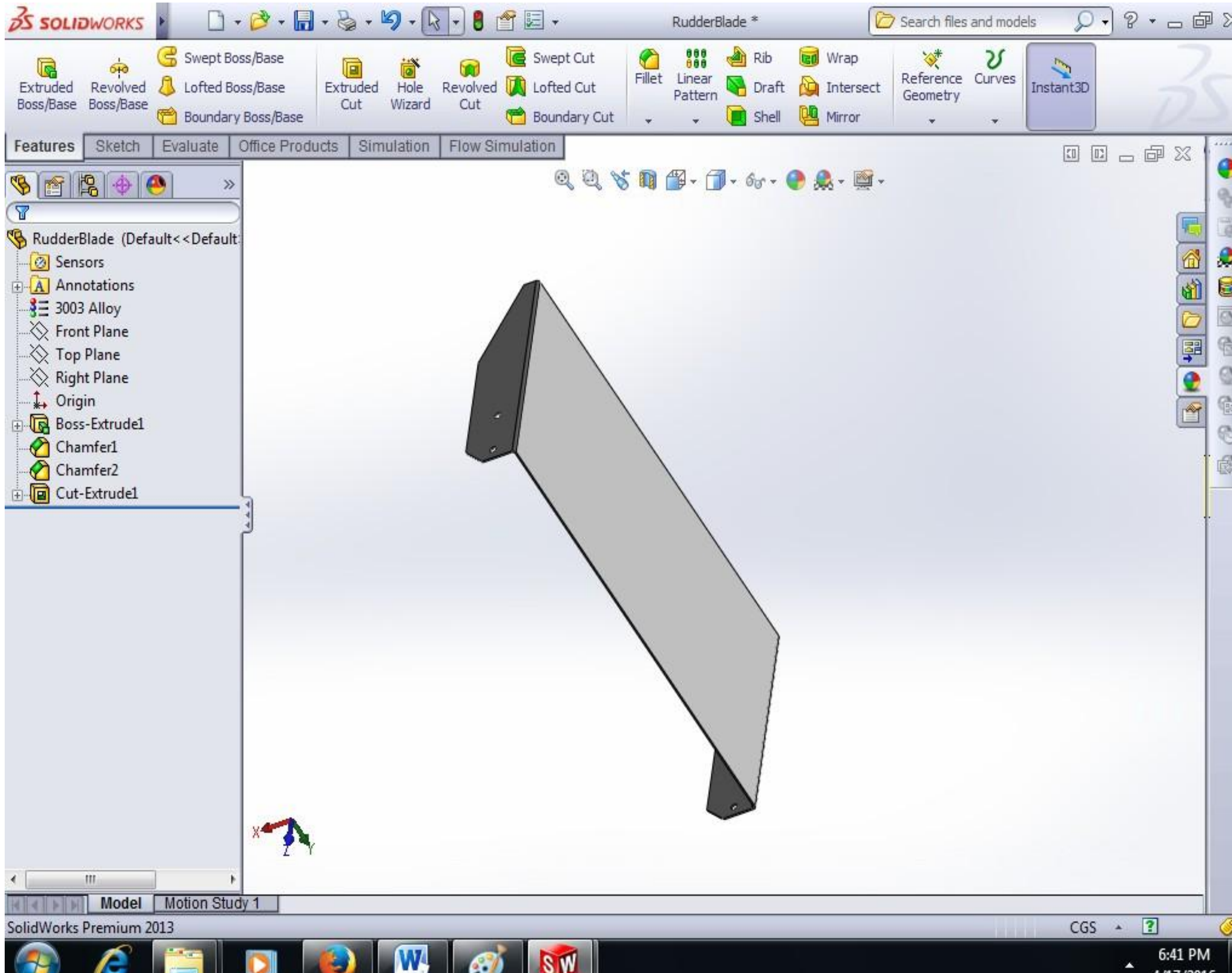
Part number:	Part description:	Quantity:	Material:
1710240008	7ZL/PAG/GREY Fan blade	5	PAG/GREY
2105070940 3	Z-Hub Plate/5/8.25 215	1	EN AC-47100
2105070010 3	Z-Retaining plate/5	1	EN AC-47100
5100000002	Z-Pitch Setting Pin/PAGI	5	PAGI

RUDDER AND STEERING SYSTEM

2D MODEL OF THE HOUSING

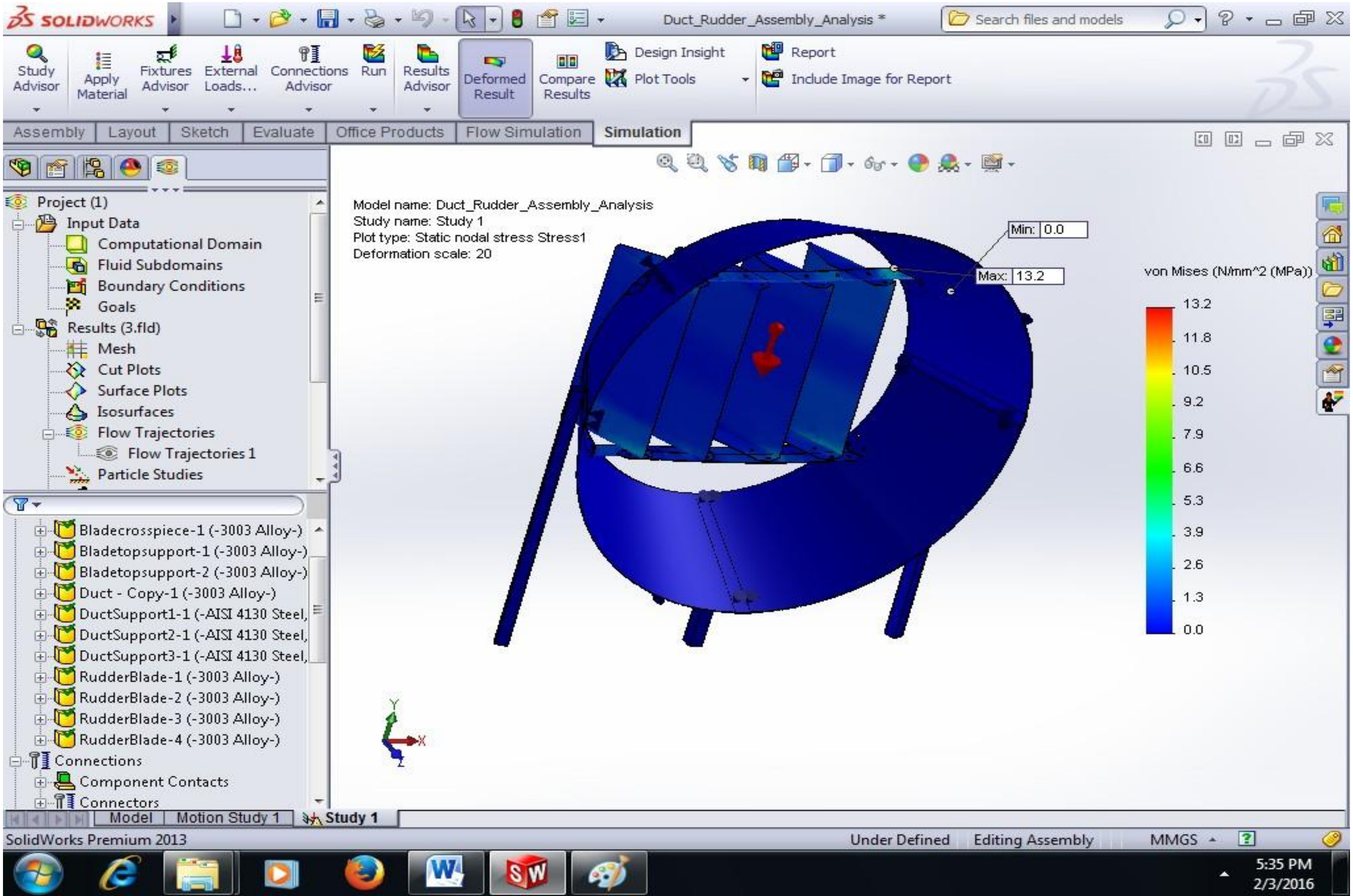


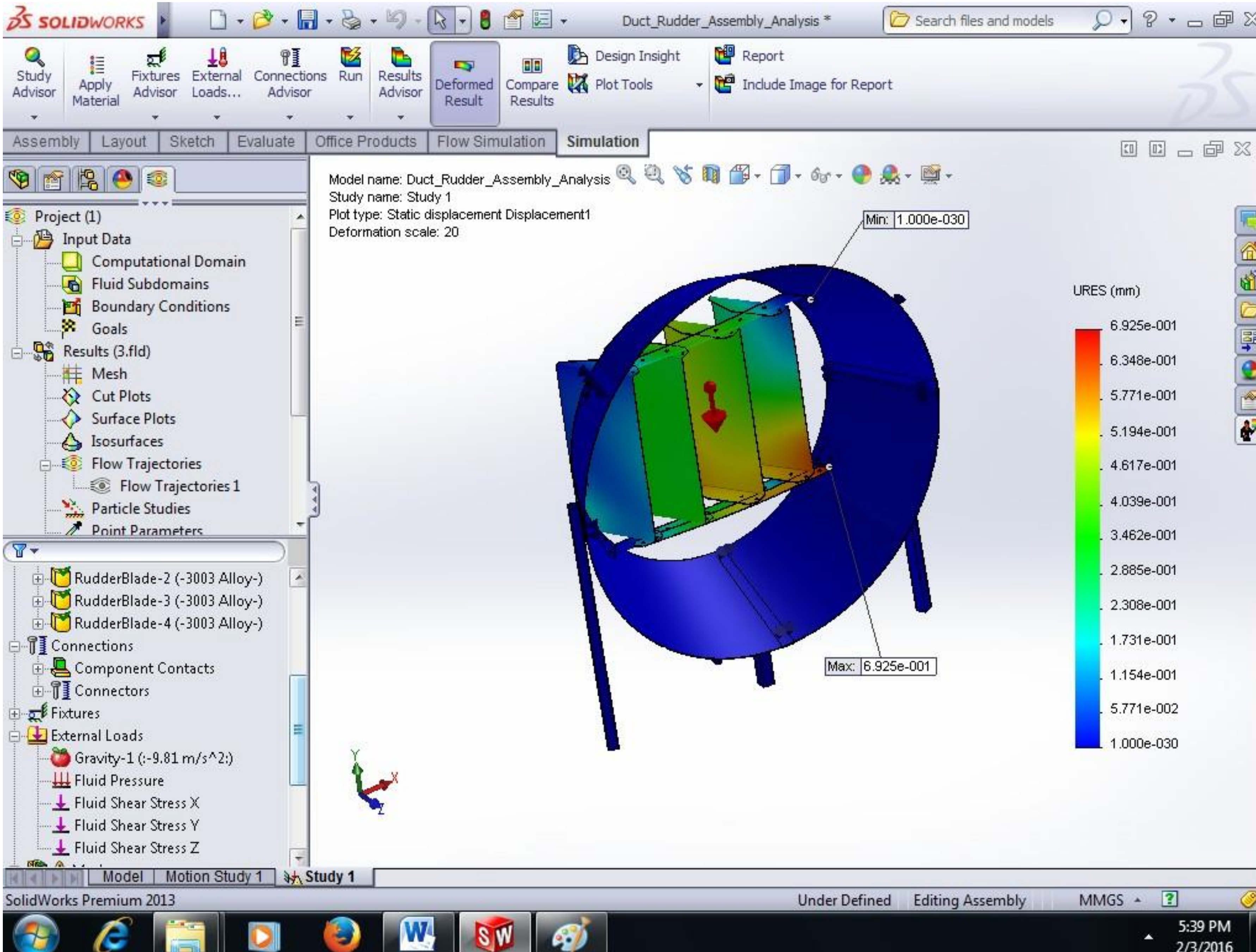
Parameter	
Material	Aluminium
Thickness	1.5 mm
Length	45 cm
Width	16 cm



Rudder assembly

Rudder and Thrust Duct assembly and analysis sw model




Duct_Rudder_Assembly_Analysis *
Study Advisor
Apply Material
Fixtures Advisor
External Loads...
Connections Advisor
Run
Results Advisor
Deformed Result
Compare Results
Design Insight
Plot Tools
Report
Include Image for Report
Assembly
Layout
Sketch
Evaluate
Office Products
Flow Simulation
Simulation
Project (1)
Input Data
Computational Domain
Fluid Subdomains
Boundary Conditions
Goals
Results (3.fld)
Mesh
Cut Plots
Surface Plots
Isosurfaces
Flow Trajectories
Flow Trajectories 1
Particle Studies
Point Parameters
RudderBlade-2 (-3003 Alloy-)
RudderBlade-3 (-3003 Alloy-)
RudderBlade-4 (-3003 Alloy-)
Connections
Component Contacts
Connectors
Fixtures
External Loads
Gravity-1 (:-9.81 m/s^2:)
Fluid Pressure
Fluid Shear Stress X
Fluid Shear Stress Y
Fluid Shear Stress Z
Model name: Duct_Rudder_Assembly_Analysis
Study name: Study 1
Plot type: Static displacement Displacement1
Deformation scale: 20
Min: 1.000e-030
Max: 6.925e-001
URES (mm)
6.925e-001
6.348e-001
5.771e-001
5.194e-001
4.617e-001
4.039e-001
3.462e-001
2.885e-001
2.308e-001
1.731e-001
1.154e-001
5.771e-002
1.000e-030
Model
Motion Study 1
Study 1
SolidWorks Premium 2013
Under Defined
Editing Assembly
MMGS
5:39 PM
2/3/2016

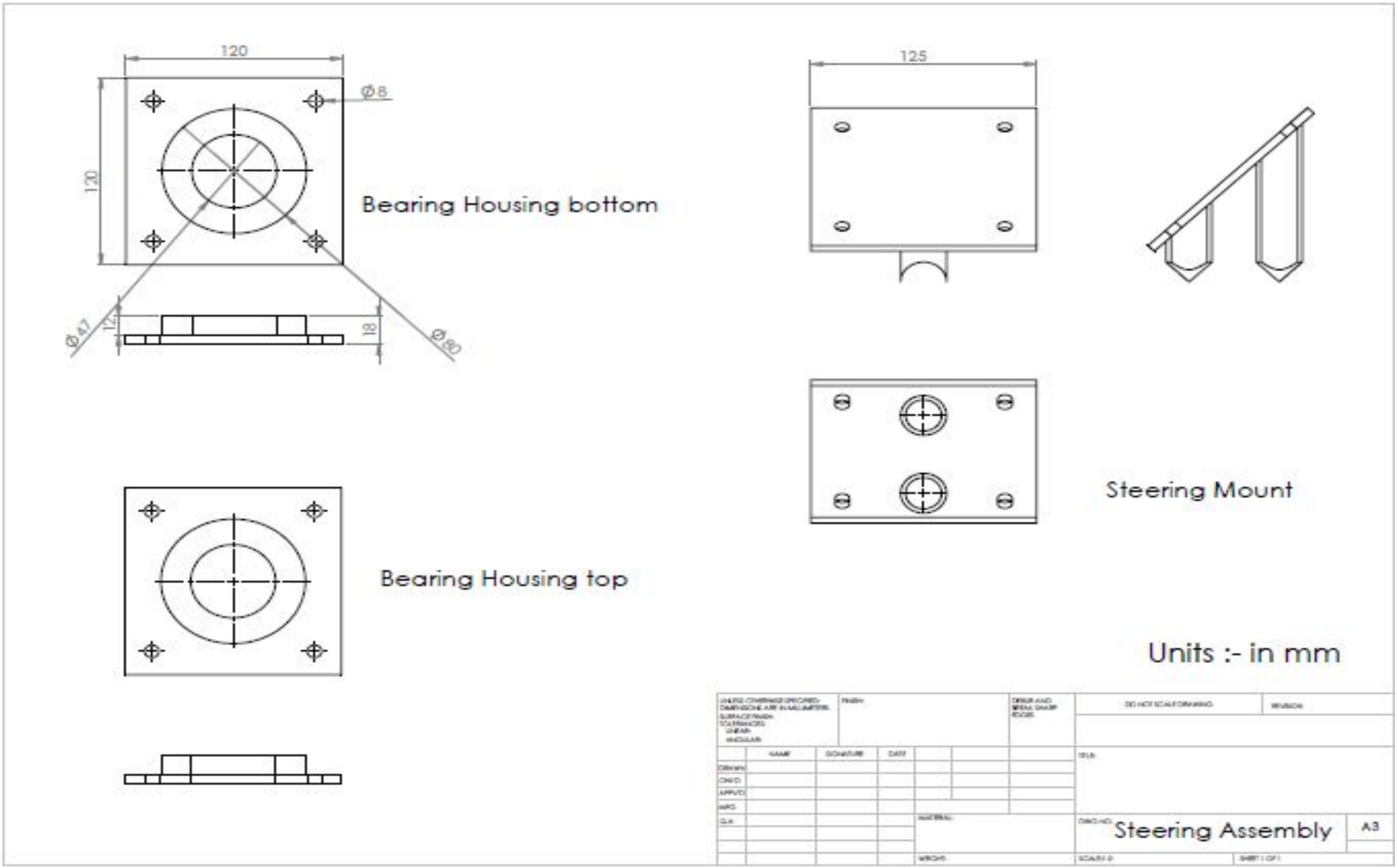
Original duct and rudder assembly

Steering Mechanism

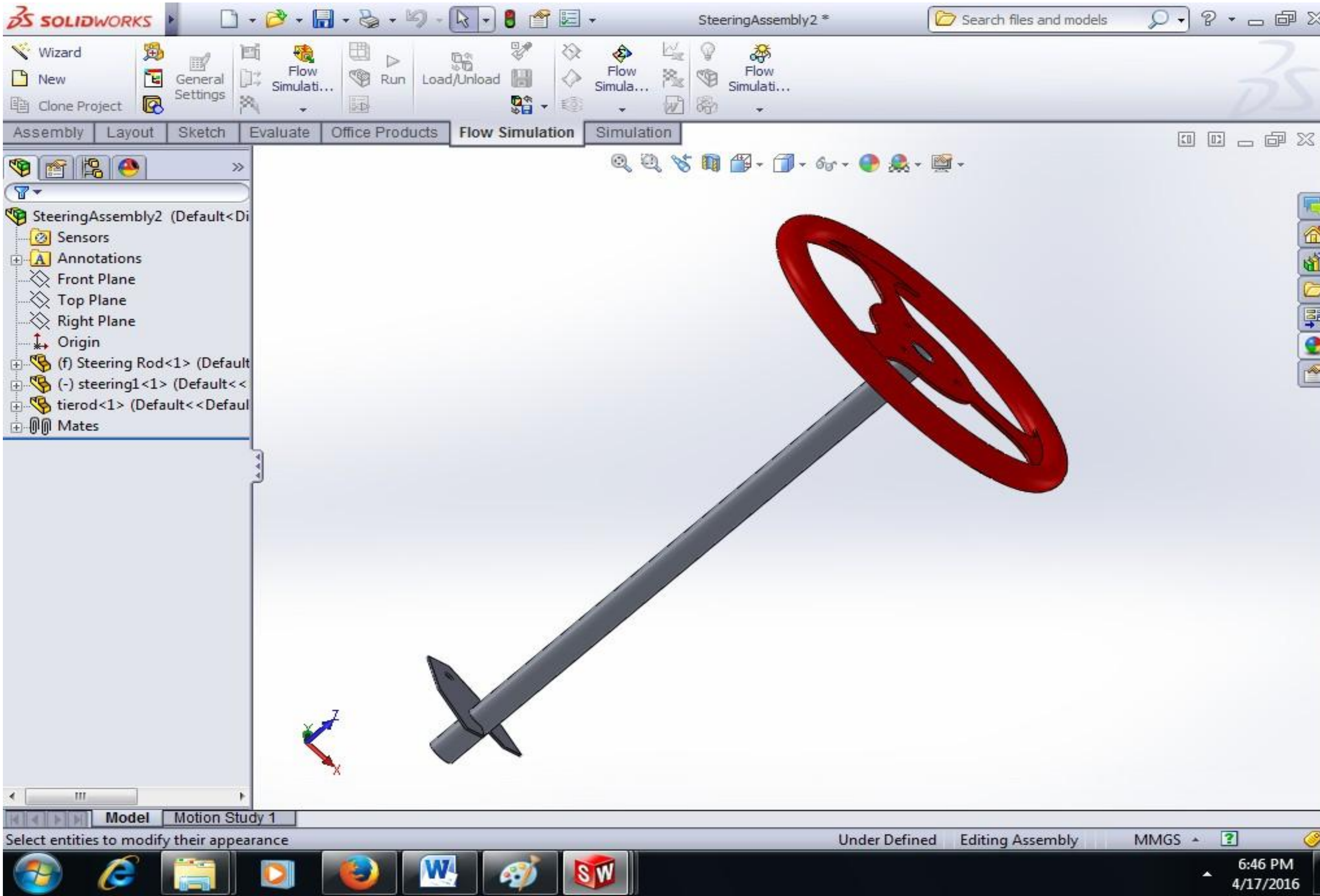
The Steering mechanism used in our vehicle has the following components:

- Steering wheel
- Steering Shaft
- Housing
- Wires and casing.

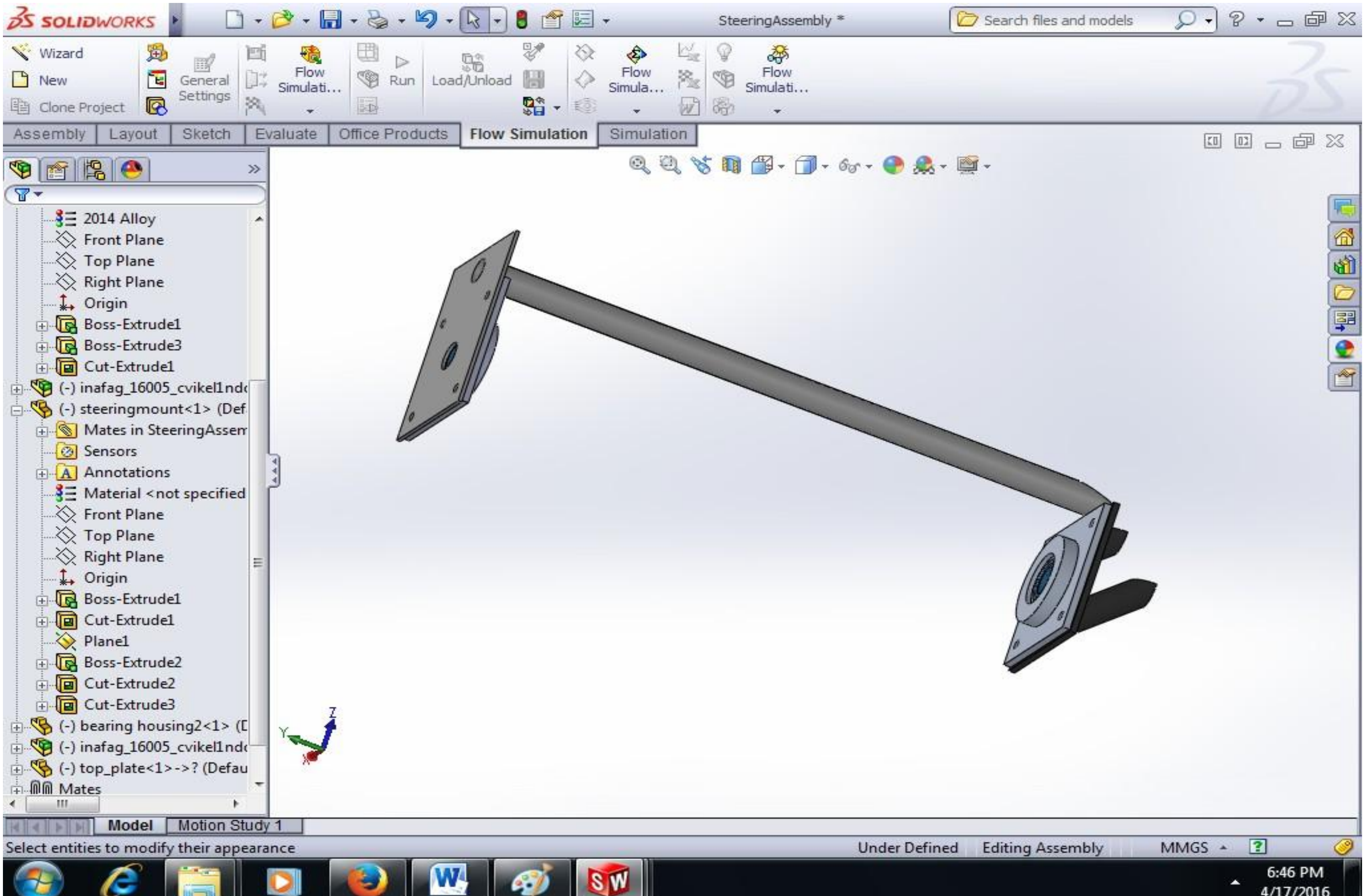
2D MODEL OF THE STEERING ASSEMBLY



Steering wheel and Shaft SW model

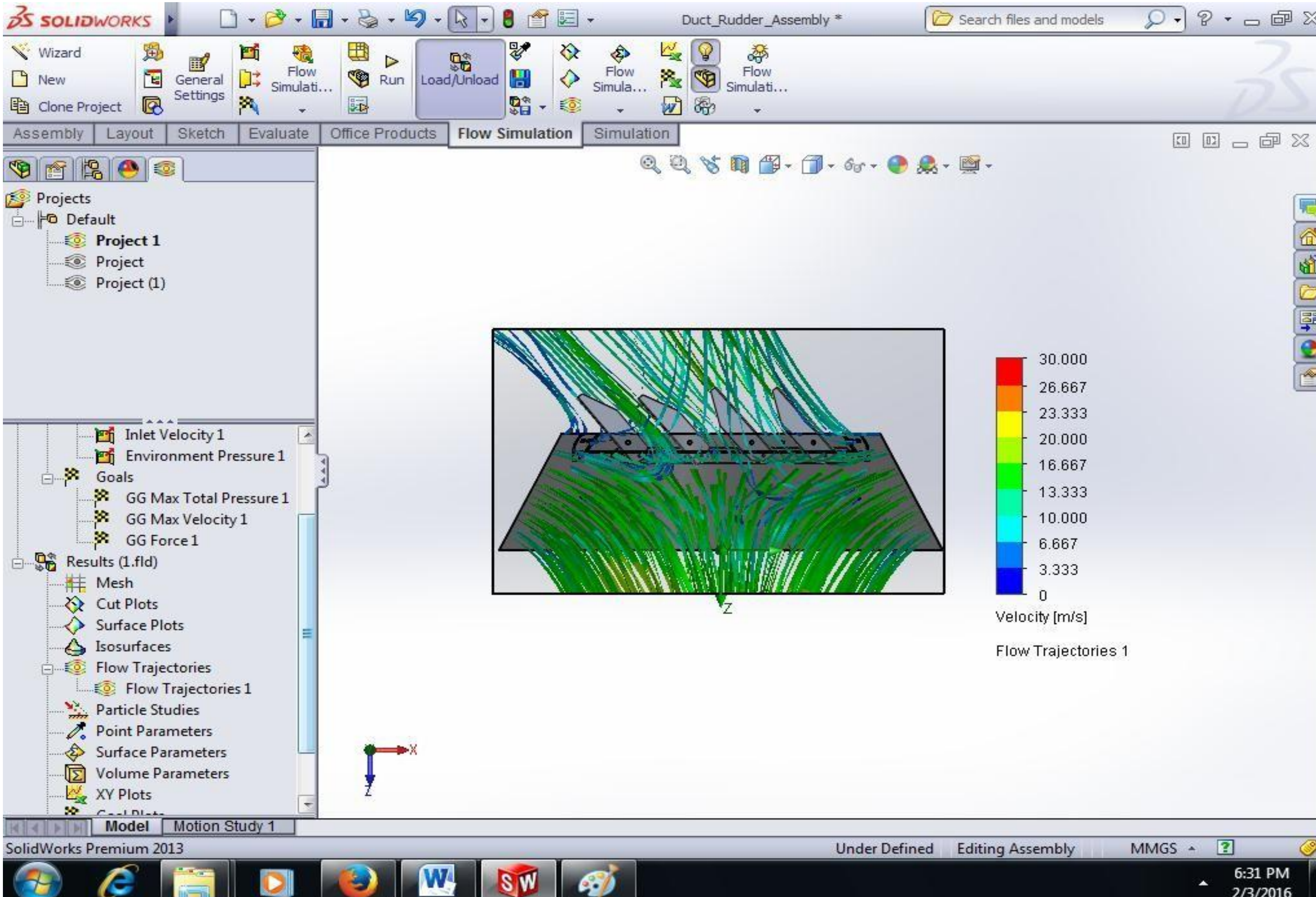


Steering shaft housing and support SW model



Steering wheel and shaft

Flow analysis on the steering connectors to the Rudder



Research and Design Parameters of Flexible Skirt

- Skirt is a cushion like structure that is attached to the hull on its edges. When the skirt is inflated it forms a dough-nut kind of shape below the hull. All modern hovercraft - large and small - use a skirt of one sort or another for their suspension system so that the power required to lift the craft can be minimized.

- A hovercraft skirt is required to fulfill the following functions:
  - Contain the cushion of air beneath the craft at the required hover height.
  - Have the ability to conform or contour efficiently over obstacles so as to keep the loss of cushion air to a minimum.
  - Return to its original shape after having been deformed.

- The material used in our ACV is ***Abrasuper 40***.

Properties of the material are as follows:

- Specific gravity= 0.98gm/cm^3
- Tensile Strength= 240kg/cm^2
- Abrasion resistance= 120N
- Colour= Pink

BAG SKIRT DIMENSIONS

- Height of the cross section of the skirt= 1/8th of the width of the skirt
- Width of the craft=4feet=1.219m
- Height of the cross section=1/8x1.219=0.152m=6 inches

Outer diameter	8inch
Inner diameter	36.24inch
Outer arc length	12.566inch
Inner arc length	10.57inch

Sticking of the Skirt on to the hovercraft

Result and Discussions

Lift Engine	10.5 Hp power required @ 4160 rpm to generate 2.07 m^3/sec of discharge and 2cm of hover gap.
Thrust Engine	6.5 Hp power required @3600 rpm to generate 28lbf of thrust to achieve maximum speed of craft at 50 km/hr
Lift Fan	Dia 24" No of blades 5 Pitch 16.5 degrees Material PAG
Rudder	Thickness of rudder- 1.5mm Length – 45 cm Width- 16 cm
Duct	Large duct diameter – 38 inches Small duct diameter – 26 inches
Bag Skirt	Outer arc length-18.849inches inner arc length<16.7499

Hovercraft pressure test results

	Hovercraft Pressure Test Rig Observations				
Load (kg)	Position	Section	Δh (m)	Pressure (Pa)	Number of holes
30	cushion	center	7	686	81
30	cushion	front	6.7	657.27	81
30	cushion	back	7.2	706	81
40	cushion	Front	6.9	676.89	81
40	cushion	center	6.5	637.65	81
40	cushion	back	6.8	667.08	81
40	hole	front	7	686	81
40	hole	back	6.6	647	81
40	hole	center	6.7	686	81
40	cushion	front	6.8	667.08	89
40	cushion	back	7	686	89
40	cushion	center	6.7	657.27	89
40	hole	front	6.9	676.89	89
40	hole	center	7	686	89
40	hole	back	7	686	89
40	cushion	front	6.66	647	100
40	cushion	center	6.6	647	100
40	cushion	back	6.7	657.27	100
40	cushion	front	6.55	642.555	95
40	cushion	center	6.6	647	95
40	cushion	back	6.6	647	95
40	cushion	front	6.55	642.555	95
40	cushion	center	6.9	676.89	95
40	cushion	back	6.7	657.27	95
44.5	cushion	front	6.35	622.935	91
44.5	cushion	center	7	686.7	91
44.5	cushion	back	6.9	676.89	91
43.5	cushion	front	6.85	671.985	91
43.5	cushion	center	6.85	671.985	91
43.5	cushion	back	6.85	671.985	91

Hovercraft pressure test results contd

Discharge

avg height of the impeller 0.025m

volume swept by the impeller in one rot. by one blade = $h \times \pi(R^2 - r^2)$

$= 0.025 \times 3.15\ (0.0929 - 0.0058)$

$= 6.837 \times 10^{-3}\ m^3/rot./blade$

thus 5 blades = $5 \times 0.006837 = 0.0341\ m^3/rot$

rpm observed by non contact tacometer = 4160 rpm

thus discharge at 4160 rotations = $0.0341 \times 4160 / 60 = 2.37\ m^3/sec$