

Discrete volume-based thermal-fluid and structural modelling for LH₂ aircraft tanks

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INTRODUCTION & AIM

- LH₂ is a key sustainable aviation fuel, but safe cryogenic storage under flight loads is a critical challenge
- Sloshing during flight induces rapid thermodynamic changes, threatening pressure stability & fuel integrity
- Existing models lacked coupled interfacial heat & mass transfer during sloshing, a gap this study fills

Aim: Develop & validate a thermal-fluid model integrating sloshing dynamics for LH₂ tanks under dynamic flight conditions

- Validated on LN₂ experimental data before LH₂ application
- Parametric study: initial pressure, fill level & excitation characteristics
- Informs thermodynamics for a safe tank design for hydrogen-powered aircraft

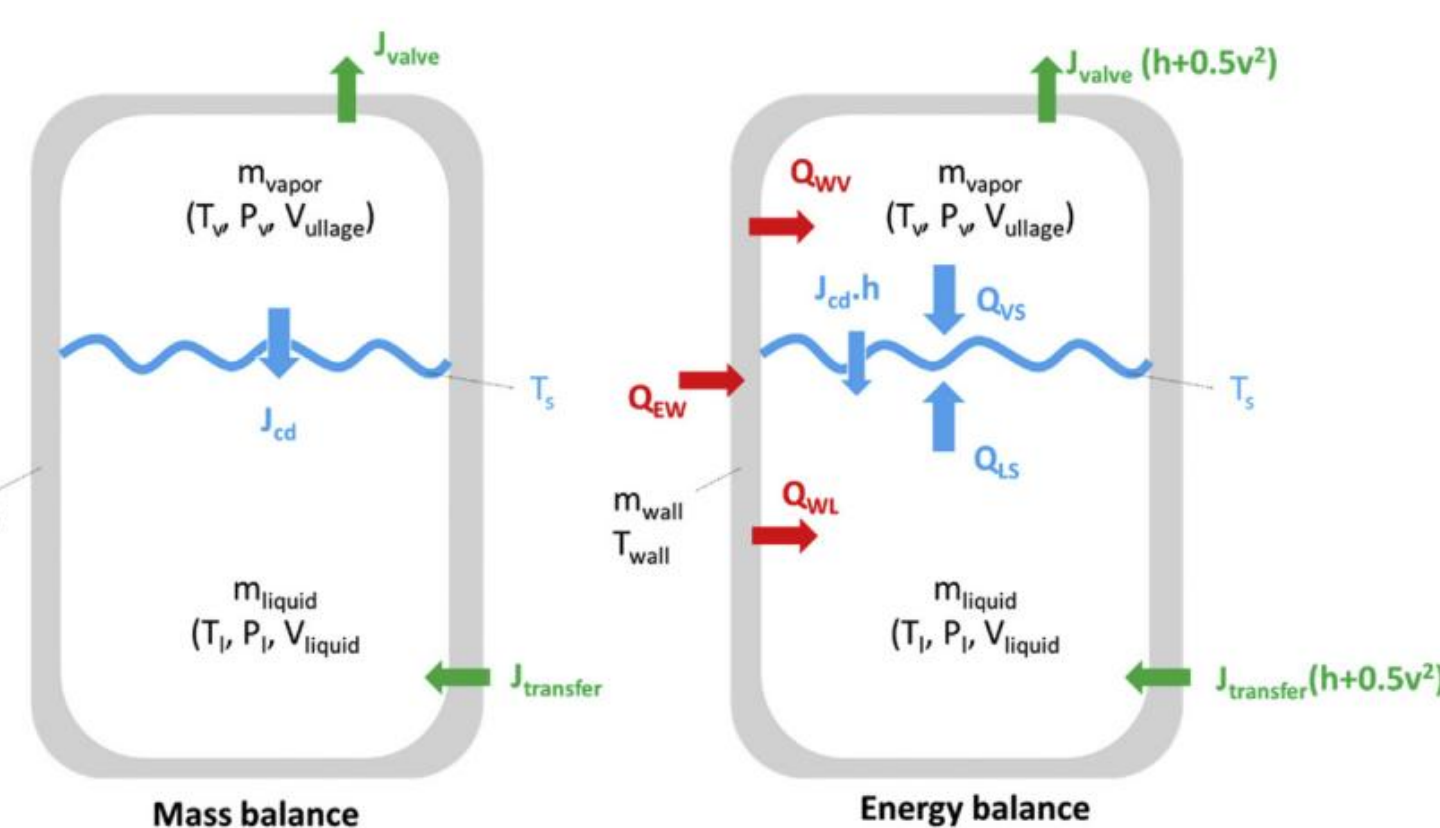


Figure 1: Illustration of the dynamic model used [1]

METHODOLOGY

- Thermal-fluid baseline:** Cranfield's in-house code; Ludwig's diffusivity model adapted to energy-based approach
- Sloshing integration:** Ludwig's sloshing dynamics embedded into Petitpas's framework; captures interfacial condensation & turbulence
- Validation:** validated against LN₂ experimental data; applied to LH₂ under cryogenic similarity assumptions

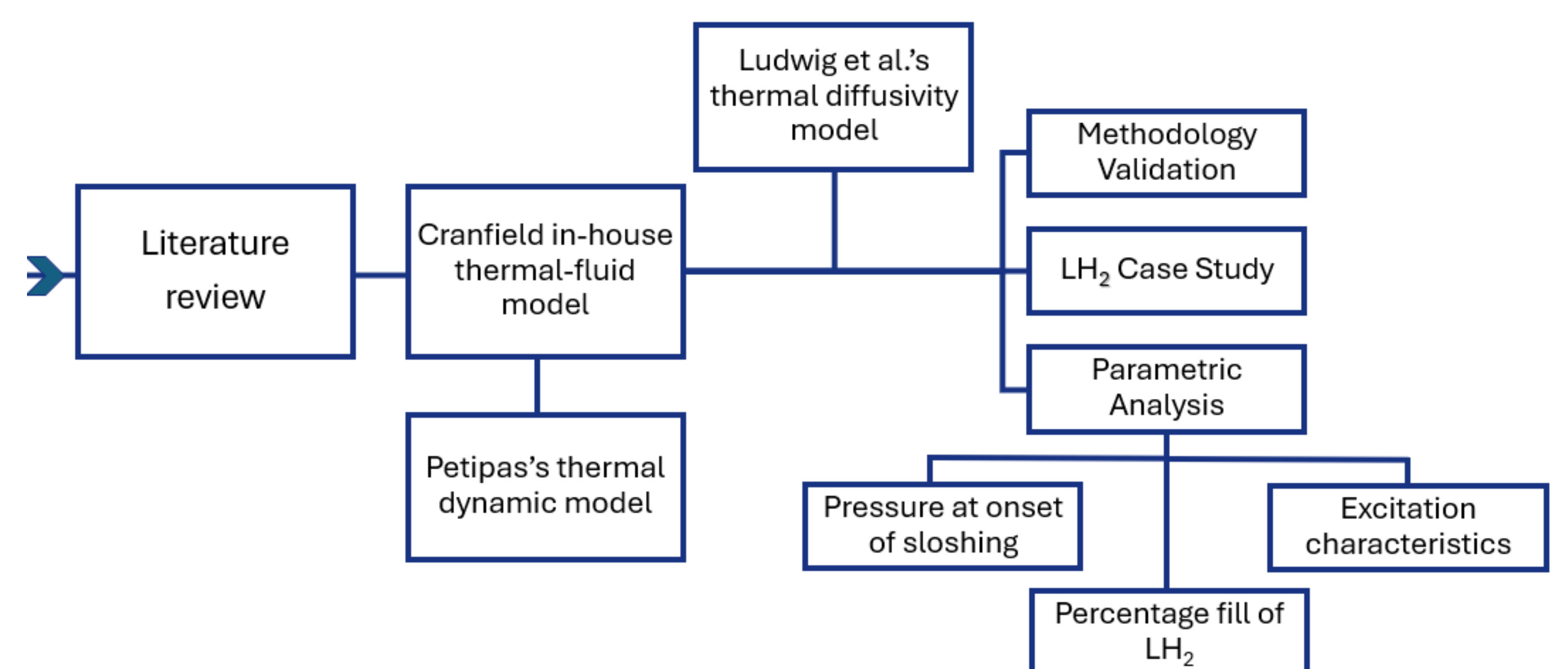


Figure 2: 3-Phase methodology overview

RESULTS & DISCUSSION

≤7%

Model deviation vs. LN₂ experiment

100 kPa

Pressure drop over 40 s (sloshing phase)

5.2 kPa/s

Chaotic sloshing rate

5–8%

Extra drop at 85% vs 75% fill level

Validation - LN₂ experimental data

- LN₂ benchmark - Ludwig et al. [3]; GN₂ pressurised to 300 kPa, followed by relaxation
- Lateral sloshing induced using planar wave at 1.49Hz & 5.1 × 10⁻³m amplitude, post-stabilisation
- Model reproduced rapid drop & stabilisation accurately, with deviation of ≤7%

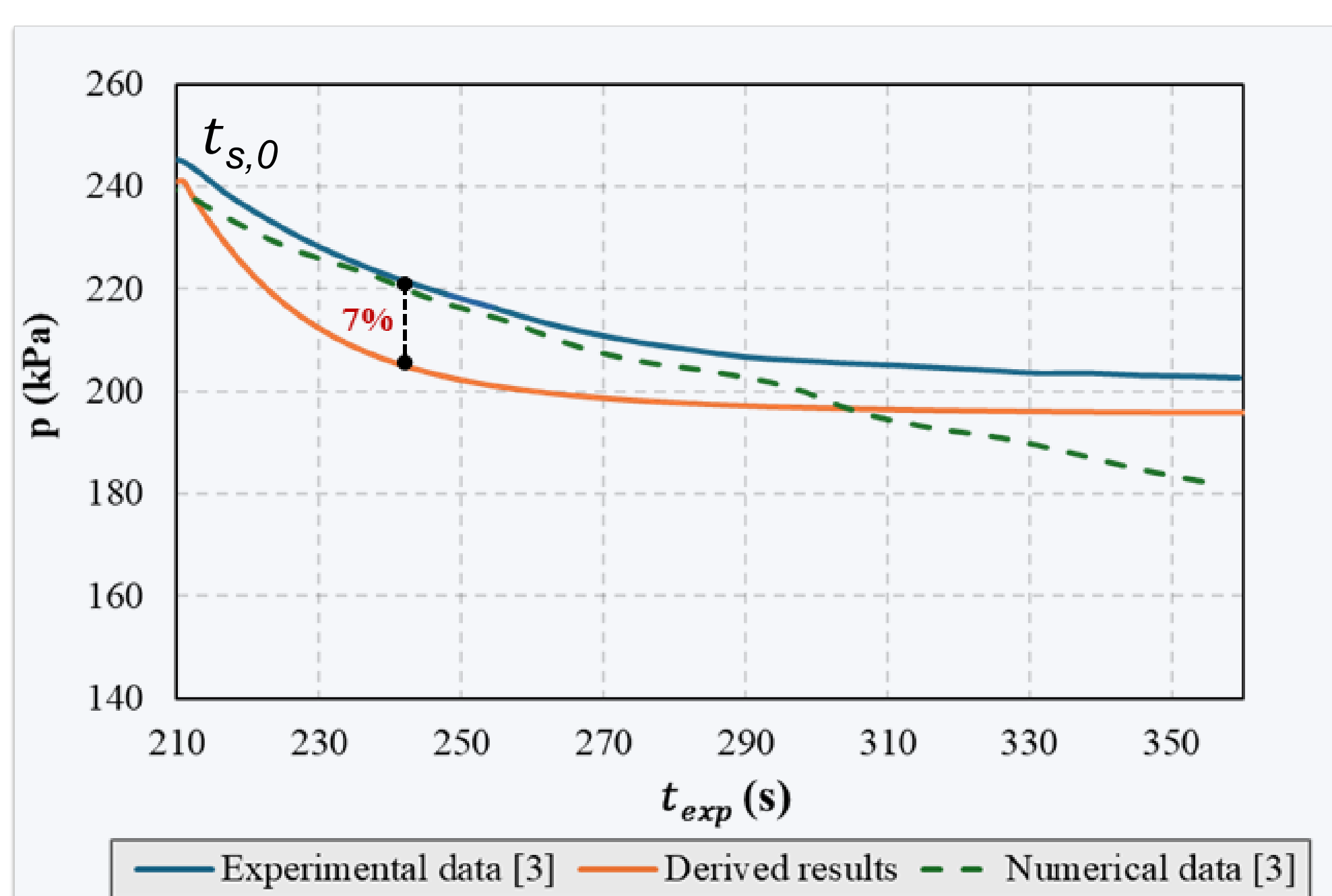


Figure 3: Tank pressure vs. time during sloshing phase: derived results vs. Ludwig et al. [3]

LH₂ case study – sloshing induced

- Instead of relaxation, hold-phase control added per Moran et al. [2]; pressure raised to 250kPa
- 100 kPa drop observed in 40s, enhanced interfacial condensation & turbulence driven by sloshing
- Chaotic patterns (5.2kPa/s), 63% faster than planar waves (3.2kPa/s)

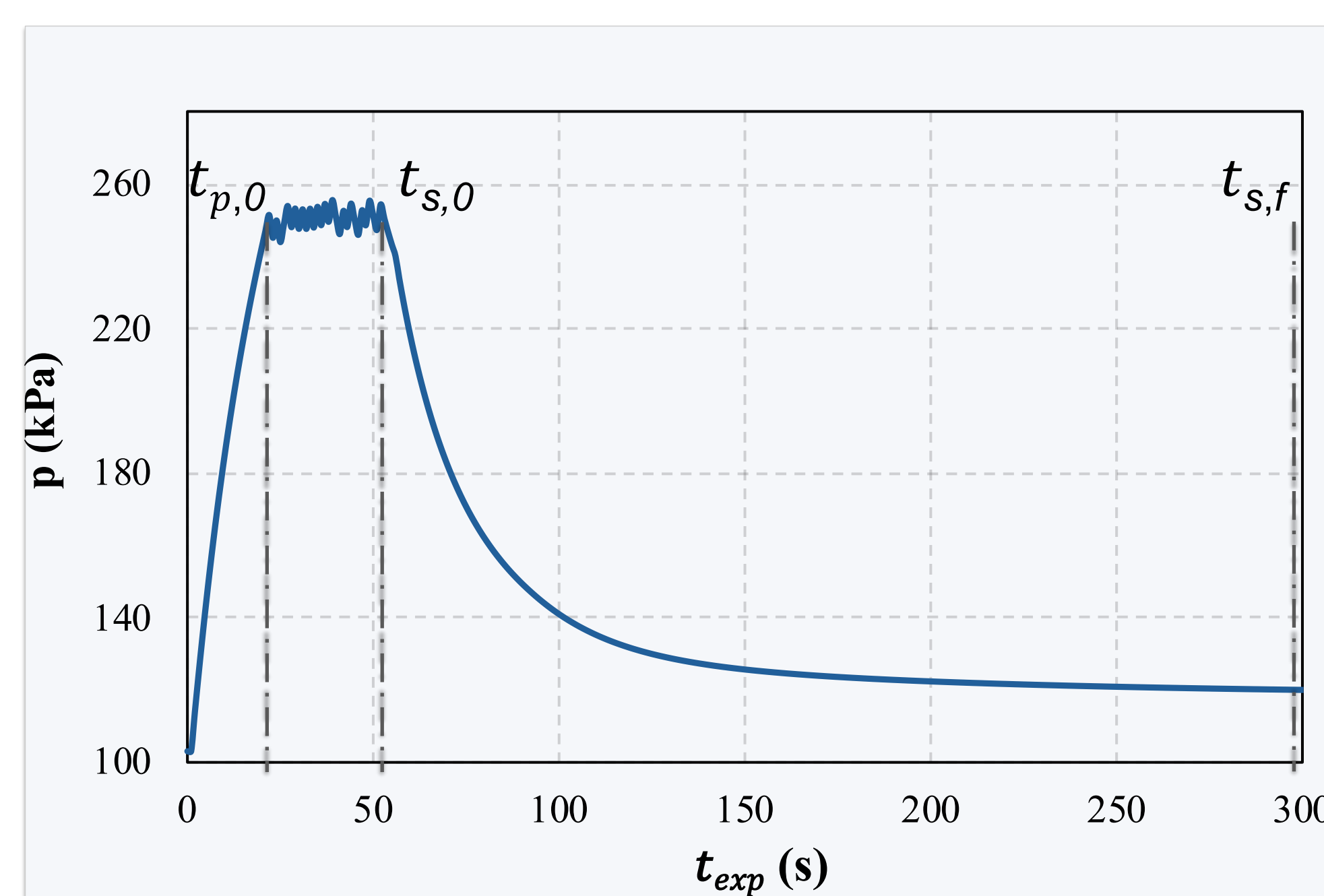


Figure 4: LH₂ Case study: tank pressure variation vs. of time

Parametric study

| PARAMETER | SLOSHING EFFECT |
|------------------------------|----------------------|
| Initial tank pressure ↑ | Pressure drop rate ↑ |
| LH ₂ fill level ↑ | Pressure drop ↑ |
| Excitation frequency ↑ | Dominant driver |
| Excitation amplitude ↑ | Secondary role |

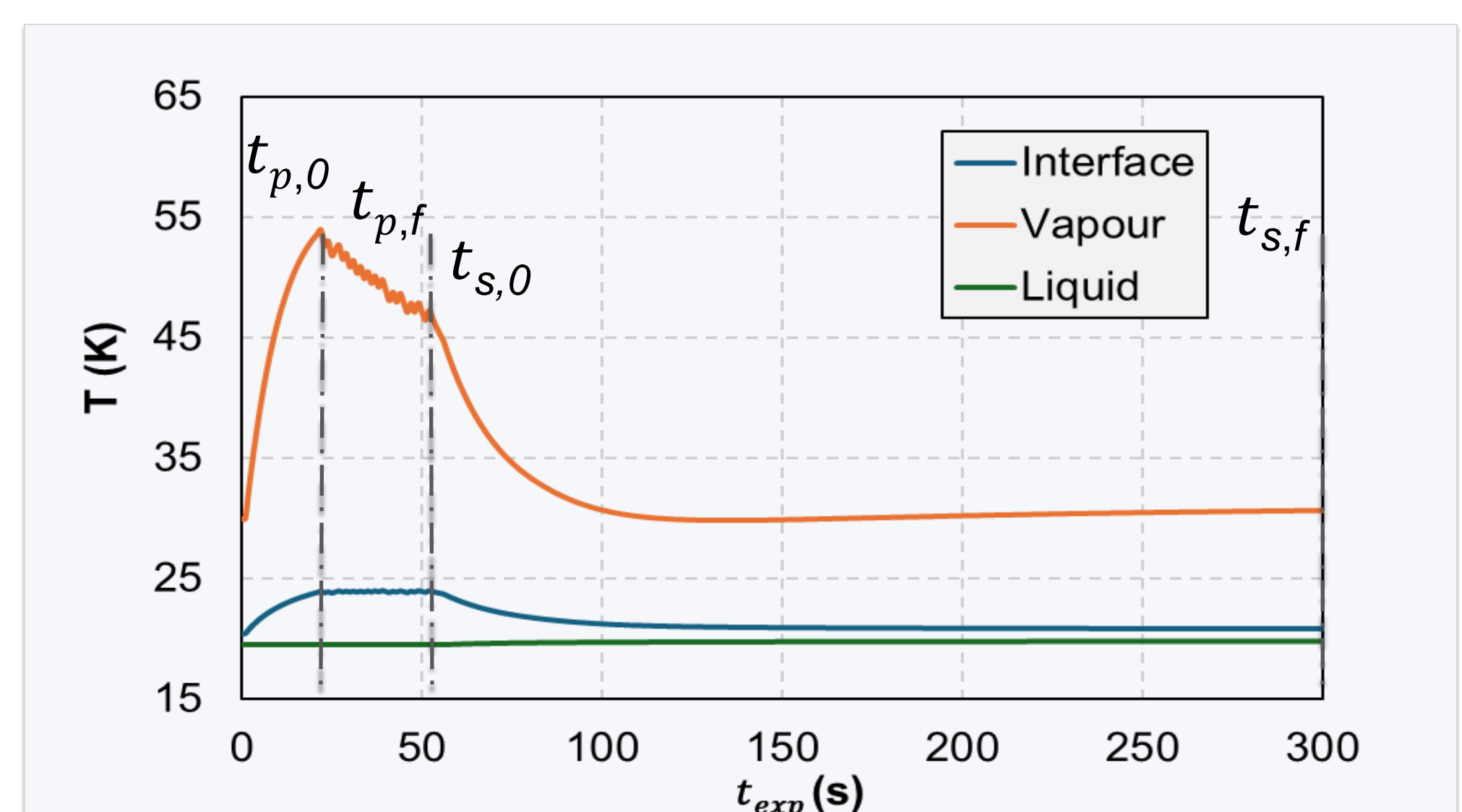


Figure 5: LH₂ Case study: temperature profiles for interface, vapour and liquid vs. time

CONCLUSIONS / FUTURE WORK

Conclusions

- Enhanced model integrates sloshing dynamics into cryogenic simulation, validated to within acceptable deviation of 7%
- Higher LH₂ fill levels & initial pressures amplify pressure drop, critical for safety design margins
- Excitation frequency is the dominant instability driver over amplitude
- Delivers design guidance for LH₂ tanks in next-gen hydrogen aircraft

Future work

- Simulate real-world gust frequencies from flight data
- Apply to actual aerospace tank geometries
- Extend to 1D spatial framework for localised phenomena

REFERENCES / ACKNOWLEDGEMENT

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