The Treatment of Non-Ideal Surface Topologies Related to High-Speed Vehicle Design
ICAS PAPER 2026_8.4.4

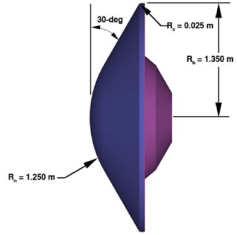
J Merrifield
Fluid Gravity Engineering Ltd

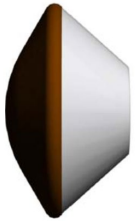


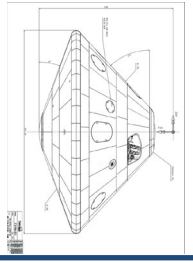
INTRODUCTION

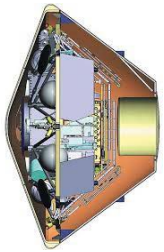
- This presentation draws on work performed at Fluid Gravity Engineering Ltd in collaboration with other organisations
- Fluid Gravity Engineering Ltd (FGE)
  - SME specialising in computational physics, test planning and test interpretation
  - Collaborate with other researchers as normal work
- Capabilities include:
  - Numerical methods
  - High speed aerodynamics
  - Aerothermodynamics
  - High temperature material response
- Contributed to design justification and post flight analysis for a number of high-speed vehicles:

Huygens (1997) Beagle2 (2003) ExoMars Schiaparelli (2016) ExoMars RFM









esa



Acknowledgements

- Colleagues at FGE: Alan Flinton, William Ivison, Emma Johnstone, Holly Whitehouse, Nathan Donaldson
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- German Aerospace Center (DLR): Ali Guelhan, Dominik Neeb
- European Space Agency (ESA): Johan Steelant, Jeroen Van den Eynde



THE CHALLENGE

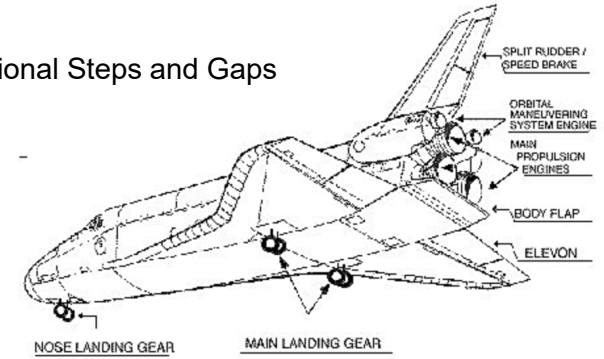
- The majority of design-level CFD runs are usually performed on idealised surface topologies
  - Surface topology can evolve in flight (e.g. from ablation or thermal expansion effects)
    - Augmented skin friction and heat transfer
    - Promotes transition
  - Roughening is an important physical process to consider for ablatives
    - Isolating roughness effects needed for Multiphysics material response model development
  - Geometric details often too fine to capture in design-level CFD but their influence can be important
- These details should be considered throughout the design phases to avoid costly late-phase design changes

Ablation



Credit Sakraker, I. et al. CEAS Space Journal 2022

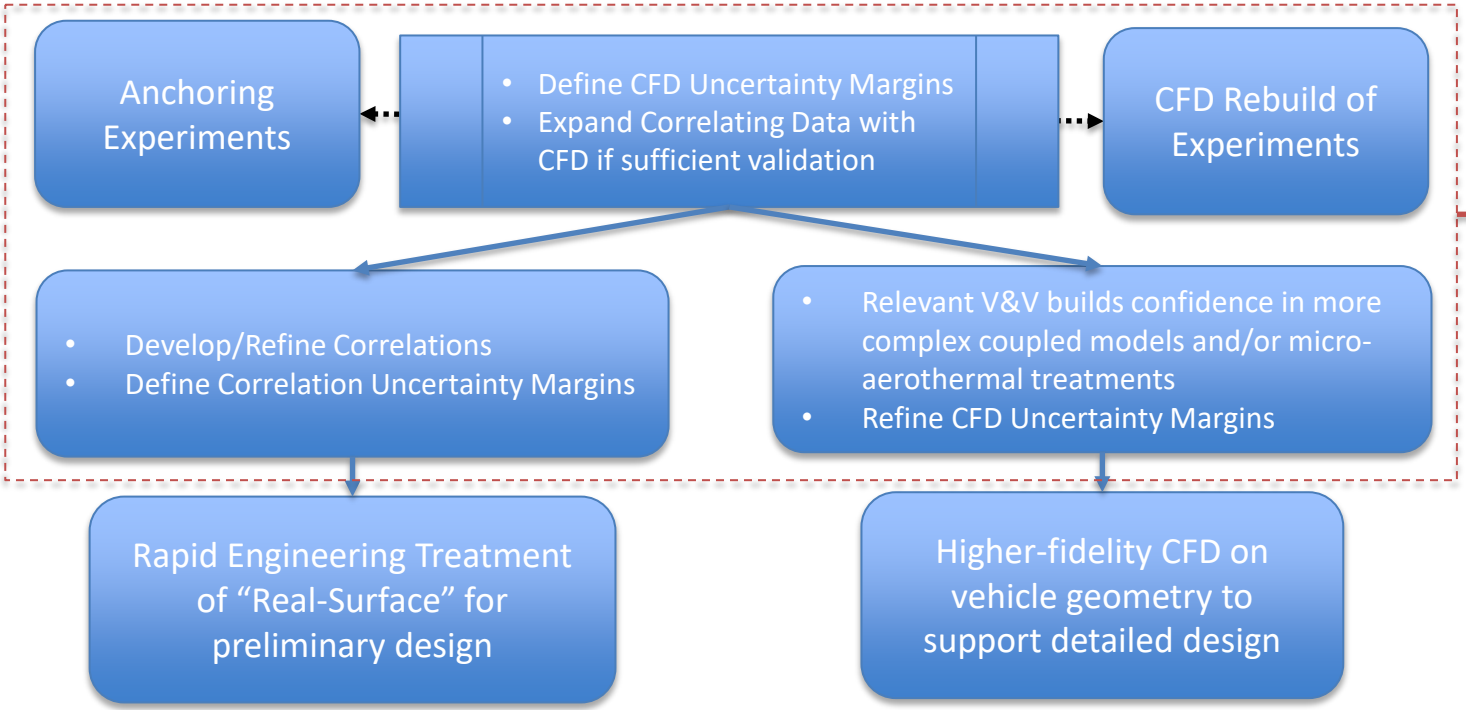
Functional Steps and Gaps



Credit NASA

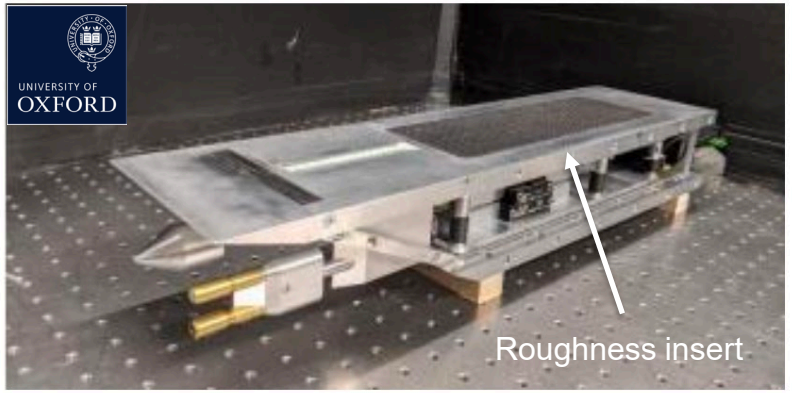


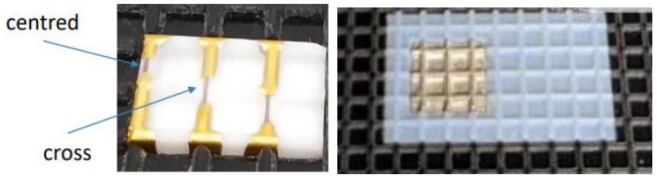
THE CHALLENGE (proposed solution)

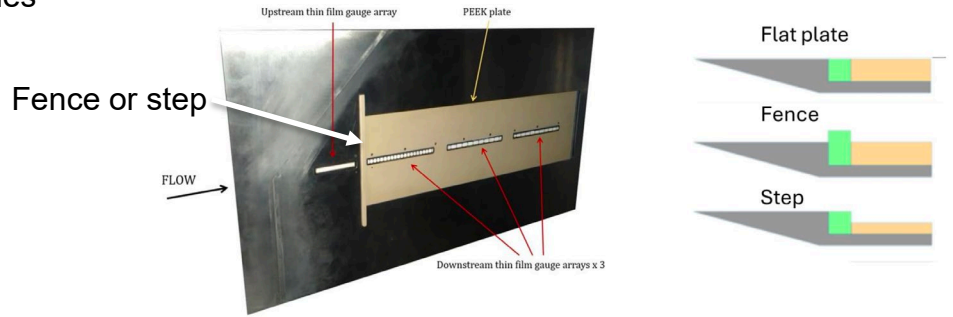


EXPERIMENTAL SUPPORT

- Important to anchor analysis with high-quality experimental data
  - Experiments performed in University of Oxford's High Density Tunnel (HDT)
- Simplified flat plate geometry with configurable roughness or fence/step topology in the measurement region
- Adjust test conditions to reproduce relevant Boundary Layer (BL) properties in measurement region
  - HEXAFLY-INT and STRATOFLY used as reference vehicles for relevant BL properties
- Utilise multiple complementary heat transfer methodologies
  - IR thermography, calorimeters, thin-film gauges
  - Ivison, HIST 2022, 2024
  - Condren, HIST 2024



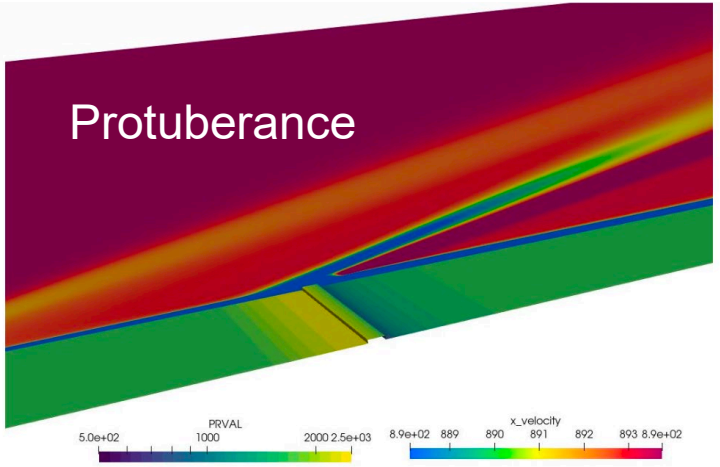


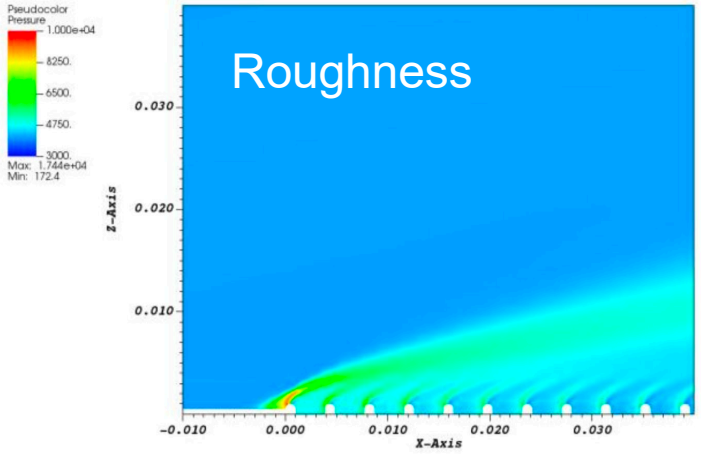




CFD REBUILDS

- Provides fundamental V&V for turbulence models and meshing methods
  - Builds confidence in using models for micro-aerothermal assessments required for detailed design
- This also allows an assessment of the models' capability to predict downstream-influence (e.g. transition promotion)
- Explicitly investigate effectiveness of meshed-form and/or sub-model (e.g. k^+) roughness treatments
  - Where to draw the line between form and roughness?
- Build confidence in onward multi-physics modelling
  - High temperature aerochemistry, catalycity and surface chemistry, blowing and mass transfer

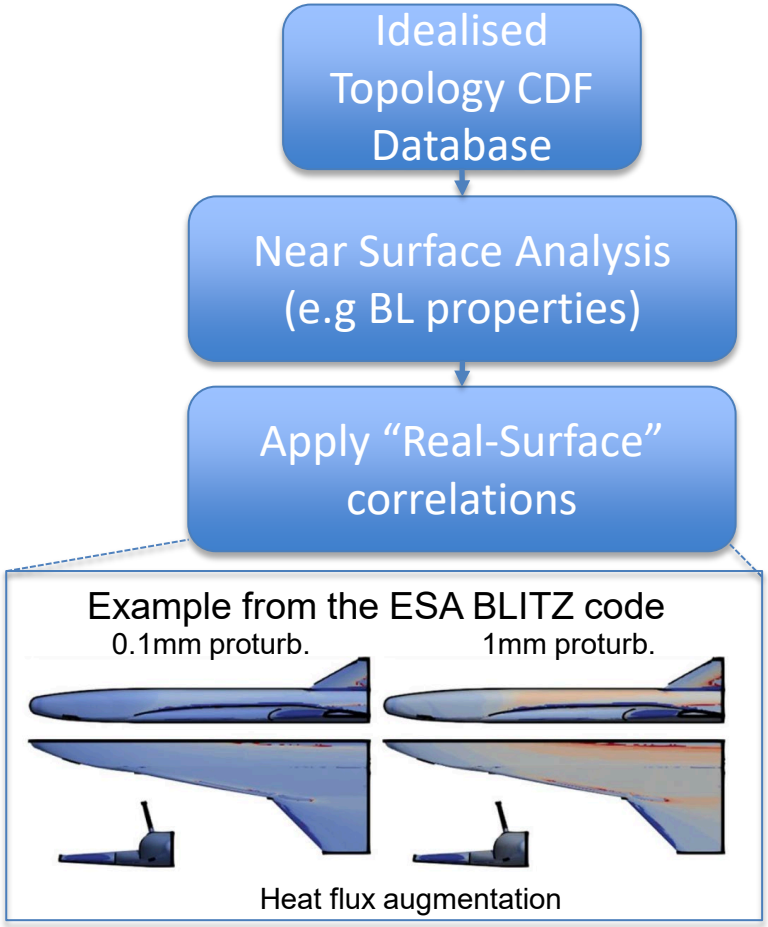






RAPID ENGINEERING TREATMENT

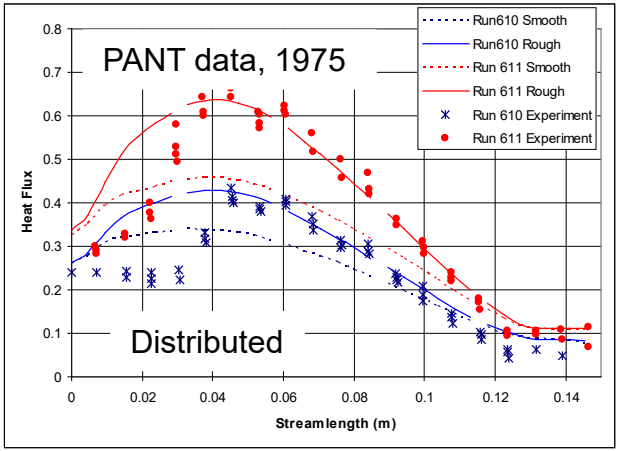
- Experimental data used to develop correlations
  - Heat flux augmentation, transition promotion
- Seek to make best use of exiting “clean” CFD through post-processing
- Efforts underway to incorporate these correlations into the ESA post-processor BLITZ
- Provide early design phase guidance for engineers

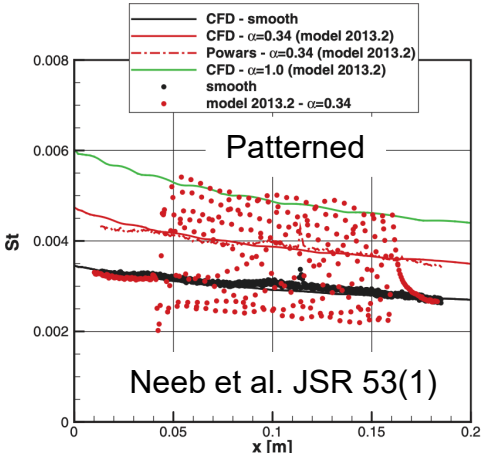




EXAMPLE RESULTS: ROUGH SURFACES

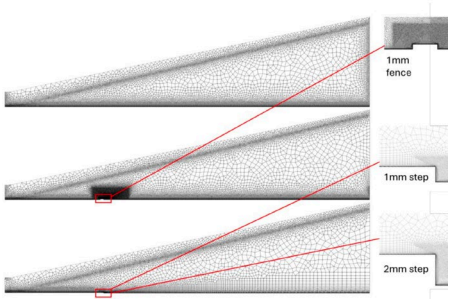
- Validation of Krogstad roughness sub-model for distributed and patterned roughness
  - Here a compressible version of $k^+$is utilised in the FGE structured CFD solver TINA
    - Merrifield 2011, ESA ATD Symposium
  - Roughness definition always problematic
    - Other compressible corrections have been suggested
    - Reference experiments required - geometric correlations are difficult to apply reliably
- Powars correlation found to be reliable in both cases
  - Despite roughness elements being reasonably large ($k > 0.2\delta$) in some cases

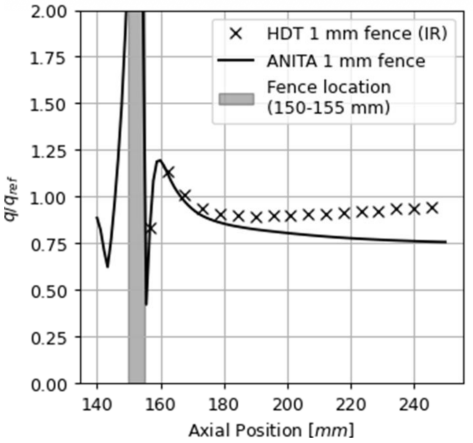




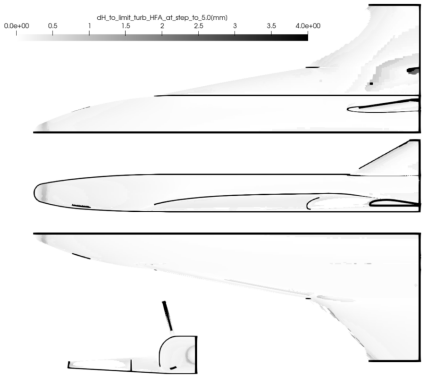


EXAMPLE RESULTS: STEPS AND GAPS





- Features explicitly meshed in FGE unstructured CFD solver ANITA
  - Flinton HIST 2024
- Transitional Langtry and Menter SST turbulence model utilised
- Reasonable agreement for first 30mm after disturbance
- CFD takes longer to trend back to undisturbed value
  - Further investigation to establish reliability CFD turbulence model as applied
  - Comparison is useful in defining uncertainty margins
- Experimental data has been used to correlate peak heat flux augmentation
  - Incorporated into the ESA BLITZ tool to aid early design studies



Required step height [mm] to limit turbulent heat flux augmentation to 5.0



OUTLOOK AND NEXT STEPS

- Range of topologies to study is seemingly endless
  - Focus on near term needs to provide insight for design engineers
  - Follow-on work planned to develop the approach
- Explore the utility of DNS and scale-resolved turbulence modelling (LES, DES etc.) to assist in expanding database of topologies
- Demonstrate applicability to micro-aerothermal analysis on vehicle geometries
- Can foresee a future need to expand the approach to consider real topologies in afterbody and regions of separation
- Plan cost-effective flight testing / instrumentation to validate approach



SUMMARY AND CONCLUSION

- A combined experimental / numerical approach to incorporate non-ideal topologies into high-speed vehicle design activities is being developed
- Developing these methodologies during active design is often impractical due to imposed timescales
  - Prepare ahead of time
- This preparatory work is aimed at providing design engineers with the necessary knowledge and tools to analyse the effect of these features at different levels of design maturity
- Challenges exist, but these provide opportunities for future collaborations



Thank you for your attention

