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FACULTY OF ENGINEERING

Heat Exchanger Optimization and 1-D Model Development According to Flight Parameters

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Furkan Kaplan

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ABSTRACT

In this thesis, the effects of crossflow air-to-air heat exchanger parameters on heat transfer and pressure loss for the fighter aircraft jet air conditioning system examined and a MATLAB application is developed. The heat exchanger parameters with altitude input according to the flight parameters is calculated via the developed application. The application is developed with technical support from TAI engineers on aviation and theoretical support from a consultant lecturer. Thermophysical properties are calculated with CoolProp. Pressure, temperature inputs are calculated with respect to compressible isentropic fluid flow and Brayton Cycle. For designing a heat exchanger e-NTU method is used due to unknown output temperatures. Since the program algorithm tends to increase effectiveness, %70 effectiveness is selected for the first iteration. For 30 kfeet input the algorithm designs a heat exchanger with effectiveness of %97 Also, the mass flow change with respect to Mach with constant effectiveness and altitude is examined. As expected, mass flow of cold side is increased and mass flow for hot side is decreased to keep effectiveness constant. A temperature difference for inlet of heat exchanger is also considered due to Mach increase and it shows reason of decreasing mass flow for hot side.

Keywords: Heat Exchanger, Pressure Drop, Heat Transfer, Open-source program, Aircraft

NOMENCLATURE

a : Speed of sound, m/s
A_c : Cross sectional area, m^2
A_b : Heat transfer area bleed side Sea
A_r : Heat transfer area ram side
$A_{fr,b}$: Frontal Area bleed side
$A_{fr,r}$: Frontal Area ram side
A_{ob} : Minimum free flow area bleed side
A_{or} : Minimum free flow area ram side
A_w : Total wall area, ^{m2}
b_b : Distance between two plates bleed side
b_r : Distance between two plates ram side
D_h : Hydraulic diameter
f : Fanning friction factor
h : Heat transfer Coefficient
h(m) : Input altitude, meter
G_b : Fluid mass velocity based on minimum free area bleed side
G_r : Fluid mass velocity based on minimum free area ram side
j : Colburn J factor
k_f : Thermal conductivity
L_1 : Length, m
L_2 : Width, m
L_3 : Height, m
l_s : Strip length of an offset fin
Mach : Mach number
$\dot{m}$: Mass flow rate, kg/s
N_p : Passages
P_0 : Sea level thermophysical conditions, Pa
P_1 : Input altitude pressure, Pa
P_2 : Heat Exchanger inlet pressure – ram side, Pa
P_3 : Heat Exchanger inlet pressure – bleed side, Pa
Pr : Prandtl number
r_c : Compression ratio
R_w : Resistance
T_0 : Sea level thermophysical conditions, K
T_1 : Input altitude temperature, K
T_2 : Heat Exchanger inlet temperature – ram side, K
T_3 : Heat Exchanger inlet temperature – bleed side, K
u : Velocity, m/s
UA : Overall heat transfer coefficient
$V_{p,r}$: Volume between plate ram side
$V_{p,b}$: Volume between plate bleed side
β_b : Heat transfer surface area density bleed side
β_r : Heat transfer surface area density ram side
η_f : Fin efficiency
η_o : Extended surface efficiency
γ : Heat capacity ratio
ρ : Density, kg/m^3
δ_w : Thickness, m

ABBREVITIONS

AMP **:** Computational Fluid Dynamics

CFD **:** Computational Fluid Dynamics

ECS **:** Environmental Control System

FA **:** Fin Area

FI **:** Fin offset Length

NTU **:** Number of Transfer Unit

OSF **:** Offset Fin

PS **:** Plate Spacing

TA **:** Total Area

TAI **:** Turkish Aerospace Industries

WI **:** Wavelength

1-D **:** One dimensional

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1. INTRODUCTION

Aviation is of great importance in the national defense industry. Since 1974, national defense industry activities have gained momentum. In this context, the optimization of the heat exchangers, which are the main parts of the cooling system in an aircraft, which is the striking power of aviation, according to flight parameters and the development of the performance model will be discussed. Since the heat exchangers are not top priority for aircraft, the algorithm is developed with core dimension input.

The research question of the project: An investigation of the effect of the heat exchanger, which is an important element in the cooling systems in aircraft, on heat transfer and pressure loss and, during the optimization process of requirements, find out whether user-interfaced outputs can be obtained if the inputs are parameterized. The goal of the project is according to flight conditions (flight speed, altitude, take-off speed, altitude dependent humidity), designing air-air crossflow heat exchangers used in aviation and preparing an optimized open-source code program.

The main objectives of the project:

1- Since the exit temperatures of the heat exchanger are not known, by using the e-NTU method, by preparing a domestic-national open-source coded program, and by changing hot-cold side, mass flow, temperature, pressure, fin type, flight conditions (altitude, flight speed, etc.), to create an interface that can calculate the heat transfer coefficient and pressure loss parametrically.

2- To calculate the two most commonly used fin types (wavy and offset) heat exchanger designs in aviation according to the parameters above and to compare the effects of these designs.

3- To make a user-friendly program that minimizes the pressure loss and maximizes the heat transfer and also takes the flight conditions as input for the designed fin type.

4- Modeling of the final design with 1D simulation program.

The aircraft air conditioning system has become one of the most important systems because it is not only responsible for air conditioning, as in the automotive industry but also for operations such as cabin pressurization, smoke removal, air filtration, fuel tank pressurization, conditioned air supply for the oxygen system, anti-g pressurization and avionics cooling. In general, this system is responsible for providing a comfortable environment for a given payload by keeping some parameters (temperature, pressure, air flow rate, etc.) within acceptable limits. [1]

So many air recirculating cooling systems have been used in the aircraft industry. A simple air cycle diagram can be found in Figure 1.

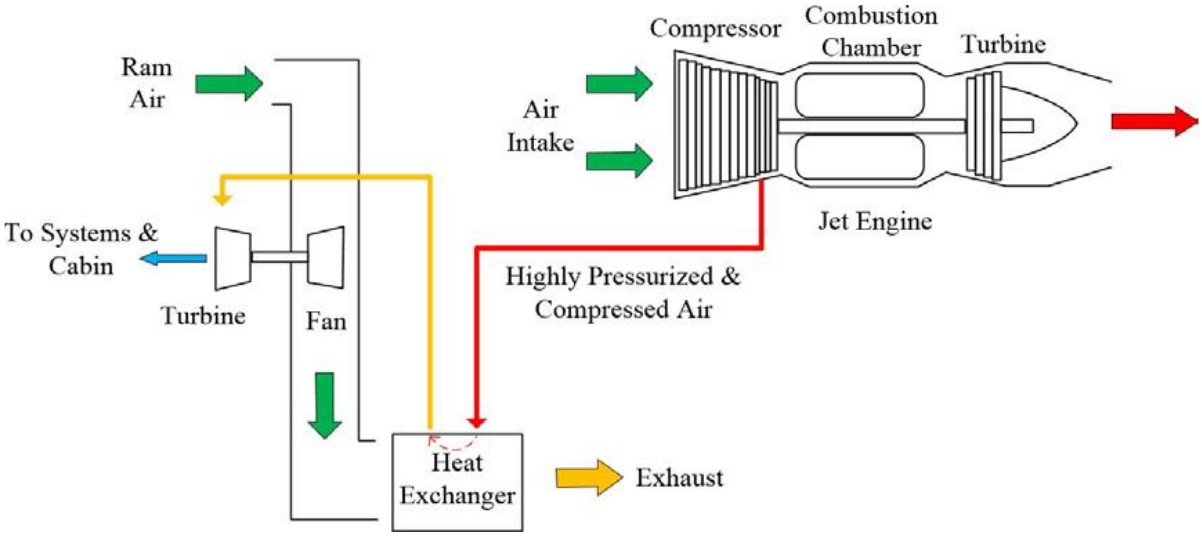

Figure 1. A simple air cycle diagram [1]

The aircraft air conditioning system is a critical system if the system fails, the mission is aborted due to insufficient avionic cooling or cabin pressurization. In this case, the aircraft should land as soon as possible. In other words, long flight is not recommended, and the pilot must decide immediately on the landing site and flight time. As a result, heat exchangers have important roles in aircraft air conditioning systems. To design a good aircraft heat exchanger, the following requirements should be considered:

1-High Effectiveness Rate

2-Lightness

3-Fire Resistance

4-Ability to Work for Long Periods

5-Clogging Resistance

6-Small Volume

Open-source programs have become critically important to almost every institution. These programs are programs developed by institutions or individuals as a solution to a certain problem. The most innovative aspect of our project is the program to be created using open-source code for the company. Thanks to this program, which will be developed by making use of the software that continues to develop day by day, many benefits will be obtained. Also, this program provides, the hardware costs for performing the necessary analyzes are reduced. Less costly programs that give consistent results with commercial programs that are used in the market, which have high costs and require high hardware features, are seen as a reason for preference for companies.

Due to the chip crisis that affects the whole world, processor costs are increasing nowadays, and this increases the importance of open-source software. Speed is not a factor that any business can easily give up, and open-source software meets this need. The flexibility offered by open-source software allows rapid development and the end product is an instant response tool.

Due to the innovative reasons mentioned above, it was thought to develop an open-source program in order to design a heat exchanger to be used in aviation. Domestic and national heat exchanger design software to be developed for Turkey's national defense industry will be of great importance.

Content of The Study:

- Searching the literature to find appropriate heat exchanger and fin type for aviation industry.
- Showing the selection procedure of fin type.
- Defining the equations which will connects the flight parameters to heat exchanger.
- Selection of proper method for designing the heat exchanger.
- Finding the thermophysical properties of heat exchanger inlet.
- Developing the mass flow parameters according to maximum effectiveness.
- Minimizing pressure losses.
- Designing the MATLAB application.

1. GENERAL INFORMATION

1.1. Classification of Heat Exchangers

Heat exchangers are devices that allow thermal energy to be transferred between two or more fluids of varying temperatures. Heat exchangers are utilized in a range of applications, including power generation, process, chemical, and food industries, electronics, environmental engineering, waste heat recovery, manufacturing, air conditioning, refrigeration, and space applications, among others. The following main characteristics can be used to classify heat exchangers: [2]

1. Recuperators/regenerators
2. Transfer processes: direct contact and indirect contact
3. Geometry of construction: tubes, plates, and extended surfaces
4. Heat transfer mechanisms: single phase and two phase
5. Flow arrangements: parallel flows, counter flows, and cross flows

1.1.1. Recuperators and Regenerators

The conventional heat exchanger, shown diagrammatically in Figure 2.a with heat transfer between two fluids, is called a recuperator because the hot stream A recovers (recuperates) some of the heat from stream B. The heat transfer occurs through a separating wall or through the interface between the streams as in the case of the direct-contact-type heat exchangers Figure 2.c. Some examples of the recuperative type of exchangers are shown in Figure 1.2.

The same flow path (matrix) is alternatively occupied by one of the two fluids in regenerators or storage-type heat exchangers. The thermal energy is stored in the matrix by the hot fluid; later, when cold fluid flows through the same route, the stored energy is removed. As a result, unlike a direct-transfer heat exchanger, thermal energy is not transported through the wall (recuperator). Figure 2.b depicts the cyclic principle in action. When a solid is in the cold stream A, it loses heat; when it is in the hot stream B, it receives heat, regenerating the heat. A rotating regenerator for preheating the air in a big coal-fired steam power plant, a gas turbine rotary regenerator, fixed-matrix air preheaters for blast furnace burners, steel furnaces, open-hearth steel melting furnaces, and glass furnaces are all examples of storage-type heat exchangers. [2]

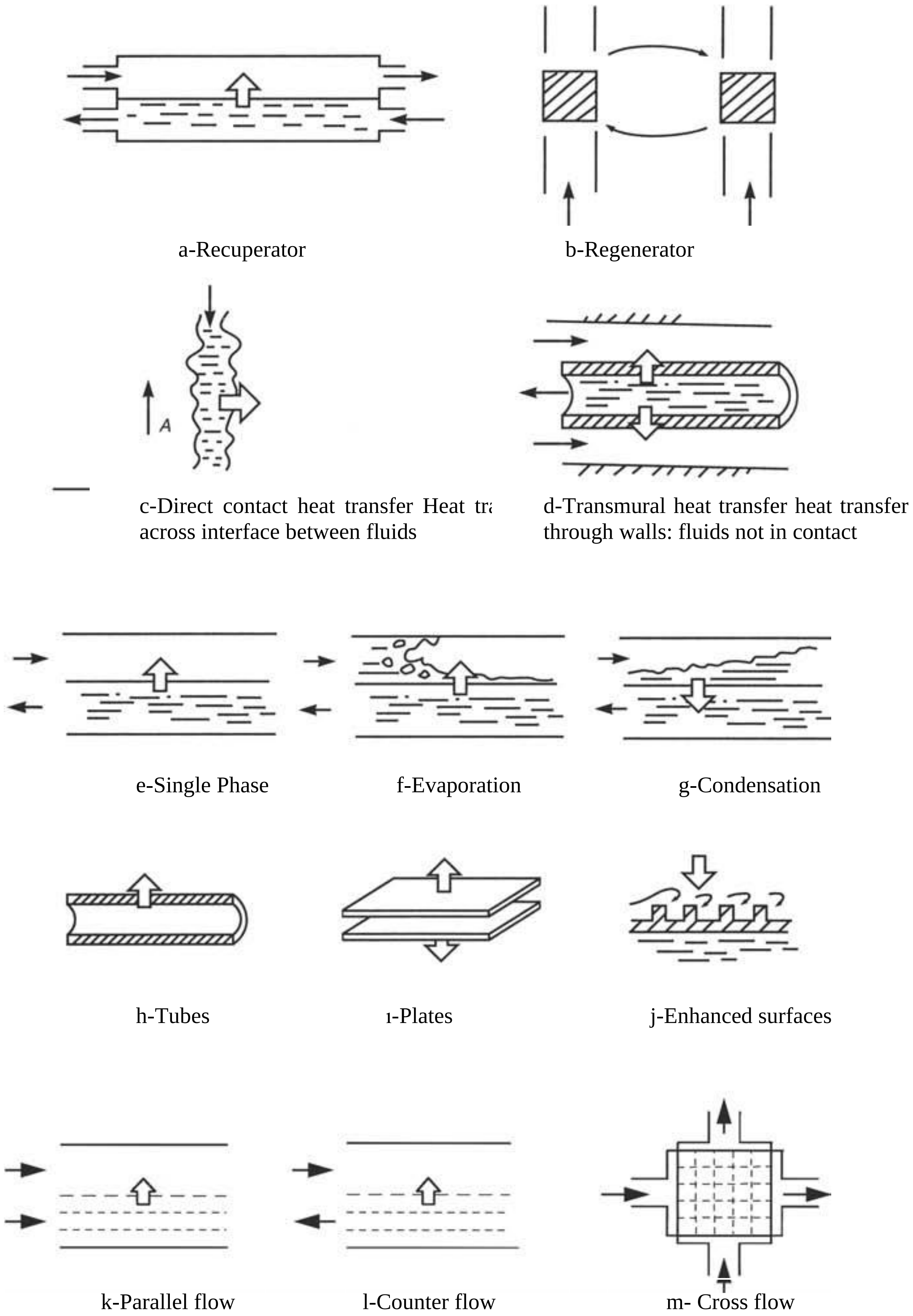

Figure 2. Classification of heat exchangers [2]

1.1.2. Heat Transfer Process (Direct Contact or Indirect Contact)

Heat exchangers are categorized as direct contact or indirect contact depending on how they transmit heat (transmural heat transfer). Heat is transmitted between the cold and hot fluids in direct-contact heat exchangers by direct contact between these fluids. As shown in Figure 2.c, there is no barrier between the hot and cold streams, and heat is transferred through the interface between them. [2]

1.1.3. Geometry of Construction

The construction aspects of direct-transfer-type heat exchangers (transmural heat exchangers) are frequently mentioned. Tubular, plate, and extended surface heat exchangers are the most common construction types. [2]

1.1.3.1. Tubular Heat Exchangers

Circular tubes make up tubular heat exchangers. One fluid circulates inside the tubes, while the other circulates outside the tubes. The tube diameter, number of tubes, tube length, tube pitch, and tube layout can all be altered. As a result, they can be designed in a variety of ways. Tubular heat exchangers are further divided into the following categories:

1. Double-pipe heat exchangers
2. Shell-and-tube heat exchangers
3. Spiral-tube-type heat exchangers

1.1.3.1.1. Double-Pipe Heat Exchangers

As shown in Figures 3, a conventional double-pipe heat exchanger consists of one pipe concentrically inside another pipe of bigger diameter with proper fittings to control the flow from one section to the next. To meet pressure-drop and mean temperature difference requirements, double-pipe heat exchangers can be constructed in various series and parallel configurations. Double-pipe exchangers are most commonly used for sensible heating or cooling of industrial fluids with limited heat transfer surfaces (up to 50 m^2). When one or both fluids are under high pressure, this design is ideal. Double-pipe heat exchangers have the significant disadvantage of being large and expensive per unit transfer surface. Inner tubing could be a single tube or a series of tubes. Axially finned inner tube (or tubes) can be employed if the heat-transfer coefficient in the annulus is inadequate. Double-pipe heat exchangers are constructed in a modular fashion, i.e., as hairpins.

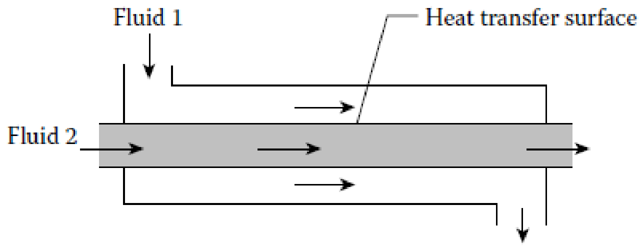

Figure 3. Double-Pipe Heat Exchanger

1.1.3.1.2. Shell-and-Tube Heat Exchangers

Round tubes are mounted in large cylindrical shells with the tube axis parallel to the shell axis in shell-and-tube heat exchangers. Oil coolers, power condensers, and preheaters in power plants, steam generators in nuclear power plants, process applications, and the chemical sector are all common uses. Figure 4 depicts the simplest form of a horizontal shell-and-tube type condenser with numerous components. One fluid stream goes through the tubes, while the other flows across or along the tubes on the shell side. The shell-side stream passes between pairs of baffles and then parallel to the tubes as it moves from one baffle compartment to the next in a baffled shell-and-tube heat exchanger. Depending on the application, shell-and-tube heat exchangers have significant variances.

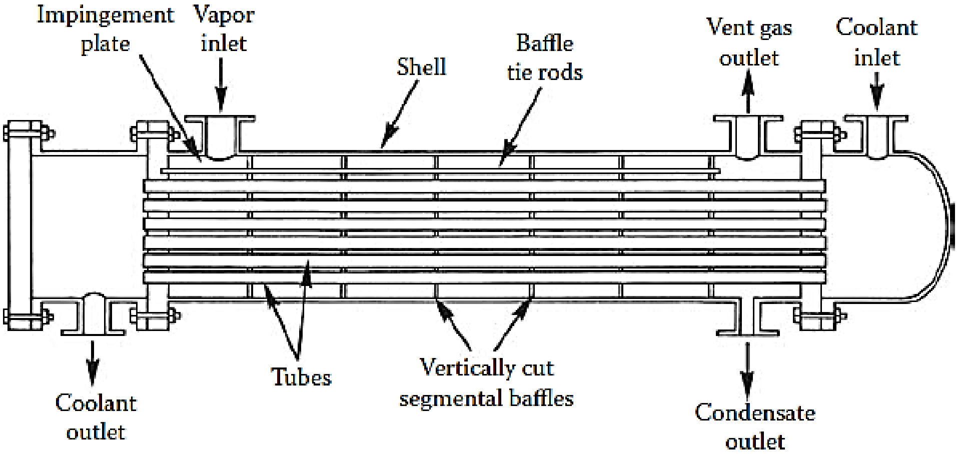

Figure 4. Shell-and-Tube Heat Exchanger

1.1.3.1.3. Spiral-Tube-Type Heat Exchanger

In refrigeration systems, this consists of spirally wrapped coils placed in a shell or constructed as coaxial condensers and coaxial evaporators. A spiral tube has a higher heat-transfer coefficient than a straight tube. Because cleaning is nearly impossible, spiral-tube heat exchangers are ideal for thermal expansion and clean fluids.

1.1.3.2. Plate Heat Exchangers

The flow channels in plate heat exchangers are formed by thin plates. The fluid streams are divided by smooth flat plates or corrugated fins between them. Plate heat exchangers are used to transfer heat between gas, liquid, and two-phase streams in any combination. Gasketed plate, spiral plate, and lamella heat exchangers are three types of heat exchangers.

1.1.3.2.1. Gasketed Plate Heat Exchanger

Figure 5 depict a typical gasketed plate heat exchanger. The fluids are separated by a series of thin plates with corrugation or wavy surfaces in a gasketed plate heat exchanger. The plates have corner sections that are positioned in such a way that the two media to be exchanged heat flow through alternate interplate volume. Compression bolts attach the end plates, allowing a stack of plates to be held together by appropriate design and gasketing. Gaskets prevent the two fluids from mixing and leaking to the outside, as well as directing the fluids in the plates in the correct direction. The flow pattern is usually chosen so that the media flow in opposite directions. Plate heat exchangers are typically confined to fluid streams with pressures of less than 25 bar and temperatures of less than 250°C. Due to the small size of the flow passageways, significant eddying produces high heat-transfer coefficients, pressure dips, and local shear, all of which reduce fouling. These heat exchangers provide a heat transfer surface that is both compact and lightweight. Because of the construction features and gasket materials, they are temperature and pressure limited. Typically, gasketed plate heat exchangers are used to transfer heat between two liquid streams. Because they can be entirely dismantled and cleaned, they have a wide range of applications in the food processing industry.

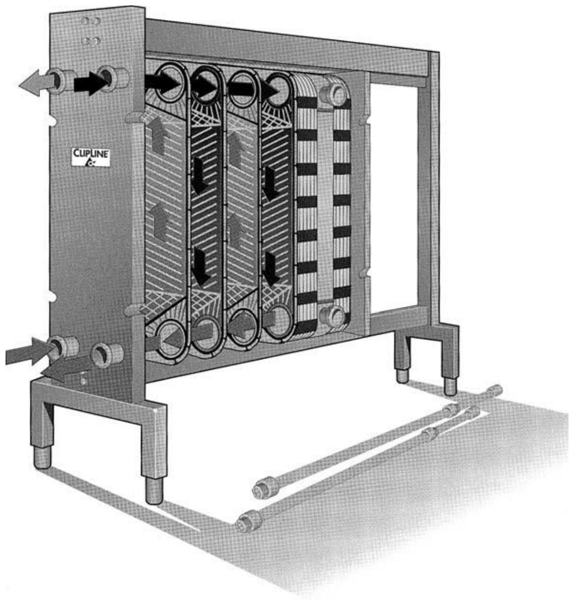

Figure 5. A Gasketed Plate Heat Exchanger

1.1.3.2.2. Spiral Plate Heat Exchanger

Spiral plate heat exchangers are made by spiraling two long, parallel plates around a mandrel and welding the plates' edges together to produce channels. Spacing pins welded to the metal sheet maintain the distance between the metal surfaces in both spiral channels. The distance pins' length can range from 5 to 20 mm. As a result, depending on the flow rate, alternative channel spacing can be used. This means that the perfect flow conditions can be achieved, resulting in the smallest feasible heating surfaces.

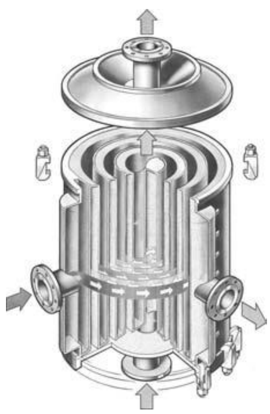

Figure 6. Spiral Plate Heat Exchangers

1.1.3.2.3. Lamella Heat Exchanger

The lamella (Ramen) heat exchanger is made up of a series of thin plate channels or lamellae (flat tubes or rectangular channels) that are welded together and positioned longitudinally in a shell

(Figure 7) It is a shell-and-tube heat exchanger with a floating-head design. Lamellae (lamellas) are flattened tubes made up of two strips of plates that are contoured and spot- or seam-welded together in a continuous operation. On the shell side, the strip formation provides room inside the lamellae and bosses that act as spacers for the flow sections outside the lamellae. Depending on the distance necessary between lamellae, the lamellae are welded together at both ends by attaching the ends with steel bars in between.

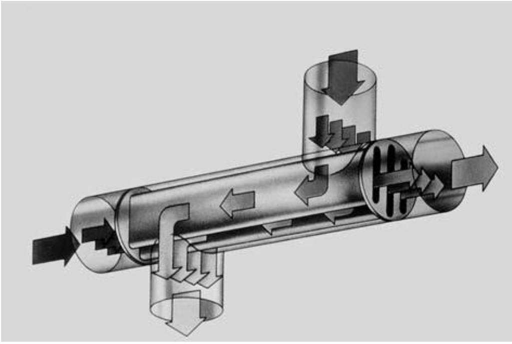

Figure 7. Lamella Heat Exchanger

1.1.3.3. Extended Surface Heat Exchangers

Extended surface heat exchangers are heat transfer devices that have fins or appendages on the principal heat transfer surface (tubular or plate) to increase the heat transfer area. Finned heat transfer surfaces are utilized on the gas side to enhance the heat transfer area since the heat-transfer coefficient on the gas side is substantially lower than on the liquid side. When the heat-transfer coefficient on one or both sides is low and a compact heat exchanger is required, fins are extensively utilized in gas-to-gas and gas-to-liquid heat exchangers. Plate-fin heat exchangers and tube-fin heat exchangers are the two most popular types of extended surface heat exchangers.

1.1.3.3.1. Plate-Fin Heat Exchangers

Plate-fin heat exchangers are typically used in gas-to-gas applications, while tube-fin exchangers are typically utilized in liquid-to-gas applications. Mass and volume reductions are very significant in most applications (e.g., trucks, vehicles, and airplanes). Compact heat exchangers are also commonly utilized in cryogenic, energy recovery, process industry, and refrigeration and air conditioning systems due to this gain in volume and mass. The general shape of a plate-fin heat exchanger is shown in Figure 8. Flat plates separate the fluid streams, with corrugated fins wedged between them.

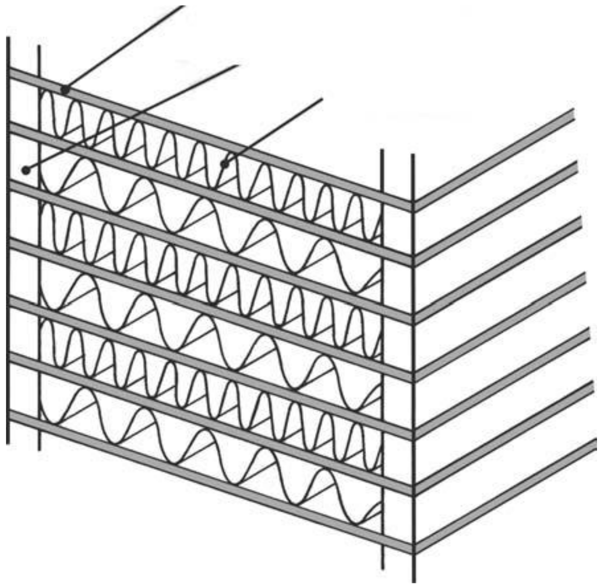

Figure 8. Plate-Fin Heat Exchanger

1.1.3.3.2. Tubular-Fin Heat Exchanger

In gas-to-liquid heat transfers, these heat exchangers are utilized. On the gas side, heat transfer coefficients are typically substantially lower than on the liquid side, necessitating the use of fins. An array of tubes with fins mounted on the outside make up a tubular-fin (or tube fin) heat exchanger. The fins on the outside of the tubes can be normal, transverse, helical, or longitudinal (or axial). Longitudinal fins are widely employed in heat exchangers with no baffles, such as double-pipe or shell-and-tube heat exchangers. Gases or viscous liquids can be used as fluids (oil coolers). Continuous plate-fin sheets, on the other hand, might be fastened to the array of tubes.

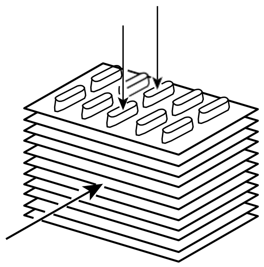

Figure 9. Tube-Fin Heat Exchanger

2. LITERATURE REVIEW

In this part, similar studies are reviewed, and the results are presented in the following paragraphs.

2.1. Heat Exchanger Types in Aircraft Industry

Several heat exchanger types have been used in the aircraft industry, Due to weight and volume constraints, compact plate-fin or shell and tube heat exchangers are mostly used. Plate-fin heat exchangers are used mostly in low-pressure applications (below 2.07 MPa (300 psia)), while shell and tube heat exchangers are used in high-pressure applications [4]. Plate-fin heat exchangers are used as the main heat exchangers in jet fighters since they have low-pressure ECS applications (usually max. 0.69 MPa (100 psia)) and require low-volume components. Only plate-fin heat exchangers are examined for design and optimization in this thesis since they are convenient for aircraft air conditioning applications. [1]

Compact plate-fin heat exchangers can provide a lot of heat transfer area for a small amount of space. Furthermore, when both fluids are gases, this form of heat exchanger is particularly useful, making it ideal for aircraft air to air heat exchanger applications. Plain fins, louvered fins, offset-strip fins, wavy fins, pin fins, and perforated fins are all types of plate-fin heat exchangers [3]. Figure 10 is illustrated three-dimensional fins, respectively. Plate-fin heat exchangers have extremely high compactness ratios (700-5000 m2/m3), which is the total heat transfer area per unit heat exchanger volume [4]. Because of the high surface densities, smaller heat exchangers may be designed.

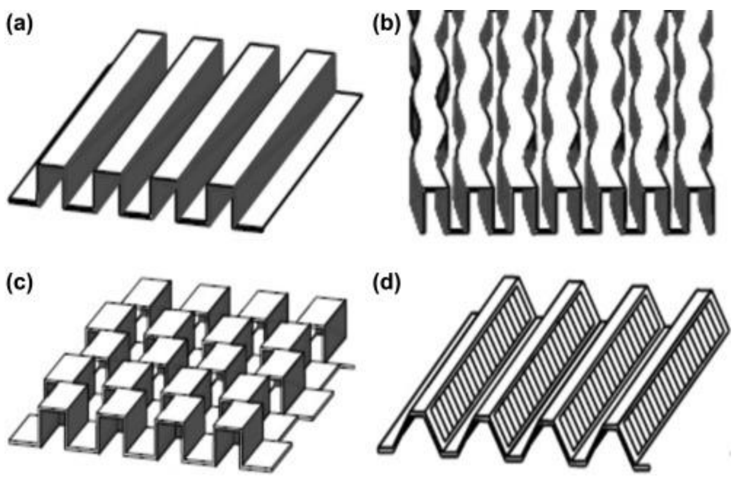

Figure 10. Fin Geometries for plate-fin heat exchangers: (a) plain rectangular fin; (b) wavy fin; (c) offset-strip fin; (d) plain triangular fin [2]

2.2. Compact Heat Exchanger Applications on Civil and Military Aircrafts

Compact plate-fin heat exchangers are a common heat exchanger type utilized in both civil and military applications. The following aviation applications use plate-fin heat exchangers: [5]

- Engine Bleed Air Precoolers
- Air Cycle ECS Heat Exchangers
- Air Cooled Oil Coolers
- Air Cooled Fuel Coolers
- Ram Air Coolers
- Electronic Liquid Cooling Loop Heat Exchangers
- Electronic Pod Coolant Heat Exchangers
- Vapor Cycle Evaporators
- Vapor Cycle Condensers

The air conditioning system on commercial airplanes is usually have a two-wheel bootstrap air cycle. For example, two-wheel bootstrap air cycle systems with compact heat exchangers are used on Boeing 767 and 747-8 airplanes [6], [7]. Recirculation air is the only difference between commercial and military applications in this cycle. Some (up to 50 percent) of the cabin air can be recirculated on commercial aircraft. Military aircraft, on the other hand, are not permitted to employ cabin recirculation air. Furthermore, for commercial aircraft, a single air conditioning pack is usually insufficient to supply the required air conditioning mass flow rates. This can be done with two or more packs [6].

Electric airplanes have recently gained popularity in the aviation industry. Air conditioning air is supplied by independent electrically driven compressors rather than bleed air from the engine. 'Bleedless' air conditioning systems are the name for this technology. This compressor's exit pressure and temperature are not as high as an engine compressor, but the temperature is still high enough that it must be conditioned. As a result, for these bleedless systems, compact heat exchangers are still used. To give you an example, the Boeing 787 Dreamliner commercial airplane incorporates bleedless ECS systems and small heat exchangers at the exit of two electrically operated ECS packs. [8]

Military applications also use compact heat exchangers. Military aircrafts include a lot of electronic equipment and need to be cooled using liquid coolant or air. Radars and avionics bays on fighter planes, for example, are typically cooled with polyalphaolefin fluid coolant and forced air.

There are many ECS designs for the F-18 fighter aircraft that include both liquid and air cooling [9]. The two-wheel bootstrap air cycle system is upgraded in certain of these systems to provide cooling not just for the avionics bay and cabin, but also for the air to liquid heat exchanger. Using conditioned cooling air, the hot fluid from the radar exit is cooled. Air to fuel heat exchangers, vapor cycle evaporators, and condensers are also available.

The most advanced version of ECS is a power and thermal management system for the next generation. This system serves as an ECS, as well as an auxiliary power unit and a thermal management system. Instead of numerous individual systems, there is a single integrated pack that is responsible for all of these systems [10]. Different modes of operation for the power and thermal management system include main engine start mode, cooling mode, and emergency power mode. It includes a three-wheel air cycle machine, fan duct heat exchangers, auxiliary heat exchangers, engine oil heat exchangers, condenser, reheater, recuperator, combustor, regulators, and valves, among other components. Some of these heat exchangers are micro channel compact heat exchangers of the advanced type [10].

3. MATERIALS AND METHODOLOGY

3.1. Compact Heat Exchanger Fin Selection

Colburn J Factor

The Colburn factor is a modified Stanton number to take into account the moderate variations in the fluid Prandtl number (representing different fluids). It is defined as

$$j = St.\mathrm{Pr}^{2/3} = \frac{Nu.\mathrm{Pr}^{-1/3}}{\mathrm{Re}}$$

Fanning Friction Factor

The ratio of wall shear stress τ_w to the flow kinetic energy per unit volume $\rho u_m^2 / 2g_c$ is defined as the Fanning friction factor:

$$f = \frac{\tau_w}{\rho u_m^2 / 2g_c}$$

By comparing the Colburn j factor, the best fin type for a plate-fin heat exchanger can be determined. Because Colburn J factor is proportional to heat transfer coefficient, and it is proportional to heat transfer. [1] Since, it is crucial for aircrafts to reduce heat exchanger capacity, a comparison is done between these two fin surfaces with similar compactness ratios, as shown in Table 1. The properties of the comparing fins are obtained from [3]. Figures 11 and 12 compare the Colburn j factors and friction factors, respectively. There are some pressure regulators on the aircraft ECS line since the air pressure from engines (up to 1.03 MPa (150 psi)) is higher than the operating pressure of primary heat exchangers (up to 0.55 MPa (80 psi). This enables high pressure drops on heat exchangers to be tolerated. As a result, heat exchanger fins with a high friction factor can be tolerated. For these reasons, only the Colburn j factor will be considered in the fin selection process. Figure 3 shows that for the same Reynolds number, **wavy and offset**-strip fins have higher Colburn j factors than other fins. As a result, this study will only look at these two fin types. [1]

Table 1. Similar Compactness Fin Parameters [3]

Parameters	Wavy Fin (11.44-3/8W)	Offset-strip Fin (3/32-12.22)	Plain Fin (11.1)	Pin Fin (PF-3)	Louvered (3/8 – 11.1)	Perforated (13.95(P))
Compactness	1152	1115	1204	1112	1204	1250
Fin Area/ Total Area	0.847	0.862	0.756	0.835-4	0.756	0.705
Fin Thickness [mm]	0.152	0.102	0.152	-	0.152	0.305
Hydraulic Diameter [mm]	3.23	3.41	3.08	1.636	3.084	2.504
Plate Spacing [mm]	10.49	12.3	6.35	19.1	6.35	5.08
Fins per meter	450.4	480.3	437.0	-	437.0	549.2

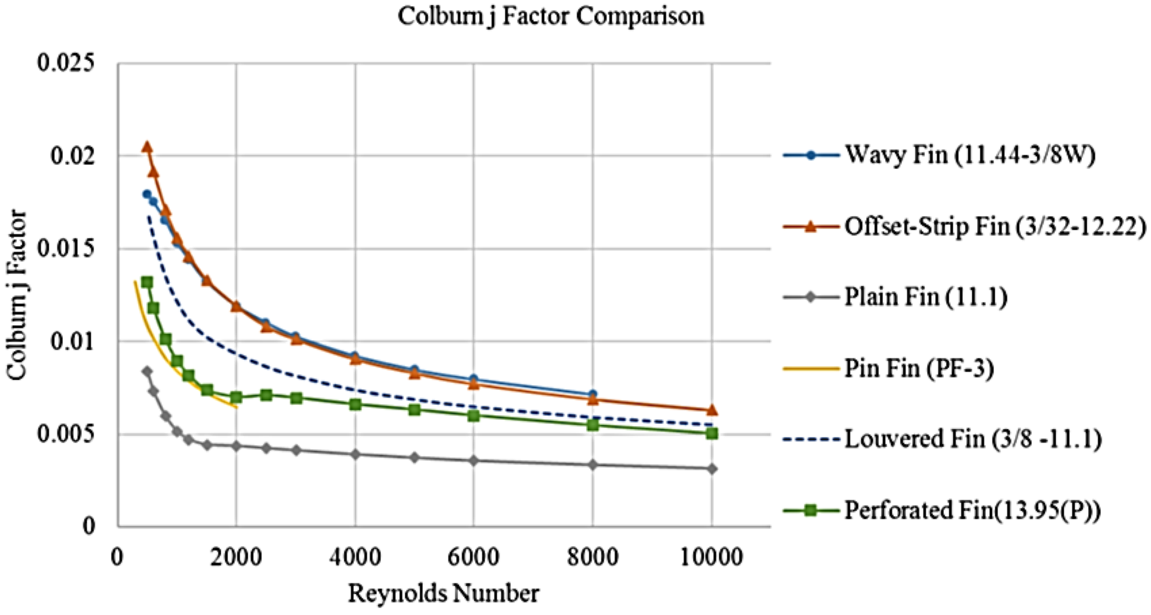

Figure 11. Colburn j Factor Comparison of Different Fins [1]

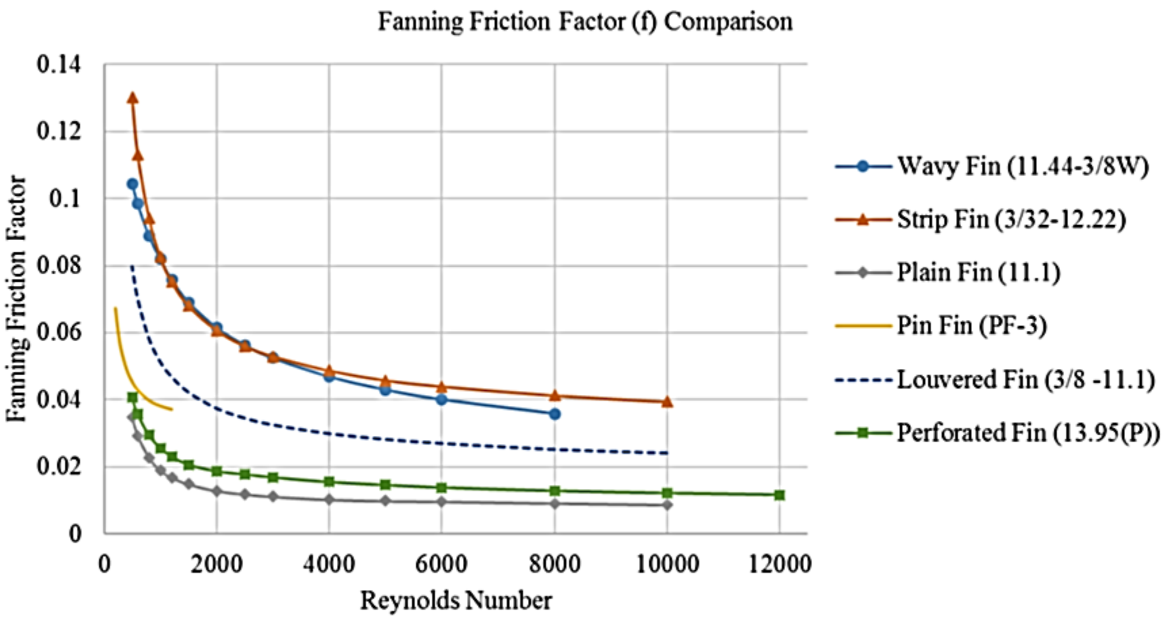

Figure 12. Friction Factor Comparison of Different Fins [1]

4. HEAT EXCHANGER DESIGN

In this section it has been dealt with air-to-air cross flow heat exchangers. There are 4 sections in this part, The first step is to obtain the thermophysical properties of air. Since the output temperatures are not known e-NTU method will be used.

4.1. Determination of Thermophysical Properties

Ram air represents cold side and bleed air represents hot side in heat exchanger. The parametric altitude to Mach and needed cooling load equations are given by TAI engineers. (Equation 3 and 13)

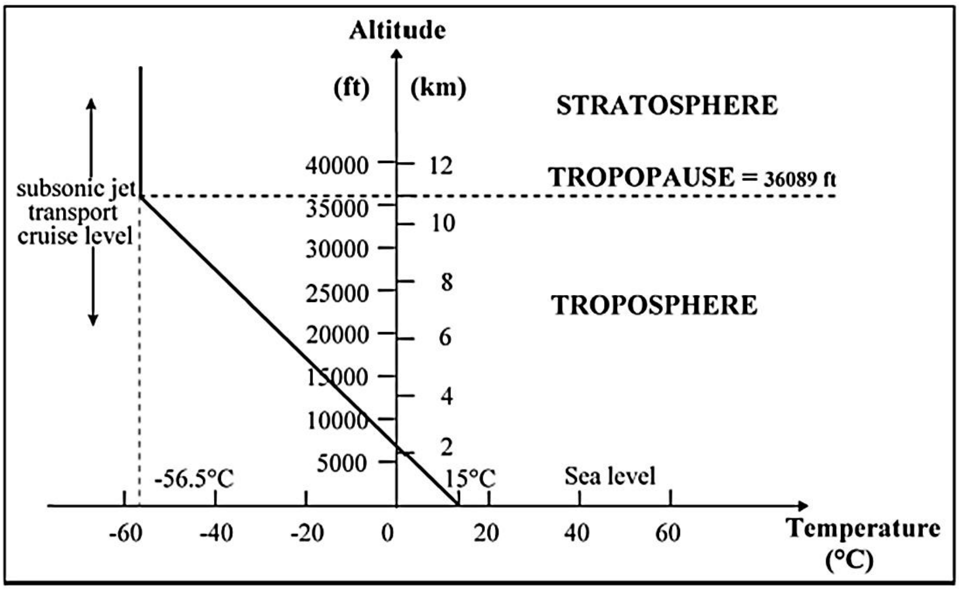

Figure 13. Temperature vs Altitude [11]

Stages are numbered as 0, 1, 2 and 3 which stands for;

Stage 0: Sea level conditions

Stage 1: Input altitude conditions

Stage 2: Inlet of heat exchanger ram side

Stage 3: Inlet of heat exchanger bleed side

Sea level conditions are taken as 101325 Pa and 15°C from International Standard Atmosphere.

Stage 0 to Stage 1;

$$T_1 = T_0 - 6.5\frac{h(m)}{1000} \tag{1}$$

$$P_1 = P_0\left(1 - 0.0065\frac{h(m)}{T_0}\right)^{5.2561} \tag{2}$$

Stage 1 to Stage 2;

The Mach number equation depending on altitude. [12]

$$\begin{aligned} &Mach = f(kfeet) \\ &Mach = 9E-07x^3 + 4E-05x^2 + 0.0043x + 0.2422 \end{aligned} \tag{3}$$

$$P_2 = P_1\left(1 + \frac{\gamma - 1}{2}M^2\right)^{\gamma/(\gamma-1)} \tag{4}$$

$$T_2 = \left(1 + \frac{\gamma - 1}{2}M^2\right)T_1 \tag{5}$$

Stage 2 to Stage 3;

In this process compression ratio is taken as input.

$$\begin{aligned} &\frac{T_3}{T_2} = \left(\frac{P_3}{P_2}\right)^{\left(1-\frac{1}{\gamma}\right)} \\ &\frac{P_3}{P_2} = r_c \end{aligned} \tag{6}$$

Mass Flow Rates

Ram air mass flow rate is calculated with equations 7 and 8. And cross section area of ram channel inlet is taken as input.

$$\begin{aligned} &Mach = \frac{u_2}{a_2} \\ &a_2 = \sqrt{\gamma R T_2} \end{aligned} \tag{7}$$

$$\dot{m}_{ram} = \rho_2 u_2 A_c \tag{8}$$

Bleed air mass flow is calculated with trial-and-error method with 0.70 effectiveness (e-NTU method).

4.2. e-NTU Method

Temperature and pressure data are obtained. So, CoolProp was used to have specific heat and density.

$$C_{\min,\max} = \dot{m}c_p \tag{9}$$

Capacity Rate Ratio;

$$C^* = \frac{C_{min}}{C_{max}} \tag{10}$$

Maximum cooling load found with equation 11,

$$\dot{Q}_{max} = C_{min}\left(T_{h,i} - T_{c,i}\right) \tag{11}$$

Effectiveness,

$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{max}} = \frac{C_h\left(T_{h,in} - T_{h,out}\right)}{C_{\min}\left(T_{h,in} - T_{c,in}\right)} = \frac{C_c\left(T_{c,out} - T_{c,in}\right)}{C_{\min}\left(T_{h,in} - T_{c,in}\right)} \tag{12}$$

Needed cooling load parametric equation with altitude variable [12]

$$Q(kW) = 4E-05x^4 - 0.0054x^3 + 0.2254x^2 - 1.6484x + 16.178 \tag{13}$$

By substituting equations 11, 12, 13 to equation 14 NTU can be founded, [3]

$$\varepsilon = 1 - e^{\frac{NTU^{0.22}\left(e^{-C^* NTU^{0.78}} - 1\right)}{C^*}} \tag{14}$$

And needed overall heat transfer coefficient can be found with equation 15.

$$NTU = \frac{UA_s}{C_{min}} \tag{15}$$

After the needed overall heat transfer coefficient was found, in the other part the required NTU was calculated.

4.3. Overall Heat Transfer Coefficient Calculation

There are 2 tables which are taken from [3]. From this tables overall heat transfer coefficient can be calculated. As it is mentioned before, only wavy, and offset fins will be considered.

Table 2. Offset-Fin Parameters [3]

OSF Type	Fin per meter [1/m]	PS [mm]	Fl [mm]	Dh [mm]	t [mm]	Compactness	FA/TA	Max Re Number
3/32-12.22	480	12.3	2.4	3.41	0.1	1115	0.86	10000
1/4(s)-11.1	437	6.35	6.35	3.08	0.15	1204	0.76	8000
1/8-13.95	549	9.53	3.18	2.68	0.25	1250	0.84	6000
1/8-15.2	598	10.5	3.18	2.65	0.15	1368	0.87	6000
1/8-15.61	615	6.35	3.18	2.38	0.1	1548	0.81	6000
1/9-22.68	893	7.65	2.8	1.74	0.1	2069	0.89	4000
1/8-19.86	782	2.49	3.18	1.54	0.1	2254	0.79	4000
1/9-25.01	985	5.08	2.8	1.5	0.1	2360	0.85	3000
1/10-19.35	762	1.91	2.54	1.4	0.1	2490	0.61	3000
1/9-24.12	950	1.91	2.8	1.21	0.1	2830	0.67	2000
1/10-27.03	1064	6.38	2.54	1.42	0.1	2466	0.89	3000
1/10-19.74	777	1.29	2.54	1.22	0.05	3028	0.51	3000
Min	437	1.29	2.4	1.21	0.05	1115	0.51	2000
Max	1064	12.3	6.35	3.41	0.25	3028	0.89	10000

Table 3. Wavy-Fin Parameters

WF Type	Fin Pitch [1/m]	PS [mm]	Wl [mm]	Dh [mm]	t [mm]	Amp [mm]	Com-pact-ness	FA/ TA	Re Max
11.44-3/8W	450.4	10.49	9.53	3.23	0.15	1.97	1152	0.85	8000
11.5-3/8W	452.8	9.53	9.53	3.02	0.25	1.98	1138	0.82	10000
17.8-3/8W	700.8	10.49	9.53	2.12	0.15	1.97	1686	0.89	5000
Min	450.4	9.53	9.53	2.12	0.15	1.97	1138	0.82	5000
Max	700.8	10.49	9.53	3.23	0.25	1.98	1686	0.89	10000

4.3.1. UA Calculation

$$N_p = \frac{L_3 - b_r + 2\delta_w}{b_b + b_r + 2\delta_w} \tag{16}$$

$$\begin{aligned} A_{fr,b} &= L_2 L_3 \\ A_{fr,r} &= L_1 L_3 \end{aligned} \tag{17}$$

$$\begin{aligned} V_{p,b} &= L_1 L_2 \left(b_b N_p \right) \\ V_{p,r} &= L_1 L_2 b_r \left(N_p + 1 \right) \end{aligned} \tag{18}$$

$$\begin{aligned} A_b &= \beta_b V_{p,b} \\ A_r &= \beta_r V_{p,r} \end{aligned} \tag{19}$$

$$\begin{aligned} A_{ob} &= \frac{\left(D_h A_b \right)}{4L1} \\ A_{or} &= \frac{\left(D_h A_r \right)}{4L2} \end{aligned} \tag{20}$$

$$G_b = \frac{\dot{m}_{bleed}}{A_{ob}}$$
$$G_r = \frac{\dot{m}_{ram}}{A_{or}} \tag{21}$$

$$\mathrm{Re} = \left(\frac{GD_h}{\mu}\right) \tag{22}$$

$$h = \frac{jGc_p}{\mathrm{Pr}^{2/3}} \tag{23}$$

$$m = \left[\frac{2h}{k_f \delta}\left(1+\frac{\delta}{l_s}\right)\right]^{1/2}$$
$$l \approx b/2 \tag{24}$$
$$\eta_f = \frac{\tanh(ml)}{ml}$$

$$\eta_o = \left[1-\left(1-\eta_f\right)\frac{A_f}{A}\right] \tag{25}$$

$$A_w = L_1 L_2\left(2N_p + 2\right)$$
$$R_w = \frac{\delta_w}{k_w A_w} \tag{26}$$

$$\frac{1}{UA} = \frac{1}{\left(\eta_o hA\right)_b} + R_w + \frac{1}{\left(\eta_o hA\right)_r} \tag{27}$$

After these calculations approximate overall heat transfer coefficient and new effectiveness were found.

4.4. Pressure Drop Calculation

In equation 23 and 28 it can be seen that Colburn J and Fanning F factors. These factors embedded to the algorithm from [3] tables which shown in table 4-5:

$$\Delta P = \frac{2 fLG^2}{D_h \rho_{avg}} \tag{28}$$

Table 4. Heat Transfer and Friction Data for Strip-Fin Plate Fin Surfaces [3]

Re	$StPr^{2/3}$	f	Re	$StPr^{2/3}$	f	Re	$StPr^{2/3}$	f
	1/4(s)-11.1			1/8-15.2			1/8-13.95	
10,000			10,000					
8,000	0.00525	0.0197	8,000			8,000		0.0628
6,000	0.00580	0.0209	6,000	0.00850	0.0487	6,000	0.01110	0.0650
5,000	0.00620	0.0218	5,000	0.00896	0.0498	5,000	0.01170	0.0664
4,000	0.00669	0.0231	4,000	0.00959	0.0516	4,000	0.01250	0.0684
3,000	0.00740	0.0253	3,000	0.01040	0.0540	3,000	0.0137	0.0712
2,500	0.00789	0.0272	2,500	0.01110	0.0558	2,500	0.0144	0.0733
2,000	0.00850	0.0298	2,000	0.01177	0.0584	2,000	0.0155	0.0765
1,500	0.00940	0.0348	1,500	0.01267	0.0628	1,500	0.0168	0.0817
1,200	0.0102	0.0394	1,200	0.01327	0.0676	1,200	0.0181	0.0870
1,000	0.0109	0.0438	1,000	0.01373	0.0726	1,000	0.0192	0.0927
800	0.0122	0.0500	800	0.01427	0.0800	800	0.0204	0.1020
600	0.0139	0.0595	600	0.01520	0.0913	600	0.0223	0.1170
500	0.0155	0.0665	500	0.01580	0.1010	500	0.0233	0.131
400			400	0.01675	0.1145	400	0.0247	0.154
300			300	0.01810	0.1390			
	1/8-15.61			1/8-19.86			1/9-22.68	
7,000	—	0.0330						
6,000	0.00758	0.0336						
5,000	0.00802	0.0343	5,000	—	0.0275	5,000	—	0.0298
4,000	0.00865	0.0355	4,000	0.00770	0.0284	4,000	0.00721	0.0310
3,000	0.00952	0.0376	3,000	0.00850	0.0306	3,000	0.00810	0.0332
2,000	0.0111	0.0420	2,000	0.00988	0.0350	2,000	0.00960	0.0382
1,500	0.0125	0.0467	1,500	0.0110	0.0396	1,500	0.0108	0.0430
1,200	0.0138	0.0519	1,200	0.0119	0.0440	1,200	0.0119	0.0476
1,000	0.0150	0.0569	1,000	0.0128	0.0484	1,000	0.0130	0.0523
800	0.0167	0.0645	800	0.0141	0.0550	800	0.0147	0.0600
600	0.0195	0.0772	600	0.0161	0.0660	600	0.0176	0.0736
500	0.0216	0.0880	500	0.0176	0.0750	500	0.0199	0.0845
400	0.0246	0.104	400	0.0198	0.0876	400	0.0234	0.0997
300	0.0295	0.131	300	0.0233	0.1090	300	0.0290	0.125
						200	—	0.172
						150	—	0.217
						120	—	0.260

1/9-25.01			1/9-24.12			1/10-27.03		
5,000	—	—				5,000	—	—
4,000	—	0.0385				4,000	—	0.0388
3,000	0.00950	0.0398	3,000	—	0.0362	3,000	0.00960	0.0401
2,000	0.0107	0.0437	2,000	0.00965	0.0398	2,000	0.0113	0.0449
1,500	0.0121	0.0483	1,500	0.0103	0.0432	1,500	0.0129	0.0497
1,200	0.0133	0.0528	1,200	0.0110	0.0467	1,200	0.0143	0.0540
1,000	0.0145	0.0573	1,000	0.0117	0.0500	1,000	0.0156	0.0586
800	0.0162	0.0647	800	0.0125	0.0551	800	0.0176	0.0663
600	0.0187	0.0772	600	0.0138	0.0639	600	0.0210	0.0810
500	0.0207	0.0880	500	0.0152	0.0713	500	0.0238	0.0922
400	—	0.103	400	0.0170	0.0828	400	—	0.108
300	—	0.128	300	0.0202	0.102	300	—	0.135
200	—	0.175	200	—	0.137	200	—	0.185
150	—	0.219	150	—	0.171	150	—	0.231
120	—	0.261				120	—	0.276

1/10-19.35			1/10-19.74			3/32-12.22		
5,000	—	—	5,000	—	—	10,000	0.00629	0.0394
4,000	—	0.0246	4,000	—	—	8,000	0.00688	0.0413
3,000	0.00830	0.0263	3,000	0.00764	0.0339	6,000	0.00770	0.0440
2,000	0.00940	0.0303	2,000	0.00843	0.0369	5,000	0.00828	0.0458
1,500	0.0105	0.0342	1,500	0.00910	0.0398	4,000	0.00903	0.0487
1,200	0.0115	0.0381	1,200	0.00974	0.0430	3,000	0.0101	0.0530
1,000	0.0125	0.0418	1,000	0.0104	0.0461	2,500	0.0108	0.0560
800	0.0138	0.0471	800	0.0114	0.0510	2,000	0.0119	0.0607
600	0.0158	0.0561	600	0.0129	0.0599	1,500	0.0133	0.0680
500	0.0174	0.0635	500	0.0141	0.0672	1,200	0.0146	0.0752
400	0.0195	0.0750	400	0.0158	0.0783	1,000	0.0156	0.0826
300	—	0.0937	300	0.0185	0.0962	800	0.0171	0.0942
200	—	0.130	200	—	0.131	600	0.0192	0.113
						500	0.0205	0.130
						400		
						300		

Table 5. Heat Transfer and Friction Data for Wavy-Fin Plate-Fin Surfaces [3]

11.44—3/8 W			11.5—3/8 W			17.8—3/8 W		
Re	$St\,Pr^{2/3}$	f	Re	$St\,Pr^{2/3}$	f	Re	$St\,Pr^{2/3}$	f
			10,000	0.00686	0.0331			
8,000	0.00712	0.0359	8,000	0.00746	0.0357			
6,000	0.00794	0.0401	6,000	0.00831	0.0398			
5,000	0.00846	0.0430	5,000	0.00890	0.0427	5,000	0.00675	0.0293
4,000	0.00920	0.0469	4,000	0.00970	0.0467	4,000	0.00740	0.0320
3,000	0.01025	0.0524	3,000	0.01077	0.0525	3,000	0.00835	0.0358
2,500	0.0110	0.0563	2,500	0.01155	0.0567	2,500	0.00900	0.0385
2,000	0.0119	0.0615	2,000	0.0126	0.0625	2,000	0.00982	0.0421
1,500	0.0132	0.0691	1,500	0.0140	0.0704	1,500	0.0110	0.0478
1,200	0.0144	0.0758	1,200	0.0150	0.0779	1,200	0.0120	0.0530
1,000	0.0153	0.0819	1,000	0.0158	0.0845	1,000	0.0129	0.0579
800	0.0165	0.0888	800	0.0167	0.0926	800	0.0142	0.0643
600	0.0175	0.0984	600	0.0178	0.1035	600	0.0158	0.0738
500	0.0179	0.1045	500	0.0185	0.111	500		
400			400	0.0194	0.118	400		
300						300		

5. RESULTS AND DISCUSSION

As a result, A MATLAB application is developed which codes added as appendix and with 30 kfeet altitude input an example shown in figure 14.

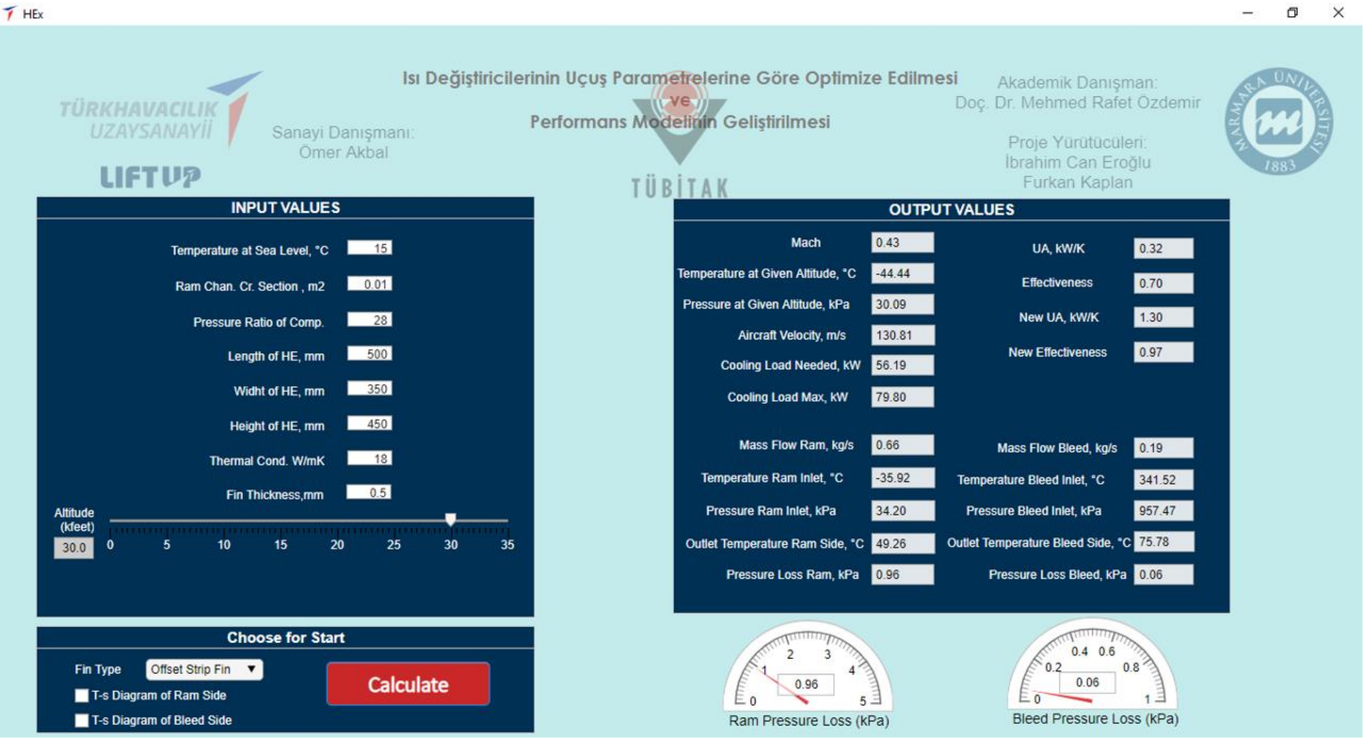

Figure 14. MATLAB Application

In the application output parameters are effectiveness, output temperatures mass flows and pressure losses. For bleed side, lower mass flow rate caused a lower pressure loss.

To illustrate clearly, T-S diagrams have added below (Figure 15 and 16).

And with constant altitude (30 kfeet) variable Mach, overall heat transfer coefficient versus Mach have plotted (Figure 17).

For better comparing by keeping effectiveness constant (0.70), mass flow rates changes have plotted. (Figure 18 and 19).

5.1. Graphs

5.1.1. Temperature versus Entropy Graphs

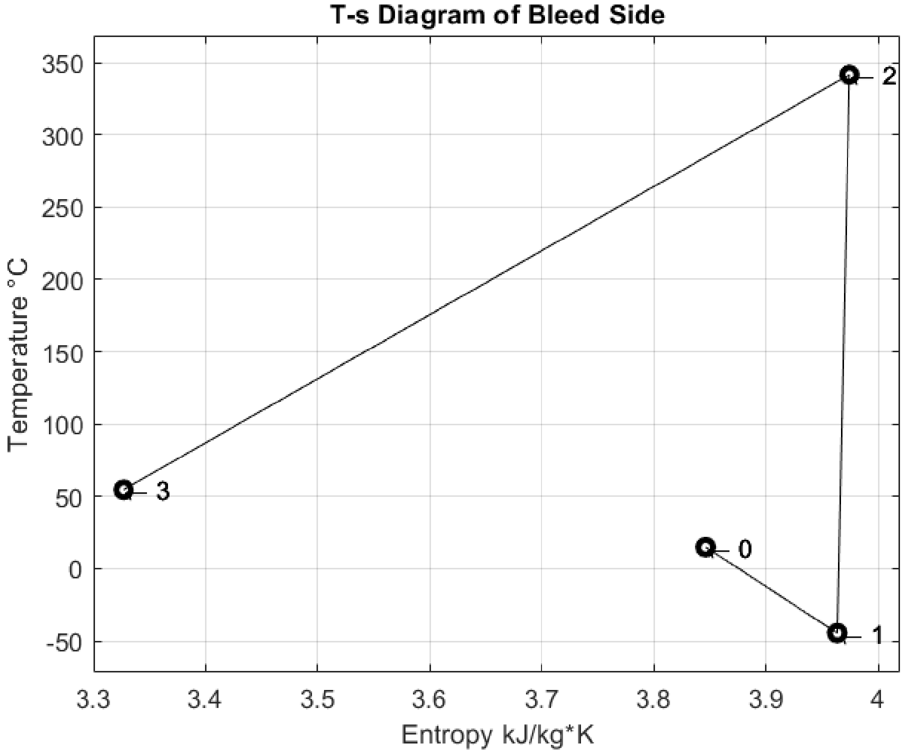

Figure 15. T-S Diagram of Bleed Side

In figure 15, stage 1 to stage 2 represents compression process. The bleed air comes from engine compressor, and it can reach 675°C [11]. Temperature 2 can be differed with respect to compression which have showed in equation 6 clearly. Temperature 3 is closed to ram air temperature 3 this shows designed heat exchanger has high effectiveness. For considered condition the effectiveness is %97.

In figure 16, there is a small change between stage 1 and 2 as expected. Because it can be seen clearly in equation 5 the only variable parameter is Mach. And the program is works with subsonic Mach. If Mach goes supersonic then it can be expected a different situation.

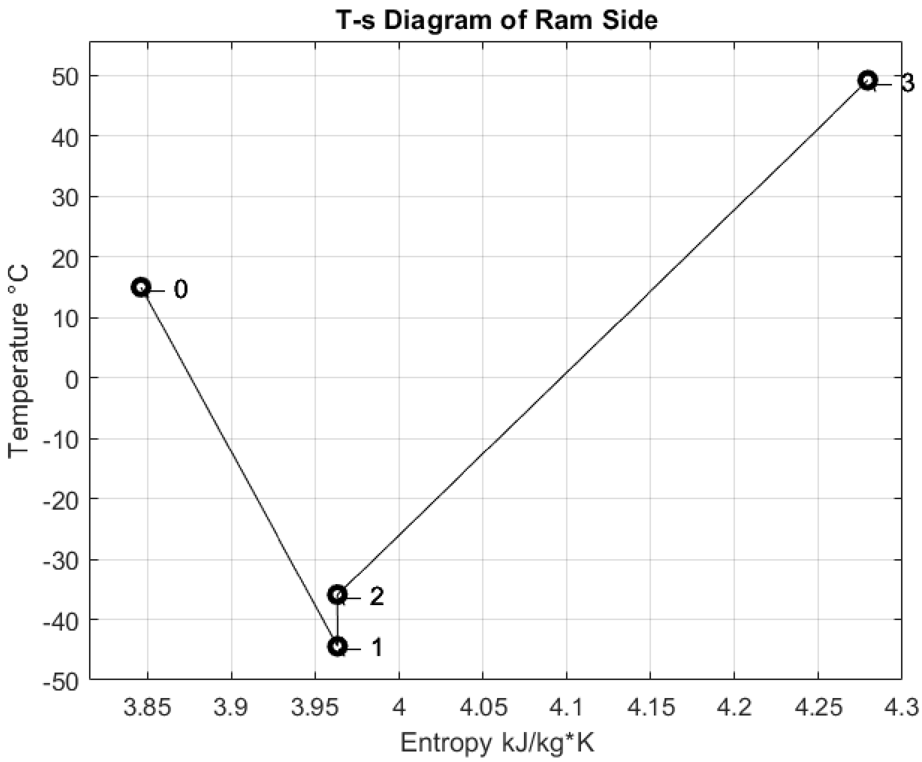

Figure 16. T-S Diagram of Ram Side

5.1.2. Flight Parameters Examination

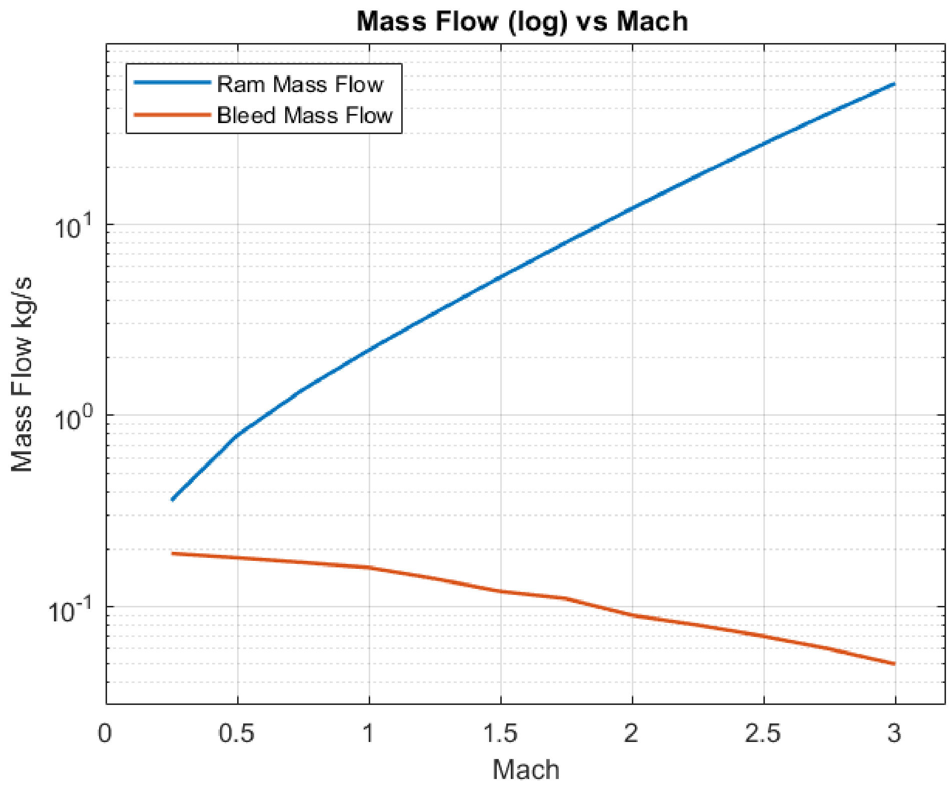

Figure 17. Constant 30 kfeet Altitude, Mach vs Mass Flow (log) with 0.70 effectiveness

It is expected an increase in mass flow for ram air due to equation 8 because the only variable parameter is Mach. And decrease in mass flow bleed is expected also because it is obvious that the effectiveness is dependent to Q_{max}. In equation 11 It is shown that Q_{max} is dependent to difference between temperatures. Since it is impossible to change temperature, the only parameter is the mass flow to change. (Figure 17)

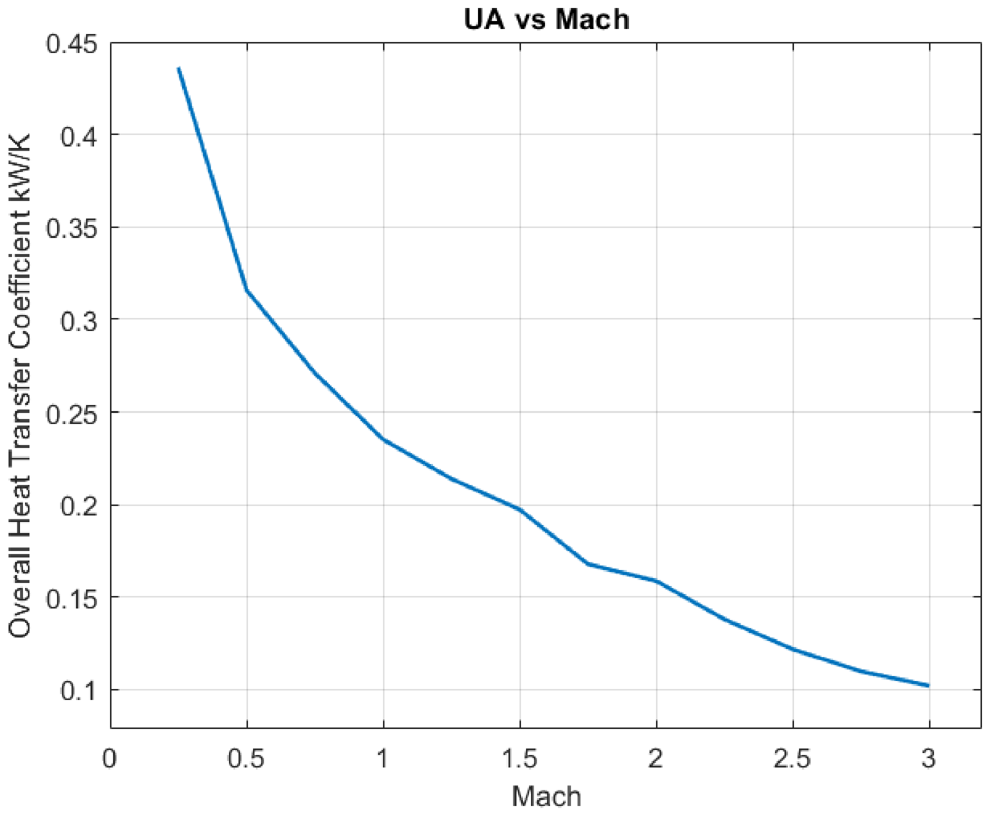

Figure 18. Constant 30 kfeet Altitude, variable Mach vs Overall Heat Transfer Coefficient with 0.70 effectiveness

Since the mass flow for bleed decreased with Mach, C_{min} is decreasing (Equation 9). And overall heat transfer coefficient is dependent to C_{min} (Equation 15). Thus, with an increase in Mach, overall heat transfer coefficient is decreased. (Figure 18)

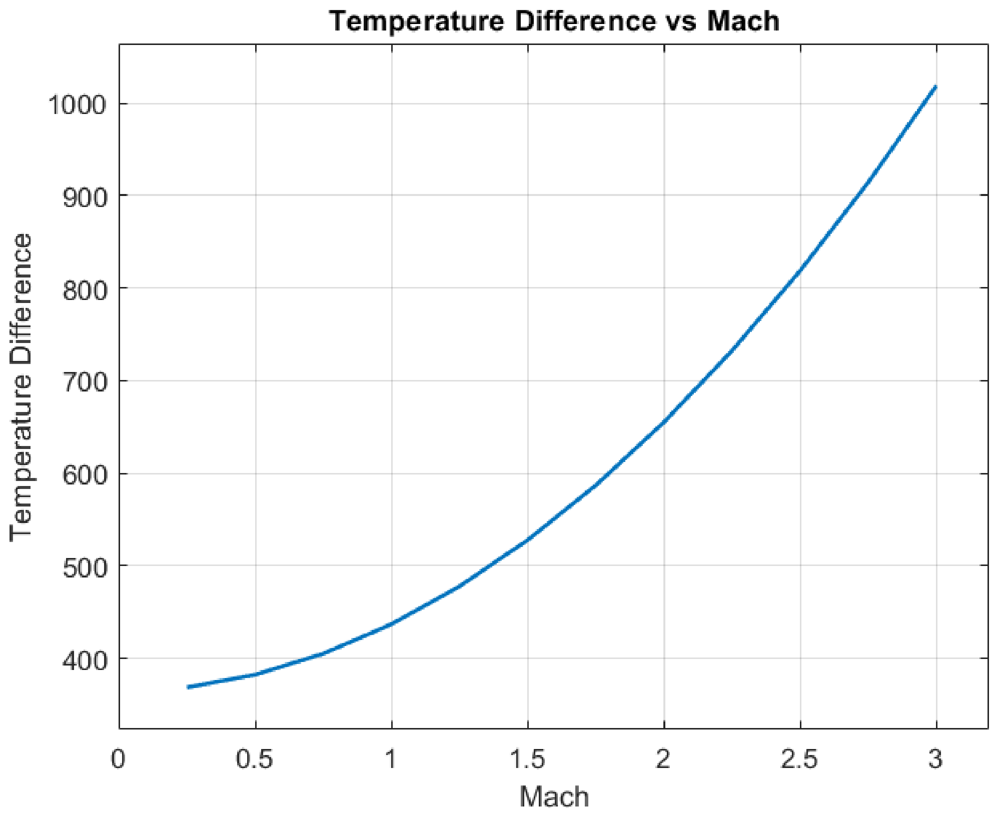

Figure 19. Temperature Difference vs Mach

As it mentioned before temperature differences is increasing with increase in Mach. Because in equation 5, it is clear that Mach square affects the stage 2 temperature.

6. CONCLUSION

To conclude, heat exchanger parameters is examined, and importance of mass flow is observed due to heat transfer and pressure drop. Overall heat transfer coefficient is decreasing with respect to Mach, it is connected to mass flow rate again. Since calculated effectiveness is high output temperatures observed close to each other.

In this thesis Colburn J factor and fanning F factor is taken from tables. It will be more correct with parametric equations. And altitude to Mach and altitude to maximum heat capacity parametric equations can be taken as input or new options can be added. Also, in this thesis parameters of fin types are taken from [3] this limited to optimize fin parameters. As future work fin parameters can be taken as variable to optimize and these variable parameters will enable to use more correct Colburn J and Fanning F.

- Literature is searched and appropriate heat exchanger is selected as cross flow, plate fin heat exchanger for aviation.
- According to Colburn J factor comparing, wavy and offset fin types are determined.
- Defining the equations which will connects the flight parameters to heat exchanger.
- Due to unknown output temperatures e-NTU method is selected for designing.
- Thermophysical properties are found with isentropic compressible flows and Brayton cycle rules. Specific heat capacity, Prandtl number and density are taken from CoolProp for the heat exchanger inlet.
- Cold side mass flow rate is determined with an input of cross-sectional area of ram channel inlet. Hot side mass flow rate is calculated with trial-and-error numeric method with respect to 0.70 effectiveness.
- Pressure losses are minimized with slowing the mass flow rate as possible.
- As a result, a MATLAB application is designed.

6.1. FUTURE WORK

- For optimizing inside of heat exchanger fin's parameters can be taken as variables and this will provide to use parametric Colburn J factor and Fanning F factor.
- An example of a selected altitude's results can be compared with CFD programs.
- Hot side thermophysical properties can be developed with other component consideration such as turbine, combustion chamber.

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8. APPENDIX

```
T0 = app.Temp.Value+273.15;
s0 = py.CoolProp.CoolProp.PropsSI('S','P',101325,'T',T0,'Air')/1000;
altitude=app.AltitudekfeetSlider.Value;
altitude = altitude*1000;
PressureRatio=app.PressureRa.Value;
across=app.acrosse.Value; %m2
L1 =app.Length.Value;
L2=app.Widht.Value;
L3=app.Height.Value;
t=app.finthick.Value;
kf=app.thermalcond.Value; %18


alt = altitude/1000; % feet to kfeet
P0 =101325; % Pa
k=1.4;


M = 9e-7*alt^3 +4e-5*alt^2 + 0.0043*alt + 0.2422; %mach
qneeded = 4e-5*alt^4 -0.0054*alt^3 + 0.2254*alt^2 - 1.6484*alt + 16.178; %in kw
h = altitude*0.3048; %feet to meter


Pressure1 = P0*(1-0.0065*(h/T0))^5.2561; % in Pa
if h <= 11000
Temperature1 = T0 - 6.5*(h/1000);
else
Temperature1 = -56.5 + 273.15;
end
s1=py.CoolProp.CoolProp.PropsSI('S','P',Pressure1,'T',Temperature1,'Air')/1000;
v = M*sqrt(1.4*287*Temperature1); % m/s


% Density in kg/m3
%DensityOut1 = py.CoolProp.CoolProp.PropsSI('D','P',Pressure1,'T',Temperature1,'Air');
%Hava aligi etkisi
%dyn = 0.5*DensityOut1*v^2;
Pressure2 = ((1+((k-1)/2)*M^2)^(k/(k-1)))*Pressure1;
% Ram Tarafi
%Pressure2 = Pressure1 + dyn;
app.PressureafterramchannelkPa.Value = sprintf('%0.2f',Pressure2/1000);
Temperature2 = (1+(k-1)/2*M^2)*Temperature1;
sri=py.CoolProp.CoolProp.PropsSI('S','P',Pressure2,'T',Temperature2,'Air')/1000;
% Density in kg/m3
DensityRam2 = py.CoolProp.CoolProp.PropsSI('D','P',Pressure2,'T',Temperature2,'Air');
% Specific Heat in J/kgK
SpecificHeatRam2 =
py.CoolProp.CoolProp.PropsSI('C','P',Pressure2,'T',Temperature2,'Air')/1000;
```

```
%Bleed Tarafi
Pressure3 = Pressure2*PressureRatio;
app.PressureBleedSidekPa.Value = sprintf('%0.2f',Pressure3/1000);
Temperature3 = ((Pressure3/Pressure2)^((k-1)/k))*Temperature2;
sbi=py.CoolProp.CoolProp.PropsSI('S','P',Pressure3,'T',Temperature3,'Air')/1000;


% Specific Heat in J/kgK
SpecificHeatBleed3 =
py.CoolProp.CoolProp.PropsSI('C','P',Pressure3,'T',Temperature3,'Air')/1000;


m_ram = DensityRam2*v*across; %!!!!
m_bleed = 5; %!!!!!
eff=0;
j=1;
while abs(eff)<=0.70
cram = m_ram*SpecificHeatRam2;
cbleed = m_bleed*SpecificHeatBleed3;
cminmax=[cram,cbleed];
cmin = min(cminmax);
cmax= max(cminmax);
cstar= cmin/cmax;
qmax = cmin*(Temperature3-Temperature2);
eff = qneeded/qmax;
m_bleed= m_bleed-0.01;
j=j+1;
end
l=1;
if eff>1
m_bleed=0.01;
while abs(eff)>0.7
cram = m_ram*SpecificHeatRam2;
cbleed = m_bleed*SpecificHeatBleed3;
cminmax=[cram,cbleed];
cmin = min(cminmax);
cmax= max(cminmax);
cstar= cmin/cmax;
qmax = cmin*(TempBleed-Temperature);
eff = qneeded/qmax;
m_bleed= m_bleed+1e-7;
l=l+1;
end
end


func = 5; ntu =1e-6; i=1;


while abs(func)>=1e-5
func = 1- exp((ntu^0.22*(exp(-cstar*ntu^0.78)-1))/cstar)-eff;
ntu = ntu + 1e-4;
i=i+1;
end
```

```
%tempave
tbi=Temperature3;
tri=Temperature2;


tbo=tbi-(qneeded/(cbleed));
tro=tri+(qneeded/(cram));
tbm =(tbi+tbo)/2;
tam=(tro+tri)/2;


PrandtlRamM = py.CoolProp.CoolProp.PropsSI('Prandtl','P',Pressure2,'T',tam,'Air');
% Density in kg/m3
DensityRamM = py.CoolProp.CoolProp.PropsSI('D','P',Pressure2,'T',tam,'Air');
% Specific Heat in J/kgK
SpecificHeatRamM = py.CoolProp.CoolProp.PropsSI('C','P',Pressure2,'T',tam,'Air')/1000;
% Viscosity in kg/ms or Pa.s
ViscosityRamM = py.CoolProp.CoolProp.PropsSI('V','P',Pressure2,'T',tam,'Air');


%Bleed Tarafi


PrandtlBleedM = py.CoolProp.CoolProp.PropsSI('Prandtl','P',Pressure3,'T',tbm,'Air');
% Density in kg/m3
DensityBleedM = py.CoolProp.CoolProp.PropsSI('D','P',Pressure3,'T',tbm,'Air');
% Specific Heat in J/kgK
SpecificHeatBleedM =
py.CoolProp.CoolProp.PropsSI('C','P',Pressure3,'T',tbm,'Air')/1000;
% Viscosity in kg/ms or Pa.s
ViscosityBleedM = py.CoolProp.CoolProp.PropsSI('V','P',Pressure3,'T',tbm,'Air');




cramM = m_ram*SpecificHeatRamM;
cbleedM = m_bleed*SpecificHeatBleedM;
cminmax=[cramM,cbleedM];
cminM = min(cminmax);
cmaxM= max(cminmax);
cstarM= cminM/cmaxM;


switch app.FinTypeDropDown.Value
case 'Offset Strip Fin'


off = xlsread('off.xls');
off(:,1)= off(:,1)/1000; off(:,4)= off(:,4)/1000; offset_findensity = off(:,1)'; %mm^-
1 0,782
offset_ps = off(:,2)'; %mm -b 2.49
offset_finoffsetlenght = off(:,3)'; %mm 3.18
offset_d = off(:,4)'; %m 0.00154
offset_finmetalthick = off(:,5)'; %mm 0.102
offset_totalarea = off(:,7)'; %0.785
offset_areavolume = off(:,6)'; %m2/m3 2254
```

```
for i=1: length(offset_ps)
Np(i) = ceil((L3-offset_ps(i)-2*t)/(offset_ps(i)+offset_ps(i)+2*t));
%afr=L2*L3;
Vpb(i) =L1/1000*L2/1000*(offset_ps(i)/1000)*Np(i); %m3
Vpr(i) =L1/1000*L2/1000*(offset_ps(i)/1000)*(Np(i)+1); %m3
ab(i) = offset_areavolume(i)*Vpb(i); %m2
ar(i) = offset_areavolume(i)*Vpr(i);%m2
aob(i) = (offset_d(i)*ab(i))/(4*L1/1000); %m2
aor(i) = (offset_d(i)*ar(i))/(4*L2/1000); %m2
sigmab(i)=aob(i)/(L2/1000*L3/1000);
sigmar(i)=aor(i)/(L1/1000*L3/1000);
gb(i)=m_bleed/aob(i);
gr(i)=m_ram/aor(i);
reb(i) = (gb(i)*offset_d(i)/ViscosityBleedM);
rer(i) = (gr(i)*offset_d(i)/ViscosityRamM);
if i==1
fd = xlsread('StripFinFrictionData.xls',1); ret = fd(:,1)'; fbt=fd(:,2)';
colj=fd(:,3)';
elseif i==2
fd = xlsread('StripFinFrictionData.xls',2); colj=fd(:,3)'; ret = fd(:,1)';
fbt=fd(:,2)';
elseif i==3
fd = xlsread('StripFinFrictionData.xls',3); colj=fd(:,3)'; ret = fd(:,1)';
fbt=fd(:,2)';
elseif i==4
fd = xlsread('StripFinFrictionData.xls',4); colj=fd(:,3)'; ret = fd(:,1)';
fbt=fd(:,2)';
elseif i==5
fd = xlsread('StripFinFrictionData.xls',5); colj=fd(:,3)'; ret = fd(:,1)';
fbt=fd(:,2)';
elseif i==6
fd = xlsread('StripFinFrictionData.xls',6); colj=fd(:,3)'; ret = fd(:,1)';
fbt=fd(:,2)';
elseif i==7
fd = xlsread('StripFinFrictionData.xls',7); colj=fd(:,3)'; ret = fd(:,1)';
fbt=fd(:,2)';
elseif i==8
fd = xlsread('StripFinFrictionData.xls',8); colj=fd(:,3)'; ret = fd(:,1)';
fbt=fd(:,2)';
elseif i==9
fd = xlsread('StripFinFrictionData.xls',9); colj=fd(:,3)'; ret = fd(:,1)';
fbt=fd(:,2)';
end
for say=1:length(ret)
if reb(i)>=ret(say)
fb(i)=fbt(say); coljb(i)=colj(say);
break;
else
fb(i)=fbt(length(ret)); coljb(i)=colj(say);
end
end
for saym=1:length(ret)
if rer>=ret(saym)
```

```
fbr(i)=fbt(saym); coljr(i)=colj(saym);
break;
else
fbr(i)=fbt(length(ret)); coljr(i)=colj(length(ret));
end
end
pb(i) = 2*fb(i)*L1/1000*gb(i)/(DensityBleedM*offset_d(i));
pbr(i) = 2*fbr(i)*L3/1000*gr(i)/(DensityRamM*offset_d(i));
hb(i)= (coljb(i)*gb(i)*SpecificHeatBleedM)/(PrandtlBleedM^(2/3));
hr(i)= (coljr(i)*gb(i)*SpecificHeatRamM)/(PrandtlRamM^(2/3));
mb(i) =
((2*hb(i)/(kf*offset_finmetalthick(i)/1000))*(1+(offset_finmetalthick(i)/offset_finoff
setlenght(i))))^(0.5);
mr(i) =
((2*hr(i)/(kf*offset_finmetalthick(i)/1000))*(1+(offset_finmetalthick(i)/offset_finoff
setlenght(i))))^(0.5);
lb(i) = (offset_ps(i)/2 - offset_finmetalthick(i))/1000;
nfb(i)=tanh(mb(i)*lb(i))/(mb(i)*lb(i));
nfr(i)=tanh(mr(i)*lb(i))/(mr(i)*lb(i));
nob(i)=(1-((1-nfb(i))*offset_totalarea(i)));
nor(i)=(1-((1-nfr(i))*offset_totalarea(i)));
aw(i)=L1/1000*L2/1000*(2*Np(i)+2);
rw(i)=(t/1000)/(kf*aw(i));
ters(i)= (1/(nob(i)*hb(i)*ab(i)))+rw(i)+(1/(nor(i)*hr(i)*ar(i)));
uas(i)=1/ters(i);
end
ua=ntu*cmin;
for m=1:12
if uas(m)>ua
reb= reb(m); rer=rer(m); gb=gb(m); gr = gr(m); dh=offset_d(m);
ntunew= uas(m)/cmin;
effnew = 1- exp((ntunew^0.22*(exp(-cstar*ntunew^0.78)-1))/cstar);
tbo=tbi-(qneeded/(cbleedM));
tro=tri+(qneeded/(cramM));
break;
end
end
case 'Wavy Fin'


wavy = xlsread('wavy.xls');
wavy(:,1)= wavy(:,1)/1000;
wavy(:,4)= wavy(:,4)/1000;
wavy_findensity = wavy(:,1)'; %mm^-1 0,782
wavy_ps = wavy(:,2)'; %mm -b 2.49
wavy_finoffsetlenght = wavy(:,3)'; %mm wı 3.18
wavy_d = wavy(:,4)'; %m dh 0.00154
wavy_amp = wavy(:,5)'; %amp mm
wavy_areavolume = wavy(:,6)'; %m2/m3 b comp
wavy_totalarea=wavy(:,7)'; %fa/ta
wavy_finmetalthick = wavy(:,8)'; %mm 0.102
t=0.5; %mm
kf=18; %W/mK inconel
```

```
for i=1: length(wavy_ps)
Npw(i) = ceil((L3-wavy_ps(i)-2*t)/(wavy_ps(i)+wavy_ps(i)+2*t));
%afr=L2*L3;
Vpbw(i) =L1/1000*L2/1000*(wavy_ps(i)/1000)*Npw(i); %m3
Vprw(i) =L1/1000*L2/1000*(wavy_ps(i)/1000)*(Npw(i)+1); %m3
abw(i) = wavy_areavolume(i)*Vpbw(i); %m2
arw(i) = wavy_areavolume(i)*Vprw(i);%m2
aobw(i) = (wavy_d(i)*abw(i))/(4*L1/1000); %m2
aorw(i) = (wavy_d(i)*arw(i))/(4*L2/1000); %m2
sigmabw(i)=aobw(i)/(L2/1000*L3/1000);
sigmarw(i)=aorw(i)/(L1/1000*L3/1000);
gbw(i)=m_bleed/aobw(i);
grw(i)=m_ram/aorw(i);
rebw(i) = (gbw(i)*wavy_d(i)/ViscosityBleedM);
rerw(i) = (grw(i)*wavy_d(i)/ViscosityRamM);
if i==1
fd = xlsread('WavyFinFrictionData.xls',1); ret = fd(:,1)'; fbt=fd(:,2)';
colj=fd(:,3)';
elseif i==2
fd = xlsread('WavyFinFrictionData.xls',2); colj=fd(:,3)'; ret = fd(:,1)';
fbt=fd(:,2)';
elseif i==3
fd = xlsread('WavyFinFrictionData.xls',3); colj=fd(:,3)'; ret = fd(:,1)';
fbt=fd(:,2)';
end
for say=1:length(ret)
if rebw(i)>=ret(say)
fb(i)=fbt(say); coljbw(i)=colj(say);
break;
else
fb(i)=fbt(length(ret)); coljbw(i)=colj(say);
end
end
for saym=1:length(ret)
if rerw>=ret(saym)
fbr(i)=fbt(saym); coljrw(i)=colj(saym);
break;
else
fbr(i)=fbt(length(ret)); coljrw(i)=colj(length(ret));
end
end
pb(i) = 2*fb(i)*L1/1000*gbw(i)/(DensityBleedM*wavy_d(i));
pbr(i) = 2*fbr(i)*L3/1000*grw(i)/(DensityRamM*wavy_d(i));
hbw(i)= (coljbw(i)*gbw(i)*SpecificHeatBleedM)/(PrandtlBleedM^(2/3));
hrw(i)= (coljrw(i)*gbw(i)*SpecificHeatRamM)/(PrandtlRamM^(2/3));
mbw(i) =
((2*hbw(i)/(kf*wavy_finmetalthick(i)/1000))*(1+(wavy_finmetalthick(i)/wavy_finoffsetle
nght(i))))^(0.5);
mrw(i) =
((2*hrw(i)/(kf*wavy_finmetalthick(i)/1000))*(1+(wavy_finmetalthick(i)/wavy_finoffsetle
nght(i))))^(0.5);
lbw(i) = (wavy_ps(i)/2 - wavy_finmetalthick(i))/1000;
nfbw(i)=tanh(mbw(i)*lbw(i))/(mbw(i)*lbw(i));
nfrw(i)=tanh(mrw(i)*lbw(i))/(mrw(i)*lbw(i));
nobw(i)=(1-((1-nfbw(i))*wavy_totalarea(i)));
```

```
norw(i)=(1-((1-nfrw(i))*wavy_totalarea(i)));
aww(i)=L1/1000*L2/1000*(2*Npw(i)+2);
rww(i)=(t/1000)/(kf*aww(i));
tersw(i)= (1/(nobw(i)*hbw(i)*abw(i)))+rww(i)+(1/(norw(i)*hrw(i)*arw(i)));
uas(i)=1/tersw(i);
end


ua=ntu*cmin;
for m=1:3
if uas(m)>ua
reb= rebw(m); rer=rerw(m); gb=gbw(m); gr = grw(m); dh=wavy_d(m);
ntunew= uas(m)/cmin;
effnew = 1- exp((ntunew^0.22*(exp(-cstar*ntunew^0.78)-1))/cstar);
% tbo=tbi-eff*qmax/(cbleed);
% tro=tri+eff*qmax/(cram);
tbo=tbi-(qneeded/(cbleedM));
tro=tri+(qneeded/(cramM));
break;
end
end
end
app.plossbleed.Value = sprintf('%0.2f',pb(i)/1000);
app.plossram.Value= sprintf('%0.2f',pbr(i)/1000);
app.Mach.Value = sprintf('%0.2f',M);
app.NewEffectiveness.Value = sprintf('%0.2f',effnew);
app.NewTemperatureBleedSideC.Value = sprintf('%0.2f',tbo-273.15);
app.NewTemperatureRamSideC.Value = sprintf('%0.2f',tro-273.15);
app.NewUAWK.Value = sprintf('%0.2f',uas(m));
app.UAWK.Value = sprintf('%0.2f',ua);
app.Effectiveness.Value = sprintf('%0.2f',eff);
app.MassFlowBleedkgs.Value = sprintf('%0.2f',m_bleed);
app.MassFlowRamkgs.Value = sprintf('%0.2f',m_ram);
app.CoolingLoadMaxkW.Value = sprintf('%0.2f',qmax);
app.TemperatureBleedSideC.Value = sprintf('%0.2f',tbi-273.15);
app.TemperatureRamInlet.Value= sprintf('%0.2f',tri-273.15);
app.PressureatGivenAltitudekPa.Value = sprintf('%0.2f',Pressure1/1000);
app.SpeedofSoundms.Value = sprintf('%0.2f',v);
app.TemperatureatGivenAltitudeC.Value = sprintf('%0.2f',Temperature1-273.15);
app.CoolingLoadNeededkW.Value = sprintf('%0.2f',qneeded);
app.ramloss.Value=pbr(i)/1000;
app.bleedloss.Value=pb(i)/1000;
app.rloss.Value=pbr(i)/1000;
app.bloss.Value=pb(i)/1000;
app.showalt.Value=app.AltitudekfeetSlider.Value;
app.AltitudekfeetSlider.Value=app.showalt.Value;


Pro=Pressure2-pbr(i);
sro=py.CoolProp.CoolProp.PropsSI('S','P',Pro,'T',tro,'Air')/1000;
Pbo=Pressure3-pb(i);
sbo=py.CoolProp.CoolProp.PropsSI('S','P',Pbo,'T',tbo,'Air')/1000;


switch app.TsDiagramofRamSideCheckBox.Value
```

```
    case 0
    case 1
       figure(1)
       plot([s0,s1,sri,sro],[T0-273.15,Temperature1-273.15,Temperature2-273.15,tro-
273.15],'ok','LineWidth',2.5)
       hold on
       grid on
       plot([s0,s1,sri,sro],[T0-273.15,Temperature1-273.15,Temperature2-273.15,tro-
273.15],'k')
       text(s0,T0-273.15,'\leftarrow 0')
       text(s1,Temperature1-273.15,'\leftarrow 1')
       text(sri,Temperature2-273.15,'\leftarrow 2')
       text(sro,tro-273.15,'\leftarrow 3')
       xlabel('Entropy kJ/kg*K')
       ylabel('Temperature °C')
       title('T-s Diagram of Ram Side')
       axis padded
end
switch app.TsDiagramofBleedSideCheckBox.Value
    case 0
    case 1
       figure(2)
             plot([s0,s1,sbi,sbo],[T0-273.15,Temperature1-273.15,Temperature3-
273.15,tbo-273.15],'ok','LineWidth',2.5)

       grid on
       hold on
       plot([s0,s1,sbi,sbo],[T0-273.15,Temperature1-273.15,Temperature3-273.15,tbo-
273.15],'k')
       text(s0,T0-273.15,'\leftarrow 0')
       text(s1,Temperature1-273.15,'\leftarrow 1')
       text(sbi,Temperature3-273.15,'\leftarrow 2')
       text(sbo,tbo-273.15,'\leftarrow 3')
       xlabel('Entropy kJ/kg*K')
       ylabel('Temperature °C')
       title('T-s Diagram of Bleed Side')
       axis padded


end

%-----UA vs Mach, mass flows and temperature differences-----
h=30000;
h=h*0.3048; %feet to meters
k=1.4;
rc = 28;
as= 0.01; %cross section
alt = 30;
qneeded = 4e-5*alt^4 -0.0054*alt^3 + 0.2254*alt^2 - 1.6484*alt + 16.178;
%State 0
P0=101325;
T0=15+273.15;
%State 1
P1 = P0*(1-0.0065*h/T0)^5.2561;
T1 = T0- 6.5*h/1000;
a = sqrt(k*287*T1);
UA=zeros(1,12);
```

```
for M=0.25:0.25:3

u = M*a;
%State 2
P2 = P1*(1+ ((k-1)/2)*M.^2 )^(k/(k-1));
T2 = T1*(1+ ((k-1)/2)*M^2 )
%Bleed State 3
P3 = P2*rc;
T3 = T2*rc^(1-(1/k))

%ram mass flow
rho2 = py.CoolProp.CoolProp.PropsSI('D','P',P2,'T',T2,'Air');
m_ram = rho2.*u.*as;
SpecificHeatRam2 = py.CoolProp.CoolProp.PropsSI('C','P',P2,'T',T2,'Air')/1000;
SpecificHeatBleed3 = py.CoolProp.CoolProp.PropsSI('C','P',P3,'T',T3,'Air')/1000;
m_bleed = 5; %!!!!!
eff=0;
j=1;
        while abs(eff)<=0.70
            cram = m_ram*SpecificHeatRam2;
            cbleed = m_bleed*SpecificHeatBleed3;
            cminmax=[cram,cbleed];
            cmin = min(cminmax);
            cmax= max(cminmax);
            cstar= cmin/cmax;
            qmax = cmin*(T3-T2);
            eff = qneeded/qmax;
            m_bleed= m_bleed-0.01;
            j=j+1;
        end
l=1;
        if eff>1
            m_bleed=0.01;
                    while abs(eff)>0.7

                            cram = m_ram*SpecificHeatRam2;
                            cbleed = m_bleed*SpecificHeatBleed3;
                            cminmax=[cram,cbleed];
                            cmin = min(cminmax);
                            cmax= max(cminmax);
                            cstar= cmin/cmax;
                            qmax = cmin*(T3-T2);
                            eff = qneeded/qmax;
                            m_bleed= m_bleed+1e-7;
                            l=l+1;
                    end
        end
        func = 5; ntu =1e-6; i=1;

        while abs(func)>=1e-3
                func = 1- exp((ntu^0.22*(exp(-cstar*ntu^0.78)-1))/cstar)-eff;
                ntu = ntu + 1e-2;
                i=i+1;
        end
mramp(M*4)=m_ram;
mbleedp(M*4)=m_bleed;
UA(M*4)=cmin*ntu;
tempdiff(M*4)=T3-T2;

end
```

```
plotm = 0.25:0.25:3;
grid on
plot(plotm,UA,LineWidth=1.5)
grid on
axis("padded")
xlabel('Mach')
ylabel('Overall Heat Transfer Coefficient kW/K')
title('UA vs Mach')
figure(2)
plot(plotm,mramp,LineWidth=1.5)
grid on
axis("padded")
hold on
plot(plotm,mbleedp,LineWidth=1.5)
grid on
title('Mass Flow vs Mach')
legend('Ram Mass Flow','Bleed Mass Flow',Location='northwest')
xlabel('Mach')
ylabel('Mass Flow kg/s')
figure(3)
semilogy(plotm,mramp,LineWidth=1.5)
hold on
semilogy(plotm,mbleedp,LineWidth=1.5)
axis("padded")
title('Mass Flow (log) vs Mach ')
legend('Ram Mass Flow','Bleed Mass Flow',Location='northwest')
xlabel('Mach')
ylabel('Mass Flow kg/s')
grid on
figure(4)
plot(plotm,tempdiff,LineWidth=1.5)
grid on
axis("padded")
xlabel('Mach')
ylabel('Temperature Difference')
title('Temperature Difference vs Mach')
```