Integrated durability approach using measured wheel forces for robust and faster design convergence

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Agenda

- Company profile
- Objective
- Current challenges in CAE
- Integrated Durability simulation (IDS) process
- RLDA Fatigue analysis
- Equivalent static load case deck generation
- Benefits of IDS process
- Conclusion

Company Profile

- Mahindra & Mahindra is $21 billion multinational group with a presence in more than 100 countries and employing over 250,000 people.

- Operation expanded to 22 key industries that form the foundation of every modern economy.

AEROSPACE	AFTERMARKET	AGRI INDUSTRY
AUTOMOTIVE	BOATS	CLEAN ENERGY
CONSTRUCTION EQUIPMENT	CONSULTING	DEFENCE
FARM EQUIPMENT	HOSPITALITY	INFORMATION TECHNOLOGY
INSURANCE BROKING	LOGISTICS	POWER BACKUP
REAL ESTATE & INFRASTRUCTURE	RETAIL	RURAL HOUSING FINANCE
STEEL	TRUCKS & BUSES	TWO WHEELERS
VEHICLE & EQUIPMENT FINANCE		

Objective

- Objective of Integrated durability simulation (IDS) is to derive generic static load cases and establish automated RLDA-integrated simulation process for Vehicle Durability evaluation.
- Typical failures on vehicle system will be observed during developmental test cycles. Failures are caused due to dynamic loads acting on these parts.
- Failure cannot be captured in CAE simulation, when static analysis was performed. Hence dynamic analysis by taking WTF of RLDA need to performed.
- Loads used for analysis form a critical step for accurate Fatigue life prediction.
- By performing dynamic fatigue analysis, realistic forces can be captured on parts and hence reduce the surprises due to load uncertainty.

Current challenges in full vehicle fatigue analysis

- Currently dynamic fatigue simulations are carried out manually. If BIW has 30 hard point locations, full vehicle unit load case deck with 180 load collectors and load steps to be created in Nastran deck.

Time consuming and prone for error

- Mapping each unit load case to corresponding Load history files manually to generate a Fatigue deck (FFJ) per track and do fatigue simulation.

Time consuming and prone for error

- Calculating total damage by linear superposition of individual damage results by applying relevant factors from Duty cycle in HYPERVIEW.

Prone to error

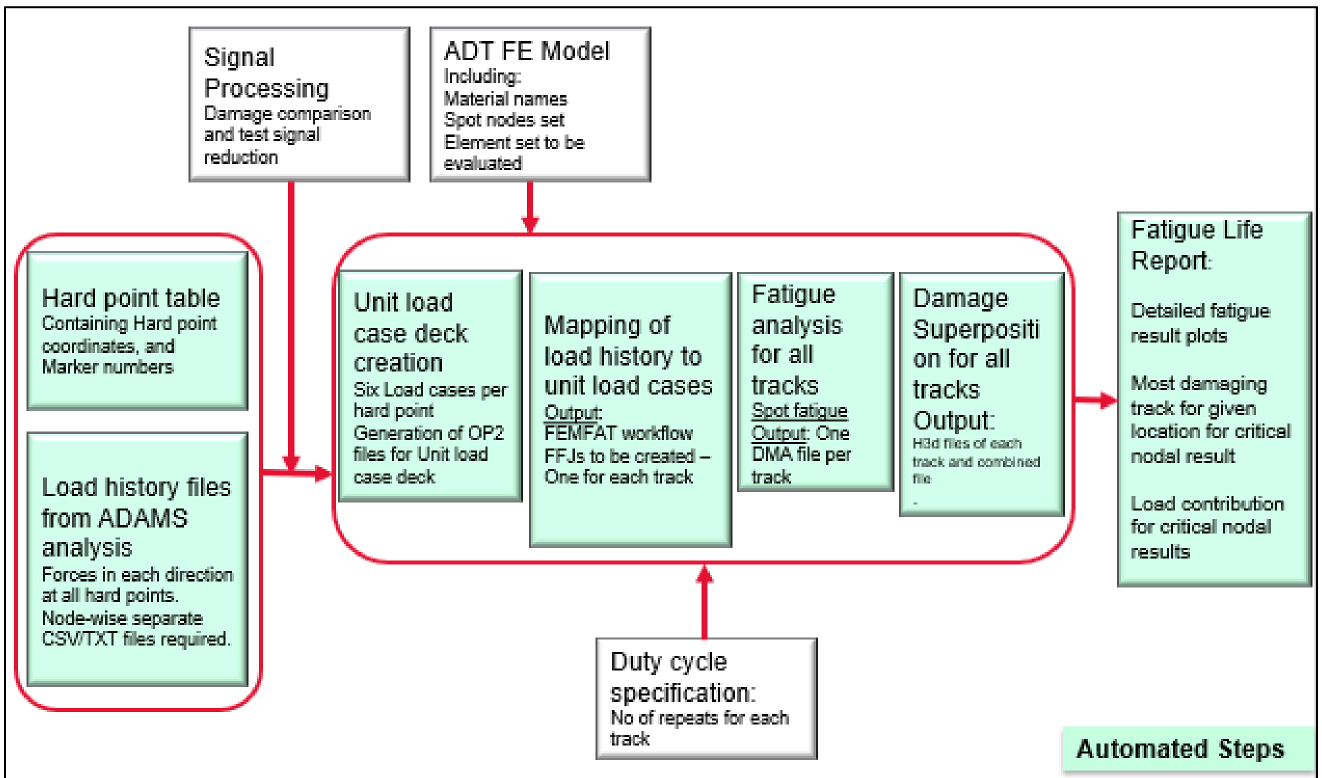
- Fatigue simulation results are hard to interpret. Unable to predict most damaging track and time point which causes the failure in part.

Challenges achieved with IDS process

Challenges	Manual process	Using IDS process
Unit load case deck	Manual setup for 180 load step in Nastran deck	Process is automated
Mapping load step number with track files column number	Mapping of 180 load case to corresponding Load history to generate a Fatigue deck (FFJ) per track	Process is automated – FFJ generated for each track has mapped 180 steps with correct column numbers
Individual fatigue files for each track	Manual mapping of FFJ for each track	Process is automated – FFJ files generated as per track
Calculating total damage	Manual calculating total damage by linear superposition of individual damage in HyperView	Process is automated. Gives total damage H3D file
Providing R2G solution	Fatigue simulation results are hard to interpret	Extraction of equivalent static load case for better visualization.

IDS Process

- Below flowchart describes the IDS process.
- Hard point table (text format) and load history files from ADAMS (ASCII format) are mapped with unit load case deck file.
- Fatigue analysis for each track is performed in FEMFAT



ADAMS Load generation

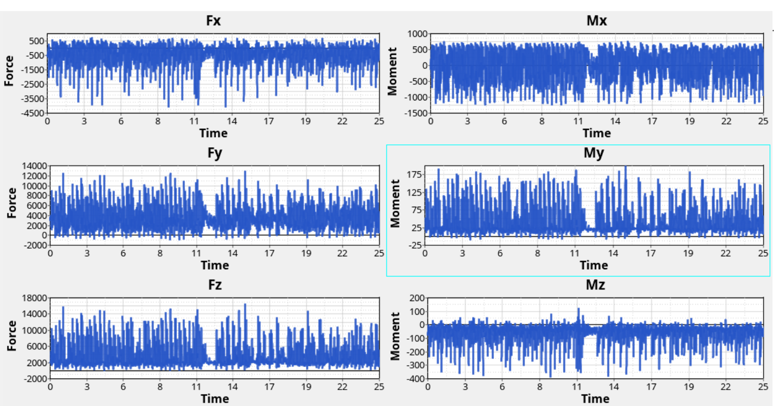
- Generation of load history files from ADAMS - using measured road profiles - in ASCII format (forces in each direction for all hard points)

- Output:

One TXT file per hard point containing Time, FX, FY, FZ, MX, MY, MZ in specified sequence. The name of the .TXT file match the hardpoint name mentioned in the hard point table.

- For e.g. In case of 30 hard points, there need to be 30 Load history TXT files for 1 track (e.g. GVWP1)

GVWP1.txt



Time	FX	FY	FZ	MX	MY	MZ
+0.0000000e+000	+8.1374799e+002	−4.4857601e+001	−5.2314301e+002	+3.7027600e+002	+2.3406100e+002	−2.9897000e+002
+7.8125000e−003	+1.3498430e+002	−6.1323609e+000	−5.8069031e+001	+7.0560493e+001	+3.9929409e+001	−3.9469280e+001
+1.5625000e−002	−1.9176701e+001	−2.7249420e+001	−3.3488930e+001	−8.3437843e+000	−7.3133111e+000	+4.7580042e+000
+2.3437500e−002	+2.1157980e+002	−6.6026253e+001	−1.3013210e+002	+1.3404671e+002	+7.0445084e+001	−7.7341377e+001
+3.1250000e−002	+4.8041800e+002	−4.1153858e+001	−2.4868250e+002	+2.4114590e+002	+1.4083870e+002	−1.6197749e+002
+3.9062500e−002	+2.1449860e+002	+8.0182123e+000	−7.7819199e+001	+1.1436970e+002	+6.7006012e+001	−6.7303177e+001
+4.6875000e−002	−6.9582947e+001	+2.5373390e+001	+1.5245710e+001	−8.6272118e+001	−4.3826950e+001	+3.8139881e+001
+5.4687500e−002	−1.4242380e+002	+1.8816620e+001	+1.6629009e+001	−1.7376320e+002	−9.0474297e+001	+6.9105003e+001
+6.2500000e−002	−1.7853050e+002	+1.5992300e+001	+8.9056435e+000	−1.8421049e+002	−9.6517479e+001	+7.2201447e+001
+7.0312500e−002	−1.7585080e+002	+3.6034911e+000	−2.3343589e+000	−1.3916161e+002	−7.4491043e+001	+5.7986931e+001
+7.8125000e−002	+1.4570930e+002	−4.1922642e+001	−9.0998253e+001	+1.0002290e+002	+5.2967720e+001	−5.6489540e+001
+8.5937500e−002	+5.0624969e+002	−8.6119972e+001	−2.9163739e+002	+2.5660379e+002	+1.4580569e+002	−1.7270160e+002
+9.3750000e−002	+9.9156387e+001	−6.0456619e+001	−8.1636681e+001	+5.8725651e+001	+2.7068090e+001	−3.0940121e+001
+1.0156250e−001	−1.3369690e+002	+2.2822020e+000	+3.0142491e+000	−1.7111710e+002	−9.1211540e+001	+6.8262100e+001
+1.0937500e−001	−1.3138890e+002	+5.1759200e+000	+1.2320500e+001	−2.0417720e+002	−1.0723360e+002	+7.8043114e+001
+1.1718750e−001	−1.8892760e+002	+6.2840271e+000	+4.9336181e+000	−1.9151480e+002	−1.0066910e+002	+7.4542839e+001
+1.2500000e−001	−9.7216599e+001	−7.2505002e+000	−1.6522200e+001	−4.0555031e+001	−2.3051861e+001	[illegible]

ADAMS Load generation

- Hard point table (HP Table.csv) : contains hard point coordinates with names
- Load files (.txt) : Load file from ADAMS matching names HPTable.csv
- Duty cycle : Has information on tracks and repeats

Hard point table

1	HP_name	x	y	z
2	W501_FS_Steering_3UJ_26032018_bgl_rack_hsg_m	831.22	-185.5	469.57
3	W501_FS_Steering_3UJ_26032018_bgr_rack_hsg_m	831.22	185.5	469.57
4	W501_FS_Steering_3UJ_26032018_bgs_rack_hsg_m	835.98	185.5	550.43
5	W501_FS_VP0_bkl_lca_front_on_ges_chassis_flex	767.31	-315	437.44
6	W501_FS_VP0_bkl_lca_rear_on_ges_chassis_flex	1290.47	-315	453.7
7	W501_FS_VP0_bkl_top_mount_on_ges_chassis_flex	1007.3	-461.88	860.77
8	W501_FS_VP0_bkl_uca_front_on_ges_chassis_flex	890.11	-444	672.21
9	W501_FS_VP0_bkl_uca_rear_on_ges_chassis_flex	1140.7	-444	650.83
10	W501_FS_VP0_bkr_lca_front_on_ges_chassis_flex	767.31	315	437.44
11	W501_FS_VP0_bkr_lca_rear_on_ges_chassis_flex	1290.47	315	453.7
12	W501_FS_VP0_bkr_top_mount_on_ges_chassis_flex	1007.3	461.88	860.77
13	W501_FS_VP0_bkr_uca_front_on_ges_chassis_flex	890.11	444	672.21
14	W501_FS_VP0_bkr_uca_rear_on_ges_chassis_flex	1140.7	444	650.83

Duty cycle

Tracks	Number of repeats in one ADT cycle (N)
GVWP1	X1
GVWP2	X2
GVWTT	X3
GVWLWP	X4
GVWHF	X5
GVWRR	X6

Track Files

Name

- GVWHF
- GVWLW
- GVWP1
- GVWP2
- GVWRR
- GVWTT

Name

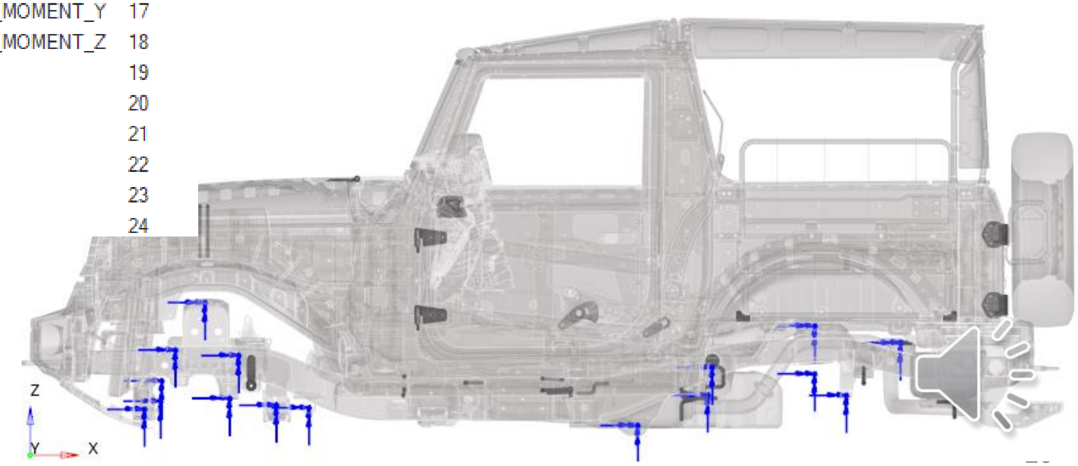
- GVWP1_W501_FS__ARB_26032018_flex_bgl_arb_bushing_on_ges_c
- GVWP1_W501_FS__ARB_26032018_flex_bgr_arb_bushing_on_ges_c
- GVWP1_W501_FS_Steering_3UJ_26032018_bgl_rack_hsg_mount_bc
- GVWP1_W501_FS_Steering_3UJ_26032018_bgr_rack_hsg_mount_bc
- GVWP1_W501_FS_Steering_3UJ_26032018_bgs_rack_hsg_mount_rh
- GVWP1_W501_FS_VP0_bkl_lca_front_on_ges_chassis_flex.txt
- GVWP1_W501_FS_VP0_bkl_lca_rear_on_ges_chassis_flex.txt
- GVWP1_W501_FS_VP0_bkl_top_mount_on_ges_chassis_flex.txt
- GVWP1_W501_FS_VP0_bkl_uca_front_on_ges_chassis_flex.txt
- GVWP1_W501_FS_VP0_bkl_uca_rear_on_ges_chassis_flex.txt
- GVWP1_W501_FS_VP0_bkr_lca_front_on_ges_chassis_flex.txt
- GVWP1_W501_FS_VP0_bkr_lca_rear_on_ges_chassis_flex.txt
- GVWP1_W501_FS_VP0_bkr_top_mount_on_ges_chassis_flex.txt
- GVWP1_W501_FS_VP0_bkr_uca_front_on_ges_chassis_flex.txt
- GVWP1_W501_FS_VP0_bkr_uca_rear_on_ges_chassis_flex.txt

NASTRAN Unit Load case deck generation

- Unit load cases created – 6 load steps for each hard point – F_x, F_y, F_z, M_x, M_y, M_z. Total load step=30x6=180 load steps

Load Steps (180)

W501_FS_Steering_3UJ_26032018_bgl_rack_hsg_mount_bottom_on_ges_chassis_flex_FORCE_X	1
W501_FS_Steering_3UJ_26032018_bgl_rack_hsg_mount_bottom_on_ges_chassis_flex_FORCE_Y	2
W501_FS_Steering_3UJ_26032018_bgl_rack_hsg_mount_bottom_on_ges_chassis_flex_FORCE_Z	3
W501_FS_Steering_3UJ_26032018_bgl_rack_hsg_mount_bottom_on_ges_chassis_flex_MOMENT_X	4
W501_FS_Steering_3UJ_26032018_bgl_rack_hsg_mount_bottom_on_ges_chassis_flex_MOMENT_Y	5
W501_FS_Steering_3UJ_26032018_bgl_rack_hsg_mount_bottom_on_ges_chassis_flex_MOMENT_Z	6
W501_FS_Steering_3UJ_26032018_bgr_rack_hsg_mount_bottom_on_ges_chassis_flex_FORCE_X	7
W501_FS_Steering_3UJ_26032018_bgr_rack_hsg_mount_bottom_on_ges_chassis_flex_FORCE_Y	8
W501_FS_Steering_3UJ_26032018_bgr_rack_hsg_mount_bottom_on_ges_chassis_flex_FORCE_Z	9
W501_FS_Steering_3UJ_26032018_bgr_rack_hsg_mount_bottom_on_ges_chassis_flex_MOMENT_X	10
W501_FS_Steering_3UJ_26032018_bgr_rack_hsg_mount_bottom_on_ges_chassis_flex_MOMENT_Y	11
W501_FS_Steering_3UJ_26032018_bgr_rack_hsg_mount_bottom_on_ges_chassis_flex_MOMENT_Z	12
W501_FS_Steering_3UJ_26032018_bgs_rack_hsg_mount_rh_top_on_ges_chassis_flex_FORCE_X	13
W501_FS_Steering_3UJ_26032018_bgs_rack_hsg_mount_rh_top_on_ges_chassis_flex_FORCE_Y	14
W501_FS_Steering_3UJ_26032018_bgs_rack_hsg_mount_rh_top_on_ges_chassis_flex_FORCE_Z	15
W501_FS_Steering_3UJ_26032018_bgs_rack_hsg_mount_rh_top_on_ges_chassis_flex_MOMENT_X	16
W501_FS_Steering_3UJ_26032018_bgs_rack_hsg_mount_rh_top_on_ges_chassis_flex_MOMENT_Y	17
W501_FS_Steering_3UJ_26032018_bgs_rack_hsg_mount_rh_top_on_ges_chassis_flex_MOMENT_Z	18
W501_FS_VP0_bkl_lca_front_on_ges_chassis_flex_FORCE_X	19
W501_FS_VP0_bkl_lca_front_on_ges_chassis_flex_FORCE_Y	20
W501_FS_VP0_bkl_lca_front_on_ges_chassis_flex_FORCE_Z	21
W501_FS_VP0_bkl_lca_front_on_ges_chassis_flex_MOMENT_X	22
W501_FS_VP0_bkl_lca_front_on_ges_chassis_flex_MOMENT_Y	23
W501_FS_VP0_bkl_lca_front_on_ges_chassis_flex_MOMENT_Z	24



Fatigue analysis using load case mapping

- Force history for each hard point is respectively applied to each unit load case in Channel MAX, FEMFAT

- One FEMFAT Job deck file (FFJ) per track viz. GVWHF.FFJ, GVWP1.FFJ etc.

```
setValue {} {} NumChannelTable 1
setValue {} {} MaxStressFileFormat 1 10
setValue {} {} MaxStressInputFile 1 {RDW501Base-D-0100-007_017.op2}
setValue {} {} LoadCaseNumber 1 1
setValue {} {} MaxScratchFileFormat 1 2
setValue {} {} MaxHistoryInputFile 1 GVWP1_W501_FS_Steering_3UJ_26032018_bgl_rack_hsg_mount_bottom_on_ges_chassis_flex.txt
setValue {} {} MaxColumn 1 2
setValue {} {} NumChannelTable 180
setValue {} {} ChannelTableCurLabel 2
setValue {} {} MaxHistoryInputFile 2 GVWP1_W501_FS_Steering_3UJ_26032018_bgl_rack_hsg_mount_bottom_on_ges_chassis_flex.txt
setValue {} {} MaxColumn 2 3
setValue {} {} ChannelTableCurLabel 3
setValue {} {} MaxHistoryInputFile 3 GVWP1_W501_FS_Steering_3UJ_26032018_bgl_rack_hsg_mount_bottom_on_ges_chassis_flex.txt
setValue {} {} MaxColumn 3 4
setValue {} {} ChannelTableCurLabel 4
setValue {} {} MaxHistoryInputFile 4 GVWP1_W501_FS_Steering_3UJ_26032018_bgl_rack_hsg_mount_bottom_on_ges_chassis_flex.txt
setValue {} {} MaxColumn 4 5
setValue {} {} ChannelTableCurLabel 5
setValue {} {} MaxHistoryInputFile 5 GVWP1_W501_FS_Steering_3UJ_26032018_bgl_rack_hsg_mount_bottom_on_ges_chassis_flex.txt
setValue {} {} MaxColumn 5 6
setValue {} {} ChannelTableCurLabel 6
setValue {} {} MaxHistoryInputFile 6 GVWP1_W501_FS_Steering_3UJ_26032018_bgl_rack_hsg_mount_bottom_on_ges_chassis_flex.txt
setValue {} {} MaxColumn 6 7
setValue {} {} ChannelTableCurLabel 7
setValue {} {} MaxHistoryInputFile 7 GVWP1_W501_FS_Steering_3UJ_26032018_bgr_rack_hsg_mount_bottom_on_ges_chassis_flex.txt
setValue {} {} MaxColumn 7 2
setValue {} {} ChannelTableCurLabel 8
setValue {} {} MaxHistoryInputFile 8 GVWP1_W501_FS_Steering_3UJ_26032018_bgr_rack_hsg_mount_bottom_on_ges_chassis_flex.txt
```

Column number in track file

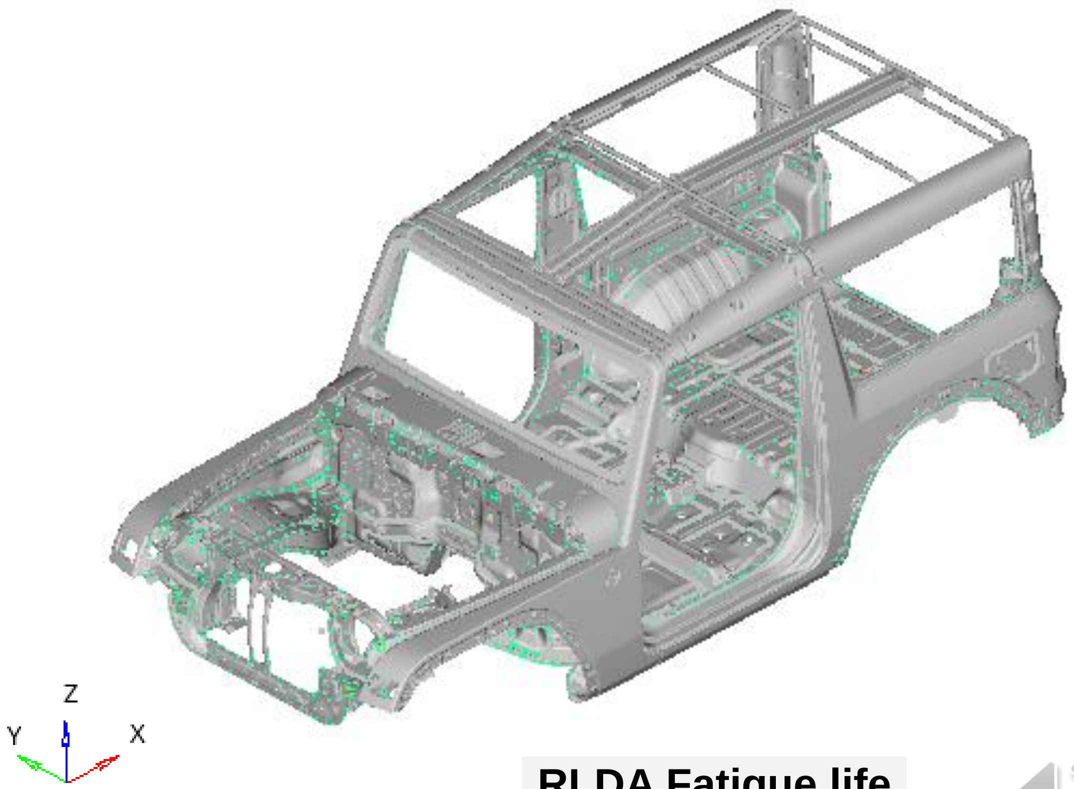
Load case number

Damage Superposition - RLDA Fatigue life

- Total damage is calculated by linear superposition of individual damage results by applying relevant factors from the given Duty Cycle.

Duty cycle

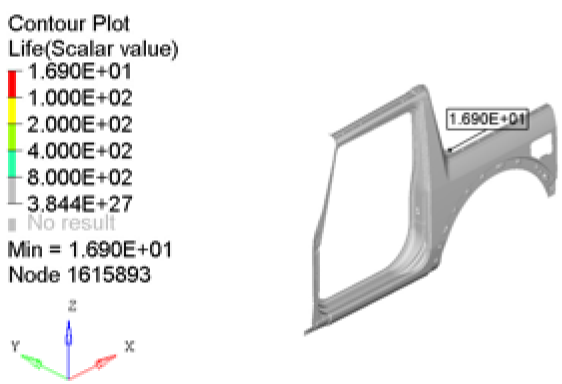
Tracks	Number of repeats in one ADT cycle (N)
GVWP1	X1
GVWP2	X2
GVWTT	X3
GVWLWP	X4
GVWHF	X5
GVWRR	X6



RLDA Fatigue life

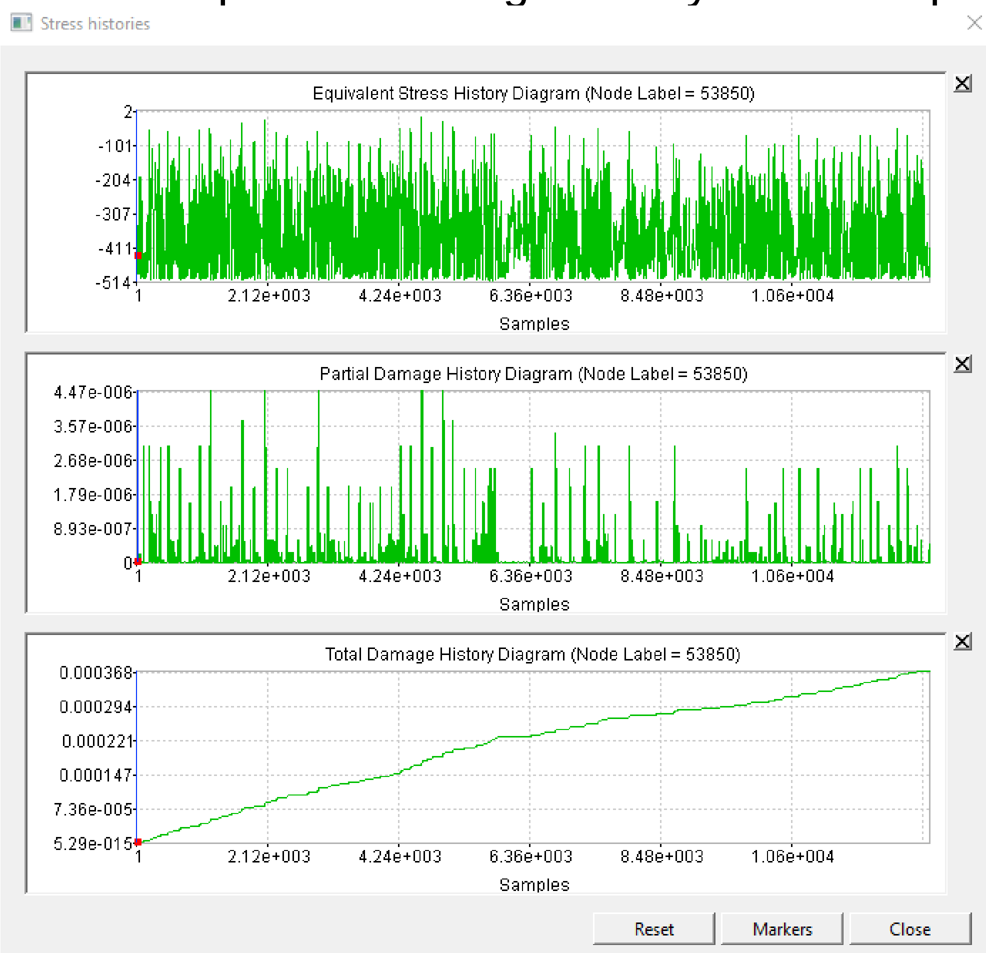
Report generation: Hotspot fatigue life

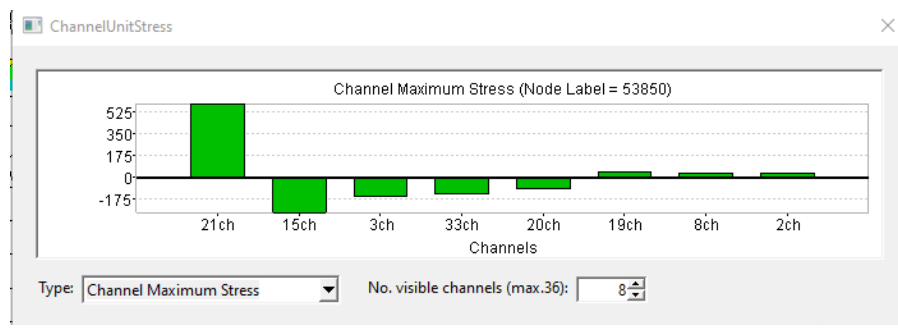
- Most damaging track is identified
- Detailed results requested at each identified Hotspot for further processing.

0101EW500040N_026-PANEL_BODY_SID	Most Damaging	GVW P2	Acceptance Criteria > 100 ADT cycles		
					

Detailed results

- Fatigue analysis is again performed for DETAILED RESULTS nodes
- Output of this fatigue analysis will be partial and total damage files (.pdh&.tdh)





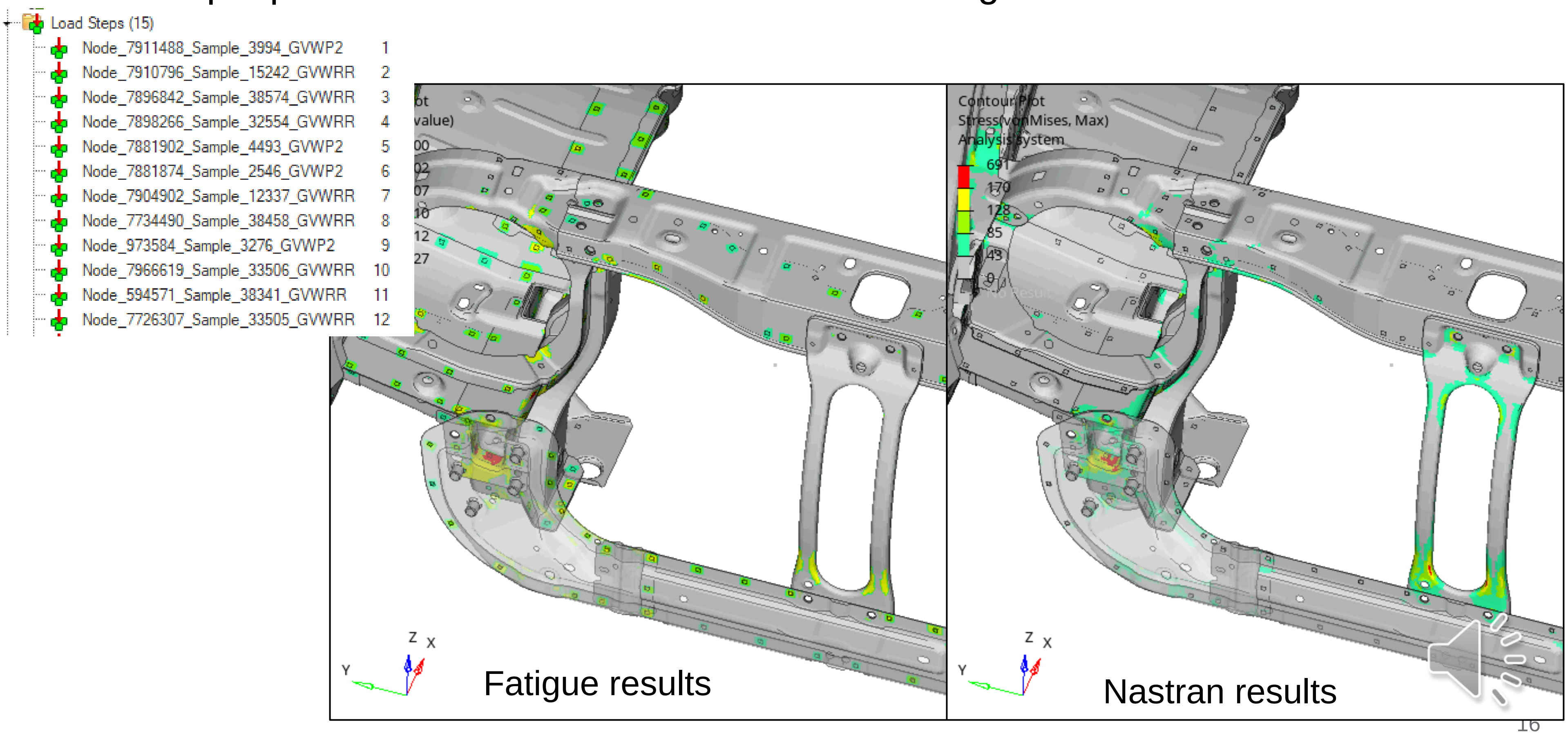
Worst Track & Sample number for Hotspots

- Most damaging track – critical track and time point is identified for each hot spot

Node ID	Individual damage from Most damaging track	Cumulative Damage for complete duty cycle	Most Damaging track	Sample No – Time point which causes highest damage
7911488	0.264700	0.711	GVWP2	3994
7911489	0.264700	0.711	GVWP2	3994
7910796	0.189200	0.619	GVWRR	15242
7910797	0.189200	0.619	GVWRR	15242
8059703	0.108600	0.336	GVWRR	15242
7896842	0.167800	0.326	GVWRR	38574
7896843	0.167800	0.326	GVWRR	38574
8059743	0.100500	0.262	GVWP2	3994
7898266	0.077800	0.218	GVWRR	32554
7898268	0.077800	0.218	GVWRR	32554
7881902	0.037630	0.087	GVWP2	4493
7881874	0.027330	0.059	GVWP2	2546
7903182	0.034700	0.059	GVWRR	38574
7896839	0.022650	0.043	GVWRR	38574
7896840	0.022650	0.043	GVWRR	38574
602492	0.012010	0.040	GVWRR	32554

Equivalent static load case

- Damage history (tdh and pdf) files post processed and worst time instance identified
- Equivalent static load case inertia relief Nastran deck is exported identified sample point which can be used for faster red to green iterations



Benefits using IDS process

- Easy to interpret the fatigue results, as most damaging track and time point contributing to it is identified and Equivalent static load case deck generated
- With this automated process, faster design iterations can be performed to identify the hot spots in CAE.
- Inputs and outputs of different software's/solution methods are integrated in common framework called as Integrated Durability Simulation.

Conclusion

- Conventional method of doing dynamic fatigue simulations is replaced with integrated durability simulation (IDS) for faster design convergence.
- Using this approach, the complete process from load synthesis, fatigue analysis, design improvement deck creation to report generation is automated in CAE simulation.
- IDS process is robust, and quality of simulation improves as there is no human interference during the simulation process.
- With this automated simulation process, time for performing design iterations is reduced. With reduced time required, cost incurred on manpower for a particular project will be lesser.
- Equivalent static load case deck generated from IDS simulation can be used for optimization. Faster design convergences can be achieved and validated for weight reduction, material changes, size and shape change proposals.
- Good correlation for dynamic strains and fatigue failure locations is demonstrated with this new real world and robust approach.

Questions…

Mahindra
Rise.