A

Appendix

A.1. CAD Modelling Minitabs (Complete Procedure)

1. Download and import the uCRM9 geometry as provided by MDO Lab[6] based on the work of Brookes et al.[2]. Scale it according to the size required by the user.

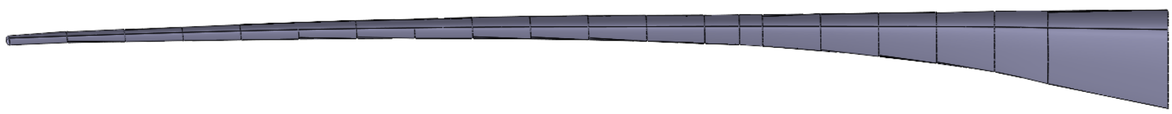

Figure A.1: CAD Model of the uCRM9 Wing

2. From a plan view, project the footprint of the wing as a sketch on to a parallel plane.

3. Next step will be to create a spline which maintains a constant local chord ratio distance from the leading edge. For this thesis, a local chord ration of x/c = 0.15 was taken. A spline here is required due to the changing chord length across the span of the wing.
    3.1. Create a parallel linear pattern of the wing root edge with 12 instances from the root to the tip.
    3.2. Trim out the excess length of the line outside the planform area of the wing. The original projection sketch of the wing planform will be the tool to trim out the excess length.
    3.3. Measure the lengths of each of these 12 instances and mark a point 15% of its respective length from the leading edge.
    3.4. Use the '**Spline Tool**' to create a spline passing through all the 12 created points.

    See Figure A.2 to obtain a visual of the sketch created in step 3.

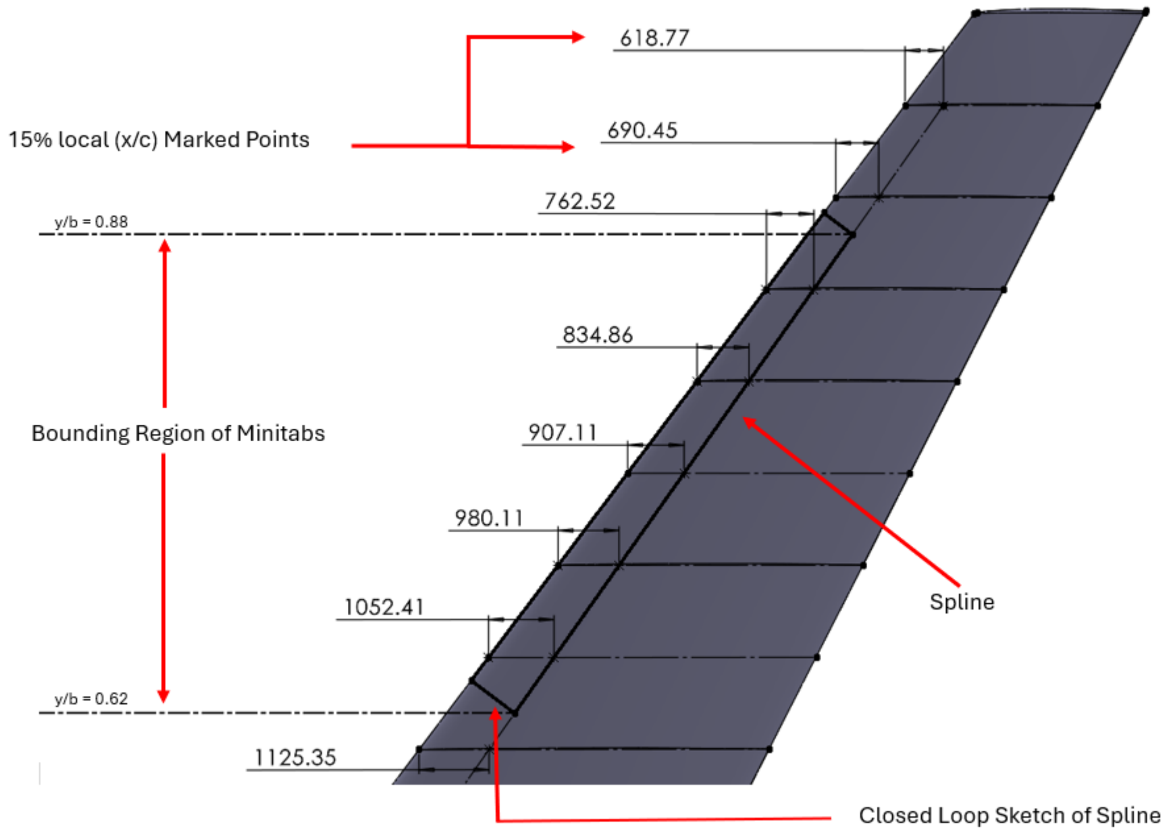

Figure A.2: Spline Sketch

4. Mark the section of the span which will have the minitabs and draw 2 construction lines parallel to the wing root, bounding the region of the minitabs. For this thesis, a span of $y/b = 0.62$ to 0.88 was chosen, which is referred from the previously conducted CFD study of minitabs[7].

   Set the parts of the Spline not within the region of the minitabs as construction lines.

5. Once the spline is complete, close the spline into a loop by creating a rectangle with the spline as one of the sides. Ensure this rectangle lies within the planform area of the uCRM9 wing. This can be seen in Figure A.2, where in the leading edge and the spline are a part of the closed loop.

   This is required since the spline will be converted into an edge in a future step. Since the edge creation process, requires a closed loop sketch, a single line/spline will not be sufficient.

6. Once the closed loop is complete, convert all the remaining sketch entities, apart from the closed loop with the spline into construction lines.

   This will ensure no visibility of these sketch entities nor unnecessary interference in future steps.

7. Select the '**Split Line**' command:

   7.1. Set the Type of Split to '**Projection**' to project this sketch back to the surface of the wing.

   7.2. In the Sketch Selections Window, select the closed loop sketch created in the previous step.

   7.3. In the Surface Selections Window, select the surface over which the user wants to create the minitab over. In this case, it is projected to the upper surface of the wing.

This step will split the wing surface and create edges in the shape of the sketch on the wing surface as seen in Figure A.3.

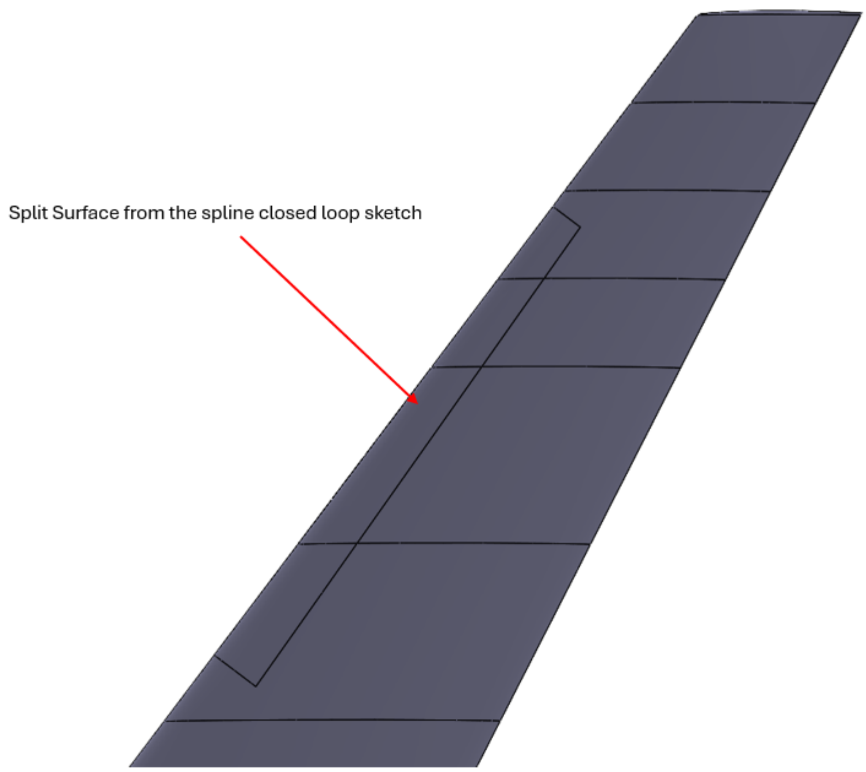

Figure A.3: Spline Surface Split Sketch

8. Select the '**Ruled Surface**' command:
   - 8.1. Set the type to '**Normal to Surface**'
   - 8.2. Set the '**Distance**' to the desired height of the minitab. For this case, 30mm was chosen.
   - 8.3. In the '**Edge Selection**' window, select the spline as the edge to draw the surface from.
   - 8.4. Ensure the option '**Connecting Surface**' is enabled. This ensures a connection between the created surface and the underlying wing body.

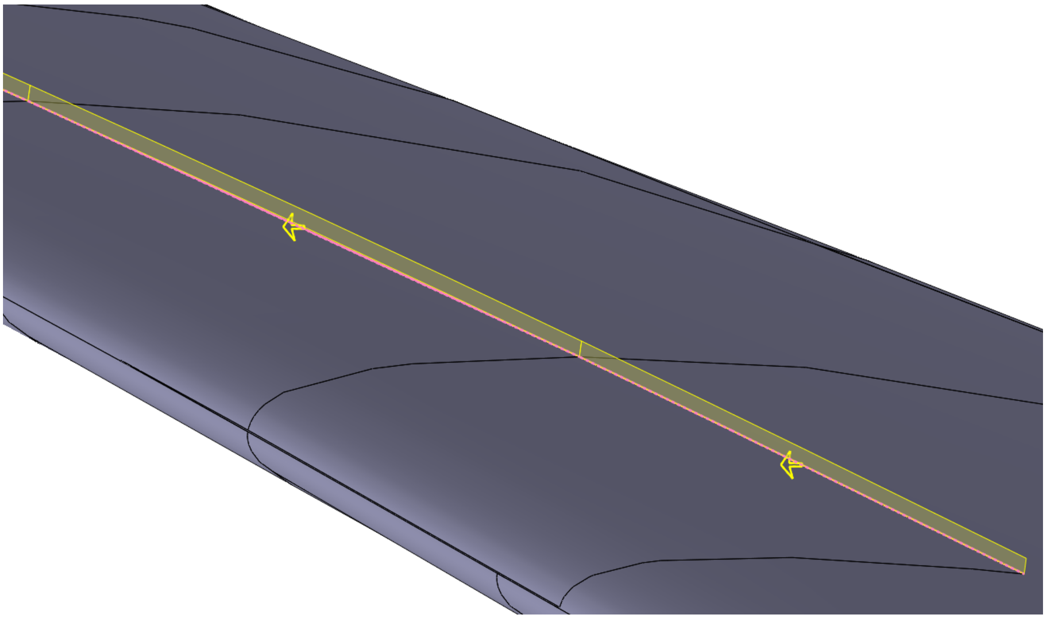

Figure A.4: Ruled Surface Preview

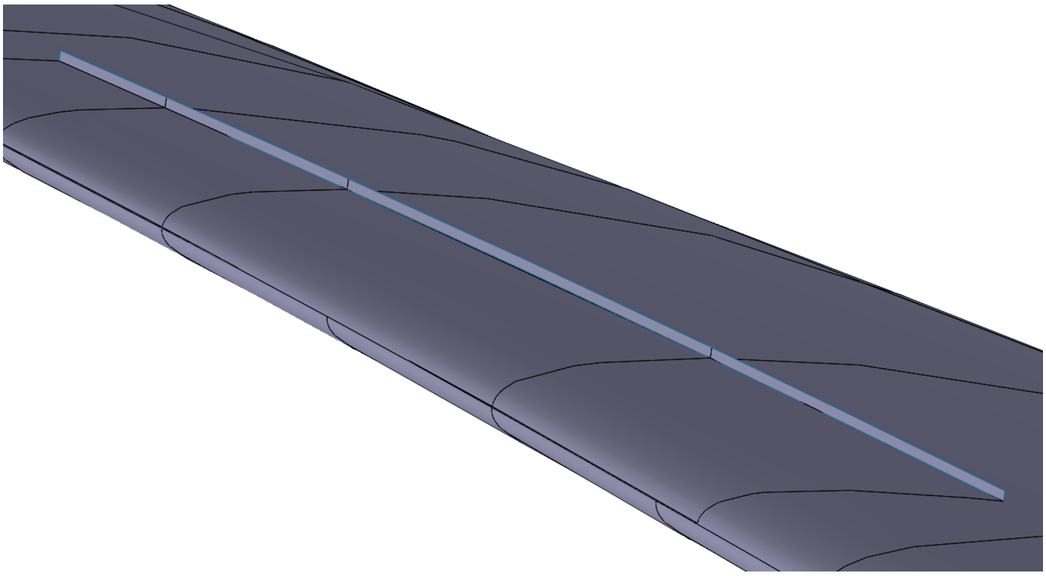

Figure A.5: Completed Minitab Surface of Wall Ratio = 1

This step will create a single continuous minitab of Wall Ratio = 1 along the chosen span of the wing.

Modelling Multiple Minitabs

9. In order to split this into multiple minitabs, section the created spline in Step 4 based on the required geometry, wall ratio and number of instances of the minitab.

   Ensure that each section of the spline that will be a minitab, should have its own separate closed loop sketch. In simpler terms, the user must repeat step 5 for each instance of the minitab.

   An advantage of this method is the ease in creating multiple iterations to the minitab layout, number of instances and sizes without recreating the spline which is the most time consuming step of the complete process for each minitab.

10. Finally, in step 8, in the '**Edge Selection**' window, only select the edges which will become the minitab instances.

A drawback to this process is the requirement for a closed loop to create the edges on the wing surface. This leads to unnecessary split of a clean wing surface into multiple smaller surfaces as seen in Figure A.6, which is an example of a model with Minitab Wall Ratio = 0.4. This can cause potential meshing and topological issues when the fluid domain is created down the line. A simple fix for this issue can be summarised into the following steps:

1. Save the created geometry at the end of Step 10 as a (.STEP) file.
2. Open a new instance of SolidWorks and import the clean uCRM9 wing from Step 1
3. Insert the created minitab geometry at the end of step 10 into the current geometry.
4. Delete the instance of the wing with the split surfaces, while retaining the minitab surface bodies
5. Enable Shared Topology between the minitab surfaces and the clean uCRM9 wing.

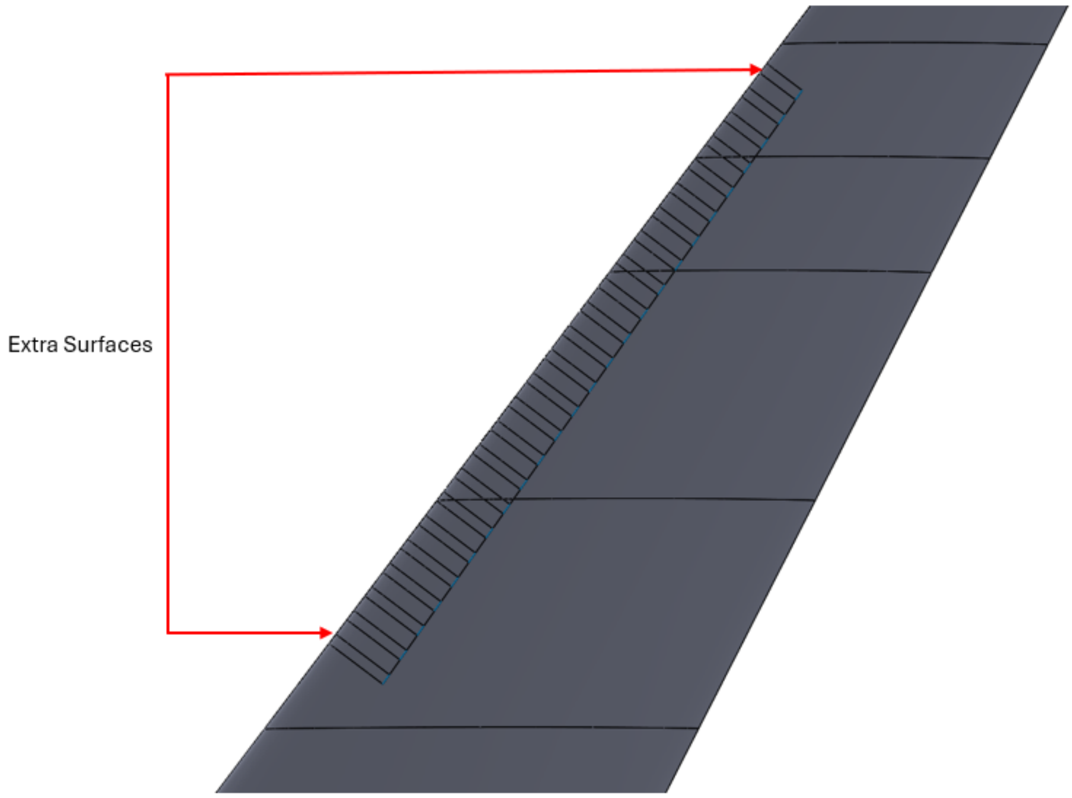

Figure A.6: Additional Surfaces due to Split Line Command (Wall Ratio = 0.4)

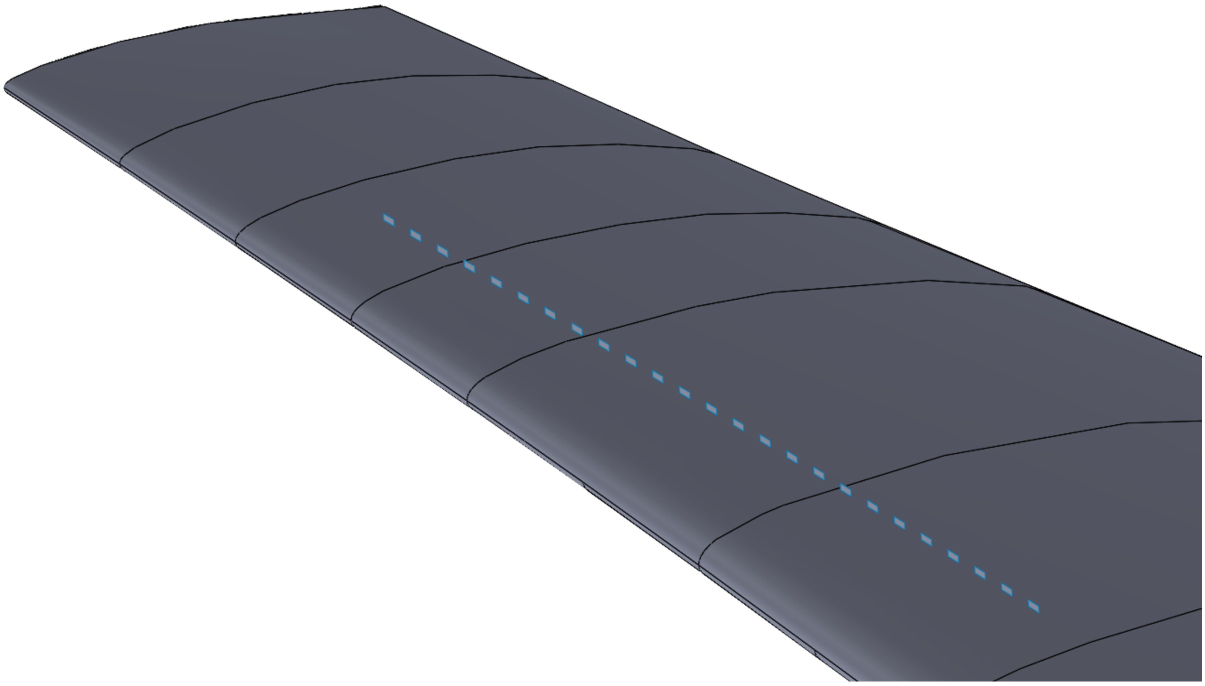

Figure A.7: Example of a Fixed Version of Minitab Surface Model (Wall Ratio = 0.4)

A.2. Damping Coefficient Sensitivity Study

Dynamic FSI Results of the clean wing in gust conditions from Pinero [4] was chosen as the comparison case. Each variation of the damping method and its parameters from Section 1.3.2 was setup as separate test cases and an overall comparison was done as seen in Figure A.10 and Figure A.8. One of the key takeaways from the study was, even a small addition of damping was sufficient to eliminate low frequency oscillations that exist with no damping included. The peak Cl values reached with all the damping cases were very similar, all ranging with 1% of each other.

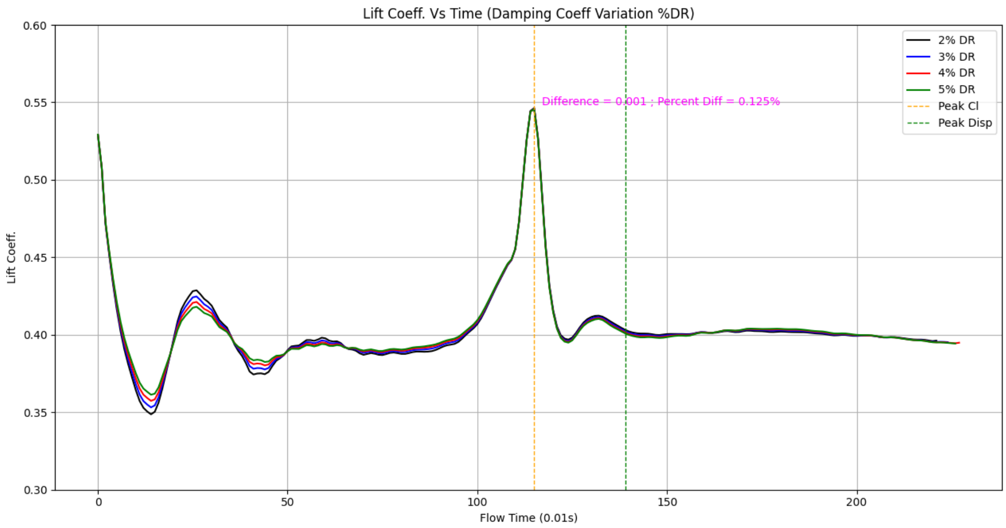

Figure A.8: Lift Coefficient vs Timestep (Modal Damping)

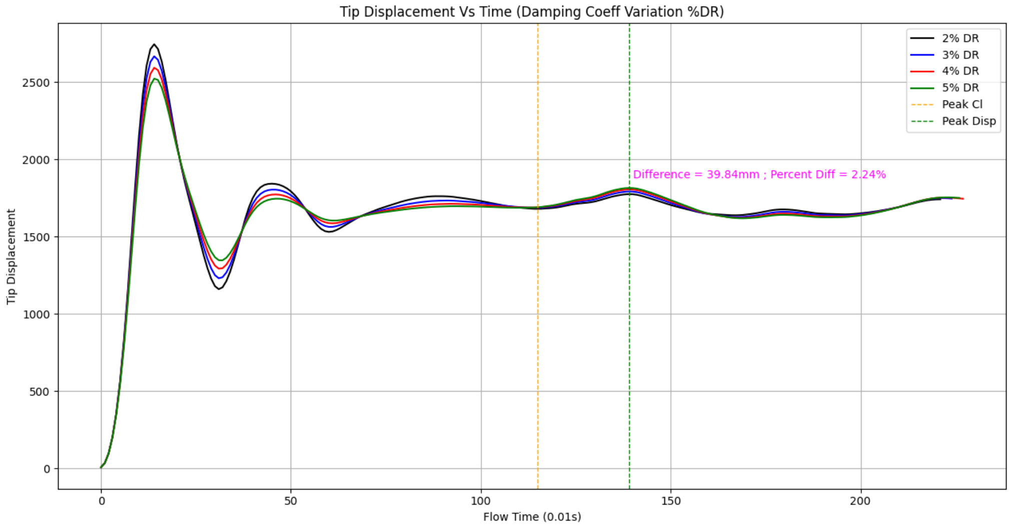

Figure A.9: Tip Displacement vs Timestep (Modal Damping)

Results from the Modal Damping cases showed small high frequency oscillations that persists throughout the simulation, but the cause was unable to be determined. However, comparing all the tested damping ratios (ζ), it showed negligible differences.

The tip displacement also showed the same high frequency oscillations, and a general lack of stability in the tip displacement, before and after the gust encounter.

Hence the modal damping method was not chosen, due to the presence of the higher frequency oscillations, lack of stability in the tip displacement and the selection of the damping ratio could not be justified without additional information.

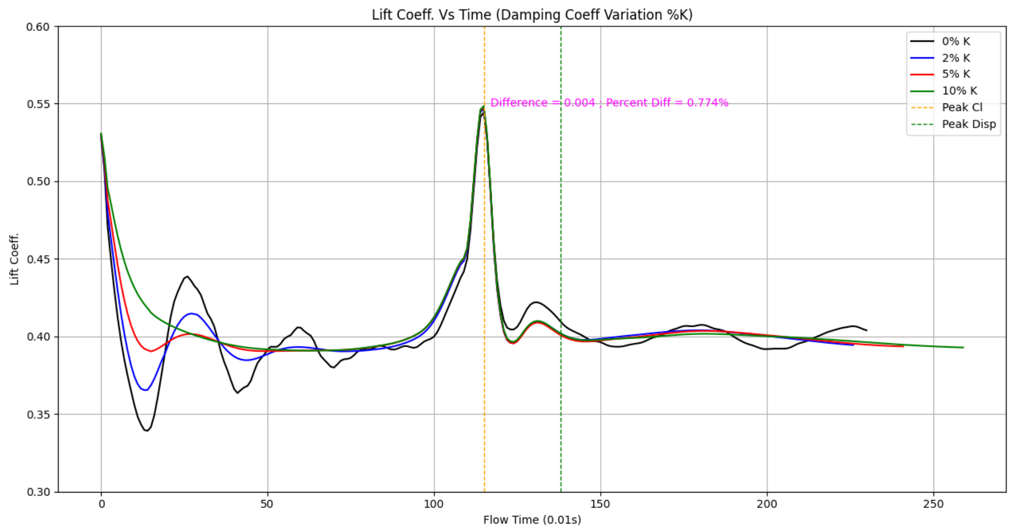

Figure A.10: Lift Coefficient vs Timestep (Rayleigh Damping)

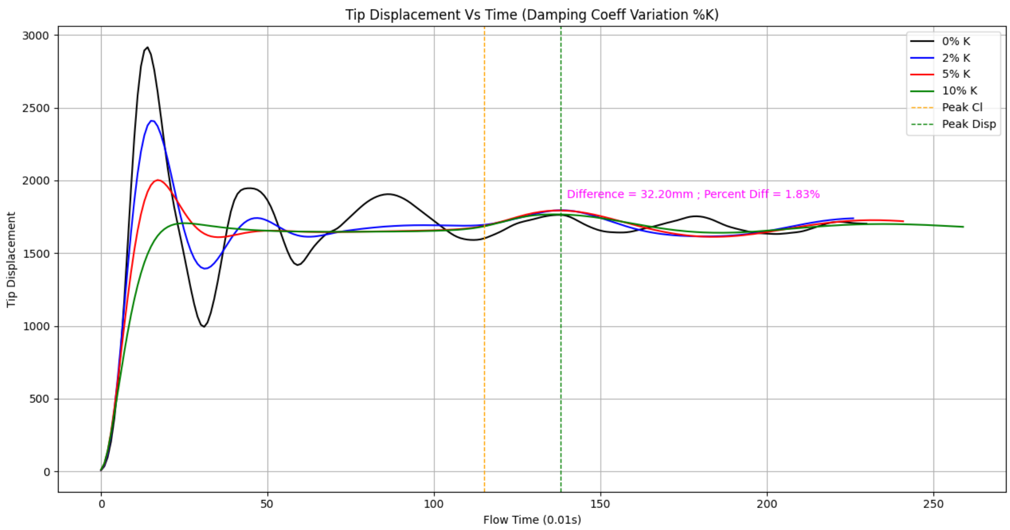

Figure A.11: Tip Displacement vs Timestep (Modal Damping)

Results from the Rayleigh Damping cases showed that 2% (K) damping was still resulting in very low frequency and low amplitude oscillations. With a value of 10% (K), the lift coefficient was over-damped, which can be noticed in the initial timesteps of the simulation, with the lack of any oscillations to a stable value. An intermediate value of 5% (K), showed slight over-damping behaviour, but is believed to show relatively good agreement with typical behaviour of structures and valid for the dynamic FSI simulations.

A.3. Minitab Deployment on Gust cases (G2, G3)

Results of the minitab deployment for gusts G2 and G3 are shown below:

A.3.1. Case 2: Gust G2

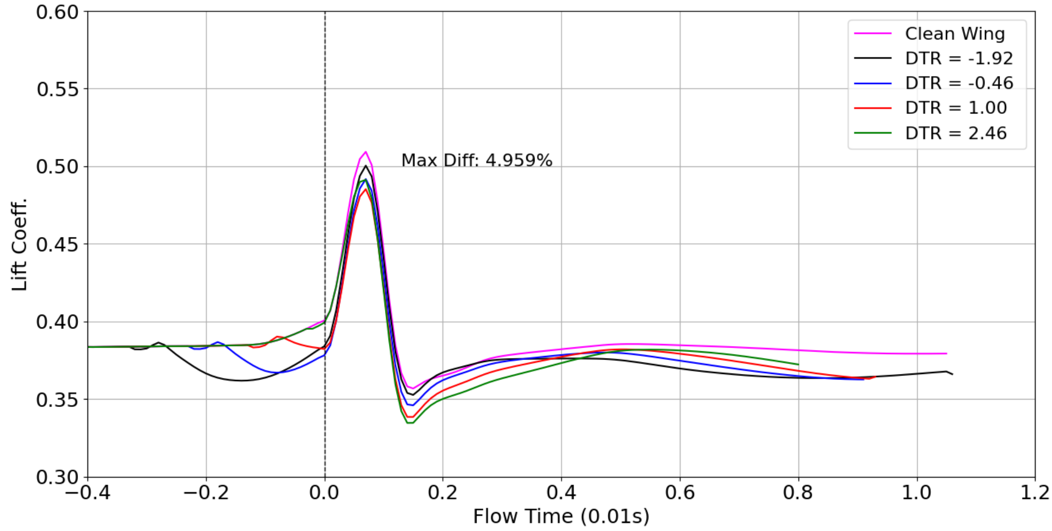

Figure A.12: Lift Coefficient vs Timestep (Gust G2)

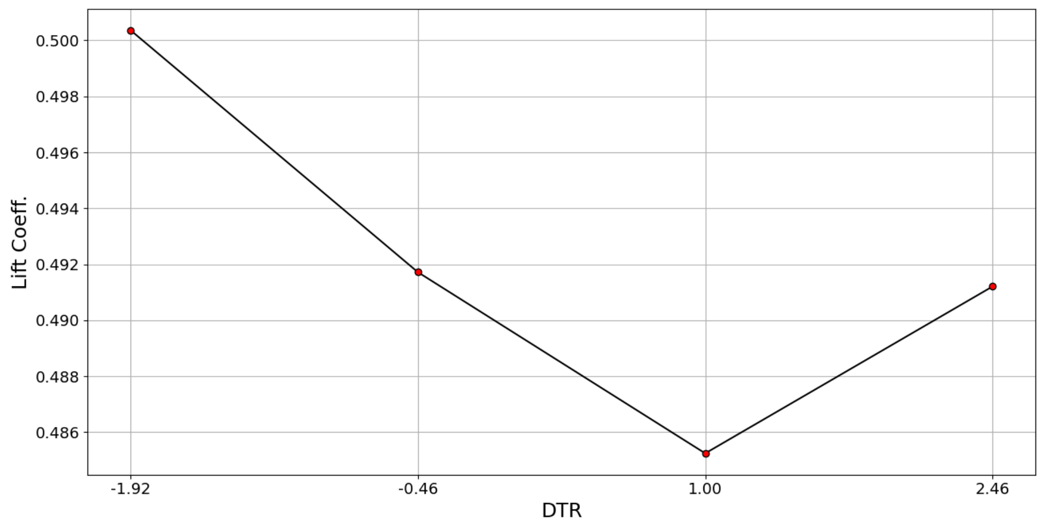

Figure A.13: Lift Coefficient at Gust Peak (G2) vs DTR Configurations

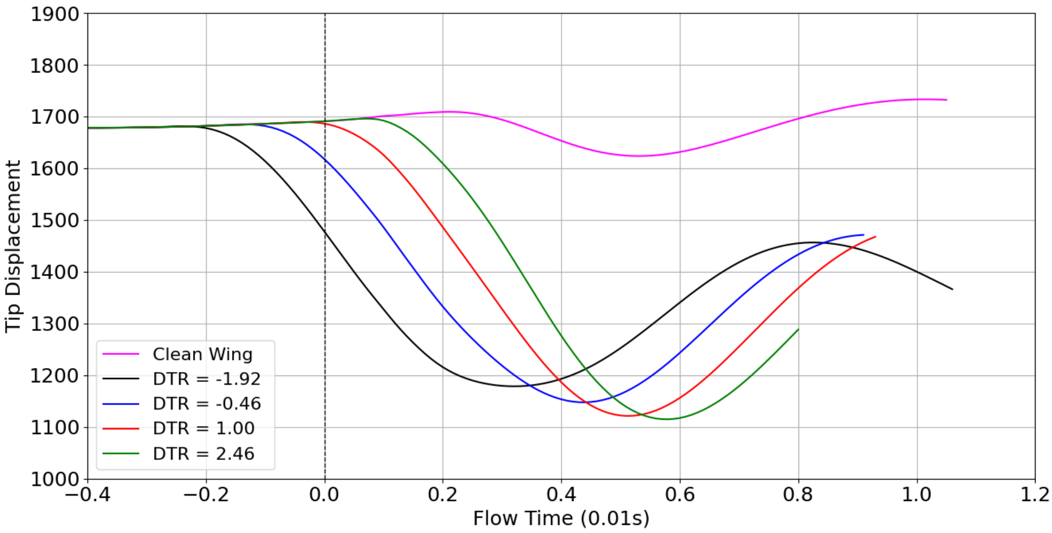

Figure A.14: Tip Displacement vs Timestep with (Gust G2)

A.3.2. Case 3: Gust G3

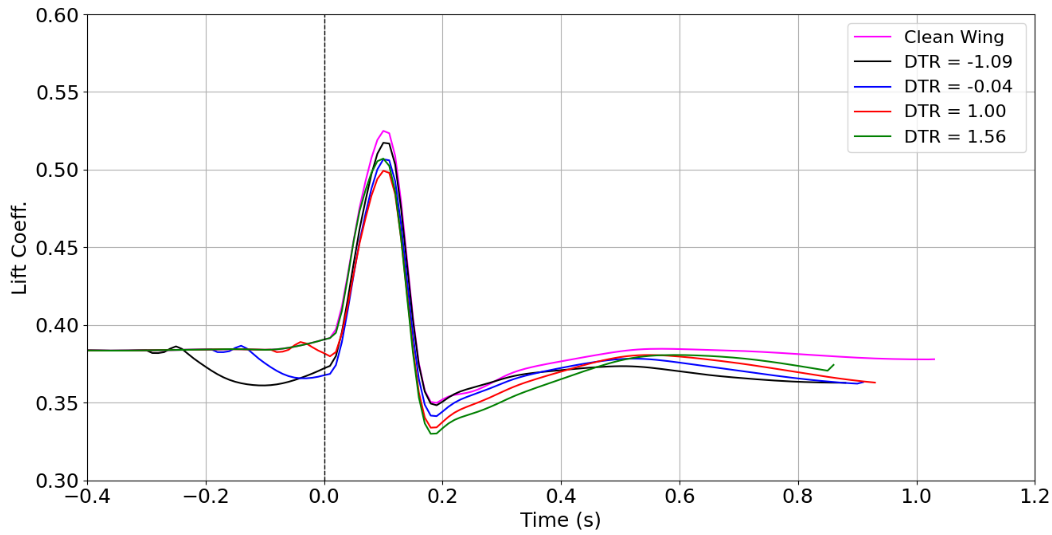

Figure A.15: Lift Coefficient vs Timestep (Gust G3)

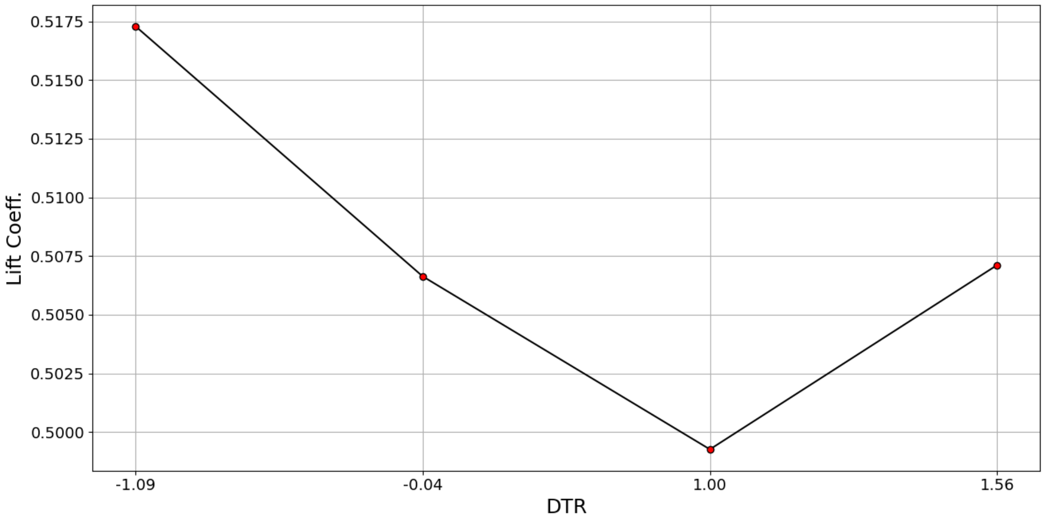

Figure A.16: Lift Coefficient at Gust Peak (G3) vs DTR Configurations

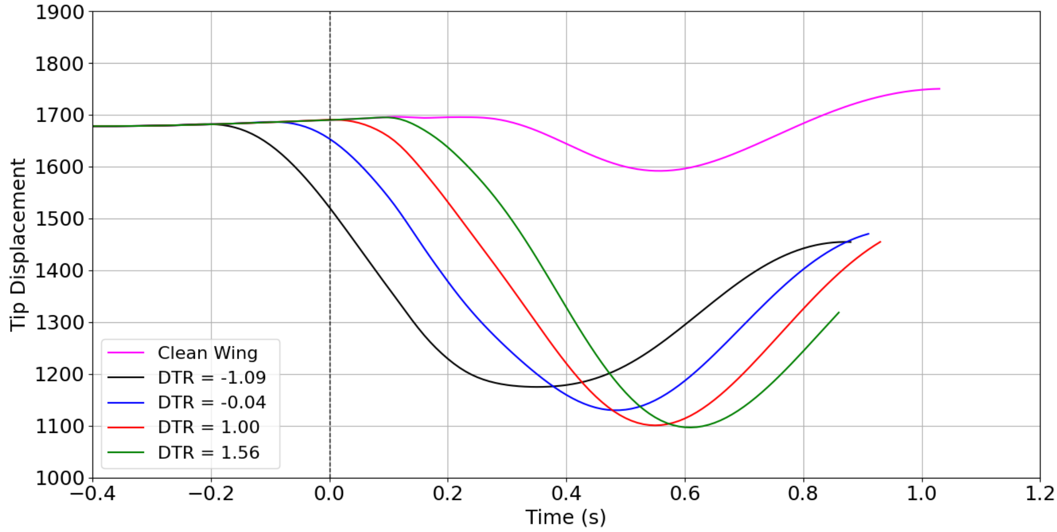

Figure A.17: Tip Displacement vs Timestep with (Gust G3)