Webinar: **Model Reduction and Superelements in NX Nastran**

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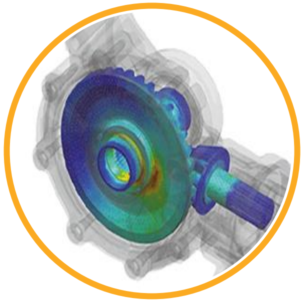

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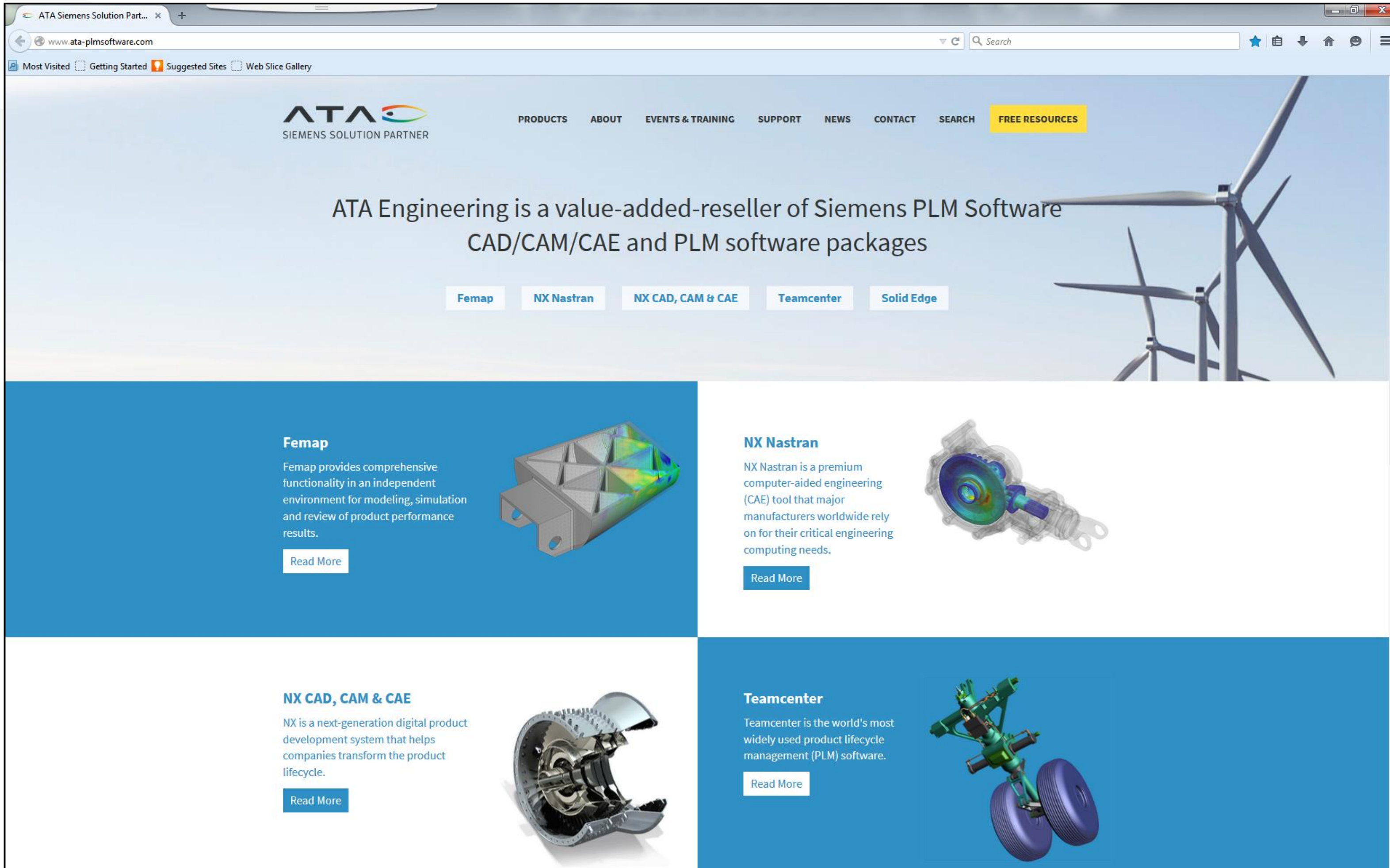


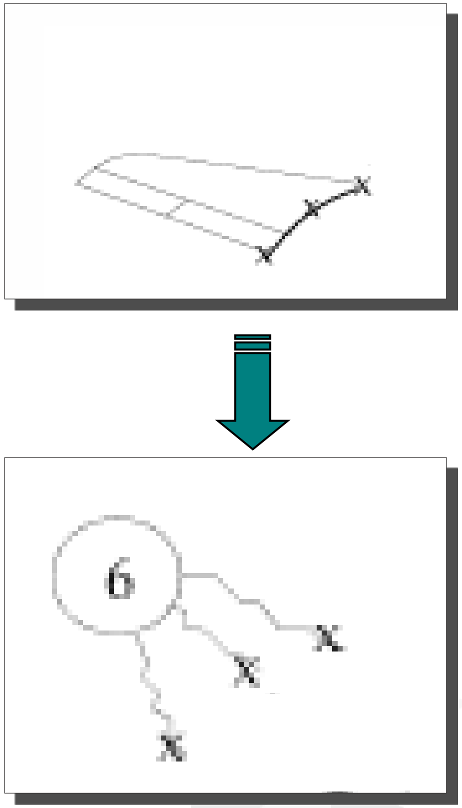
Outline

1. What are Superelements?
2. Static vs. Component Mode Superelements
   - Guyan vs. Craig-Bampton reduction
3. Three types of Superelements
   1. External
   2. Part
   3. Bulk data
4. Guidelines for using Superelements

Note this condenses a 2 day class into ±45 minutes

What is a Superelement?

- A superelement is a reduced representation of a portion of a finite element model
  - Each portion of the finite element model is reduced independently
  - The superelement matrices can represent the static and dynamic behavior of the component and allows coupling to the rest of the structure
- Yields a model with combination of physical DOF on the boundary (to connect to rest of structure) and optionally modal DOF representing component modes (if a dynamic reduction)
  - If boundary is small superelement model is MUCH smaller the corresponding partition of FEM
- Solution sequences 101-200 support superelements



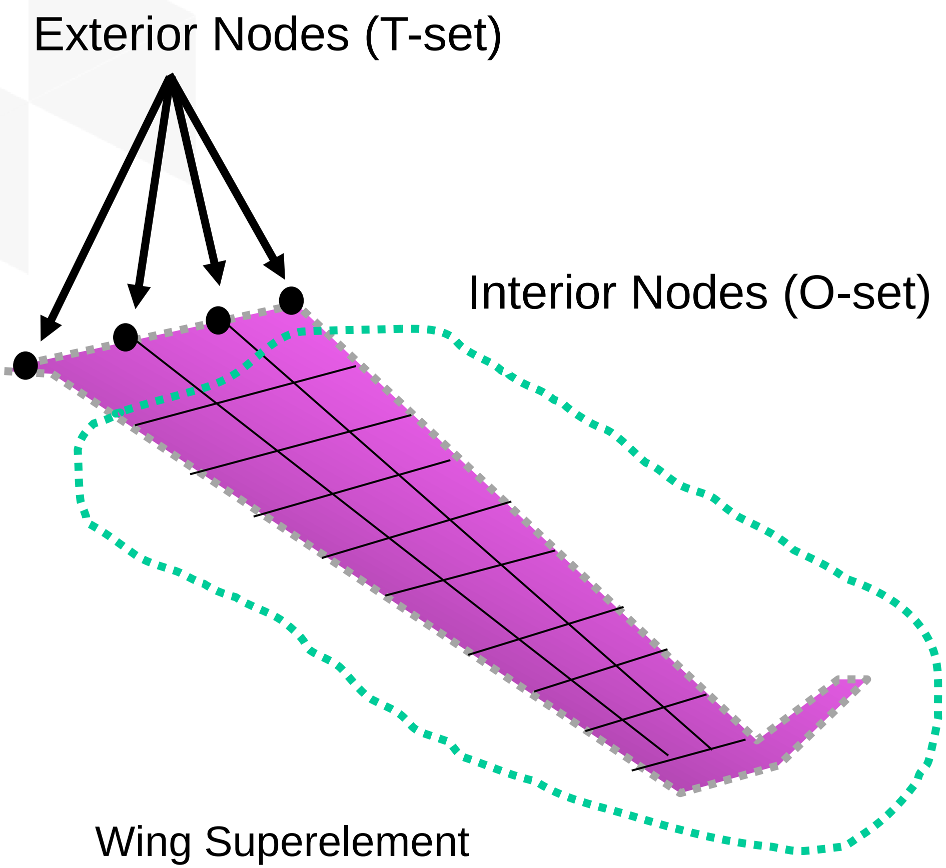
Advantages of Superelement Analysis

- Allows or facilitates the following:
  - Solution of large problems that exceed your hardware capabilities
  - Less CPU or wall clock time per run (sometimes)
  - Partial redesign that requires only partial solution using restarts
  - More control of resource usage
  - Partitioned input (organization, repeated components)
  - Partitioned output (organization, comprehension)
  - Components that may be modeled by subcontractors
  - Efficient non-linear analysis when non-linearity is localized
  - Multi-step reduction for dynamic analysis
  - Use of proprietary models without divulging geometry
  - Use of different model parameters on different regions of the model
  - Damping can be handled at a component level (Component mode damping)

Disadvantages of Superelement Analysis

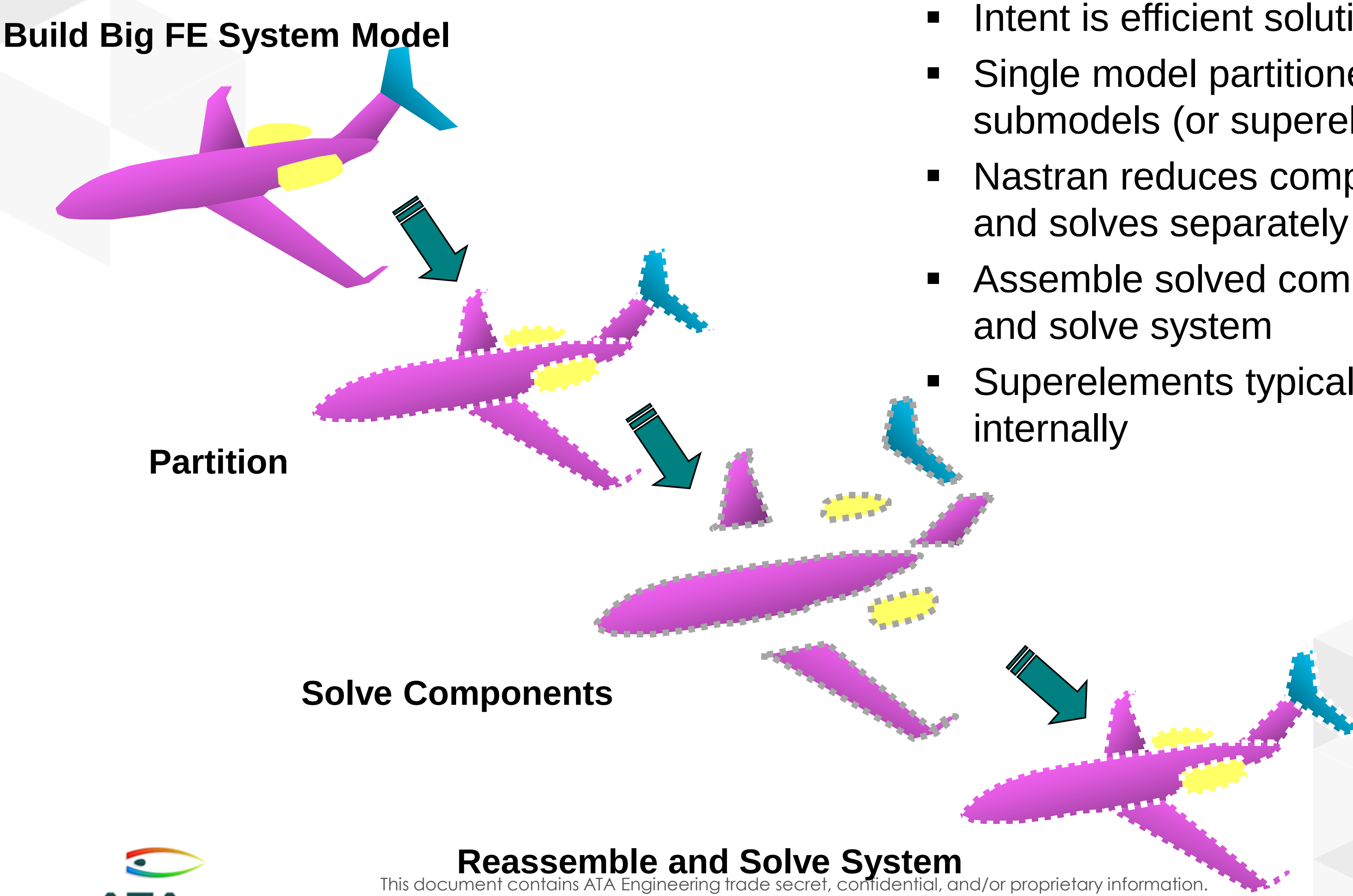
- Static condensation may cancel numerical advantages of reduced models
- Superelement model can be considerably more complex than non-superelement equivalent
- Residual structure mass and stiffness matrices are usually dense (therefore it should be a small part of the model)
  - Unless you're careful superelement models can be computationally more intensive
- All superelements must be linear
  - Residual structure does not need to be linear
  - Superelements work very well with localized non-linearities
- Approximations must be made in dynamics for mass and damping through static, component mode, or generalized dynamic reduction

Superelement Terminology



- Exterior Nodes – Nodes on boundary of superelement, connect to other superelement or residual
- Interior Nodes – Nodes inside the superelement, reduced out of model
- Generalized DOF – Used to represent modal DOF of superelement component (for dynamic reduction)
- Residual – Assembled system model that is solved (set of all exterior nodes, nodes not in a superelement, and generalized DOF)

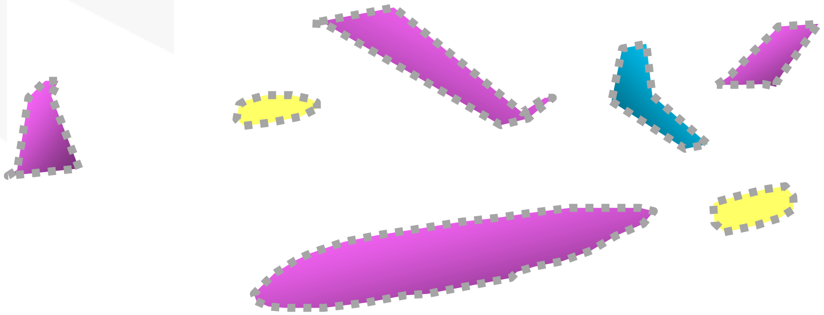
Top-Down Approach to Superelement Analysis



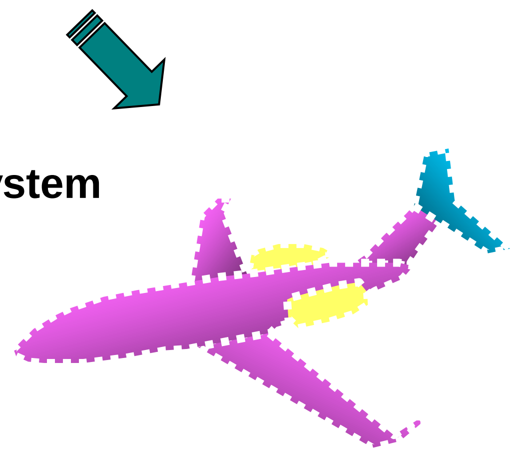
- Intent is efficient solution
- Single model partitioned into submodels (or superelements)
- Nastran reduces components and solves separately
- Assemble solved components and solve system
- Superelements typically created internally

Bottom-Up Approach to Superelement Analysis

Build and Solve Components



Assemble and Solve System



- Building block assembly of components and subsystems
- Intent is efficient enterprise system modeling
- Either combine several stand-alone models (part superelement), or reduce individual models and export as external superelement
- External superelements assembled and solved in separate system model run

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Static vs. Dynamic Reductions

- Two types of reductions are typically used for superelement analysis:
  - Static (Guyan) reduction exactly matches stiffness and mass of original FEM but does not represent internal dynamic behavior
  - Component Mode Synthesis (CMS) reduction adds component modes of model partition to static reduction to approximate internal dynamic behavior of component (mass and stiffness)
  - Superelements are a generalization of Craig-Bampton (CB) reduced models
    - CB models can easily be generated in Nastran without need for any special purpose DMAPs or procedures
    - CB models have all interface DOF fixed when calculating component modes (all DOF in the B-set)
    - NXN allows some DOF to be free (C-set). This is not a CB reduction.

Static or CMS Reduction?

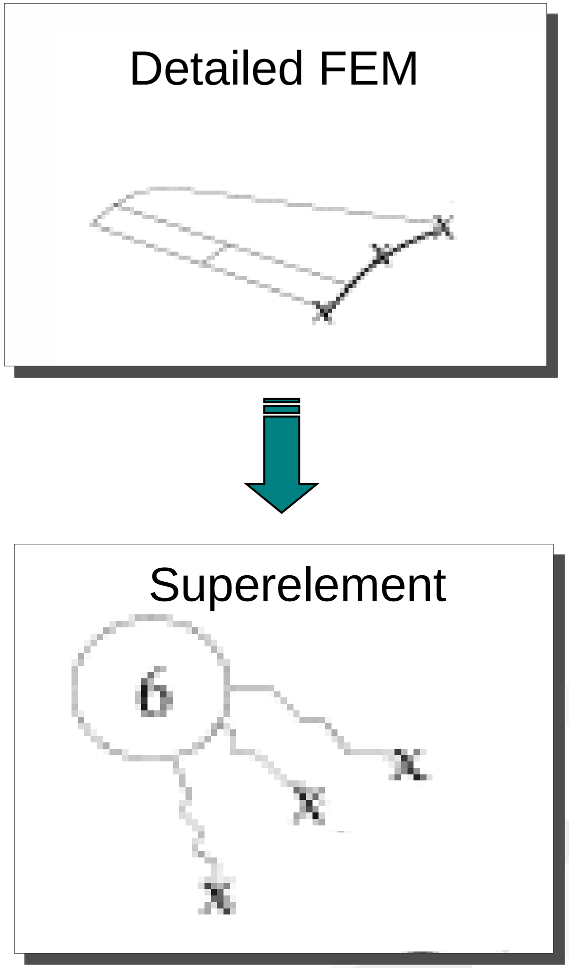
- A dynamically reduced superelement will yield accurate results when used for a static solution
  - Modes are ignored in a static solution
  - Can be computationally expensive to calculate component modes
- A statically reduced superelement will **NOT** necessarily yield accurate results when used for a dynamic solution
- How many modes to include in dynamic reduction?
  - Rough rule of thumb: Use 1.5-2x frequency content in each component as in system
  - Many other considerations such as multi-level vs. flat superelement tree, size of component, etc., so rule of thumb not always appropriate

Three Superelement Partitioning Strategies

- NX Nastran allows three different strategies to partition model into superelements
  - <u>External superelements</u>
    - Reduces a component FEM into a superelement and stop (do not combine with system)
    - Convenient if desire is one-and-done reduction, transferring proprietary models
  - <u>Part superelements (bottom-up approach)</u>
    - Superelements created from independent FEMs that are included in same deck
    - BEGIN SUPER cards used to partition deck
    - Each piece is completely standalone, duplicate IDs across superelements OK
    - Compromise between bulk data and external superelements
  - <u>Main bulk or internal superelements (top-down approach)</u>
    - Traditional superelement approach
    - User partitions large FEM into pieces by defining region internal to each superelement
    - Nastran determines which nodes are external to each superelement
- Note that these are simply different partitioning strategies with different levels of automation
  - Mathematically, superelement reduction process is the same for all

What is an External Superelement?

- A model of a component represented by matrices
  - Can either be a static or dynamic reduction
  - No internal geometry available, only boundary grids and modal DOF (if dynamic reduction)
  - Can be coupled to another model using part superelements (described later)
  - May include internal data recovery (disp, stress, elfor, etc.) and internal load vectors
  - Available in several output formats
    - OUTPUT2, OUTPUT4, DMIG, etc.
  - Superelement license not required to create external SE (only to combine them)



NXN Offers Multiple External SE Formats

- MATOP4
  - Matrices written in OUTPUT4 (formatted or binary)
  - Interface data written to .pch file
  - Most common format for sharing data in CLA community
- DMIGOP2
  - All data written to OUTPUT2 (binary)
  - Compact, full precision – typically for internal usage
- DMIGPCH
  - Matrices written to .pch file in DMIG format (ASCII)
  - Interface data written to .pch file
  - Very flexible option
  - DMIG matrices can be used without superelement license
  - DMAP can be used to write out higher precision stiffness
- MATDB and DMIGDB
  - Less commonly used database options

NXN Deck to Generate External SE (MATOP4 option)


```
ASSIGN OUTPUT4='gpsc_se_ant1.op4', FORMATTED, UNIT=13
$
SOL     103     $ Normal Modes Solution
CEND
TITLE    =GENERAL PURPOSE SPACECRAFT (GPSC)
SUBTITLE =EXTERNAL SUPERELEMENT REDUCTION
LABEL    =REDUCTION
$
SET 1 = 1 THRU 20
DISP(PLOT) = 1
$
SET 2 = 21 THRU
ELFORCE(PLOT) = 2
$
METHOD = 1
$
EXTSEOUT(EXTID=100, ASMBULK, MATOP4=13)
$
BEGIN BULK
$
EIGRL   100         100.
$
BSET1   123456  30
$
SPOINT  900101  THRU    900120
QSET1   0       900101  THRU    900120
$
INCLUDE '..\BULK\gpsecant.blk'
$
ENDDATA
```

- OUTPUT4 file for matrices
- Output requests generate DRMs (optional)
- METHOD card for component modes (dynamic reduction)
- EXTSEOUT card controls output format
- Frequency cutoff for component modes
- Fixed-interface DOF
- QSET1 for component modes
- Bulk data for external superelement

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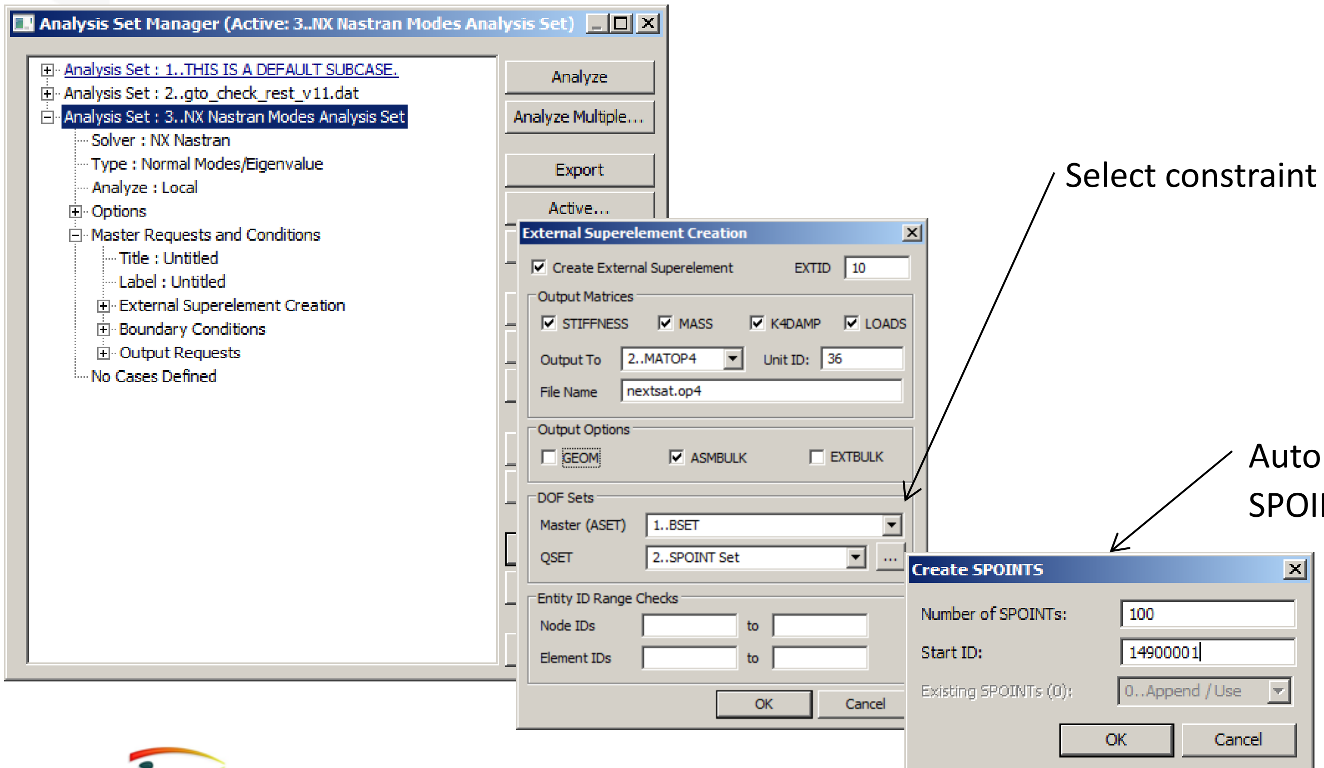
Creating External Superelements in FEMAP

- Create a constraint set for the interface DOF (BSET/CSET)
- Open “Master Requests and Conditions” on Analysis Set Manager to expose “External Superelement Creation”
  - Supports DMIG, DMIGOP2 and MAT0P4 options

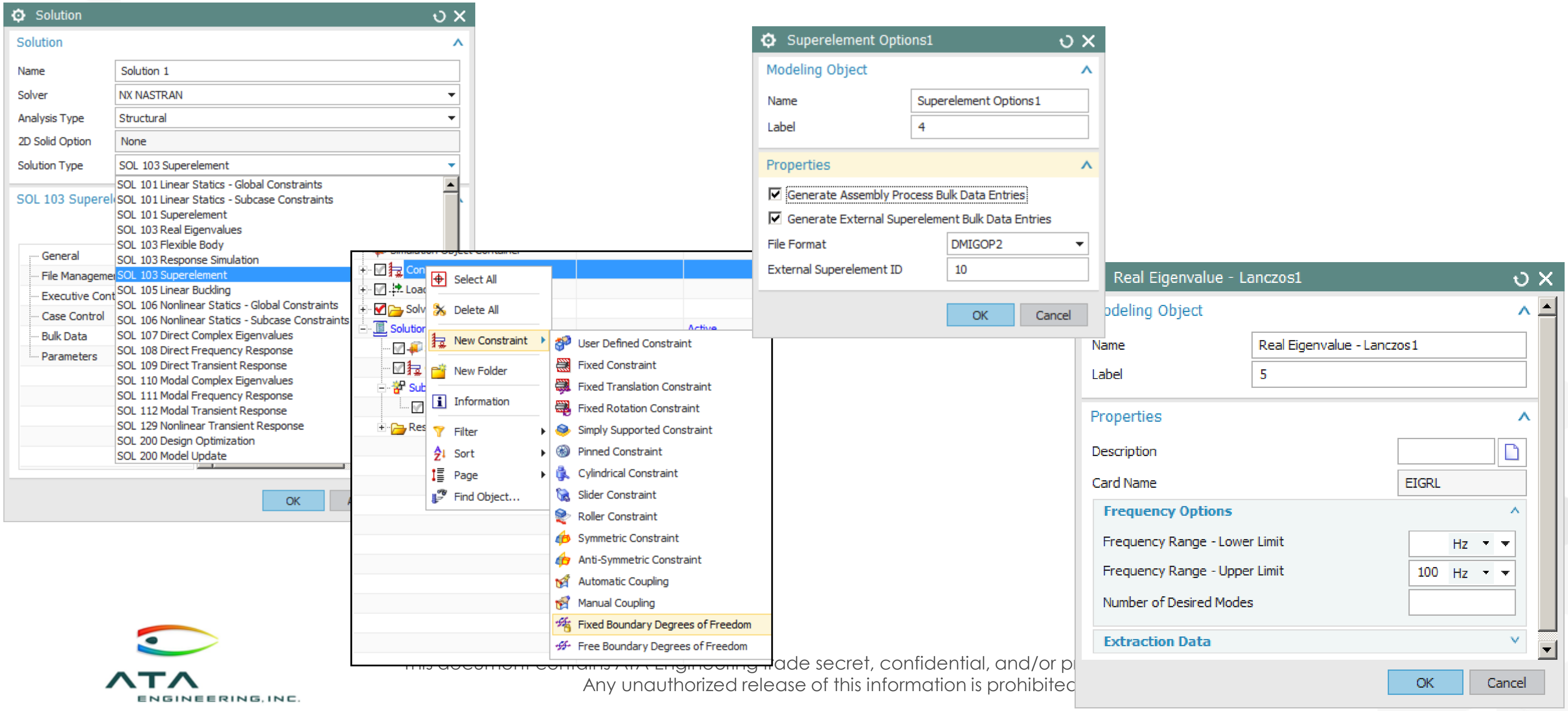


Select constraint set for interface DOF

Automate creation of SPOINTs for modal DOF

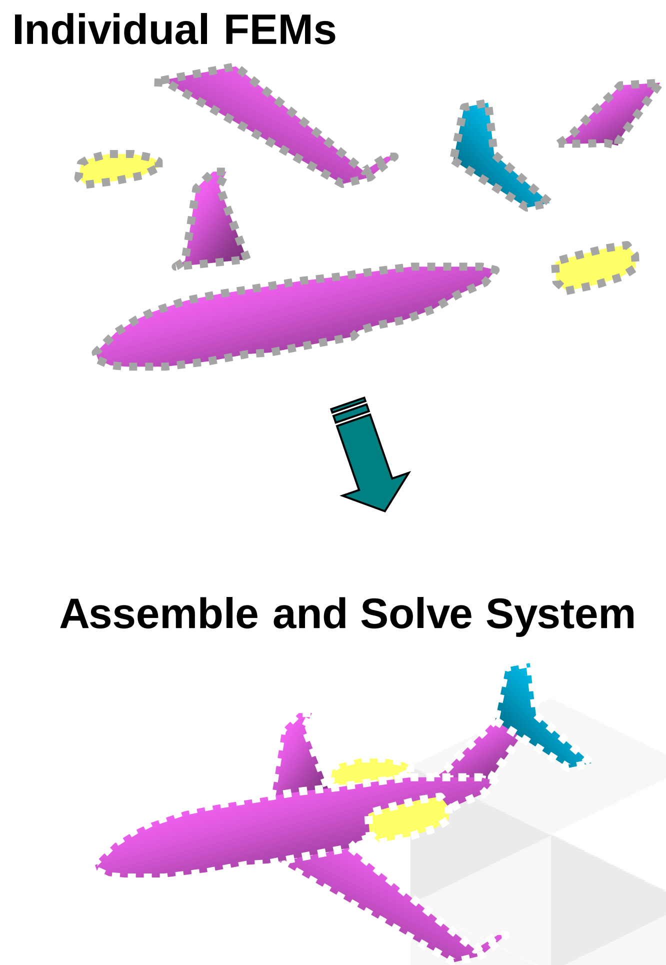
Creating External Superelements in NX

- Create a "SOL 101 Superelement" or "SOL 103 Superelement" simulation
- Create a constraint set for the interface DOF (Fixed boundary/Free boundary)
- Set number of generalized DOF in case control solution options form
- Set the case control superelement options and eigenvalue parameters (for dynamic reduction)



What are Part Superelements?

- Part superelements are a model partitioning strategy where several separate, stand-alone FEMs included in same Nastran deck
- BEGIN SUPER cards used to partition deck into distinct regions (PARTs)
  - Each PART may be a FEM or a previously-reduced external superelement
- Nastran can automatically detect connecting points between superelements or manual connections can be defined
- Part superelements used to combine external superelements



Bulk Data Used to Define "PARTs"

- Each PART is defined in a separate section of the input file
- These sections follow the main bulk data section (BEGIN BULK)
- The section containing the data for a PART will begin with:

BEGIN SUPER i

  - where i is the superelement ID to be defined by the following input
- The section containing the data for a PART will end with either:

BEGIN SUPER j

  - where j is the superelement defined in the next section of the input file

or

ENDDATA

  - which indicates the end of the input file

Sample Part Superelement Deck

Case Control

```
SOL     103
CEND
$
DISP(PLOT) = ALL
PARAM,RESVINER,YES
$
SUBCASE 100
  SUPER = 100
  LABEL = FAIRING
  METHOD = 2
SUBCASE 200
  SUPER = 200
  LABEL = PAYLOAD
  METHOD = 2
SUBCASE 1000
  METHOD = 1
  SPC = 1
$
```

Main Bulk (Residual)

```
BEGIN BULK
$
INCLUDE 'bus.blk'
EIGRL   1           50.
$
SENQSET      ALL      20
$
SETREE, 0, 1, 2
$
SEBULK   100    PRIMARY   AUTO
SEBULK   200    PRIMARY   AUTO
$
```

Part SE 100

```
BEGIN SUPER 100
$
PARAM,WTMASS,0.00259
EIGRL   2          100.
INCLUDE 'fairing.blk'
$
```

Part SE 200

```
BEGIN SUPER 200
$
PARAM,COUPMASS,1
EIGRL   2          100.
INCLUDE 'payload.blk'
$
ENDDATA
```

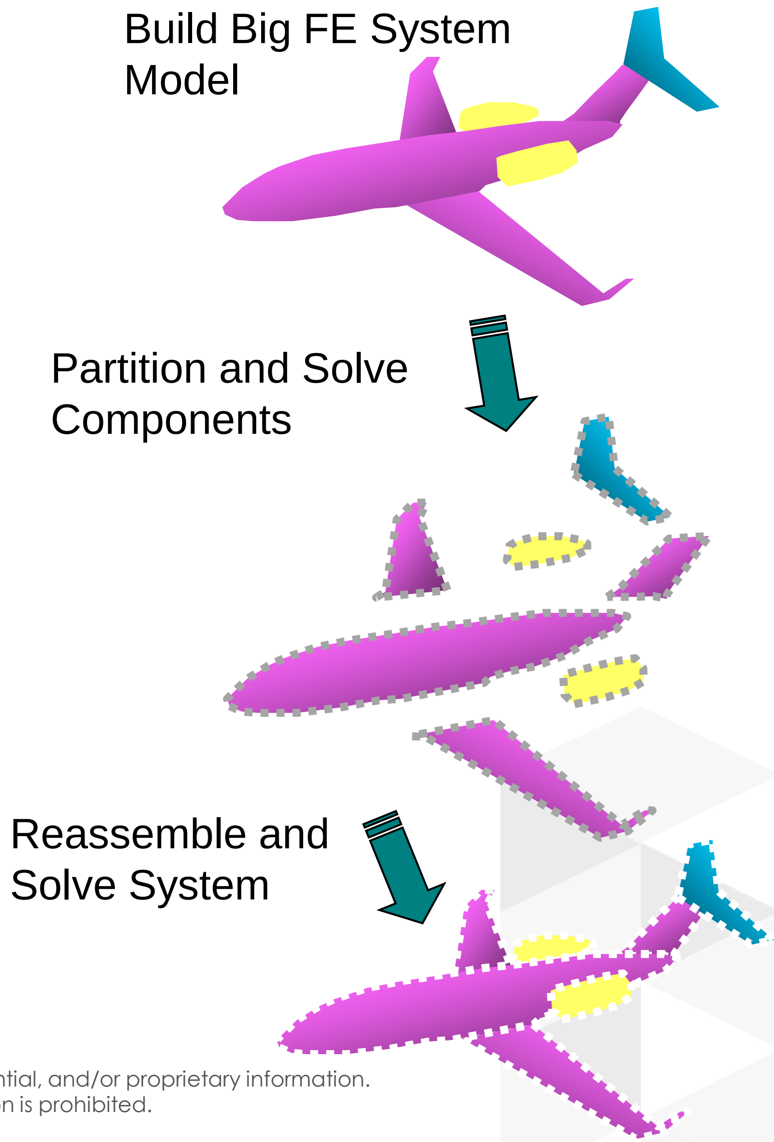
- FEM in residual (optional) → INCLUDE 'bus.blk'
- Modes of residual structure → EIGRL 1 50.
- Automatic generation of Q-set DOF for all SE → SENQSET ALL 20
- Superelement tree definition → SETREE, 0, 1, 2
- Superelement connection cards → SEBULK
- Fairing superelement → EIGRL 2 100. (SE 100)
- Payload superelement → EIGRL 2 100. (SE 200)

Advantages of Part Superelements

- Full solution can be completed in a single run
  - As opposed to external superelements where each is reduced manually
- May simplify incorporating FEMs from different vendors
  - Only need to specify location of interface grids (grid IDs not important)
  - Allows repeated IDs across different PARTs
- No ambiguity regarding grid/element superelement assignment
- Superelements can be reoriented using SELOC without re-reducing to boundary
- Since full bulk data is available no limitations in data recovery
  - Thermal loads handled correctly
  - No need to specify all outputs at time that superelement is reduced

What are Main Bulk Superelements?

- A model partitioning strategy where a single (system) FEM is partitioned into superelements using bulk data cards
  - Starts with single FEM that is valid without superelements
- User defines grids interior to each superelement, Nastran finds boundary grids automatically
- Nastran's traditional superelement approach
- Division of model into superelements is largely transparent to the user



Sample Main Bulk Superelement Deck

Case Control

```
SOL     103
CEND
$
DISP(PLOT) = ALL
$
SUBCASE 100
  SUPER = 100
  LABEL = FAIRING
  METHOD = 2
SUBCASE 200
  SUPER = 200
  LABEL = PAYLOAD
  METHOD = 2
SUBCASE 1000
  METHOD = 1
  SPC = 1
$
BEGIN BULK
$
EIGRL   1          50.
EIGRL   2         100.
$
INCLUDE 'sample_fem.blk'
$
$ INTERIOR GRIDS
SESET    100    1001   THRU   1999
SESET    200    2001   THRU   2999
$
$ FAIRING MODAL DOF
SPOINT  100001 THRU 100100
SEQSET1    100     0 100001 THRU 100100
$
$ PAYLOAD MODAL DOF
SPOINT  200001 THRU 200100
SEQSET1    200     0 200001 THRU 200100
$
ENDDATA
```

Standard Model Definition

Cards for Superelement Definition

SUBCASEs used to control each superelement

Mode extraction (varies by superelement)

FEM of entire structure

Superelement tree definition

Grids interior to each superelement

Fairing modal DOF

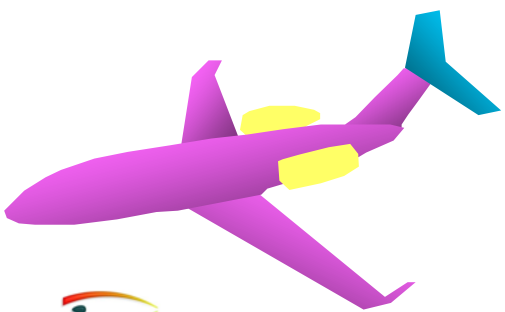
Payload modal DOF

Efficient Design Studies with Restarts

- Superelements can make design studies significantly more efficient when using restarts
  - Only superelement that is changed are re-calculated
  - Can reap significant cost benefits if superelements and tree are organized with design studies/restarts in mind
- Using restarts lets Nastran compare new/old FEM data and decide what superelements need to be recreated
- Without superelements, any design change would require complete re-analysis
- Example: Performing trade studies on airplane tail:

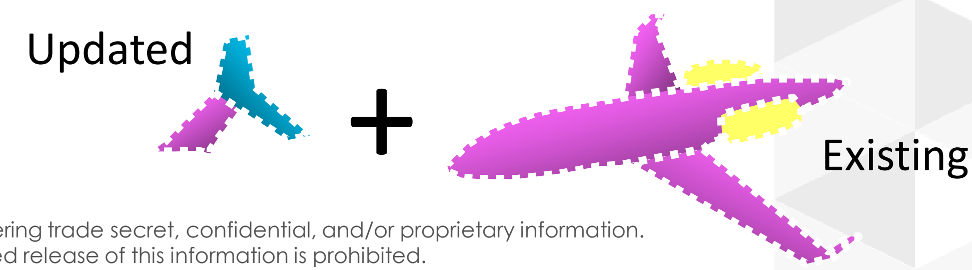
Without SE

Each simulation starts over



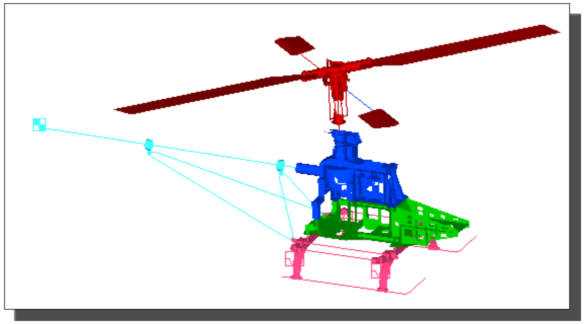
With SE

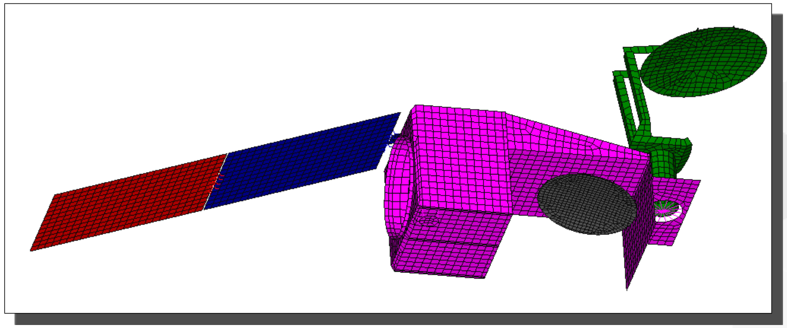
New reduction of tail, combine with existing reduced models, solve for system modes



Considerations when Partitioning a FEM into Superelements

- Keep computing resource limitations in mind
- Use logical partitions of the overall structure
  - Try to limit number of interface grids between superelements
- If portion of model has been correlated to test data, may be appropriate to partition as superelement
- If modal damping properties available for a component, separate as a superelement
- May allow efficient restart analyses for trade studies
- Keep type of reduction of each component in mind (static vs. dynamic reduction)





Summary and Guidelines

- Superelements provide a very powerful method for reducing complexity of detailed FEMs and sharing component models among organizations
- Both static reduction and component mode reduction/synthesis supported by NXN
  - Guyan and Craig-Bampton reduction
- NXN supports three different SE methods
  - External – Bottom up approach
  - Part – Compromise between bottom-up/top-down
  - Bulk data – Top down approach
- Biggest trick to effective superelements is minimizing the number of nodes at the boundary

Thank You for Participating!

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