Nov. 27, 2000 Submission for:
First MIT Conference on Computational Fluid and Structural Mechanics (CFSM) - 2001

Enhancing Engineering Design and Analysis Interoperability Part 2: A High Diversity Example

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Abstract

This is Part 2 in a series about knowledge representations that enable enhanced cooperation between engineering design and analysis models. A basic flap link example shows how the multi-representation architecture (MRA) analysis integration strategy supports computing environments that have a diversity of analysis fidelities, physical behaviors, and CAD/CAE tools. The constrained object (COB) technique from Part 1 provides the MRA with reusable, modular, multi-directional capabilities.

Key Words

CAD-CAE interoperability; Multi-representation architecture (MRA); Simulation-based design (SBD); Multi-fidelity; Multi-directional

1 Introduction

At this conference Wilson *et al.* [1] overviews constrained objects (COBs) as an object-oriented representation of engineering concepts (Part 1), and Dreisbach and Peak [2] discuss COB-based steps towards multi-functional optimization (MFO) (Part 3). This paper (Part 2) presents a basic example to show how COBs facilitate design-analysis integration for simulation-based design (SBD) as a step towards MFO. In this context, simulation and analysis refer to modeling physical behavior such as stress or temperature.

Peak [3] overviews recent developments in X-analysis integration[1] (XAI) technology including the COB-based multi-representation architecture (MRA). The MRA achieves advanced CAD-CAE interoperability in environments that have a diversity of tools and models. Interoperability can be defined as the ability for tools and models to communicate and share information in a seamless computer-based manner.

[1] X = design, manufacture, sustainment, etc.

2 Flap Link Tutorial Example

Figure 1 overviews the main MRA concepts via an example. Traditional CAD tools (left side) are used to define the manufacturable description of this product. On the right are traditional CAE tools that solve discretized and symbolic mathematical problems. In between are the four main types of MRA objects: solution method models (SMMs), analysis building blocks (ABBs), analyzable product models (APMs), and context-based analysis models (CBAMs). These are stepping stones to help connect diverse tools and models in a flexible and modular manner.

Analyzable product models (APMs) [4] help coordinate and merge design-oriented details coming from possibly many design tools and libraries. The lower-middle portion of Figure 1 shows the flap link APM constraint schematic, which has objects such as sleeves, shaft, cross-section, and ribs. The blue design-oriented relations show how design parameters like sleeve width and shaft width are related.

APMs add idealizations (red) that may be used by multiple analysis models. For example, the 1D torsion and extensional analysis models (Figure 1) both use a parameter called effective length, L_{eff}. This parameter is the distance between the edges of the sleeves; it is a geometric idealization of the main material region connected by the sleeves. While such a parameter is useful from an analysis point of view, it would not likely be included as a CAD parameter used to manufacture this part. Yet it is related to such parameters, so the APM provides a place to capture such relations.

Analysis building blocks (ABBs) represent analytical engineering concepts as semantically rich objects independent of solution method and product domain. The upper-middle portion of Figure 1 contains constraint schematics for a material model ABB and two continuum ABBs. The continuum ABBs are extensional and torsional rods, as covered in undergraduate mechanics courses. Applying object-oriented reasoning similar to that in [1], one recognizes that these and other continuum primitives are built from the same linear elastic stress-strain-temperature concepts. Thus the `1D linear elastic model` ABB captures this knowledge to reduce manual re-creation, provide **modularity**, and facilitate **reusability**.

Whereas ABBs represent concepts at the analytical level, **solution method models (SMMs)** represent them at the detailed solution method level. SMMs can be viewed as object-oriented wrappers around CAE solution tools that obtain analysis results in a highly automated manner (Figure 1 far right). They support white box reuse of existing tools (e.g., FEA tools, math tools, and in-house codes) within a uniform constraint-based framework. ABBs generate SMMs based on solution technique-specific considerations such as symmetry and mesh density.

Context-based analysis models (CBAMs) explicitly represent the fine-grained associativity between a design model and its possibly many analysis models (i.e., between ABBs and APMs). CBAMs are also known as **analysis modules** and **analysis templates**. Figure 1 depicts three flap link CBAMs and their macro-level connections to the APM. The right side of Figure 2 is the `flap link extensional model` annotated with its key MRA and CBAM features. It captures explicit CAD-CAE associativity, i.e., how a subset of APM attributes like effective length, L_{eff}, are connected to the extensional rod ABB it is using. Note that this same type of ABB can be used in other CBAMs for other types of products (e.g., circuit board solder joint analysis [3]). In addition to *how* the analysis is "wired" to work, the CBAM shows *why* the analysis exists: to determine if the calculated stress exceeds the allowable stress. It uses a margin of safety ABB for this purpose as seen in the lower left corner of the constraint schematic.

Similar to the spring examples in [1], Figure 3 shows how a single CBAM can be run in several directions. In state 1, the APM details are inputs, and stress and margin of safety are outputs. In state 3 (the lower portion), the situation is reversed in that margin of safety is now an input and APM cross-sectional area is an output. This capability allows one to directly compute the "optimum" design variable (e.g., cross-section area) in subgraph cases where systems of relations analytically support directional changes. The same CBAM can be used to check the design again after its details have been developed.

Considering the engineering semantics of the problem, one sees that state 1 typifies a simple design verification scenario, where the "natural inputs" (physical design properties and a load) are indeed inputs and a "natural output" (a physical response to the load) is the requested output. Hence, the design is being checked to ensure it gives the desired response. As a design synthesis (sizing) scenario, state 3 reverses the situation by making one natural output into an input and one natural input into the desired output. It effectively asks "what cross-sectional area (a design-oriented variable) do I need to achieve the desired margin of safety (which depends on the stress physical response)?" This COB capability to change input and output directions with the same object thus has important engineering utility. It is a **multi-directional** capability in that there are generally many possible input/output combinations for a given constraint graph.

Figure 1 also contains the `flap link plane strain model`, which simulates the same type of physical behavior (extension) as the `flap link extensional model`. It utilizes a finite element-based SMM to obtain more detailed stress and deformation answers (over a 2D field versus the 1D field in `flap link extensional model`). Its constraint schematic graphically shows that its ABB connects with more APM geometric and material model idealizations than does the 1D case. Thus, it is a higher fidelity CBAM and illustrates the **multi-fidelity** capabilities of the MRA. Typically engineers use quick lower fidelity models early in the lifecycle to size the design, and more costly higher fidelity models later to check the design more accurately.

Finally, the `flap link torsional model` in Figure 1 illustrates the **multi-behavior** capability of the MRA. This CBAM simulates a different type of physical behavior (torsion) versus the previous two extension CBAMs. Note that it uses the torsional rod ABB described before and connects to different idealized attributes in the APM (e.g., polar moment of inertia) as well as to some of the same ones (e.g., effective length). The analysis tool *Mathematica* again solves the formula-based relations as an example of CAE **tool re-usage**.

3 Discussion

The left side of Figure 2 is a traditional documentation-oriented view of the 1D extensional analysis. Shortcomings of this view are that it imposes a unidirectional sequence, it limits modularity and reusability, and it typically does not contain idealization relations like effective length. COBs overcome some of these problems today. In the future such documentation views may be automatically derived from COBs using technologies like XML.

In cases where relations can not be inverted, at a minimum COBs can be used to try various inputs and attempt to achieve desired result (a kind of manual optimization). Part 3 discusses steps towards automated optimization [2].

4 Summary

This paper describes constrained objects (COBs) for a flap link analysis integration tutorial. It overviews concepts from the multi-representation architecture (MRA) that enable advanced CAD-CAE interoperability. Employing an object-oriented approach, the MRA defines natural partitions of engineering concepts that occur between traditional design and analysis models. The MRA is particularly aimed at capturing reusable analysis knowledge at the preliminary and detailed design stages. Other work [3] describes industrial applications including highly automated analysis module catalogs for chip packages that have reduced simulation cycle time by 75%.

References[2]

1. Wilson MW, Peak RS, Fulton RE. Enhancing Engineering Design and Analysis Interoperability - Part 1: Constrained Objects. First MIT Conference CFSM, 2001.
2. Dreisbach RL and Peak RS. Enhancing Engineering Design and Analysis Interoperability - Part 3: Steps toward Multi-Functional Optimization. First MIT Conference CFSM, 2001.
3. Peak RS. X-Analysis Integration (XAI) Technology. Georgia Tech Report EL002-2000A, March 2000.
4. Tamburini DR. *The Analyzable Product Model Representation to Support Design-Analysis Integration*, Doctoral Thesis, Georgia Tech, 1999.

Figure Captions

(see figures in separate MS PowerPoint file)

Figure 1 - COB-based Constraint Schematic for Multi-Fidelity CAD-CAE Interoperability: Flap Link Tutorial

Figure 2 - Traditional Documentation vs. a COB-based CBAM: `flap link extensional model`

Figure 3 - Multi-Directional Capabilities of COB-based CBAMs
(Two Constraint Schematic Instance States of the `flap link extensional model`)

[2] Some references are available at *http://eislab.gatech.edu/*.

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<u>*Figures for Paper:*</u>

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version 1: 11/27/2000

Note: Figures have been originally created in PowerPoint and thus are included here in their native form.

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Figure 1 - COB-based constraint schematic for multi-fidelity CAD-CAE interoperability (flap link tutorial)

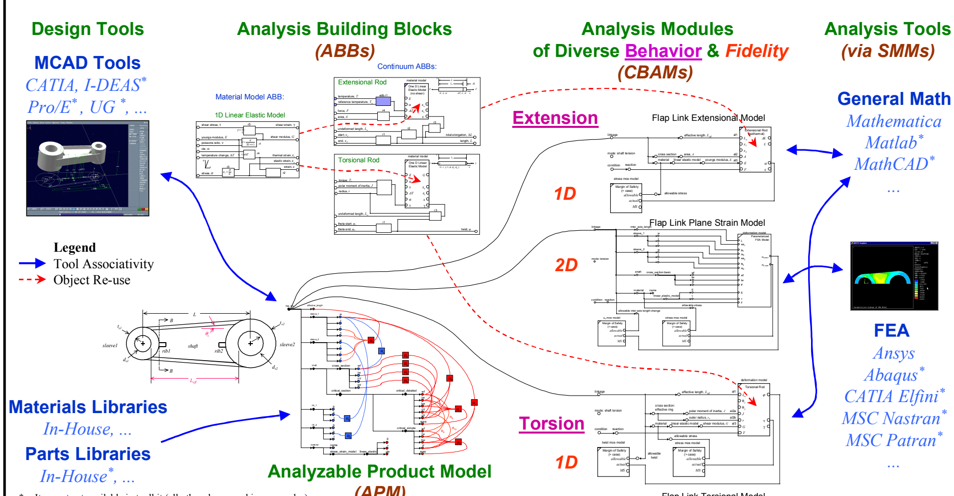

Figure 2 - Traditional documentation vs. a COB-based CBAM
(flap link extensional model)

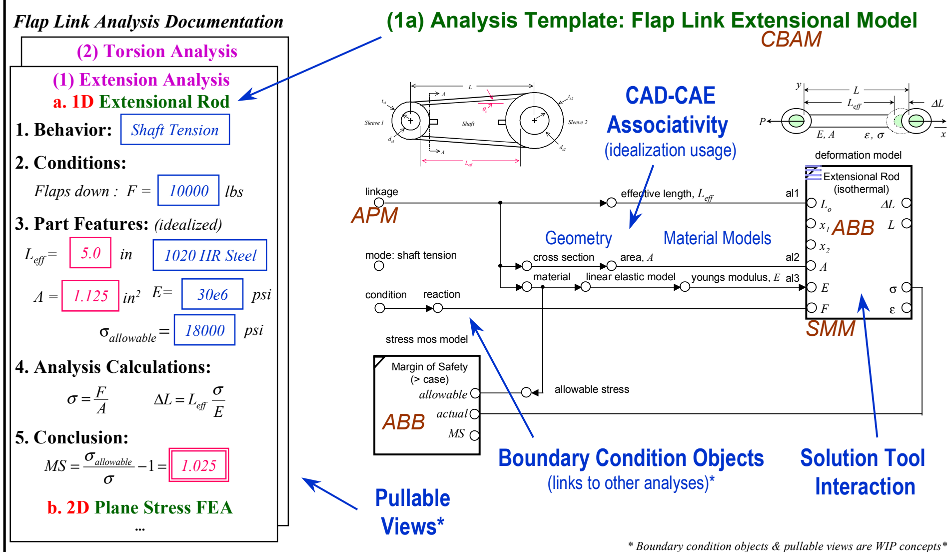

Figure 3 - Multi-directional capabilities of COB-based CBAMs
(two constraint schematic instance states of the flap link extensional model)