ME 140
Advanced Thermal Systems

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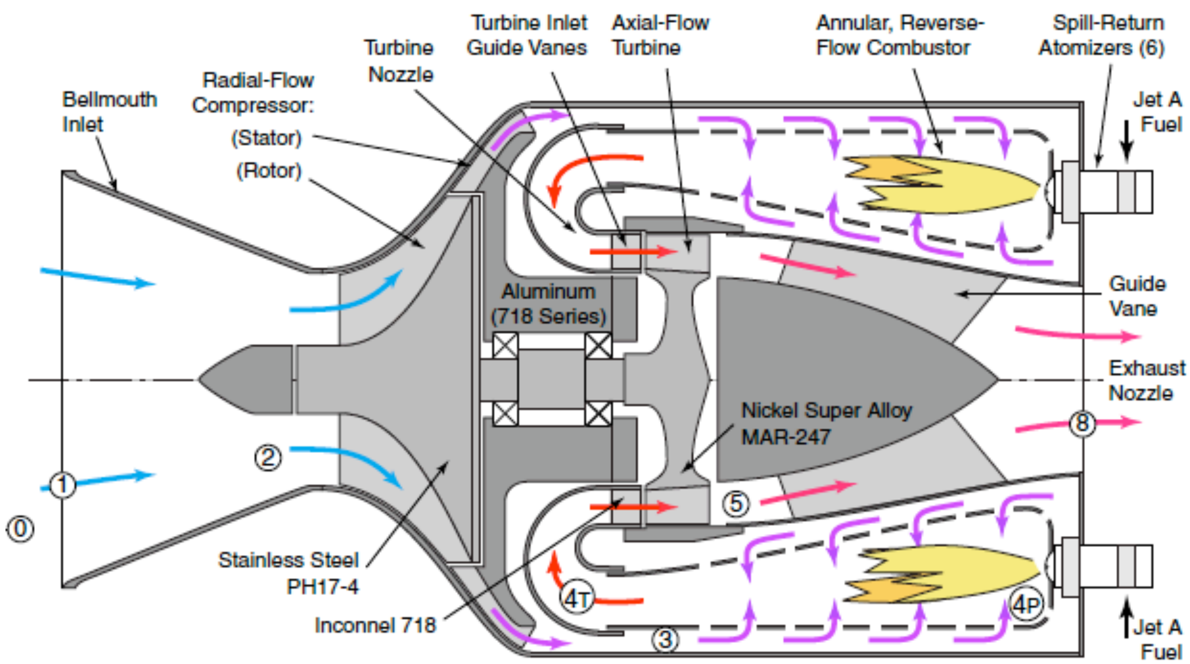
Spring 2018

Project #2: SR30 Turbojet Performance Analysis

(Due Wednesday, April 18)

<u>The System</u>

The Turbine Technologies SR30 is a single-spool turbojet engine designed to be inexpensive to produce in low volume and have a long service life (>2000 hours between overhauls). It features a single-stage, radial-flow compressor, an annular, reverse-flow combustor, and a single-stage, axial-flow turbine. The exhaust nozzle on the SR30 is slightly convergent, producing a jet with a subsonic exit velocity.



Since the engine is to be evaluated under stationary (static thrust) conditions, it is not equipped with a diffuser (or cowl). Instead, air enters through a bellmouth inlet (a nozzle), which contours the streamlines to provide a near-uniform velocity at the face of the radial-flow compressor. The compressor consists of a rotor (40,000 – 90,000 RPM), which increases the kinetic energy of the stream, and a stator, which diffuses the high-velocity stream, so that the desired pressure ratio is obtained.

The compressed air then enters an annular combustor where liquid fuel (Jet A) is sprayed into the air through six atomizers. Once a source of ignition (spark) is provided, the mixture forms a self-sustaining, turbulent, "diffusion" flame. It is referred to as a diffusion flame since for chemical reaction to occur, the air and fuel (which are initially segregated from each other) must diffuse towards each other. (If the fuel were supplied in the form of vapor and pre-mixed with the air before being ignited, we would refer to the resulting flame as being a "premixed" flame.)

Note that the air is admitted to the combustor gradually using a series of holes in the liner of the combustor. This helps to enhance flame stabilization and assist in combustion of the fuel. The overall ratio of fuel to air is much less than the stoichiometric (balanced) proportions—this is necessary to keep gas temperatures within acceptable limits for the downstream turbine.

After exiting the combustor, the hot gases are accelerated through an annular nozzle and directed by a set of guide vanes to impinge on the blades of an axial-flow turbine. The turbine extracts energy from these gases in an amount equal to the work required to compress the incoming air stream and to support frictional losses (both mechanical and fluidic) of the turbomachinery. The enthalpy remaining in the gases is available for use by the exit nozzle to produce thrust. Since the flow exiting the turbine has a rotational component to its velocity, it is first passed through a set of guide vanes (flow straighteners) to remove this before being expanded to atmospheric pressure in the nozzle.

The engine you will operate is instrumented with pressure and temperature probes at stations 3, 5, and 8 in the diagram. Stations 4P and 4T host pressure and temperature probes, respectively. A pitot-static probe and temperature sensor are also included at station 2. Sensors for the mass flow rate of fuel, the net thrust produced by the engine, and ambient conditions (pressure, temperature, and humidity) are also incorporated in the test stand or are available in the laboratory. Measurements of relevant flow areas can be made using the cut-away engine in the lab.

Over the next two weeks you will characterize the performance of this engine (both overall and individual components) with an eye towards evaluating its present performance and the potential for improving the design. To achieve that objective, your team will need to spend several sessions in the laboratory planning, observing, and making physical and operational measurements to support your analysis.

The Assignment

We would first like to understand the operation and performance of the SR30 as a unit, then analyze its internal operation and individual components, and finally its combustion process. This will put you in a position to assess the quality of the present design and to determine how best to improve it.

The Objectives of this Project

(1) to understand and experience operation of a turbojet engine,
(2) to gain experience working with measured temperature and pressure data,
(3) to gain experience working with compressible flows, including the use of the mass flow parameter, and
(4) to be able to evaluate system and component efficiencies from measured data.

Requirements:

(1) 20 points: Develop a table showing a refined form of the data from the measurements you took in the laboratory. This table should follow the exact format specified below (for grading purposes), include your temperature and pressure measurements in units of °C and kPa, and should indicate whether the pressure measurements are absolute, gage, or differential. Also include the mass flow rate of fuel at each operating point as determined from your

measurements (kg/s) and the measured thrust (N). Please submit only this table on Canvas for the assignment "Project 2" as an Excel spreadsheet (.xls or .xlsx) so that we may grade your submission with your group's specific data. Provide a separate table showing the relevant flow areas (m^2) needed in your analysis by station number.

RPM	T2_C	T3_C	T4_C	T5_C	T8_C	P2_D_kPa	P3_G	P4_G	P5_G	P8_G	Fuel_kgs	Thrust_N
						Your data	here					

(2) 30 points: Use your performance data and area measurements (listed in Appendix) to construct a series of plots showing how the following quantities vary with spool speed: station stagnation temperature (K), station stagnation pressure (kPa, absolute), station Mach number, and station velocity (m/s). Make sure to include Station 1 in all of your plots. Plot the mass flow rates of air and fuel (g/s) and the air-fuel ratio vs. spool speed. For determining the air mass flow rate, it may be helpful to know that the effective flow area (product of area and flow coefficient) at the location of the pitot-static probe (2) is 6.4 in^2. (This was determined by ME140 staff using a calibrated laminar flow meter. It corresponds to a flow coefficient that is essentially unity.) Use your data to calculate the net thrust force and plot this along with the measured thrust (from the strain gage) vs. spool speed. Use air with variable specific heats as the working fluid. (Next week you will add products of combustion to your analysis and thereby be able to see the affect on your results.)

(3) 20 points: Construct performance-metric plots showing how specific thrust, thrust specific fuel consumption, and thermal efficiency vary with spool speed. Use the lower heating value of Jet A (42,800 kJ/kg) for your thermal efficiency calculation, and base your performance metrics on the calculated thrust.

(4) 30 points: Using your stagnation temperature data, find the power consumed by the compressor and produced by the turbine and plot these on the same graph vs. spool speed. Use these data to find the adiabatic efficiencies of these components. Find the stagnation pressure ratio across the combustor (essentially that across the liner since the pressure drop along the axis of the combustor is very small) and the adiabatic efficiency of the nozzle. Since we are modeling combustion as though it were heat transfer to air, it is also possible to define an "apparent combustion efficiency" as the change in enthalpy of the air (as determined from T measurements) per unit heating value of the fuel used. Calculate this value from your data. Plot each of these quantities as a function of engine speed. Keep these metrics in mind for Project 3 when you will be asked how you could improve the SR-30.

Some Things to Consider

(1) What do the temperature and pressure probes actually measure? What is "recovery factor" and how might measurements be corrected to account for it? In what parts of the analysis

can constant (or average) values of specific heats, ratio of specific heats, etc., be used? In what parts must you include the effects of temperature dependence of specific heats?

(2) When a Mach number needs to be determined from measured data, there is sometimes more than one way to determine it (*e.g.,* mass flow parameter vs. static/stagnation pressure ratio). If the two disagree, which is "correct"? Which is likely to be more accurate/insensitive to experimental uncertainty?

(3) What do you do when data don't make sense? How do you know if it is correct or incorrect, or if it is just interpreted incorrectly? How can you debug anomalous findings?

No need to provide answers to these questions in your report, but do think about them as you are developing your models!

<u>The Write-Up</u>

The write-up for this first part of the assignment should take the form of a progress report. (Next week you will generate a comprehensive, composite report of your overall assessment of the engine.) Your progress report should include tables with the basic information requested above, the requested set of figures, and a brief explanation of anything unusual that you found in your analysis. The figures and tables should be clean, clear, and professional.

To assist in evaluating your analysis (and the assignment), please include the following items not normally included in a professional write-up FOR EACH TEAM MEMBER:

(1) a brief statement of how much time was spent on each part of the analysis and write-up, and
(2) a brief statement giving your opinions of the most and least useful aspects of the assignment.
(3) a brief comment about anything that is still unclear to you

<u>The Deliverables</u>

1) Table of data from lab (temperature, pressure, fuel flow, thrust). Make sure to submit on Canvas as well.
   Table of relevant flow areas
2) Plots (four) of the following quantities vs. spool speed
   - Station (1-5,8) stagnation pressure
   - Station (1-5,8) stagnation temperature
   - Station (1-5,8) Mach number
   - Station (1-5,8) velocity

   Plot of air flow rate, fuel flow rate, and air-fuel ratio vs. spool speed
   Plot of measured thrust and calculated thrust vs. spool speed
3) Plot of specific thrust and thrust specific fuel consumption vs spool speed
   Plot of thermal efficiency vs spool speed
4) Plot of compressor power and turbine power vs spool speed
   Plot of compressor, turbine, and nozzle adiabatic efficiencies, combustor stagnation pressure loss, and "apparent combustion efficiency" vs spool speed

Appendix:

When building your MATLAB model of the SR-30 you may find it useful to have measurements of the area the fluid is flowing through. Other useful information below includes thermocouple orientations and SR-30 measurement clarifications.

Measurement Units used in labview:

Area	= in^2
Temperature	= ˚C
Pressure	= kPa
Fuel Mass Flow	= kg/s
Thrust	= lbf

Area Measurements (all measurements are in in^2):

% Geometry measured from cut-away model in [in^2]
A1 = 27.3; % Flow area at inlet of bellmouth
A2 = 6.4; % Effective flow area at pitot-static probe
A3 = 9.0; % Area of compressor exit
A4 = 7.2; % Area before bend to turbine inlet
A5 = 4.7; % Area of turbine outlet
A8 = 3.87; % Area of nozzle exit

Thermocouple orientations (all measurements in degrees C):

T2: cross-flow
T3: cross-flow
T4: cross-flow
T5: axial-flow
T8: cross-flow

Pressure measurements (all in kPa):

All measurements are gauge (except DP2, which is differential)
Any measurement that has a "t" in it, for example PT3, is a stagnation pressure.
DP2 means the measurement was a differential pressure (stagnation - static)