



Solar Panel in Periodic Flow

Using Cmsol

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PROJECT REPORT APPROVAL

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DEDICATION

We dedicate our thesis work to our family. A special feeling of gratitude to our loving parents. In addition, we express our deep gratitude towards our respected thesis supervisor Professor Dr. Md. Fokhrul Islam.

We also dedicate this thesis to our many friends who have supported us throughout the process. We will always appreciate what they have done.

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“In the name of ALLAH, Most Gracious, Most Merciful”

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ABSTRACT

Solar panel in one of the appealing topics and a work of importance for the current world. For this renewable energy the new energy surge of the whole world has increased. With the increasing growth of this renewable energy (solar energy) and the increase of solar panels the world is now focusing on the greater efficiency of the solar panels. In this study the main case is the periodic flow on solar panel and a model simulation created in COMSOL.

This model represents the investigation of solid breeze stream around a solar panel and the comparing basic relocation because of the breeze's heap. The solar panel is situated in a variety of similarly separated indistinguishable boards, which takes into account the supposition that the occasional stream conditions can be applied in the stream wise direction. The model sets the free flow velocity flow field of 25 m / s ($Re = 6.6 \times 10^6$) and incorporates structural pressures caused by the displacement of people in their areas. The model uses two different tests the first defines a storm stream around the solar panel using the Turbulent Flow, $k-\epsilon$ physics interface; some solves structural and relocation pressures using the Solid Mechanics physics interface. Fluid-Structure Combination, Fixed Geometry Multiphysics coupling is used to pair the fluid flow limits of fluids from liquids to solids.

CHAPTER ONE

INTRODUCTION

1.1 GENERAL

The world is currently craving for RE (renewable energy) and from those energies the energy that has the most appeal is Solar Energy. It's not only for the availability or the infinite amount of the source but also the easiest one to convert or bend to human will. Bangladesh is one of the leading countries who are using solar energy for making more than 1GW of solar energy. Bangladesh is a country of 147,570 km² with a population of 159 million. The country has shown significant growth in recent years, and has achieved an average growth rate of 6 percent. Growing economic growth, rapid urbanization, and industrial expansion and development have increased the country's demand for electricity. It is well-known that energy is a key factor in eradicating poverty and improving the social and economic well-being of the people of Bangladesh. Government's vision to make electricity available to all by 2021. To achieve this, Government has prioritized the energy sector and prepared for short-term, medium and long-term power generation projects using gas, coal, petrol, nuclear power, nuclear and renewable energy sources. Renewable energy will play an important role in meeting the demand for electricity, especially in non-electricity areas in the country. Government has set a target to produce 5% of total energy from renewable energy services by 2015 and 10% by 2020.

1.2 SOLAR ENERGY

Solar energy is radiant sunlight and heat combined in a variety of ever-changing technologies, such as solar heating, photovoltaics, solar thermal energy, solar molten salt plants and artificial photosynthesis. It is an important source of renewable energy, and its systems, depending on how they absorb and transmit solar energy or convert it into solar energy, are widely described as active or active solar systems. In order to harvest electricity, effective solar techniques include the use of photovoltaic devices, concentrated solar energy and solar water heating.

1.3 SOLAR PANEL

Solar panels are those devices that are used to absorb solar radiation and turn it into heat or Electricity. A solar panel is actually a collection of solar cells (or photovoltaic), which can be used to generate electricity with the effect of photovoltaic. These cells are arranged in a grid-like pattern on the surface of the solar panels. Therefore, it can also be described as a set of photovoltaic modules, housed in a supporting structure. A photovoltaic (PV) module is an integrated and connected assembly of 6×10 solar cells. When it comes to wear and tear, these panels are very durable. Solar panels wear very slowly. Annually, their performance decreases only by about 2 percent (sometimes, or less). Most solar panels are made using crystal solar cells. Installation of solar panels in homes helps to combat harmful emissions of greenhouse gases and thus helps to reduce global warming. Solar panels do not lead to any kind of dirt and are clean. It also reduces our reliance on (limited) energy and traditional energy sources. Nowadays, solar panels are used in various electrical appliances, such as counters, which work as long as sunlight is available. However, the only major response of solar panels is that they are very expensive. Also, solar panels are installed externally as they require sunlight to be charged.

1.4 PERIODIC FLOW

Periodic flow occurs when the apparent geometry of interest and the expected pattern of the flow heat solution have a recurring environment from time to time. Two types of flow can be modeled on FLUENT. In the first type, no pressure drop occurs on certain planes from time to time. A major special class of fluid motions shapes time-periodic flows. For instance, the many well-known families of linear propagating waves include this class. In geophysical and classical fluid dynamics, nonlinear time-periodic flows have gained increased attention in many contexts recently. Temporary speed fields can create complex, A periodic Lagrangian movements, despite the relative simplicity of their Eulerian representation; models of this sort can be useful.

1.5 OBJECTIVE OF STUDY

This model is an investigation of a solar panel structure set in an intermittent stream field. The solar panel being referred to be situated inside a routinely dispersed exhibit of boards exposed to an approaching solid breeze; see Figure 1. The model unravels for the stream around the board and the auxiliary dislodging because of the liquid burden. It is expected that enough boards are situated both upstream and downstream of the board for occasional stream conditions to be material in the stream wise direction. Seen from a position high over the ground, the exhibit of solar panels goes about as a harsh limit for the atmospheric flow.

The current investigation consists of two main parts:

- Solving for the fluid flow around the solar panel with a free stream velocity above the solar panel of 25 m/s (90 km/h).
- Study the twisting of a solar panel caused by a liquid load.

1.6 SCOPE OF STUDY

There were several tasks that were necessary to be done in order to complete the before mentioned objectives which are given below:

1. Establishing the appropriate instruments for conducting research on the periodic flow on solar panels.
2. Simulating the real life issue in Comsol and checking the efficiency points
3. Comparing the theoretical simulation with the real life situation.

1.7 THESIS LAYOUT

CHAPTER 1: This chapter includes a general introduction, solar energy, solar panel, periodic flow, objectives, and scope of study

CHAPTER 2: This chapter includes basic idea of solar panel, periodic flow, turbulent flow, fluid structure analysis and the effectiveness discussion of the model.

CHAPTER 3: Methodology of the given model geometry.

CHAPTER 4: Results and Discussions.

CHAPTER 5: This chapter includes the conclusion from the experiments conducted on Periodic flow on Solar Panel.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Energy is defined as capacity to produce an effect to do work. Energy has been an important component to meet the day to day needs of human beings. Human society require increasing amount of energy for industrial, commercial, domestic, agriculture, and transport uses. Different forms of energy are defined as primary and secondary energy, commercial and noncommercial energy, renewable and nonrenewable energy. Renewable energy is obtained from natural sources. These resources can be used to produce energy again and again eg. Solar energy, wind energy, tidal energy etc. Nonrenewable resources cannot be replaced once they are used eg. Coal, oil, gas etc. these energy resources are limited and would be exhausted within prescribed period of time. Primary energy refers to all types of energy extracted or captured directly from natural resources. Primary energy can be further divided into two parts namely renewable and non-renewable energy. Primary energy is transformed into more convenient form of energy such as electricity, steam etc. these form of energy are called secondary energy. Energy that is available in the market for a definite price is known as commercial energy. And Solar Energy is molded to a new form of commercial energy in current days.

2.2 SOLAR ENERGY

The earth receives the solar energy in the form of solar radiation. These radiations comprising of ultra-violet, visible and infrared radiation. The amount of solar radiation that reaches any given location is dependent on several factors like geographic location, time of day, season, land scope and local weather. Because the earth is round, the sun rays strike the earth surface at different angles (ranging from 0° to 90°). When sun rays are vertical, the earth's surface gets maximum possible energy. Most of the part of India receives 4 to 7 kWh of solar radiation per square meter per day. India receives solar energy equivalent more than 5000 trillion kWh per year.

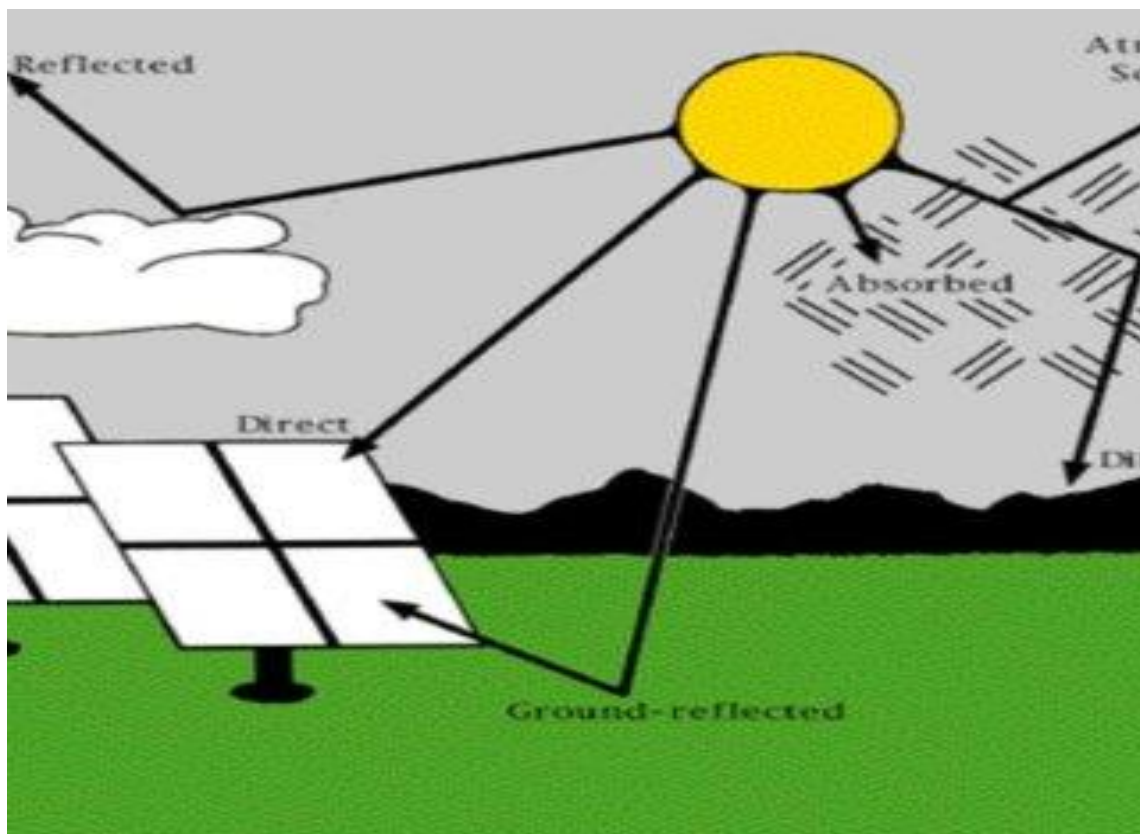


Fig: 2.2 Solar Energy and Radiation

2.3 CONCEPT OF SOLAR PANEL

A solar cell is nothing but a PN junction diode under light illumination. Sun light can be converted into electricity due to photovoltaic effect. Sun light composed of photons (packets of energy). These photons contain various amount of energy corresponding to different wave lengths of light. When photons strike a solar cell they may be reflected or absorbed or pass through the cell. And in further creates energy surge to store.

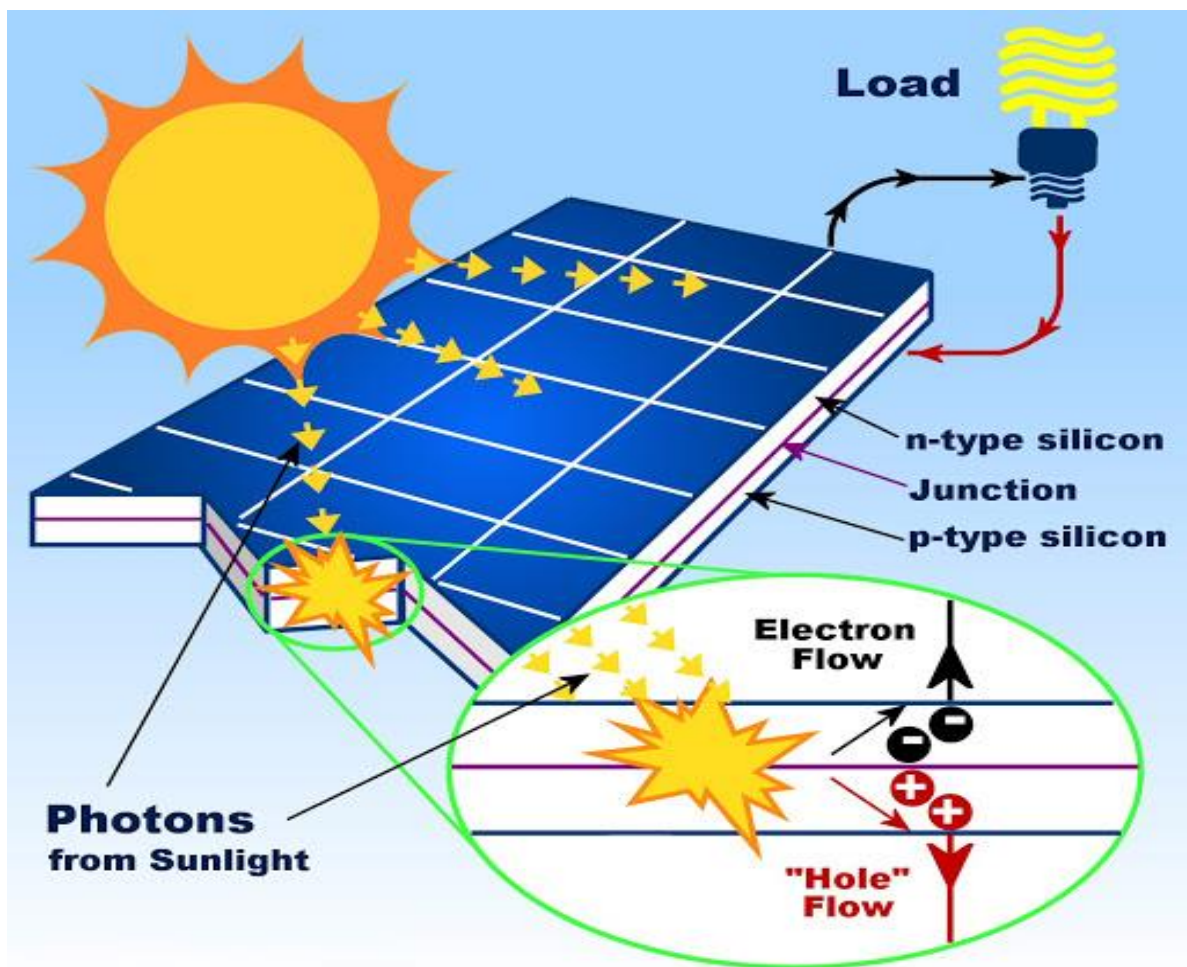


FIG: 2.3.1 Photovoltaic effects

Solar panels are devices that convert light into electricity. They are called "solar" panels because most of the time, the most powerful source of light available is the Sun, called Sol by astronomers. Some scientists call them photovoltaic which means, basically, "light-electricity." A solar panel is a collection of solar *cells*. Lots of small solar cells spread over a large area can work together to provide enough power to be useful. The more light that hits a cell, the more electricity it produces, so spacecraft are usually designed with solar panels that can always be pointed at the Sun. The circuit of the solar panel is as simple as it can get. A panel board is directly connected to the circuit that goes to the voltage storage.

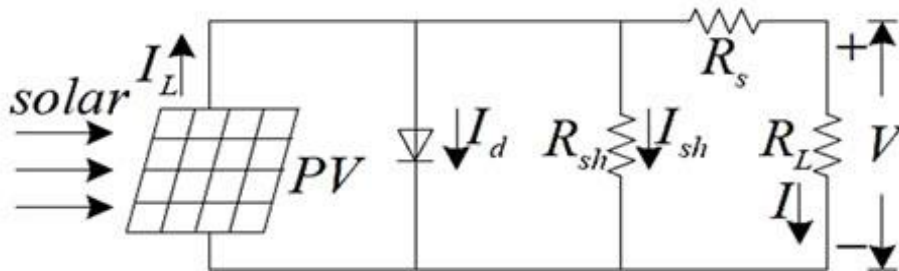


FIG: 2.3.2 Solar Panel Connection Circuit

2.4 WORK PROCESS & ENERGY CONVERSION OF A SOLAR PANEL

When photons strike a solar cell they may be reflected or absorbed or pass through the cell. When solar radiation is absorbed in PN junction diode, electron-hole pairs (EHP) are generated. Electron hole pair (EHP) generated in depletion layer. Electrons of EHP will be repelled towards N side because of electric field and holes of EHP will be repelled towards P side because of electric field. Electron hole pair (EHP) generated in quasi neutral region. In this region, the electron and holes of EHP will wander around in the region randomly. There is no electric force to guide them in any direction. Minority carriers of P and N regions. The minority carrier near the depletion region will also get direction by electric field. In this way there will be increase of positive charge at P side and increase of negative charge at N side. This build up of positive and negative charge causes a potential difference to appear across the PN junction due to light falling on it. This generation of photo voltage is known as photovoltaic effect.

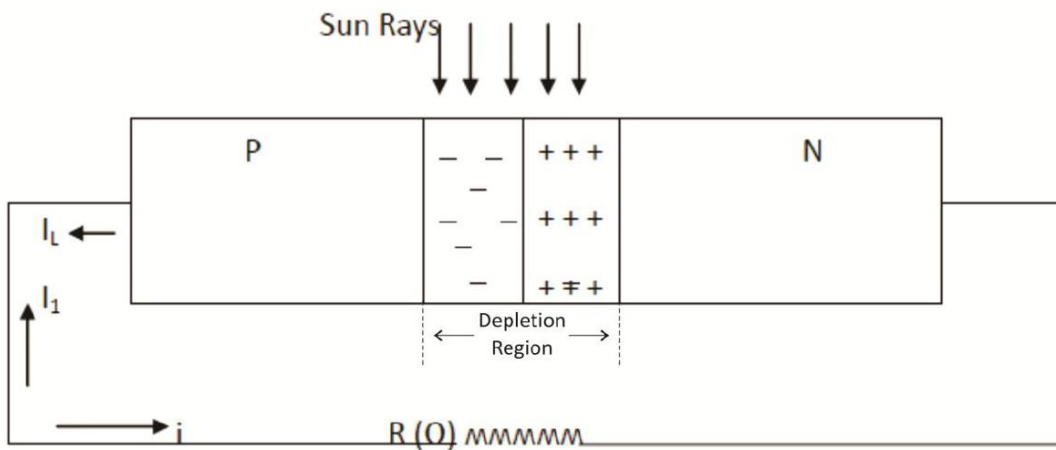


Fig: 2.4 Photovoltaic cell performance

Consider a PN junction with resistive load as shown in figure. When solar cell is illuminated, electron hole pair is generated in the depletion region. This electron hole pair when separated from each other across junction then a current (I_L) flows in external circuit by photovoltaic effect. This photo current (I_L) produces a voltage drop across resistive load and this voltage will forward bias the PN junction. Forward bias voltage produces forward current (I_1).

So the net current will be, $I = I_L - I_1$

$$I = I(L) - I(0)\left[\exp\left(\frac{eV}{kT}\right) - 1\right]$$

For short circuit

When $R=0$ and $V = 0$ then $I_1 = 0$ so $I = I_L = I_{SC}$

Open circuit voltage (VOC)-

When $R=\infty$ then $I = 0$

$$V_{OC} = \frac{nkT}{q} \ln \left(\frac{I_L}{I_0} + 1 \right)$$

Power delivered to load-

$$P = V \cdot I$$

For maximum power delivered to load, $dP/dV=0$

$$1 + \frac{I(L)}{I(0)} = \exp\left(\frac{e \cdot V_m}{kT}\right) \cdot \left[1 + \frac{e \cdot V_m}{kT} \right]$$

Where V_m is the voltage which produces maximum power

Maximum Current -

If we put the value of $\text{Exp}(e.V_m/kT)$ from the equation we get the maximum value of Current (I_m)

Maximum Power:

the maximum power is obtained by multiplying v_m and I_m

$$P_m = V_m \cdot I_m = V_m \frac{e \cdot V_m \cdot (I_L + I_0) / kT}{1 + e^{V_m / kT}}$$

2.5 MOST EFFICIENT SETTING OF A SOLAR PANEL

Bury Conduit and Build a Platform:

Bury conduit from the house or building that will receive the power to the area where the solar panel array will be located.

With the conduit in place, build a platform consisting of concrete pillars and 4x4s that will support the solar array.

Mount the Panels:

Once the platform is finished, the experts are ready to get started. For the solar array, the team uses eight 24-volt 110-watt PV panels that have been pre-fastened to create the array. For the upstairs loft, four 12-volts, 255-amp sealed batteries will store power collected by the panels. And finally, a 5500-watt power inverter and 40-amp charge controller will be installed in the garage near the standard electrical box. This expandable system should produce 35,000 watt hours per month -- enough to power a deep well water pump, interior lights and a few appliances. Moving on, the team mounts the panels to the platform. Angle brackets are used at the mounting points, and the front feet are mounted first. The feet are squared and centered before being secured into place.

Secure the Rear Legs:

Use meteorological data to determine the proper angle for the array, then elevate and secure the rear legs

Wire the Solar Modules:

Wire the solar modules together and join them at a junction connector or fuse combiner box. The modules should be stripped and wired in pairs before being connected to the fuse box mounted at the platform and connected to underground conduit output cables.

Note: When performing any electrical work, remember to take all safety precautions. Because of the danger involved, intricate electrical work is often best left to professionals.

In the terminal box, the stripped wires must be connected properly. In this instance, the red wires are connected to the positive terminal, and the black wires to the negative terminal. Once connected, the wires are fed up through the bottom of the junction box and connected to the corresponding positive and negative terminal blocks.

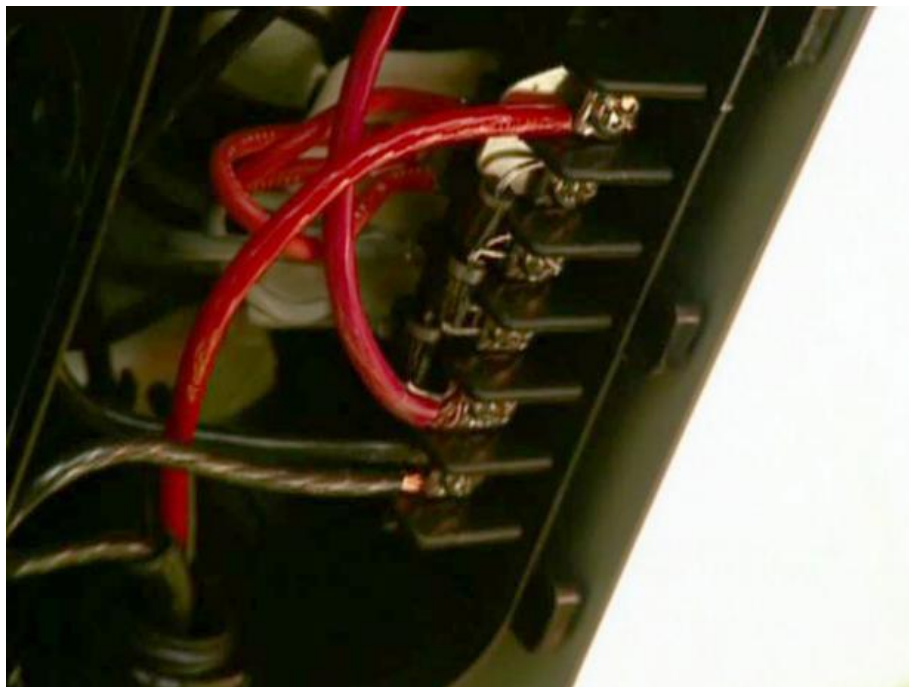


Fig 2.5.1 Wire the Solar Modules

Understand the Wire Connections:

With the solar array assembled, correctly angled and wired, it's time to connect the exterior wiring to the interior control panels. The solar breaker will first be connected to a circuit breaker

disconnect. The energy will flow to a charge controller and then to a battery bank to be stored. When needed, energy flows from the batteries back to the circuit breaker connecting to a power inverter (this will change the power from DC to AC). Finally, this converted power will flow into an electric panel -- where it will provide electrical power for the home.

In this instance, a back-up gas generator and well pump are also connected to the solar system. To handle all this, the solar installer recommends the installation of two 240-volt power converters to the right of the main breakers. All of the components -- including the new converters -- must be connected to the home's main electrical system to function.

Connect the Cables to the Control Panels:

Run the electrical cable from the solar array into the house through the underground conduit. Connect the cables to nylon rope for easy threading, and then pull through the conduit to inverter panels. Connect the cables at the fuse combiner box located at the base of the solar array. The green cables are first connected to the grounding strip. The red cables are connected to the PV out positive terminal block; and the black cables are connected to the PV out negative terminal block

Ground the System:

To finish the exterior work, tap a grounding rod into the earth near the array. Leave the long rod extending above the ground about 6". Run copper grounding wire from the rod to the fuse box and from the solar panels to the fuse box.

Make the Electrical Connections Inside:

After the grounding wire is run, make the proper electrical connections inside. Run the cables from the array to the inverter panel disconnect. Again the red wire is connected to the positive

terminal; the green grounding wire is connected to the grounding terminal; and the black wire is connected to the negative terminal.

The team installs the battery bank in the loft area above the new control panels. First, run conduit through the ceiling into the inverter panel. Next, feed two heavy-duty battery cables into the panel disconnect. The other ends of the cables will be connected to the battery pack.

The battery system must be installed in a series -- alternating positive and negatives -- and secured into place. Complete final tests and attach the component covers.



Fig 2.5.2 Interior Electrical Connections

Solar Panel System for Home:

Step 1: Gather solar power components

It all begins with gathering the basic ingredients of a solar power unit. You will need four major items – solar panels, charge controller, inverter, and a battery pack. In addition to these items, you will require a breaker, meter, MC4 connector, and fuses among other things. Keep in mind that it is essential to read the solar panel module instructions.

Step 2: Calculate your power load

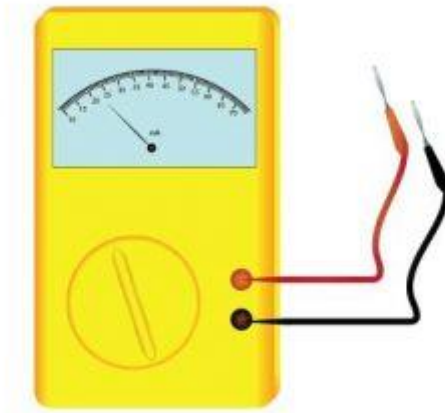


Fig 2.5.3 Watt-meter

Before getting to the solar installation task, it is crucial to sum up the power that you use at your home. This isn't rocket science. All you have to do is to note down the home appliances that you use on a daily basis, which include television, lights, fan, and so on. Next, add the time for which these appliances run in a day. Go through the specification chart in your household electric appliances to check their usage duration or run time, and their power rating.

Now calculate the ‘Watt-Hour’ by multiplying the runtime of an appliance with its power rating. Follow this step for each electrical device, then sum up the individual watt-hour numbers to get the grand total. You can also simplify this calculation by using an online off-grid load calculator.

Step 3: Select and charge the battery



Fig 2.5.4 Battery

A major hiccup with solar power is that it doesn't provide electricity when the sun goes down. However, you can easily crack this problem by using a battery. A lead-acid or a lithium-ion battery stores solar power generated during the daytime and discharges it at night. This provides a steady supply of energy, provided you have selected the optimum battery storage capacity. You will need a power controller to monitor your battery's charging. These come between the panels and the battery. Such controllers are typically fitted with a small LED light that announces the charging state of the battery, and it adjusts the power that flows into the battery.

Step 4: Set up the inverter

Solar arrays produce electricity in direct current (DC), but electrical appliances use power in the form of alternating current (AC). Inverter is a device that saves the day by allowing you to use electrical devices without using adaptors. Inverters come in varying power wattages and types including square wave, modified sine-wave, and pure sine-wave inverters. Square waves are not compatible for all devices, while the output of modified sine wave is not suitable for certain appliances such as a fridge. This makes a pure sine wave inverter the best choice for your solar system.

Step 5: Fix the solar panels on your roof

Once the battery, controller, and the inverter are ready, you need to get started with mounting the solar panels. Select the best spot for the panels on the roof or on open ground that receives an unhindered supply of the sun's radiation. You can either make a mounting stand yourself or get it from the market. The tilt of the mounting stand should almost be equal to the latitude angle of your location. The proper setting of the solar panels is critical for their operation & maintenance. Hence, it is essential to ensure that the panels face the sun throughout the day.

In the last phase of this step, wire the solar panels. You can trace a small junction box at the back of the solar panel. The junction box has negative and positive signs of polarity. In a large sized-panel, the junction box has terminal wires too with an MC4 connector. However, you will have to align the junction box with external wires yourself if you use small solar panels. Use the black and red wire for negative and positive terminal connections, respectively.

Step 6: Connect the solar panels with battery

You need to connect the solar panels with the battery. In certain PV systems, these come paired together, so you don't have to put in the additional effort. In cases that are not given as a single unit, you need to make series and parallel connections. You can make a series connection by connecting a device's positive terminal with another device's negative terminal. For a parallel connection, you need to connect one device's negative terminal with another device's negative terminal and so on.

Step 7: Setup stands for inverter and battery

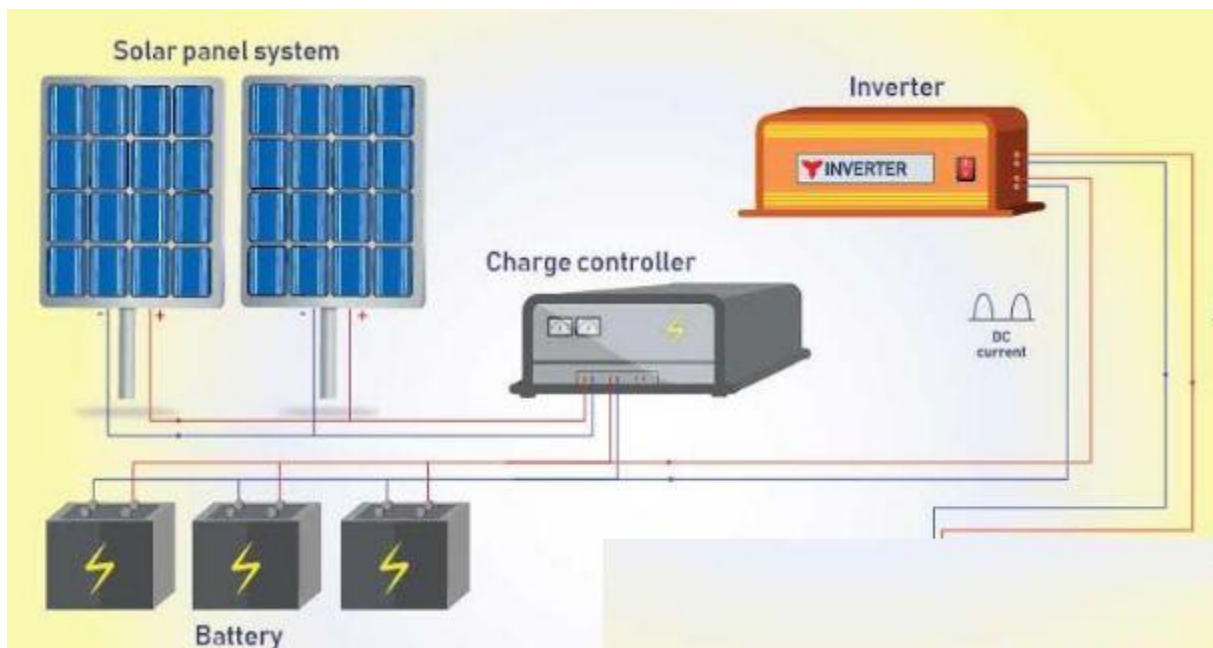


Fig 2.5.5 Overview of Solar Panel System

Your residential solar unit is incomplete without stands for the battery and inverter. Again, you have the option of building the stands or getting them. Once the allocated positions for the inverter and battery are ready, you can start working on the wiring. Start with wiring the controller. The first connection from the left is for connecting the controller with the solar panels. The second connection is for pairing the battery with the controller. The last connection is for connecting the controller to the direct DC load connection.

For connecting the solar panel with the charge controller, you will need a separate connector called an MC4 connector. Once the controller is connected to the battery, its LED lights should light up. Similarly, you will have to connect the inverter terminal with the battery's terminal.

Following these steps can guide you to set up a solar power unit at your home. The high costs incurred in installing one can be reaped later on as solar energy is not only clean but also a cost-effective investment.

Solar Panel System For Home

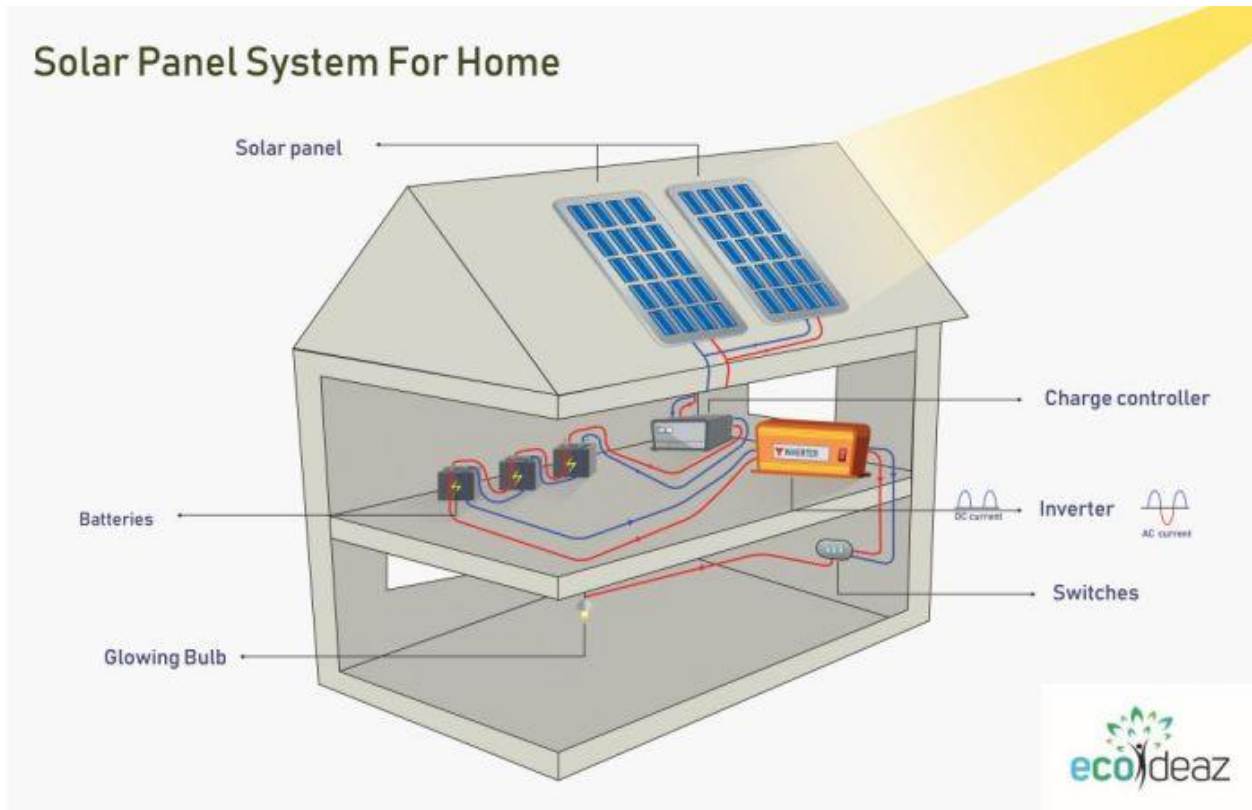


Fig 2.5.6 Solar Panel System for Home

2.6 PERIODIC FLOW PHENOMENA

Within the sixties a contemporary and wide field of intermittent stream marvels was discovered within the earth's air by meteoric satellites: the von Karman street-like vortex trails behind the islands of Madeira, an Mayen, and Guadalupe , to title because it were the 3 most important locations. one among the objectives of this report is to look at the address whether or not these celestial sphere marvels have any which means for or hold trendy knowledge for the understanding of the stream past impediments of the estimate often handled in natural philosophy or structural best style. A specialize, may talk about a Meso-scale part marvel, demonstrating by the term medium live that the stream and weight square measures are still very little to own any consequence for climate, however that they're too huge, on the opposite hand, to be recognized by coordinate human sight. at intervals the sunshine of those basic comments it have to be compelled to be clear that we wish to look at streams during which the cyclically might be a characteristic marvel, besides, are going to be committed to streams past feign bodies, principally circular barrels. Later, we have a tendency to avoid all problems managing with occasional flows beneath the command of a ace clock, like the stream of blood shut the center or the gulf associate degreed run through stream of the operating gas of an inner combustion engine; besides we'd not agitate bitable stream configurations like those happening in pressure driven computing machines. Periodic flow happens once the physical pure mathematics of intrigued and therefore the anticipated style of the flow/thermal arrangement have an often continuation nature. 2 types of periodic flow may be sculptural in ANSYS Fluent. At intervals the primary kind, no weight drop happens over the intermittent planes.

2.7 TURBULENT FLOW

Turbulence is that the chaotic movement of liquid happening in most of the common and alternative stream areas. Since it's exceptionally hard to treat the turbulent stream analytically, numerous methods and models are created to depict turbulent stream - with the help of the increasing management of computers- numerically. The current study consolidates a numerical treatment of a turbulent stream over a backward facing step having a circular deterrent turbulence. The quality k-epsilon show is employed to reenact and find the numerical comes concerning. This turbulence show has unraveled utilizing Galerkin weighted leftover restricted element strategy. The result of live and position of the circular impediment on the streamlines, speed magnitude, weight conveyance, speed profiles and turbulent motor energy profiles are displayed diagrammatically. The result seems that estimate and position of the obstacle has important impact on the antecedently mentioned parameter profiles. The Navier-Stokes equations that describe all the flow of fluids can also be accustomed depict the flow. But this could want a vast method price and time. As a results of all the scales from the foremost necessary to the tiniest will have to be compelled to be resolved that do not facilitate economy in any respect. Associate degree honest numerous is to separate the larger and smaller scales where the larger scales area unit resolved and thus the smaller scales area unit sculptured. The target of this turbulence model is to be galore cheaper than the entirely resolved flows. There area unit several kinds of turbulent models supported the modification on the Navier-Stokes equations. The modification referred to as the Sir Joshua Reynolds averaging procedure and thus the following equations area unit known as the Reynolds-Averaged Navier-Stokes (RANS) equations.

2.8 THE FLUID STRUCTURE INTERACTION ANALYSIS

Fluid Structure Interaction (FSI) is that the interaction of a few mobile or deformable structure with an indoor or surrounding liquid stream. There square measure elective ways by that fluid structure-interaction examination are regularly dispensed.

An adaptable solid structure reaching a streaming liquid is subjected to a weight which may cause distortion in the structure. As a return, the twisted structure modifies the flow field. The changed streaming field, in turn, applies another frame of pressure on the structure with rehashes of the method. A adaptable solid structure reaching a streaming liquid is subjected to a weight which may cause distortion in the structure. As a return, the twisted structure modifies the flow field. The changed streaming field, in turn, applies another frame of pressure on the structure with rehashes of the method. A divided approach is utilized for realizing the arrangement of the coupled issue. The partitioned approach empowers the advancement of a measured FSI tool chain, where the two fields could be fathomed independently utilizing the foremost productive strategies accessible for each field problem. An in-house coupling apparatus is utilized to connect the liquid solver with the auxiliary solver and manage the information trade between the two solvers. The coupling condition between the two fields is implemented at the interface. The coupling conditions incorporate kinematic coherence condition, which ensures that the liquid and structure interface lie on each other amid the simulation and energetic progression condition, which takes care of preservation of the tractions which are mapped from the liquid interface to structure interface. The work flow chart can be written as:

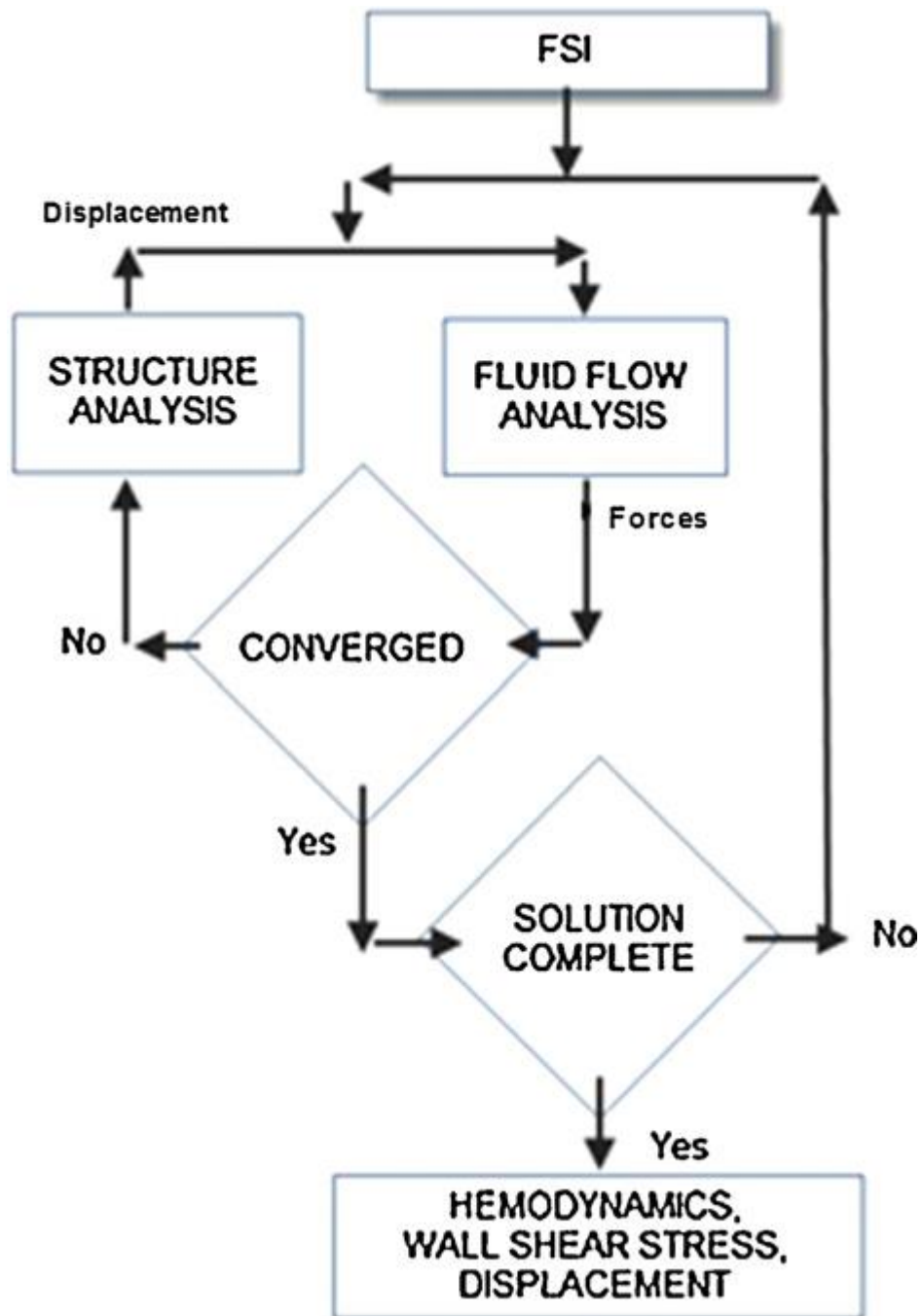


Fig 2.8 Flow chart of the fluid structure interaction analysis

2.9 INCREASE OF EFFICIENCY AFTER LESSENING DISPLACEMENT

Before calculated efficiency of an average solar panel should be theoretically around 15-20% but for the periodic fluid flow and other strong natural phenomena it usually gives out only about 10-13%. Our model will increase the efficiency at about around 13-17% because of the supportive backbone we used here. Tilting the module to the incoming light reduces the module output for that light rays to have effect for longer period of time during the day. Now for our model this module and this setup will remain still even if the periodic flow phenomenon occurs.

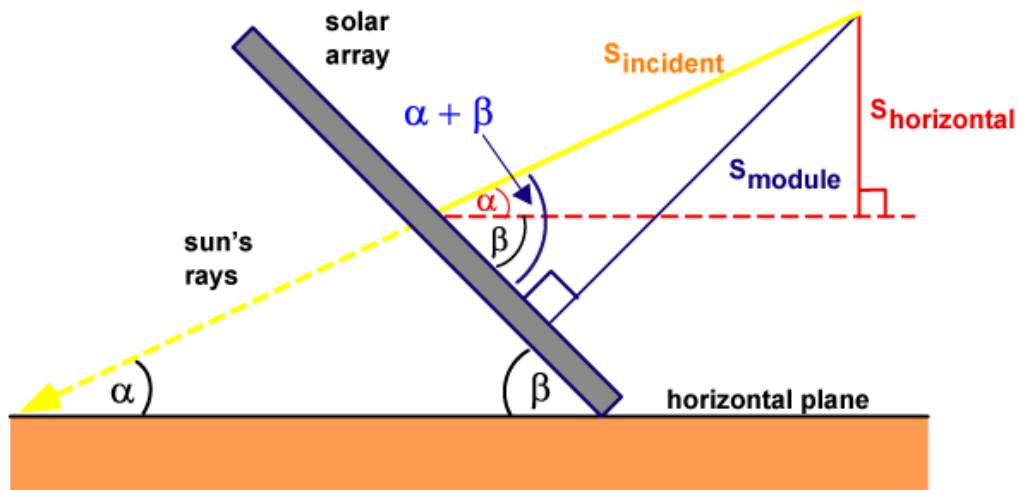


Fig 2.9.1 Tilting the module to the incoming light reduces the module output.

The amount of solar radiation incident on a tilted module surface is the component of the incident solar radiation which is perpendicular to the module surface. The following figure shows how to calculate the radiation incident on a tilted surface (S_{module}) given either the solar radiation measured on horizontal surface (S_{horiz}) or the solar radiation measured perpendicular to the sun (S_{incident}).

For our backbone structure the support is still on the setup positioning point as a result the desired outcome or efficiency. And following will be discussed on methodology and result and discussion.

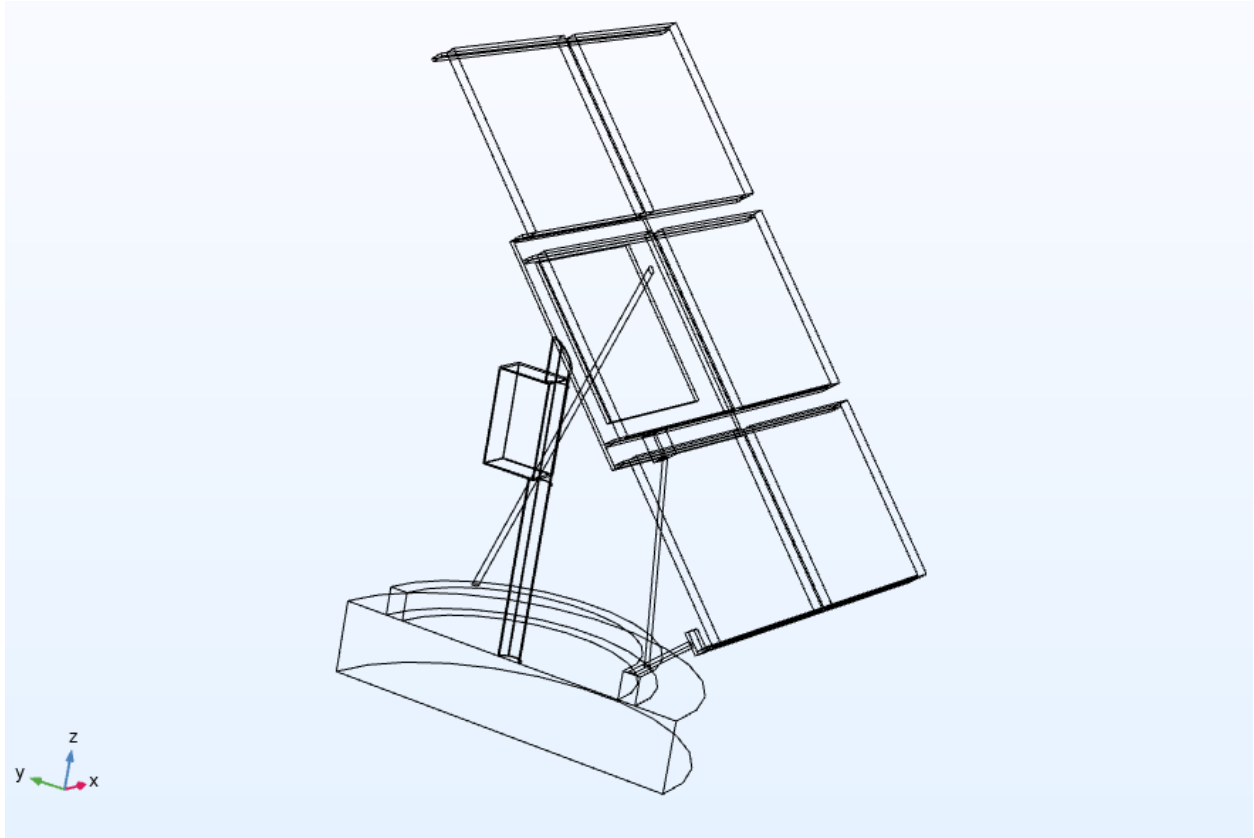


Fig 2.9.2 Model that increased the efficiency

2.10 COMPARISON WITH REAL LIFE SCENARIO

For theory here we can see it as a possibility of getting a huge advantage on the efficiency but thing will be a bit more challenging when we work in the real life, because of the material cost and easy setup we cannot overlook the natural phenomenon and human error that occurs in between the set up and the selection of materials and measurements etc. Sometimes, even it can give you huge drawbacks if it's miscalculated or if the measurement is wrong. Bust mostly the wind will be in our favor, as the calculations, material selection and measurements will be taken by professionals. As a result, our desired efficiency will be achieved.

For a real-life analysis, we did a thorough examination and checked the perspective of the work by ourselves and faced many challenges on the way, one of the main challenges was the calculations were a bit off then we did on COMSOL. So we had to check our faults again and again to find out where we were lacking in this issue. Then find out finally, about some basic human error occurred by us. As a result, our results were a bit hasty at first but later on the idea was clear as the bright sunny day that helps the solar panel to work properly.

So, overall, we can say the work in the software is always easier and precise then the real life scenario, but the desired outcome can be achieved almost as much as close possible by reexamine again and again and finally coming close to the desired result.

2.11 ADVANTAGES OF THE MODEL

For this model the efficiency of the solar panel in turbulent flow has increased.

The stability of the model gives a strong base as a result the solar panel array maintains its original modeled form

The wind or fluid flow can't change the position or angle of the solar panel, and its important cause it was built and set-in order to get the maximum efficiency.

The supportive base and the main part of this model was some simple aluminum or steel rod which is semi-flexible as a result even if the bending happens it will get back to its initial position eventually.

2.12 LIMITATIONS OF THE MODEL

The model will be a bit costly

This model will need expert manpower for supervision and for the manufacturing

#This model will give a bit of efficiency boost but many will prefer the flat based solar panel

This model will need precise calculated cut out because of any hindrance happens in this and the efficiency won't work.

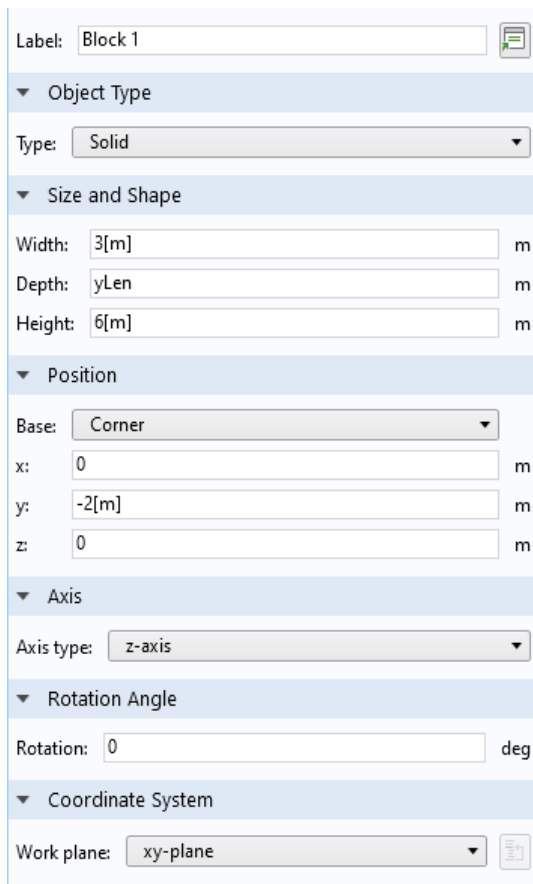
CHAPTER THREE

METHODOLOGY

This chapter is consisting of the work processes and methods used to build the desired model we are discussing for the whole book. The project was totally dependent on Comsol. As a result, the work process will be mostly as modeling instructions and methods provided for only Comsol.

Modeling Instructions:

GLOBAL DEFINITIONS:



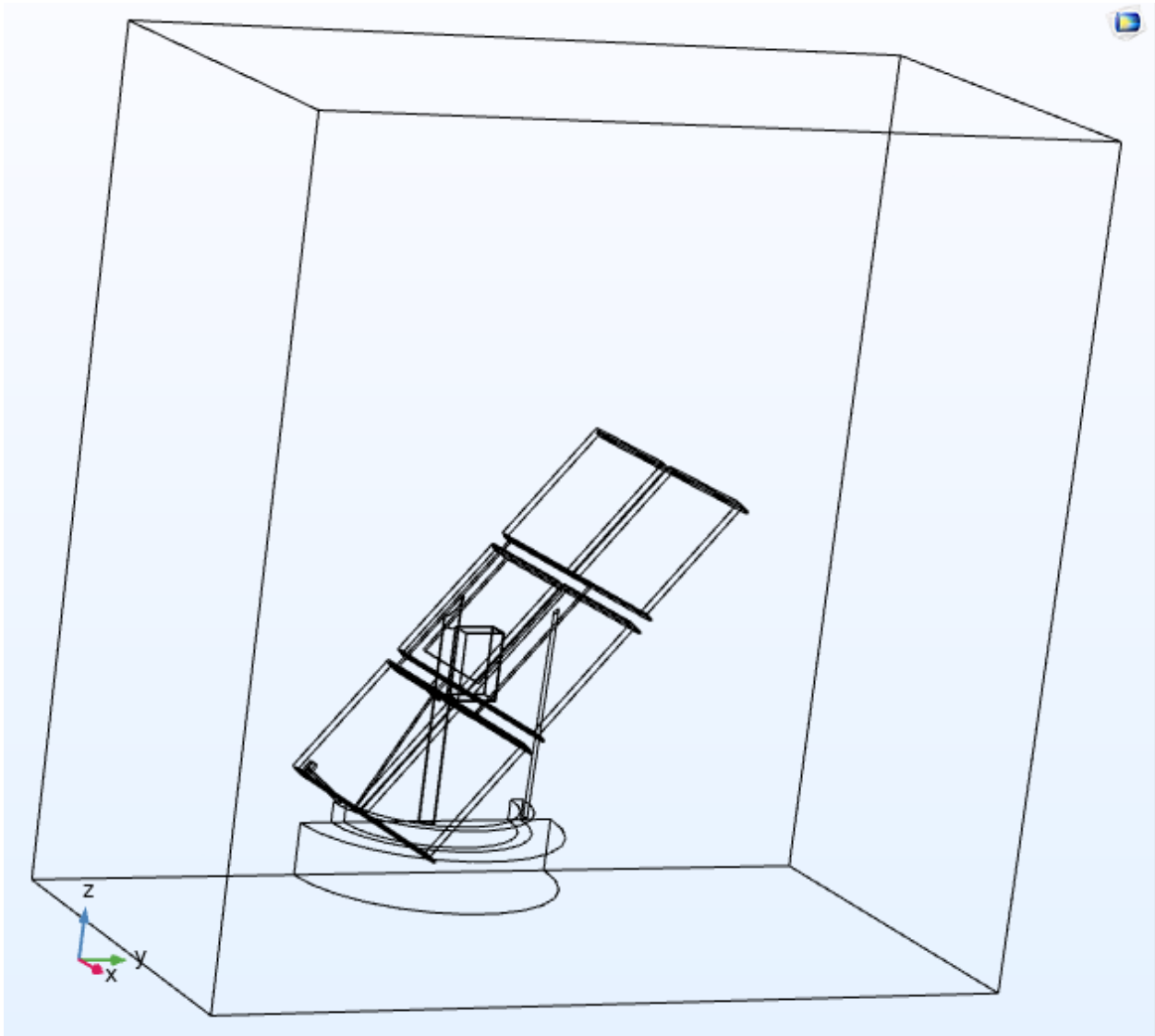
The screenshot shows the 'Global Definitions' panel for a 'Block' object in Comsol. The panel is organized into several sections:

- Label:** A text input field containing 'Block 1'.
- Object Type:** A dropdown menu set to 'Solid'.
- Size and Shape:** Three input fields for dimensions: 'Width' (3[m]), 'Depth' (yLen), and 'Height' (6[m]).
- Position:** A dropdown menu for 'Base' set to 'Corner', and three input fields for coordinates: 'x' (0), 'y' (-2[m]), and 'z' (0).
- Axis:** A dropdown menu for 'Axis type' set to 'z-axis'.
- Rotation Angle:** An input field for 'Rotation' set to 0, with the unit 'deg'.
- Coordinate System:** A dropdown menu for 'Work plane' set to 'xy-plane'.

Model Geometry:

In the Model Builder window, expand the Component 1 (comp1)>Definitions node.

Import the geometry of the solar panel.



Import 1 (imp1)

1 In the Home toolbar, click Import.

2 In the Settings window for Import, locate the Import section.

3 Click Browse.

4 Browse to the model's Application Libraries folder and double-click the file

solar_panel_geom_solid.mphbin.

5 Click Import.

Inscribe the solar panel in what will later become the fluid domains.

Block 1 (blk1)

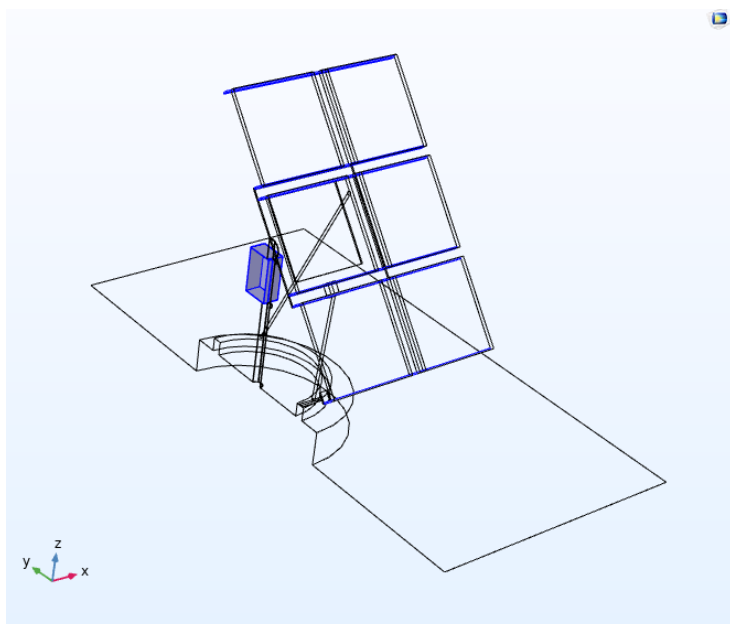
1 In the Geometry toolbar, click Block.

2 In the Settings window for Block, locate the Size and Shape section.

3 In the Width text field, type 3[m].

4 In the Depth text field, type yLen.

5 In the Height text field, type 6[m].



6 Locate the Position section. In the y text field, type -2[m].

Difference 1 (dif1)

1 In the Geometry toolbar, click Booleans and Partitions and choose Difference.

2 Select the object blk1 only.

3 In the Settings window for Difference, locate the Difference section.

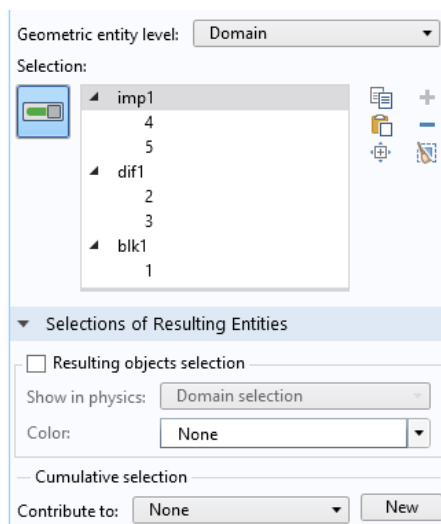
4 Find the Objects to subtract subsection. Select the Activate selection toggle button.

5 Select the object imp1 only.

6 Select the Keep input objects check box.

Delete the parts of the structure that will not be simulated.

Delete Entities 1 (del1)



1 In the Model Builder window, right-click Geometry 1 and choose Delete Entities.

2 In the Settings window for Delete Entities, locate the Entities or Objects to Delete section.

3 From the Geometric entity level list, choose Domain.

4 On the object imp1, select Domains 4 and 5 only.

5 On the object dif1, select Domains 2 and 3 only.

6 On the object blk1, select Domain 1 only.

Union 1 (uni1)

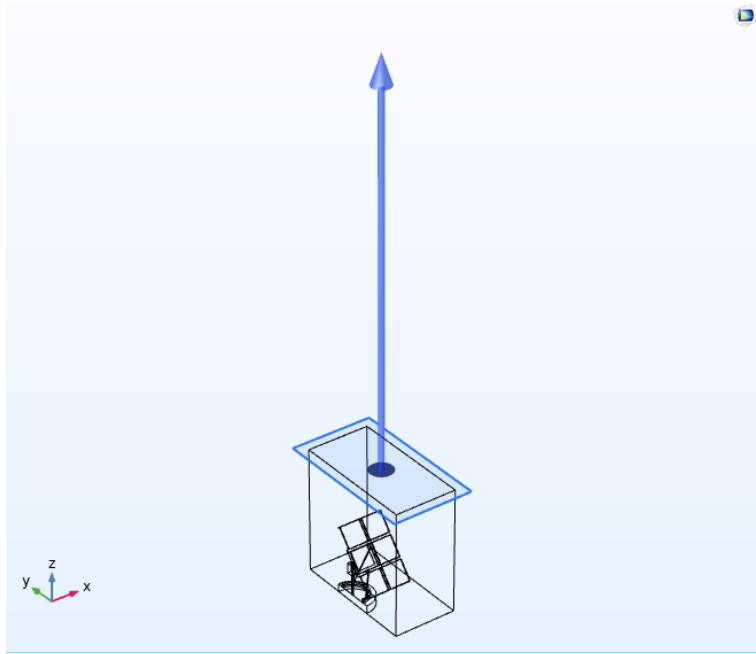
1 In the Geometry toolbar, click Booleans and Partitions and choose Union.

2 Select the objects del1(1) and del1(2) only.

Create a fluid domain tall enough to capture the boundary layer.

Extrude 1 (ext1)

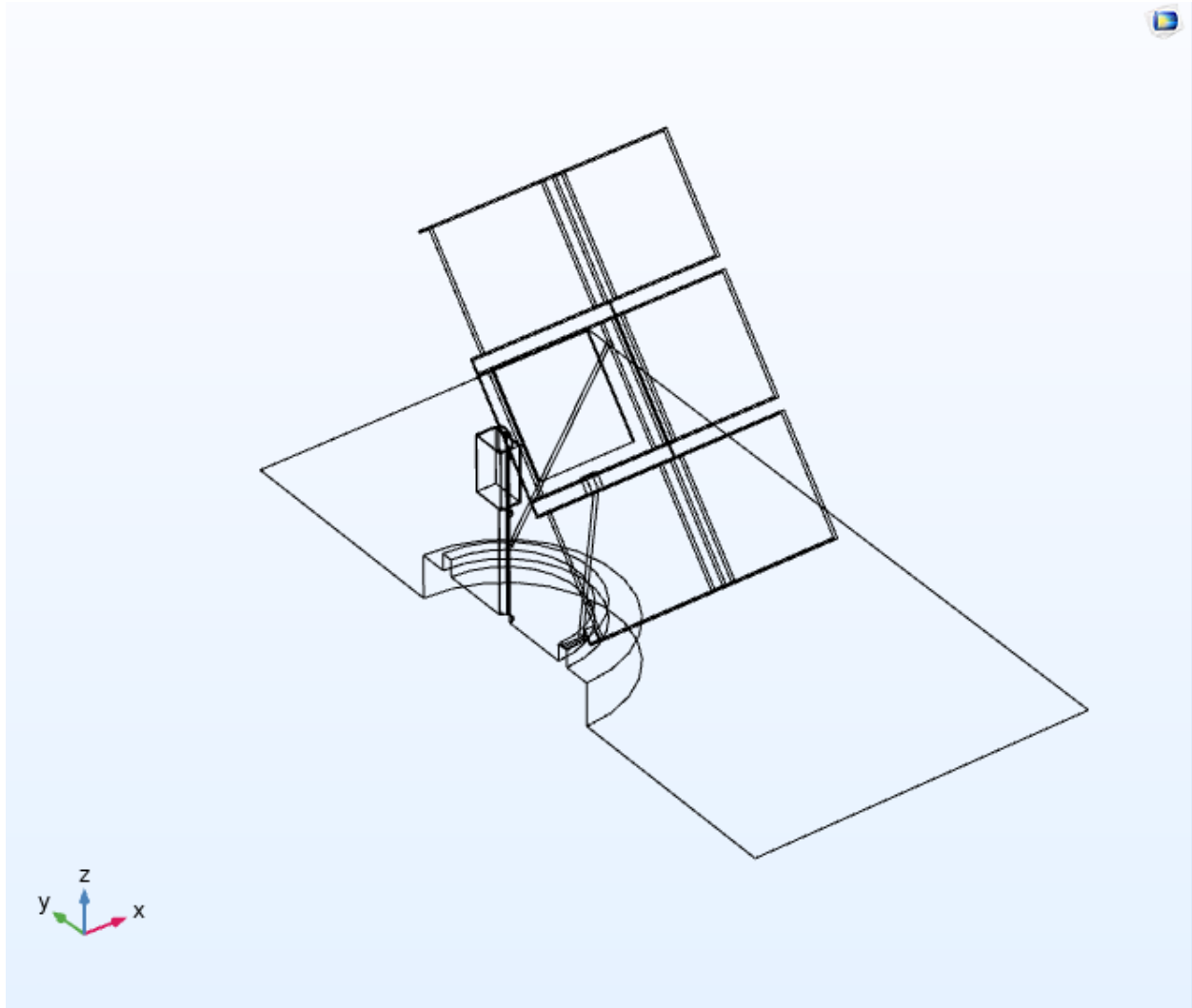
1 In the Geometry toolbar, click Extrude.




2 On the object uni1, select Boundary 4 only.

3 In the Settings window for Extrude, locate the Distances section.

4 In the table, enter the following settings:



Next, partition the geometry in order to facilitate the creation of a mapped mesh

Label: 

▼ Axis

x minimum: m

x maximum: m

y minimum: m

y maximum: m


View scale: ▼


▼ Grid

Manual spacing

x spacing: m

y spacing: m

Extra x: m 

Extra y: m 

Work Plane 1 (wp1)

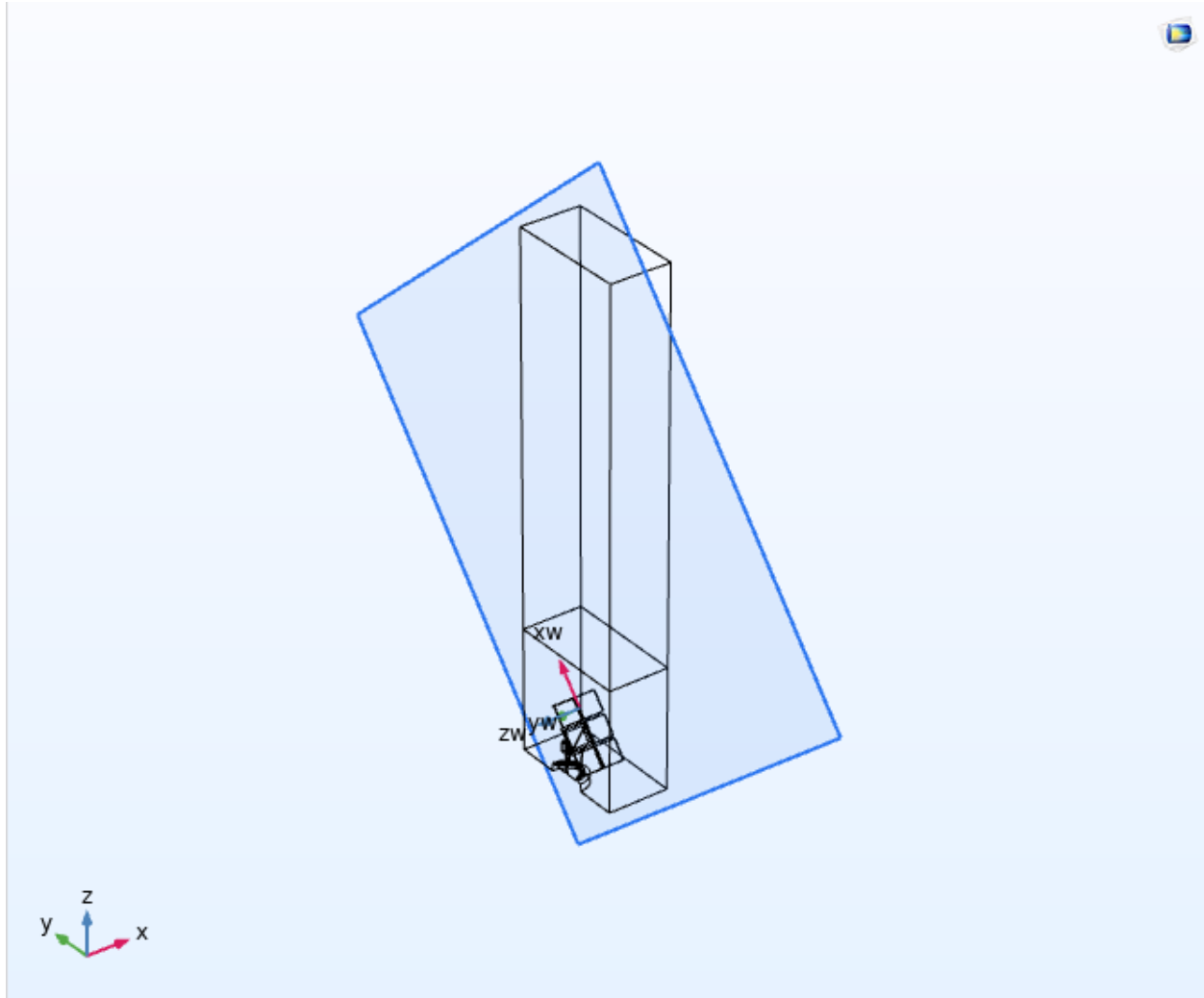
1 In the Geometry toolbar, click Work Plane.

2 In the Settings window for Work Plane, locate the Plane Definition section.

3 From the Plane type list, choose Face parallel.

4 On the object ext1, select Boundary 166 only.

Partition Domains 1 (pard1)



1 In the Geometry toolbar, click Booleans and Partitions and choose Partition Domains.

2 On the object ext1, select Domains 6, 8, 15, and 16 only.

Work Plane 2 (wp2)

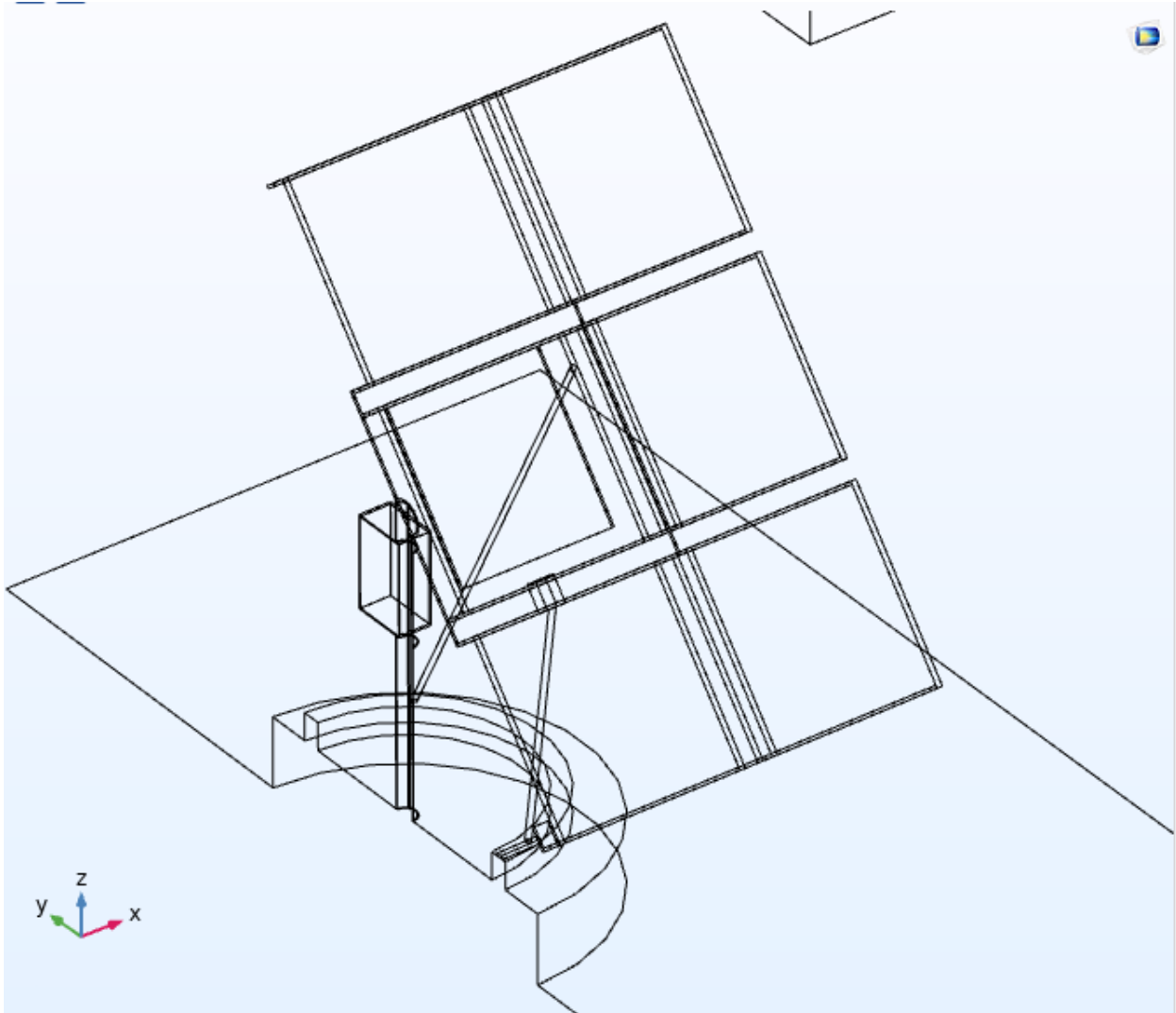
1 In the Geometry toolbar, click Work Plane.

2 In the Settings window for Work Plane, locate the Plane Definition section.

3 From the Plane type list, choose Face parallel.

4 On the object pard1, select Boundary 189 only.

Partition Domains 2 (pard2)



1 In the Geometry toolbar, click Booleans and Partitions and choose Partition Domains.

2 On the object pard1, select Domains 3, 17, and 23–29 only.

Distances (m)

19[m]5 | SOLARPANELINPERIODICFLOWTEMPLATE

Delete Entities 2 (del2)

1 Right-click Geometry 1 and choose Delete Entities.

2 On the object pard2, select Boundaries 189, 192, 199, 203, 208, 215, 219, 223, and 230 only.

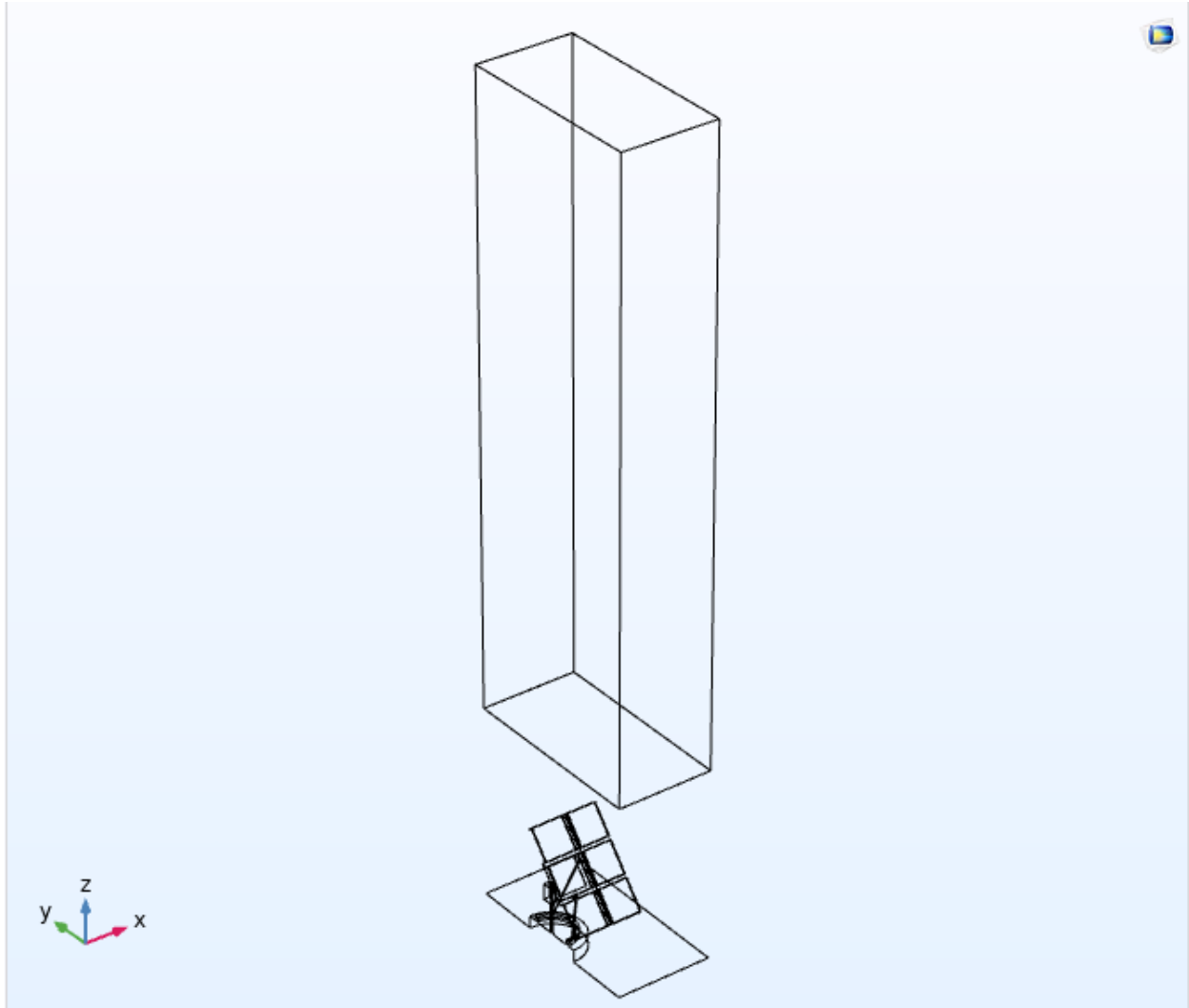
Partition Domains 3 (pard3)

1 In the Geometry toolbar, click Booleans and Partitions and choose Partition Domains.

2 On the object del2, select Domain 7 only.

3 In the Settings window for Partition Domains, locate the Partition Domains section.

4 From the Partition with list, choose Extended faces.



5 On the object del2, select Boundary 37 only.

Extrude 2 (ext2)

1 In the Geometry toolbar, click Extrude.

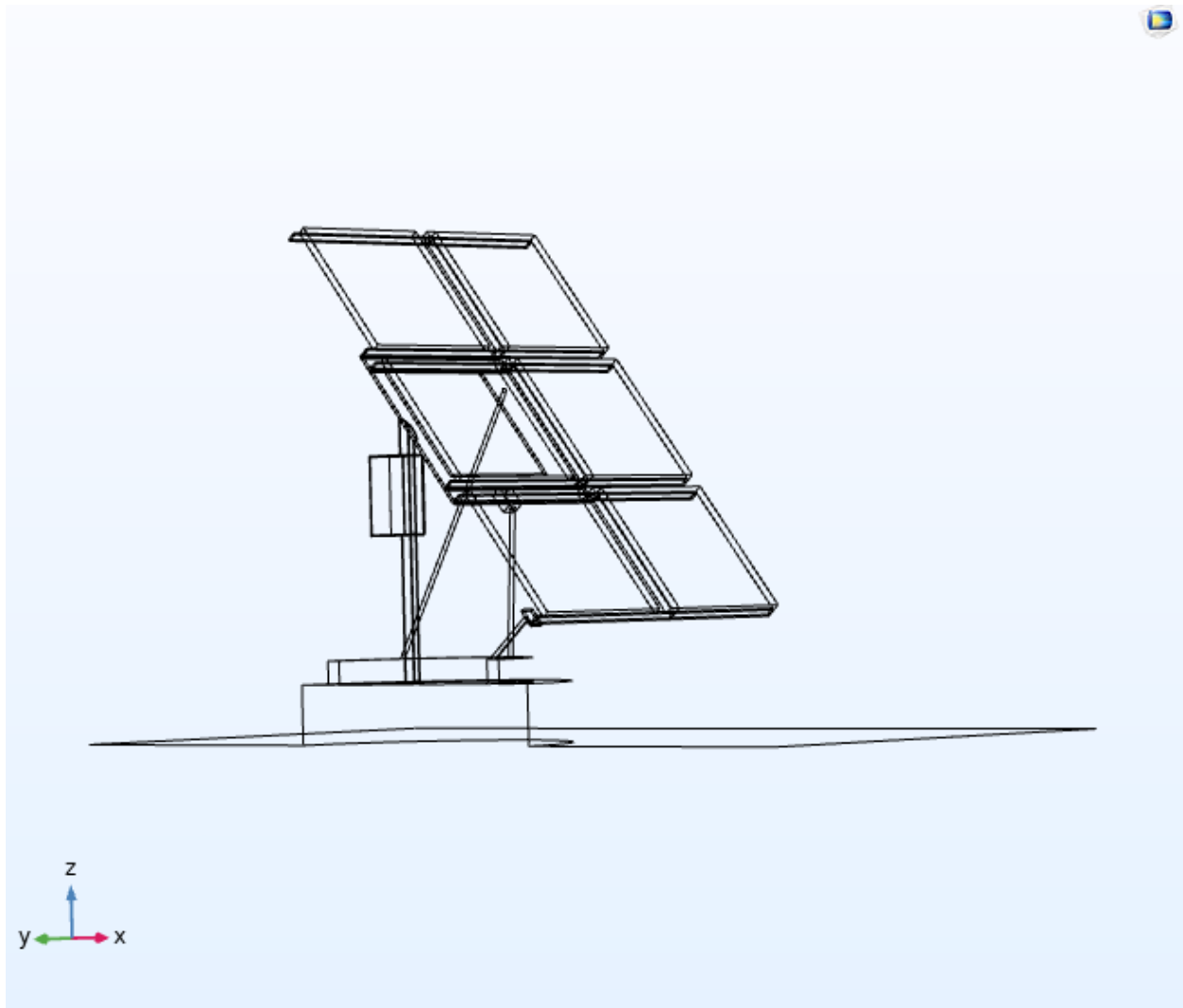
2 In the Settings window for Extrude, locate the General section.

3 From the Extrude from list, choose Faces.

4 On the object pard3, select Boundaries 34, 42, 81, 89, 167, 173, 182, and 188 only.

5 Locate the Distances section. In the table, enter the following settings:

Extrude 3 (ext3)



1 In the Geometry toolbar, click Extrude.

2 In the Settings window for Extrude, locate the General section.

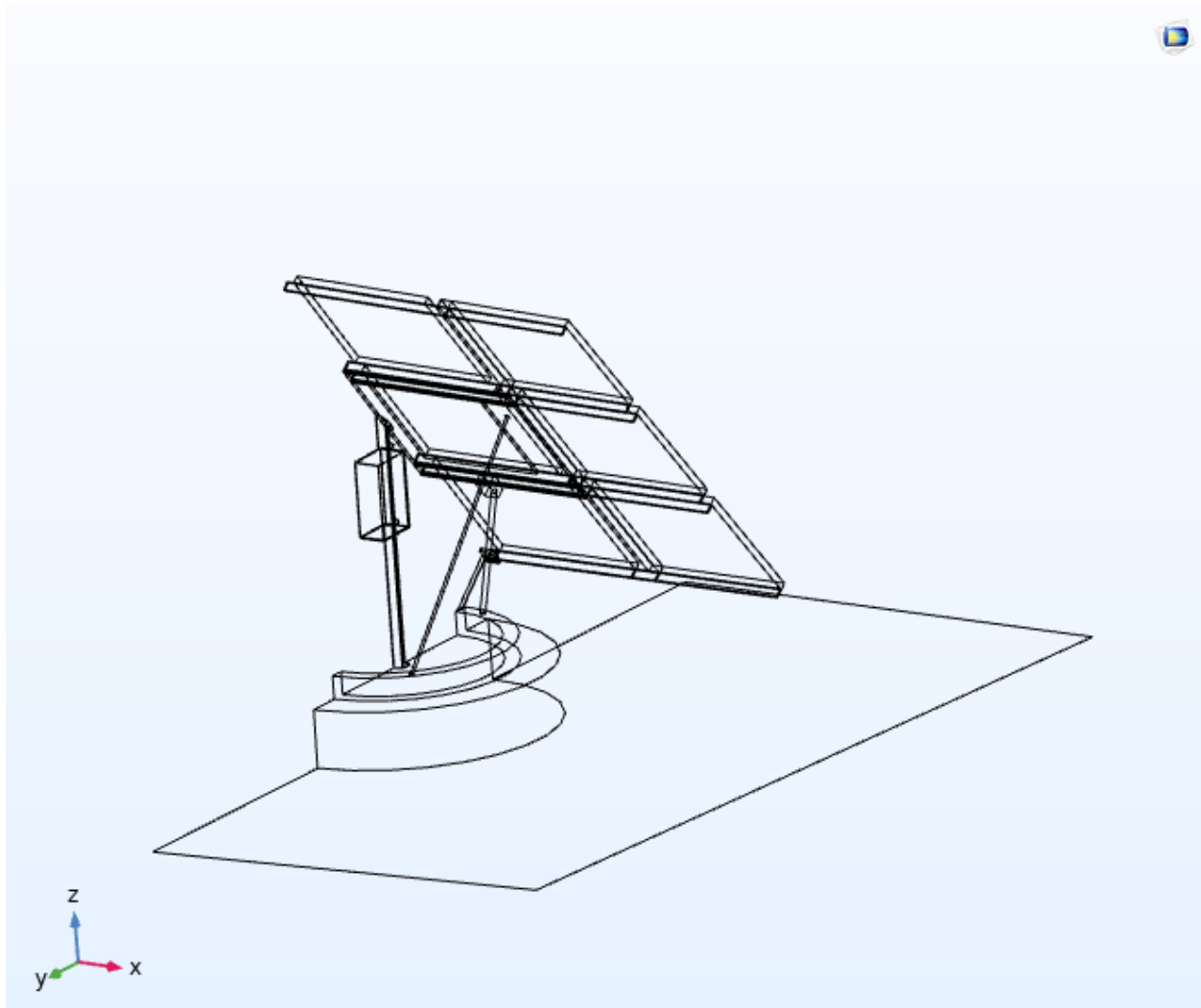
3 From the Extrude from list, choose Faces.

4 On the object ext2, select Boundary 13 only.

5 Locate the Distances section. In the table, enter the following settings:

6 Select the Reverse direction check box.

Extrude 4 (ext4)



1 In the Geometry toolbar, click Extrude.

2 In the Settings window for Extrude, locate the General section.

Distances (m)

0.02[m]

Distances (m)

0.02[m]6 | SOLAR PANEL IN PERIODIC FLOW TEMPLATE

3 From the Extrude from list, choose Faces.

4 On the object ext3, select Boundary 125 only.

5 Locate the Distances section. In the table, enter the following settings:

Partition Domains 4 (pard4)

1 In the Geometry toolbar, click Booleans and Partitions and choose Partition Domains.

2 On the object ext4, select Domain 16 only.

3 In the Settings window for Partition Domains, locate the Partition Domains section.

4 From the Partition with list, choose Extended faces.

5 On the object ext4, select Boundary 76 only.

Partition Domains 5 (pard5)

1 In the Geometry toolbar, click Booleans and Partitions and choose Partition Domains.

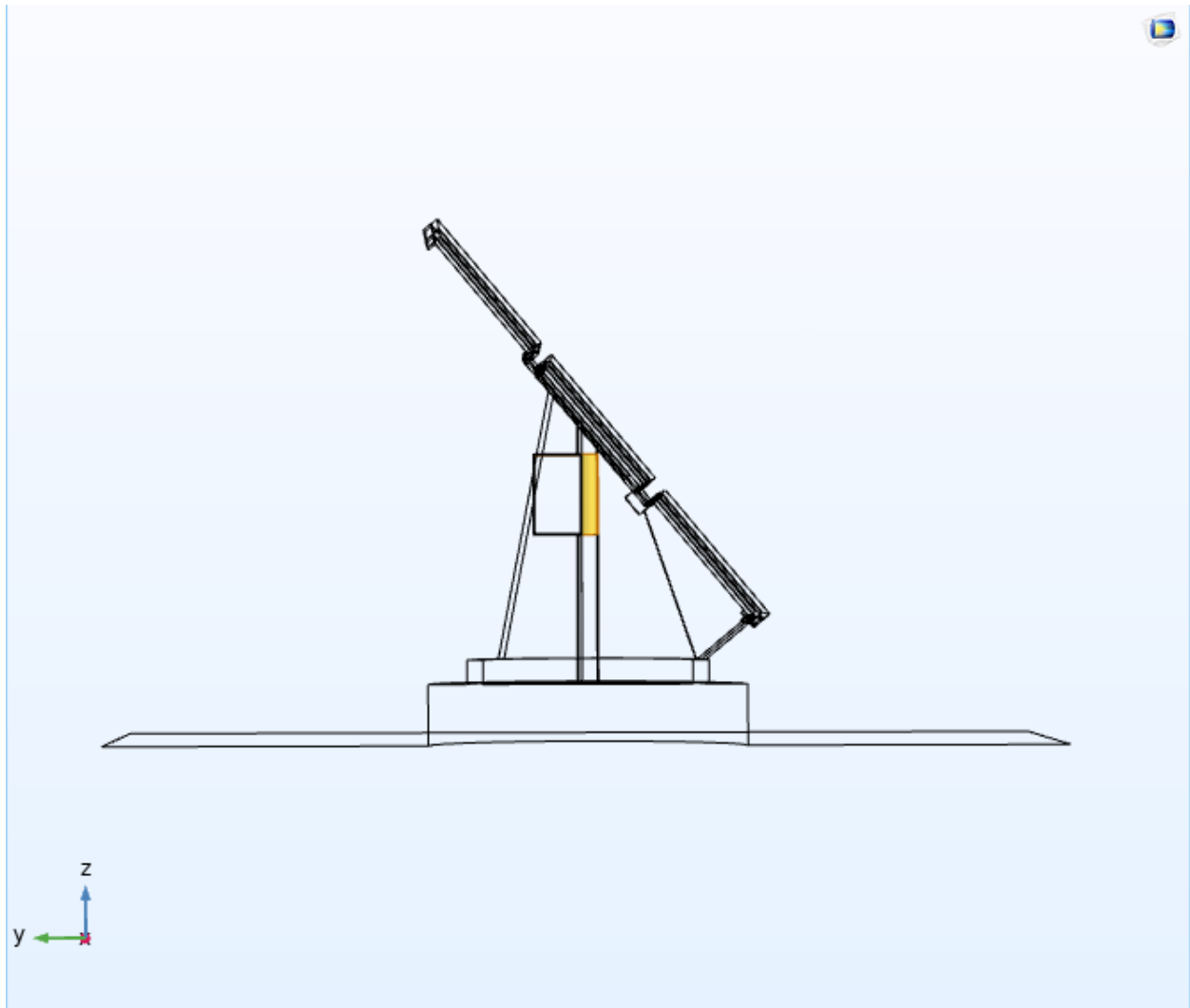
2 On the object pard4, select Domain 16 only.

3 In the Settings window for Partition Domains, locate the Partition Domains section.

4 From the Partition with list, choose Extended faces.

5 On the object pard4, select Boundary 78 only.

Partition Domains 6 (pard6)



1 In the Geometry toolbar, click Booleans and Partitions and choose Partition Domains.

2 On the object pard5, select Domain 14 only.

3 In the Settings window for Partition Domains, locate the Partition Domains section.

4 From the Partition with list, choose Extended faces.

5 On the object pard5, select Boundary 78 only.

Partition Domains 7 (pard7)

1 In the Geometry toolbar, click Booleans and Partitions and choose Partition Domains.

2 On the object pard6, select Domain 14 only.

3 In the Settings window for Partition Domains, locate the Partition Domains section.

4 From the Partition with list, choose Extended faces.

5 On the object pard6, select Boundary 79 only.

Next, add selections for the walls, supports, symmetry boundaries, and structural materials.

Distances (m)

0.06[m]

Explicit Selection 1 (sel1)

1 In the Geometry toolbar, click Selections and choose Explicit Selection.

2 In the Settings window for Explicit Selection, type Walls in the Label text field.

3 Locate the Entities to Select section. From the Geometric entity level list, choose Boundary.

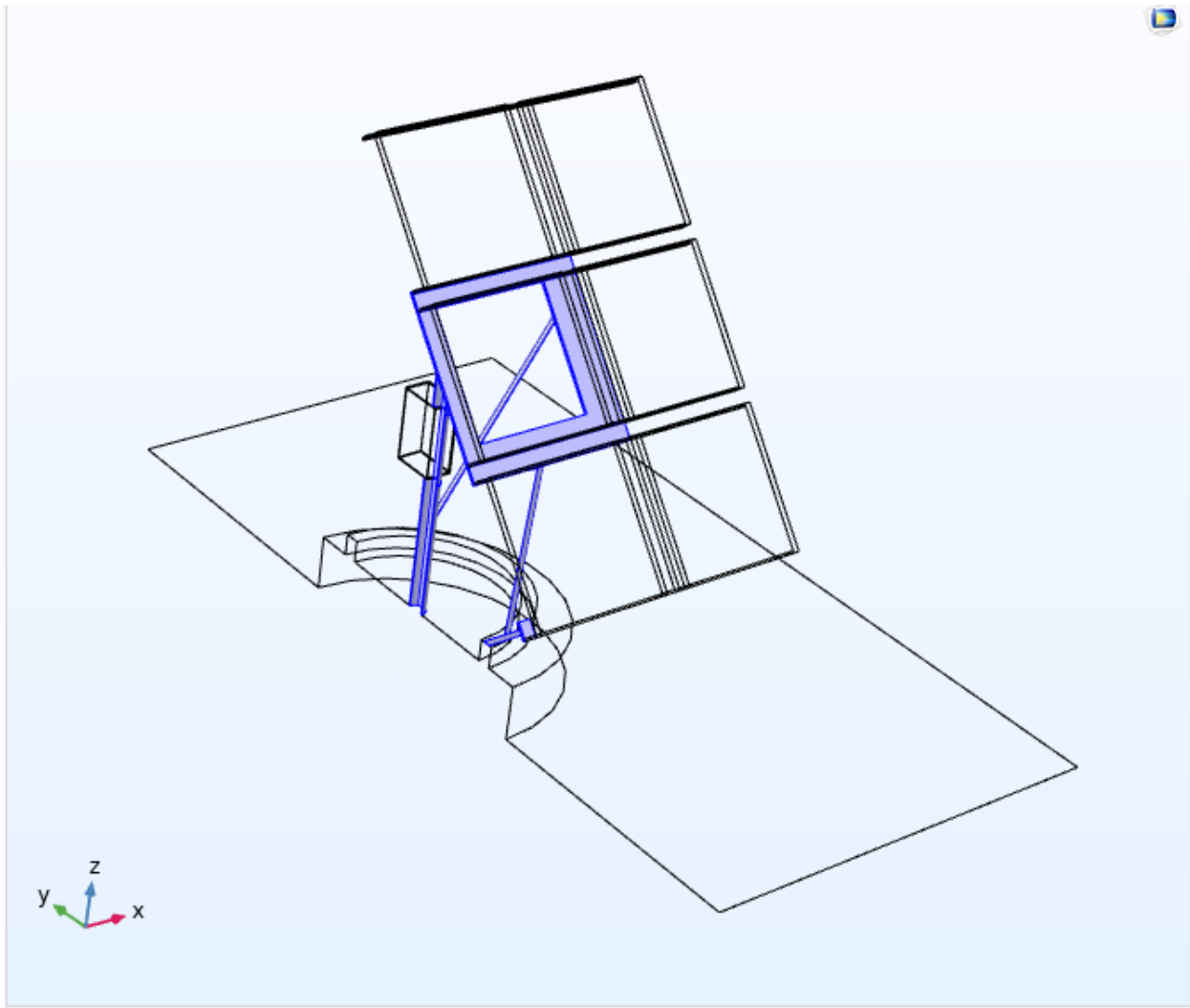
4 On the object pane, select Boundaries 3, 9–11, 14, 17–19, 22–28, 30, 31, 33–35, 38, 41–43, 45–47, 53–55, 57, 60, 63, 66, 69, 99–102, 104–106, 112–114, 116, 117, 120–123, 127, 128, 130–133, 141–143, 146–148, 150, 152–154, 156, 157, 159–161, 163, 164, 166–174, 176, 177, 179–181, 183–185, 187, 189, 192, 194–198, 200, 202–212, 214–216, 218, 219, 222–226, 229, 231, 234–236, 241, 242, 245–249, 254, 257–259, 263–265, 267, 268, 270–274, 276–282, 284–290, 292–298, 300–305, and 307–318 only.

Explicit Selection 2 (sel2)

1 In the Geometry toolbar, click Selections and choose Explicit Selection.

2 In the Settings window for Explicit Selection, type Supports in the Label text field.

3 Locate the Entities to Select section. From the Geometric entity level list, choose Boundary.



4 On the object pard7, select Boundaries 29, 58, 93, 175, and 182 only.

Explicit Selection 3 (sel3)

1 In the Geometry toolbar, click Selections and choose Explicit Selection.

2 In the Settings window for Explicit Selection, type Symmetry in the Label text field.

3 Locate the Entities to Select section. From the Geometric entity level list, choose

Boundary.

4 On the object part7, select Boundaries 8, 12, 15, 20, 32, 36, 39, 44, 48, 51, 56, 59, 62, 65, 68, 78, 81, 84, 91, 95, 103, 107, 110, 115, 118, 124, and 129 only.

Explicit Selection 4 (sel4)

1 In the Geometry toolbar, click Selections and choose Explicit Selection.

2 In the Settings window for Explicit Selection, type Structural steel in the Label text field.

3 On the object part7, select Domains 4–6, 8, 9, 11–17, 21, 22, 24, 25, 27, 33–35, 40, 42, 45, and 47 only.

Explicit Selection 5 (sel5)

1 In the Geometry toolbar, click Selections and choose Explicit Selection.

2 In the Settings window for Explicit Selection, type Aluminum in the Label text field.

3 On the object part7, select Domains 3, 7, 10, 18–20, 23, 26, 28, 30, 36, 38, 41, 43, and 46 only.

Explicit Selection 6 (sel6)

1 In the Geometry toolbar, click Selections and choose Explicit Selection.

2 In the Settings window for Explicit Selection, type Glass in the Label text field.

3 On the object part7, select Domains 29, 31, 32, 37, 39, and 44 only.

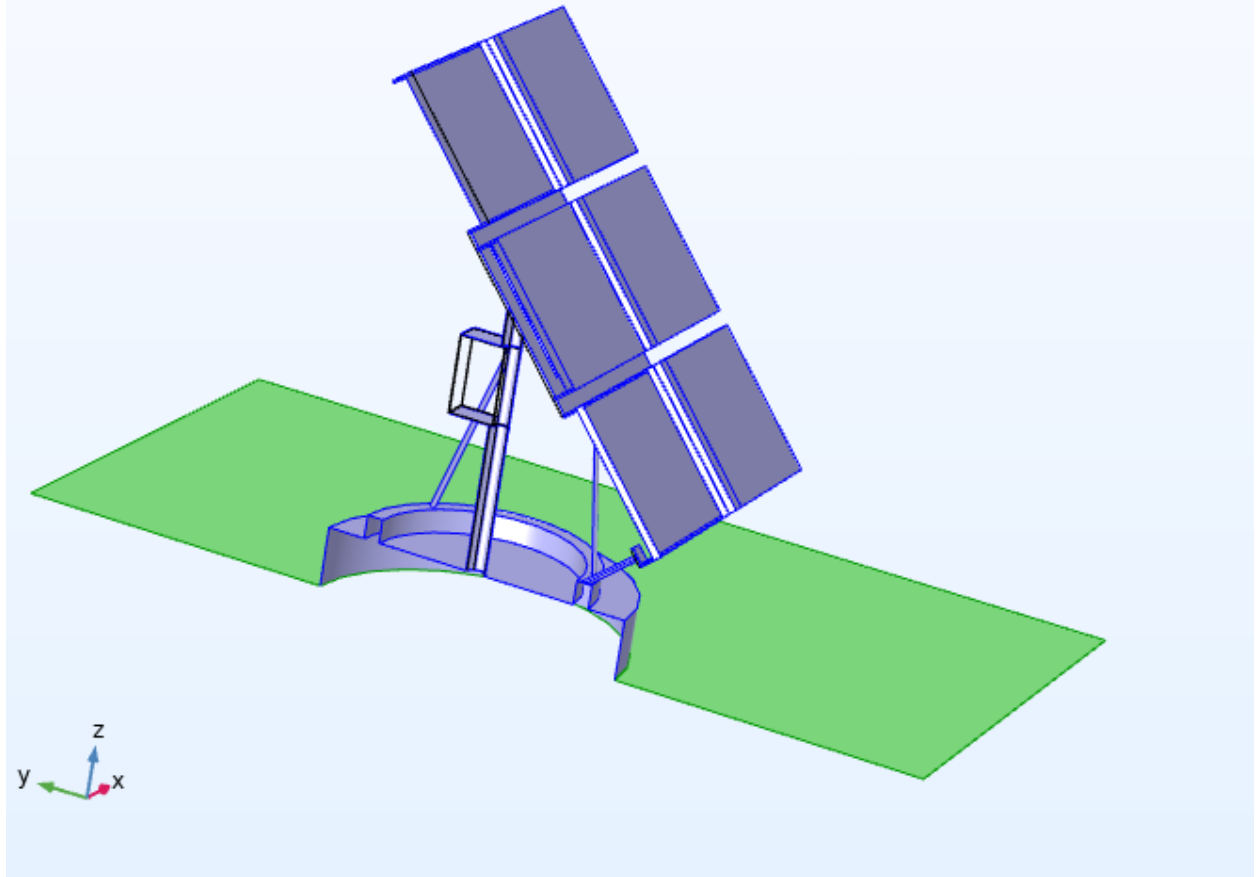
Finally, use the Remove Details functionality to remove unnecessary vertices.

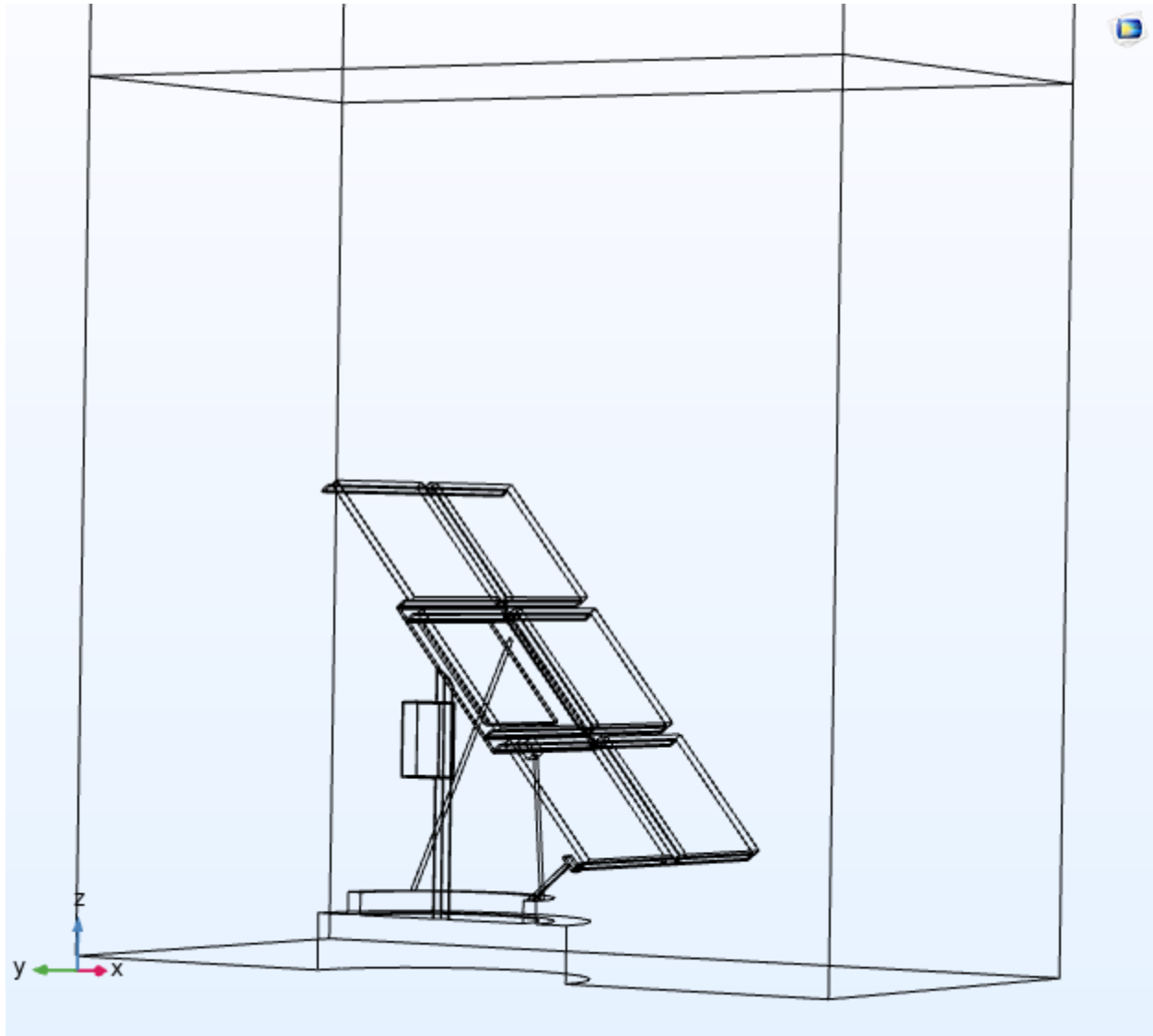
Remove Details 1 (rmd1)

1 In the Geometry toolbar, click Remove Details.

2 In the Settings window for Remove Details, locate the Details to Remove section.

2 Clear the Short edges check box.





4 Clear the Small faces check box.

5 Clear the Sliver faces check box.

6 Clear the Narrow face regions check box.

7 Clear the Thin domains check box.

8 Right-click Remove Details 1 (rmd1) and choose Build All Objects.

9 Click the Zoom Extents button in the Graphics toolbar.

The final geometry with boundaries 1, 2, 4, 5, 6, 7, 134, 135, 319 and 320 hidden is shown in the figure below.

DEFINITIONS

Hide for Geometry 1

In the Model Builder window, under Component 1 (comp1)>Definitions>View 1 right-click Hide for Geometry 1 and choose Delete.

The geometry contains both the fluid and solid domains. Proceed with the mesh.

MESH 1

The following meshing instructions are rather long. In practice, advanced meshing requires several views, but to follow the instructions below, the best way is to use the selection list.

1 In the Settings window for Mesh, locate the Mesh Settings section.

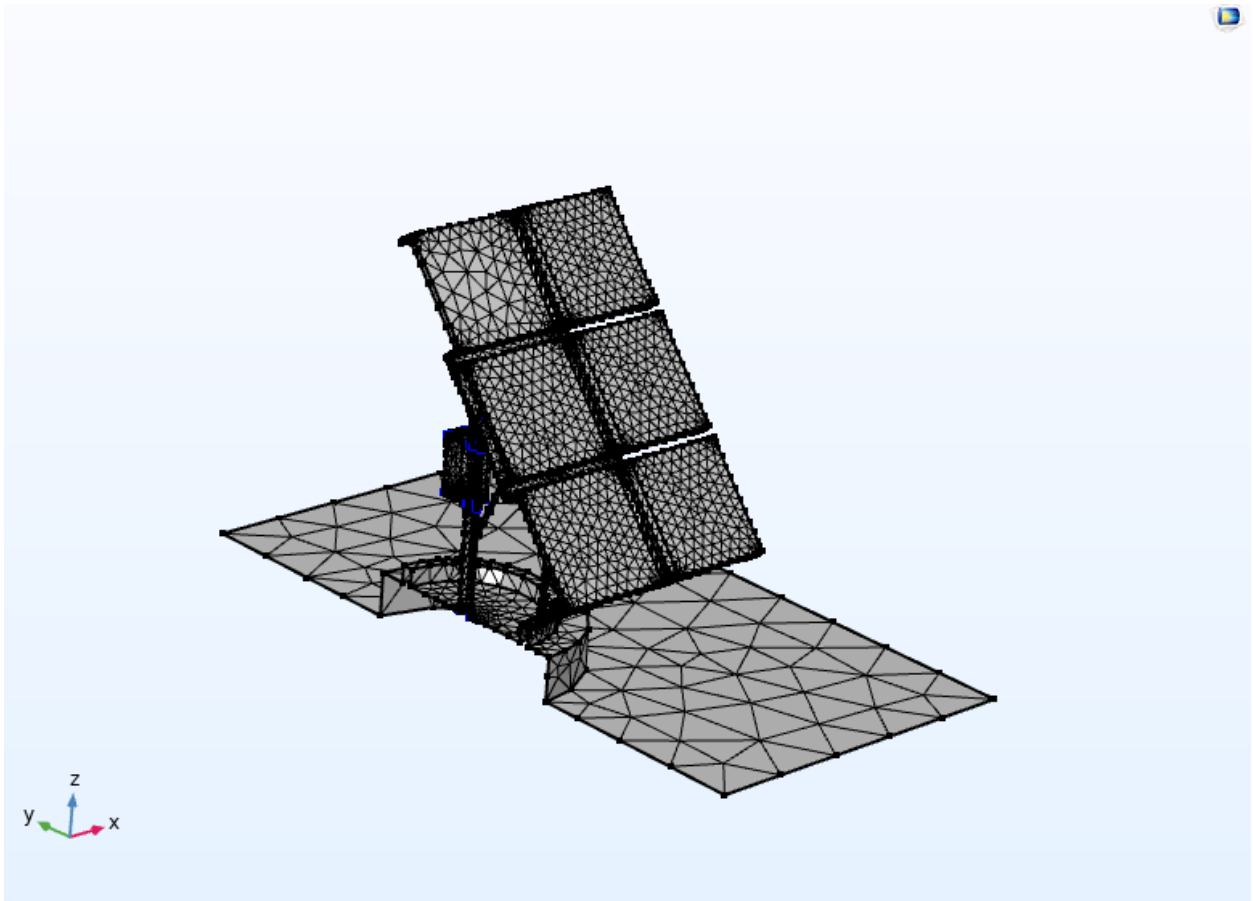
2 From the Sequence type list, choose User-controlled mesh.

Size

1 In the Model Builder window, under Component 1 (comp1)>Mesh 1 click Size

2 In the Settings window for Size, locate the Element Size section.

3 From the Calibrate for list, choose Fluid dynamics.



4

4 Click the Custom button.

5 Locate the Element Size Parameters section. In the Minimum element size text field, type 0.005.

6 Click Build Selected.

Size 1

In the Model Builder window, right-click Size 1 and choose Delete. Delete also Corner Refinement 1 and Free Tetrahedral 1.

TURBULENTFLOW , K - ε (S P F)

1 In the Model Builder window, under Component 1 (comp1) click Turbulent Flow, k-ε (spf).

2 Select Domains 1 and 2 only (fluid domains).

Initial Values

Velocity field:

	0	x	
u	$f(c1hs(z[1/m]-5,5))*Utop$	y	m/s
	0	z	

Pressure:

p 0.5[Pa]*(yEnd-y)/yLen Pa

Turbulent kinetic energy:

k spf.kinit m^2/s^2

Turbulent dissipation rate:

ϵp spf.epinit m^2/s^3

Global Equations

Label: Global Equations 1

Global Equations

$f(u, u_t, u_{tt}, t) = 0, u(t_0) = u_0, u_t(t_0) = u_{t0}$

Name	$f(u, u_t, u_{tt}, t)$ (m/s)	Initial value (u_0) (Pa)	Initial value (u_{t0}) (Pa/s)	Description
pdiff	-aveop1(v)+Utop	0.5[Pa]	0	
		0	0	

Name:

$f(u, u_t, u_{tt}, t)$ (m/s):

Initial value (u_0) (Pa):

Initial value (u_{t0}) (Pa/s):

Description:

Units

Dependent variable quantity	Unit
Pressure	Pa

Source term quantity	Unit
Velocity	m/s

Add isotropic diffusion to improve convergence. Specify the coefficient to be inversely

proportional to the pseudo time-stepping parameter CFLCMP so that the isotropic

Linear Elastic Material

Equation

Show equation assuming:

Study 1, Stationary

$$0 = \nabla \cdot \mathbf{S} + \mathbf{F}_V$$

$$\mathbf{S} = \mathbf{S}_{ad} + \mathbf{C} : \boldsymbol{\epsilon}_{el}, \quad \boldsymbol{\epsilon}_{el} = \boldsymbol{\epsilon} - \boldsymbol{\epsilon}_{inel}$$

$$\boldsymbol{\epsilon}_{inel} = \boldsymbol{\epsilon}_0 + \boldsymbol{\epsilon}_{ext} + \boldsymbol{\epsilon}_{th} + \boldsymbol{\epsilon}_{hs} + \boldsymbol{\epsilon}_{pl} + \boldsymbol{\epsilon}_{cr} + \boldsymbol{\epsilon}_{vp}$$

$$\mathbf{S}_{ad} = \mathbf{S}_0 + \mathbf{S}_{ext} + \mathbf{S}_q$$

$$\boldsymbol{\epsilon} = \frac{1}{2} [(\nabla \mathbf{u}_2)^T + \nabla \mathbf{u}_2]$$

$$\mathbf{C} = \mathbf{C}(E, \nu)$$

Model Input

Volume reference temperature:

T_{ref} Common model input

Absolute pressure:

p_A User defined

1[atm]

Pa

Coordinate System Selection

Coordinate system:

Global coordinate system

Linear Elastic Material

Solid model:

Isotropic

Specify:

Young's modulus and Poisson's ratio

Young's modulus:

E From material

Poisson's ratio:

ν From material

diffusion added tends to zero when CFLCMP increases.

3 Click the Show More Options button in the Model Builder toolbar.

Equation

Show equation assuming:
Study 1, Stationary

$$[-\rho \mathbf{I} + \mathbf{K}] \mathbf{n} = -f_0 \mathbf{n}$$

$$\begin{cases} \nabla k \cdot \mathbf{n} = 0, \nabla \epsilon \cdot \mathbf{n} = 0 & \text{if } \mathbf{u} \cdot \mathbf{n} \geq 0 \\ k = \frac{3}{2}(U_{\text{ref}} I_T)^2, \epsilon = C_{\mu} \frac{3/4 k^{3/2}}{L_T} & \text{if } \mathbf{u} \cdot \mathbf{n} < 0 \end{cases}$$

Boundary Condition

Boundary condition:
Normal stress

Normal stress:
 f_0 N/m²

Turbulence Conditions

Specify turbulent length scale and intensity
 Specify turbulence variables

Turbulent intensity:
 I_T 1

Turbulence length scale:
 L_T m

Reference velocity scale:
 U_{ref} m/s

4 In the Show More Options dialog box, in the tree, select the check box for the node

Physics>Stabilization.

Equation

Show equation assuming:
Study 1, Stationary

$$\mathbf{u}_{\text{src}} = \mathbf{u}_{\text{dst}}, p_{\text{src}} = p_{\text{dst}}$$

$$k_{\text{src}} = k_{\text{dst}}, \epsilon_{\text{src}} = \epsilon_{\text{dst}}$$

Pressure Difference

Pressure difference:
 $p_{\text{src}} - p_{\text{dst}}$ Pa

5 Click OK.

6 In the Model Builder window, click Turbulent Flow, k- -ε (spf).

7 In the Settings window for Turbulent Flow, k- -ε, click to expand the

Equation

Show equation assuming:
Study 1, Stationary

$$g(\sigma) = \sqrt{\frac{1}{2} \left(\frac{(\sigma_{p1} - \sigma_{p2})^2 + (\sigma_{p2} - \sigma_{p3})^2 + (\sigma_{p1} - \sigma_{p3})^2}{\sigma_{ts}^2} \right)} - 1 \geq 0$$

Inconsistent Stabilization section.

Equation

Show equation assuming:
Study 1, Stationary

$\mathbf{u} \cdot \mathbf{n} = 0$

$\mathbf{K}_n - (\mathbf{K}_n \cdot \mathbf{n})\mathbf{n} = \mathbf{0}, \mathbf{K}_n = \mathbf{K}n$

$\nabla k \cdot \mathbf{n} = 0, \nabla \epsilon \cdot \mathbf{n} = 0$

8 Find the Navier-Stokes equations subsection. Select the Isotropic diffusion check box.

9 In the Tx id text field, type 0.5/CFLCMP.

Equation

Show equation assuming:
Study 1, Stationary

$$g(\sigma) = \max \left(\frac{|\sigma_{p1}|}{\sigma_s}, \frac{|\sigma_{p2}|}{\sigma_s}, \frac{|\sigma_{p3}|}{\sigma_s} \right) - 1 \geq 0$$

$\sigma_{pi} \geq 0 \rightarrow \sigma_s = \sigma_{ts}$

$\sigma_{pi} < 0 \rightarrow \sigma_s = \sigma_{cs}$

Prescribe an approximate streamwise velocity profile and a streamwise pressure drop to go

with it.

$\mathbf{u} \cdot \mathbf{n} = \mathbf{u}_{tr} \cdot \mathbf{n}$

$\mathbf{K}n = -\rho \frac{u_{\tau}}{u^+} \mathbf{u}_{rel, tang}$

$\mathbf{u}_{rel} = \mathbf{u} - \mathbf{u}_{tr}, \mathbf{u}_{rel, tang} = \mathbf{u}_{rel} - (\mathbf{u}_{rel} \cdot \mathbf{n})\mathbf{n}$

$\nabla k \cdot \mathbf{n} = 0, \epsilon = \rho \frac{C_{\mu} k^2}{\kappa_v \delta_w^+ \mu}$

MATERIALS

Air (mat1)

1 In the Model Builder window, under Component 1 (comp1)>Materials click Air (mat1).

Property Group

Label: Basic

Output Properties

Property	Variable	Expression	Unit	Size	Info
Coefficient of thermal expansion	alpha_iso ; alphiai = al...	alpha_p(pA, T)	1/K	3x3	
Mean molar mass	Mn	0.02897	kg/mol	1x1	
Bulk viscosity	muB	muB(T)	Pa-s	1x1	
Relative permeability	mur_iso ; murii = mur...	1	1	3x3	
Relative permittivity	epsilon_r_iso ; epsilon_r...	1	1	3x3	
Dynamic viscosity	mu	eta(T)	Pa-s	1x1	
Ratio of specific heats	gamma	1.4	1	1x1	
Electrical conductivity	sigma_iso ; sigma_ii = ...	0[S/m]	S/m	3x3	
Heat capacity at constant pressure	Cp	Cp(T)	J/(kg-K)	1x1	
Density	rho	rho(pA, T)	kg/m ³	1x1	
Thermal conductivity	k_iso ; kii = k_iso, kij = 0	k(T)	W/(m-K)	3x3	
Speed of sound	c	cs(T)	m/s	1x1	

2 In the Settings window for Material, locate the Geometric Entity Selection section.

Property Group

Label: Nonlinear model

Output Properties

Property	Variable	Expression	Unit	Size	Info
Parameter of nonlinearity	BA	(def.gamma+ 1)/2	1	1x1	

3 From the Selection list, choose Manual.

Property Group

Label: Refractive index

Output Properties

Property	Variable	Expression	Unit	Size	Info
Refractive index, real part	n_iso ; nii = n_iso, nij...	1	1	3x3	
Refractive index, imaginary part	ki_iso ; ki_ii = ki_iso, kiij...	0	1	3x3	

5 Click Clear Selection.

Material

Label: Air

Geometric Entity Selection

Geometric entity level: Domain

Selection: Manual

Override

Material Properties

Material Contents

Property	Variable	Value	Unit	Property group
Coefficient of thermal expansion	alpha_iso ; alp...	alpha_p(pA,T)	1/K	Basic
Mean molar mass	Mn	0.02897	kg/mol	Basic
Bulk viscosity	muB	muB(T)	Pa·s	Basic
Relative permeability	mur_iso ; muri...	1	1	Basic
Relative permittivity	epsilon_iso ; e...	1	1	Basic
Dynamic viscosity	mu	eta(T)	Pa·s	Basic
Ratio of specific heats	gamma	1.4	1	Basic
Electrical conductivity	sigma_iso ; sig...	0[S/m]	S/m	Basic
Heat capacity at constant pressure	Cp	Cp(T)	J/(kg·K)	Basic
Density	rho	rho(pA,T)	kg/m ³	Basic
Thermal conductivity	k_iso ; kii = k_i...	k(T)	W/(m·K)	Basic
Speed of sound	c	cs(T)	m/s	Basic
Refractive index, real part	n_iso ; nii = n_i...	1	1	Refractive index
Refractive index, imaginary part	ki_iso ; kiii = ki...	0	1	Refractive index
Parameter of nonlinearity	BA	(def.gamma+1)/2	1	Nonlinear model

6

5 Select Domains 1 and 2 only.

Materials

Material Overview

Material	Selection
Air (mat1)	No domains
Structural steel (mat2)	Domains 2-4, 6-7, 9-15, 19-20, 22-23, 25, 30-32, 37, 39, 42, 44
Aluminum (mat3)	Domains 1, 5, 8, 16-18, 21, 24, 26, 28, 33, 35, 38, 40, 43
Material 4 (mat4)	Domains 27, 29, 34, 36, 41

Structural steel (mat2)

1 In the Model Builder window, click Structural steel (mat2).

Property Group

Label: Young's modulus and Poisson's ratio

Output Properties

Property	Variable	Expression	Unit	Size	Info
Young's modulus	E	200e9[Pa]	Pa	1x1	
Poisson's ratio	nu	0.30	1	1x1	

Property Group

Label: Basic

Output Properties

Property	Variable	Expression	Unit	Size	Info
Relative permeability	mur_iso ; murii = m...	1	1	3x3	
Heat capacity at constant pressure	Cp	475[J/(kg*K)]	J/(kg*K)	1x1	
Thermal conductivity	k_iso ; kii = k_iso, kij...	44.5[W/(m*K)]	W/(m*K)	3x3	
Electrical conductivity	sigma_iso ; sigma_ii = ...	4.032e6[S/m]	S/m	3x3	
Relative permittivity	epsilon_iso ; epsilon...	1	1	3x3	
Coefficient of thermal expansion	alpha_iso ; alpha_ii = ...	12.3e-6[1/K]	1/K	3x3	
Density	rho	7850[kg/m^3]	kg/m^3	1x1	

2 In the Settings window for Material, locate the Geometric Entity Selection section.

Property Group

Label: Isotropic strength parameters

Output Properties

Property	Variable	Expression	Unit	Size	Info
Tensile strength	sigmat	250[MPa]	Pa	1x1	
Compressive strength	sigmac		Pa	1x1	
Biaxial compressive strength	sigmacb		Pa	1x1	

3 From the Selection list, choose Structural steel.

Property Group

Label: Lamé parameters

Output Properties

Property	Variable	Expression	Unit	Size	Info
Lamé parameter λ	lamLame	1.15e11[Pa]	N/m ²	1x1	
Lamé parameter μ	muLame	7.69e10[Pa]	N/m ²	1x1	

4 Locate the Material Contents section. In the table, enter the following settings:

Material

Label: Structural steel

Geometric Entity Selection

Geometric entity level: Domain

Selection: Manual

2
3
4
6
7
10

Override

Material Properties

Material Contents

Property	Variable	Value	Unit	Property group
Compressive strength	sigmac		Pa	Isotropic strength parameters
Biaxial compressive strength	sigmabc		Pa	Isotropic strength parameters
<input checked="" type="checkbox"/> Density	rho	7850[kg/m^3]	kg/m ³	Basic
<input checked="" type="checkbox"/> Young's modulus	E	200e9[Pa]	Pa	Young's modulus and Poisson's ratio
<input checked="" type="checkbox"/> Poisson's ratio	nu	0.30	1	Young's modulus and Poisson's ratio
<input checked="" type="checkbox"/> Tensile strength	sigmat	250[MPa]	Pa	Isotropic strength parameters
Relative permeability	mur_iso ; murii...	1	1	Basic
Heat capacity at constant pressure	Cp	475[J/(kg*K)]	J/(kg*K)	Basic
Thermal conductivity	k_iso ; kii = k_i...	44.5[W/(m*K)]	W/(m*K)	Basic
Electrical conductivity	sigma_iso ; sig...	4.032e6[S/m]	S/m	Basic
Relative permittivity	epsilon_iso ; e...	1	1	Basic
Coefficient of thermal expansion	alpha_iso ; alp...	12.3e-6[1/K]	1/K	Basic
Murnaghan third-order elastic moduli	l	-3.0e11[Pa]	N/m ²	Murnaghan
Murnaghan third-order elastic moduli	m	-6.2e11[Pa]	N/m ²	Murnaghan
Murnaghan third-order elastic moduli	n	-7.2e11[Pa]	N/m ²	Murnaghan
Lamé parameter λ	lambLame	1.15e11[Pa]	N/m ²	Lamé parameters
Lamé parameter μ	muLame	7.69e10[Pa]	N/m ²	Lamé parameters

Aluminum (mat3)

1 In the Model Builder window, click Aluminum (mat3).

Material

Label: Aluminum

Geometric Entity Selection

Geometric entity level: Domain

Selection: Aluminum

1
5
8
16
17
18

Override

Material Properties

Material Contents

Property	Variable	Value	Unit	Property group
Compressive strength	sigmac		Pa	Isotropic strength parameters
Biaxial compressive strength	sigmacb		Pa	Isotropic strength parameters
Density	rho	2700[kg/m ³]	kg/m ³	Basic
Young's modulus	E	70e9[Pa]	Pa	Young's modulus and Poisson's ratio
Poisson's ratio	nu	0.33	1	Young's modulus and Poisson's ratio
Tensile strength	sigmat	270[MPa]	Pa	Isotropic strength parameters
Relative permeability	mur_iso ; mur...	1	1	Basic
Heat capacity at constant pressure	Cp	900[J/(kg*K)]	J/(kg·K)	Basic
Thermal conductivity	k_iso ; kii = k...	238[W/(m*K)]	W/(m·K)	Basic
Electrical conductivity	sigma_iso ; si...	3.774e7[S/m]	S/m	Basic
Relative permittivity	epsilon_iso ; ...	1	1	Basic
Coefficient of thermal expansion	alpha_iso ; alp...	23e-6[1/K]	1/K	Basic
Murnaghan third-order elastic moduli	l	-2.5e11[Pa]	N/m ²	Murnaghan
Murnaghan third-order elastic moduli	m	-3.3e11[Pa]	N/m ²	Murnaghan
Murnaghan third-order elastic moduli	n	-3.5e11[Pa]	N/m ²	Murnaghan
Lamé parameter λ	lamBLame	5.1e10[Pa]	N/m ²	Lamé parameters
Lamé parameter μ	muLame	2.6e10[Pa]	N/m ²	Lamé parameters

2 In the Settings window for Material, locate the Geometric Entity Selection section.

Property Group

Label: Basic

Output Properties

Property	Variable	Expression	Unit	Size	Info
Relative permeability	mur_iso ; murii = mur_iso, murij = 0	1	1	3x3	
Heat capacity at constant pressure	Cp	900[J/(kg*K)]	J/(kg·K)	1x1	
Thermal conductivity	k_iso ; kii = k_iso, kij = 0	238[W/(m*K)]	W/(m·K)	3x3	
Electrical conductivity	sigma_iso ; sigma_ii = sigma_iso, sigma_ij = 0	3.774e7[S/m]	S/m	3x3	
Relative permittivity	epsilon_iso ; epsilon_ii = epsilon_iso, epsilon_ij = 0	1	1	3x3	
Coefficient of thermal expansion	alpha_iso ; alpha_ii = alpha_iso, alpha_ij = 0	23e-6[1/K]	1/K	3x3	
Density	rho	2700[kg/m ³]	kg/m ³	1x1	

3 From the Selection list, choose Aluminum.

Property Group

Label:

Output Properties

Property	Variable	Expression	Unit	Size	Info
Tensile strength	sigmat	270[MPa]	Pa	1x1	
Compressive strength	sigmac		Pa	1x1	
Biaxial compressive strength	sigmacb		Pa	1x1	

4 Locate the Material Contents section. In the table, enter the following settings:

Property Group

Label:

Output Properties

Property	Variable	Expression	Unit	Size	Info
Lamé parameter λ	lambLame	5.1e10[Pa]	N/m ²	1x1	
Lamé parameter μ	muLame	2.6e10[Pa]	N/m ²	1x1	

Property Variable Value Unit Property group

Property Group

Label:

Output Properties

Property	Variable	Expression	Unit	Size	Info
Murnaghan third-order elastic moduli	l	-2.5e11[Pa]	N/m ²	1x1	
Murnaghan third-order elastic moduli	m	-3.3e11[Pa]	N/m ²	1x1	
Murnaghan third-order elastic moduli	n	-3.5e11[Pa]	N/m ²	1x1	

Property Group

Label:

Output Properties

Property	Variable	Expression	Unit	Size	Info
Young's modulus	E	70e9[Pa]	Pa	1x1	
Poisson's ratio	nu	0.33	1	1x1	

Tensile strength sigmat 250[MPa] Pa Isotropic strength

parameters

Property Variable Value Unit Property group

Tensile strength sigmat 270[MPa] Pa Isotropic strength

parameters

Material 4 (mat4)

1 In the Model Builder window, right-click Materials and choose Blank Material.

Property Group

Label: Isotropic strength parameters

▼ Output Properties

Property	Variable	Expression	Unit	Size	Info
Tensile strength	sigmat	45[MPa]	Pa	1x1	
Compressive strength	sigmac	45[MPa]	Pa	1x1	
Biaxial compressive strength	sigmabc		Pa	1x1	

Property Group

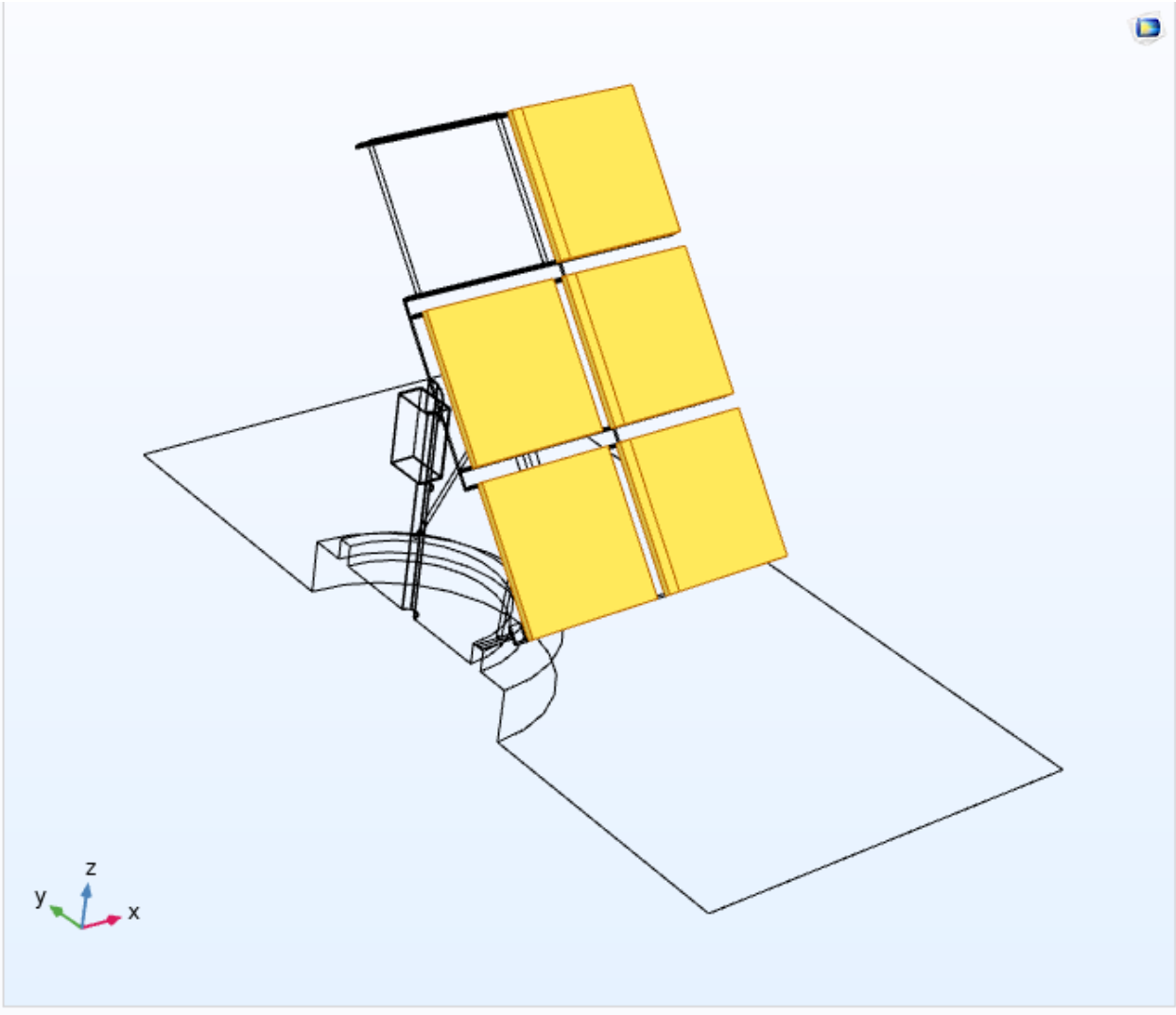
Label: Basic

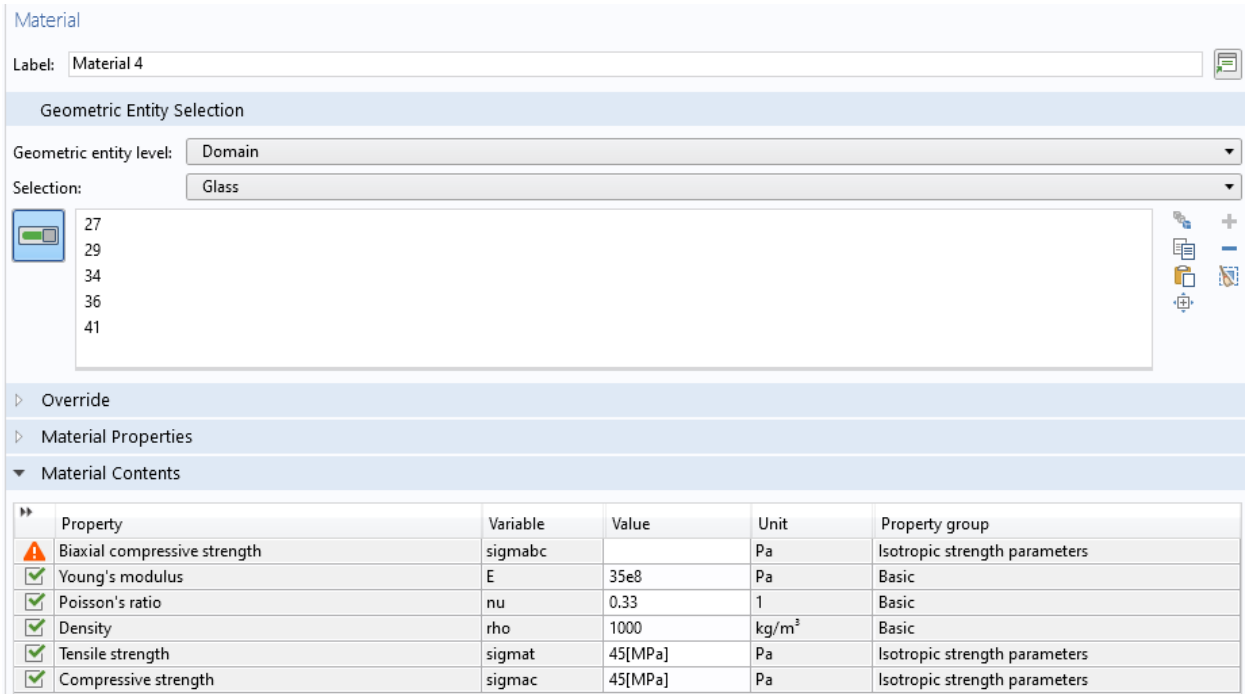
▼ Output Properties

Property	Variable	Expression	Unit	Size	Info
Young's modulus	E	35e8	Pa	1x1	
Poisson's ratio	nu	0.33	1	1x1	
Density	rho	1000	kg/m ³	1x1	

2 In the Settings window for Material, locate the Geometric Entity Selection section.

3 From the Selection list, choose Glass.





4 Locate the Material Contents section. In the table, enter the following settings:

Fixed Constraint 1

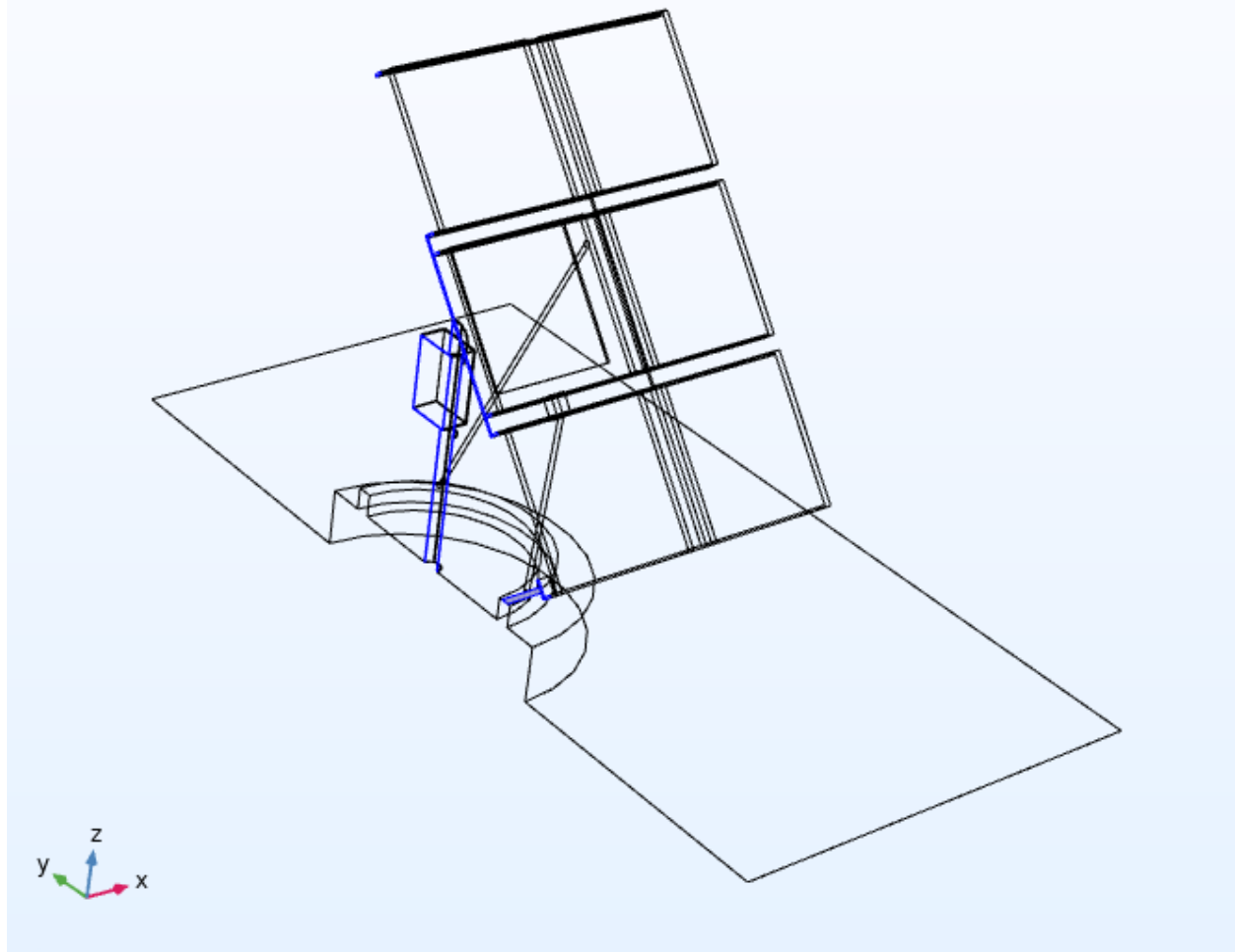
1 In the Physics toolbar, click Boundaries and choose Fixed Constraint.

2 In the Settings window for Fixed Constraint, locate the Boundary Selection section.

3 From the Selection list, choose Supports.

Symmetry 1

1 In the Physics toolbar, click Boundaries and choose Symmetry.



2 In the Settings window for Symmetry, locate the Boundary Selection section.

3 From the Selection list, choose Symmetry.

ADD STUDY

1 In the Home toolbar, click Add Study to open the Add Study window.

2 Go to the Add Study window.

3 Find the Studies subsection. In the Select Study tree, select General Studies>Stationary.

4 Click Add Study in the window toolbar.

5 In the Home toolbar, click Add Study to close the Add Study window.

Property Variable Value Unit Property

group

Young's modulus E 35e8 Pa Basic

Poisson's ratio nu 0.33 1 Basic

Density rho 1000 kg/m³ Basic

Tensile strength sigmat 45[MPa] Pa Isotropic

strength

parameters

Compressive strength sigmac 45[MPa] Pa Isotropic

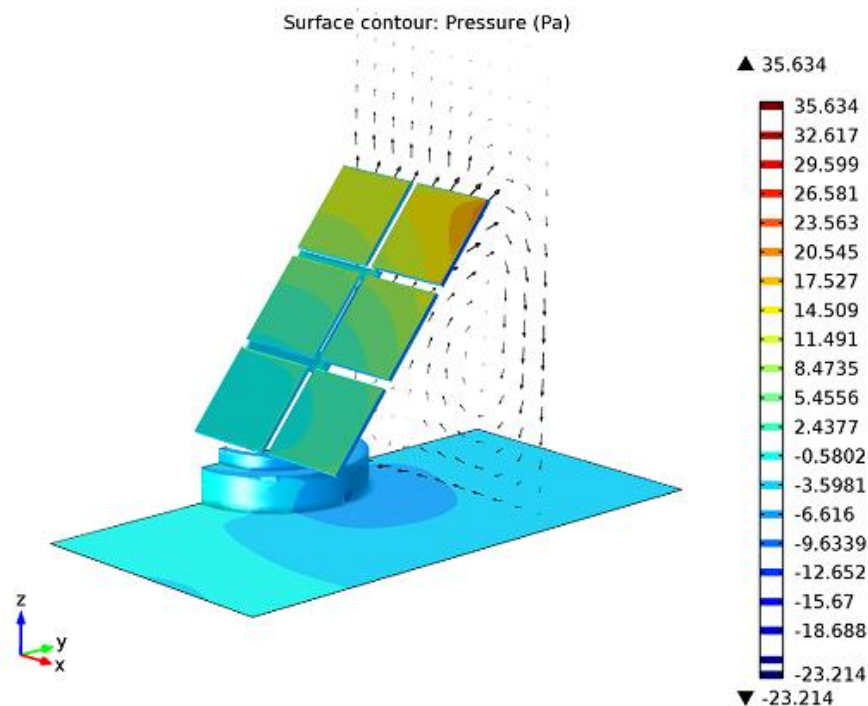
strength

parameters

CHAPTER FOUR

RESULTS & DISCUSSIONS

This figure appears the flow-field arrangement around the solar panel board. The figure appears the flow field within the center plane of the solar panel board employing a surface plot combined with velocity vectors at the channel and outlet. The stream field over the board is of boundary layer type with a greatest speed of 25 m/s within the free stream. The speed greatness within the vicinity of the sun powered board is additionally altogether lower due to protecting from the boards positioned upstream and downstream.



The stream field can in this manner be said to compare to a rough wall turbulent boundary layer, where the solar panel boards act as harshness elements. The taking after Figure appears the weight on the sun powered board structure due to the encompassing stream.

v m/s

z component:

w m/s

Description: Velocity field

Parameters

Name	Value	Unit	Description
solid.refpntx	0	m	Reference point for moment computation, x coordinate
solid.refpnty	0	m	Reference point for moment computation, y coordinate
solid.refpntz	0	m	Reference point for moment computation, z coordinate

▼

▶ Title

▼ Streamline Positioning

Positioning: Starting-point controlled

Entry method: Coordinates

x: $-1.75 \cdot 1^{\text{range}(1,7)}, -0.5 \cdot 1^{\text{range}(1,7)}, 0.5 \cdot 1^{\text{range}(1,7)}, 1.75 \cdot 1^{\text{range}(1,7)}$ m

y: -2 m

z: $\text{range}(0.5, 3/6, 3.5), \text{range}(0.5, 3/6, 3.5), \text{range}(0.5, 3/6, 3.5), \text{range}(0.5, 3/6, 3.5)$ m

▼ Coloring and Style

Line style

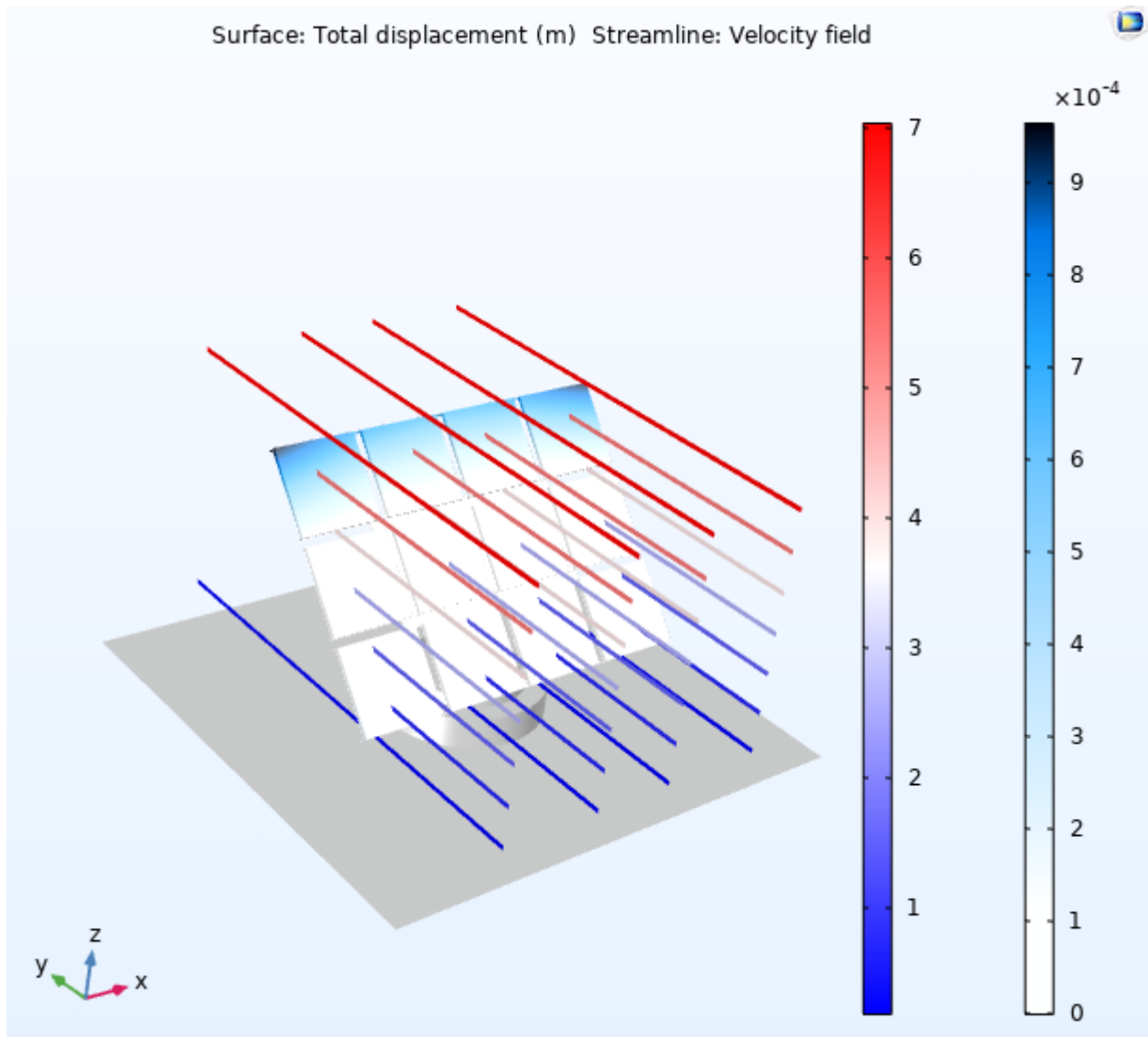
Type: Ribbon

Width expression: 0.03 m

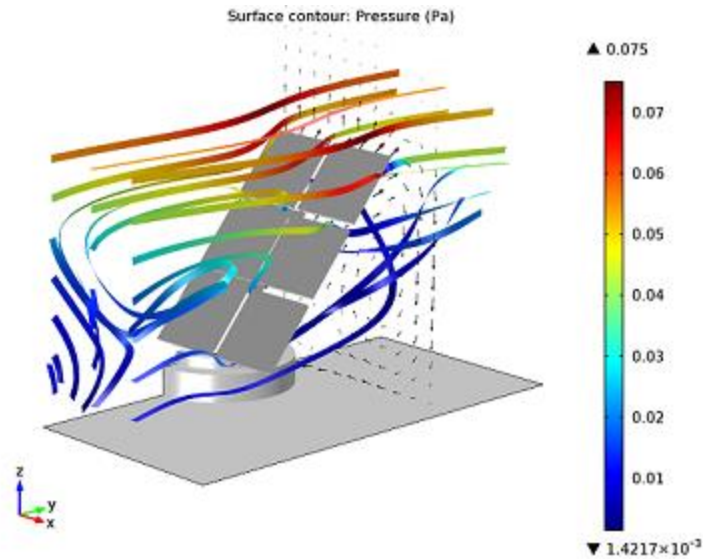
Width scale factor: 1

The maximum relative weight, approximately 70 Pa, happens within the panel's upper-right corner. By also plotting the in-plane speed components in a plane opposite to the stream direction, it is conceivable to discover the reason for the weight most extreme at the upper-right

corner.

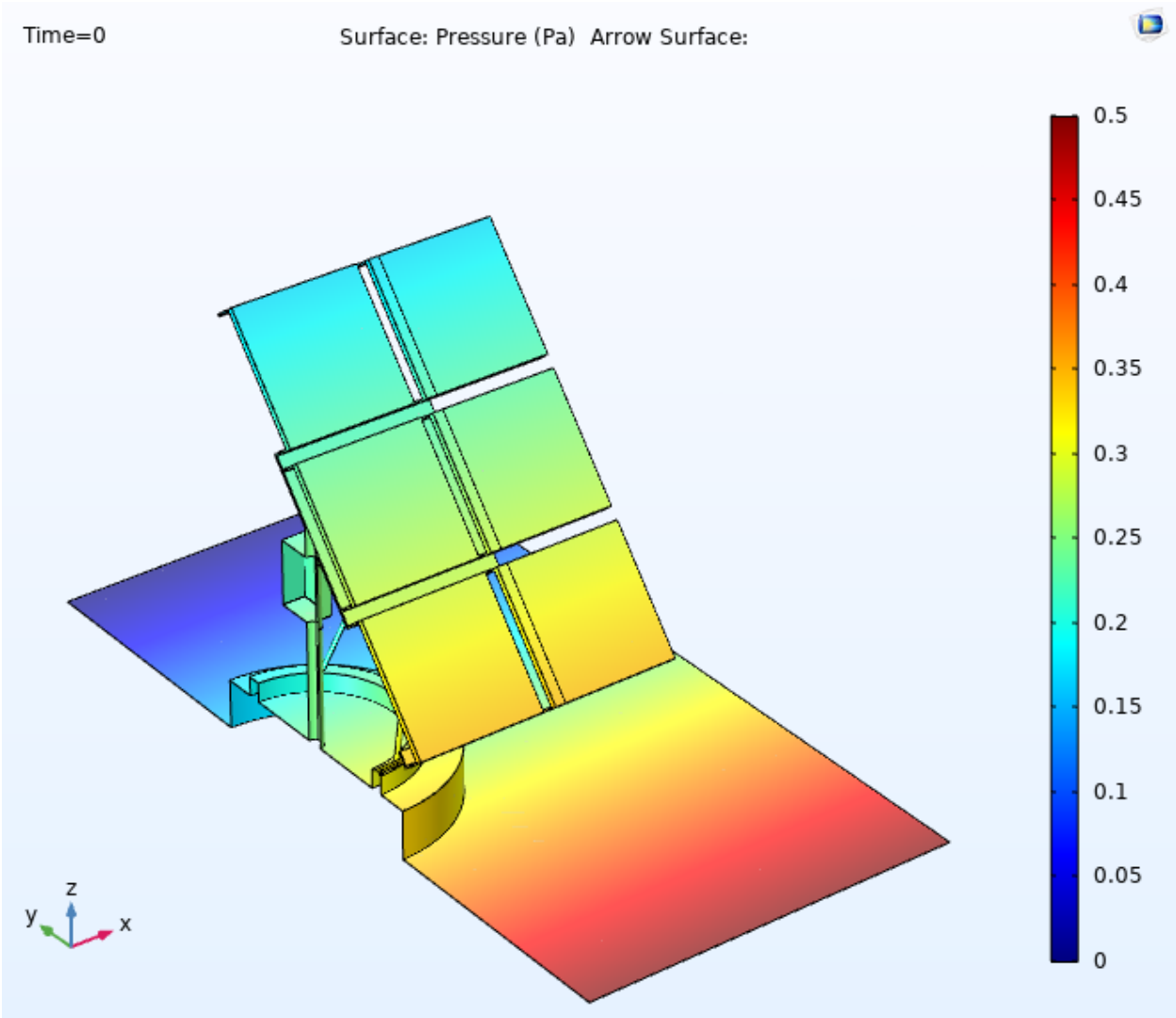


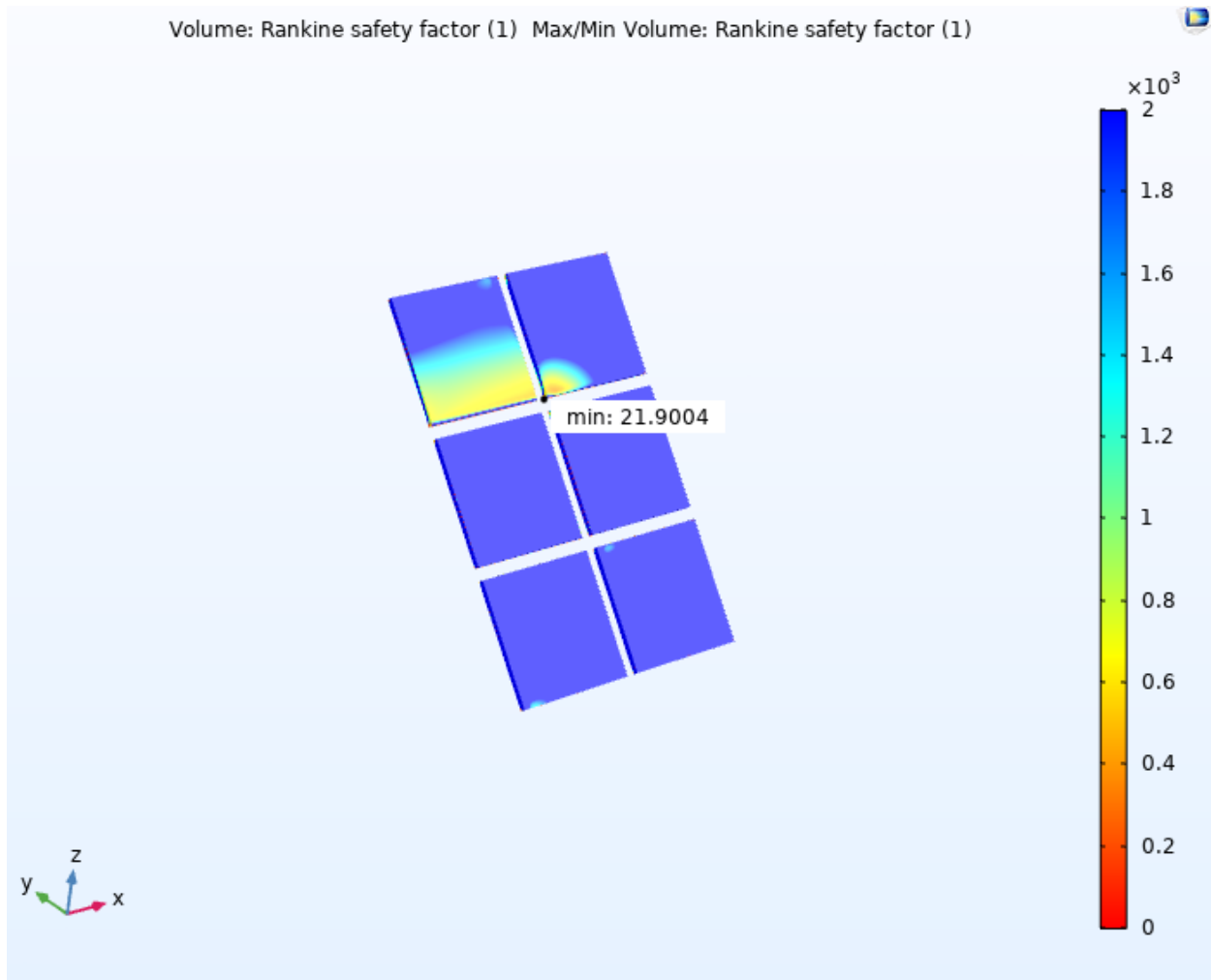
A large streamwise vortex is created behind the board, the center of which is adjusted with the panel's external side. At the upper-right corner, the tall weight connects with a high degree of avoidance of the stream and arrangement of the streamwise vortex. The stream around the solar panel board is inspected in Figure upcoming, which appears streamlines originating at the gulf. Note that a few streamlines close the center of the sun powered board enter the space and after that turn around and exit, demonstrating that a circulation zone is present between the boards within the cluster.




The streamlines are colored utilizing the local turbulent kinetic vitality, normalized by the dynamic energy within the free stream. The active vitality is low within the circulation zone in front and within the stream wake behind the board. This can be as expected since they are portion of the same stream structure. The turbulent dynamic energy increases with the separate from the ground, particularly when the stream passes the best of the panel. The tall active vitality at this position relates with a huge slope of the stream wise mean-flow speed, as can be seen in that Figure. Figure upcoming appears the coming about uprooting of the point-by-point structure, and the velocity streamlines around the full board. In correspondence with the weight plot in

Figure in previous, the biggest relocation happens within the upper-right corner.









Be that as it may, the maximum displacement is little, around 1 mm. This shows that the encompassing sun powered panels effectively shield the solar panel board from oncoming stream. It moreover focuses within the course that for a sun powered board situated inside a huge cluster, the liquid stack on the structure at the current free stream speed isn't critical sufficient to manage the plan of the structure. This conclusion is upheld by the least security figure gotten, which is much bigger than one.

Label: 

▼ Data

Dataset: 

▼ Expression    

Expression:

Unit:

Description:

— Parameters

▶▶ Name	Value	Unit	Description
solid.refpntx	0	m	Reference point for moment computation, x coordinate
solid.refpnty	0	m	Reference point for moment computation, y coordinate
solid.refpntz	0	m	Reference point for moment computation, z coordinate

 ▼


▶ Title

▼ Plane Data

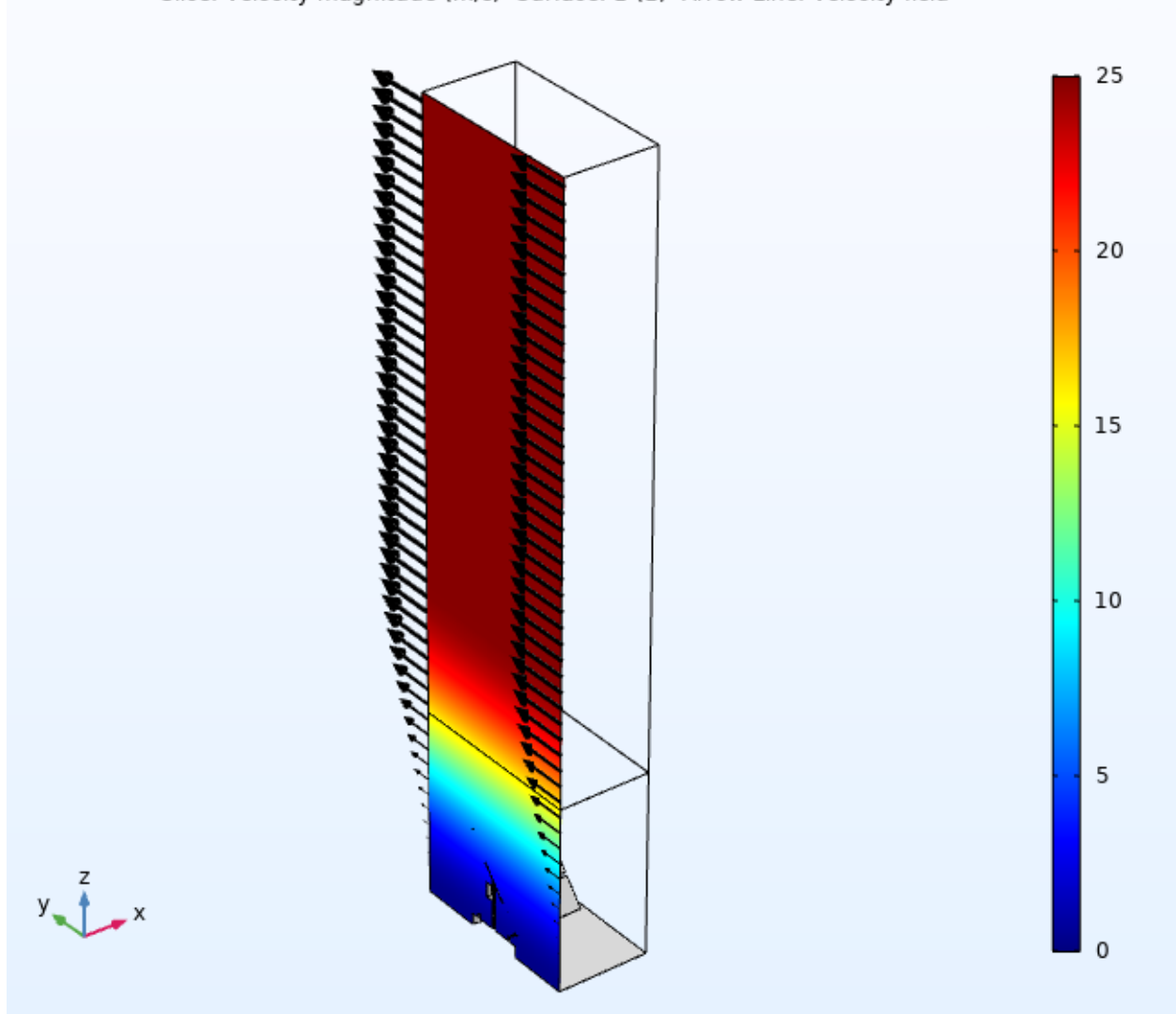
Plane type:

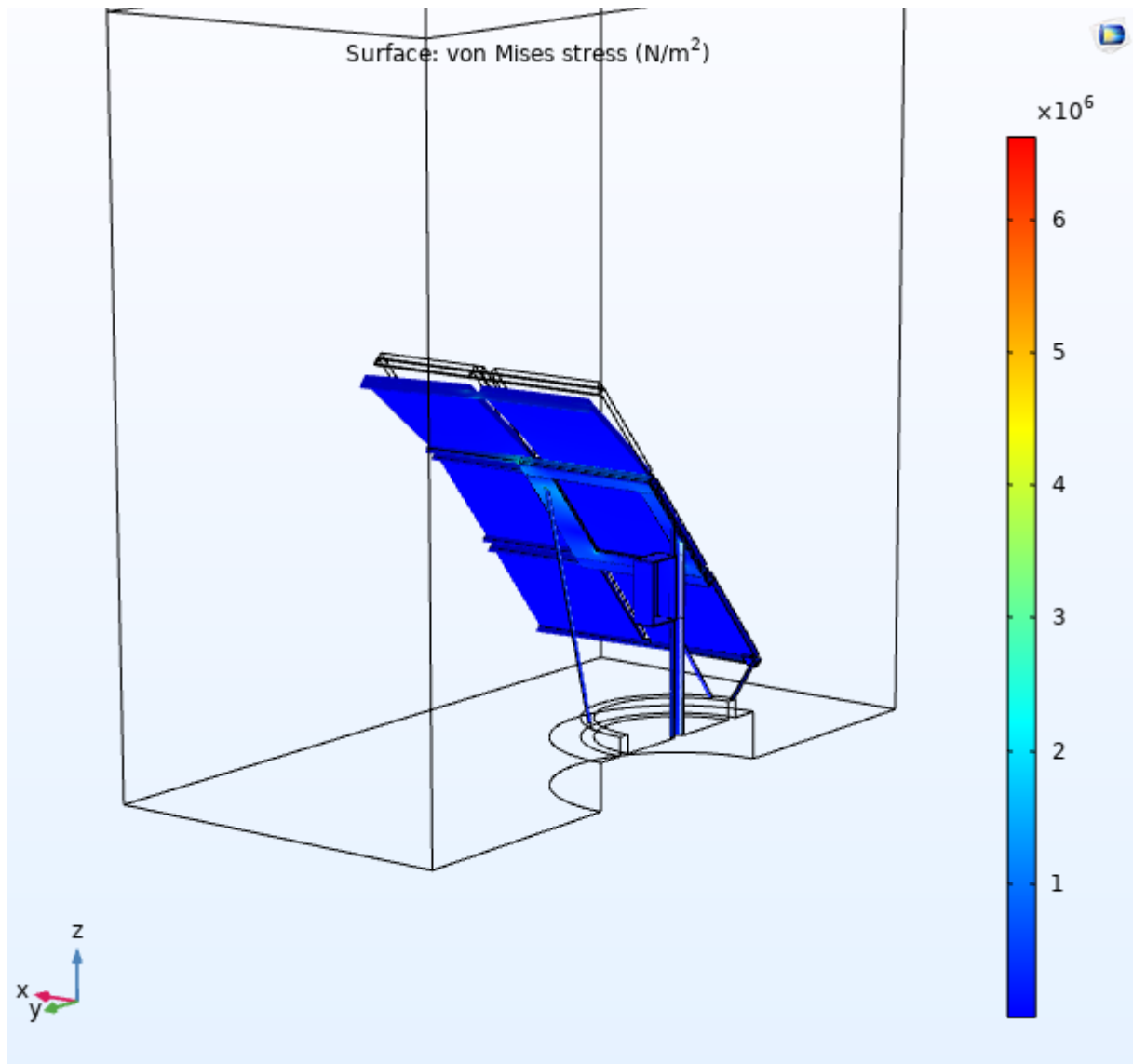
Plane:

Entry method:

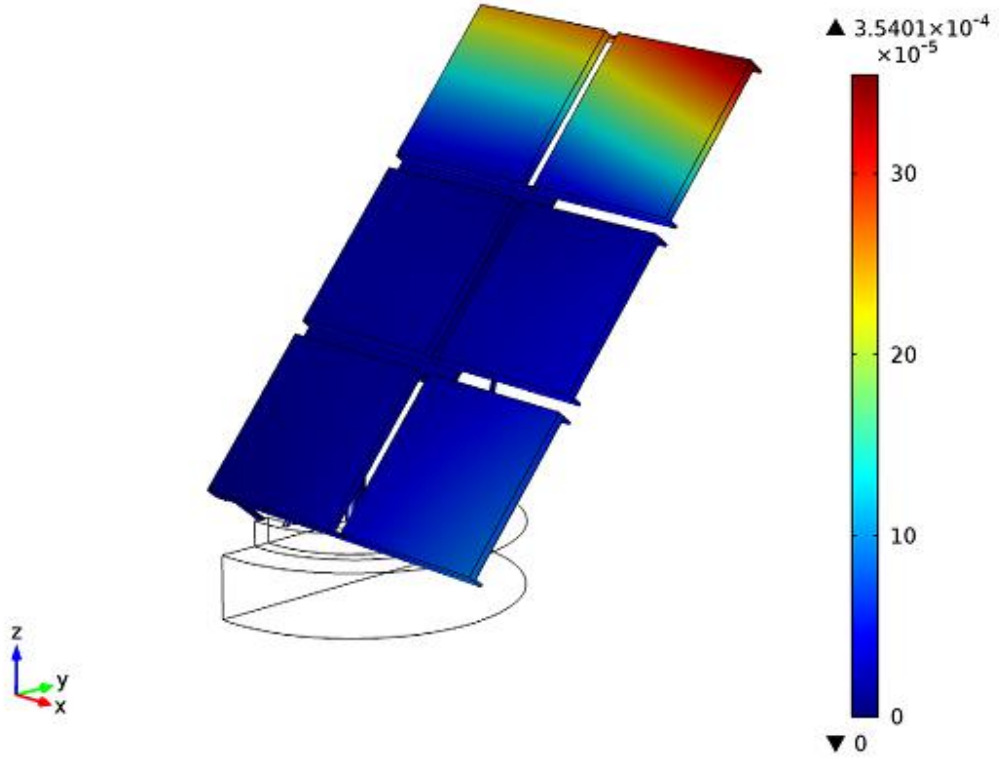
x-coordinates: m 

Time=0 Slice: Velocity magnitude (m/s) Surface: 1 (1) Arrow Line: Velocity field

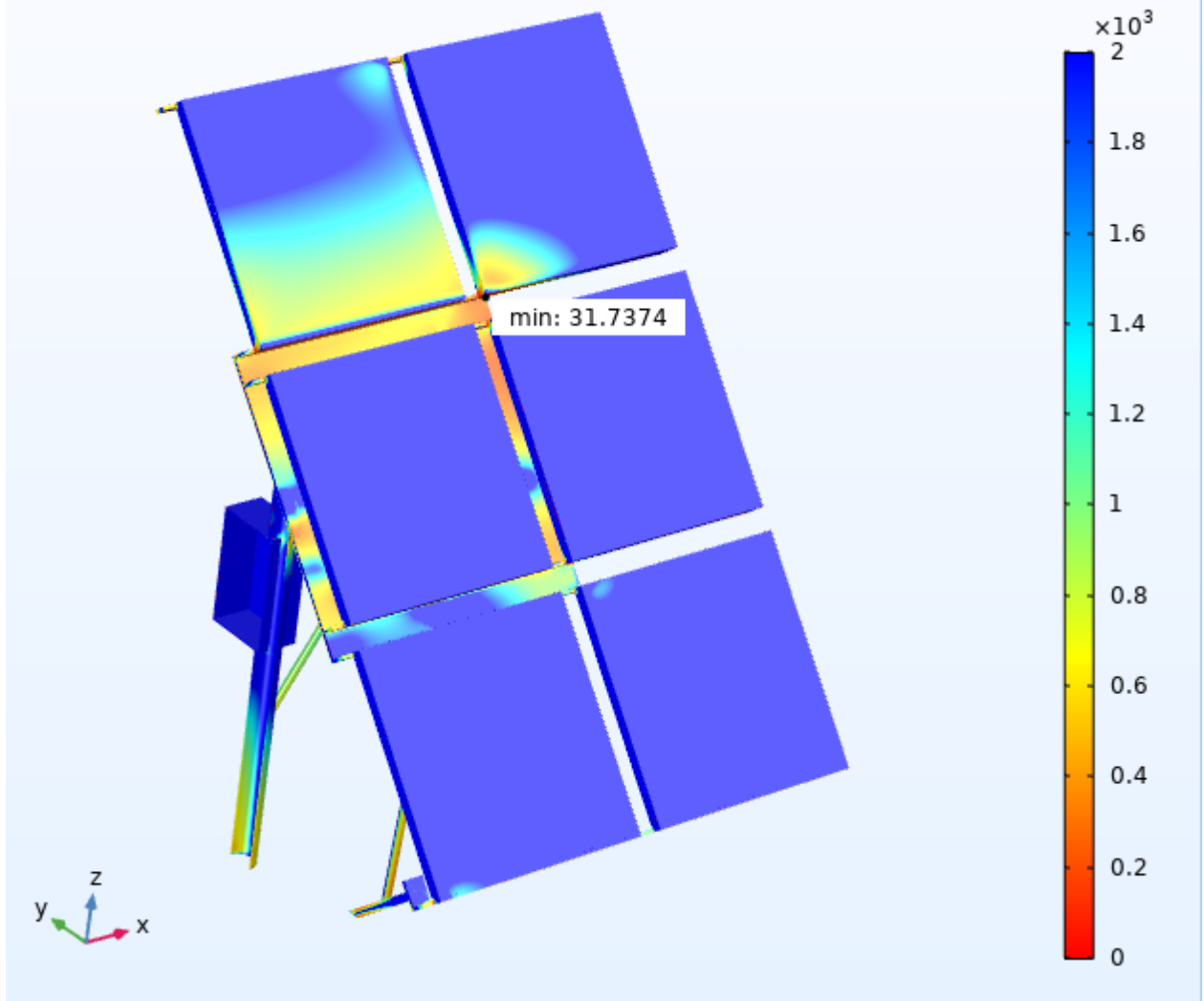




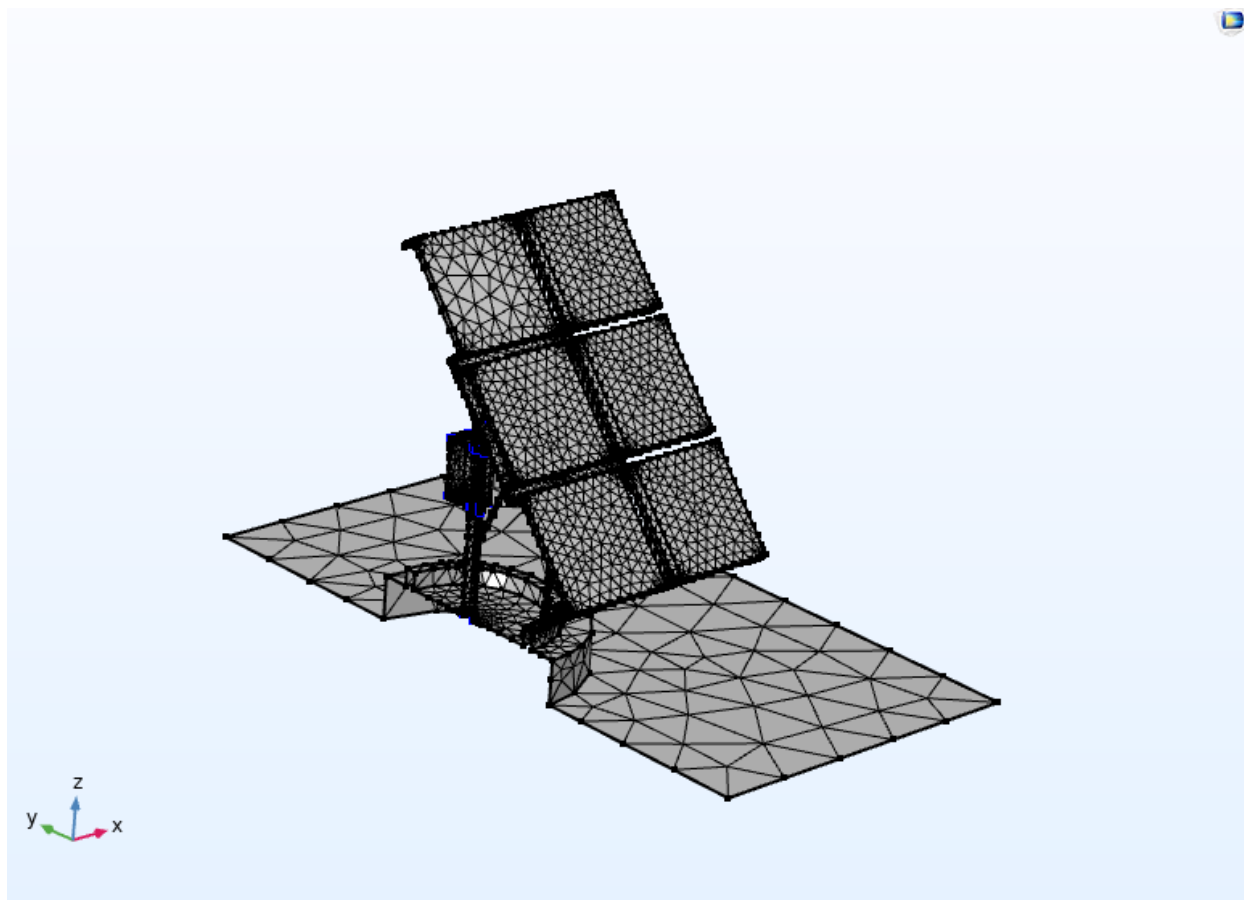
Surface: Total displacement (m)

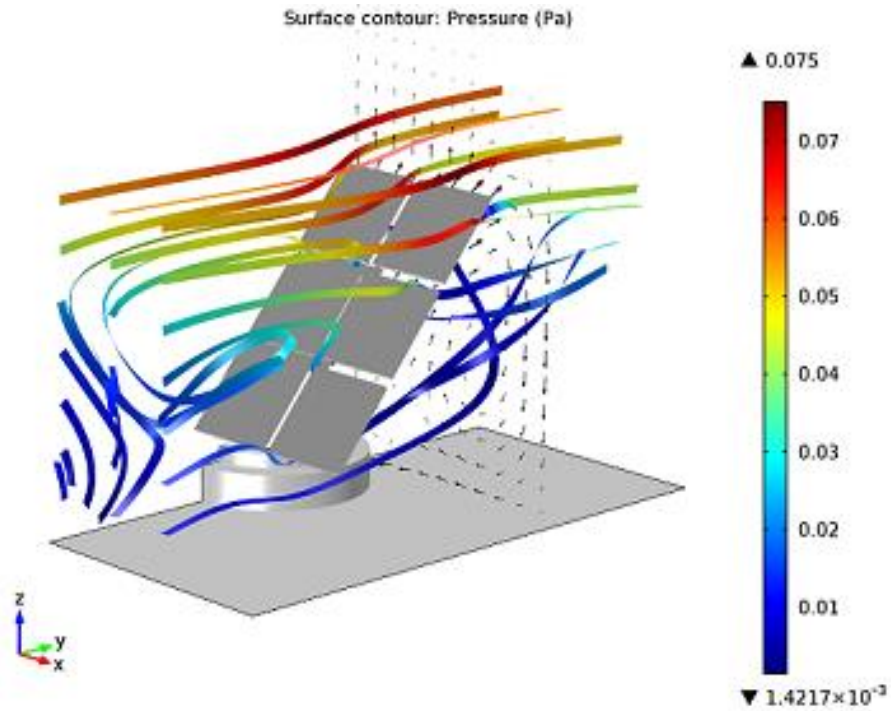



Volume: von Mises safety factor (1) Max/Min Volume: von Mises safety factor (1)



Velocity streamlines, colored by the kinetic energy normalized by the kinetic





Label: 

▼ Data

Presentation format:

▼ Storage

Store table:

Maximum number of rows:

▼ Column Headers

» Column	Header
1	x
2	y
3	z
4	Rankine safety factor (1)

Turbulent kinetic energy in the free stream, and in-plane velocity c

Label:

▼ Data

Presentation format:

▼ Storage

Store table:

Maximum number of rows:

▼ Column Headers

Column	Header
1	x
2	y
3	z
4	von Mises safety factor (1)

components-6cm-behind the panel.

Label:

▼ Data

Dataset:

▼ Expression ← →

Expression:

Unit:

Description:

— Parameters

Name	Value	Unit	Description
solid.refpntx	0	m	Reference point for moment computation, x coordinate
solid.refpnty	0	m	Reference point for moment computation, y coordinate
solid.refpntz	0	m	Reference point for moment computation, z coordinate

▶ Title

▼ Plane Data

Plane type:

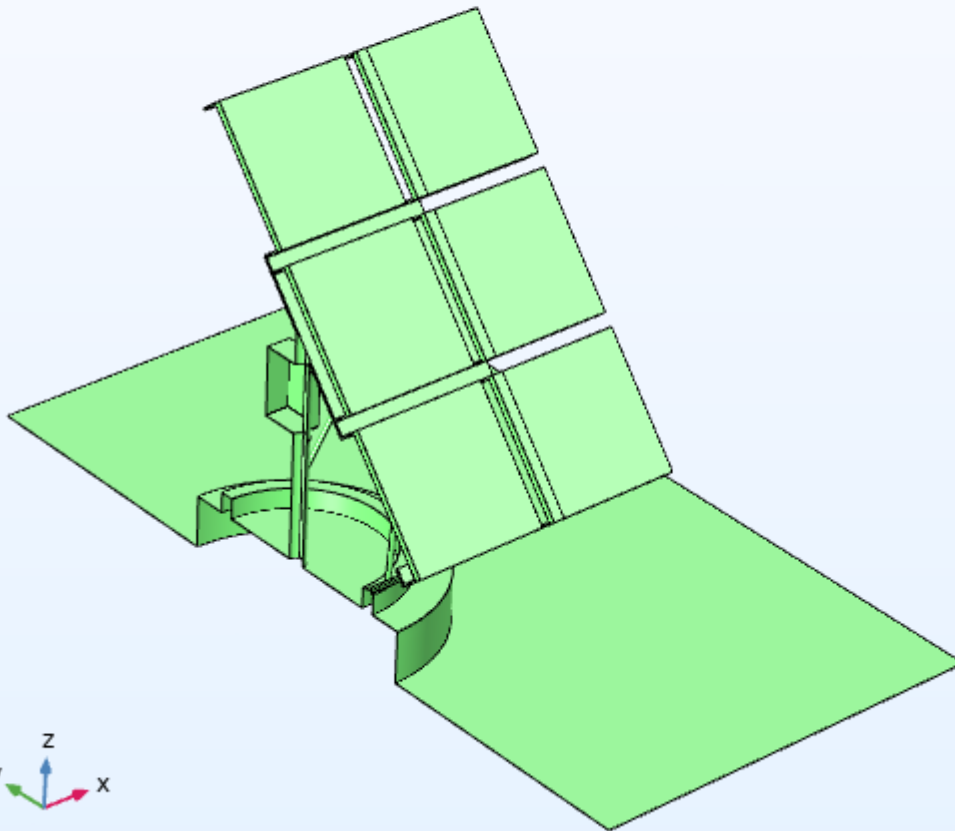
Plane:

Entry method:

x-coordinates:

Time=0

Surface: Wall resolution in viscous units (1)



Label: Surface 1

▼ Data

Dataset: Exterior Walls

Time: 0

▼ Expression ← → ↻

Expression:
1

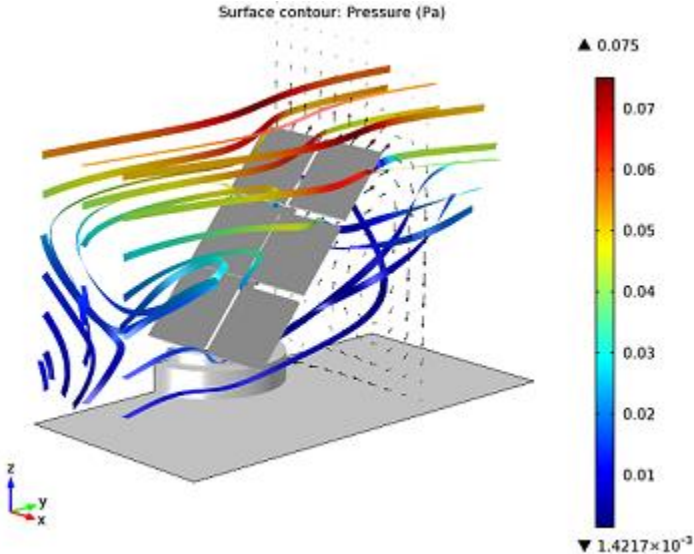
Unit:
1

Description:
1

Parameters

Name	Value	Unit	Description
solid.refpntx	0	m	Reference point for moment computation, x coordinate
solid.refpnty	0	m	Reference point for moment computation, y coordinate
solid.refpntz	0	m	Reference point for moment computation, z coordinate

Structural displacement of the solar panel due to the fluid-flow load, and velocity streamlines colored by the velocity magnitude.



CHAPTER FIVE

CONCLUSION

The object of this study is to have a proper knowledge of solar panel in period flow. The main focus of this study is to review the structural changes of solar panel in periodic flow. The data collection was done carefully in Comsol before analyzing the output. The model analysis showed significant phenomena of the turbulent flow on the surface of solar panel. This experiment can be done where turbulent flow is available specially in the coast side and also sunny in day times.

This case may be a think about of a solar panel board structure put in an intermittent stream field. The solar panel in address is found interior a frequently divided cluster of boards subjected to an oncoming solid wind. The show understands for the stream around the board and the auxiliary relocation due to the liquid stack. It is accepted that sufficient boards are positioned both upstream and downstream of the panel for intermittent stream conditions to be applicable within the streamwise heading. Seen from a position tall over the ground, the array of solar panel boards acts as an unpleasant boundary for the climatic flow.

Solar power is a big power of our lives and will become a huge part of our future, and increasing the efficiency and working process stability is the utmost priority of the current generation. Thus, this project is the one step forward to that future.

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