Faculty of Aerospace Engineering

April 6th, 2021

Part Air breathing propulsion

1. Please fill in your name and student number on all the answer sheets.
2. This part of the exam has one multiple-choice question with 3 parts and 1 question to be answered on paper, for a total of **50 points** (maximum).
3. For the **questions to be answered on paper**, please follow the instructions given in the text of each specific question. *Please make use of the* ***results summary table*** *in addition to your workout. This will help you in drawing the T-s-diagram and us in checking your exam.*
4. This is a closed-book exam. The only material you are allowed to use for the exam are the formula sheet attached at the end of this document and a calculator. You are not allowed to bring your own formula sheet (unless previously agreed with the teachers and approved by them).
5. Use of graphical calculators is permitted under the condition that the memory is cleared before the exam starts.
6. Please write the answers clearly. Unclear or unreadable derivations/answers will be considered as wrong answers.
7. Make appropriate assumptions if required. Clearly specify these assumptions in your answer sheets.

→ *Please observe the above mentioned rules carefully. Non-compliance can result in lower or no grade!*

In case of suspicion of fraud, the Board of Examiners will be informed.

Undersigned lecturers have approved the exam:

1. A. Cervone

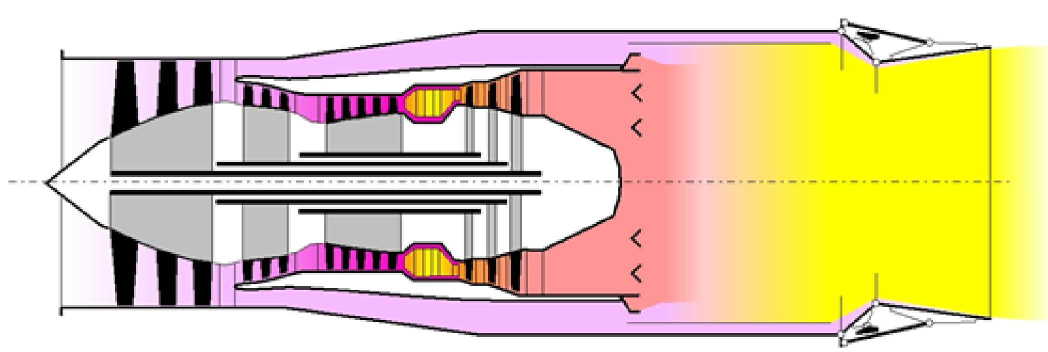
2. J.A. Melkert

Question 1

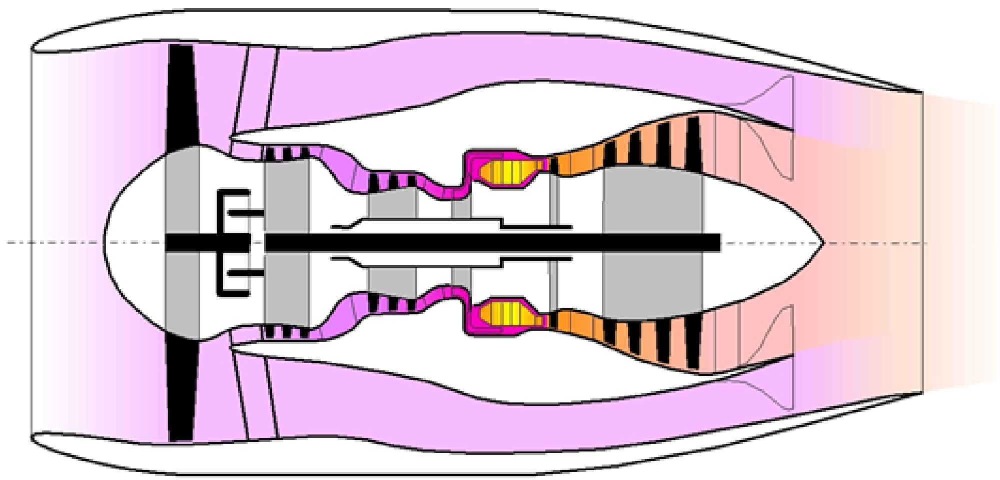
(6 pts) The three engines in the following pictures are (give the most complete answer)?

a) Straight turbojet engine
b) A twin-spool turbofan engine
c) A triple-spool turbofan engine
d) A twin-spool turboprop engine
e) A turboprop engine
f) A turbojet engine with afterburner
g) A turboprop engine with afterburner
h) A turboprop engine with a radial compressor
i) A turboprop engine with an intercooler
j) A turboshaft engine with recuperator
k) A propeller engine
l) A supersonic jet engine
m) A twin-spool turboprop engine with a gearbox
n) A triple spool turbofan engine with afterburner
o) A twin spool turbofan engine with mixed flow
p) A twin spool turbofan engine with separated flow
q) A geared twin spool turbofan engine with mixed flow
r) A geared twin spool turbofan engine with separated flow

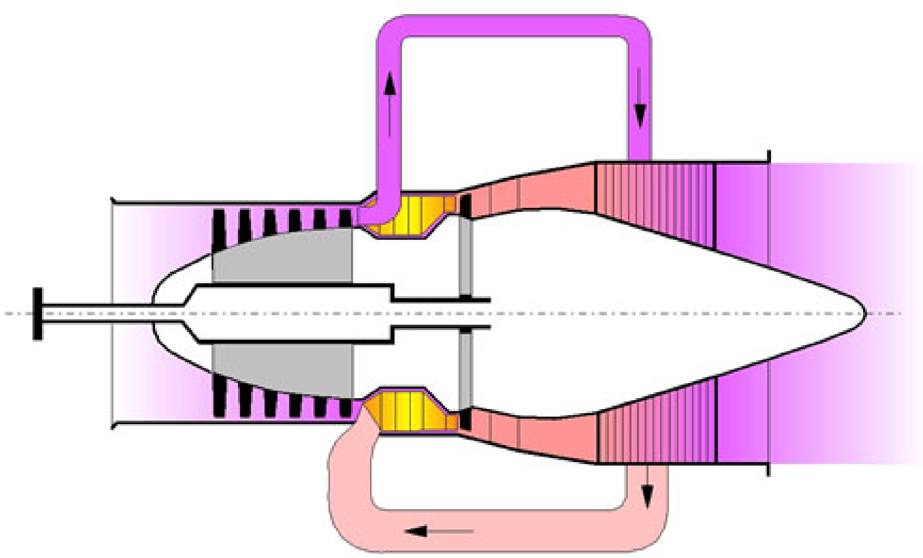
1a) Engine 1



1b) Engine 2



1c) Engine 3

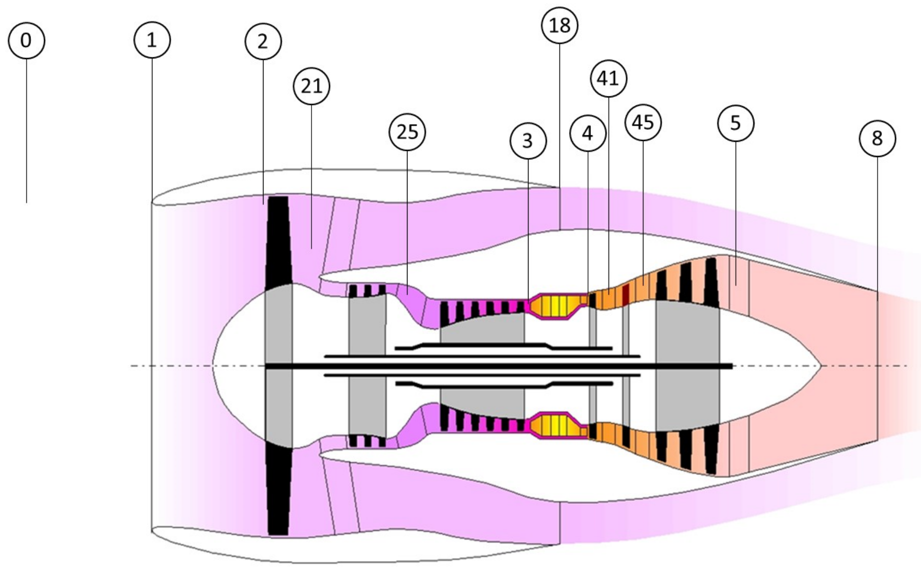


Question 2

This question has 12 subparts (a-l). The points division is as follows:

(a-2 / b-2 / c-4 / d-3 / e-4 / f-3 / g-5 / h-3 / i-3 / j-1 / k-5 / l-9)

Now consider the following triple spool turbofan engine



This engine is used on a large twin engine aircraft that is in its initial climb after take-off. The engine is running at maximum continuous power. For your analysis you must make use of the station numbering as is indicated in the picture above. The following data is available:

cruise altitude h_{cruise} = 1,000 m
ambient pressure at cruise altitude p_0 = 89,874 Pa
ambient temperature at altitude T_0 = 281.65 K
density ρ = 1.1118 kg/m^3
climb speed M_0 = 0.40
flight speed V_0 = 134.56 m/s
air mass flow rate $\dot{m}$ = 1440 kg/s
bypass ratio λ = 9.6
inlet pressure ratio Π_{inlet} = 0.98
fan pressure ratio Π_{fan} = 1.54
intermediate pressure compressor pressure ratio Π_{IPC} = 9.61
high pressure compressor pressure ratio Π_{HPC} = 3.38
fan isentropic efficiency η_{fan} = 0.94
IPC isentropic efficiency η_{IPC} = 0.991
HPC isentropic efficiency η_{HPC} = 0.92
Turbine entry temperature $T_{0,4}$ =1,838 K
combustor pressure ratio Π_{cc} = 0.99
combustor efficiency η_{cc} = 0.985

HPT efficiency η_{HPT} = 0.96
IPT efficiency η_{IPT} = 0.965
LPT efficiency η_{LPT} = 0.97
spool mechanical efficiency for all three spools η_{mech} = 0.995
fan nozzle efficiency $\eta_{noz,cold}$ = 0.96
core flow nozzle efficiency $\eta_{noz,hot}$ = 0.95
gas constant R = 287.0 J/kg.K
fuel calorific value LHV= 43 MJ/kg
specific hear at constant pressure for air $c_{p,air}$ = 1,000 J/kg.K
specific hear at constant pressure for hot gas $c_{p\ gas}$ = 1,150 J/kg.K
ratio of specific heats for air κ_{air} = 1.4
ratio of specific heats for hot gas κ_{gas} = 1.33

2a) Calculate the total temperature and pressure at station 0 and station 2.

2b) Calculate the core (hot) and bypass (cold) mass flow rates $\dot{m}_{hot}$ and $\dot{m}_{cold}$.

2c) Calculate the total temperature and pressure at station 21 and the temperature and pressure station 18.

2d) Calculate the thrust of the bypass flow

2e) Calculate the total temperature and pressure at station 25 and station 3.

2f) Calculate the amount of fuel used, $\dot{m}_f$.

2g) Calculate the power that is needed for driving the fan, the intermediate pressure compressor and the high pressure compressor $\dot{W}_{fan}$, $\dot{W}_{IPC}$ and $\dot{W}_{HPC}$

2h) Calculate the total temperature and pressure at stations 41, 45 and station 5.

2i) Calculate the thrust of the core flow

2j) Calculate the specific fuel consumption of the engine

The engine uses kerosene as fuel. Kerosene is a blend of several hydrocarbons. Its average chemical composition can be written as $C_{13}H_{25}$.

2k) Knowing that atmospheric air consists of 21% oxygen and 79% nitrogen (by volume) and using the molecular weights given in the table, calculate the equivalence ratio, ϕ.

H	1.008
C	12.011
N	14.007
O	15.994

2l) Draw an accurate T-s-diagram of the engine on the template. In the diagram show all points in the cycle and indicate all relevant isobars.

Name:………………………………………………………………………………………….......... Student number:………………….

Results summary table air breathing propulsion

	Question 1			
	1a) N	1b) Q	1c) J	
	Question 2			
a	$p_{0,0}$ = 100,349 Pa	$T_{0,0}$ = 290.7 K	$p_{0,2}$ = 98,343 Pa	$T_{0,2}$ = 290.7 K
b	$\dot{m}_{hot}$ = 135.8 kg/s	$\dot{m}_{cold}$ = 1304.2 kg/s		
c	$p_{0,21}$ = 151,447 Pa	$T_{0,21}$ = 331.3 K	p_{18} = 89,874 Pa	T_{18} = 287.2 K
d	T_{bypass} = 211,597 N			
e	$p_{0,25}$ = 1,455,410 Pa	$T_{0,25}$ = 635.1 K	$p_{0,3}$ = 4,919,286 Pa	$T_{0,3}$ = 922.4 K
f	$\dot{m}_f$ = 3.377 kg/s			
g	$\dot{W}_{fan}$ = 58.46 MW	$\dot{W}_{IPC}$ = 41.27 MW	$\dot{W}_{HPC}$ = 39.03 MW	
h	$p_{0,41}$ = 2,666,269 Pa	$T_{0,41}$ = 1593 K	$p_{0,45}$ = 1,267,264 Pa	$T_{0,45}$ = 1334 K
	$p_{0,5}$ = 330,414 Pa	$T_{0,5}$ = 967K		
i	T_{core} = 85,703 N			
j	SFC = 11.36 g/kN.s			
k	ϕ = 0.340			