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Research Article

Study of Effect of Change in Air Properties and Angle of Attack on Aerodynamic Forces of NACA0018

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Abstract

A detailed experimentation is carried out in open wind tunnel on an airfoil i.e. NACA0018 with same number of simulation by using ANSYS fluent 15.0 commercial software for characterizing fluid flow and aerodynamic forces. With change in air properties like temperature and relative humidity and other parameter like angle of attack and air speed. This study is carried out since there is very limited study for such a large combination of changing parameters. With the development of CFD software technology the study becomes easy as it saves lots of resources with proper visualization at each and every point. From experiments and simulation lot of conclusions are made of which it is observed that air speed and angle of attack is the most dominant factor in aerodynamic forces however, it also depends on temperature then humidity in a decreasing order. Hot and humid condition is the worst condition for aerodynamic forces i.e. lift forces and drag forces and is followed by hot condition and then humid condition.

Keywords: *Computational fluid dynamics ,Wind tunnel , Digital psychrometer ,Anemometer ,Relative humidity(RH), Drag Force(FD) ,Lift Force(FL) .*

1. Introduction

It is well known fact that weather condition plays a vital role in aerodynamic performance as well as engine performance of aircraft. So a detailed study towards understanding effects of air speed, angle of attack, temperature, relative humidity parameters are done on airfoil. In the early development of aerodynamics research work, the effect of different air properties were studied in a new concept at that time called wind tunnel.

For stagnation pressure of 1 bar and stagnation temperature giving no heat transfer at wall, no humidity effects were noticeable if absolute humidity is less than $2×10^{-4}$ at Mach no. 2.48, $3×10^{-4}$ at Mach no. 3.12, and about $5×10^{-4}$ at Mach no. 3.8 (R.J.monoghan,1955). With improvement of testing equipment further ,the focus was shifted to transonic speeds also, the effects of humidity at near sonic speed was studied and investigation of effects of dew points at stagnation temperature of 48.9°C and effect of stagnation temperature at relatively high dew point of 15.6°C were done and it is observed that decreasing tunnel stagnation temperature resulted in humidity effect similar to those incurred by increasing dew point and increasing temperature resulted in reduction of these humidity effect (Frank L .Jordon,1972) .

Other parameter like angle of attack and Reynold number effect on airfoil were studied experimentally and the results found clearly indicates that stall angles and lift coefficient increased with increase in Reynold number (Onur yemenici,2014).

Relationship of various properties were studied (P.T.Tsilingiris,2007) for humid air ranging between 0°C and 100°C,Experiments for studying the flow and heat transfer characteristic over an airfoil i.e.NACA0018 (M.Sri RamaMurthy)are carried out. Results shown that pressure distribution was varying with non-dimensional distance and with position of airfoil.

Flights while taking off and landing remain only for 6% of total flight journey but contribute to 61% of total accidents (statistical summary of commercial jet airplane accidents, 2014)

From above literature it can be observed that there is very limited research done on combined effect of various parameters like angle of attack, air speed, temperature and relative humidity which is generally seen in practical situation. With the development of Micro Air vehicles and Unmanned Air vehicle which are used for special operations like policing surveillance ,non-military security work ,nature observation for scientific studies and lot more applications. These air vehicles have to work in harsh atmospheric condition so a detailed scientific study of the effect of weather on airfoil will help in research for betterment of such aircrafts.

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2. Objective

- To study the effect of change in air properties on aerodynamic forces of NACA0018.
- To study the effect of various angle of attack on aerodynamic.
- To investigate the effect with different air speed, temperature and humidity.
- To analyse experimental results by CFD software.

3. Experimental setup and procedure

The experiments are carried out on airfoil in an open wind tunnel. Its purpose is to provide a region of controlled air flow in which models can be placed. This region is called working space or test section .The wind tunnel is closed working section with bell mouth entry. The tunnel is of simplest tube section open type along which air is propelled .The propulsion is usually provided by a fan downstream of working section.

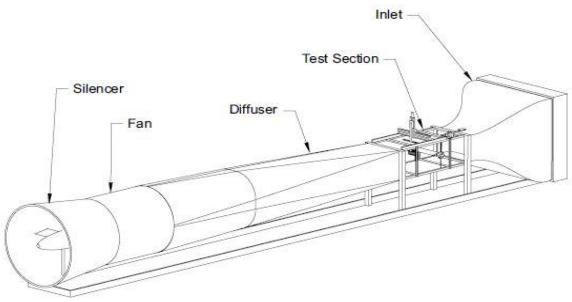


Figure 1: Schematic of open wind tunnel

The entry is shaped to guide the air smoothly into the tunnel. Settling chamber and contraction cone is so designed to make the flow more parallel and more uniform. The mouth is followed by settling chamber which leads to the contraction chamber to get velocity increase ,which is connected with working section .Contraction is specially designed to give good results in test section . The settling chamber usually includes a honey comb structure and nylon mesh screens to filter and stabilize the incoming air flow.

Figure 2: Photograph of open wind tunnel

Working section/test section is used to fit models and to use this space for experimentation .Tunnel is having 300×300 mm^2 test section with 1000 mm length and two windows to insert models. A fan is fitted to sturdy frame work and is coupled to a motor .This motor is controlled with a variable frequency drive. Digital display which gives smooth variation of air velocity in test section which can be seen on the digital anemometer and one can set the velocity of air to desired value. Open return tunnel is considered to be simple kind of low speed wind tunnel .The room containing the tunnel is in fact part of tunnel since it provides the path by which the air returns from the downstream end to upstream end.

Wind tunnel consists of 5 HP, 3000 RPM AC motor, Excitation voltage is 440V and consists of 3 phase. Air velocity in the tunnel ranges between 3 m/sec to 20 m/sec. Before starting the experimentation the equipment are assembled properly. The opening of tunnel is extended by rectangular duct made up of Galvanized Iron sheet of size 930×920×1250 mm^3.The duct is attached with wind tunnel opening and is perfectly sealed to prevent air infiltration .At the entrance of duct, water sprayer is installed after the room heater, to change temperature and humidity of air flowing inside tunnel.

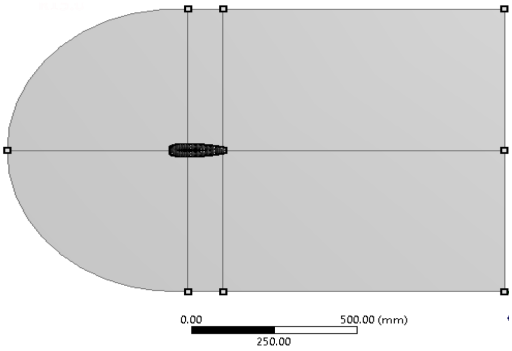
At first motor is started, initially readings are taken at room conditions. Temperature and relative humidity is measured by digital psychrometer, air speed is measured by digital anemometer. At second set of reading angle of attack and air speed kept constant and temperature and humidity is changed. Air speed is changed and angle of attack kept constant and same procedure is followed as stated above and readings are taken. Now angle of attack is changed and same procedure is followed again i.e. changing temperature and humidity at first then changing air speed.

4. Simulation using CFD

A commercial ANSYS fluent 15.0 was used for calculating aerodynamic forces i.e. drag force and lift forces also velocity, pressure and temperature profiles. Instead modeling whole of the tunnel conditions similar to wind tunnel are modeled with far field .Since it is an open wind tunnel boundary condition at outlet is considered as pressure outlet and velocity at inlet condition. The two dimensional Reynolds Average Navier Stokes (RANS) equation is solved using commercial ANSYS fluent 15.0 for simulation. Coupled velocity pressure algorithm with the second order upwind spatial discretization is used. SST kω model was used. pressure at outlet is considered as atmospheric pressure since the wind tunnel is an open wind tunnel. Least square cell based schemes and second order pressure interpolation is used for better convergence rate.

A Computational Fluid Dynamics model is generated in commercial CFD software i.e. ANSYS 2015 is as shown in figure (3). A 2D geometry is considered here for simulation purpose. Length of Airfoil model is 150mm.

A structured grid is generated as shown in figure (4). The complete mesh model consists of 67872 nodes and 67200 elements .Fine meshing is done at the airfoil wall in mesher.



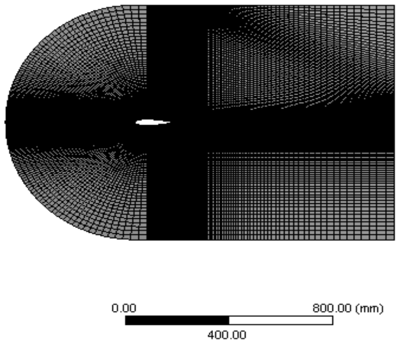


Figure 3: Simulation model for NACA0018 **Figure 4:** structured mesh generated on NACA0018

Table 1: Experimental and Simulation Results at Angle of Attack 0° and 15 m/s

AOA (°)	Velo (m/s)	Temp. (°C)	RH (%)	Experimental Results		Simulation Results	
				FD	FL	FD	FL
0	15	31.7	29.3	0.01	0.00	0.01404	$-3.56e^{-4}$
0	15	33.1	28.1	0.01	0.00	0.01393	$-4.62e^{-4}$
0	15	33.8	27.8	0.01	0.00	0.01387	$-4.89e^{-4}$
0	15	34.3	26.7	0.01	0.00	0.01388	$-5.07e^{-4}$
0	15	34.9	25.9	0.01	0.00	0.01379	$-5.24e^{-4}$
0	15	30.8	32.8	0.01	0.00	0.01410	$-3.24e^{-4}$
0	15	29.2	41.7	0.01	0.00	0.01420	$-2.71e^{-4}$
0	15	28.7	42.3	0.01	0.00	0.01422	$-2.51e^{-4}$
0	15	27.8	45.3	0.01	0.00	0.01431	$-2.22e^{-4}$
0	15	31.9	30.9	0.01	0.00	0.01399	$-3.74e^{-4}$
0	15	31.4	29.6	0.01	0.00	0.01406	$-3.47e^{-4}$
0	15	31.4	32.5	0.01	0.00	0.01404	$-3.56e^{-4}$

Table 2: Experimental and Simulation Results at Angle of Attack 0° and 17 m/s

AOA (°)	Velo (m/s)	Temp. (°C)	RH (%)	Experimental Results		Simulation Results	
				FD	FL	FD	FL
0	17	31.2	29.2	0.02	0.00	0.02242	$1.88e^{-3}$
0	17	32.9	27.9	0.02	0.00	0.02222	$1.63e^{-3}$
0	17	33.4	27.0	0.02	0.00	0.02215	$1.59e^{-3}$
0	17	34	26.9	0.02	0.00	0.0220	$1.56e^{-3}$
0	17	34.3	26.2	0.02	0.00	0.0220	$1.55e^{-3}$
0	17	30.8	32.5	0.02	0.00	0.02246	$1.90e^{-3}$
0	17	29.4	40.8	0.02	0.00	0.0225	$1.98e^{-3}$
0	17	28.6	41.3	0.02	0.00	0.02269	$2.04e^{-3}$
0	17	27.6	44.6	0.02	0.00	0.02283	$2.12e^{-3}$
0	17	29.9	32	0.02	0.00	0.02256	$1.96e^{-3}$
0	17	30	30.5	0.02	0.00	0.02256	$1.96e^{-3}$
0	17	30.8	32	0.02	0.00	0.02246	$1.90e^{-3}$

Table 3: Experimental and Simulation Results at Angle of Attack 0° and 19 m/s

AOA (°)	Velo (m/s)	Temp (°C)	RH (%)	Experimental Results		Simulation Results	
				FD	FL	FD	FL
0	19	30.4	29.2	0.03	0.00	0.0341	$6.10e^{-3}$
0	19	32.4	27.8	0.03	0.00	0.03369	$5.84e^{-3}$
0	19	32.9	27.1	0.03	0.00	0.03359	$5.77e^{-3}$
0	19	33.1	26.9	0.03	0.00	0.03353	$5.73e^{-3}$
0	19	33.7	26.1	0.03	0.00	0.03344	$5.66e^{-3}$
0	19	30.2	32.2	0.03	0.00	0.03410	$6.10e^{-3}$
0	19	29	40.6	0.03	0.00	0.03430	$6.24e^{-3}$
0	19	28.4	41.7	0.03	0.00	0.03440	$6.31e^{-3}$
0	19	27.3	44	0.03	0.00	0.03461	$6.45e^{-3}$
0	19	29.9	32.2	0.03	0.00	0.03415	$6.14e^{-3}$
0	19	30.8	29.2	0.03	0.00	0.03400	$6.03e^{-3}$
0	19	30.5	31.8	0.03	0.00	0.03405	$6.06e^{-3}$

Table 4: Experimental and Simulation Results at Angle of Attack 5° and 15 m/s

AOA (°)	Velo (m/s)	Temp (°C)	RH (%)	Experimental Results		Simulation Results	
				FD	FL	FD	FL
5	15	33	30.2	0.01	0.12	0.01892	0.1217
5	15	33.6	28	0.01	0.12	0.01887	0.1213
5	15	34.2	27.6	0.01	0.12	0.01881	0.1209
5	15	34.8	26.2	0.01	0.12	0.01875	0.1204
5	15	35.1	25.3	0.01	0.12	0.01871	0.1204
5	15	31.2	33.4	0.01	0.12	0.01912	0.1202
5	15	29	34.6	0.01	0.12	0.01939	0.1234
5	15	28.2	35.4	0.01	0.12	0.01948	0.1255
5	15	27.3	39.2	0.01	0.12	0.01958	0.1262
5	15	31.4	28	0.01	0.12	0.01912	0.1269
5	15	32.2	30.1	0.01	0.12	0.01894	0.1234
5	15	32.8	32.3	0.01	0.12	0.01892	0.1221

Table 5: Experimental and Simulation Results at Angle of Attack 5° and 17 m/s

AOA (°)	Velo (m/s)	Temp. (°C)	RH (%)	Experimental Results		Simulation Results	
				FD	FL	FD	FL
5	17	32.8	30	0.03	0.2	0.0327	0.2214
5	17	33.3	29.2	0.03	0.2	0.0325	0.2198
5	17	34.2	28	0.03	0.2	0.0322	0.2174
5	17	34.8	28	0.03	0.19	0.032	0.2162
5	17	35.2	27.1	0.02	0.19	0.0317	0.2135
5	17	32.4	25.7	0.03	0.2	0.0327	0.2214
5	17	30.3	33.9	0.03	0.2	0.0325	0.2215
5	17	29.2	35.6	0.03	0.2	0.0325	0.2201
5	17	28.6	37.9	0.03	0.2	0.0324	0.2193
5	17	31.6	38.8	0.03	0.2	0.0327	0.2215
5	17	32.8	29	0.03	0.2	0.0326	0.221
5	17	33.3	30.2	0.02	0.19	0.0325	0.2195

Table 6: Experimental and Simulation Results at Angle of Attack 5° and 19 m/s

AOA (°)	Velo (m/s)	Temp. (°C)	RH (%)	Experimental Results		Simulation Results	
				FD	FL	FD	FL
5	19	32.8	27	0.04	0.33	0.0470	0.3254
5	19	33.3	26.2	0.04	0.33	0.0469	0.3247
5	19	33.8	25.7	0.04	0.33	0.0467	0.323
5	19	34.6	22.3	0.04	0.32	0.0465	0.3212
5	19	35	20.6	0.04	0.32	0.0464	0.3206
5	19	31	35	0.04	0.33	0.0473	0.3286
5	19	30.2	37.8	0.04	0.33	0.0476	0.3305
5	19	29.3	39.3	0.04	0.33	0.0479	0.3329
5	19	28.4	46	0.04	0.33	0.048	0.3341
5	19	30.2	27.6	0.04	0.33	0.0477	0.3317
5	19	30.8	28.3	0.04	0.33	0.0475	0.3299
5	19	31.4	30.4	0.04	0.33	0.0473	0.3286

Table 7: Experimental and Simulation Results at Angle of Attack 10° and 15 m/s

AOA (°)	Velo (m/s)	Temp. (°C)	RH (%)	Experimental Results		Simulation Results	
				FD	FL	FD	FL
10	15	32.4	25.7	0.04	0.2	0.03340	0.2317
10	15	32.8	27.8	0.04	0.2	0.03330	0.2309
10	15	33.0	27.2	0.04	0.2	0.03330	0.2309
10	15	33.5	27.1	0.04	0.2	0.03310	0.2300
10	15	34.2	26.3	0.04	0.2	0.03300	0.2288
10	15	31.7	28.7	0.04	0.28	0.03357	0.2331
10	15	30.9	30.4	0.04	0.28	0.03386	0.2354
10	15	31.1	30.3	0.04	0.29	0.03360	0.2340
10	15	30.9	31.1	0.04	0.28	0.03360	0.2340
10	15	31.4	29.2	0.04	0.28	0.03355	0.2336
10	15	31.7	27.8	0.04	0.29	0.03350	0.2331
10	15	31.9	28.3	0.04	0.29	0.03352	0.2327

Table 8: Experimental and Simulation Results at Angle of Attack 10° and 17 m/s

AOA (°)	Velo (m/s)	Temp. (°C)	RH (%)	Experimental Results		Simulation Results	
				FD	FL	FD	FL
10	17	32.2	26.3	0.05	0.4	0.05476	0.3876
10	17	33.1	27.6	0.05	0.4	0.0543	0.3848
10	17	33.8	27.2	0.05	0.4	0.05412	0.3827
10	17	34.1	26.7	0.05	0.39	0.05403	0.382
10	17	34.6	26.2	0.05	0.39	0.05384	0.3806
10	17	31.2	32.1	0.05	0.4	0.055	0.3899
10	17	30.6	35.4	0.05	0.4	0.0552	0.3913
10	17	29.8	37.3	0.05	0.4	0.05548	0.3934
10	17	29.1	42.4	0.05	0.4	0.05566	0.3948
10	17	30.8	27.9	0.05	0.4	0.05529	0.392
10	17	31.2	28.3	0.05	0.4	0.05511	0.3906
10	17	31.6	28.7	0.05	0.4	0.05492	0.3892

Table 9: Experimental and Simulation Results at Angle of Attack 10° and 19 m/s

AOA (°)	Velo (m/s)	Temp. (°C)	RH (%)	Experimental Results		Simulation Results	
				FD	FL	FD	FL
10	19	32.6	27.2	0.09	0.66	0.08451	0.608
10	19	32.8	27.8	0.09	0.66	0.08457	0.608
10	19	33.1	26.2	0.09	0.66	0.08422	0.6059
10	19	33.9	25.3	0.08	0.65	0.0838	0.6026
10	19	34.4	23.9	0.08	0.65	0.08366	0.6015
10	19	31.6	32.9	0.09	0.66	0.0849	0.6116
10	19	30.1	34	0.09	0.66	0.08576	0.6182
10	19	29.6	34.8	0.09	0.66	0.086	0.6204
10	19	29.1	35.2	0.09	0.66	0.0863	0.6226
10	19	31.2	28	0.09	0.66	0.0853	0.6149
10	19	31.9	29.1	0.09	0.65	0.0849	0.6116
10	19	32.4	30.2	0.09	0.65	0.0844	0.6083

At the inlet velocity is kept at 15 m/sec initially. Angle of attack kept at 0° and hence X component of velocity is 1 and Y component of velocity is 0.With the same angle of attack and velocity of air ,temperature and humidity changed and its effect on density is calculated as given by P. T. Tsilingiris and the value of density is taken in ANSYS fluent 15.0 setup for simulation. For each case same procedure is followed.

5. Results and Discussion

Extensive experiments are carried out for better accuracy with different parameters and then drag and lift forces are noted down.

CFD simulation is done with same parameter with each case of experimental parameters and results are noted down. It is observed that the maximum error occurred is about 16%

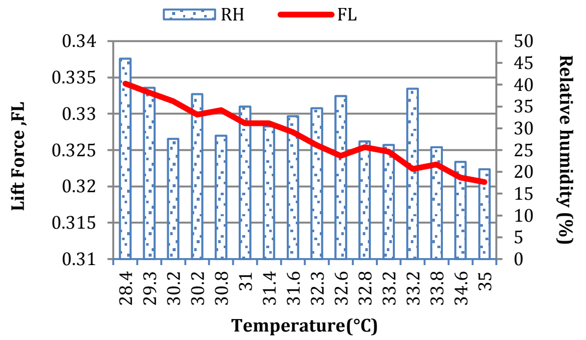
The error observed is may be due to the order of accuracy for experimental setup is only 2,further simulation model does not include manufacturing joints and inaccuracies due to fabrication in experimental setup. The average error observed is about 7% which is in the range of acceptance.

Results clearly indicates that with increase in speed by 2 m/s keeping same angle of attack on an average

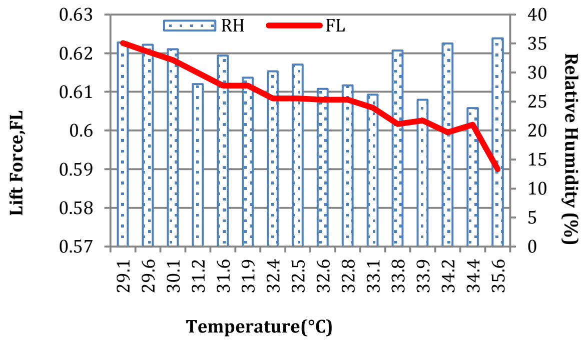
32% increase in lift forces are observed. Keeping same speed and increasing angle of attack by 5° a 42% increase in lift forces are observed.

Temperature also plays a crucial role in changing aerodynamic force. With slight change in temperature observable change in aerodynamic forces were observed.

Relative humidity also plays a role in changing aerodynamic forces but at high percentage values i.e above 50% and the effects are severe when increase in relative humidity and temperature simultaneously occur. Graph showing CFD obtained drag and lift forces is shown.



Graph 1: Graph of temperature vs Relative humidity and lift force at 19m/s and Angle of Attack 5°



Graph 2: Graph of temperature vs Relative humidity and lift force at 19m/s and Angle of Attack 10°

Conclusion

Lift forces observed at low speed i.e. 15m/s and 0° angle of attack are very less compared to 5° and 10° angle of attack. Negative lift observed at 0° angle of attack and 15 m/sec speed and this lift is increasing with increase in temperature. With increase in temperature drag forces observed at 0° angle of attack and 15m/sec to be decreased.

With slight increase in humidity aerodynamic forces i.e. lift and drag forces increases may be due to slight increase humidity will result in decrease in temperature and the effect of temperature are observed to be dominant over relative humidity on aerodynamic forces. Humidity effects on aerodynamic forces can be observed at higher value of percentage.

At same angle of attack if speed is increased aerodynamic forces are observed to be increased. At higher angle of attacks, both lift forces and drag forces are decreasing with increasing temperature.

A slight change in temperature will result in an observable change in aerodynamic forces but it is not the case with humidity. Severe effects are observed at hot and humid condition.

From the changing parameters considered in this study i.e. angle of attack ,air speed, temperature and humidity, it is observed that air speed and angle of attack are the most dominating factor on aerodynamic forces after that temperature and then humidity.

Regarding air properties considered over here high temperature high humidity after that hot condition and then humid condition will affect aerodynamic forces in a decreasing order of their severity.

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