MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

AIRCRAFT PERFORMANCE UNDER DOWNCOMING BURST HAZARD

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ABSTRACT

Wind tunnel simulation of the downcoming burst hazard, which is the most dangerous form of wind shear, is performed on an airplane model similar to the B-747. The performance of the airplane model is studied through its lift, drag and side forces along with the pitch, yaw and roll moments. The effect of the model sideslip angle was of particular emphasis in the study. The results substantiate that the lift was continuously depleted as the downcoming burst intensified. In order to maintain the same lifting force under increasing wind shear, the thrust should be increased. The sideslip angle did not demonstrate much influence on the lift and drag forces in the presence of wind shear. Meanwhile, the downcoming burst has been found to decrease the rolling moment induced by sideslip at low angles of attack only. For small sideslip, the downcoming burst contributes positive yaw at low angles of attack. Intensifying wind shear improves the stability margin while it displaces the equilibrium point towards negative lift values.

INTRODUCTION

According to the National Transportation Safety Board (NTSB) reports, there has been at least 32 aircraft accidents and incidents occured over the period 1964-86 in which wind shear was identified as a contributing factor. These accidents and incidents resulted in over 600 fatalities and 250 injuries. Weather condition of drastic changes in wind direction and/or speed is referred to as "wind shear". During extreme weather conditions dramatic shears might be produced at low flight levels. Wind shear is most severe at low altitudes when the aircraft are in approach for landing or during takeoff. In both situations the aircraft has relatively low speed and is therefore vulnerable to down-coming low altitude wind shear, also called downcoming burst. During most of these flight conditions, the aircraft may well be in turning flight mode and, at the same time, the burst flow might be inclined, thus adding sideslip effect to the motion of the aircraft.

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The most prominent meteorological factors which activate wind shear are thunderstorms and frontal systems near the airport. The mechanism for an aircraft entering the dangerous downburst region is as follows: as the downdraft approaches the ground, it turns 90° and becomes a strong horizontal wind flowing radially outward from the center. An aircraft entering this region will gain extra lift and an increase in the angle of attack at first, then suddenly tremendous drop in lift would occur. When the latter takes place, the aircraft would be very close to the ground and at a very slow speed, leaving no choice but to hit the ground nose down before the runway.

Research work done in this field comprises five fields: Meteorological measurements near the airport, wind shear sensors, wind tunnel measurements for the influence of wind shear on an aircraft model, analytical/numerical wind shear modeling for downdraft estimation, and finally actual testing of the performance of a full scale aircraft as it encounters wind shear physically.

Tragedies due to wind shear that the aviation world had been through were not simple. The situation dictated quick solutions as the problem was getting worse. Therefore most of the research was in the first two -of the five- fields defined earlier. The role of these two research and development areas are to enable early detection of downdrafts and, consequently, alert the pilot to "escape". Though many detection systems had been developed and incorporated in all todays commercial airliners, the work is going on to come-up with highly advanced sensors for the earliest possible detection of microburst.

Among the early wind shear detection/warning systems introduced in the market were by Sperry Corporation, Ref. [1], and Safe Flight Instrument Corporation, Ref. [2]. Such detection/warning devices were installed in the three main commercial airlines: Airbus, Ref. [3], McDonnell Douglas, Ref. [4], and Boeing, Ref. [5].

There had been an extensive program to monitor and record abrupt weather changes that might lead to wind shear. This project is referred to as the Joint Airport Weather Studies (JAWS) project, and it was carried out in many major airports in the US. Doppler radar were used to get the wind velocity distribution. Huge amount of data was collected, and its feasibility for early warning of wind shear was studied by McCarthy, Blick and Elmore [6]. Chang [7] investigated the dynamic response of aircraft to low level wind shear of the (JAWS) project. Nelles and Stanfenbiel [8] introduced a simple device to measure wind shear.

Extensive improvements are still taking place in the field of precise sensors to detect highly turbulent weather conditions, thus by revealing signs of low-level wind shear. Kessler [9] discussed the accuracy of telemetered anemometers and Doppler radar to help in alerting low-level wind shear at terminals. Campbell [10] presented an expert system being developed at MIT for Doppler weather radar interpretation of collected data. The approach followed was by capturing the expertise of a radar meteorologist in recognizing microburst hazard. Leitmann and Pandey [11] designed a feedback controller that works on climb rate information only. Its robustness was verified via simulations of four wind shear models. Peloubet, Haller and Bolding [12] demonstrated the performance of an adaptive flutter suppression system on a flutter model in a wind tunnel. A statistical approach to automate landing in turbulent weather conditions was proposed by Zhu [13]. Bird, Proctor and Bowles [14] investigated the wind shear hazard index, known as the F-factor, for application with look-ahead sensors. A relationship was developed for approximating the total F-factor using horizontal wind shear and altitude only.

Aly et al. [15] tested the effect of simulated wind shear on the lift, drag and pitching moment of a wing. The experiments, were performed in a wind tunnel using a three components balance. Considerable loss of lift was observed because of wind shear. The loss was decreased as the tunnel velocity increased. Using the same facility, Olwi et al. [16] investigated the effect of wind shear on an aircraft model. They concluded that if a pilot encounters wind shear he should increase the angle of attack and apply more thrust.

The effect of wind shear on the pressure distribution of a 2-D wings was studied by Al-Bahi et al [17]. The airfoils used were NACA 0018 and 0012. Though both models suffered drops in the favourable pressure difference (i.e. drop in lift), the NACA 0012 airfoil performed better than the 0018 airfoil in terms of favourable pressure distribution.

In this paper, we present an experimental investigation of an airplane model subjected to downcoming burst simulated in a wind tunnel. The corresponding forces and moments acting on the model are reported. Parameters of investigation include downburst velocity and model sideslip angle and angle of attack.

TEST FACILITY AND INSTRUMENTS

The investigation was carried out in an open type low speed wind tunnel. The downburst was simulated by external air supply from two compressors of 6 kW each. the downflow was supplied to the tunnel test section through an opening at the upper wall of the test section in such a way that the test model was right at the middle of the downcoming flow. A setting chamber was installed in the external air supply system to ensure uniformity of the air supplied from the two compressors. The test model is an airplane similar to the Boeing 747. It had 0.586 m of length, 0.505 m of span, 0.2 m of mean aerodynamic chord, and 0.0406 m^2 of wing area. The aircraft model was mounted on a six component sting balance (Fig. 1) to measure the three force components and three moment components. The tests were done for a free stream velocity of 20 m/s. Downflow supplied from the compressor-duct system was varied such that the downward velocity to tunnel free stream velocity ratio (V/U) assumed the following values: 0.1, 0.2, 0.3, 0.4 and 0.545.

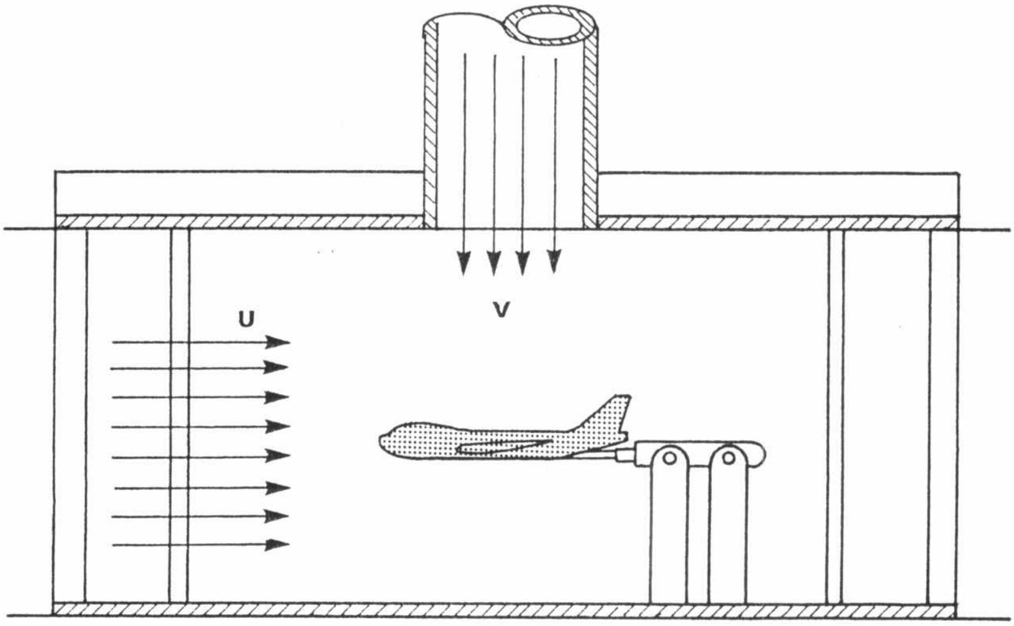


Fig. 1. The test model under downcoming burst.

RESULTS AND DISCUSSION

The aerodynamic forces and moments are recorded at different wind shear/free stream velocity ratios, V/U, where V is the simulated downburst velocity and U is the free stream wind tunnel velocity. These forces and moments are measured at different angles of attack and sideslip angles.

Lift Measurements

The most important finding of this investigation lies in the set of lift measurements. Figure 2 displays the variation of lift coefficient , C_L, against the angle of attack, α, at zero sideslip angle, β, and different wind shear/free stream velocity ratios. Drastic loss of lift is observed in this figure as a consequence of the downcoming burst. This hazard can reverse the lift to become a downward force at low angles of attack. As a result, the zero lift angle is displaced to have positive values during severe wind shear conditions. In addition, the slope of C_L-α curves increases as V/U increases for angles of attack that are higher than the zero lift angles.

The lift coefficient is plotted versus the wind shear/free stream velocity ratio for different angles of attack at zero sideslip angle in Fig. 3. It is noticed that for moderate angles of attack, the rate of lift reduction is lower than that taking place at low angles of attack under small wind shear ratios. Under high wind shear, the lift reduction is homogeneous over this range of angles of

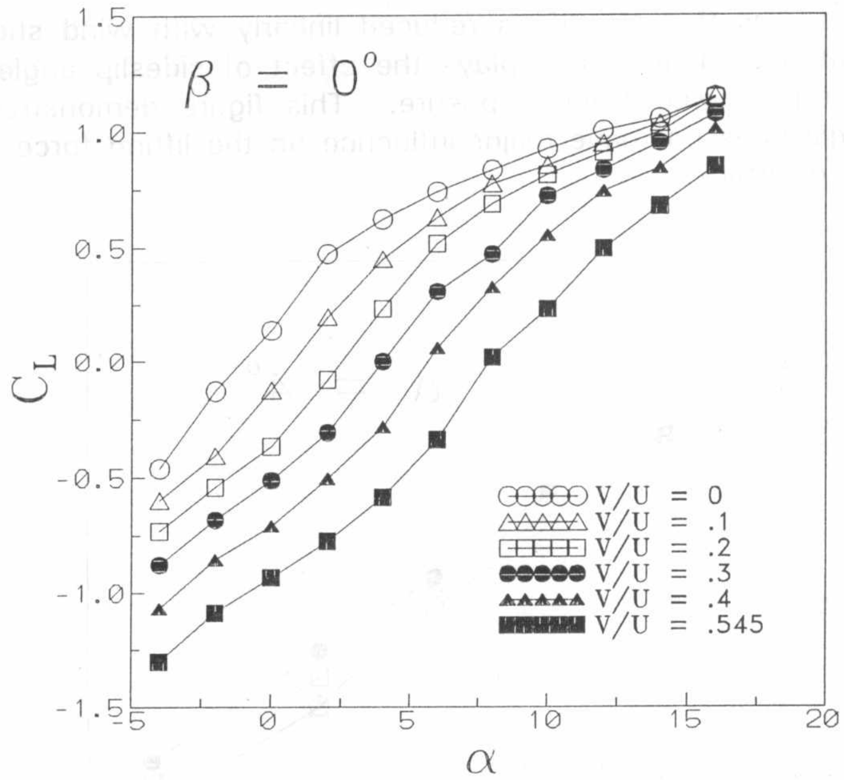


Fig. 2. Lift depletion under downcoming burst.

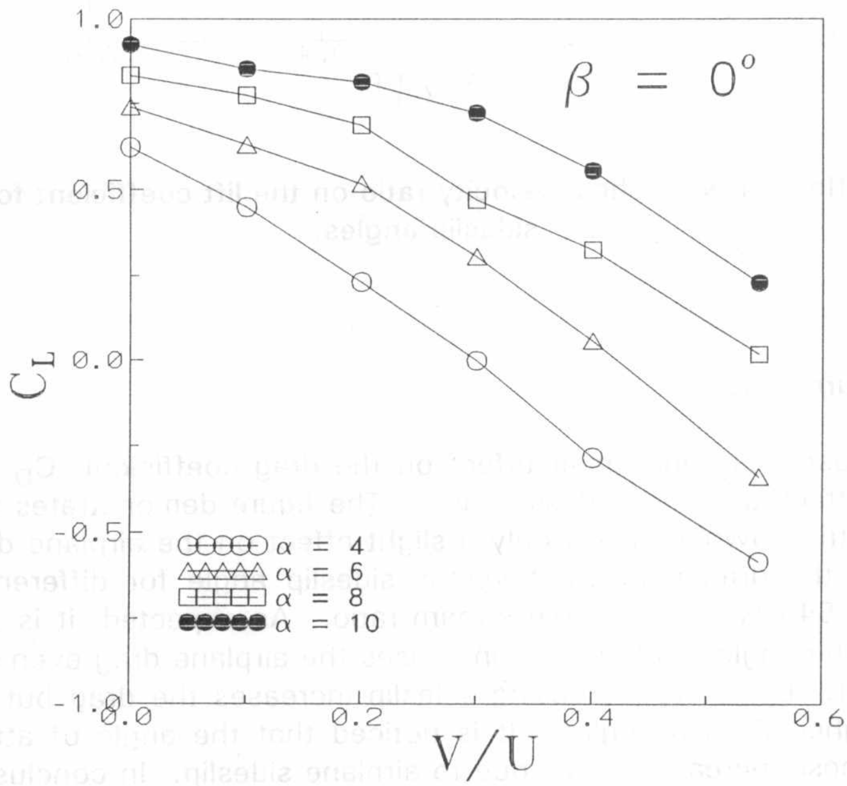


Fig. 3. Effect of wind shear velocity ratio on the lift coefficient at no sideslip.

attack. It seems that the lift is reduced linearly with wind shear for small angles of attack. Figure 4 displays the effect of sideslip angle, on the lift coefficient under wind shear exposure. This figure demonstrates that the sideslip angle does not have major influence on the lifting force at small and high angles of attack.

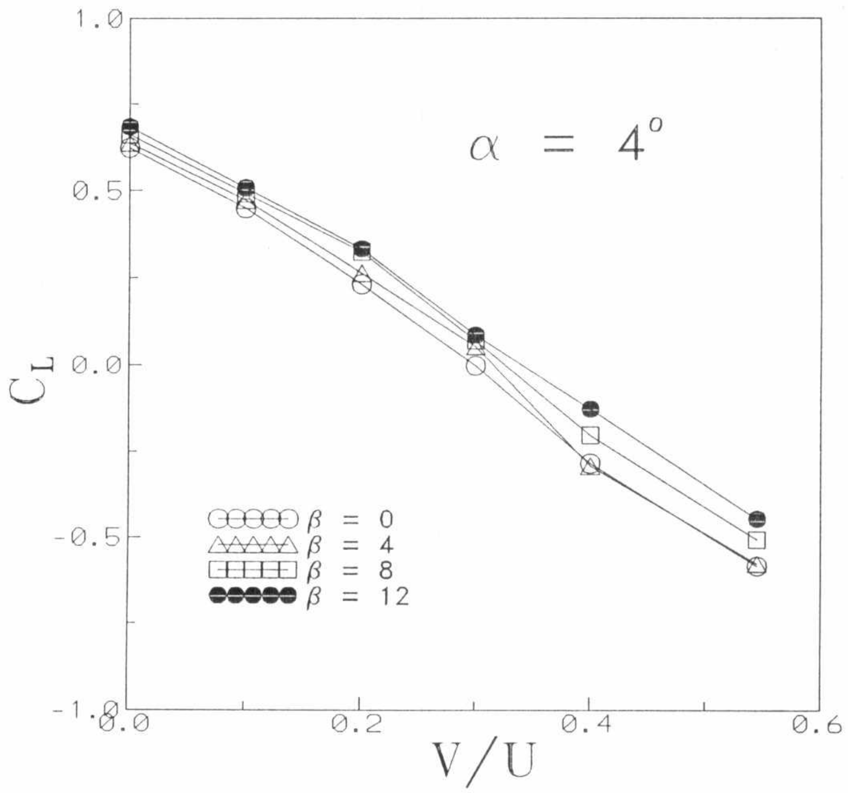


Fig. 4. Effect of wind shear velocity ratio on the lift coefficient for various sideslip angles.

Drag Measurements

Figure 5 illustrates wind shear effect on the drag coefficient, C_D, at different angles of attack and zero sideslip angle. The figure demonstrates that for V/U up to 0.5, the downburst has only a slight effect on the airplane drag. Figure 6 presents the drag coefficient versus sideslip angle for different angles of attack at 0.545 wind shear/free stream ratio. As expected, it is noticed that increasing the angle of attack the increases the airplane drag even during wind shear effect. Likewise, increasing sideslip increases the drag but at a higher rate for higher sideslip angles. It is noticed that the angle of attack has no effect on these increasing rates due to airplane sideslip. In conclusion, Figs. 5 and 6 reveal that wind shear has a slight effect on the drag performance (up to $\alpha = 10^o$) and small sideslip angles.

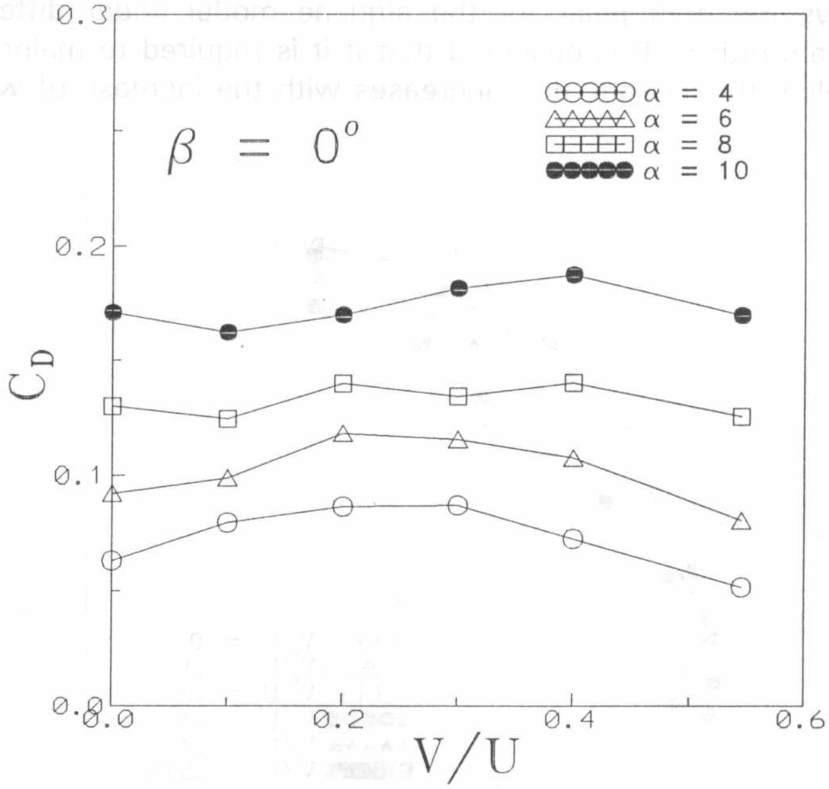


Fig. 5. The drag coefficient at no sideslip.

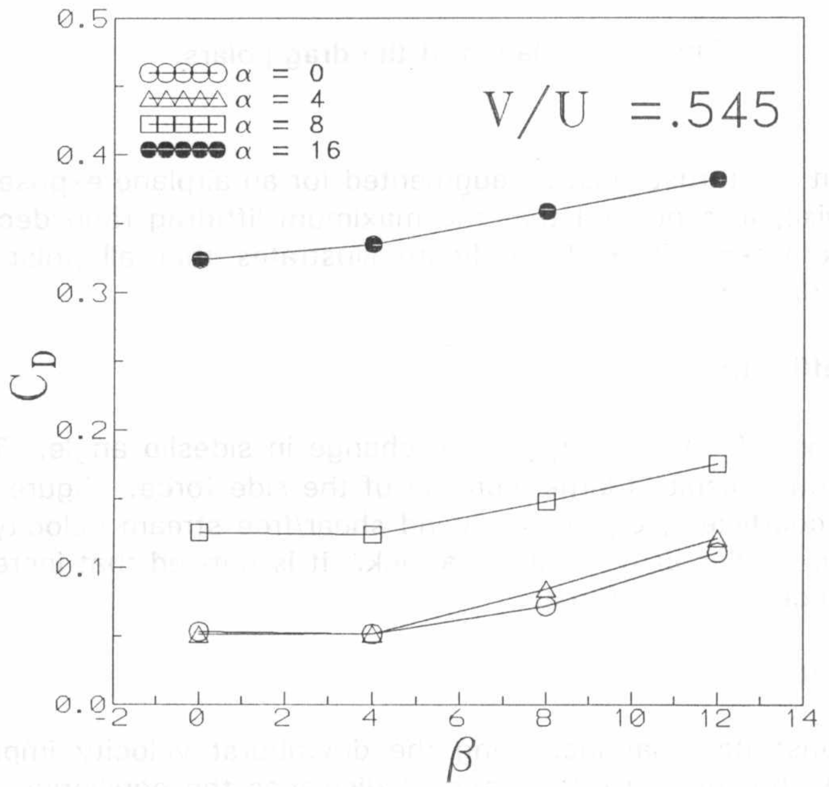


Fig. 6. Variation of the drag coefficient with sideslip under high wind shear.

Figure 7 shows the drag polar for the airplane model under different wind shear/free stream ratios. It is observed that if it is required to maintain the lift at a certain value, the airplane drag increases with the increase of wind shear.

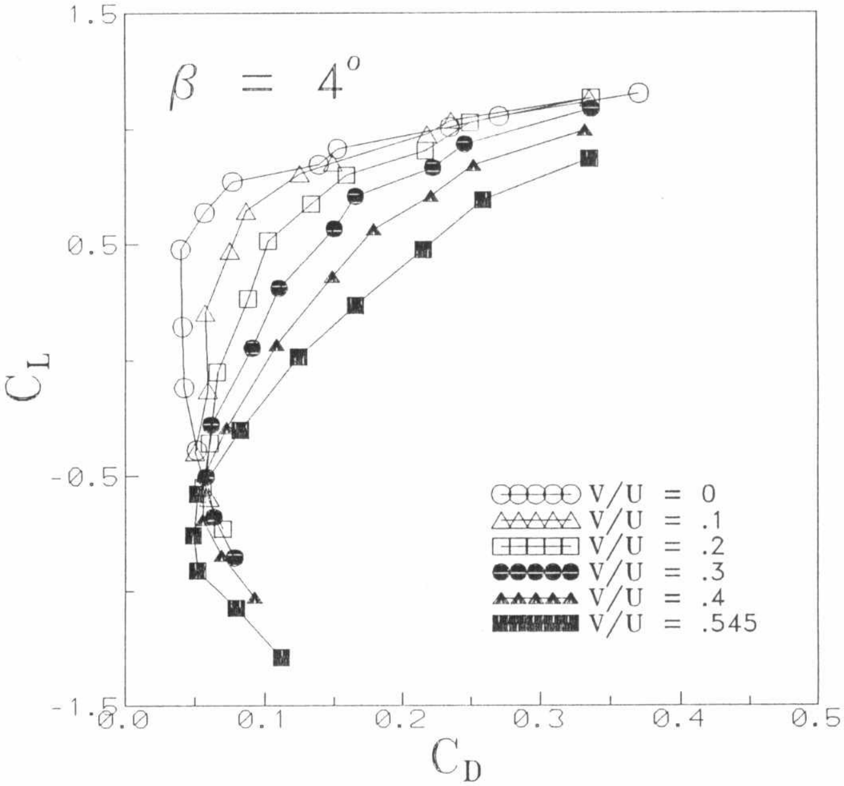


Fig. 7. Variation of the drag polars.

This means that the thrust must be augmented for an airplane exposed to wind shear. Likewise, it is noticed that the maximum lift/drag ratio decreases as wind shear increases. The above figure illustrates that all polar diagrams intercept at a unified point.

Side Force Coefficient

The side force is affected mainly by the change in sideslip angle. Therefore, increasing β would result in large increase of the side force. Figure 8 depicts the side force coefficient, C_S, versus wind shear/free stream velocity ratio for different sideslip angles at 6° angle of attack. It is noticed that increasing the wind shear reduces the side force.

Pitching Moment

Figure 9 demonstrates that increasing the downburst velocity improves the aircraft stability, but on the other hand, it displaces the equilibrium condition towards negative lift values. It means that the aircraft must be equipped with

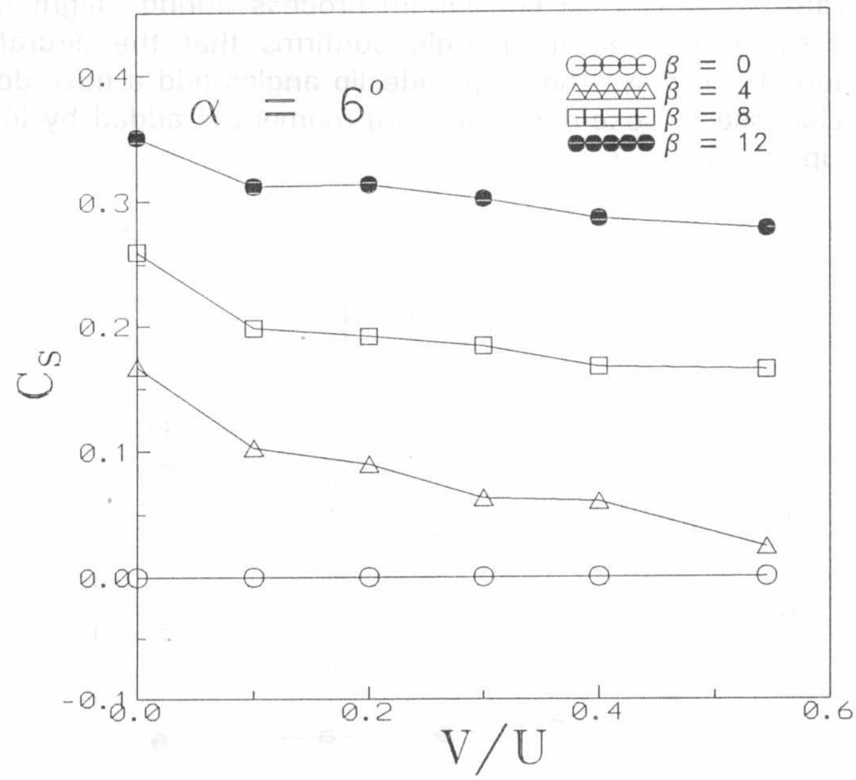


Fig. 8. Contribution of wind shear and sideslip on the side force coefficient.

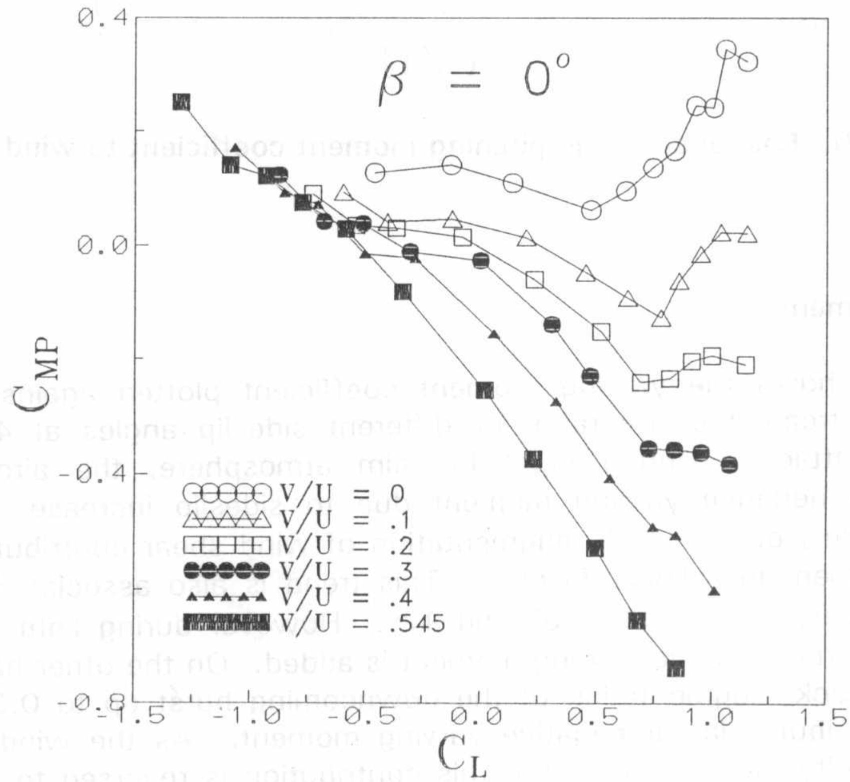


Fig. 9. Longitudinal stability under downcoming burst.

a large elevator to satisfy he equilibrium process during flight under strong wind shear, since the stability margin confirms that the aircraft is always stable. Figure 10 displays that high sideslip angles add a nose-down pitching moment. Likewise, a nose-down pitching moment is added by increasing the wind shear up to V/U=0.2.

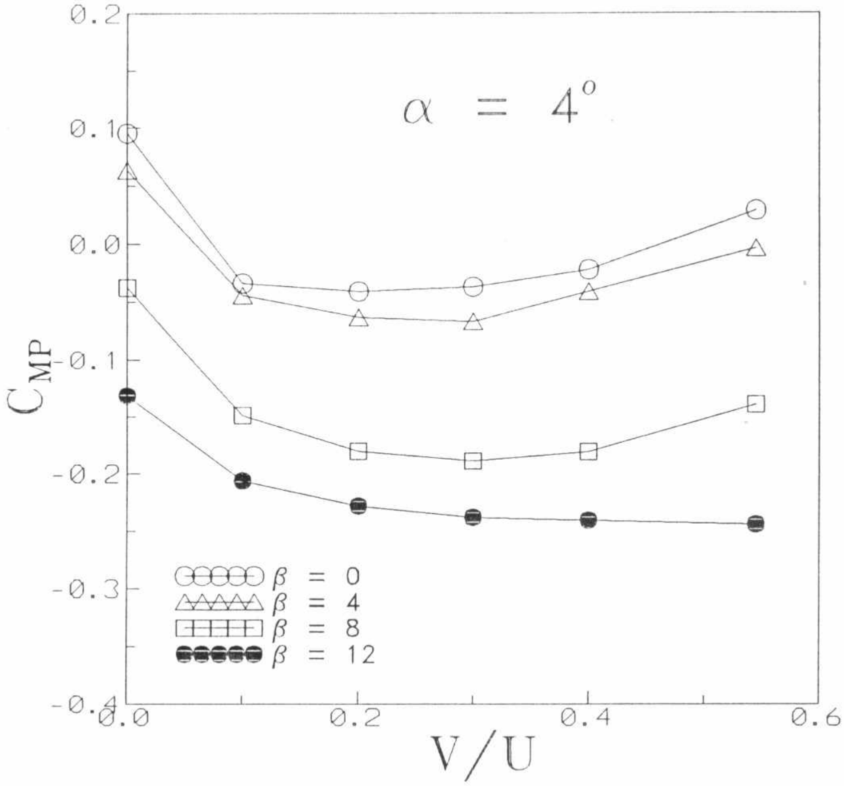
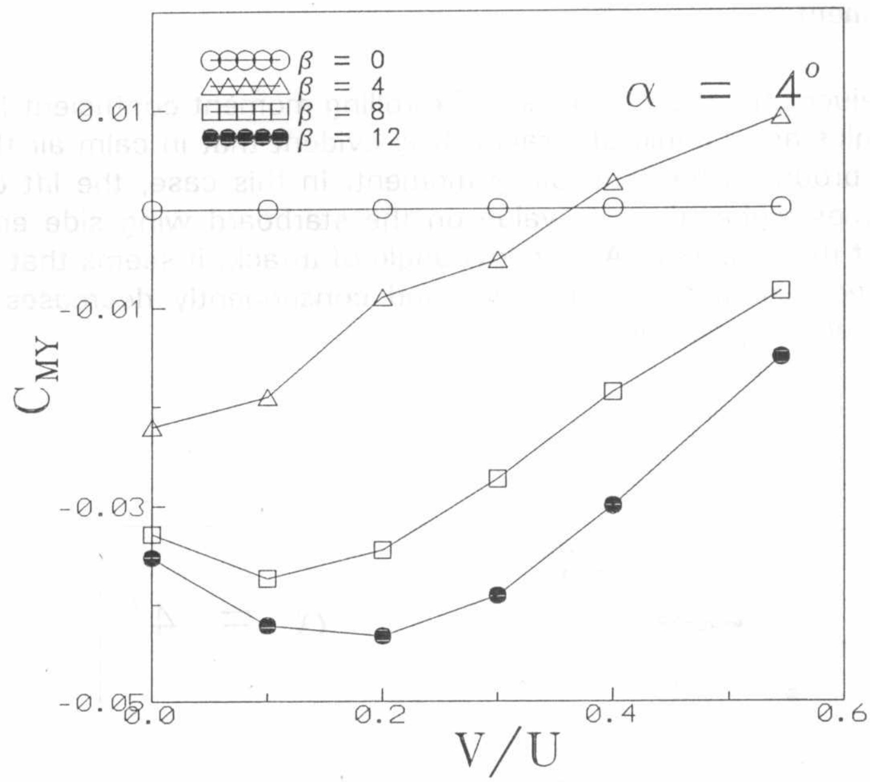


Fig. 10. Response of the pitching moment coefficient to wind shear.

Yawing Moment

Figure 11 shows the yawing moment coefficient plotted against the wind shear/free stream velocity ratio for different sideslip angles at 4° and 16° angles of attack. During flight in calm atmosphere, the aircraft model experiences negative yawing moment due to sideslip increase. For small sideslip angle , e.g. β = 4°, augmentation of wind shear contributes positive yawing moment in a linear fashion. This trend is also associated with high sideslip angles, such as β = 8° and 12°. However during light wind shear conditions, little negative yawing moment is added. On the other hand, at 16° angle of attack, augmentation of the downcoming burst up to 0.25 the free stream contributes larger negative yawing moment. As the wind shear/free stream velocity ratio exceeds 0.5, this contribution is reversed to be positive yawing moment.



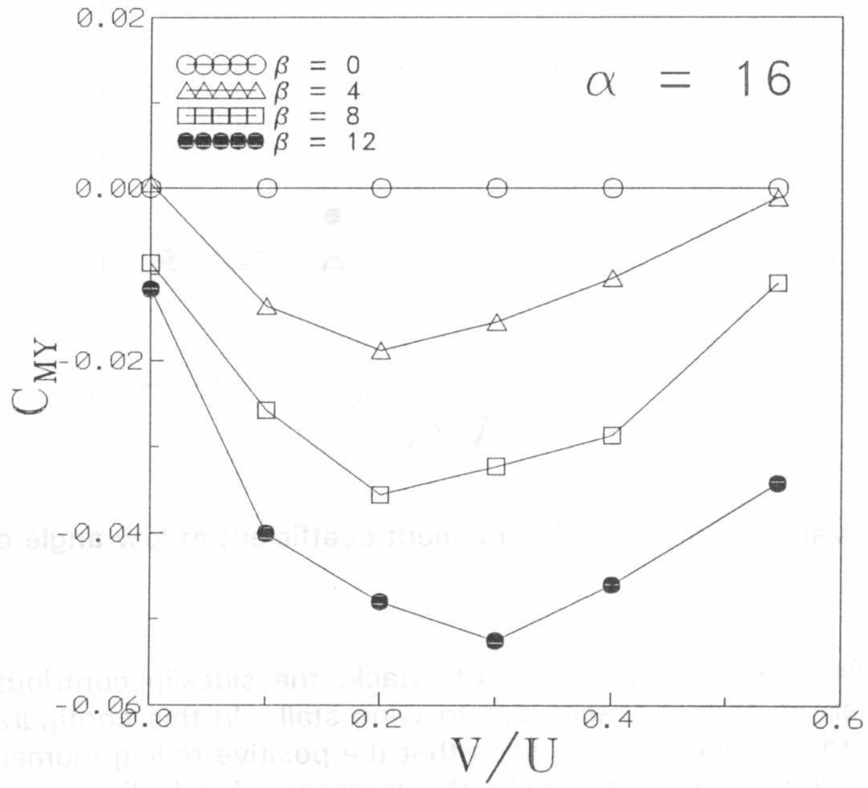


Fig. 11. Contribution of wind shear and sideslip on the yawing moment coefficient at low and high angles of attack.

Rolling Moment

Figure 12 elucidates the variations of the rolling moment coefficient for different sideslip angles at 4° angle of attack. It is evident that in calm air the increase of sideslip produces positive rolling moment. In this case, the lift on the port wing becomes higher than its value on the starboard wing side embedded in the wake of the fuselage. At this low angle of attack, it seems that wind shear tends to decrease this lift difference and consequently decreases the rolling moment induced by sideslip.

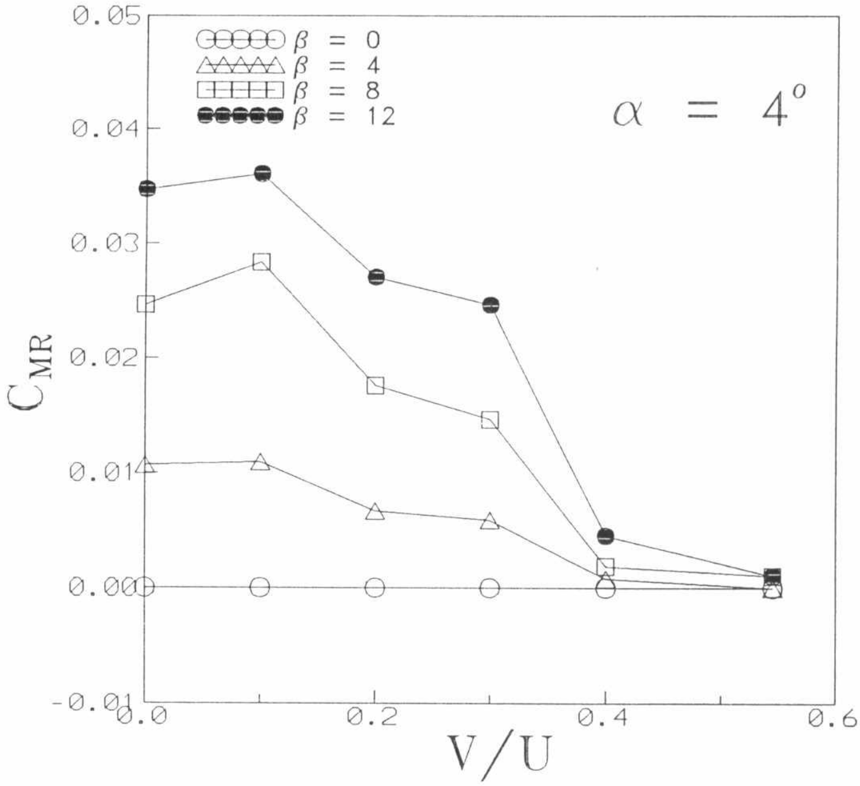


Fig. 12. Variation of the rolling moment coefficient at low angle of attack.

On the other hand, at high angles of attack, the sideslip contribution to the rolling moment is almost absent due to wing stall. In this configuration, wind shear tends to reattach the flow such that the positive rolling moment appears. This rolling moment increases with the increase of sideslip and wind shear velocity ratio as shown in Fig. 13.

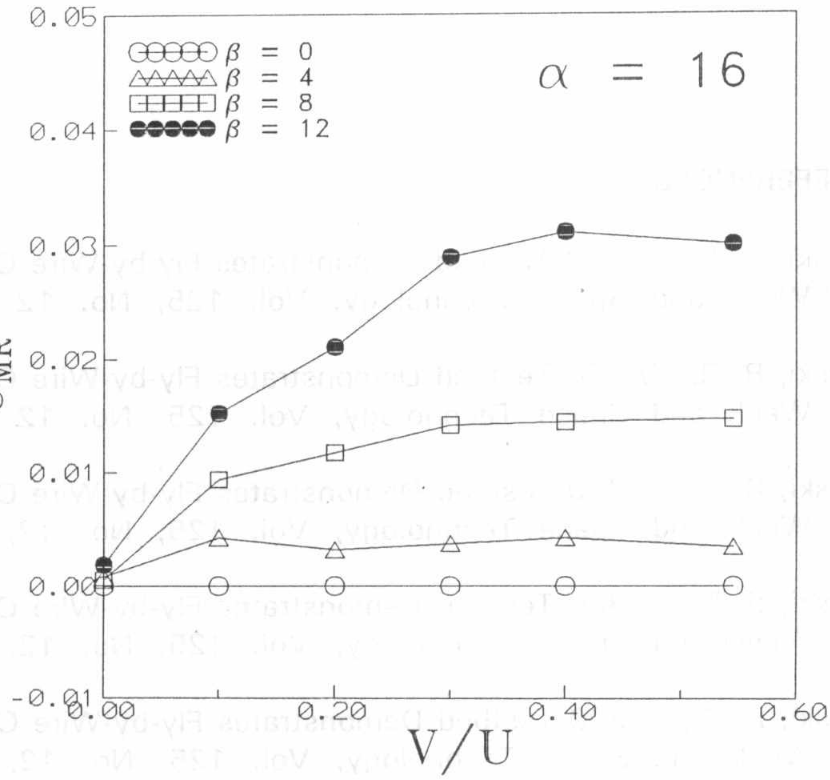


Fig. 13. Variation of the rolling moment coefficient at high angle of attack.

CONCLUDING REMARKS

Performance of an aircraft with/out sideslip subjected to downcoming burst is experimentally investigated. Under the effect of downcoming burst, the aircraft suffers great loss of lift to become a downward force at low angles of attack. The sideslip angle did not portray major influence on the lifting force. If it is desired to maintain the lift at a certain magnitude, the airplane drag would increase with the increase of wind shear. This means that the thrust must be augmented for an airplane exposed to wind shear. The downcoming burst has been found to reduce the side force. Severe downcoming burst flow improves the aircraft stability. But it displaces the equilibrium condition towards negative lift values. Therefore, the aircraft must be equipped with a large elevator to satisfy the equilibrium process during flight under strong wind shears. During flight in calm atmosphere, the aircraft model experiences negative rolling moment due to sideslip increase. Meanwhile, augmentation of wind shear contributes positive yawing moment in a linear fashion. At low angles of attack, wind shear decreases the roll induced by sideslip. However, at high angles of attack, the rolling moment increases with increasing sideslip and wind shear velocity ratio.

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