Interpolation Error of FGM Tabulation in an Unnormalised Progress Variable Subspace

M. Kovaleva[1,2], M. Rieth[1], J. H. Chen[1]
1. Combustion Research Facility, Sandia National Laboratories, Livermore, USA
2. College of Physical Sciences and Engineering, Cardiff University, Cardiff, UK

Corresponding author:
Marina Kovaleva
Email:
kovalevam@cardiff.ac.uk

1. INTRODUCTION

- When considering preferential diffusion effects in tabulation of thermochemical states employed in the flamelet-generated manifold (FGM) method, tables are stored by lookup of various control variables. These control variables typically include mixture fraction, Z and normalised progress variable, PV.
- If preferential diffusion effects are considered, mixture fraction is not constant for each flamelet, and insufficient data to define the progress variable boundaries leads to many studies undertaking interpolation in the unnormalised progress variable space, [1-3].
- This causes flamelet lengths to vary in the unnormalised progress variable subspace (relative to other nearby flamelets), causing interpolation and extrapolation to be undertaken across incorrect values (Fig 1.)
- Various types of FGM errors have been previously quantified, including error due to steep thermochemical value gradients and non-monotonic progress variable defintions. However, to best knowledge, no work highlights the very significant errors arising from interpolation in an unnormalised progress variable subspace.

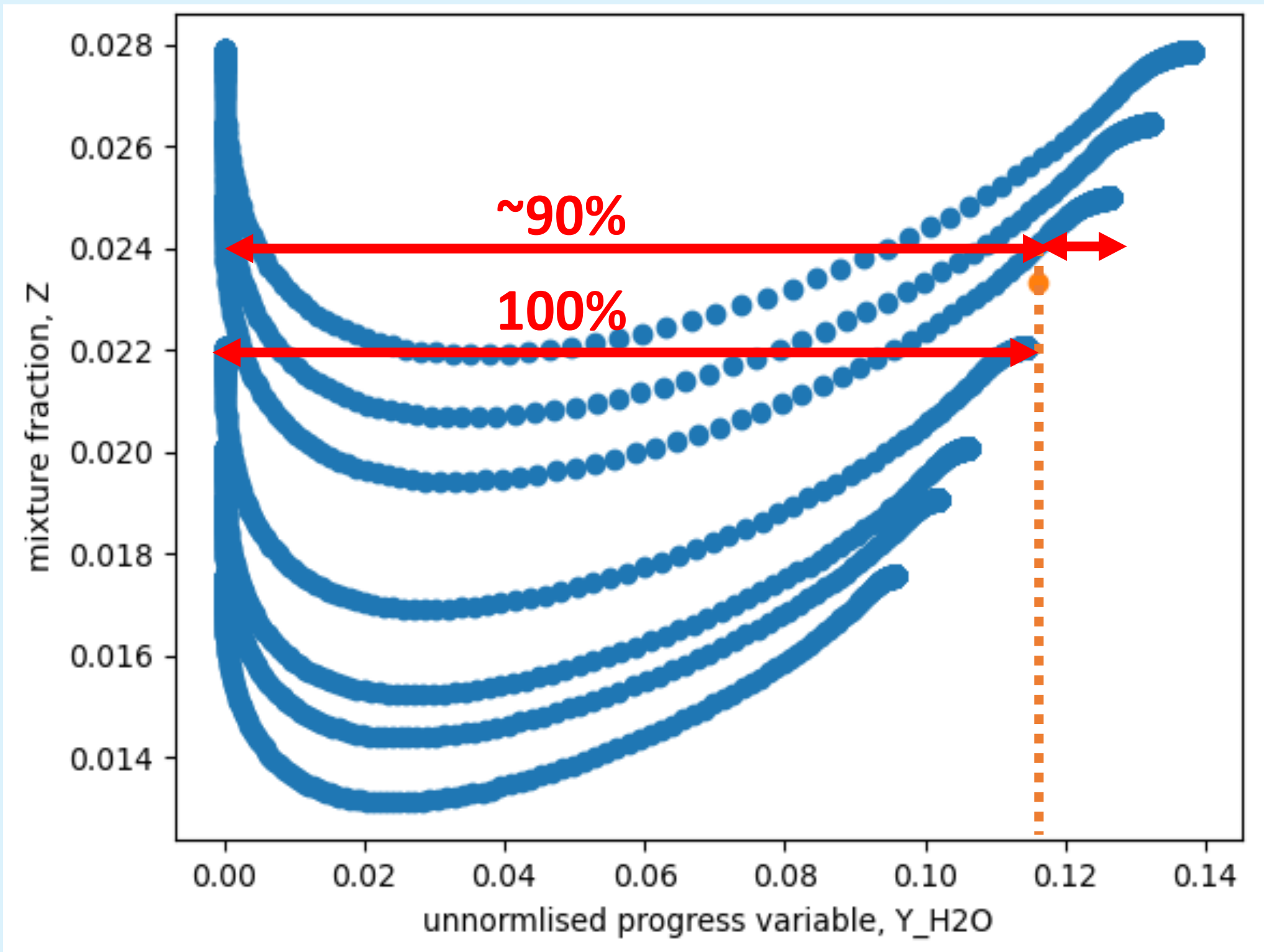

Figure 1 - Schematic of FGM interpolation

2. BASELINE PERFORMANCE

- Performance of error reduction methods is analysed by comparing the result interpolated from two flamelets against the original flamelet data.
- The original flamelet data is modelled using 1D FreeFlame model in Cantera software with the following conditions:

Fuel Blend: 0.4/0.45/0.15 (mol) $NH_3/H_2/N_2$
Oxidiser : 0.21/0.79 O_2/N_2 (mol)
Equivalence ratio : 0.13 - 0.6; **Inlet Temperature :** 750K

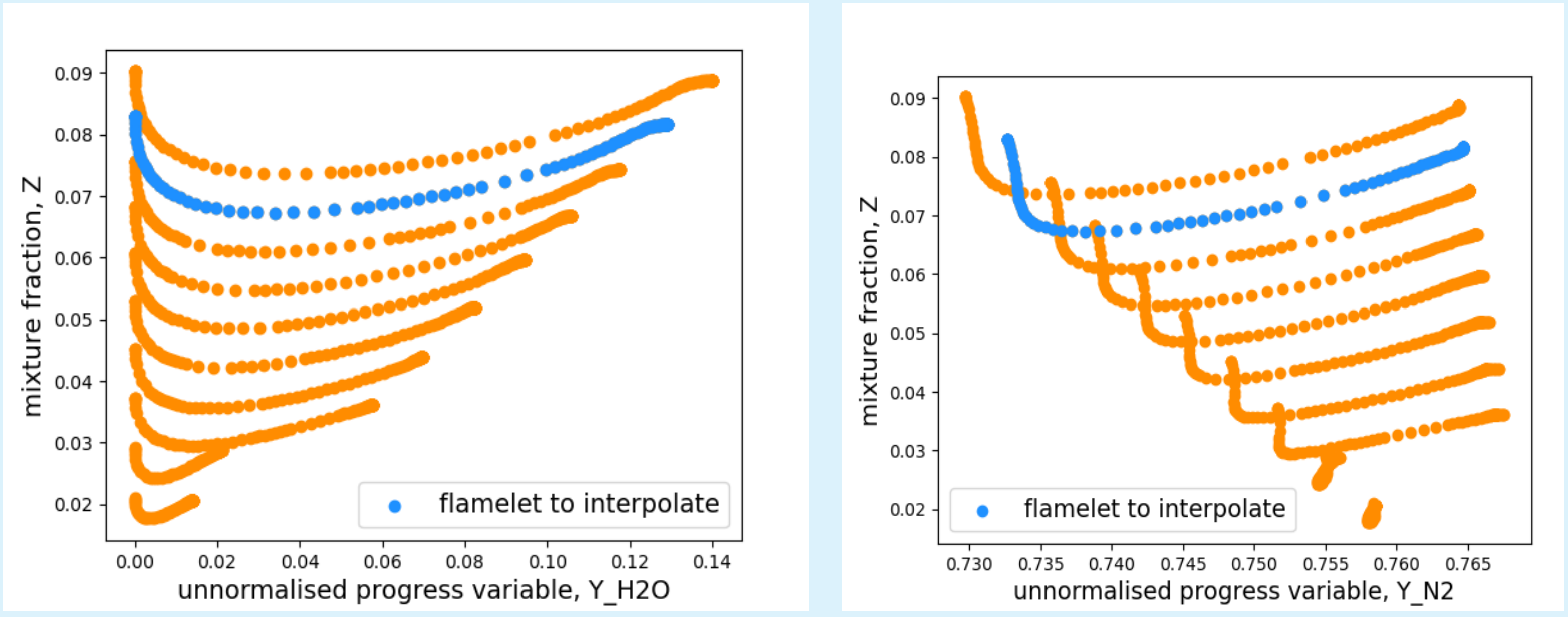

Figure 2 - Z-PV space for two progress variable definitions

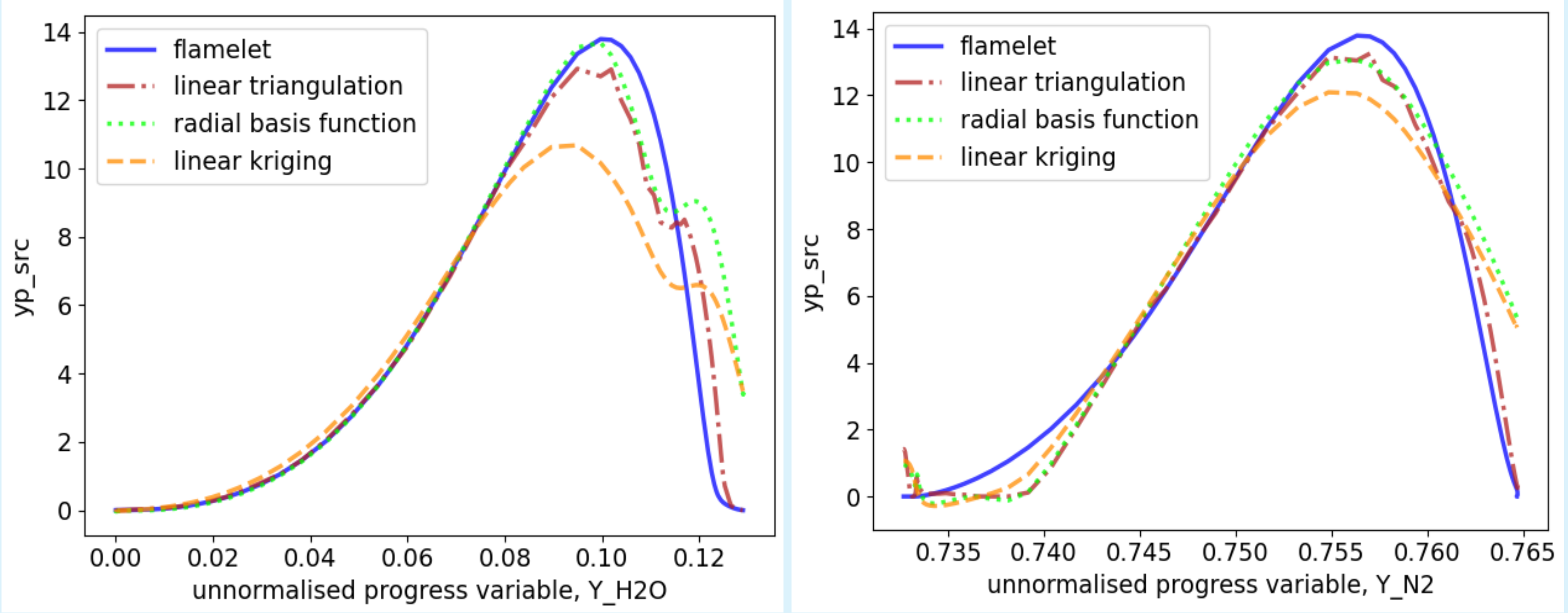

Figure 3 - Source term for flamelet with different interpolation methods vs. original 1D flamelet data (Z spacing = 0.052)

3. COMPARISON OF METHODS

Additional Parameter for Normalisation

- During interpolation, an additional lookup step is undertaken to find the nearest flamelet and its boundaries for normalisation. Interpolation is then conducted on a normalised progress variable.

Mixture Fraction Spacing

- Smaller mixture fraction interval during tabulation leads to interpolation between two flamelets that have less variation in length in the PV subspace.

Multi-Objective Normalisation of Progress Variable Definition

- A genetic algorithm was utilised to find the progress variable defintion that is a compromise between uniform progress variable boundaries and a monotonic definition. No valid solution that meets both monotonic and equal boundaries criteria was found.

Perspective Transformation Mapping

- In cases where the distribution of data in the Z-PV space can be captured by a quadrilateral shape, a perspective mapping matrix can be applied to remap the Z-PV space, allowing normalised progress variable to be used as a control variable.

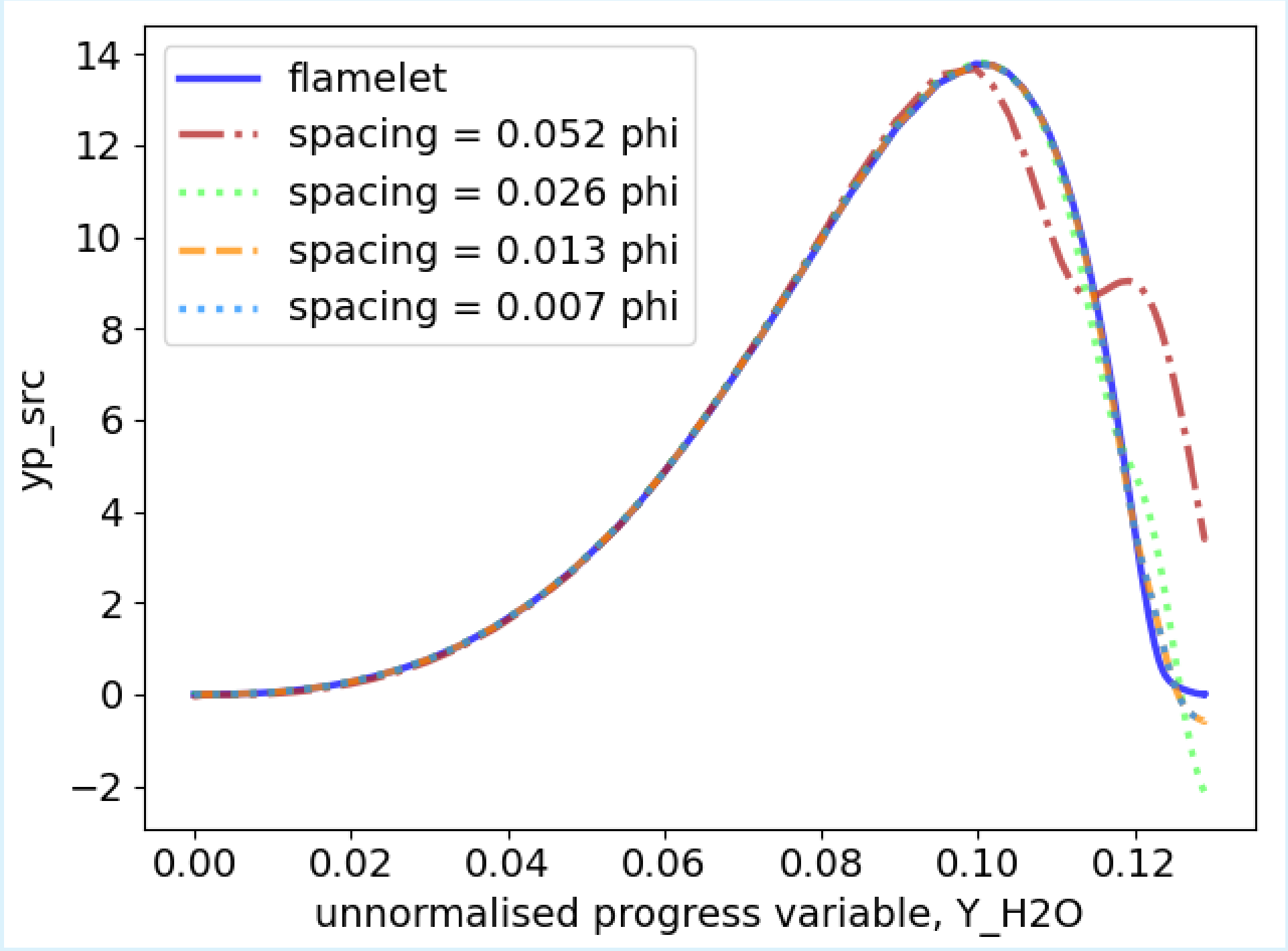

Figure 4 - Impact of mixture fraction spacing on interpolation error

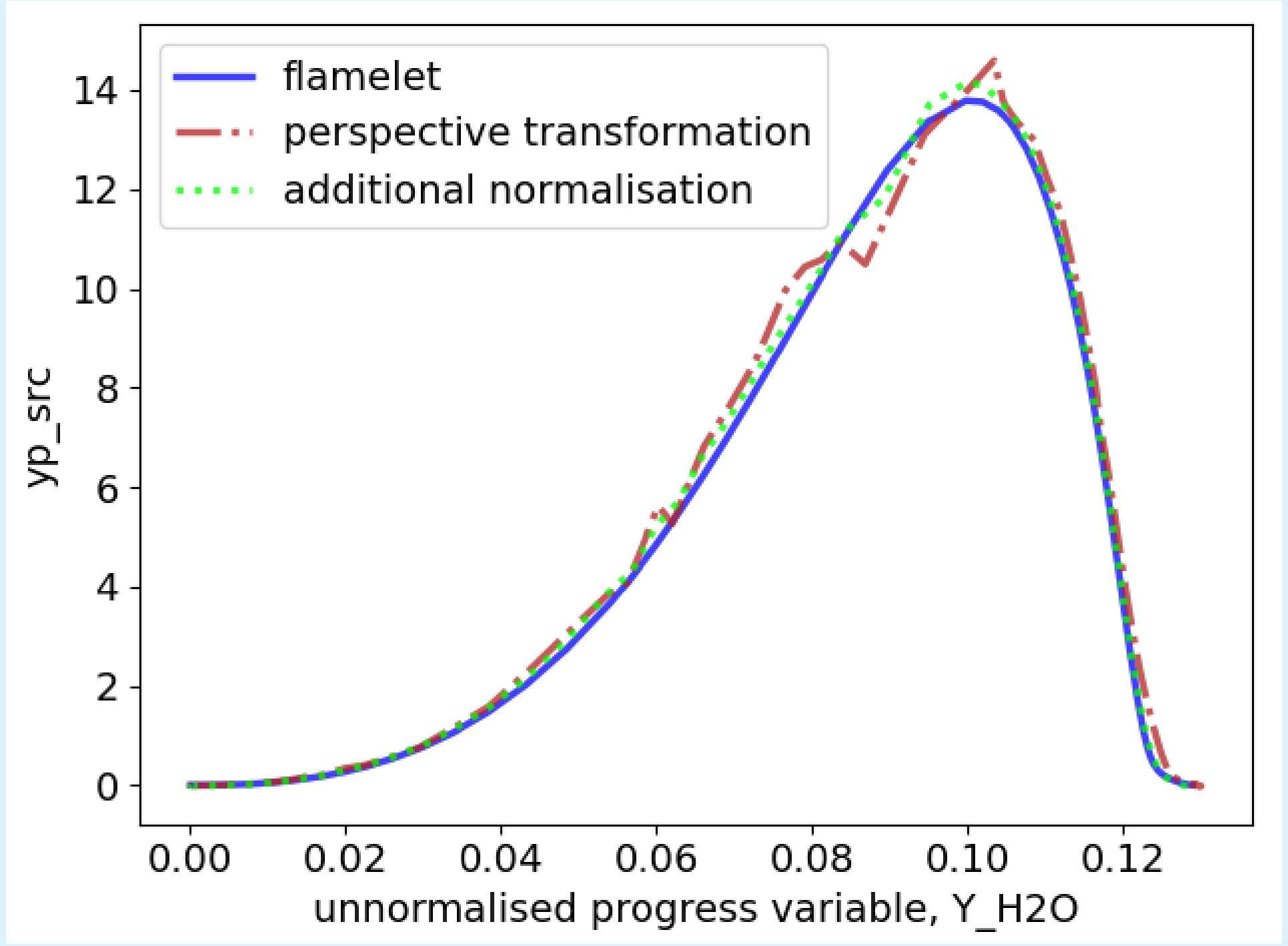

Figure 5 - Impact of other solutions on interpolation error (Z spacing = 0.052)

4. CONCLUSION

- Significant interpolation errors can arise from FGM tabulation using an unnormalised progress variable, often undertaken when considering preferential diffusion effects.
- This work provides a comparison of solutions to tackle this error.
- The most accessible solutions are: additional dimension for normalisation and decreasing Z spacing. However, further Z spacing reduction below 0.013 was found to have minimal effect.
- Perspective mapping may be viable, but is constrained by a loss of precision based on density of points along PV.
- For the blend explored in the present study, optimisation of progress variable defintion does not produce a viable solution due to the difficulty in balancing monotonic criteria against uniform boundaries on both the burnt and unburnt side of the flamelet.

5. ACKNOWLEDGEMENTS

The authors gratefully acknowledge funding from the US-UK Fulbright Commission. The authors would also like to thank Siemens Digital Industries Software on their insight on Simcenter STAR-CCM+ software FGM tabulation. The work at Sandia National Laboratories was supported by the US Department of Energy, Office of Basic Energy Sciences, Division of Chemical Sciences, Geosciences, and Biosciences. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.

6. REFERENCES

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