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ORIGINAL ARTICLE

EXPERIMENTAL MEASUREMENT AND ANALYSIS OF SUPERCRITICAL AIRFOIL WAKE USING HOT WIRE ANEMOMETER IN 0.5 MACH

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ABSTRACT: This research has studied and measured developed wake in downstream of supercritical airfoil which belongs to wing of F5 war plane. These experiments were conducted by help of hot wire sensors and angles of attack -2, 0 and +2 and mach 0.5. All tests were carried out in supersonic wind tunnel in Qadr Center in Imam Hussein University. By analyzing results of 13 hot wires which were installed on a rick, width of back tail for supercritical airfoil was measured and recorded in distance 0.25 airfoil chord. Hot wires sensors are hot films and data gathering was conducted by frequency 5 kHz. Results of each probe were analyzed in frequency range and wake extent was calculated using them. Results analysis showed that because this airfoil is asymmetrical, wake of wing is pulled to one side by increasing angle of attack.

KEYWORDS: experimental measurement, supercritical airfoil, hot wire ammeter, F5 airplane, wake

INTRODUCTION

Study of compressible flow has great importance because of its wide use in various flying devices. Most flies of airplanes and war planes are done in compressible flow extent. For this reason, concept of supercritical airfoils that their design concept was optimal function in sound transition flow, in addition to acceptable performance in infrasonic flow has widely developed during 60s and 70s. Despite advantages like decreasing wave drag in sound transition and presence of stroke-wave free region in supercritical airfoils experimental and numerical results related to them in sound transition flow in present resources are lower than common airfoils.

Frank and John, (1982) in NASA in 1982 studied characteristics of compressible flow on airfoil by accurate experimental and numerical tests and calculated drag factor and pressure curves using these analyses and compared these values with numerical results.

Mateer *et al.*, (1992) conducted accurate measurements on a supercritical airfoil in different ranges of velocity and compressible state. Jaquin *et al.*, (2005) studied shock phenomenon on a supercritical airfoil that comparing its results with results of other airfoils showed its aerodynamic value of this airfoil. Gregry and Jung-Sheng, (2006) used imaging velocity of fluid particles in order to find flow characteristics on supercritical airfoil and showed that these imaging is consistent with other researchers' results.

Jons and Cagle, (2006) have conducted wide researches to obtain all details of this flow and airfoil. Swan Son *et al.*, (2006), using numerical studies and solving flow equations, could simulate this flow by writing numerical code which created a suitable space for comparing experimental and numerical data. Lee *et al.*, (2006) also wrote a separate code for this flow. Both of them used different turbulence models which caused comparison of two turbulences. Ghodarzi, (1998) measured wake of an airfoil using hot wire and showed that disturbing velocity of flow in upward and downward movement of airfoil is different.

Salari, (1998) studied wake of a symmetric airfoil wake experimentally using hot wire and flow disclosing in 1989. Their results showed that velocity profiles in sequences follows fluctuating form of foil except in angles that foil reaches static fatigue. Koochesfahani, (1989) studied circular vortexes in airfoil sequence. He calculated mean velocity in flow direction using laser speedometer. He studied relation of backward and forward forces with frequency and fluctuation ranges using obtained velocity distribution.

Purpose of this study is experimental measurement of dominate frequencies for vortexes and width of wake area in downstream of a supercritical airfoil using hot wire ammeter. One of innovations in this research is selecting applied airfoil which has chord thickness 10% chord for tests. These airfoils are cross-section of F5 war plane. Experimental measurement of

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wake in compressible flow by hot wire is not reported yet in Iran.

STATEMENT OF THE PROBLEM AND EXPERIMENTAL METHOD

2.1. Experimental data analysis

One of common methods for measuring wake area behind airfoils is measuring pressure behind airfoils or measuring velocity behind airfoil such that pressure or velocity sensors installed in wake region and outside of it and send changes in velocity and pressure to data gathering system and by analyzing this data we can measure wake area.

In this research which was conducted by hot wires to study disturbances in fluid velocity, development and analysis of these disturbances was done in frequency range. Analyzing disturbances in fluid velocity in frequency range expresses distribution of fluid velocity disturbances in relation with frequency. When disturbances in fluid velocity transform from time u(t) to frequency u(f) domain, $u^2(f)$ shows energy in band (f-Δf/2 ,f+Δf/2) where f is frequency and Δf is frequency change range.

Transforming fluid flow disturbances from range to frequency is possible by hardware and software methods. In this method, using data gathering software, flow velocity disturbances were transformed to digital form using A/D card and transferred to computer. Then using Fourier transformations, fluid velocity disturbances were transferred from time to frequency domain.

2.2. Geometry and model

Airfoil geometry has direct effect on area in different flow velocities. Airfoil which was considered for this study was supercritical airfoil which is known as SC0410 (Becker, 1980). Its thickness was 10% chord and was designed for sound transition flows. Figure (1) shows dimensionless profile of airfoil.

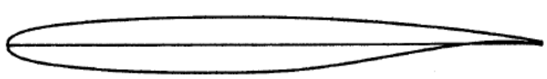

Figure1: view of geometry SC 0410 (Becker, 1980)

2.3. Wind tunnel

All experiments were conducted in wind tunnel in Qadr Aerodynamic Research Center in Imam Hussein University. This is a suction and open circuit tunnel and airflow was provided with two turbofan D30 engines with power 7000kw and suction with mass rate 125kg/s and D30ku with power 10000kw and suction with mass rate 125kg/s. Tunnel disturbance intensity in tunnel rest chamber was measured by hot wire sensors which was 0.5. Work section dimensions of tunnel are 150*60*60. Figure (2) shows schematic of tunnel.

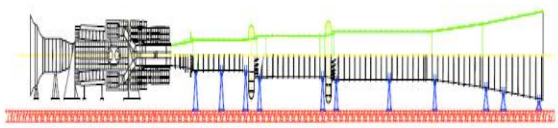

Figure2: schematic of Gadr wind tunnel

2.4. Hot wire anemometer sensors

Hot wire ammeter is one of most used equipments for measuring instant velocity in sensitive and accurate flows. Its performance is based on transferring convection from heated sensor to fluid flow. Its sensor is like hot wire or hot film which acts like electric resistance in whetstone bridge circuit. By changing transient fluid flow on sensor its heat transfer changes and as a result electric resistant changes. This change in resistance leads to instable Whetstone Bridge. For this, device should change high voltage of bridge to bring it back to balance condition. Required voltage for maintain sensor temperature (or electric resistance) is a direct criterion for measuring transient flow velocity in wire. Therefore, in order to measure instant velocities with high frequency and when quick response of measuring device is considered, we can use hot wire ammeter. Figure (3) shows performance of hot wire ammeter and different parts of data gathering chain.

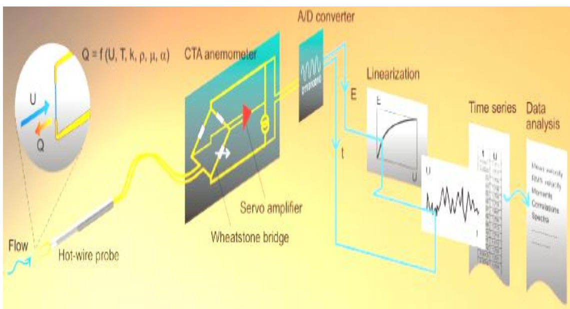

Figure 3: shows performance of hot wire

13 hot wire sensors which were installed on a rick were used in this study. These sensors are installed on rich according to figure (4). This rick is installed in tunnel such that its width distance from volatile edge of airfoil is 25% chord. Number of hot wire sensor is presented in table (1). As seen, sensor 8 is exactly placed along with volatile edge of airfoil (in zero angle of attack).

Table 1: Position sensors inside the tunnel

Vertical distance from the center of the tunnel	Number of sensors	Vertical distance from the center of the tunnel	Number of sensors
0.0	8	-4.9	1
0.7	9	-4.2	2
1.4	10	-3.5	3
2.1	11	-2.8	4
2.8	12	-2.1	5
3.5	13	-1.4	6
		-0.7	7

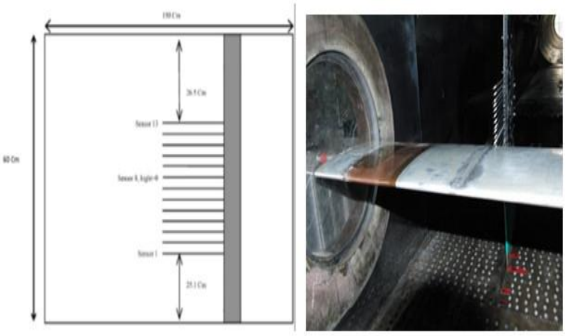

Figure 4: Schematic view of the situation and wings and sensors in test section

EXPERIMENTAL RESULTS

Because this study was only concerned with measuring wake extent in downstream and because calibrating sensors i.e. finding relationship between real velocities of flow with output voltage of hot wire ammeter in compressible flow is difficult and needs especial calibrator, this study only used voltage changes processing to find internal and external areas in wake. Output of all sensors is presented in frequency domain. Selected Mach number for flow relates to a condition that there is no vertical shock on airfoil. Sensors are arranged according to table 1. It is expected that highest disturbances range occurs in wake border because large eddies will be in edge of wake free jet. On the other hand, turbulence vortexes with high frequency and low range are located in center of wake; therefore, center of wake area and its border were considered for identifying size of wake.

3.1. Analysis results for Mach 0.5 and angle of attack -2 degrees

Figure (5) shows voltage-frequency graphs which are recorded by different sensors. Considering graphs in figure 5, figure 1 has similar behavior to results of free monotonous flow; therefore, they are out of airfoil wake extent. Sensor 2 is located in downward border of wake because it has high energy disturbances in certain range of frequencies. Sensors 3 to 11 are completely located inside wake. Sensor 12 is located on upper border of wake. For same reason, sensor 13 like sensor 1 is out of range. Sensor 8 is center of wake. In this case, wake has symmetrically distributed.

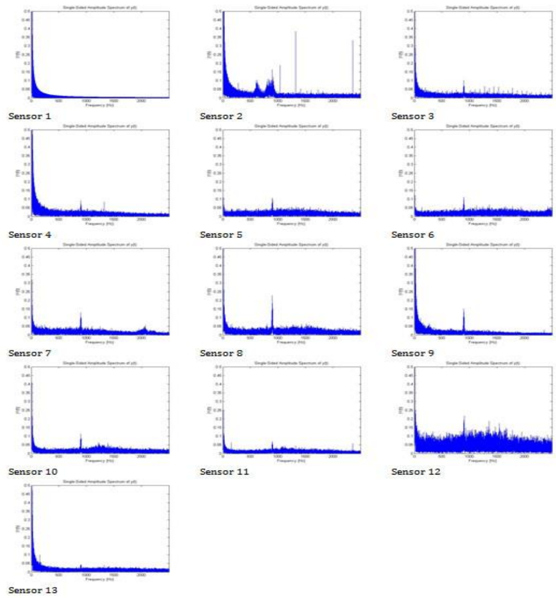

Figure 5: shows voltage-frequency graphs for Mach 0.5 and angle of attack -2 degrees

3.2. Analysis results in Mach 0.5 and angle of attack 0 degree

Figure (6) shows voltage-frequency graphs which were recorded with different sensors. Regarding graphs in figure 6, sensors 1 and 2 has similar behavior to free monotonous flow; therefore, it is out of airfoil wake. Sensor 3 is located in lower border of wake because it has high energy disturbances in certain range of frequencies. Sensors 4 to 12 are completely inside wake. Sensor 13 is located on upper borer. Sensor 8 is center. In this case, wake is asymmetrically distributed and wake distribution is higher in upper part.

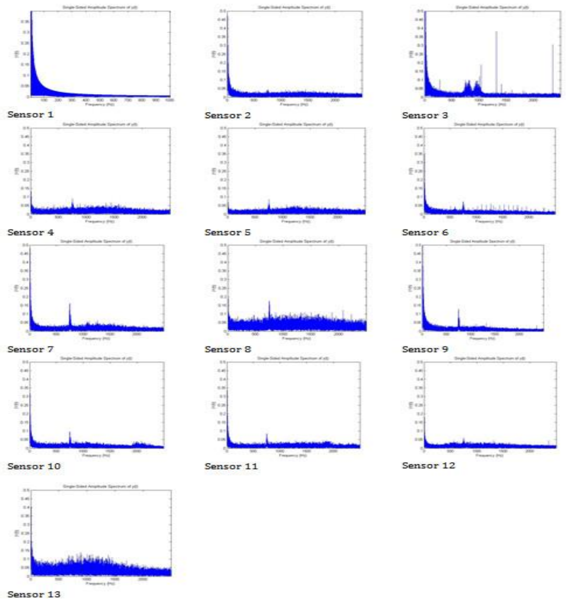

Figure 6: shows voltage-frequency graphs for Mach 0.5 and angle of attack 0 degrees

3.3. Analysis results in Mach 0.5 and angle of attack 2 degree

Figure (7) shows voltage-frequency graphs which were recorded with different sensors. Regarding graphs in figure 6, sensors 1 and 2 has similar behavior to free monotonous flow; therefore, it is out of airfoil wake. Sensor 3 is located in lower border of wake because it has high energy disturbances in certain range of frequencies. Sensors 4 to 12 are completely inside wake. Sensor 13 is located on upper borer. Sensor 9 is center. In this case, wake is asymmetrically distributed and wake distribution is higher in upper part.

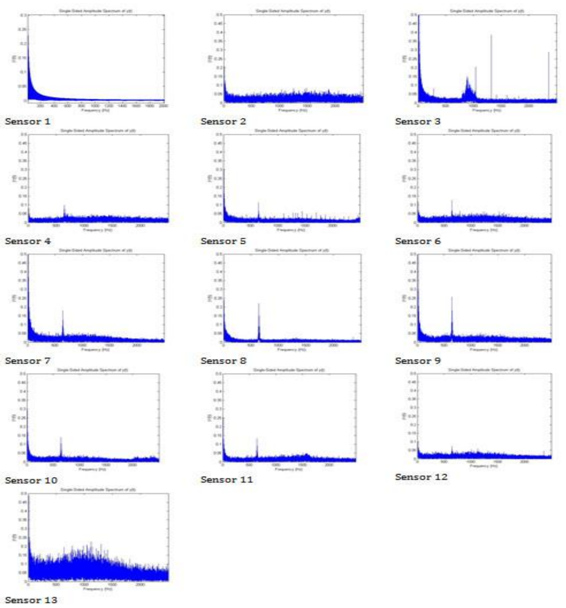

Figure 7: shows voltage-frequency graphs for Mach 0.5 and angle of attack 2 degrees

RESULTS ANALYSIS

By studying frequency range graphs in different angles we can draw these conclusions:

- By studying frequency range graphs we can find presence of wake behind airfoil in all angles such that by considering error in frequency range by 5% in each angle we can obtain size of wake based on table (2).

Table 2: wake width in different angle of attack

Sensor of center	Wake width (cm)	Angel of attack	Mach number	Number 0f test
8	5.6	-2	0.5	1
8	6.3	0	0.5	2
9	6.3	2	0.5	3

- U(f) increases in wake area in certain frequency and outside wake it approaches to zero and has no difference with neighbor frequencies regarding u(f).
- By studying changes in frequency range and wake in table (2) we can find that increasing angle in airfoil transfers wake upward and decreasing angle leads it downward.

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