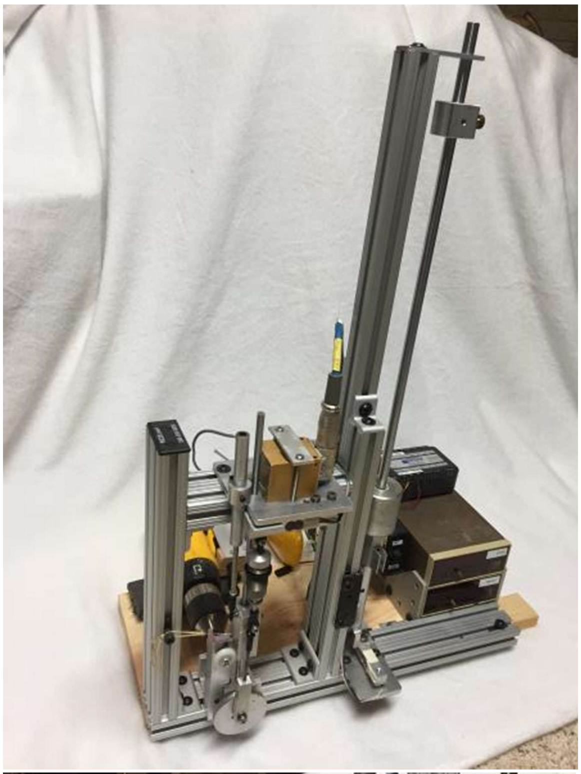
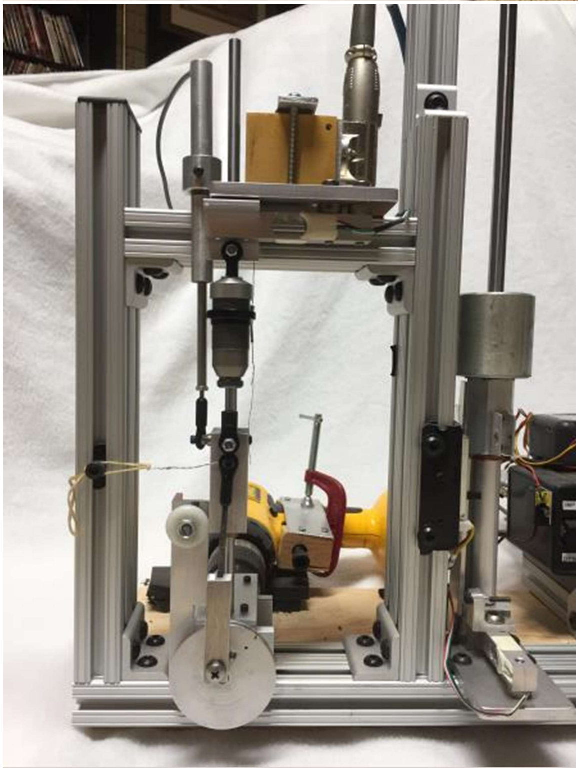
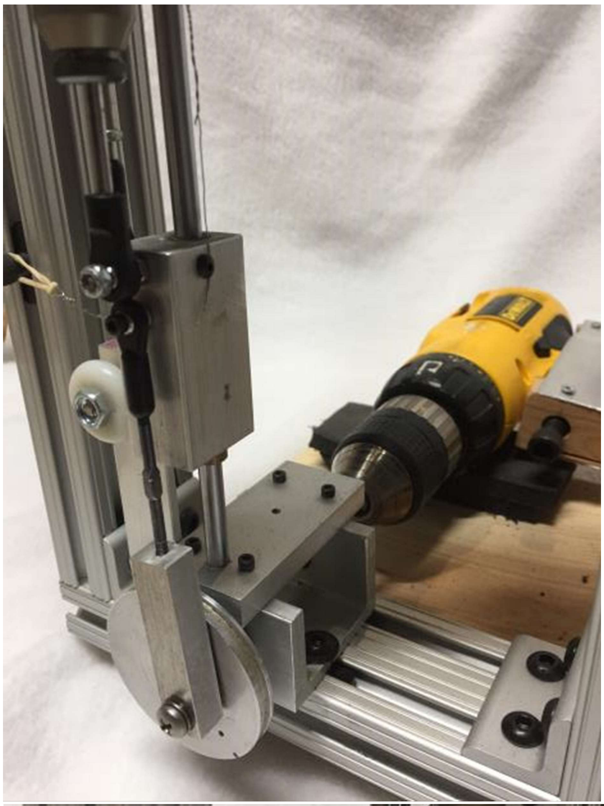
14. APPENDIX

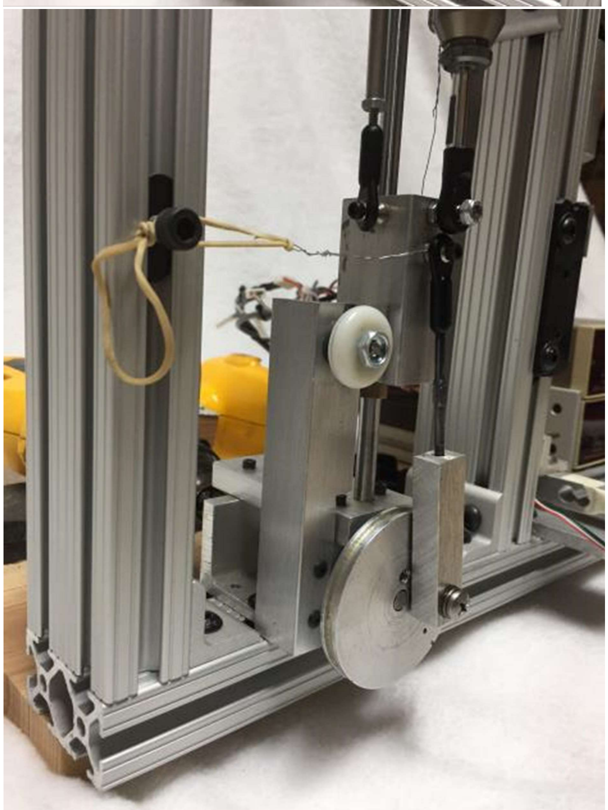
14.1. Scott Fredrickson's Exclusive Shock Dyno Written Work





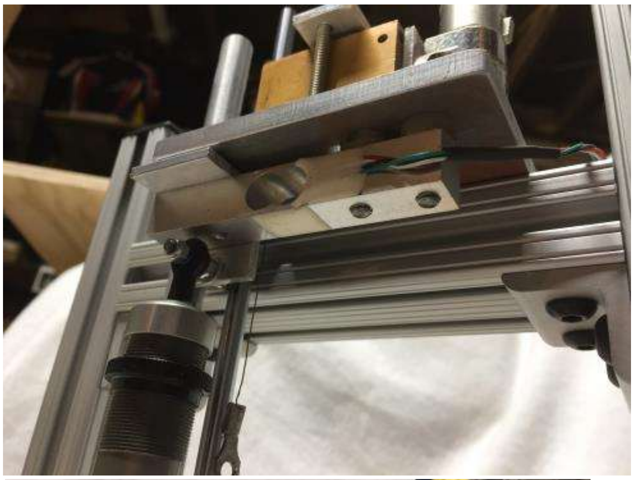
Overall photos of the dyno. The left shows the entire test rig (dyno and impact tester), with instrumentation. The tall square pillar with rod is part of the impact tester, and is not within the scope of this paper. The right photo contains the main dyno rig. Notice the base platform, the two vertical pillars, and the upper horizontal platform. The crank, arm, and shock are also apparent in the right photo. The drill, seen in the background is used to power the dyno.

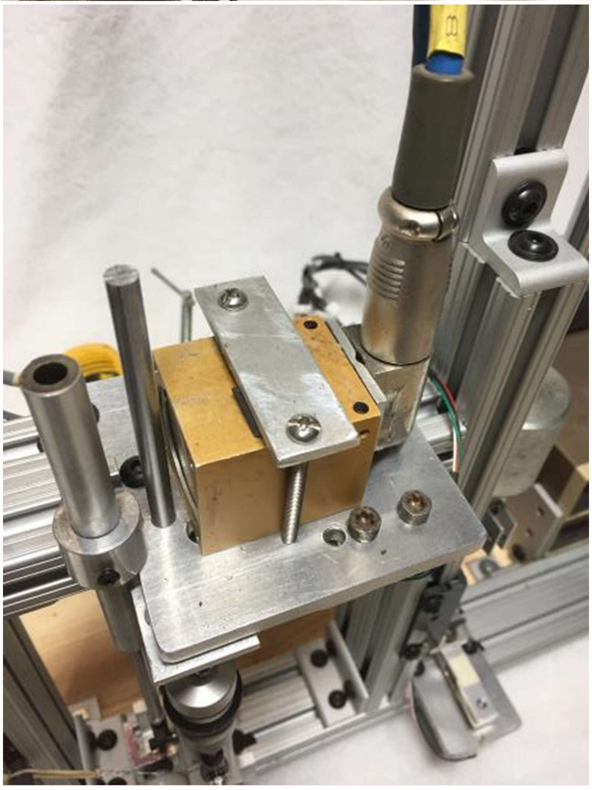




These photos highlight the base block with the crank, arm, and slider joints. The left photo shows the block with spacing on the bearings from the input shaft using a U-channel piece of aluminum. There are two bearings sized to fit on the uprights. The horizontal block with four screws is simply a flat piece of aluminum thick enough to support the vertical slider shaft. The crank pulley is an aluminum disk with a hole drilled at a radial distance to equal stroke/2. The crank arm is a standard turnbuckle with a plastic rod end on the top (it's just a pivot joint), and the bottom rotational joint was made with a square aluminum piece with a bronze bushing sized to fit over a shoulder bolt and into the block. This joint needs to be oiled.

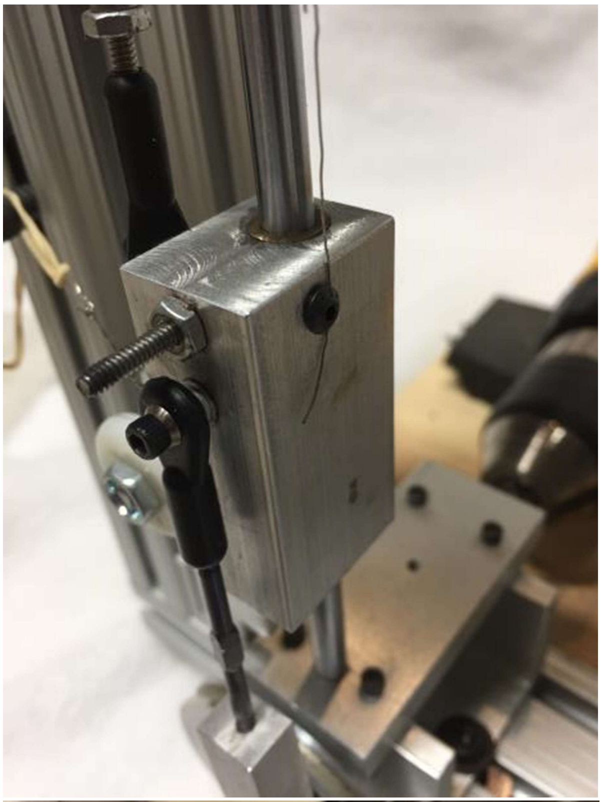
The right photo also shows the slider block. The height is to provide bearing stability for smooth sliding. The depth and width is to accommodate bushings and mounting studs. The plastic wheel was found to be necessary because as the crank rotates Counter Clockwise, the block would want to move side to side. The wheel prevents this motion. However, during a short portion of the motion, the block twists away from the wheel, so a simple spring (rubber band) provides plenty of reliable force to keep the block in contact with the wheel.





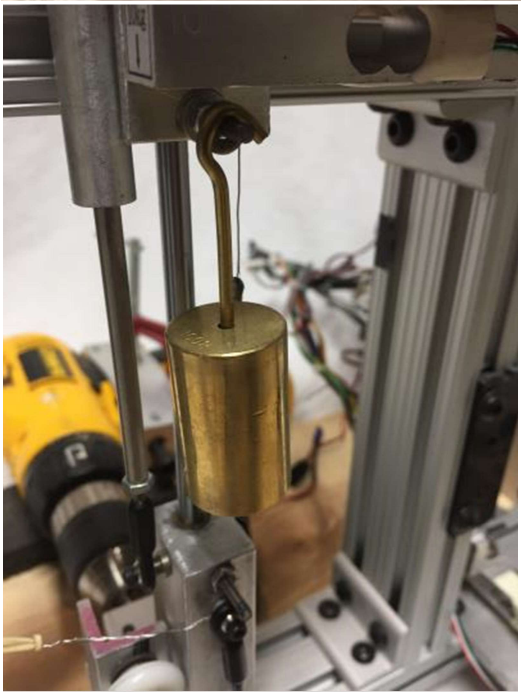
These photos show the upper platform. The left one shows the mounting of the strain gauge force transducer, and the shock. The right photo shows the upper part of the platform where you can see the string transducer (gold block), and the velocity transducer (hollow cylindrical tube). The slider shaft protrudes out the top to allow for upper platform height adjustability.

The left photo is the DATAQ data acquisition unit used to sample and collect the data. You can see I've connected up four channels. The dyno only uses three channels (D DISP, FORCE, VELOC). The right photo is the strain conditioner used to amplify the force transducer, only the top one is used for the dyno.

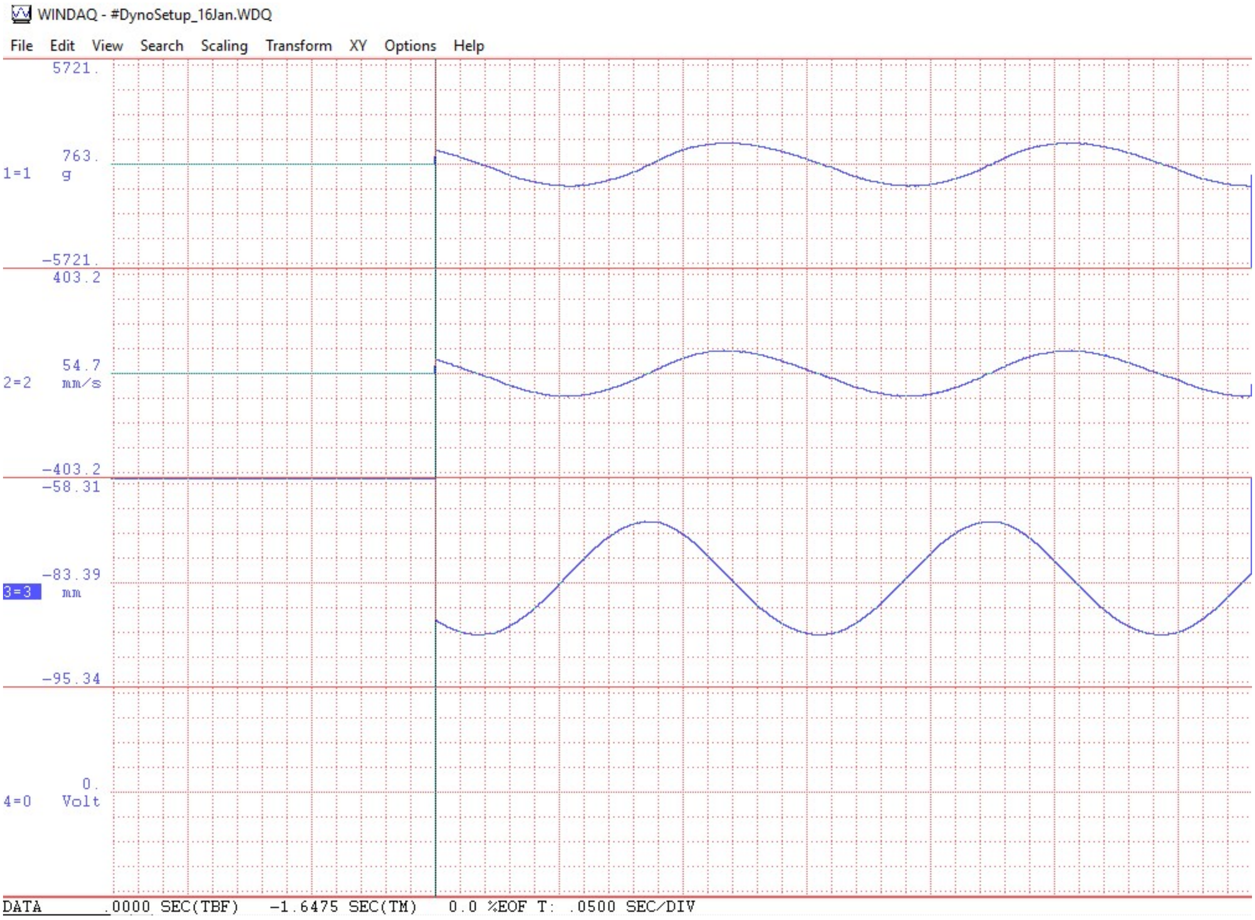


The left photo shows detail of the slider block. Notice the bronze bushing pressed into the block, the small screw holding the string transducer wire, the arm eyelet attached to the front of the block, and most importantly, the stud to hold the shock lower rod end. I recommend a stud because it's steel and you won't wear out aluminum threads. You can lock in the stud with the nut and Loctite. Then the rod end can be secured with a basic nylock nut for no play. The upper mounting position was made to center the shock underneath the strain gauge transducer to prevent twisting. The L-bracket was attached to the top making contact, then it comes down the back without contact, and a screw is used as a stud to hold the shock. The washer is used to ensure vertical alignment of the shock. The studs might be the weakest points of the structure being a cantilever design. However, it allows for better securement of the ball-ends to prevent slop. With a u-shaped clevis, it’s more difficult to get a good solid hold of the rod end because you need tight tolerances to fit into, and you must rely on pinching the ball. This design also makes it easier to install/remove the shock for multiple testing iterations. I believe the forces in the shock are low enough to make the deflection of these components negligible compared to the parameters being measured.

To test the shocks and reduce play, the cap must be modified to have a plastic ball end on it. Cut off the eyelet to make a flat surface, and drill a hole through it at the tap size of the screw. This way, you can seal the screw/hole with thread lock and simply mount the rod end onto a stud. I tried many other ways to reduce the slop before resorting to this modification, but once I did this, the data became perfectly slop free from the exterior mounting.

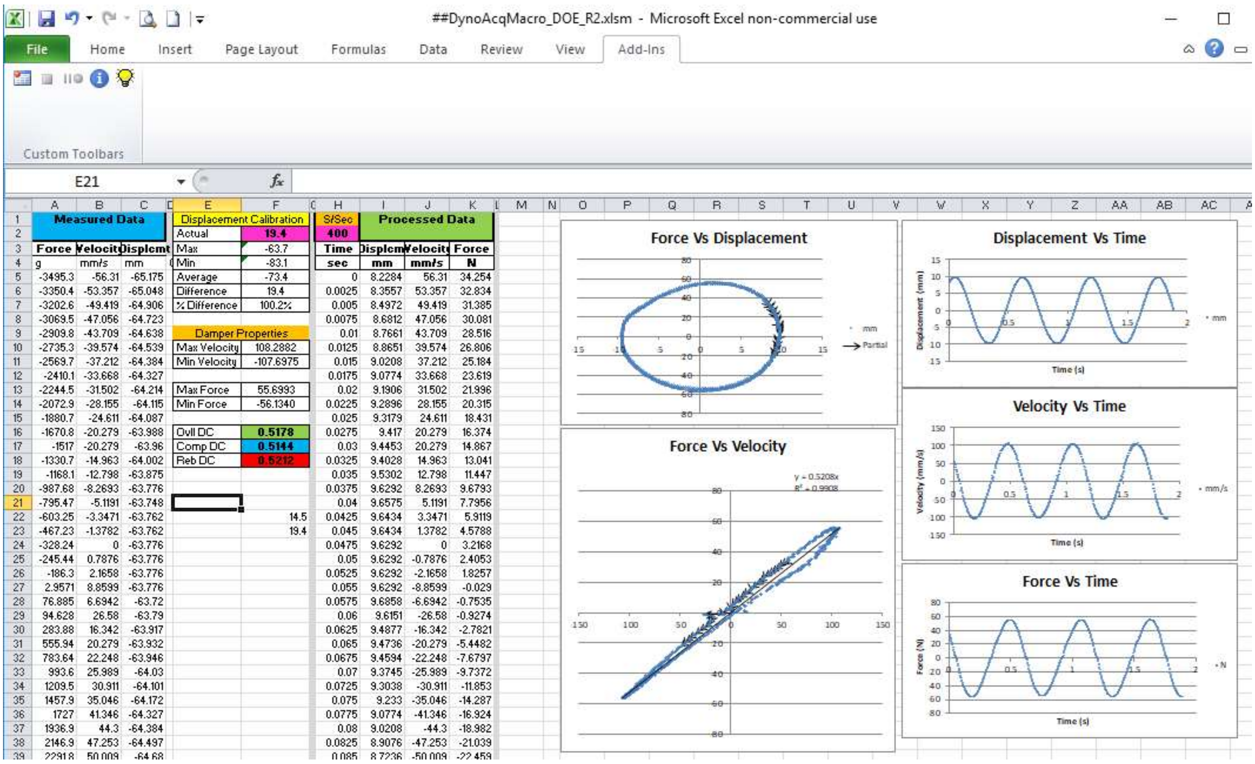


To calibrate the force transducer, I simply used a set of weights (verified the weight values with multiple scales and averages), and hung them from the force transducer's stud mount. I then adjusted the strain conditioner until it read the proper weight value for the force.

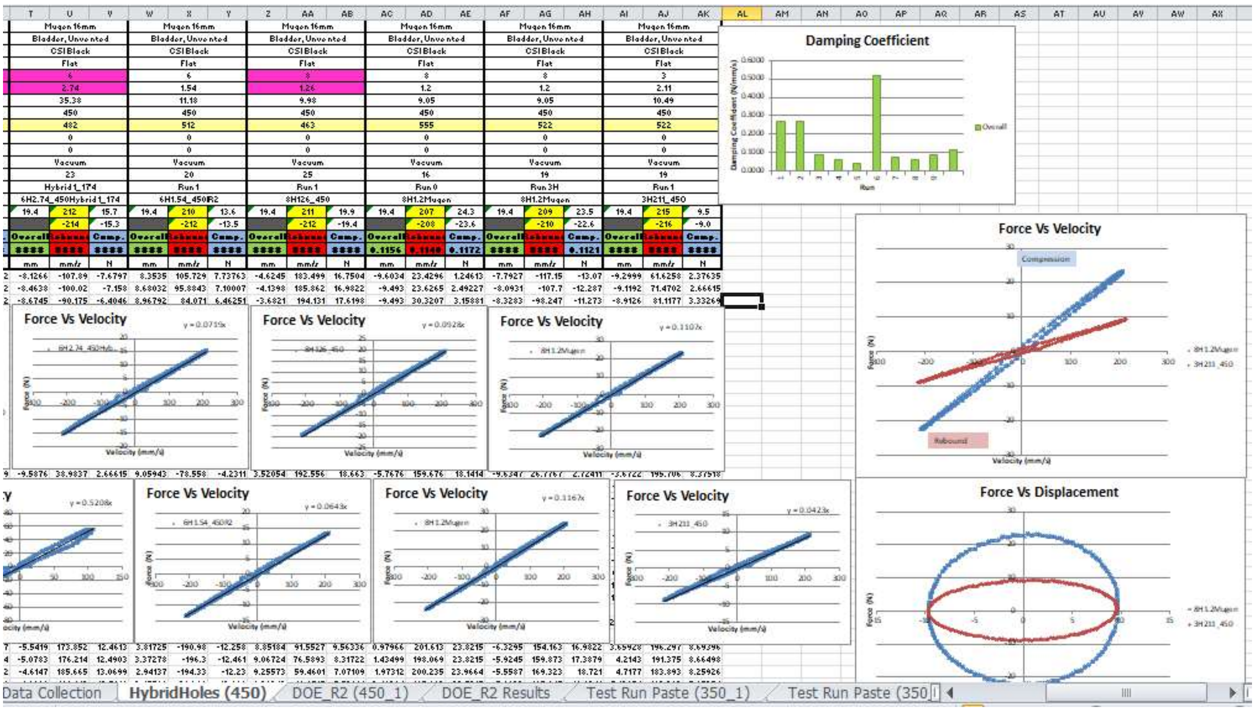


Screenshot of the WINDAQ software as I see it while collecting data. Each wave is one channel of data. In this case, the top channel, Ch 1, is the force in grams. Ch2 is the velocity in mm/s, and Ch3 is the displacement in mm. You will notice I'm using grams instead of Newtons. If I recall, I did this so I could quickly check my calibration by hanging a weight and making sure that number matched. I did the conversion later in post-processing. The velocity is accurate, but you can see my displacement seems to be way off. The number shown is somewhat irrelevant, but what is important is the peak to trough height difference. In this case, it is 19.4mm which is the actual stroke length. In post processing, I zeroed this value out so that BDC is zero, and TDC is 19.4mm. I had to do this because while the relative linearity was consistent, the absolute value changed over time because the batteries I was using as excitation would drop in voltage. Doing a calibration in post processing eliminated drift concerns.

If you look at the waveforms, you can gain an intuition of the data by drawing a vertical line through all of the waves. You can see how the force and the velocity are in phase, while the displacement is 90deg out of phase. So, this makes sense. When the displacement is in the middle of the stroke, the velocity is highest, and thus, the force is highest. When the displacement reaches either BDC or TDC, the velocity becomes zero as the rod changes direction and thus, the force drops to zero as well. The zero's will always happen no matter how fast or slow you spin the crank. The speed of the crank will only affect the peak velocity (and the resultant force) you see in this graph. The displacement will never change as long as you don't have something mechanically failing.



This is my Excel sheet that I use to collect the data. Notice the small icon with the red dot right below the "file" menu item. That is the add-in macro button that ties directly to the WINDAQ software. I click this when I'm ready to record, it records for a few revolutions, then it pastes the data into the first three columns. I have the graphs set up so I can quick glance and make sure it makes sense (looks like what you see, and not some really wild lines all over). The processed data under the green cells are where I have my equations to take the raw data and convert to Newtons, mm/s, and mm since they needed a little bit of calibration manipulation. I then also have the sampling rate (400 S/sec) to fill out the time difference between each data point. Once I have this, I have another macro to copy the processed data, then I paste it into the next sheet (below) to compare the data and generate the damping coefficient.



This is where the data gets incredibly lengthy, and I'll admit, this isn't the most efficient way of viewing and comparing data. Custom code could easily clean this up. Perhaps Access would be a good way to dump the data and easily sort it for comparisons.

14.2. Scott Fredrickson's Calibration and Processing Method

Each of the channels is set up as a units/V per the transducer that is connected. Again, for example, the displacement has a constant excitation voltage input, and a proportional voltage output linearly related to the distance the string is pulled due to the change in resistance of the potentiometer. Since the output voltage is linearly proportional to the displacement, you can plot the units on the Y-axis, and the voltage on the X-axis for multiple points, and the slope of the line becomes your calibration conversion factor in units/V. You may also want to set your Y-intercept in case there is an offset to begin with. This is called your Zero balance. Find the voltage at your lowest point (Bottom Dead Center), and simply make that displacement value zero at whatever voltage it happens to be, call it Vo. Then any displacement value above that will have a corresponding voltage, call it V1. So, your total displacement = (V1-Vo)*slope. This will be the position of your rod end at any point in time that you have a measurement value. All you care about is its position relative to BDC, so make that zero, or reference value. It makes no difference what the absolute value is within the shock body (as long as you aren't at the extreme ends of travel). This greatly simplifies any potential fluid dynamic complexities.

The same procedure as above can be done with Velocity, but you need some way of calibrating. Since you have calibrated your displacement transducer with precise measurements and voltage readings, you can now trust the displacement measurement. Now, you can set up your data acquisition to record displacement. Since you will be sampling in a digital format, e.g. one discrete positional data point for each time increment point, you can calculate the displacement and divide by the time. This is where you may want to get creative and take many points so you can average out many readings. Averaging several points will statistically hone in on the true calibration value (slope) of the velocity per voltage output. It is critical that the displacement and the velocity transducers are connected to the same bodies of motion and travel in parallel paths so they are both reading the same values. Once you calculate the slope, this becomes your calibration value in mm/s / V that you will use for your data acquisition.

The force transducer is a little more complex, but it ends up behaving exactly the same way as the others in that it will output a Force / V. The only difference is that the actual strain gauged instrument must first pass through a strain amplifier to supply that output. A good strain amplifier will provide a stable excitation voltage to the gauges. Then, it will perform its Wheatstone bridge magic to provide an amplified voltage signal output that is large enough to measure and read by your data acquisition unit. But before doing this, you must calibrate the output first. Fortunately, with a good conditioner, this too is a simple process. First, set up the force gauge so that gravity will allow you to hang a weight from it in the same (or directly opposite) direction as your force from the shock. It doesn't matter if the force is pushing or pulling (bending up or down), because it is linear in both directions. Next, make sure there is no weight on it other than your usual mounting hardware you will use to hold the shock (that weight will be measureable). Then, on your strain conditioner, turn the dial that says "zero" until the numbers read 0.00 on the display. It may be quite sensitive, but get it close for now. Next, hang a known weight from it and turn the "span" dial until the display reads that weight value (I recommend making that known weight in Newtons to make all your analysis easier). Use a weight that you expect to be a little higher than the maximum force you expect, this will ensure your measurements are always interpolating rather than extrapolating to reduce the measurement error. Now, you might notice that it won't display 500, but it will display 5.00. This is a simple move the decimal solution because the conditioner is outputting the voltage you see in the display, so obviously, it won't be outputting 500V. It should be pretty apparent, and it's easy to adjust in the calibration settings. This process sets the two points of your linear line… first your zero, then your end point. Now, you may find when you remove the weight, it doesn't go back to zero. No problem, simply repeat this process a few times, and it will settle itself out. Sometimes, the electronics literally need to warm up to output stable values. To check the calibration, just hang another weight on it and it should be the exact value. Congratulations, you now have a fast response digital scale. Now that your strain conditioner is outputting a voltage signal that matches your force, you will need to use your decimal adjustment as your calibration factor, in other words, for the example above, you will say your cal factor is 1V/100N, or 100N/V.

14.3. Scott Fredrickson's Data Acquisition Method

Now that you have the dyno set up, instruments calibrated, and channels connected to collect data with the correct units, you must record that data to get it into some processing software to make comparisons and discoveries. As mentioned previously, this is where your sampling is important. Your data will follow a sinusoidal motion. Because you will be testing at known speeds (50-300mm/s), you can predict how many samples per cycle you will be getting based on your sampling rate. While too low of a sampling rate will miss a lot of positions during the cycle, too high of a sampling rate will create a large file size, or just a large amount of data to deal with. Sure, computers can handle large amounts, and honestly, each file size may still be less than 1MB, but there is another reason you don't need or want too fast of a sampling rate. The determining factor is the precision of your instruments. If your instrumentation gives you a resolution of only 1mm (exaggerating for example), and the sampling rate collects data every 0.001mm of actual travel, you simply have 2 "good" data points, and 998 "bad" or redundant data points. Depending on how you have your analysis sift through the redundant points, it might end up showing you "noisy" data, which sometimes is worse than no data. I was a test engineer for 15yrs, and one thing I really learned is to not overdo your data. Keep it as simple as possible while still being able to capture what you need, and this will make your life a whole lot easier. Believe me on that one. This was a very hard concept for me to teach the PhD's I worked with, but sooner or later they figured that out too.

Like I mentioned earlier, I ended up settling on 400Hz sampling rate, and I found it produced good consistent results capturing the data I needed to compare damper behavior for cyclic motion at velocities under 300mm/s. For the most part, you will be looking at Force/Velocity curves on the macro level. If you are looking for subtle nuances, such as piston "slop", then you may need to increase your sampling rate to see the step changes near the zero velocity regions. 400Hz will still capture most of that slop though, and higher rates will provide diminishing returns. I encourage you to test this out yourself, but I just wanted to give you a starting point. One way I could make a good visual reference was to look at the individual captured data points, not a curve, plotted on a graph. If the gaps between the points appeared to be too far apart, my sampling rate wasn't fast enough. If the data points appear to be nearly touching, the sampling rate was good. If the data points appear to create a line, the sampling rate was too high.

14.4. Scott Fredrickson's Post-Processing Method

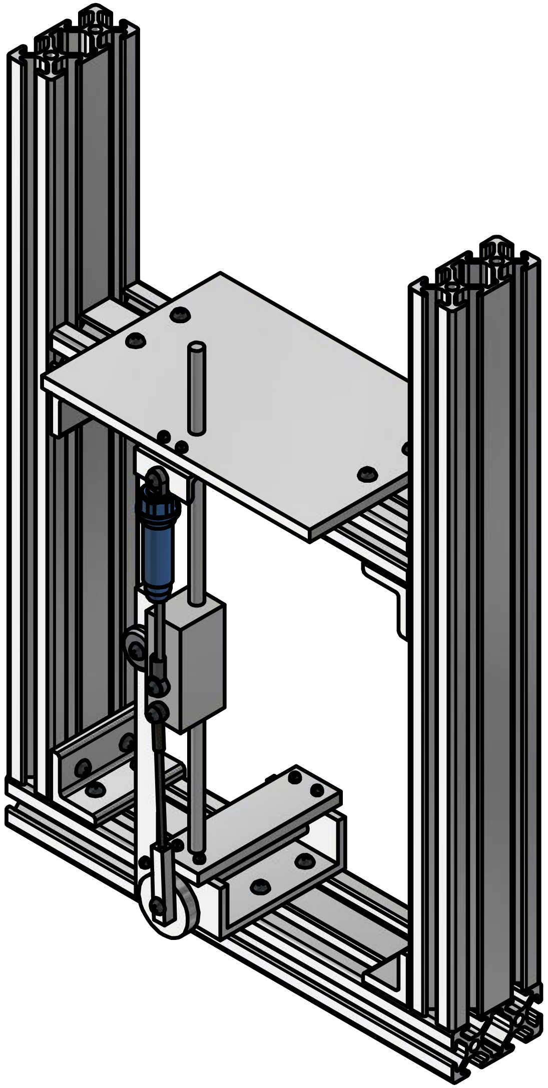
Ok, the fun part: organizing your data to produce graphs and numbers that you can use to characterize each damper combination. There are many ways in which you can do this: hand drawn graphs (yeah right!), custom coded MATLAB program (awesome and powerful if you can do it), or a simple spreadsheet (most universal, and it gets the job done). I used excel because that is what I knew best. So, I'll explain the post processing goals, then I'll explain how I accomplished them using excel to do it.

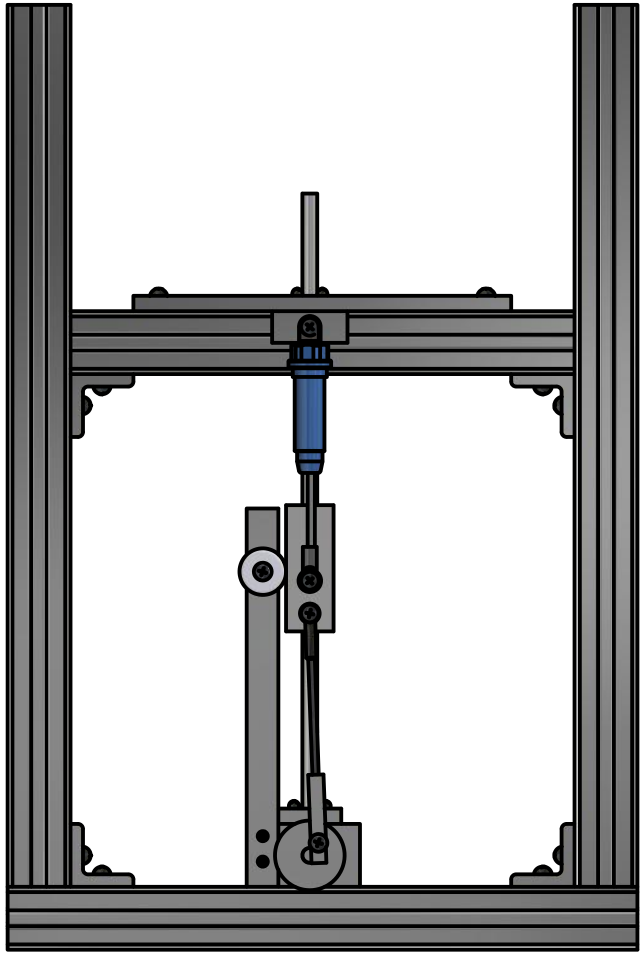
The two most basic graphs you will produce are the Force vs Displacement curves (FD), and the Force vs Velocity curves (FV). These two graphs alone will accomplish the most fundamental characterization of damper performance. I'd argue, the FV graph is THE most important because it gives you the actual damping coefficient value. The subtleties of the FV curve and the FD curve will help you understand the operation of the damper as it goes through its cyclic motions, but the FV curve will provide the most important properties of the damper: damping force, or the resistive friction to the motion. Since a damper's force is speed dependent, this makes velocity king.

To generate each of these curves, all you have to do is simply align the force, velocity, and the displacement at each point in time (each sample). Then, you plot the displacement or velocity on the X-axis, and the force on the Y-axis. How easy is that! In excel, the beautiful thing is that if you set up your data acquisition to output your data in excel format, it will do that exact alignment because that is how it collects the data. For each sample, it takes a snapshot of each measured channel and records all of them at the same time. So, in excel, each row will show up with four columns of data TIME, DISPLACEMENT, VELOCITY, FORCE. Then, you simply plot them as they sit next to each other.

With my data acquisition unit (WINDAQ), I was able to purchase an additional software that is a plugin for excel. This allowed me to control the data transfer directly to start and stop the DAQ unit with a macro button in excel. A timer was set to record a certain amount of data so I would be consistent each time (not important, but kept the acquired data manageable). Since the motion is cyclic (repeatable over and over) you really only need to capture a couple of revolutions. I made the assumption that the first two revolutions were the same as the 32nd revolution and the same as the 100th revolution (it didn't matter statistically once it reached steady state**). So, capture was just a snapshot sample. I'd often get three runs to compare to make sure I didn't get some kind of outlier, but I eventually found the data was quite repeatable. **One thing to consider though was that as you cycle the damper, the oil WILL heat up, and change the viscosity, thus, reducing the damping coefficient. So, when making comparisons, I tried to keep my "warmup" cycles and timing between runs consistent. It did take a pretty big difference in run time to show any noticeable difference, so just keep your run times within reason of each other.

14.5. The Shock Dyno Blueprints





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UNIVERSITAT POLITECNICA DE CATALUNYA	MACHINE TO MEASURE THE CHARACTERISTICS OF THE DAMPERS OF A RADIO CONTROL VEHICLE		
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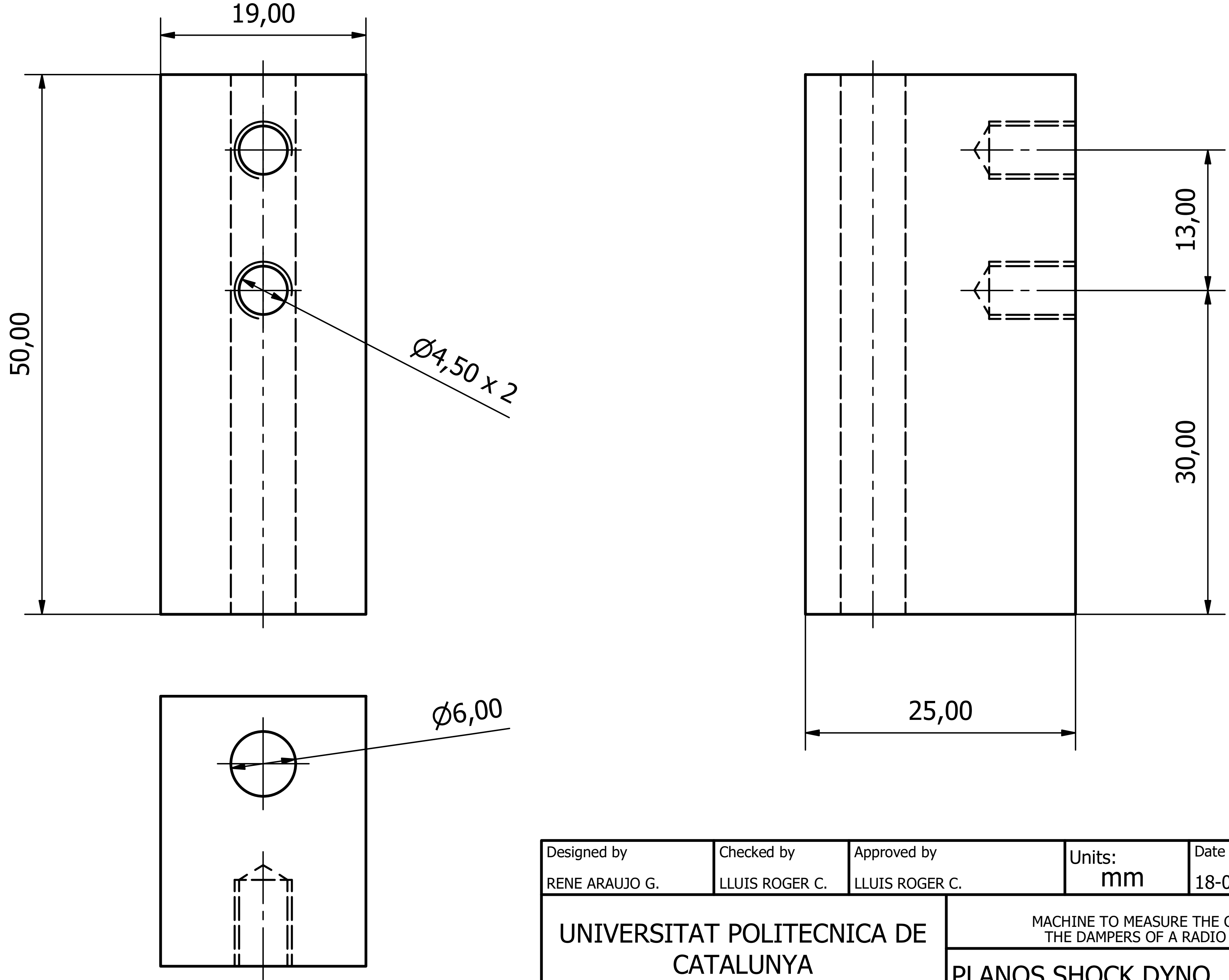

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	PLANOS SHOCK DYNO	Edition	Sheet 2 / 21

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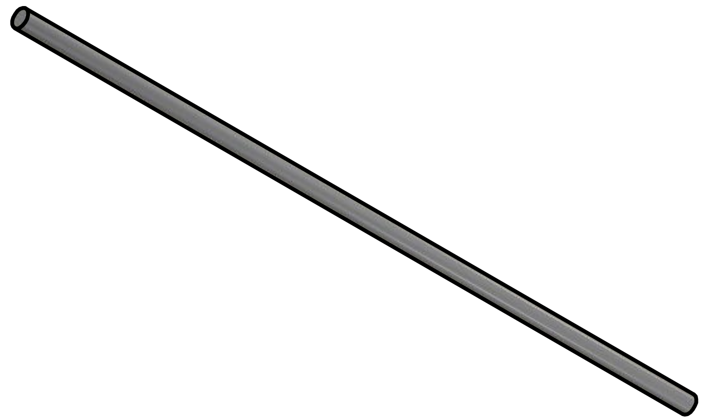

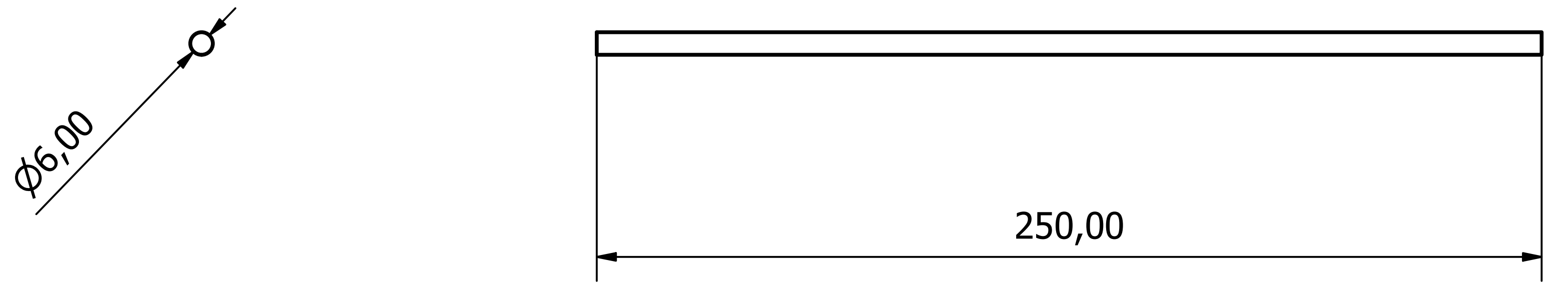

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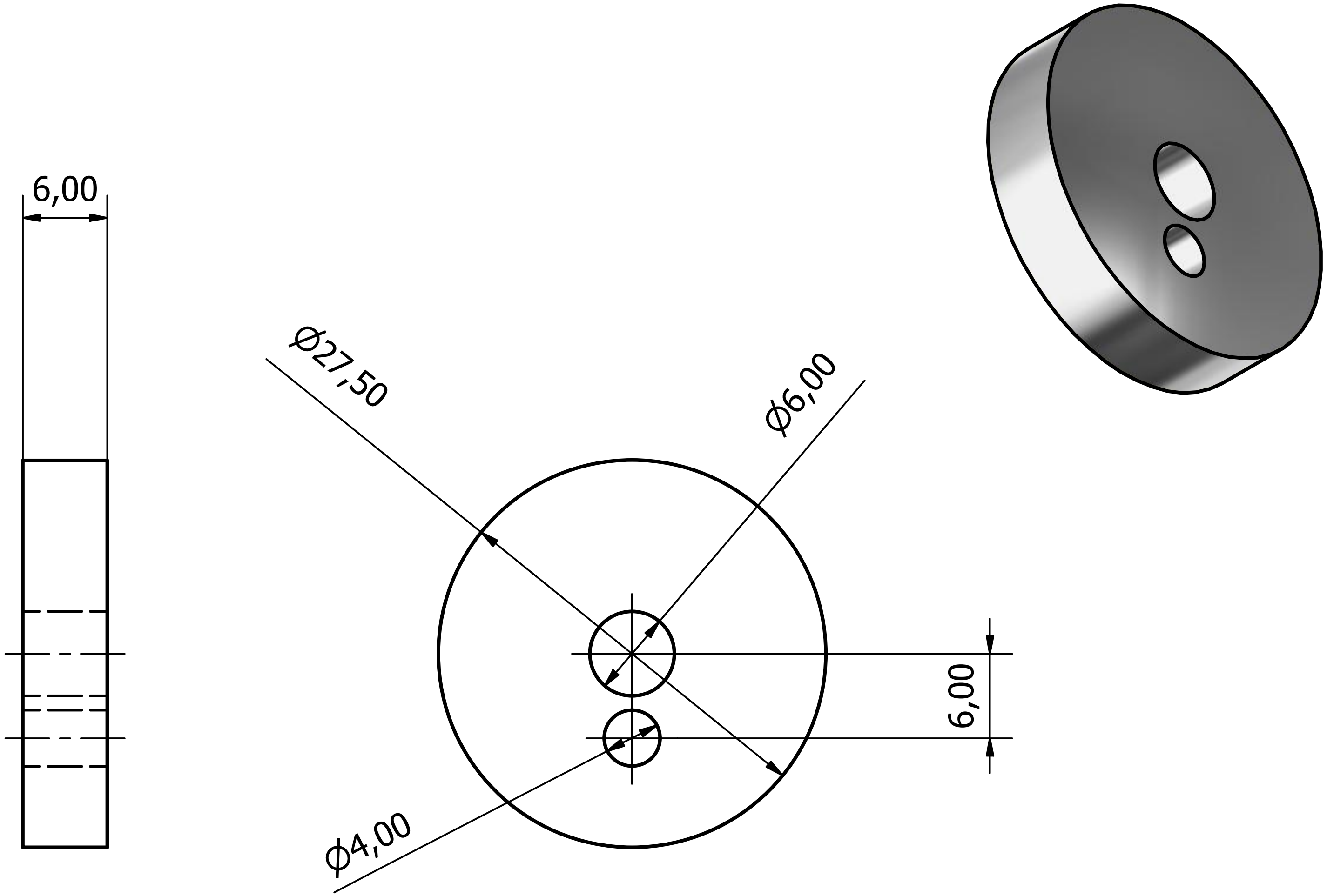

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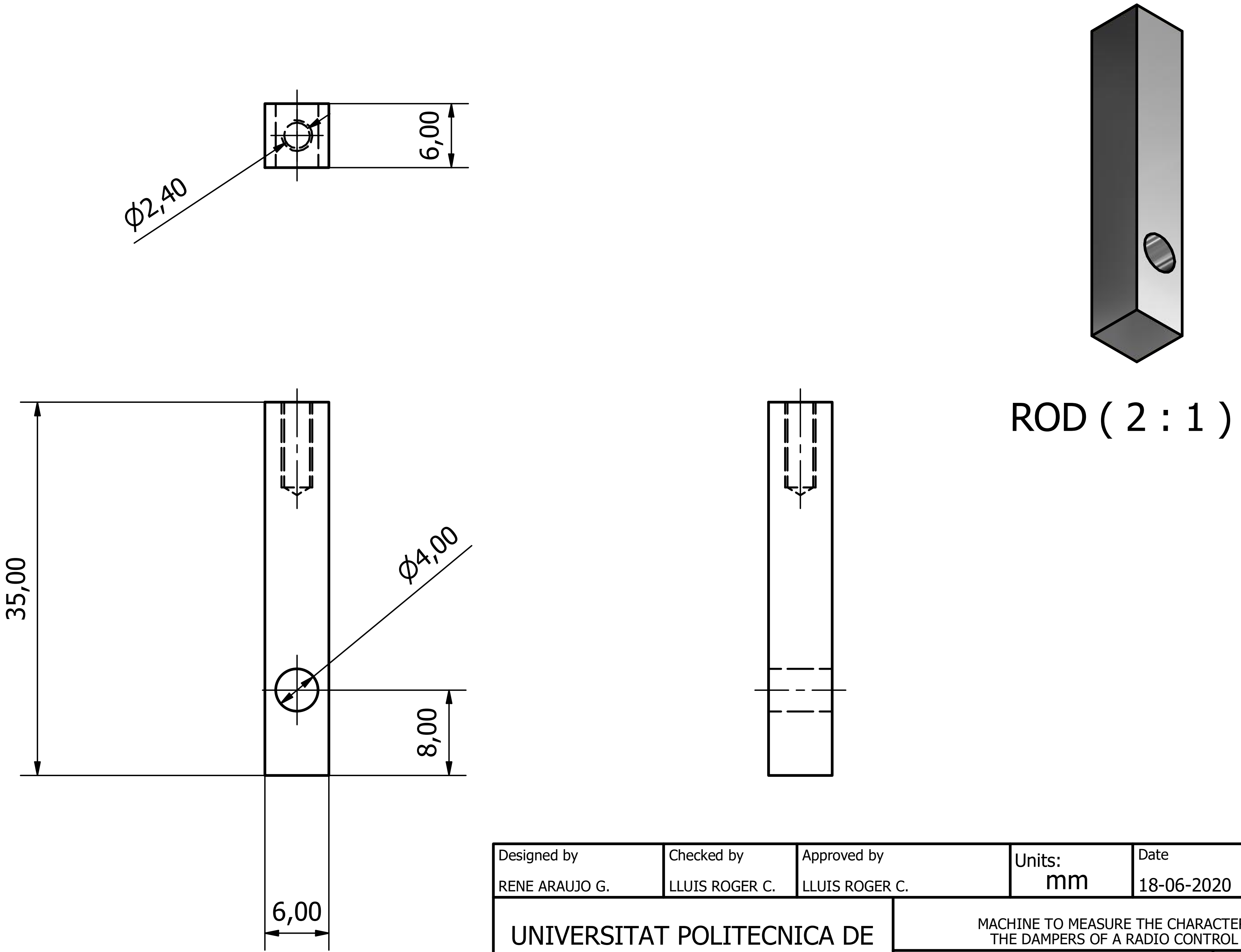

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	PLANOS SHOCK DYNO	Edition	Sheet 5 / 21

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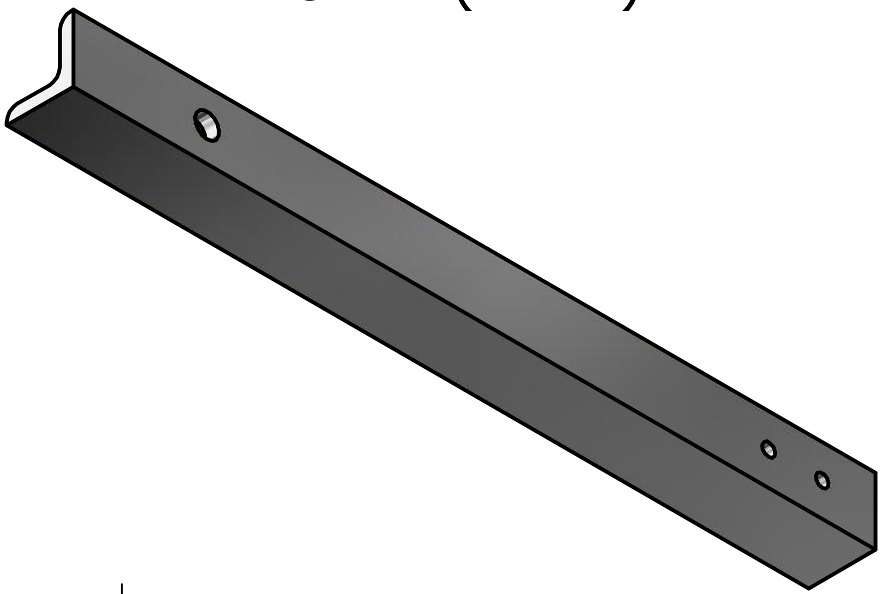

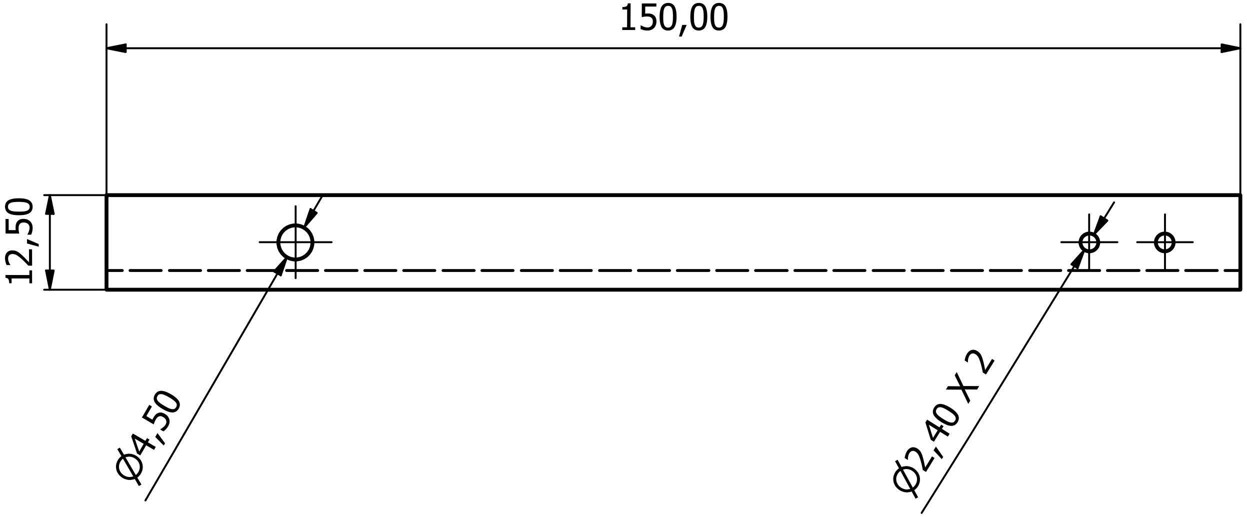

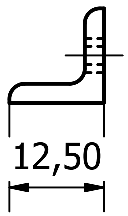

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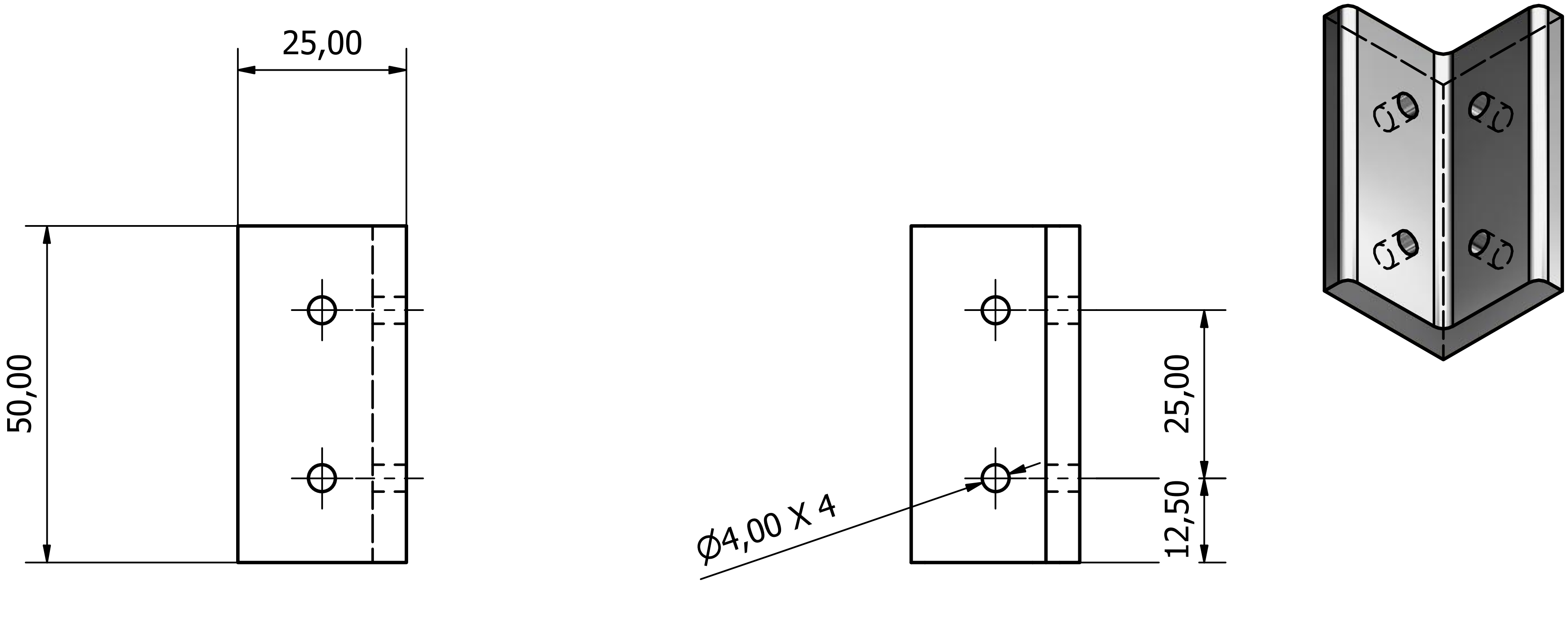

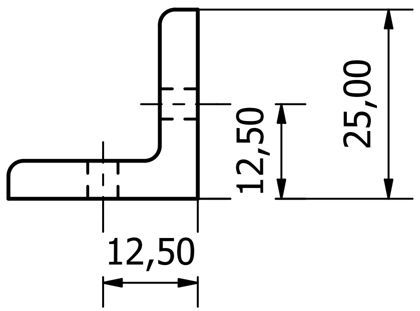

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	PLANOS SHOCK DYNO	Edition	Sheet 7 / 21

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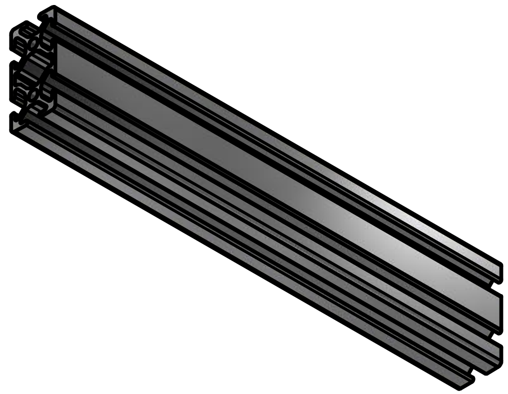

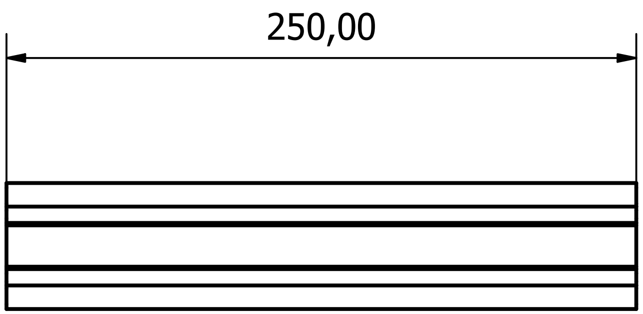

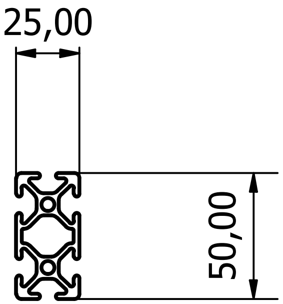

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		PLANOS SHOCK DYNO		Edition	Sheet 8 / 21

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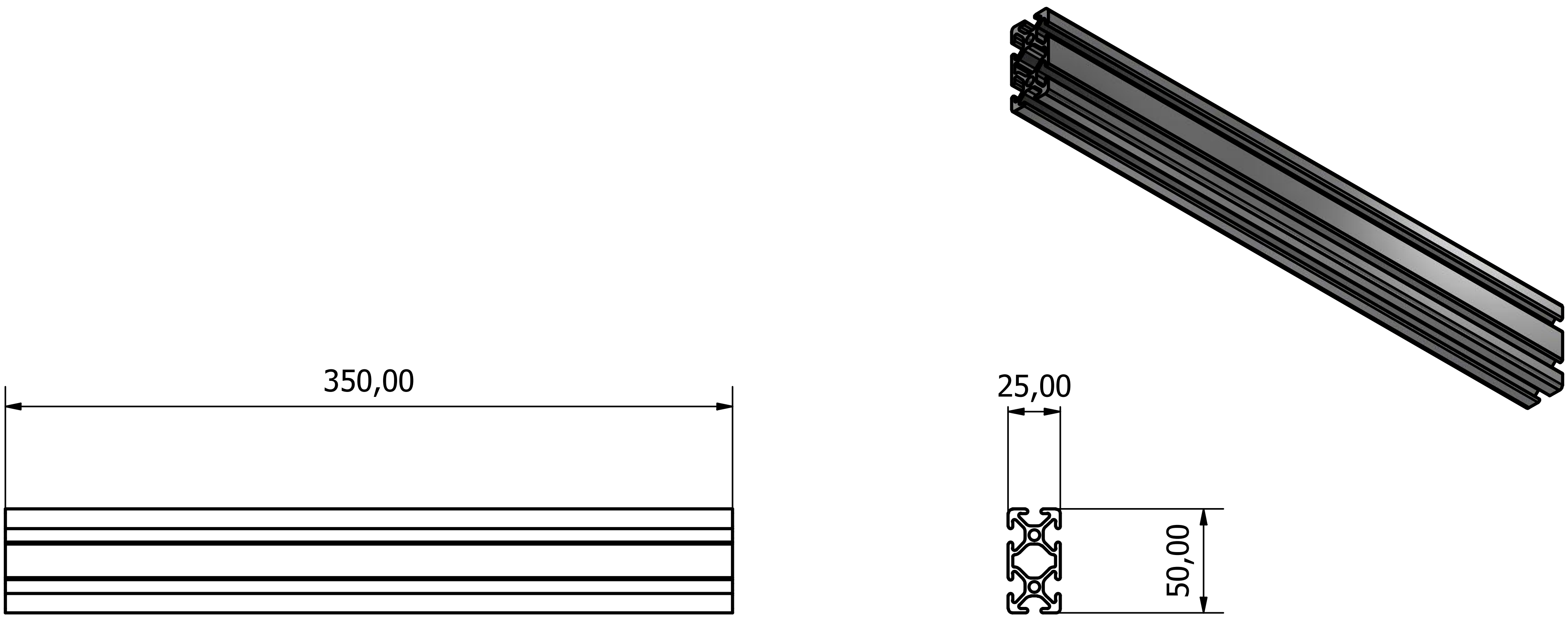

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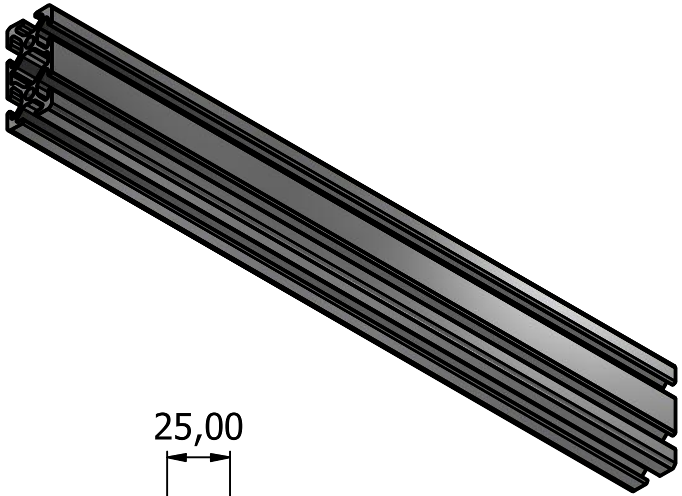
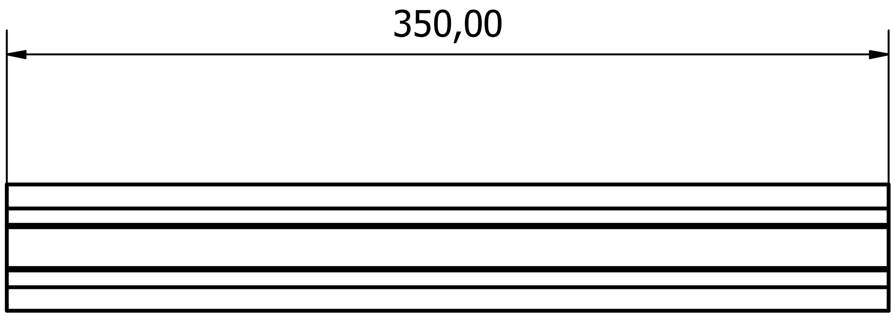
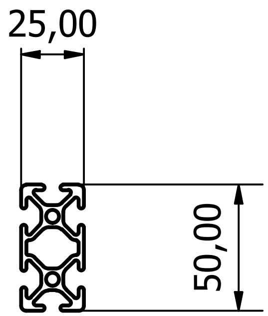
	PLANOS SHOCK DYNO	Edition	Sheet 9 / 21

FRAME (1 : 3)







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RENE ARAUJO G.	LLUIS ROGER C.	LLUIS ROGER C.	mm	18-06-2020	
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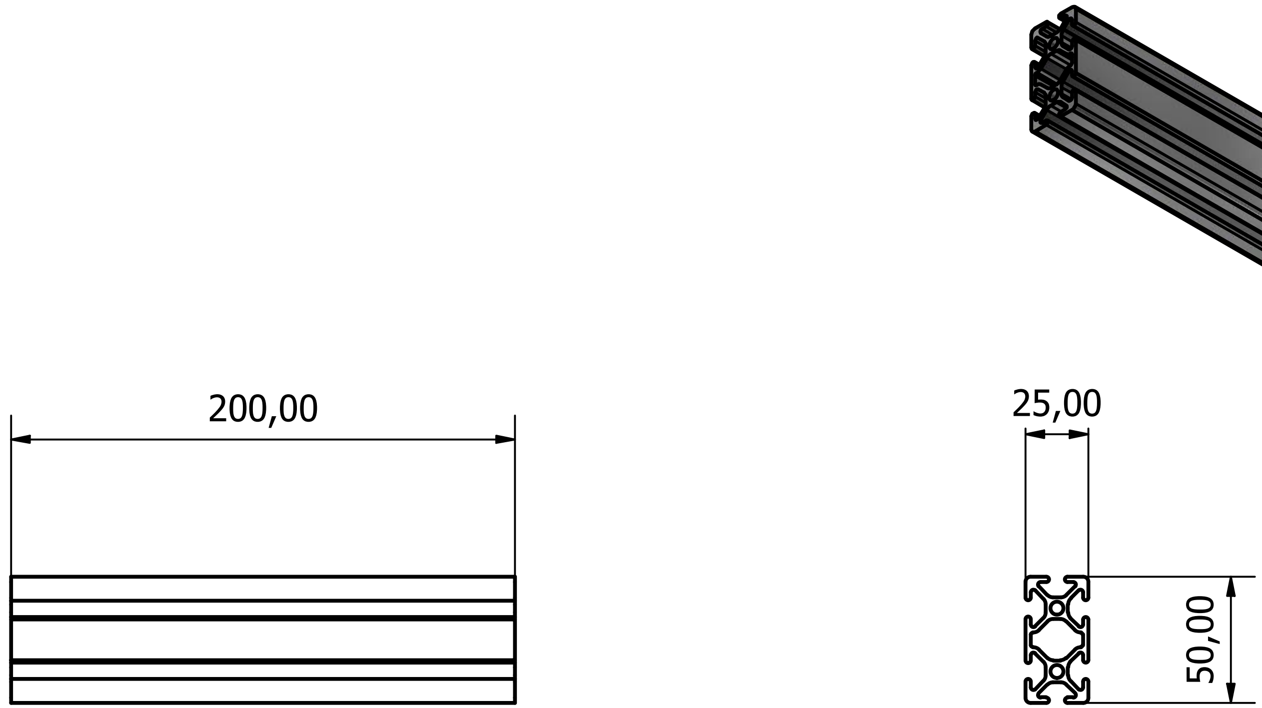
FRAME (1 : 3)



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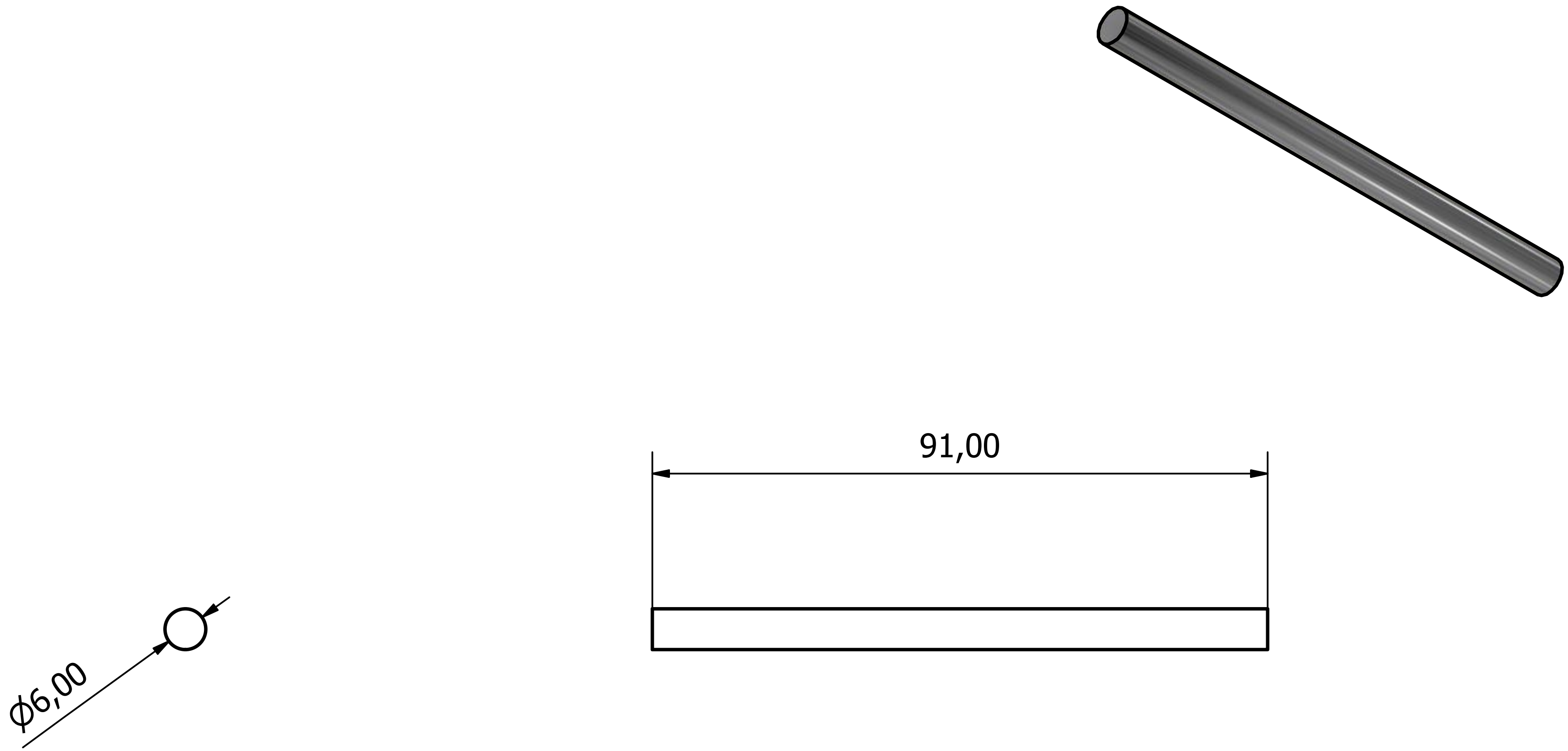
SHAFT (1 : 1)



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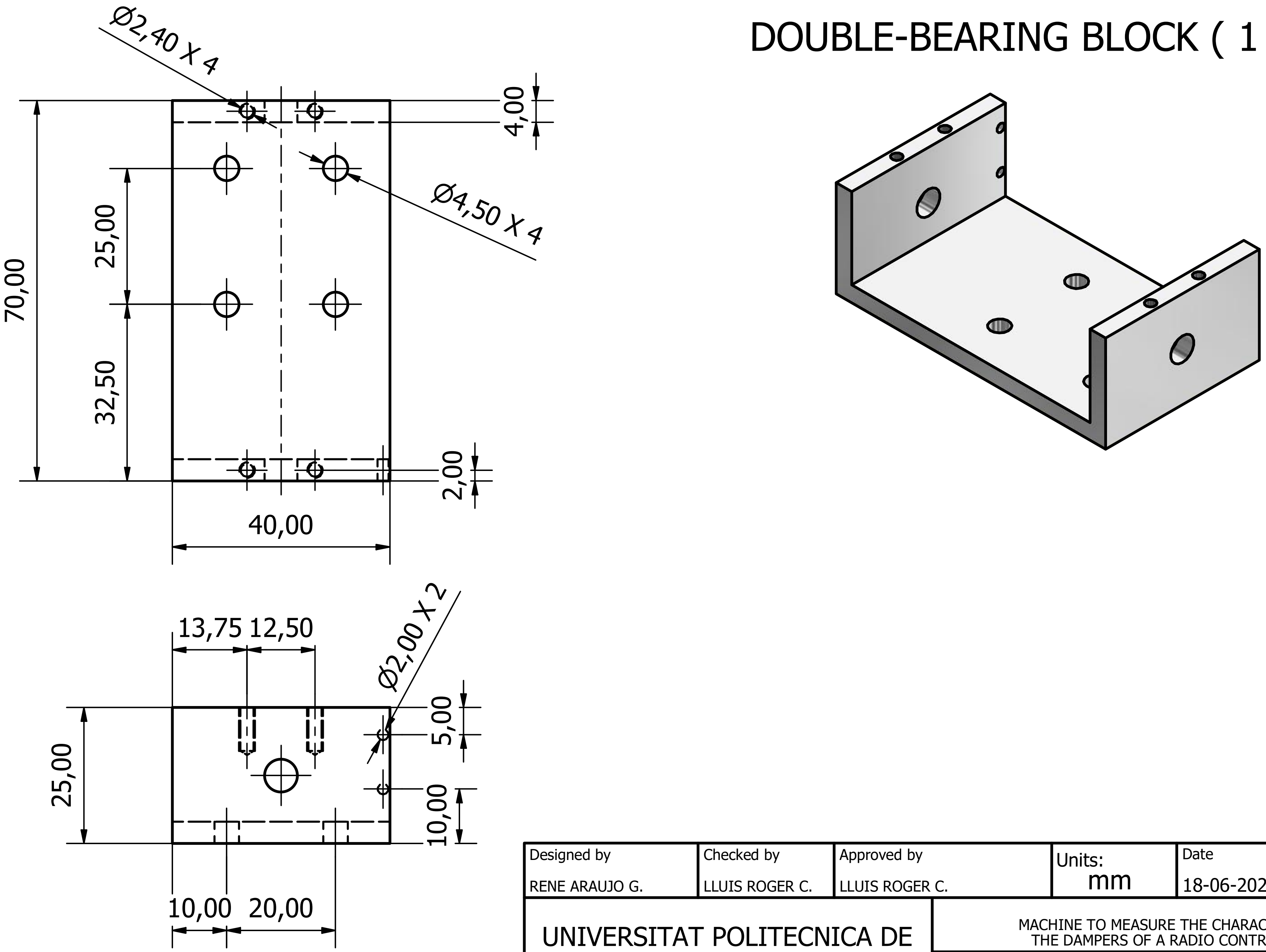
DOUBLE-BEARING BLOCK (1 : 1)



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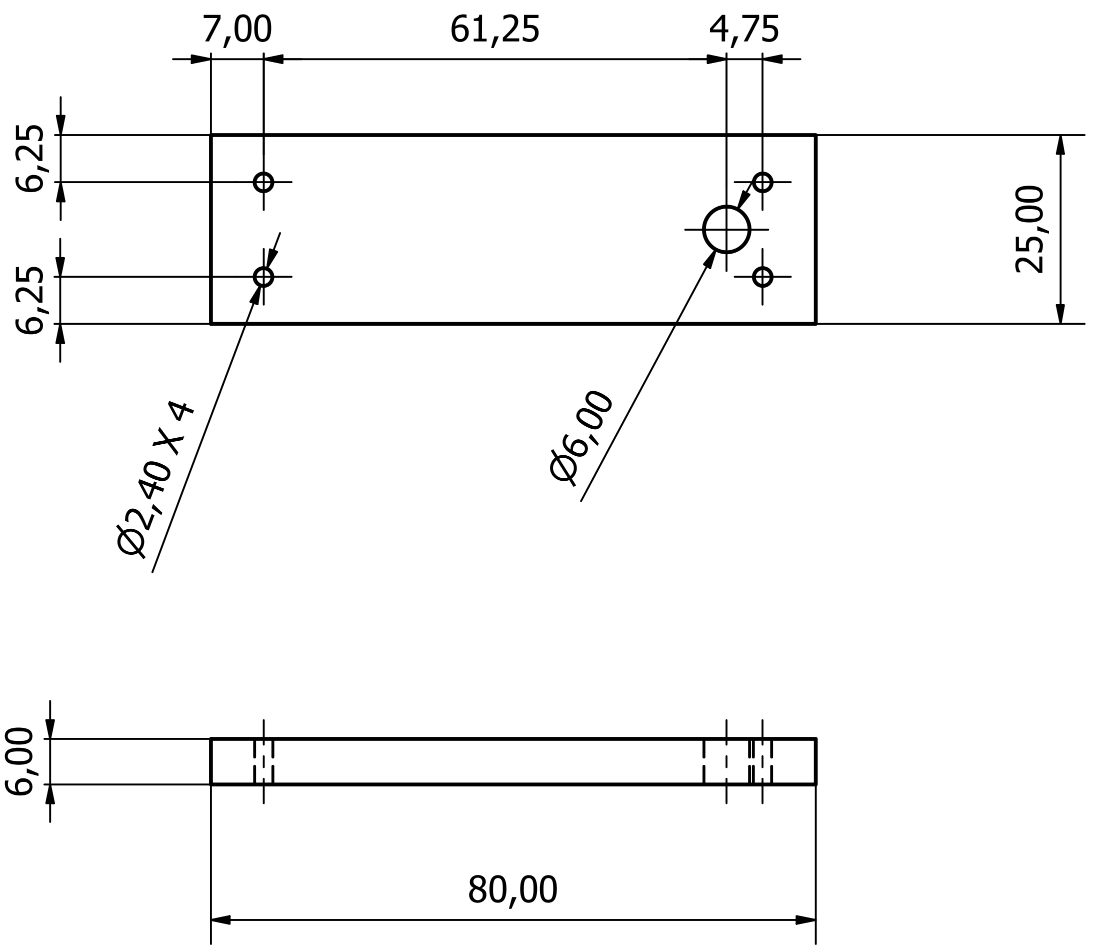
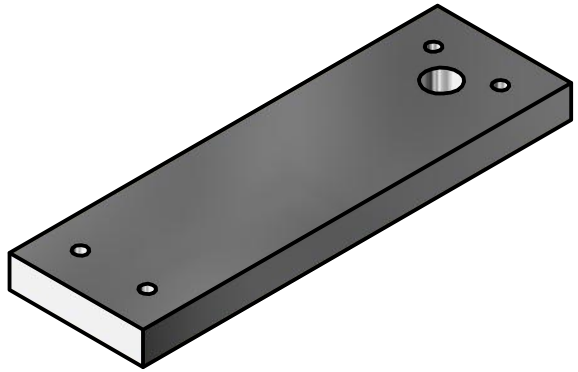
LOWER PLATE (1 : 1)





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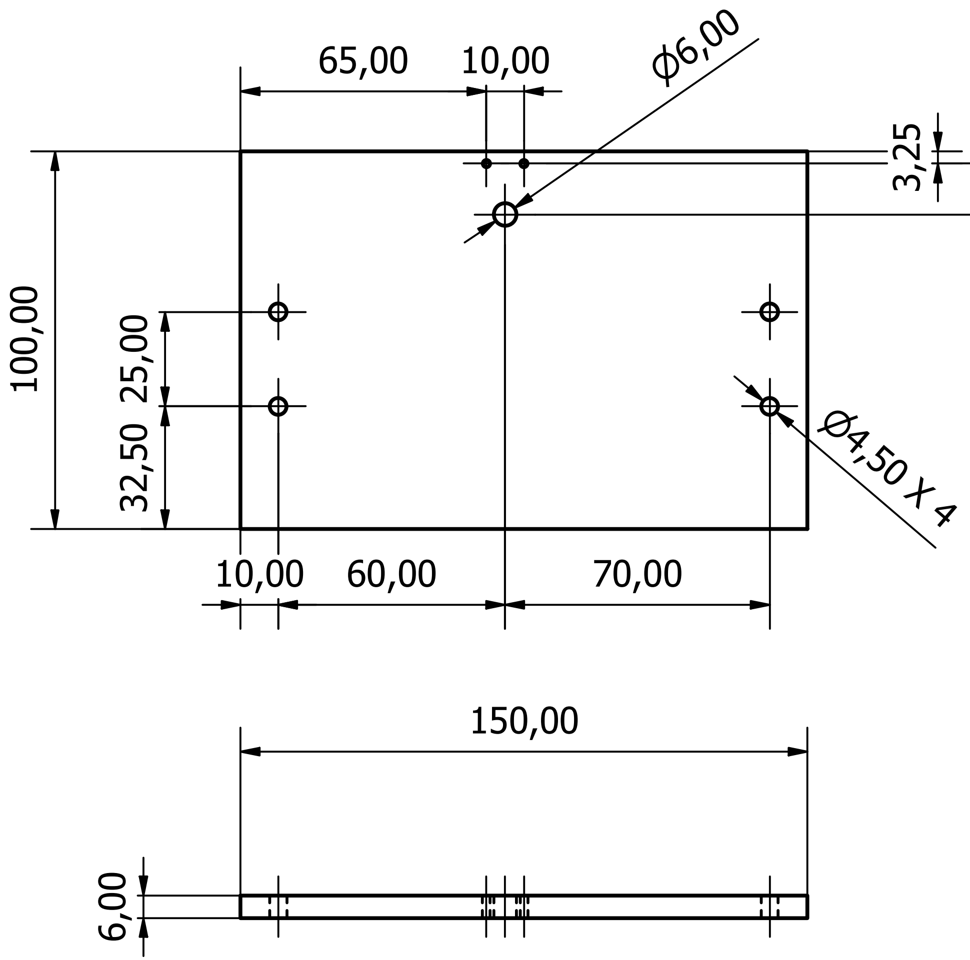
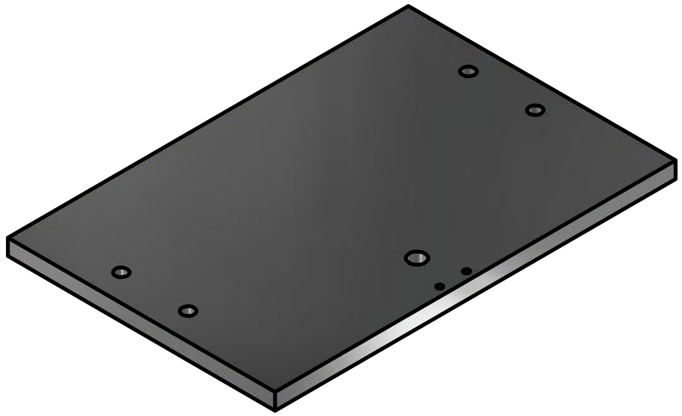
UPPER PLATE (1 : 2)





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UNIVERSITAT POLITECNICA DE CATALUNYA		MACHINE TO MEASURE THE CHARACTERISTICS OF THE DAMPERS OF A RADIO CONTROL VEHICLE			
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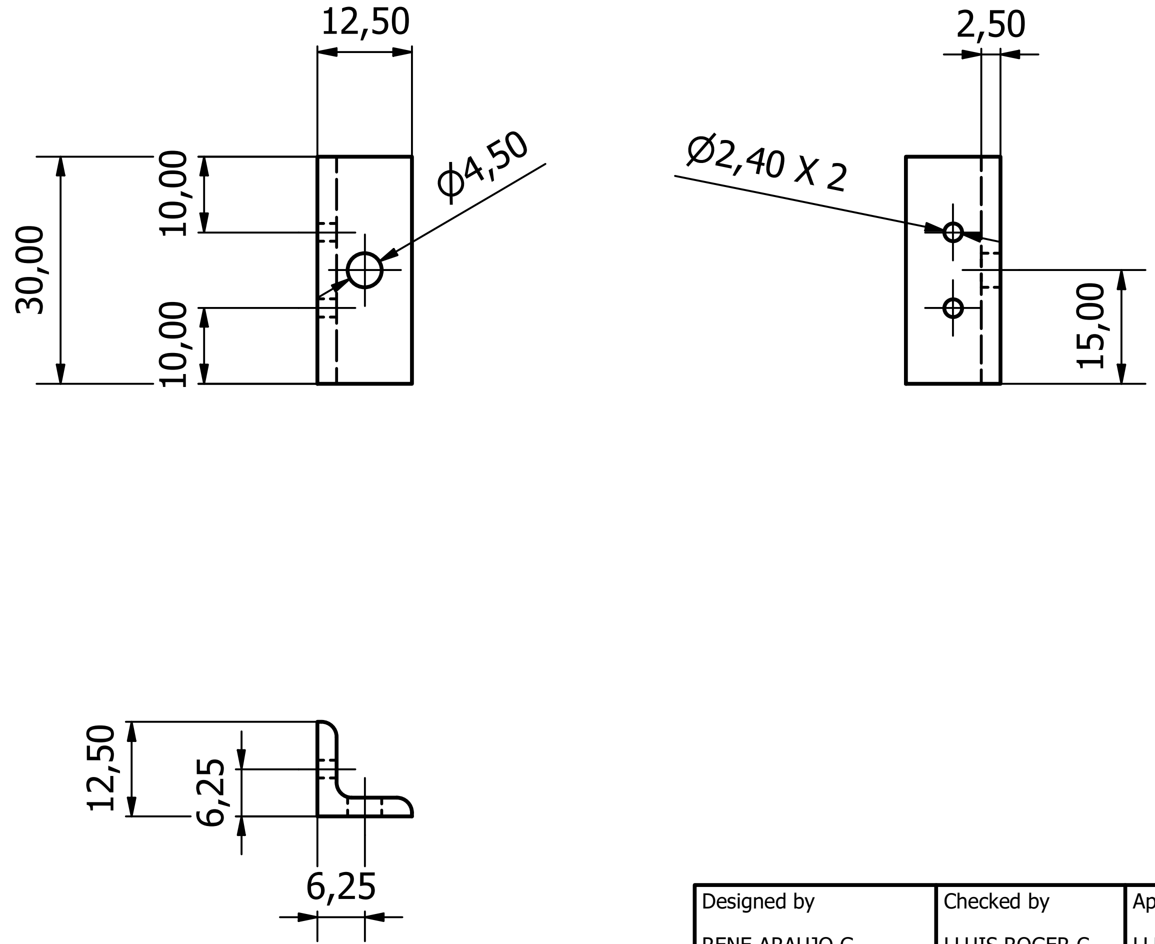

PROFILE (1 : 1)

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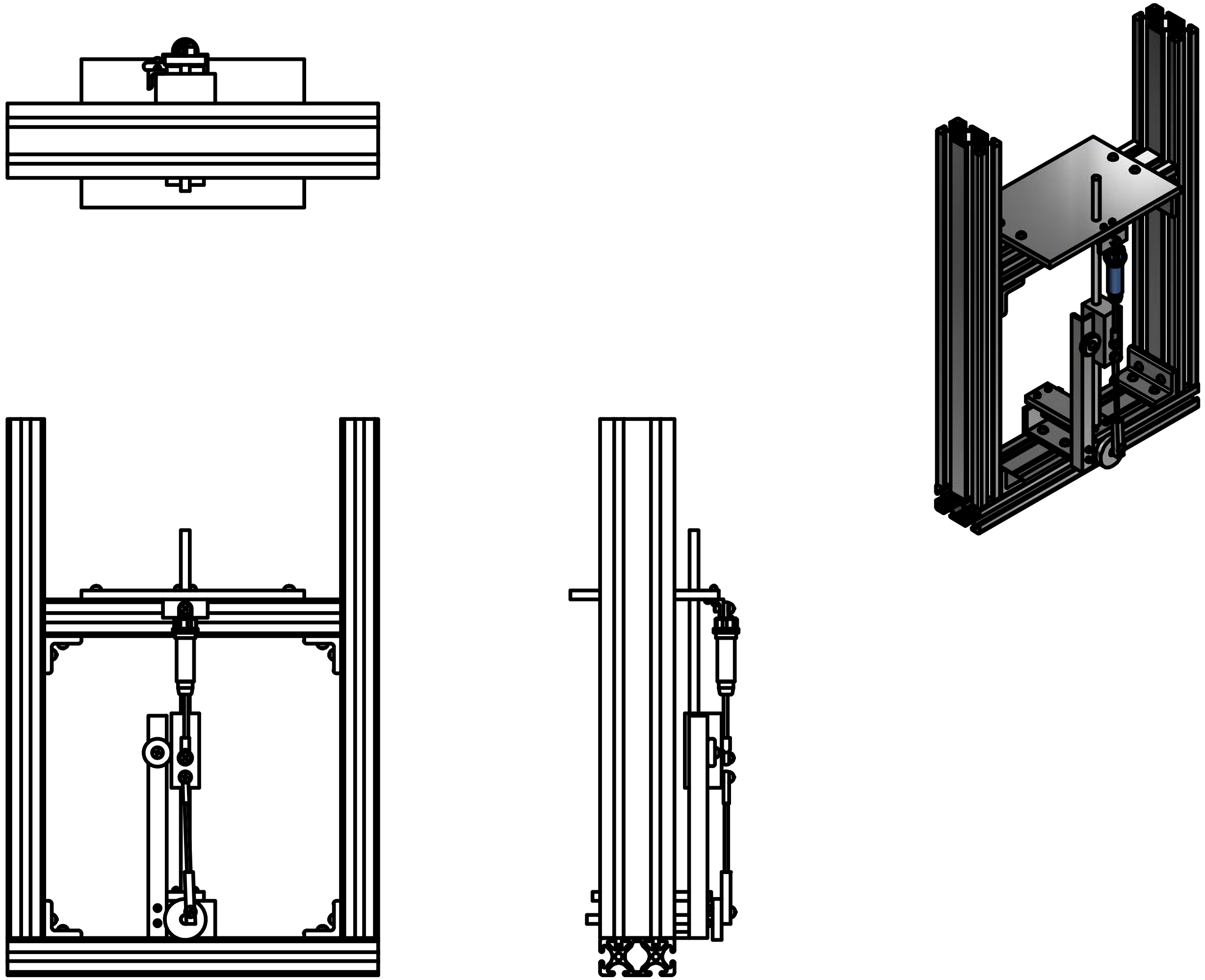
ASSEMBLY (1 / 6)

PARTS LIST		
ITEM	QTY	PART
1	1	Double-Bearing Block
2	1	Shaft
3	1	Round Disk
4	1	Lower Plate
5	1	Rod 1
6	1	Turnbuckle Head
7	1	Rod 2
8	1	Slider Block
9	1	Slider Shaft
10	1	Profile 2
11	1	Plastic Wheel
12	1	Frame 1
13	1	Frame 2
14	1	Frame 3
16	1	Frame 4
17	4	Profile 1
18	1	Upper Plate
19	1	Profile 3
20	8	M2 Screws
21	29	M4 Screws



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MACHINE TO MEASURE THE CHARACTERISTICS OF THE DAMPERS OF A RADIO CONTROL VEHICLE

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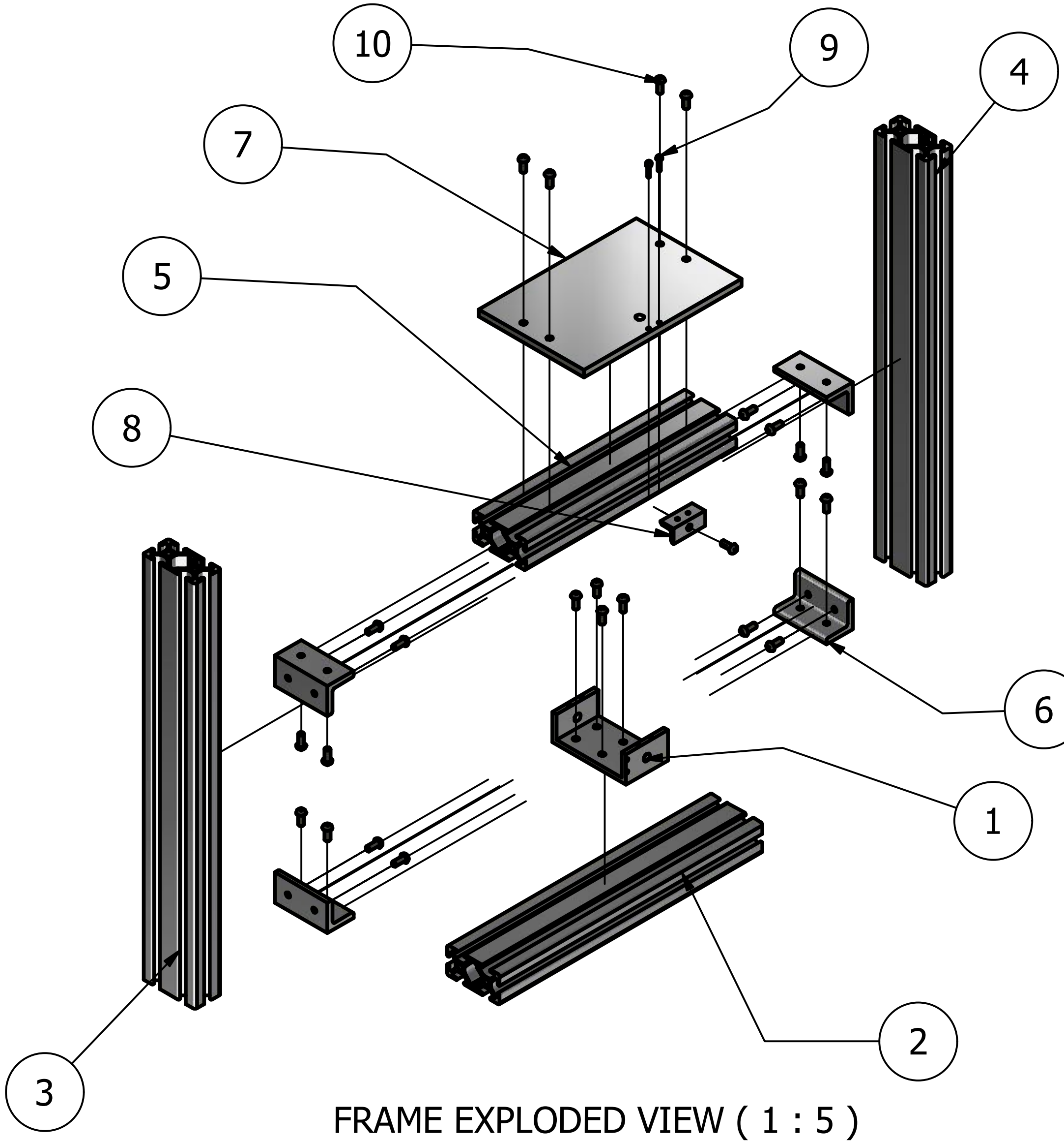
PARTS LIST		
ITEM	QTY	PART
1	1	Double-Bearing Block
2	1	Frame 1
3	1	Frame 2
4	1	Frame 3
5	1	Frame 4
6	4	Profile 1
7	1	Upper Plate
8	1	Profile 3
9	2	M2 Screws
10	25	M4 Screws



FRAME EXPLODED VIEW (1 : 5)

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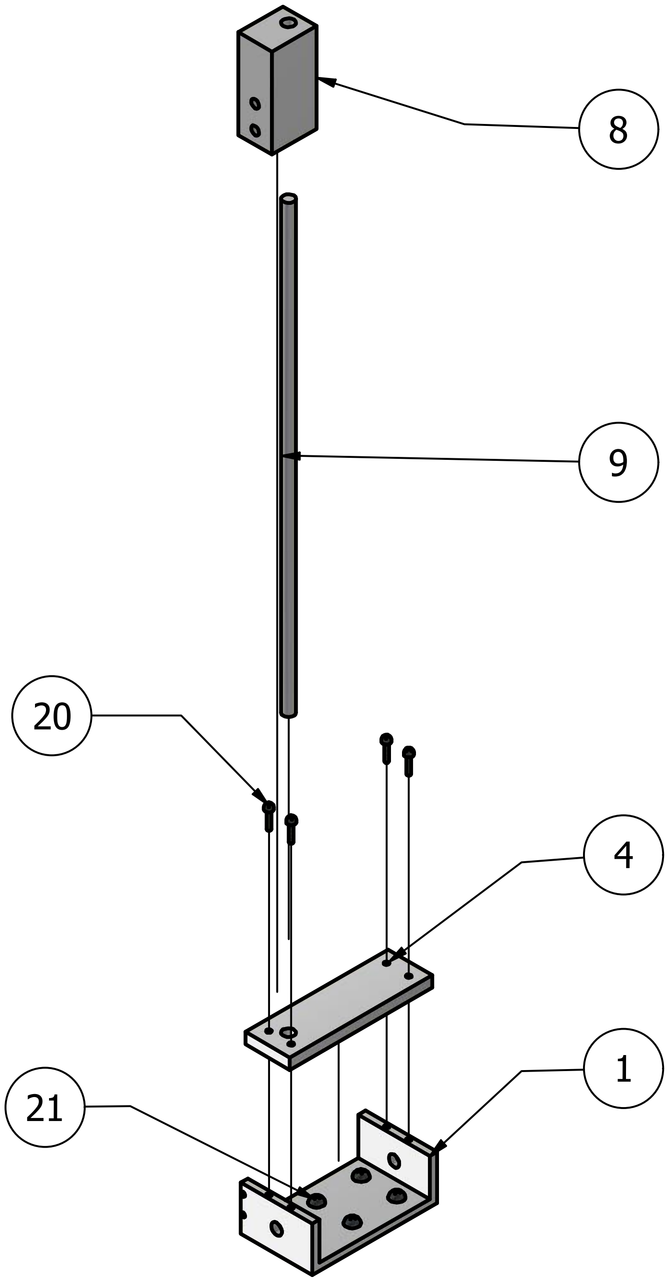

MECHANISM EXPLODED VIEW (1 : 3)

PARTS LIST		
ITEM	QTY	PART
1	1	Double-Bearing Block
4	1	Lower Plate
8	1	Slider Block
9	1	Slider Shaft
20	4	M2 Screws
21	4	M4 Screws

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UNIVERSITAT POLITECNICA DE CATALUNYA

MACHINE TO MEASURE THE CHARACTERISTICS OF THE DAMPERS OF A RADIO CONTROL VEHICLE

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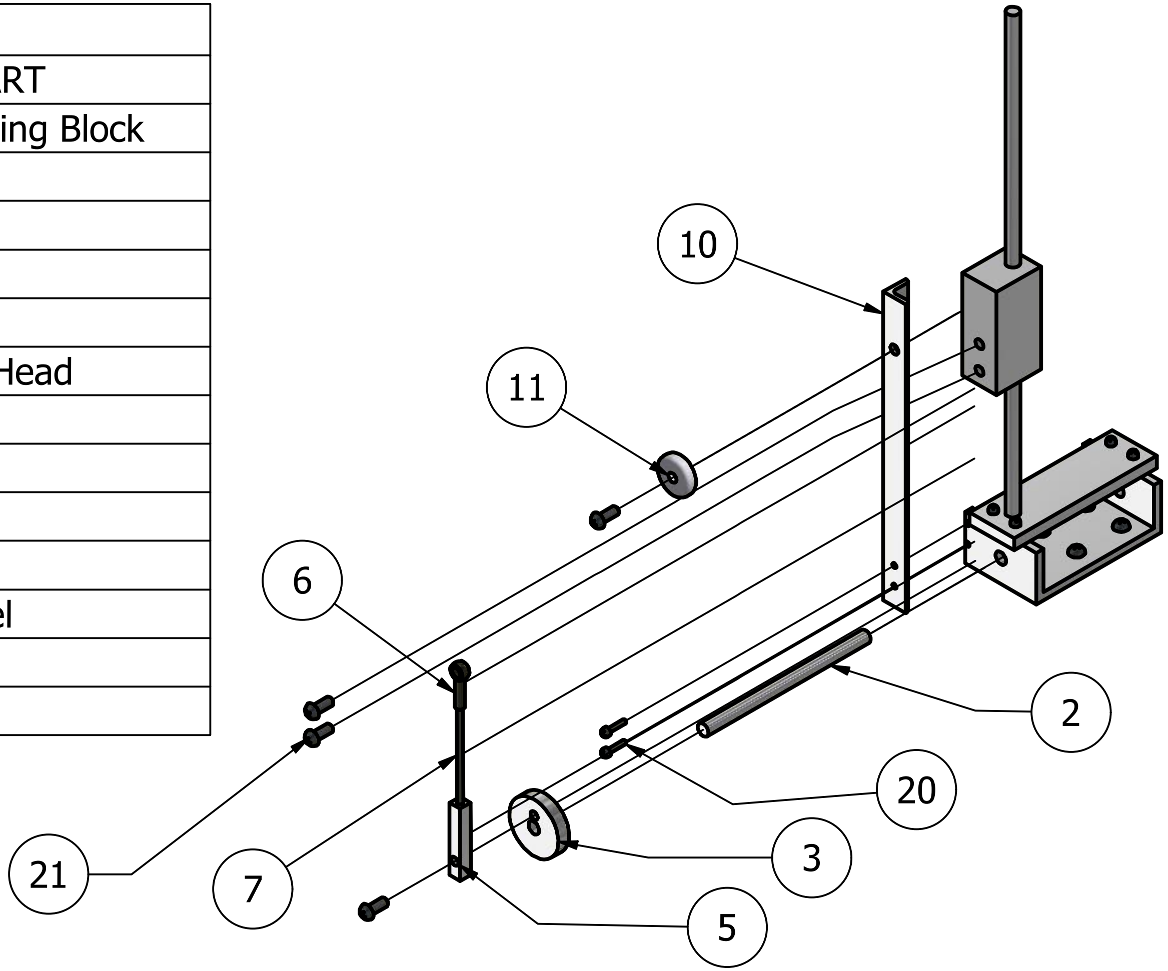
MECHANISM EXPLODED VIEW (1 : 3)

PARTS LIST		
ITEM	QTY	PART
1	1	Double-Bearing Block
2	1	Shaft
3	1	Round Disk
4	1	Lower Plate
5	1	Rod 1
6	1	Turnbuckle Head
7	1	Rod 2
8	1	Slider Block
9	1	Slider Shaft
10	1	Profile 2
11	1	Plastic Wheel
20	6	M2 Screw
21	8	M4 Screw



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MACHINE TO MEASURE THE CHARACTERISTICS OF THE DAMPERS OF A RADIO CONTROL VEHICLE

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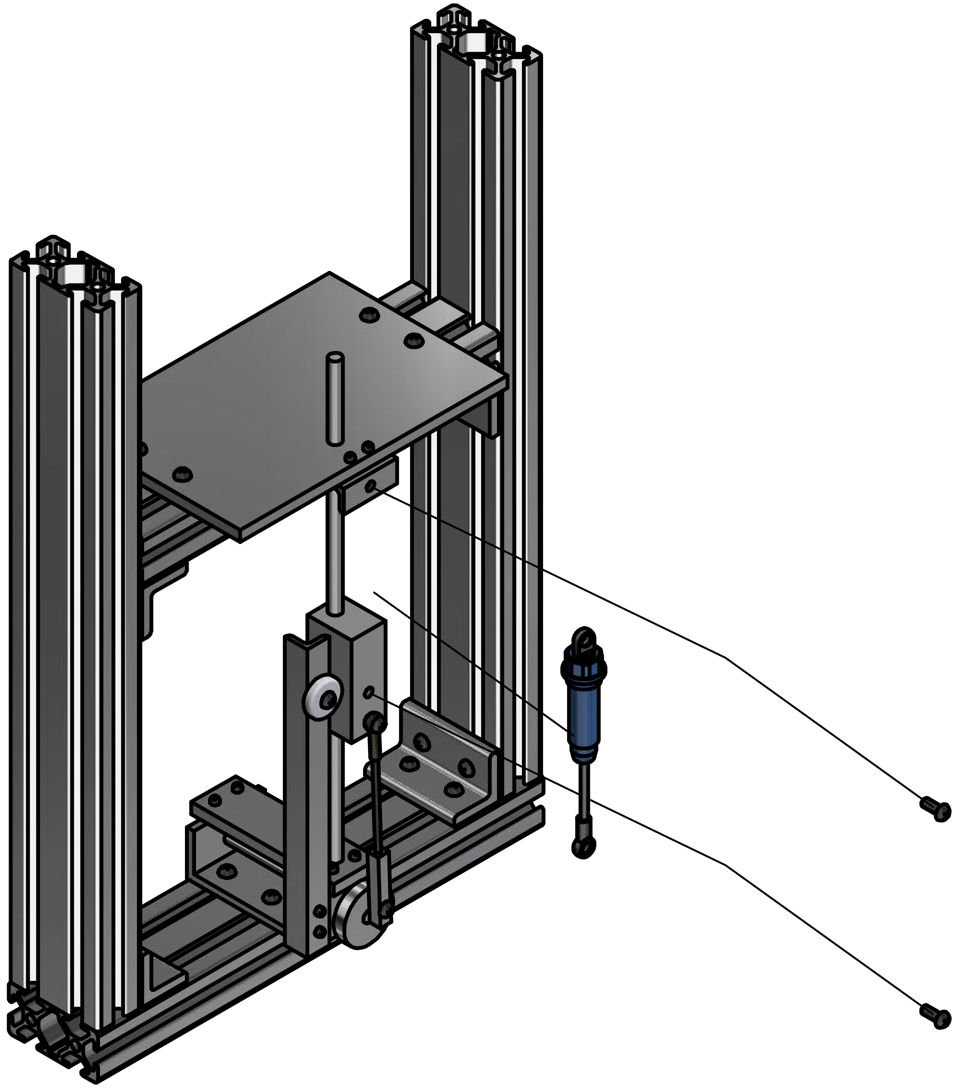

PLACEMENT OF THE DAMPER (1 : 3)

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