Gas Technology Institute

UTSR Fellow: Miad Karimi

> Summer 2017

About the Fellow

- Graduated from Georgia Institute of Technology with BS in Aerospace Engineering, May 2014
- Enrolled in 3rd year of PhD in Aerospace Engineering at Georgia Institute of Technology
- Areas of interest: Combustion kinetics, aerodynamics and optical diagnostics in reacting flows
- Current research project: Shock-driven autoignition delay of oxy-combustion

http://www.comblab.gatech.edu/

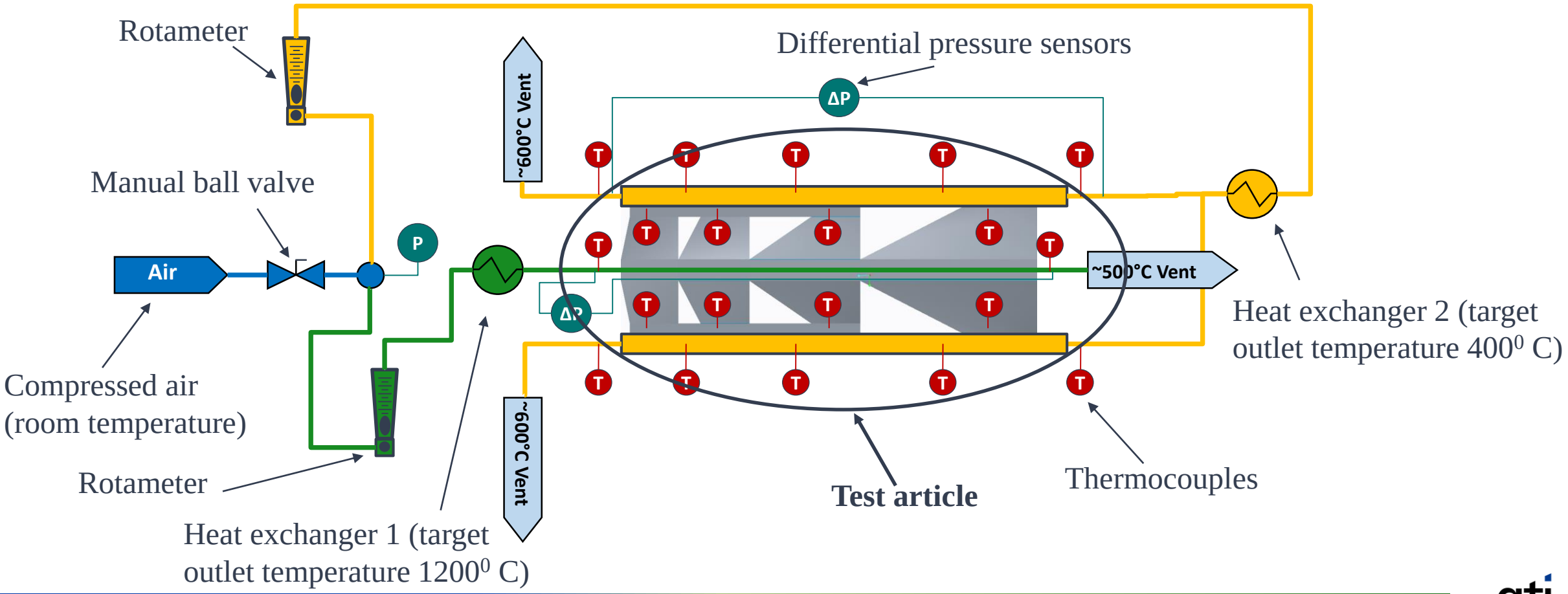
Project

Low Reynolds number heat transfer coefficient experiment

Tasks overview:

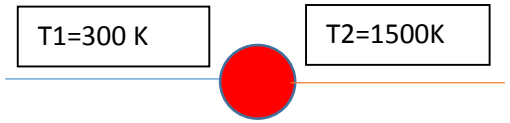
- Experimental setup schematic
- Preliminary heat exchanger sizing calculations
- Development of the experimental facility
- Preliminary exhaust duct sizing of the test article

Experimental setup schematic



Preliminary heat exchanger sizing calculations (I)

- Heat exchanger 1 sizing:



Required surface area

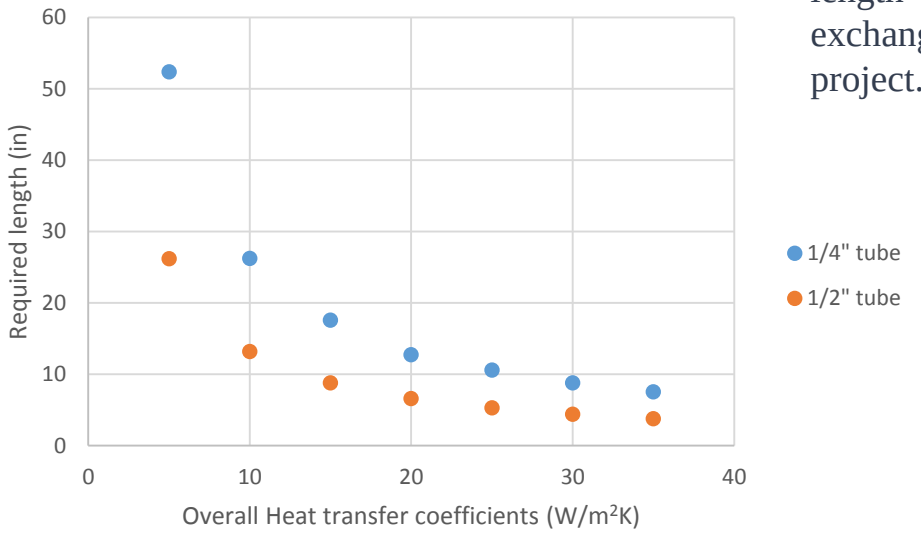
$$Q = mc_p\Delta T$$

$$Q = \left(\frac{0.680kg}{hr}\right)\left(1.005\frac{KJ}{kgK}\right)(1200K) = 0.3KW$$

$$Q = AU\Delta T_m$$

$$\Delta T_m = \left(\frac{\Delta T}{\ln(\Delta T)}\right) = 1122.54K$$

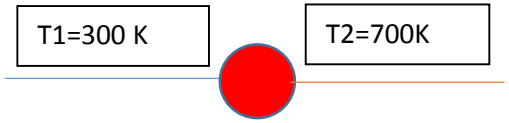
U(W/m²K)	A(m²)	A(in²)
5	0.053	82.2
10	0.0267	41.4
15	0.0178	27.6
20	0.01336	20.7
25	0.0107	16.6
30	0.0089	13.8
35	0.0076	11.8



The required area needs to be validated experimentally and the heat exchanger for this test should be capable of having at most 82.2 in² surface area. ½" diameter tube is recommended considering the overall length of the heat exchanger assigned to the project.

Preliminary heat exchanger sizing calculations (II)

- Heat exchanger 2 sizing:



$$Q = mc_p\Delta T$$

$$Q = \left(\frac{0.680kg}{hr}\right)\left(1.005\frac{KJ}{kgK}\right)(700K) = \frac{478.38KJ}{hr}$$

$$m = \frac{\left(1.005\frac{KJ}{KgK}\right)(200\ K)}{\frac{478.38KJ}{hr}} = 0.420\frac{Kg}{hr}\ (for\ one\ side)$$

$$m_{total} = 0.840Kg/hr$$

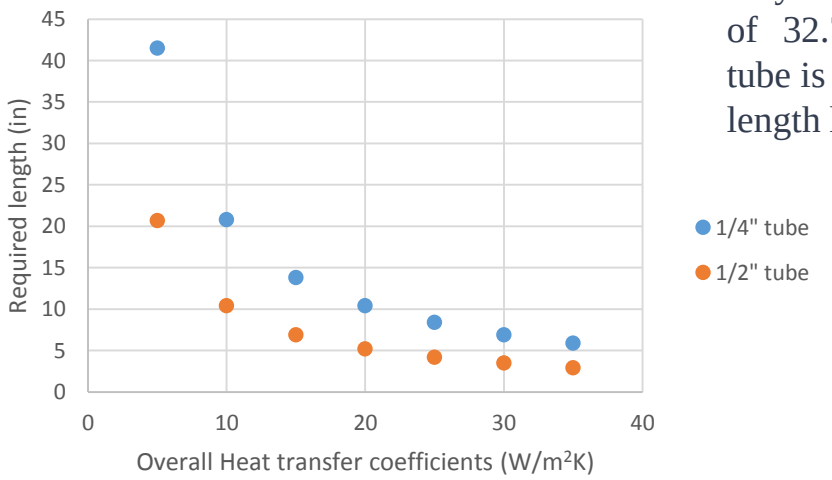
$$Q = \left(\frac{0.840kg}{hr}\right)\left(1.005\frac{KJ}{kgK}\right)(400K) = 0.1KW$$

$$Q = AU\Delta T_m$$

$$\Delta T_m = \left(\frac{\Delta T}{\ln(\Delta T)}\right) = 472.09K$$

Required surface area

U(W/m²K)	A(m²)	A(in²)
5	0.042	65.1
10	0.0211	32.7
15	0.014	21.7
20	0.0106	16.4
25	0.0085	13.2
30	0.007	10.9
35	0.006	9.3



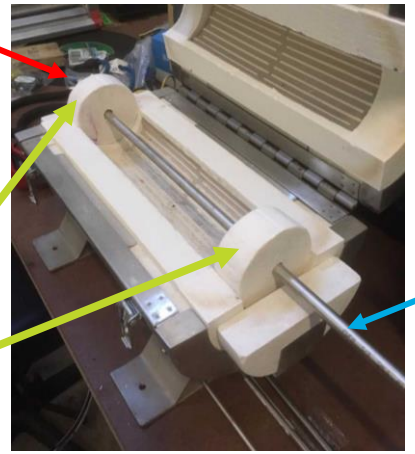
The required area needs to be validated experimentally and the heat exchanger for this test should be capable of having at most 65.1 in² surface area. However, due to the length of the heat exchanger assigned to the project the validation can only be done for maximum of 32.7 in². ½" diameter tube is recommended due to length limitations.

Development of the experimental facility

Heat exchanger 1

Heat exchanger 2

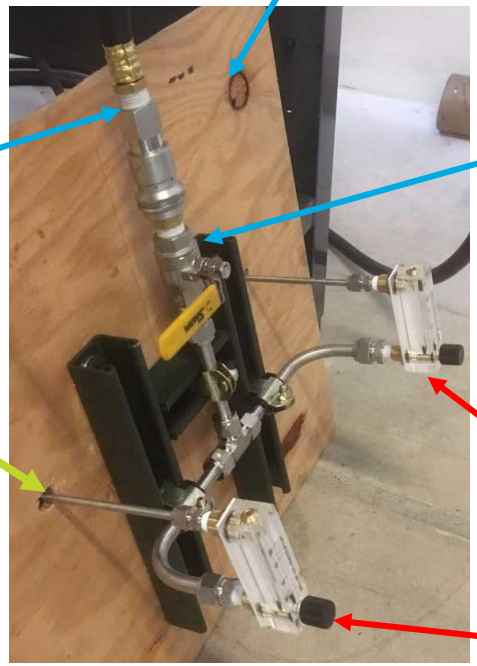
Hot flow out
To the test article



Cold flow in

Thermal insulator
fabricated

Mounting panel



Manual ball valve

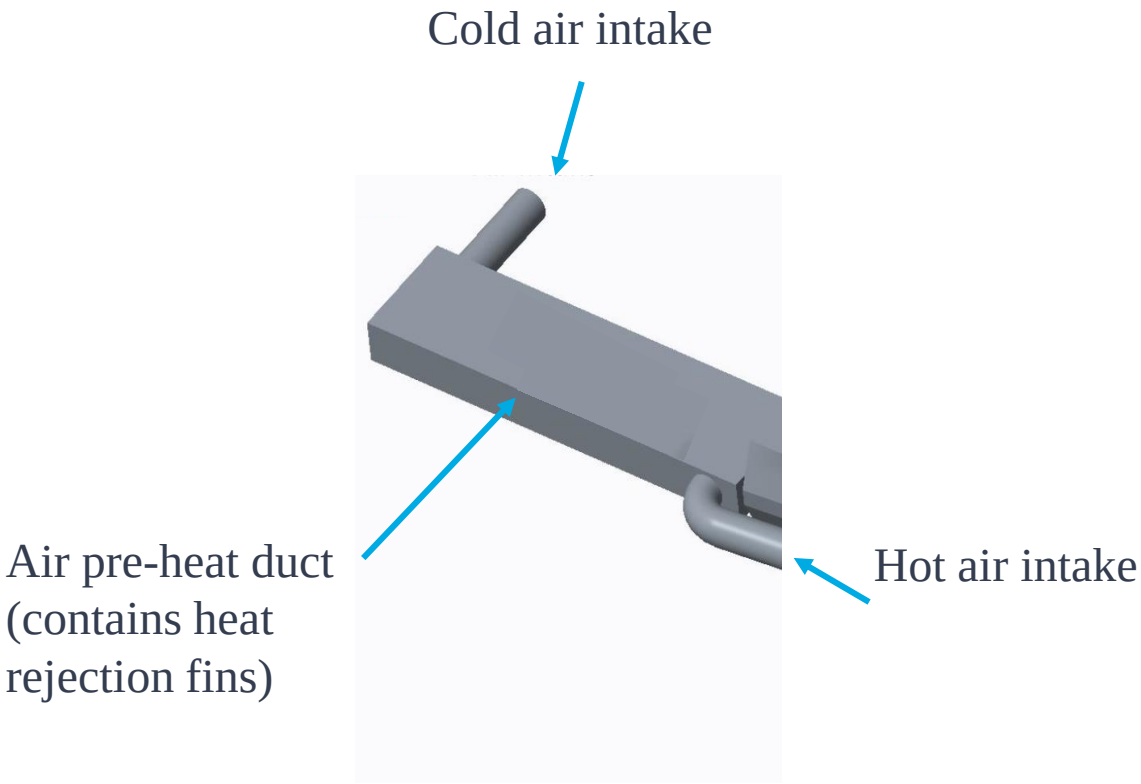
Compressed air

Outflow to heat
exchangers

Rotameters

Preliminary exhaust duct sizing of the test article

- Air pre-heat duct is by itself a counter flow heat exchanger
- For a given amount of heat available for preheating cold intake air, due to size restrictions of the test article, the amount of surface area available in the duct is limited
- One possible solution is to add cylindrical pins along the duct
- The size and number of pins required need to be calculated



Preliminary exhaust duct sizing of the test article

Test conditions:

$$\Delta T_1 = 163.9K$$

$$\Delta T_2 = 269.9K$$

$$\Delta T_m = \frac{\Delta T_2 - \Delta T_1}{\ln(\frac{\Delta T_2}{\Delta T_1})} = \frac{106}{0.5} = 212K$$

wetted diameter (D_m) = $0.0028\ m$

Average Reynolds number:

$$T_{in} = 294.26K \rightarrow \rho_1 = \frac{1.204kg}{m^3}$$

$$T_{out} = 644.26K \rightarrow \rho_2 = \frac{0.57kg}{m^3}$$

$$\rho_{avg} = 0.887k\ g/m^3$$

$$V = \frac{\dot{m}}{\rho_{avg} A} = \frac{0.000154k\ g/s\ ec}{(0.887k\ g/m^3)(0.000262m^2)} = 0.663\ m/s\ ec$$

$$Re = \frac{VD_m}{\vartheta_{avg}} = \frac{(\frac{0.663m}{sec})(0.0028m)}{24.055 \times 10^{-6}\ m^2/s\ ec} = 77.17$$

Preliminary exhaust duct sizing of the test article

Overall heat transfer coefficient:

$$\frac{1}{U} = \frac{1}{h_1} + \frac{L}{k} + \frac{1}{h_2}$$

- h_1, h_2: Heat transfer coefficients
- k: Thermal conductivity
- L: Inside duct length

$$h_1 = \frac{Nu\ k}{D} = 50.85\frac{W}{m^2K}$$

$$h_2 = \frac{Nu\ k}{D} = 14.27\frac{W}{m^2K}$$

$$U = 11.14\frac{W}{m^2K}$$

Pin design:

$$A_{required} = \frac{Q}{U\Delta T_m} = 0.023m^2 = 35.65in^2$$

Initial design surface area without pins $19.5in^2$, therefore $16.15\ in^2$ additional surface area needs to be implemented into the new design. Including 30% of calculations margin the number of cylindrical pins required is 200 with diameter of 0.25” and 0.125” of height.

Conclusion

- Preliminary heat exchanger sizing calculations completed
- Experimental facility assembly started and currently under development
- Preliminary exhaust duct sizing calculation completed
- At this stage of the project no test data to be shared