Thermal Modeling Process Optimization

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Abstract *— Currently, Company XYZ conducts thermal validation using two approaches: full vehicle and local thermal models. In order to perform these analysis, three different software are used. STAR-CCM+ is used to run full vehicle models, while TAITherm and ANSA are used for the local models. STAR-CCM+ and TAITherm local model simulations were performed in order to compare their results and validate that STAR-CCM+ can be used for both full vehicle and local models. On all test cases, STAR-CCM+ presented robust results and savings in total simulation time. Therefore, STAR-CCM+ was recommended as the preferred software for thermal validation. The consolidation of the thermal space under one software will also represent a significant reduction in licenses, immediately supporting the bottom line of the company.*

Key Terms *— CAE for thermal validation, car manufacturing industry, thermal modeling, vehicle development*

INTRODUCTION

Car manufacturing companies have been developing mobility devices since the 19th century. In the developmental process of a vehicle, automakers invest millions of dollars to create the best possible product for their customers. The development phases of a vehicle run from its first stages in research and design up to later phases such as validation. When a vehicle undergoes a validation process, all its features are tested in order to prove its performance and safety. Major vehicle validations include cybersecurity, aerodynamics, vehicle dynamics, safety and thermal. Most of the validation processes conducted in the car manufacturing industry are performed using hardware as the developmental system. With the increasing complexity of the vehicle systems and the move from the industry to the electric vehicle (EV) sector, the automakers need more efficient validation processes that can save money and time.

In order to thermally validate a vehicle, different scenarios must be tested. Typically, these scenarios are at high temperature, high solar loads and grade changes were the vehicle could surpass the temperature limits for some of its components. By performing these tests, the durability and performance of the vehicles can be examined under the worst-case scenarios a customer can face.

One of the methods used to thermally validate a product is by using a prototype research vehicle. These research vehicles are expensive because they need to be calibrated and instrumented for testing purposes.

Over time, companies have had access to Computer Aided Engineering (CAE) software that have helped to aid in engineering analysis including validation. By using CAE, design candidates can be evaluated and refined using computer simulation rather than physical prototyping to save money and time [1].

There are two models that can be used to conduct a virtual thermal validation of a vehicle. The first model is a full vehicle model. This type of approach uses the complete vehicle inside a simulated wind tunnel. The second type is a local model. This type of model only uses certain subsystems of the vehicle. This last approach is used when refinements in the development of the system need to be done.

At the moment, company XYZ utilizes different Computational Fluid Dynamic (CFD) software to conduct these analyses. The full vehicle model is prepared and conducted entirely in STAR-CCM+ (CFD software). The local model uses two different software. The geometry preparation for the local models is done in ANSA (CAE software) and the fluid dynamics part of the simulation is run later in TAITherm (CFD software).

Even though at the moment, the thermal validation space is divided into one CAE and two CFD software, it can be consolidated under one CFD software (STAR-CCM+). This consolidation will enable the company to reduce its software licensing contracts and will improve employee productivity. In order to consolidate the thermal space into one CFD software, the solving capabilities for both CFD software need to be compared and analyzed to verify correlation when adding the same boundary conditions.

LITERATURE REVIEW

CAE has enabled a world of opportunity for several industries, including the automakers. Apart from early design evaluation, CAE permits engineers to have an early product development in which they can understand performance and manage risks. These benefit enables car manufacturers to have faster developmental plans and better product quality. Today's modern automobiles have benefited from the extensive use of computer-aided engineering (CAE) to make them quiet, durable, comfortable, stable and safe [2].

Thermal validation has been one of the spaces that has benefited the most from the development of CAE and CFD tools. Thermal validation is complex, with thermal engineers needing to validate the engine bay components, air induction system, engine, exhaust system and underbody thermal lines. With the increasing popularity of EVs, thermal engineers will also need to validate lidars, sensors and battery packs for vehicles with this new technology. Therefore, there is an increasing need to develop robust methods for thermal simulations. Transient vehicle thermal management simulations have the potential to be an important tool to ensure long component lifetimes in heavy-duty vehicles, as well as save development costs by reducing development time [3].

METHODOLOGY

In order to compare and analyze both software capabilities, the test cases on Table 1 were performed. Same geometry and boundary conditions were applied for each of the separate tests. All test cases included the three modes of heat transfer: convection, radiation and conduction. The comparison of both software was done by conducting thermal mapping of the surfaces. Boundary conditions included material emissivity, ambient temperature and heat transfer coefficient. In some cases, the virtual simulation results were compared to hardware data.

Table 1
Test Cases Conducted

Steady State Simulation	Transient Simulations
Simple geometry	Simple geometry 48 minutes transient (warm up+ grade + soak)
Geometry with multiple parts	
Geometry with variable thickness	Simple geometry 4-hour Thermal Sequence
Fluid domain/ stream included	

For all the simulations conducted in TAITherm, the geometry parts and mesh were prepared using ANSA. The mesh used for steady state simulation was a surface mesh with a virtual thickness that was inputted in TAITherm. The geometries for transient simulations were meshed as surface mesh and as solids separately. The mesh used for the TAITherm models had quad elements with a target length of 7mm. The simulations conducted in STAR-CCM+ were prepared, meshed and conducted on the same software. All the geometries executed in STAR-CCM+ were meshed as solids. The base size for the elements was 7mm and the mesh was a polyhedral one.

For all test cases, the time for geometry/mesh generation and solution were recorded in order to quantify the potential simulation time (employee productivity) that can be saved by consolidating the thermal modeling under STAR-CCM+.

RESULTS AND DISCUSSION

The test cases from Table 1 were conducted for this study. For the first two steady state simulations (simple exhaust and heat shield and geometry with multiple parts) there weren't any major difference between the solutions given by TAITherm and STAR-CCM+. The first discrepancy with the solution of both software was encountered when conducting the simulation for geometry with variable thickness. This was expected because TAITherm uses a virtual thickness that is applied to the entire geometry. Therefore, changes in the geometry thickness are not considered and are ignored for the calculation of heat transfer.

Differences were also encountered when using the fluid domain/fluid stream capabilities on the software. The fluid domain/fluid stream simulation has the goal to recreate a moving fluid inside a cavity and calculate the resulting temperature of the fluid based on heat transfer. In order to perform this type of simulation, boundary conditions needed to be added to the fluid apart from the boundary conditions of the system. The fluid had an assigned inlet temperature of 500°C and a mass flow rate of 0.08 kg/s for both software.

When analyzing the results, it was noted that in some spatial regions the difference between both software was above 20C. The differences between the two software results are driven by how each one creates the fluid inside the parts. TAITherm uses a fluid node approach, therefore the flow is only 1D. Since TAITherm solves the fluid as a 1D, there are no velocity profiles inside the pipe. In STAR-CCM+, the fluid is continuous and 3D. Therefore, the fluid inside the exhaust interacts with the pipe walls. In order to understand which of the software was the most representative of a real scenario, the data was compared with hardware test data. As seen in Figure 1, STAR-CCM+ correlates better with hardware data.

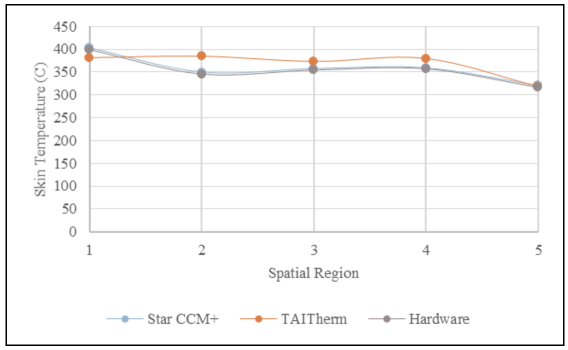

Figure 1
Spatial Exhaust Skin Temperature

For transient analysis, two different simulations were performed. First simulation performed was a 48-minute transient case with warm-up, grade and soak. For this simulation, it was noted that there was a consistent difference between TAITherm and STAR-CCM+. This difference got accentuated at the peak of the grade simulated, as it can be seen in Figure 2. Even though 4°C is under an acceptable level of discrepancy, a new simulation was performed using a solid mesh for TAITherm. The solid mesh would let the geometry have a real thickness once the simulation had to be run in TAITherm. It was noted that STAR-CCM+ and the TAITherm solid mesh variant correlated perfectly. A 4-hour thermal sequence was also analyzed, same behavior on peak grade was noted. In this case the discrepancy between TAITherm and STAR-CCM+ was of 6°C.

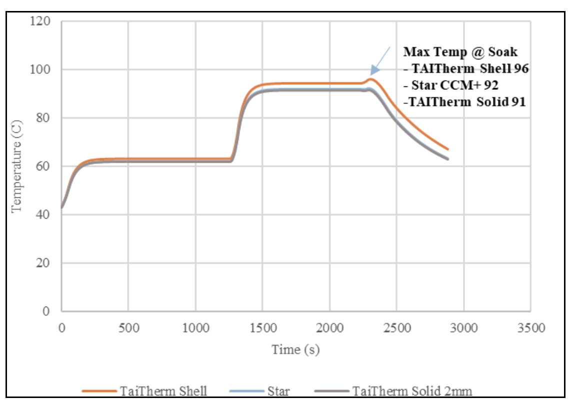

Figure 2
Simple Case 48 Minutes Transient Plate Temperature

In order to compare both software from a productivity standpoint, the solution (geometry and software preparation) times were recorded for each of the simulations. As it can be seen in Table 2, all STAR-CCM+ simulations presented a savings in total productivity time.

Table 2
Simulations Productivity

STAR-CCM+ Simulations	Solution Time (mins)	Geometry & Software Preparation (mins)	Total Time (mins)
Simple geometry	15	35	50
Geometry with multiple parts	85	51	136
Geometry with variable thickness	13	27	40
Fluid domain/ stream included	20	40	60
Simple geometry 48 minutes transient	91	26	117
Simple geometry 4-hour Thermal Sequence	147	26	173
TAITherm Simulations	**Solution Time (mins)**	**Geometry & Software Preparation (mins)**	**Total Time (mins)**
Simple geometry	5	57	62
Geometry with multiple parts	20	125	145
Geometry with variable thickness	8	61	69
Fluid domain/ stream included	7	68	75
Simple geometry 48 minutes transient	53	67	120
Simple geometry 4-hour Thermal Sequence	113	67	180

It must be noted that TAITherm presented better solutions times for all the simulations. The difference in the total productivity time comes when adding the geometry and software preparation. As stated before, the geometry preparation for TAITherm simulations is performed in ANSA. In ANSA, all geometries need to be prepared by erasing the thickness for all the model before uploading them to TAITherm. Sometimes this is a very time-consuming task depending on the complexity of the geometry. Once the thickness is erased, the geometry needs to be meshed on the same software. STAR-CCM+ presents higher solution times, but the geometry and software preparation are what makes this software better in terms of productivity. STAR-CCM+ user interface is much easier to navigate than ANSA. Also, all geometries are meshed as solids, therefore the geometry barely has to be prepared for the mesh.

CONCLUSION

The results of this study showed that STAR-CCM+ can perform local heat transfer modeling with similar fidelity as TAITherm. It was noted that when using a fluid domain approach, STAR-CCM+ solved the simulation in a more accurate way presenting results that correlated with hardware data. On transient simulations, STAR-CCM+ results correlated better with TAITherm solid meshing, indicating that a solid mesh approach tends to be more accurate. The study showed that STAR-CCM+ has faster model preparation, therefore employees can use the time saved on other tasks increasing their productivity. Also, employees are very familiar with STAR-CCM+ because full vehicle models are performed entirely on this software.

STAR-CCM+ demonstrated to be capable of performing local models, therefore its use is recommended. This study was of strategic value to the thermal validation space as it will result in a transfer of work from one software to another, enabling a significant reduction in licenses which will immediately support the bottom line of the company.

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