MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

EXPERIMENTAL INVESTIGATION OF AERODYNAMIC CHARACTERISTICS OF AIRFOILS WITH SPOILERS

S.F.Aly * M.H.Katary ** M.E.Essawy *** O.E.Abd ElHamid ****

ABSTRACT

An experimental study on airfoils with spoilers is performed. The study was carried out by testing of a two dimensional model in the Military Technical College low speed wind tunnel. At Reynolds numbers of approximately $5.3 * 10^5$, steady pressure distributions and force measurements were conducted. The study predicted effects of spoiler location, dimensions, and setting angles on lift, drag, pitching moment coefficients, centre of pressure and aerodynamic centre in a wide range of angles of attack. Obtained experimental results were compared with results of two theoretical methods based on linearized potential flow theory (LPT), and wake source model for airfoils with separated flow (WSM), respectively. The study helped in clarifying the flow nature of the airfoil spoiler combination, understanding effects of spoiler on airfoil aerodynamic characteristics, and checking the relevant computational codes.

INTRODUCTION

Spoilers are plates located spanwise on the upper surface of the wing. They are used to "spoil" the flow around the wing section, and to modify overall wing loads. When deflected symmetrically they act as speed brakes, or as lift dumpers, and when deflected asymmetrically they provide an effective roll control. Spoilers are also used as an effective means for producing rapid lift variations required by gust alleviation, or turbulence reduction systems [1]. Over the years, testing and development of particular airfoil spoiler configurations has produced performance data for spoiler design. Yet, knowledge of the fundamentals of the aerodynamics of spoilers are by no means complete. The difficulty comes from the complex nature of the airfoil with spoiler flow field. As the flow separates at the spoiler tip and the airfoil trailing edge, it forms a large bubble downstream of the trailing edge. This separated flow affects the velocity and pressure distributions, and promotes earlier separation at the upstream side of the spoiler airfoil

* Lecturer Assistant, Department of Aeronautics, M.T.C.
** Assistant Professor, Department of Aeronautics, M.T.C.
*** Assistant Professor, Department of Mechanics, B.H.I.T.
**** Professor, Department of Aeronautics, M.T.C.

joint. In fact, separated shear layers and vorticity shed into the wake induce a highly turbulent region behind the spoiler and make the problem far more difficult [2]. The present investigation is undertaken to enhance the basic understanding of the airfoil spoiler combination aerodynamics, to conduct an experimental parametric study of effects of different spoiler settings, and to test the validity of suitable mathematical models.

EXPERIMENTATION AND MEASURING SETUP

Measured model is an untwisted rectangular wing formed by NACA 64A012 airfoil (Fig.1). Spoilers of two different heights 6%c and 10%c are located on the wing upper surface at 10%c, 30%c and 75%c with three different angles of setting. An insertion piece for pressure distribution measurements is arranged confining 22 orifices of 0.8 mm diameter. Wing and spoiler fittings are produced from duraluminium alloy. Spoilers and wing mountings are produced from steel, while for pressure insert brass is used. Wing model is connected to aerodynamic balance by means of two struts and a rear wire, with axis of rotation of the model at mid chord position. Spoilers are fixed to wing surface by fittings regularly distributed spanwise. Three different sets of these fittings were used for the spoiler setting angles 30°,60°,and 90°.

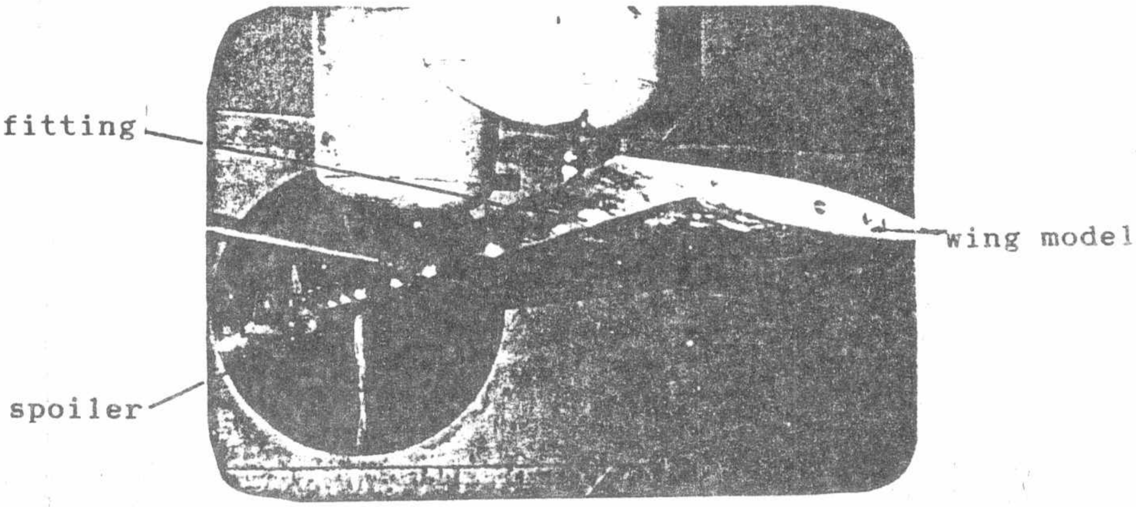


Fig.1. Wing model with spoiler in wind tunnel test section.

The model is tested in the Military Technical Collage low speed wind tunnel. The tunnel has a closed test section of rectangular shape (1.5 m x 1.15 m x 3.0 m) with tapered corners. Quality of flow at the test section was checked through velocity profile and turbulence level measurements. These measurements provided that this wind tunnel has a good and acceptable flow characteristics (turbulent factor $\tau = 1.132$, maximum velocity deviation is smaller than 0.45%). The tunnel has a highly accurate six-component electromechanical balance.
Model is tested at constant speed of airstream 40 m/s which is corresponding to a Reynolds number $5.3 * 10^5$ approximately. Tests

are elaborated in a wide range of angles of attack covering both pre and post-stall regions. Pressure distribution, lift, drag, and pitching moment were measured for the following cases:

1) Clean configuration.
2) Spoiler of hight 6%c positioned at 10 , 35 ,and 75 %c with angles of setting 30°, 60°, 90°.
3) Spoiler of hight 10%c positioned at 10 , 35 ,and 75 %c with angles of setting 30°, 60°, 90°.

where c is the airfoil chord length.

RESULTS AND ANALYSIS

Steady state pressure distributions on upper and lower wing surfaces are shown (Fig.2) for angle of attack $\alpha=3°$as an example. From the figure it is seen that downstream of the spoiler a constant low pressure cavity is generated. Upstream of the spoiler the suction on the upper airfoil surface decreases. The suction in

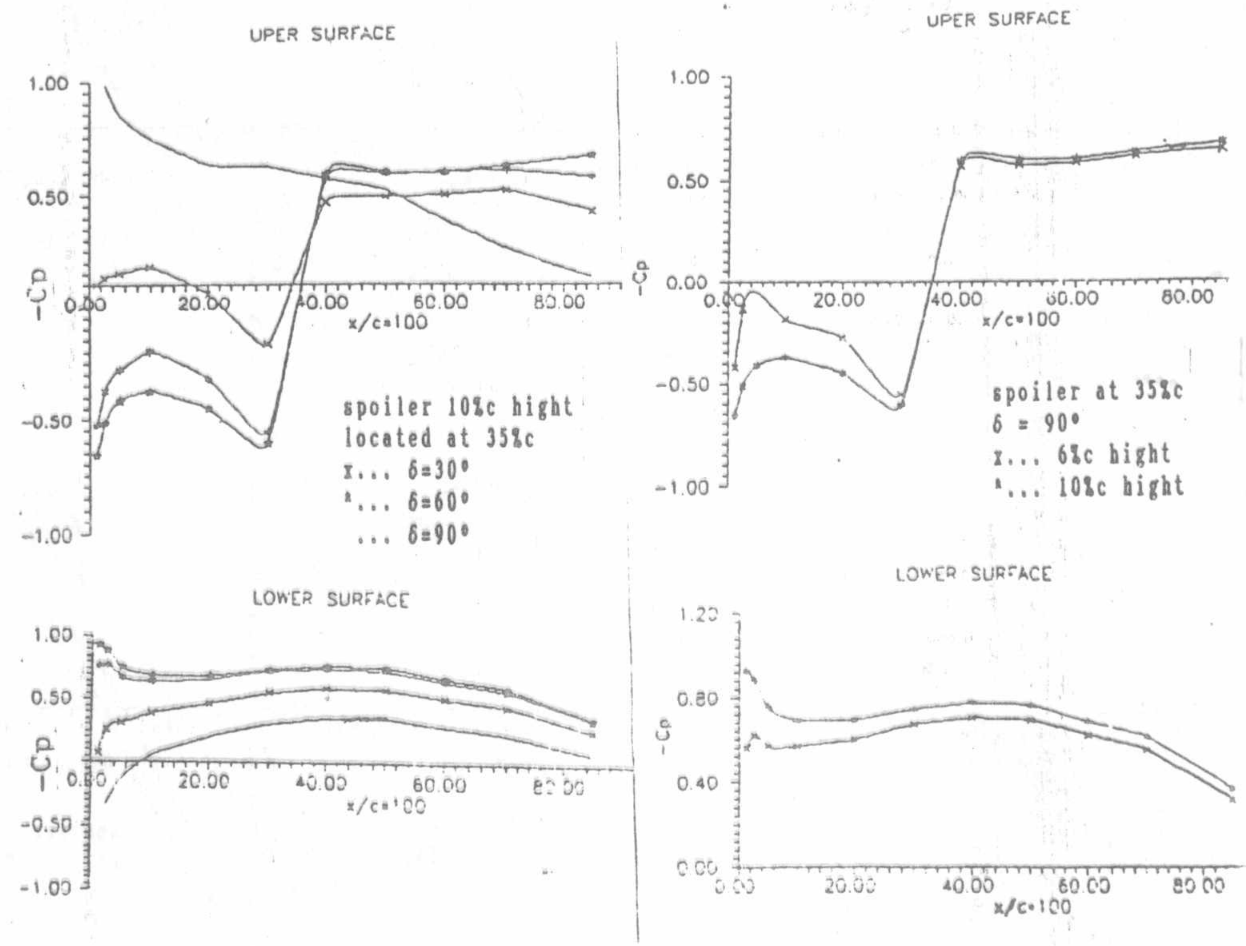


Fig.2. Pressure distribution on upper and lower surfaces of the airfoil with spoiler at angle of attack $\alpha=3°$.

the separated region aft of spoiler, through the trailing edge condition (Kutta condition), reduces the lower surface pressure. Usually the loss of suction and pressure on the upper and lower surfaces is greater than the gain of suction behind the spoiler, which makes the lift coefficient to decrease with spoiler erection. As the spoiler deflection angle or spoiler hight increases, the loss of suction on the upper surface increases (back pressure from spoiler increases), and the loss of pressure on the lower surface also increases (increase of suction in the cavity). As a result, a decrease in lift coefficient (c_y) is be expected. An increase in drag coefficient (c_x) is also expected as the pressure downstream of the spoiler is smaller than the pressure upstream of it, and the difference increases with increasing spoiler hight and deflection angle.

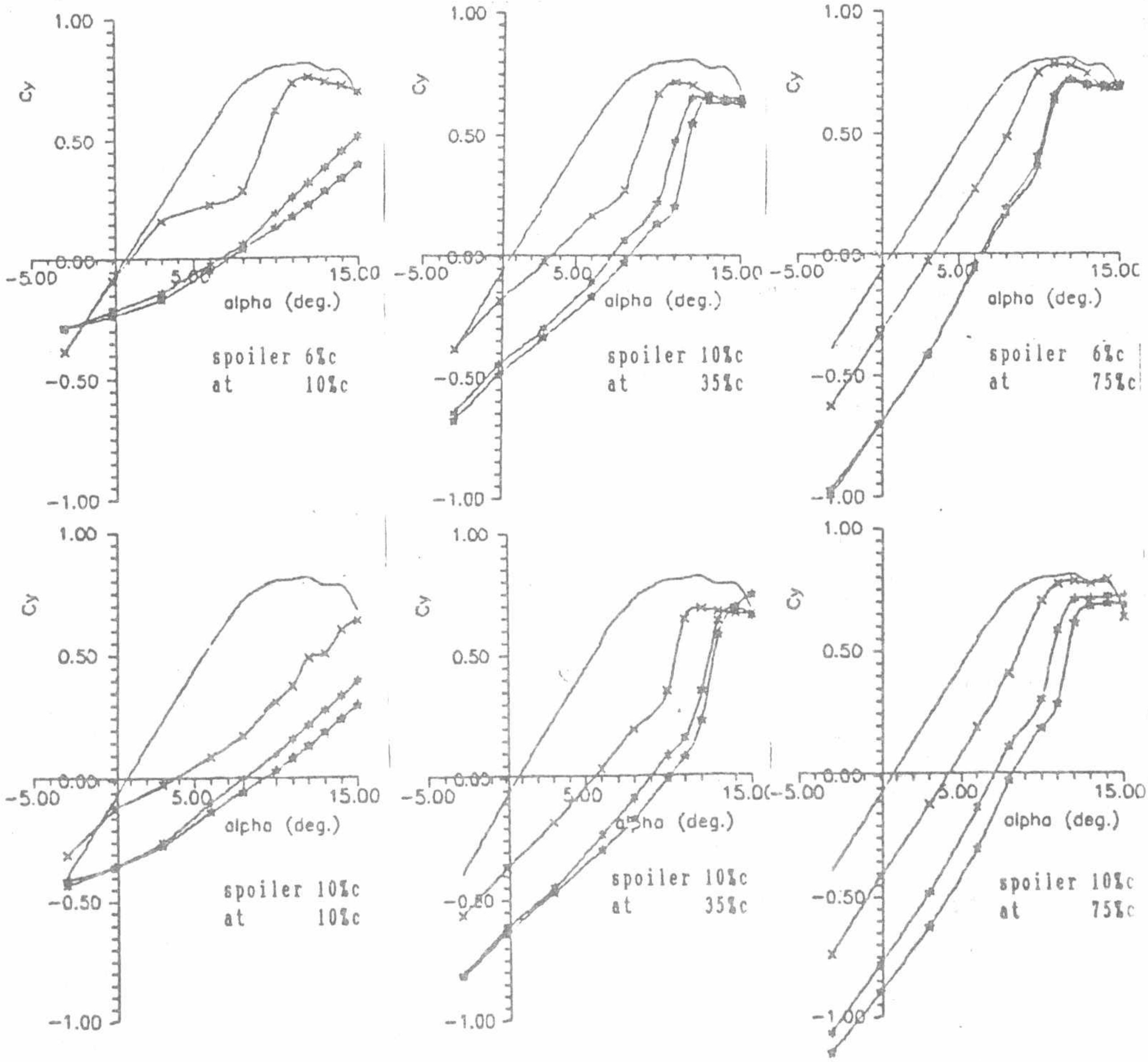


Fig.3. Measured lift curves for different configurations, clean, x... δ=30°, •... δ=60°, and •... δ=90°.

The slope of lift curve of airfoil with spoiler (Fig.3) was found to be smaller than that of the clean configuration. This effect is recognizable when the spoiler is in the front position. The slope increases as the spoiler moves downstream till it approaches that of clean configuration when the spoiler is at the rear position. The linearity of the curve deteriorates with the presence of spoiler. The curve is totally nonlinear when the spoiler is at the front position, but the linearity improves as the spoiler moves downstream. This behaviour can be related to the nonlinear character of the cavity flow which is dominant when the spoiler is placed at the front position, and decreases as the spoiler moves downstream. On the other hand, the effect of spoiler angle and hight on the linearity and slope was found to be very week. The critical angle of attack α_{cr} increases as a result of presence of spoiler. This may be related to the ability of spoiler to work as a vortex generator at high angles of attack, which delays the stall and flattens the lift curve. Large critical angles are obtained with high spoiler, $\delta=90°$ and spoiler at front position. It decreases with decreasing the spoiler hight and setting angle, and shifting it backward. The maximum lift coefficient c_{ymax} of the airfoil with spoiler is found to be smaller than that of clean configuration. Thus, even with the spoiler working as a vortex generator at high angles of attack and delaying stall, the net area under the pressure distribution curve is smaller than that of clean configuration. The minimum value of c_{ymax} is obtained by the higher spoiler at front position with $\delta=90°$, and increases with decreasing spoiler hight and setting angle, and backward spoiler movement.
The zero lift drag coefficient c_{x0} of the airfoil with spoiler is greater than that of the clean configuration (Fig.4). This can be related to the loss of suction upstream of the spoiler, and building-up of it downstream. This effect is dominant in the case of high spoiler with $\delta=90°$ placed in the front position which makes c_{x0} to be maximum. When the spoiler dimension and angle decrease, and position moves backward, the suction upstream of the spoiler improves and c_{x0} decreases. The behaviour of the drag curve was found to be strongly dependent on the spoiler position. When spoiler is at the front and mid positions, c_x increases with α, and no minimum was detected. On the other hand, spoiler at rear position gives drag curve approximately parallel to the clean configuration one. This is related to the sensitivity of the cavity suction to the angle of attack which is dominant when the spoiler is at the front position and decreases at rear positions. It has been noticed that drag of the airfoil with spoiler near the stalling zone begins to be smaller than that of clean configuration, specially when the spoiler is at rear positions. This can be explained as, at high angles of attack the flow on the airfoil upper surface separates well ahead of the spoiler hinge line. The spoiler is immersed inside the separated region working as a vortex generator which improves suction on airfoil upper surface, and decreases the drag. Course of drag variation with the spoiler hight and setting angle is reversed near α_{cr}. This is related to the efficiency of spoiler as a vortex generator which increases with spoiler hight and setting angle.

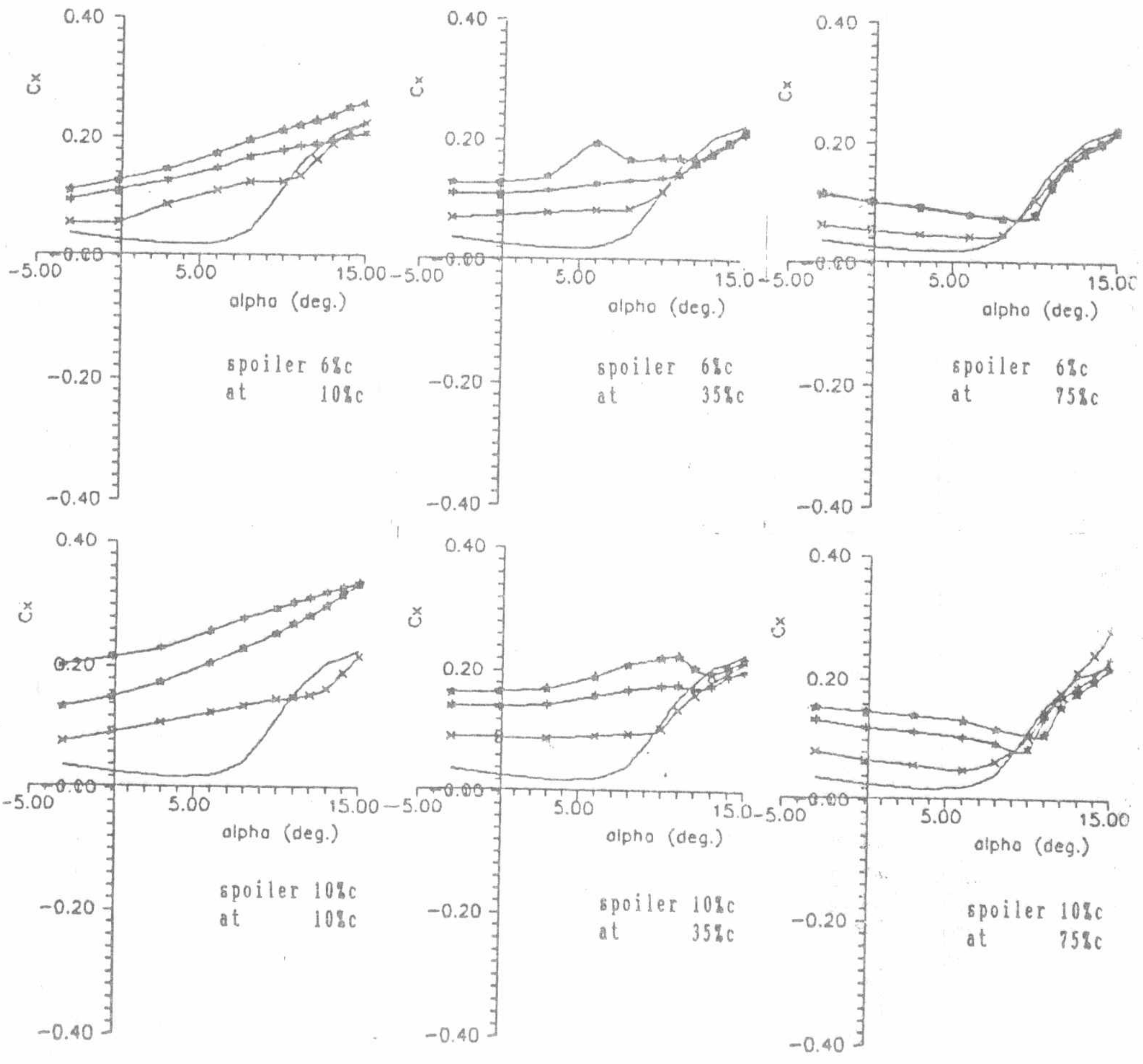


Fig.4. Measured drag curves for different configurations, clean, x... δ=30°, ·... δ=60°, and *... δ=90°.

Polar curves are shifted downwards and to the right (Fig.5). That is, the value of c_y/c_x decreases with spoiler erection. The decrease of c_y/c_x value increases with spoiler hight and setting angle. Also, forward shifting of spoiler results in decreasing c_y/c_x. It was also noted that, a forward movement of spoiler results in clockwise tilting of the curve. That is, the rate of c_y/c_x decrease increases with α increase. The value of $(c_y/c_x)_{max}$ decreases with spoiler erection. It increases with spoiler hight and setting angle, and with spoiler forward shifting.

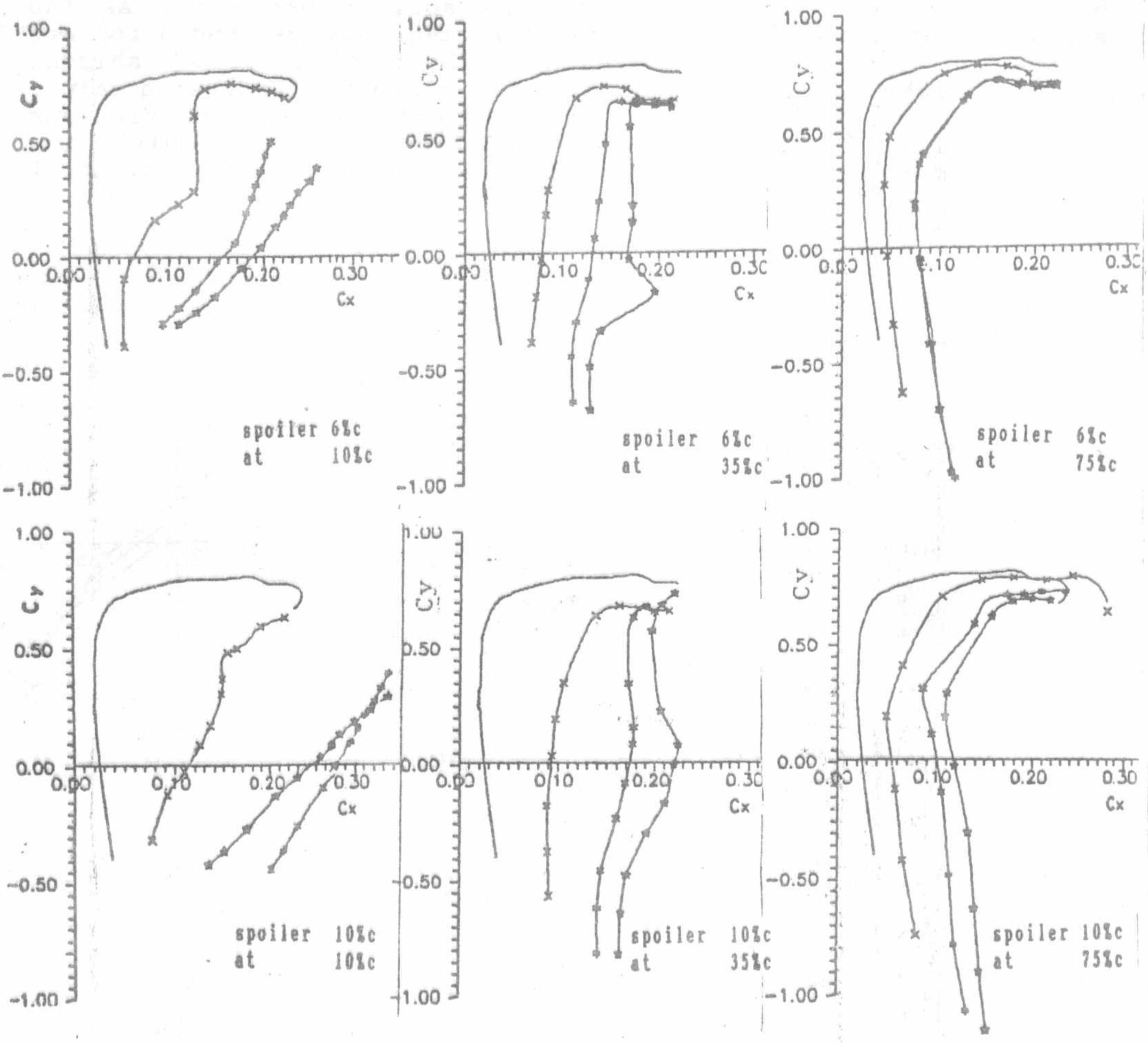


Fig.5. Polar curves for different configurations, clean, x...δ=30°, *...δ=60°, and ·...δ=90°.

Slope and linearity of the moment curve are approximately unaffected with the presence of spoiler (Fig.6). The position of aerodynamic centre x_{ac} equals that of clean configuration, and is approximately independent on the spoiler geometric conditions. The zero lift moment coefficient c_{m0} was found to be strongly dependant on the spoiler position, but approximately independent on the spoiler dimension or angle (for NACA 64A012 $c_{m0} = 0$, i.e. $x_{ac} = x_{cp} = 0.25c$). When the spoiler is placed in the front position, c_{m0} takes a negative value, which corresponds to a backward shift of the pressure centre (c_{m0}=-0.05 , x_{cp}=0.32c). This was expected as a great part of the suction upstream of the spoiler was lost. As the spoiler moves downstream recovery of suction occurs, and a forward movement of the pressure centre takes place. With spoiler shifted to rear position, c_{m0} is greater than the clean configuration value. This indicates that there is a place before the rear position for which x_{cp} & c_{m0} of the airfoil with spoiler are approximately the same as for clean configuration. The position was found to be about 53%c.

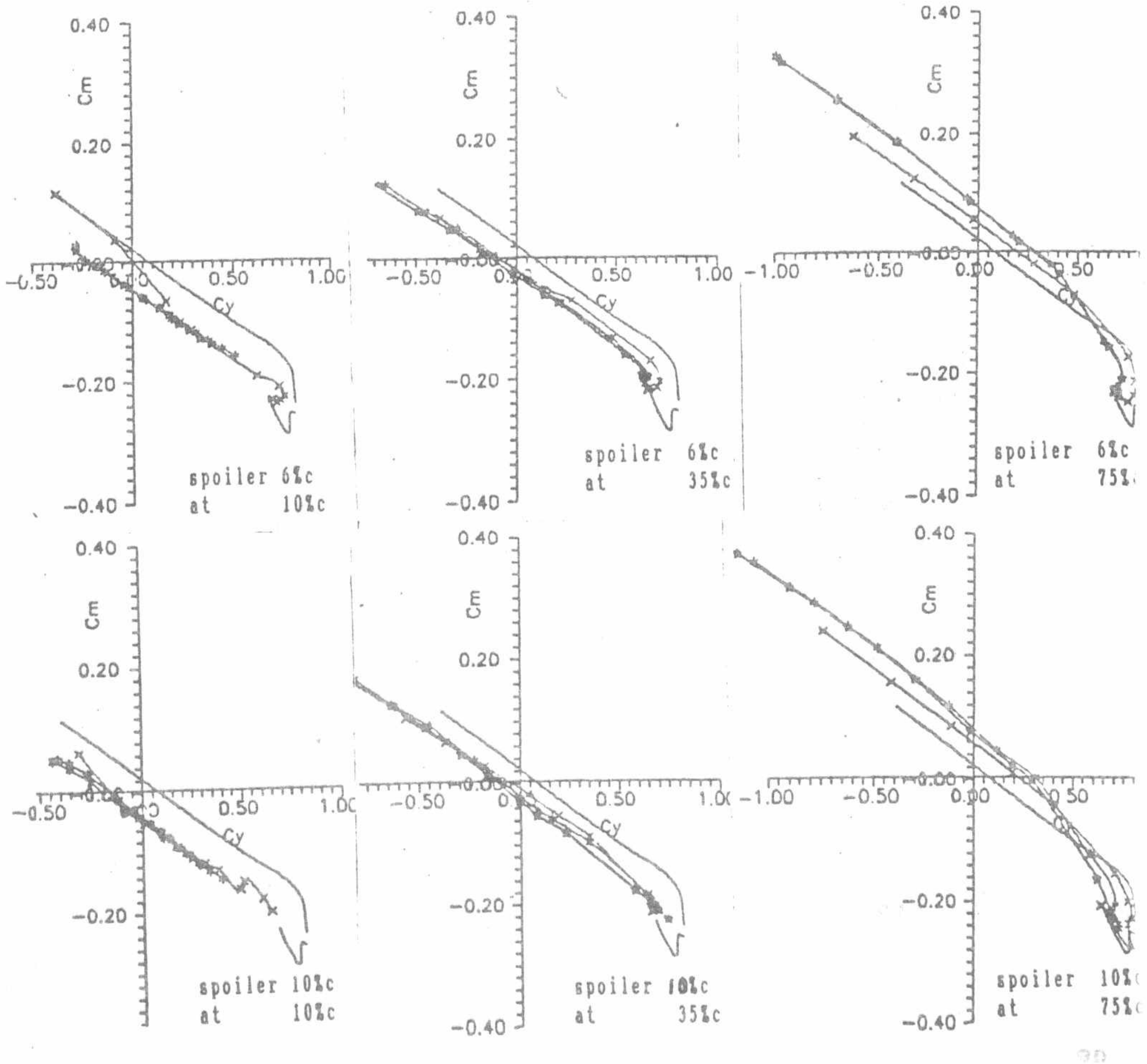


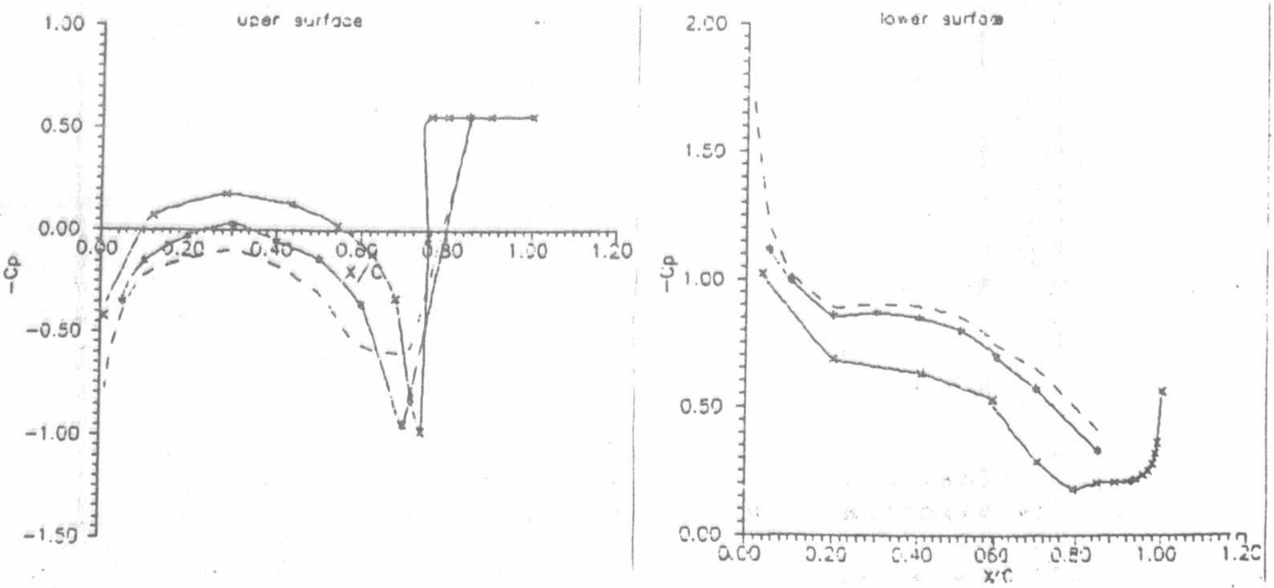
Fig.6. Moment curves for different configurations, clean, x...δ=30°, *...δ=60°, and •...δ=90°.

To enable comparison with results of available theoretical techniques, aerodynamic characteristics of airfoils with spoilers are determined by using:

a) Linearized potential flow theory for airfoils with spoilers (LPT) [4].

b) Wake source model for airfoils with separated flow (WSM) [5].

Both results of theoretical methods and experimental data are plotted together (Fig.7).



A) Pressure Distribution at $\alpha=3°$, --- Exp., x ... LPT.and * ... WSM.

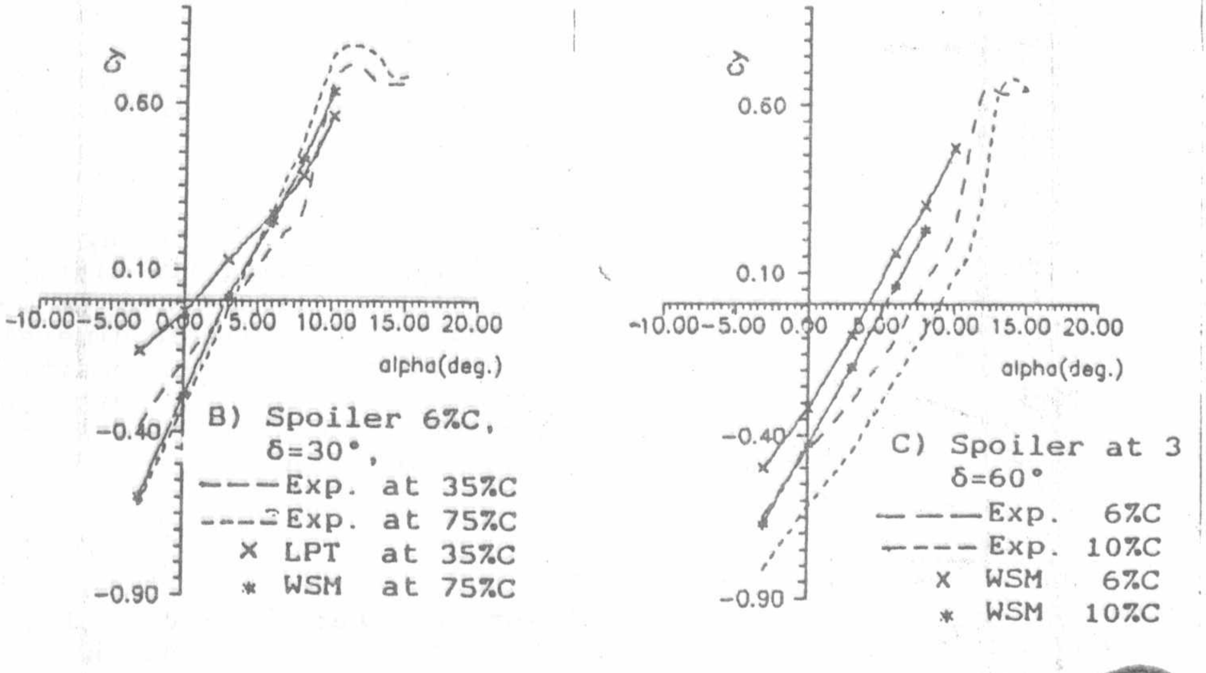


Fig.7. Comparison with theoretical results.

The wake source model gives more closer pressure distributions to experimental results than the linearized potential flow theory (Fig.7-a) as the second method considers linearized pressure coefficient. Both methods assume stagnation point at the spoiler position, while the experiment shows a separation bubble at the spoiler hinge. This can be considered as inadequacy of modelling of the problem, which is a source of error. The spoiler in the LPT method is assumed to be a point where the stagnation boundary condition is to be applied. That, the spoiler tip height from the airfoil surface is not considered, which has a great effect on the suction upstream of the spoiler. This explains the higher suction upstream of the spoiler obtained by LPT method than that obtained by WSM method and experiment. A good agreement was found between the trend of variation of lift with the spoiler geometric parameters predicted by the two theoretical models (Fig.7-b,c), and that obtained by the experimental work. That, c_y decreases with increasing spoiler deflection angle and hight, and the slope of lift curve decreases by moving the spoiler upstream.

CONCLUSIONS

From all obtained results and experiences during the fulfilling of this work, the following conclusions could be introduced :

1)Lift and drag characteristics of airfoils are strongly affected by spoiler erection which justifies its use as an effective drag increase, roll control and gust alleviation means.

2)The position of spoiler with respect to the airfoil chord is a very strong parameter which affects the slope and linearity of lift curve, shape of drag curve, position of pressure centre x_{cp}, and zero lift moment coefficient c_{m0}. Spoiler at the rear part of airfoil is prefered from stability and control points of view, as lift and drag curves are parallel to the clean configuration one, and moment curves are closer to that of clean configuration. For airfoil NACA 64A012, spoiler at 53%c could give linear lift curve, parallel lift and drag curves to the clean configuration, and unchanged moment curve.

3)The spoiler can work as a vortex generator at high angles of attack, and its efficiency increases with increasing its hight and setting angle. As a result stall is delayed, lift curve is more flat, and the sense of variation of c_y with δ and spoiler dimension is reversed. The cases of high spoiler at mid and rear positions give improvement in lift at the stalling zone, but the post stall characteristics of airfoils with spoilers need more study as most of the cases give no recognizable improvement in lift.

REFERENCES

1)Consigny,H.,Gravelle,A.,and Mdinro,R.,"Aerodynamic Characteristics of a Two dimensional Moving Spoiler in Subsonic and Transonic Flow",Journal of Aircraft,Vol.21,No.9,September 1984.

2)Chyang,S.,and Bodapati,S.,"Experimental Investigations of the flow field of an airfoil with spoiler",AIAA,Vol.25,No.11,November 1987.

3)Aly,S.F.,"Aerodynamic Characteristics of airfoils with spoilers", M.Sc. Thesis,Aeronautical Department,Military Technical College, Cairo,Egypt,1990.

4)Brown,G.P.,and Parkinson,G.V.,"A Linearized Potential Flow Theory for Airfoils with Spoilers",Journal of Fluid Mechanics,Vol.57,Part 4,pp.695-719,1973.

5)Parkinson,G.V.,and Yeung,W.,"A Wake Source Model for Airfoils with Separated Flow",Journal of Fluid Mechanics,Vol.179,pp.41-57, 1987.

6)Parkinson,G.V.,Doo,P.T.,and Bernier,R.,"A Prediction Method for Spoiler Performance",S.A.E. paper 770459,1978.

7)Pfeiffer,N.J.,and Zumwalt,G.W.,"Computational Model for Low Speed Flows Past Airfoils with Spoilers",AIAA Journal,Vol.20,No. 3, pp.376-382,1981.

8)Wentz,W.H.,and Ostwari,C.,"Wind Tunnel Studies of Spoiler Flow Characteristics",Depart. of Aeronautical Engineering,AR79-6r, Witchita State Univ.,KS,1979.

9)Bodapati,S.,Mack,M.D.,and Karamcheti,K.,"Basic Studies of Flow Fields of Airfoil-Flap and Spoiler System",AIAA paper 82-0173,Jan. 1982.

10)Mclanchlan,B.J.,Ayoub,A.,and Hadjidakis,G.,"A Stedy Flow Field of an Airfoil with deflected spoiler",AIAA paper 83-2130,1983.