Excavator chassis stiffness

Early design risk and cost management

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Determination of operational envelope – with certainty

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Reference : chassis20100219v1.0

1.1 Forward

This article is not meant as a design guide but as an informative and interesting insight ONLY.

The article is not meant to be 'watertight' and may be amended without any notice.

Oxford Analysis Consultants are presenting some of their capability in this article.

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1.2 Abstract

Variability management must form part of a design. Some variability can be controlled and some cannot; but all variability needs to be considered in order to create a robust design. This must be done as early in the design process as possible. The earlier this is done the cheaper it is. The cost of testing and failing a detailed design is expensive and increases with project maturity.

The objective of producing high level analytical models with uncertainty built in is to meet the required minimum performance envelope with certainty or with better quantified risk.

A typical four wheeled excavator arm, when loaded, has a maximum permitted operating radius. This maximum radius must be affected by the angle the arm is to the vehicle centreline; an arm extending along the longer vehicle axis is likely to cope with higher loads.

The safe operation envelope of the vehicle is defined by many factors possibly dominated by vehicle mass and centre of gravity. However, the chassis of the vehicle has bending and torsional stiffnesses and the chassis is supported by tyres and suspension components with their own stiffness characteristics. Additionally, the ground has stiffness and shape and the suspension components' stiffness characteristics may be affected by variable environmental conditions; for example, altitude for gas pressurised systems.

For the purposes of this article, a definition of safe operation could be the load value and position that causes the reaction of any single [or more] wheel to fall to zero. Other structural considerations may further limit the operational envelope. For example; a load at a position that causes a suspension unit or structural member to become overloaded.

This article begins to explore a method whereby the effect of chassis and suspension stiffness variation on safe operational envelope can be determined given the definition of failure is the position that causes the reaction of a any single wheel fall to zero for a specified load.

The generic method discussed is not limited to four wheeled vehicles.

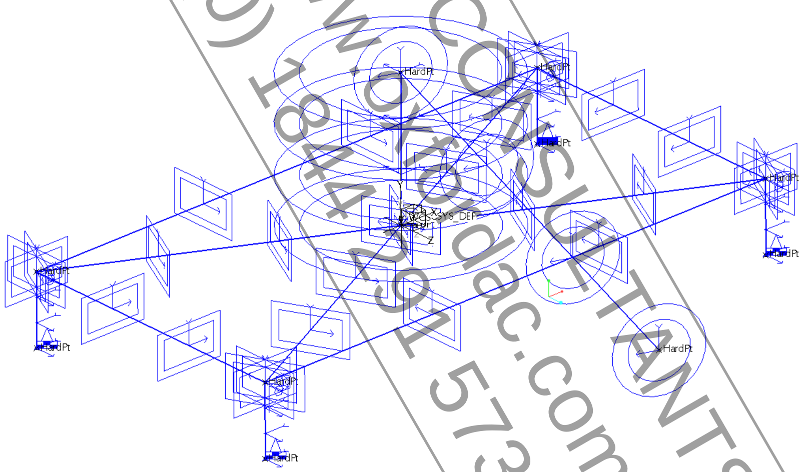
Tools such as design of experiments (Taguchi Methods) could be employed to determine variables that have the greatest impact on performance and thus help direct development effort, reduce risk and therefore reduce cost.

1.3 High level methodology

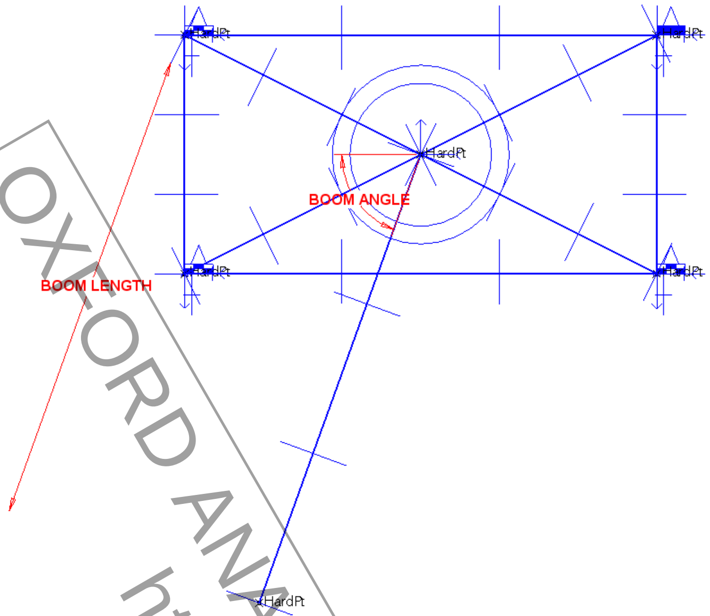
The model developed needed to deal with uncertainty regarding the actual real structure, suspension behaviour and variable environment. The implication was that in order to characterise the systems' safe envelope a number of experiments would need to be performed in the virtual environment.

The performance of a chassis was determined from a solid model using finite element analysis. The time to perform the analysis for a single system configuration was satisfactory but was too long to enable a significant number of experiments.

The chassis finite element model was twisted and bent about the two axes parallel to the ground to determine the relevant stiffnesses and the suspension stiffness was estimated. [1] From these stiffness values, a 'stick' beam element model was designed to have the same flexing behaviour as the full solid model. The advantage of this abstraction over a full solid model is speed of analysis with only fractions of a second required for each calculation, enabling thousands of experiments in a reasonable time. The ground was assumed flat; the vehicle level.

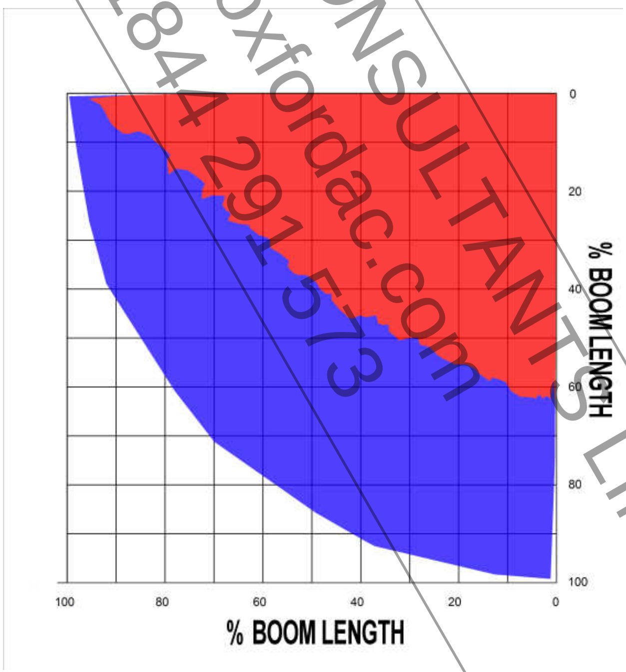


The length of the loaded boom and the angle of the boom to the vehicle centreline were defined as geometry variables. The effective stiffness of the beams representing the suspension and wheels were defined as numerical variables.



For a single value of load, with the chassis under the influence of gravity and consistent suspension stiffness, a large number of experiments were run. For each experiment, a boom operational length and angle (between 0º and 90º) to machine centreline were selected.

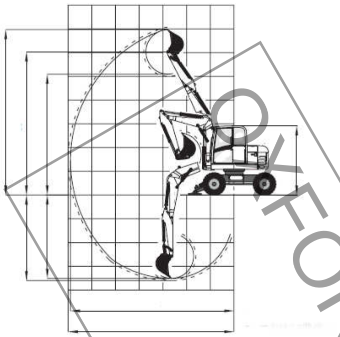
NB. For the purposes of this article, the chassis was made geometrically symmetrical such that only experiments over 90º degrees of boom movement were required.



RED = ALL WHEELS HAVE REACTION WITH THE GROUND

BLUE = AT LEAST ONE WHEEL DEMONSTRATES A NEGATIVE REACTION

It is usual to describe the behaviour of a vehicle as a table indicating the working envelope as follows:



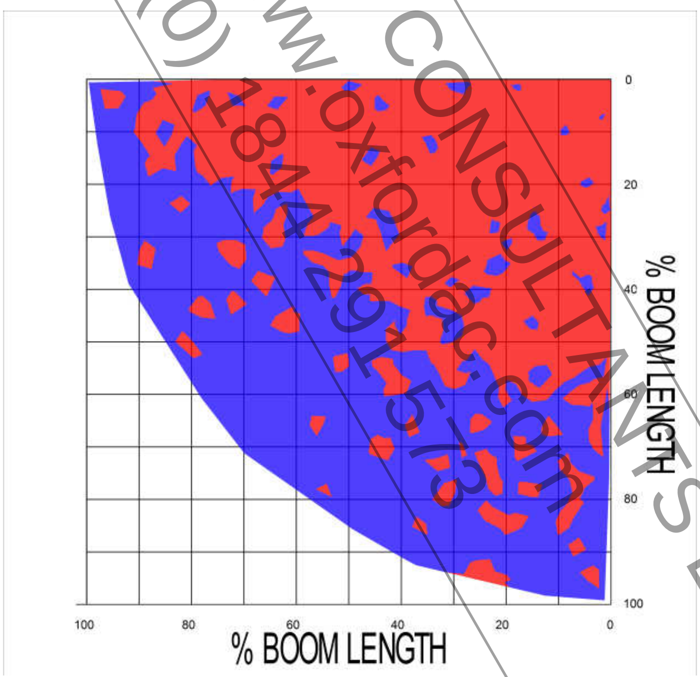
		Load radius from centre of ring gear							
		3m		4m		5m		6m	
		End	Side	End	Side	End	Side	End	Side
3m	S	1.52	1.31	1.3	1.09	1.07	0.89	0.96	0.67
	T	1.48	1.31	1.27	1.09	0.88	0.82	0.68	0.62
1.5m	S	1.79	1.47	1.35	1.16	1.2	0.84	0.96	0.65
	T	1.71	1.47	1.22	1.08	0.84	0.77	0.66	0.6
0m	S	2.4	1.75	1.68	1.14	1.22	0.84	0.94	0.69
	T	1.8	1.61	1.16	1.04	0.84	0.76	0.7	0.64
-0.9m	S	2.37	1.69	1.68	1.1	1.17	0.83	0.9	0.72
	T	1.7	1.56	1.13	1.02	0.83	0.75	0.71	0.67

S = SUPPORTED BY BLADE
T = TRAVELLING

VALUES IN TONS DETERMINED ACCORDING TO ISO 10567 AND INCLUDE A STABILITY FACTOR OF 1.33 OR 87% OF HYDRAULIC LIFTING CAPACITY AND DETERMINED USING A HOOK

1.4 Adding uncertainty

The real environment has variability. To add uncertainty to the performance of this model and thus a probability to the performance envelope, the value of stiffness for each suspension unit at each corner, for each design position was permitted to exist randomly within a range of values. No two suspension points necessarily had the same stiffness value for any experiment, (at any given location of the end of the boom).



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For the purposes of this article the suspension variable ranges were unreasonably wide such that the effects would be visually clear.

The conclusion for this design can only be that it is far from certain that all four wheels are guaranteed to be on the ground or that the working envelope has a crisp edge for specification purposes.

1.5 Brief notes

The contour map in the case where all suspension stiffnesses are constant and invariant should give rise to a smooth contour. The lack of smoothness is due to the graphing tool used. The results for this linear model could be more 'clinically' or methodically produced to give perfect envelope contours; but the purpose of this study was to develop a model that enabled uncertainty to be added.

For the purposes of this article the suspension variable ranges were unreasonably wide such that the effects were clear.

The results presented are not statistical but are absolute experiment results presented based on a PASS (all wheels in contact with the ground) or FAIL (at least one wheel would lift) plot. No experiment is repeated. The results for the model with suspension variability could be presented in a probabilistic manner such that the chances of a wheel lifting for any boom configuration can be presented.

1.6 References

[1] The exercise of estimating the stiffness of the chassis and the reduction of these values to beam element section is itself an interesting process that may be covered later in another article if time permits. The measurement of chassis stiffness in the virtual environment could replicate those physically used in vehicle chassis tests.

1.7 Document history

Date	Revision	Author	Comment
19th Feb 2010	**v1.0**	**Charles Simpson**	**New document**