

Improving Coordination Between Aircraft Development Processes Through Process Mapping and Simulation

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ABSTRACT

Aircraft development projects at Bombardier Aerospace involve a large number of tasks executed by a network of professionals from various disciplines. As the complexity of products and the development process increases, it becomes more difficult to manage the interactions among tasks and people. In fact, it may be impossible to even predict the impact of a single design decision across the development process. At Bombardier, investigation has shown that there was a lack of communication between design processes when dealing with aeroelasticity information. This resulted in duplicated design effort, reduced quality, and increased time to complete tasks when small design changes from one task induced delays in other tasks. Processes that deal with aeroelasticity work integrate system inertial, aerodynamics and structural information to make aircraft models and perform analyses. These processes have been creating similar models to perform aeroelasticity analyses. A study was started to determine the effect of using a single aeroelastic model to reduce overall design effort. Due to the complexity of the engineering design processes, they were mapped and analyzed in order to gain insight into the structure of the aircraft development process. The work involved in aeroelasticity analyses was mapped using an activity-based approach where processes were decomposed into a series of individual tasks, then the pieces of information that were exchanged between pairs of tasks were mapped to determine information flows. Processes were then analyzed using several techniques, including structural analysis, critical input analysis, simulation, and resource requirements. The aircraft development process was improved by reducing the amount of aircraft model generation effort. This was done by sharing a single aeroelasticity model between the Dynamic and Loads processes. Results indicated that this would reduce development effort by 900 hours per aircraft development program.

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INTRODUCTION

Development projects at Bombardier Aerospace involve a large number of tasks executed by a network of professionals from various disciplines. As the complexity of products and the development process increases, it becomes more difficult to manage the interactions among tasks and people. In fact, it may be impossible to even predict the impact of a single design decision across the development process.

At Bombardier, investigation showed that there was a lack of communication between processes dealing with aeroelasticity information. This resulted in duplicated effort, reduced quality, and increased time to complete the project, where shared data or small design changes from one task induced delays in other tasks. Aeroelasticity deals with the integration of system inertial, aerodynamics and structural information. Design departments make aircraft models to perform analyses. The Loads and Dynamics activities were

creating similar models and performing their own aeroelasticity analyses. The Loads activity performs several calculations to determine the loads at various points in an aircraft. The Dynamics activity performs several calculations to validate the aircraft design when the aircraft performs certain operational movements.

The objectives of the present project were:

1. to determine the effect of creating a single aeroelasticity model in order to reduce overall design effort, and
2. to investigate other possible techniques that could improve the aeroelasticity process at Bombardier Aerospace.

The particular focus of the research was on the two activities most involved in creating aeroelastic models, the loads and dynamics processes.

Load calculations are central to aircraft design as they are on the critical path for all aircraft development activities. Even when there is a delay in input data, deadlines for loads information are never pushed forward. Therefore, the Loads process normally only receives half of the span time compared to other processes during each design cycle to perform its calculations. This puts quality at risk and constrains the use of updated input data. Generally, within the process itself, there exist two types of activities:

1. processing of input data and generation of aircraft models (Nastran, Matlab, etc.), and
2. running analyses and integrating results.

Running analyses and integrating results are dependent on the generation of aircraft models. Thus, any error or delay in receiving input data to create aircraft models can propagate errors or extend the time to obtain results. Results are used to create outputs that are awaited by other processes to progress with their tasks.

Dynamics calculations are the most sensitive to change in input data, and models are always rebuilt when there is updated data. All stakeholders have varying sensitivity to receiving an updated aircraft model. Therefore, it was anticipated that overall process outcomes would be helped by sharing a single aircraft model among processes.

In view of the desired outcomes of the study, the overall goals of this paper can be decomposed into the following three primary objectives:

1. Document the design process in order to identify the critical input data being received and the outputs being produced at different points during aeroelasticity calculations. Knowledge of these particular aspects of the process can help engineers and managers to detect redundant and duplicated pre-processing of input data when two or more aircraft models are used.
2. Develop a baseline process model that can be used for simulation of the “as-is” process. Hence, this as-is process execution sets the baseline for the process performance

parameters, i.e., process span times and critical paths. The model can also be used to study the effects of early and late arrival of input data on model performance in order to identify critical inputs.

3. Develop “to-be” scenarios. The simulation of to-be scenarios can assist in deciding whether task interdependencies between activities are detrimental to design quality or process performance in terms of span time. Process simulation can quantify the impact of using a single model for loads and dynamics calculations as well as identify opportunities for other process improvements in the design process.

METHODOLOGY

Mapping Design Processes

Product development is an endeavour comprised of myriad, multi-functional activities done between defining a technology or market opportunity and starting production (Browning et al., 2006). A process is an organized group of related activities that work together to create a result or value (Browning et al., 2007). A model is an abstract representation of reality that is built, validated, analyzed, and manipulated to increase understanding of the reality (Krishnan et al., 1997).

A process model can be used: to visualize an existing or proposed process; to support project planning, execution and control; to improve existing processes; to develop new processes; or to manage a project by estimating the project critical path, task durations, etc. (Kerley et al., 2009, 2011). Here, a process model was created to better understand two design processes at Bombardier Aerospace and to investigate the specific process change of using a single aeroelastic model in order to support design calculations. To accomplish this, an activity-based model of the information flow within the activities was built.

A simple approach was adopted to capture the development processes of interest in order to create a computer model. The model of the design process was segregated into the loads and dynamics processes. A high level process map was created for each process emphasizing the activities as well as crucial inputs and outputs. These activities served as a starting point for mapping the details of the processes by capturing the links between tasks and then subtasks.

To complete the process map, the whole process was divided into a number of different analyses conducted within each process. Each subprocess was carried out by one or more design engineers depending on the design function and the availability of resources. Informal meetings with functional experts who performed the analyses made it possible to obtain the process, critical data. These interviews with the functional experts provided validation of the process model by building confidence in the exact details of the process.

Once the processes were captured, the structure of the map was converted into the form of swim lanes. Several

design pre-processing tasks were further placed into individual swim lanes for better visualization. A great deal of effort was expended on how the model represented the engineers' design knowledge. The initial description and details added to the model during mapping were not sufficient; so, further individual sessions were arranged to gather more data to be added to the model to be able to perform simulations.

Data Gathering

Besides interviews, internal department memos and project plans were analyzed to obtain process information. Time data was also collected in order to complete the process map. Time data helped interviewees to identify missing activities/tasks, dependencies, and relationships between tasks. Three time values (maximum, average and minimum) were collected for task durations. These values helped in statistical analyses of process times to find the sources of process variation. Similarly, a distribution of the durations of iterative tasks was also captured along with the number of iterations.

Model Validation

Model validation was done through meetings with design engineers, and it was a highly iterative process. Overall, the model validation process was carried out in three steps.

First, individual designer's tasks were validated through one-on-one meetings.

Secondly, after all the individual tasks were validated, the integration of the processes was done. At this stage, the integrated model was reviewed once again with the key experts to check the sequence of tasks, the relationships among activities, i.e., information dependencies, and concurrency.

After initial simulations, the model was verified with senior engineers and management to ensure its completeness and accuracy. The task durations, span time, and critical paths were compared with data from the actual process.

Simulation

The Cambridge Advanced Modeller (CAM¹) was used to perform simulation. CAM is a discrete event modeler and simulator that is able to model, simulate and analyze the dependencies and information flows in a complex system (Wynn et al., 2006, 2009). It was developed by the Engineering Design Center (EDC) at Cambridge University. Processes require different metrics to completely define them. The engineering process has attributes that include the availability of inputs, duration variability, iterations, and rework cycles that limit the use of most other simulation software. As CAM has features to include variable task durations, to capture rework iterations, and to modify the number of available inputs, it is possible to simulate the behavior of a process very realistically. Once the computer model was created using the validated process map, four scenarios were simulated:

I. Modelling the Loads and Dynamics processes without aircraft model sharing (as-is)

II. Modelling without aircraft model sharing, but with different delivery times for input data (to-be)

III. Having aircraft model sharing with the Loads and Dynamics processes starting at the same time (to-be)

IV. Having aircraft model sharing with the Dynamics process starting at different times earlier than the Loads process (to-be).

Scenario-I set the baseline for the time taken to complete the development process with no aircraft model sharing between processes.

RESULTS

Process Characteristics and Model Structure

A process map of the Loads and Dynamics processes made it possible to understand process characteristics, such as types of activities and the process structure used by the processes. The Loads process had two major sets of activities: i) aircraft model generation and data verification, and ii) analysis. The model generation activities included: converting file formats, data verification, and running test runs to rate the quality of inputs. Rating the quality of inputs avoided major rework later in the analyses part of the process. As a consequence, this step in the process triggered several informal iterations before the formal deadlines. This delayed the beginning of downstream analysis activities, which themselves had more or less fixed durations. Within

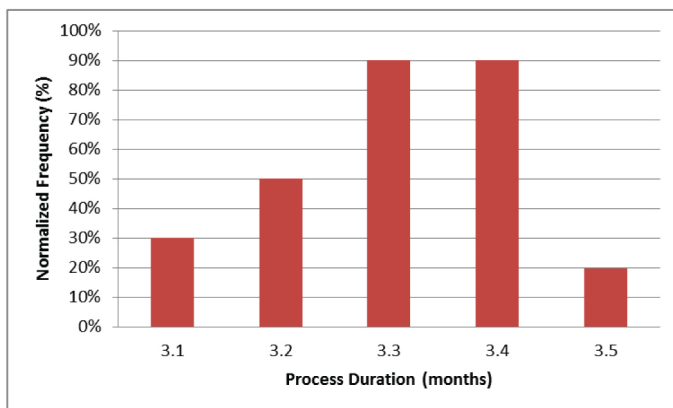


Figure 1. Durations of Process Durations from a Simulation of the Base Line Case of the Process Model.

Thirdly, once data were gathered, the model was setup for simulation. Figure 1 shows an example of the expected range of process durations for the simulation of a single scenario.

¹CAM should not be confused with the term computer aided manufacturing