Analysis of active vibration reduction systems in helicopters incorporating structural uncertainty

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Vibration palliatives

- Structural modifications to reduce vibration are developed from a unique model. These are not guaranteed to work on all structures as they are optimised for a unique one.
- Active vibration control systems are adaptive and so work better across a family of structures, but are they adaptive enough?
- Given a choice of number and placement of exciters, which combination is best for a family of structures?
- How will the vibration response vary with an active control system in place?

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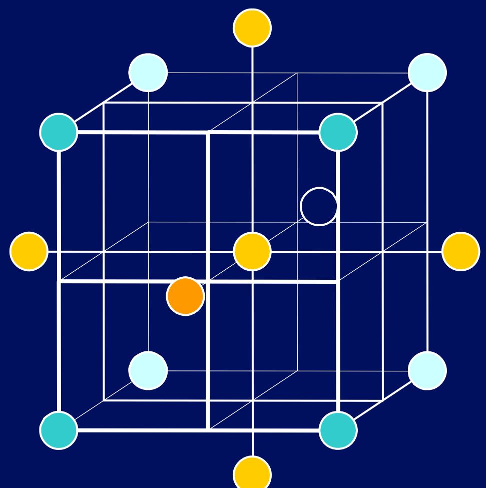
Modelling the variability in dynamics

- Need to take into account variability in loading, materials and manufacturing tolerances.
- Monte-Carlo approach will always work providing we know input variability, but will take a very long time if directly linked with a finite element analysis.
- Replace finite element model with response surface making Monte-Carlo approach practical.
- Model contains active control loop which minimises the vibration for the size and number of actuators available.

Response surface model for eigenvalues and eigenvectors

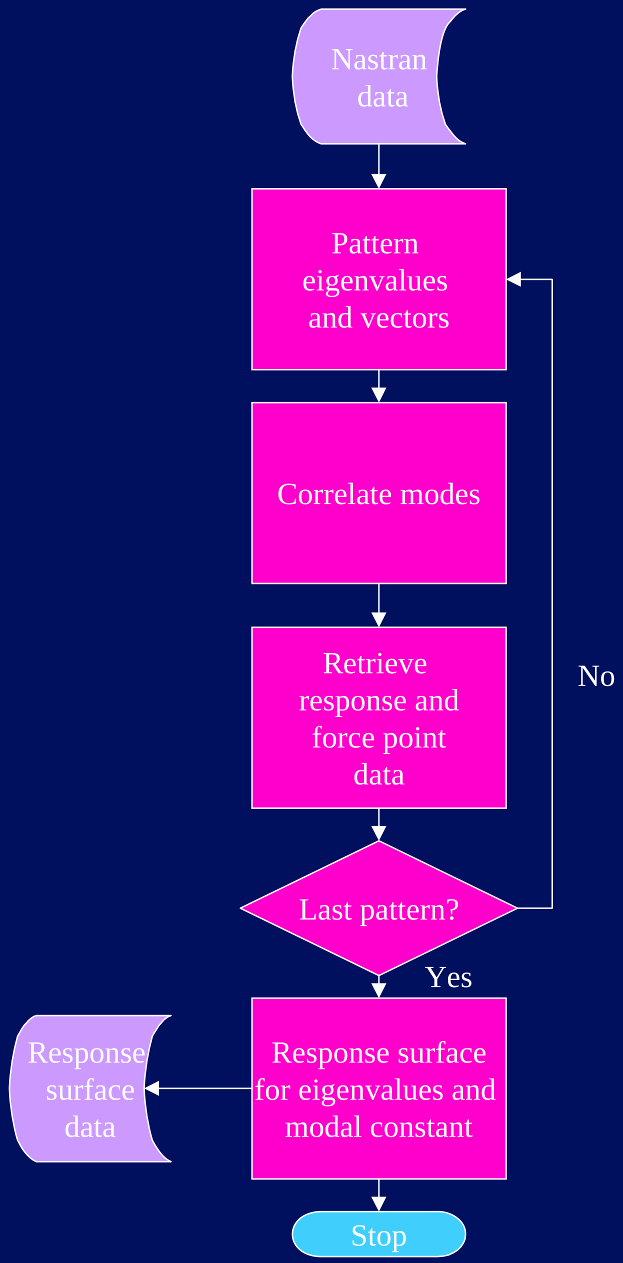
$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i<j}\sum \beta_{ij} x_i x_j + \varepsilon$$

- Response surface model includes quadratic and cross product terms.
- Coefficient solution by least squares approach.



Design variable changes

- Linked to NASTRAN code using MDO features.
- Necessary changes for each experimental design are generated automatically by a specialised application and are easily incorporated in the NASTRAN deck.
- Material property, structural property and geometric changes are allowed.



Response surface calculation

- Fortran executable picks up eigenvalues and vectors from NASTRAN runs.
- Modes are correlated in case order changes.
- Calculates response surface coefficients for specific response points.

Response model

$$u_j = \sum_{i=1}^{n} \frac{\phi_{ij} f_i \left\{ \left(\omega_i^2 - \omega^2 \right) - 2i\omega\omega_i c \right\}}{\left\{ \left(\omega_i^2 - \omega^2 \right)^2 + 4c^2\omega^2\omega_i^2 \right\}}$$

Mode component

Mode eigenvalue

Active control equations

$$U_e = DR_e$$

Response to environmental forces

$$U = D\left(R_e + R_c\right)$$

Response to environmental and control forces

Find control forces to minimise the sum square response

$$F = U'U = R_e{}' D'DR_e + R_c{}' D'DR_c + 2\Re\left(R_e{}' D'DR_c\right)$$

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Force representation

- Environmental forces result from aerodynamic excitation of the rotor. Forces were represented as 6 d.o.f. at rotor head, each with magnitude and phase.
- Control forces were represented in terms of amplitude and phase at each actuator position.
- Control force representation allows constraint to be placed on force magnitude appropriate to chosen actuators.

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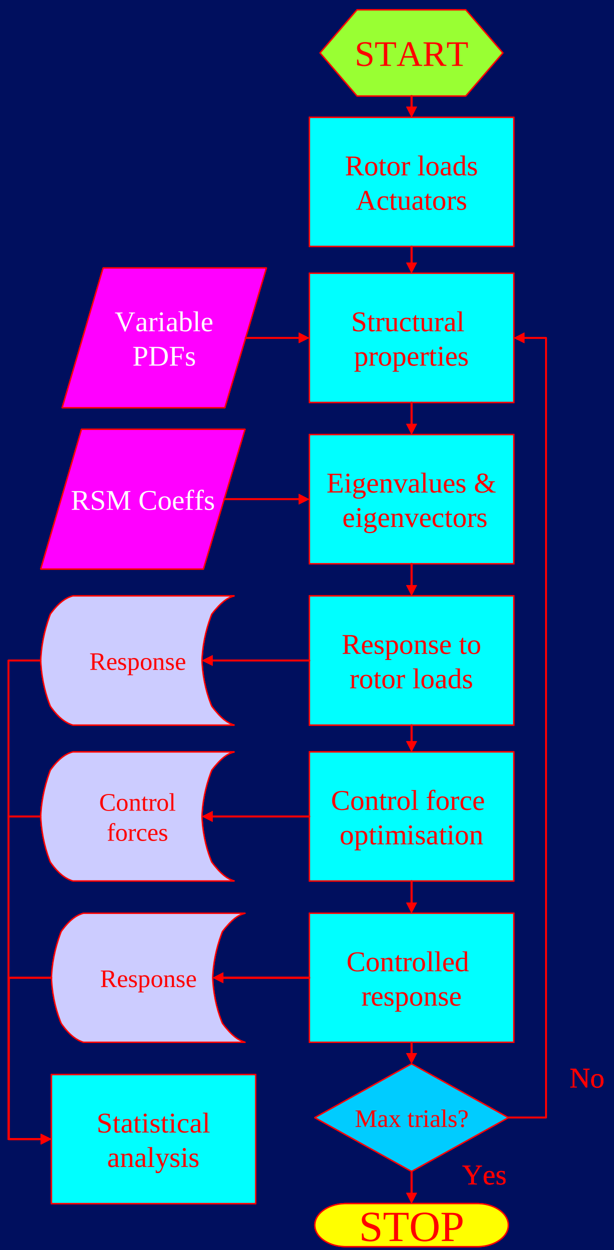
Monte Carlo Analysis



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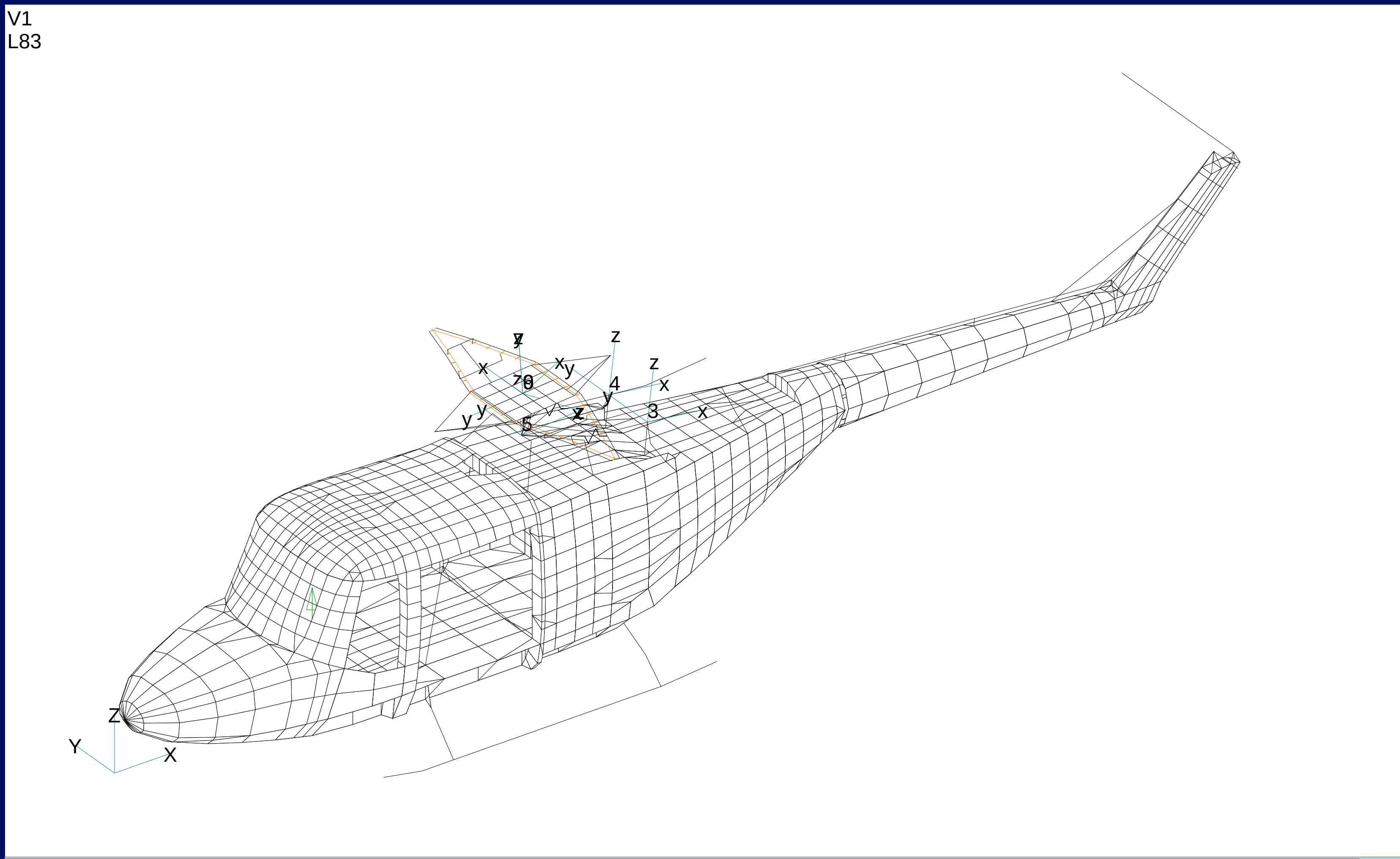
Lynx Prototype Helicopter Model



Lynx pre-production variant

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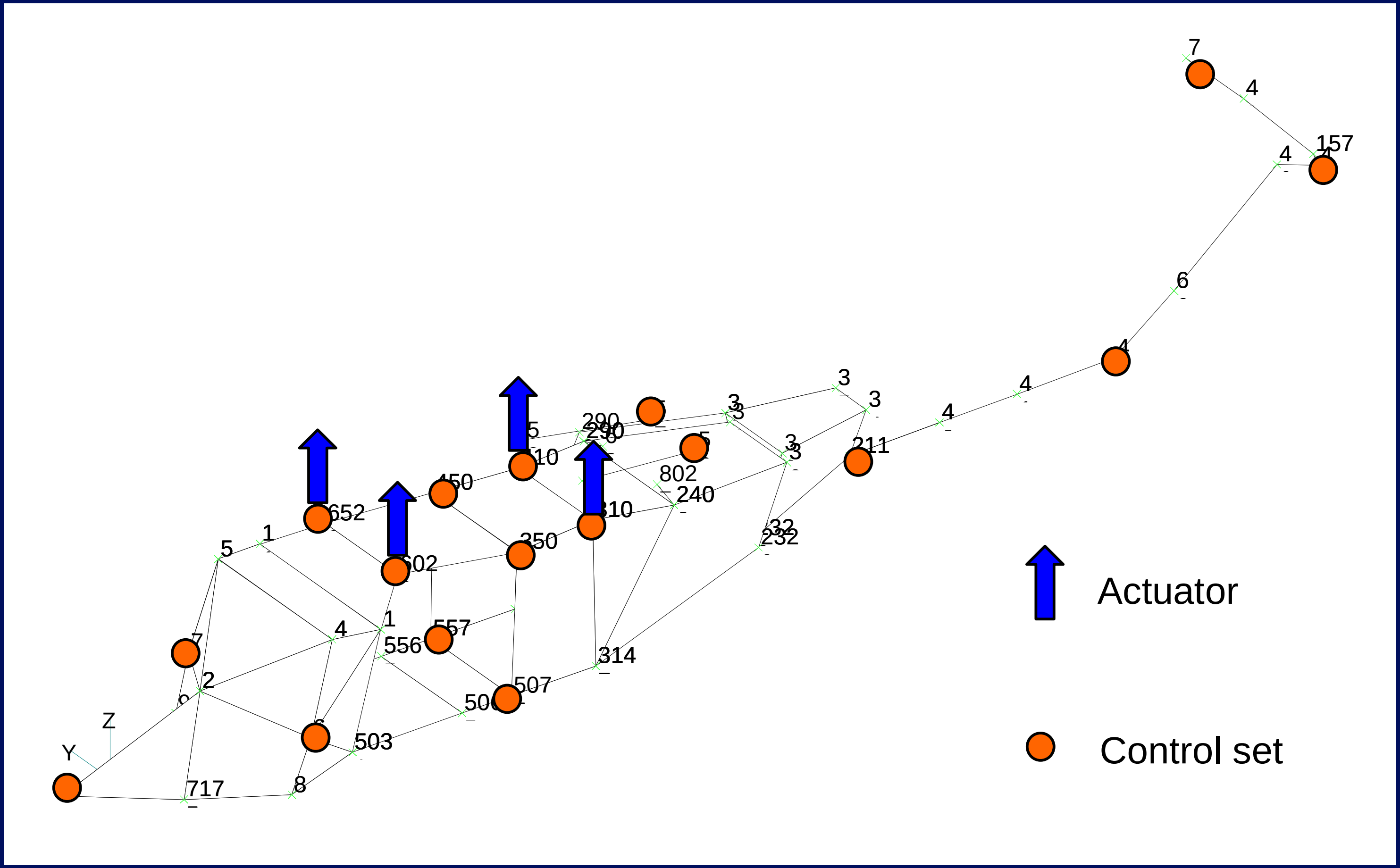
Control points and actuators



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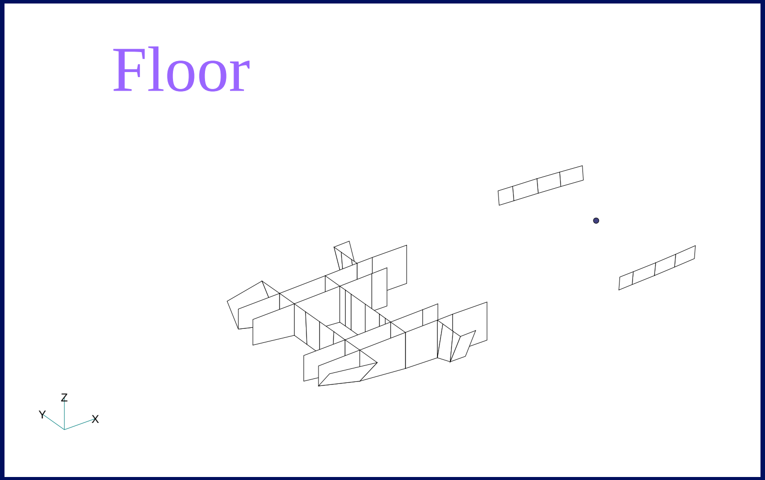
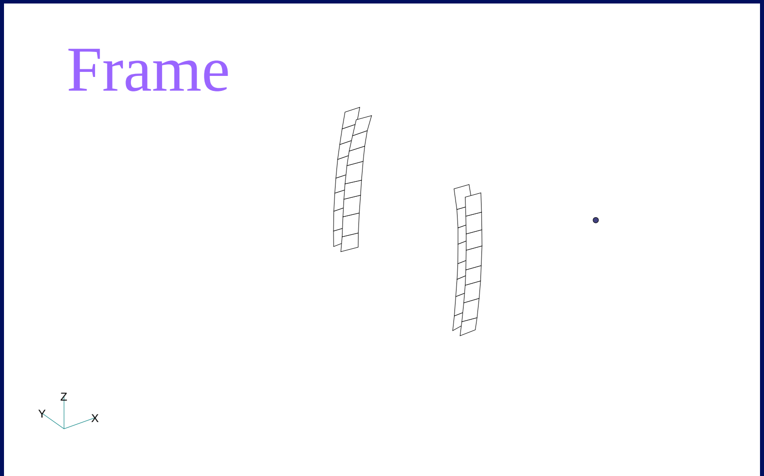
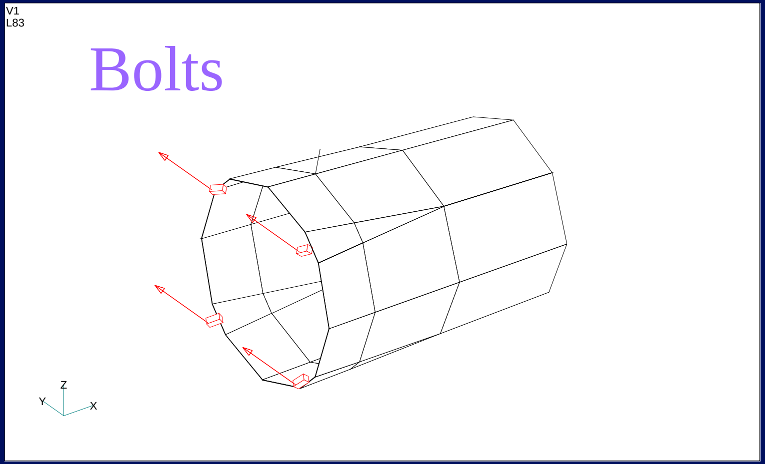
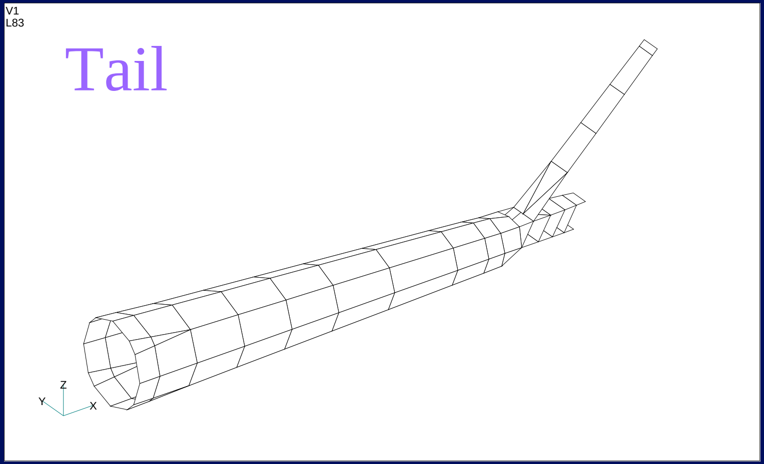
Variables for Lynx exercise









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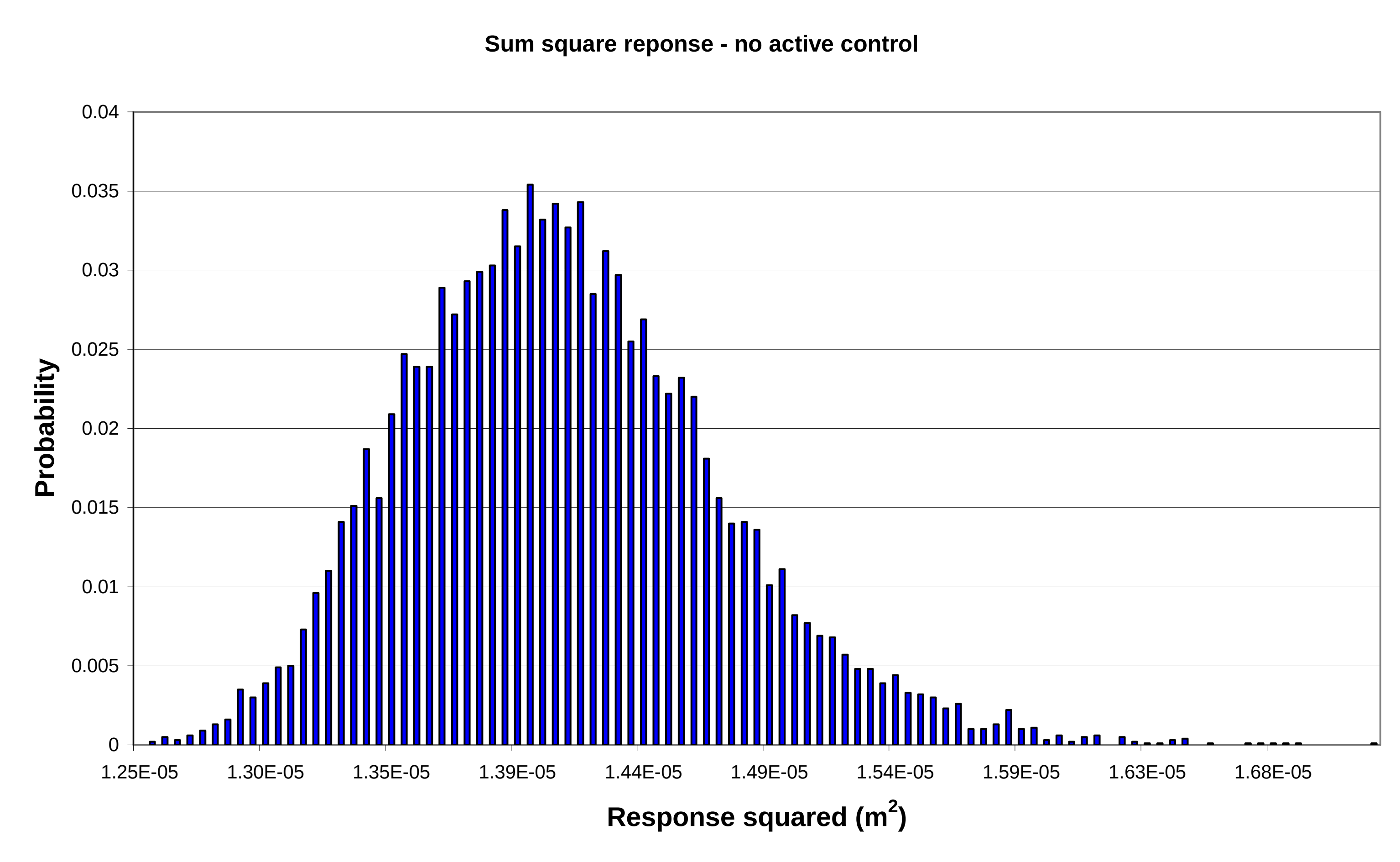
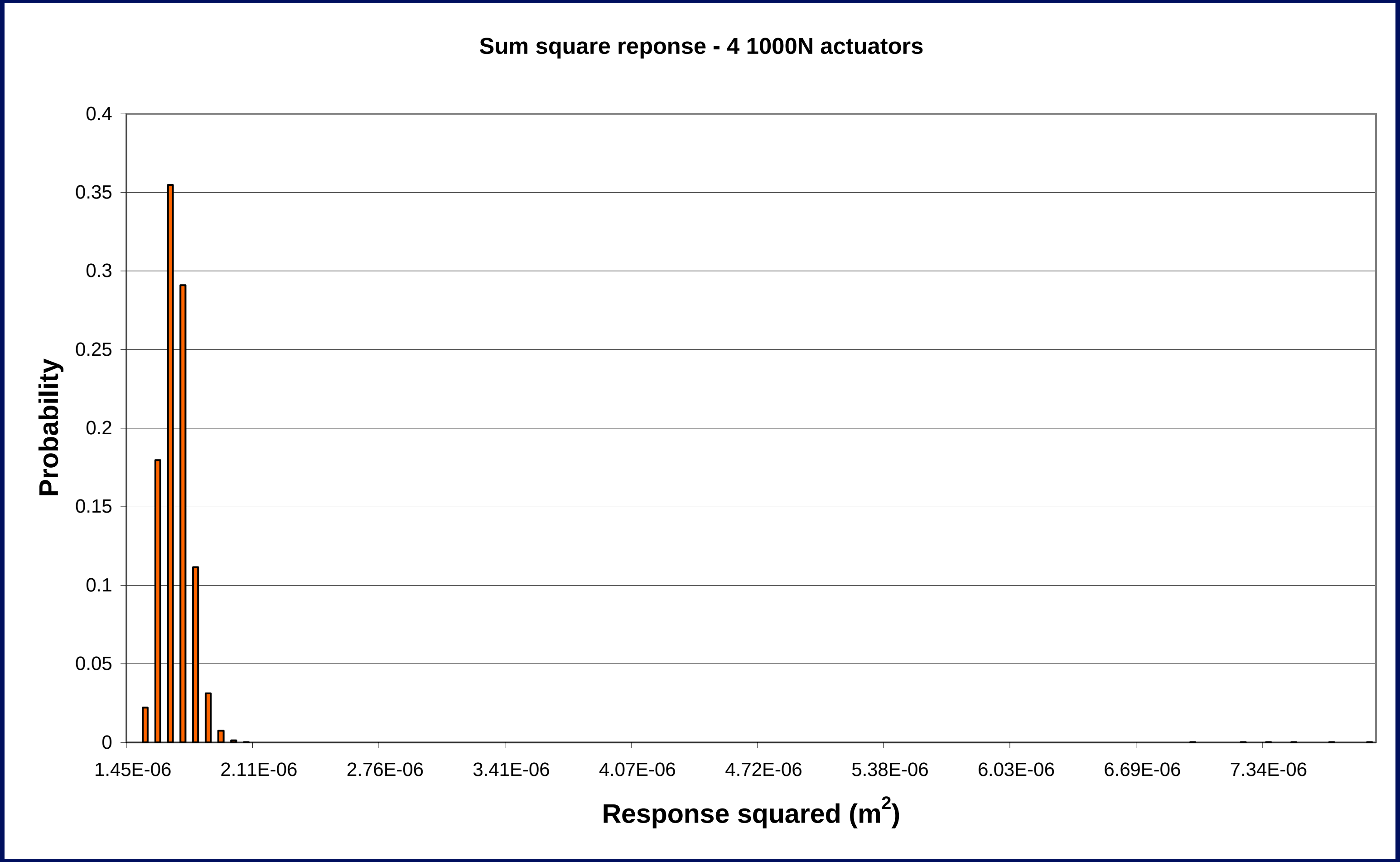
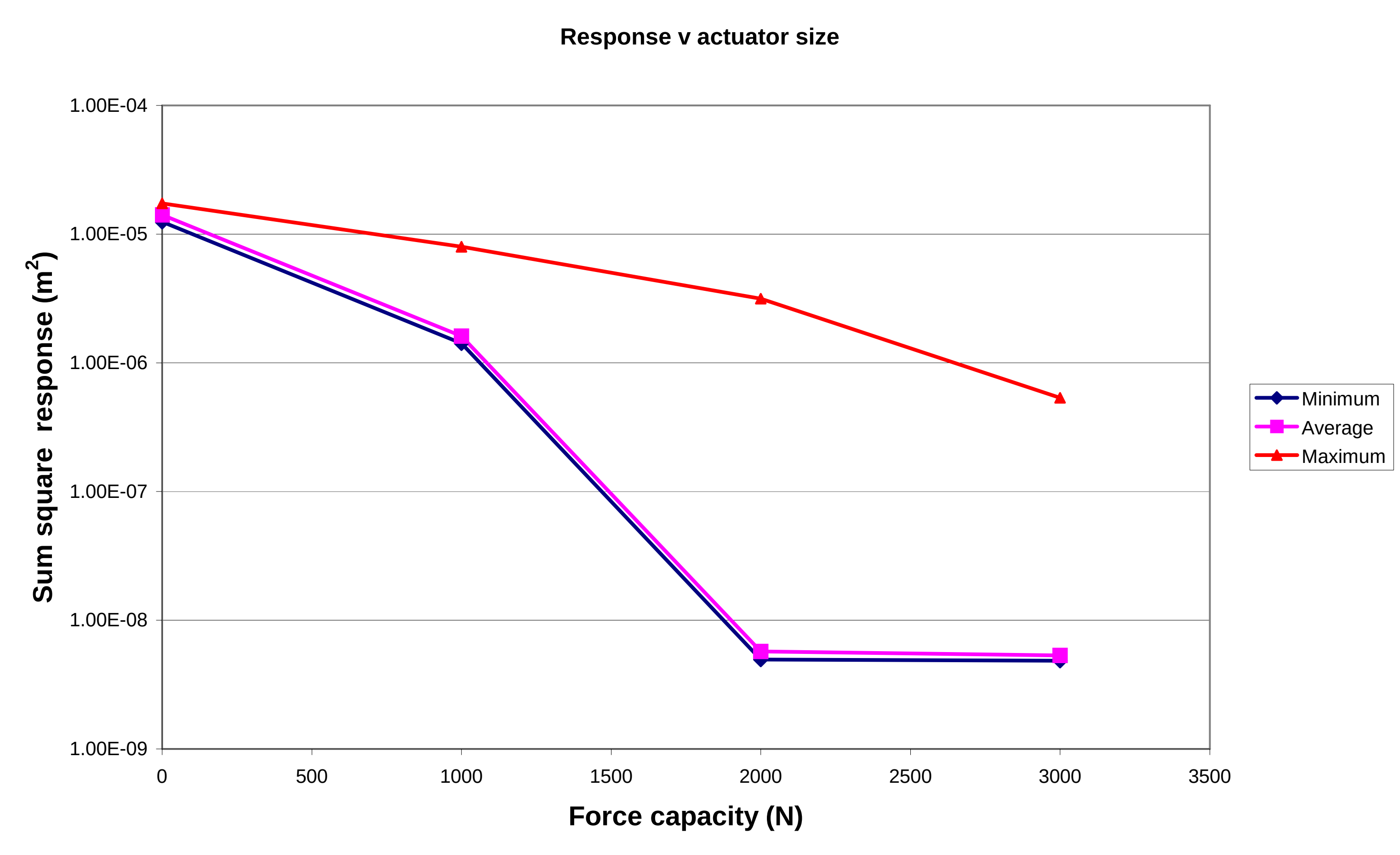
PDF of response – no control



PDF with control – 4 x 1000N actuators



Variation with actuator capacity



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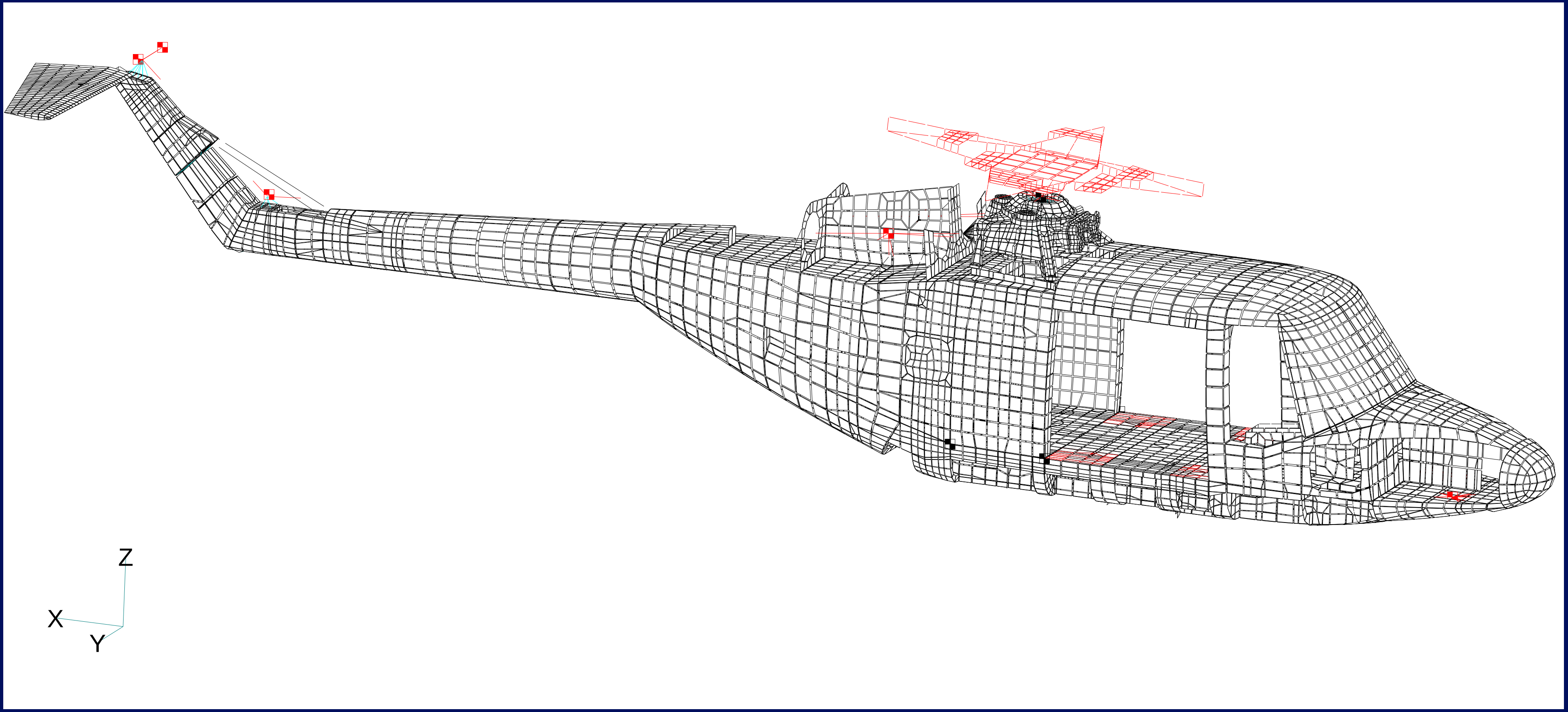
Lynx Mk 7 FE model



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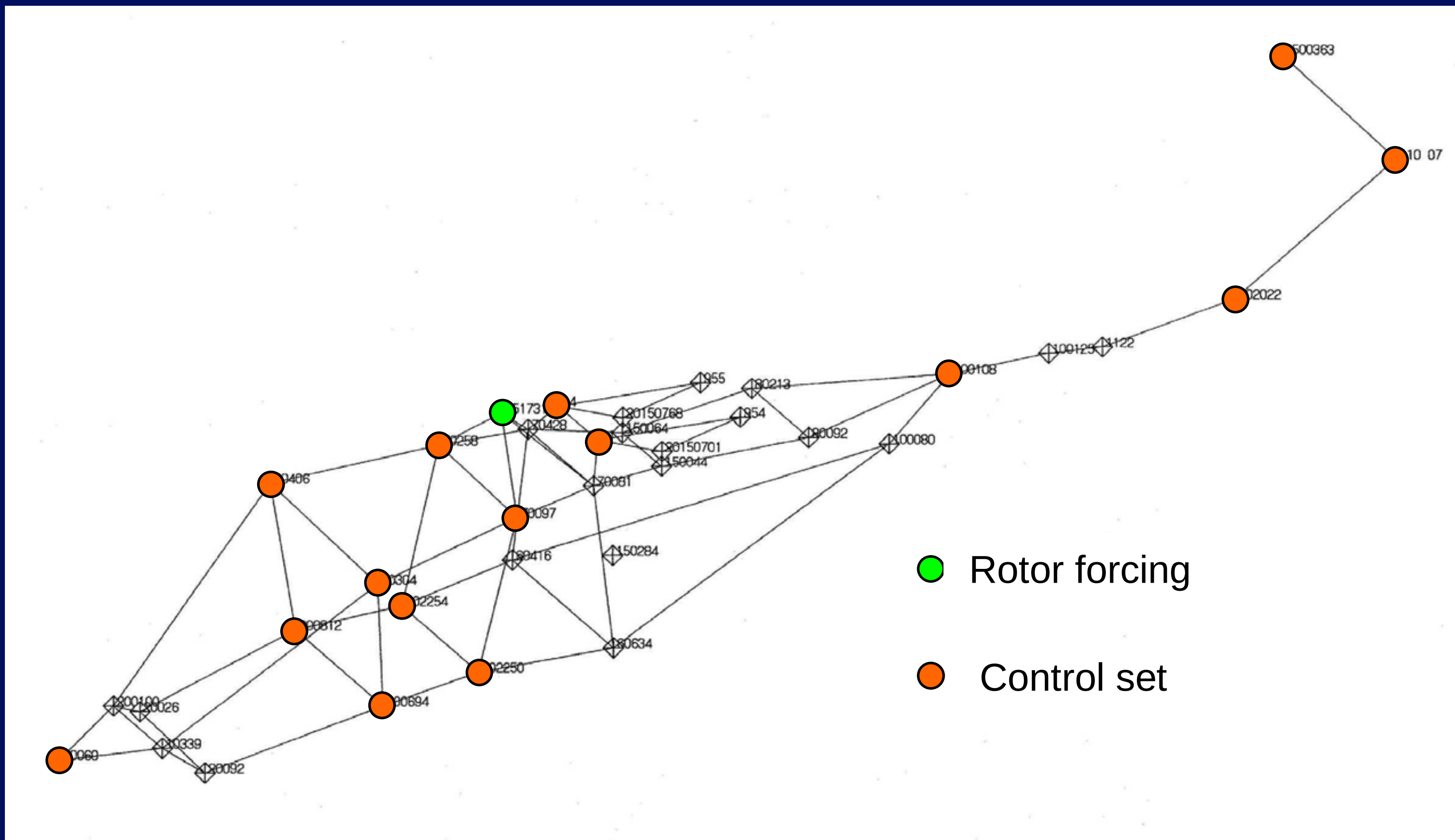
Control set for Lynx Mk 7



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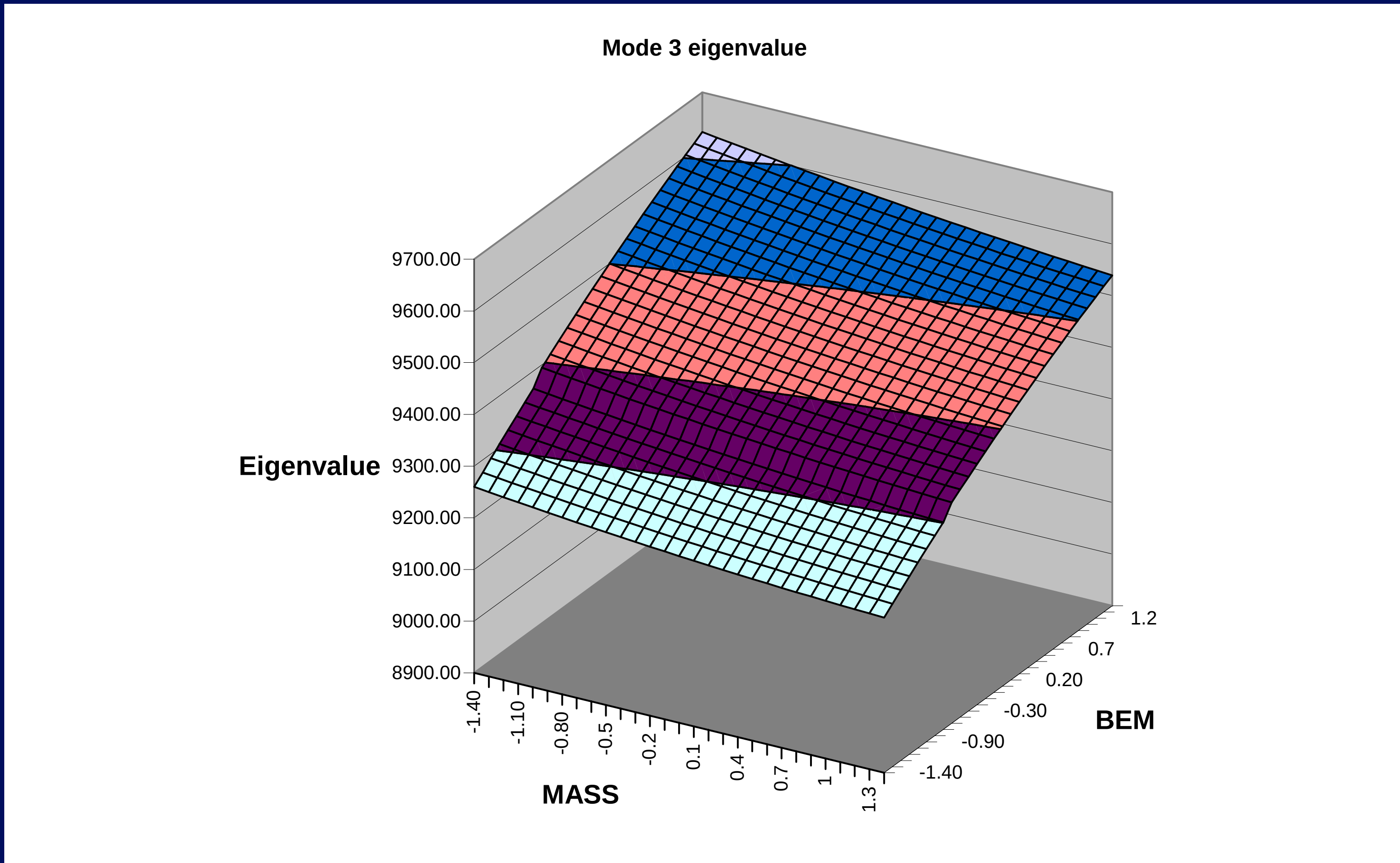
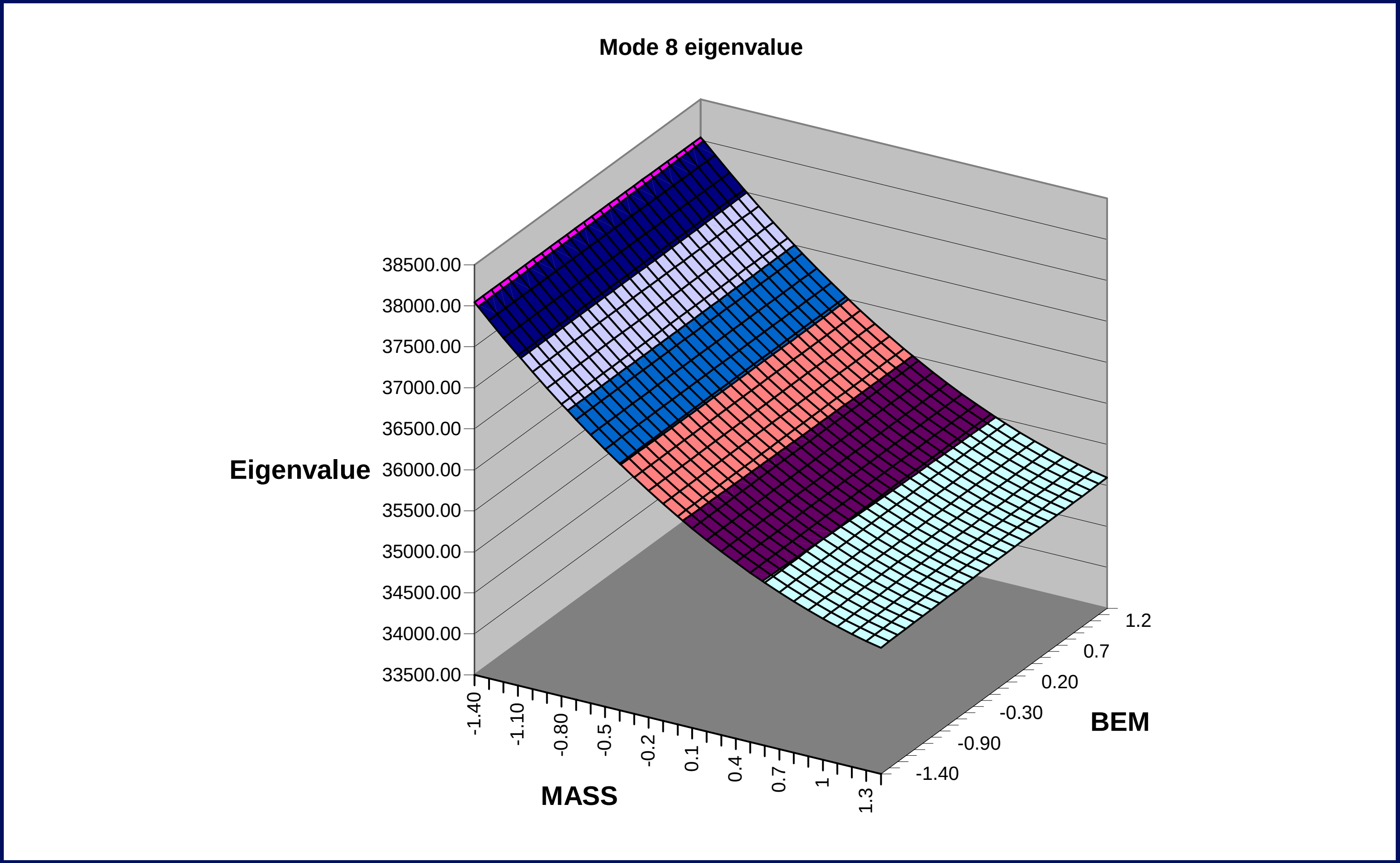
Uncertain properties

- Fuel mass – nominally half full tanks, but allowed to vary between full and empty (MASS).
- Horizontal tailplane attachment stiffness (BEM).

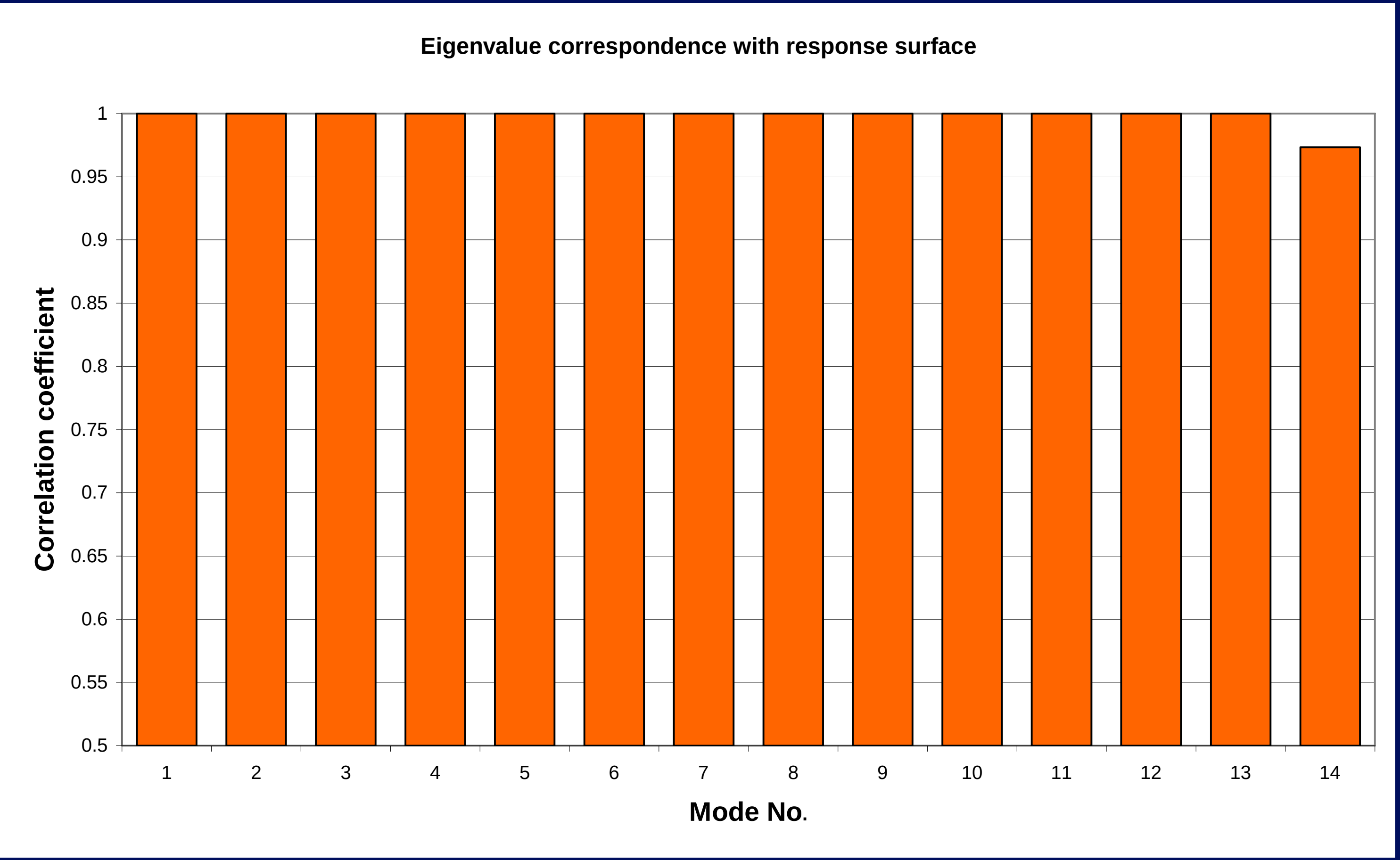
RSM for mode 3



RSM for mode 6



Eigenvalue RSM accuracy



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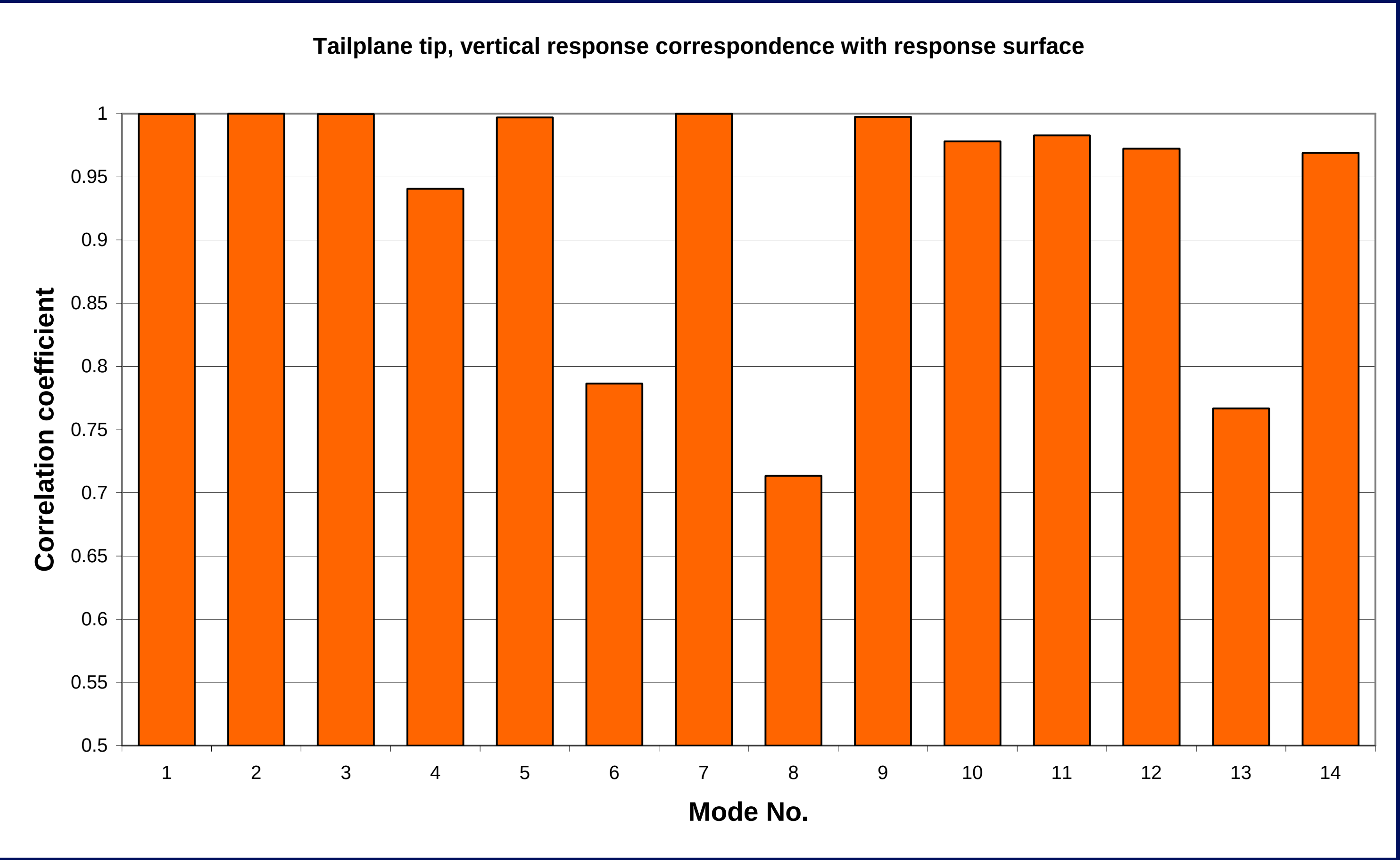
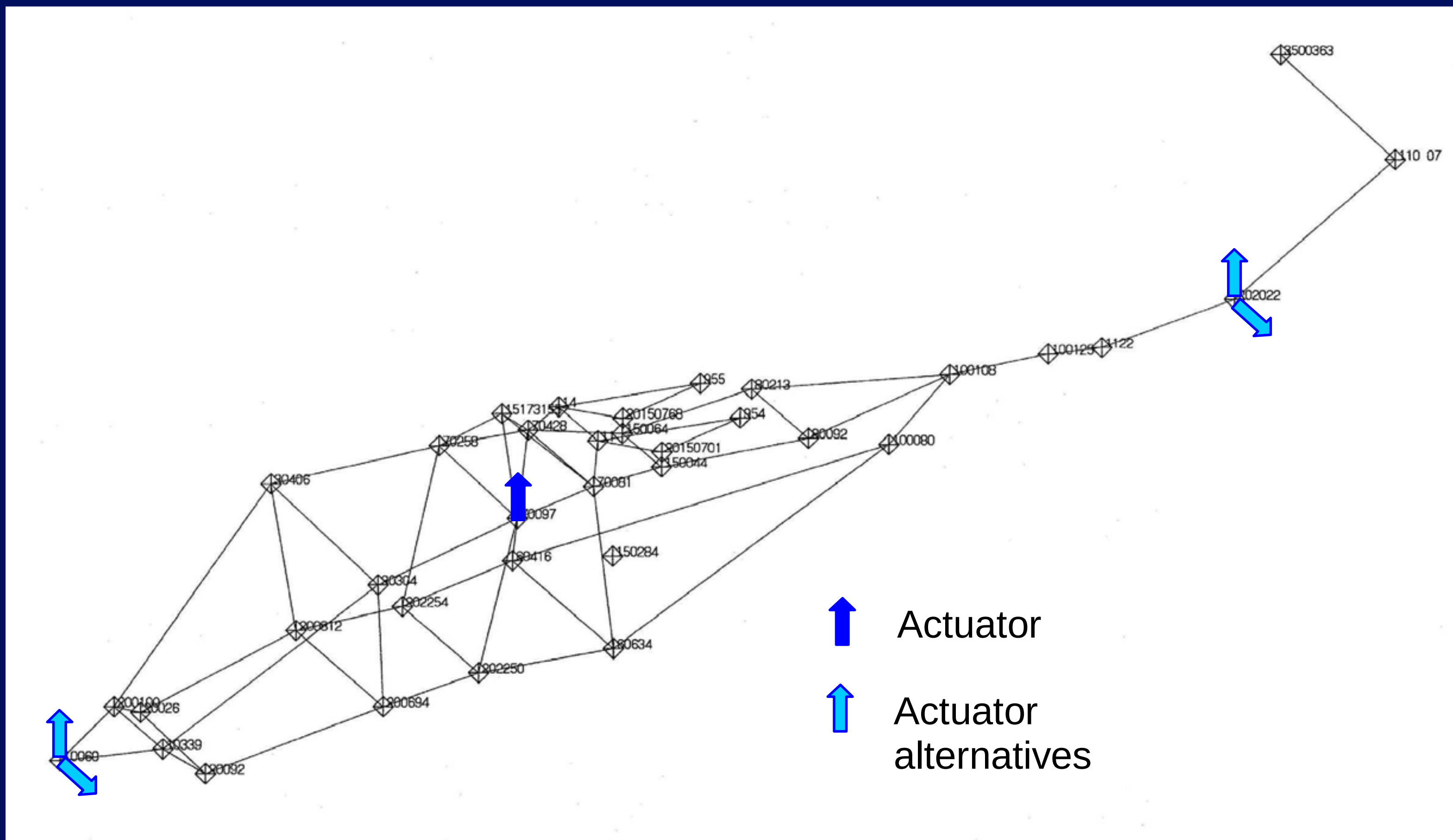
Response RSM accuracy



Control actuators



Actuator force limits

- Roof – 3000 N.
- Nose – 2000 N.
- Tail 200 N.

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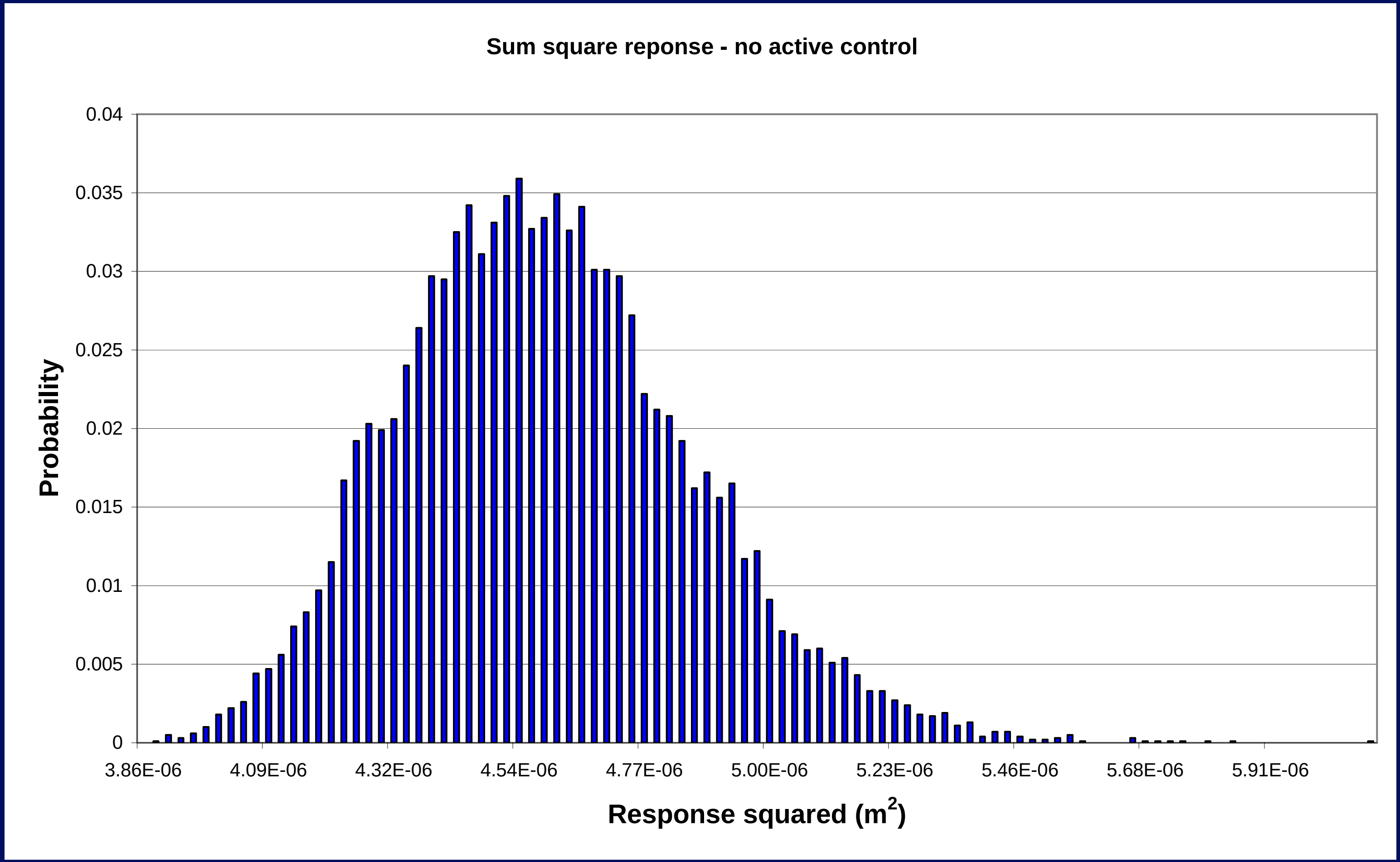
Response PDF – no control



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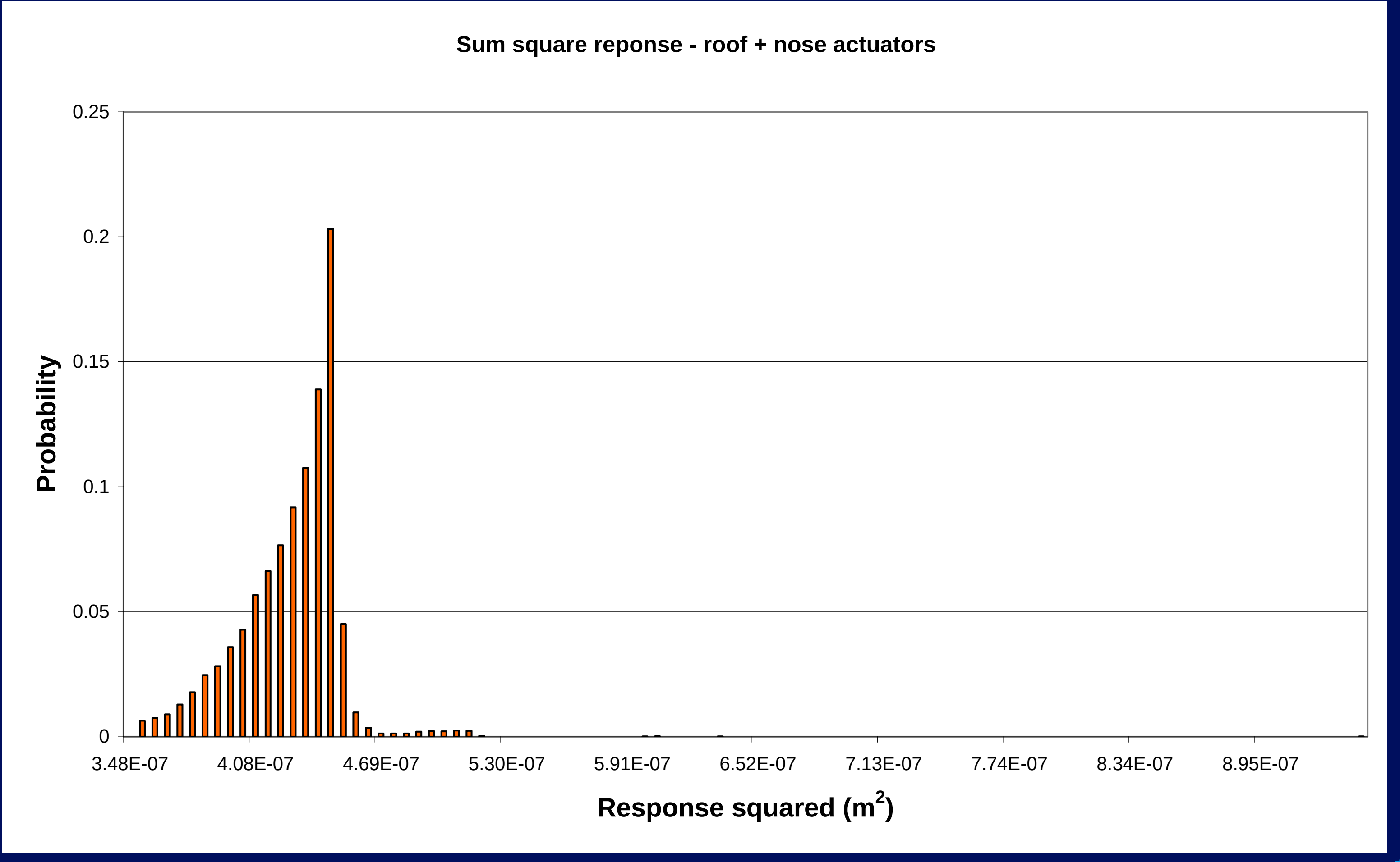
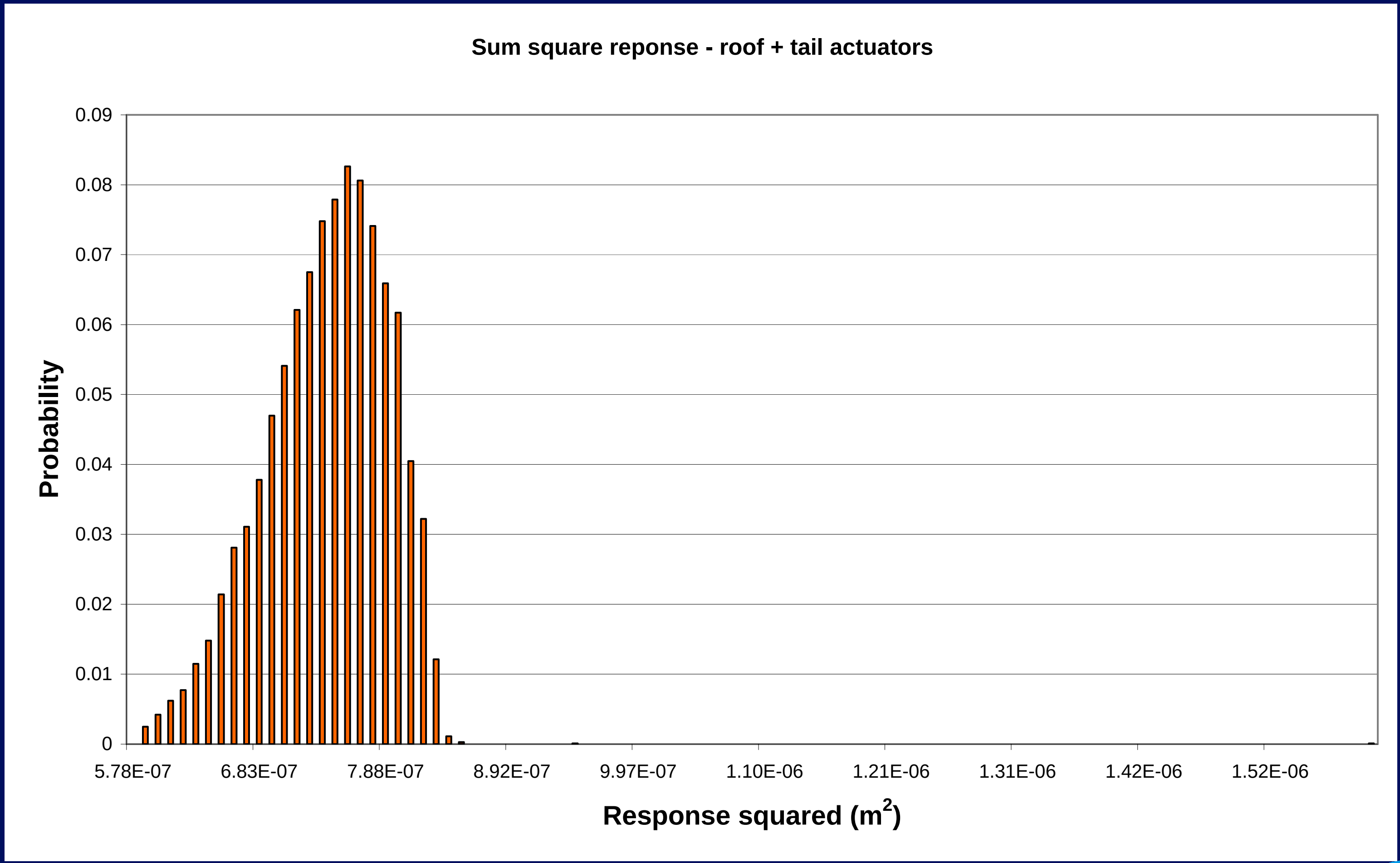
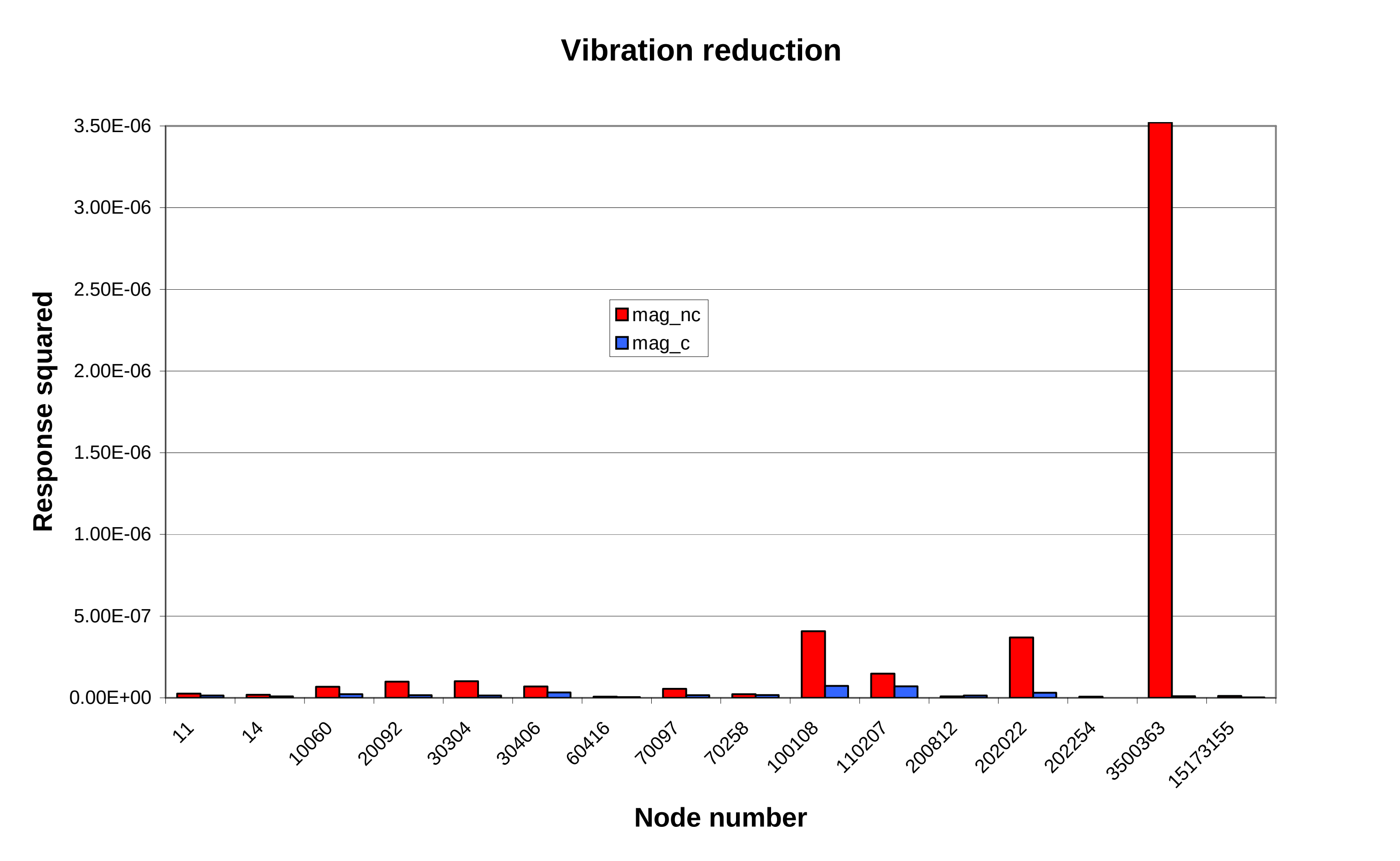
Response PDF – roof and nose actuators



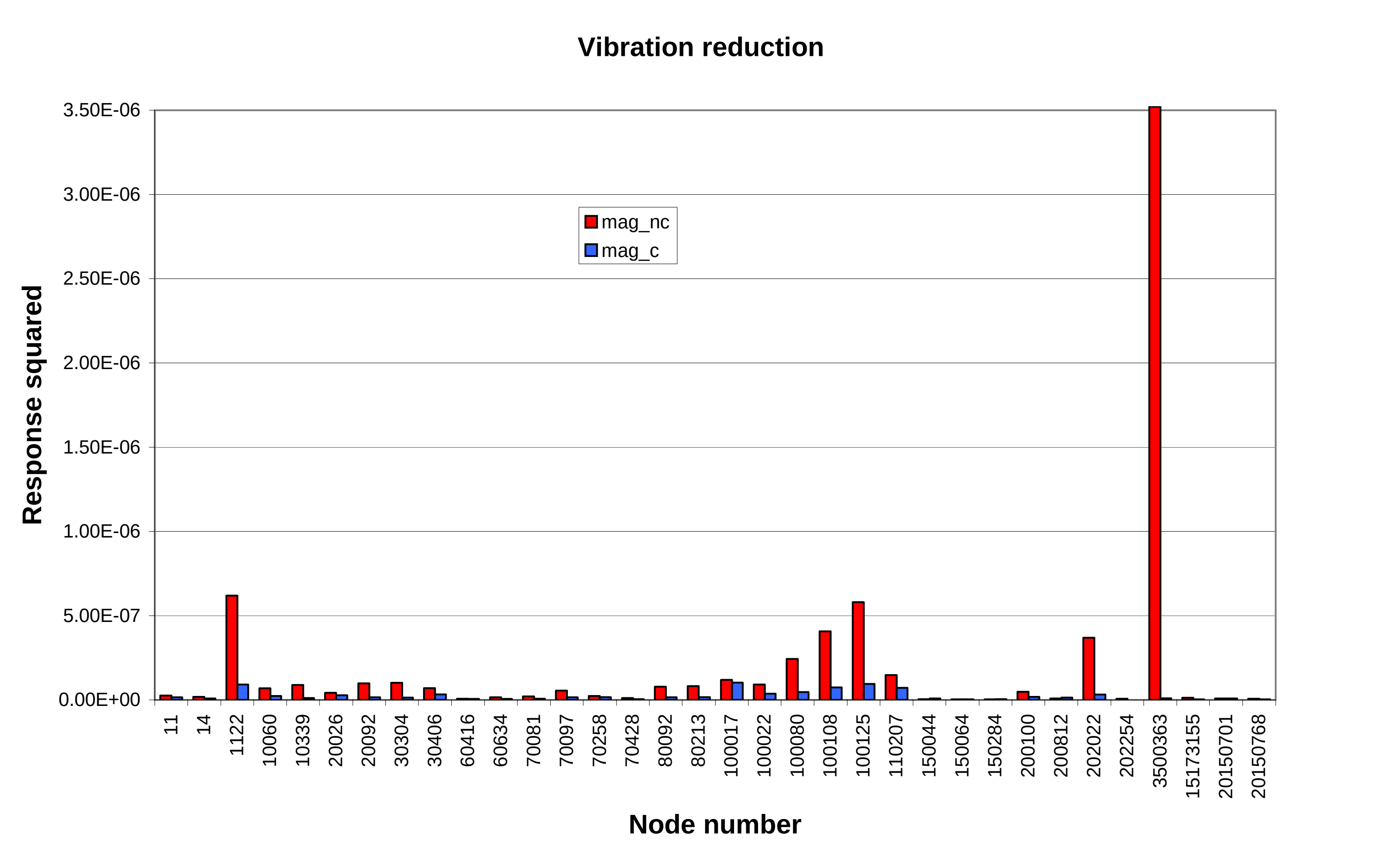
Response PDF – roof and tail actuators



Vibration reduction – control points



Vibration reduction – all nodes



Response comparison with NASTRAN

State	NASTRAN	Current programme
No active control	4.94e-06	4.58e-06
With control	3.47 e-07	4.21e-07

Conclusions

- Demonstrated a process to analyse fleet wide vibration variation for helicopters of active control.
- System takes into account variation in structural properties and fuel mass, etc.
- Method has been applied to 2 helicopter models and shows that active vibration control does not reduce vibration to a uniform level.
- Vibration level depends on the number, positioning and authority of control actuators and the structural variability.