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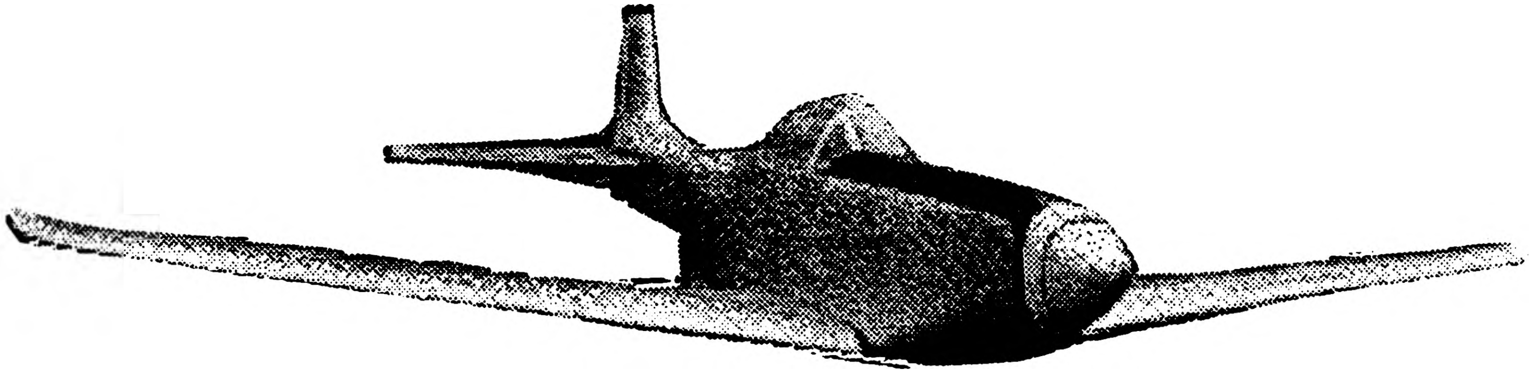
March 22, 1993



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EXPERIMENTAL INVESTIGATION ON THE LONGITUDINAL STABILITY OF A P51 MUSTANG AIRCRAFT MODEL

Erich Fitzpatrick

ABSTRACT

This project involved the development of a test model of the P-51 Mustang aircraft and an experimental investigation of its stability. The model was developed to investigate the influence of the main horizontal tail parameters (tail incidence, position of c.g., stabilizer moment arm,etc.)on the pitching moment around the aircraft's center of gravity. To accomplish such a task, a test model was designed and fabricated with flat plate and airfoil wing configurations. The tail incidence of the flat plate stabilizer is adjustable over the entire range of positive and negative angles. A rechargeable, electric motor mounted in the fuselage adjusts the position of the stabilizer within a range of two inches on each side of the standard location. Furthermore, the revised model incorporated a series of nose weights which allowed the center of gravity to be placed at five different locations. After evaluating the model at different test configurations, the influence of each of these parameters can be studied.

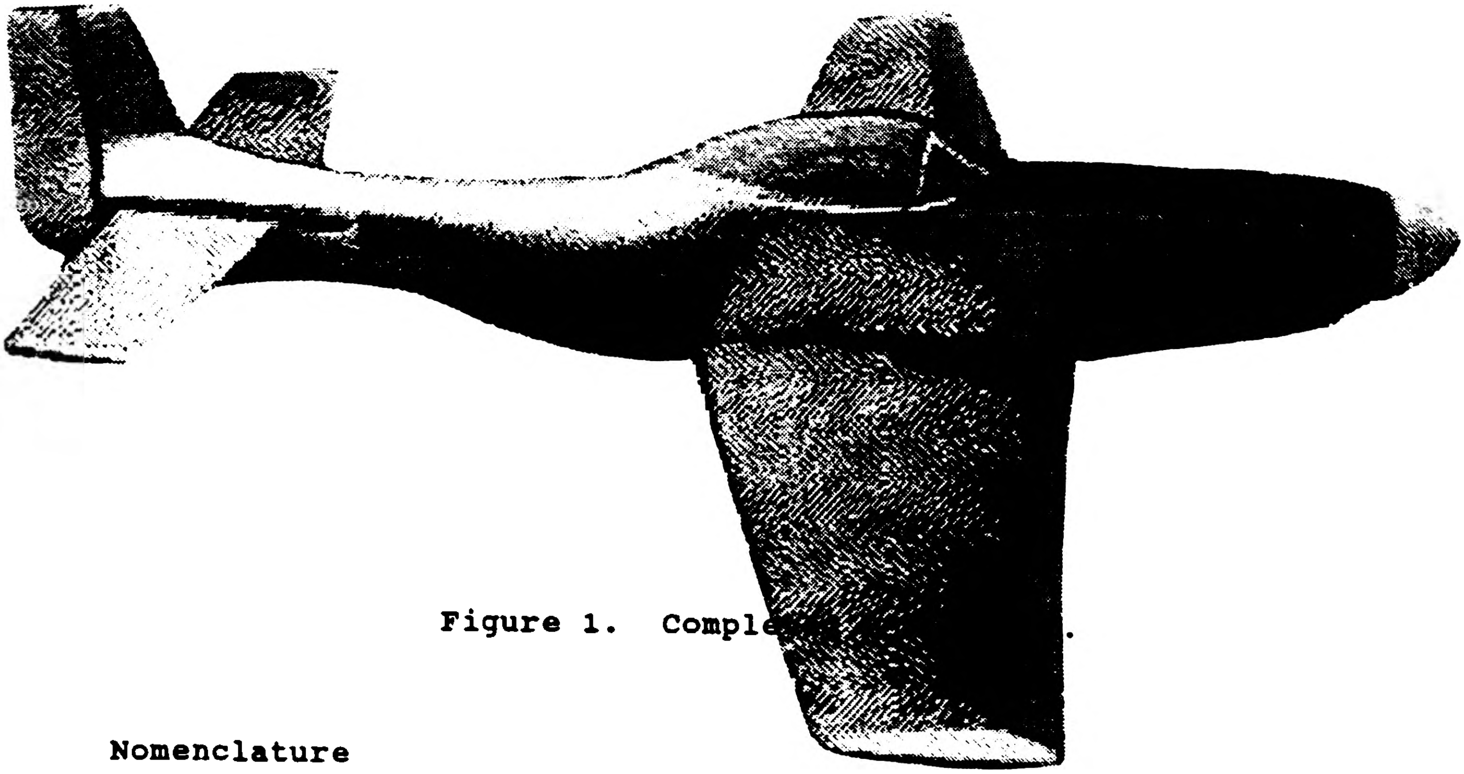

Figure 1. Compl .

Nomenclature

c.g. = Center of Gravity

INTRODUCTION

The stability and control of an aircraft is very important in its design. This deals with the motion of the aircraft and its response to different disturbances, i.e. updrafts or turbulence. The two unsteady motion areas of stability and control are longitudinal and lateral stability. Longitudinal stability deals with the motion about the center of gravity of the aircraft with the wings remaining level. Lateral stability is concerned with the side motion around the center of gravity on the horizontal plane.

For this experiment longitudinal stability was studied do to its greater importance. The response of the aircraft to unsteady motion determines if the plane can be flown. An unstable plane without active control would not be safe. Therefore, a thorough understanding and implementation of the longitudinal stability rules must be applied to each aircraft. The parameters that effect the longitudinal stability of the aircraft are the focus of this experiment.

Governing Equations

The longitudinal stability equations employed in this series of experiments are based upon the forces acting upon the aircraft in flight. These forces are represented by figure 2. The moment about the center of gravity of the model is directly related to its stability. Stability is defined as the response of the model from a disturbance to return to its initial position.

$$V_H = (l_t / C)(\text{Tail area} / \text{Wing area}) \qquad (1)$$

Tail volume is varied by changing l_t as shown in (1).

$$Cmo = Cmo,wb + a_t V_H(\epsilon_0 + i_t) \qquad (2)$$

The variance of i_t can be seen in (2). The program uses after directional conversion of the forces about the c.g. this equation to find the moment.

$$M_{c.g.} = M_{data} + F_n \times X_{c.g.} + F_a \times Y_{c.g.} \qquad (3)$$

$$Cm,c.g. = M_{c.g.} / ((\tfrac{1}{2} \times \rho \times V \hat{} 2) \times C) \qquad (4)$$

Equation (4) calculates the resultant moment coefficient which is then plotted versus the angle of attack of the model to calculate $\delta Cm / \delta\alpha$. The slope of this curve shows the stability of the model (negative slope is stable).

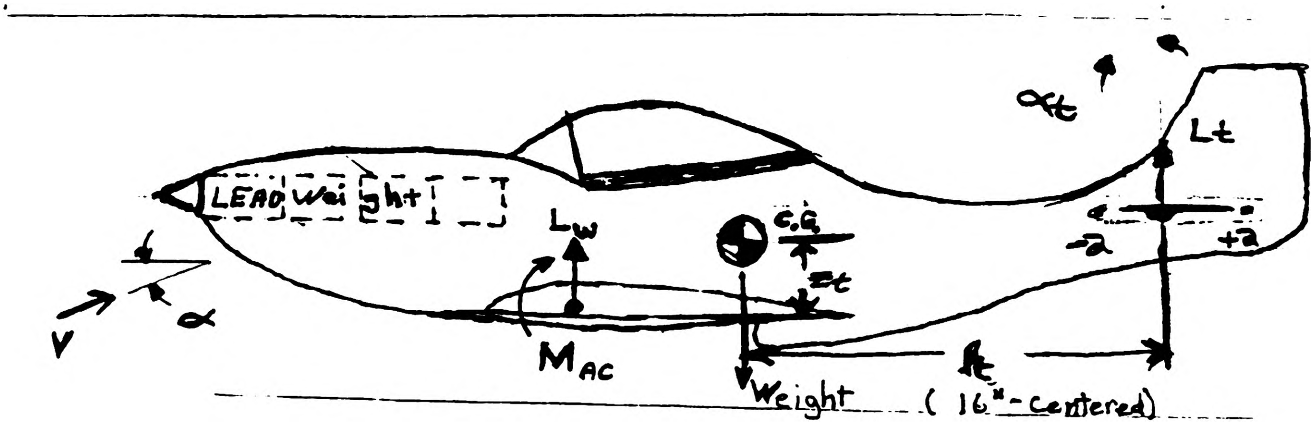

Figure 2. Basic force and moment diagram of model with weights shown.

AIRCRAFT DEVELOPMENT

In order to accomplish this investigation, a suitable model had to be designed and fabricated. The initial conceptual design was to consist of simple flat plates connected by an adjustable mechanism to vary tail volume parameters. This basic idea was to incorporate a high drag structure and seemed more of an apparatus than an aircraft. In order to enclose the controlling motor and mechanisms, an aircraft [illegible] was to be utilized to better emulate an aircraft's actual behavior. The obvious model choice was the North American P-51 Mustang from WWII vintage, which was one of the most aerodynamic aircraft of its period with a top speed in excess of 430 mph! A basic set of plans were scaled up from a simple flying model. Over a period of evolution, the fuselage was carved from butternut and bass wood until its present form. The model picture (figure 1) shows the completed model. The motor to move the stabilizer was modified from a rechargeable screwdriver (refer to figure 3) and turned a threaded bolt that moved the stabilizer. The flat plate wing was aluminum while the airfoil wing was carved from yellow pine. After initial evaluation, a method for moving the center of gravity was deemed necessary. This system involves four .75 lb. lead weights, which when inserted in the nose of the aircraft can vary the c.g by over three inches. The actual form of this system is illustrated in figure 4. The latest version of this model then underwent further studies in the wind tunnel.

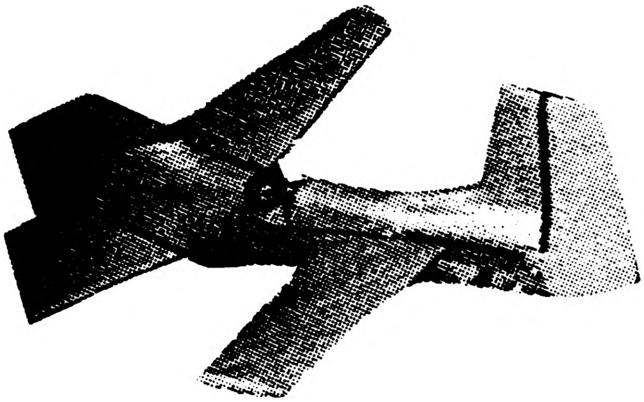

Figure 3. View of Motor drive.

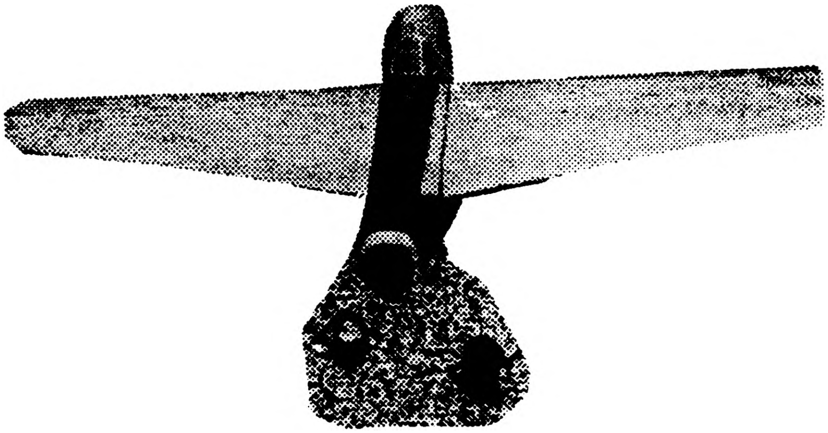

Figure 4. Nose weight close-up.

TEST FACILITY

The experiments were conducted in a subsonic, closed circuit wind tunnel. This atmospheric wind tunnel has a 9:1 contraction ratio with feedback command control of fan speed. A supercharged, diesel engine powered the hydraulically actuated fan blades. This particular wind tunnel has a maximum velocity of 400 feet per second. A contraction was upstream of the test section with a diffuse downstream. Its test section was 32 inches by 48 inches in cross-sectional area and was inclosed in clear plexiglass. Test velocities were set around 109 feet per second and were maintained for all of the test configurations. The forces acting upon the model in the test section were tabulated by a force - moment balance arm which sent the data directly to an IBM PC. The test stand allowed the angle of attack of the model to vary from minus four to plus eight degrees.

EXPERIMENTAL PLAN \ PROCEDURE

The testing of this model involved three basic configurations. These configurations varied tail incidence, center of gravity, and tail position over the entire spectrum of angles of attack. One parameter was modified in incremental steps while the rest were held constant. By following this basic plan a good representative data set could be generated to show the stability performance of the model. The basic routine of each test configuration once the tunnel was operating included:

1. The test configuration of the model would be adjusted with the remaining physical parameters held constant.
2. Temperature, Pressure, and angle of attack would be entered.
3. The strain gauges would be zeroed and then the tunnel would be accelerated to the test velocity of 109 feet per second.
4. The recorded force and moment measurements would be recorded.
5. From this the fan would be turned off and the angle of attack would be incremented.
6. The process would be repeated from step 2 until cycle completion.

This experimental plan was implemented with nearly eighty individual runs. This large amount of data was narrowed to the following results.

EXPERIMENTAL RESULTS

The initial experimental results showed an aft location of the center of gravity (C.G.) which led to a positive Cm vs. Alpha slope as noted in the accompanying graph (Fig. 5). The effect of lt and tail position, is shown. From this, the angle of incidence of the tail was also varied from -5 to +3.5 degrees. In order to finish this experiment, the C.G. must be moved forward 3 inches by the addition of nose weights and reduction in tail weight. This modified prototype will provide more accurate results and a stable aircraft.

After c.g. relocation, the modified aircraft proved to be stable after three sets of runs with maximum nose weights and the tail incidence set at -4 degrees. From figure. 6. the positive Cmo with the negative $\delta Cm / \delta\alpha$ is evident. With the weight modifications, the c.g. can travel up to three inches. This shows that tests can be initiated from an unstable model to a stable model with varying degrees of stability. By the addition of nose weights, the slope of $\delta Cm / \delta\alpha$ can be decreased in four steps from completely unstable to stable. The corresponding figure 3. illustrates the effect of the change in l_t,while showing the weight change.

Perhaps one of the most notable configurations of this experiment is how important the role of tail incidence, i_t is on the stability of the aircraft model. Refer to figure 7 illustrating this effect on stability. The effect of the tail incidence can allow the value of Cmo to be fixed at a given location and configuration. Small changes in the tail incidence resulted in substantial differences.

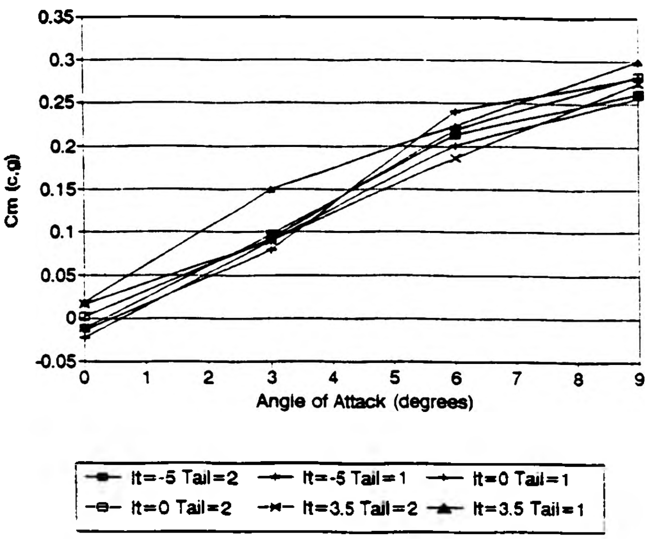

FIGURE 5. Initial model configuration with unstable characteristics

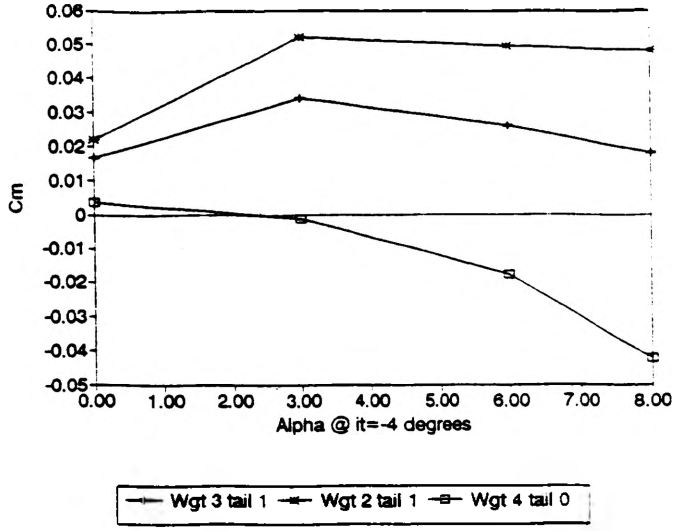

FIGURE 6. After nose weight addition these configurations are also possible. (Note: bottom curve is stable)

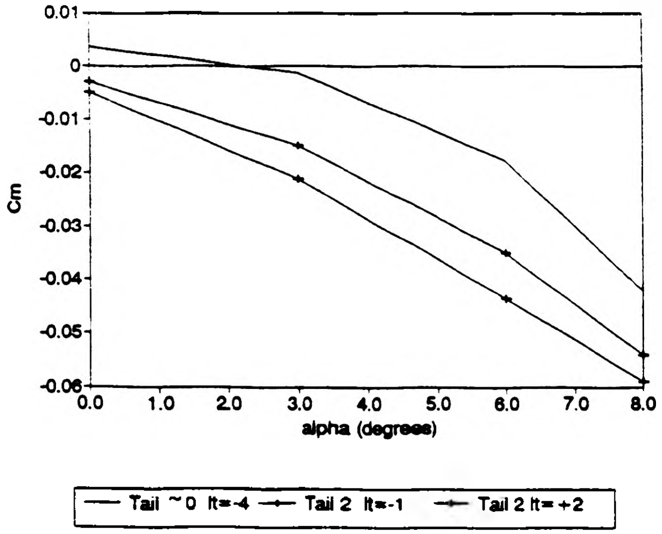

FIGURE 7. Effect of Tail incidence on Stability.

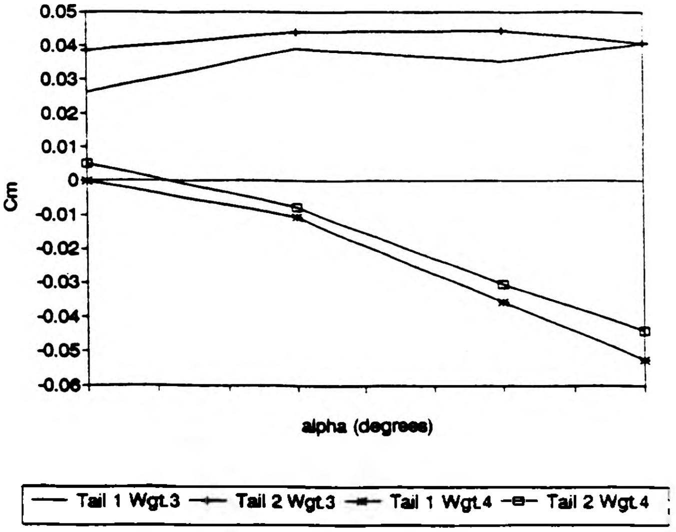

Fig. 8. The influence of tail position (position 1 is lt=14" while 2 is at 18").

CONCLUSION

This aircraft model is capable of studying the effects of many parameters on longitudinal stability. The c.g. location, tail position, wings, stabilizers, and tail incidence can be varied to see the effect of each change. A better understanding of the concept of stability can come from this experiment. The aircraft model is capable of being upgraded at a latter date to include flaps or any other control device. While the stability of this model was only studied, the program in the appendix could be modified to also calculate the lift and drag coefficients. The versatility of this model should contribute to aeronautical research in some small way.

REFERENCES

(1) Anderson, John D., Jr. Introduction to Flight. McGraw-Hill, Inc. 1989.

(2) Etkin, Bernard. Dynamics of Flight: Stability and Control

ACKNOWLEDGEMENTS

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Nomenclature

c.g. = Center of Gravity
$l_{t'}$ = Length between tail and wing aerodynamic center
$\delta Cm / \delta \alpha$ = Slope of moment coefficient and angle of attack
Cmo = Moment coefficient at zero angle of attack
Cmo,wb = Moment coefficient at zero angle of attack
Cm,c.g. = Moment coefficient about center of gravity
V_H = Tail Volume
V = Flow Velocity
a_t = Lift slope of tail
ϵ_0 = Downwash angle
i_t = Tail angle of incidence
z_t = Vertical distance between wing and aircraft c.g.
ρ = Density of air
C = Mean chord length
$M_{c.g.}$ = Moment about c.g.
M_{data} = Data Moment
F_n = Normal Force
F_a = Axial Force
$X_{c.g.}$ = X distance from c.g.
$Y_{c.g.}$ = Y distance from c.g.

REFERENCES

(1) Anderson, John D., Jr. Introduction to Flight. McGraw-Hill, Inc. 1989.

(2) Etkin, Bernard. Dynamics of Flight: Stability and Control

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'*****************************************************************************
REM MUSTANG STABILITY PROGRAM
REM WRITTEN BY ERICH FITZPATRICK
REM 1993
REM
REM THIS PROGRAM CALCULATES THE LIFT AND PITCHING MOMENT
REM EXPERIENCED BY THE MODEL IN THE WIND TUNNEL WITH APPROXIMATIONS
REM FOR TUNNEL LOSS FACTORS
REM A DATA FILE MUST BE IN THE FOLLOWING FORM
' Nf,PITCH,NA,T,P,ALPHA,VELOCITY
DECLARE SUB slope ()
DECLARE SUB writ ()
DECLARE SUB readdata ()
DECLARE SUB calculate ()
DECLARE SUB see ()
REM P-51 ANALYSIS PROGRAM
REM VARIABLES
'        nf= normal force
'        pitch=pitching moment read by force arm
'        na=axial force
'        t=temperature
'        p=pressure
'        alpha= angle of attack
'        v=velocity
REM initial given values

        DIM SHARED fora(50), forn(50), v(50), alpha(50), Pb(50), t(50), p(50)
        DIM SHARED nf(50), af(50), TP(50), Pcg(50), Cl(5), Cd(50), Cm(50)
        DIM SHARED slop(40), ycpt(40), y2(40)
        COMMON SHARED num, C, E, fil$
        COMMON SHARED shon, xmax
        CLS
        Wvol = .017: Bvol = .157: C = 6.75
        S = 1.49: b = 3: Cdu = .001
        Ck = 9.6: delta = .115: taul = .896
        K3 = .94: K1 = .86
        REM change
        hnw = .25: h = .47: z = 2 / C
        'lt'=16+2:lt=lt'-(h*C-hnwb*C)

REM CORRECTION FACTORS

        Esb = K1 * taul * Wvol / (Ck ^ 1.5) + K3 * taul * Bvol / (Ck ^ 1.5)
        Ewb = S * Cdu / (4 * Ck)
        E = Esb + Ewb

REM calculations
CALL readdata
CALL calculate
CALL slope
CALL see
'INPUT "Enter file name"; fil$
CALL writ
CLOSE
END


SUB calculate
REM calculate values
FOR o = 1 TO num
```

```
REM LOGIC WRITTEN FOR DATA FILE -mUST BE MODIFIED TO DATA SET
        IF o < 4 THEN cgx = 1.25: cgy = 2.75
        IF o < 8 AND o > 3 THEN cgx = 1.35: cgy = 2.75
        IF o > 7 AND o < 13 THEN cgx = .25: cgy = 2.75
        IF o > 12 THEN cgx = .35: cgy = 2.75
       ' INPUT a$
        Pcg(o) = Pb(o) + forn(o) * cgx - fora(o) * cgy

        qb = (.5 * (p(o) / (1716 * (t(o) + 460))) * (v(o) * 12) ^ 2 * (1 + 2 * E
        Cm(o) = Pcg(o) / (qb * C)
        PRINT o
      '  Cl(o) = (forn(o) * COS(alpha(o) / 57.3) - fora(o) * SIN(alpha(o) / 57.3
NEXT
END SUB


SUB readdata
'INPUT "enter filename"; fil$
OPEN "c:\mustang\wgt2.dat" FOR INPUT AS #1
INPUT #1, num
FOR t = 1 TO num

        INPUT #1, nf(t), Pb(t), af(t), t(t), p(t), alpha(t), v(t), TP(t)
        IF alpha(t) = 3 THEN nf(t) = nf(t) - .1: Pb(t) = Pb(t) - .15: af(t) = af
        IF alpha(t) = 6 THEN nf(t) = nf(t) - .3: Pb(t) = Pb(t) - .3: af(t) = af(
        IF alpha(t) = 9 THEN nf(t) = nf(t) - .4: Pb(t) = Pb(t) - .4: af(t) = af(
        forn(t) = nf(t) * COS(9.5 / 57.3) - af(t) * SIN(9.5 / 57.3)
        fora(t) = nf(t) * SIN(9.5 / 57.3) + af(t) * COS(9.5 / 57.3)
NEXT
END SUB


SUB see
PRINT "Cm,alpha,Cl"
FOR q = 1 TO num
        PRINT Cm(q), alpha(q)
        NEXT
PRINT "slopes"; shon
FOR i = 1 TO shon
        PRINT slop(i), ycpt(i), i
NEXT
END SUB


SUB slope
REM calculate least squares curve line
REM Cm(tt), alpha(tt)
REM normal equations
'PRINT num: INPUT a$
shon = (num + 1) / 4
FOR sho = 1 TO shon
        aa = 0: bb = 0: cc = 0: dd = 0
        IF sho = 1 THEN nn = 3 ELSE nn = 4
        FOR jjj = 1 TO nn
        aa = alpha(jjj * sho) ^ 2 + aa
        bb = alpha(jjj * sho) + bb
        cc = alpha(jjj * sho) * Cm(jjj * sho) + cc
        dd = Cm(jjj * sho) + dd
        xmax = alpha(4)
        'PRINT aa, bb, cc, dd, sho: INPUT a$
```

```
        NEXT
        slop(sho) = ((cc * 4) - dd * bb) / ((aa * 4) - (bb * bb))
        ycpt(sho) = ((aa * dd) - bb * cc) / ((aa * 4) - (bb * bb))
        y2(sho) = (slop(sho) * 8 + ycpt(sho))
        PRINT slop(sho); ycpt(sho); y2(sho)
NEXT
END SUB

SUB writ
'INPUT "save as"; fil$
CLOSE #1
OPEN "c:\mustang\dat5" FOR OUTPUT AS #1
FOR tt = 1 TO num
        WRITE #1, Cm(tt), alpha(tt), TP(tt)
NEXT
FOR tt = 1 TO shon
'WRITE #1, shon, slop(tt), ycpt(tt), y2(tt)
NEXT
END SUB
```