Turboelectric Propulsion Worksheet

1. Instructions

Complete the tasks set out below and submit your work in the Assignments Section of the Module's Blackboard Website. The number of marks for each sub-task are indicated. Answer all sections of the Assignment.

A portion of the marks are available for communication and presentation. You should show your working and state clearly assumptions that you make. You should write in a formal style appropriate for work to be submitted to an engineering research journal. You must not exceed the word count if one is specified. Figure captions, equations and references are not included in the word count.

By submitting your work for assessment you are asserting that you have complied with the University's Academic Integrity regulations. In particular, your submission must be your own independent work and you must make clear anywhere that you reproduce material drawn from another source.

Before attempting this assignment you are advised to attempt the Exercise questions in relevant chapters of the module Course Book.

2. Introduction

The following analysis considers the performance of a single-aisle commercial aircraft similar to the STARC-ABL described by Welstead and Felder (2016). The motivation for the use of turbo-electric propulsion and for the aft boundary layer ingestion fan are set out by Welstead and Felder, and you are advised to read and refer to their paper as you work through this assignment (a copy is provided in the assignments folder).

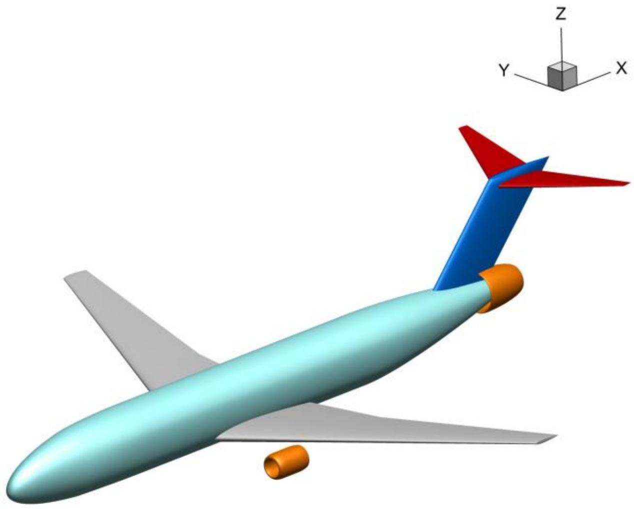

Figure 1. STARC-ABL isometric view. Key features include the rear fuselage BLI fan, the T-tail empennage, and the reduced size turbofans allowed by the turboelectric propulsion system (Welstead and Felder, 2016).

The propulsion system consists of two generator-fan (genFan) units that both provide thrust and some electrical power to the one tail cone fan

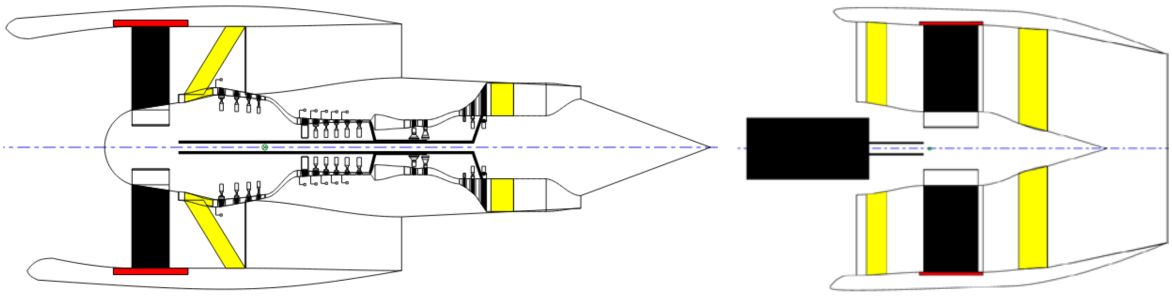

Figure 2. Conceptual drawings of the turbofan with generator (genFan) and rear fuselage propulsor (aft-fan) for the turboelectric propulsion system. Turbofan configuration with aft generator pulling power from the fan shaft (genFan) (left) and electric motor driven aft-fan located at the tip of the aircraft tail cone (right) (Welstead and Felder, 2016).

The mechanical power transmitted to the generator in the genFan is converted to mechanical power in the tail cone fan with an overall electrical efficiency of 90 %.

The aft fan ingests part of the fuselage boundary layer. For the present analysis, it is assumed that the fuselage boundary layer is cylindrically symmetric with a 1/7th power law dependence on radius.

$$\frac{V(r)}{V_\infty} = \left(\frac{r - R_1}{\delta}\right)^{1/7}$$

for $(r - R_1) < \delta$, where r is radius, V_∞ is the flight velocity, δ is a nominal boundary layer thickness. R_1 and R_2 are the inner and outer radii of streamtube entering the tail cone fan. Assuming uniform density, integrating of the velocity profile gives a mass-weighted average velocity of the boundary layer ingestion of:

$$V_{BLI} = V_\infty \delta^{-1/7} \frac{\left[\frac{7}{16}(R_2 - R_1)^{\frac{16}{7}} + \frac{7}{9}R_1(R_2 - R_1)^{\frac{9}{7}}\right]}{\left[\frac{7}{15}(R_2 - R_1)^{\frac{15}{7}} + \frac{7}{8}R_1(R_2 - R_1)^{\frac{8}{7}}\right]}.$$

Treat the flow through the aircraft boundary layer as adiabatic, implying constant specific stagnation enthalpy, giving $h_{02,BLI} = h_{02}$, where stations 2 and 2_{BLI} denote the entries to the genFan and the tail cone fan respectively).

Treat the air and combustion products as flows of perfect gases with properties given in Table 1. Neglect the addition of fuel mass, assume all nozzles are fully-expanded, and neglect any pressure drop in intakes or ducts.

Parameters for use in the analysis are given in Table 1. While some of the parameters assumed in the present analysis are the same as those used by Welstead and Felder there are also differences in the analysis set out below that mean you should expect to obtain different numerical answers.

Table 1. Parameters for coursework analysis

Cruise	Mach 0.7 at 35,000 ft, International Standard Atmosphere
Fan	Pressure ratio: 1.45; Isentropic efficiency 94%
LPC	Pressure ratio: 1.45; Isentropic efficiency 92%*
HPC	Pressure ratio: 27.9; Isentropic efficiency 92%
HPT	Isentropic efficiency: 92%
LPT	Isentropic efficiency: 94%
Tail cone Fan	Pressure ratio: 1.25; Isentropic efficiency 96%
Overall electrical efficiency	90%
T_{04}	1540 K
Air properties	c_p: 1005 $J.kg^{-1}.K^{-1}$; $c_p/c_v = 1.4$
Combustion products	c_p: 1100 $J.kg^{-1}.K^{-1}$; $c_p/c_v = 1.3$
Number of fan-generators	$n_{FG} = 2$
Overall Bypass Ratio	$(n_{FG} \times \dot{m}_{Bypass} + \dot{m}_{TCF})/(n_{FG} \times \dot{m}_{Core}) = 14.4$
Fan-Gen Bypass Ratio	$\dot{m}_{Bypass}/\dot{m}_{Core} = 6.4$
R_1	0.35 m
R_2	1.0 m
Pressure loss in combustor	5% of stagnation pressure
Boundary layer thickness	δ: 1.0 m

*The flow through the core of the fanGen passes through the fan, then the LPC then the HPC, giving an overall pressure ratio of approximately 58.

Where you provide graphs as part of your submission, the following suggestions may be helpful:

- Label axes;
- Non-dimensionalise variables if that is appropriate, defining the non-dimensionalisation, otherwise state their units;
- Use a reasonable number of markers for each axis (usually 3-6);
- Set the font size of axis labels so that they remain large enough when the figure is inserted into a report;
- Choose to use lines/points/curve fits appropriately for the kind of data you are reporting;
- Consider using a legend or a second axis if you have more than one set of data on the graph.
- How to write a figure caption for a technical/scientific report: see

  https://www.internationalscienceediting.com/how-to-write-a-figure-caption/.

3. References

Welstead, J. and Felder, J.L., 2016. Conceptual design of a single-aisle turboelectric commercial transport with fuselage boundary layer ingestion. In 54th AIAA Aerospace Sciences Meeting (p. 1027).

4. Analysis

4.1. Showing the working for your calculations, complete the following table for the fanGen:

[12 marks]

Flight velocity	$V_\infty =$	
Fan inlet	$T_{02}=$	$P_{02}=$
Fan outlet	$T_{013}=$	$P_{013}=$
LPC outlet	$T_{023}=$	$P_{023}=$
HPC outlet	$T_{03}=$	$P_{03}=$
HPT outlet	$T_{045}=$	$P_{045}=$
Bypass jet velocity	$V_{jB}=$	

4.2. Showing the working for your calculations, complete the following table for the Tail Cone Fan:

[14 marks]

Inlet *static* state	$T_{BLI}=$	$P_{BLI}=$
Inlet velocity and area	$V_{BLI}=$	$A_{in} =$
Density and mass flow	$\rho_{BLI}=$	$\dot{m}_{TCF}=$
Inlet *stagnation* state	$T_{02,TCF}=$	$P_{02,TCF}=$
Tail Cone Fan outlet	$T_{013,TCF}=$	$P_{013,TCF}=$
Tail Cone Fan jet velocity	$V_{jTCF}=$	
Net thrust (kN)	$F_{N,TCF}=$	
Shaft power (kW)	$\dot{W}_{x,TCF}=$	
Propulsive efficiency of tail cone fan	$\eta_{p,TCF}=$	

4.3. Produce a graph and caption to illustrate how propulsive efficiency is affected by the outer radius of the tail cone fan.

[7 marks]

4.4. In no more than 200 words, comment on the value of the tail cone fan's propulsive efficiency, explaining why it depends on the fan outer radius selected.

[10 marks]

4.5. Showing the working for your calculations, complete the following table for the overall turboelectric propulsion system:

[7 marks]

Core mass flow in one fanGen	$\dot{m}_{core}=$	
Bypass mass flow in one fanGen	$\dot{m}_{bypass}=$	
LPT power in one fanGen (kW)	$\dot{W}_{xLPT}=$	
LPT outlet	$T_{05}=$	$P_{05}=$
Core jet velocity	$V_{j,core}=$	
Overall net thrust	$F_N=$	