The Development of the new XJ Jaguar in Advanced Aluminium; Opportunities and Challenges

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- Design considerations
- Safety considerations
- Models database creation
- Conclusions
The XJ Saloon

- Flagship Jaguar, essence of the brand
- Over 800,000 sold - over half of all Jaguars ever made
- Seventh generation XJ since 1968

34 Years of the Jaguar XJ Saloon

XJ Series I
1968-73

XJ Series II
1973-79

XJ Series III
1979-86

XJ 40
1986-94

X300
1994-1997

X308
1997-2002
New XJ LWV Targets

- 40% body weight saving for complete body and increase torsional stiffness.
- Meet world safety standards
- Ease of repair. Bolt-on front end for low speed damage repair
- Improved performance, economy, emissions
- Enhanced feature specification
- Improved interior/ luggage space.
- Durability to be at least as good as steel

New XJ Delivers

- 40% body weight saving - 60% increase in stiffness
- Up to 200kg reduction in vehicle weight (3.0 v 3.2)
- Excellent safety and corrosion performance
- Reduced cost of ownership with competitive insurance ratings
- Improved performance, economy, emissions
- Improved headroom, legroom, luggage space
- Instantly recognisable Jaguar design
- Acknowledged Jaguar ride & handling balance
Gauge Reduction Rationale

Basic equation to convert steel gauge to aluminium gauge:

\[ \text{Gauge}_{Al} = \frac{1}{3} \left( \frac{\text{Gauge}_{St}}{t} \right)^3 \]

Conversion results in stiffness match between steel & aluminium

<table>
<thead>
<tr>
<th>Steel gauge</th>
<th>Al. Gauge</th>
<th>% Weight Save</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.75 mm</td>
<td>1.08 mm</td>
<td>52%</td>
</tr>
<tr>
<td>1.00 mm</td>
<td>1.44 mm</td>
<td>52%</td>
</tr>
<tr>
<td>1.20 mm</td>
<td>1.73 mm</td>
<td>52%</td>
</tr>
</tbody>
</table>

Multiply by 1.48 for aluminium gauge (for thin sheet bending stiffness)
Structural Panel Development

- Aluminium design & stamping guidelines used on all parts.

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Structural Castings

- Castings selected in key areas for:-
  - Complex geometry - unfeasible as stamped parts
  - Local stiffness in high load input areas
  - Improve part integration
  - Reduce tooling investment
  - Reduce multiple sheet stack-up issues
  - Self pierce rivet joining to other parts
Exterior Panel Development

- Extensive use of CAE & development die program to validate style
- Spring back compensation major issue with aluminium
**Extrusions**

- Extrusions selected in key areas for:—
  - Weight save & reduced part count
  - Reduced tooling investment
  - High strength applications
  - Ability to form simple shapes/profiles

- Application includes:—
  - Cant Rails, Bumper Beams,
    Side Impact Beams, Door Frames
  & Crush cans

- **Material selected**
  6063-T6, 6060, 6082, 7108-T6

**Door Assembly**

Hybrid of aluminium grades, processes
and joining technologies

**Sheet Material**
- Outer AA6111-T4
- Inner AA5754-H0

**AA6060 Extrusion**
- Upper Frame
- Waist Rail
- Side Impact Beam

**Die Casting C446**
- Hinge Reinf. Panel

- MIG welding
- Rivets
- Adhesive

<table>
<thead>
<tr>
<th></th>
<th>Equivalent steel</th>
<th>XJ alu hybrid</th>
<th>Weight saved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Door</td>
<td>19Kg</td>
<td>10.48Kg</td>
<td>45%</td>
</tr>
<tr>
<td>Rear Door</td>
<td>15Kg</td>
<td>8.72Kg</td>
<td>42%</td>
</tr>
</tbody>
</table>

Equivalent steel to aluminium hybrid

XJ alu hybrid to steel
Henrob Self-Piercing Rivets

- SPRs selected as the best joining technology for the LWV structure:
  - Preferred joining technology of the aircraft industry
  - Increased performance versus welding
  - Cold joining process – no heat distortion of parts
  - Material thickness & stack-up combinations
  - Compatible with adhesive bonding process

Riveting Process Simulation

New Jaguar XJ - the world’s first volume riv-bonded monocoque vehicle
Adhesive Bonding

- Challenge was to find the best joining technology for the LWV structure:
  - FEA used to select optimum joints for adhesive bonding
  - Enhances Strength, Durability & Stiffness - selective bonding
  - Single part heat curing epoxy
  - Pumpable paste applied in BIW assembly
  - Compatible with PT2 surface pre-treatment & AL070 stamping lubricant

Riv-Bonding Rationale

<table>
<thead>
<tr>
<th>Material</th>
<th>Pull Strength</th>
<th>Vibration (fatigue)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spot welded steel (1.2 mm CR2)</td>
<td>74 Kg</td>
<td>12 Kg</td>
</tr>
<tr>
<td>Spot welded aluminium (2.0 mm 5754-0)</td>
<td>78 Kg</td>
<td>5 Kg</td>
</tr>
<tr>
<td>Riveted aluminium (2.0 mm 5754-0)</td>
<td>215 Kg</td>
<td>17 Kg</td>
</tr>
<tr>
<td>Bonded aluminium (2.0 mm 5754-0)</td>
<td>174 K</td>
<td>62 Kg</td>
</tr>
</tbody>
</table>
New XJ BIW information

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self pierce rivets</td>
<td>3204</td>
</tr>
<tr>
<td>Clinch spots</td>
<td>78</td>
</tr>
<tr>
<td>Structural adhesive (m)</td>
<td>104</td>
</tr>
<tr>
<td>MIG weld (metres)</td>
<td>2</td>
</tr>
<tr>
<td>Weld studs (trim fix)</td>
<td>40</td>
</tr>
<tr>
<td>Weld studs (ground)</td>
<td>26</td>
</tr>
<tr>
<td>Blind rivets</td>
<td>180</td>
</tr>
<tr>
<td>Cast parts</td>
<td>15</td>
</tr>
<tr>
<td>Extruded parts</td>
<td>35</td>
</tr>
<tr>
<td>Stamped parts</td>
<td>284</td>
</tr>
</tbody>
</table>

Panel Repairability

- Worked with insurance organisations to establish repair strategy
- All exterior panels designed to be replaced easily
- Rivet/adhesive repair procedure established
- Equipment & procedures specified
- Repair guidelines established

Green – Bolt On Repair
Yellow – Unstitch & Repair
Red – Main Structure
New XJ Safety Philosophy

- Engineered to be amongst the worlds safest vehicles

- World safety standards Proven via:
  - 1000+ CAE virtual crash tests using 175,000 hrs of computing power
  - 79 full vehicle crash tests

Crash Requirements have formed a 3D array

- By impact configuration
  - Front Impact
  - Side Impact & Side Pole Impact
  - Rear Impact
  - Low speed
  - Others

- By country
  - USA
  - Europe
  - Japan
  - Australia
  - Rest of the world

- By governing body
  - Legislative (pass / fail)
  - Consumer (USNCAP, LINCAP, Euro NCAP, IIHS, Thatcham, GDV)
  - Internal (Corporate Acceptance Criteria)
Crash Structure Simplified

New XJ Restraints System

- A.R.T.S. key elements
  - occupant weight & position sensing
  - dual stage driver & passenger airbags
  - multi-point distributed crash sensing
  - safety belts with pyrotechnic pre-tensioner for all occupant positions
  - fronts safety belts with limiting retractor

- Combined with
  - side curtain & front seat thorax airbags
  - “beltminder”
  - anti-whiplash front seats
Split Hopkinson Bar apparatus

High Speed Crash Performance

CAE accurately predicting and allowing virtual world optimisation of crash performance
High Speed Crash Performance

- Very stable structure delivering excellent occupant protection
  - minimal a pillar deformation (at roof)
  - good door aperture stability
    - all doors openable after crash
  - controlled bulkhead intrusion providing a stable platform for the IP beam;
    - minimising steering column intrusion
    - providing stable deployment of front airbag restraint system
- low toeboard intrusion to minimise lower leg injury
- limited floorpan deformation in seat mounting area
- Delivering controlled occupant kinematics

The New FMVSS208

- Probably the most comprehensive measure to date for all round frontal crash performance, the new FMVSS208 is introduced 2003-06
- Test consists of 25-30 mph belted and unbelted tests into full frontal and angled barriers, plus verification of safe airbag deployment.
- The Jaguar XJ’s crash architecture and ARTS equipment is expected to make this the first passenger car to meet this legislation
Front Impact

Euro NCAP – ODB 64 kph

Vehicle Collapse Mechanisms Using Films and Photos, Post test and Strip Down
New XJ Safety Performance

- New XJ has excelled in Jaguar's internal testing and makes significant strides in safety protection
- Strong aluminium body structure provide excellent occupant protection
- The vehicle includes a comprehensive array of safety technology including Jaguars sophisticated ARTS system
- Low speed performance has resulted in very competitive insurance group ratings ahead of key competitors
- Non derivatised safety features mean all customers benefit from a vehicle engineered to world safety standards

XJ common model

Pre-process
Simulate
Post-process

550000 elements
1600 Parts
3 months to build
2 days to run (4 CPU’s)
Current process

- The model building process is extensive. Engineers spend months building the models for just one vehicle configuration.
- Even with experienced engineers, it take a long time to debug complex models.
- New engineers take a long time to build crash models and even longer time to debug them.
- Storage space needed for every engineer to perform its own analysis.
- Connecting shared components isn’t easy because of design changes.
- Simulation is not as effective as it could be because models take too long to build.
- Quality, cost and stress.

Why we need the new process?

No more Bad supplier models !!!!
Component models from suppliers...

There may be 50+ separate component models from suppliers...

... must be integrated into crash models
Integration needs work from Team C

Error checking
Numbering system
Connection methods
Model organisation

Chance of errors…
Repeat the work for each new release of component model…
Some of these issues also arise with Jaguar-generated component models

Some components go into several models

How to ensure ALL master models are updated when one component gets updated?
Problems of Model Organisation:

- How to achieve reliable system when so many separate components are provided by different suppliers?

- How do we ensure that all the correct component models are chosen for each crash load case?

- How do we ensure that the most recent frozen version of a given component is used in every crash load case?

Target process.. So what does this all mean

Automatic assembly & checking of component models...

Run

Automatic report generation
**Concept**

- Database of “ingredients”: components and other model data
- Entry to database controlled by nominated Jaguar person
- Software can check the models prior to entry to database for conformity to Jaguar system
- Database will contain only checked, error-free models and data

**Database**

<table>
<thead>
<tr>
<th>Control data</th>
<th>General vehicle contact</th>
</tr>
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<tbody>
<tr>
<td>ODB loadcase</td>
<td>Sled velocity</td>
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</table>

**Concept**

Supplier

Automatic check – conform to Jaguar system?

- Yes
- No

Yes

No

System can be used to allow only correct models into the database

**Database**

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Concept

Supplier

System can be used to allow only correct models into the database

Automatic check – conform to Jaguar system?

Yes

Yes

Database

Control data

General vehicle contact

ODB loadcase

Sled velocity

Concept

• Combination of components and other data automatically picked from database using a pre-defined TEMPLATE (e.g. LHD Cockpit ODB with Intrusion)
Concept

- Different loadcases from different templates (e.g. Dummy+seat+belt test)
- The correct connections between components are automatically selected

Example – selecting components from the database

Component models in database are presented graphically, in a hierarchical tree structure.
Users can click to select each component…
…or use a ready-made template containing the correct pattern of ticks for each loadcase
Benefits of new process

Because the errors are easily identified and corrected in the new system, we could quickly fix them. All green means OK.

Even the X600 model showed up lots of errors (red boxes), and departures from Jaguar’s preferred methods (orange), when first run through this new system...

Investigating errors – contact penetrations

Because the errors are easily identified and corrected in the new system, we could quickly fix them. All green means OK.

Models are automatically checked against Jaguar guidelines. They can be returned to the supplier if they do not comply.

In this example, interference between airbag and steering wheel infringes Jaguar guidelines and will cause errors and wasted time if allowed to pass undetected.
Result: ready-to-run, error-free model

Installing a component model

All these items can be edited at any time using this method
Checking the component models

This means that the component model has not yet been saved into the database (because we haven’t finished checking it yet) – don’t worry.

No missing items inside the component model.

No problems with numbering.

Don’t worry – connections to other components have been deleted.

Checking the component models

If the model check shows any errors, EITHER reject the component model OR investigate the errors and decide if they are acceptable. Some “errors” identified by Primer don’t cause problems for LS-DYNA.
Investigating errors – element quality check

Elements failing the quality checks shown in white (NB checks are not applied to rigid elements)

Investigating errors – contact penetrations

Use these buttons to draw the penetrations and crossed edges

Summary of errors in each contact
Investigating errors – contact penetrations

Automatic post-processing

- Report generated automatically from LS-DYNA results
- Same report template easily applied to different models
- All Euro-NCAP injury measures are calculated
- Writes report in web-ready or printable format
- Next slides show example pages
Data for traceability (e.g. version of LS-DYNA, any errors reported during the run) are taken from the output files.

**Conclusions**

- We chose the lightweight vehicle architecture for the New XJ not because it was new, but because it would help us deliver significant benefits for our customers.
- *Ls_Dyna* was effectively used for the new XJ car from concept to production.
- Opportunities was identified for further *LS_DYNA* development to models complexities such as:
  - Structure: casting, rivets, adhesive, material failures
  - Restraints: airbags, seatbelts, Composite materials.
- More automation is needed in producing high standards models so that engineer could concentrate in helping design than debugging models.