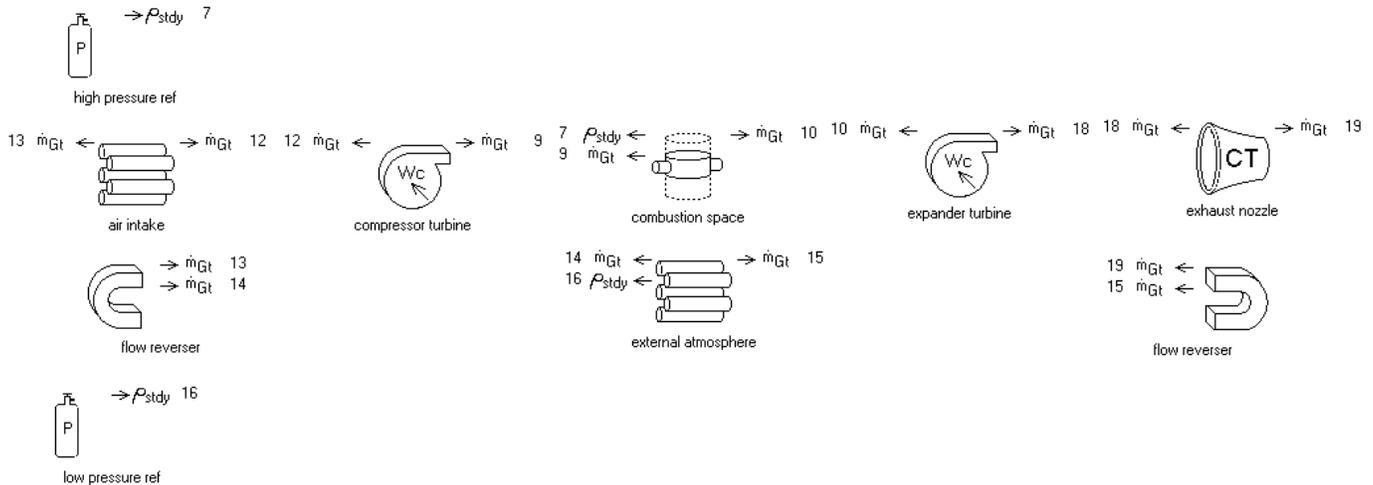


Sage Model Notes

turbojet.ltc

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A somewhat whimsical model of a turbojet engine implemented in the low-T cooler model class:



This model is nothing like a low-temperature cooler but it does demonstrate the flexibility of the Sage model components. Two adiabatic compressors components represent the *compressor turbine* and *expander turbine* of a jet aircraft engine. None of the details of turbine blades and gas flows are modeled. Instead, all turbine details are encapsulated into the inputs for *adiabatic efficiency*. A combustion space gas domain represents the combustion heating inside the *combustion space*. All combustion details are encapsulated in the *FQcombust* heating input. A tapered compliance tube serves as the *exhaust nozzle*.

The model is sort of a block diagram for the turbojet thermodynamic cycle. It represents the overall system in terms of its component parts each of which is relatively easy to understand. The Sage solver matches them all together to produce a complicated result — namely, bottom-line jet thrust.

This model might also be starting point for other thermodynamic cycles involving turbines. For example, by replacing the *combustion space* and *external atmosphere* with some heat exchangers and a recuperator the model could be reconfigured to represent a closed Brayton-cycle heat engine or heat pump. See also the sample model *turbofan.ltc*.

Turbojet Operation

Proceeding from left to right in the above illustration, combustion air (modeled as nitrogen) enters the *air intake*, then is adiabatically compressed by the *compressor turbine*, then is heated in the *combustion space*, then flows through the *expander turbine* and exits from the *exhaust nozzle*. The mass flow rate is uniform through the system so unlike a real jet engine the mass flow rate of the fuel is not present in the exhaust stream. Since Sage cannot model open flow loops the *external atmosphere* is represented by a

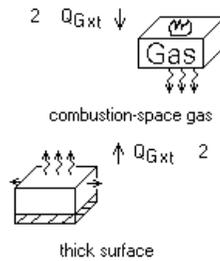
large heat exchanger into which the hot exhaust jet enters at the right, cools and emerges at the left where it flows back into the *air intake*.

Air Intake and Exhaust Nozzle

The *air intake* and *exhaust nozzle* are adiabatic flow channels represented by single tubes with adiabatic walls (thick surface components). In the case of the *exhaust nozzle* the compliance-tube component is used so that the tube diameter can decrease toward the exit, accelerating the exhaust to a high velocity for thrust. The only heat transfer in the model occurs in the *combustion space* and *external atmosphere* heat exchanger.

Combustion Space

The combustion space inputs heat directly via the combustion-space gas component and otherwise has an adiabatic wall surface.



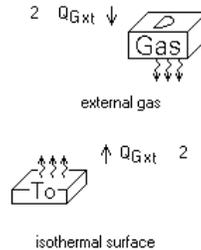
Combustion heating input is recast in terms of the gas mass flow rate to

$$FQ_{\text{combust}} = 5.00E+05 * \text{MdotFlow}$$

Where the coefficient 5.00E+005 represents the heating value of fuel combustion. The heating input scales with the mass flow rate to regulate the temperature at the *combustion space* exit.

External Atmosphere

The *external atmosphere* heat exchanger has a conventional isothermal wall surface fixed at the ambient temperature.



Pressure References

The *low pressure ref* establishes the atmospheric pressure and the *high pressure ref* establishes the combustion space pressure. Two pressure sources are required because otherwise the model pressures would be indeterminate. As with all Sage models one

pressure source is required to establish the mean pressure. If there were just one adiabatic compressor component in the model then that one pressure source would suffice because the other components in the flow loop would determine the pressure change across the compressor as a function of mass flow rate. But with two adiabatic compressor components in series there are two compressor pressure drops to determine, requiring two pressure sources.

Generally speaking the pressure change across an adiabatic compressor component is not specified in the component. Rather Sage solves it implicitly as part of the total solution.

Special Variables

The root model level contains some user-defined inputs and outputs:

Inputs

MdotFlow	gas mass flow rate (kg/s)	1.8000E-01
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Outputs

Wnet	excess turbine shaft power	9.7371E+03
Wexpander + Wcompressor		
Thrust	net thrust	7.1269E+01
MdotFlow * (Uexhaust - Uintake)		

MdotFlow

The mass flow rate inputs for the *compressor turbine* and *expander turbine* are both recast to the root-level input *MdotFlow* for convenience and to ensure they remain equal.

Wnet

The power outputs for the *compressor turbine* (negative) and *expander turbine* (positive) are added together in *Wnet* to get the excess shaft power — the excess expander power not absorbed by the compressor. In principle this could go to powering auxiliary components (which are not modeled).

Thrust

Jet thrust is not a normal Sage output. Instead it is calculated in the user-defined variable *Thrust* at the root model level in terms of the gas mass flow rate and intake entrance velocity and exhaust exit velocity. In other words the change in momentum of the exhaust jet relative to the air intake according to Newton's law of motion $F = M\Delta V / \Delta t$.

Variables *Uexhaust* and *Uintake* are user-defined variables in the *intake gas* and *exhaust gas* components. The Sage model is somewhat realistic in that *Uexhaust* approaching the speed of sound will cause convergence problems, corresponding to choked flow in an actual nozzle.

Convergence Issues

The model is sensitive to the mass flow rate input *MdotFlow* and the *high pressure ref* input *Pcharge*. The solution may not converge if either value is too high. Particularly if they lead to high Mach numbers in the *exhaust nozzle*.