Hybrid Electric Turbofan Example Model

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Outline

- Background
- Model
- TODOs/Questions
- Current State of Power Library

Background

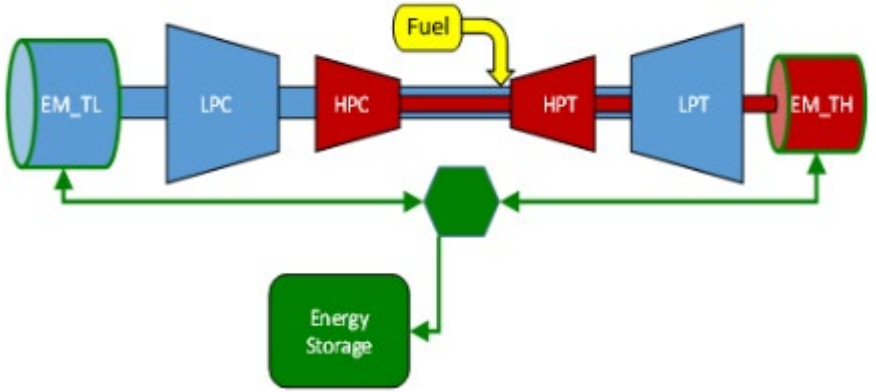
- Electrical Port to be released soon in NPSS
- NASA Power Systems Library available on GitHub

- No official, comprehensive electrified propulsion example model exists
  - Having one would help establish standard/best practices

- Propose a parallel hybrid electric turbofan model as this example
  - Hybrids include and integrate both turbine and electrical domains
  - Consider release in EMI/consortium examples package
  - Model currently on GitHub

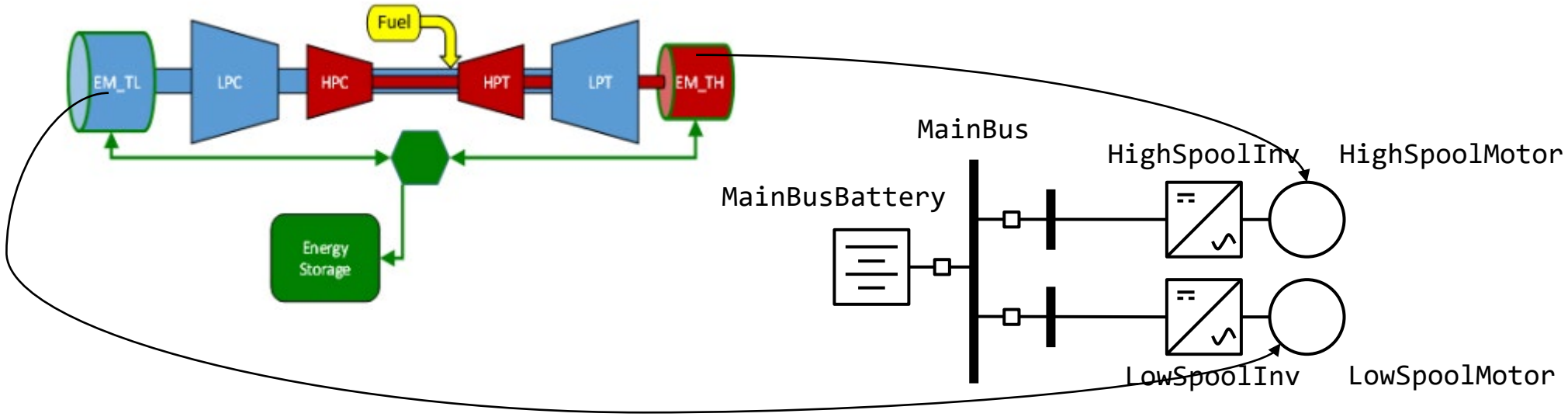
Model – Hybrid Electric Turbofan

- Propose two spool parallel hybrid turbofan
  - 28 klbf thrust class
    - High technology turbomachinery assumptions
  - 1 MW low spool machine
    - Primarily motor but can run as generator/brake
  - 200 kW high spool machine
    - Primarily starter/generator but can add torque
  - 1.5 MW battery
    - Not sizing for energy at this time
  - Circuit protection consistent with IEEE red book
- Work in progress, built to demonstrate model construction



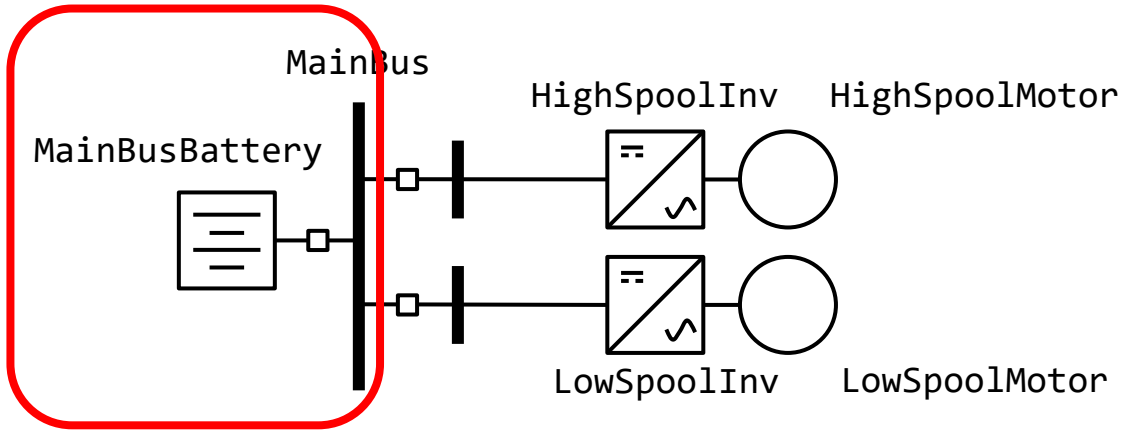
Model – Hybrid Electric Turbofan

- Hybrid systems combine multiple engineering domains
  - Hybrid system diagrams may not follow domain standards, may omit details
  - Recommend developing accurate power diagrams along with high level system diagrams (e.g. one-line diagrams)
  - E.g., one line diagram for this concept's power system shown on right



Model – Hybrid Electric Turbofan

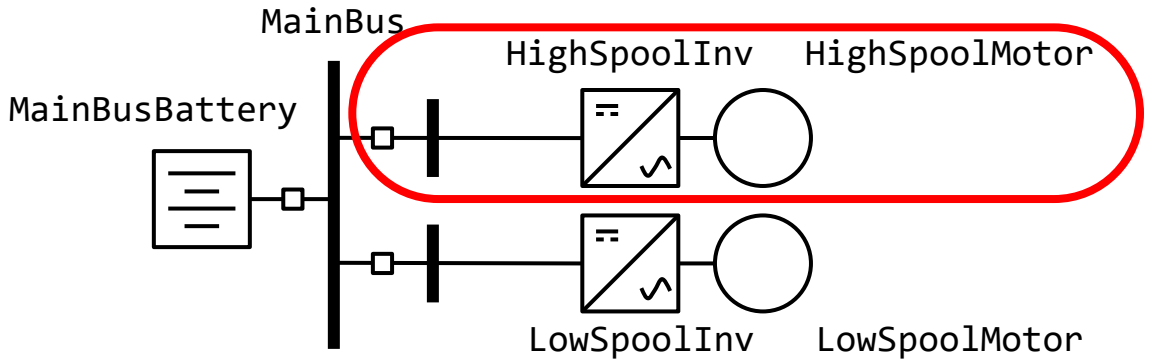
- Main bus




```
Element Battery MainBusBattery {
  // Cell performance data mapped to pack level within component
  #include <18650_cell.map>
  Vout_des = 1000;
  Vout_guess = 1000; // guess value [volts]
  SpecificEnergy = 2; // Wh/kg
}
Element Breaker MainBusBreaker {
  effDes=0.995;
  SpecificPower=250.0;
  Ireal  = 1000;                // guess value [amps]
  Iimag  = 0;                   // guess value [amps]
}
Element Enode MainBus{
  ElectricInputPort EP_I;
  ElectricOutputPort EP_O_LPS;
  ElectricOutputPort EP_O_HPS;
  ComplexNumber IaddionalLoad;
  VrealRMS  = 990;            // guess value [volts]
  VimagRMS  = 0;              // guess value [volts]
}
```

Model – Hybrid Electric Turbofan

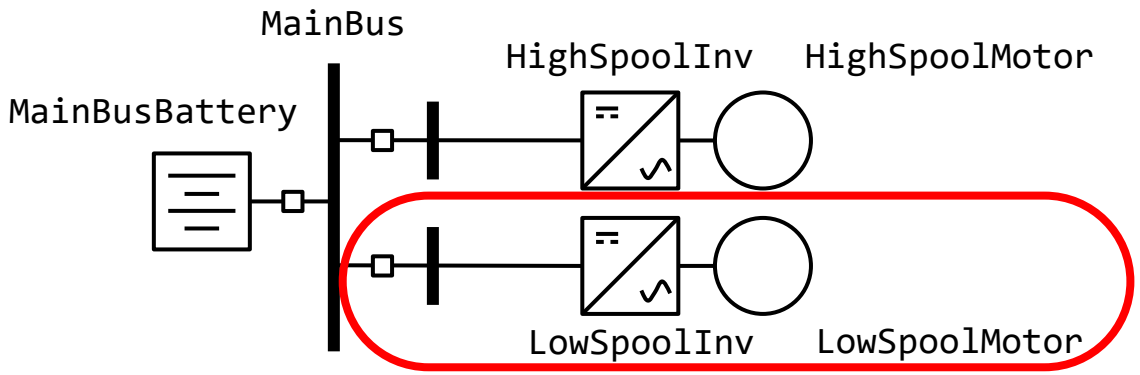
- High spool bus




```
Element Breaker HighSpoolBusBreaker {
  effDes=0.95;
  SpecificPower=250.0;
  Ireal  = -100;                // guess value [amps]
  Iimag  = 0;                   // guess value [amps]
}
Element Enode HighSpoolBus{
  ElectricInputPort EP_I;
  ElectricOutputPort EP_O;
  VrealRMS  = 970;             // guess value [volts]
  VimagRMS  = 0;               // guess value [volts]
}
Element AeroCable HighSpoolBusCable {
  length = 25;
  Ireal  = -100;                // guess value [amps]
  Iimag  = 0;                   // guess value [amps]
}
Element Inverter HighSpoolInv {
  #include <modelInverterRectifier.map>
  effDes = .95;
  frequency = 400;
  Vreal  = 670;  // guess value [volts]
  Vimag  = 0;    // guess value [volts]
}
Element AeroCable HighSpoolMotorCable {
  length = 0.2;
  Ireal  = -60;                 // guess value [amps]
  Iimag  = 35;                 // guess value [amps]
}
Element Motor HighSpoolMotor {
  real Pout_setpoint = -100; // kW
  #include <STARCABLmotorGenerator.map>
  effDes = 0.96;
  SpecificPower = 13;
  Vreal  = 650;  // guess value [volts]
  Vimag  = 0;    // guess value [volts]
  powerfactor = 0.99;
  Dependent dep_motor_power {
    eq_lhs = "Pout";
    eq_rhs = "Pout_setpoint";
    autoSetup = TRUE;
  }
}
```

Model – Hybrid Electric Turbofan

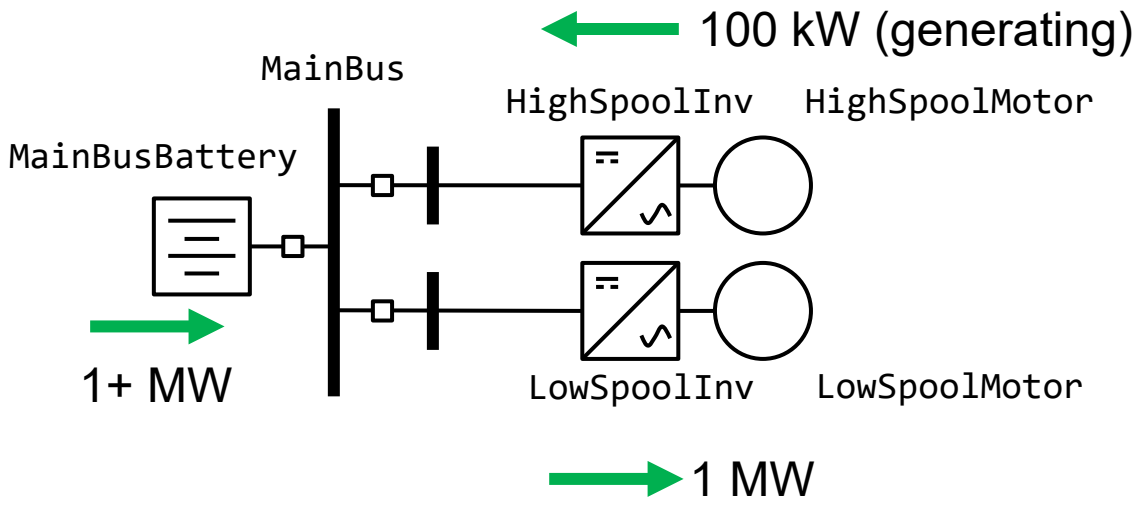
- Low spool bus




```
Element Breaker LowSpoolBusBreaker {
  effDes=0.95;
  SpecificPower=250.0;
  Ireal  = 1000;                // guess value [amps]
  Iimag  = 0;                   // guess value [amps]
}
Element Enode LowSpoolBus{
  ElectricInputPort EP_I;
  ElectricOutputPort EP_O;
  VrealRMS  = 970;             // guess value [volts]
  VimagRMS  = 0;               // guess value [volts]
}
Element AeroCable LowSpoolBusCable {
  length = 25;
  Ireal  = 1000;                // guess value [amps]
  Iimag  = 0;                   // guess value [amps]
}
Element Inverter LowSpoolInv {
  #include <modelInverterRectifier.map>
  effDes = .95;
  frequency = 400;
  Vreal  = 670;  // guess value [volts]
  Vimag  = 0;    // guess value [volts]
}
Element AeroCable LowSpoolMotorCable {
  length = 0.2;
  Ireal  = 600;                 // guess value [amps]
  Iimag  = -350;                // guess value [amps]
}
Element Motor LowSpoolMotor {
  real Pout_setpoint = 1000; // kW
  #include <STARCABLmotorGenerator.map>
  effDes = 0.96;
  SpecificPower = 13;
  Vreal  = 650;  // guess value [volts]
  Vimag  = 0;    // guess value [volts]
  powerfactor = 0.99;
  Dependent dep_motor_power {
    eq_lhs = "Pout";
    eq_rhs = "Pout_setpoint";
    autoSetup = TRUE;
  }
}
```

Model – Hybrid Electric Turbofan

- Nominal power flow



- Model could run with power in other directions
  - Power could flow into high spool motor (i.e., for operability boost)
  - Power could flow back into battery for recharging

TODOs and Questions

- Variable/component naming not hammered out
  - Any suggestions?

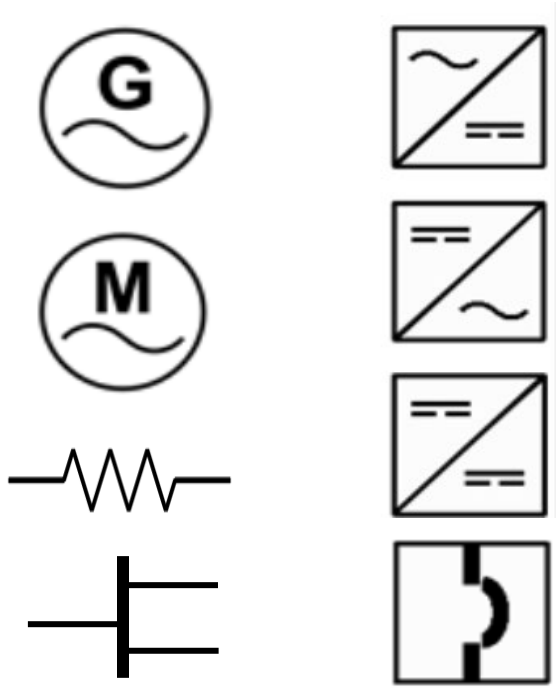
- This model and others in NASA's NPSS Power Systems Library are set up for interpreted port
  - Need updated when electric port is officially released

- Do we want this model in EMI package (or in consortium models?)
  - How about any other models (esp those from NASA's power library)?
- Do we want power component models in EMI package?
  - Use NASA's?

Current State of Library

- Open source library of components, to be used with electric port
  - https://github.com/nasa/NPSS-Power-System-Library
- Interpreted version of electric port included
- Component list and capabilities

ELEMENT	MAP	DC	AC, 1-PHASE	AC, 3-PHASE
CABLE		X	X	X
MOTOR	X			X
GENERATOR	X			X
RECTIFIER	X	X		X
INVERTER	X	X		X
DC-DC CONVERTER	X	X		X
BATTERY	X	X		
BREAKER		X	X	X
LOAD		X	X	X
SOURCE		X	X	X
RESISTOR		X	X	
CAPACITOR		X	X	
INDUCTOR		X	X	



- Do we want to see these in EMI?