Modelling and simulation of the Stralis Bonanza A36-HE hydrogen-electric aircraft

emission free aircraft

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Introduction

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- iMOVE CRC project
- Bonanza A36-HE technology demonstrator
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  - Modelling approach
  - Hydrogen and fuel cell system modelling
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- Challenges, opportunities & next steps

Stralis Aircraft overview


Stralis will deliver 50,000 x 50-seat hydrogen-electric aircraft by 2050

The Stralis SA-1

50% cheaper to operate

Compared to fossil fuel powered alternatives.

Powered by Hydrogen

The SA-1 only emits water vapour.

Propulsion Type	Hydrogen Electric
Fuel Type	Liquid Hydrogen
Max. Passengers	50
Max. Payload	5000 kg (11,000 lb)
Max. Range	3000 km (1620 nm)
Cruise Speed	580 km/h (313 kts)

Stralis SA-1

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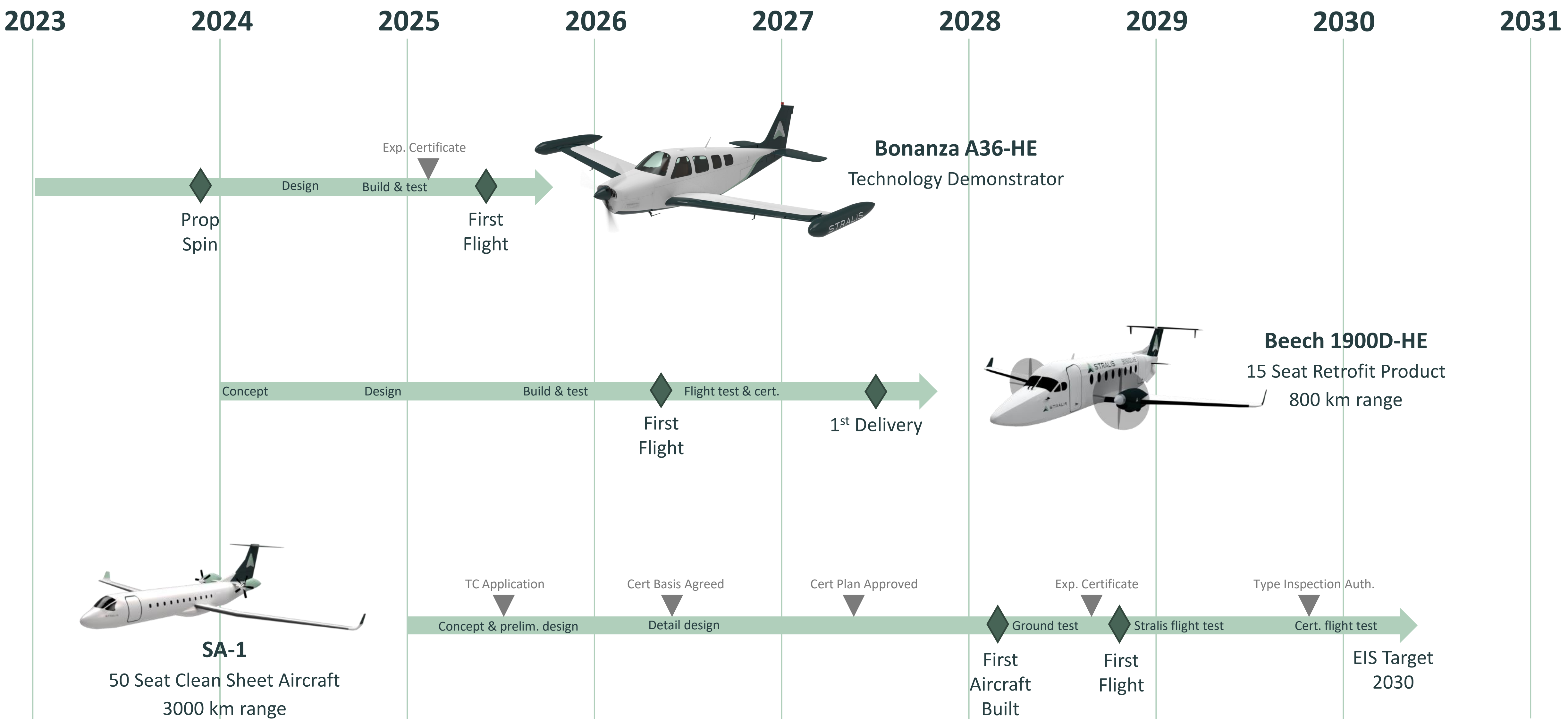
Roadmap



Our team

Our founding team has a track record of rapidly developing aircraft for leading programs worldwide.

Bob Criner
Co-founder & CEO

Stuart Johnstone
Co-Founder & CTO

Steffen Geries
COO

Steven Holden
Chief Aircraft Engineer

Dr Emma Whittlesea
Head of Partnerships

Dr Mark Broadmeadow
Prop. Control System Lead

Grant Hiller
Propulsion Lead

Dr Peter Mauracher
Elec. Engineering Lead

Luciano Serra
Head of Certification

Dr Andrew Dicks
Fuel Cells Lead

Darren Matthews
Lead LAME

Tom Benedetti
Prop. Test Systems Eng.

Google[x]
AIRBUS
magniX
AMPAIRE
Gulfstream
Heart Aerospace
BETA TECHNOLOGIES

Hydrogen Flight Alliance (HFA)

ALLIANCE

Ensuring Australia's leading role in the aviation industry's transition towards net-zero by 2050

HFA HYDROGEN FLIGHT ALLIANCE

- → Green hydrogen production, distribution, transportation, storage, and dispensing.
- → Green hydrogen energy and aircraft integration, in and around the airport and airspace.
- → Aircraft design, certification, manufacturing, maintenance, ground handling, refuelling and flight ops.

STRALIS · Aviation Australia · BNE Brisbane Airport · Griffith University Queensland Australia · Gladstone Airport Corporation · Skytrans · h2ec h2 energy company · QUT · CQUniversity Australia · BOC A Linde company

iMOVE CRC project

iMOVE CRC project

- Six-month collaboration between Stralis and QUT
- Conducted over three, 2-month phases
  - Increasing model complexity and fidelity

Objectives

1. Validate the design requirements for the Bonanza A36-HE
2. Inform the design of systems and components (trade studies)
3. Provide a plant model as the basis for developing control software
4. Provided a basis for Hardware-in-the-Loop (HiL) testing

Australian Government
Department of Industry, Science and Resources

Bonanza A36-HE technology demonstrator

Bonanza A36-HE

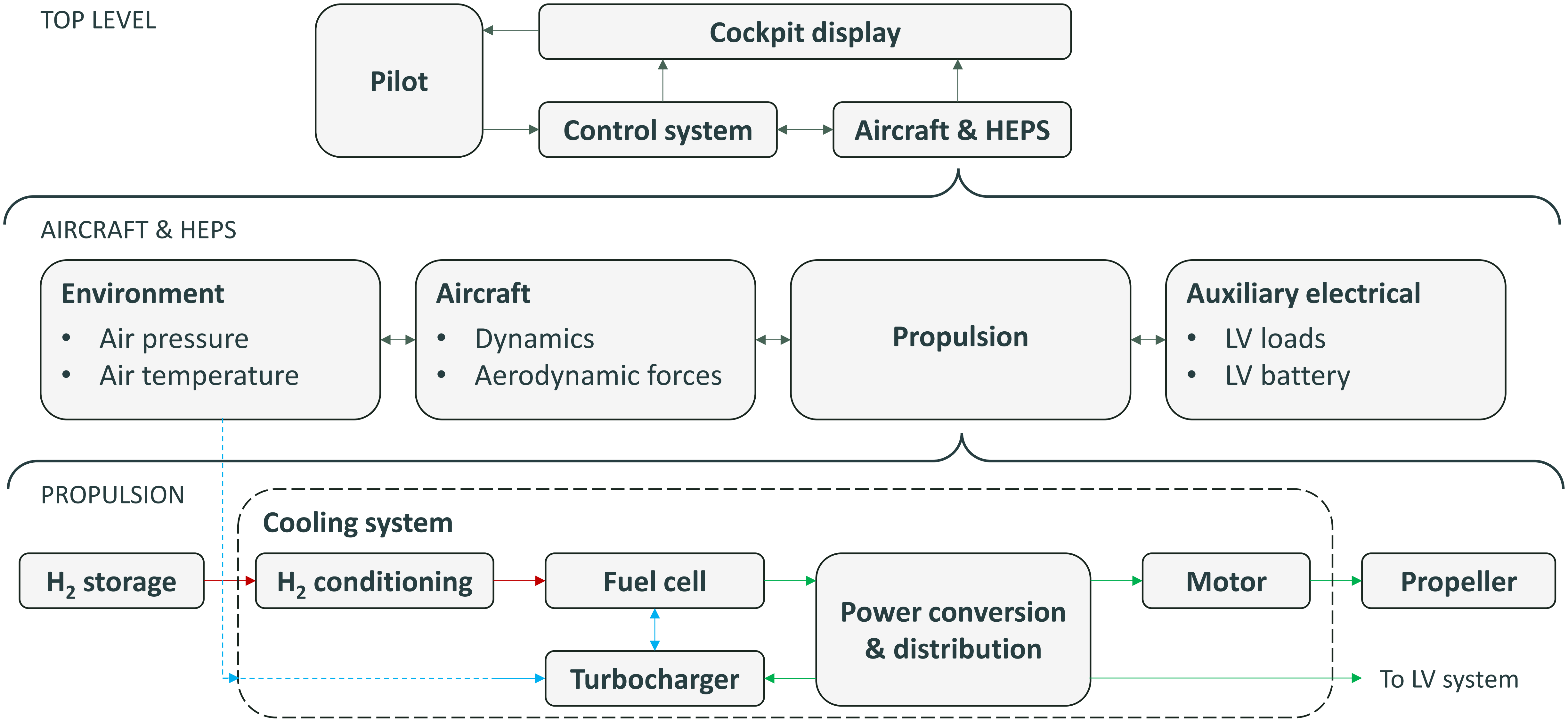
- Beechcraft Bonanza A36 retrofitted with Stralis hydrogen-electric propulsion system
- 26 kg LH_2 carried in wing-tip tanks
- 180 kW electric motor with integrated drive
- 2x 110 kW HT-PEM fuel cells
- 10,000 ft operating altitude
- 156 kt cruise speed
- 500 km range

Flying test bed "Bonnie"

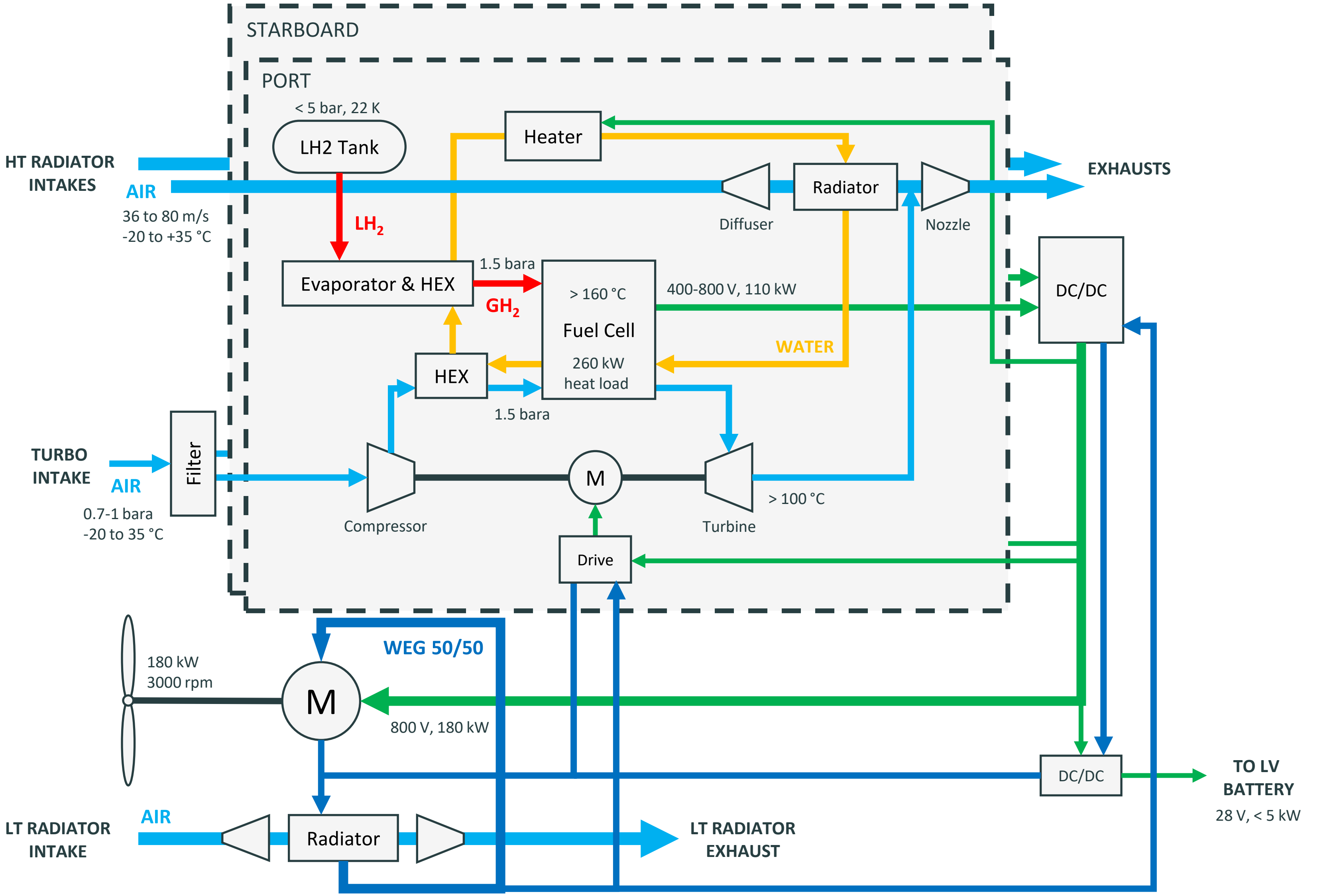
Iron-bird "Clyde"

Modelling the Bonanza A36-HE

System architecture



Propulsion system overview

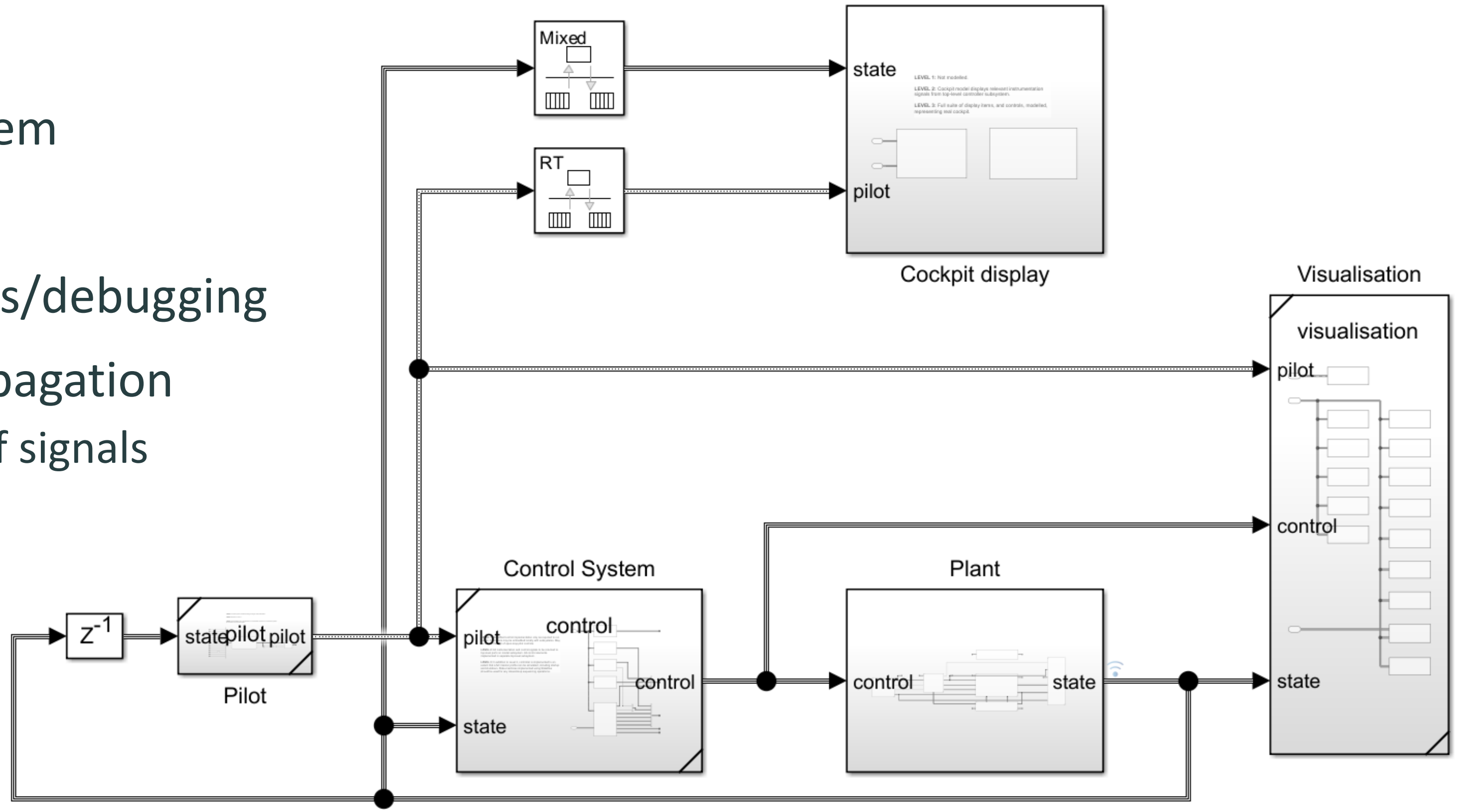


Modelling approach

- Simulink time-domain model
- Ultimately suitable for real-time simulation
  - Fixed time step
  - Only components that support code generation
- Incremental approach
  - Subset of systems initially; systems added over time
  - Analytical models transitioned to physical Simscape networks
- Modelled based on public domain component data
  - Individual components and systems validated using test benches
  - Overall model validated using aircraft mission profile

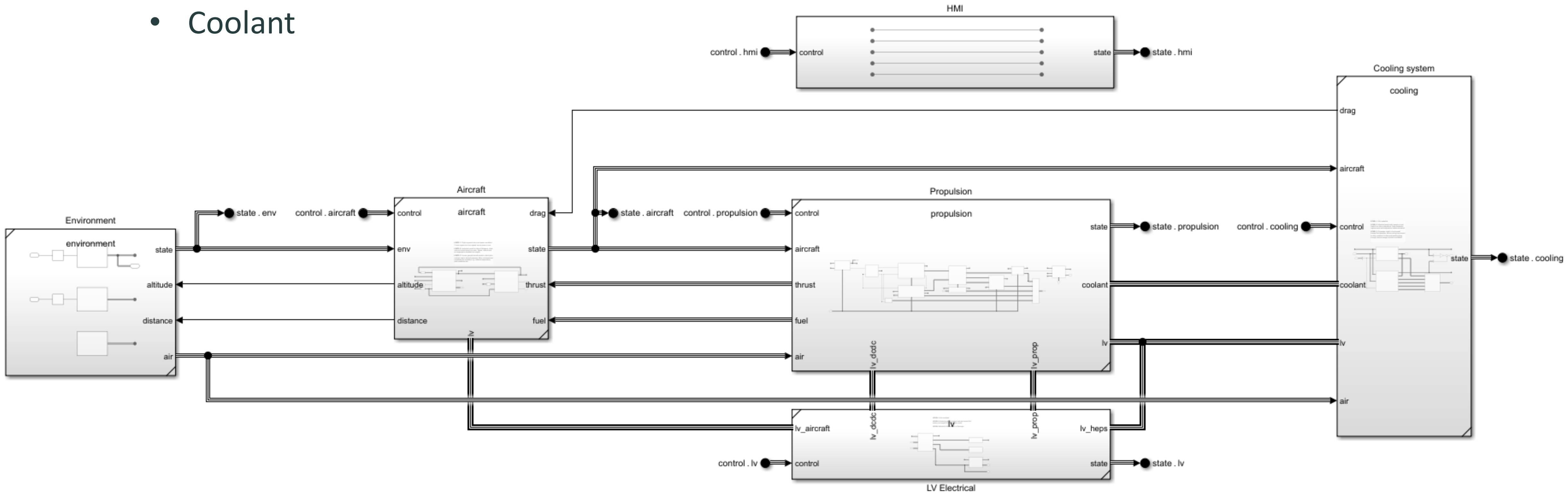
Top-level model structure

- Plant takes control action as input and produces state signals as output
- Control in separate top-level subsystem
  - Facilitates future code generation
- Pilot modelled in separate subsystem
- Cockpit visualization
- Visualisation subsystem for analysis/debugging
- Simulink buses used for signal propagation
  - Rapid prototyping and addition of signals

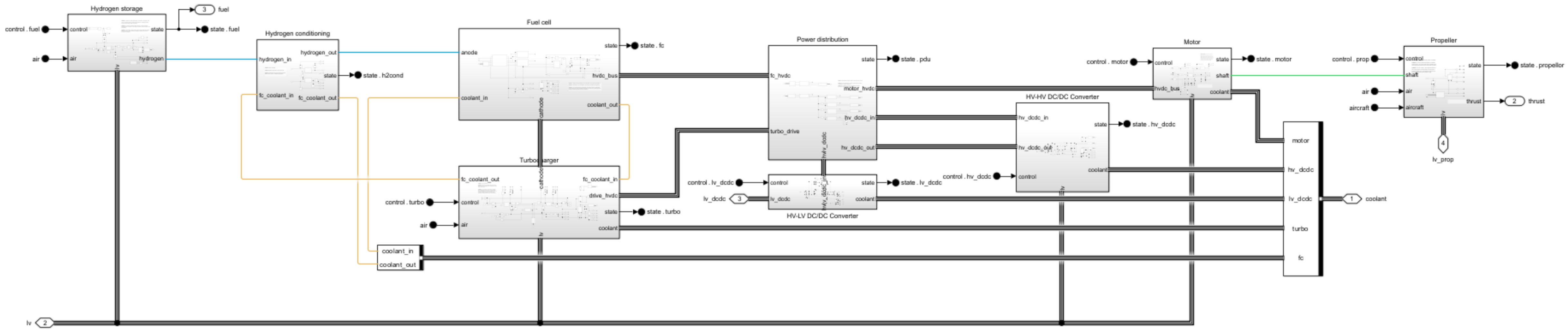


Plant system

- Simscape busses used to collect physical networks into single ports
  - LV electrical
  - Coolant



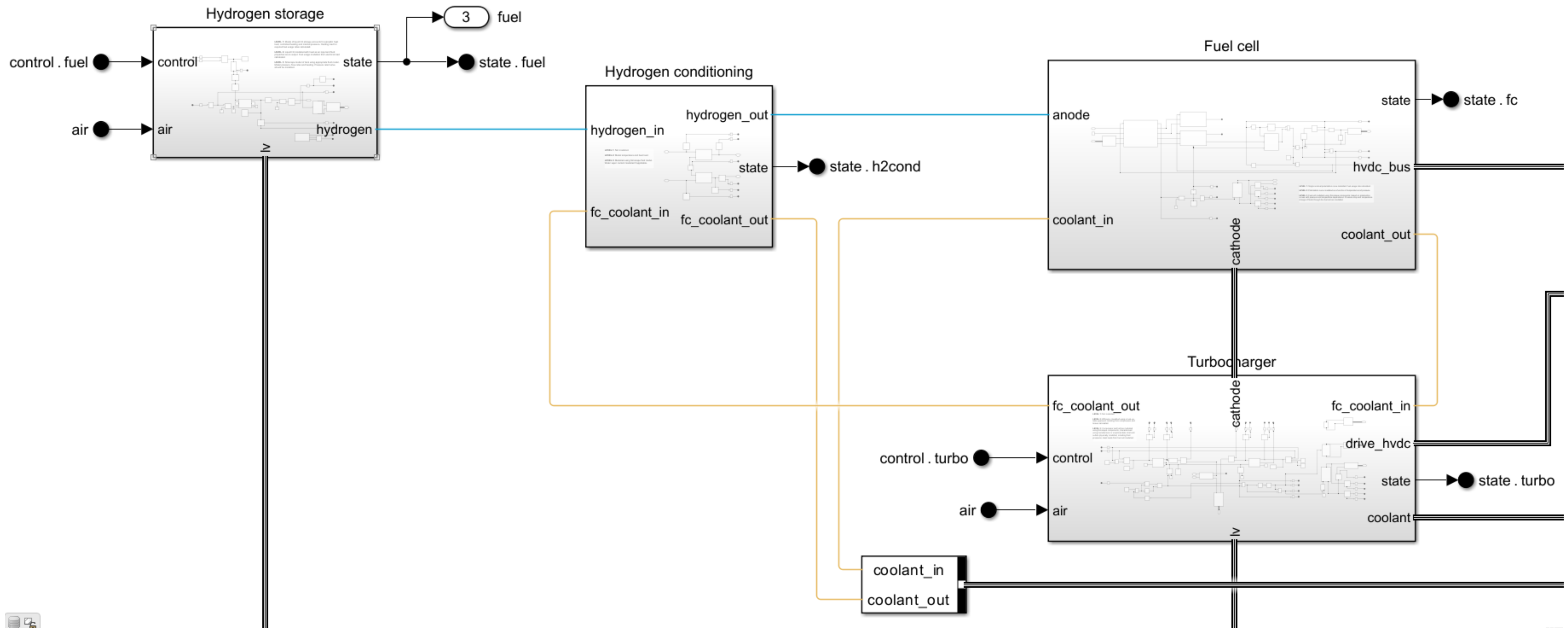
Propulsion system model



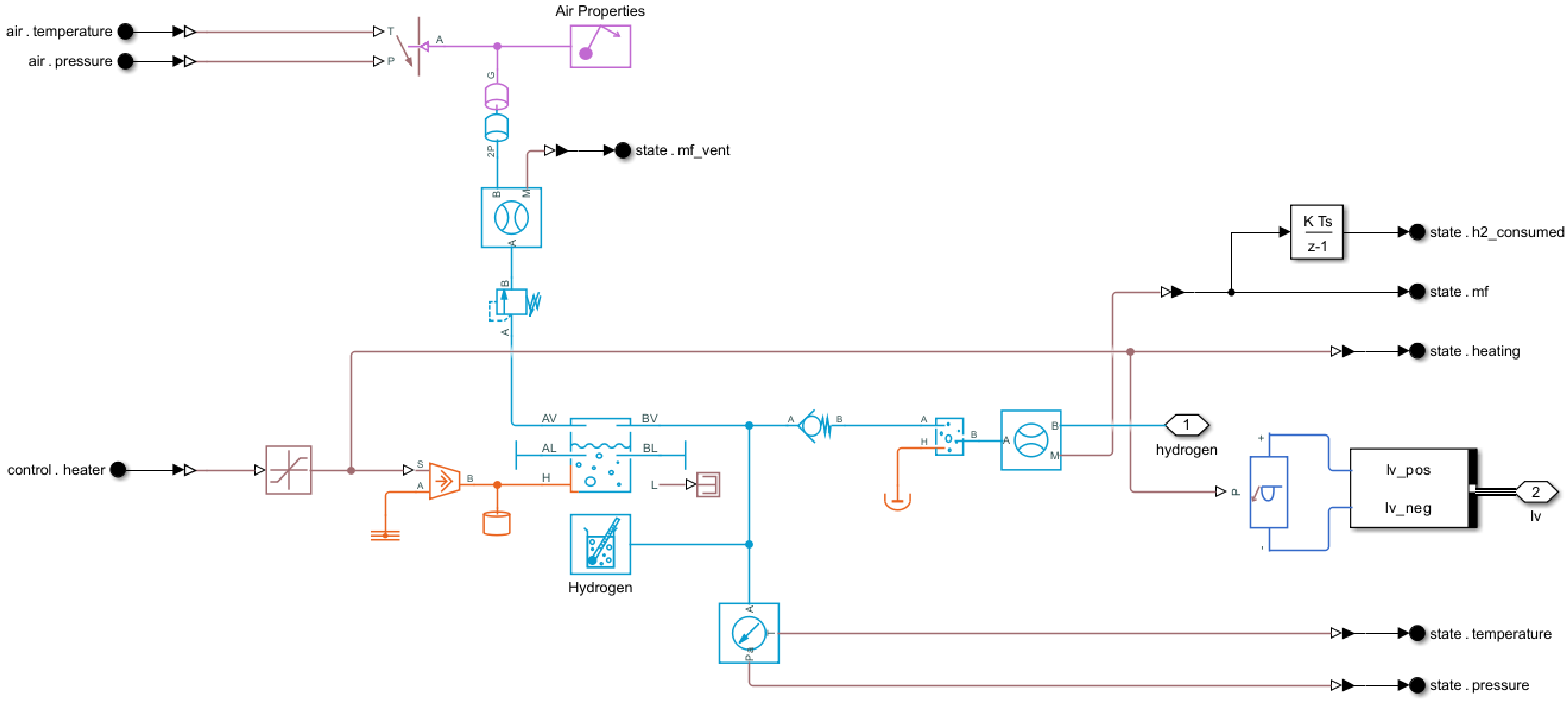
Single coupled Simscape physical network, 10 ms simulation timestep

- Hydrogen: Two-phase fluid network (hydrogen)
- Electrical: HV (800 V), LV (28 V)
- Cathode air supply: Gas (air) and moist air (nitrogen, oxygen, water vapor) fluid networks
- High-temperature cooling: Thermal liquid (water)
- Low-temperature cooling: Thermal liquid (water/ethylene glycol)
- Air cooling: Gas (air)
- Motor & propeller: Mechanical

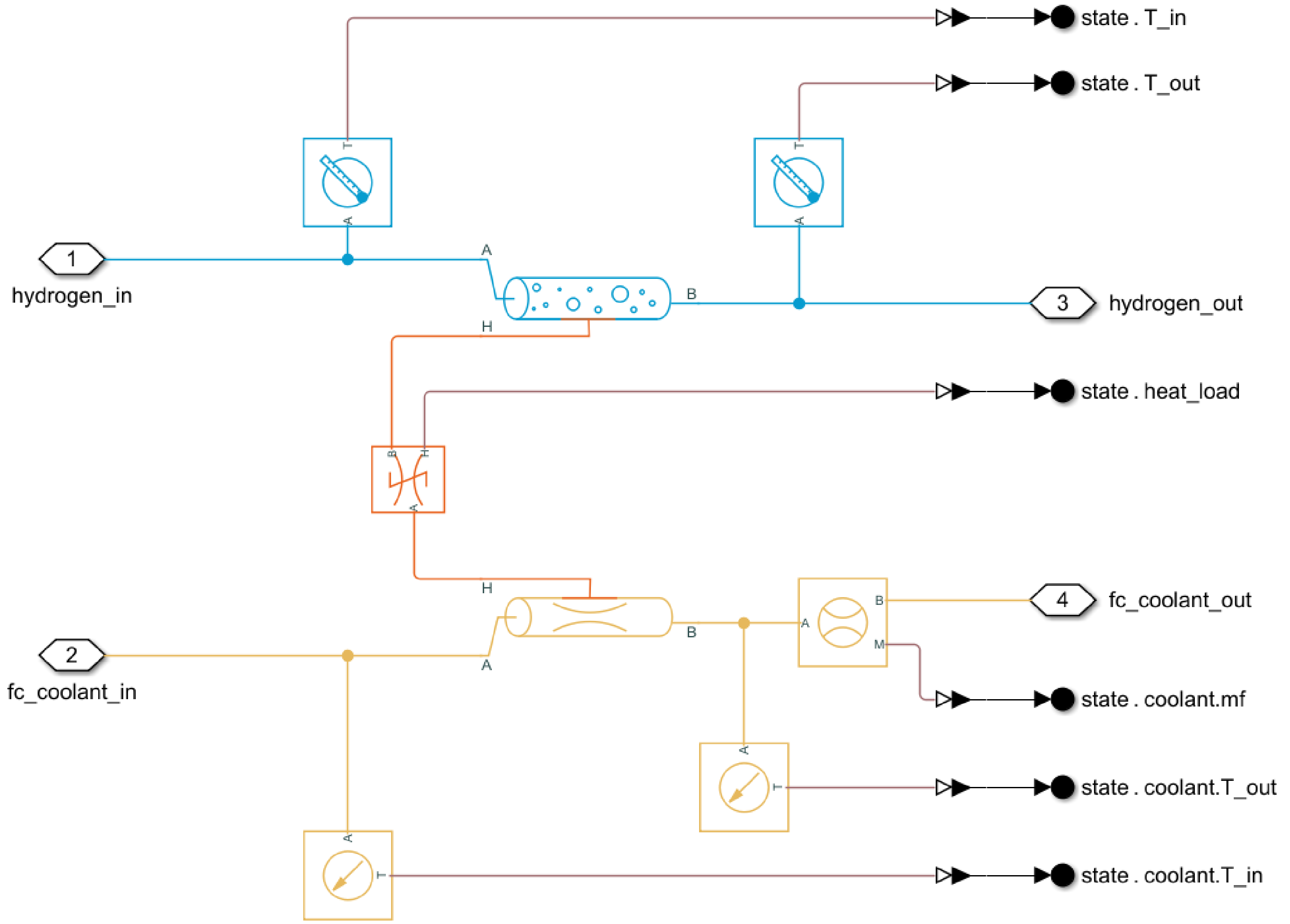
Hydrogen and fuel cell systems



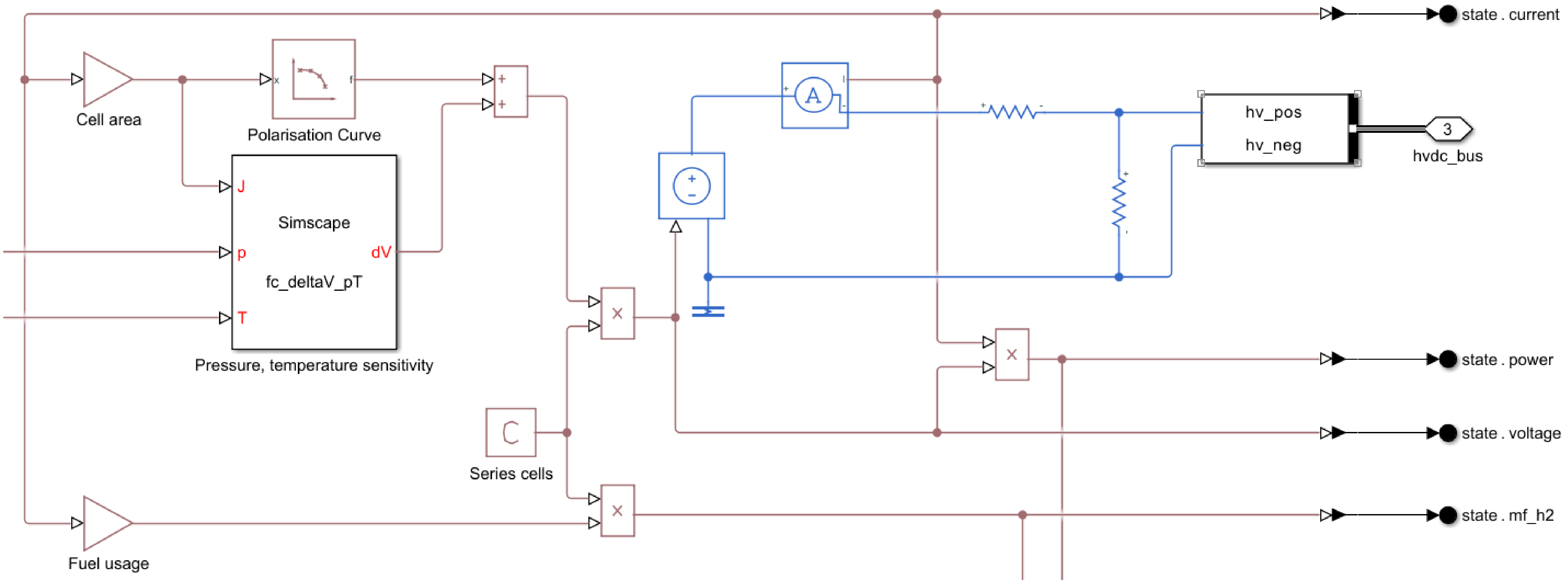
Hydrogen storage



Hydrogen conditioning



Fuel cell: Electrical

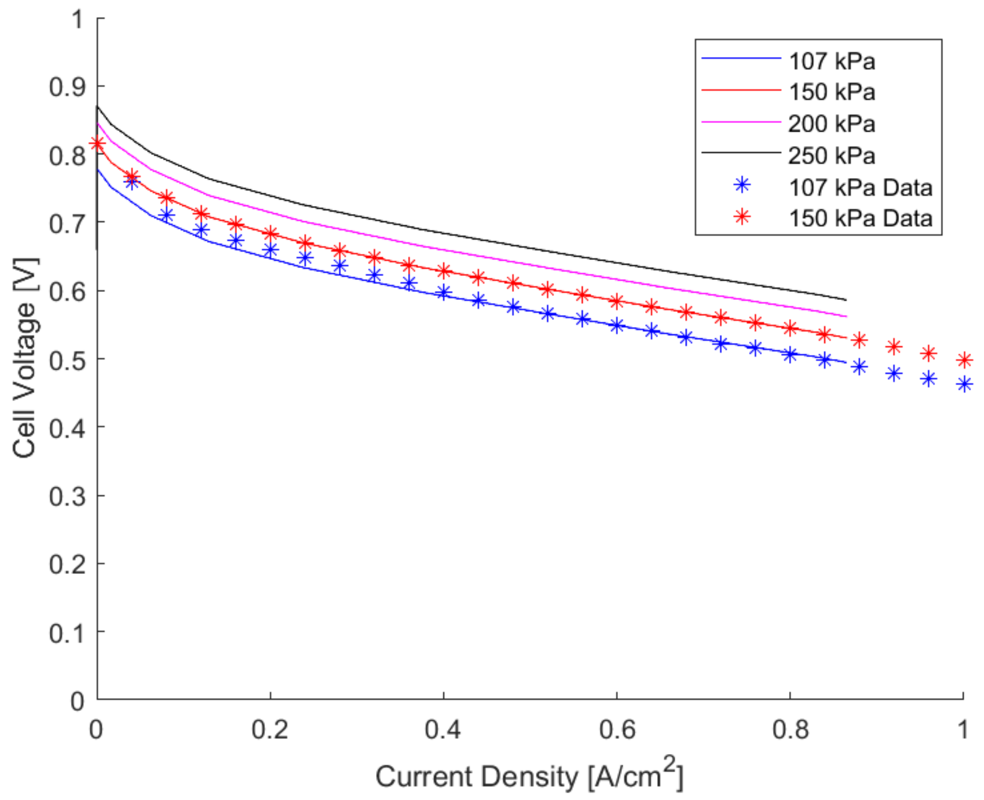


$$\Delta V_T = (c_T + a_T \cdot J^{b_T})(T - T_{\text{ref}})$$

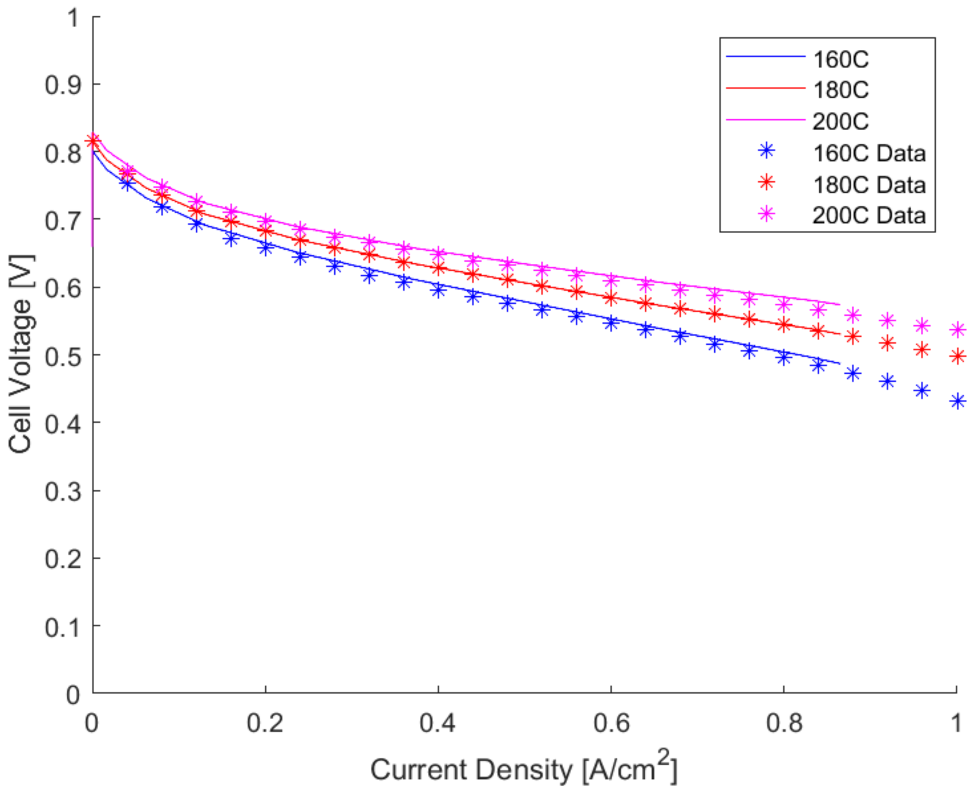
$$\Delta V_p = (c_p + a_p \cdot J^{b_p}) \ln \frac{p}{p_{\text{ref}}}$$

Fuel cell: pressure & temperature

Pressure

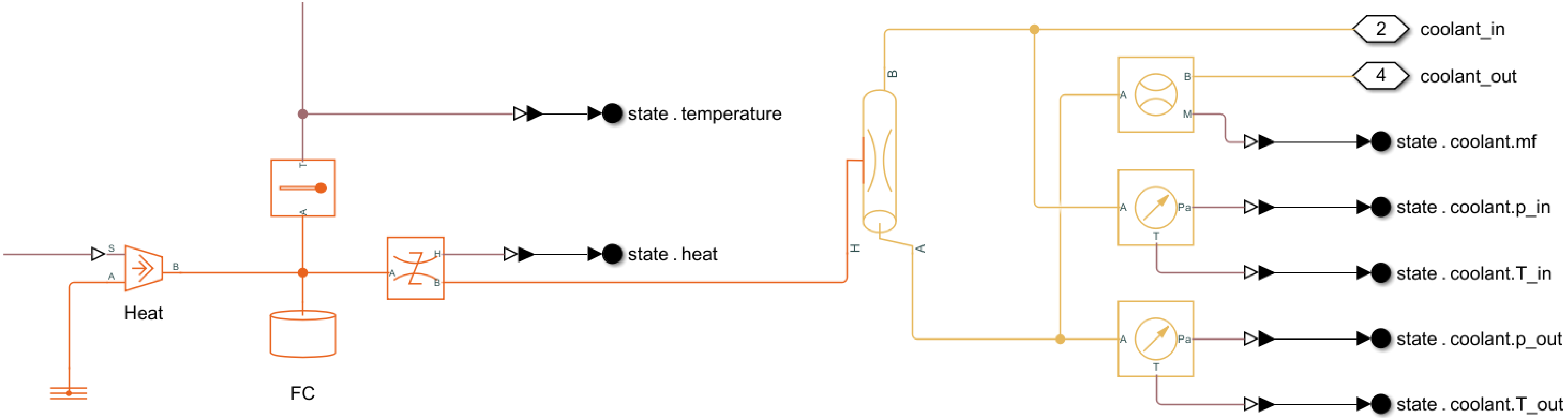


Temperature

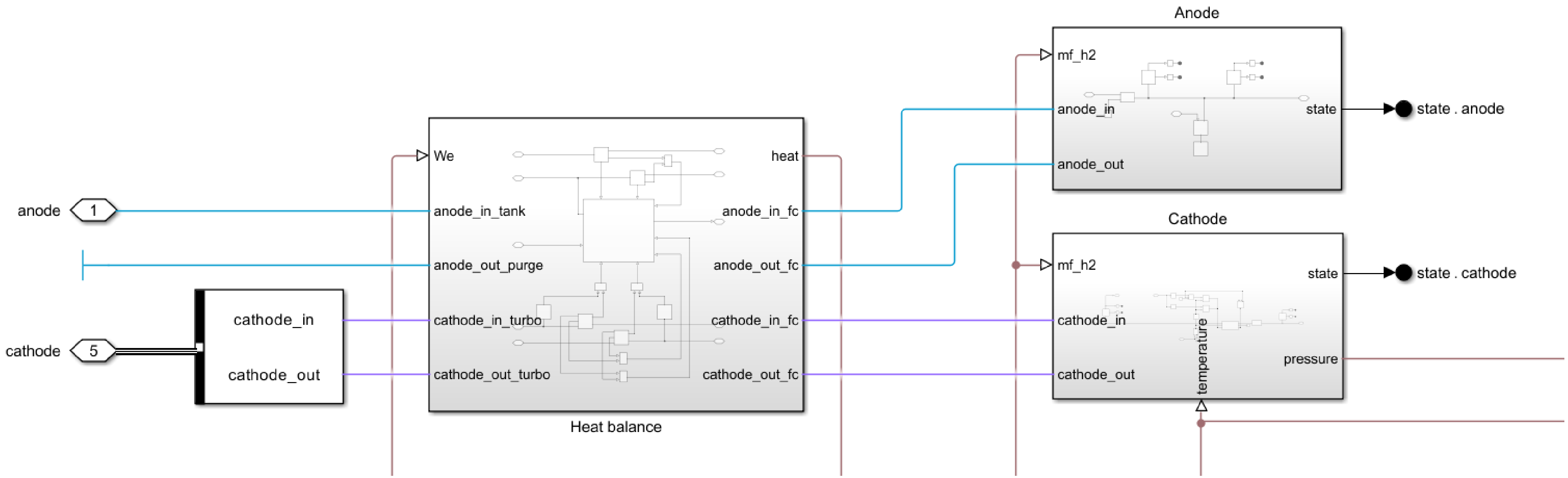


https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/review20/fc320_hibbs_2020_o.pdf
https://data.epo.org/publication-server/rest/v1.0/publication-dates/20220928/patents/EP4064397NWA1/document.pdf

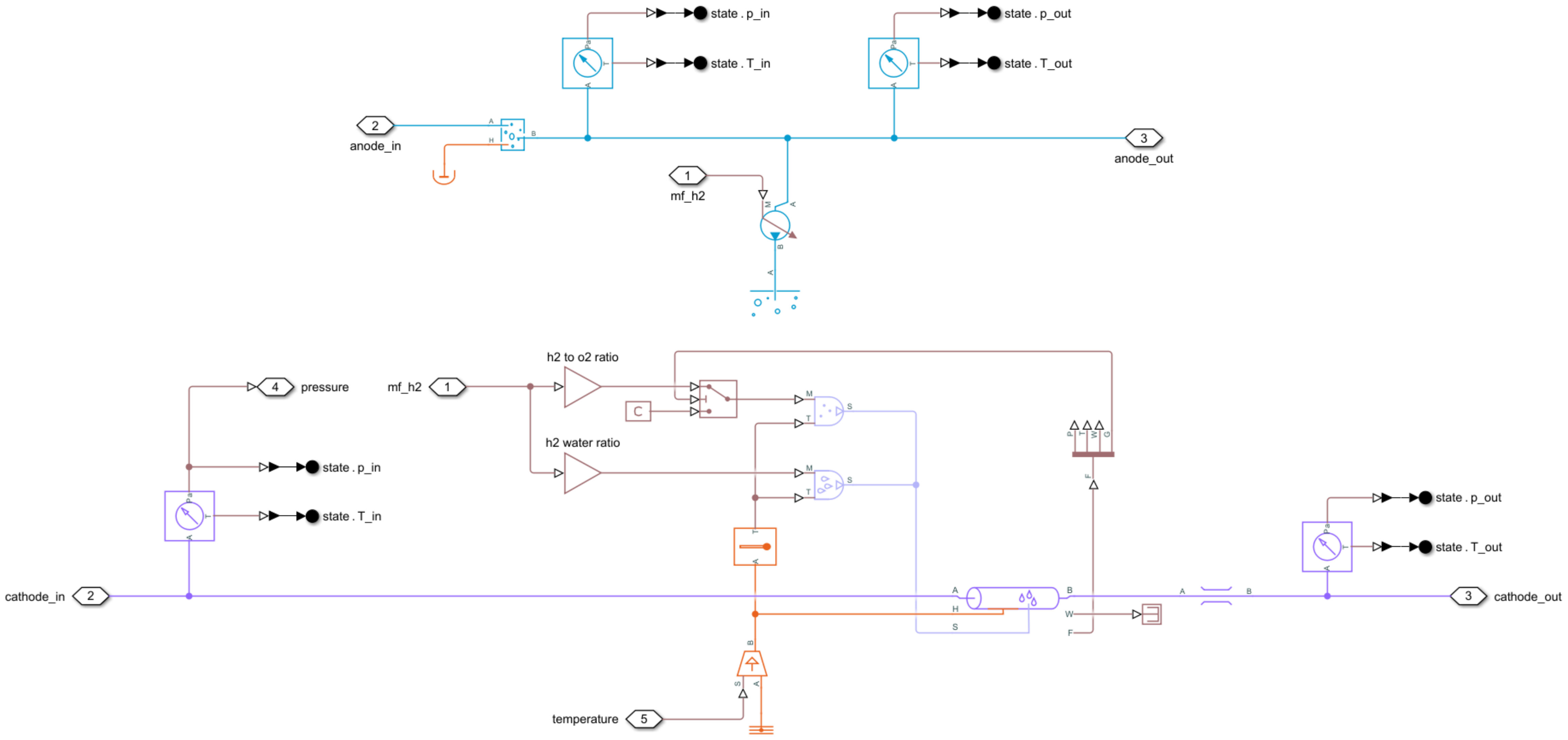
Fuel cell: Thermal



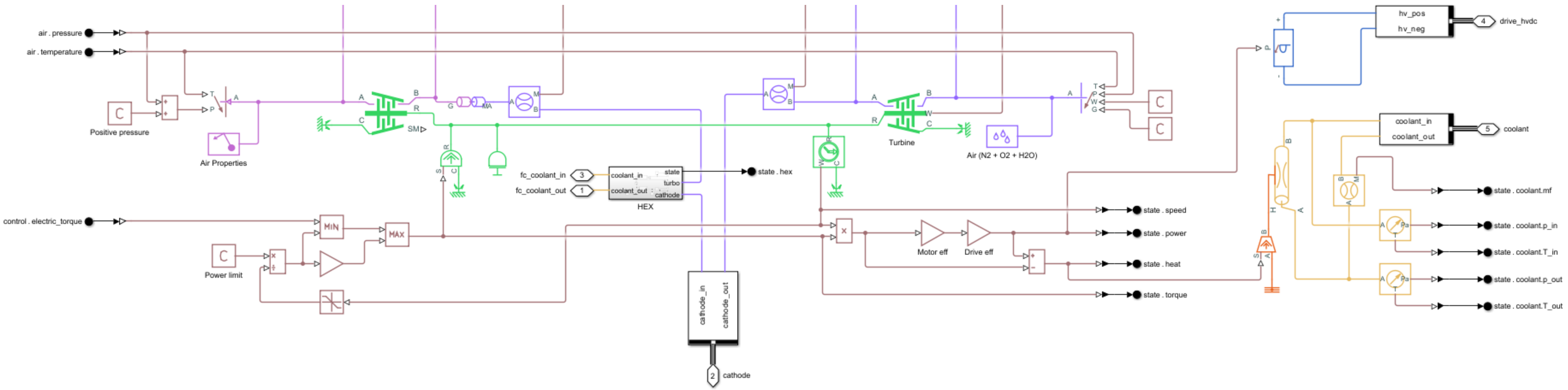
Fuel cell: anode & cathode



Fuel cell: anode & cathode

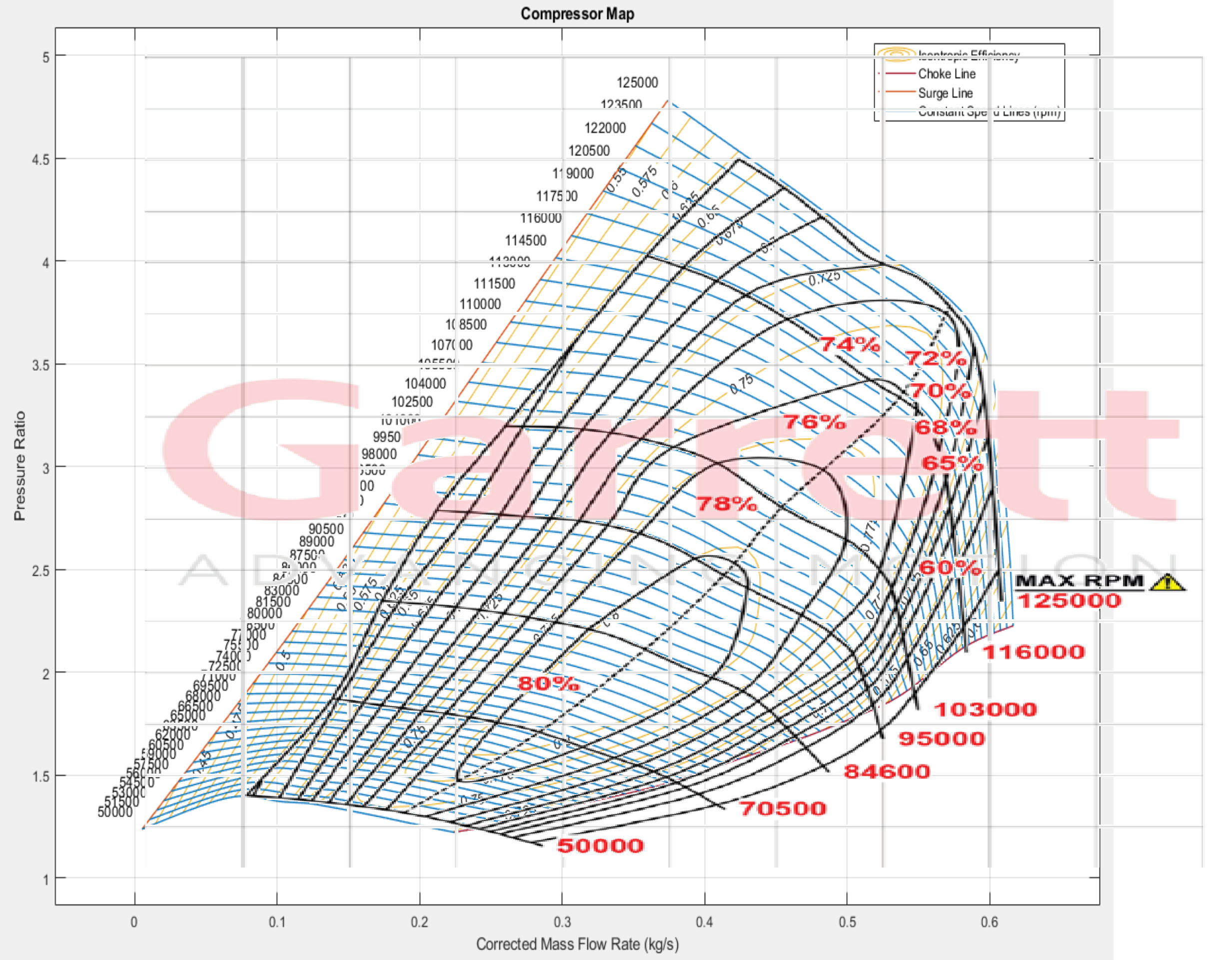


Turbocharger

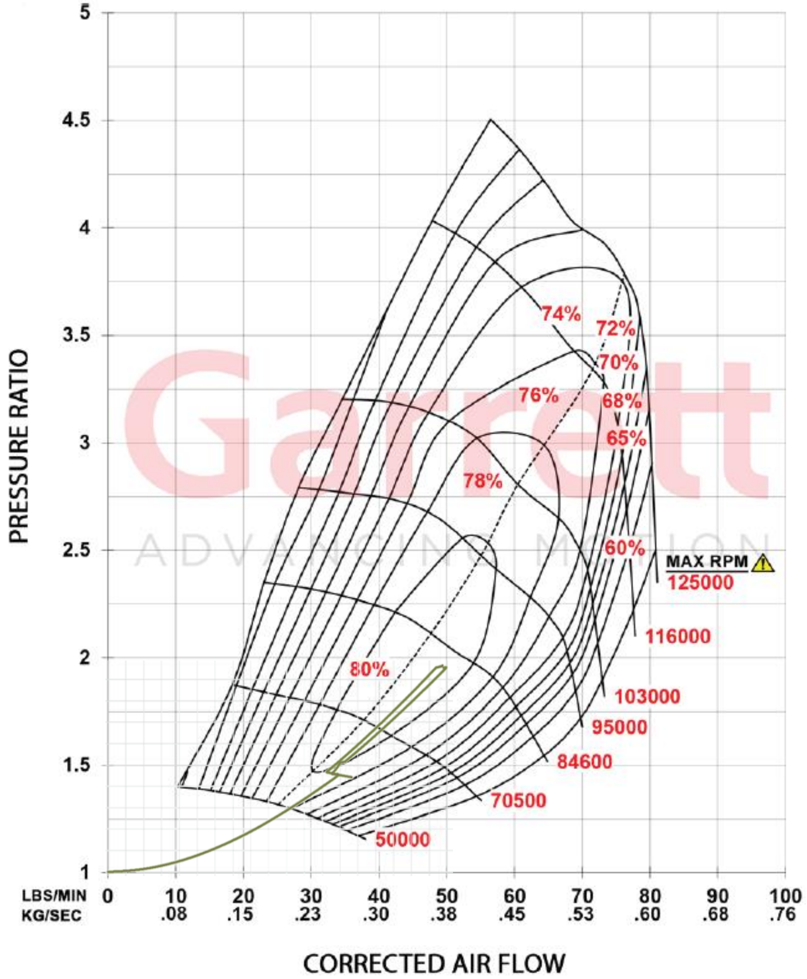


Turbocharger: compressor modelling

Compressor map matching

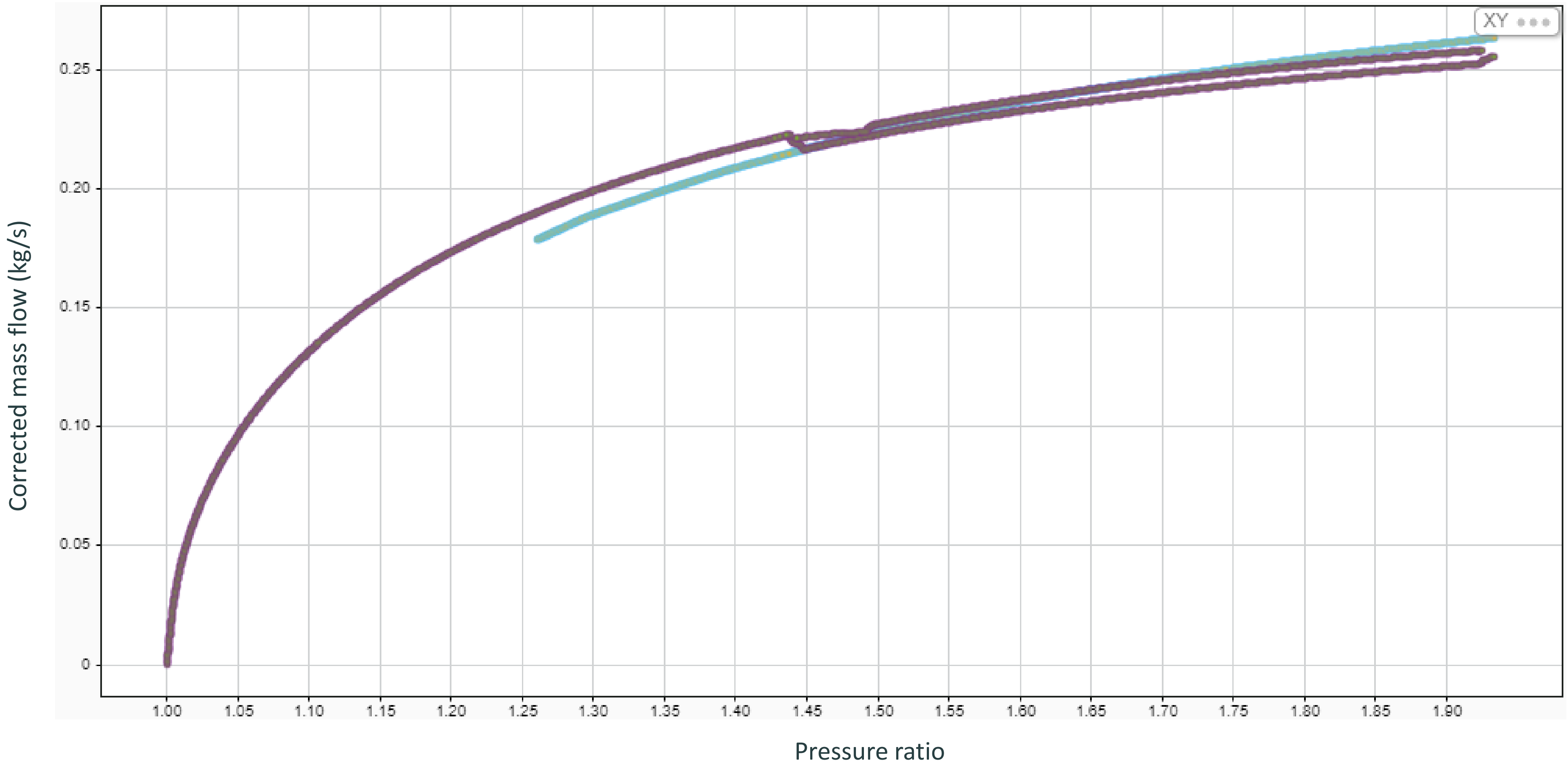


Compressor operating point



Garrett G40-900 84 trim T4 1.06 A/R. https://www.garrettmotion.com/wp-content/uploads/2022/07/Garrett_Performance_Catalog_Volume-9_2022.pdf

Turbine operating point (vs. Garrett G40-900 84 trim T4 1.06 A/R)



Garrett G40-900 84 trim T4 1.06 A/R. https://www.garrettmotion.com/wp-content/uploads/2022/07/Garrett_Performance_Catalog_Volume-9_2022.pdf

Outcomes

Model features

Environment

- Air temperature, pressure with altitude
- Weather (wind speed, air temperature)
- Route (latitude, longitude, heading)

Aircraft

- Lift & drag, including flaps & gear position
- 3-degree-of-freedom dynamics
- Longitudinal stability
- Dynamic fuel mass
- Single point gear interaction with ground

Visualization

- Full analogue of cockpit with instruments
- 3D visualization with capacity for satellite imagery

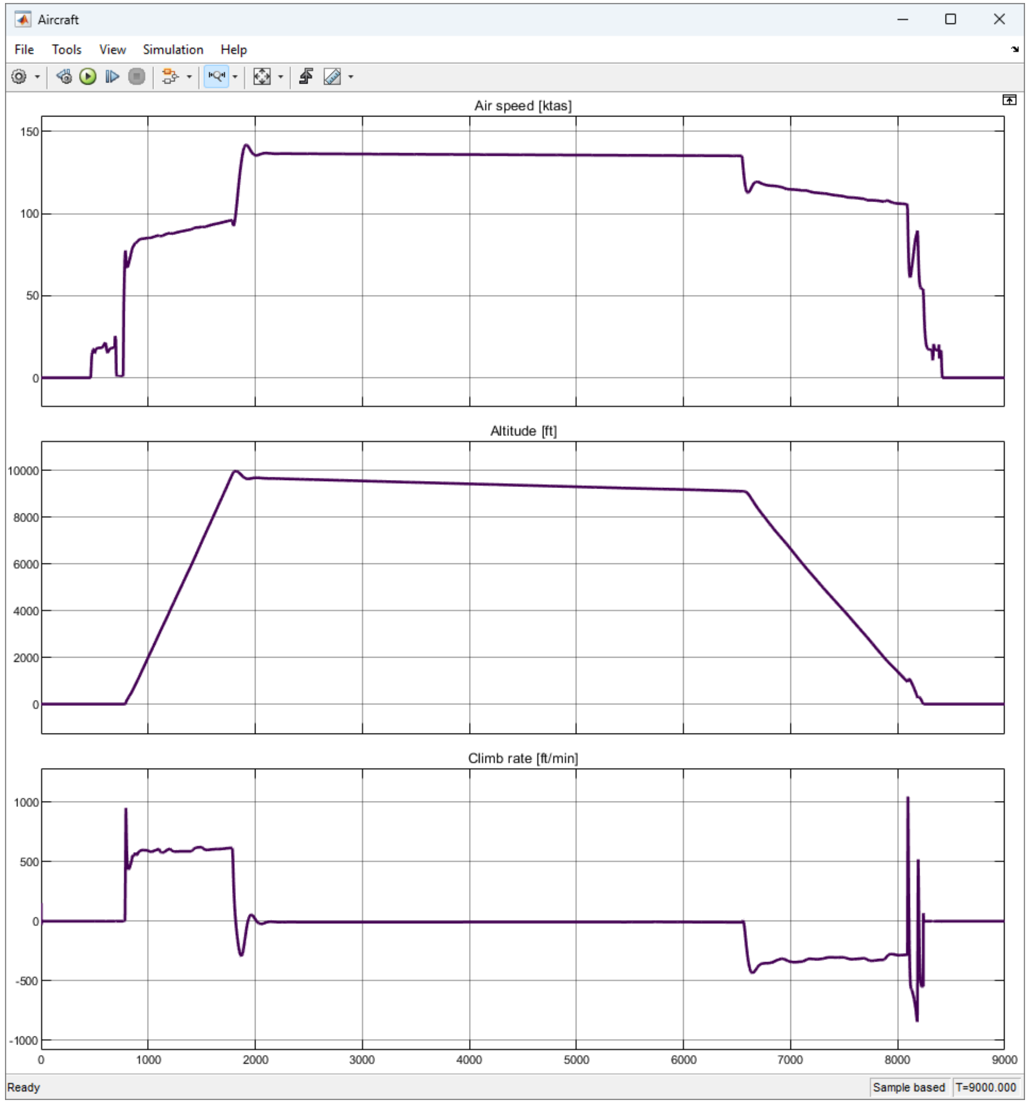
Propulsion

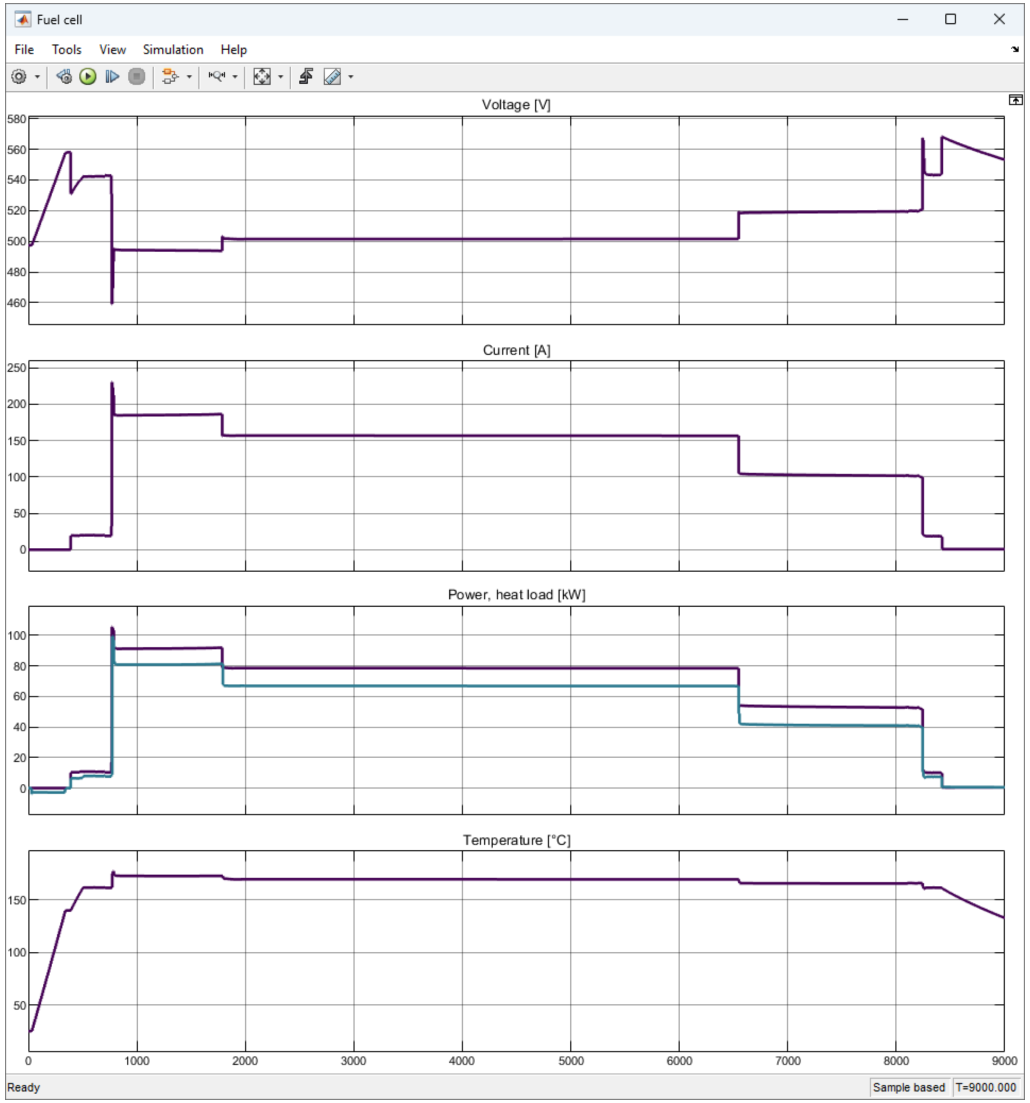
- LH_2 tank with electric heater
- Hydrogen conditioning from FC coolant
- Turbocharger based on manufacturer performance maps
- HV-HV and HV-LV DC/DC converters
- Propulsion motor with efficiency map and voltage sensitivity
- Propeller model based on manufacturer performance map
- Electrically actuated propeller pitch
- Low- and high-temperature coolant loops
- Radiator modelling including ram air and propeller wash

Cockpit visualisation

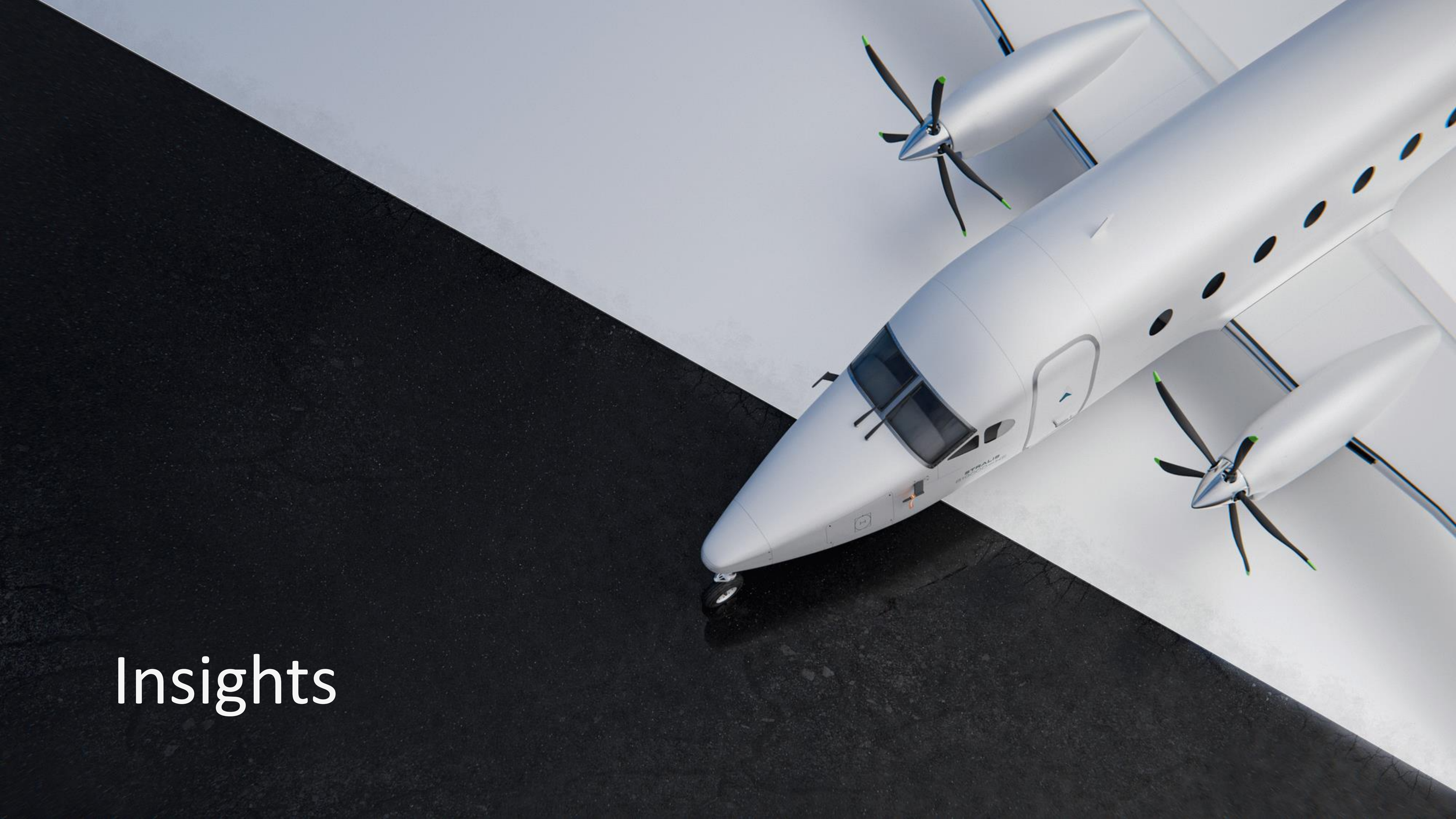
3D visualisation

Simulation outputs





Insights



1. Fixed pitch vs constant speed propeller
    - Determined early in the project that a fixed pitch propeller would not be sufficient to meet the target performance of the aircraft
    - Implemented constant speed propeller with electric actuator for final model

2. Fuel cell voltage constraints
    - Pressure/temperature sensitivity of fuel cell voltage highlighted voltage constraints
    - Fuel cell must be at temperature for take-off; may need engine run-up under brakes

3. Fuel cell thermal management during idle/taxi
    - Determined that under low power conditions, cathode air supply alone exceeded fuel cell cooling requirements
    - Required cathode air flow to be throttled for idle/taxi (via turbo)

Challenges, opportunities, and next steps

Challenges

- Large model; single Simscape physical network & solver
  - Runs better than real-time, but barely
  - Solution of initial condition is fragile
  - Small changes can result in crashes
  - Some issues of scale (Simulink to Simscape signal conversion)
- Available input data
  - Fuel cell characteristics
    - Sensitivity to oxygen partial pressure
    - Independent anode/cathode pressures
  - Turbine maps
  - Heat exchangers
  - Aircraft aerodynamics
- DC-DC converter modelling
  - Issues with initial condition solution
  - Missing current/power limit behavior

Opportunities

- Partition model
  - Multiple, smaller, physical networks with independent solvers
  - Opportunity to set different timescales for different modelling domains
  - Simulation can leverage parallel processing
- Fuel cell
  - Model sensitivity to oxygen partial pressure in cathode
  - Voltage behavior during startup/shutdown
- Decouple visualization from simulation
  - Simulation data playback
  - 3D scene visualisation

Next steps

- Improve model performance, targeting hard real-time simulation
- Enhance fuel cell model
  - Model sensitivity to oxygen & water vapor partial pressures
  - Model anode and cathode pressure sensitivity independently
- Revisit aircraft modelling
  - Flight control surfaces
  - Longitudinal stability
- Trade studies to support design process
  - Parameter sweeps
  - Mission profiles
  - Optimisation studies

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Questions?