Development of a Comprehensive Tool for Calculating the Aeromechanics Characteristics of High-Speed Aircraft

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Abstract- One of the decisive steps in the aircraft preliminary design process is the calculation of all aerodynamic and mechanics of flight characteristics (i.e., Aeromechanics). Despite the availability of some tools that can be used to estimate part of the aerodynamic data, such tools have numerous limitations (e.g., confined speed ranges, large computation time and power, difficulty of use, lack of mechanics of flight analysis, etc.). Thus, a suitable aeromechanics tool that operates from low to high-speed ranges is yet a challenge. In this research, comprehensive mathematical formulations gathered from diverse aeromechanics references are implemented in a user-friendly tool that enables calculating all aeromechanics characteristics of different aircraft types (e.g., airplanes, bombs, missiles) from subsonic to transonic and supersonic speeds. Additionally, the developed tool digitizes more than 98 aerodynamic Figs from different sources (where the variables in these Figs vary from two to five parameters). These unique capabilities make the developed tool surpasses all relevant available tools worldwide. In order to assess the validity of the developed tool, it is used to calculate the aeromechanics data of the F4-Phantom aircraft and compared the results with the experimental published data. The comparison gives a very good agreement (for the preliminary design phase) with average error about 8%.

I. INTRODUCTION

A. Background

There are basically four approaches for solving aerodynamic problems:

1) Analytical approach (historically old)

It is to find solution to aerodynamic problem using fundamental laws and basic mathematics (differential, integral approach) of potential flow calculations, thin airfoil theory.

2) Experimental approach (Testing).

A model is to be designed and built with provisions for measuring the required data.

The model is tested (in wind tunnels) with a certain experimental setup and the data are obtained with corrections if needed.

3) Computational approach (Numerical)

Equations of flow field are discretised by numerical techniques and solved on high-speed digital computers.

4) Empirical approach

A set of data sheets containing aerodynamic characteristics of standard simple shapes (cones, boat tails, cylinders, wings, …, etc.) of different geometries from which airplanes and missile are composed and their mutual interferences are obtained experimentally.

Table 1: COMPARISON BETWEEN APPROACHES

Approaches	Advantages	Disadvantages
Analytical Approach	Closed form solution. Minimum amount of computations cost.	Restrictive simplifying assumptions (linear problems). Simple configurations. Limited aerodynamic data. This approach is useful in preliminary design work.
Experimental Approach	Testing is realistic (actual configuration). Possibility of observing new phenomena.	Equipment required (model, W.T., tunnel line…). Very high cost. Tunnel dependent flow conditions. Scale effect. Limited amount of aerodynamic data. Some measurements are difficult to be performed.

Numerical Approach	Few restrictive and simplifying assumptions. Complete flow field definition. Treatment of complicated contours. No Mach number limitations. Cost moderate.	Lack of storage and speed. Accuracy of numerical scheme (discretization and truncation error). Inadequate turbulence modelling. Boundary conditions problems.
Empirical Approach	Normal computing devices can be used (desktops, laptops) as no high storage memory or speed are needed. Quick results for wide range aerodynamic data (lift and moment coefficients or stability and control derivatives). Low cost.	It is applied for standard shapes only.

B. Overview

Aerodynamic characteristics for airplanes, rockets and missiles, are represented as the variation of forces and moments and its different components, are regarded as the main method to compute the data related to its mechanics of flight such as its range, endurance, maximum speed, stall speed, min allowable flight altitude, ceiling altitude and climb or descent rate.in addition to the best paths to achieve its aims of bombing, chasing, fighting or manoeuvring.

Thus, aerodynamic characteristics are regarded from the engineering design secrets of that equipment as the production authorities do not publish it to the users hanging on possessing the design details which allow knowing the best utilization abilities in addition to monopolization of the necessary scientific background for making any modification or development.

Aerodynamic characteristics are determined by numerical methods on computers or by experimental measurements in wind tunnels or by flight tests after manufacturing, modern computational methods rely on discretising the outer surface of the airplane or the rocket to a fine mesh and here the role of supercomputers arise for computing large number of mathematical equations in the same time as they compute the aerodynamic effects on these different components and then summarize these effects to determine the resultant of these effects on the full airplane or rocket.

But this approach (Numerical) faces many obstructs such:

1. Needed supercomputers are un-available in Egypt and computing this calculation in foreign countries disagree with secretes and secureness affairs.
2. Long period for entering the input data for the airplane or rocket.
3. The High cost of working hours.

while the experimental approach in determining that characteristics before production relies on designing and manufacturing similar models for the airplane or the rocket with a special specification and high accuracy to be tested in wind tunnels in similar conditions such as flight angles, speeds and altitudes.

But also, this approach faces some problems such:

1. High speed wind tunnels are not available in Egypt and executing the measurements in foreign countries disagree with secretes and secureness affairs.
2. Long period and high costs for manufacturing the airplane models.
3. The high cost of wind tunnels working hours and the necessary time waited and adherence to the time lists for executing those experiments.
4. the risks to be taken after production in real flight tests.

After the development of designing and increasing the complexities of the equipment shapes, the characteristics determination became more difficult and the hence the increase in cost and time related to obtaining it, in addition to regarding it as critical ruling technology that international manipulation is strictly forbidden.

In the other hand the requirements of different branches and departments of armed forces are established in finding suitable means to obtain the aerodynamic characteristics for the present airy equipment and this requirements to know its best usage abilities and to know the effect resulted from modifying it, the increase and variety of that equipment along the last twenty years guided to face this problem in special researches and projects with the ability to increase the different missiles and artillery rockets range and the effect of outer airplane assembles (fuel tanks -armament) on the speed and range of flight unit with the ability of exchanging the outer armament between different airplanes ,in addition to the required reverse engineering calculations for local manufacturing oat military production industries and the Arabic commission for manufacturing and also for designing new equipment and finding out the equipment characteristics of enemies for satisfying the needs of military intelligence and reconnaissance commission.

The impossibility of obtaining these characteristics from outward in the shadow of banning, monopolization, excessive costs and wasting of time and secretes. while the importance of providing the necessary scientific background for R&D affairs, manufacturing for armed forces and military production, the main idea for this researching project was raised in 1978.

The research main idea depends on studying the available methods and data for determining the analytical and practical aerodynamic characteristics that can be obtained from eastern and western references and selecting the best and most accurate of it while using the most modern owned computers and the fastest available in that time to employ it as computer tools allowing entering the data and geometry of the airplane.

This idea will determine the aerodynamic characteristics for main components of the airplane or rocket (body, wings, tail surfaces…. etc.) separated and finding their mutual interference effect on each other and then collecting these characteristics to compute the total airplane or rocket aerodynamic characteristics.

This Paper includes:

1. Identification of different programs computing the aerodynamic characteristics:
    - i) Bodies aerodynamic characteristics.
    - ii) Surfaces aerodynamic characteristics.
    - iii) Mutual interference aerodynamic characteristics.
    - iv) Airplane or missile aerodynamic characteristics.
2. Identification of airplane and missile data and engineering geometries that needed in advanced programs.
3. applying the constructed programs on calculation of aerodynamic characteristics for some modern airplanes that its data sheets are published aiming for testing, comparison and validation.
4. overview and conclusions.

C. Comparison Between Available Aero-mechanics tools

Table 2: Summary of the capabilities for the available Aeromechanics tools

Criteria	*Digital DATCOM*	*AVL*	*Tornado*	*XLFR5*	*CDF*	*Developed Aero-Mechanics tool*
All Basic Aerodynamics	√	√	√	√	√	√
All static stability derivatives	√	√	√	√	√	√
All dynamic stability derivatives	√	×	-	×	×	√
All control derivatives	√	-	√	×	√	√
Subsonic Measurement Capability	√	√	√	√	√	√
Transonic Measurement Capability	×	-	-	×	√	√
Supersonic Measurement Capability	×	√	√	×	√	√
Performance Estimation	√	×	×	×	×	√
Dynamic Stability Estimation	√	√	√	√	√	√
User Friendly	×	×	×	√	×	√
Man Hours & cost	×	√	√	√	×	√
Viscous Effect	√	×	√	×	√	√

II. METHODOLOGY

The methodology of program depends on dividing the functions into several tasks and dividing the airplane into several parts (fuselage or missile body, front panel, rear panel, control surfaces, etc.).

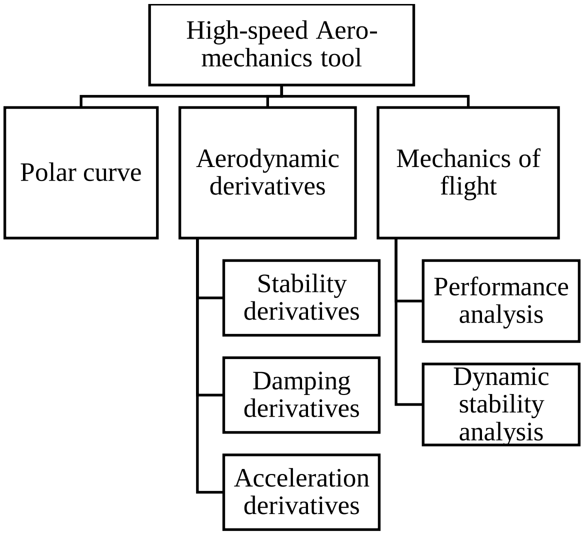

Fig. 1 Functions programming map

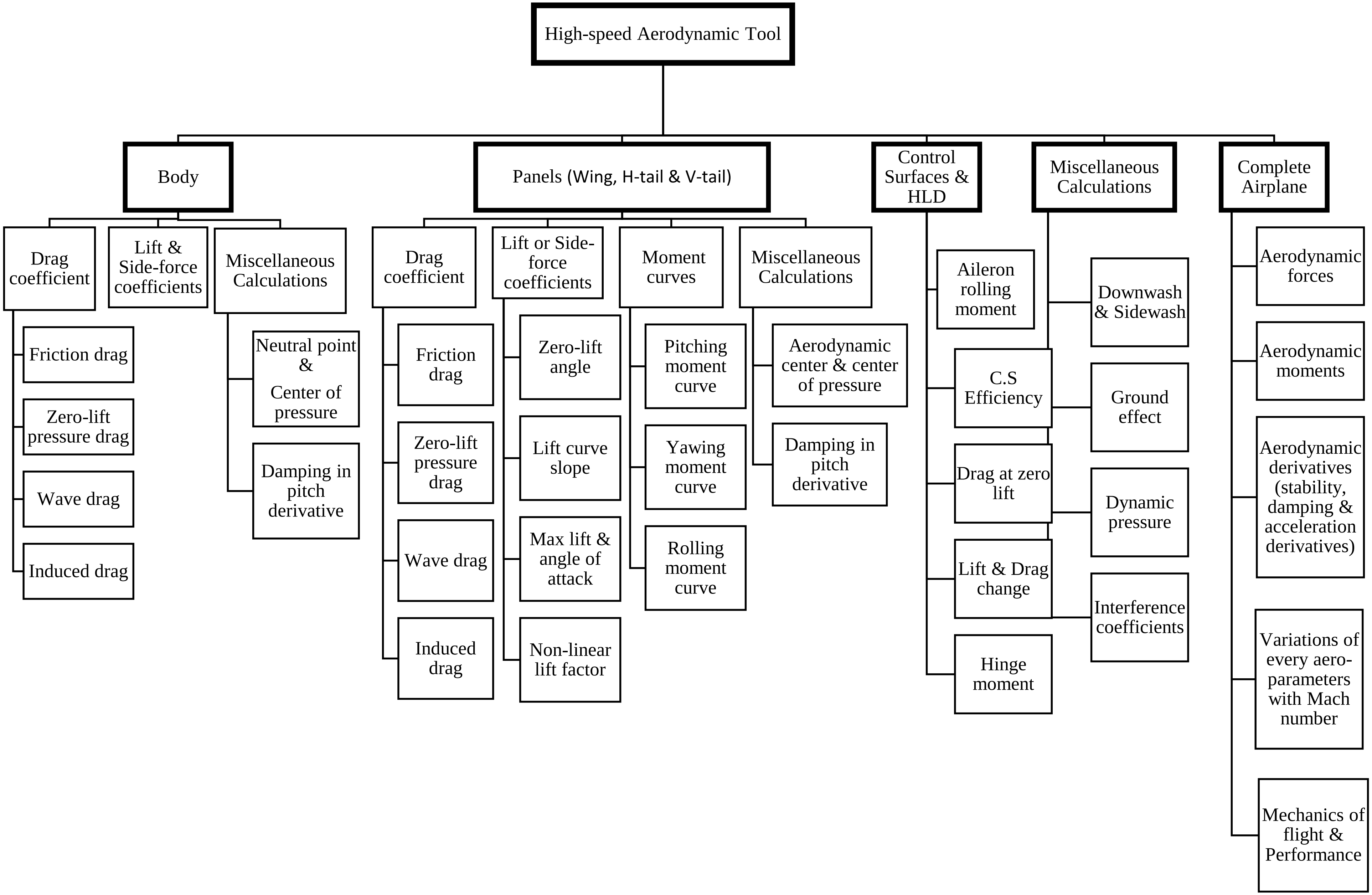

Fig. 2 Airplane parts programming map

A. Body Contribution

1) Body Total Drag

$$C_{D_b} = C_{D_o} + C_{D_f} + C_{D_i} + C_{D_w} \qquad (1)$$

a) Body friction drag

Body friction coefficient calculation is based on the body location, surface finish conditions, geometrical characteristics and flow Mach number.

$$C_{D_f} = 1.1\, C_{fc}\ ff \quad k_{bl.}\, b_{\omega s} \,/\, S_{max} \qquad (2)$$

Where:

C_{fc} = Is turbulent boundary layer skin friction drag coefficient with effect of compressibility.

M_∞= Undisturbed flow Mach number.

$k_{b \cdot l}$ = Surface roughness factor.

$b_{\omega s}$ = Body welted area (m^2).

S_{max}= Body maximum cross section area (Reference area).

ff = Component form factor.

b) Body zero lift pressure drag

the zero lift drag and zero side force pressure drag and wave drag coefficients calculation based on its geometrical characteristics, air intake location, engine operation condition.

$$C_{D_o} = C_{D_n} + C_{D_r} + C_{D_{\mathrm{base}}} \qquad (3)$$

Where:

C_{D_n} = Drag coefficient of nose part.

C_{D_r} = Drag coefficient of rear part.

$C_{D_{\mathrm{base}}}$ = Base drag coefficient.

c) Body induced drag

$$C_{D_i} = (C_{L_b} + \xi \sin 2\alpha) \sin \alpha \qquad (4)$$

Where:

ξ = Is body nose suction parameter and is function of nose shape, M_∞ and nose aspect ratio.

C_{L_b} = Body lift coefficient.

α =Airplane angle of attack.

2) Body Lift & Side-force coefficients

Here, calculation of the lift or side force coefficient and lift curve slopes of body parts.

$$C_{L_b} = C_{L_a} + C_{L_{cf}} \qquad (5)$$

$$C_{L_a} = 57.3\, C_{L_b}^{\alpha}\, \chi^{\alpha}\, sin\alpha\, cos\alpha \qquad (6)$$

Where:

$C_{L_{cf}}$= cross flow lift component.

$C_{L_b}^{\alpha}$ = body lift curve slope.

χ^{α} = flow separation correction factor.

3) Body Miscellaneous Calculations

The position of body neutral point, centre of pressure, moment curve slope and longitudinal/lateral motion damping calculation as function of its centre of gravity position and flow Mach number.

a) Body Neutral point & Centre of pressure

Position of body neutral point:

$$x_{np} = \frac{\left(C_{L_{nc}}^{\alpha} + C_{L_p}^{\alpha}\right) x_{fnc} + C_{L_r}^{\alpha} x_{fr}}{C_{L_b}^{\alpha}} \qquad (7)$$

Position of body centre of pressure:

$$x_{cp} = \frac{C_{L_b}\, x_{np} + 0.5\, L_b C_{L_{cf}}}{C_{L_b}^{\alpha}} \qquad (8)$$

Where:

x_{fr} = Position of rear part neutral point.

x_{fnc} = Position of nose centre part neutral point.

$C_{L_{nc}}^{\alpha}$ = Blunt nose cylinder lift curve slope.

$C_{L_r}^{\alpha}$ = Rear part lift curve slope.

$C_{L_p}^{\alpha}$ = Power contribution to body lift curve slope.

b) Body Damping in pitch derivative

$$C_m^q = -57.3\, C_{L_{nc}}^{\alpha}\, (x_{c.g} - x_{fnc})^2 \,/\, L_b^2 \qquad (9)$$

Where:

L_b = Body total length.

$x_{c.g}$ = Body centre of gravity.

B. Panels Contribution (Wing, H-tail & V-tail)

Determination of the mounted panel perpendicular and tangential force coefficients, normal and axial force coefficients and lift and drag coefficients, its effective angle of attack, aerodynamic centre and damping in longitudinal/lateral motion derivative.

1) Panel Drag coefficient

The panel perpendicular and tangential force coefficients, normal and axial force coefficients are the solution key of drag coefficient as perpendicular force will indicate the contribution of induced drag while the tangential force will indicate the pressure and friction drag.

a) Panel Friction drag

the tool calculates panel turbulent friction drag coefficient as function of panel geometry and surface conditions.

$$C_{f_p} = 2\, C_{fc}\, f\, k_{b.l} \qquad (10)$$

Where:

C_{f_c} = Is turbulent B.L. skin friction drag coefficient with effect of compressibility.

$k_{b.l}$ = body boundary layer interference factor.

f = component form factor.

b) Panel Zero-lift pressure drag

c) Panel Wave drag

$$C_{D_w} = C_{D_w}\left(M_\infty, \lambda_p, \eta_p, \chi_{0.5}, \text{profile shape}\right)$$

Where:

λ_p = Panel aspect ratio.

$\chi_{0.5}$ = Panel half-chord sweep back angle.

η_p = Panel taper ratio.

d) Panel Induced drag

$$C_{D_i} = C_{D_i}(C_L, \alpha, \text{body interference}, \text{profile shape})$$

2) Panel Lift or Side-force coefficients

$$C_L = \frac{K_{\alpha\alpha}}{k_{\alpha\alpha}} C_n \cos(\alpha + \sigma_p) \cos \gamma - C_t \sin(\alpha + \sigma_p) \quad (11)$$

Where:
C_n = panel tangential force coefficient.
C_t = panel tangential force coefficient.
$K_{\alpha\alpha}, k_{\alpha\alpha}$ = panel body interference factor.
γ = Panel dihedral angle.
σ_p = Panel downwash/sidewash angle.

a) Panel Zero-lift angle

The panel zero lift angle calculated in degrees as function of panel geometry, camber and twist.
its value is considered negligibly variable with Mach number.

$$\alpha_0 = \alpha_0\left(\text{Airfoil max camber, twist}, \chi_p, \text{profile shape}\right)$$

b) Panel Lift curve slope

Isolated panel lift curve slope is calculated in degree as function of panel geometry and flight Mach number and swept-back angle and maximum camber.

$$C_{L_p}^{\alpha} = C_{L_p}^{\alpha}\left(M_\infty, \lambda_p, \text{Airfoil max camber}, \chi_{0.5}\right)$$

c) Panel Max lift & angle of attack

panel maximum lift and angle of attack are calculated as function of flight Mach number, taper ratio, swept-back angle and profile shape.

Also, $\alpha_{max} = \alpha_{max}\left(M_\infty, \eta_p, \chi_{LE}, \text{profile shape}\right)$
Where: χ_{LE} = Panel leading edge sweep back angle.

d) Panel Non-linear lift factor

The panel nonlinear lift factor is calculated as function of geometry, angle of attack, panel setting and control deflection angles and flow Mach number.

$$A = A_{ref} + \Delta A \quad (12)$$

$$A_{ref} = \frac{\left(C_{L_{max}} / \cos \alpha_{max}\right) - C_{L_p}^{\alpha} \cdot \frac{1}{2} \sin 2\alpha_{max}}{\sin \alpha_{max} \quad |\sin \alpha_{max}|} \quad (13)$$

Where:
A_{ref} = reference nonlinear lift factor.
ΔA = Is the incremental factor given as Function of ratio of tangents of angle of attack, the maximum angle of attack and the wing shape parameter.

3) Panel Miscellaneous Calculations

Determination of the position of panel aerodynamic centres w.r.t angle of attack and control deflection angle, centre of pressure and damping in longitudinal/lateral motion derivative as function of panel geometry, location, aircraft centre of gravity position, panel control deflection angle, angle of attack and flight Mach number.

e) Panel Aerodynamic centre

$$\bar{X} = \left(\lambda_p, \ \eta_p, X_{l.E}, M_\infty\right)$$

f) Panel Damping in longitudinal/lateral motion derivative

$$C_{m_W}^{q} = -57.3\, C_{L_p}^{\alpha} \cos\gamma \left(A + B\lambda \tan X_{0.25} + c\lambda^2 \tan^2 X_{0.25}\right) \quad (14)$$

C. Control Surfaces & HLD

1) Control surface Efficiency

The panel control efficiency in all flight speeds as function of Mach number.

$$n = \bar{n}_1 \bar{n}_2 \, k_g \cos X_c \quad (15)$$

Where:
$\bar{n}_1$ = Effect of control surface relative span.
$\bar{n}_2$= Effect of control surface relative chord.
K_g = Gap effect factor $(0.8 : 0.95)$.
X_c = Sweep angle of control surface deflection axis.

2) Control surface drag at zero lift

The increase of the panel zero lift drag due to trailing edge flap deflection at low speeds.

$$\Delta C_D = K_1 K_2 \ \bar{S}_{c.s} \quad (16)$$

Where:
K_1 = Trailing edge flap relative chord factor.
K_2 = Trailing edge flap relative span factor.
$\bar{S}_{c.s}$ = Relative wing area to trailing edge flap.

3) Control surface effect on maximum lift coefficient

$$\Delta C_{L_{max}} = \Delta C_{L_{max}}\left(\text{flap type, max camber}, \bar{S}_{c.s}\right)$$

4) Control surface hinge moment

The control surface hinge moment coefficient is calculated and its variation with angle of attack and control surface deflection angle.

$$m_h = m_{ho} + m_h^{\alpha} \alpha + m_h^{\delta} \delta \quad (17)$$

5) Aileron rolling moment

D. Miscellaneous Calculations

1) Downwash & Sidewash

The tool calculates the downwash and Sidewash angles derivatives w.r.t angle of attack and front panel control deflection and the mean downwash angle at the rear panel location.
Mean downwash angle in degrees:

$$\varepsilon_m = \frac{57.3}{2\pi} \frac{i}{\bar{Z}v_{r.p.}} \frac{L(front.p)}{L(rear.p)} \frac{C_{n_{f.p}}}{\lambda_{r.p}} \frac{\psi_\varepsilon}{K_{\alpha\alpha(rear.panel)}} \quad (18)$$

Where:
i = Vortex interference factor
ψ_ε = is relative area of rear panel affected by downwash caused by front panel vortex system.
$C_{n_{f.p}}$ = Front panel normal force coefficient.
$\lambda_{r.p}$ = Rear panel aspect ratio.
$\bar{Z}v_{r.p}$ = Vortex position w.r.t H.tail connection chord

2) Ground effect

The tool determines the change of downwash at the horizontal tail position due to the effect of ground vicinity at low speeds.

$$\Delta C_{L_{gr}} = -\Delta\alpha_{gr}\ \mathrm{C}_{\mathrm{L_{wb}}}^{\alpha} \qquad (19)$$

Where:

$\Delta\alpha_{\mathrm{gr}}$= is the change of the wing body angle of attack due to ground effect.

$\mathrm{C}_{\mathrm{L_{wb}}}^{\alpha}$= wing body lift curve slope.

3) Dynamic pressure

The tool calculates the dynamic pressure ratio at the place of front and rear panels according to their dimensions, locations, effect of body nose part as function of angle of attack and flight Mach number.

Flow braking coefficient at place of rear panel:

$$k_T = k_t^{\backslash}\ k_t^{\backslash\backslash} \qquad (20)$$

Where:

$k_t^{\backslash}$ = Flow braking coefficient due to body nose shock wave.

$k_T^{\backslash\backslash}$ = Effect of rear panel vertical position.

4) Interference coefficients

The panel body interference coefficients are calculated according to body dimensions, panel dimensions and location and flow Mach number.

Alfa – Alfa coefficients:

$$k_{\alpha\alpha} = k_{\alpha\alpha}^{*}\ X_{B,L}\, X_M\, X_N \qquad (21)$$

$$K_{\alpha\alpha} = \left[k_{\alpha\alpha}^{*} + (K_{\alpha\alpha}^{*} - k_{\alpha\alpha}^{*})F\left(L_{r.p}\right)\right] X_{B,L} X_M\, X_N \qquad (22)$$

Delta zero coefficients:

$$k_{\delta_0} = k_{\delta_0}^{*}\, X_{B,L}\, X_M \qquad (23)$$

$$K_{\delta_0} = \left[k_{\delta_0}^{*} + \left(K_{\delta_0}^{*} - k_{\delta_0}^{*}\right)F\left(L_{r.p}\right)\right] X_{B,L} X_M \qquad (24)$$

Where:

$k_{\alpha\alpha}^{*}$, $K_{\alpha\alpha}^{*}$ $k_{\delta_0}^{*}$, $K_{\delta_0}^{*}$ =uncorrected interference coefficients.

$X_{B,L}$ = Boundary layer thickness correction factor

X_M = Mach number correction factor.

X_N = Nose length correction factor.

$F\left(L_{r.p}\right)$ = Rear length correction factor.

E. Complete Airplane

1) Aerodynamic forces

The tool summarizes the contributions of body and all panels to determine the overall airplane lift, drag and side force and their acceleration derivatives.

g) Lift coefficient

$$C_{L_{airplane}} = C_{L_{wing}} + C_{L_{H.tail}} + C_{L_{fuslage}} \qquad (25)$$

h) Drag coefficient

$$C_{D_{airplane}} = C_{D_{wing}} + C_{D_{H.tail}} + C_{D_{H.tail}} + C_{D_{fuslage}} \qquad (26)$$

i) Side-force coefficient

$$C_{Y_{airplane}} = C_Y^{\alpha}\alpha + c_Y^{\delta_r}\delta_r \qquad (27)$$

$$C_Y^{\alpha} = c_{Y_{fuslage}}^{\alpha} + c_{Y_{V.tail}}^{\alpha} + \frac{c_{Y_{wing}}^{\alpha} + c_{Y_{H.tail}}^{\alpha}}{57.3} \qquad (28)$$

$$c_Y^{\delta_r} = c_{Y_{V.tail}}^{\delta_r} \qquad (29)$$

2) Aerodynamic moments

The tool summarizes the contributions of body and all panels to determine the overall airplane pitching, rolling and yawing moments.

j) Pitching moment

$$C_m = C_{mo} + C_m^{\alpha}\alpha + C_m^{\delta_e}\delta_e + C_m^{q}q \qquad (30)$$

k) Yawing moment

$$C_n = C_n^{\beta}\beta + C_n^{\delta_r}\delta_r + C_n^{r}r \qquad (31)$$

l) Rolling moment

$$C_l = C_l^{\beta}\beta + C_l^{\delta_r}\delta_r + C_l^{p}p \qquad (32)$$

3) Aerodynamic derivatives (stability, damping & acceleration derivatives)

the tool summarizes the contributions of body and all panels to determine the overall airplane longitudinal and lateral stability and control derivatives.

m) Aircraft lift curve slope w.r.t angle of attack

$$C_L^{\alpha} = {C_L}^{\alpha}_{body}\,\overline{S}_b + {C_L}^{\alpha}_{wing}\ \bar{S}_w\, K_w + {C_L}^{\alpha}_{H.T}\,\overline{S}_{H.T}\, K_{H.T} \qquad (33)$$

n) Aircraft lift curve slope w.r.t HLD deflection

$$C_L^{\delta} = {C_L}^{\delta}_{w}\,\bar{S}_w K_w + {C_L}^{\delta}_{H.T}\,\bar{S}_{H.T}\, K_{H.T} \qquad (34)$$

o) Aircraft lift curve slope w.r.t elevator deflection

$$C_L^{\delta_e} = Cy_{H.T}^{\alpha}\, K_{\delta o}\, n_{H.T}\,\overline{S}_{H.T}\, K_{H.T} \qquad (35)$$

p) Pitching moment curve slope w.r.t angle of attack

$$\mathrm{C}_{\mathrm{m}}^{\alpha} = \mathrm{C}_{\mathrm{L}}^{\alpha}\frac{X_{cp} - X_F^{\alpha}}{L} \qquad (36)$$

q) Pitching moment curve slope w.r.t HLD deflection

$$\mathrm{C}_{\mathrm{m}}^{\delta} = \mathrm{C}_{\mathrm{L}}^{\delta}\frac{X_{cp} - X_F^{\delta}}{L} \qquad (37)$$

r) Pitching moment curve slope w.r.t elevator deflection

$$\mathrm{C}_{\mathrm{m}}^{\delta_e} = \mathrm{C}_{\mathrm{L}}^{\delta_e}\frac{X_{cp} - X_F^{\delta_e}}{L} \qquad (38)$$

s) Aircraft damping in pitch derivative

$$C_m^q = \left(C_m^q \bar{S}\,\bar{L}^2\right)_{body} + \left(C_m^q \bar{S}\,\bar{b}_{MAC}^2 \sqrt{K}\right)_{wing} + \left(C_m^q \bar{S}\,\bar{b}_{MAC}^2 \sqrt{K}\right)_{H.T} \quad (39)$$

t) Aircraft pitch acceleration derivative due to change in angle of attack

$C_m^{\dot{\alpha}}$)

u) Aircraft pitch acceleration derivative due to change in flap deflection

$$C_m^{\dot{\delta}} = C_m^{\dot{\alpha}} \left(\frac{K_{\delta o}^{\alpha}\, n}{K_{\alpha\alpha}^{\alpha}} \right)_{Wing} \quad (40)$$

v) Acceleration derivative

$$C_L^{\dot{\alpha}} = -C_m^{\dot{\alpha}} \left(\frac{L}{x_{H.T}^{\alpha} - x_{C.g}} \right) \quad (41)$$

4) Variations of all aero-parameters with Mach number

As all the coefficients and derivatives include many parameters which is function of Mach number so the tool can calculate the same parameters at different speeds and plot them which show their accurate variation with Mach number which will explain their variation in subsonic, transonic and supersonic speeds.

III. CASE STUDY (F4-E PHANTOM)

In this section, a comparison between the calculated data results from the developed tool and the experimental data of the F4-E Phantom airplane is presented.

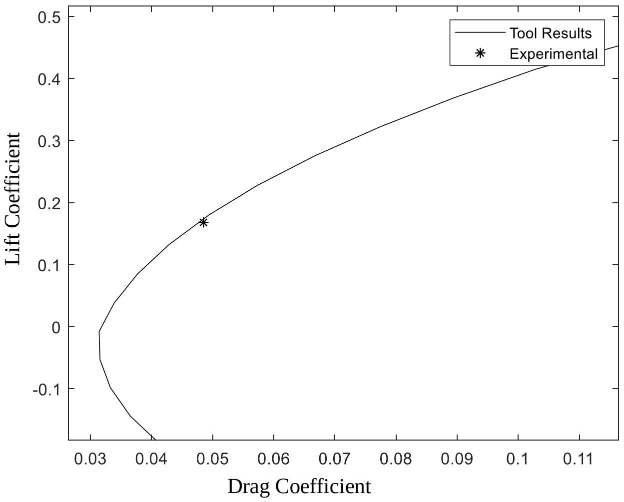

Fig. 3 Polar Curve at Mach number=1.8

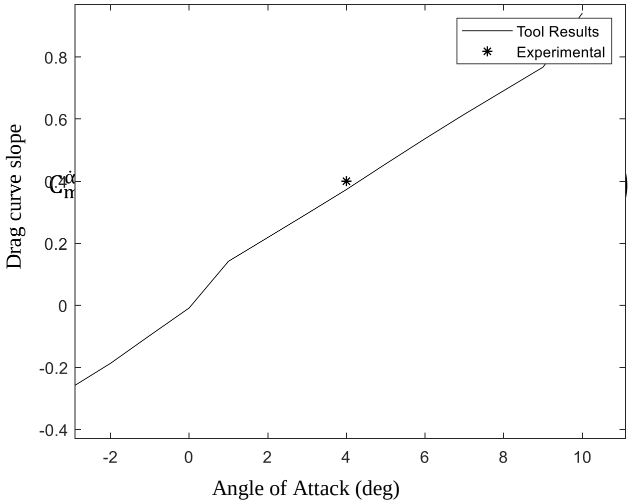

Fig. 4 Drag curve slope at Mach number=1.8

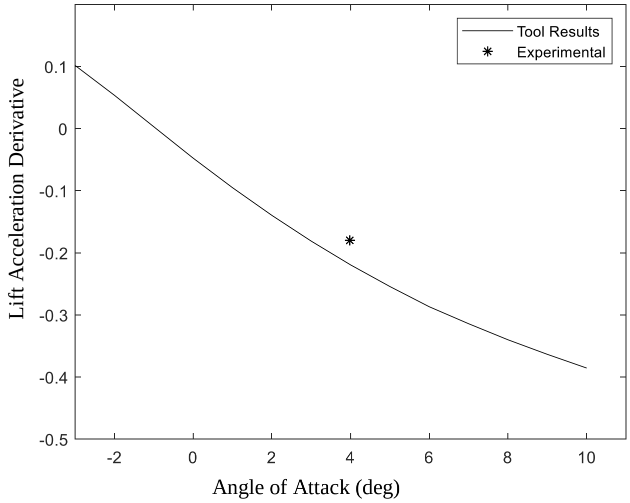

Fig. 5 Lift Acceleration Derivative at Mach number=1.8

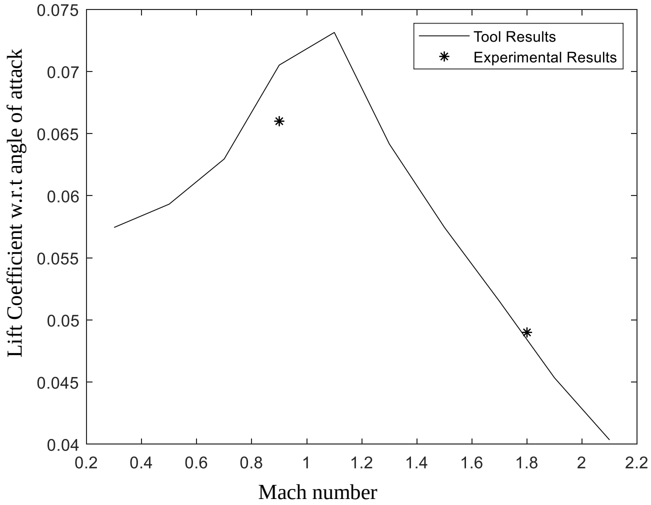

Fig. 6 Lift Curve Slope

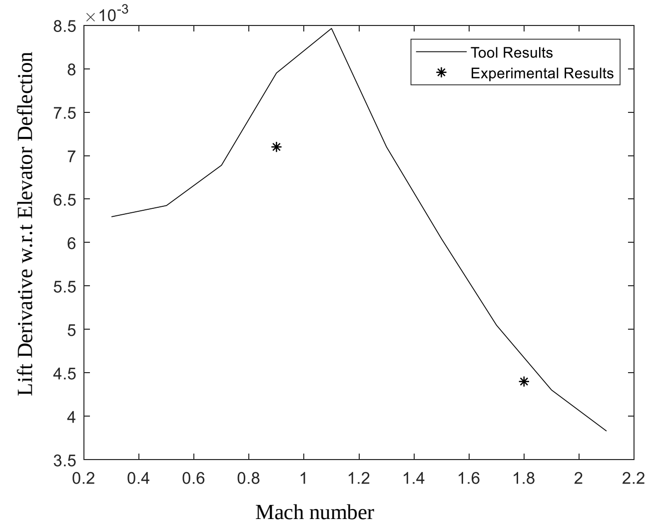

Fig. 7 Lift Derivative w.r.t Elevator Deflection

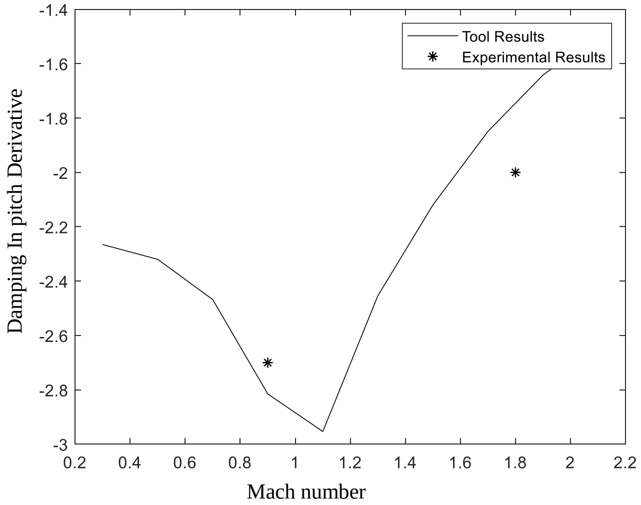

Fig. 10 Damping In pitch Derivative

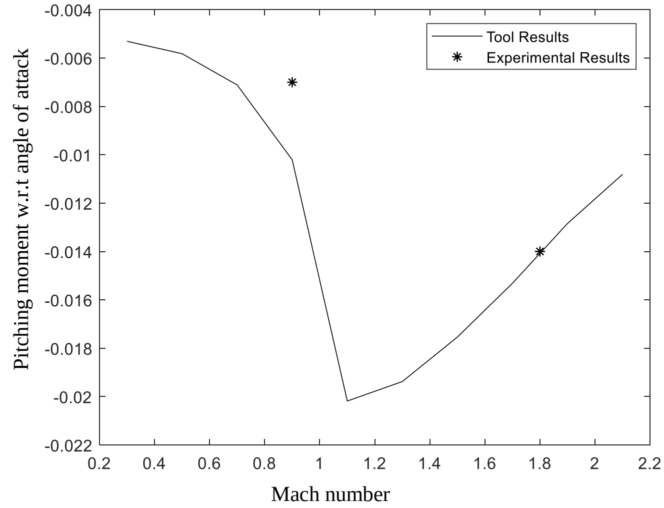

Fig. 8 Pitching moment Curve Slope

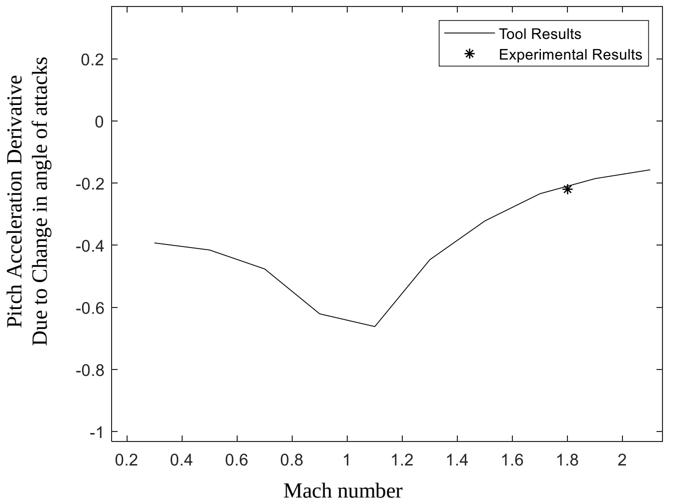

Fig. 11 Pitch Acceleration Derivative Due to Change in angle of attack

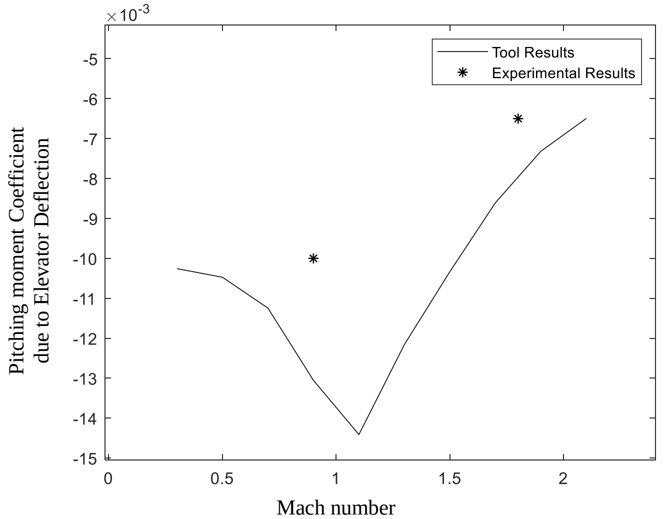

Fig. 9 Pitching moment Derivative w.r.t Elevator Deflection

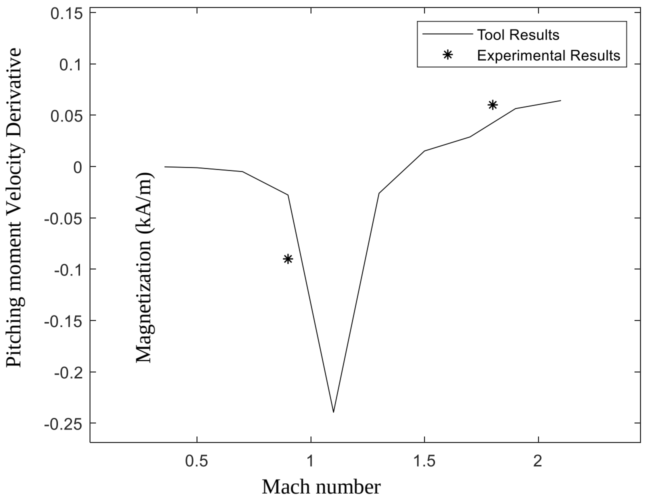

Fig. 12 Pitching moment Velocity Derivative

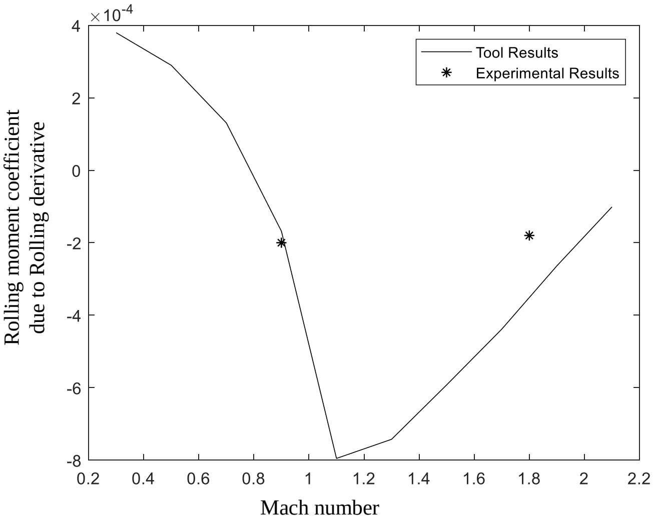

Fig. 13 Yawing moment due to Sideslip angle

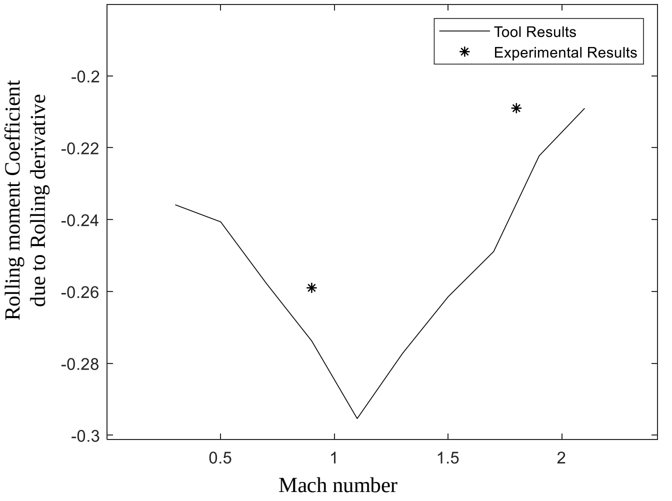

Fig. 14 Rolling moment due to Rolling derivative

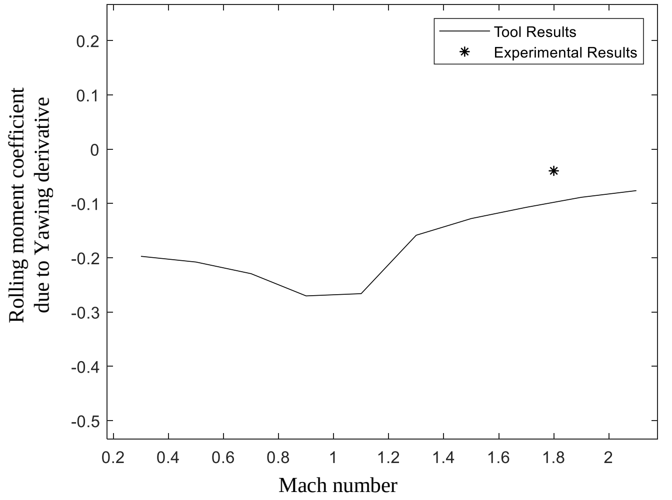

Fig. 15 Rolling due to Yawing derivative

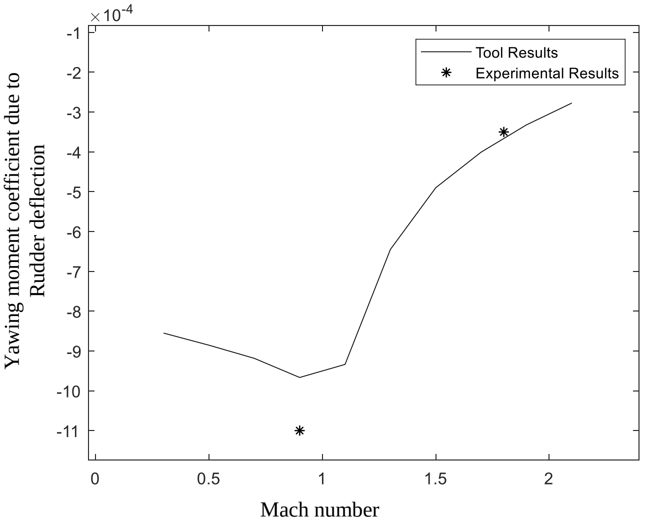

Fig. 16 Yawing moment due to Rudder deflection

IV. CONCLUSIONS

In this paper, a generalized aeromechanics tool that includes all necessary equations, lookup tables, and empirical charts is developed that the software uses more than 98 Figs from different sources where the variation may reach five parameters in some Figs.

The ultimate goal is to enable a quick and reliable estimation of aerodynamic characteristics for military/civilian airplanes, missiles, bombs and bullets in a broad speed range (subsonic, transonic, and supersonic). The developed tool is validated by published experimental data for the F4-Phantom supersonic airplane giving average error of 8 percent, which is a very acceptable deviation at the phase of preliminary design. The software presents a very good base for comparison of aerodynamic characteristics of airplanes and missiles and enables the investigation of the effect of shape changes, modifications, addition of external stores on original vehicle performance and flying qualities. Further applications of this software will be the integration of this tool in the aircraft iterative design and optimization process to enable new aircraft configurations that fulfil the design requirements.

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