

The Application of Data Modelling Techniques to Engine Testing

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Overview



- Background – *the need for modelling techniques*
- Methodology – *outline approach*
- Case Study 1 – *cold start catalyst light-off strategy optimization*
- Case Study 2 – *part load variable valve timing optimization*
- Summary – *limitations & benefits*

Background



Base engine development requirements:

- 1) Find optimum EMS settings to determine status and allow a meaningful comparison of hardware options
- 2) Understand engine characteristics across EMS settings and engine speed/load range
 - ➔ Define optimum hardware
 - ➔ Define optimum operating strategies

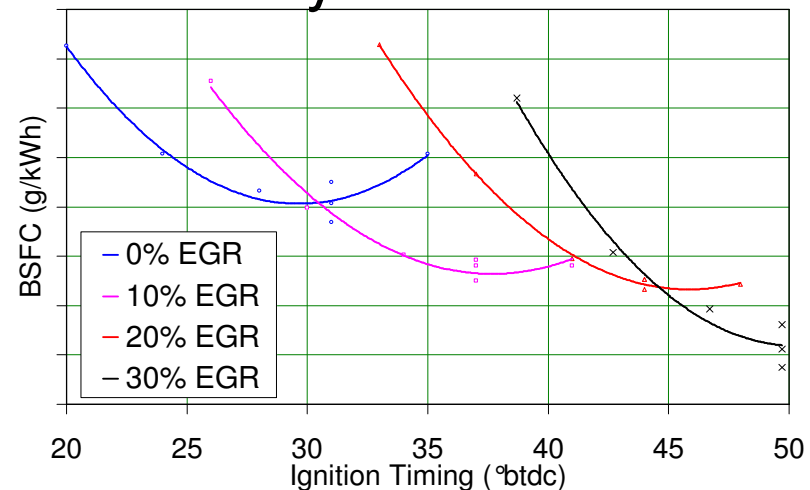
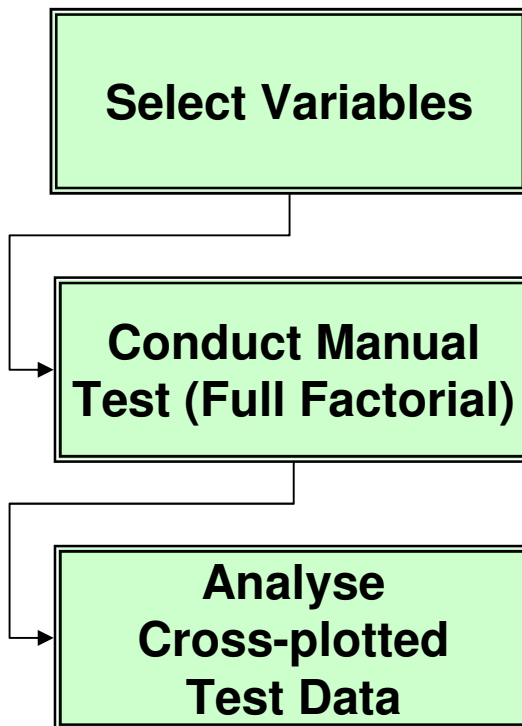
Background



Conventional approach

Example: Engine with fixed cam timing and EGR

- Variables: *AFR, Spark, EGR, Injection Timing*
 - *AFR* & *Inj. timing* typically optimized separately
 - Two variables for optimization task: *Spark & EGR*
- IGN sweeps conducted over range of EGR
- Data plotted and analysed



Background



Problems with conventional approach

For systems with more than two degrees of freedom conventional methods:

- require large number of test points & increased test time
- finding optimum set point can be difficult/impossible
- the relationships/interactions are not easily visualised
- it is difficult to make a judgment of the data quality without taking repeat measurements

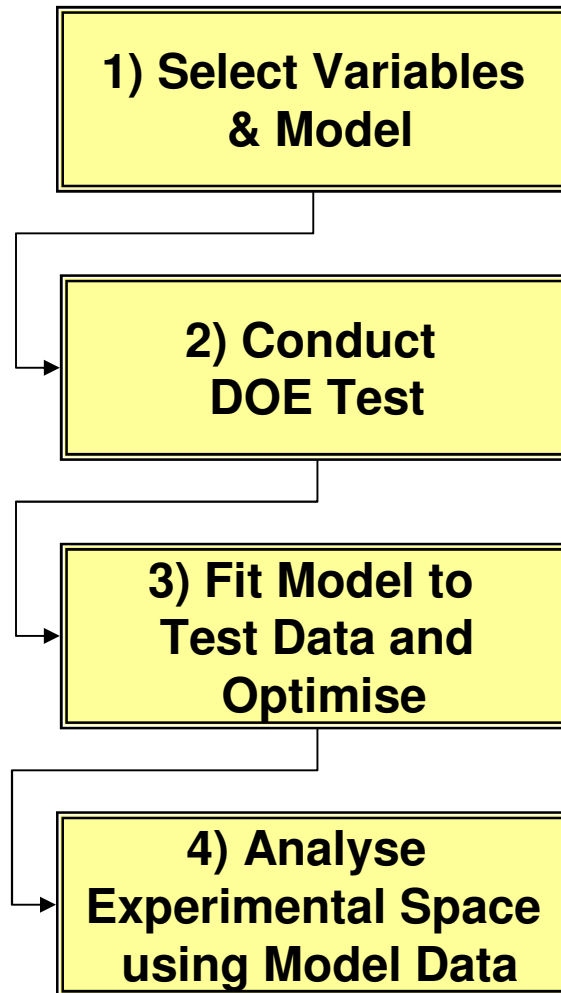
→ A different approach is therefore required...



Methodology



Model-based approach



Advantages:

- ➔ Potential for significant reduction in test points
- ➔ Plotting & analysis of data simplified due to model form
- ➔ Process of finding optimum settings/understanding trade-offs is simplified
- ➔ Potential to separate real physical response from experimental noise

Methodology



- Mathworks MBC toolbox used to:
 - generate DOE
 - fit models to test data
 - assess and improve the quality of the model
 - explore the model space
- Model quality assessed using two parameters:
 - R^2 → measures how well the model fits the test data but can always be improved by increasing model terms (>0.8)
 - PRESS R^2 → gives indication of predictive power of model and guards against over-fitting, i.e. modelling experimental noise (>0.8)
- Model optimization conducted to remove model terms that do not improve the predictive power of the model

Case Study 1

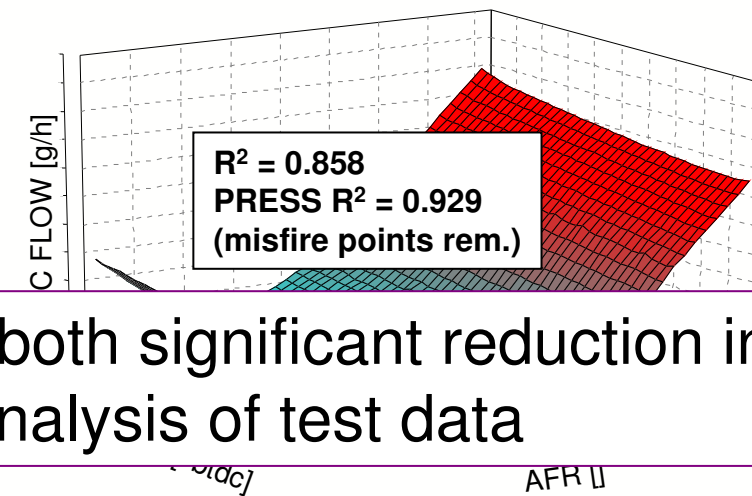
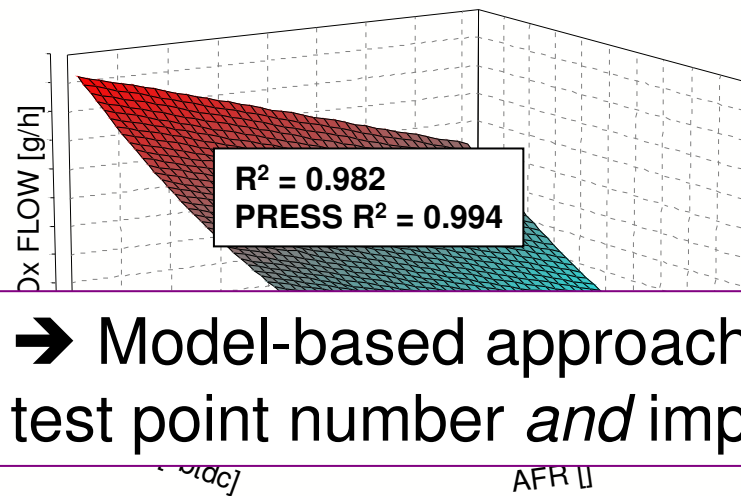
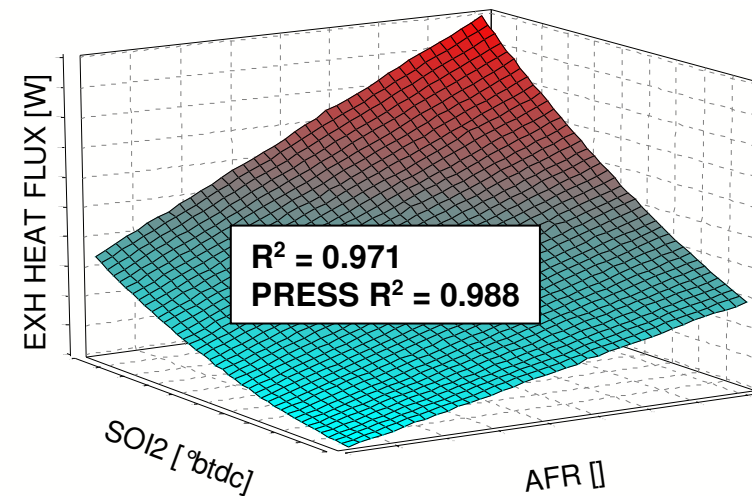
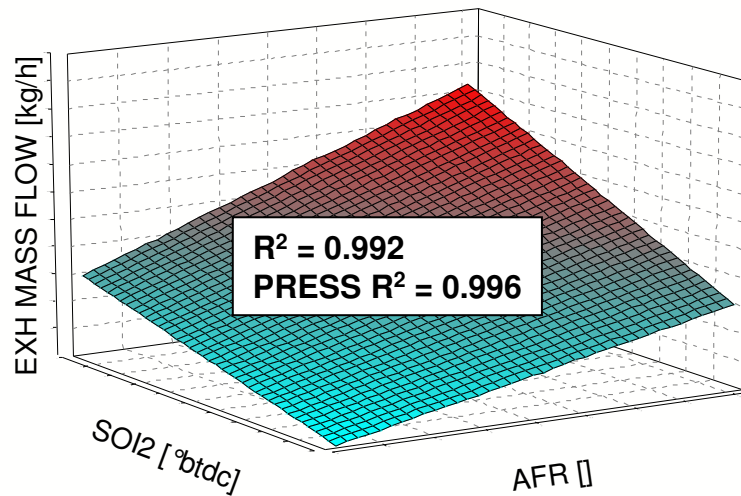


Engine & test details

- Objective: find optimum EMS settings for post-start catalyst warm-up phase
- Engine: gasoline direct injection engine
- Operating Strategy: IGN (Ignition) after top dead centre for maximum heat flux, improved stability with split injection
- Degrees of Freedom: 3 → IGN, AFR, SOI2 (Start of 2nd Injection)
- Test condition: cold start stabilised idle simulation – constant load, cold fluids
- Model Type: 2nd order (10 terms)
- DOE: space filling design with 27 test points (full factorial=100 test points)

Case Study 1

Results – “Slice” through global model at one ignition setting:



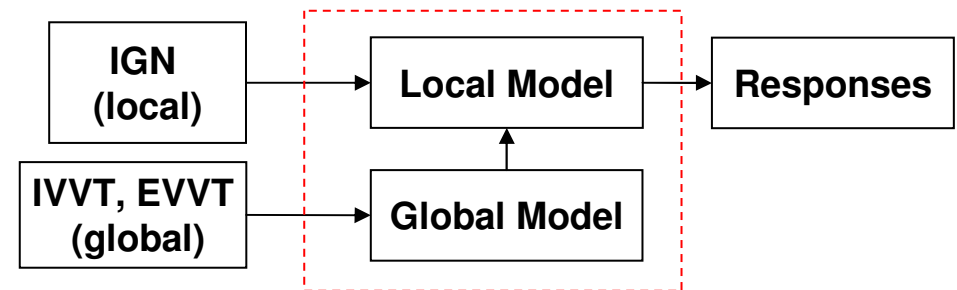
➔ Model-based approach allows both significant reduction in test point number *and* improved analysis of test data

Case Study 2



Engine & test details

- Objective: find optimum VVT strategy for part load operating condition and understanding trade-offs/operating characteristics
- Engine: medium sized gasoline engine with dual independent variable valve timing
- Degrees of Freedom: 3 → IGN, IVVT, EVVT
- Test condition: typical part load operating condition
- Model Type: 2-stage, 2nd order
 - Local variables: IGN
 - Global variables: IVVT, EVVT
- Global DOE:
 - space filling design with 18 IVVT/EVVT combinations (full factorial = 49 combinations)
- Testing: fully automated

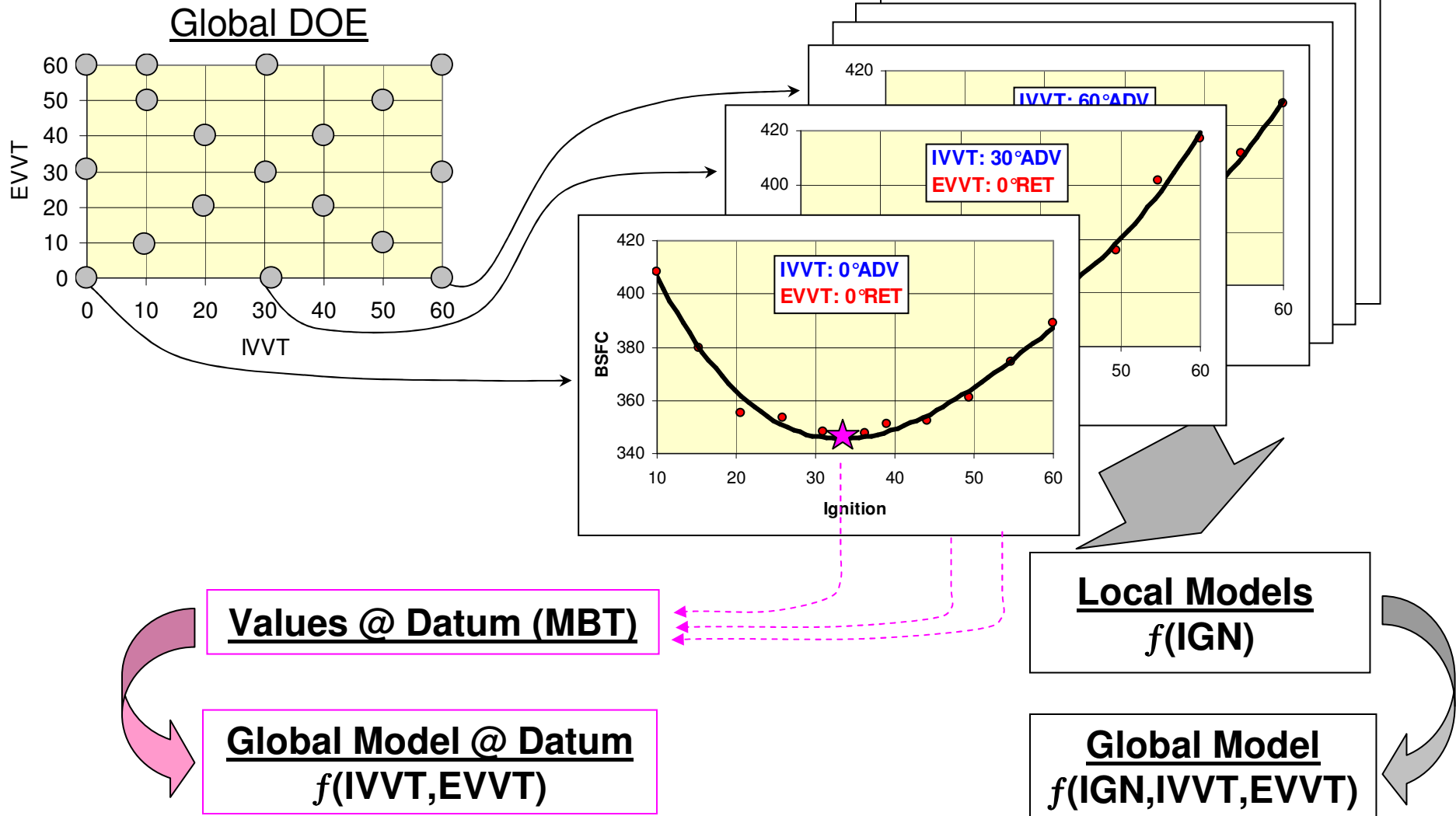


Case Study 2



Approach

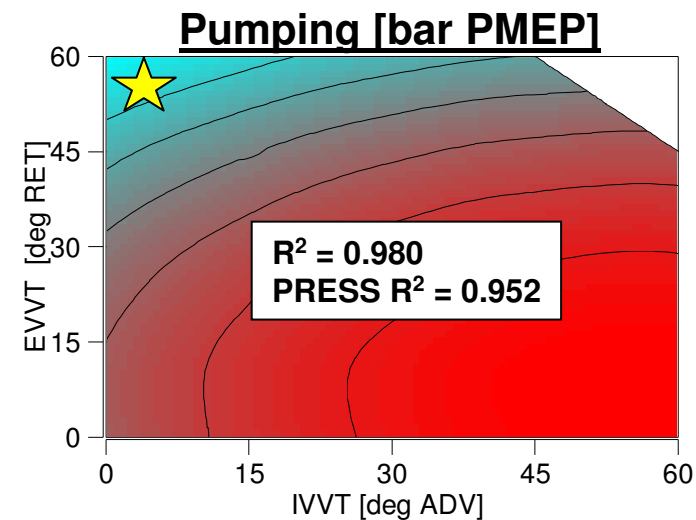
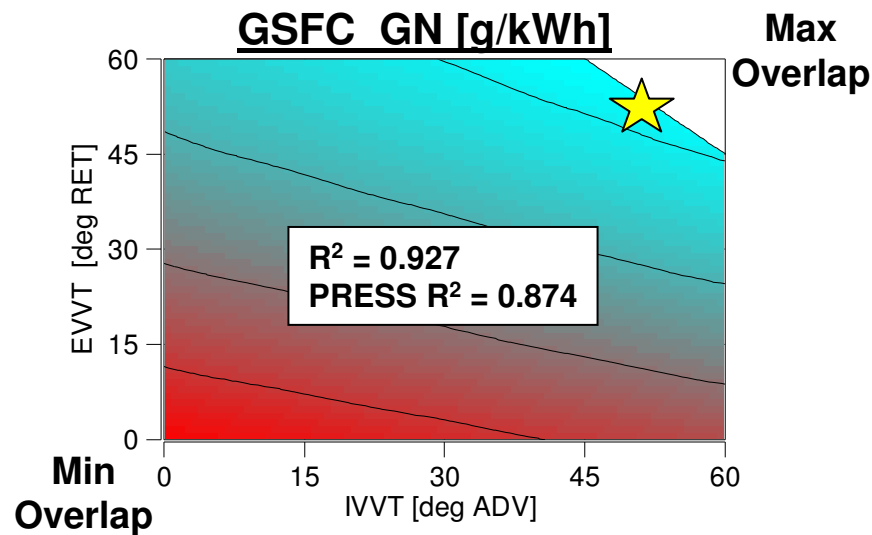
Local Constant Load IGN Sweeps



Case Study 2

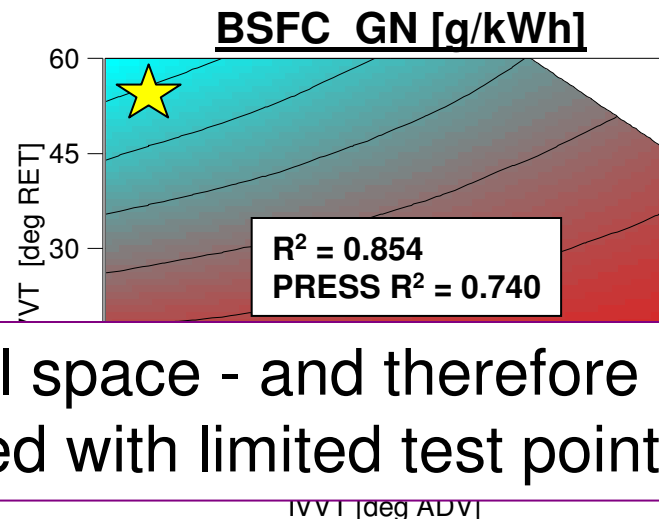


Results – Global model at MBT:



Model analysis indicates that:

- Best GSFC at high overlap
- But minimum pumping at maximum “dual equal retard”

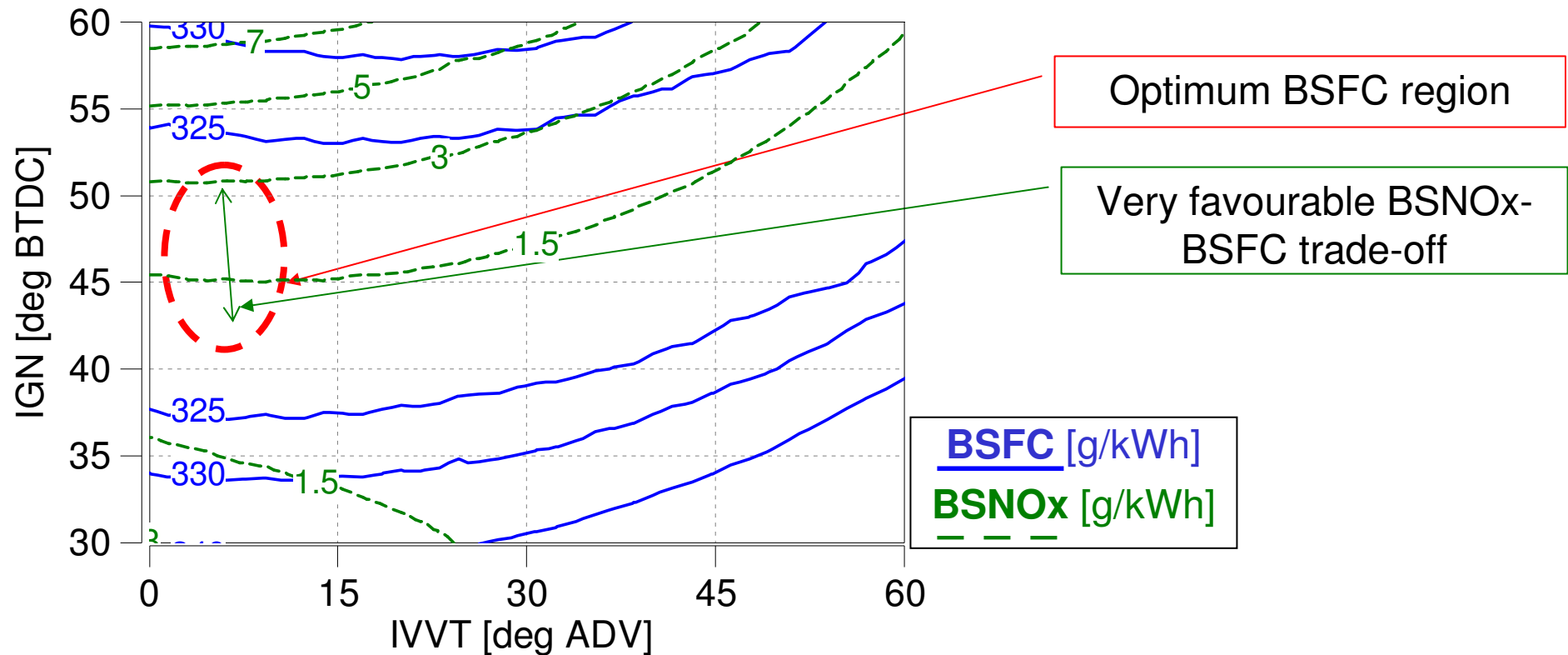


➔ Good definition of experimental space - and therefore engine operating characteristics - achieved with limited test points

Case Study 2



Results - Slice through global model at max. exhaust retard:



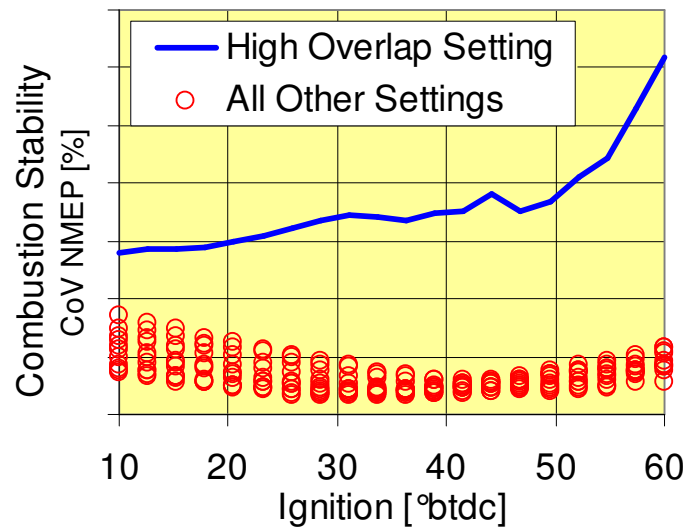
➔ In model form data can be more easily manipulated and visualized - this allows trade-offs to be more easily understood.

Case Study 2



Constraints within DOE space

- Analysis of preliminary BSFC model data indicated poor model correlation as a result of poor stability in max overlap region



Two options:

1. Use higher order model to capture real instability effect
2. Retain 2nd order model and ignore model data in high overlap region

➔ Option 2 chosen as response is essentially 2nd order and minimum model complexity is desirable

➔ Model-based approach requires understanding of constraints within DOE space – otherwise incorrect predictions can be made

	with max overlap region	w/o max overlap region
R ²	0.24	0.97

Case Study 2



Data quality issues

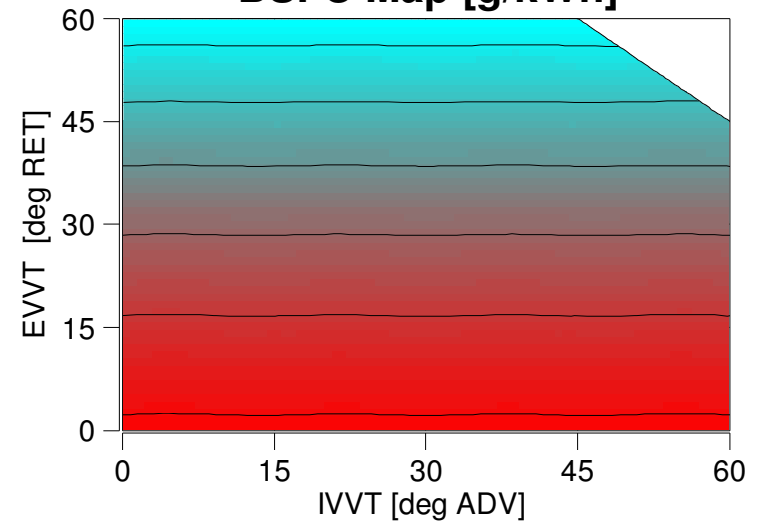
- Initial optimization of BSFC model resulted in all IVVT terms being removed due to their low statistical significance
- Analysis of data revealed that magnitude of experimental noise was similar/greater than actual response to IVVT



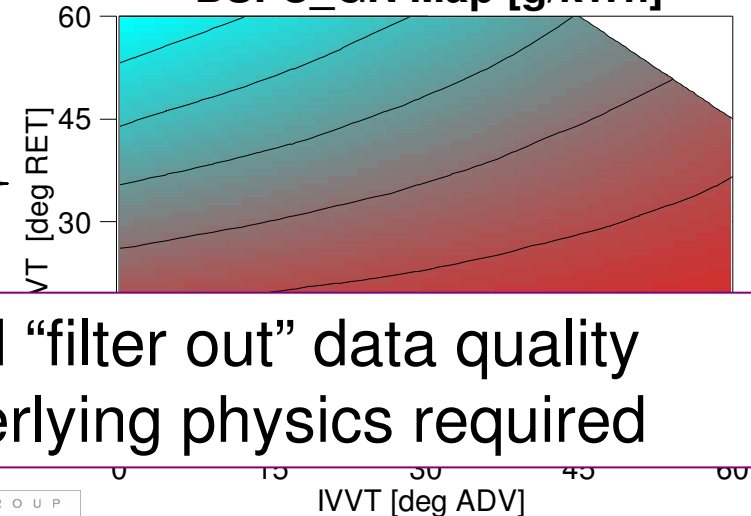
- New response model based on alternative BSFC parameter (BSFC_GN) calculated from MAF signal derived (less accurate, but more repeatable)
- IVVT dependent terms now retained and “true”



BSFC Map [g/kWh]



BSFC_GN Map [g/kWh]



➔ Optimization process can highlight and “filter out” data quality issues – but some understanding of underlying physics required

Summary



Limitations of model-based approach:

- Significant benefit only for tests with more than two degrees of freedom
- Good understanding of constraints within DOE space required to prevent incorrect prediction of response in these regions
- Consideration of data quality and nature of underlying response required – otherwise incorrect conclusions can be drawn

Summary



Benefits of model-based approach:

- Significantly reduced test time (>50%)
 - Greatly improved analysis of test data due to ease of manipulation and visualisation in model form
 - Ability to filter out the experimental noise and analyse the underlying “real” response
 - Improved understanding of optimum settings, underlying characteristics and trade-offs
- ➔ Reduced time from start of test to definition of optimum hardware and EMS strategy