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Mechanical & Mechanics Engineering

Roughness and Temperature

Fluids of Sulfuric Acid and Air

Highlights

Using Dry & MQL Techniques

Leakage & Thermal Characterisation

Discovering Thoughts, Inventing Future

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Experimental Investigation of Surface Roughness and Temperature on a Surface Grinding of HC-HCr Steel using Dry and MQL Techniques

By Ch. N. V. Jaswanth, M. Rajasekhara Rao, Ch. V. S. Parameswara Rao & S. S. N. M. Rao

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Abstract- In machining of metals, application of cutting fluids improves machinability and tool life due to their cooling and lubrication characteristics. The traditional methods of cutting fluid applications may create problems for the operator and not Eco-friendly. Minimum quantity lubrication (MQL) Technique can minimize these problems to a considerable extent. The use of nano-material and nanotechnology can improve the performance of cutting fluids. In the present work, an attempt has been made with MQL to investigate the performance of vegetable oil along with different volume proportions of Al2O3 nanoparticles on surface grinding of HC-HCr workpiece. The influence of oil is evaluated regarding surface finish and Temperature of the workpiece.

Keywords: MQL, Al2O3 nanoparticles, RSM, multi-response optimization, surface grinding.

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Experimental Investigation of Surface Roughness and Temperature on a Surface Grinding of HC-HCr Steel using Dry and MQL Techniques

Ch. N. V. Jaswanth [α], M. Rajasekhara Rao [σ], Ch. V. S. Parameswara Rao [ρ] & S. S. N. M. Rao [ω]

Abstract- In machining of metals, application of cutting fluids improves machinability and tool life due to their cooling and lubrication characteristics. The traditional methods of cutting fluid applications may create problems for the operator and not Eco-friendly. Minimum quantity lubrication (MQL) Technique can minimize these problems to a considerable extent. The use of nano-material and nanotechnology can improve the performance of cutting fluids. In the present work, an attempt has been made with MQL to investigate the performance of vegetable oil along with different volume proportions of Al2O3 nanoparticles on surface grinding of HC-HCr workpiece. The influence of oil is evaluated regarding surface finish and Temperature of the workpiece. According to central composite design, sixteen experiments are conducted in dry and MQL with nanoparticles. Experimental results of surface roughness and temperature are evaluated using response surface methodology (RSM) and analysis of variance to identify significant parameters. A multi-response optimization technique is used to optimize processes parameters for minimum surface roughness and temperature. The optimal values of % of Nanoparticles, cutting speed, table feed and depth of cut are found to be 0.3636%, 9.166 m/s, 7.12m/min and 10μm respectively.

Keywords: MQL, Al2O3 nanoparticles, RSM, multi-response optimization, surface grinding.

I. Introduction

Grinding is one of the metal removal processes used in finishing of components that require close dimensional tolerances and smooth surfaces. Cutting fluid is commonly used to flood the grinding zone, to meet both cooling and lubrication requirements. The ingredient of conventional cutting fluids causes skin and respiratory problems to machine operators. The high cost of disposal or recycling of the grinding fluids is another major concern, especially in the environmental pollution point of view. Use of vegetable oils along with nanomaterials makes possible the developments in the new generation of cutting fluids to achieve high performance in machining, combined with good environmental compatibility. The traditional methods of applying cutting fluid are not ecological, and hence the Minimal Quantity Lubrication (MQL) has been gaining as an alternative solution for flood cooling. [1-4].

Alves et al. [5] developed water-based grinding fluids consists of sulfonate vegetable oil in water to meet CBN grinding needs and is of environmentally friendly. The quality of oil was evaluated by conducting various tests and proved that the proposed oil is readily biodegradable. The performance of new oil was evaluated and expressed regarding of G-ratio (volume of metal removed per unit volume of wheel wear). The results compared with semi-synthetic oil and mineral oil. The semi-synthetic oil acts as a good coolant but not a good lubricant and hence less G-ratio. The mineral oil acts as both lubricant and coolant hence high G-ratio. The proposed oils have G-ratio almost same that of mineral oil. Bin shen et al. [6] Performed experiments on surface grinding with the applications of water-based Al2O3 and diamond nanofluids by MQL. The experiments results were compared with dry machining and reveal that the volume of metal removed per unit volume of wheel wear has improved with the application of highly concentrated nanofluids in addition to the reduction of cutting forces, improvement in surface finish and minimized the workpiece burning. Ramana et al. [7] prepared a green and petroleum-free cutting fluid by mixing canola oil with nano-crystalline boric acid. They conducted experiments on turning of AISI 1040 to study the effect of nano-level boric acid particle size and its percentage of weight in lubricant on surface roughness, cutting forces and cutting zone temperature. The surface roughness, cutting forces and cutting zone temperature are found to be directly proportional to the percentage of weight and inversely proportional to the nanoparticle size.

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Nihat Tosun and Hasim Pihtili [8] experimented MQL in the face milling process with different machining parameters such as spindle speed, feed on 7075 Al alloy. The optimum cutting parameters were determined by Gray relation analysis for improving surface finish and metal removal rate. Lee et al. [9] conducted experiments with compressed air as cutting fluid in micro-grinding to reduce the cutting forces and improving the surface finish while maximizing the metal removal rate. The response surface models were prepared by using experimental results, for grinding forces and surface finish in terms of depth of cut, feed rate and air temperature Using Multi-objective optimization technique, the optimal values of depth of cut, feed rate, and air temperature are obtained for minimum Specific grinding force, surface roughness and maximum specific MRR and then the models are validated.

Vasu and Pradeep Kumar Reddy [10] investigated the effect on surface roughness, tool wear, and temperature dissipation of suspending Al2O3 nanoparticles in Coolube 2210EP eco-friendly vegetable MQL oil when machining Inconel 600 alloy at different cutting parameter combinations by coated carbide cutting tools on a precision engine lathe machine. Experimental results show that surface roughness, temperature, cutting force, and tool wear are reduced significantly by MQL with (6 vol. % of the Al2O3 particle) nanofluids than dry. Neseli et al.[11] Conducted experiments on CNC grinding Machine to determine the process parameters for improving surface finish and reducing the wheel vibrations for AISI 8620 sheets of steel. With experiments and Taguchi method the optimal process parameters were determined. Using Response surface analysis, two optimized models were developed to predict the most significant grinding parameters for minimum surface finish and vibrations. The results are further validated.

Hadad and Hadi [12] investigated the grinding of S34700 steels and AA6061 Al alloy on NC- Grinding machine by using vegetable & synthetic ester oil in MQL system. The performance of oils was evaluated for surface quality, cutting forces and surface temperatures. The result shows that the good grinding performance was found with synthetic ester oil than vegetable oil in MQL system. But in case of AA6061 Al alloy, the use of vegetable oil MQL system was found to produce a smooth surface. Nageswara Rao and Vamsi Krishna [13,14] conducted experiments on turning EN8 steel using carbide cutting tools using Boric acid as solid lubricant have reported considerable improvement in the machining performance by reducing cutting forces and tool wear, and improved surface finish in comparison with dry and wet machining. Vafaeesefat [15] performed tests on creep feed grinding of Rene 80 nickel-based superalloy. An ANN-based model used for optimal machining parameters to predict the grinding forces for maximizing MRR. Shen et al. [16] performed experiments in MQL grinding on cast iron by water-based Al2O3 and diamond nanofluids. The performance of grinding was evaluated by wheel wear and tribological characteristics in dry, pure water, and MQL grinding processes. The results show an improvement in surface finish with reduction of grinding forces and grinding zone temperature.

Rodrigo Panosso et al. [17] studied the of Drilling alpha–beta Ti6Al4V alloy plates using class K10 carbide drills with and without hard coating (TiAlN, CrCN or TiCN) in MQL. The performance of the drilling was evaluated by considering the temperature rise with external MQL by the nozzle and also internal MQL of the drill. From the experimental results, it has been concluded that temperatures observed in MQL applied with an external nozzle is 50% greater than that of MQL internally through the cutting tool. The effect of coatings on drills has no influences on temperature variation in MQL applied with an external nozzle. It also observed that the feed forces were reduced with a rise in temperature. A case study was conducted by Domnita Fratila and Cristian Caizar[18] on face milling of AlMg3 in MQL using LUBRIMAX oil and flood lubrication using SAROL 474 EP emulsion with face milling cutter. The Taguchi technique was employed for determining optimal process parameters and lubricant flow rate to minimize surface roughness and power consumption. From the results, they concluded that with the combination of high cutting speed and low values of depth of cut, feed rate, lubricant flow rate produce a good surface finish. Similar results were observed when using MQL and flood lubrication.

From the literature, it has been found that the surface finish is influenced by machining parameters like wheel speed, depth of cut and table feed rate. In addition to that, cutting fluids and its method of application will also affect the surface finish, the surface temperature of workpiece and cutting force needed for machining.

a) Response Surface Methodology

Nowadays, the RSM has become a popular optimization tool used for multi-response optimization of process parameters in different applications. RSM is a statistical technique to develop mathematical models or relations between responses and controllable process parameters. These models are also called as prediction models used to predict process variables for required responses. In RSM, the quantitative relationship between input and output variables is presented as follows [19]:

$$Y = f(x_1, x_2, x_3, \ldots, x_n) +- er \quad (1)$$

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'y' is desired response and 'f' is the response function, dependent variable and x_1, x_2, x_3, …..,x_n independent variables and 'er' is the fitting error.

In the present work, sixteen experiments have been planned according to central composite design. The RSM technique is used to analyze the experimental data to identify significant parameters that affect the surface roughness and temperature. In addition to that, three-dimensional plots are constructed to study the two-factor interaction on the responses using Design Expert 8.3 software. The same RSM is used for multi-response optimization of process parameters for dry and MQL grading.

Fig. 1: Experimental Set up

b) Materials and Cutting Fluids

The experimental investigation is performed on HC-HCr steel having specifications of 150X25X25mm. The chemical composition of HC-HCr steel is presented in Table 1. The workpiece used in this work has 0.4% of carbon content with greater strength and 95.25HRB of hardness.

Table 1: Chemical composition of HC-HCr

S. No.	Elements	Percentage
1	Carbon	0.37 – 0.44 %
2	Sulphur	0.05% max
3	Manganese	0.6 – 0.9 %
4	Phosphorus	0.04% max
5	Iron	Balance

In the present work, four cutting fluids are prepared by mixing of castor vegetable oil with different proportions (0%, 1%, 2% and 4% by volume) of Al2O3 nanoparticles to investigate its effect on surface roughness and temperature. The castor vegetable oil is abundantly available in the India and has a thermal conductivity of 0.179 to 0.188 w/mok and kinematic viscosity of 78.2 mm2/sec. The mixture of oil and nanoparticles are stirred well of about 1hour before using it for experimentation. The percentage of nanoparticles is restricted to 4% because it is increasing the density of cutting fluid [6].

c) Experimentation

The experimental work is conducted on GREAT precision Oil dip surface grinding machine. The experimental setup is shown in Figure 1. Two experimental plans are prepared for dry and MQL grindings separately with four levels of cutting speed, depth of cut, table feed and % by weight of nanoparticles in the cutting fluid as shown in Table 2.

Table 2: Cutting parameters for dry grinding

Factors	Level1	Level2	Level3	Level4
Cutting speed, m/sec	9.166	13.75	18.33	22.97
Depth of cut, um	10	20	25	30
Table feed, m/min	5	8	12	15
MQL with Nano particles	0	1	2	4
Vegetable oil	Canola oil			
Nanoparticles	40 nm			

According to Taguchi orthogonal array of L16, sixteen experiments are planned for the two cases as shown in the Tables 5 and 6. Each experiment is started with the new working condition, and experimental data of surface roughness and temperature are collected and presented in the Tables 2 and 3. In the first stage, the grinding experiments are conducted in dry condition and in second stage, experiments are conducted with vegetable oil as cutting fluids along with different mixing ratios of the nanoparticle.

Table 3: Experimental Conditions

Grinding Machine	Great Precision Oil Dip Surface Grinder
Workpiece material	HC-HCr steel
Size of work piece	l20 x 60 x 25mm
Grinding wheel	Al_2O_3 dia of wheel 175 mm width of 12.7mm width
Flow rate of vegetable oil	25ml/hr at an air pressure of 1.8bar
Thermocouple used	k-type

The workpiece is provided with a hole at its bottom, and a thermocouple is inserted in the workpiece to measure the temperature rise while machining. A digital temperature indicator is connected to the thermocouple to display temperature. An MQL fluid delivery system is designed, fabricated and provided to the machine for the supply of cutting fluid. The delivery system consists of a mixing chamber that is connected to nanofluid tank and air compressor. Nanofluid entered into the mixing chamber and delivered to grinding zone with the help of compressed air through a nozzle.

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The flow of oil and air into the chamber is regulated with a control valve provided to the delivery system. In the present work, the flow of air and oil is kept at constant pressure for all experimental runs. After each experiment, the surface roughness of the machined surface is measured with METACO METRIX MICROSURF-10, a portable surface tester at three different locations and an average Ra value is taken.

II. Results and Discussions

Experimental results of surface roughness, grinding temperature for sixteen experiments in dry and wet grinding are presented in the Tables 4 and 5 respectively.

Table 4: Design of experiments and experimental results for dry grinding

Exp. No.	Design of Experiments			Ra (μm)	Temp °C)
	CS	TF	DOC		
1	9.17	5	10	1.16	110
2	13.8	8	20	1.13	181
3	18.3	12	25	1.68	462
4	23	15	30	1.74	719
5	9.17	8	25	1.37	314
6	13.8	5	30	1.39	441
7	18.3	15	10	1.16	234
8	23	12	20	1.14	337
9	9.17	12	30	1.59	490
10	13.8	15	25	1.61	442
11	18.3	5	20	1.25	250
12	23	8	10	0.93	234
13	9.17	15	20	1.41	258
14	13.8	12	10	1.13	208
15	18.3	8	30	1.79	538
16	23	5	25	1.38	357

a) Analysis of surface roughness under dry grinding

The experimental data of surface roughness is analyzed with ANOVA and it is carried out at 95% confidence level to identify significant process parameters on the response. The p-value of process parameters indicates their significance on the surface roughness. The process parameters in the ANOVA table, which are having a p-value less than 0.05, are indicated as significant parameters [20]. Table 6 shows the dry machining data that has been analyzed with ANOVA for surface roughness, at 95% confidence to identify significant process parameters. As shown in Table 5, the model term is having a p-value of 0.0004 that indicates that the ANOVA of surface roughness is acceptable. The p-value of the depth of cut is 0.0001. Therefore the depth of cut is a significant parameter which affects the surface finish.

b) Analysis of grinding temperature under dry grinding

Table 7 shows the dry machining data that has been analyzed with ANOVA for grinding temperature at 95% confidence to identify significant process parameters.

The model term having a p-value of 0.0001, hence the ANOVA of surface roughness is acceptable. The p- values of cutting speed, table feed and depth of cut are less than 0.05 and reflect that all the selected parameters will affect the grinding temperature significantly. In dry grinding, there is no lubrication or cooling medium at the interface of grinding wheel and workpiece. Hence, an increase of cutting parameters results load on the grinding wheel and generates friction and temperatures at grinding zone. Since there is no chip flushing by cutting fluid, some of the chips accumulated near the grinding zone and result increased surface roughness by rubbing.

Table 5: Design of experiments and experimental results for MQL grinding

Exp. No.	Design of Experiments				Ra (μm)	Temp (°C)
	% of wt.	CS	TF	DOC		
1	0	9.166	5	10	0.94	108
2	0	13.75	8	20	0.85	182
3	0	18.33	12	25	0.92	233
4	0	22.97	15	30	1.4	274
5	1	9.166	8	25	0.92	133
6	1	13.75	5	30	0.83	172
7	1	18.33	15	10	0.86	196
8	1	22.97	12	20	0.85	197
9	2	9.166	12	30	0.92	164
10	2	13.75	15	25	0.9	217
11	2	18.33	5	20	0.8	181
12	2	22.97	8	10	0.73	182
13	4	9.166	15	20	0.86	150
14	4	13.75	12	10	0.8	175
15	4	18.33	8	30	0.79	192
16	4	22.97	5	25	0.69	190

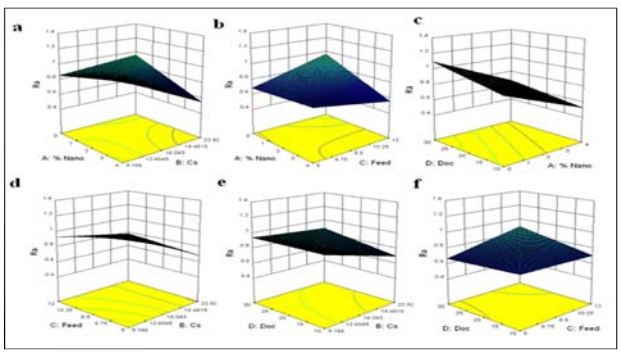

Fig. 2: 2 factor interaction of nanoparticles in MQL on surface roughness

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Table 6: ANOVA for Response Surface for Ra under dry grinding

Source	Sum of Squares	Df	Mean Square	p-value (Prob>F)
Model	0.76	3	0.25	0.0004
A-Cs	1.840E-003	1	1.840E-003	0.7629
B-Feed	0.083	1	0.083	0.0598
C-Doc	0.67	1	0.67	0.0001
Residual	0.23	12	0.019	
Cor	0.99	15		

Table 7: ANOVA for Response Surface for Temperature under dry grinding

Source	Sum of Squares	Df	Mean Square	p-value (Prob>F)
Model	3.253E+005	3	1.084E+005	0.0001
A-Cs	33503.33	1	33503.33	0.0137
B-Feed	37130.28	1	37130.28	0.0103
C-Doc	2.546E+005	1	2.546E+005	0.0001
Residual	48315.83	12	4026.32	
Cor	3.736E+005	15	1.084E+005	

Table 8: ANOVA for Response Surface for Ra

Source	Sum of Squares	Df	Mean Square	p-value (Prob>F)
Model	0.21	3	0.054	0.0305
A-% Nano	0.10	1	0.10	0.0187
B-Cs	1.021E-004	1	1.021E-004	0.9320
C-Feed	0.075	1	0.075	0.0368
D-Doc	0.037	12	0.037	0.1247
Residual	0.15	15	0.013	
Cor Total	0.36			

c) Analysis of surface roughness with MQL

Similarly, ANOVA is further extended to the analysis of surface roughness which has been obtained with MQL. As shown in Table 8, the model term is having a p-value of 0.0305 that indicates that the ANOVA of surface roughness is acceptable. Percentage of nanoparticles in MQL and table feed is having a p-value of 0.0187 and 0.0368 respectively, indicates that these factors will affect the surface finish predominantly when it is machined with MQL grinding process.

Similarly, ANOVA is further extended to the analysis of surface roughness which has been obtained with MQL. As shown in Table 9, the model term is having a p-value of 0.0305 that indicates that the ANOVA of surface roughness is acceptable. Percentage of nanoparticles in MQL and table feed is having a p-value of 0.0187 and 0.0368 respectively, indicates that these factors will affect the surface finish predominantly when it is machined with MQL grinding process.

d) Effect of process parameters on surface roughness

Figures 2(a to f) are the three-dimensional surface plots for the surface roughness of the ground workpiece. The figures show the two-factor interaction of percentage of nanoparticle in MQL cutting speed, table feed and depth of cut on surface roughness. Figures 2 (a to c) show that the surface roughness is found to be minimum at 4% of nanoparticles in MQL, cutting speed of 22.92m/s, depth of cut of 10 μm and 12 m/min of feed rate. In figure 2(d to f), the surface roughness is found to be minimum at 4m/min of table feed, 22.92 m/sec of cutting speed. The depth of cut has a moderate effect on the surface roughness. When the cutting oil is applied as MQL, the lubrication minimizes the friction and cutting forces during machining. In addition to this, the air flushes the chips and minimizes the rubbing of chips on ground surface. While cutting fluids are used along with nanoparticles, a few of nanoparticles deposited on the wheel surface and perform additional fine machining and results in enhancement of surface finish [6].

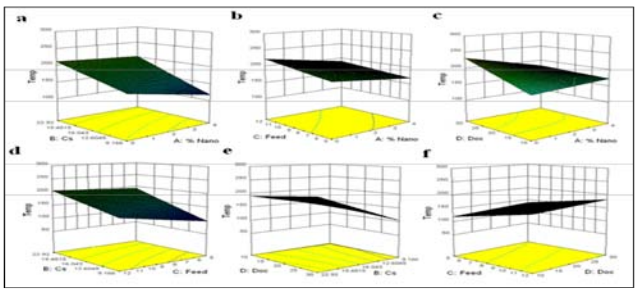

Fig. 3: 2 factor interaction of nanoparticles in MQL on surface temperature

Empirical relations between surface roughness, and temperature are formulated with cutting speed, depth of cut, table feed rate and % nanoparticles in the cutting fluid as shown below:

$$Ra=0.646-0.0539*A+4.916E-004*B+0.018*C+6.498E-003*D \quad (2)$$

$$T=25.317-4.042*A+4.997*B+4.698*C+1.82*D \quad (3)$$

e) Optimization Results

In the present work, multi-response optimization is carried out for optimization of process parameters using MINITAB 17 software. The figure 4 shows the response surface optimizer plotted from the experimental results. Response optimizer is a tool to identify the optimal controlling variables to achieve required responses with a concept of Desirability.

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Desirability is a measure of the effectiveness of optimization using individual desirability function (d) and 1. The maximum value of desirability indicates the closer the predicted response value to the desired response [21]. Composite desirability function (D). The values of D and d are calculated between 0 to 1.

The optimization carried out for minimization of surface roughness and temperature. The desirability of surface roughness and temperature and composite desirability are found to be 1. That indicates that the optimization is valid for minimum values of responses. The optimal values of % of Nanoparticles, cutting speed, table feed and depth of cut are found to be 0.3636%, 9.166m/s, 7.12m/min and 10μm respectively.

III. Conclusion

In the present work, experimental investigation of surface roughness and the temperature is conducted on surface grinding of AISI 1030 in dry and MQL along with nanoparticles. According to CCD of RSM technique, sixteen experiments are conducted in both the cases and experimental results of surface roughness and temperature are analyzed. The following conclusions can be drawn from this work:

In the dry grinding process, the depth of cut is found to be significant in ANOVA of surface roughness. Whereas in the ANOVA of temperature, all the parameters are found to be significant.

In MQL grinding process, the percentage of nanoparticles in the MQL and table feed is found to be significant in ANOVA of surface roughness, whereas in the ANOVA of temperature, except nanoparticles remain parameters are found to be significant.

The surface roughness is found to be minimum at 4% of nanoparticles in MQL, cutting speed of 22.92 m/sec, depth of cut of 10μm and 12 m/min of feed rate. While cutting fluids are used along with nanoparticles, a few of nanoparticles deposited on the wheel surface and perform additional fine machining and results in enhancement of surface finish.

The temperature is found to be minimum at 4% of nanoparticles in MQL, cutting speed of 9.166 m/sec, depth of cut of 10μm and 5 m/min of feed rate. Due to low thermal conductivity of nanoparticles in the cutting fluid, there is no much improvement in the thermal conductivity of cutting fluid.

A multi-response optimization is carried out for optimization of process parameters for minimum surface roughness and temperature. The optimal values of % of Nanoparticles, cutting speed, table feed and depth of cut are found to be 0.3636%, 9.166m/s, 7.12m/min and10μm respectively.

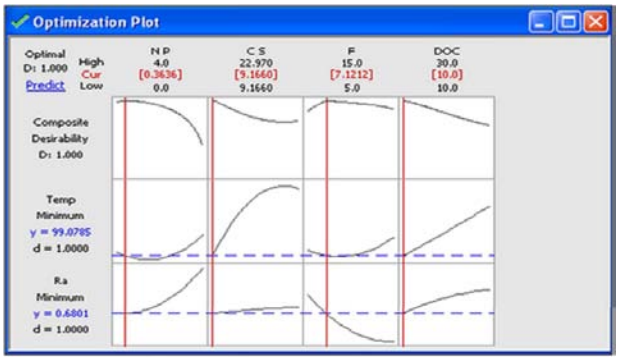

Fig. 4: Response optimizer of Nanoparticle in MQL

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Leakage and Thermal Characterizations of Canted Labyrinth Seals

By R Mohana Rao & Dr. Manzoor Husain

Abstract- Labyrinth seals are the simple and most commonly used rotating seal in cold (compressor) and hot (turbine) regions of gas turbine engines. In order to achieve successful engine design estimating accurate leakage flow rates, windage heating and heat transfer coefficients are critical for rotor dynamic stability. The windage effect inside the flow creates direct loss of power also increase fluid temperature. In this paper numerical simulation of a canted stepped labyrinth seal is performed using commercial Fluent CFD code with 2D axisymmetric is used to study leakage flow and windage heating for various seal clearances for solid (smooth) stator land geometry. The 2D model is subsequently used to determine average heat transfer coefficients on the rotor and stator for heating and cooling situations.

Keywords: *CFD, labyrinth seal, windage effect, gas turbine.*

GJRE-A Classification: *JEL Code: 091399p*

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Leakage and Thermal Characterizations of Canted Labyrinth Seals

R Mohana Rao [α] & Dr. Manzoor Husain [σ]

Abstract- Labyrinth seals are the simple and most commonly used rotating seal in cold (compressor) and hot (turbine) regions of gas turbine engines. In order to achieve successful engine design estimating accurate leakage flow rates, windage heating and heat transfer coefficients are critical for rotor dynamic stability. The windage effect inside the flow creates direct loss of power also increase fluid temperature. In this paper numerical simulation of a canted stepped labyrinth seal is performed using commercial Fluent CFD code with 2D axisymmetric is used to study leakage flow and windage heating for various seal clearances for solid (smooth) stator land geometry. The 2D model is subsequently used to determine average heat transfer coefficients on the rotor and stator for heating and cooling situations.

Keywords: CFD, labyrinth seal, windage effect, gas turbine.

Abbreviations: RANS – Reynolds-Averaged Navier-Stokes.

Nomenclature

$a = \sqrt{kRT_{static,in}}$ = speed of sound (m/s)
$C_D = \dot{m}/\dot{m}_{id}$ = discharge coefficient
C_p = specific heat capacity (J/Kg K)
$H = Cp.\dot{m}.\Delta T_{total}$ = windage heating power (kW)
$K = V_t/U$ = preswirl ratio
$\dot{m}$ = mass flow rate (kg/s)
$Mu = U/a$ = circumferential March number
n = rotor speed (rpm)
p = static pressure (Pa)
P_t = total pressure(Pa)
$R = 287.2$ = specific gas constant (J/Kg K)
R_m = averaged rotor radius (m)
$Re_x = \dot{m}/\mu_m \pi R_m$ = Axial Reynolds number
T = temperature (K)
$U = \omega . R_m$ = rotor circumferential velocity (m/s)
V_t = fluid tangential velocity (m/s)

ε - Dissipation of turbulent kinetic energy
κ - Turbulent Kinetic energy
s- Tooth pitch, mm
A: Area [m2]
L: Step height [mm]
h: Teeth height [mm]
N: Number of teeth
s: radial clearance

Greek Letters

Δ= difference between inlet and outlet
κ = ratio of specific heats
μ = dynamic viscosity (N s/m^2)
$\pi = P_{t_{in}}/p_{out}$ = pressure ratio
π = effective pressure ratio
ρ = density (kg/m^3)
$\sigma = 2C_p\Delta T_{total}/U^2$ = windage heating number
ω = rotor angular velocity (rad/s)

Subscripts

in/out = inlet/outlet condition
m = arithmetic average of inlet and outlet
r/t/x = radial/tangential/axial direction
static/total = static/total value

I. Introduction

As the airline industry is growing OEMs are working improved and efficient Aero Engine Technologies to offer to their customers. As per ACARE 2020 norms Fuel burn, Noise and NOx emissions are to be improved significantly, in order to achieve this either new technologies that radically improve performance or identify the current design leakages so that gaps can be filled & improved.

In this paper the leakage & windage thermal characterization behaviors of Lab seals are worked, the ability to accurately model lab seals leakage flows is extremely important, as leakages can significantly affect latter stages of compressor and turbine efficiencies that cause undesirable hot gas ingestion. In order to meet the stringent norms the component material durability studies in heat generated boundary conditions by viscous dissipation or windage flow environment. Lab seals are exposed to high flow velocities contributing to elevated temperatures further enhance heat transfer coefficients.

II. Literature Review

Lab seals windage heating effect was performed initially with experimental methods subsequently correlations are derived. The first of this experiment was prepared by Stocker H[3] subsequently Tipton [8]conducted test that resulted temperature profile by variable factors of pressure ratio, clearance and rotor speed. He measured the total temperature increase in the seal and reported that the total

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temperature difference between the seal outlet and inlet total can reach upto 19.4K. McGeehan and Ko[4] experimented to investigate the windage heating effect and derived a correlation equation to predict the windage power loss in the labyrinth seal. The influence of the mass flow rate, rotor speed, inlet preswirl, and friction factor, the wall surface has taken into consideration in their equation.

Wróblewski [6] analyzed radiation affects that intensifies heat transfer leading temperature differences in the casing elements caused by radiation, are much smaller than those resulting from different thermal conductivity coefficient much greater than the one resulting from convection. Piotr et al [9] investigated tip leakage off-design conditions the effect of tip leakage flow rate and the tip leakage swirl angle was found to bring up to a 1.5% decrease in enthalpy losses. D. Frączek et al [11] worked out geometry for rubbing effect by modifying the fin tip inclination geometry resulted by mass flow reduction of 13%.

Denecke et al. [1]used scaling & dimensional methods to analyze the leakage and windage heating of rotating seals. By adopting the Buckingham-theorem, they found that the discharge behavior, exit swirl, and windage heating in the contact less seal can be uniquely expressed by several non-dimensional numbers. They also presented a rule to scale the engine seal to the laboratory conditions .Moreover; they measured the total temperature increase in as tepped lab yrinth seal with smooth stator.

III. Present Work

In this work, combination of parameters to improve the seal design, the experimental case of seal configuration reported by J. Denecke, K. Dullenkopf, S. Witting and H.-J. Bauer in [1] is considered as baseline case for smooth land. In the present work, the authors conducted a CFD investigation on different configurations of canted teeth as Design 1, canted with Wavy surface as Design 2 and canted with hat step and way surface as Design 3.The design evolved while conducting a parametric study on teeth height, teeth tip thickness, stepped teeth, inclined teeth etc. The baseline configuration is a simple sharp teeth labyrinth seal. The results obtained for the baseline configurations using this methodology were validated by comparing against 2D and 3D experimental data with smooth land.

a) Baseline Geometry: Sharp Teeth

Fig. 1 shows labyrinth seal geometry with dimensions. The labyrinth seal test section consists of an upper part, stepped, and a lower part with teeth. In a real engine, the upper and lower parts correspond to the stationary and rotating parts, respectively, have 4 teeth with sharp teeth. The seals have almost similar teeth dimensions. Geometry definition: Pitch – 8 mm; step height – 2 mm; Knife height – 4 mm; Teeth included angle 20 deg; and seal canted angle 50 deg.

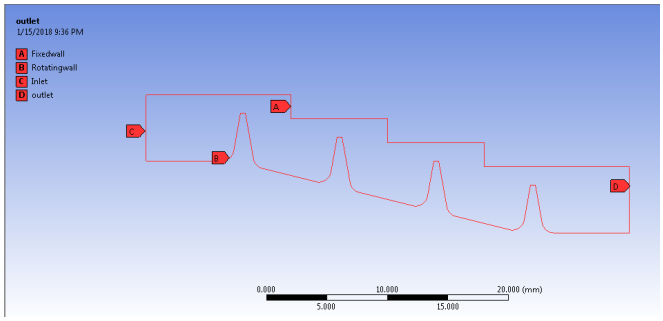

Fig. 1: Base line Design

b) New Geometry: Canted Advanced Teeth

In this work there are 3 computational geometries considered.

Design 1 – canted teeth.
Design 2 – canted teeth with wavy surface.
Design 3 – canted teeth with wavy surface having hat step.

Fig. 2 depicts the seal sharp teeth are modified to inclined to 50 Deg, rest of parameters are kept same as original design.

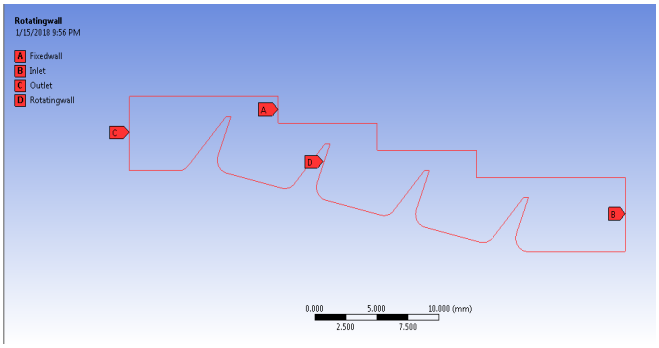

Fig. 2: Design 1 – 50 Degree canted teeth

Fig. 3 depicts the seal sharp teeth are modified to inclined to 50 Deg, with 2 wavy surfaces rest of parameters are kept same as original design.

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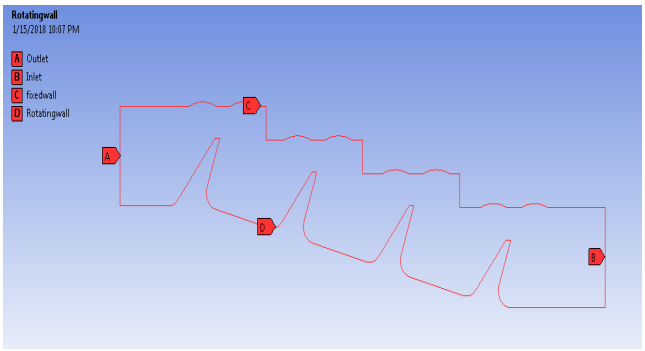

Fig. 3: Design 2 – canted teeth with wavy surface

Fig.4 depicts the seal sharp teeth are modified to inclined to 50 Deg, with 2 wavy surfaces with step 1 x 0.7 mm rest of parameters are kept same as original design.

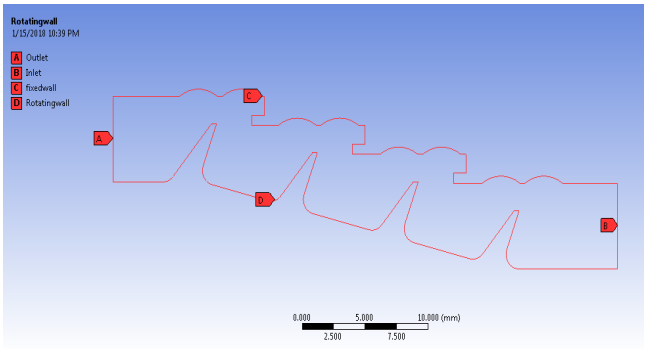

Fig. 4: Design 3 – canted teeth with wavy surface having step

c) Performance Parameters

The performance of a seal can be described by the relation between the pressure ratio and a flow parameter. The most common flow parameter is the following flow function:

$$\frac{\dot{m}\sqrt{T_{o,in}}}{A_c P_{o,in}}$$

$$C_d = \frac{\dot{m}}{\dot{m}_{id}}$$

The discharge coefficient depends on the pressure ratio, number of used seals, leakage mass flow rate. The flow through an ideal labyrinth seal.

Windage Heating:

The total temperature increase due to the internal losses in adiabatic flow is called windage heating,

$$H = C_p \dot{m} \Delta T_{total}$$

The windage heating number σ is defined as

$$\sigma = \frac{2 C_p \Delta T_{total}}{U^2}$$

IV. Analysis

a) Numerical Analysis

Computational Fluid Dynamics (CFD) is extensively used because its capability to analyze a large number of design configurations and parameters in a relatively short period of time. Therefore, with the development of commercial codes, the use of CFD analysis has been increasing rapidly in recent years in 2 or 3 dimensional analysis. The test cases adopted in this work are two-dimensional with number of different operating conditions are analyzed.

b) Boundary Conditions

A commercial finite volume code, Ansys Workbench with Fluent 16.1v [10] is used. This commercial tool has wave linking geometry that eliminates loss of geometry while importing from CAD model to Fluent, manages entire problem in project charter. It was assumed that air was an incompressible ideal gas and the flow was steady and adiabatic. Various turbulence models available in Fluent [10] were considered for the current simulations.

Table 1

Average rotor radius	0.253m
Inlet total temperature	300K
Outlet static pressure	200,000Pa
Turbulence model	Realizable k-epsilon,
Fluid	Air (ideal gas)
Wall Properties	Adiabatic, smooth surface

Fig. 5, 6 & 7 shows an example of generated computational grids. The grid density in the clearance area was refined to locate sufficiently large number of meshes, this is done using inflation of smooth transition with 8 ~ 10 layers.

c) Mesh

Design 1: Canted with 1.3 ~1.9 gap, Mesh .02 mm to. 035 max

Inflation: smooth with 10 layers. 192625 mixed cells.

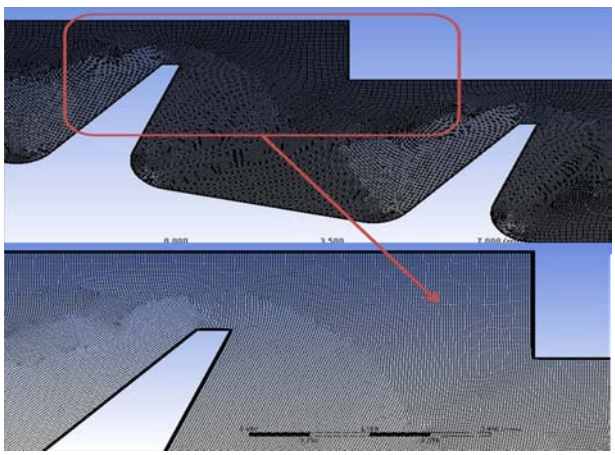

Fig. 5: Mesh Details of Design 1

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Design 2: Canted with 1.3 ~1.9 gap, Mesh .025 mm to. 035 max. Inflation: smooth with 10 layers. 214923 mixed cells.

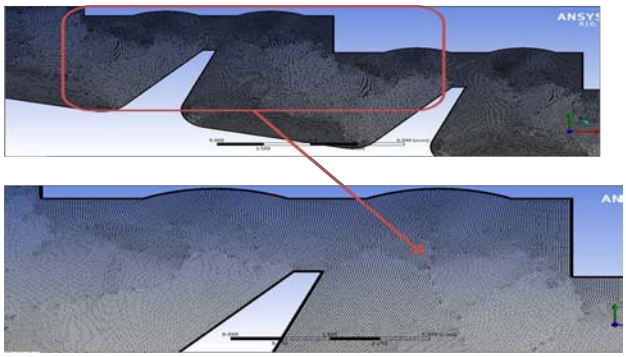

Fig. 6: Mesh Details of Design 2

Design 3: Canted with 1.3 ~1.9 gap, Mesh. 025 mm to. 035 max.
Step Height: 1x.7.
Inflation: Smooth with 10 layers. 220485 mixed cells.

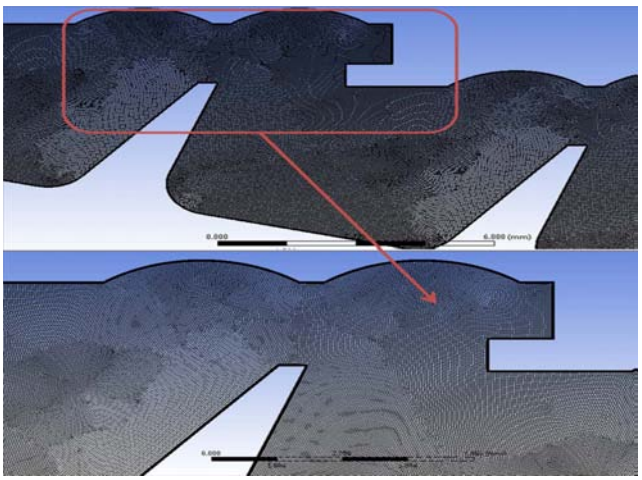

Fig. 7: Mesh Details of Design 3

d) Mesh Sensitivity

Grid dependence was checked to produce sufficiently converged solutions according to mesh size. grid dependence in the case of the Base geometry seal, ranges from 26,000 to 220,000 considered variation of pressure ratio with the number of meshes for a given mass flow rate. Convergence plots for basic design and design 1 are shown below.

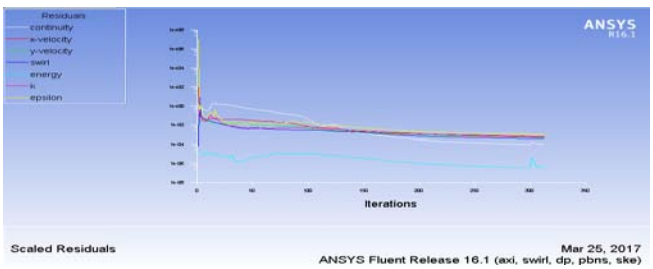

Fig. 8: Convergency plot for designs for double precision- Basic Design

The convergence plots are done for mass flow 0.15 m/s. number of iteration for basic design is very less compared to Design 1 and others.

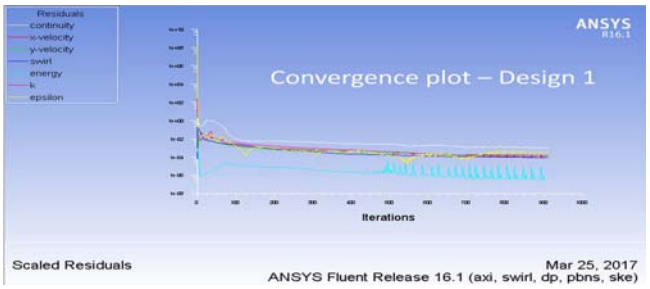

Fig. 9: Convergency plot for designs for double precision- Design 1

Analysis is carried out with basic design with Inlet and outlet conditions as per the reference[1] with Convergent and divergent labyrinth seal. The conditions are matched with the experimental resulted. Solution is imposed values for convergence factors equal to 10^{-2} exception is the energy equation with factors of convergence 10^{-3}

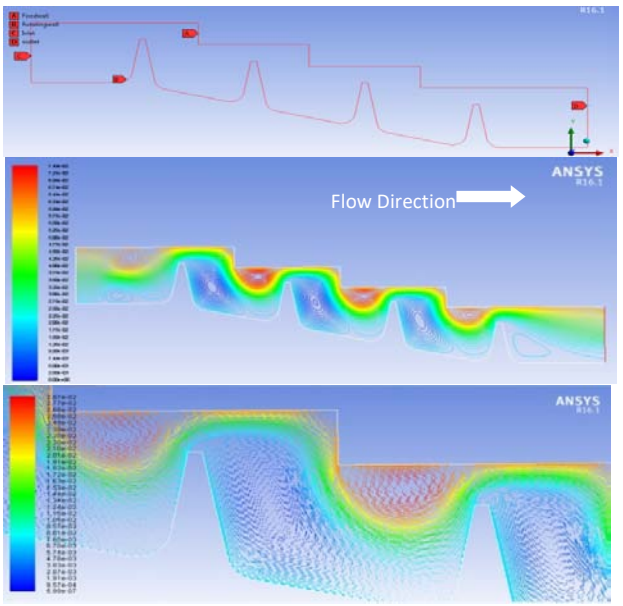

Fig. 10: Basic Design

The flow directions is reversed [Basic design] and analysis is carried out with various mass flow conditions at speed of 20,000 r.p.m., the delta temperature difference for basic design is gradually reduced as the mass flow increases where as the basic design with reverse flow the delta temperature is almost study. With clearance of 1.5 the temperature rise is high until mass flow of 0.15 then gradually reduced whereas for clearance 1.7 & 1.9 the temperature rise is study, Refer fig. 11 for the graph.

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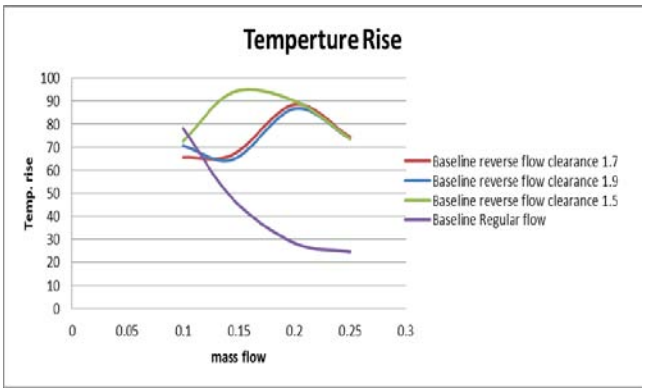

Fig. 11: Basic Design flow vs delta temperature rise

The flow in the labyrinth seal is mainly dominated by pressure difference in the axial direction. The study of interest is on reverse flow direction. The Models of basic design and Design 1 to 3 are run through by varying mass flow with boundary condition as per table 1.

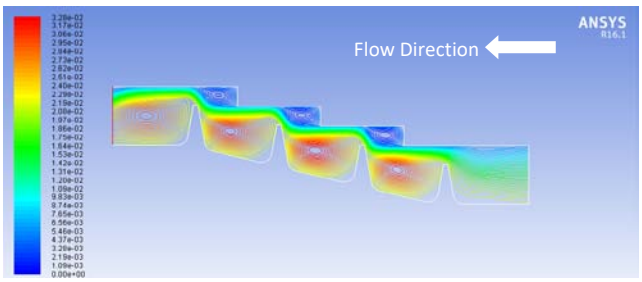

Fig. 12: Basic Design velocity contours

The Wall shape change introduced in the fixed wall refer design 1 to design 3 , two things will happen either wall shear increase or decrease and second one will be flow circulations. Design 1 will be canted shape and fixed wall is straight. Design 2 the seal shape is canted and fixed wall is having 2 dimple shapes. Design 3 is having canted seal with fixed wall having dimple shape with hat projection.

The analysis is run with Table 1 boundary condition and the mass flow is varied with .1 to .25 kg/s for basic design and design 1 to 3 with fow direction as shown in figs 12 to 15. The jet stream in design1 continues its full contact with fixed wall at exit.

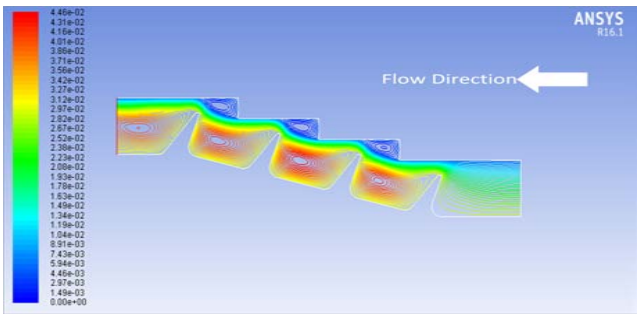

Fig. 13: Design1 velocity contours

In Design 2, the jet stream slides over the concave surface of fixed wall , the velocity vectors hits down ward path by not sliding over the remaining straight surface of fixed wall as shown in Fig. 14.

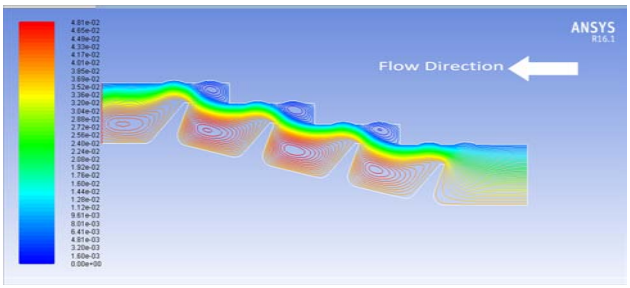

Fig. 14: Design 2 velocity contours

In Design 3, the velocity vectors hit the walls of stationery surface of concave with double step creating static current that obstruct the main jet shown in Fig. 11, at the exit the jet diffuse compared to Design 2.

In design 3 the jet stream hits the concave surface of fixed wall and reflects back to downwards their by losing its velocity. In this the jet is like jig jag pattern. The hat shape cavity at fixed wall creates a seal lock hence reduce leakage.

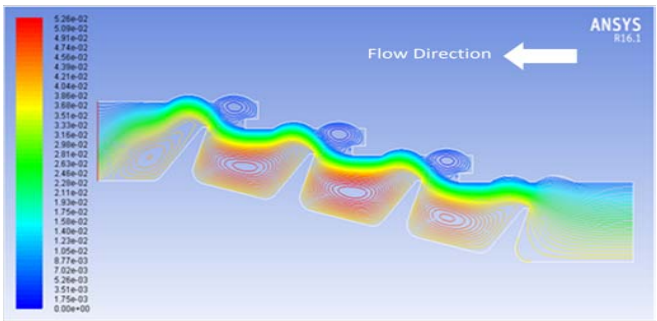

Fig. 15: Design 3 velocity contours

The results are plotted with flow rate with pressure ratios windage heat, swirl velocity and temperature variation. Refer figs 16 to 19.

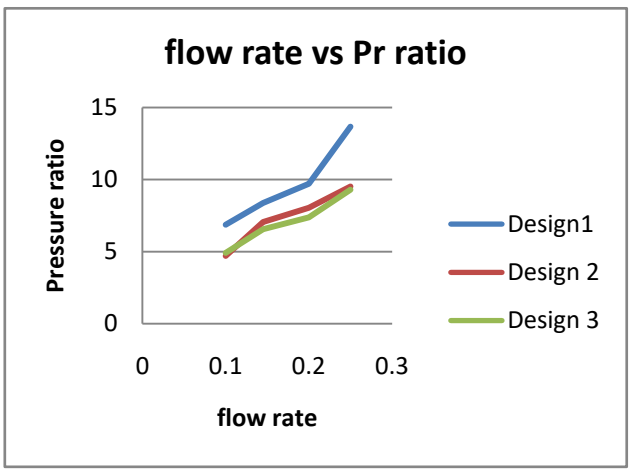

Fig. 16: Mass flow vs Pressure ratio for various shapes

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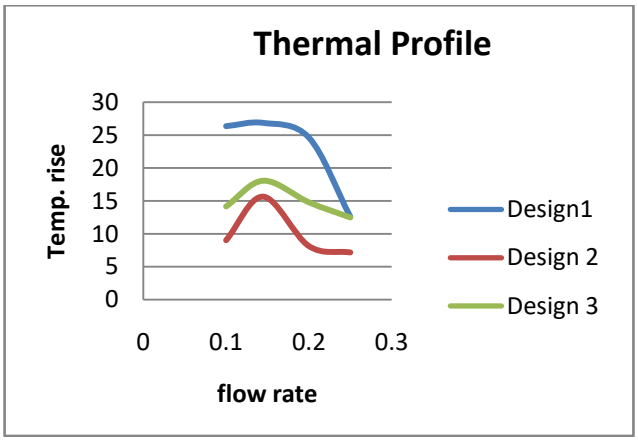

Fig. 17: Thermal profile of various designs

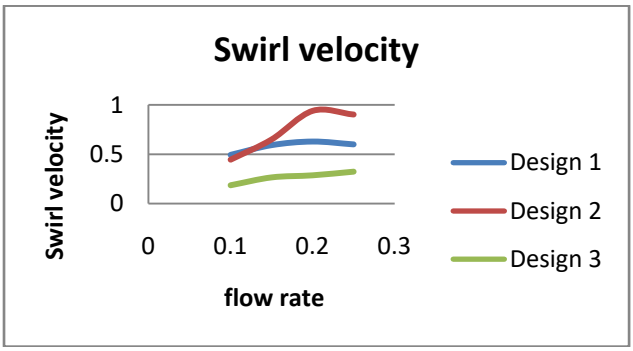

Fig. 18: Swirl Velocity

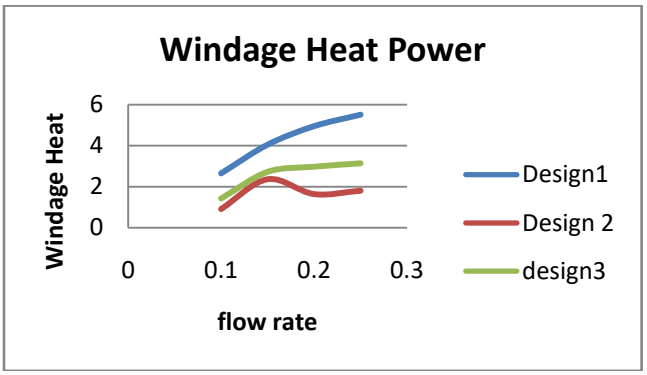

Fig. 19: Windage Heat Power

V. Results and Discussion

a) Turbulence Model Study

2D axisymmetric analysis of the Labyrinth Seal geometry (with rotation speed of 20,000 rpm) was first carried out. The objective was to establish baseline capability to run lab seal CFD analysis using Fluent and validate the experimental results.

b) Analysis of Results with Different Seal Configurations

As observed in Figures 13 to 15 the fluid flow into the seal and accelerated towards the clearance gap. The jet separates the flow into two counter rotating vortices causing the pressure to increase, it disrupts flow entering the clearance region and increases flow blockage thereby reducing the exit pressure at each tooth.

Refer figures 16 to 19, as the flow rate increases the pressure ratios is also increased thus linear in nature for all the 3 designs. Its observed that the design 1 is having higher pressure ratios then other two designs. The temperature rise in Design 1 is higher than the other two designs. Design 3 shows that less swirl velocity compared to two other designs. Design 1 and 2 are starting with same swirl velocity but as it progresses design 2 has steep increase. The windage heat power is higher in design 1 compared to two other designs.

The seals can further be studied with honeycomb fixed wall by various speed parameters. It may further studied by introducing air injection between knife edges and swirl interrupting steps thatwould create turbulence flow in the flow path that restricts movement.

VI. Conclusions

A new model of canted teeth with different wall shapes for labyrinth seals has been studied numerically and compared to base line sharp teeth with smooth land. The temperature rise and windage heat power is high in Design 1. Analyses indicate that the design 3 is capable of reducing overall seal leakage by generating more turbulence and friction flow.

Acknowledgment

The authors wish to thank kondala Rao N and Suresh B for his guidance during case studies.

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Numerical Study on Dynamic Stall of Low Reynolds Number Flow Around Boom Mounted U-Tail of FARIDUAV

By Emad Hasani Malekshah & Mofid Gorji-Bandpy
Imam Hossein University

Abstract- This study focuses on tail aerodynamic modeling with CFD simulation of an experimental unmanned aerial vehicle (UAV) in horizontal and vertical section separately. This aircraft with special capabilities has moderate maneuver performance, and predicting the aerodynamic behavior requires knowing that when dynamic stall will occur even in tail. The unsteady nature of the flow field around UAV tail, and the configuration of the generated lift and drag forces must be understood in order to optimize the comfort control system. As a result, flow around the tail and trailing-edge separation of elevator and rudder in horizontal and vertical tail at low Reynolds number with special angle of attack has been simulated .Finally, a custom three-component force balance for measuring lift, drag and moment is described in detail. The results indicate that maximum allowable angles of deflection are about 13 and 17 degree in horizontal and vertical tail, respectively. Moreover, each 1degree of deflection decreases almost 0.35 degree horizontal tail stall angle.

Keywords: *numerical investigation; UAV; dynamic stall; low reynolds number flow.*

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Emad Hasani Malekshah[α] & Mofid Gorji-Bandpy[σ]

Abstract- This study focuses on tail aerodynamic modeling with CFD simulation of an experimental unmanned aerial vehicle (UAV) in horizontal and vertical section separately. This aircraft with special capabilities has moderate maneuver performance, and predicting the aerodynamic behavior requires knowing that when dynamic stall will occur even in tail. The unsteady nature of the flow field around UAV tail, and the configuration of the generated lift and drag forces must be understood in order to optimize the comfort control system. As a result, flow around the tail and trailing-edge separation of elevator and rudder in horizontal and vertical tail at low Reynolds number with special angle of attack has been simulated. Finally, a custom three-component force balance for measuring lift, drag and moment is described in detail. The results indicate that maximum allowable angles of deflection are about 13 and 17 degree in horizontal and vertical tail, respectively. Moreover, each 1degree of deflection decreases almost 0.35 degree horizontal tail stall angle.

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I. Introduction

Unmanned aerial vehicles (UAV) have a great application in military services [1]; further, their usage in civilian missions has been increasing incredibly [2, 3]. The higher locomotion and maneuverability of UAVs have made aerial vehicles the common way to approach a goal to get data from ground or even to accomplish some actions such as the deployment of instrumentation. Aerial robotics seems an applied instrument to perform duties such as information and image detection of areas inaccessible using ground means, artistically photography, tracking, map building, and others. UAVs have been widely used for military applications, but, recently, they have been extended to civilian applications such as natural and human-made disasters scenarios, search and rescue, law enforcement, aerial mapping, traffic surveillance, inspection [4, 5, 6, 7]. Their typical tasks include the reconnaissance of hazardous areas, commercial missions, traffic-controlling, and even in agricultural industry and so on [8, 9, 10]. Interest in aerobatic aircraft flight dynamic has also been fueled in recent years by the rapid growth in UAVs because of their mission capabilities [11] like approaching to birds landing maneuver that involves high angle-of-attack [12] in order to reduce the landing distance. Flight outside the normal envelop like this can be encountered in airplane stall situations or more generally upset scenarios, which demands a deep and wide research on the aerodynamics of two-dimensional airfoils and three-dimensional wings and tails. It is obvious that many significant aerodynamics problems occur in low Reynolds numbers. Compared with high Reynolds numbers, low Reynolds number aerodynamics is quite different. Also characteristics of laminar separation at low Reynolds numbers have been widely studied by analytical, experimental and computational methods for decades. From analytical and experimental aspects, Horton [13] studied both theoretical and experimental method to recognize the short type of bubble in flow field around wing at low Reynolds number. Pauley et al. [14] simulated the flow around a two-dimensional airfoil and observed periodic vortex shedding. Phillips et al. [15] showed the effect of tail dihedral on the static stability and the usage of negative and positive tail dihedral. Dynamic stall occurs when unsteady angle of attack motion delays stall. This phenomenon is associated with leading edge vortex (LEV) formation. As the low pressure LEV grows, lift and drag coefficient rise until the stall point and then they drop dramatically. During the stage of dynamic stall beginning the concentrated vortex starts to develop and lifts off the upper surface thereafter. This procedure is influenced by different flow phenomena: In a low Reynolds number, flow transition from laminar to turbulent plays an important part in the development of the flow close to the airfoil leading edge [16-19].

Because of this significant load variation, understanding dynamic stall phenomena is critical for designing and controlling system operating under these conditions [20]. It is obvious that most of the research devoted on wings CFD simulating which characterized the flow behavior of the wings and debate on lift, drag

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and lift/drag curves but we know that tails are essential for plane stability. Thus this paper studies aerodynamic of both horizontal and vertical tail with different angles of attack and different angles of control surface which will affect stall point, in order to identify stall point in UAVs movement for better designing.

II. Specifications of Simulated Cases

a) Aircraft Model

The aircraft model considered in this study is based on a remote-control unmanned airplane FARID5 which is designed in Babol University of Technology. It has fixed-wing configuration with composite structure. There are three control surfaces; one of them in wing: aileron and the others in tail: elevator and rudder. The motor and propeller are mounted at the back of fuselage which makes the plane safer to operate [21]. The mentioned UAV presented in Fig.1 and its essential properties are given in Table 1.

Fig. 1: FARID5 UAV

Table 1: Aircraft mass and geometry properties

Quantity	
Mass m	8 kg
Chord c	0.25 m
Span	3.1 m
Wing surface area S_{wing}	0.775 m^2

b) Tail Model

The tail specifications are necessary requirements for aerodynamic modelling. The boom mounted U-tail type, shown in Fig.1, which is used on the mentioned UAV, has three control surfaces. Two vertical components (rudder) obtain yawing stability and the horizontal one (elevator) generate pitching moment to control air craft rotation around the side-to-side axis. Tail configuration simulated is shown in Fig.2 and Table.2 presents the details.

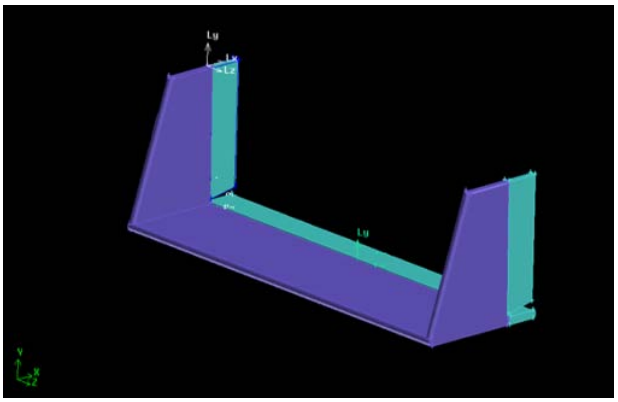

Fig. 2: Tail Configuration

It is obvious that tail of the aircraft has rectangular plan form; furthermore, the designer was reluctant to use common symmetrical airfoil; consequently, they applied flat plate instead.

Table 2: Tail geometry properties

Quantity	Value
Horizontal tail surface area	0.825 m^2
Vertical tail surface area	0.040 m^2
Elevator surface area	0.0275 m^2
Rudder surface area	0.020 m^2

III. Computation Scheme

a) Governing Equation

We consider that the governing equations are the RANS equations where the two-dimensional, unsteady and incompressible assumed for flow specifications. Also gravity and the body force items in Cartesian tensor form are neglected:

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \upsilon \frac{\partial^2 u_i}{\partial x_i \partial x_j} - \frac{\partial \overline{u_i' u_j'}}{\partial x_j} \tag{2}$$

Where υ is the kinematic viscosity of the air, u_i is the velocity, ρ and p are the density and pressure respectively and $\overline{-u_i' u_j'}$ is the Reynolds stress. [22, 23]

b) Turbulence Model

For adverse pressure gradient flows and airfoil flows prediction, we should choose a proper turbulence model. For this reason, the shear stress transport (SST) k-ω turbulence model [24] can precisely conduct this simulation. The SST model is written [25]:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left(\gamma_k \frac{\partial k}{\partial x_j}\right) + \bar{G}_k - D_k \tag{3}$$

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$$\frac{\partial}{\partial t}(\rho w)+\frac{\partial}{\partial x_i}(\rho w\, u_i)=\frac{\partial}{\partial x_j}\left(\gamma_w \frac{\partial w}{\partial x_j}\right)+G_w-D_w+C_w \qquad (4)$$

where γ_k and γ_w indicate the effective diffusivity of k and w, $\overline{G}_k$ and G_w indicate generation of turbulence kinetic energy and generation of w respectively, D_k and D_w show the dissipation of k and w in turbulence, C_w represents the cross-diffusion factor.

c) Grid and boundary conditions

For horizontal tail, an O-type layout, Fig.3, has been generated by elliptical method. The external computational boundaries are fixed at 40c from the surface, Fig.4. The location of the first row of cells bounding the surface kept $y^+<1$.

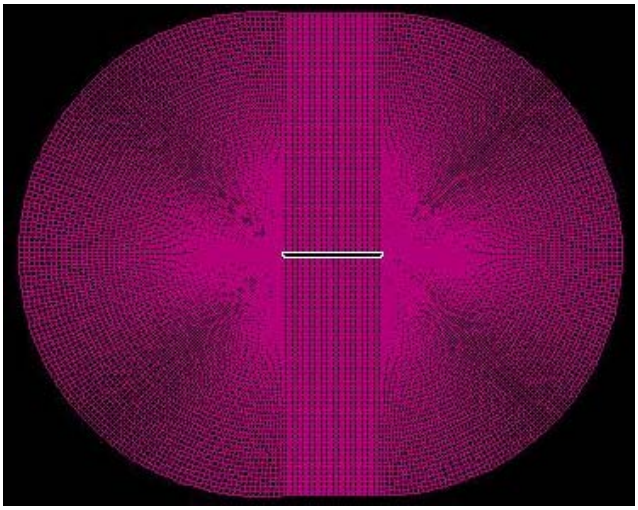

Fig. 3: 2D mesh grid around horizontal tail

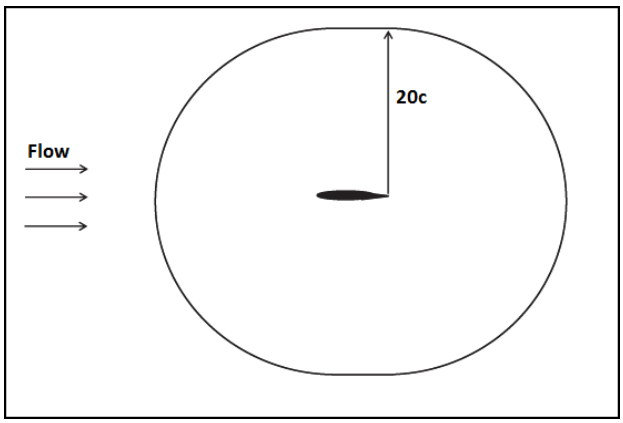

Fig. 4: Unstructured mesh topology with boundary conditions

For vertical tail, an unstructured grid, Fig.5 and Fig.6, has been generated. These kinds of grid are identified by irregular connectivity and employ triangles in 2D and tetrahedral in 3D commonly [26].

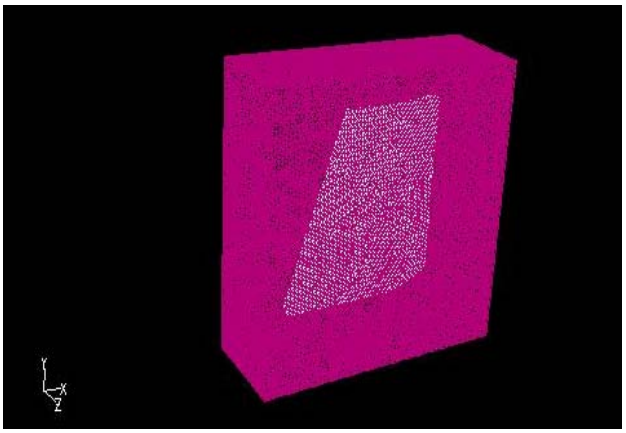

Fig. 5: 3D mesh grid around vertical tail

IV. Result and Discussion

a) Horizontal tail results

The elevator effectiveness is a measure of how effective the elevator deflection is in producing the desired pitching moment. There is a constraint on the elevator design which must be considered and checked. The elevator deflection must not cause the horizontal tail to stall but the results show, shown in Fig.6, when elevator is deflected more than 13-15 degrees, flow separation over the tail tends to occur and lift coefficient decrease dramatically. Thus, the elevator will lose its effectiveness. Furthermore, close to horizontal tail, even a small downward elevator deflection can produce flow separation and lose of pitch control effectiveness. To prevent pitch control effectiveness, it is recommended to consider the elevator maximum deflection to be less than 15 degrees. This strategy can prevent the first stall which is the result of increasing angle of elevator deflection.

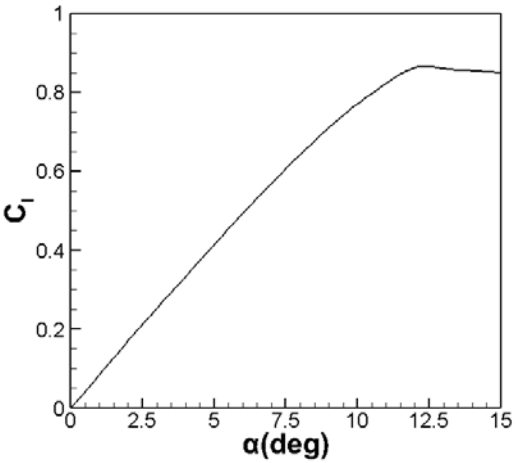

Fig. 6: Lift coefficient of horizontal tail section over the 0-deg angle of attack for elevator deflection of 0 to 15-deg

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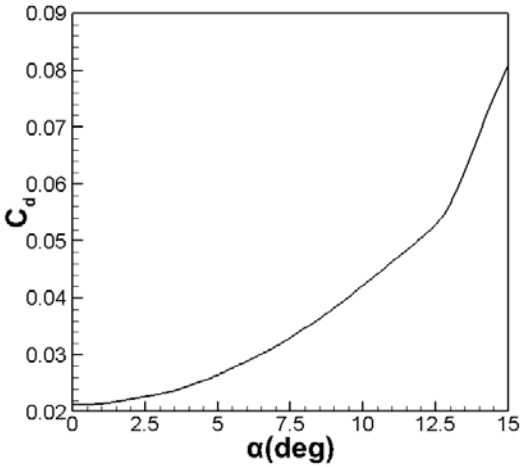

Fig. 7: Drag coefficient of horizontal tail section over the 0 - deg angle of attack for elevator deflection of 0 to 15 - deg

Flow structure around tail section can reveal much more details transient behavior of laminar flow separation and the evolution of a laminar separation on airfoil at different angle of deflection. So, to examine flow structure Figs. 8-11 are provided.

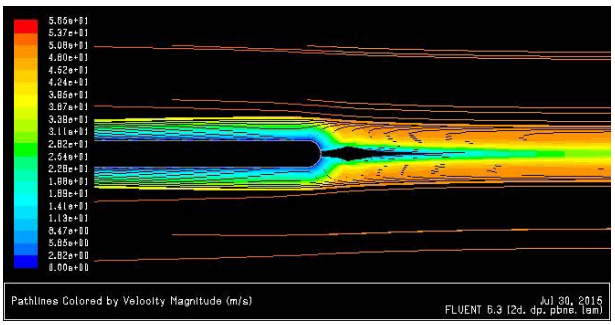

Fig. 8: Pathline colored by velocity magnitude at 0 degree angle of elevator deflection

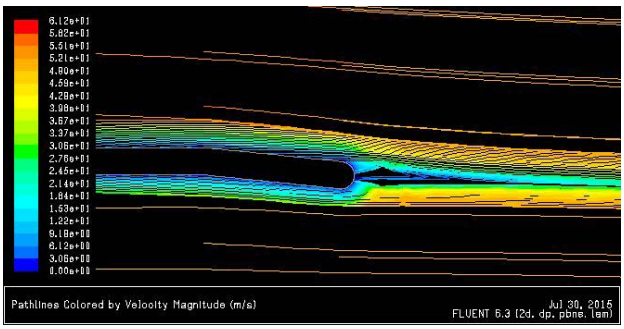

Fig. 9: Figure 9.Pathline colored by velocity magnitude at 5 degree angle of elevator deflection

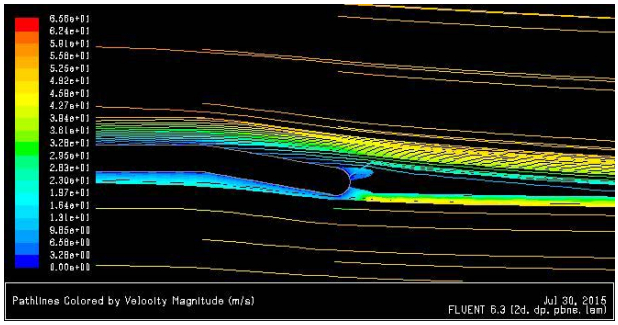

Fig. 10: Pathline colored by velocity magnitude at 10 degree angle of elevator deflection

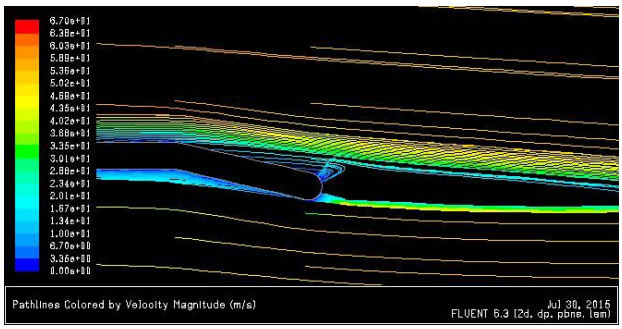

Fig. 11: Pathline colored by velocity magnitude at 13 degree angle of elevator deflection

It is obvious that stall phenomenon will occur with horizontal tail angle of attack increasing, even without elevator deflection, but it is important to know when it will show itself with elevator deflection. The results show that elevator deflection will decrease the tail stall angle; furthermore, the lift coefficient curve, shown in Fig.6, presents that each angle of deflection decreases almost 0.35 degree of tail stall angle.

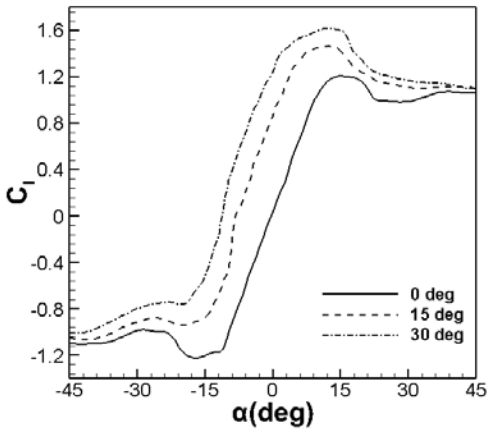

Fig. 12: Lift coefficient over the ±45-deg angle of attack range for elevator deflection of 0, +15 and + 30

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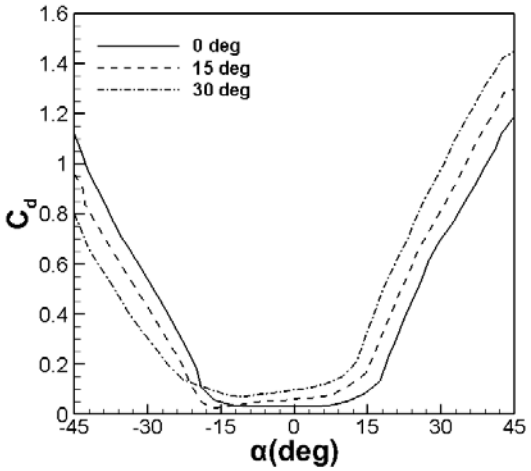

Fig. 13: Drag coefficient over the 45-deg angle of attack range for elevator deflection of 0, +15 and +30

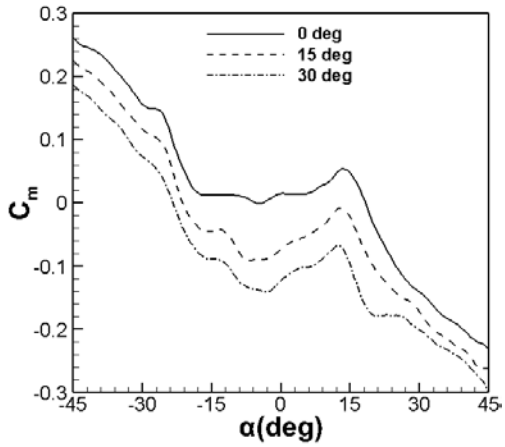

Fig. 14: Moment coefficient over the ±45-deg angle of attack range for elevator deflection of 0, +15 and +30

At last, the lift and drag forces, shown in Table 3, which are generated by horizontal tail at 0 –degree angle of attack and 1 to 15 degree angle of deflection are provided.

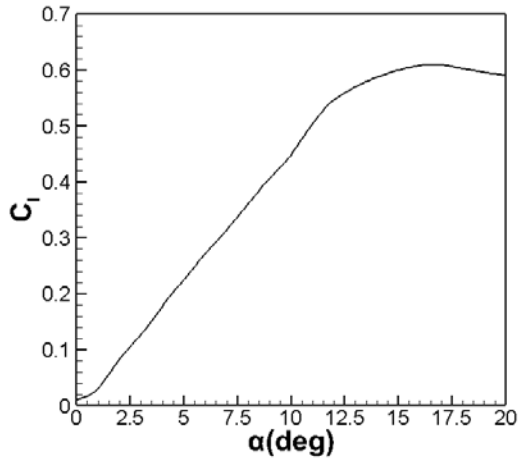

Fig. 15: Lift force generated by horizontal tail over 1 to 15 degree of elevator deflection

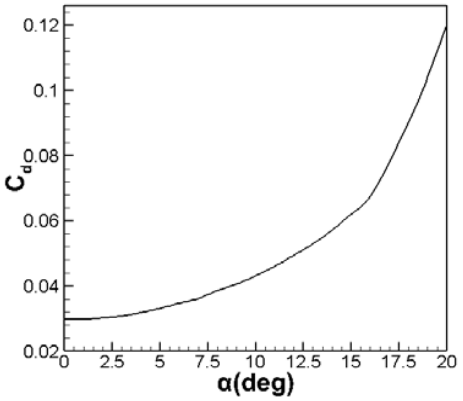

Fig. 16: Drag force generated by horizontal tail over 1 to 15 degree of elevator deflection

b) Vertical tail results

The rudder control power must be sufficient to accomplish directional trim and control requirement. The maximum allowable angle of rudder deflection should be found which will guarantee the high effectiveness of rudder and prevent the flow separation over the vertical tail. As shown in Fig.12, the lift coefficient decrease at 17 degree dramatically; furthermore; drag coefficient will plunge from this angle of deflection, shown in Fig.13.

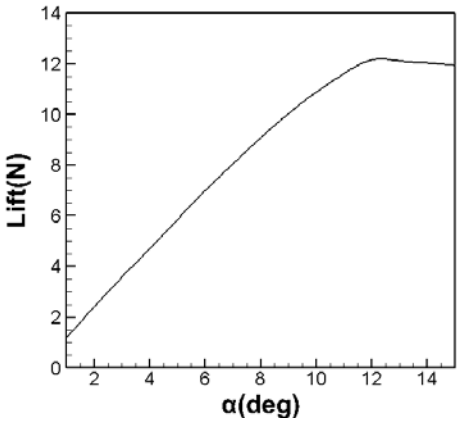

Fig. 17: Lift coefficient of vertical tail section over the 0 - deg angle of attack for rudder deflection of 0 to 20 - deg

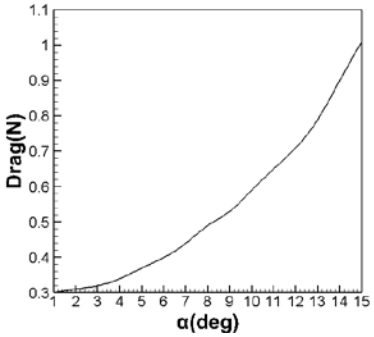

Fig. 18: Drag coefficient of vertical tail section over the 0- deg angle of attack for rudder deflection of 0 to 20 - deg

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Flow near the surface of vertical tail with different angle of rudder deflection is shown in Figs.14-17. It is observed that by the rudder angle increasing, some turbulence is appeared.

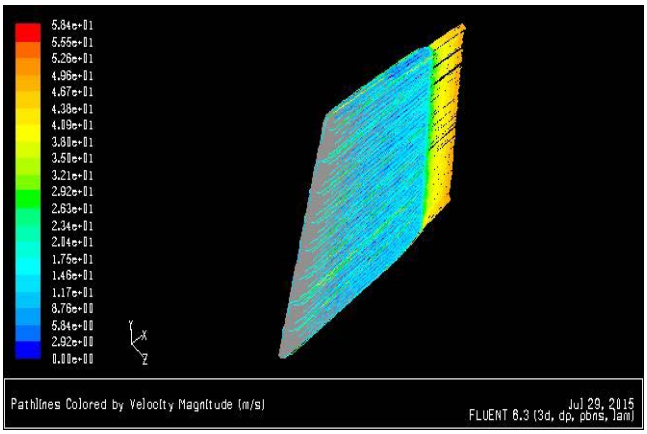

Fig. 19: Pathlines colored by velocity magnitude at 0-deg angle of rudder deflection

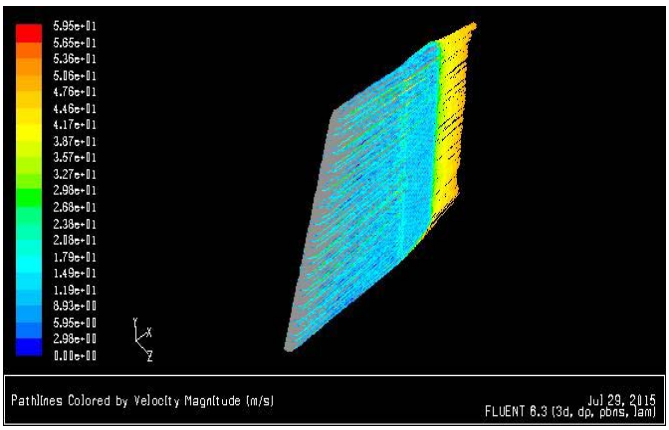

Fig. 20: Pathlines colored by velocity magnitude at 5 -deg angle of rudder deflection

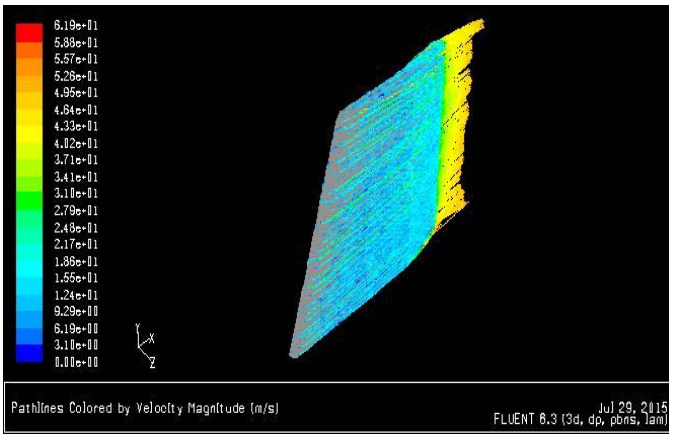

Fig. 21: Pathlines colored by velocity magnitude at 10-deg angle of rudder deflection

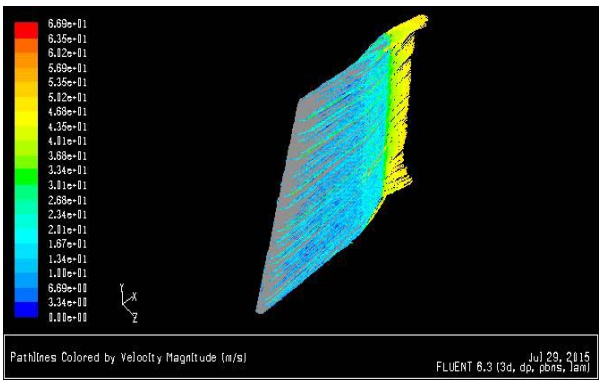

Fig. 22: Pathline colored by velocity magnitude at 15-deg angle of rudder deflection

Finally, the lift and drag forces, shown in Table 3, are provided which are generated by horizontal tail at 0–degree angle of attack and 1 to 20 degree angle of deflection.

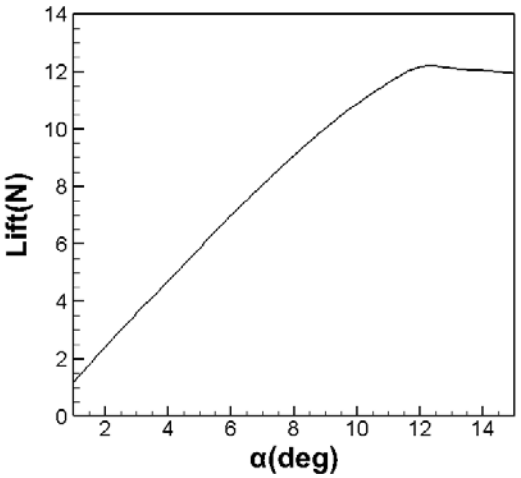

Fig. 23: Lift force generated by vertical tail over 1 to 20 degree of rudder deflection

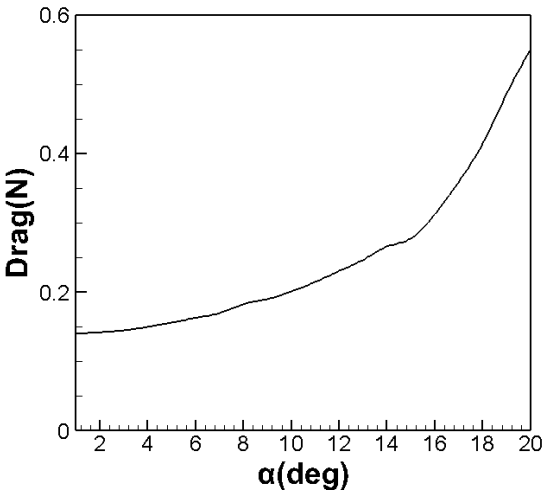

Fig. 24: Drag force generated by vertical tail over 1 to 20 degree of rudder deflection

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V. Conclusions

Stall phenomenon and separation of horizontal and vertical tail were simulated numerically using Navier-Stokes equations to understand the angle of dynamic stall to preserve the effectiveness of tails at low Reynolds number. At low Reynolds number, turbulence occurs on both horizontal and vertical tail of UAV even with small angle of control surface deflection. As it increases, laminar separation emerges on upper trailing edge of tail; furthermore; its influence on lift and drag coefficient will be appeared.

In horizontal tail, elevator deflection causes the stall phenomenon even at 0 degree AOA (angle of attack). Approaching the angle of deflection which reduces by enhancing of AOA, help us to find the maximum allowable angle of deflection which will prevent stall occurrence of horizontal tail, and also it will preserve tail's maximum effectiveness. The results show that mentioned angle of deflection is about 13 degree. Elevator deflection should be decreased 0.35 degree in front of every 1 degree growing of AOA in order to prevent stall.

In vertical tail, the maximum allowable angle of rudder's deflection is investigated without AOA consideration. According to explanation in horizontal tail section, the mentioned degree is estimated about 17 degree which will guarantee the vertical tail highest efficiency.

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Heatline Visualization of Natural Convection in Cavity Subjected by Different Heat Flux Profiles and Filled with two Immiscible Fluids of Sulfuric Acid and Air

By Mahmoud Salari, Abbas Kasaeipoor & Emad Hasani Malekshah
Imam Hossein University

Abstract- The natural convection heat transfer is investigated in the cavities filled with two immiscible fluids of sulfuric acid-water (25-75%) and air with different profiles of heat flux from side walls. The heatline visualization approach is employed to detect the heat energy path in the cavity from heat sources to heat sinks. The operating fluid is sulfuric acid-water (25-75%) at the bottom region and air at the top of the cavity. The Navier-Stokes equations are solved based on two-dimensional form, and finite volume approach is utilized. The side walls are heated variable heat flux and no-slip condition is applied to them. The top and bottom walls are cooled by environment temperature with no-slip condition.

Keywords: natural convection; heatline visualization; tall cavity; variable heat flux; sulfuric acid-water (25-75%).

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HEATLINEVISUALIZATIONOFNATURALCONVECTIONINCAVITYSUBJECTEDBYDIFFERENTHEATFLUXPROFILESANDFILLEDWITHTWOIMMISCIBLEFLUIDSOFSULFURICACIDANDAIR

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Heatline Visualization of Natural Convection in Cavity Subjected by Different Heat Flux Profiles and Filled with two Immiscible Fluids of Sulfuric Acid and Air

Mahmoud Salari [α], Abbas Kasaeipoor [σ] & Emad Hasani Malekshah [ρ]

Abstract- The natural convection heat transfer is investigated in the cavities filled with two immiscible fluids of sulfuric acid-water (25-75%) and air with different profiles of heat flux from side walls. The heatline visualization approach is employed to detect the heat energy path in the cavity from heat sources to heat sinks. The operating fluid is sulfuric acid-water (25-75%) at the bottom region and air at the top of the cavity. The Navier-Stokes equations are solved based on two-dimensional form, and finite volume approach is utilized. The side walls are heated variable heat flux and no-slip condition is applied to them. The top and bottom walls are cooled by environment temperature with no-slip condition. The influences of different governing parameters of Rayleigh number (〖10〗^3<Ra<〖10〗^5), and four different variable distributions of heat flux on the flow structure, temperature field, velocity and temperature distributions, average Nusselt number, skin friction coefficient and heatlines have been presented comprehensively.

Keywords: *natural convection; heatline visualization; tall cavity; variable heat flux; sulfuric acid-water (25-75%).*

Nomenclature:

AR	aspect ratio($\frac{H}{L}$)		
H	high of enclosure (m)		
			Greek symbols
L	width of enclosure (m)	α	Thermal diffusivity($\frac{k}{\rho c_p}$)
b	Height of air phase (m)	β	Thermal expansion coefficient
g	gravity ($\frac{m}{s^2}$)	θ	dimensionless of temperature
k	thermal conductivity ($\frac{W}{mk}$)	μ	dynamic viscosity
Nu	local Nusselt number	ν	kinematic viscosity
Nu_{avg}	average Nusselt number	ρ	density
q''	heat generation per area ($\frac{W}{m^2}$)		
P_r	Prandtl number		
R_a	Rayleigh number		
T	temperature (c°)		Subscribes
T_c	cold temperature (c°)	c	cold
$\vec{U}$ and $\vec{V}$	dimensionless velocity components($U = uH/\alpha$, $V = vH/\alpha$)	h	heat
x, y, z	Cartesian coordinates (m)		
X, Y	dimensionless of Cartesian coordinates ($\frac{x}{L}, \frac{y}{H}$)		

I. Introduction

The natural convection heat transfer and fluid flow attracts many interests due to many applications in the engineering applications and industrial projects. Some these applications can be mentioned as solar collectors, passive cooling, double pane windows, ventilation systems, lead-acid batteries, furnaces, etc. (***).

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The natural convection phenomenon is investigated my many researchers who analyzed the influence of different governing parameters on the fluid flow and heat transfer. In this context, Alshuraiaan and Khanafer[1] examined the effects of the heated thin porous fin position on the laminar natural convection in a square cavity. It was found that the average Nusselt number enhances with the presence of fin compared with heated cavity without fin.Kefayati and CheSidik[2] simulated the natural convection and entropy generation in inclined square cavity filled by non-Newtonian nanofluid using Buongiorno's mathematical model. It was observed that the augmentation of the power-law increases various entropy generations in different inclined angles and Rayleigh number. Khatamifar et al. [3] studied the conjugate natural convection in a square cavity which is divided into two parts and heated partially for different Rayleigh number in range of 10^5 to 10^9. The results indicate that the average Nusselt number reduces with increasing of partition thickness and enhances with Rayleigh number. Sathe and sammakia[4] obtain a review on developments in practical studied of air-cooled electronic packages. They studied various cases of cavities of single heat source, two heat sources with same dissipation rate and two heat sources with different dissipation rates. In all cases, the heat sources were located at vertical wall. They analyzed different parameters which are important in the natural convection such as Rayleigh number, the ratio between heat sources dissipation rates, the distance between heat sources and the aspect ratio of the cavities. Ye [5] investigated the thermal and hydraulic performance of natural convection in a rectangular storage cavity. The fluid flow and temperature field were analyzed to identify the type of heat transfer mechanism during different stages of melting process. It was shown that the conduction mechanism was dominant heat transfer mode at the first levels of melting process. Subsequently, by transition from conduction mechanism to convection mechanism, the convection heat transfer became dominant mode of heat transfer. Mahdavi et al. [6] carried out an experimental and numerical investigation on the hydrodynamic and thermal characteristics of laminar free convection in a rectangular cavity filled by different fluids such as water, ethylene glycol-water and air. They presented the three-dimensional distribution of local Nusselt number on the surfaces of active walls. It was found that the impact of adiabatic walls on the Nusselt number is significant when the studied fluid is air compared with other type of fluids, in addition; the convective terms were dominant compared with thermal diffusion.Teamah and Shehata[7] carried out a numerical investigation to analyze the natural convection with considering magnetohydrodynamic double diffusion in a trapezoidal cavity. It was shown that the heat and mass transfer reduces with increasing of inclined wall inclination. Da Silva et al. [8] numerically investigated the natural convection within a trapezoidal enclosure with different physical and geometric parameters. They proposed a correlation for the average Nusselt number based on Ra and Pr numbers and the inclination angle of upper surface for each baffle height.

The main aim of this article is to consider the natural convection in a rectangular enclosure filled with two immiscible fluids (air and sulfuric acid) heated from side walls with different profile of heat flux and investigate the effect of different governing parameters such as heat flux profiles and Rayleigh number on heat transfer characteristics and flow pattern.

II. Physical Model

In this study, the side walls are exposed to four special profile of heat flux, while, the part of walls that located the air phases are exposed to constant heat flux. The equation profiles of these heat fluxes are:

(a): $q'' = Ay$, (b): $q'' = By^2$, (c): $q'' = Cy^{0.5}$ and (d): $q'' = Constant$

Where: $A = 416.67$, $B = 6696.35$ and $C = 96.4236$. For all profile of heat flux, the total heat flux (q') entire to side walls is identical. The top and bottom walls are cold and kept at the constant temperature. The ratio of height of air phase to height of enclosure is constant and equal $\frac{b}{H} = \frac{1}{5}$. Also, the ratio of height of enclosure to weight of enclosure is defined by $AR = \frac{H}{L}$ and equal 5, 10, 15 and 20.

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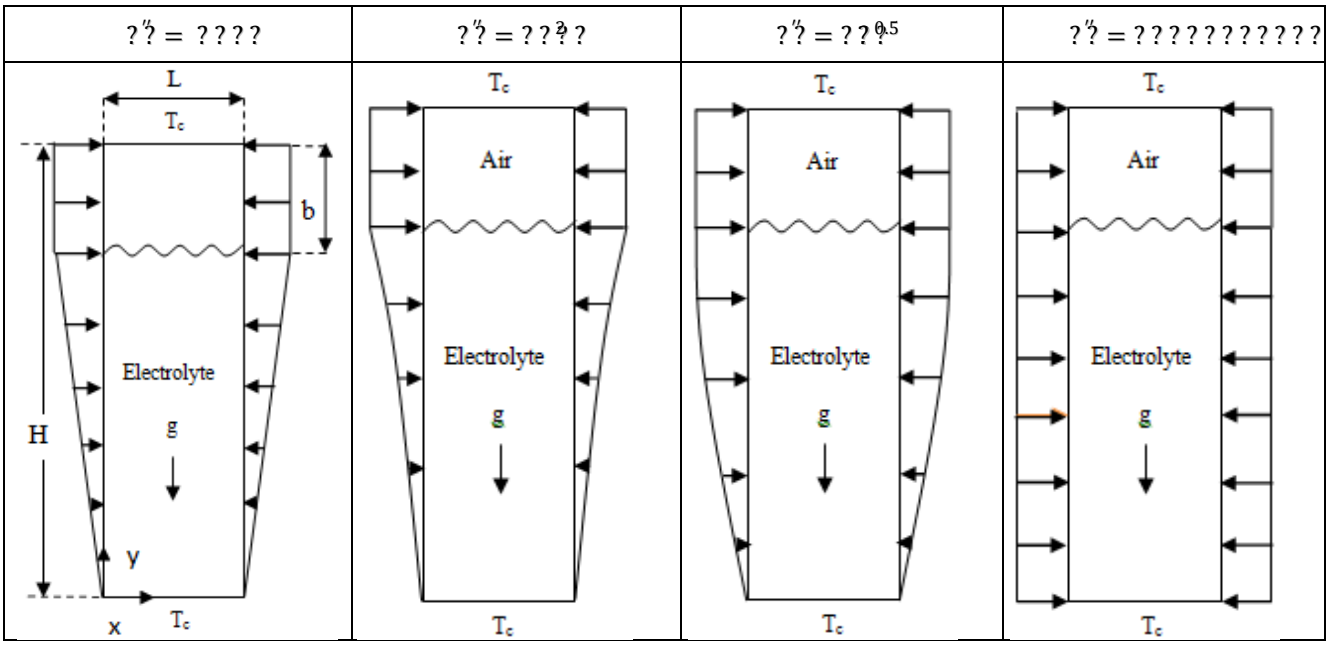

Fig. 1: Schematics of considered geometries with different heat flux distributions

III. Mathematical Formulation

In this study the governing equations are solved in two dimensional forms. The two dimensional form of continuity, momentum and energy equations for laminar and steady natural convection can be written as follows:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\frac{1}{\rho}\left[-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)\right] \tag{2}$$

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=\frac{1}{\rho}\left[-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+\rho\beta g(T-T_c\right] \tag{3}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \tag{4}$$

By introduction of the following dimensionless parameters:

$$X=\frac{x}{L},Y=\frac{y}{H},U=\frac{uH}{\alpha},V=\frac{vH}{\alpha},\theta=\frac{T-T_c}{\Delta T},P=\frac{pH^2}{\rho\alpha^2},pr=\frac{\nu}{\alpha},Ra=\frac{g\beta H^3\Delta T}{\nu\alpha},\Delta T=\frac{q'' H}{k},$$

$$C_f=\frac{\tau_w}{\frac{1}{2}\rho\bar{u}^2},$$

Where $q''=\frac{q}{H}$ and $\bar{u}=5e^{-6}$.

The dimensionless form of the governing equations can be obtained as follows:

$$\frac{\partial U}{\partial X}+\frac{\partial V}{\partial Y}=0 \tag{5}$$

$$U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}=-\frac{\partial P}{\partial X}+\frac{\nu}{\alpha}\left(\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2}\right) \tag{6}$$

$$U\frac{\partial V}{\partial X}+V\frac{\partial V}{\partial Y}=-\frac{\partial P}{\partial Y}+\frac{\nu}{\alpha}\left(\frac{\partial^2 V}{\partial X^2}+\frac{\partial^2 V}{\partial Y^2}\right)+Ra.Pr.\theta \tag{7}$$

$$U\frac{\partial \theta}{\partial X}+V\frac{\partial \theta}{\partial Y}=\left(\frac{\partial^2 \theta}{\partial X^2}+\frac{\partial^2 \theta}{\partial Y^2}\right) \tag{8}$$

The local Nusselt number of fluid on the side walls can be obtained from following equation:

$$Nu_s=\frac{hH}{k_{el}} \tag{9}$$

Whereas, the convection heat transfer coefficient can be determined by following:

$$h=\frac{q''}{T_s-T_c} \tag{10}$$

The total heat flux entry to side walls (q') is same for all heat flux profiles and q'' at the equation (10) is equal $q''=\frac{q'}{L}$.

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The heat line can be used to visualize the path-line and intensity of heat flow which is similar to streamlines. The heatlines are applicable to visualize and identify the heat flow from heat sources to heat sinks in the cavities. The heat filed within a two-dimensional cavity for convective transport process was mathematically studied by Kimura and Bejan [9]. The heatlines are represented by heat functions ($\bar{h}$) which can be applied to plot the heatlines in the cavity and also obtained from the conductive heat fluxes ($-\frac{\partial T}{\partial x}, -\frac{\partial T}{\partial y}$) and convective heat fluxes (uT, vT). The heatfunctions parameter ($\bar{h}$) satisfies the energy conservation equation for fluid media:

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \quad (11)$$

So:

$$\frac{\partial \bar{h}}{\partial y}=\rho c_p u(T-T_0)-k\frac{\partial T}{\partial x} \quad (12a)$$

$$-\frac{\partial \bar{\bar{h}}}{\partial x}=\rho v(T-T_0)-k\frac{\partial T}{\partial y} \quad (12b)$$

To make dimensionless form of heatfunctionsΠ, the above-mentioned dimensionless variables are used:

$$\frac{\partial \Pi}{\partial Y}=U\theta-\frac{\partial \theta}{\partial X}, \quad (13a)$$

$$-\frac{\partial \Pi}{\partial X}=V\theta-\frac{\partial \theta}{\partial Y}, \quad (13b)$$

This can be written in a single equation as follows:

$$\frac{\partial^2 \Pi}{\partial X^2}+\frac{\partial^2 \Pi}{\partial Y^2}=\frac{\partial}{\partial Y}(U\theta)-\frac{\partial}{\partial X}(V\theta) \quad (14)$$

It should be noted that the counter clockwise circulation is represented by positive sign ofΠ, and the clockwise circulation is represented by negative sign ofΠ.

IV. Numerical Methodology

The above-mentioned equations have been solved based on the finite volume approach and the SIMPLE algorithm has been employed. To discrete the convection terms, the second-order upwind approach is employed. Also, the central differencing scheme is used to discrete the diffusive terms. In order to perform the grid independency analysis, 5 different structured grids are used. The value of average Nusselt number for left wall with constant heat flux in $Ra = 10^5$ is evaluated and shown in Table.1. The grid distribution of 80×40 is selected for further simulations. Moreover, the numerical result obtained by Oztop and Abunada[10] is selected in order to verify the obtained results in the present investigation. It can be observed that there are close consistencies between obtained mean Nusselt number of present code and the previous one in a range of Rayleigh number ($10^3 < Ra < 10^5$).

AR=5, Ra= 〖10〗 ^5

Table 1: Grid independency for ? ? ?=5, ? ? ?=10^5 and all heat flux distributions.

Mesh size		10×50	20×60	30×70	40×80	50×90
Average Nusselt number	$q'' = By^2$	2.632	2.691	2.704	2.710	2.712
	$q'' = Ay$	2.476	2.498	2.500	2.501	2.503
	$q'' = Cy^{0.5}$	2.184	2.200	2.279	2.286	2.281
	$q'' = Constant$	1.101	1.117	1.121	1.123	1.123

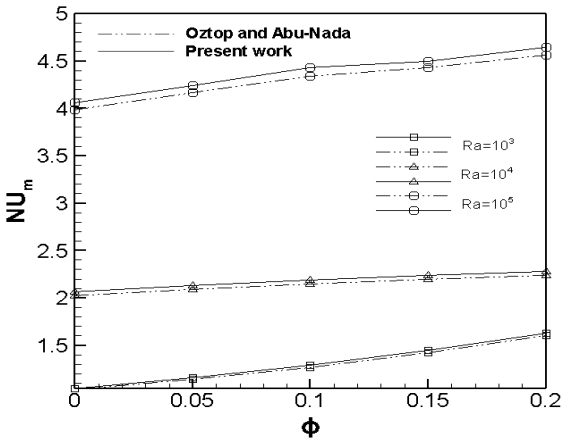

Fig. 2: Validation of the present work for Al2O3–water nanofluid compared with Oztop and Abu-Nada [10]

V. Results and Discussion

a) Convective flow analysis

In the natural convection phenomenon, the fluid flow depends on many different parameters which have influences on the flow structure in confined environments.

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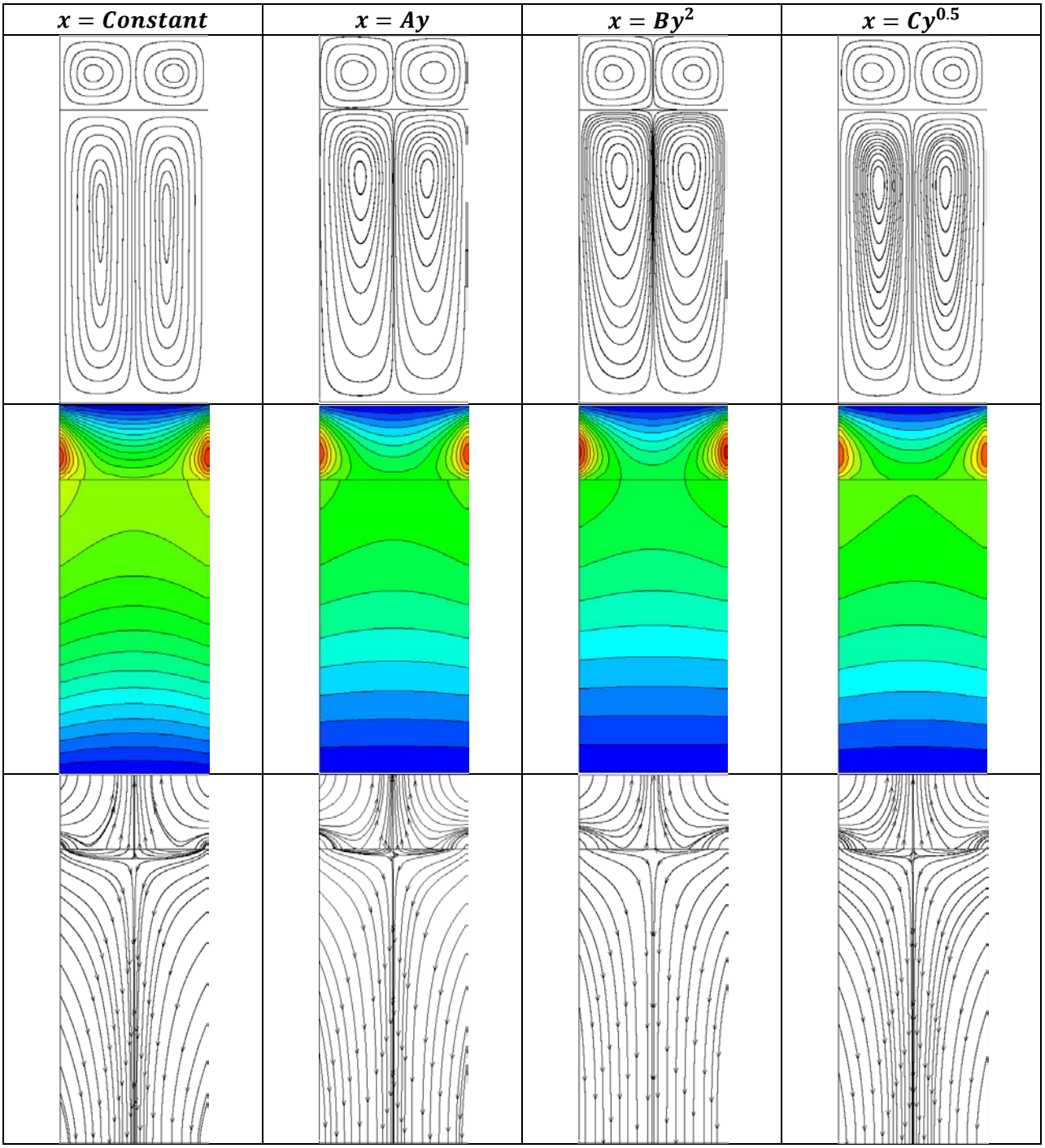

Fig. 3: Flow structure, temperature filed and heatlines for different heat flux distributions in $Ra = 10^3$.

Some these effective parameters are gravity acceleration, thermo-physical properties of operating fluid, thermal boundary condition, physical boundary condition, geometry of considered enclosure, external forces like magnetic force, etc. As a result, it can be concluded that to analyze the natural convection heat transfer, the influences of these parameters must be identified and considered in the investigation. In this study, the cavity is filled with two immiscible fluids, liquid and gas, and heated from side walls with different kind of temperature distribution. The temperature of the electrolyte stream at the adjacent of side walls enhances. As a result of this matter, the density of the electrolyte stream at these regions, sides of the cavity, reduces causing ascending the electrolyte stream forced by buoyancy force in presence of gravity

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acceleration. So, the electrolyte stream goes up along the side walls to reach the interface of liquid and gas. At this part, the electrolyte stream transfers its heat energy to the gas phase causing decreasing the temperature of the electrolyte stream. The density of electrolyte stream enhances again resulted by lower temperature, and the electrolyte stream descending from the collision point of two ascending electrolyte stream from sides at the surface of interface. This process occurs again and again which creating two main clockwise and counter-clockwise circulations at the left and right sides of the cavity, respectively. The similar process occurs at the gas phase creating two main circulations.

b) Temperature field analysis

In the engineering applications, it is necessary to find the different parameters to control the temperature distributions in the confined environment such as cavity. For example, in some industrial applications, it is desirable to hold the temperature distribution uniform throughout the enclosure which prevents creating very high temperature stream in some regions and using special strong alloys which is not cost effective. The temperature fields within the cavity for different linear and non-linear heat flux profiles of heated side walls and different aspect ratio of cavities are depicted in Fig.5. It is obvious that the heat flux profiles at the side walls have considerable influence on the temperature field. The cold regions in case with heat flux profile of $q'' = By^2$ is wider with respect to other cases since the amount of heat flux offloaded at the above regions of the cavity is more than other cases, although the total amount of heat flux is constant for all cases.

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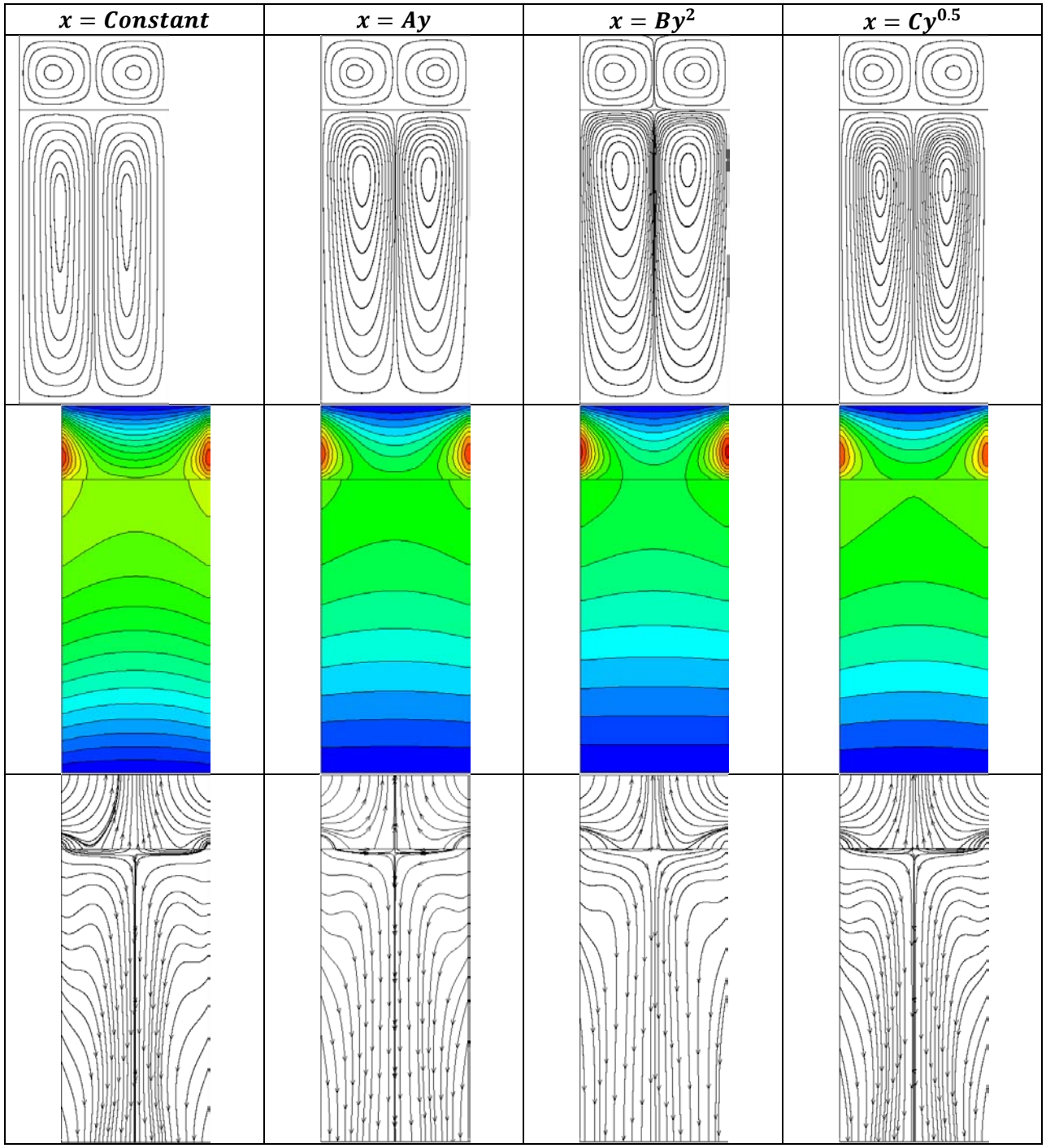

Fig. 4: Flow structure, temperature filed and heatlines for different heat flux distributions in $\boldsymbol{Ra = 10^4}$.

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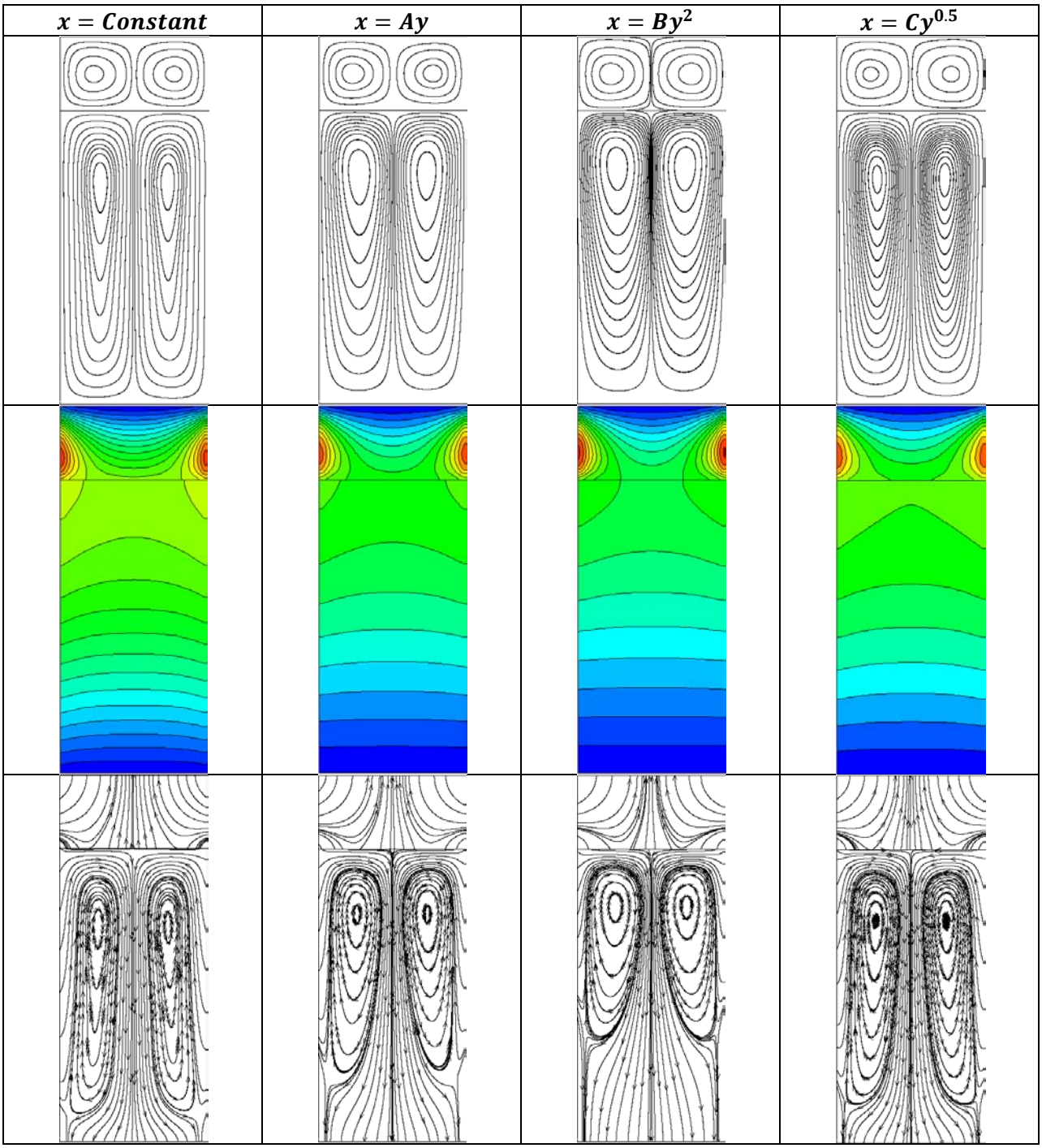

Fig. 5: Flow structure, temperature filed and heatlines for different heat flux distributions in $Ra = 10^5$.

c) Flow structure analysis

The flow structures for different profiles of heat fluxes within the cavity are presented in Figs.***. The profiles of heat flux of side walls have influences on determining the configurations of the circulations. In constant heat flux of $q'' = constant$, the configuration of the circulations are completely similar at the top region and bottom region due to symmetric heat flux profile of side walls. On the contrary, it is clear that the streamlines are compacted at the top region. It is due to the fact that the amount of offloading heat flux at top region is more than bottom region causing stronger electrolyte flow at top region. On the other hand, the configurations of the circulations in the gas phase are completely similar to each other in all cases with different heat flux profiles.

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d) Heatline Visualization

The influences of heat flux profile of the cavities on the heatlines for both air phase and electrolyte phase at different Rayleigh numbers are presented graphically in Fig.9. It can be observed that the heat flux profiles at side walls have no pronounced effects on the heatlines as a result of limited space of air phase. On the contrary, the influences of Rayleigh numbers on the heatlines are significant. As Rayleigh number enhances, the fluid flow becomes stronger as a consequence of increases temperature difference. As a result of this matter, the fluid flow will be able to transfer the heat energy in the fluid media. As Rayleigh number enhances, the heatline maps at the air phase have no considerable differences. It is due to the fact that the volume of air phase is limited. On the other hand, in the electrolyte phase, the fluid flow becomes stronger as Rayleigh number increase and the main circulations will be able to transfer the heat energy. As a result of this matter, it can be observed that the heat energy is entrapped in the circulations at high Rayleigh number.

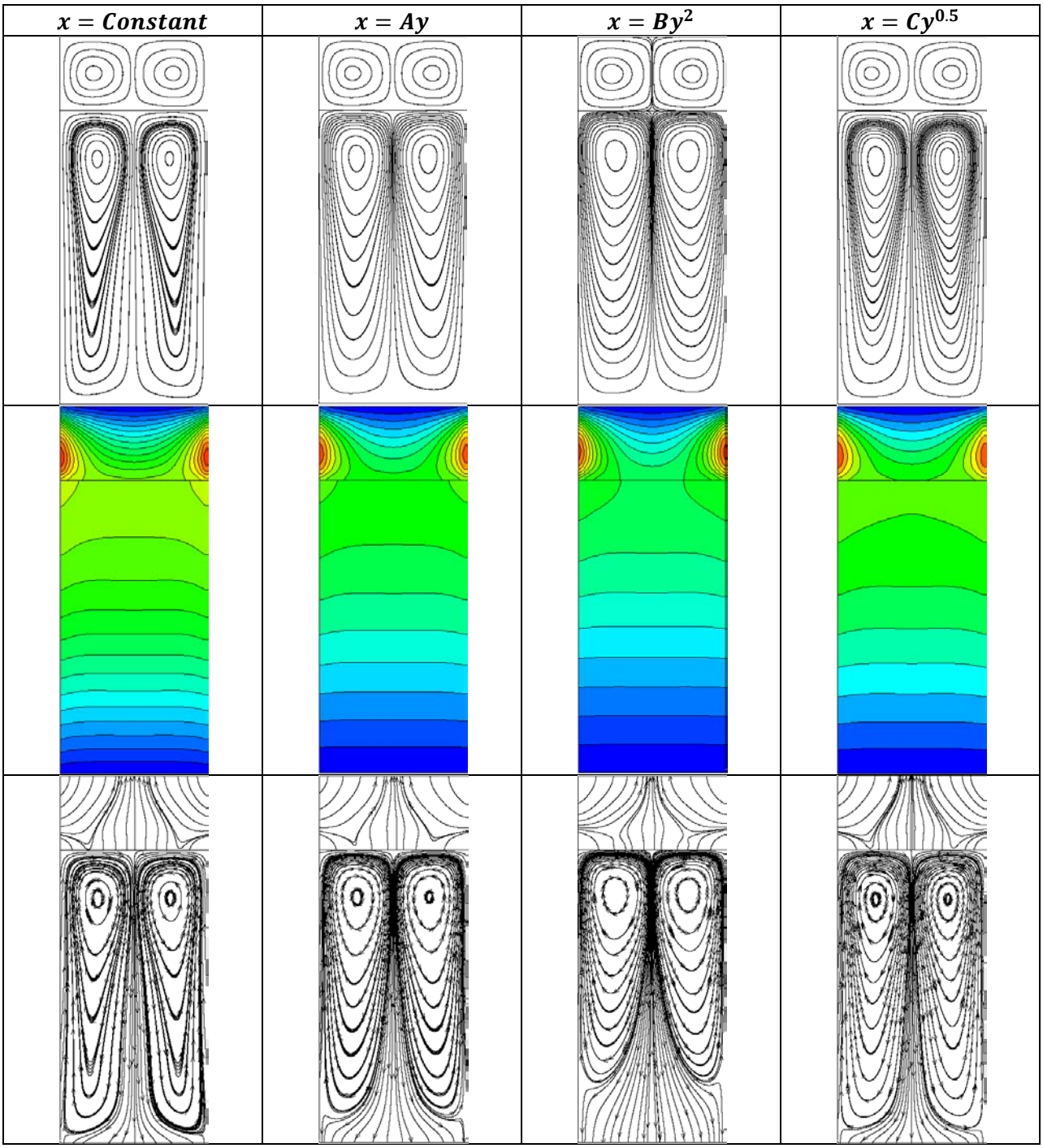

Fig. 6: Flow structure, temperature filed and heatlines for different heat flux distributions in $Ra = 10^6$.

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e) Skin friction coefficient analysis

The values of skin friction coefficient with respect to dimensionless height of the cavity as a function of different profiles of heat flux on side heated walls are presented in Fig.7. It should be noted that the skin friction coefficient is calculated for the electrolyte phase. The value of skin friction coefficient or the similar quantities such as wall shear stress are important in some engineering applications. For an instance of an industrial application needing to enhance the skin friction coefficient, in the lead-acid batteries, it is important to design the gap distance of the cells to increase the skin friction coefficient in order to omit the created bubbles at the surface of the anodes and cathodes.Because, the effective area of electrodes is reduce when the bubbles located on the surface of them. Then, the performance of battery will be reduced.

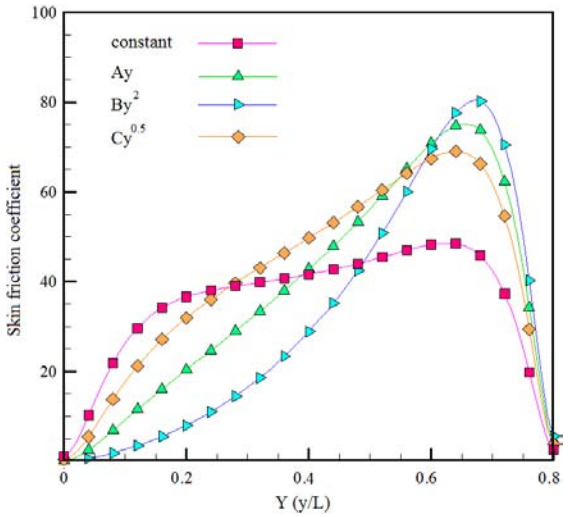

Fig. 10: Skin friction coefficient with respect to dimensionless height of cavity as a function of different heat flux distributions in $\boldsymbol{Ra = 10^5}$

The results show that the profiles of the heat fluxes at the side walls have pronounced influences of the distributions of the skin friction quantity. It should be noted that the distribution of the skin friction coefficient has direct relationship with the profile of the heat fluxes. It can be observed that the distribution of the skin friction coefficient for the case with linear heat flux profile $(q'' = constant)$ is almost linear except at the corners which are caused by the secondary eddies and weak electrolyte stream at these regions. For $q'' = Ay$, the distribution of the skin friction coefficient is linear with constant slope as same as the heat flux profile. For other case, $q'' = Cy^{0.5}$and $q'' = By^2$, the distribution of the skin friction coefficient and heat flux are similar as well. So, it can be concluded that the heat flux profile of the side walls is an effective approach to control the distribution of the skin friction coefficient.

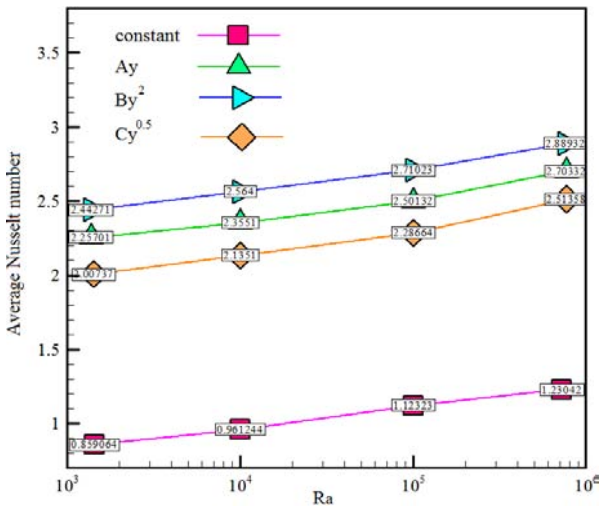

Fig. 11: Average nusselt number for different heat flux profile and Rayleigh number

f) Averaged Nusselt Number

The values of averaged Nusselt number with respect to Rayleigh number as a function of different heat flux profiles are presented in Fig.8. The Nusselt number is a dimensionless parameter which denotes the share of each mechanism of conduction and convection on the heat transfer within the enclosure. At high value of Nusselt number, the convection is the main heat transfer mechanism, and the conduction is the dominant heat transfer mechanism at low Nusselt numbers. It can be seen from Fig.8 that the profiles of heat flux have considerable effect on determining the value of average Nusselt number. The maximum values of average Nusselt number at all Rayleigh numbers occurs as the heat flux profile is $q'' = By^2$. Moreover, the heat flux profile of $q'' = constant$ has not considerable influence on creating convective flow as the average Nusselt number is close to unity in all Rayleigh number.

VI. Conclusion

The natural convection heat transfer in cavities with different profiles of heat flux and filled with two immiscible fluids of sulfuric acid-water (25-75%) and air has been studied. The heatline visualization approach has been utilized to detect the heat energy path within the cavity. The physical and thermal boundary conditions are as follows:

1. Side wall: heaters with variable heat flux with no-slip boundary condition
2. Bottom wall: cold wall, no-slip boundary condition
3. Top wall: cold wall, no-slip boundary condition
4. Interface: heat transfer and shear stress are applied

Different governing parameters such as aspect ratio$(5 < AR < 20)$, Rayleigh number $(10^3 < Ra < 10^5)$

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and different heat flux distributions on the flow structure, temperature filed, Nusselt number and heatlines have been analyzed systematically. The results can be summarized as follows:

- The heat flux distributions have pronounced effect on the flow structure at the liquid phase and negligible effect at air phase.
- The value of skin friction coefficient has close similarity with the heat flux profile.
- The value of average Nusselt number has direct relationship with the Rayleigh number.
- Two main circulations are created in heatline maps at high Rayleigh number.
- Maximum temperature value occurs when the heat flux distribution is constant.

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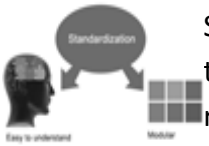

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The page length of this segment is set by the sum and types of data to be reported. Carry on to be to the point, by means of statistics and tables, if suitable, to present consequences most efficiently.You must obviously differentiate material that would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matter should not be submitted at all except requested by the instructor.

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Content

- Sum up your conclusion in text and demonstrate them, if suitable, with figures and tables.
- In manuscript, explain each of your consequences, point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation an exacting study.
- Explain results of control experiments and comprise remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or in manuscript form.

What to stay away from

- Do not discuss or infer your outcome, report surroundings information, or try to explain anything.
- Not at all, take in raw data or intermediate calculations in a research manuscript.
- Do not present the similar data more than once.
- Manuscript should complement any figures or tables, not duplicate the identical information.
- Never confuse figures with tables - there is a difference.

Approach

- As forever, use past tense when you submit to your results, and put the whole thing in a reasonable order.
- Put figures and tables, appropriately numbered, in order at the end of the report
- If you desire, you may place your figures and tables properly within the text of your results part.

Figures and tables

- If you put figures and tables at the end of the details, make certain that they are visibly distinguished from any attach appendix materials, such as raw facts
- Despite of position, each figure must be numbered one after the other and complete with subtitle
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- All figure and table must be adequately complete that it could situate on its own, divide from text

Discussion:

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- Make a decision if each premise is supported, discarded, or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."
- Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work
- You may propose future guidelines, such as how the experiment might be personalized to accomplish a new idea.
- Give details all of your remarks as much as possible, focus on mechanisms.
- Make a decision if the tentative design sufficiently addressed the theory, and whether or not it was correctly restricted.
- Try to present substitute explanations if sensible alternatives be present.
- One research will not counter an overall question, so maintain the large picture in mind, where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

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Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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