Polytropic Index Model & TJI Combustion System for Commercial ICE

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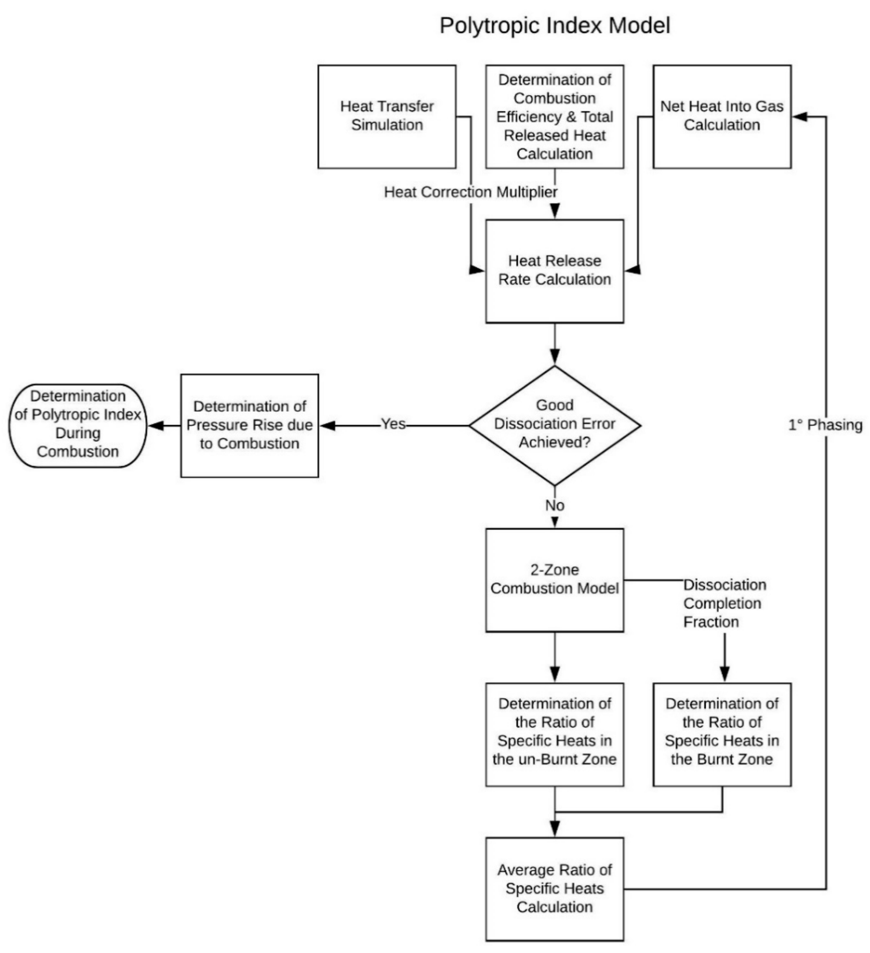
Introduction

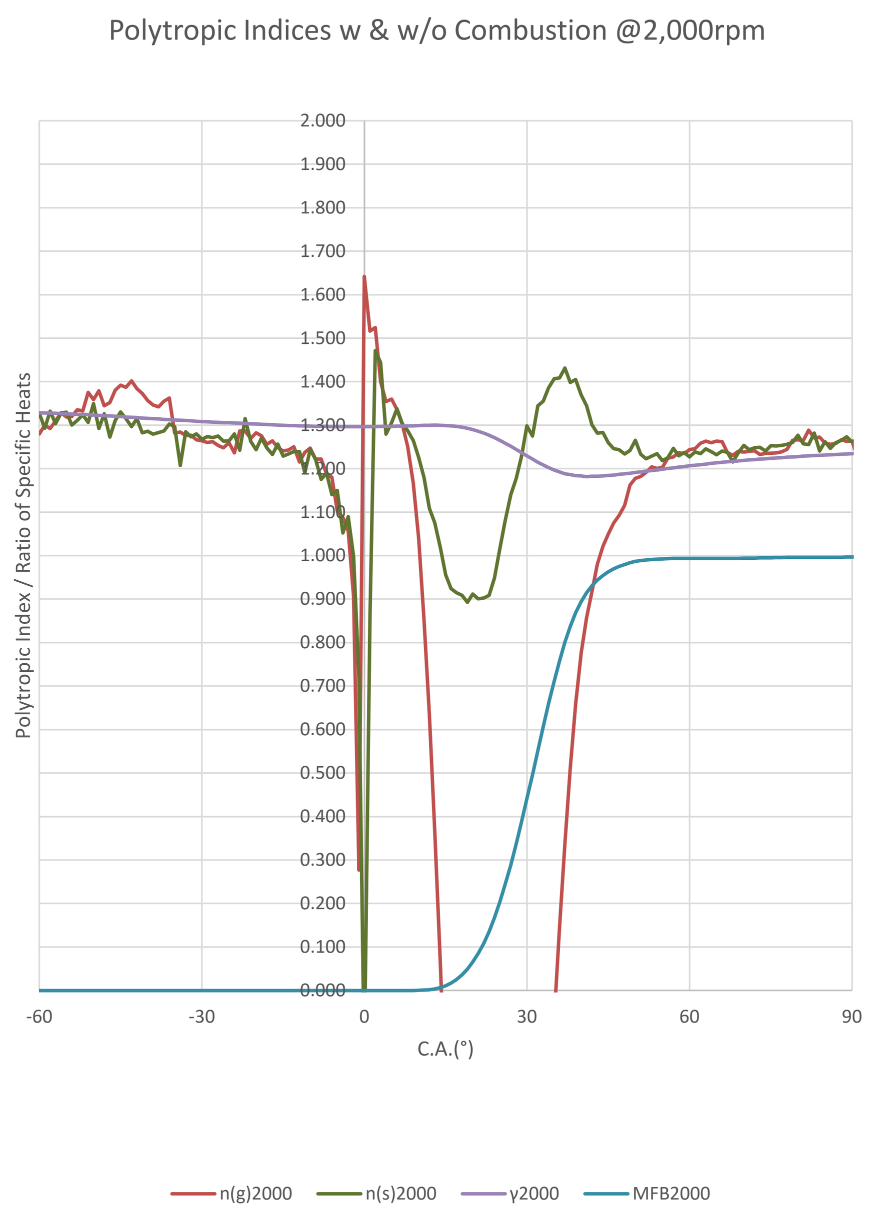
Powertrain industry is under pressure to create engines which produce less emissions, more power and require less fuel, more than ever before due to environmentally driven legislation, as well as the increasing consumer competitiveness of electrification. One of the technologies proven to greatly benefit the ICE efficiency is Turbulent Jet Ignition (TJI). As the technology is still novel for the industry, author has decided to investigate TJI systems and develop feasible design which can be relatively easily and cheaply implemented into the Ford Ecoboost 1.0l inline 3, codenamed "Fox". To do so, author at first developed a novel 0D self-correcting combustion analysis model, which calculated the real polytropic index during combustion and so, allowed for more accurate calculation of Heat Release Rate (HRR). Converge CFD package was used to simulate 3D combustion in the stock ICE, as well as eight different TJI designs.

Polytropic Index During Combustion Model

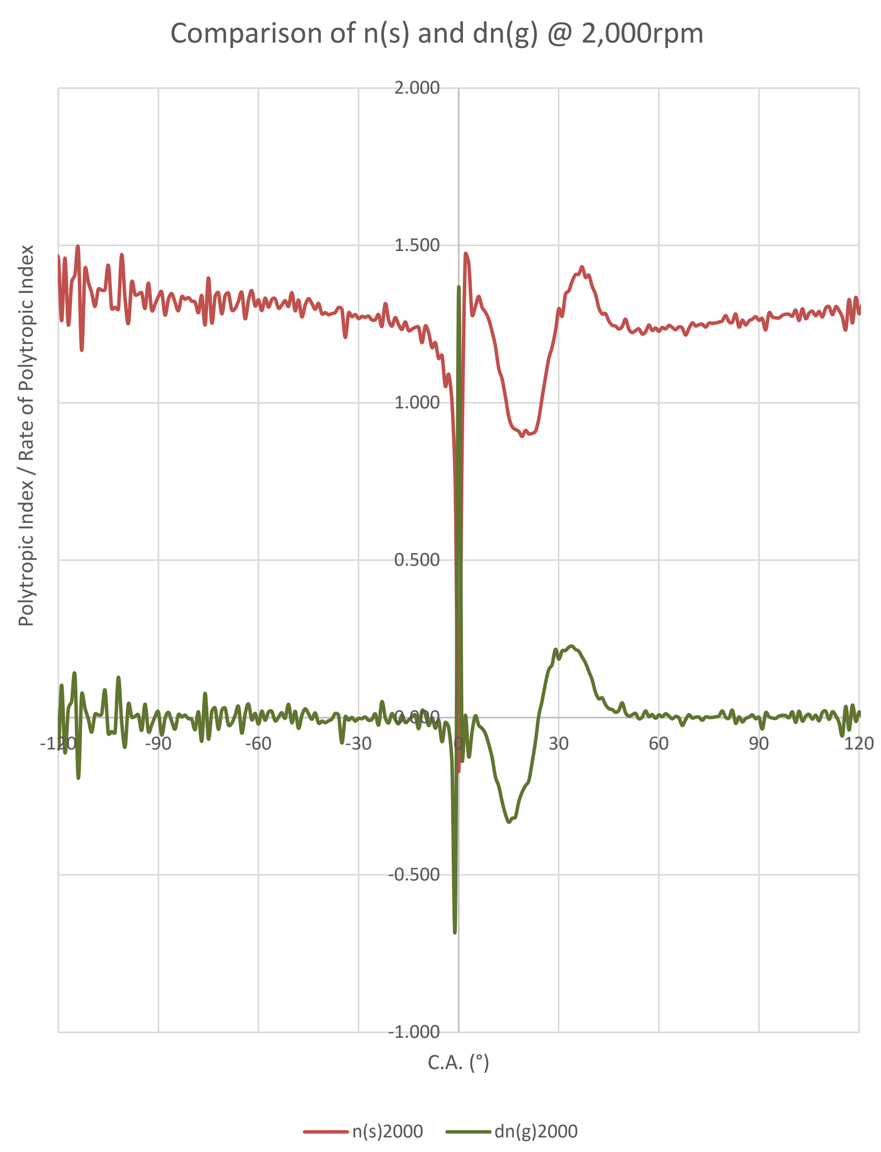
Author has developed a novel 0D 2-zone combustion model which is self-correcting inaccuracies regarding heat transferred and absorbed by the gas. The model was based around the combustion efficiency, which was retrieved from the analysis of exhaust gasses. A quasi-static 1D heat transfer model has been developed based on classical techniques and so included convection, conduction and radiation. The 2-zones allowed for accurate calculation of combusted temperature, which was utilised to calculate the ratio of specific heats, including the dissociation of CO_2 and H_2O, of which completion fraction was adjusted by the self-correction feature. The combination of corrected heat absorbed and transferred by the gas resulted in comprehensive HRR, which allowed accurate calculation of the polytropic index during combustion. The cause of the resultant profile has shown to be very abstract but physically linkable back to the data, although lack of equipment has unabled author to further investigate the matter, preventing confirmation of the findings. Most importantly, the polytropic comparison has shown the difference between adiabatic and polytropic process to be negligible and so, if the results are to be believed, author recommends assuming expansion polytropic index during the combustion phase, when modelling combustion by utilising classical methods. The results have been very thought provoking, ultimately extending the understanding of the ICE.



Schematic of the 0D Polytropic Index Model



Graph comparing the real polytropic index during combustion: n(s), to polytropic index of the gas: n(g).



Graph comparing the real polytropic index during combustion: n(s), to the differential of polytropic index of the gas: dn(g).

3D Combustion Modelling & Validation

The Converge CFD combustion model was validated by simulating the standard Ford Fox engine and comparing various, cylinder averaged results, the most important being the formation of thermal efficiency, which was 97.6% accurate.

Table of Simulated TJI Designs

Case Name	Nozzle Diameter & Type (mm)	Pre-chamber geometry	Pre-Chamber λ	Main-Chamber λ	Nozzle Length (mm)
A	1.0 - straight	Square	1.0	1.51	3.0
B	1.0 - straight	Cone	1.0	1.51	3.0
C	1.0 - straight	Over-Square	1.0	1.51	3.0
D	2.0 - straight	Cone	1.0	1.51	3.0
E	0.5 - straight	Cone	1.0	1.51	3.0
F	1.0 – 10° inc.	Cone	1.0	1.51	1.0 std. 2.0 div.
G	1.0 - straight	Cone	0.8	1.51	3.0
H	2x 0.7 - straight	Cone	0.8	1.51	1.0

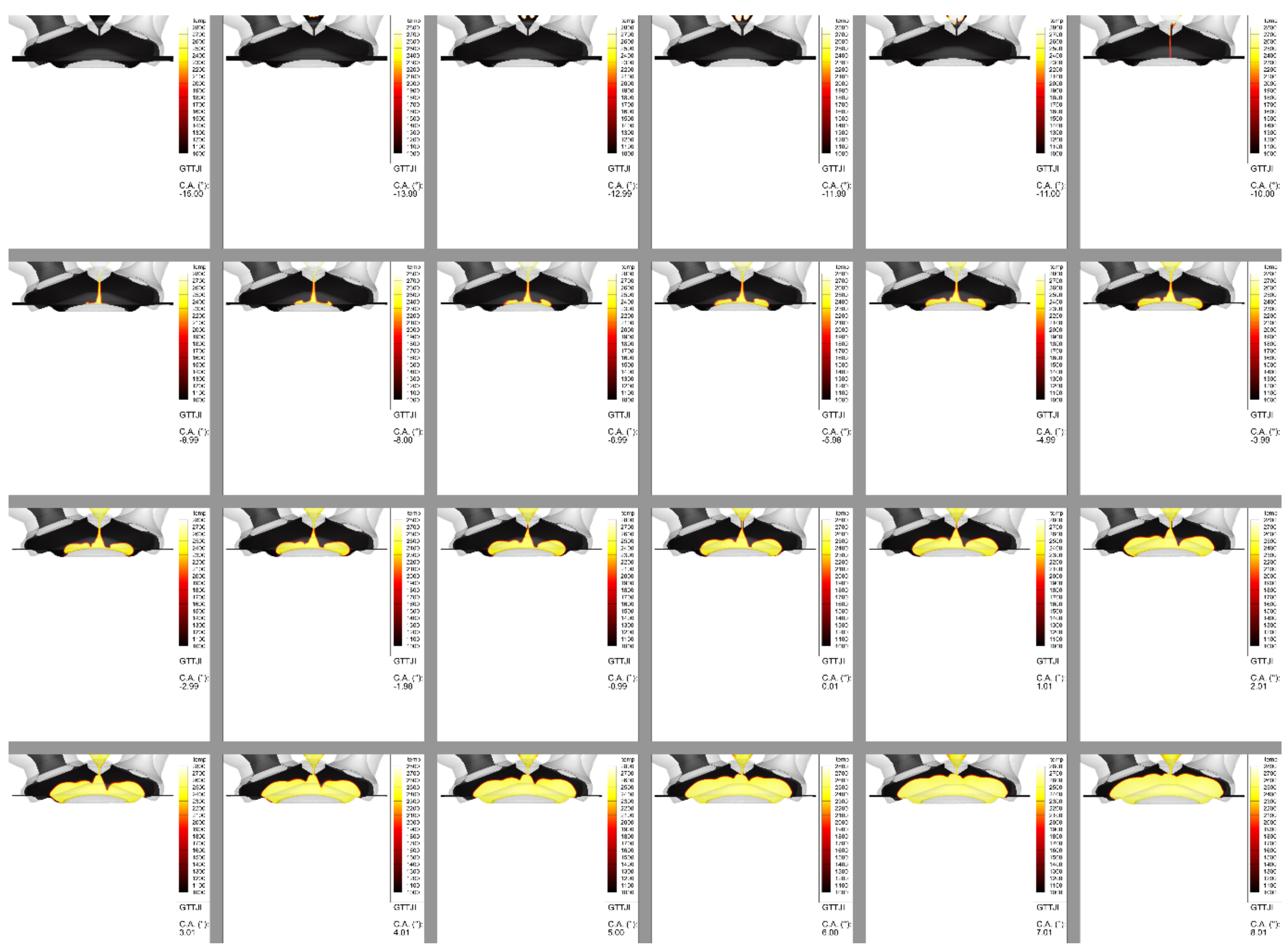
Turbulent Jet Ignition Targets

Objectives:

1. Increase indicated thermal efficiency to 50.0%
2. Reduce NOx concentration at EVO point by 50.0%

Limitations:

1. Peak pressure of standard ICE cannot be exceeded
2. Power output must not be reduced
3. Required modifications must be kept to minimum



Temperature (K) plots of the simulated Turbulent Jet Ignition inside Ford Ecoboost 1.0l.

TJI Modelling Results & Conclusion

Final design has achieved 42.3% indicated thermal efficiency, causing 24.1% reduction in fuel consumption. Results as well as literature suggest that the efficiency could be greatly improved by optimising the design, which would allow adherence to the set limitations.

Author was able to develop a rudimentary fuelling/ EGR strategy, which in combination with TJI, would result in practically 0 NOx emissions at all engine loads.