Robustness Measures in System Engineering

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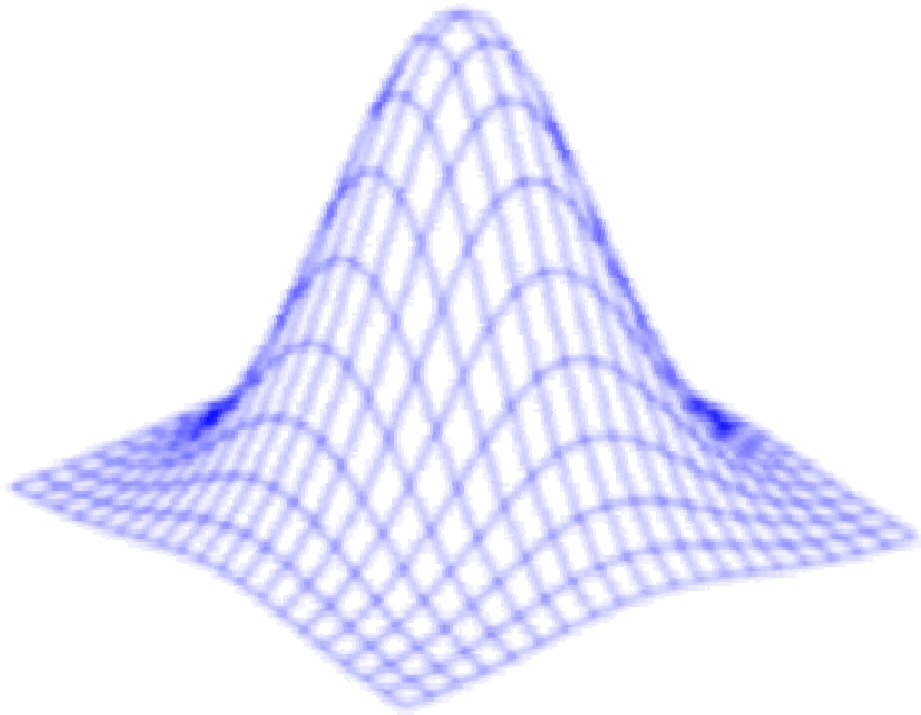


CONTENT

- **What is robustness**
- **Measures of robustness**
- **Sources of non-robustness**

What is a robust system

A system is said to be robust if it performs in an acceptable manner in the face of expected variations in certain parameters, but also in the presence of unexpected variations in other unknown parameters.

Today, a robust system is mistakenly thought to be a system with little scatter in performance.

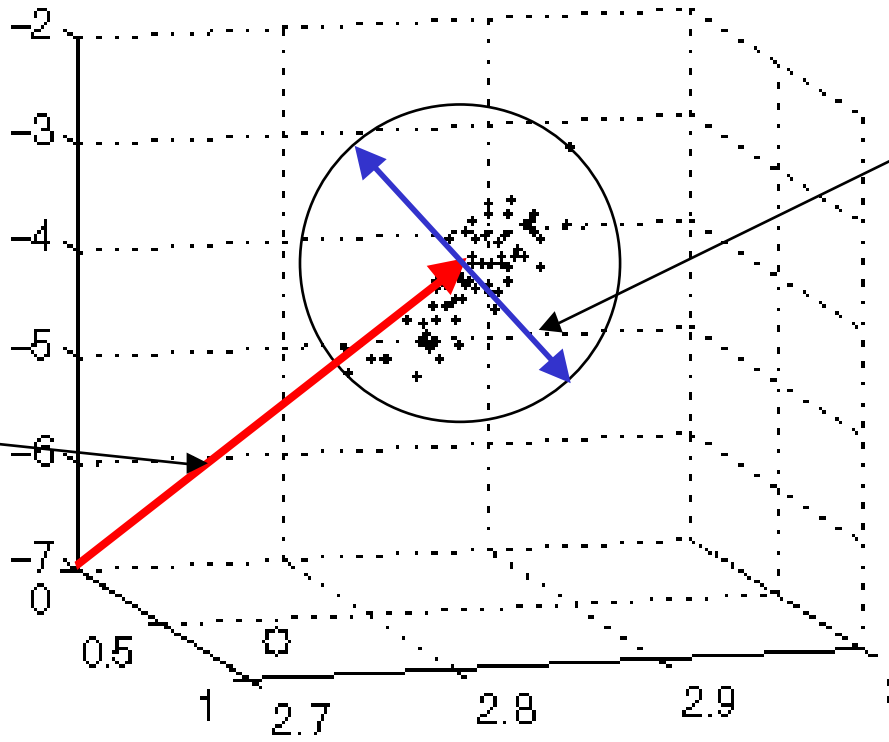
Scatter in performance is a reflection of quality, not robustness.

Measures of robustness

Robustness of a design is reflected in the convexity of the multi-dimensional output response cloud. This is equivalent to:

- Unimodal PDFs of ALL outputs (no clustering)
- No outliers

Performance, quality and robustness



Performance (position of centre of mass of output response cloud)

Quality of production (diameter of response cloud)

Large cloud diameter points to low quality (dispersion). In the figure, axes represent performance quantities.

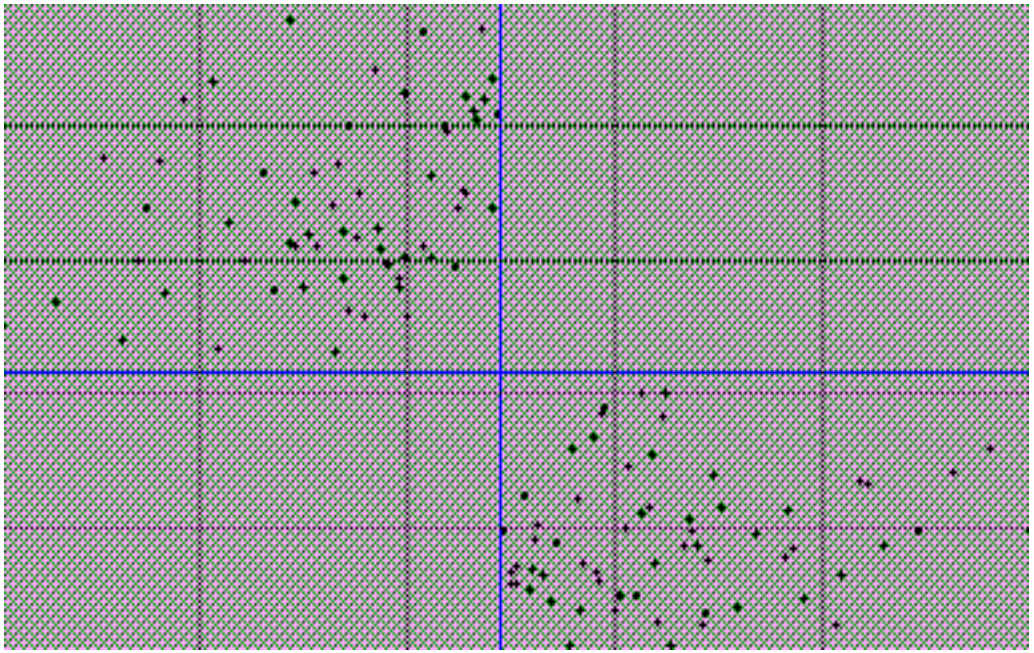
Robustness is reflected in the shape of the cloud, not it's size.

Clustering

Multi-modal PDFs reflect the existence of clusters in the output response cloud. This, in turn, points to bifurcations and is reflected in sudden jumps in the CDF.

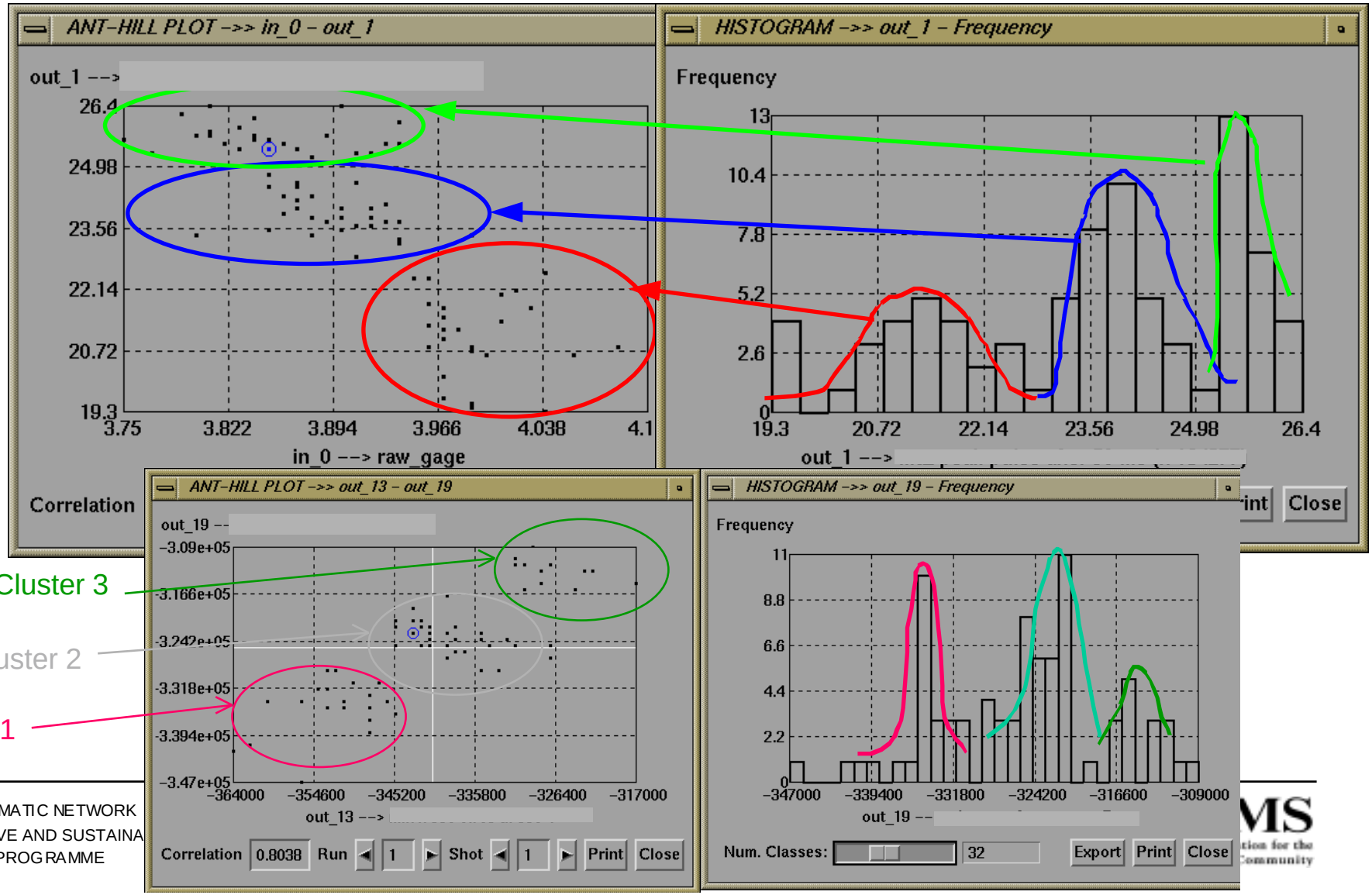
The number of clusters is equal to the number of bifurcations + 1.

Example of non-robust behavior (car crash)

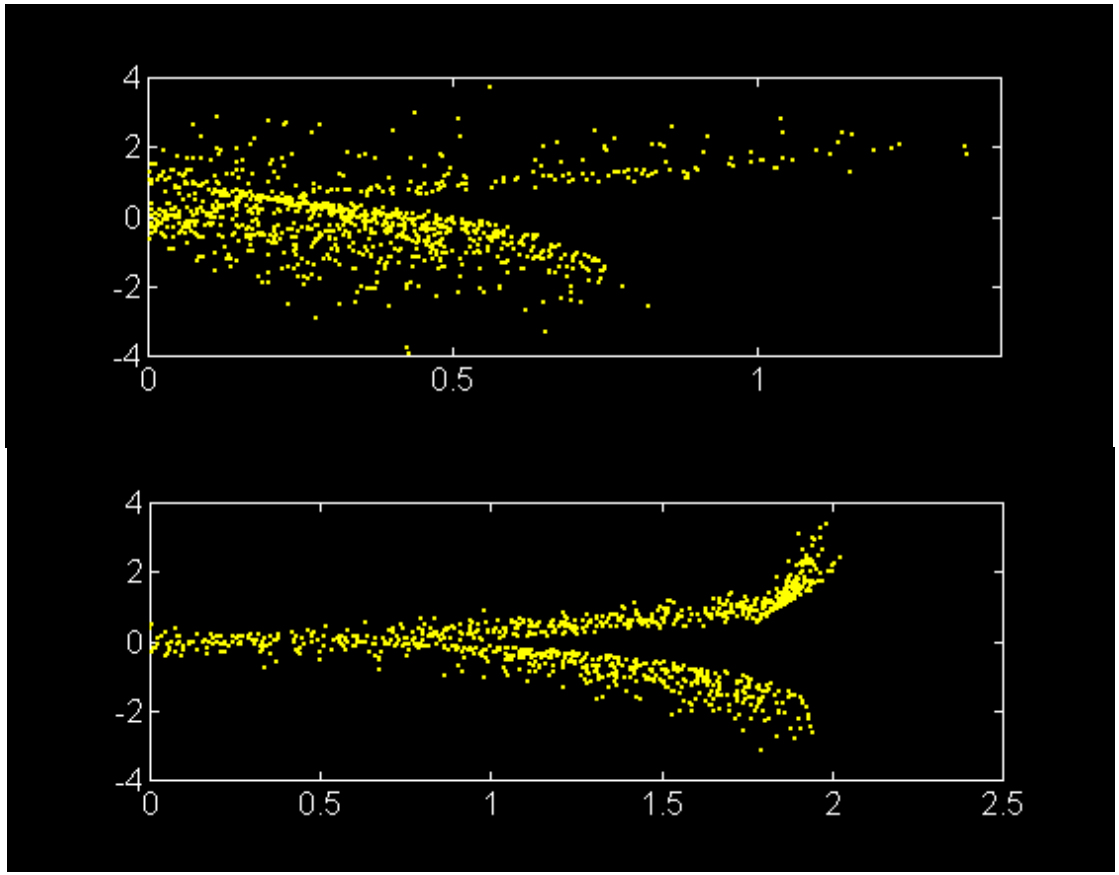


Two clusters, of approximately the same size can be seen. The system can therefore be expected to function in each cluster with a probability of 50%. However, it is a-priori unknown in which cluster the system will be located. The axes correspond to output (performance) quantities.

Clusters, bifurcations and multi-modality



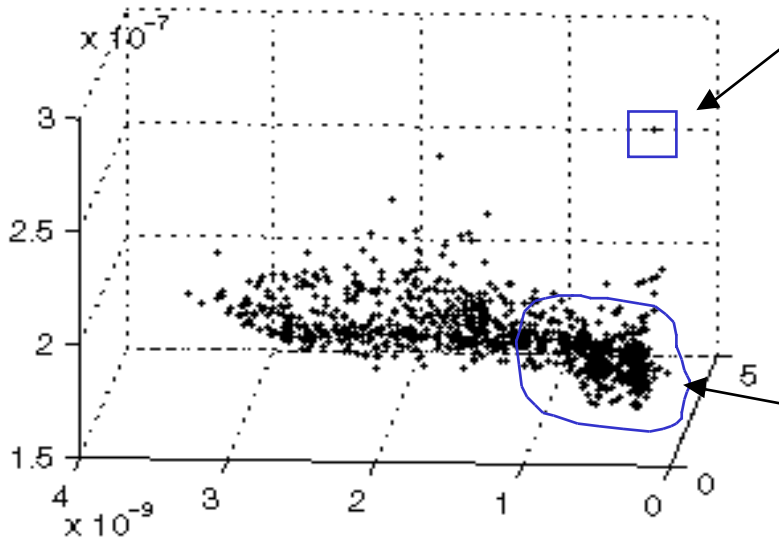
More examples of bifurcations



The horizontal axis is relative to the input (design) variable, the vertical one to performance. In the lower figure, values of input greater than (approximately) 1, lead to two possible states of functioning. This behaviour may or may not be acceptable.

Non-robustness and risk

Essentially, risk is associated with the existence of outliers



Outlier:
- warranty
- recall
- lawsuit

Most likely response (highest density)

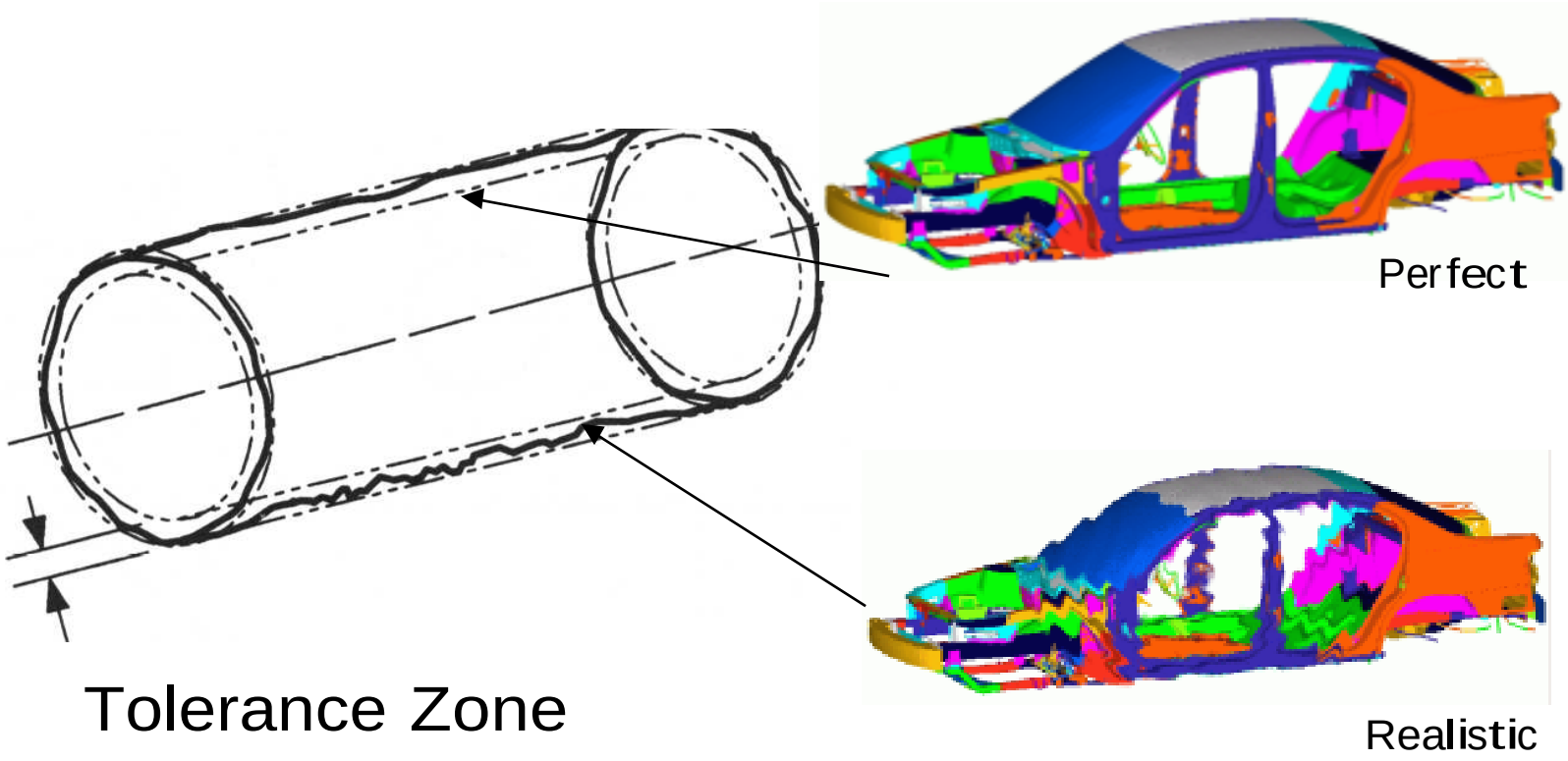
Outliers constitute a very dangerous, often difficult to anticipate form of non-robustness.

What is Risk and Uncertainty Management?

- **Understand and remove outliers**
- **Shift entire distribution (but make it unimodal first!)**

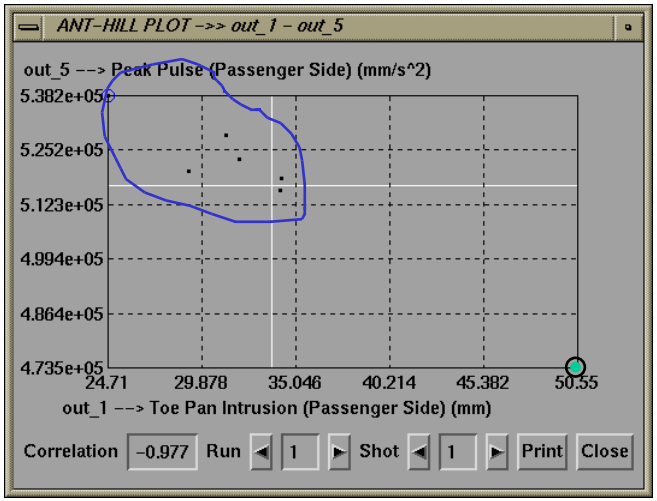
Outliers: unfortunate combinations of operating conditions and design parameters that lead to unexpected behaviour.

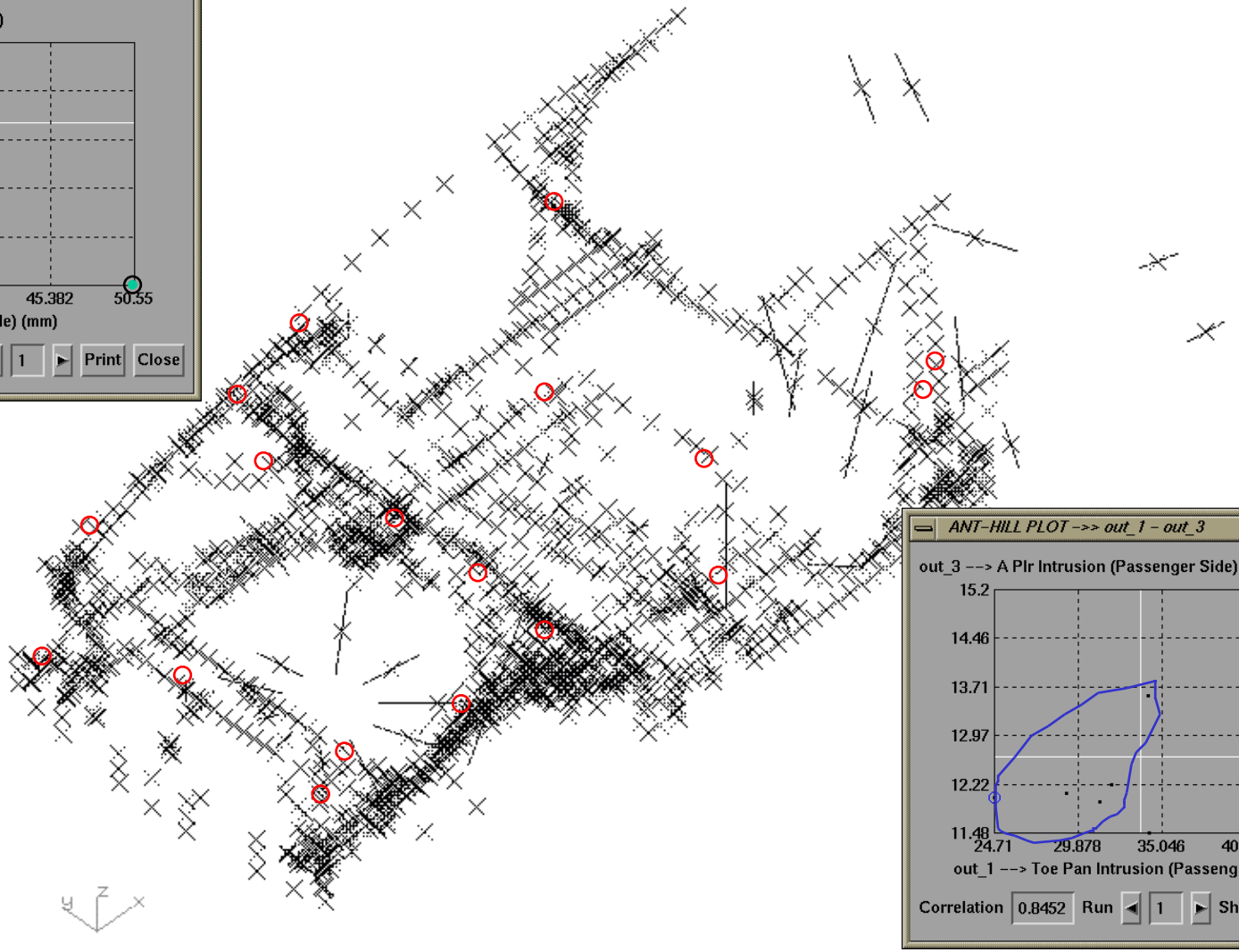
Geometry imperfections as source of non-robustness



The spatial distribution and properties of geometry errors may be described by a stochastic field. Realistic (imperfect) geometries often lead to bifurcations in behaviour (crash, buckling, etc.)

Random weld failure as source of non-robustness





Necessary Steps to achieve Robustness

- **Create realistic simulation models**
- **Use Monte-Carlo Techniques to find**
  - Outliers
  - Bifurcations
- **Find explanations for Non-Robustness**

- **Then: Improve quality and performance of the design**

The ST-ORM Technology

- **ST-ORM** is the first HPC-based simulation software that specifically addresses **complexity and uncertainty management.**
- **ST-ORM** introduces real world tolerances of material, geometry, production process and uncertainties in loading/operational conditions into the virtual model.
- Today, products are designed based on idealized, nominal assumptions. Instead **ST-ORM uses stochastic simulation** to characterize product behavior on a statistical basis.
- Furthermore **ST-ORM** uses the statistical product description to rapidly improve the performance of a product.

Thank you.

Please find further information at

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