

I-ACT Modular UAV

Literature Survey

April 28th, 2017



DELFT UNIVERSITY OF TECHNOLOGY

[AE4180] FLOW MEASUREMENT TECHNIQUES



Laboratory Exercise Report

PIV and HWA Results for a NACA-0012 Airfoil

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ABSTRACT

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May 30, 2019

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List of Symbols

ABCD Ayy Bee See Dee

Roman Symbols

C_L Lift Coefficient —

V Velocity kg m^{-1}

S Wing Area m^2

Greek Symbols

ρ Density of Air kg m^{-3}

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1 Example L^AT_EX Elements

This template has been developed for the [AE3200] Design Synthesis Exercise. THIS TEMPLATE CANNOT BE USED WITHOUT EXPRESSED PERMISSION FROM: Şan Kılış and Munyung Kim.

1.1 Tables & Figures

An example Table 1.1 and an example Figure 1.1 can be found in this section. When you label tables or figures, make sure to use ‘tab:name’ or ‘fig:name’, this is not necessary for syntax but makes organization and look-up of labels easier. For inserting 2+ figures in a row, look at the formatting of Figure Figure 1.2. Using the `cleveref` package negates the need for manually typing ‘Table’ or ‘Figure’. The syntax is as follows, note that the ‘tab’ in ‘tab:exampletable’ is not necessary for `cref` and is purely for organizational reasons. However a ‘,’ cannot be utilized as this is interpreted as a list.

```
\cref{tab:exampletable}
```

The Tables below use the package `tabularx` which adjusts column spacing automatically to fit the table within the margins of the page. The syntax is as follows where ‘L’ is for Left Aligned, ‘C’ for Centered, and ‘R’ is for Right Aligned:

```
\begin{tabularx}{\textwidth}{L C C C}
```

In order to keep up the same appearance for all tables use the commands `toprule`, `midrule`, `bottomrule`, and `hdashline` to create the horizontal lines. NO VERTICAL LINES ARE ALLOWED!

Table 1.1: Example Table

| Component | Mass [kg] | Location [m] | Location [% MAC] |
|-----------------------|--------------|--------------|------------------|
| Wing | 425.4 | 5.74 | 40.00 |
| Main Landing Gear | 243.1 | 5.82 | 45.00 |
| Fuel System | 80.74 | 5.91 | 50.00 |
| Flight Control System | 48.61 | 6.08 | 60.00 |
| Hydraulics | 4.660 | 6.08 | 60.00 |
| Wing Group | 802.5 | 5.80 | 43.85 |
| Fuselage | 265.2 | 5.74 | 40.00 |
| Engine | 409.4 | 1.64 | - |
| Avionics | 490.9 | 4.39 | - |
| H. Tail | 42.93 | 13.2 | - |
| V. Tail | 66.43 | 12.6 | - |
| Nose Gear | 54.58 | 2.50 | - |
| Electrical | 217.4 | 6.16 | 67.12 |
| AC & Anti-Ice | 215.7 | 6.16 | 67.12 |
| Furnishings | 241.5 | 6.16 | 67.12 |
| Fuselage Group | 2004 | 5.01 | -2.32 |
| OEW C.G. | 2806 | 5.24 | 10.88 |

Table 1.2: Example Table II

| m | $\Re\{\mathfrak{X}(m)\}$ | $-\Im\{\mathfrak{X}(m)\}$ | $\mathfrak{X}(m)$ | $\frac{\mathfrak{X}(m)}{23}$ | A_m | $\varphi(m) / ^\circ$ | $\varphi_m / ^\circ$ |
|-----|--------------------------|---------------------------|-------------------|------------------------------|-------|-----------------------|----------------------|
| 1 | 16.128 | +8.872 | 16.128 | 1.402 | 1.373 | -146.6 | -137.6 |
| 2 | 3.442 | -2.509 | 3.442 | 0.299 | 0.343 | 133.2 | 152.4 |
| 3 | 1.826 | -0.363 | 1.826 | 0.159 | 0.119 | 168.5 | -161.1 |
| 4 | 0.993 | -0.429 | 0.993 | 0.086 | 0.08 | 25.6 | 90 |
| 5 | 1.29 | +0.099 | 1.29 | 0.112 | 0.097 | -175.6 | -114.7 |
| 6 | 0.483 | -0.183 | 0.483 | 0.042 | 0.063 | 22.3 | 122.5 |
| 7 | 0.766 | -0.475 | 0.766 | 0.067 | 0.039 | 141.6 | -122 |
| 8 | 0.624 | +0.365 | 0.624 | 0.054 | 0.04 | -35.7 | 90 |
| 9 | 0.641 | -0.466 | 0.641 | 0.056 | 0.045 | 133.3 | -106.3 |
| 10 | 0.45 | +0.421 | 0.45 | 0.039 | 0.034 | -69.4 | 110.9 |
| 11 | 0.598 | -0.597 | 0.598 | 0.052 | 0.025 | 92.3 | -109.3 |



Figure 1.1: TU Delft Logo Flame



(a) TU Delft Logo Flame



(b) TU Delft Logo Flame

Figure 1.2: Two Figures Side-by-Side

1.2 References & Citations

The `biblatex` package is used for references with the default ‘numeric’ style for in-text citations and references [1]. The references sorting style is set to ‘none’ meaning that the references are sorted by the order in which they appear in text. A sample file `samplerefs.bib` is included to help when dealing with different types of publications.

```
\cite{citationtag}
```

1.3 Equations & Nomenclature

When typesetting equations, you need to use a nomenclature code when you introduce a variable for the FIRST time, such that the variable is listed on the list of symbols. An example is given below by Equation 1.1. With the current implementation, duplicate nomenclature items are not automatically removed.

$$L = \frac{1}{2}\rho V^2 S \cdot C_L \quad (1.1)$$

The the list of symbols for the above equation were generated with the code below:

```
\nomenclature[A]{ABCD}{Ayy Bee See Dee}
\nomenclature[B]{C_L}{Lift Coefficient \nomunit{-}}
\nomenclature[B, 01]{V}{Velocity \nomunit{kg.m^{-1}}}
\nomenclature[B, 02]{S}{Wing Area \nomunit{m^2}}
\nomenclature[G]{\rho}{Density of Air \nomunit{kg.m^{-3}}}
```

1.4 Units and Numbers

```
\SI{5}{\kilogram}
```

References

- [1] Lots of Coffee and Caffiene. *LaTeX: A Lovely Typesetting Language*. No One Publishing House of Bravos, 2019.

A MATLAB Code

A.1 Main Script [main.m]

```
clear all;
close all;
clc;

gamma=1.4; %Ratio of Specific Heats (Air)

%% Importing Tables from Nozzle1.csv and Nozzle2.csv

global NoZ1 NoZ2

NoZ1.data=readtable('Nozzle1.csv'); %NoZ1 = Nozzle1
NoZ2.data=readtable('Nozzle2.csv'); %NoZ2 = Nozzle2

%% Importing Experimental Data

NoZ1.ExperimentSUP=readtable('2017-02-17_12-21-48.txt');
NoZ1.ExperimentSUB=readtable('2017-02-17_12-24-22.txt');
NoZ2.Experiment1=readtable('2017-02-17_12-37-39.txt');
NoZ2.Experiment2=readtable('2017-02-17_12-31-42.txt');
NoZ2.Experiment3=readtable('2017-02-17_12-34-20.txt');

%% Theoretical Supersonic Flow for First Nozzle [Choked Flow Conditions At=A*]

NoZ1.SUP.A=NoZ1.data.A;
NoZ1.SUP.MACH=zeros(length(NoZ1.SUP.A),1);
NoZ1.SUP.P=zeros(length(NoZ1.SUP.A),1);
for i=1:length(NoZ1.SUP.A);
    if i<6
        [NoZ1.SUP.MACH(i), ~, NoZ1.SUP.P(i), ~, ~]=flowisentropic(gamma, NoZ1.SUP.A(i), 'sub')
    else
        [NoZ1.SUP.MACH(i), ~, NoZ1.SUP.P(i), ~, ~]=flowisentropic(gamma, NoZ1.SUP.A(i), 'sup')
    end
end

%% Theoretical Subsonic Flow for First Nozzle [Non-Choked Flow Conditions At/=A*]

PRatio=NoZ1.ExperimentSUB.P_Pt(1); % Measured Pressure Ratio at First Pressure Measurement

[~, ~, ~, ~, NoZ1.SUB.A_star]=flowisentropic(gamma, PRatio, 'pres');
NoZ1.SUB.A_correction=NoZ1.SUB.A_star*(1/NoZ1.data.A(1)); %A(x0)/A_star * A_t/A(x0) = A_t/A_star
NoZ1.SUB.A=NoZ1.SUB.A_correction.*NoZ1.data.A;

for i=1:length(NoZ1.SUB.A);
    [NoZ1.SUB.MACH(i), ~, NoZ1.SUB.P(i), ~, ~]=flowisentropic(gamma, NoZ1.SUB.A(i), 'sub');
end

%% Obtaining Experimental Mach Number using Isentropic Relations

NoZ1.SUP.MACH_EXP=zeros(length(NoZ1.ExperimentSUP.mm),1);
NoZ1.SUB.MACH_EXP=zeros(length(NoZ1.ExperimentSUB.mm),1);

for i=1:length(NoZ1.ExperimentSUP.mm)
    [NoZ1.SUP.MACH_EXP(i), ~, ~, ~, ~]=flowisentropic(gamma, NoZ1.ExperimentSUP.P_Pt(i), 'pres');
    [NoZ1.SUB.MACH_EXP(i), ~, ~, ~, ~]=flowisentropic(gamma, NoZ1.ExperimentSUB.P_Pt(i), 'pres');
end

%% Calculating Area Ratio at Shock Location

NoZ2.x_shock=[390 530 630];
[hk2,dh,h0]=meter2geo(15,10); %Input Experiment Meter Values Here (meter4,meter5)
A_ratio=(dh*NoZ2.x_shock(2:3)+h0)/hk2;
```

```

62 for i=1:length(A_ratio)
63     [~, ~, NoZ2.SUB.Pe3(i), ~, ~]=flowisentropic(gamma, A_ratio(i), 'sub');
64     [NoZ2.SUP.MACH_XSHOCK(i), ~, NoZ2.SUP.Pe6(i), ~, ~]=flowisentropic(gamma, A_ratio(i), 'sup
65     ');
66     [~, ~, NoZ2.SUP.Pe5(i), ~, ~, ~]=flownormalshock(gamma, NoZ2.SUP.MACH_XSHOCK(i), 'mach'
67     );
68     NoZ2.SUP.Pe5(i)=NoZ2.SUP.Pe5(i)*NoZ2.SUP.Pe6(i);
69 end
70
71 %% Plotting Figures
72
73 %Part I:
74
75 Margin=0.125; %Control Figure Margins
76 LabelSize=9; %Control Label Text Size
77 AR=[8 5]; %Aspect Ratio
78 NF=0.01; %Distance to Nudge Plot to Compensate for Axis Labels
79
80 figure('Name','MachNoZ1');
81 hold on; grid on; grid minor;
82 line([65 65],[0 NoZ1.SUB.MACH(5)], 'Color','k','LineStyle','- -'); %Drawing a Vertical Line to
83     Indicate Throat Sonic Value
84 line([0 65],[1 1], 'Color','k','LineStyle','- -'); %Drawing a Horizontal Line to Indicate
85     Throat Sonic Value
86 line([0 194.8],[2.1 2.1], 'Color','k','LineStyle','- -'); %Drawing a Horizontal Line to
87     Indicate Throat Sonic Value
88 text(65.5,0.75, '$\leftarrow x_t = 65 \left[ mm \right]$', 'Interpreter','LaTeX','FontSize',8)
89 text(50,1.05, 'M = 1', 'Interpreter','LaTeX','FontSize',8)
90 text(120,2.15, ['$M_{e} = $ ' num2str(NoZ1.SUB.MACH(26))], 'Interpreter','LaTeX','FontSize',8)
91 line1=plot(NoZ1.data.x,NoZ1.SUB.MACH, 'LineWidth',1);
92 line2=plot(NoZ1.data.x,NoZ1.SUP.MACH, 'LineWidth',1);
93 line3=plot(NoZ1.ExperimentSUB.mm,NoZ1.SUB.MACH_EXP, 'Color',[0 174 255]/255, 'marker','o',
94     'MarkerFaceColor','w', 'MarkerSize',3, 'LineWidth',1);
95 line4=plot(NoZ1.ExperimentSUP.mm,NoZ1.SUP.MACH_EXP, 'Color',[221 135 51]/255, 'marker','o',
96     'MarkerFaceColor','w', 'MarkerSize',3, 'LineWidth',1);
97 axis([44.8 194.8 0 2.5])
98 xlabel('Position [mm]', 'fontsize',12, 'Interpreter','LaTeX');
99 ylabel('Mach Number [-]', 'fontsize',12, 'Interpreter','LaTeX');
100 legend([line1,line3,line2,line4], {'Subsonic [Theory]', 'Subsonic [EXP1A]', 'Supersonic [Theory]'
101     , 'Supersonic [EXP2A]}, 'Location','East'); %Creating Legend
102 set(gca,... %Formatting Axis Text
103     'XMinorTick','on',...
104     'YMinorTick','on',...
105     'FontSize',LabelSize/1.5,...
106     'TickLabelInterpreter','LaTeX',...
107     'LabelFontSizeMultiplier',1.5,...
108     'Position',[(Margin+NF)/2 ((0+((AR(1)/AR(2))*(Margin)))/2) (1-Margin) (1-((AR(1)/AR(2))*
109     Margin))]);
110 set(gcf, 'InvertHardCopy', 'off');
111 set(gcf, 'PaperPosition', [0 0 AR(1) AR(2)]); %Position plot at left hand corner with width 6
112     and height 5.
113 set(gcf, 'PaperSize', [AR(1) AR(2)]); %Set the paper to have width 6 and height 5.
114
115 figure('Name','PressureNoZ1');
116 hold on; grid on; grid minor;
117 line([65 65],[0 NoZ1.SUB.P(5)], 'Color','k','LineStyle','- -'); %Drawing a Vertical Line to
118     Indicate Throat Sonic Value
119 line([0 65],[0.528 0.528], 'Color','k','LineStyle','- -'); %Drawing a Horizontal Line to
120     Indicate Throat Sonic Value
121 text(65.5,0.1, '$\leftarrow x_t = 65 \left[ mm \right]$', 'Interpreter','LaTeX','FontSize',8)
122 text(66,0.528, '$\leftarrow \frac{p}{p_t}=0.528$', 'Interpreter','LaTeX','FontSize',8)
123 line1=plot(NoZ1.data.x,NoZ1.SUB.P, 'LineWidth',1);
124 line2=plot(NoZ1.data.x,NoZ1.SUP.P, 'LineWidth',1);
125 line3=plot(NoZ1.ExperimentSUB.mm,NoZ1.ExperimentSUB.P_Pt, 'Color',[0 174 255]/255, 'marker','o',
126     'MarkerFaceColor','w', 'MarkerSize',3, 'LineWidth',1);
127 line4=plot(NoZ1.ExperimentSUP.mm,NoZ1.ExperimentSUP.P_Pt, 'Color',[221 135 51]/255, 'marker','o'
128     , 'MarkerFaceColor','w', 'MarkerSize',3, 'LineWidth',1);
129 xlabel('Position [mm]', 'Interpreter','LaTeX', 'Color','k');
130 ylabel('Pressure Ratio $\left[ \frac{p}{p_t} \right]$', 'Interpreter','LaTeX', 'Color','k');
131 legend([line1,line3,line2,line4], {'Subsonic [Theory]', 'Subsonic [EXP1]', 'Supersonic [Theory]',
132     'Supersonic [EXP2]}, 'Location','East'); %Creating Legend
133 axis([44.8 194.8 0 1]) %Setting Axis Limits

```

```

set(gca,... %Formatting Axis Text
'XMinorTick','on',...
'YMinorTick','on',...
'FontSize',LabelSize/1.5,...
'TickLabelInterpreter','LaTeX',...
'LabelFontSizeMultiplier',1.5,...
'Position',[(Margin+NF)/2 ((0+((AR(1)/AR(2))*(Margin)))/2) (1-Margin) (1-((AR(1)/AR(2))*
Margin))]);
set(gcf, 'InvertHardCopy', 'off');
set(gcf, 'PaperPosition', [0 0 AR(1) AR(2)]); %Position plot at left hand corner with width 6
and height 5.
set(gcf, 'PaperSize', [AR(1) AR(2)]); %Set the paper to have width 6 and height 5.

%Part II:

figure('Name','PressureNoZ2');
hold on; grid on; grid minor;
line1=plot(NoZ2.Experiment1.mm,NoZ2.Experiment1.P_Pt,'marker','o','MarkerFaceColor','w','
MarkerSize',3,'LineWidth',1);
line2=plot(NoZ2.Experiment2.mm,NoZ2.Experiment2.P_Pt,'marker','o','MarkerFaceColor','w','
MarkerSize',3,'LineWidth',1);
line3=plot(NoZ2.Experiment3.mm,NoZ2.Experiment3.P_Pt,'marker','o','MarkerFaceColor','w','
MarkerSize',3,'LineWidth',1);
line4=line([NoZ2.x_shock(1) NoZ2.x_shock(1)],[0 1],'Color','k','LineStyle','-.');
line5=line([NoZ2.x_shock(2) NoZ2.x_shock(2)],[0 1],'Color','k','LineStyle','--');
line6=line([NoZ2.x_shock(3) NoZ2.x_shock(3)],[0 1],'Color','k');
point1=scatter(NoZ2.x_shock(2:3),NoZ2.SUB.Pe3,'*','MarkerEdgeColor',[0 0.60 0.50]);
point2=scatter(NoZ2.x_shock(2:3),NoZ2.SUP.Pe5,'*','MarkerEdgeColor',[0.80 0.40 0]);
point3=scatter(NoZ2.x_shock(2:3),NoZ2.SUP.Pe6,'*');
xlabel('Position [mm]','Interpreter','LaTeX','Color','k');
ylabel('Pressure Ratio $\left[ \frac{p}{p_t} \right]$', 'Interpreter','LaTeX','Color','k');
legend([line1,line2,line3,line4,line5,line6,point1,point2,point3],{'Experiment 3A','Experiment
4A','Experiment 5A','Shock at Throat','Shock at $x=530$ [mm]','Shock at $x=630$ [mm]','
Maximum Pressure Ratio [$p_{e3}/p_t$'],'Pressure Ratio After Norm. Shock [$p_{e5}/p_t$]
','Minimum Pressure Ratio [$p_{e6}/p_t$]'}, 'Location','West','Interpreter','LaTeX'); %
Creating Legend
set(gca,... %Formatting Axis Text
'XMinorTick','on',...
'YMinorTick','on',...
'FontSize',LabelSize/1.5,...
'TickLabelInterpreter','LaTeX',...
'LabelFontSizeMultiplier',1.5,...
'Position',[(Margin+NF)/2 ((0+((AR(1)/AR(2))*(Margin)))/2) (1-Margin) (1-((AR(1)/AR(2))*
Margin))]);
set(gcf, 'InvertHardCopy', 'off');
set(gcf, 'PaperPosition', [0 0 AR(1) AR(2)]); %Position plot at left hand corner with width 6
and height 5.
set(gcf, 'PaperSize', [AR(1) AR(2)]); %Set the paper to have width 6 and height 5.

clear vars Margin LabelSize AR NF

%% Saving/Overwriting Figures in the Images Folder as a .pdf

choice=questdlg('Would you like to close and save all figures to ../Figures?',...
'Figure Save Dialog', ...
'Yes','Just Save','Specify Directory','Specify Directory');
switch choice
case 'Yes'
if exist('Figures','dir')==0
mkdir('Figures')
end
cd('Figures')
b1=waitbar(0,'1','Name','Please Wait');
H=gcf;
i_prime=H.Number;
for i=1:i_prime
waitbar(i/i_prime,b1,sprintf('Saving Figure (%d/%d)',i,i_prime))
saveas(i, get(i,'Name'), 'pdf')
end
cd('../')
close all
delete(b1)
b2=msgbox('Operation Completed','Success');

```

```

case 'Just Save'
    if exist('Figures','dir')==0
        mkdir('Figures')
    end
    cd('Figures')
    b1=waitbar(0,'1','Name','Please Wait');
    H=gcf;
    i_prime=H.Number;
    for i=1:i_prime
        waitbar(i/i_prime,b1,sprintf('Saving Figure (%d/%d)',i,i_prime))
        saveas(i, get(i,'Name'), 'pdf')
    end
    cd('../')
    delete(b1)
    b2=msgbox('Operation Completed','Success');
case 'Specify Directory'
    old_dir=cd;
    new_dir=uigetdir('','Select Figure Saving Directory');
    cd(new_dir)
    b1=waitbar(0,'1','Name','Please Wait');
    H=gcf;
    i_prime=H.Number;
    for i=1:i_prime
        waitbar(i/i_prime,b1,sprintf('Saving Figure (%d/%d)',i,i_prime))
        saveas(i, get(i,'Name'), 'pdf')
    end
    cd(old_dir)
    close all
    delete(b1)
    b2=msgbox('Operation Completed','Success');
end

```

A.2 Table Look-Up Function [meter2geo.m]

```

function [hk2, dh, h0] = meter2geo(meter4, meter5)
% METER2GEO Utilizes provided Table 2 Data to read out the value of the 2nd
% throat height and parameters for the variable diffuser height function ( dh/dx & h0)

global NoZ2

hk2=0; dh=0; h0=0;

for i = 1:length(NoZ2.data.meter4)
    if NoZ2.data.meter4(i)==meter4 && NoZ2.data.meter5(i)==meter5
        hk2=NoZ2.data.hk2(i);
        dh=NoZ2.data.dh(i);
        h0=NoZ2.data.h0(i);
    end
end

if hk2==0 && dh==0 && h0==0
    disp('WARNING: No Valid Entry was Found in Look-up Table')
end

```