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Vessel Motion Modelling

MySep and Computational Fluid Dynamics (CFD) compared

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SUMMARY

- New module in MySep v3.0 calculates liquid levels for vessels subjected to motion
- Rapid design and evaluation for fast track projects
- Excellent agreement with general trends in CFD predictions
- Greatly reduces scope of CFD simulations recommended for final evaluation
- Major reductions in engineering cost and project time

INTRODUCTION

Floating production facilities are increasingly important as a cost effective means of exploiting sub-sea oil and gas reservoirs. Sea surface motion subjects the entirety of a Floating Production Storage and Offloading (FPSO) to movement and acceleration forces. This in turn causes movement of the liquid inside the process vessels used for separation of liquids and gas. Liquid will tend to slosh from end to end and from side to side within a separator vessel and liquid levels will vary locally over time. This time-dependent variation in liquid level height has the potential to exceed level control bands or set points. A designer needs to ensure that separation internals and vessel nozzles are suitably located and dimensioned to avoid control or separation performance issues. The dynamic behaviour must be carefully considered in design of both the vessel and its internals. Perforated anti-sloshing baffles are commonly placed within the vessel to mitigate severe liquid motion.

In evaluating a design, it is critical to avoid situations such as:

- Partial submergence of the inlet device resulting in excessive re-entrainment (carryover);
- Liquid level reaching the bottom of a demisting device resulting in syphoning through the drain pipe and consequent excessive carryover;
- Liquid outlet nozzles becoming exposed to gas with consequent gas flow penetrating the liquid handling system;
- Level control issues due to the liquid level exceeding the instrumentation range.

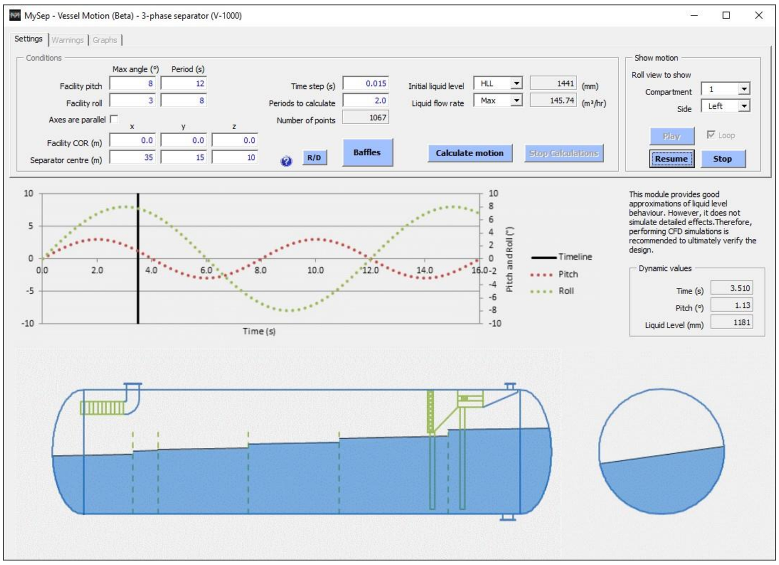
During design, the process engineer faces the challenge of determining suitable locations, heights and nett free area of the anti-sloshing baffles, as well as determining what local extreme liquid levels will be achieved. These interactions can then be accounted for in the overall design of the vessel and its internals.

Commonly, two approaches are used: Simple trigonometry (spirit level) calculations and/or Computational Fluid Dynamics (CFD). Both methods have pro's and con's. The trigonometric calculations can be undertaken rapidly but these are not sufficiently accurate since they neglect the flow of liquid between baffled chambers and acceleration forces acting on the liquid. CFD on the other hand, when performed correctly, takes into account all the relevant factors and provides very detailed and representative results for the liquid behaviour. As such, CFD would be recommended to ultimately verify a vessel and internals design for liquid motion. Successful application of CFD however, requires very significant experience in modelling the geometric features of separation equipment and representing adequately phase and surface interaction effects. In addition, comprehensive CFD analysis for a range of baffle configurations, internal arrangements and different process conditions can be immensely time consuming. The time needed for creation of the geometric model, computational time to solve the simulation and extraction and analysis of results is typically measured in weeks for a single vessel configuration and process operating condition. If the results show that there are issues with the design, the modelling process needs to be repeated for the adjusted design. This can have a huge impact on project timescales.

To address the technical deficiency of the simple trigonometric approach and the extreme time and cost associated with comprehensive CFD modelling, a Motion module has been introduced into MySep (process engineering software for separation vessels). This provides the process engineer with a sufficient precision to undertake preliminary design for separation vessels subject to imposed sea motion or primary evaluation of behaviour of existing equipment on floating facilities. This paper discusses the MySep Motion module and shows how its results compare with CFD simulation predictions.

MYSEP - MOTION

In MySep v3.0 the Motion module was introduced to mitigate the con's of the trigonometry and CFD approaches to liquid motion modelling, whilst retaining their pro's as much as possible. The new capability provides the process engineer with a means to rapidly analyse liquid motion in a separation vessel with reliable results in minutes rather than days/weeks.



The calculations that resolve the liquid level behaviour are based on the physics of fluid dynamics. As the vessel is subjected to motion (pitch and roll), the liquid in the separator is subjected to a number of forces, in addition to gravity. These forces are dependent on the pitch and roll angels and periods, as well as on the location of the separator relative to the centre of rotation of the floating facility. While these accelerations induce the flow of liquid, perforated anti-sloshing baffles in the vessel provide a restriction of flow.

All these factors are taken into account in the calculations in a time transient manner for each compartment of the vessel formed by a pair of perforated baffles. This results in resolution of liquid level heights for each compartment versus time. The Motion module also hosts a number of tools to assist the user in analysis of liquid levels and their impact. An important and time saving capability is verification of internals layout against peak liquid levels. This verification is done automatically when the calculations are complete and warnings are presented whenever liquid levels cause operating issues over the entire cycle of simulated motion. The user can swiftly review warnings and adjust the design to vary: baffle arrangement and geometry; separation device location and dimensions; nozzle locations or overall vessel dimensions within MySep. It is quick and easy to re-run the motion calculation for further verification.

KEY FEATURES

- Time transient calculation of liquid level heights
- Automatic checking of internals against the dynamic liquid levels
- "Video" mode that shows the dynamic level behaviour in the vessel (pitch and roll views)
- Level monitor graphs vs time
- Data export to Excel

Running the motion calculations followed by verification and adjustment of the design can be completed in minutes, a vast time saving compared with the days/weeks required for similar verification using CFD.

A prospective user of the MySep Motion module should ask: *How representative of reality are dynamic liquid level calculation results of the MySep Motion module?* This question is addressed qualitatively and quantitatively in the next section, where MySep results are compared with CFD simulation results.

COMPARISON WITH COMPUTATIONAL FLUID DYNAMICS

The method developed and adopted in the MySep Motion module to resolve liquid motion is a simplified model as compared to CFD. In CFD modelling with industry-leading proprietary software, the fluid volume in the separator is divided into a large number of volume elements sometimes call the mesh. For each element within the mesh the Navier-Stokes equations are solved to ultimately, via many iterations, yield the behaviour of the entire flow field for all of the fluids present. Providing a valid and accurate result requires skill and experience in defining many details of the modelling including turbulence models, wall interactions and fluid-fluid interactions. In the MySep Motion module, the fluid volume in the separator is divided into a modest number of larger elements and the liquid motion calculation is characterised by simplified fluid dynamic equations. CFD simulation results are therefore much more detailed and accurate. For example, CFD simulations can reveal waves or disturbances on the liquid surface as a result of sloshing, whereas in MySep Motion the liquid surface is considered to be flat.

Qualitative Comparison

Firstly, let us consider a qualitative comparison between MySep Motion and CFD as illustrated by the example of a horizontal 2-phase separator with two perforated anti-sloshing baffles. The vessel dimensions and motion parameters are shown in Table 1.

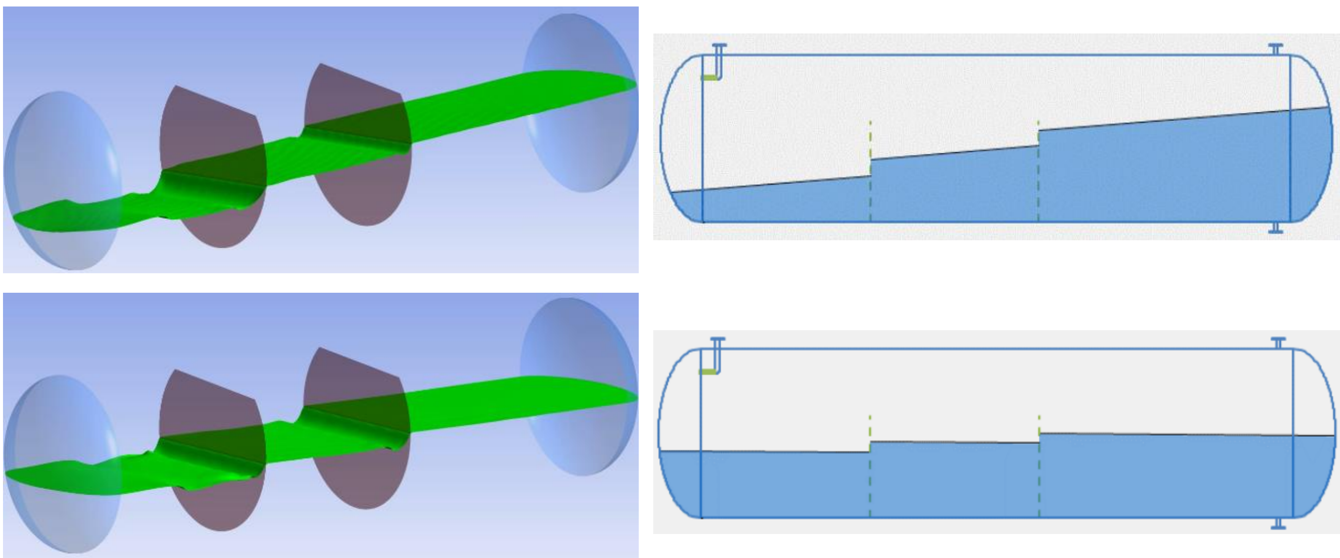
Table 1 Data for motion and vessel used in the comparison

Vessel settings	
Orientation	Horizontal
Inside diameter	2000 mm
T-T length	7000 mm
Location of Baffle 1	2000 mm
Location of Baffle 2	4000 mm
Net Free Area of baffles	36%

Motion parameters	
Facility Pitch Angle / Period	8° / 24 seconds
Facility Roll Angle / Period	10° / 20 seconds
Facility and separator axes	Parallel
Facility Centre of Rotation (x, y, z)	(0, 0, -1)
Separator centre (x, y, z)	(0, 0, 0)
Initial liquid level	900 mm
Calculation time step	0.0375 seconds

The values in Table 1 were chosen somewhat arbitrarily, however the baffles were purposely located asymmetrically along the vessel. Similarly, the pitch and roll periods were set to differ in order to reveal out-of-phase effects.

Figure 1, below, shows a visual comparison of the liquid surface at three separate time intervals with the 3-D representation of CFD results on the left and MySep Motion elevations on the right. The MySep images shown here correspond to the liquid level along a central cross-section of the vessel. If we consider the height difference on either side of each baffle, as well as the maximum and minimum levels reached in the vessel heads we can observe good qualitative agreement. The images also illustrate that MySep Motion can only resolve a planer liquid-gas interface, whereas CFD can resolve wave motion in the liquid, as previously described.



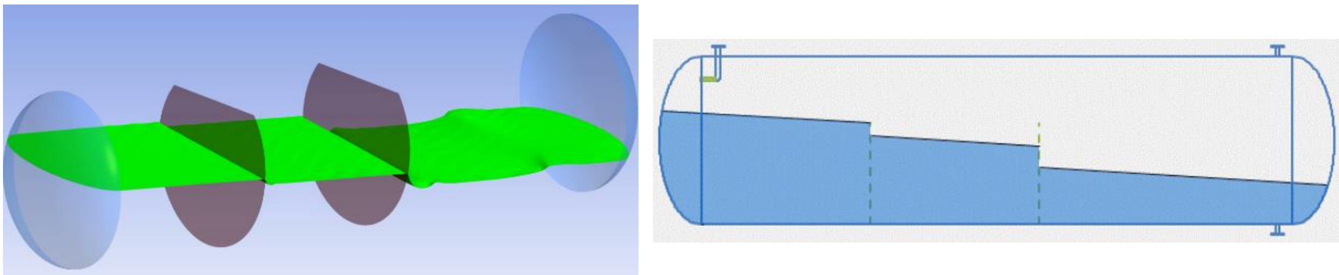


Figure 1 Visual comparison of CFD (left hand images) and MySep Motion (right hand images)

Quantitative Comparison

Let us now consider a quantitative comparison whereby we consider the predicted liquid flow rates through the baffles as well as the liquid level heights at various locations in the separator. Figure 2, below, shows the comparison for the liquid flow rates through each of the two baffles versus time. At the start of the both simulations (t=0), the vessel is level (both pitch and roll are 0°), the liquid surface throughout the vessel is level (at the initial height of 900 mm) and the liquid is not in motion. When the motion starts (pitch and roll angles increase), the liquid starts to move both longitudinally from one end of the vessel to the other and transversely from one side of the vessel to the other. As can be seen, this initial increase in flow is more rapid in MySep predictions than those of CFD.

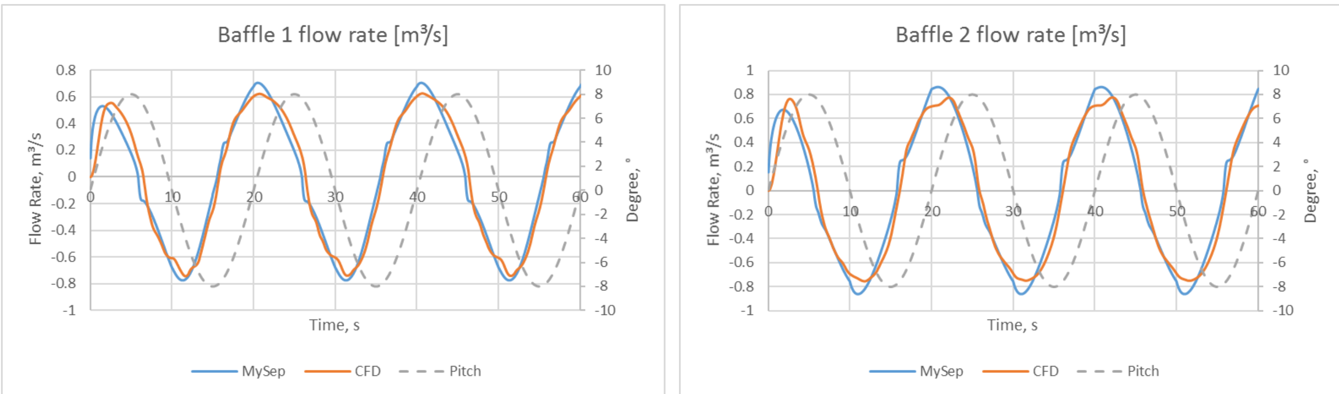


Figure 2 Comparison of liquid flow rate through the baffles

After the first cycle of vessel pitch and roll (i.e. one up and down swing), a consistent repetitive pattern emerges, both in MySep and CFD results, with very close agreement between predictions of maximum and minimum flow rate. The peaks predicted by CFD for Baffle 2 are not rounded but appear flattened with a double inflection. This is the local effect of the passage of the waves, predicted by CFD, negotiating the resistance of the perforated baffle.

An interesting, and perhaps counter-intuitive observation from Figure 2, is that the maximum, zero and minimum flow rates do not coincide with the maximum, zero and minimum angle of the separator pitch. This illustrates the presence of time dependent factors that affect and together result in a certain liquid behaviour. MySep and CFD both predict the aforementioned counter-intuitive effect with a very close level of agreement.

Further Quantitative Comparisons

The liquid level heights predicted by MySep and CFD are further compared at various locations throughout the vessel. Figure 3, below, shows how MySep defines the locations at which a user may choose to see calculated results for the time variation of local liquid level. A range of these comparisons for all liquid level monitor points in our three-compartment, two-baffle example are presented in the Appendix below. In all the charts which follow, the MySep and CFD level prediction trends correspond to the vertical scale on the left of the graph (liquid level, mm), whereas the vessel pitch trend line is read of the right hand axis (pitch angle, degrees).

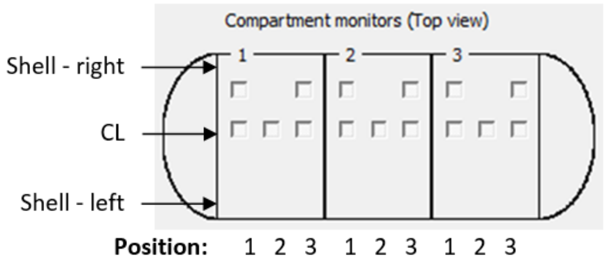


Figure 3 Definition of liquid level monitors

Figure 4, below, shows the comparison for the liquid level height monitor located on the vessel centre line at the upstream vessel tan line. MySep and CFD are in very good agreement in terms of synchronicity. For this monitor location, the maximum liquid level values from MySep are somewhat higher than those from CFD. We could say that here MySep predictions of liquid level interaction with any internal devices would be somewhat more conservative than those of CFD.

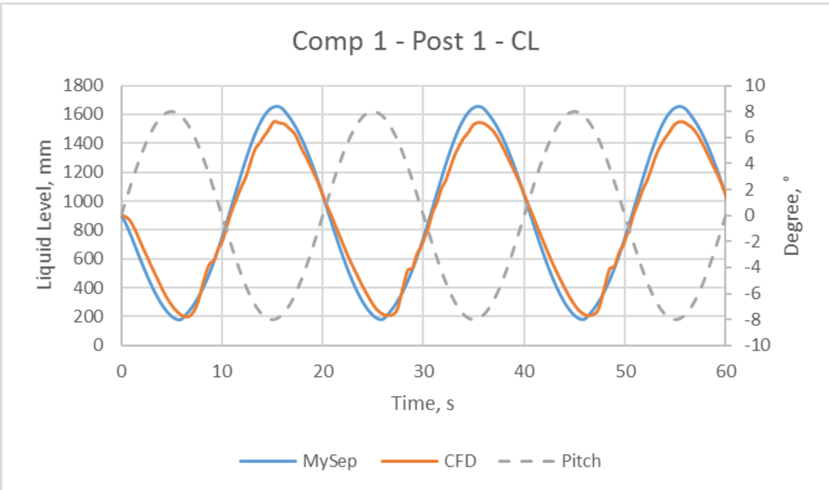


Figure 4 Liquid level on vessel centre line at upstream Tan line

Figure 5, below, shows the liquid level height in the central compartment (2), at Baffle 2, along the vessel shell. At this location, the effect of vessel roll on the liquid level behaviour is naturally greater than on the vessel centre line. The central compartment interacts with two compartments, which implies a greater degree of complexity to resolve the liquid level behaviour. This, along with the presence of waves or level disturbances may be an explanation for the somewhat erratic nature of the CFD predictions up to approximately t=35 seconds, thereafter we can see our CFD and MySep motion predictions falling into closer agreement. It appears that in some locations we can expect it will take 2 or more motion cycles before a repetitive pattern of behaviour to be established. Once this is the case, MySep and CFD are in good agreement.

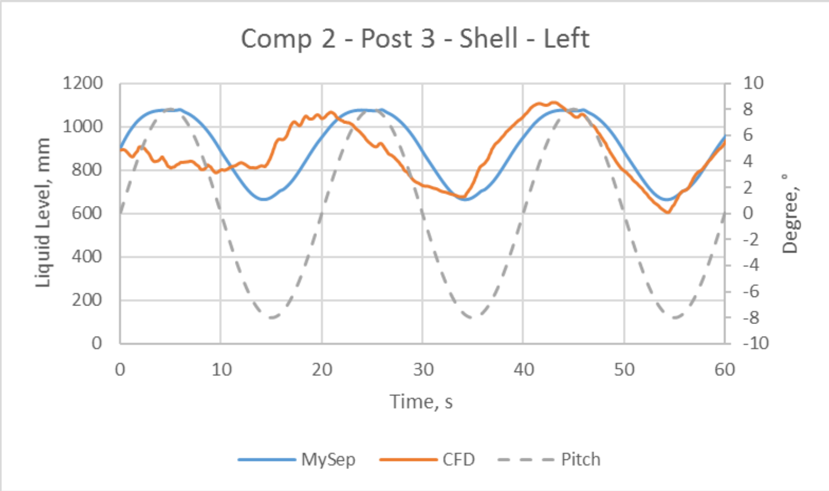


Figure 5 Liquid level in central compartment at vessel shell

Comparison charts for all liquid level monitors throughout the vessel are shown in the Appendix. Overall, reasonable to very good agreement is seen.

CONCLUSION

The Motion module is introduced in MySep v3.0 to enable process engineers to swiftly perform basic verification of vessel and internals designs against dynamic liquid levels resulting from vessel motion.

Although the calculation model is a simplified approach, the comparison with Computational Fluid Dynamics gives a high degree of confidence that it provides reliable liquid level height predictions.

The MySep Motion module is a very convenient and time saving tool for design verification and optimisation. Non-viable designs can be rapidly screened out so that any final CFD verification is only necessary for a small sub-set of near-optimum arrangements. This has major impact on design engineering cost and project execution time.

More information on MySep

Video showing the Motion module:	www.mysep.com/Videos/Motion-video.aspx
MySep extension for process simulators:	www.mysep.com/Videos/RunTime-introduction-video.aspx
MySep news and users:	www.mysep.com/News.aspx
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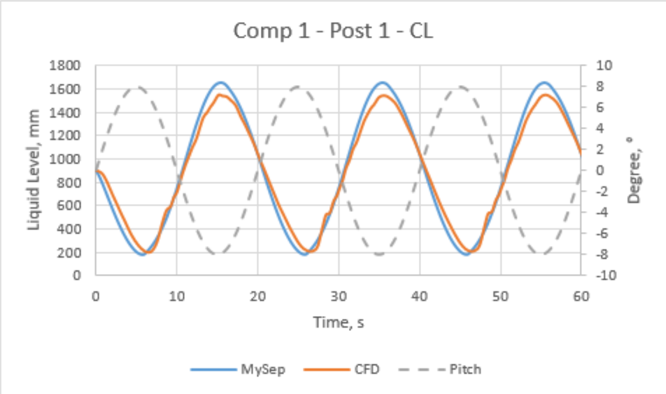
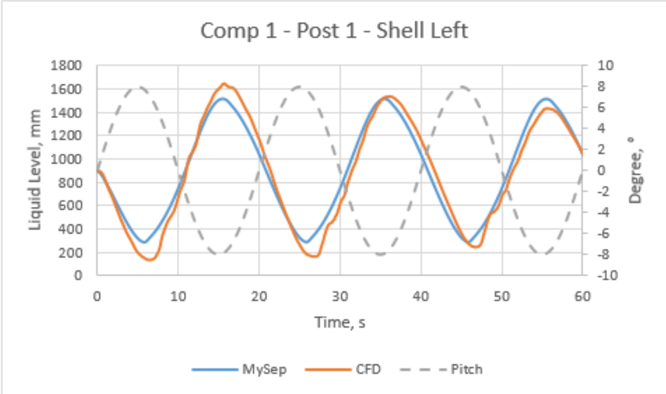
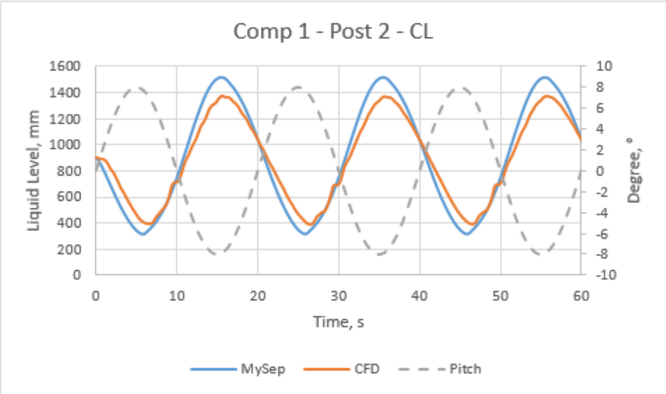
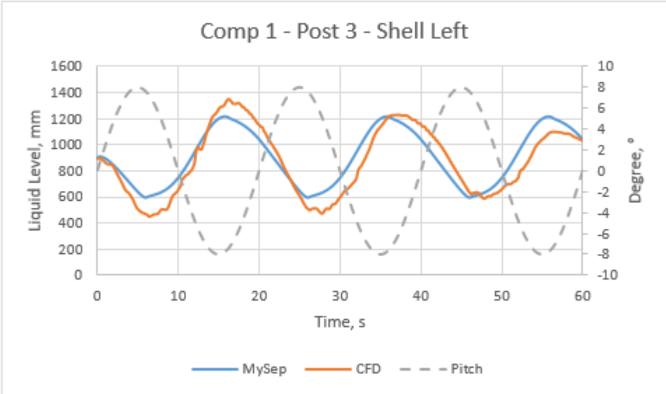
APPENDIX – COMPARISON CHARTS

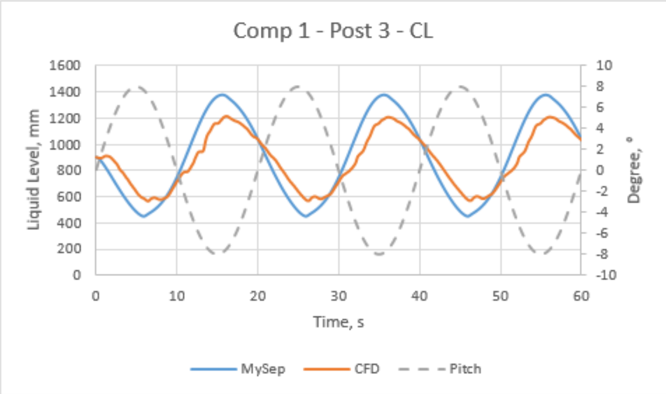
Compartment 1

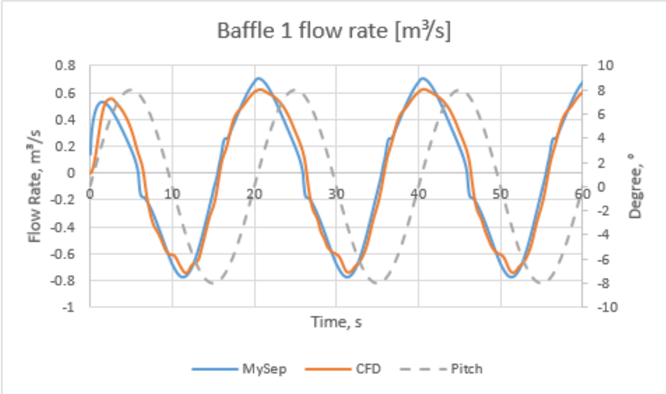




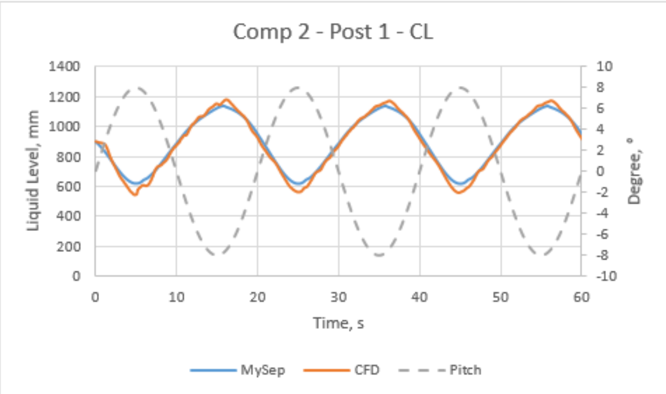


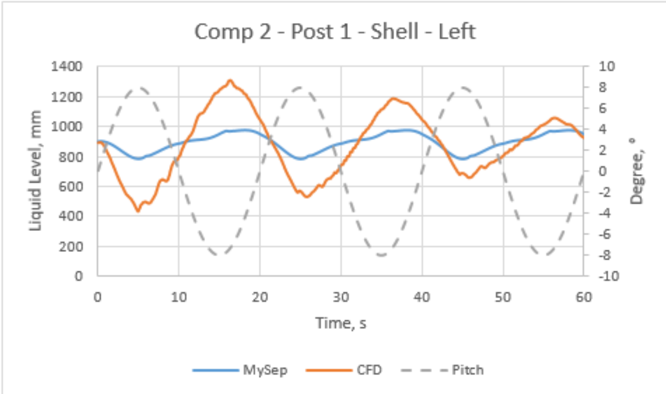


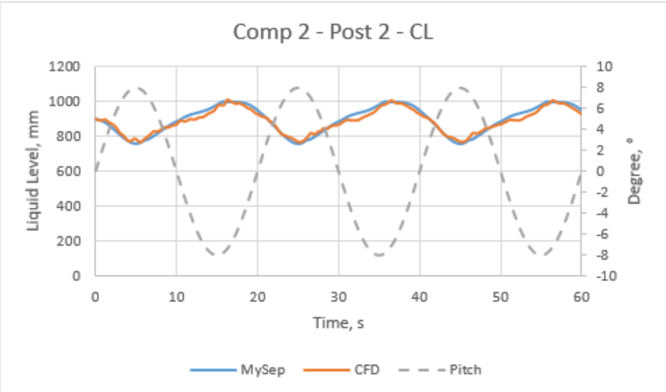


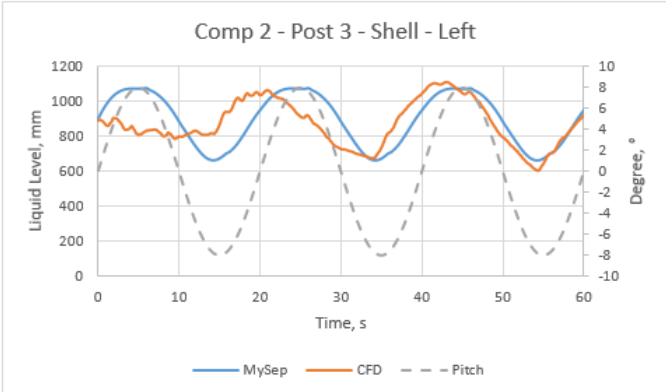


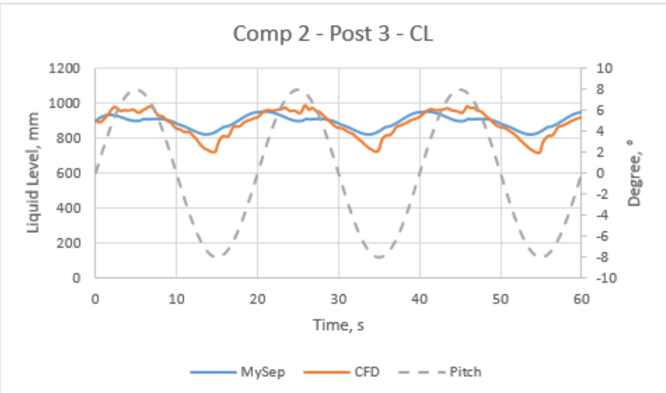
Compartment 2

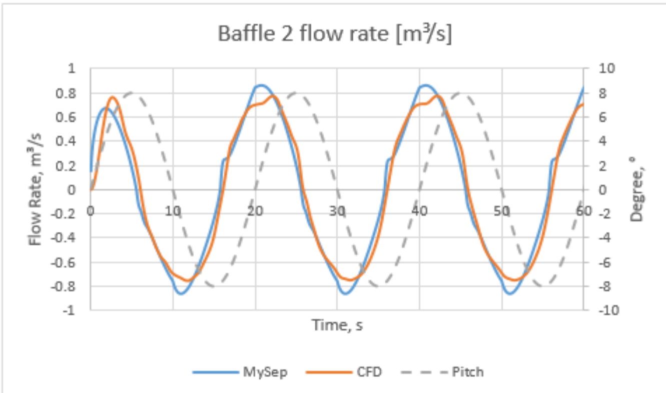












Compartment 3