Process Improvement Through Tool Integration In Aero-Mechanical Design

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Emerging capabilities in commercial design tools promise to significantly improve the multi-disciplinary and inter-disciplinary design and analysis coverage for aerospace mechanical engineers. This paper explores the analysis process for two example problems of a wing and flap mechanical drive system and an aircraft landing gear door panel. The examples begin with the design solid models and include various analysis disciplines such as structural stress and aerodynamic loads. Analytical methods include CFD, multi-body dynamics with flexible bodies and structural analysis. Elements of analysis data management, data visualization and collaboration are also included.

Nomenclature

CAD	=	Computer Aided Design
CAE	=	Computer Aided Engineering
CFD	=	Computational Fluid Dynamics
COTS	=	Commercial Off The Shelf
IPDT	=	Integrated Product Development Team
PDM	=	Product Data Management
PLM	=	Product Life Cycle Management

I. Introduction

MANY aerospace and defense organizations are struggling to knock down silos in support of Integrated Product Development Teams (IPDTs). Rapid system development times coupled with the increasingly complex nature of advanced systems requires tightly integrated design and analysis capabilities. Multi-disciplinary analyses involving thermal, structural and optical analysis and external aerodynamics and structural analysis are foundational to aircraft and spacecraft design. The time required to pass data from discipline to discipline to effect such studies can no longer be afforded. Integrated tools that automate and assist such multi-disciplinary analyses have existed in the form of specialized, and often in-house, developments. This paper explores the emerging capabilities in a commercial tool set that has proven scalability to large detail design projects.

The paper is not intended to be an advocacy statement for the example tool set. On the other hand, the intent of the paper is not to survey multiple tool sets. Similar capabilities can be assembled from individual tools from multiple vendors but, here, the tools are all from the same vendor. In the author's experience, this provides significant improvement due to inherent compatibility and avoids the finger pointing that so often arises when difficulties occur with integration of tools from multiple vendors.

The tools used are from Siemens PLM and include brand components known as NX, NX Nastran, and Teamcenter. These are the strategic design tools at JPL and the mechanical design process is structured around their use and support. The NX CAD and CAE tools are based on the legacy brands UG, I-DEAS and TMG that may be more familiar.

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II. Aero-Mechanical Example Problems

Two example problems are considered. They are intended to be visually realistic but are filled out only to the conceptual design level. The data sets were provided by Siemens and are commonly used for demonstration activities.

The Landing Gear Door example looks at the design loads imposed on a door that forms part of the closure to a retractable aircraft main landing gear. See Figure 1 where the door is shown in green.

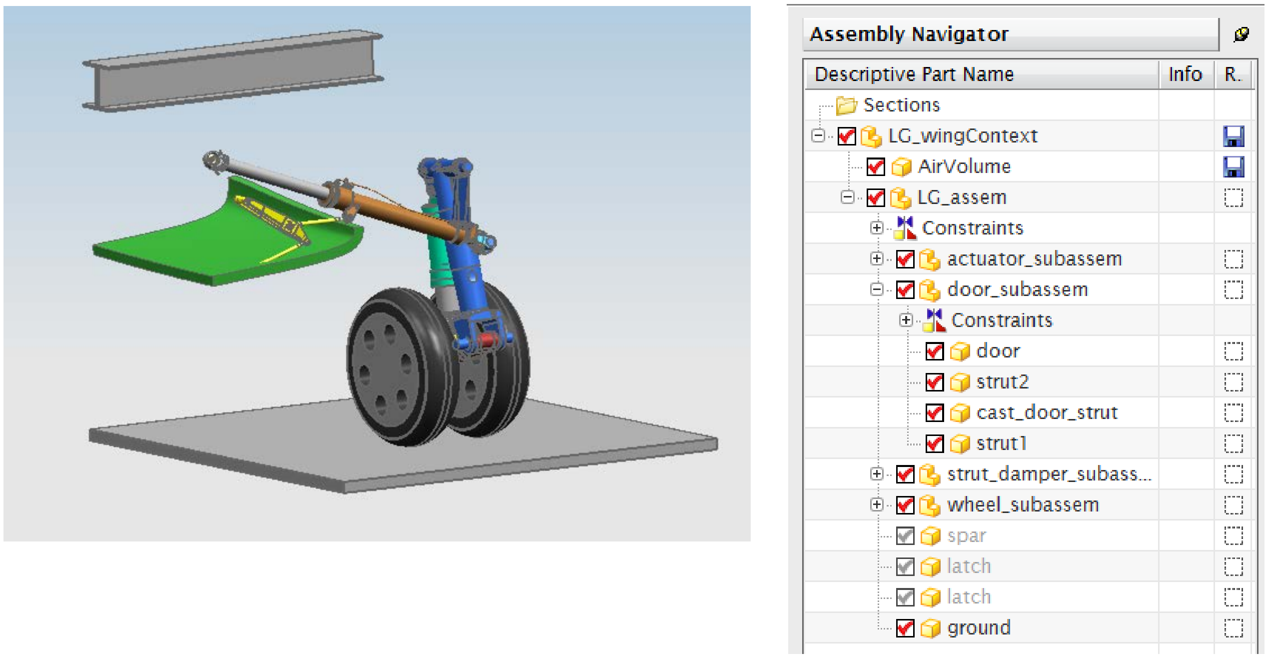


Figure 1. Landing Gear Example

The CAD design model is quite simple and is sufficient to satisfy layout, spacing and deployment envelope activities. The dataset obtained included multi-body motion analysis that covers extension from stowed to ground impact. See Figure 2 for snapshots from the motion solution captured in the CAD model.

An objective of this example is to illustrate the integration of CFD analysis, used to compute loads on the door, with the structural analysis of the door. To that end, a localized aerodynamic model of the flow regime under the wing was constructed and is shown in Figure 3. To support illustration of the integrated analysis process, much of the detail of the flow surrounding the landing gear has been omitted. The door profile was extended to provide a lower fuselage surface and a lower wing surface. The level of detail required and its impact on the process will be discussed.

The CFD mesh and door structural mesh are illustrated in Figure 4. The CFD mesh refinement around the door is intended only to characterize the pressure across the door in order to structurally size the door based on stress and displacement at the various positions of deployment. The structural model is a typical midsurface plate model with constraints representing the hinge and push rod supports.

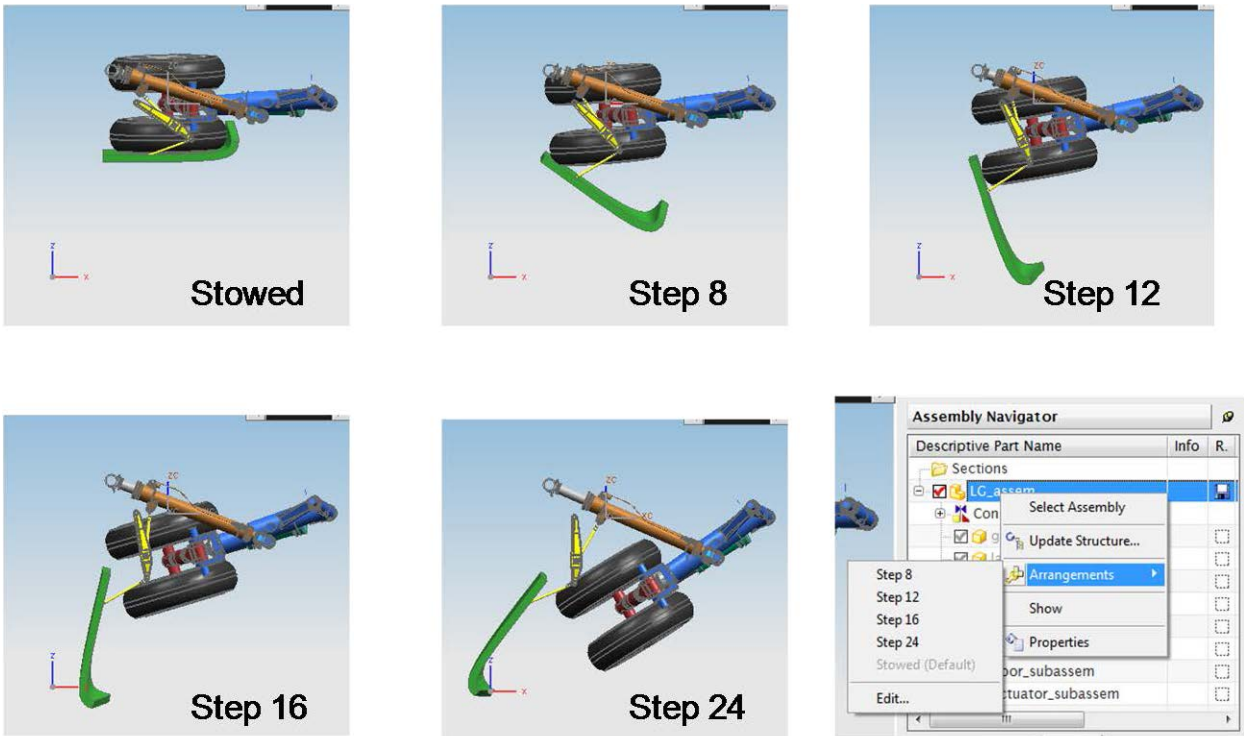


Figure 2. Extension Motion Simulation

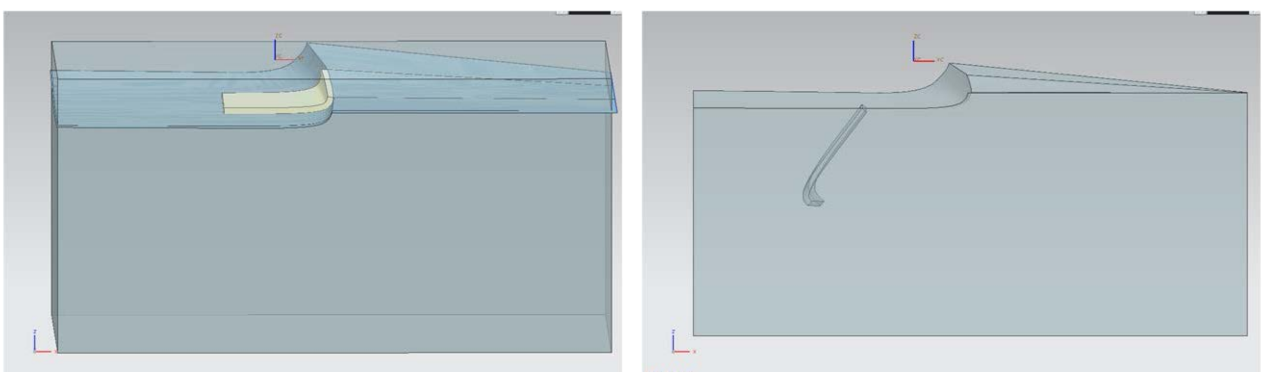


Figure 3. The Aerodynamic Context for the Door

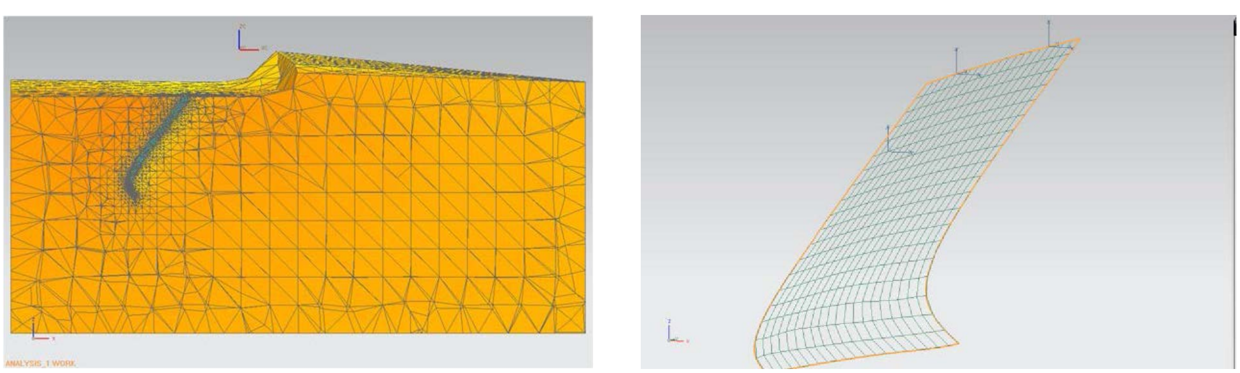


Figure 4. Illustration of the CFD Mesh and the Door Structural Mesh

The second problem incorporates a more complex set of inter-disciplinary analyses. A constant chord airfoil has been extruded to form a short wing section and a two piece flap incorporated. The example focuses on the flap drive mechanism design process. Figure 5 shows the profile with the flaps partially extended. The aerodynamic context for the wing is a simple bounding box with a modest computational grid sufficient to explore the analysis process. Figure 6 illustrates the grid and sample velocity results. The aerodynamic forces and moments were applied to the flap bodies in the multi-body simulation and resulting internal forces on the mechanism links computed. Figure 7 shows the required drive torque and the internal load in a typical link.

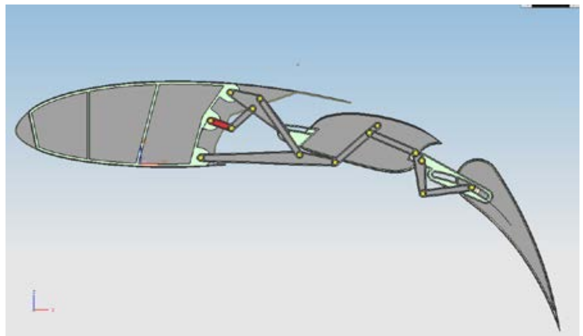


Figure 5. Wing and Flaps Example

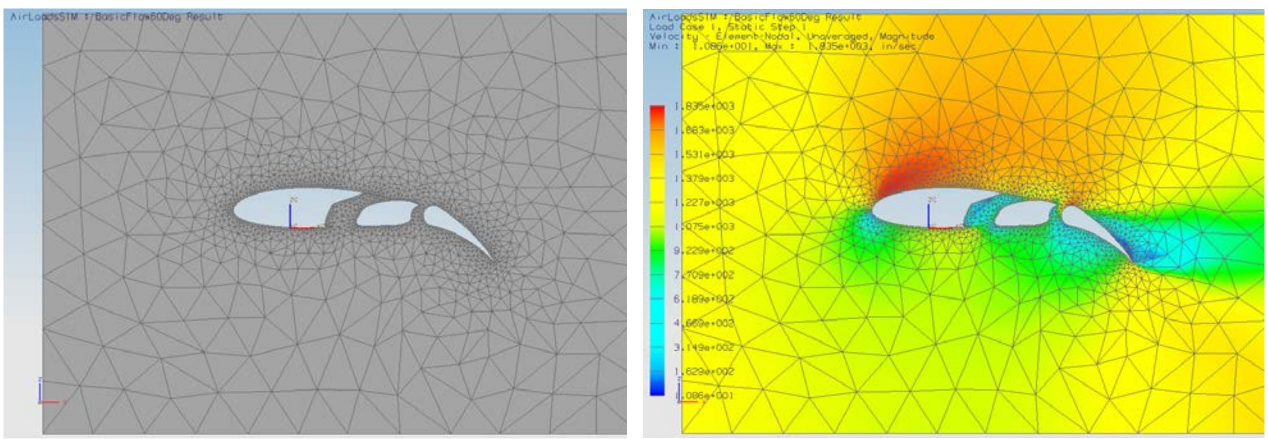
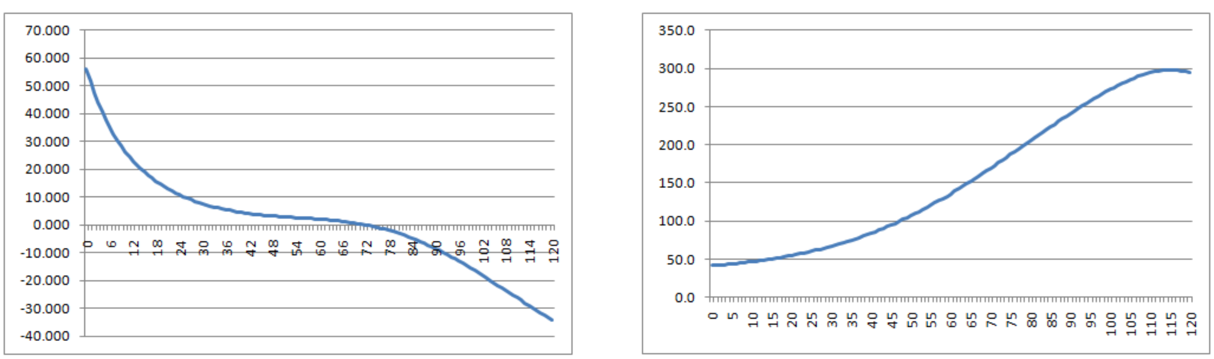


Figure 6. CFD Grid and Example Velocity Result



Drive Link Torque   Link 3 Force

Figure 7. Mechanism Internal Force Examples

III. The Process Domain

The target problems are cast in a local sub-context relevant to a mechanical engineer's focused problem. The goal is to provide the mechanical engineer with a bounded aero analysis context to explore the localized problem domain. The project external aerodynamicists and CFD experts would guide or set up the local CFD problem giving consideration to computational responsiveness, dominant phenomena and requisite accuracy.

Once set up, the mechanical engineer could iterate independently. At appropriate occasions, the aerodynamicists would consult, provide interpretive guidance and tune the aero model as needed. At major epochs, the mechanical design would be folded back into the external aero model and the aerodynamicists would update their design loads.

There are limitations on the aerodynamics problem that arise from several sources. For example, to keep the responsiveness of the modeling process up, the incorporation of design updates and the rebuilding of models needs to be highly automated. The current tools can handle much of this better than in the past, but complex geometry still requires manual intervention. The conceptual design models inherently have less detail and better fit current capabilities. Fortunately, this is where much of the motivation to explore the design space occurs. The CFD models are simplest when smooth bodies in streamlined flow are involved and bluff bodies, separated flow and unsteady situations can be avoided.

The set of localized problems owned by the mechanical engineer that involve external aerodynamics include the current example of flap drive mechanism and similar problems like spoiler drives (although the spoiler aerodynamics are not simple), ducts with external openings for ram air or venting, deployable ram air turbines, landing gear doors and stores bay doors that open in flight, wing leading edge flaps, and control surfaces like ailerons and elevators. There are also simpler problems with fixed structures in the airstream such as blade antennas.

The current examples rely on revisitation and manual acceptance of all the update steps since intervention is sometimes required, especially in the early stages of assembling the models. A future of push button automation for design updates and space exploration is a long ways away, even if it is desirable. For example, the landing gear problem can be walked through the steps from setting the design model to a extension position, updating the CFD volume, remeshing, and solving, followed by updating the door structural mesh, interpolating the pressures and solving for the displacements without fixing any of the models, just accepting the updates.

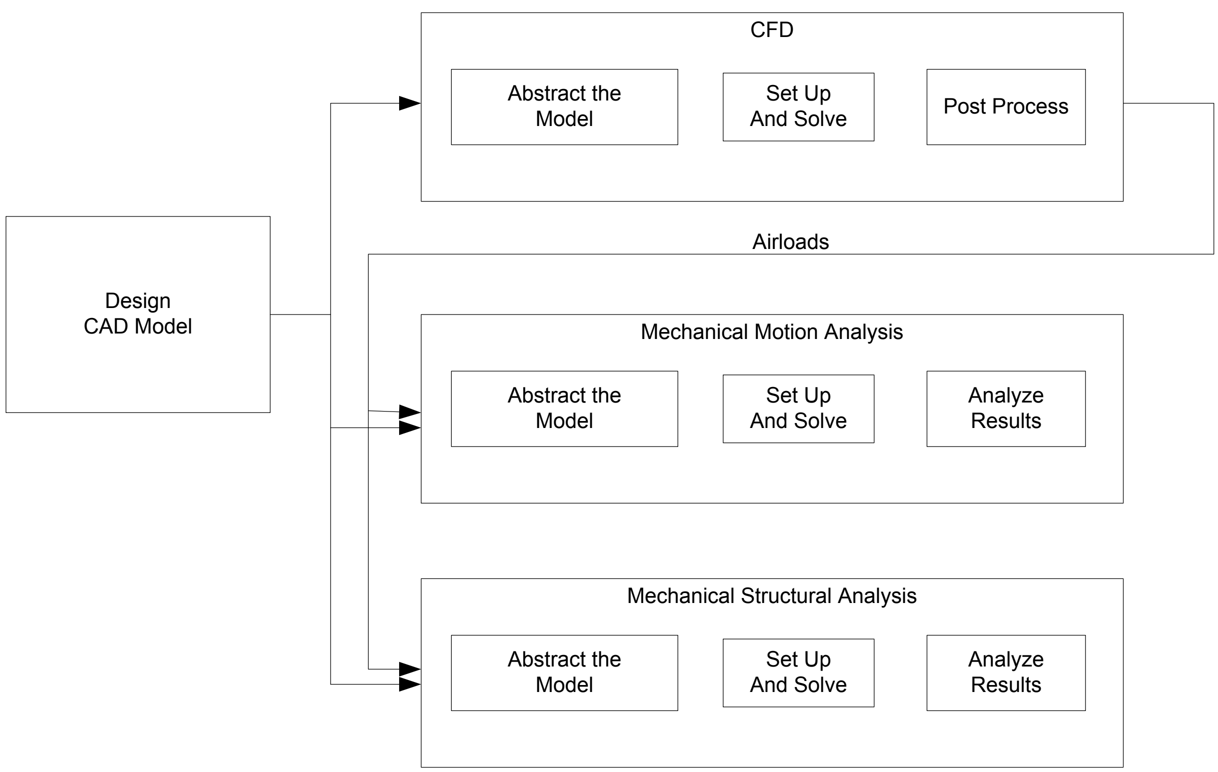


Figure 8. Process Flow

The discipline domains and data flow in the current process examples are illustrated in Figure 8. Since the process improvement arises from all of these occurring in a single tool, data access is facilitated. For example, the design CAD model is used as an input to each of these discipline activities. The analysis disciplines must abstract the design models in different ways and in the current tool, the CAD operations and the analysis operations are generally both available in the abstraction context. The engineer faces the trade of investing in associative and updatable operations which require some ingenuity, creativity and effort against the expediency of getting through the problem once any way possible.

The other data path illustrated in Figure 8 is transfer of the aero loads to the structural analysis and motion analysis. In NX, the required interpolation from the CFD surface mesh to the structural mesh has been automated and will replay upon update. For multi-body motion analysis, the CFD resultant forces and moments can be calculated in a loads report but have to be manually entered as body forces. It is possible to use the same coordinate system in the design model for both analyses so that the coordinate transformation doesn't have to be done manually.

With the models constructed, exploration of the design space could proceed in a number of directions. In the examples presented, the as-designed mechanical motion is studied at various positions. The loads on the landing gear door are calculated for various extension positions and the flap drive link loads are calculated for various flap extension positions. Aerodynamic parameters can be varied to survey the flight regime. Here, a slide slip for the landing gear and angle of attack for the wing were evaluated. Of course, flight parameters such as altitude and speed can be cases.

A more ambitious meaning of design space might include studying shape or size parameters. This would be accomplished by altering the design CAD models and pushing the changes through the analyses. The investment in robust abstraction and meshing pays off here.

All of this has been done in mixes of tools from different vendors. The novelty here is all the tools come from a single vendor. The most popular current implementation approach is to use a software integration structure to lash up individual tools into a work flow and facilitate the passage of the correct datasets. Examples of companies with implementations include Phoenix Integration, Engineous and Comet Solutions, although each uses different technologies and approaches that provide market differentiation. In fact, these softwares still have a place in the automation of the current examples in NX by, for example, automating the sampling and evaluation of the design space.

IV. Process Qualification

The credibility of the end-to-end tool chain rests on the individual tool components and the integration methods between them. Each of the tools used in these examples is a COTS tool, as mentioned, with significant heritage. The structural solver, for example, is NX Nastran which has a 35 year history and is widely accepted in the industry. The structural pre and post processor is NX and, while new to the NX brand, has a significant legacy in I-DEAS. The NX Flow CFD component is relatively new, but has heritage in the Electronic System Cooling component for internal flows. Each of these components has its documented basis in user studies, as well as vendor documentation. Clearly, the ensemble may be no better than its worse component.

The interface components each have their own history. For example, JPL worked with Siemens to understand the methods used for transferring temperatures from the thermal solution to the structural grid. The algorithms were studied and test problems run to check the component performance since this was a critical step in the new thermal, structural and optical analysis capability being implemented.

Success of the process also depends on the quality of the various discipline models. Here, the mechanical engineer is supported by an aerodynamicist in setting up an appropriate CFD model. The organizational culture will have a significant impact on both the suitability and success of this cooperative arrangement. For example, in a certain small company, the mechanical engineer was solely responsible for the loads used in design of a prototype air vehicle and he constructed a similar environment from separate tools.

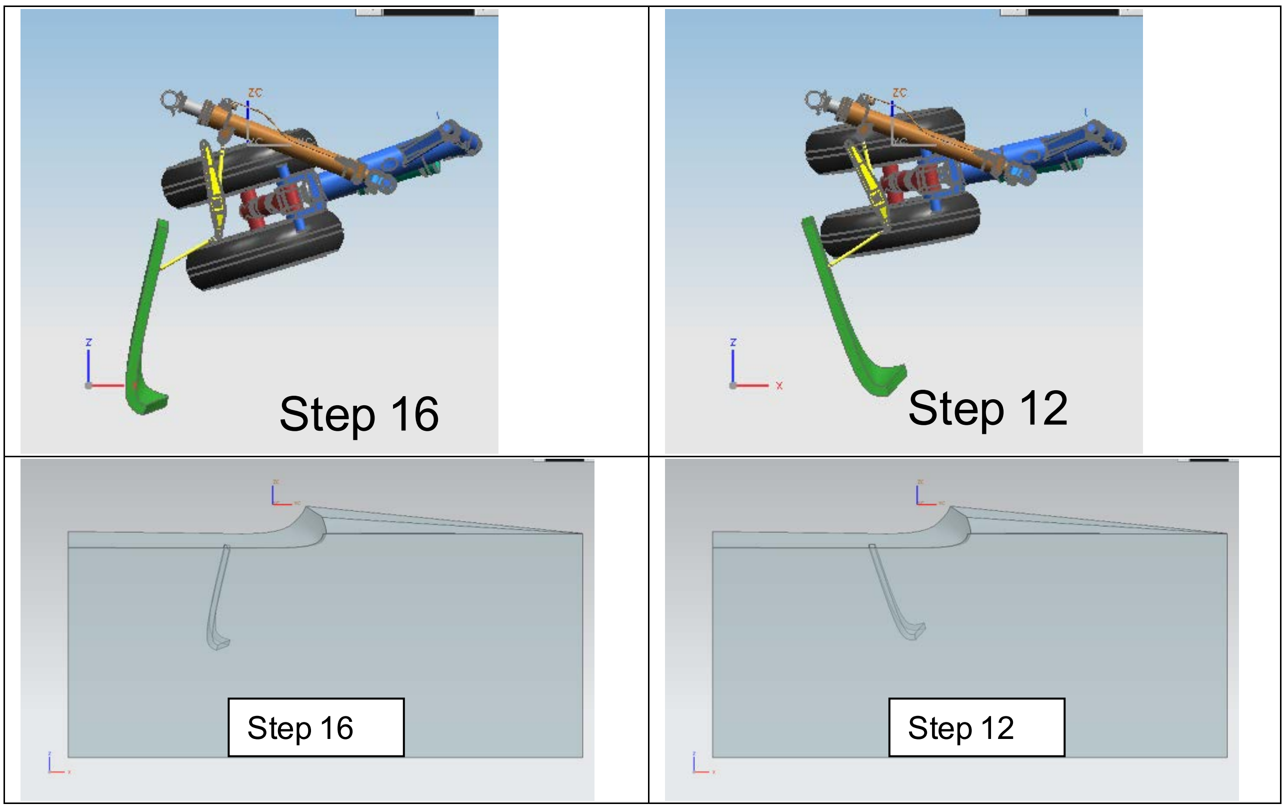
Broader experience is needed in the transformation of the design CAD models into the simplified and abstracted form needed for CFD and CAE modeling. This is a key component here. The NX tools provide individual datasets for the simulation, the CFD or FEA model, and the abstracted geometry. The analyst selects appropriate CAD design assemblies and components for inclusion in the simulation model and this step will replay on update. The abstraction and simulation operations are captured in the abstracted geometry model and will also replay on update.

In the examples presented here, all of the analyst's datasets are distinct from and do not alter the design CAD models. When combined with a PDM or PLM system for configuration control of the model datasets, the mechanical engineer's design context can track the IPDT's progress. The PDM or PLM system can also provide collaborative access for the IPDT members to the mechanical engineer's models and results.

V. Integration and Automation Illustrations

In this section, selected illustrations of the discipline integration and automation such as geometry updates are presented. There are many steps in either of these examples and not all can be documented. The objective is point out the innovation possible in such single family tools.

Within a discipline tool set such as structural analysis, it is common for the software to propagate design model geometry changes through the abstraction step and on into the mesh update. In Figure 9, the design model is changed from the pose labeled "Step 16" to "Step 12" and both the CFD context geometry and the door FEA mesh follow the move. Had the door shape changed, for example, as part of a change to the under wing Outer Mold Line, the FEA model, which is a mid-surface plate model, would have taken the new shape. Properly constructed, the FEA mesh would follow a different twist of the mid plane, lengthened or shorted if the door size was changed and changed element layout as captured in the mesh recipe.



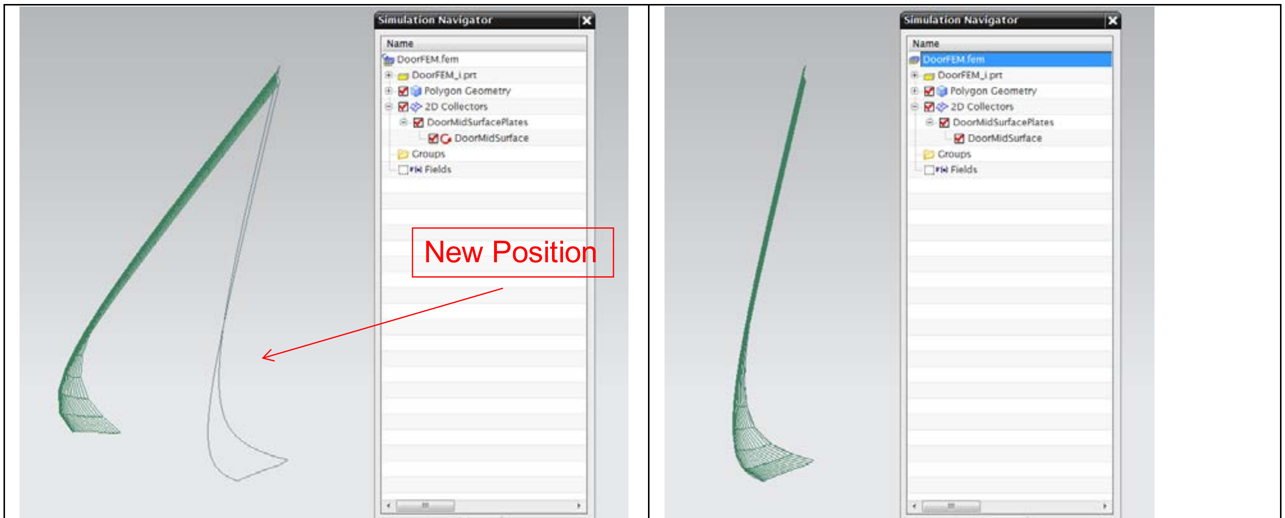


Figure 9. Design Model Change Propagated to the CFD Context and the Door FEA Model

Two examples of moving data between disciplines include computing the pressure on the door for the structural stress problem and the aero resultants on the flap segments for the motion solution.

For the pressure transfer example, the NX tools have automated this step. The recipe for this step is captured in a dialog that points to the CFD solution and the FEA mesh. In the left frame of Figure 10, the mapping set up dialog points to the flow results and in the right frame the structural solution picks up these pressures as Loads. The resulting Loads will update if the CFD solution changes or if the structural geometry and its mesh changes.

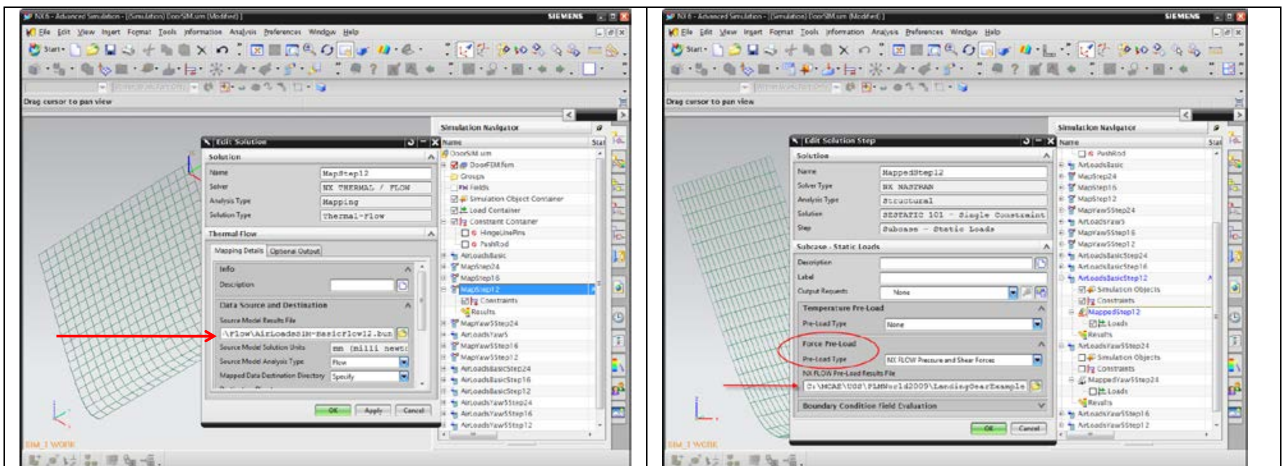


Figure 10. Transferring CFD Pressure Results to the Structural FEA Model

For the multi-body motion problem, the resultant forces on each of the three wing and flap bodies are computed by the CFD solver and reported in a spreadsheet. Figure 11 illustrates the lift and drag forces over the range of motion. Notice the embedded coordinate systems in each body that were used to define the directions. The resultants in the spreadsheet produced by the CFD post processor must be manually entered into a table format in the input data deck for the NX Motion solver. These are then used in the solution as flap body forces across the range of motion.

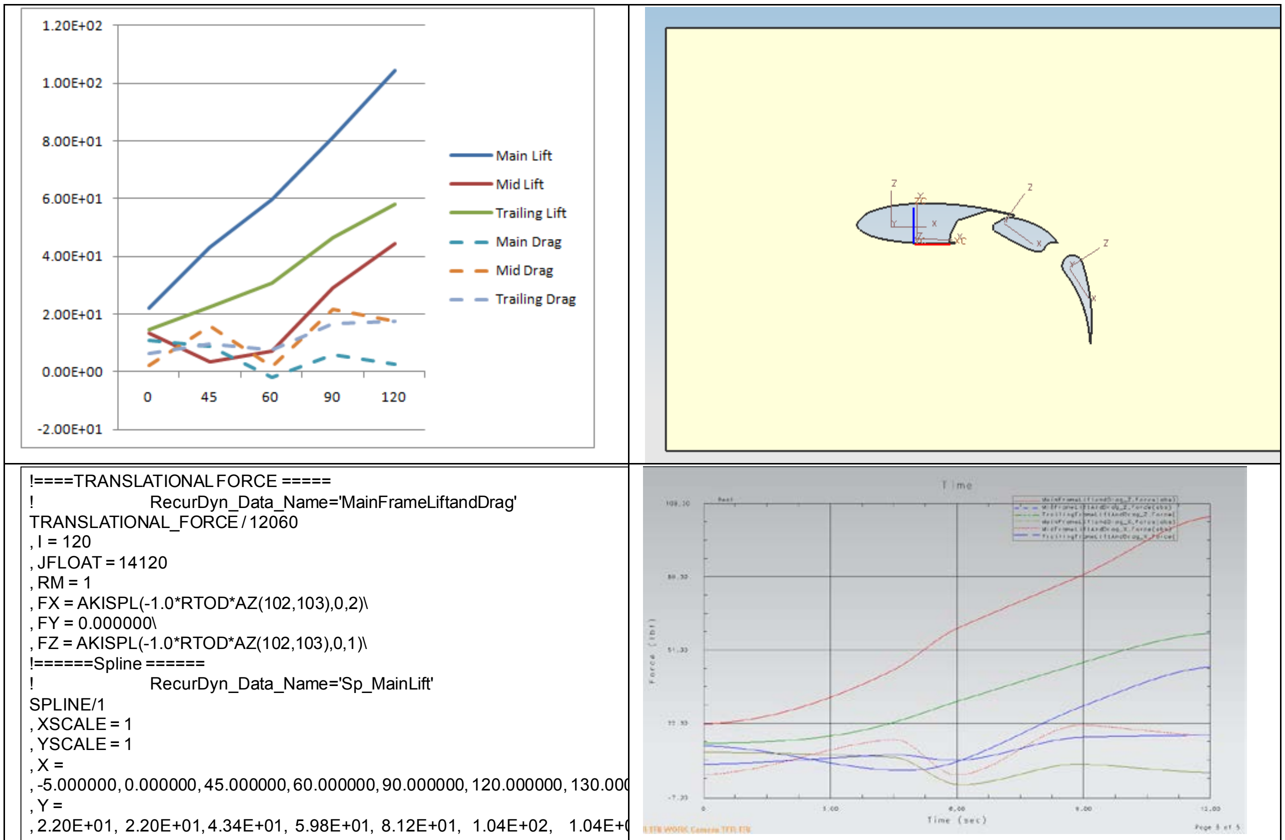


Figure 11. CFD Body Forces Must Be Manually Moved from Lift Report to Table in Motion Data Deck

VI. Use in a Product Lifecycle Management Environment

The Siemens software suite includes a collaborative data management environment in the Teamcenter set of products. When all of the CAD and CAE design activities are executed in the Teamcenter managed environment, the design data and analysis results are available to the entire IPDT regardless of their location.

Fig. 12 illustrates a typical data set display. The analysis models and result data sets are maintained in a revisionable data structure. The analyst can launch working sessions from here and all the activity data are automatically saved in the data vault.

For tracking the relationship between the design that has been analyzed and the modeling results, the Teamcenter CAE Manager application uses three coordinated tab panes. Fig. 13 shows flap drive example design data, model data and simulation data sets. Each of these panes can have a visualization window to review the models and results in the data manager.

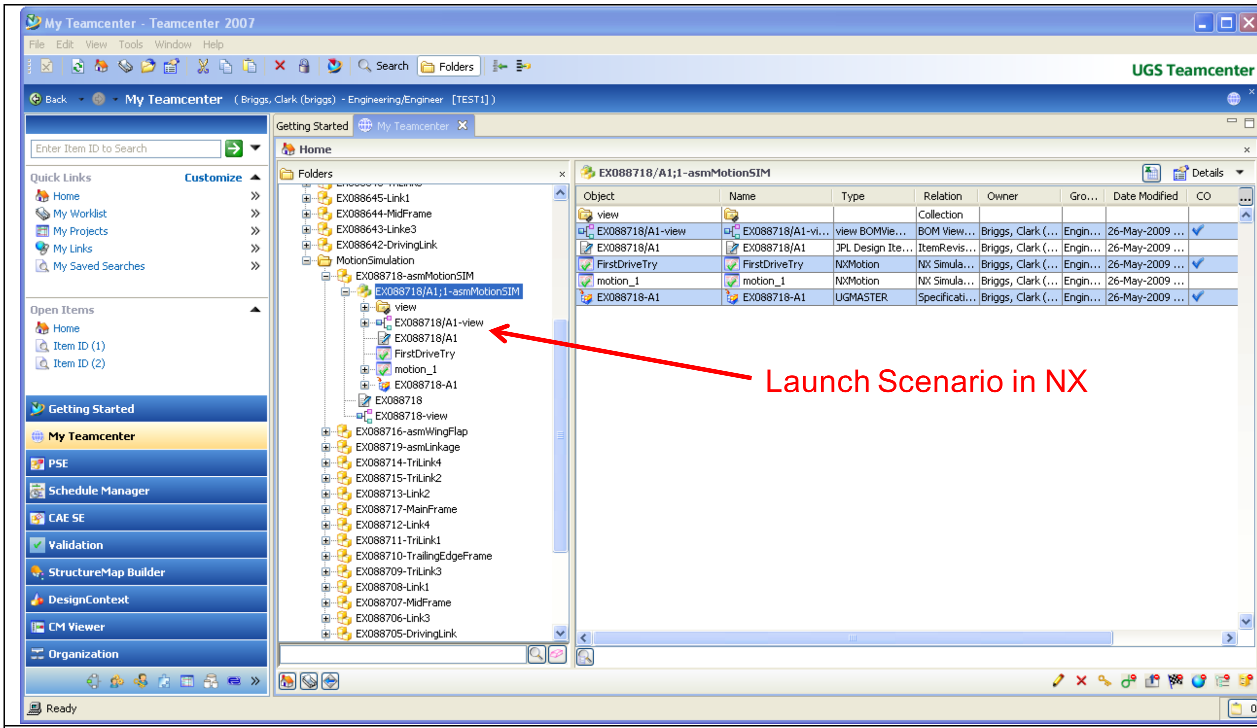


Figure 12. Teamcenter managed analysis data

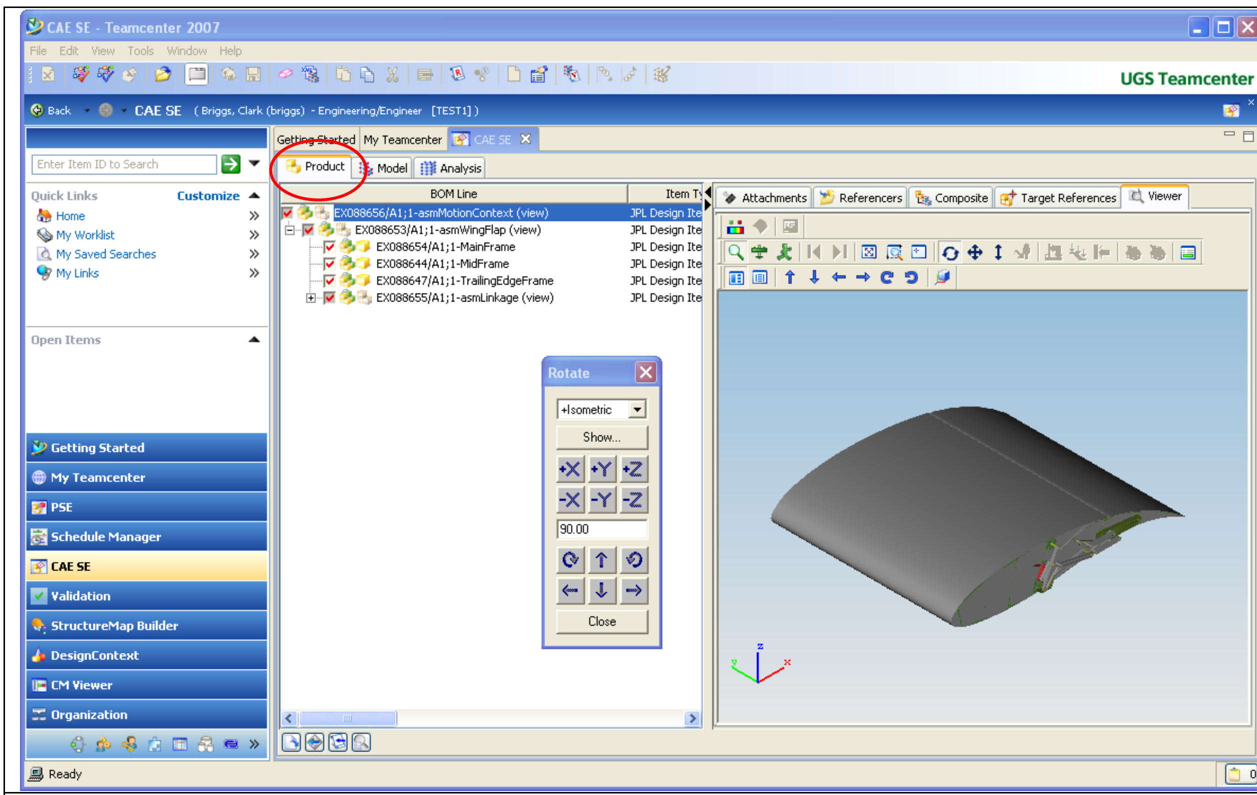


Fig 13a. The Design Data Tab with Visualization Pane

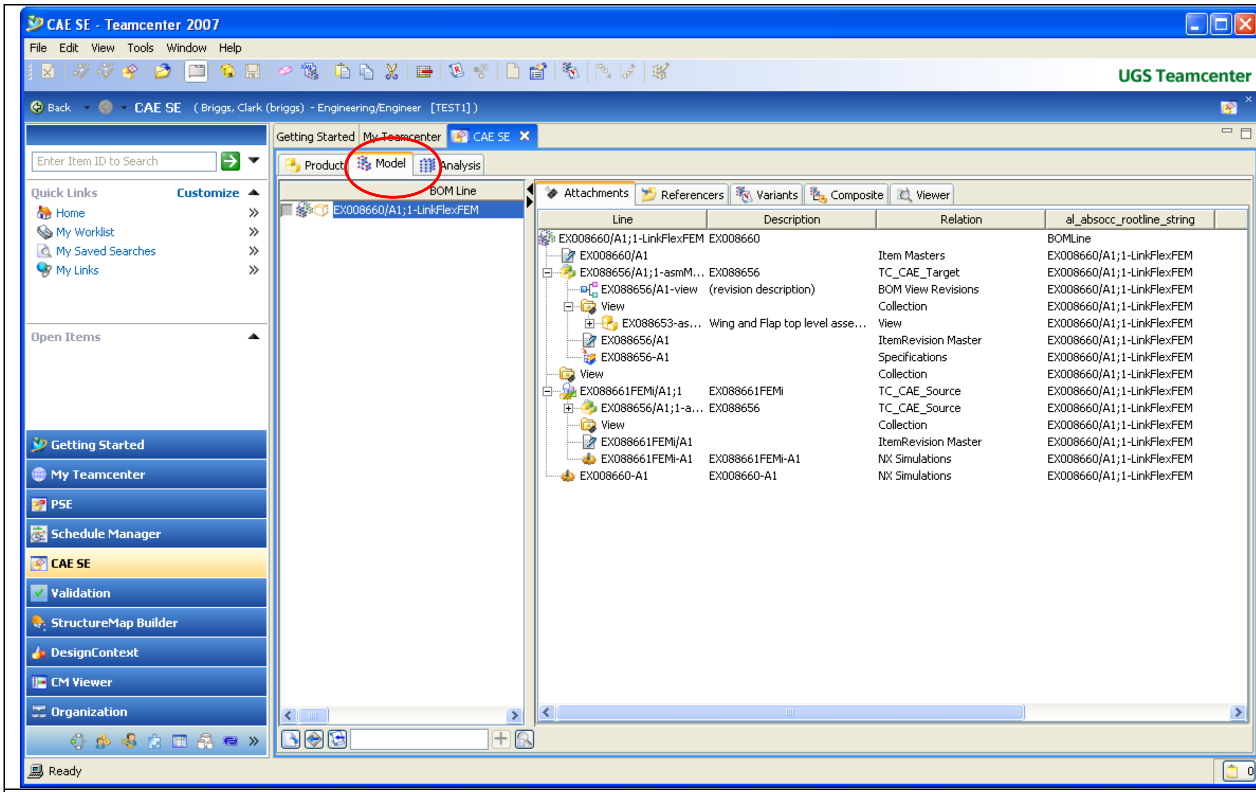


Fig 13b. The Model Tab with Data Dependencies

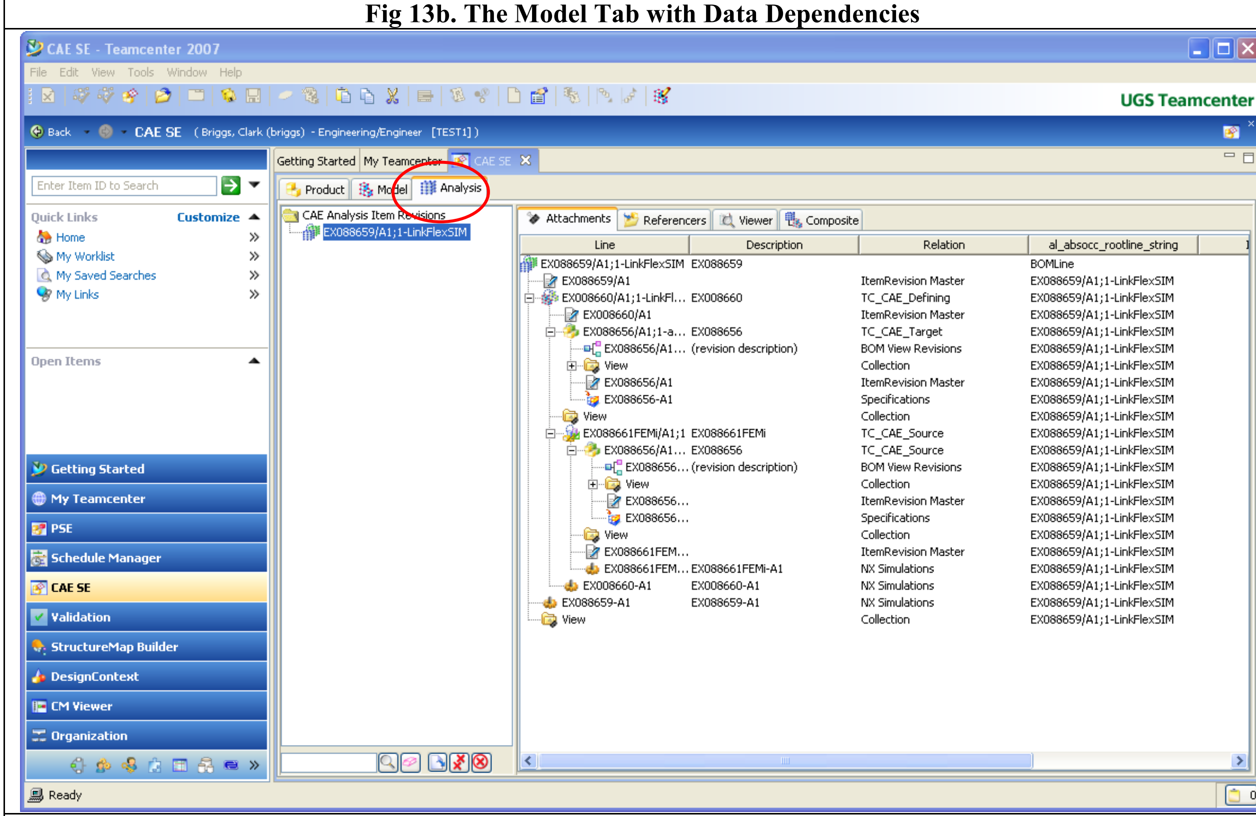


Fig 13c. The Simulation Data Tab with Result Data Sets

Figure 13. Managing the Relationship Between Design Data and Analysis Data

VII. Conclusion

The examples presented illustrate complex multi-disciplinary design activities that can benefit from emerging capabilities of commercially available design tools. Significant benefit comes from working in a single tool family where data incompatibility and poor workflow impedance have been beat down. The examples contain design and data complexity more typical of conceptual design, but the tools have a demonstrated capability for detail design.

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References

[1]Briggs, C., "Aero-Mechanical Aircraft Design Examples," Siemens PLM Connections Americas User Conference, Nashville, TN, 1-4 June, 2009.