Solver Embedded Fatigue Life Calculations and Optimization For Durability

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Introduction

• Traditional CAE methods for calculating fatigue (FATIGUE AS A POSTPROCESSING STEP)

• Limitations of current approaches

• Nastran Embedded Fatigue (FATIGUE AS THE ANALYSIS STEP)

• Optimising with Fatigue
Fatigue (Stress-Life) curves

Can we get this and this right?
In order to get this right?

From measurements or analysis
History of Fatigue Methods and Their Integration into the CAE Environment

- **175 yrs ago**: S-N
- **50 yrs ago**: Crack propagation
- **45 yrs ago**: NASTRAN
- **14 yrs ago**: MSC Fatigue (Dynamics & Fatigue)
- **10 yrs ago**: Integration with MBD
- **8 yrs ago**: Use of non-linear (Marc) FE results
- **20 yrs ago**: P_Fatigue
- **107 years ago**: 1st major transportation disaster, Versailles, May 11th, 1842
- **175 yrs ago**: Failure Mechanisms
- **50 yrs ago**: Crack propagation

**CAE**

Fatigue

Dynamics

Nastran Embedded Fatigue TODAY
Existing Concepts For CAE Based Fatigue Calculations
Traditional FE Based Fatigue Design (eg MSC Fatigue)

Materials Information

Loading and/or Test (Lab) Results

Geometry & FEA (Stress/strain) Results

Analysis Options
- Stress (total) Life
- Strain (initiation) Life
- Crack Propagation
- Vibration Fatigue
- Multiaxial Fatigue
- Spot & Seam Weld
- Wheels Fatigue
- Software Strain Gauge
- Utilities

Fatigue Life Contours

Sensitivity Analysis and Optimization

Damage Distributions

Tabular Results

After calculating stress, everything else is post processing
A reminder – What is MSC Fatigue

MSC Fatigue Modules
Simple Problem description

With current approaches stress fields are produced by a solver step and then combined with loads in a fatigue post processing step. With Nastran Embedded Fatigue these 2 steps will be simultaneous.
MSC Fatigue Product Roadmap

- An upgraded (nCode) solver,
- Better ancillary components (eg vibration fatigue, etc)
- A more modern user interface.

- Work implemented in a phased process over 2-3 releases.
  [2011, 2012 and 2012.2 already released]

<table>
<thead>
<tr>
<th>Themes</th>
<th>Key Features</th>
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<tbody>
<tr>
<td>Incorporate DTLIB</td>
<td>Spotweld, Seamweld Duty cycle, hybrid loadings</td>
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<tr>
<td>Refresh GUI</td>
<td>New ribbon plus updated forms</td>
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<tr>
<td>Rest of DTLIB</td>
<td>Virtual Shaker Table S-N and E-N update</td>
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<tr>
<td>Ancillary comps</td>
<td>Upgraded vibration fatigue</td>
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</table>
Current Fatigue Work Flow and Limitations
How do the Fatigue and Stress Solvers interface?

**Analysis Model**
- Geometry
- Elements
- Loads
- Boundary Conditions
- Materials
- Properties

**Solver**
- Displacements
- Velocities/accelerations
- Stresses
- Forces
- Strains (elastic/plastic/creep)
- Eigen frequencies
- Eigen vectors
- Buckling load factors

**Solver Processing**
- Contour Plots
- Graphs
- Listings

**Solver Solution**
- Fatigue
- Fracture
- Reliability
- Damage Tolerance

**Solver Pre-Processing**

**Solver Post-Processing**
In traditional approaches how do the stress solver and fatigue solver interface?

**Stress solver**

- **Build FE model** and check global FE model quality.
- Apply unit loads to FE stress model to produce stress fields.

**Fatigue solver**

- Identify material parameters.
- Identify loads, constraints.
- Calculate stress time histories for Fatigue analysis.
- Plot results, identify critical (hot spot) locations.
- FE modelling/meshing quality in critical locations?
- More sophisticated fatigue method required?
- Perform sensitivity analysis.

This is true for static and dynamic problems.
An example with MSC Fatigue

The OP2, Patran DB and FES files are significant bottlenecks making the analysis of large models difficult or impossible.

All major competitive products have the same bottlenecks.
Its Not About The Stresses!

Nastran Embedded Fatigue

Put the fatigue solver at the same point as the stress solver
Nastran File Flow

Preferred GUI

Short term output options
- ANSYS
- FER
- UNV Universal
- CSV File
- FEF (Patran results file)
- Hyperworks
- Medina BOF
- ABAQUS ODB

Optional output files

OP2
Current Fatigue Analysis Process

**FE model input**

**Nastran output files**

Pain here because sometimes file size limitations mean results have to be broken into multiple files and can be difficult to manage

**OP2 file translation**

Pain here because these file transfers can be time consuming

**Fatigue input file.**

Pain here because this can be **very** large

**Fatigue material properties and cyclical loads data**

**Fatigue calculation**

Pain here because CPU and memory restrictions mean there are repeated read-write operations to disk

**Fatigue Job.**

Pain here because this can only be done as a post-processing operation meaning early design changes are difficult

**Fatigue output**

**Manual Optimization loop**

If optimization is attempted there will be significant pain because the process is a crude manual loop
Nastran Embedded Fatigue (NEF) Process

- No large data files to transfer.
- No complicated file management.
- Significant reduction in CPU requirements.
- Likely that whole fatigue calculation process can be done in memory.
- Will open up opportunity to perform full optimization for fatigue calculations. (improved designs – potential areas of improvement include reduction in body shell thickness, improved component shapes or reduction in spot weld numbers)
- Full Body Fatigue calculations, including dynamic behaviour, will be practical option. (better analysis – some large problems are currently too big to handle. Anticipate increase in model DOF that can be handled by factor 5 or more)
Benefits of Nastran Embedded Fatigue (Nastran 2013)

• No large data files to transfer.
• No complicated file management.
• Significant reduction in CPU requirements.
• Likely that whole fatigue calculation process can be done in memory.
• Will open up opportunity to perform full optimization for fatigue calculations.
• Full Body Fatigue calculations, including dynamic behavior, will be practical option.

“The most important development in CAE Fatigue since the introduction of MSC Fatigue.”
Bulk Data Entries

Overall Case Control

**FATIGUE** (case control) - Requests one or more fatigue analyses

Define Elements for Fatigue Analysis:

**SET** (bulk data) - Defines unique set of elements by referring to their element properties

**FTGDEF** (bulk data) - FaTiGue DEFinition: Defines the part(s) of the model for fatigue analysis

Define Loading:

**FTGLOAD** (bulk data) - FaTiGue LOADing: Defines load variations with time (time histories) or frequency (Input PSDs)

**FTGEVNT** (bulk data) - FaTiGue EVeNT: Defines a loading event that is made up of a sequence of fatigue loads

**FTGSEQ** (bulk data) - FaTiGue load SEQuence: Specifies a time based loading sequence made up of loading events.

**TABLFTG** (bulk data) - TABLE FaTiGue: Defines actual tabular data of fatigue loading

Define Properties:

**PFTG** (bulk data) - Property FaTiGue: Defines properties for fatigue analysis (surface finish, surface treatment, etc.)

Define Materials:

**MATFTG** (bulk data) - MATerial FaTiGue: Defines materials for fatigue analysis (S-N & e-N curves)

Define General Parameters:

**FTGPARM** (bulk data) - FaTiGue PARaMeters: Defines fatigue parameters

MSC Software
Simulating Reality, Delivering Certainty
**Integration of fatigue in SOL. 200**

**DRESP1** - A modified card to include fatigue as a constraint

- Fatigue responses like LIFE, DAMAGE are integrated with other standard responses like stress, strain, displacement etc.

- Fatigue responses may be defined as objective function and/or as constraints

- In release 1, fatigue responses will only be allowed for static analysis
### Nastran Embedded Fatigue (Nastran 2013)

#### Fully embedded Bulk Data File driven fatigue analysis

<table>
<thead>
<tr>
<th>Nastran Fatigue 2013</th>
<th>Fatigue solutions</th>
<th>Nastran solution routines</th>
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<tr>
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<td>Stress-Life solver</td>
<td>SOL 101 - statics</td>
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<td>Strain-Life solver</td>
<td>SOL 103 – modal stresses</td>
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<td>Multi Thread Processing</td>
<td>SOL 112 – modal loads</td>
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<td>SOL 200 - optimization</td>
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<td>Spot Weld solver</td>
<td>SOL 108 – direct time dom</td>
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<td>Seam Weld solver</td>
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<td>Vibration Fatigue solver</td>
<td>SOL 111 – modal frequency</td>
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<td>Temperature Loads</td>
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### 2014 Roadmap
- Short Fibre Composites, Thermo Mechanical Fatigue,
Pre & Post support for NEF 2013

Patran (Pre&Post) preference for NEF 2013

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<td>SOL 112</td>
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<td>SOL 200</td>
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</table>

From September 2013

Other Post support options for NEF 2013

- ANSYS
- Medina BOF
- FER
- Hyperworks
- ABAQUS
- UNV Universal
- CSV File
- FEF (Patran results file)

NB. Post support will be available from day 1 of NEF 2013. A lack of immediate Pre support is not a barrier to customer use.
FATIGUE

Fatigue Output Request

Requests one or more fatigue analyses for use in pseudo-static (SOL 101), modal (SOL 103) and modal transient (SOL 112) runs.

Format:
FATIGUE[ ( [PRINT,PUNCH,PLOT], FORMAT=[CODE], [BULK/SET] ) ] = n

Examples:
FATIGUE=100
SET 99 = 100, 200
FATIGUE(SET)=99

Normal output type
Special output type, eg Hypermesh

References to 1 or more fatigue jobs
Sample Model
run with NEF

• Symmetric Keyhole Model
  – used extensively throughout MSC Fatigue documentation

• Loading
  – applied at far end
  – time history variation of force
  – induces stress at keyhole tip
Fatigue Input
keyhole model

Case Control
- request fatigue analysis
  - FATIGUE bulk = x
  - x references fatigue specific parameters
    below in bulk data
    - FTGSEQ
    - FTGPARM
- loading definition for individual events

Bulk Data
- fatigue sequencing
  - FTGSEQ
- fatigue events
  - FTGEVNT
- fatigue parameters
  - FTGPARM
- fatigue materials
  - MATFTG
- fatigue loading
  - FTGLOAD
  - reference to load time histories
    - TABLFTG
Fatigue Output

keyhole f06

- All the standard outputs available
- Reported Individually
  - per event
  - per duty cycle
  - allows for subsequent re-combination damage studies

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<th>LOG (EQUIV. LIFE)</th>
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Fatigue Input
keyhole optimization (SOL 200) input

- Consistent Input for SOL 200
  - Design Variables
  - Targets

- Now Includes Fatigue Variables
  - Life
  - Damage
  - etc.

SOL 200

CENM

FATIGUE bulk - 10
DESGLB = 20
doobj = 5
analysis = statics

SUBCASE 1
  SUBTITLE=Case_1
  SPC = 2
  LOAD = 6
  STRESS(SORT4,REAL,VEONIMIES)-ALL

BEGIN BULK

**PFTG 10 1**

**FTGPARM 10 5 1.0**
  STRESS VEONIMIES ELEM

**MATFIG 1**
  STATIC 1000. 552. 0 RRATIO

**FTGLOAD 10 1001 1**
  dname 1001
  unitload.dac
  desvar 101 thick 1.0 .01 10.0
  desvar 102 thick 1.0 .01 10.0

**DUPREL1 10**
  PSHELL 101 1
  101 9.525

**DUPREL2 20**
  PSHELL 102 1
  102 9.525

**drespt 5**
  volume volume

**drespt 20**
  stftfg fatigue elen 4 10 1

**dconstr 20 20 1.0e5**

**doptprm p1 1 p2 15**
Multi-Threaded Performance Improvements
DTLIB solver in NEF

- Initial studies reveal significant speed-up in fatigue simulations
Differentiating between a GUI Based Approach and Solver Embedded

MSC Fatigue (GUI driven)

**When to use**
- Failure investigation.
- Sensitivity studies (e.g., effect of load change).
- Where stresses are from non Nastran solvers.
- For highly interactive analysis.
- Where a large amount of post processing is anticipated.

Nastran Fatigue (Solver Embedded)

**When to use**
- Well defined processes.
- Large models.
- Many load inputs.
- For optimisation of parts or systems.
- Simpler and more concise file management.
- Extremely fast analysis.
- BDF file auditable process.
Nastran Embedded Fatigue in 2013

“The most important development in CAE Fatigue since the introduction of MSC Fatigue.”
Thank You!
**FTGDEF**

Defines elements and their associated fatigue properties to be considered for fatigue analysis.

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**Examples:**

Which elements to include – exclude – and special properties

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</tbody>
</table>
FTGEVNT

Groups simultaneously applied loads into loading events for pseudo-static fatigue analysis using SOL 101 or modal analysis using SOL 103 by referencing FTGLOAD entries.

Format:

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<tr>
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</table>

Example:

FTGEVNT 22 4 11

Individual loads that make up an event
FTGLOAD

Defines loading time variation for pseudo-static fatigue analysis using SOL 101 or modal analysis using SOL 103.

**Format:**

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<thead>
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<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Examples:**

FTGLOAD 55 4 2 1.0 1.0 0.0
FTGLOAD 23 4 5 1.0 1.0 0.0 DB

What is the type of load and other relevant conditions.
**FTGSEQ**

Defines the loading sequence for pseudo-static fatigue analysis using SOL 101 or modal transient fatigue analysis using SOL 103 or SOL 112.

**Format:**

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<tr>
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<td>-etc.-</td>
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<td>EQUIV</td>
<td>EQNAME</td>
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<td></td>
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</tr>
</tbody>
</table>

**Examples:**

```
FTGSEQ 1
  6 1
```
Example of FTGSEQ entries

SET 1=22,33,44
FATIGUE=1
BEGIN BULK
$
FTGSEQ,22 <-- 1 country road only
,2
FTGSEQ,33 <-- 1 torture track only
,3
$combined
FTGSEQ,44 <-- 6 torture track, 5 country road, + 1 of each
,3,6.0,2,5.0,3,1.0,2,1.0
$country road:
FTGSEQ,2
,8,10.0,9,10.0 <-- 10 cornering left + 10 cornering right
$torture track:
FTGSEQ 3
,5,5.0,6,6.0,7,3.0 <-- 5 cobblestones, 6 potholes, 3 speed bumps
$
FTGEVNT,5... <-- cobble stones
FTGEVNT,6... <-- potholes
FTGEVNT,7... <-- speed bumps

FTGEVNT,8... <-- cornering right
FTGEVNT,9... <-- cornering left
FTGPARM

Defines parameters for a fatigue analysis.

**Format:**

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<td>LOGLVL</td>
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<td>&quot;STRAIN&quot;</td>
<td>&quot;RAINFLOW&quot;</td>
<td>&quot;CERTNTY&quot;</td>
<td>&quot;FOS&quot;</td>
<td>&quot;STRESS&quot;</td>
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<td>INTERP</td>
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</tr>
</tbody>
</table>

**Examples:**

- If FOS is required: `FTGPARM 22 SN`
- How is RCC to be done: `FTGPARM 22 STRESS SN SGVON NONE`
MATFTG
Defines fatigue material properties.

Format:

<table>
<thead>
<tr>
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<th>2</th>
<th>3</th>
<th>4</th>
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<td>b2</td>
<td>Nfc</td>
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<td>TID2</td>
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<td>c</td>
<td>Eb</td>
<td>Sd</td>
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<td>b</td>
<td>c</td>
<td>Ef</td>
<td>n</td>
<td>K</td>
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<td>SEp</td>
<td>SEc</td>
<td>Ne</td>
<td>FSN</td>
<td>S</td>
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</tr>
</tbody>
</table>

Examples:

MATFTG 9
STATIC 430 682
MATFTG 9
STATIC 430 682
SN 3095 -0.1339 1.e6 0.0 50 0.1

Stress-Life curve parameters
FKM mean stress parameters
S-N curve as x-y pairs
Stress-Life curve parameters
PFTG

Defines fatigue properties.

| Format: |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| PFTG | ID | LAYER | FINISH | KFINISH | KF | SCALE | OFFSET |
| SHAPE | KTREAT |

**Examples:**

PFTG 3 0 POLISH | NONE | 1.2

Surface finish or treatment
SET4

Defines a list of property IDs

**Format:**

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<th>10</th>
</tr>
</thead>
<tbody>
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<td>CLASS</td>
<td>TYPE</td>
<td>ID1</td>
<td>ID2</td>
<td>ID3</td>
<td>ID4</td>
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<tr>
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<td>-etc-</td>
<td></td>
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</tr>
</tbody>
</table>

**Example:**

SET4 22  PROP  PSOLID  1  THRU  20
# TABLFTG

Defines tabular data for defining fatigue loading with respect to time (time history).

## Format:

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<th>10</th>
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</thead>
<tbody>
<tr>
<td>TABLFTG</td>
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<td>y2</td>
<td>y3</td>
<td>y4</td>
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<td>y6</td>
<td>y7</td>
<td>&quot;ENDT&quot;</td>
</tr>
</tbody>
</table>

## Example:

```
TABLFTG 1
0.000 -0.601 0.968 0.515 -0.263 -0.090 -0.582 -0.592
-0.877 -0.726 0.297 -0.899 -0.899 -0.165 0.907 0.936
-0.308 -0.308 -0.689 0.592 0.609 -0.600 -0.492 -0.492
-0.224 ENDT
```
UDNAME

Provides the name of a file that can be referenced from other bulk data entries such as FTGLOAD.

<table>
<thead>
<tr>
<th>Format:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<tr>
<td>UDNAME</td>
</tr>
<tr>
<td>NAME</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Example:</th>
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</thead>
<tbody>
<tr>
<td>UDNAME</td>
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<tr>
<td>\textbackslash/sine01.dac</td>
</tr>
</tbody>
</table>
DTI,UNITS

Defines units necessary for conversion during the analysis for the Nastran/ADAMS interface and Nastran Fatigue analysis.

Format:

```
1  2  3  4  5  6  7  8  9  10
DTI UNITS 1 MASS FORCE LENGTH TIME STRESS
```

Example:

```
1  2  3  4  5  6  7  8  9  10
DTI UNITS 1 KG N M S MPA
```
DRESP1

This is an update to DRESP.

Example: This example defines a fatigue life response on entities defined by FATIGUE entry ID 44. A label called FLIGHTS is used to name the response.
ThankYou!