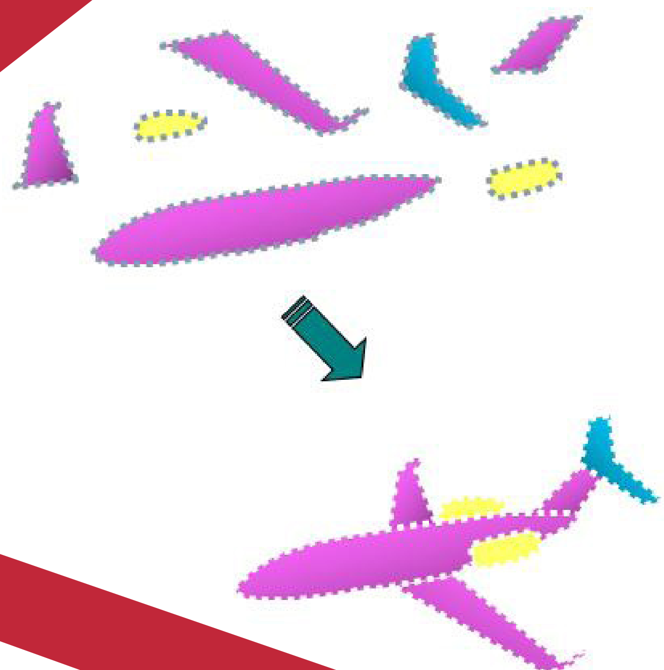
WHITEPAPER

NX Nastran Model Reduction and Superelements: Top-Level Overview



ATA ENGINEERING, INC.

www.ata-plmsoftware.com
844-756-7638 (844-PLM-SOFT)

NX Nastran Model Reduction and Superelements: Top-Level Overview

Software:
NX Nastran 10

Introduction

A strong yet sometimes underutilized feature of NX Nastran is superelements (SEs). SEs provide a means of automatically creating accurate representations of detailed finite element (FE) models with many orders of magnitude fewer degrees of freedom. This whitepaper contains an overview of the types of SEs with a discussion of the reduction process and other SE considerations. More information on superelements can be found in the NX Nastran Superelement User's Guide or through participation in the NX Nastran Superelements training course offered by Siemens.

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Benefits of Superelements

- Reduce runtime when used appropriately, which can dramatically increase the speed of trade studies by creating accurate representations of large portions of a model with many orders of magnitude fewer DOF
- Enable sharing proprietary or classified models without revealing internal information such as geometric or construction details
- Lock a component model's results or apply specific component properties (e.g., easily scale mass or stiffness or apply specific component damping)

Overview of Superelements in NX Nastran

The workflow when using superelements is that a system-level model is partitioned into components, a reduced representation of each component is created, the system model is reassembled, and then the simulation is performed. NX Nastran's implementation of superelements includes the ability to seamlessly integrate reduced component models into system-level models so the user does not need to perform manual matrix manipulations. All of these operations—both the reduction process and the assembly process—can be performed with standard Nastran statements and do not require customized DMAP scripting. NX Nastran has three different superelement partitioning schemes to support different FE modeling workflows, illustrated in Figures 1 and 2. While the assembly method and Nastran statements required for these three methods are different, they use the same reduction process.

The first partitioning scheme, called main bulk superelements, supports a top-down modeling approach beginning with a detailed FE model of the entire assembly. This system-level FE model must be valid without superelement definitions and has all of the same caveats as a full model, such as the need to renumber overlapping grids, elements, materials, etc., across different components because duplicate IDs are not allowed or having parameters applied to everything. For main bulk superelements, the user must explicitly define which DOF are internal to each superelement using Nastran statements such as SESET, SEQSET, SEBSET, and SECSET, among others, and Nastran automatically determines the boundary DOF. Nastran then performs each superelement reduction independent of the other components, assembles the system model, and then performs the system-level analysis.

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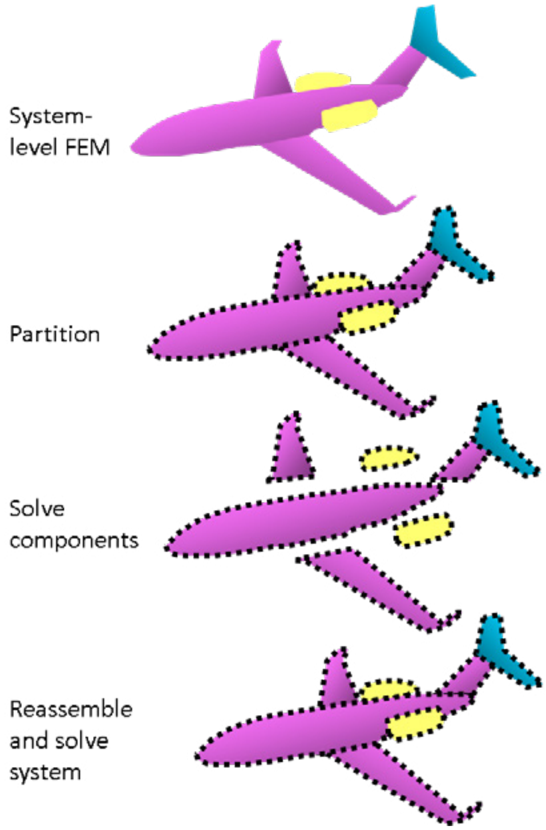

Figure 1: ▲
Main bulk superelements (top down)

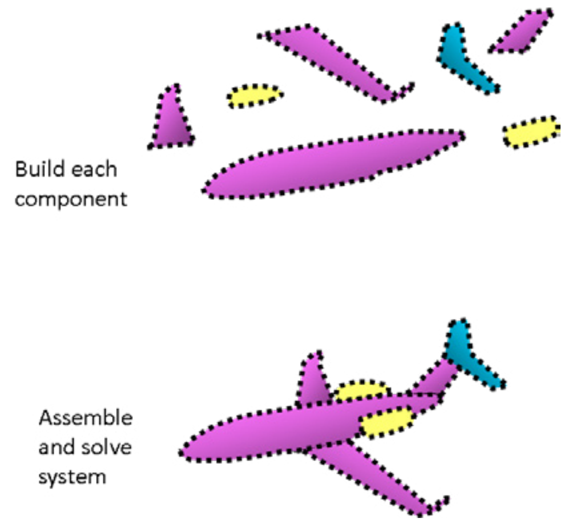

Figure 2: ▲
Part superelements (bottom up)

A second superelement partitioning scheme is called part superelements. In this bottom-up modeling approach, several independent FE models can be concatenated into the same Nastran input file by partitioning the input file into different "parts" with BEGIN SUPER statements and copying the FE models into each region. In this case, the DOF internal to each superelement is implicitly defined by the BEGIN SUPER statements. Part superelements are often used in a distributed modeling scenario where multiple organizations are providing independent component FE models that must be combined into a system-level model. Part superelements eliminate the need to renumber overlapping grids, elements, materials, etc., across different components because duplicate IDs are allowed across the different parts. Connections between the parts can be automatically determined by Nastran based on the location of grids, but the user can exert considerable control over the connection using SECONT, SEBNDRY, and SEEXCLD statements.

The third and simplest implementation of superelements in Nastran is external superelements. This functionality is useful when the user wishes to create a reduced representation of a single component without assembling it into a system model. External superelements are often used to share proprietary models without revealing geometric or construction details or to provide a single component to another organization for incorporation into a system model. For example, a very detailed spacecraft FE model (> 1M DOF) may be reduced to a dynamic superelement (< 1000 DOF) and then given to a launch vehicle provider for a coupled loads analysis. Creating the external superelement can be performed with very few modifications to a static (SOL 101) or modes (SOL 103) solution: a few bulk data statements identifying the retained DOF (ASET, BSET/BNDFIX, and/or CSET/BNDFREE), assigning the modal DOF for dynamic reductions (QSET and SPOINT), and specifying the output format on the case control EXTSEOUT statement. Several binary output formats (database, OP4-unformatted, OP2) and ASCII formats (OP4-formatted, and DMIGPCH) are available, and while each format has its advantages and disadvantages, they are functionally the same. External superelements can be easily incorporated into a standard system-level model when using the DMIG SE format, or any format can be inserted as a part when using the part superelement partitioning strategy by referencing the reduction output as a model's part (after a BEGIN SUPER statement) along with an SEBULK statement defining a few connection parameters.

Static or Dynamic Reduction?

When using superelements, the user must decide whether static or dynamic reductions are most appropriate for each superelement. Static reduction uses a Guyan process that provides exact representations of the mass and stiffness of the detailed FE model between the user-defined boundary DOF. Static reductions, however, do not attempt to represent the internal dynamic characteristics, so they should generally be avoided when performing dynamic simulations. Statically reduced superelements are often used in situations when an exact representation of the stiffness of a structure is desired without the additional runtime associated with the detailed FEM. A few examples are accurate representations of a test fixture for pretest simulations when the fixture responses are not of primary interest, exact representations of stiffness characteristics of complex structures such as flexures, or when there is a need to incorporate proprietary models.

Dynamic reductions use a component mode synthesis (CMS) reduction scheme to generate an approximation of the internal dynamic characteristics of the detailed FE model while also including an exact representation of the mass and stiffness of the boundary DOF. Like all modal processes, dynamic reductions require user judgment to determine how many component modes should be included. The typical rule of thumb is to use a component mode frequency cutoff about 1.5–2x the system-level frequencies of interest; however, like all rules of thumb, this is only a general guideline and may not be appropriate for all applications.

Nastran's default behavior for dynamic reductions is to use a Craig-Bampton reduction scheme, which is the special case of CMS where the internal component modes are computed with all interface DOF held fixed. The user can optionally specify that component modes are computed with some interface DOF left free, which may be appropriate for some specific scenarios (for attachment to very small/light components, when internal DOF are used for MPC equations that cross SE boundaries, etc.). However, absent a specific reason for leaving some boundary DOF free during modal extraction, the most efficient use of dynamic SE can be achieved by using Craig-Bampton reductions with fixed-interface modes.

Other Superelement Considerations

For both static and dynamic reductions, the number of boundary grids should be kept small (< 100) for the most efficient use of superelements. With very large numbers of boundary DOF, the computational advantage of superelements is very quickly lost as the reduction process grows exponentially. Partitioning the full model into superelements should also take into consideration the natural interfaces between components so that the component mode shapes (for dynamic reductions) resemble the behavior of the component when coupled to the entire system. For dynamic simulations, damping can also be applied to each superelement independently, so that may also dictate the location of partitions. Also, forethought into the future use of the partitioned system model may help decide the interfaces. For example, if trade studies of specific spring/joint stiffnesses are wanted, it is generally most advantageous to keep those in the system or residual partition.

Internal responses can be recovered from superelements using output transformation matrices (OTMs). For main bulk and part superelements, the user can request outputs using the normal case control commands (DISPLACEMENT, STRESS, ELFORCE, etc) and NASTRAN to seamlessly recover internal superelement responses. For external superelements, extra planning is needed, as the OTMs must be created during the reduction run using case control output requests. It is generally advantageous to limit the number of internal recoveries, since that can incur additional computational costs during the system-level run or, in the case of external superelements, require additional organization. Generally, the user should avoid creating OTMs using output requests on the entire model (DISP=ALL, STRESS=ALL, etc.).

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ATA Engineering

ATA ENGINEERING, INC.

Solution Partner
PLM
SIEMENS

www.ata-e.com
ata-engineering
@ataengineering
sales@ata-e.com
858.480.2000

www.ata-plmsoftware.com

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