FAA-ADS-33

EQUATIONS AND PROGRAMS FOR THE USE OF LOW COST DIGITAL COMPUTING EQUIPMENT IN AERODYNAMIC DESIGN SYNTHESIS AND ANALYSIS OF GENERAL AVIATION AIRCRAFT CONFIGURATIONS

TECHNICAL REPORT

March 1965

by
Daniel O. Dommasch
DODCO, INC.
Blawenburg, New Jersey
Under Contract FA-WA-4293

for

FEDERAL AVIATION AGENCY

AIRCRAFT DEVELOPMENT SERVICE

EASE

Best Available Copy

EQUATIONS AND PROGRAMS FOR THE USE OF LOW COST DIGITAL COMPUTING EQUIPMENT IN AERODYNAMIC DESIGN SYNTHESIS AND ANALYSIS OF GENERAL AVIATION AIRCRAFT CONFIGURATIONS

TECHNICAL REPORT

FAA-ADS-33

Contract FA-WA-4293

by

Daniel O. Dommasch

March 1965

Prepared For
THE FEDERAL AVIATION AGENCY
Under Contract No. FA-WA-4293

by

DODCO, INC.
Blawenburg, New Jersey

DODCO, INC.
Blawenburg, New Jersey
EQUATIONS AND PROGRAMS FOR THE USE OF LOW COST DIGITAL COMPUTING EQUIPMENT IN AERODYNAMIC DESIGN SYNTHESIS AND ANALYSIS OF GENERAL AVIATION AIRCRAFT CONFIGURATIONS, by Daniel O. Dommasch, March 1965
155 pages, 24 references, Technical Report
Contract No. (FA-WA-4293)

ABSTRACT

This report presents a summary of analysis methods and digital computer programs developed to date in the conduct of the General Aviation Safety Development program of the FAA. This report is complete in itself but does not present detailed derivations of the numerous equations utilized, nor does it constitute a definitive text on digital methods, per se. It is designed to acquaint the General Aviation Industry with the methods and programs developed for low cost simulation of aircraft dynamics and parametric studies of design parameters. The equations and programs presented are completely checked, and approximations, when they are involved, are specifically described. Complete digital programs for longitudinal dynamics, (including air turbulence effects, propeller effects, configuration change effects etc.), three axis controlled six degree of freedom motion and spin simulation are presented as appendices, while a full description of the governing equations is given in the text. Programs are written in the DICTATOR II language and a description of the DICTATOR II language is also presented. The DICTATOR language is a programming software system designed especially to expedite solution of engineering and scientific problems on digital computers. It can be learned in about 2 hours, and its use, on low cost computers, makes it possible for almost anyone to effectively use a computer for even the most commonplace problems. To demonstrate such use, a chapter on the topic of digital programming is included in this report.

This program is under the direction of Mr. Colin G. Simpson of the FAA and questions on the report content will be answered by Mr. Simpson or by DODCO, INC., the responsible contractor under Contract FA-WA-4293.

TABLE OF CONTENTS

Chapter		Page
1.)	Introduction	1
2.)	Equations of Motion and Kinematic Relations	4
3.)	Environmental Definitions	13
4.)	Basic Aerodynamic Factors	18
5.)	Specialized Spin Equations	32
6.)	Use of Digital Computers in the Solution of General Aviation Engineering Problems	43
7.)	Equation Flow for Spin Simulation	66
8.)	Sample Outputs of the Spin Program	72
9.)	Program Flow for Normal Flight Regions	81
10.)	Typical Results of the Six Degree of Freedom and Longitudinal Dynamics Programs	87
11.)	Concluding Remarks	95
	References	96
	Appendix I -- The Spin Program	98
	II -- The Multi Degree of Freedom Program	112
	III -- The Longitudinal Dynamics Program Including Overlays	130

1.) INTRODUCTION

The mission of the General Aviation Safety Development Program involves analysis and improvement of the pilots environment insofar as this environment influences his ability to safely, easily and conveniently learn to fly and to operate his airplane under all conditions. The operating environment is determined by the aircrafts handling characteristics, the instrumentation display, communication system, data dissemination documents, cockpit visibility and control placement and type. Training operations are conducted in all aircraft (at least for check out purposes), and these as well as normal operations are always involved in a study of the pilot environment.

Whereas the General Aviation Safety Development Program under the direction of Mr. C. G. Simpson involves all aspects of the operational environment, the part of the program assigned to DODCO, INC., under Contract FA-WA-4293 is concerned principally with handling qualities as these influence pilot performance. Previous reports (see references) prepared by DODCO, INC., for this project have dealt mainly with the design and use of parallel stability augmentation systems designed to cheaply tailor handling qualities to better suit the needs of human pilots. As part of these studies, low cost digital synthesis and analysis methods were developed for rapid examination of the effects of design parameter changes on systems performance. The methods of analysis are applicable to broader problem areas than this, and can be used to effect cost reduction in the airplane design process itself. Thus, the methods and programs developed have significance independently of the results they have produced to date. This report has been prepared to provide a presentation of the analysis methods and associated digital programs required for implementation. The methods are applicable to aerodynamic configuration analysis, performance studies, examination of stability and control characteristics, reduction of flight test data, parameter study, synthesis and analysis of automatic control devices, and so on.

The particular advantages of the methods reside in their ability to quickly and economically produce quite precise answers to complex problems.

The use of digital computing techniques for analysis of performance, stability and control problems is not new to the aircraft industry as a whole, however such usage has, in the past, been confined mainly to the military and transport types of aircraft because of manpower and cost considerations. However, low cost computers of relatively small size are now available which are quite capable of handling G. A. problems and proper use of this equipment can lead to substantial development savings.

Because of the difficulties involved in obtaining valid, closed form solutions to many aerodynamic problems, particularly those involving pressure distributions, values of stability parameters and assessment of control force characteristics, the G. A. industry has depended heavily in the past upon experimental techniques for design development. Whereas, these techniques will remain essential in the foreseeable future, some reduction in the amount of empirical effort due to employment of simulation procedures is possible, which at the very least, will provide a way of not only analysing test data but of defining the avenues of investigation.

Examination of dynamic processes through use of high speed computing equipment is known as simulation. Either digital or analog computers are usable for simulation, however when analog computers are used, every program must be "scaled" by the programmer to ensure that generated numerical values do not fall outside of the usable range of specific amplifiers of the analog circuits and special provisions are required to handle nonlinear problems. On the other hand, analog computers are inherently capable of producing "real time" outputs relatively more cheaply than digital equipment. Hardware and software available in digital systems eliminates the requirement for problem "scaling" and, digital computers, since they function on an increment basis are inherently adapted to solution of nonlinear problems.

For simulation efforts directed toward design goals rather than real time investigation of man-machine interactions, the smaller digital computers such as the IBM 1130 series, CCC DDP-116 and similar equipment available at a yearly rental of around $10,000 are very well suited to economical and rapid solution of design analysis and synthesis problems. Effective use of these low cost, minimum systems, depends on the programming systems (software) utilized. If compiler type software (such as FORTRAN) is used, efficient operation normally requires a considerable amount of peripheral equipment which increases costs, however if systems such as DICTATOR are used such peripheral units are not required, and operations are actually simpler and more rapid than with compilers. Since proper engineering employment of digital computers depends so much on the programming technique employed, a special chapter on computer programming is provided in this report.

The results obtained with a simulation program can be no more accurate than the equations and data used by the program and the accuracy is also influenced by the numerical techniques and word length employed. Inherently the digital computer is a more accurate device than an analog system, however its full accuracy is not required for all problems, and the basic advantage of the digital equipment resides in the fact that it is simple to program a digital computer for most problems.

Good simulation programs faithfully reproduce the actual motions and characteristics of the system being simulated and this means that the equations of motion are not nearly so idealized as those used to obtain closed form solutions on a slide rule or by hand computation. Moreover, to provide a good simulation an essentially complete problem definition is required since computers are naturally incapable of making plausible assumptions, and decision paths and conditional tests must be established by the programmer on an a-priori basis. Therefore, to obtain valid results from computers, one must either start with a good problem analyst or a proven program. This report presents several proven programs of broad application and also presents a discussion of analysis techniques pertinent to the G. A. field.

This report is intended to be of use to the G. A. industry, however a report such as this cannot answer all specific questions nor be written to fit in with the background of all its readers. Therefore it is anticipated that a number of questions will arise because of its publication and these questions need to be answered before the potential benefits of the methods can be realized.

To provide for such questions, personnel of DIDCO, INC., are available to provide a limited amount of consultation to the industry in connection with the content of this report. Questions should be directed either to the FAA or directly to DIDCO, INC.

Although the emphasis in this report is on problems not readily solved without a digital computer, it is recognized that, from an economic standpoint, the real "pay off" in the use of digital computers in the General Aviation industry depends on their day to day employment in routine computations, and the analysis of this type of effort can only be carried out in terms of operating circumstances in specific companies. To aid such analysis, it is recommended that Chapter 6 on digital programming be studied carefully.

2.) EQUATIONS OF MOTION AND KINEMATIC RELATIONS

The equations governing airplane motion are derived directly from Newton's three basic laws as these apply to a mass particle and to a rotating body. Complications arise only because any axis system attached to an airplane is moving and accelerating in inertial space and because the aerodynamic forces and moments are inherently associated with a different axis system than the body axes of the airplane. Newton's laws, in their basic form, apply only to an axis system fixed in inertial space and therefore they need to be transformed for a study of airplane motion. Moreover, convenient reference axes are not necessarily the principal axes of the body and therefore products of inertia and cross products of rotary velocities enter into analysis in some cases.

The study of aeroelastic phenomena (including flutter and other structural deformation effects) involves consideration of structural elasticity and damping influences as well as the characteristics of the separate components of the aircraft as they may move and deform independently of the mass center motion.

We shall not present a dissertation on rigorous methods of aeroelastic analysis it being outside the scope of this document to do much more than mention that such studies are well conducted on digital equipment. Thus the equations which follow apply to a structurally rigid system, which, however has movable control surfaces.

The axes systems utilized have been selected to permit study of flight at any angle of attack or sideslip and are illustrated in Figure 2:1.

The basic earth reference system is defined by the coordinates h (geometric altitude), N (true North) and E (true East). The azimuth angle ψ, is measured from true North in a clockwise sense.

If we were to consider a long range navigational problem or flight at hypersonic speeds, recognition would be required of the fact that the N-E coordinate grid is coincident with the approximately spherical figure of the earth (geoid). That is, N and E are perpendicular axes only on a spherical surface and are approximately circular arcs rather than straight lines. We would also have to account for the fact that the earth is rotating in inertial space and is simultaneously moving in its orbit about the sun. However, at the speeds of flight of G. A. equipment consideration of effects of this is unwarranted, since they are too small to provide significant, measurable influences on numerical results.

Thus, we treat the N-E plane as flat, and h as a true normal to that plane. The earths rotation acts to slightly reduce the gravitic acceleration, measured on the earth surface, however this influences only the fourth significant figure of the value of "g", and one can normally neglect this influence in the study of G. A. dynamics.

Aerodynamic forces are referenced to a wind axis system which has its x_w axis along the path of flight of the airplane. The angle between the horizontal (N-E plane) and x_w is denoted by γ. The y_w axis is parallel to the N-E plane and orthogonal to x_w, while the z wind axis, z_w is orthogonal to both x_w and y_w. The wind axis system is defined, analytically in terms of the earth reference axis system by first rotating about h through the azimuth angle ψ and thence upward about y_w through the angle γ. The net aerodynamic lift, L, does not normally lie in the $x_w - z_w$ plane but acts at an angle ϕ_w to this plane as shown in Figure 2:1. The angle ϕ_w (aerodynamic bank angle) is a rotation about x_w only, since lift is defined as acting perpendicular to x_w. The angle of attack, α, is measured in the plane of L and x_w (i.e., it is a rotation in this plane) and the pitch attitude angle θ is measured in the same plane. The sideslip angle β is a rotation perpendicular to the $L - x_w$ plane as shown in Figure 2:1. Rotations through ϕ_w, α and β in that order from the wind axis system provide transformation to the body axis system denoted by x, y and z in Figure 2:1. Note that the body axis system is a conventional right handed axis system, whereas the wind axis system has it positive z_w direction reversed from the right hand axis convention.

The body axes x, y and z are generally defined somewhat arbitrarily in that x may simply be the zero fuselage station or parallel to the normal zero lift axis of the wing. The y axis is normally perpendicular to the plane of symmetry of the airplane while the z axis is orthogonal to x and y. The center of the axis system is taken to be the center of gravity of the airplane and this is also the origin for the wind axis system.

Aerodynamic moment parameters are normally measured or computed with respect to the x, y, z body axis system while the force parameters are defined in terms of the wind axis system. Because the x, y, z, axis system is not necessarily the principal axis system of the airplane, the equations of motion about these body axes involve both product of inertia and angular velocity cross product terms. As long as angular velocities are relatively small, however, there are many cases when it is legitimate to drop all inertial terms other than those involving products of angular accelerations and moments of inertia.

Aside from the case of unequal fuel loading of wing and tip tanks, the xz plane is a plane of dynamic symmetry so that the y axis is a principal axis and the products of inertia involving y coordinates, J_{xy} and J_{yz}, vanish. Under these circumstances the equations of rotary motion become (reference 14)

$$\left.\begin{aligned} I_x\dot{p} &= J_{xz}(\dot{r} + pq) - (I_z - I_y)qr + \ell \\ I_y\dot{q} &= J_{xz}(r^2 - p^2) + (I_z - I_x)pr + m \\ I_z\dot{r} &= J_{xz}(\dot{p} - qr) - (I_y - I_x)pq + n \end{aligned}\right\} \qquad \text{..........2:1}$$

wherein:

I_x = mass moment of inertia about the x roll axis, slug-ft.^{2}

I_y = mass moment of inertia about the y (pitch) axis, slug-ft.^{2}

I_z = mass moment of inertia about the z yaw axis, slug-ft.^{2}

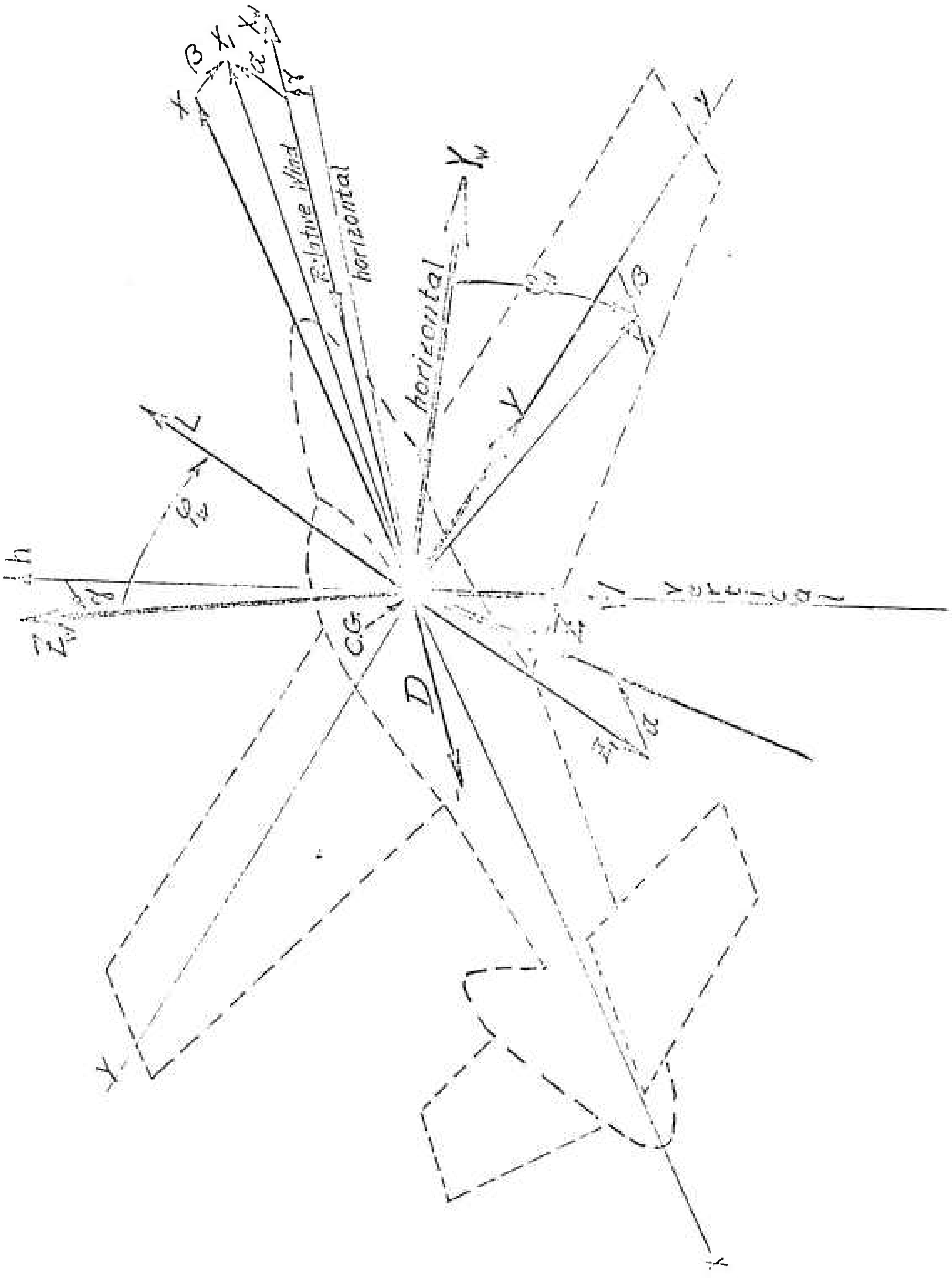


FIGURE 2:1

J_{xz} = product of inertia in the xz plane, slug-ft.^{2}

ℓ = external rolling moment, ft-lbs.

m = external pitching moment, ft-lbs.

n = external yawing moment, ft-lbs.

p = roll rate, rad./sec.

q = pitch rate, rad./sec.

r = yaw rate, rad./sec.

$(\dot{\ })$ signifies the first time derivative

For studies involving only small excursions from equilibrium flight or when roll, yaw and pitch rates are small, it is frequently assumed that the rotational rate, cross product terms are of a small order and that J_{xz} can be neglected. In such an event equations 2:1 are simplified to yield

$$\left.\begin{aligned} I_x\dot{p} &= \ell \\ I_y\dot{q} &= m \\ I_z\dot{r} &= n \end{aligned}\right\} \qquad \ldots\ldots\ldots\ldots\ldots 2:2$$

The equations governing motion of the airplane mass center in still air are:

$$\left.\begin{aligned} \dot{V} &= g\left[(C_T\cos\gamma_T - C_D)/C_L - \sin\gamma\right] \\ \dot{\gamma} &= (g/V)\left[\left\{(C_L + C_T\sin\gamma_T)\cos\phi_w - C_y\sin\phi_w\right\}/C_L - \cos\gamma\right] \\ \dot{\psi} &= (g/VC_L\cos\gamma)\left[(C_L + C_T\sin\gamma_T)\sin\phi_w + C_y\cos\phi_w\right] \end{aligned}\right\} \qquad \ldots\ldots 2:3$$

in which:

V = true airspeed in still air, ft/sec.

$\dot{V}$ = dV/dt, ft/sec.^{2}

g = acceleration of gravity, ft/sec.^{2} (taken as a constant 32.17 which includes the influence of centrifugal relief due to earth rotation at 45°N latitude)

C_T = thrust coefficient, dimensionless, T/qS

T = propeller thrust, lbs.

q^* = dynamic pressure, lb/ft.^{2}, [illegible]

S = wing area, ft.^{2}

ρ = air density, slugs/ft.^{3}

α_T = inclination of thrust axis [illegible], radians

C_D = drag coefficient, [illegible]

D = drag, lbs.

C_{L_L} = level flight lift coefficient, [illegible]

W = aircraft gross weight, lbs.

γ = flight path inclination angle, radians (see Figure 2-1)

$\dot{\gamma}$ = $d\gamma/dt$, rad/sec.

ϕ_W = aerodynamic bank angle, radians (see Figure 2-1)

C_Y = side force coefficient, Y/qS

Y = side force, lbs.

$\dot{\zeta}$ = rate of change of azimuth, [illegible].

These equations apply only in still air, in which case the [illegible] inertial speed relative to the [illegible] the [illegible] quantity. For flight [illegible] speed of an relative air [illegible] relative to the fixed gravity [illegible] turbulent air, changes to the [illegible] velocity of the air creates [illegible] vertically or horizontally. [illegible] produces a random distribution [illegible] characterized by their [illegible] of the [illegible]. Turbulence [illegible] change or extreme in [illegible] [illegible]. On a statistical, [illegible] is given in terms of the speed [illegible] given [illegible] is called a [illegible] but [illegible] as a useful analysis [illegible] in dynamic studies.

Programming of a wide variety of turbulence conditions is intended mainly for study of longitudinal dynamics and control, particularly to determine gust responses to periodic gusts [illegible] and for examining ability to recover rapidly from disturbances during [illegible]. Lateral-directional turbulence effects studied at [illegible] involved only the input of external step changes in yawing and rolling [illegible] simultaneously with more [illegible] descriptions of [illegible].

Both the magnitude and direction of the relative wind are altered by gusts, [illegible] the magnitude and direction of the lift and drag vectors [illegible] with the [illegible]. These [illegible] are conveniently [illegible] following considerations.

If V_{wH} is the instantaneous horizontal component of the air disturbance, positive if a headwind, and V_{wV} is the instantaneous vertical component, positive if upward, the velocity of the airplane relative to the disturbed air is given by

$$V_R^2 = (V\cos\gamma + V_{wH})^2 + (V\sin\gamma - V_{wV})^2 \qquad \ldots\ldots\ldots\ldots\ldots 2:4$$

where:

V is the inertial speed relative to the earth's surface

V_R is true airspeed

γ is the inclination of V as illustrated in Figure 2:1

The relative velocity vector, V_R, being no longer coincident with V makes an angle γ_r to the horizontal defined by

$$\tan\gamma_R = (V\sin\gamma - V_{wV})/(V\cos\gamma + V_{wH}) \qquad \ldots\ldots\ldots\ldots\ldots 2:5$$

For study of pure longitudinal motion the change in angle of attack is given by

$$\Delta\alpha = \gamma - \gamma_r \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2:6$$

However this equation is not valid when the airplane is banked.

Determination of $\Delta\alpha$ in a general case will be dealt with in the discussion of kinematic relations which follows [illegible].

Assuming that $\Delta\alpha$ is known and using the aerodynamic angle of attack to define C_L, C_D etc., the equations of motion [illegible]

$$\dot{V} = g\left[(C_T\cos\alpha_T - C_D\cos\text{[illegible]} + C_L\sin\text{[illegible]})/C_{\text{[illegible]}} - \sin\gamma\right]$$

$$\dot{\gamma} = (g/V)\left[\left\{(C_L\cos\text{[illegible]} + C_{\text{[illegible]}}\sin\text{[illegible]}\ \text{[illegible]} - C_y\sin\text{[illegible]}\right\}/C_{\text{[illegible]}} - \cos\text{[illegible]}\right]$$

$$\dot{\text{[illegible]}} = (g/VC_{LL}\cos\gamma)\left[C_L\cos\text{[illegible]} + C_y\text{[illegible]}\right]$$

....................2:7

wherein α_T is the inclina[illegible] of [illegible] V, and to V[illegible].

The kin[illegible]tic relations are [illegible] which also define the velocity [illegible]. Thus, considering first the velocity [illegible], the [illegible]

$\dot{h} = V\sin\gamma$ 2:8

and the vertical acceleration, [illegible] is [illegible] by direct differentiation as

$\ddot{h} = \dot{V}\sin\gamma + \dot{\gamma}V\cos\gamma = \dot{V}\sin\text{[illegible]}$ 2:9

$\dot{x}$, the instantaneous horizontal [illegible] is given by

$\dot{x} = V\cos\gamma$ 2:10

while the Northerly component of [illegible]

$V_{NS} = V\cos\gamma\cos\text{[illegible]} = \dot{x}\cos\text{[illegible]}$ 2:11

and the Easterly component of [illegible],

$V_{EW} = V\cos\gamma\sin\text{[illegible]} = \dot{x}\sin\text{[illegible]}$ 2:12

Since N and E are fixed [illegible], we have that

$\dot{V}_{NS} = \ddot{x}\cos\text{[illegible]} - \dot{x}\dot{\text{[illegible]}}\sin\text{[illegible]}$ 2:13

$$\dot{V}_{EW} = \ddot{x}\sin\psi + \dot{x}\dot{\psi}\cos\psi \qquad \text{...............2:14}$$

Whereas the equations for $\dot{p}$, $\dot{q}$ and $\dot{r}$ (set 2:1) may be integrated to define p, q, r, respectively, roll, pitch and yaw angles are measured between sets of axes rotating with respect to one another so that a second integration cannot be legitimately conducted to define these relative angles, and a kinematic resolution is required to determine $\dot{\alpha}$, $\dot{\beta}$ and $\dot{\varphi}_W$. This resolution (refer to Figure 2:1) yields, for a still atmosphere

$$\left.\begin{aligned} \dot{\alpha} &= q\cos\beta - p\sin\beta - (\dot{\gamma}\cos\varphi_W + \dot{\psi}\cos\gamma\sin\varphi_W) \\ \dot{\beta} &= \dot{\psi}\cos\gamma\cos\varphi_W\cos\alpha - \dot{\gamma}\sin\varphi_W\cos\alpha - r - \dot{\psi}\sin\gamma\sin\alpha \\ \dot{\varphi}_W &= p\cos\beta\cos\alpha + q\sin\beta\cos\alpha + r\sin\alpha + \dot{\psi}\sin\gamma \end{aligned}\right\} \qquad \text{..........2:15}$$

When the air mass is moving, $\dot{\alpha}$ and $\dot{\beta}$ are obtained by using $\dot{\gamma}_R$ in place of $\dot{\gamma}$ in the first and second of the above relations. For longitudinal plane motion (i.e., $\beta = \dot{\beta} = \varphi_W = \dot{\varphi}_W = 0$) we have that

$$\dot{\alpha} = q - \dot{\gamma}_r \qquad \text{...............2:16}$$

since, for this case both γ and q are measured with respect to the fixed earth reference axes, integration can be performed to give

$$\alpha = \theta - \gamma_r \qquad \text{...............2:17}$$

where θ = pitch angle, radians, so that

$$\Delta\alpha = \gamma - \gamma_r \qquad \text{...............2:18}$$

These latter relationships hold only for flight in a vertical plane, since under other conditions the measurement plane for α and θ is rotating in inertial space.

If the air mass through which the airplane flies is moving, the relative wind vector continuously changes for two reasons, the first involving motion of the aircraft with respect to the ground and the second motion of the air with respect to the ground. Only the components of V_R (i.e., V_{RV} and V_{RH}), here assumed independent of azimuth, are measured in a non-rotating system and therefore only these components can be directly differentiated to yield acceleration components in inertial space. The vectors V_{RV} and V_{RH} are defined by

Revised April 7, 1965

$$\left.\begin{aligned} V_{R_V} &= V\sin\gamma - V_{W_V} \\ V_{R_H} &= V\cos\gamma + V_{W_H} \end{aligned}\right\} \qquad \ldots\ldots\ldots\ldots\ldots 2:19$$

Differentiating

$$\left.\begin{aligned} \dot{V}_{R_V} &= \dot{V}\sin\gamma + \dot{\gamma}V\cos\gamma - \dot{V}_{W_V} = \ddot{h} - \dot{V}_{W_V} \\ \dot{V}_{R_H} &= \dot{V}\cos\gamma - \dot{\gamma}V\sin\gamma + \dot{V}_{W_H} = \ddot{x} + \dot{V}_{W_H} \end{aligned}\right\} \qquad \ldots\ldots\ldots\ldots\ldots 2:20$$

Projecting these components along the V_R axis, inclined at the angle γ_R to the horizontal

$$\dot{V}_R = \dot{V}_{R_V}\sin\gamma_R + \dot{V}_{R_H}\cos\gamma_R \qquad \ldots\ldots\ldots\ldots\ldots 2:21$$

While normal to V_R we have

$$\dot{\gamma}_R V_R = \dot{V}_{R_V}\cos\gamma_R - \dot{V}_{R_H}\sin\gamma_R \qquad \ldots\ldots\ldots\ldots\ldots 2:22$$

where $\dot{\gamma}_R V_R$ is a ficticious centrifugal acceleration component based on the rate of change of γ_R.

This completes the presentation on dynamic and kinematic relations, and in Chapter 3, we shall consider the environmental inputs to the simulation program.

3.0 ENVIRONMENTAL DEFINITIONS

The external operating environment for an airplane is the earth's atmosphere and this is described by specifying the distribution of density, pressure, temperature, moisture and velocity [illegible] within the air mass occupied by the airplane in terms of time and the [illegible] space coordinates x, y and h.

For dynamic analysis purposes, the presence of condensed water vapor in the form of cloud particles, rain or ice [illegible] considered, however for performance studies it is necessary [illegible] that, since water vapor, as [illegible] is less dense than dry air [illegible], the presence of water vapor reduces air density by [illegible] conditions. This reduction in density affects [illegible] airplane performance and may induce critical conditions [illegible] circumstances. Similarly, although standard atmospheric [illegible] for many study purposes it is often essential to [illegible]. It is to be remembered that a "standard atmosphere" is [illegible] with little [illegible] under operational conditions [illegible] for legal and comparison purposes than for operational [illegible].

Although one may use exact definitions [illegible] atmospheric properties as they vary with height, such [illegible] for most studies, and we have adopted curve fit [illegible] which closely simulate the standard atmosphere over the [illegible] ft. of altitude. These are given by the following relationships:

$$\sigma = e^{-0.297h \times 10^{-4}} \qquad \text{.....................3:1}$$

$$\delta = e^{-0.347h \times 10^{-4}} \qquad \text{.....................3:2}$$

where:

σ = density ratio = ρ/ρ_o 3:3

δ = pressure ratio = p/p_o 3:4

ρ = ambient density, slugs/ft.^{3}

p = ambient pressure, lbs/ft.^{2}

ρ_o = 0.0023769

p_o = 2116.2

h = geometric height, ft. ([illegible])

Of significance in studies of [illegible] derivatives $\dot{\sigma}$ and $\dot{\delta}$. By [illegible] are given by:

$$\dot{\sigma}/\sigma = -\,0.297\dot{h} \times 10^{-4} \qquad \ldots\ldots\ldots\ldots 3:5$$

$$\dot{\delta}/\delta = -\,0.347\dot{h} \times 10^{-4} \qquad \ldots\ldots\ldots\ldots 3:6$$

where the ($\cdot$) signifies a time derivative.

For study of subsonic flight [illegible] be of great importance, [illegible] condition of [illegible] which yields

T = temperature, [illegible] $\ldots\ldots\ldots\ldots$ 3:7

Nonstandard conditions can be [illegible] of 3:1 and 3:2 to [illegible].

[illegible] motion may be [illegible] of various types. [illegible], however, two basic types of [illegible] (1) [illegible] disturbances and (2) [illegible] variations in temperature, [illegible] of thermodynamics, and [illegible] involving substantial turbulence, [illegible] analysis are more important [illegible] for describing its effects on the [illegible] addition to simulation of [illegible] provide a thermodynamic analysis [illegible].

Three [illegible] gusts and other [illegible] they do not occur [illegible] in nature, are useful in analysis [illegible] of the aircraft. [illegible] first one way and then the [illegible] that provide a [illegible] which are applied [illegible] in V_x and V_y [illegible] as functions either of time or [illegible].

The recent occurrence of air [illegible] involving [illegible] clear air turbulence (CAT) and unstable [illegible] addition [illegible] not only on jet [illegible] longitudinal [illegible] than it having [illegible] periodic CAT incidents have been reported only at high altitudes and have involved only heavy, relatively flexible types of aircraft.

Thus there seems to be little reason to anticipate that periodic turbulence of this type introduces any new problems in the [illegible] design field. On the other hand, study of the effects of periodic disturbances on autopilot-airplane coupling is useful in determining if such problems can exist with a given control logic, and for this reason a model for simulating periodic clear air turbulence is presented.

Physically speaking, air turbulence is always associated with vorticity of the air, and periodic turbulence is more specifically associated with vortex systems. To describe periodic turbulence mathematically one may impose a pattern of symmetric vorticity in the air mass and compute the trajectory of an aircraft in the neighborhood of the vortex system; [illegible] of different periodic distributions of conditions can be obtained. In order to predict the presence of periodic turbulence, the origin(s) of the vortex system causing it must be established, but such a discussion of the possible origins is not within the scope of our present task. The only stable vortex system known to exist is the Karman Street which can be created by any [illegible] situation or by any type of partial blockage of air flow. This system has the ability to move along its axis away from its point of origin, which may explain why periodic clear air turbulence is sometimes found [illegible] where no origin mechanism exists. For simulation studies, the following equations are used to define the velocity field of the Karman Street.

Following the convention that a tail wind carries a plus sign, for an airplane flying on a positive x heading, V_{wx}, the horizontal wind due to vortex street is given by:

$$V_{wx} = \frac{k\pi}{a} \left\{ \frac{\sinh(y - \frac{b}{2})2\pi/a}{\cosh(y - \frac{b}{2})2\pi/a - \cos 2\pi x/a} - \frac{\sinh(y + \frac{b}{2})2\pi/a}{\cosh(y + \frac{b}{2})2\pi/a - \cos(x-a/2)2\pi/a} \right\} \quad \ldots\ldots\ldots\ldots 3{:}8$$

while, V_{wy}, vertical wind due to vortex street, plus upward, is given by:

$$V_{wy} = \frac{k\pi}{a} \left\{ \frac{\sin 2\pi x/a}{\cosh(y - \frac{b}{2})2\pi/a - \cos 2\pi x/a} - \frac{\sin(x-a/2)2\pi/a}{\cosh(y + \frac{b}{2})2\pi/a - \cos(x-a/2)2\pi/a} \right\} \quad \ldots\ldots\ldots\ldots 3{:}9$$

where k is the strength of an individual vortex of the street.

The entire system, as an entity, moves to the right with a velocity of

$$V_{wsy} = -\frac{k\pi}{a} \tanh\left(\frac{\pi b}{a}\right) \quad \ldots\ldots\ldots\ldots 3{:}10$$

The system also induces a flow of air [illegible] which has an average [illegible] at the centerline of

$$V_{H_{av}} = -\frac{k\pi}{a}\left\{\tan\left(\frac{\pi b}{a}\right) + \frac{1}{\tanh(\ldots)}\right\} \qquad \ldots\ldots\ldots\ldots\ldots\ldots 3:11$$

(this is the numerical average of the [illegible] maximum and minimum horizontal winds encountered along the x axis).

The frequency of the horizontal [illegible] is [illegible] that of the vertical gusts along a central traverse with [illegible]:

Horizontal gust period, seconds, [illegible]

where V is the true airspeed [illegible] 3:12

Vertical gust period, seconds, [illegible]

From equation 3:12, it can be [illegible] the true airspeed - not indicated airspeed - which influences the [illegible] of the encounter.

For simulation purposes, it is [illegible] the derivatives [illegible]. These are obtained by logarithmic differentiation of equations 3: [illegible] of the form

$$\dot{V}_{H} = \frac{\ldots^2}{a^2}\left\{\frac{\sinh\zeta_1}{\cosh\zeta_1 - \cos\zeta_3}[\ldots] - \frac{\sinh\zeta_2}{\cosh\zeta_2 - \cos\zeta_4}[\ldots]\right\} \qquad \ldots\ldots 3:13$$

$$\dot{V}_{V} = \frac{\ldots^2}{a^2}\left\{\frac{\sin\zeta_3}{\cosh\zeta_1 - \cos\zeta_3}[\ldots] - \frac{\sin\zeta_4}{\cosh\zeta_2 - \cos\zeta_4}[\ldots]\right\} \qquad \ldots\ldots 3:14$$

where

$$\zeta_1 = (y-b/2)\frac{2\pi}{a},\ \zeta_2 = (y+b/2)\ldots,\ \zeta_3 = \ldots,\ \zeta_4 = (x-a/2)\ldots \qquad \ldots\ldots 3:15$$

In the above:

$$\dot{x} = V\cos\gamma$$

$$\dot{y} = \dot{h} = \text{rate of change of altitude} = V\sin\gamma$$

where V is true speed and γ is true flight path attitude angle.

In the examination of specific dynamic problems one requires values of, and derivatives of, the indicated airspeed, or more properly of calibrated airspeed. At the flight speeds involved here, it is permissible to equate indicated, equivalent and calibrated airspeeds and symbolize the three by the term V_i, where,

$$V_i = \text{indicated airspeed, ft/sec.} = \sqrt{2q^*/\rho_o} \qquad \text{..........3:16}$$

in which,

$$q^* = \frac{1}{2}\rho V_R^2 = \frac{1}{2}\rho_o V_i^2 \qquad \text{....................3:17}$$

ρ and V_R are defined by equations 3:1 and 3:4 respectively.

By direct differentiation, we have

$$\dot{q}^*/q^* = \dot{\rho}/\rho + 2\dot{V}_R/V_R = 2\dot{V}_i/V_i \qquad \text{....................3:18}$$

in which $\dot{\rho}$ is given by equation 3:5 and $\dot{V}_R$ by equation 2:21.

It is readily possible to amplify the environmental definitions provided here to include Mach number computations, Reynolds number computations and so on to handle other types of problems, however such amplifications are not required for this present study. This, therefore, completes the environmental definition set, and in the next chapter we shall consider basic aerodynamic inputs to the simulation program.

4.1 BASIC [illegible] FACTORS

The three orthogonal force [illegible] acting on the airplane are lift, L, drag, D, and side force Y. [illegible] L and Y act [illegible] perpendicular to the relative wind. With [illegible] drag acts along x_s, lift along z_s and side force [illegible] y_s. [illegible] designated by "ℓ", rolling [illegible] and n, yawing [illegible]. These moments are defined as [illegible] axes, x, y and z respectively.

At speeds less than [illegible] it is [illegible] to consider that the forces and moments are primarily functions of [illegible] (C_L = [illegible]), [illegible] and the angular rates, [illegible] rate [illegible]. At high speeds and at higher [illegible] influences need to be included. [illegible] Reynolds number effects are [illegible], [illegible] introduction is a relatively simple matter.

To eliminate the need for dealing directly with dynamic pressure in description of aerodynamic factors, the [illegible] are used, specifically the [illegible] are expressed in the coefficient form.

$$C_L = L/q^*S$$

$$C_D = D/q^*S$$

$$C_Y = Y/q^*S$$

$$C_\ell = \ell/q^*Sb \qquad \text{.....................1:1}$$

$$C_m = m/q^*S\bar{c}$$

$$C_n = n/q^*Sb$$

in which

q^* = dynamic pressure, [illegible]

S = wing area, ft.^{2}

$\bar{c}$ = mean aerodynamic chord, ft.

b = wing span, ft.

All of the coefficients are functions of [illegible], p, q and r, but the degree of dependence on these five [illegible] greatly. The accuracy of determination of the coefficients [illegible], from wind tunnel tests or by a combination of both [illegible] limited to approximately the following accuracies:

C_L, ± 5% C_ℓ, ± 1[illegible]

C_D, ± 10% C_m, ± 1[illegible]

C_Y, ± 15% C_n, ± 1[illegible]

A carefully conducted flight [illegible] can provide considerably improved [illegible], particularly of C_L [illegible] of the [illegible]. The relation between C_L and C_D [illegible] in this way to an accuracy of ± [illegible]. However, flight [illegible] establish values of rate [illegible] or [illegible], [illegible] extensive data reduction analysis is required [illegible] of these quantities. Digital procedures provide [illegible] of isolating cross [illegible] and [illegible] derivatives [illegible] from properly designed and conducted flight test [illegible].

Depending on the accuracy required, the coefficients may be expressed by [illegible] of varying complexity. [illegible] wing lift is taken to be a function of angle of attack, α, flap deflection [illegible] and aileron deflection δ_a. Thus,

$$C_{L_W} = f(\alpha, \delta_f, \delta_a) = \text{wing lift coefficient} \qquad \text{..........4:2}$$

This relation ignores the effects of sideslip and only partially deals with the effects of roll rate due to [illegible].

For many studies the δ_a effects are ignored since data are not available to properly describe them. This reduces the functional dependence to

$$C_{L_W} = f(\alpha, \delta_f) \qquad \text{....................4:3}$$

At angles of attack below the stall [illegible], for the aspect ratios of present G. A. aircraft, it is normally [illegible] to consider that the slopes of the curves of C_L vs. [illegible] and C_L vs. [illegible] are constants and that

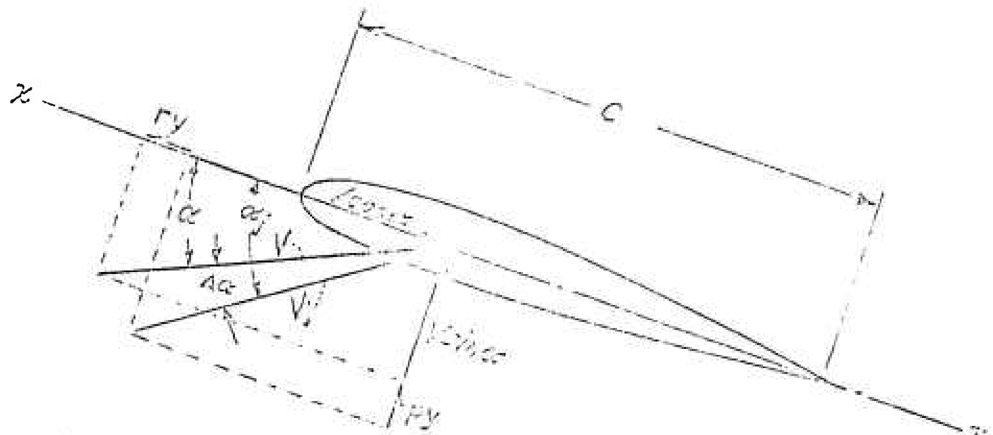
$$C_L = \frac{\partial C_L}{\partial \alpha}\alpha + \frac{\partial C_L}{\partial \delta_f}\delta_f \qquad \text{....................4:4}$$

where α is measured from the zero lift chord of the wing. Note the zero lift chord of the wing generally differs (except for symmetric airfoils) from the [illegible] or geometric chord by a fixed angle. If this angle is $\alpha_{\ell=0}$ and α_g is the angle of attack of the [illegible] chord then,

$$\alpha = \alpha_{\ell=0} + \alpha_g \qquad \text{....................4:5}$$

For [illegible] of flight [illegible] such as [illegible] involving [illegible] the differences [illegible] in the velocity and angle of [illegible] on the [illegible] the lift slope reverses its sign. [illegible] with in [illegible]. The effects of rolling and [illegible] (less than stalling) angles of attack are analysed [illegible].

If V is velocity of the c.g. [illegible] angle of attack of the [illegible], then at some section of the [illegible] distance "y" [illegible] from the c.g., the flow is as shown in [illegible].



α_j = local section angle of attack
V_j = local section velocity

[illegible]

From Figure 4:1

$$\tan\alpha_j = (V\sin\alpha + py)/(V\cos\alpha - \text{[illegible]}) \qquad \ldots\ldots\ldots\ldots\ldots 4{:}6$$

while

$$V_j^2 = (V\sin\alpha + py)^2 + (V\cos\alpha - \text{[illegible]})^2$$

$$= V^2 + 2Vy(p\sin\alpha - \text{[illegible]}) \text{[illegible]} \qquad \ldots\ldots\ldots\ldots 4{:}7$$

Also

$$\tan\Delta\alpha = \frac{py\cos\gamma + ry\sin\gamma}{V + py\sin\gamma - ry\cos\gamma} \qquad \text{..............4:8}$$

For the small $\Delta\alpha$ values considered with normal flight maneuvers it is satisfactory to let:

$$\Delta\alpha = py/V \qquad \text{..................4:9}$$

$$V_j = V - ry \qquad \text{..................4:10}$$

Moreover the drag of the wing is expressible by the equation,

$$C_{D_w} = C_{D_o} + KC_L^2 \qquad \text{..................4:11}$$

where C_{D_o} is the profile drag coefficient and K is the drag due to lift factor. Moreover, $C_L = a\alpha$, where a is the lift slope and α is measured from zero lift.

Under the circumstances that equations 4:1 through 4:10 apply we have that

$$dL_j = (\rho V_j^2/2)c\,dy(a\alpha_j)$$

$$dD_j = (\rho V_j^2/2)c\,dy[C_{D_o} + K(a\alpha_j)^2]$$

Taking components perpendicular to and along the V vector,

$$dL = dL_j\cos\Delta\alpha_j + dD_j\sin\Delta\alpha_j$$

$$dD = dD_j\cos\Delta\alpha_j - dL_j\sin\Delta\alpha_j$$

Aside from the case of the flat spin, the angle $\Delta\alpha$ is small enough to permit the assumption that $\cos\Delta\alpha = 1$ and $\sin\Delta\alpha = \Delta\alpha$; therefore we may say that:

$$dL = dL_j + \Delta\alpha_j dD_j$$

$$dD = dD_j - \Delta\alpha_j dL_j$$

[illegible] left [illegible], [illegible] elements of [illegible]:

$$dL_{j_r} = \frac{\rho(V-ry)^2}{2}\, c\,dy(a)(\text{[illegible]} + \text{[illegible]})$$

$$dD_{j_r} = \frac{\rho(V-ry)^2}{2}\, c\,dy[C_{D_o} + \text{[illegible]}]$$

$$dL_{j_l} = \frac{\rho(V+ry)^2}{2}\, c\,dy(a)(\text{[illegible]} - \text{[illegible]})$$

$$dD_{j_l} = \frac{\rho(V+ry)^2}{2}\, c\,dy[C_{D_o} \text{[illegible]} - \text{[illegible]}]$$

where sub (r) means right wing and sub (l) means left wing and where [illegible] $= py/V$.

Since ry is small compared to V [illegible] is small compared to [illegible] for the conditions of interest, we may [illegible] terms in ry/V and any terms involving $ry/V \cdot py/V$. Thus,

$$dL_{j_r} = q^* c\,a\,dy(\alpha + \Delta\alpha - \frac{\text{[illegible]}}{V})$$

$$dL_{j_l} = q^* c\,a\,dy(\alpha - \Delta\alpha + \frac{\text{[illegible]}}{V})$$

and if $C_D = C_{D_o} + Ka^2\alpha^2$

$$dD_{j_r} = q^* c\,dy(C_D - \frac{\text{[illegible]}ry}{V} C_D + \text{[illegible]})$$

$$dD_{j_l} = q^* c\,dy(C_D + \frac{2ry}{V} C_D - \text{[illegible]})$$

Considering the net lift and drag [illegible] with respect to V of the two opposing elements

$$2dL = dL_{j_r} + dL_{j_l} + \text{[illegible]}$$

where

$$\Delta\alpha_{j_l} = -\Delta\alpha_{j_r} = -\Delta\alpha$$

or

$$2dL = q^\infty c\,dy \left\{ 2C_L + \Delta\alpha \left[C_D - \text{[illegible]} - C_D - \frac{2ry}{V} C_D + \text{[illegible]} \right] \right\}$$

or since $\Delta\alpha$ and ry/V are small

$$2dL = 2q^\infty c\,dy\,C_L,$$

and

$$C_{L_W} = C_L.$$

Thus to the first order there is no change in C_{L_W} due to rolling and yawing velocities. For drag determination,

$$2dD = dD_{j_r} + dD_{j_l} - \text{[illegible]} = q^\infty c\,dy \left\{ 2C_D - \Delta\alpha \left(C_{L\alpha} - \frac{2ry}{V} \right) \right\}$$

and thus, to the first order

$$C_{D_W} = C_{D_0} + KC_L^2$$

Rolling and yawing moments are introduced by the unbalance of normal and chord forces of the two wing panels. The differential normal and chord forces are given by:

$$dN = dL_j\cos\alpha_j + dD_j\sin\alpha_j$$

$$dC = dD_j\cos\alpha_j - dL_j\sin\alpha_j$$

where $\alpha_j = \alpha + \Delta\alpha$, and α is large compared to $\Delta\alpha$. Under these circumstances,

$$\cos(\alpha + \Delta\alpha) = \cos\alpha - \Delta\alpha\sin\alpha = A - B = \cos\alpha_{j_r}$$

$$\cos(\alpha - \Delta\alpha) = \cos\alpha + \Delta\alpha\sin\alpha = A + B = \cos\alpha_{j_l}$$

$$\sin(\alpha + \Delta\alpha) = \sin\alpha + \Delta\alpha\cos\alpha = C + D = \sin\alpha_{j_r}$$

$$\sin(\alpha - \Delta\alpha) = \sin\alpha - \Delta\alpha\cos\alpha = C - D = \sin\alpha_{j_l}$$

The incremental rolling moment due to right and left hand elements at $\pm$ y is,

$$d\ell = - y(dL_{j_r}\cos\ldots + dD_{j_r}\sin\ldots) + y(dL_{j_\ell}\cos\ldots + dD_{j_\ell}\sin\ldots)$$

$$= q^*cydy\left\{ a \left[\ldots - \ldots + \Delta\gamma - \frac{\ldots}{V} \right) (\ldots) \right] \right.$$

$$\left. + \left(C_D + \frac{2ry}{V} C_D - \ldots\right) (\ldots) - \left(\ldots - \frac{2ry}{V} C_D + \ldots\right) (\ldots) \right\}$$

or since $\Delta\gamma = py/V$ and $Ka^2 \ldots = \ldots C_{L_W}$,

$$d\ell = q^*cydy\left\{ \frac{py}{V} [- 2a\cos \ldots + \ldots \sin \ldots - \ldots \cos \ldots - 4KC_{L_W}\sin\ldots] \right.$$

$$\left. + \frac{ry}{V} (4C_{L_W}\cos\ldots + 4C_{\ldots}\sin\ldots) \right\}$$

integrating between y = 0 to y = b/2 for a constant chord wing, noting that cb = S, and transforming to coefficient form,

$$C_{\ell_W} = \frac{pb}{2V}\left[- \frac{(a + C_{D_\ldots})\cos\ldots}{6} - \frac{C_{\ldots}}{\ldots}(\ldots - 1)\sin\ldots \right] + \frac{rb}{2V}\left[\frac{C_{L_W}\cos\ldots + C_{\ldots}\sin\ldots}{3} \right]$$

......................4:13

The first term is the rolling [illegible] due to roll rate while the second represents the rolling moment due to [illegible].

For most purposes involving [illegible] flight, we may write that

$$C_{\ell_W} = \frac{pb}{2V}\left(- \frac{a}{6}\right) + \frac{rb}{2V}\frac{C_{L_W}}{3}$$

......................4:14

For a typical G. A. aircraft [illegible] chord wing, the constant a/6 lies between [illegible] 1/3 [illegible] to 1/4. Thus, typically,

$$\frac{\partial C_{\ell_W}}{\partial\left(\frac{pb}{2V}\right)} = - 0.4 \text{ to } - 0.5$$

$$\frac{\partial C_{\ell_W}}{\partial\left(\frac{rb}{2V}\right)} = \frac{C_{L_W}}{4}$$

To obtain the [illegible]:

$$dN = y[dD]_{j_r} \cos j_r - [illegible]$$

$$- q'\,[illegible] \left\{ (C_D - [illegible] \right.$$

$$+ [illegible]$$

since [illegible] $= ry/V$,

$$dN = q\,[illegible] \left\{ \frac{ry}{V} ([illegible] \right.$$

$$+ \frac{ry}{V} (4C_{[illegible]} \sin [illegible]$$

Integrating as before, we [illegible]:

$$C_{n_W} = \frac{rb}{2V} \left[- \frac{C_{L_W} \cos [illegible]}{6} (1 + [illegible] \right]$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1:15$$

The factor $C'a$ has a value of [illegible], we have that:

$$C_{n_W} = - \frac{rb}{2V} \cdot \frac{C_{L_W}}{6} - \frac{rb}{[illegible]} [illegible] \qquad \ldots\ldots\ldots\ldots\ldots 1:16$$

so that

$$\frac{\partial C_{n_W}}{\partial(\frac{rb}{2V})} = - \frac{C_{L_W}}{6}$$

$$\frac{\partial C_{n_W}}{\partial(\frac{rb}{2V})} = - \frac{C_{D_W}}{3}$$

The derivative with respect [illegible] the adverse yaw effect, while the one in $rb/2V$ is [illegible].

We now turn to presentation [illegible]. [illegible] configurations the drag coefficient curv[illegible]

$$C_D = C_{D_o} + KC_L^{\,2} \qquad \text{.....................4:17}$$

where

$$K = \partial^2 C_D / \partial C_L^{\,2}$$

and

$$C_D = C_{D_o} + \text{other parasite drag [illegible] etc.}$$

However, this equation does not [illegible] in the stall region and under stall conditions we have the approximation [illegible],

$$C_D = C_{D_o} + K_d \alpha^2$$

Since, in the unstalled region of flight, [illegible] that without flap deflection, $C_L = a\alpha$, it follows that,

$$K_d = Ka^2 \qquad \text{.....................4:18}$$

Near maximum speed, (i.e., at low C_L [illegible]) equation 4:17 may not properly fit the drag data for airplanes [illegible] sections because certain of these sections do not [illegible] drag at zero lift. For such aircraft we use an equation of the type

$$C_D = C_{D_o} + K(C_L + \Delta C_L)^2 \qquad \text{.....................4:19}$$

where ΔC_L may be plus or minus depending on the value of C_L for minimum drag.

More elaborate curve fit relationships [illegible] developed to suit unusual characteristics of specific aircraft.

The [illegible] and lift equations of an airplane are influenced by its c.g. location and [illegible] stability coefficients as [illegible] of maneuvers being [illegible]d. Specifically the horizontal tail [illegible] adds or subtracts from the wing lift, and surface deflection [illegible] drag. Generally these effects are accounted for by using a 'trim [illegible]' equation applicable to a given c.g. condition which accounts for static moment influences but not for rotational inertia or dynamic influences. The trimmed lift-drag relationship utilizes modified values of [illegible] drag coefficient C_{D_o} and drag due to lift factor to account for tail sizing and vehicle attitude effects.

We next consider the quantities determining C_m, the pitching moment coefficient. Functionally,

$$C_m = f(\alpha, \delta_e, q, \dot{\alpha}, \dot{\delta}_e, \dot{\delta}_{[illegible]}, [illegible] \ldots) \qquad \text{................4:20}$$

For our purposes, the important factors are

α, angle of attack

$\dot{\alpha}$, angle of attack rate

δ_e, elevator deflection

δ_f, flap deflection

V, flight speed

$\dot{\theta}$, pitch rate = q

$\dot{\delta}_f$, flap rate

These dependences may be separated and it is easily shown that (see references):

$$C_m(\alpha) = C_{mac} + (C_T/2)\left[\frac{l_p}{c}(\alpha - i_T) - 3.75\frac{D_p}{c}\right] - C_T\frac{z_p}{c}$$

$$+ a\alpha'[(x_{cg}/c)\cos\alpha + (z_{cg}/c)\sin\alpha] - R_q a_t[\alpha + i_T - KK_1 a\alpha] \quad \ldots .4{:}21$$

$$C_m(\delta_f) = \frac{\partial C_{mac}}{\partial\delta_f}\delta_f + a\frac{\partial i_w}{\partial\delta_f}\delta_f\left[\frac{x_{cg}}{c}\cos\alpha + \frac{z_{cg}}{c}\sin\alpha\right] + R_q a_t KK_1 a\frac{\partial i_w}{\partial\delta_f}\delta_f \quad \ldots 4{:}22$$

$$C_m(\delta_e) = - R_q a_e \delta_e \quad \ldots\ldots\ldots\ldots\ldots 4{:}23$$

$$C_m(\dot{\alpha}) = - \frac{R_q a_t KK_1 a l_t \dot{\alpha}}{V} \quad \ldots\ldots\ldots\ldots\ldots 4{:}24$$

$$C_m(q) = - R_q a_t K_2 l_t q/V \quad \ldots\ldots\ldots\ldots\ldots 4{:}25$$

$$C_m(\dot{\delta}_f) = - \frac{R_q a_t KK_1 a l_t}{V} \cdot \frac{\partial i_w}{\partial\delta_f}\dot{\delta}_f \quad \ldots\ldots\ldots\ldots\ldots 4{:}26$$

in which:

V = true airspeed, ft/sec.

g = acceleration of gravity, ft/sec.^{2}

γ - flight path angle, radians

D = drag, lbs.

m = airplane gross mass, slugs

$\Delta\alpha$ = increment in angle of attack due to winds and gusts, radians

L = lift, lbs.

T = thrust, lbs.

θ = pitch attitude angle, radians

i_T = incidence angle of thrust line, radians

i_t = horizontal tail incidence with respect to zero lift wing axis, radians

q = angular rotation rate in pitch, radians/sec.

q^* = dynamic pressure, lbs/ft.^{2} $= \frac{1}{2}\rho V_R^2$

ρ = air density, slugs/ft.^{3}

V_R = true relative airspeed, ft/sec.

c = mean aerodynamic chord, ft.

S = wing area, ft.^{2}

J_y = moment of inertia in pitch, slugs-ft.^{2}

C_{mac} = moment coefficient about the aerodynamic center, no dimensions

δ_f = flap deflection, radians

$C_T = T/q^*S$ = propeller thrust coefficient

l_p = distance from propeller disc to c.g. along fuselage x axis, ft.

β = sideslip angle, radians

D_p - propeller diameter, ft.

z_p = moment arm of thrust axis about c.g., ft.

$a = \partial C_L/\partial\alpha$ = lift slope of wing, per radian

α = angle of attack with respect to V_R axis, radians

i_w = incidence of zero lift axis to wind, radians

x_{cg} = horizontal distance from c.g. to a.c., + if c.g. is aft of a.c., ft.

z_{cg} = vertical distance from c.g. to a.c., + if c.g. is above a.c., ft.

$R_q = c_t S_t l_t / q^* S c$, no dimensions

S_t = total horizontal tail area, ft.^{2}

l_t = horizontal tail moment arm, ft.

q_t = dynamic pressure at horizontal tail, lbs/ft.^{2}

K_1 = downwash distribution factor, dimensionless

$K = \partial C_D / \partial C_L^{\,2}$, dimensionless

K_2 = damping in pitch multiplier accounting for fuselage damping, dimensionless

$a_e = \partial C_{L_t} / \partial \delta_e$, elevator effectiveness parameter, per radian

δ_e = elevator deflection, radians, plus downward

$(\dot{\ })$ = first time derivative

The total airplane lift coefficient, including the effects of thrust axis inclination and tail load is given by

$$C_{L_a} = C_{L_w} + C_{L_t}\frac{q_t S_t}{qS} + \frac{C_T}{2}(\alpha - i_T)\cos\ \qquad \ldots\ldots\ldots\ldots\ldots 4{:}27$$

where

$$C_{L_t} = a_t \alpha_t + a_e \delta_e \qquad \ldots\ldots\ldots\ldots\ldots 4{:}28$$

and

$$\alpha_t = \alpha + i_T - K_1 K\left[a\left(\alpha + \frac{\partial i_w}{\partial \delta_f}\delta_f\right) - \frac{a\ell_t}{V}\left(\dot{\alpha} + \frac{\partial i_w}{\partial \delta_f}\dot{\delta}_f\right)\right] + \frac{\ell_t q}{V} \qquad \ldots\ldots 4{:}29$$

The total airplane parasite drag coefficient is given by

$$C_{D_e} = C_{D_{e_0}} + \frac{\partial C_{D_e}}{\partial \delta_f}\delta_f + \Delta C_{D_g} + \frac{\partial C_{D_e}}{\partial \beta}\beta \qquad \ldots\ldots\ldots\ldots\ldots 4{:}30$$

where $C_{D_{e_0}}$ is the basic (clean) value of C_{D_e}, ΔC_{D_g} is the increment due to landing gear and $\partial C_{D_e}/\partial \delta_f$ and $\partial C_{D_e}/\partial \beta$ are the gradients due to δ_f and β.

Propeller thrust is given by

$$T = 550\eta_p BHP/V_R$$

when

BHP is the shaft brake horsepower

η_p is the propulsive efficiency of the propeller

For analysis of the other than [illegible] condition, several [illegible] may be dropped from the equations [illegible] sufficient and these simplifications will be discussed in [illegible] chapter.

The moments about the lateral and [illegible] (x,z) axes of the airplane are of two types, direct and cross [illegible] of important effect follows:

A) Yawing Moments

1. Due to sideslip (directional stability)

2. Due to yaw rate (damping in yaw)

3. Due to roll rate and aileron deflection (adverse aileron yaw)

4. Due to rudder deflection (control moment)

5. Due to angle of attack of propeller disc (direct propeller yawing moment)

B) Rolling Moments

1. Due to sideslip (dihedral effect)

2. Due to rate of roll (damping in roll)

3. Due to rate of yaw

4. Due to aileron deflection (control moment)

5. Due to rudder deflection (rolling control moment)

Additionally lateral-directional [illegible] the equation for side force with the following dependence:

C) Side Force

1. Due to sideslip angle

2. Due to rudder deflection

3. Due to propeller [illegible] by sideslip of the propeller disc.

Simplified equations for side force, yawing and rolling moment equations are listed below:

$$C_Y = -\beta(\partial C_Y/\partial\beta) \quad \text{(principal part)} \qquad \ldots\ldots\ldots\ldots\ldots 4:31$$

$$C_n = \frac{l_{vt}}{b}\,\frac{S_{vt}}{S}\,(a_r\delta_r + [illegible]) - [illegible] + \frac{C_n}{[illegible]}) - \frac{C_L}{8}\left(\frac{pb}{2V}\right) \quad \ldots 4:32$$

$$C_{\ell} = 0.12\delta_a - 0.5\,\frac{pb}{2V} + \frac{C_L}{4}\,\frac{rb}{2V} - 0.25\,(\Gamma a_w + C_L \sin 2\Lambda) \qquad \ldots\ldots\ldots 4{:}33$$

where:

b = wing span, ft.

δ_a = mean aileron deflection angle, radians

Γ = adjusted geometric dihedral angle, radians

a_w = wing lift slope, per radian

Λ = wing sweep angle, radians

ℓ_{vt} = vertical tail moment arm, ft.

$a_r = \partial C_{\ell vt}/\partial\delta_r$, per radian

δ_r = rudder deflection, radians

a_{vt} = vertical tail lift slope, per radian

S_{vt} = total vertical tail area, ft.^{2}

$\partial C_y/\partial\beta$ = side force derivative

For specific aircraft the numerical constants in equations 4:32 and 4:33 will have to be modified, however the values listed are broadly representative of G. A. equipment. In these equations, propeller influences are not included, however they can be added quite readily if the analysis warrants this.

The next chapter deals with the changes in the coefficients caused by wing stall.

[illegible] SPECIALIZED SPIN EQUATIONS

As an example of the scope of [illegible] this chapter presents a specialized set of relations [illegible] study of spinning motions.

In a normal spin the vertical [illegible] so that recovery is possible through use of rudder [illegible] effective in most G. A. aircraft, however [illegible] principal aerodynamic moments [illegible] of the airplane (in the absence of control) [illegible]. This [illegible] or fully developed, with the [illegible] during several turns to stabilize and in [illegible]. [illegible] the aircraft design and c.g. [illegible] of both normal and flat spins, with the flat [illegible] vertical and horizontal tail surfaces so that spin recovery [illegible]. For the [illegible] here, we shall restrict ourselves [illegible] the elevators and rudder(s) remaining effective for recovery [illegible].

Normally, at stall the wing [illegible] the aerodynamic center becomes more negative tending [illegible], however as the angle of attack increases well beyond [illegible] reverse. For simplicity we shall assume [illegible] in a stalled attitude by the horizontal tail [illegible] flight, neglecting the tail angle of attack change [illegible] it is [illegible], but retaining angle of attack [illegible] pitching moment coefficient defined by:

$$C_m = C_{mac} + C_{L_W}\left[(x_{cg}/c)\cos [illegible] + (z_{[illegible]}/c)\sin [illegible]\right] - R_q a_t([illegible] + i_t)$$

$$- R_q a_e \delta_e - R_q a_t K_{[illegible]} [illegible] c/V - [illegible]/V \qquad \text{.................5:1}$$

where

$$K_3 = KK_1 a$$

For angles of attack near the stall, either slightly above or below the stall, we also have the approximate relationship,

$$C_{L_W} = a_1\alpha - a_2\alpha^2 \qquad \text{.....................5:2}$$

where

$$a_1 = 2C_{L_{max}}/\alpha_s \qquad \text{.....................5:3}$$

$$a_2 = C_{L_{max}}/\alpha_s^2 \qquad \text{....................5:4}$$

a_1 has a value of approximately [illegible] and a_2 a value of approximately 11.32 for a typical case.

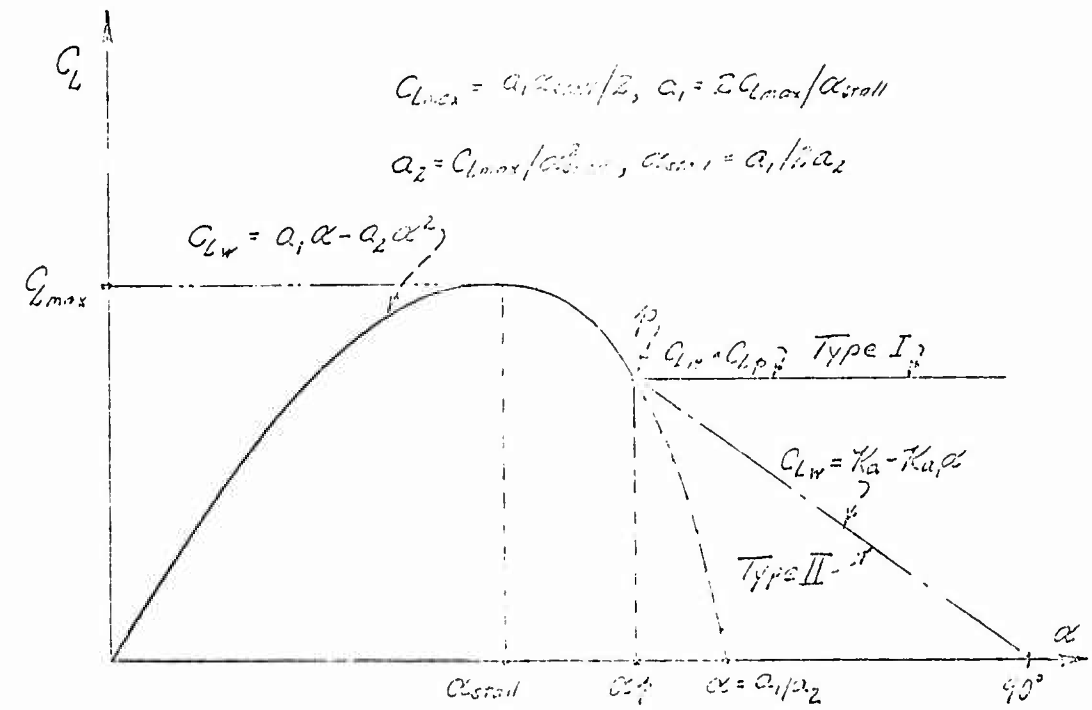
The shape of the stalled lift curve varies greatly from airplane to airplane and the shape of this curve, together with the inertial characteristics of the airplane and pilot control [illegible] determines the incipient tendencies of the airplane once it has been [illegible] stalled. Some aircraft, (reference [illegible]) are inherently incapable of [illegible] rotations, while many display characteristics making it quite difficult to induce a spin. The maneuvers which may result after stall are:

1. snap rolls
2. normal spins
3. flat spins
4. tumbling
5. oscillatory spins (large changes in angle of attack and bank angle in the spin)
6. combined motions
7. inverted spins, following a snap roll.

The snap roll involves high rolling velocities at moderate flight path angle (γ) inclinations. Normal spins occur at angles of attack in the approximate range of [illegible] to 60° at flight path angles of from -60° to -85° while flat spins normally are at angles of attack in excess of 60° and at flight path angles close to -90°.

The ability of the airplane to continue flight at angles of attack above 30° depends on the fact that partial stall of the horizontal tail is involved which reduces the tail damping and restoring moments, and very little experimental data exists to describe exactly what occurs in actual aircraft. Additionally the value of the product of inertia term J_{xz} in the equations of rotary motion has a significant influence on the type of spin which can occur, although little data exists to assign values to the term for typical G. A. aircraft since it is normally not computed by the aircraft manufacturer. If the product of inertia, J_{xz}, is positive, a normal spin is favored, while if negative a flat spin tendency exists.

To account for varying lift curve slopes above the moderate stall angle region the equations for two possible types are described below. The two types are illustrated in Figure [illegible].



[illegible]

For the type I curve the relation [illegible] $- a_2\alpha^2$ holds to some angle α_p after which C_L is a constant having [illegible]. For type II, C_L decreases from C_{L_p} at α_p to 0 at [illegible] 90°. [illegible] $- a_2\alpha^2$ is seen to yield zero C_L at $\alpha = a_1/a_2$.

The value of α_p associated with a [illegible] value of C_{L_p} is

$$\alpha_p = \frac{a_1}{2a_2} \pm \sqrt{\left(\frac{a_1}{2a_2}\right)^2 - \frac{C_{L_p}}{a_2}} \qquad \text{..................... 5:5}$$

For an airplane with $C_{L_{max}}$ of 1.[illegible] [illegible] angle of attack of 0.365 radians (or [illegible]°) [illegible] from [illegible], a_1 = [illegible] and a_2 = 11.3[illegible]. If C_{L_p} = 1, α_p = 0.[illegible] radians [illegible] while if C_{L_p} = 1.4, α_p = 0.[illegible] radians ([illegible]°).

The equation for the type II [illegible] curve for angles of attack greater than α_p is

$$C_{L_W} = C_{L_p} - \frac{C_{L_p}(\alpha - \alpha_p)}{\pi/2 - \alpha_p} \qquad \text{.....................5:6}$$

which may be written as

$$C_{L_W} = K_a - K_{a1}\alpha \qquad \text{.....................5:7}$$

where

$$K_a = C_{L_p}/(1-2\alpha_p/\pi) \qquad \text{.....................5:8}$$

$$K_{a1} = C_{L_p}/(\pi/2-\alpha_p) \qquad \text{.....................5:9}$$

For $C_{L_p} = 1.4$, $K_a = 2.055$ and $K_{a1} = 1.3$[illegible]5.

The airplane drag coefficient is of the form

$$C_D = C_{D_e} + K_d\alpha^2 \qquad \text{.....................5:10}$$

The maximum value of C_D is limited so that we may say that $K_d\alpha < K_{1d}$, where K_{1d} is a limiting value for a given airplane. At angles of attack greater than $\alpha = K_{1d}/K_d$ we have that,

$$C_D = C_{D_e} + \frac{(K_{1d})^2}{K_d} \qquad \text{.....................5:10A}$$

$$C_{D_e} = C_{D_{eo}} + (\partial C_{D_e}/\partial\beta)/\beta/ \qquad \text{.....................5:11}$$

while the side force coefficient is

$$C_Y = -\beta(\partial C_Y/\partial\beta). \qquad \text{.....................5:12}$$

In the drag equation, C_{D_e} has a value of about 0.02 while K_d varies, for a stalled airplane from 1 to 2.

For the wing,

$$C_{D_W} = C_{D_o} + K_d\alpha^2 \text{ or } C_{D_o} + \frac{(K_{1d})^2}{K_d} \text{ when } \alpha > \frac{K_{1d}}{K_d} \qquad \text{..........5:13}$$

[illegible] from the [illegible] for the [illegible] slip [illegible] from the various lift and dr[illegible] referring to Chapter 4 we define

$$A = \cos\alpha \qquad \text{.....................5:14}$$

$$B = \Delta\alpha\sin\alpha \qquad \text{.....................5:15}$$

$$C = \sin\alpha \qquad \text{.....................5:16}$$

$$D = \Delta\alpha\cos\alpha \qquad \text{.....................5:17}$$

Then, for the strip element [illegible] in Chapter 4, it is [illegible] shown that, in general, the [illegible] by opposite elements of the wing [illegible] are given by

$$\frac{d\ell}{y} = A(dL_{j_\ell}-dL_{j_r}) + B(dL_{j_\ell}+dL_{j_r}) - C(dD_{j_\ell}-dD_{j_r}) - D(dD_{j_\ell}+dD_{j_r}) \quad ..5:18$$

$$\frac{dn}{y} = C(dL_{j_\ell}-dL_{j_r}) - D(dL_{j_\ell}+dL_{j_r}) - A(dD_{j_\ell}-dD_{j_r}) - B(dD_{j_\ell}+dD_{j_r}) \quad ..5:19$$

For the portion of the lift curve defined by

$$C_{L_w} = a_1\alpha - a_2\alpha^2$$

and with

$$C_{D_w} = C_{D_o} + K_d\alpha^2$$

we have

$$dL_j = \frac{\rho V_j^2}{2} c\,dy(a_1\alpha_j - a_2\alpha_j^2)$$

$$dD_j = \frac{\rho V_j^2}{2} c\,dy(C_{D_o} + K_d\alpha_j^2)$$

where

$$V_j = V - ry$$

$$\alpha_j = \alpha + \frac{ry}{V} = \alpha + \Delta\alpha$$

thus,

$$V_j^2 = V^2 - 2Vry + r^2y^2.$$

For a speed of 100 fps if r = 2 radians/sec. and a y arm of 10 ft., $r^2y^2 = 400$ compared to $V^2 = 10{,}000$ and $2Vry = 4{,}000$ so that the term r^2y^2 can be ignored for a normal spin which has yawing rates seldom greater than a radian per second, hence

$$V_j^2 = V^2\left(1 - \frac{2ry}{V}\right) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 5{:}20$$

Thus for the region of flight considered,

$$dL_j = q^*cdy\left(1 - \frac{2ry}{V}\right)\left(C_L + a_1\Delta\alpha - 2a_2\alpha\Delta\alpha - a_2\Delta\alpha^2\right)$$

$$dD_j = q^*cdy\left(1 - \frac{2ry}{V}\right)\left(C_D + 2K_d\alpha\Delta\alpha + K_d\Delta\alpha^2\right)$$

and,

$$dL_{j_\ell} + dL_{j_r} = q^*cdy\left[2C_L - 2a_2\Delta\alpha^2 + \frac{2ry}{V}\left(4a_2\alpha\Delta\alpha - 2a_1\Delta\alpha\right)\right]$$

$$dL_{j_\ell} + dL_{j_r} = q^*cdy\left[4a_2\alpha\Delta\alpha - 2a_1\Delta\alpha + \frac{2ry}{V}\left(2C_L - a_2\Delta\alpha^2\right)\right]$$

$$dD_{j_\ell} + dD_{j_r} = q^*cdy\left[2C_D + 2K_d\Delta\alpha^2 - \frac{2ry}{V}\left(4K_d\alpha\Delta\alpha\right)\right]$$

$$dD_{j_\ell} - dD_{j_r} = q^*cdy\left[-4K_d\alpha\Delta\alpha + \frac{2ry}{V}\left(2C_D + 2K_d\Delta\alpha^2\right)\right].$$

Using 5:18 and 5:19 and integrating from y = 0 to y = b/2 for an untapered wing,

$$C_{l_W} = \frac{r b}{2V} \left(\frac{1}{6}\right) [(2a_2\alpha - a_1 - [illegible])[illegible] + (C_{D_{[illegible]}} - 2K_d[illegible])\sin[illegible]]$$

$$+ \frac{rb}{2V} \left(\frac{1}{3}\right) [C_{L_W}\cos[illegible] + C_D \sin[illegible]] - \left([illegible]\right)^3 \left(\frac{1}{[illegible]}\right) [a_2\sin[illegible] + K_d\cos[illegible]]$$

$$+ \frac{rb}{2V} \left(\frac{pb}{2V}\right)^2 \left(\frac{1}{5}\right) [(-a_2 + [illegible])\cos[illegible] + ([illegible] - a_1 + K_d)\sin[illegible]] \quad \ldots 5{:}[illegible]$$

$$C_{n_W} = \frac{pb}{2V} \left(\frac{1}{[illegible]}\right) [(2a_2\alpha - a_1 - [illegible])\sin[illegible] - (C_{D_{[illegible]}} - 2K_d[illegible])\cos[illegible]]$$

$$+ \frac{rb}{2V} \left(\frac{1}{3}\right) [C_{L_W}\sin[illegible] - C_D\cos[illegible]] + \left([illegible]\right)^{[illegible]} \left(\frac{1}{[illegible]}\right) [a_2\cos[illegible] - K_d\sin[illegible]]$$

$$+ \frac{rb}{2V} \left(\frac{pb}{2V}\right)^2 \left(\frac{1}{5}\right) [(-a_2 + [illegible])\sin[illegible] - ([illegible] - a_1 + K_d)\cos[illegible]] \quad \ldots 5{:}[illegible]$$

In which the constants 1/3, 1/[illegible], 1/[illegible] and 1/10 must all be reduced for a tapered wing.

For the type I lift curves, we have [illegible] angle of attack above [illegible], that C_{l_W} and C_{n_W} are obtained by adding [illegible] in 5:21 and 5:[illegible], while for the type II curves, we have that:

$$dL_{j_r} = q^*cdy\ (1 - 2ry/V)\ [[illegible] - K_{[illegible]}([illegible] + \Delta\alpha)]$$

$$dL_{j_l} = q^*cdy\ (1 + 2ry/V)\ [[illegible] - K_{[illegible]}([illegible] - \Delta\alpha)]$$

whence,

$$dL_{j_l} + dL_{j_r} = (2C_{L_W} + \frac{4ry}{V}[illegible])[illegible]$$

$$dL_{j_l} - dL_{j_r} = (\frac{4ry}{V} C_{L_W} + [illegible])[illegible]$$

and the rolling and yawing moments for [illegible] right and left elements are:

$$d\ell = q^*cydy\ [\cos[illegible] (\frac{4ry}{V} C_{L_W} + [illegible]) + [illegible]\sin[illegible](2C_{L_W} + \frac{4ry}{V} K_{a_1}\Delta\alpha) + f(C_D)]$$

$$dn = q^*cydy\ [\sin[illegible] (\frac{4ry}{V} C_{L_W} + [illegible]) - [illegible]\cos[illegible](2C_{L_W} + \frac{4ry}{V} K_{a_1}\Delta\alpha) + f_1(C_D)]$$

where $f(C_D)$ and $f_1(C_D)$ are the [illegible] terms previously examined.

Due to the lift vector alone, we then get:

$$C_{\ell_{w\ell}} = \left(\frac{pb}{2V}\right)\left[\frac{C_{L_w}\sin\alpha + K_{a_1}\cos\alpha}{6}\right] + \frac{rb}{2V}\left[\frac{-C_{L_w}\cos\alpha}{3}\right] + \left(\frac{pb}{2V}\right)^2\left(\frac{rb}{2V}\right)\frac{1}{5}K_{a_1}\sin\alpha$$

$$C_{n_{w\ell}} = \left(\frac{pb}{2V}\right)\left[\frac{K_{a_1}\sin\alpha - C_{L_w}\cos\alpha}{6}\right] + \frac{rb}{2V}\left[\frac{C_{L_w}\sin\alpha}{3}\right] - \left(\frac{pb}{2V}\right)^2\left(\frac{rb}{2V}\right)\frac{1}{5}K_{a_1}\cos\alpha$$

and the complete equations are

$$C_{\ell_w} = \frac{pb}{2V}\left(\frac{1}{6}\right)\left[(K_{a_1} - C_{D_w})\cos\alpha + (C_{L_w} - 3K_d)\sin\alpha\right]$$

$$+ \frac{rb}{2V}\left(\frac{1}{3}\right)\left[C_{L_w}\cos\alpha + C_{D_w}\sin\alpha\right] - \left(\frac{pb}{2V}\right)^3\left(\frac{1}{10}\right)K_d\cos\alpha$$

$$- \frac{rb}{2V}\left(\frac{pb}{2V}\right)^2\left(\frac{1}{5}\right)\left[2K_d\cos\alpha + (K_{a_1} + K_d)\sin\alpha\right]. \qquad \text{..........5:23}$$

As previously noted the numerical constants must be reduced if a tapered wing is considered.

$$C_{n_w} = \frac{pb}{2V}\left(\frac{1}{6}\right)\left[(K_{a_1} - C_{D_w})\sin\alpha - (C_{L_w} - 3K_d)\cos\alpha\right]$$

$$+ \frac{rb}{2V}\left(\frac{1}{3}\right)\left[C_{L_w}\sin\alpha - C_{D_w}\cos\alpha\right] + \left(\frac{pb}{2V}\right)^3\left(\frac{1}{10}\right)(-K_d\sin\alpha)$$

$$+ \frac{rb}{2V}\left(\frac{pb}{2V}\right)^2\left(\frac{1}{5}\right)\left[2K_d\sin\alpha - (K_{a_1} + K_d)\cos\alpha\right] \qquad \text{..........5:24}$$

These relations are obtained from 5:21 and 5:22 by setting $a_2 = 0$ and $C_{D_0} - a_1 = K_{a_1}$.

Dihedral effect in a normal spin, for a fully stalled wing is reversed by the stall. Thus, due to sideslip at values of the angle of attack we have that because of dihedral, $\Delta\alpha = \beta\Gamma'$ in radians, (Γ' = dihedral angle, radians), and

$$dL_j = [a_1(\alpha + \Delta\alpha) - a_2(\alpha + \Delta\alpha)^2]qc\,dy.$$

Since $\Delta\alpha$ is small, drag changes can be ignored and for opposing elements at $\pm$ y

$$d\ell_j = - yq^* c dy [a_1 (\alpha + [illegible]) - a_2 (\alpha + [illegible])^2 - [illegible]_1 ([illegible]) + [illegible]_2 ([illegible])^2]$$

$$= - yq^* c dy [2a_1 [illegible] - [illegible]a_2 [illegible]]$$

Considering a constant chord wing [illegible] from $y = 0$ to $y = b/2$,

$$C_\ell = - \frac{[illegible]\Gamma}{4} (a_1 - 2a_2 \alpha) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 5{:}25$$

or,

$$\frac{\partial C_\ell}{\partial \beta} = - \frac{\Gamma}{4} (a_1 - 2a_2 \alpha) = \frac{\Gamma}{4} ([illegible] - a_1) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 5{:}26$$

The sign of $\partial C_\ell / \partial \beta$ is seen to reverse [illegible].

For the type I lift curve, the [illegible] is zero, while for the type II curve

$$d\ell_j = - yq^* c dy [K_a - K_{a_1} ([illegible]) - [illegible] + K_{a_1} ([illegible])] = - yq^* c dy [-2K_{a_1} [illegible]]$$

and

$$\frac{\partial C_\ell}{\partial \beta} = + \frac{\Gamma}{4} (2K_{a_1}) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 5{:}27$$

When the angle of attack exceeds [illegible], assumes its limiting value of [illegible] + $(K_{1_d})^2 / K_d$ and the terms [illegible] in [illegible], 5:[illegible], 5:[illegible] and 5:24 are set to zero.

The complete aerodynamic rolling [illegible] moment equations are, then

$$C_n = \frac{\ell_{v_t}}{b} \frac{S_{v_t}}{S} (a_r \delta_r + [illegible]_{v_t}) + [illegible] - [illegible] \left(\frac{[illegible] \ell_{v_t}^2 S_{v_t}}{b^2 S}\right) \qquad \ldots\ldots 5{:}28$$

where $K_{[illegible]}$ is a factor introduced to account for increased damping in yaw due to fuselage and vertical tail [illegible] influencing the yawing moments.

$$C_\ell = \frac{\partial C_\ell}{\partial \delta_a} \delta_a + \frac{\partial C_\ell}{\partial \beta} \beta + C_{\ell_{[illegible]}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 5{:}29$$

The complete equations for rotary motion are:

$$I_x\dot{p} = J_{xz}(\dot{r} + pq) - (I_z - I_y)qr + \ell$$

$$I_y\dot{q} = J_{xz}(r^2 - p^2) + (I_z - I_x)pr + m$$

$$I_z\dot{r} = J_{xz}(\dot{p} - qr) - (I_y - I_x)pq + n$$

the first and last equations must be solved simultaneously for $\dot{r}$, whence

$$\dot{r} = \frac{qr\left(\frac{I_z-I_y}{I_x} + 1\right) - pq\left(\frac{J_{xz}}{I_x} - \frac{I_y-I_x}{J_{xz}}\right) - \frac{q^*C_\ell Sb}{I_x} - \frac{q^*C_n Sb}{J_{xz}}}{\left(\frac{J_{xz}}{I_x} - \frac{I_z}{J_{xz}}\right)} \qquad .....5:30$$

$$\dot{p} = \frac{J_{xz}}{I_x}(\dot{r} + pq) - \left(\frac{I_z-I_y}{I_x}\right) qr + \frac{q^*C_\ell Sb}{I_x} \qquad ....5:31$$

$$\dot{q} = \frac{J_{xz}}{I_y}(r^2 - p^2) + \left(\frac{I_z-I_x}{I_y}\right) pr + \frac{q^*C_m cS}{I_y} \qquad ....5:32$$

If the spin is "power off"

$$\dot{V} = - g\left(\frac{C_D}{C_{L_L}} + \sin\gamma\right) \qquad ....5:33$$

$$\dot{\gamma} = (g/V)\left[(C_L\cos\phi_W - C_Y\sin\phi_W)/C_{L_L} - \cos\gamma\right] \qquad ....5:34$$

$$\dot{\psi} = (g/VC_{L_L}\cos\gamma)(C_L\sin\phi_W + C_Y\cos\phi_W) \qquad ....5:35$$

The rotary kinematic equations are:

$$\dot{\alpha} = q\cos\beta - p\sin\beta - \dot{\gamma}\cos\phi_W - \dot{\psi}\cos\gamma\sin\phi_W \qquad ....5:36$$

$$\dot{\beta} = \dot{\psi}\cos\gamma\cos\phi_W\cos\alpha - \dot{\gamma}\sin\phi_W\cos\alpha - r - \dot{\psi}\sin\gamma\sin\alpha \qquad ....5:37$$

Revised April 7, 1965

$$\dot{\psi}_W = p\cos[illegible]\cos[illegible] + q\sin[illegible]\cos[illegible] + r\sin[illegible] + \dot{[illegible]}\sin[illegible]. \qquad \text{..........}[illegible]$$

The topic of programming equations such as [illegible] for solution on a digital computer, as well as the procedures [illegible] to more routine [illegible] computations are considered in [illegible] chapter. Chapter V provi[illegible], as an illustrative example, the program[illegible] analysis required to [illegible] the spin equations in a form directly us[illegible] on a digital computer.

[illegible] DIGITAL COMPUTERS [illegible] ANALYSIS [illegible] PROBLEMS

[illegible] engineering design and development [illegible] from its configuration - or the modification of an existing configuration - in common with other problems of engineering or scientific [illegible], [illegible] a large amount of computing effort, ranging from the numerical [illegible] weight and balance studies to the solution of sets of nonlinear [illegible] equations in stability analysis [illegible] inversion of large [illegible]. Computation of section properties, [illegible] thrust [illegible], wing lift [illegible] distributions, and [illegible] structural [illegible] amount of time and effort [illegible] analysis. [illegible] of the design process involves [illegible] of computation, [illegible] repetitive while others are [illegible] time [illegible].

A general purpose digital computer, [illegible] a very flexible computing [illegible] encountered in science or engineering, [illegible] or not, [illegible] for use in a given organization [illegible] with its price [illegible] determines [illegible] is involved through its use.

Slide rules, desk calculators [illegible] are considered "adopted" to [illegible] little difficulty in [illegible] desk [illegible] amount of money is [illegible] than the monthly [illegible] overhead is included, [illegible] investment [illegible] it is generally considered [illegible] one.

Costs of digital computers have [illegible] over the years so that at this time one can obtain a general [illegible] computer at a rental cost of [illegible] a month ([illegible] maintenance costs), in what is referred to as a minimum [illegible]. [illegible] costs, since they are less than the [illegible] salary of a typical [illegible] computers well within the reach of even small engineering [illegible]. [illegible] in these computers is justified if they can be used to increase existing engineering output (by their presence) by something more than the increase provided by a single additional engineer.

The modern, small, high speed computers in the lowest category are normally binary logic machines - that is [illegible] using the number base (radix) 2 rather than the familiar base 10 [illegible]. In this respect they are similar to the largest, high speed systems [illegible] it is possible to program them in binary terms, such a [illegible] operation costs since it requires, at the least, the [illegible] skilled programmer to go with the [illegible]. There are other [illegible] involve lost motion of various [illegible], and accordingly [illegible] scientific applications programs are [illegible] written in the [illegible], but are prepared in a problem (or user) oriented [illegible] is translated by the computer as part of the computing process.

Use of such a language requires [illegible] the compiler which enables the c[illegible] oriented language into a set of [illegible] which can be processed by the computer. [illegible] of such programs is referred to [illegible], and must be considered in [illegible] in the consideration of just how [illegible] be utilized in a given installation.

The vast majority of engineering [illegible] which require numerical input and [illegible] is in most [illegible] of the languages in the compiler. [illegible] Fortran, Cobol, Algol etc. There are [illegible] with the intention of minimizing the [illegible], to learn to program the computer. Compil[illegible] by the computer to convert the [illegible] language) into an "object" program ([illegible] the computer). Because of the [illegible] compilers are generally suited to minimum configuration [illegible] with input and output [illegible] on similar equipment), and [illegible] to larger computers. Through [illegible] such as disc and magnetic tape, disc fil[illegible] input/output (I/O) devices the compiler [illegible] of compiler software, however this [illegible] involving more "down time" [illegible] system.

The use of compilers poses [illegible] involve what is referred to as "debugging", that is, [illegible] and elimination of errors which may have been introduced [illegible] commands being used, mispunching [illegible] and so on. [illegible] is [illegible] to determine what errors [illegible] program [illegible] correction of these errors requires [illegible] compiled repeatedly until all errors have been removed. [illegible] learning a language such as Fortran [illegible] study on the part of [illegible] is by no means [illegible] difficult to [illegible]. This is [illegible] by the numerous texts which have [illegible] of Fortran programming. Clearly [illegible] as a practical tool for its [illegible] does not [illegible] of operation.

In spite of its drawbacks, [illegible] has proved a valuable tool particularly for [illegible] provides the engineer with a basic tool [illegible]. However, there exist programming systems [illegible] far better suited to engineering applications. [illegible] expensive peripheral equipment, do not limit the [illegible] in a fraction of the time required to learn Fortran. [illegible] interpreters which also provide a user oriented language, [illegible], and which our experience has [illegible] suited to the engineer than the [illegible] [illegible] interpreters, extensive [illegible] [illegible] "[illegible] interpreter" requires [illegible] amount of learning [illegible] [illegible] an engineer, for the basic [illegible] is identical in procedure [illegible] [illegible] employs when using a [illegible] or desk calculator. [illegible] is virtually nothing conceptually [illegible] learn which an engineer [illegible] [illegible] address interpreter [illegible] for [illegible] [illegible] the term "address" [illegible]. The DICTATOR [illegible] [illegible], INC., is a three [illegible], interpretive [illegible] [illegible] a wide variety of computers. [illegible] the use of [illegible] [illegible] directly by [illegible] [illegible], provides very [illegible] [illegible] checking procedures [illegible] (i.e. [illegible] and print out of program [illegible]), requires a minimum of [illegible] and since no [illegible], changes in the program can [illegible] with [illegible] any time [illegible] running a program.

[illegible] recognition that it is [illegible] [illegible] demonstrate the use of the [illegible] than to [illegible], [illegible] the less efficient, of this [illegible], to indicate how easy it is to [illegible] digital computer when the DICTATOR [illegible] is employed.

The DICTATOR system, in common with all other interpreters (but unlike a compiler) is [illegible] in the computer [illegible] [illegible] instructions in a user [illegible]. It controls [illegible] continuously interprets the [illegible] instructions for the computer [illegible] views each instruction in terms of its own basic [illegible] the necessary steps. All input, [illegible] computation and output is [illegible] interpreter, so that, computer [illegible] occurs in [illegible]. The [illegible] "interpretive" follows [illegible] this type of [illegible] performs a function analogous to that performed by a bilingual [illegible] presence enables two other [illegible] which is not possible without the interpreter unless one or [illegible] time to learn a new tongue. [illegible] also view interpretive [illegible] training procedure for the [illegible], or as an [illegible]. From the users standpoint, [illegible], it simply [illegible] as if it is a basic language [illegible] to the user since it is [illegible] [illegible] evident that part of the [illegible] is being [illegible] by software. When the [illegible] system is used [illegible] of a stored program digital [illegible] flexibility [illegible] equals or exceeds that of any [illegible] device [illegible], and it is easier to learn to use DICTATOR than it is to [illegible] rule.

[illegible] engineering and scientific [illegible] require accuracy based on the [illegible] of significant digits [illegible] DICTATOR system uses what is referred to [illegible] "floating decimal" arithmetic. Use of this type of arithmetic not only [illegible] accuracy [illegible] automatically takes care of the location of the decimal point. [illegible] recall that when working either [illegible] desk calculator or [illegible] computation or a special [illegible]; each [illegible] as a [illegible] times a power of 10, e.g., [illegible] = 0.[illegible] x [illegible] [illegible] = 0.[illegible] x [illegible], and then [illegible] separately from the power of [illegible] (exponents [illegible]), [illegible] x 0.[illegible] = [illegible] x 0.[illegible] x [illegible], [illegible] decimal points.

It [illegible] this [illegible] DICTATOR [illegible] the [illegible] point [illegible] in the following format and the [illegible] having properly placed the decimal [illegible]. The [illegible] the input and output [illegible] DICTATOR (the name for the IBM [illegible] in this [illegible]) [illegible] for printing [illegible] the word is [illegible] word is obtained by adding [illegible]. For [illegible]:

$$[illegible] = 56\ [illegible]$$

exponent [illegible]

This is read as 0.[illegible] x [illegible]. The [illegible] is [illegible] (and [illegible] last digit [illegible]. The number [illegible] is [illegible], including [illegible] and exponent, is called a "[illegible]".

In the DICTATOR system it is [illegible] of the locations of data and instruction words, in [illegible] locations [illegible] calculation. The location of [illegible] the "address" [illegible] of the [illegible] in a [illegible] of a [illegible].) The [illegible] of [illegible] is the [illegible] much of [illegible], but you [illegible] a little [illegible] back.

[illegible] instruction words and data [illegible] along the [illegible] the computer [illegible]. In the DICTATOR system, [illegible] small computers, [illegible] for instruction and data words [illegible] DICTATOR itself. The [illegible] system. The use of these [illegible] first [illegible] instructions [illegible] procedure, [illegible] likely to produce [illegible] errors.

Thus it is natural to [illegible] A + B = C or A x B = C or A/B = C, and so on, [illegible]. These are three address [illegible] because they involve [illegible] the word A, the address of the word B [illegible] the address of the result C.

In the DICTATOR system for the IBM [illegible] used to indicate the arithmetic operations. [illegible] and are:

1 add

2 substract

3 multiply

4 divide

5 negative multiply (same as multiply, but the result is multiplied by minus 1)

6 move (this moves data from one address to another)

7 table look up (this [illegible] in memory and picks up the two words closest to an input [illegible]. This function permits the computer to use tabular data [illegible] within a table).

An example of an arithmetic instruction [illegible] is as follows: suppose we wanted to add [illegible] to [illegible].0 and [illegible] was in address 450 while the [illegible] in [illegible]. If we [illegible] in address 600 (for future use) [illegible] first give an instruction [illegible] into address 450 and [illegible] into 592 (this is just like [illegible] on a tabular form) and then give the instruction

1 450 592 600

in some convenient address (this is like saying add column 450 to column 592 and put the result in column 600 [illegible] in a tabular form). If we put the instruction in address 400, we would then, from the console, or by internal [illegible] tell the computer to [illegible] and start working. If all we wanted to do was to just add these two numbers [illegible] the result, we would add a command to print what was in location [illegible] the computer would type out the result. [illegible], this constitutes using [illegible] in the same way as a desk calculator (which is not very [illegible], [illegible] easier since the computer [illegible] of the decimal point), [illegible] is sometimes used when one has to extract a square root, or [illegible] or some similar function which cannot be obtained accurately enough on a slide rule.

The use trigonometric functions, [illegible] exponential functions and square roots [illegible] frequently in calculations, [illegible] a special set of instructions to perform operations of this [illegible]. This set of instructions is referred to as the transcendental set, and [illegible] instructions are "two address" since this reflects the way we normally [illegible] functions. The command for sine is [illegible], cosine [illegible] etc. [illegible] the sine of a number (in radians) in location [illegible] and wanted the result in [illegible]. The instruction appears as

0091[illegible]906

[illegible] has many other instructions which [illegible] be used, and which provide for simple programming of decision [illegible] by the computer, choice of computational [illegible], handling of matrix algebra [illegible] other functions.

Including [illegible] operator control [illegible] direct control of the [illegible] series [illegible] that [illegible] may [illegible] this [illegible] division by zero [illegible] occurring during [illegible] simply [illegible] DICTATOR [illegible] be made to [illegible] provide [illegible] rapid "[illegible]ing".

Use of DICTATOR does not [illegible] of the computer in [illegible] applications, however [illegible] problems which [illegible]. The [illegible] is used when [illegible] variability [illegible] systems.

The complete list of DICTATOR [illegible] system is as follows:

[illegible]

1. Clear Memory

   a. Set parity switch to stop.

   b. Set I/O switch to stop.

   c. Set O flow switch to program.

   d. Set program switches 1, 2, 3 and 4 to off.

   e. Depress "reset".

   f. Depress "insert".

   g. Type 16 00010 00000.

   h. Depress "release".

   i. Depress "start".

   j. After the "1" light of the ten thousands position of the M.A.R. flashes at least twice, depress "instant stop/sce".

If a check stop is encountered, set parity and I/O switches to program; re-execute steps 1-a to 1-j, then re-execute 1a to 1j. If no check stop encountered, proceed to read tape.

2. Read Tape

   a. Insure that the strain/reel switch is in reel position (to the right).

   b. Thread tape (non-punched side of tape to bottom of feed reel and inside of reader).

   c. Push "reel power" on reader.

   d. Depress "reset" on console.

   e. Depress "insert".

   f. Type 36 00000 00300.

   g. Depress "release".

   h. Depress "start".

If "reader no feed" light comes on, check threading of tape in reader.

   i. After tape has been read in, run tape through reader by depressing "non proc. R.O." on reader (it is not necessary to hold this [illegible] and run [illegible] vicinity of [illegible] [illegible]ly.

[illegible] information is [illegible].

[illegible] to accept [illegible] is:

1. [illegible]

2. [illegible]

3. [illegible]

4. [illegible]

[illegible] may be [illegible] of the [illegible]

[illegible] in the [illegible] each [illegible] This will [illegible] In the [illegible] out from the [illegible]

[illegible]

[illegible] in the [illegible] is in the [illegible]. In [illegible] the [illegible] is followed [illegible] follows:

[illegible]

[illegible]:

[illegible] = location of instruction [illegible]

[illegible] = instruction [illegible] instruction [illegible]

[illegible] = [illegible] of information.

[illegible]

[illegible] instruction is [illegible] in-[illegible].

[illegible]

[illegible]

9 000 000 000	Stim	Re-interpret the last instruction.
9 001 000 CCC	Interp. Transfer	Transfer to the instruction at location CCC and begin executing interpretively.
9 002 000 CCC	Read Typewriter	Read from the typewriter into locations CCC, CCC + 1, CCC + 2 .... etc., until reaching a terminate input code or completion of 4-button sequence.
9 003 000 000	Read Tape Reader	Read from the tape reader. The tape must contain a start fill code at the beginning and a terminate input code at the end.
9 004 BBB CCC	Print Typewriter	Print on the typewriter the contents of locations BBB through CCC where BBB ≤ CCC.
9 005 BBB CCC	Punch Tape	Punch the contents of locations BBB through CCC on paper tape. BBB ≤ CCC. This command automatically generates a start fill code and a terminate input code on the paper tape.

SPECIAL CODES

9 010 000 000	Start Fill Code on Paper Tape	This code is generally not used by the programmer. It is automatically generated by the punch command.
9 012 000 000	Terminate Input	Causes the interpreter to terminate input and await a new keyboard command.

[illegible]

[illegible]

1 AAA BBB CCC	Add	[illegible] contents of location [illegible] [illegible] contents of location [illegible]. The [illegible] in location CCC [illegible] the [illegible].
2 AAA BBB CCC	Subtract	[illegible] contents of location [illegible] [illegible] the contents of location [illegible]. [illegible] difference is [illegible] in location [illegible] [illegible] remainder.
3 AAA BBB CCC	Multiply	[illegible] contents of location AAA [illegible] [illegible] contents of location [illegible]. [illegible] product is stored in location [illegible] accumulator.
4 AAA BBB CCC	Divide	[illegible] contents of location AAA [illegible] divided [illegible] contents of location [illegible]. [illegible] is stored in location CCC [illegible] remainder.
5 AAA BBB CCC	Neg. Multiply	[illegible] contents of location AAA [illegible] multiplied [illegible] contents of location [illegible]. [illegible] [illegible] multiplied by [illegible] (-1). [illegible] final product is stored in location CCC and the remainder.
6 AAA BBB CCC	Move	[illegible] defined by AAA [illegible] [illegible], ... [illegible] CCC, CCC+1, CCC+2, ... CCC [illegible]-1. [illegible] in [illegible] location [illegible] CCC and the [illegible].
7 AAA BBB CCC	T.L.U.	[illegible] table stored in location [illegible], ... [illegible] is searched [illegible] in location AAA. [illegible] table [illegible] is found [illegible] value is less than that of the [illegible], the search is terminated. The [illegible] table values [illegible] placed [illegible] locations CCI and CCI [illegible] location CCI. [illegible] stored in [illegible], CCC+1, CCC+2, ... [illegible] locations CCC and CCI.

Halt Group

0 000 000 CCC	Halt and transfer	The program halts. Upon receipt of a start signal, the program transfers to location CCC.
0 001 000 CCC	Halt and transfer on switch 1	If switch one is set to "on" instruction is the same as halt and transfer. If switch one is set to "off", the program transfers to location CCC without halting.
0 002 000 CCC	Halt and transfer on switch 2	Same as above but involving switch 2.
0 003 000 CCC	Halt and transfer on switch 3	Same as above but involving switch 3.
0 004 000 CCC	Halt and transfer on switch 4	Same as above but involving switch 4.
0 005 000 CCC	Halt and transfer on zero	If the accumulator contains zero, instruction is the same as halt and transfer. If accumulator contains others than zero, the program transfers to CCC without halting.
0 006 000 CCC	Halt and transfer on negative	If the accumulator contains a negative number, instruction is the same as halt and transfer. If accumulator contains a positive number, the program transfers to CCC without halting.
0 007 E3 CCC	Halt and transfer on exponent	If the numerical value expressed by E3 (E3 does not refer to a memory location in this instruction), is equal to or larger than the two digit exponent of the number in the accumulator, instruction is the same as halt and transfer. Otherwise, the program transfers to CCC without halting.
0 008 000 000	Halt and transfer out	The program halts. Upon receipt of a start the interpreter is set to receive a keyboard command.
0 009 000 000	No Op	No operation is performed and the program proceeds sequentially.

Transfer Group

0 010 000 CCC	Unconditional transfer	Transfer to location CCC.
0 011 BBB CCC	Transfer on switch 1	If switch one is on, transfer to location CCC. If switch one is off, transfer to location BBB.
0 012 BBB CCC	Transfer on switch 2	If switch two is on, transfer to location CCC. If switch two is off, transfer to location BBB.
0 013 BBB CCC	Transfer on switch 3	If switch three is on, transfer to location CCC. If switch three is off, transfer to location BBB.
0 014 BBB CCC	Transfer on switch 4	If switch four is on, transfer to location CCC. If switch four is off, transfer to location BBB.
0 015 BBB CCC	Transfer on zero	If the accumulator contains zero, transfer to location CCC. If the accumulator contains other than zero, transfer to location BBB.
0 016 BBB CCC	Transfer on sign	If the number in the accumulator is negative, transfer to location CCC. If the number in the accumulator is positive, transfer to location BBB.
0 017 0BB CCC	Transfer on exponent	If the numerical value expressed by EE (EE does not refer to a memory location in this instruction), is equal to or greater than the the digit [illegible] present in the accumulator, transfer to location CCC. Otherwise proceed sequentially.
0 018 000 000	Transfer out	Execution of the stored program is terminated and the interpreter awaits a keyboard command.
0 019 BBB CCC	Transfer and set CCC	The program transfers to location CCC and the CCC digits of the instruction stored there is set equal to BBB before it is executed.

Input/Output Group

0 020 BBB CCC	Write typewriter, full length	The contents of location BBB through CCC inclusive are printed via the typewriter.
0 021 BBB CCC	Write typewriter, less 1 digit	Same as above but the last digit of the mantissa is not printed.
0 022 BBB CCC	Write typewriter, less 2 digits	Same as above but the last two digits of the mantissa are not printed.
0 023 BBB CCC	Write typewriter, less 3 digits	Same as above but the last three digits of the mantissa are not printed.
0 024 BBB CCC	Write typewriter, less 4 digits	Same as above but the last four digits of the mantissa are not printed.
0 025 000 000	Read tape	Read from the paper tape reader. The tape must contain a start fill code and a terminate input code.
0 026 BBB CCC	Punch tape	The contents of locations BBB through CCC inclusive are punched on paper tape. The start fill code and terminate input code are automatically generated by this instruction.
0 027 000 CCC	Read typewriter	Read from the typewriter into locations CCC, CCC+1, CCC+2, ... etc. This instruction is terminated by receipt of a terminate input code. Each word entered from the typewriter must be followed by depression of the release and start buttons.
0 028 000 000	C.R.	Execute a carriage return on the typewriter.
0 029 000 000	Tab	Execute a tab on the typewriter.

Instruction Modification Group

0 030 [illegible] CCC	Set O_1	The O_1 digit of the instruction at [illegible] is replaced by the digit C.
0 031 [illegible] CCC	Increment AAA	The [illegible] of the instruction at [illegible] is incremented by the [illegible] CCC.
0 032 [illegible] CCC	Increment [illegible]	[illegible] of the instruction at [illegible] is incremented by the [illegible] CCC.
0 033 [illegible] CCC	Increment CCC	The CCC [illegible] of the instruction at [illegible] is incremented by the [illegible] CCC.
0 [illegible] CCC	Decrement AAA	The [illegible] of the instruction at [illegible] is decremented by the [illegible]
0 [illegible] CCC	Decrement [illegible]	[illegible] of the instruction at [illegible] is decremented by the [illegible] CCC.
[illegible] CCC	Decrement CCC	[illegible] of the instruction at [illegible] is decremented by the [illegible]
[illegible] CCC	Set AAA	[illegible] of the instruction at [illegible] is set equal to the [illegible]
[illegible] CCC	Set [illegible]	[illegible] of the instruction at [illegible] is set equal to the [illegible]
[illegible] CCC	Set CCC	[illegible] of the instruction at [illegible] is set equal to the [illegible] CCC.

Index Register Group

0 04A 000 CCC	Increment index register A	Index register A ($0 \leq A \leq 9$) is incremented by the amount CCC.
0 05A 000 CCC	Decrement index register A	Index register A ($0 \leq A \leq 9$) is decremented by the amount CCC.
0 06A 000 CCC	Set index register A	Index register A ($0 \leq A \leq 9$) is set equal to the number CCC.
0 07A BBB CCC	Branch on equal index register	Branch to location CCC if index register A ($0 \leq A \leq 9$) is equal to BBB. Otherwise proceed sequentially.
0 08A BBB CCC	Branch on low index register	Branch to location CCC if BBB is greater than index register A ($0 \leq A \leq 9$). Otherwise proceed sequentially.

Transcendental Group

0 090 BBB CCC	Sq. Rt.	The square root of the contents of location BBB is stored in location CCC and the accumulator.
0 091 BBB CCC	Sine	The sine of the contents of location BBB is stored in location CCC and the accumulator.
0 092 BBB CCC	Cosine	The cosine of the contents of location BBB is stored in location CCC and the accumulator.
0 093 BBB CCC	Arctangent	The arctangent of the contents of location BBB is stored in location CCC and the accumulator.
0 094 BBB CCC	Exponential	e raised to the power designated by the contents of location BBB is stored in location CCC and the accumulator.
0 095 BBB CCC	Log_e	Log_e of the contents of location BBB is stored in location CCC and the accumulator.

0 006 BBB CCC	Absolute	The absolute value of the contents of location BBB is stored in location CCC and the accumulator.
0 007 BBB CCC	Reverse storage	The contents of locations BBB and CCC are interchanged. At the completion of the instruction, the accumulator is set equal to the number in location CCC.
0 008 BBB CCC	Larger algebraic value	The contents of locations BBB and CCC are compared. The number having the smaller algebraic value is stored in location BBB. The number having the larger algebraic value is stored in location CCC and the accumulator.
0 009 BBB CCC	Larger absolute value	The contents of locations BBB and CCC are compared. The number having the smaller absolute value is stored in location BBB. The number having the larger absolute value is stored in location CCC and the accumulator. This instruction does not absolute the quantities (i.e., the signs of the numbers are unchanged).

This is the total list of instructions which [illegible] II will recognize. If an attempt is made to interpret a data word as an instruction word, an error code will be generated. However, if the data word is a configuration of digits which identically resembles an instruction, the interpreter has no recourse other than to interpret it as an instruction. This [illegible] can be useful to an [illegible] in that data and instructions may be [illegible] should such the need arise.

DICTATOR II

ERROR CODES

ERROR CODES are defined by the printing of a single digit (1 through 9) preceded by a 3 digit number. The single digit identifies the type of error and the 3 digit number is the memory address of the instruction causing the error. This 3 digit address only has significance if the error occurred during interpretation of a stored program. If the error occurred during loading of memory or while executing keyboard commands, the 3 digit address has no significance.

Error Code	During Loading or Interpreting Keyboard Commands	During Interpretation of Stored Program
1.	Attempting to enter an illegal configuration of digits.	Attempting to interpret an illegal configuration of digits as an instruction.
2.	Attempting to load beyond memory location 999.	Attempting to interpret instructions from beyond location 999; attempting to move to or from beyond location 999; attempting to search a table beyond location 999; or attempting to increment an address beyond 999 or decrement an address below 000.
3.	No start fill code at beginning of tape	Attempting to generate an exponent larger than 99 or smaller that 00.
4.		Attempting to increment an index register beyond 999 or attempting to index an address beyond 999.
5.		Argument for logarithm equal to zero or negative.
6.		Attempting to take the square root of a negative number.
7.		Argument for sine or cosine equal to or greater than 100 radians (exponent > 52).
8.		Attempting to divide by zero or an unfloated number.
9.		Argument for exponential equal to or greater than 100.

The typical sequence of operations [illegible] in writing a digital program, using the DICTATOR language, is [illegible] illustrated by example than by pure rhetoric. We shall therefore consider a simple problem familiar to most aeronautical engineers, that of determining a true speed versus power required curve for a given airplane. For this problem, the gross weight of the airplane, its effective [illegible], its lift-drag relationship, the altitude of flight, the speed range of interest, and the maximum lift coefficient value need to be first determined as [illegible] data. If the lift drag data are in the form of curves, these data [illegible] into the computer as a table of drag coefficients versus lift coefficients. If an equation of the type $C_D = C_{D_0} + KC_L^2$ applies, C_{D_0} and K are input data.

If curves at many altitudes are desired, the computer may be programmed to automatically compute air density as a function of input height.

The purposes of our illustrative example will be served by considering the case where $C_D = C_{D_0} + KC_L^2$ and where [illegible] only under standard sea level conditions is desired. We [illegible] the basic data of the problem have been established for us (this might [illegible] by another digital program in the case of the drag formula.) [illegible] data are as follows:

gross weight, W, 2500 lbs.

parasite drag coefficient, C_{D_0}, [illegible]

drag due to lift factor, K, [illegible]

air density, ρ, 0.002[illegible] slugs/ft.^{3}

$C_{L_{max}}$, 1.5

wing area, S, 170 ft.^{2}

maximum speed, 250 mph.

The formulae which apply to [illegible] standard ones (derived in most basic aerodynamics texts) [illegible]:

$$V = \sqrt{[illegible]W/\rho SC_L}$$

$$THP\ req. = [illegible]VC_D/550C_L$$

$$C_D = C_{D_0} + KC_L^2$$

To program the problem, we [illegible] in [illegible] the same fashion as if we were laying out a tabular chart. The first [illegible] do is to put the basic data where we can readily obtain it [illegible]. [illegible] arbitrarily pick some [illegible] in which to store [illegible], [illegible] location [illegible] (which for programming convenience is [illegible] results temporarily occupy so that if the output of an instruction is only needed for use by the next instruction it does not have to be stored in a permanent address). Location 000 is called an "accumulator". We arbitrarily start assigning addresses for data at 100. Thus, we make the following memory assignments:

Address	Quantity	Floated Number
100	gross weight, W	54 2500 0000
101	wing area, S	53 1700 0000
102	C_{D_o}	49 2000 0000
103	K	49 5000 0000
104	$C_{L_{max}}$	51 1500 0000
105	air density, ρ	48 2376 9000
106	V_{max} (mph)	53 2500 0000
107	1.467 (conversion factor mph to fps)	51 1467 0000
108	the constant 2	51 2000 0000
109	the constant 550	53 5500 0000
110	decrement factor for C_L (= 0.05)	49 5000 0000

Having prepared this table, we could if we wanted, immediately store it in the computer, or we could wait until the rest of the program were written. In either case, it would be stored (referring to the DICT/TOP instrument list) in the following fashion:

1. Push the 4 console buttons "reset", "insert", "release" and "start" in sequence.
2. Type 9 002 000 100
3. Depress release-start key (RS).
4. Type the first data word, 54 2500 0000
5. Depress release-start key
6. Type the next data word, 53 1700 0000
7. Depress release-start key
8. Continue until all data words have been typed into the computer.

If a mistake is made in number of characters or [illegible] ours the computer will automatically type an error [illegible] for what error has occurred. Corrections are made by simply [illegible] the "four button" sequence typing in 9 002 000 XXX RS where XXX is the location of the word to be corrected, followed by the correction. RS stands for the return-reset key. Inputing data is seen to basically involve the simple process of typing it in.

We now must write the program. Since the conditions CW/oS and W/330 are going to have constant values, these values can be computed and stored for later use. The performance of preliminary [illegible] this is referred to as "initialization", and the block of commands required to do this is commonly referred to as a "start block". Following initialization we compute V and C_D for $C_{L_{max}}$ and then THP, convert V to mph [illegible] for a print out of V and THP followed by a [illegible] instruction which is [illegible] here to provide a location for calling for additional output if this is desired later on. A test to see if V_{mph} has been exceeded is [illegible]. If V_{mph} has not been exceeded, C_L is decremented by 0.05 and the [illegible] till the test shows that V exceeds 350 mph. When this occurs, [illegible] calls for the computer to stop and await a command from the operator. The program to accomplish this effort follows and is arbitrarily located in the computer starting at location 200 (any other address could have been [illegible] as long as there was no overlapping of prior input)

Address	Operation	Instruction
200	2W (note use of accumulator)	3 102 100 000
201	2W/ρ	4 000 105 000
202	2W/ρS	4 000 101 100
	the constant [illegible] is now stored in address [illegible]. A separate table of [illegible] would be maintained if [illegible] program were being [illegible].	
203	load [illegible] for later use	4 100 103 121
204	move $C_{L_{max}}$ [illegible] location	5 000 104 122
205	compute [illegible]	4 120 122 000
206	compute V(fps) = $\sqrt{[illegible]}$	0 000 000 123
207	V(mph) = V(fps)/1.[illegible], store in 124	4 000 107 124
208	C_L^2	3 122 122 000
209	C_{D_i} = [illegible]C_L^2	3 000 107 000
210	$C_D = C_{D_0} + C_{D_i}$	1 000 102 000

211	C_D/C_L	4 000 122 000
212	VC_D/C_L	3 000 123 000
213	THP req. = WVC_D/C_L 550, store in 125	3 000 121 125
214	output V(mph) and THP req. to 4 places of accuracy	0 024 124 125
215	NOOP	0 009 000 000
216	test for maximum speed	2 106 124 000
217	transfer on sign, if + continue if - stop	0 016 218 220
218	decrement C_L by 0.05	2 122 110 122
219	transfer back to 205 to cycle program	0 010 000 205
220	end of program, halt and wait for operator command	0 003 000 000

This completes the program, and as can be seen, the actual programming procedure and time of preparation is about the same as required to design a tabular form for hand computations.

The program is placed in the machine by the same procedure as used to input data, excepting that the keyboard command is 9 000 000 200 to start the entry at location 200.

Individual data items such as the weight, wing area, drag parameters, lift coefficient increment can all be changed by simply filling new data into the proper locations. The input command automatically erases old data in a given location to avoid overlap.

Operation of the program is initiated by pushing the console buttons (in sequence) reset, insert, release and start and then typing 9 001 000 200 RS which causes the computer to start executing the program.

An actual trace of the program is reproduced as Figure 6:1 and Figure 6:2 is a reproduction of the actual output. Time to complete computation and print out the power required data was 1 minute 35 seconds on an IBM 1620 model 1 computer with typewriter output. Programming involves under 20 minutes of engineering effort, so that the direct cost of obtaining the power required curve is only a few dollars.

The example here, while simple in nature might well occupy a days time to compute by non-electronic procedures. Moreover, once the program is available it can be applied to any airplane configuration and need not be rewritten in the future.

[illegible]201[illegible]02[illegible]		
200	310310000[illegible]	5[illegible]
201	40001050[illegible]	5721[illegible]
202	4[illegible]0111120	[illegible]
203	410[illegible]100121	51[illegible]
204	[illegible]10[illegible]122	[illegible]
205	4120122[illegible]	[illegible]
206	[illegible]123	52[illegible]
207	40[illegible]107125	52[illegible]
208	312[illegible]122[illegible]	51[illegible]
209	30[illegible]10[illegible]	[illegible]
210	1[illegible]102[illegible]	[illegible]
211	40[illegible]122[illegible]	[illegible]
212	3[illegible]12[illegible]	51[illegible]
213	3[illegible]121125	523[illegible]
5[illegible]191	523[illegible]	
214	[illegible]024124125	523[illegible]
215	[illegible]	[illegible]
216	21[illegible]124[illegible]	[illegible]
217	[illegible]1[illegible]21[illegible]220	[illegible]
218	212211[illegible]122	511[illegible]
219	[illegible]	[illegible]
220	412[illegible]	[illegible]

Figure 6:1

Trace

V(ph)	TFreq.
[illegible]	[illegible]
[illegible]7	[illegible]
5273[illegible]	5235[illegible]
5273[illegible]2	523[illegible]
[illegible]2777[illegible]	[illegible]
[illegible]27[illegible]2	5235[illegible]2
[illegible]	52[illegible]21
[illegible]31[illegible]22	[illegible]
5[illegible]1[illegible]2	[illegible]
5[illegible]11[illegible]	[illegible]
[illegible]11[illegible]	[illegible]
[illegible]12[illegible]1	[illegible]
[illegible]1[illegible]	5273[illegible]
[illegible]1[illegible]	5312[illegible]
[illegible]1[illegible]57	531[illegible]
[illegible]7	[illegible]

Figure 6:2

Programming for more complex problems involves exactly the same procedures as presented here, but applied to lengthier equations. Elaborate or complex equation sets, which in many cases cannot be readily solved by hand computation procedures because of the prohibitive number of man-hours involved, are solved in a straight forward and economical manner on an electronic digital computer.

Decisions on the benefits to be provided by computers in a given organization can only be based on managements understanding of how computers are most efficiently usable, and it is hoped that the short description of programming procedure presented in this chapter provides a basic understanding of this topic insofar as day to day type problem solving is concerned. In the following chapters are presented programs for more involved type analyses concerning problems one would not normally attempt to solve without a digital computer. These programs provide an indication of the scope of work which can be handled by even the lowest cost, modern digital computers of the CCC DDP-116 and IBM 1130 type. Programs are written in the DICTATOR II language for the IBM 1620 system since such equipment was in use at DODCO when the programs were developed.

7.3 EQUATION FLOW FOR SPIN SIMULATION

The equations defining spinning [illegible] flow presented in the previous chapters comprise (from the mathematical [illegible]) a set of simultaneous nonlinear differential equations with [illegible] coefficients expressed in terms of aerodynamic and environmental [illegible]. They are solved, by a digital computer, in such the [illegible] will be solved using a typical desk computer and a set of [illegible] by the [illegible] operator. Specifically, all pertinent [illegible] in a convenient form, a set of initial conditions is specified and a stepwise set of equations devised, on the basis of Taylor [illegible] integration formulas, which define a specific solution for the given set of initial conditions and [illegible] constants. All operations are conducted [illegible] as explained in Chapter 6.

A breakdown of operations in a form suitable for stepwise computation is referred to as equation flow analysis [illegible] analysis, along with the definition of groups of coefficients [illegible] constants of the analysis provides the [illegible] operations required to provide for numerical integration [illegible]. There follows immediately the definition of [illegible] coefficients required by the program and the equation flow follows after this.

$$K_{1i} = (I_z - I_y)/I_x \qquad \text{.....................7:1}$$

$$K_{2i} = (I_z - I_x)/I_y \qquad \text{.....................7:2}$$

$$K_{3i} = (I_y - I_x)/J_{xz} \qquad \text{.....................7:3}$$

$$K_{4i} = bS_w/I_x \qquad \text{.....................7:4}$$

$$K_{5i} = cS_w/I_y \qquad \text{.....................7:5}$$

$$K_{6i} = bS_w/J_{xz} \qquad \text{.....................7:6}$$

$$K_{7i} = J_{xz}/I_x \qquad \text{.....................7:7}$$

$$K_{8i} = J_{xz}/I_y \qquad \text{.....................7:8}$$

$$K_{9i} = I_z/J_{xz} \qquad \text{.....................7:9}$$

$$K_{10i} = (I_z - I_y)/I_x + 1 = K_1 + 1 \qquad \text{.....................7:10}$$

$$K_{11i} = J_{xz}/I_x - (I_y - I_x)/J_{xz} = K_7 - K_3 \qquad \text{.....................7:11}$$

$$K_{12i} = J_{xz}/I_x - I_z/J_{xz} = K_7 - K_9 \qquad \text{.....................7:12}$$

$$\Delta t^2/2 \qquad \text{.....................7:13}$$

$$S_t/S_w \qquad \text{.....................7:14}$$

$$(c_t/\bar{c})(S_t/S_w) \qquad \text{.....................7:15}$$

$$R_q = \eta(\ell_t/\bar{c})(S_t/S_w) \quad \ldots\ldots\ldots\ldots 7:16$$

$$W/S \quad \ldots\ldots\ldots\ldots 7:17$$

$$(\ell_{v_t}/b)(S_{v_t}/S_w) \quad \ldots\ldots\ldots\ldots 7:18$$

$$a_{v_t}(\ell_{v_t}/b)^2(S_{v_t}/S_w) \quad \ldots\ldots\ldots\ldots 7:19$$

$$2a_{v_t}(\ell_{v_t}/b)^2(S_{v_t}/S_w)(K_{13}) \quad \ldots\ldots\ldots\ldots 7:20$$

Spin entry definition requires the specification of the following quantities

α

φ_W

p

q

r

V

h

δ_e

δ_r

δ_a

β

γ

From start the program transfers to the main block while during running the integration block precedes the main block. The integration block is as follows:

$$t_{n+1} = t_n + \Delta t \quad \ldots\ldots\ldots\ldots 7:21$$

$$h_{n+1} = h_n + \dot{h}_n\Delta t + \ddot{h}_n\Delta t^2/2 \quad \ldots\ldots\ldots\ldots 7:22$$

$$d_{NS_{n+1}} = d_{NS_n} + V_{NS}\Delta t + \dot{V}_{NS}\Delta t^2/2 \qquad \ldots\ldots 7:23$$

$$d_{EW_{n+1}} = d_{EW_n} + V_{EW}\Delta t + \dot{V}_{EW}\Delta t^2/2 \qquad \ldots\ldots 7:24$$

$$\phi_{w_{n+1}} = \phi_{w_n} + \dot{\phi}_{w_n}\Delta t \qquad \ldots\ldots 7:25$$

$$\alpha_{n+1} = \alpha_n + \dot{\alpha}_n\Delta t \qquad \ldots\ldots 7:26$$

$$\beta_{n+1} = \beta_n + \dot{\beta}_n\Delta t \qquad \ldots\ldots 7:27$$

$$V_{n+1} = V_n + \dot{V}_n\Delta t \qquad \ldots\ldots 7:28$$

$$\gamma_{n+1} = \gamma_n + \dot{\gamma}_n\Delta t \qquad \ldots\ldots 7:29$$

$$\psi_{n+1} = \psi_n + \dot{\psi}_n\Delta t \qquad \ldots\ldots 7:30$$

$$p_{n+1} = p_n + \dot{p}_n\Delta t \qquad \ldots\ldots 7:31$$

$$q_{n+1} = q_n + \dot{q}_n\Delta t \qquad \ldots\ldots 7:32$$

$$r_{n+1} = r_n + \dot{r}_n\Delta t \qquad \ldots\ldots 7:33$$

$$\delta_{e_{n+1}} = \delta_{e_n} + \dot{\delta}_{e_n}\Delta t \qquad \ldots\ldots 7:34$$

$$\delta_{r_{n+1}} = \delta_{r_n} + \dot{\delta}_{r_n}\Delta t \qquad \ldots\ldots 7:35$$

From the integration block or flight block we transfer to the atmosphere block which, in this case, involves only the following computation :

$$\rho = \rho_o e^{-0.297h \times 10^{-4}} \qquad \ldots\ldots 7:36$$

$$q^* = \rho V^2/2 \qquad \ldots\ldots 7:37$$

Next transfer to control block for computation of δ_e and δ_r as required

$$\dot{\delta}_e = f(t) \qquad \text{.....................7:38}$$

$$\dot{\delta}_r = f(t) \qquad \text{.....................7:39}$$

δ_e, δ_a and δ_r may also be set by the operator at any time during the run.

From here we proceed to the aerodynamic and differential equation block. Compute

$$C_{L_W} = a_1\alpha - a_2\alpha^2 \qquad \text{.....................7:40}$$

or if $\alpha > a_p$

$$C_{L_W} = K_a - K_{a_1}\alpha \qquad \text{.....................7:41}$$

$$\alpha_t = \alpha + i_t + \ell_t q/V \qquad \text{.....................7:42}$$

$$C_{L_t} = a_t\alpha_t + a_e\delta_e \qquad \text{.....................7:43}$$

$$q_t^* = \eta q^* \qquad \text{.....................7:44}$$

$$C_L = C_{L_W} + C_{L_t} q_t^* S_t / qS \qquad \text{.....................7:45}$$

$$C_{D_e} = C_{D_{eo}} + (\partial C_{D_e}/\partial\beta)/\beta/ \qquad \text{.....................7:46}$$

$$C_D = C_{D_e} + K_d\alpha^2,\ C_{D_W} = C_{D_o} + K_d\alpha^2 \qquad \text{.....................7:47}$$

or, when $K_d\alpha > K_{I_d}$

$$C_D = C_{D_e} + \frac{(K_{I_d})^2}{K_d},\ C_{D_W} = C_{D_o} + \frac{(K_{I_d})^2}{K_d} \qquad \text{.....................7:48}$$

$$C_{L_L} = W/q^*S \qquad \text{.....................7:49}$$

$$\dot{V} = -\ g(C_D/C_{L_L} + \sin\gamma) \qquad \text{.....................7:50}$$

$$C_Y = -\ (\partial C_Y/\partial\beta)\beta \qquad \text{.....................7:51}$$

$$\dot{\gamma} = (g/V)\,[(C_L \cos\mu_w - C_Y \sin\mu_w)/C_{L_1} - \cos\gamma] \qquad \text{.................7:52}$$

$$\dot{\chi} = (g/VC_{L_1}\cos\gamma)(C_L \sin\mu_w + C_Y \cos\mu_w) \qquad \text{.................7:53}$$

$$C_m = C_{mac} + C_{L_W}\,[(x_{cg}/\bar{c})\cos\alpha + (z_{cg}/\bar{c})\sin\alpha]$$

$$- R_a\,\left\{a_t\,[\alpha + i_t + \frac{\ell_t}{V}(\dot{\alpha} + K\dot{\theta})] + a_e\delta_e\right\} \qquad \text{..........7:54}$$

$$C_\ell = \frac{\partial C_\ell}{\partial \delta_a}\,\delta_a - \frac{\partial C_\ell}{\partial \beta}\,\beta + C_{\ell_W} \qquad \text{.................7:55}$$

where $\partial C_\ell/\partial \delta_a$, aileron effectiveness [illegible], is taken as a constant and where $\partial C_\ell/\partial\beta$ is given [illegible] depending on the region of operation along the wing lift curve. C_{ℓ_W} is given by equation 5:21 for angles of attack up to [illegible], [illegible] is set to zero and the quantity $C_{L_\alpha}\alpha - a_1$ is replaced [illegible]. [illegible] angles of attack above [illegible] K_{1d}/K_d, the further change of [illegible], which [illegible] contain K_d as a factor (rather than C_{L_W}), to zero is [illegible]

$$C_n = \frac{\ell_{vt}}{b}\,\frac{S_{vt}}{S}\,(a_r\delta_r + [illegible]) - [illegible]\,\left(\frac{[illegible]\,S_{vt}}{b^2 S}\right) + C_{n_W} \qquad \text{.....7:56}$$

in which C_{n_W} is defined by equation [illegible] for angles of attack up to α_p, while for angles greater than this the [illegible] discussed in connection with equation 7:55 are employed.

This completes the aerodynamic [illegible] of the program and as well provides the quantities $\dot{V}$, $\dot{\gamma}$ and $\ddot{\gamma}$.

[illegible] compute the angular [illegible] from the set of equations 5:30, 5:31 and 5:32 expressed in [illegible] listed at the beginning of this chapter. Thus

$$\dot{r} = \left\{qr K_{10i} - pq K_{11i} - [illegible]\right\} / K_{10i} \qquad \text{..........7:57}$$

$$\dot{p} = (\dot{r} + pq)K_{7i} - qr K_{1i} + [illegible] \qquad \text{......................7:58}$$

$$\dot{q} = (r^2 - p^2)K_{3i} + pr[illegible] + [illegible] \qquad \text{......................7:59}$$

The kinematic equations yield for [illegible],

$$[illegible] = q\cos\phi - p\sin[illegible] - \dot{\gamma}\cos[illegible] - [illegible]\sin\mu_w \qquad \text{..........7:60}$$

$$\dot{\psi} = \dot{\theta}\cos\gamma\cos\varphi_W\cos\alpha - \dot{\gamma}\sin\varphi_W\cos\alpha - r - \dot{\theta}\sin\gamma\sin\alpha \quad \ldots\ldots\ldots\ldots\ldots 7{:}61$$

$$\dot{\varphi}_W = p\cos\beta\cos\gamma + q\sin\beta\cos\gamma + r\sin\gamma + \dot{\psi}\sin\gamma \quad \ldots\ldots\ldots\ldots\ldots 7{:}62$$

The remaining kinematic quantities are obtained from:

$$\dot{h} = V\sin\gamma \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 7{:}63$$

$$\dot{x} = V\cos\gamma \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 7{:}64$$

$$\ddot{h} = \dot{V}\sin\gamma + \dot{\gamma}\dot{x} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 7{:}65$$

$$\ddot{x} = \dot{V}\cos\gamma - \dot{\gamma}V\sin\gamma = \dot{V}\cos\gamma - \dot{\gamma}\dot{h} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 7{:}66$$

$$V_{NS} = \dot{x}\cos\psi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 7{:}67$$

$$V_{EW} = \dot{x}\sin\psi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 7{:}68$$

$$\dot{V}_{NS} = \ddot{x}\cos\psi - \dot{x}\dot{\psi}\sin\psi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 7{:}69$$

$$\dot{V}_{EW} = \ddot{x}\sin\psi + \dot{x}\dot{\psi}\cos\psi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 7{:}70$$

Print Block

Set sense switch to print every point or every "n" point.

Print

t	h	$\dot{h}$	V	$\dot{V}$	d_{NS}
d_{EW}	γ	α	[illegible]	φ_W	ψ
$\dot{\gamma}$	p	q	r	δ_e	δ_r

Typical results obtained with a program conforming to this equation flow are presented in the next chapter, while the program itself, in the DICTATOR II language, is listed in an appendix.

Revised April 7, 1965

[illegible] SAMPLE OUTPUTS OF THE SPIN [illegible]

The typical data presented in this chapter are not intended to do more than illustrate the functioning of the spin program. The airplane characteristics used for the simulation are somewhat similar to those of a Cessna [illegible], however the aerodynamic data are [illegible] estimated since no experimental information was available describing the aircraft in the angle of attack region involved. The data used [illegible] the airplane are as listed below and are derived as explained in Chapter 3 excepting that the factors [illegible] and [illegible] were set to give a [illegible] lift curve in the post-stall region. This was done to retard the spin rate. Also to provide a lower spin rate [illegible] the aircraft was operated below full gross weight. In this connection, other factors being equal, (i.e., [illegible] products of inertia) the gross weight directly affects the spin rate [illegible] the driving energy of a power off spin is the potential energy ([illegible]) available to overcome drag energy dissipation and to provide the rotational kinetic energy of the spin. Thus if the gross weight is lowered, the spin rate also is lowered.

The slope of the lift curve above the stall affects the spin rate because the autorotative moments depend directly on this slope. The incipient spin characteristics of an airplane, from the aerodynamic standpoint, are determined mainly by the post-stall shape of the lift curve, however the nature of the final autorotative [illegible] depends not only on this curve but also on the directional stiffness [illegible] of the vertical tail, the moment of inertia ratios and the value of the product of inertia J_{xz}. Positive values of J_{xz} favor a normal spin while negative values favor a flat spin.

The forces which actually cause the flight path to curve and produce a heading change are the fuselage side force and the component of the lift vector which acts horizontally. [illegible] the fuselage side force is large, a smaller angle of aerodynamic bank is [illegible], however substantial aerodynamic bank angles are required in any case. The aerodynamic bank angle is the inclination of the lift vector to the z_w wind axis and should not be confused with the [illegible] angle of the wings with respect to the ground since these two quantities differ substantially.

The hypothetical airplane used for program check-out had the following characteristics:

S	wing area, 175 ft.^{2}
W	gross weight, [illegible] lbs.
I_x	roll moment of inertia, [illegible] slugs/ft.^{2}
I_y	pitch moment of inertia, [illegible] slugs/ft.^{2}
I_z	yaw moment of inertia, [illegible] slugs/ft.^{2}
S_{vt}	vertical tail area, [illegible] ft.^{2}
S_t	horizontal tail area, [illegible] ft.^{2}

$\bar{c}$ mean aerodynamic chord, 4.9 ft.

b wing span, 36.5[illegible]3 ft.

l_{vt} vertical tail arm, 17.[illegible] ft.

l_t horizontal tail arm, 1[illegible].[illegible] ft.

a_1 lift curve parameter, .[illegible]

a_2 lift curve parameter, 11.[illegible]

α_{stall} stall angle of attack to zero lift, 0.[illegible] radians ([illegible].[illegible]°)

α_p plateau angle of attack, 0.[illegible] radians ([illegible].65°)

$C_{L_{max}}$ maximum lift coefficient, 1.[illegible]

C_{L_p} plateau lift coefficient, 1.[illegible]

a_t horizontal tail lift slope, [illegible].[illegible] per radian

a_e elevator deflection lift slope, [illegible].[illegible] per radian

i_t tail incidence from wing zero lift, - .1744 radians (-10°)

a_{vt} vertical tail lift slope, [illegible].[illegible] per radians

a_r rudder lift slope, 1.16 per radian

$C_{M_{ac}}$ moment coefficient about a.c., - 0.[illegible]

$x_{cg}/\bar{c}$ horizontal arm of a.c. to c.g., 0.0109

$z_{cg}/\bar{c}$ vertical arm of a.c. to c.g., 0

η tail efficiency factor, 1.0[illegible]

K_q damping in pitch factor, 1.5

$K_{\dot{\alpha}}$ angle of attack damping factor, [illegible].45

$\partial C_Y/\partial\beta$ side force coefficient slope, 1.[illegible] per radian

$\partial C_D/\partial\beta$ drag gradient with side slip, 1.0 per radian

Γ' adjusted geometric dihedral angle, 4.5° (0.07[illegible] radians)

K_d drag factor, 1.25 per (radian)^2

K_{l_d} limit drag factor, 1.[illegible]

C_{D_e} parasite drag coefficient, 0.[illegible]

C_{D_o} profile drag coefficient of wing, 0.011

J_{xz} product of inertia, [illegible]

K_a lift curve parameter, 1.8[illegible]

K_{a_1} lift curve parameter, .9[illegible]

K_{13} yaw damping parameter, [illegible].00

$\partial C_l/\partial \delta_a$ aileron effectiveness parameter, .12

Numerous runs have been made with the spin program, however results from only one need be presented to illustrate the operation. The initial conditions represent a stall out of a gliding descent during which the pilot completely stalls the aircraft so that the [illegible] reduces the speed well below the normal stall speed before the nose of the airplane falls through. Under these conditions the [illegible] to initial complete snap roll does not occur although the airplane rolls to aerodynamic bank angles in excess of 90°. Additionally the remaining initial conditions were:

$\alpha = 45.82°$ (angle of attack)

$\varphi_w = 23.[illegible]$ (aerodynamic bank angle)

$p = 0$ (roll rate)

$q = 0.573°$/sec. (pitch rate)

$r = 0$ (yaw rate)

$V = 40$ f.p.s. (flight path speed)

$h = 10,000$ ft. (standard altitude)

$\delta_e = -$ [illegible].6° (up elevator setting)

$\delta_r = +$[illegible]° (right rudder)

$\delta_a = 0$ (aileron setting), set to $-11.46°$ at $t = 2.5$ sec.

$\beta = 0$ (side slip angle)

$\gamma = -11.46°$ (flight path at $-11.46°$ to horizontal)

The integration interval was [illegible] seconds with print out at every 0.25 seconds. Larger intervals than this are not [illegible] because of the fairly high roll rates generated during the spin.

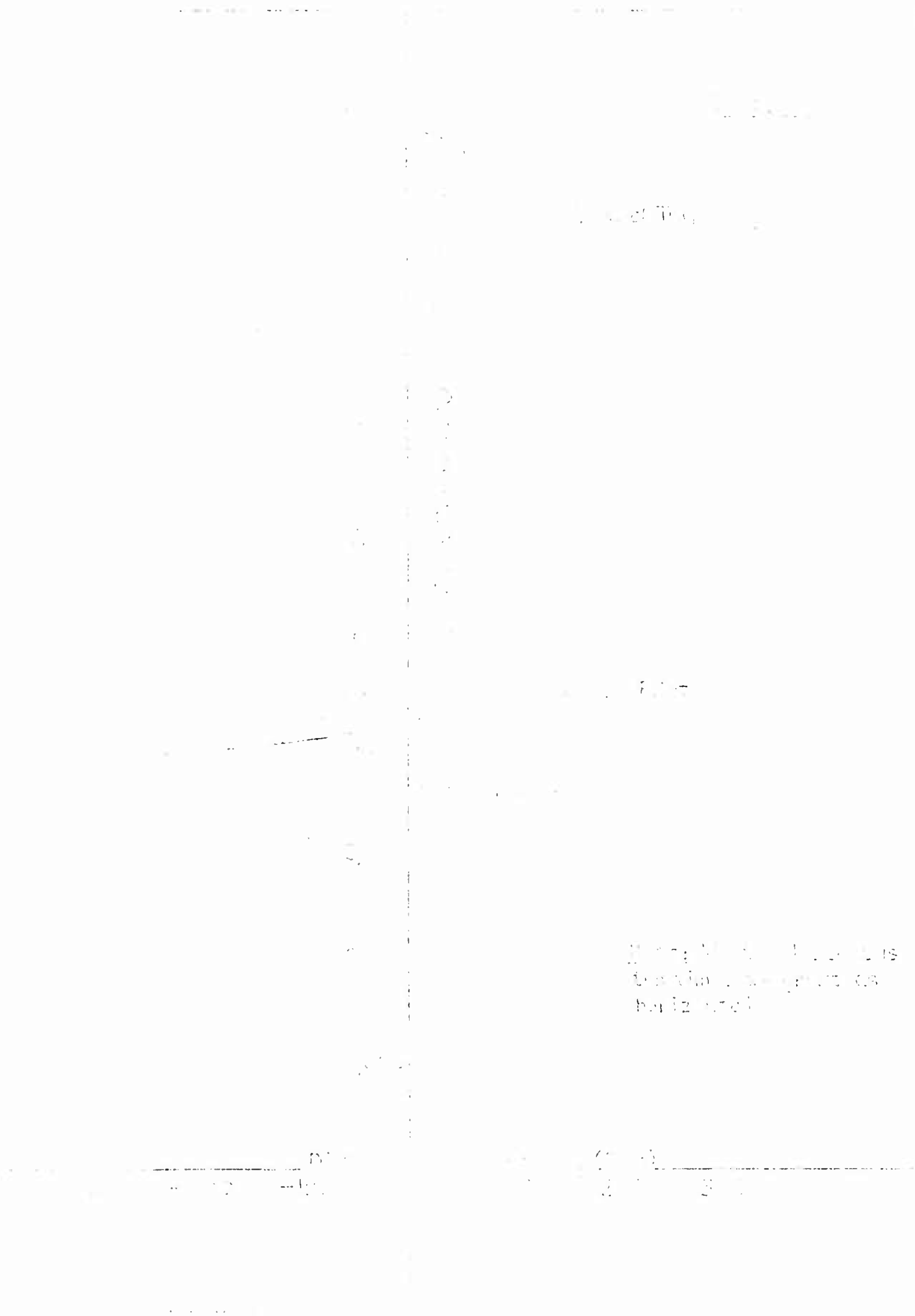
Revised April 7, 1965

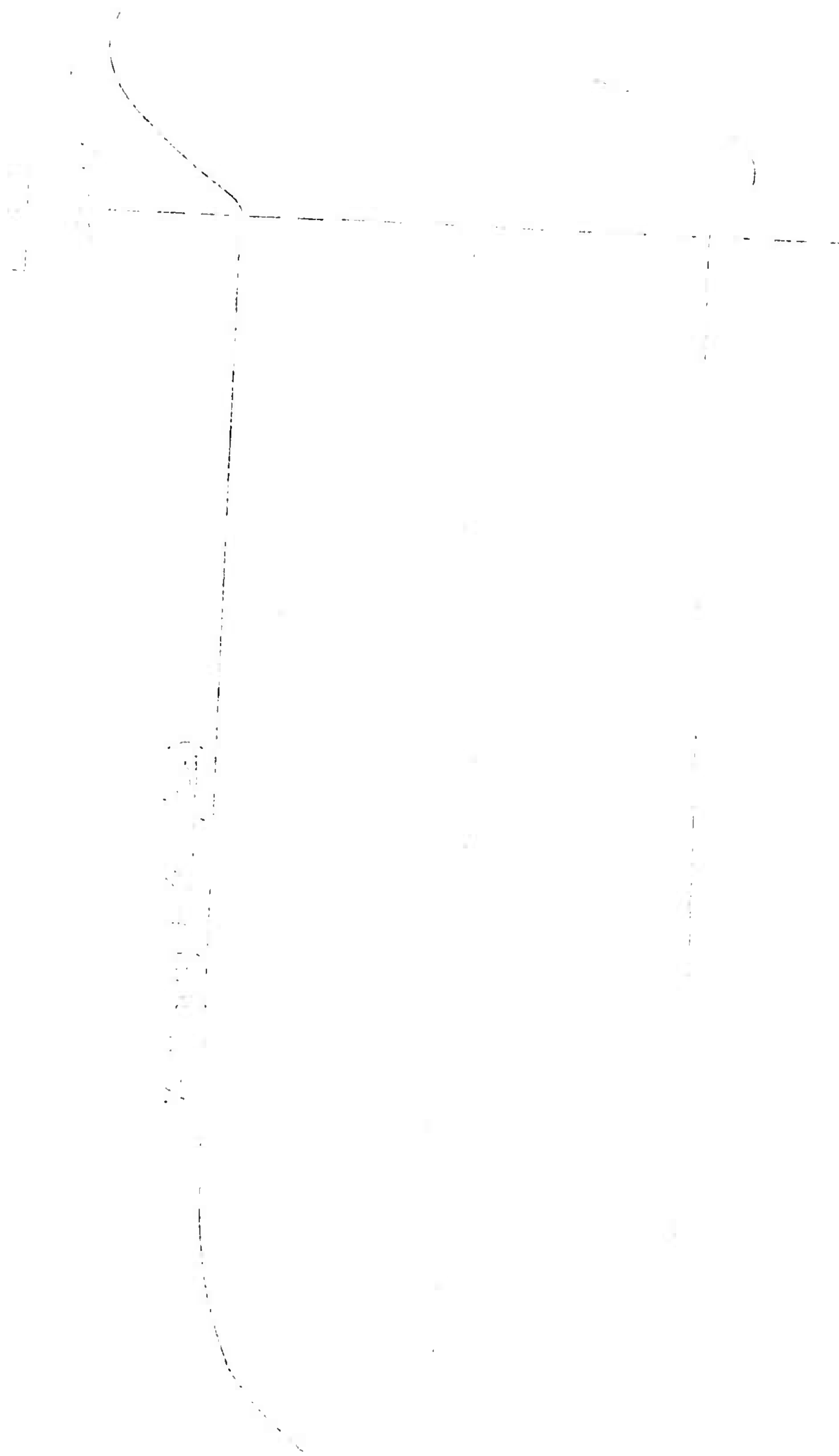
The rudder and elevator positions [illegible] during the spin and the [illegible] were initially [illegible]. [illegible] the spin [illegible] in a stalled [illegible]. [illegible] 2.5 [illegible] on ailerons [illegible]. In the [illegible] of this [illegible] control only rolls occur [illegible]. [illegible] all controls were [illegible] occurred in [illegible] turn. Spin rate [illegible] four full turns. The spin took [illegible] which [illegible] more turns. Results [illegible] in Figures [illegible], with Figure [illegible] showing [illegible]. The [illegible] the spin helix [illegible] the size of the [illegible] flight path [illegible]. The wing span of the [illegible] airplane is [illegible]. [illegible] that the airplane [illegible] forward [illegible] of the [illegible] in Figure 8:1. Figure [illegible] view of the trajectory.

The remaining figures provide [illegible] of other pertinent parameters [illegible] self explanatory.

This concludes the presentation of typical results of the spin program and [illegible] next chapter simulation [illegible] flight) in three dimensional space is considered [illegible] with a specialized program for [illegible] of longitudinal motion.

Revised April 7, 1965





9.1 PROGRAM FLOW FOR NORMAL FLIGHT REGIONS

This chapter presents a summary of the program used to examine pure longitudinal motion in the presence of coupled control and environmental disturbances, and a separate program permitting study of controlled six degree of freedom flight with control exerted about all three rotation axes. Considering first the longitudinal motion program, an initialization block is provided which establishes the airplane in trimmed level flight for any set of specified start conditions consisting of the following:

t, time, seconds

h_G, geometric height, ft.

V, true airspeed, ft/sec.

γ, flight path attitude, degrees

δ_e, initial elevator setting (if incidence trim is used)

Given these initial conditions, for a given airplane configuration the required horsepower, angle of attack and pitch attitude are determined together with a setting for the trim tab or tail incidence (if an adjustable stabilizer is employed) through a closed loop iterative procedure. Provisions are made for variation of throttle and elevator setting as well as for gust inputs and other disturbance factors. Space is provided for simulation of control logic simulation and for use of various types of feedback control logic which control parameters such as speed, height, pitch attitude and so on. The equations employed in the program are as follows:

$$\dot{V} = -g\sin\gamma - (D/m)\cos\Delta\gamma + (L/m)\sin\Delta\gamma + (T/m)\cos(\theta-\gamma-i_T) \qquad .....9:1$$

$$\dot{\gamma} = -\frac{g\cos\gamma}{V} + \frac{L\cos\Delta\gamma}{mV} + \frac{D\sin\Delta\gamma}{mV} + \frac{T}{mV}\sin(\theta-\gamma-i_T) \qquad .....9:2$$

$$\dot{q} = \frac{q^{*}cS}{I_y}\Big[C_{M_{ac}} + \frac{\partial C_{M_{ac}}}{\partial\delta_f}\delta_f + C_{N_{p_\alpha}}\left\{\frac{\ell_p}{c}(\alpha-i_T) - 3.75\beta\frac{D_p}{c}\right\} - C_T\frac{z_p}{c}$$

$$+ a(\alpha + \frac{\partial i_w}{\partial\delta_f}\delta_f)(\frac{x_{cg}}{c}\cos\alpha + \frac{z_{cg}}{c}\sin\alpha) - R_q a_t\Big\{\alpha + i_T - KK_1 a(\alpha + \frac{\partial i_w}{\partial\delta_f}\delta_f)$$

$$+ (KK_1 a\ell_t/V)(\dot{\alpha} + \frac{\partial i_w}{\partial\delta_f}\dot{\delta}_f) + \frac{K_1\ell_t\dot{\theta}}{V}\Big\} - R_q a_e\delta_e\Big] \qquad .....9:3$$

Wind effects are represented by the following equations:

$$V_R^2 = (V\cos\gamma + V_{W_H})^2 + (V\sin\gamma - V_{W_V})^2 \qquad \text{..........9:4}$$

where:

V_{W_H} = instantaneous horiz[illegible], + if head wind, ft/sec.

V_{W_V} = instantaneous vertic[illegible], + if upward, ft/sec.

$$\tan\gamma_R = (V\sin\gamma - V_{W_V})/(V\cos\gamma + V_{W_H}) \qquad \text{....................9:5}$$

$$\Delta\alpha = \gamma - \gamma_R \qquad \text{....................9:6}$$

$$\alpha = \theta - \gamma_R \qquad \text{....................9:7}$$

$$\dot{\alpha} = \dot{\theta} - \dot{\gamma}_R \qquad \text{....................9:8}$$

$$\dot{V}_R = \dot{V}_{R_V}\sin\gamma_R + \dot{V}_{R_H}\cos\gamma_R \qquad \text{... ....9:9}$$

$$\dot{V}_{R_V} = \dot{V}\sin\gamma + \dot{\gamma}V\cos\gamma - \dot{V}_{W_V} \qquad \text{....................9:10}$$

$$\dot{V}_{R_H} = \dot{V}\cos\gamma - \dot{\gamma}V\sin\gamma + \dot{V}_{W_H} \qquad \text{....................9:11}$$

$$\dot{\gamma}_R = \frac{\dot{V}_{R_V}\cos\gamma_R - \dot{V}_{R_H}\sin\gamma_R}{V_R} \qquad \text{....................9:12}$$

$$q^* = \rho V_R^2/2 \qquad \text{....................9:13}$$

$$V_i = \sqrt{2q^*/\rho_o}\text{ , indicat[illegible], [illegible]} \qquad \text{...............9:14}$$

$$\frac{\dot{q}}{q} = \frac{\dot{\rho}}{\rho} + \frac{2\dot{V}_R}{V_R} = \frac{2\dot{V}_i}{V_i} \qquad \text{....................9:15}$$

Aerodynamic drag is describ[illegible] relations:

$$D = q^*C_DS \qquad \text{....................9:16}$$

$$C_D = C_{D_o} + KC_L^2 \qquad \text{....................9:17}$$

$$C_{D_e} = C_{D_{e_0}} + \frac{\partial C_{D_e}}{\partial \delta_f}\delta_f + \Delta C_{D_{eG}} + \frac{\partial C_{D_e}}{\partial \beta}|\beta| \qquad \text{..............9:18}$$

where:

$C_{D_{e_0}}$ = basic parasite drag coefficient, dimensionless

$\Delta C_{D_{eG}}$ = increment in drag due to landing gear

$\partial C_{D_e}/\partial \delta_f$ and $\partial C_{D_e}/\partial \beta$ are the parasite drag coefficient gradients due to δ_f and β respectively.

Propeller thrust is obtained from

$$T = 550\eta_p BHP/V_R \qquad \text{..................9:19}$$

where:

η_p = propeller efficiency

BHP = brake horsepower

Atmospheric properties are defined in terms of standard NASA conditions by the following approximate relations valid from sea level to 10,000 ft.

$$\rho = 0.0023769e^{-0.2970h \times 10^{-4}} \text{ (air density)} \qquad \text{..............9:20}$$

$$p = 2116e^{-0.374h \times 10^{-4}} \text{ (ambient pressure)} \qquad \text{..............9:21}$$

The kinematic relations defining location are:

$$\dot{x} = V\cos\gamma \qquad \text{...................9:22}$$

$$\dot{h} = V\sin\gamma \qquad \text{...................9:23}$$

For simulation of periodic clear air turbulence the vertical and horizontal winds are defined by the Karman street relations

$$V_{iy} = \frac{k\pi}{a}\left\{\frac{\sinh(y - \frac{h}{a})\frac{2\pi}{a}}{\cosh(y - \frac{h}{a})\frac{2\pi}{a} - \cos[illegible]} - \frac{\sinh(y + \frac{h}{a})\frac{2\pi}{a}}{\cosh(y + \frac{h}{a})\frac{2\pi}{a} - \cos(x - \frac{b}{2})\frac{2\pi}{a}}\right.$$

$$\left. + \tan\frac{\pi h}{a} + \frac{1}{\tanh[illegible]}\right\} \qquad \ldots\ldots\ldots\ldots\ldots 2:04$$

$$V_{iy} = \frac{k\pi}{a}\left\{\frac{\sin 2\pi x/a}{\cosh(y - \frac{h}{a})\frac{2\pi}{a} - [illegible]} - \frac{\sin(x - [illegible])\frac{2\pi}{a}}{[illegible]\frac{2\pi}{a} - \cos(x - \frac{b}{2})\frac{2\pi}{a}}\right\}$$

$$\ldots\ldots\ldots\ldots\ldots 2:05$$

where k is the strength of [illegible] the [illegible].

Data printed out by the [illegible], in [illegible] furniture, in normal sequence

t	h_G	V		[illegible]^{o}	[illegible]^{o}
[illegible]^{o}	$\dot{h}_G$	$\dot{V}$	[illegible]	[illegible]	[illegible]
δ_e^{o}	x	T (thrust)	[illegible]	[illegible]	
V_i	$\dot{V}_i$	$\dot{V}_{i_o}$	[illegible]	[illegible]	
L	D	M	[illegible]	[illegible]	

an optional load factor [illegible] as well as print out of other quantities which may be [illegible].

For combined study of motion [illegible] equations for $\dot{p}$, $\dot{q}$ and $\dot{r}$ are obtained from the [illegible] (2.2) since the rotary rates p, q and r are [illegible] small [illegible] effects of [illegible] terms, thus with the further [illegible] moments are ignored we have that

$$\dot{p} = \frac{q^*Sb}{I_x}\,[0.12\delta_a - 0.[illegible] - [illegible](C_{\ell_\beta} + C_L\sin 2\Lambda)]$$

$$\ldots\ldots\ldots\ldots\ldots 2:06$$

$$\dot{q} = \frac{q^*Sc}{I_y}\,[C_{m_o} - C_{[illegible]}\frac{x}{c} + [illegible]\frac{x}{c}[illegible])$$

$$- [illegible]\left\{[illegible] + i_t - [illegible]\right\} - [illegible]] \quad \ldots\ldots 2:07$$

$$\dot{r} = \frac{[illegible]}{J_z} [\frac{\ell_{v_t}}{b} \frac{S_{v_t}}{S} \{C_{n_r} [illegible] \} - ([illegible] \frac{\ell_{v_t}^2 S_{v_t}}{b^2 S} [illegible] \frac{C_D}{S}) \frac{rb}{[illegible]} - \frac{C_n}{[illegible]} (\frac{pb}{[illegible]})]$$ ....9:[illegible]

The [illegible] equations for particle [illegible], for this case

$$\dot{V} = g(\frac{C_T - C_D}{C_{L_L}}) - g\sin\gamma$$ 9:29

$$\dot{\gamma} = \frac{g}{V} [\frac{1}{C_{L_L}} (C_L \cos\phi_W - C_Y [illegible]) - [illegible]]$$ 9:30

$$\dot{[illegible]} = \frac{g}{V C_{L_L} \cos\gamma} (C_L \sin\phi_W + C_Y [illegible])$$ 9:31

[illegible]:

C_{L_L} = [illegible]/q[illegible]S = level flight lift coefficient at [illegible] and q* .....9:[illegible]2

ϕ_W = bank angle of lift vector, radians

C_Y = side force coefficient = Y/[illegible]S = [illegible] 9:33

Y = side force

[illegible] = heading angle, radians

The normal load factor, n is defined by,

$n = C_{L_a}/C_{L_L}$; 9:34

the rates of change of the [illegible] angles [illegible], [illegible] and ϕ_W are obtained from the kinematic resolutions:

$\dot{[illegible]}$ = [illegible] cos[illegible] - [illegible] sin[illegible] - ([illegible]) ....9:[illegible]

$\dot{[illegible]}$ = [illegible] cos[illegible] cos ϕ_W cos[illegible] - [illegible] - r ....9:[illegible]

*The term [illegible] sin [illegible] is [illegible].

[illegible] April 7, 19[illegible]

$\dot{\varphi}_W$ = pcos.cos + qsin cos + [illegible] sin ....[illegible]:[illegible]7

Integration is performed on:

$\dot{h}$, $\dot{V}$, $\dot{\gamma}$, $\dot{\psi}$, $\dot{\beta}$, $\dot{\varphi}_W$, $\dot{\alpha}$, $\dot{p}$, $\dot{q}$ and $\dot{r}$,

to determine

h, V, γ, ψ, β, φ_W, α, p, q and r

respectively.

The print out sequence, in floating [illegible] form is:

t	h_G	V	γ	ψ	n
α°	β°	φ_W°	p	q	r
δ_a°	δ_r°	δ_e°	T	V_i	

where n = load factor.

Initial conditions required are:

t	h	V	γ	ψ
α	φ_W	δ_a	δ_r	δ_e

where angles are expressed in degrees.

The [illegible] planning to run this program, the [illegible] coding sheets supplied in the appendices should be [illegible] for the [illegible] of additional [illegible] storage. If questions [illegible] should be directed to [illegible], [illegible], [illegible] State Road, Princeton, New Jersey [illegible].

In the next chapter typical [illegible] results are presented.

10.) TYPICAL RESULTS OF THE SIX DEGREES OF FREEDOM AND LONGITUDINAL DYNAMICS PROGRAMS

To illustrate the results obtainable with the programs described in Chapter 9 an airplane with the following characteristics was assumed:

W, weight, 3100 lbs.

S, wing area, 175.5 ft.^{2}

S_t, horizontal tail area, 3[illegible].6[illegible] ft.^{2}

S_{vt}, vertical tail area, 1[illegible].[illegible]7 ft.^{2}

b, wing span, 36.[illegible]83 ft.

c, mean aerodynamic chord, 4.[illegible] ft.

ℓ_t, horizontal tail moment arm, 15.00 ft.

ℓ_{vt}, vertical tail moment arm, 1[illegible].83 ft.

$\partial C_Y/\partial\beta$, rate of change of C_Y with sideslip angle, 0.393 rad.$^{-1}$

a_w, lift slope of wing, 4.[illegible] rad.$^{-1}$

a_t, lift slope of horizontal tail, 3.62 rad.$^{-1}$

a_e, elevator effectiveness, 2.[illegible]65 rad.$^{-1}$

a_r, rudder effectiveness, 1.1[illegible] rad.$^{-1}$

a_{vt}, lift slope of vertical tail, 2.06 rad.$^{-1}$

I_x, rolling moment of inertia, 1[illegible] slugs-ft.^{2}

I_y, pitching moment of inertia, 2000 slugs-ft.^{2}

I_z, yawing moment of inertia, [illegible]0 slugs-ft.^{2}

$C_{D_{oo}}$, basic drag coefficient, 0.021

$\Delta C_{D_{oG}}$, drag coefficient increment due to lowering landing gear, 0.025

$\partial C_{D_o}/\partial\beta$, rate of change of C_{D_o} with sideslip angle, 0.025 rad.$^{-1}$

$\partial C_{D_o}/\partial\delta_f$, rate of change of C_{D_o} with flap deflection, 0.063[illegible] rad.$^{-1}$

K, drag due to lift factor, $\partial C_D/\partial C_L^2$, 0.0[illegible]8

η, propeller efficiency, 0.[illegible]5

K_1, downwash distribution factor, 1.0

M_{q}, damping in pitch [illegible] factor, 1.0

$C_{m_{ac}}$, moment coefficient [illegible], − [illegible]

$\partial C_{m_{ac}}/\partial \delta_f$, rate of change of [illegible] deflection, − 0. [illegible] rad.$^{-1}$

z_p, thrust axis moment arm, 0.1 [illegible] ft.

x_{cg}, horizontal distance from [illegible] c.g. to a.c., 0.0[illegible] ft.

z_{cg}, vertical distance from c.g. to [illegible], − [illegible] ft.

Λ, sweep angle, 0.0 deg.

C_{ℓ_β}, dihedral effect, [illegible] − [illegible], [illegible] geometric dihedral − 4.72°

i_T, thrust incidence angle, − [illegible]

A, propeller disc area, [illegible] ft.^{2}

ℓ_p, distance from propeller disc to c.g., [illegible] ft.

D_p, propeller diameter, [illegible] ft.

$\partial i_w/\partial \delta_f$, variation in [illegible] incidence with flap deflection, 0.025

H_{max}, maximum horsepower, [illegible]

$\delta_{f_{max}}$, total flap deflection, [illegible]

The directional damping factor [illegible] 1.5 and the directional stability factor to 0.0 for the lateral-[illegible] the operation of a [illegible] axis [illegible] (SAS) [illegible]. For these runs the following control [illegible] rate limits were employed:

deflections

ailerons ± 16.5°

rudder ± 24°

elevator ± 19°

aileron rate 11.46°/sec.

rudder rate 5.73°/sec.

elevator rate 10°/sec.

For all runs elevator control was exerted using a velocity PSAS system applying the following control law:

$$\delta_e = \int_0^t G_v \left\{ \left[\frac{e_v - \Delta t_{pv} \dot{V}_i}{\tau_v} \right]_{a_\ell} - \dot{V}_i \right\} d\tau - G_v \dot{V}_i \Delta t_{pv} \qquad \text{..........10:1}$$

where:

G_v = system gain = 0.0005

Δt_{pv} = lead time = 4.0 sec.

τ_v = 4.0 sec.

a_ℓ = 2.0 ft/sec.^{2} (clipped level)

δ_e = elevator displacement from initial neutral (trim)

$e_v = V_{i_d} - V_i$

For study of the velocity PSAS the $\dot{V}_i$ input signal to the control logic was lagged to simulate operation of a noise filter. The lagged value of $\dot{V}_i$ (called $\dot{V}_{i_o}$) was obtained by integrating a lagged equation for $\ddot{V}_i$, i.e.,

$$\dot{V}_{i_o} = \int_0^t \frac{\dot{V}_i - \dot{V}_{i_o}}{\tau_f} d\tau \qquad \text{...............10:2}$$

where:

τ_f = 0.15 seconds

τ_f is the first order lag constant in the equation

$$\dot{V}_{i_o} = \dot{V}_i - \tau_f \ddot{V}_{i_o} \qquad \text{...............10:3}$$

The lags were neglected in the full six degree of freedom dynamic program.

For the runs presented, the lateral-directional control was exerted via a canted axis rate gyro stability augmenter having a cant angle of 50° (i.e., the axis of the rate gyro case lies at 40° to the longitudinal reference axis, x).

The canted axis rate gyro control law is:

$$\Delta\delta_a = G_c (p \cos i_g + r \sin i_g) \qquad \text{...............10:4}$$

where:

$\Delta\delta_a$ = increment in aileron [illegible] to be applied

i_g = [illegible]°

G_c = - 0.04 for integration [illegible] of 0.01 seconds

p = roll rate, radians/[illegible].

r = yaw rate, radians/[illegible].

$$\delta_r = G_p \delta_a \qquad \text{..................10:5}$$

G_p = 0.50

δ_r = total rudder displ[illegible]

δ_a = total aileron displac[illegible]

Equation 10:4 is a digital [illegible]. Its analog equivalent is the r[illegible] equation:

$$\dot{\delta}_a = - 4.0(p\cos i_g + r\sin i_g) \qquad \text{..................10:6}$$

Figure 10:1 is an illustration of the r[illegible] with three axis FSAS with and without rudder servos in [illegible]. The initial conditions imposed were:

V_i = 103 fps = 70 mph ([illegible] flight)

φ_W = [illegible]°

h - 5000 ft.

γ = - 3°

The task of the FSAS syst[illegible] flight while holding indicated speed constant. [illegible] time histories are shown since [illegible] in [illegible] quantities. Of interest in [illegible] use of proportional rudders completely [illegible] us when rudders are not employed. The airplane [illegible] Cessna [illegible] but has greater damping in yaw and [illegible] than the actual [illegible]. Integration intervals were 0.[illegible]. [illegible] of the operation of the longitudinal simulation [illegible] illustrate an approach and touch down of a Cessna [illegible]. The [illegible] of events is as follows:

Initiate with trimmed flight at V_i = 176.33 fps, γ = - 3°, h = 1010 ft., α = 6.31°, δ_e = 0.0°, thrust = 44.97#. Speed select is set to approach speed of V_i = 132 fps = 90 mph. At 1000 ft. the landing gear is lowered. At h = 600 ft. flaps are started down (0 to 40°) at 8°/sec. At h = 200 ft. power is increased by 53 HP to maintain a glide slope of -3°. At h = 15 ft. power is increased by 52 HP for performance of a throttle flare. The task of the velocity PSAS system is to reduce speed gently from 176.33 fps to 132 fps and maintain this speed in the face of power and configuration variations. Integration intervals were set to 0.1 sec. The figures are self explanatory.

This concludes the presentation of typical outputs of the computer programs. The programs are flexible and are usable for many other purposes than illustrated. Their use for other purposes depends, however, on understanding how to input data and set transfers and so on. Complete coding sheets and the instruction list for the DICTATOR II program method are included in the appendices to this report to permit further study on the part of the reader. Additionally DODCO, INC., is prepared to answer questions on the methods.

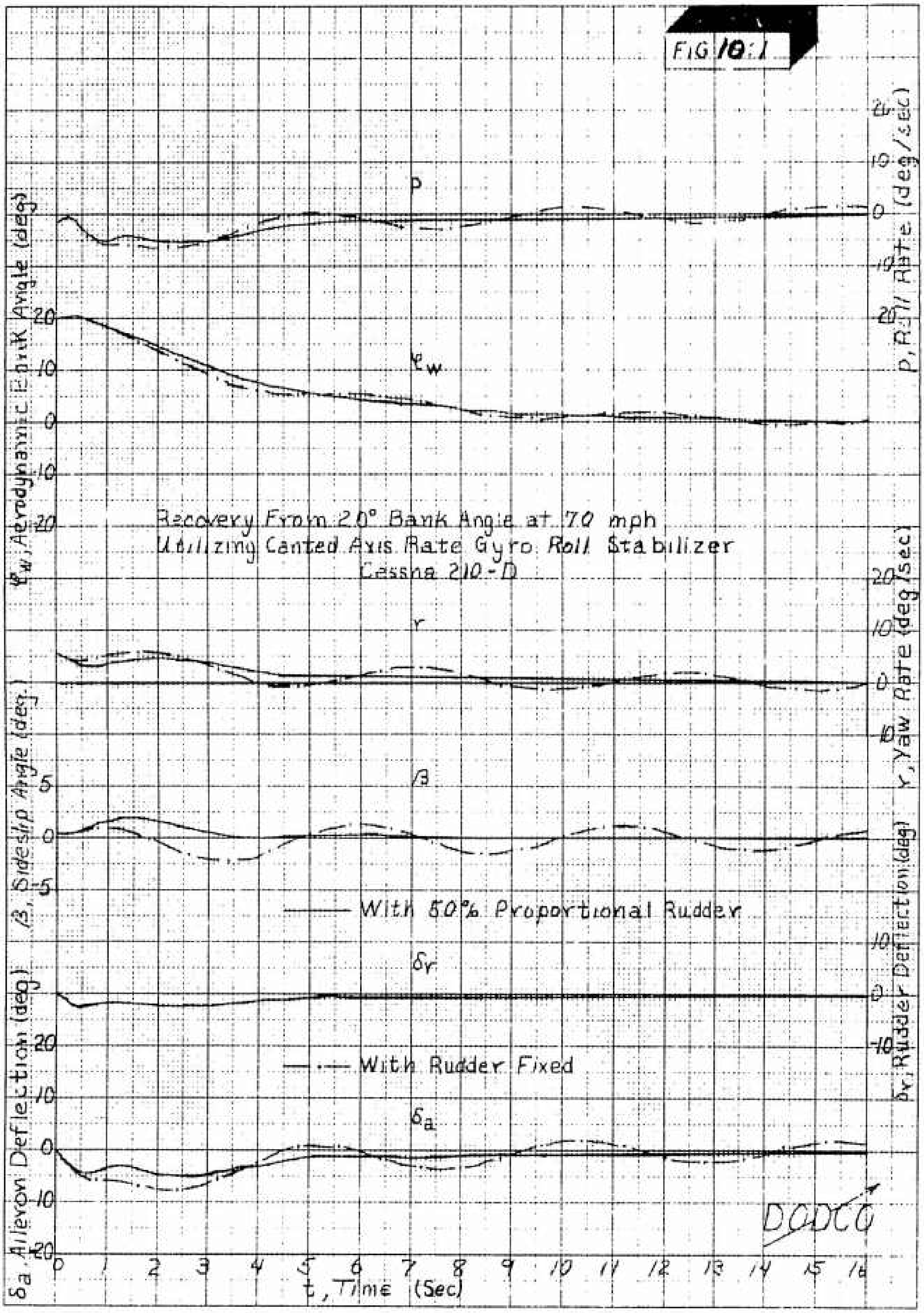


FIG 10.1
Recovery From 20° Bank Angle at 70 mph
Utilizing Canted Axis Rate Gyro Roll Stabilizer
Cessna 210-D
With 50% Proportional Rudder
With Rudder Fixed
p
r
β
δr
δa
t, Time (Sec)
p, Roll Rate (deg/sec)
r, Yaw Rate (deg/sec)
β, Sideslip Angle (deg)
δr, Rudder Deflection (deg)
δa, Aileron Deflection (deg)
DODCO

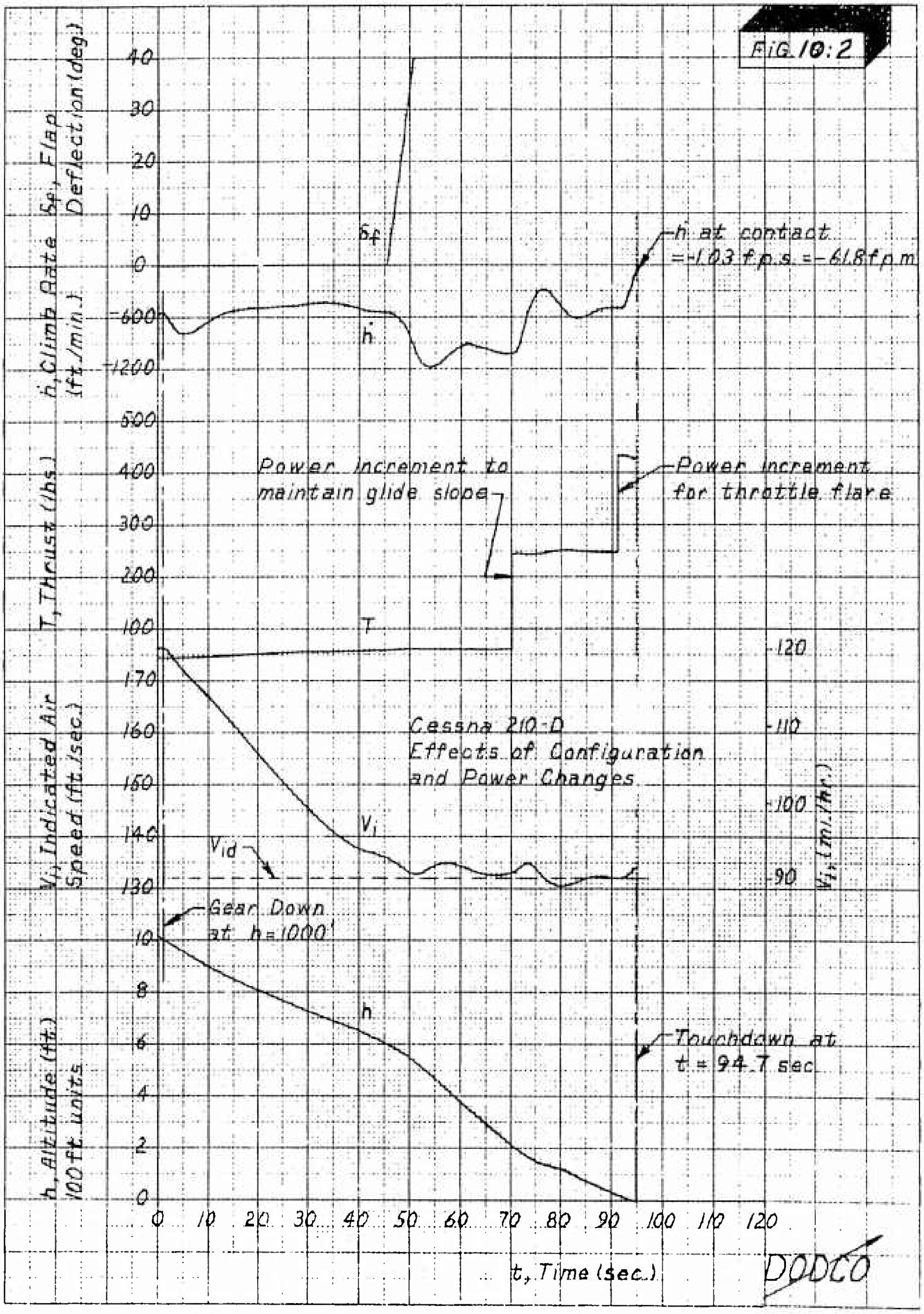


FIG. 10:2
$\dot{h}$, Climb Rate (ft./min.)
δ_f, Flap Deflection (deg.)
T, Thrust (lbs.)
V_i, Indicated Air Speed (ft./sec.)
h, Altitude (ft.) 100 ft. units
V_i, (mi./hr.)
δ_f
$\dot{h}$
T
V_i
V_{id}
h
$\dot{h}$ at contact = -1.03 f.p.s. = -61.8 f.p.m.
Power increment to maintain glide slope
Power increment for throttle flare
Cessna 210-D
Effects of Configuration and Power Changes
Gear Down at h = 1000'
Touchdown at t = 94.7 sec
t, Time (sec.)
DODCO

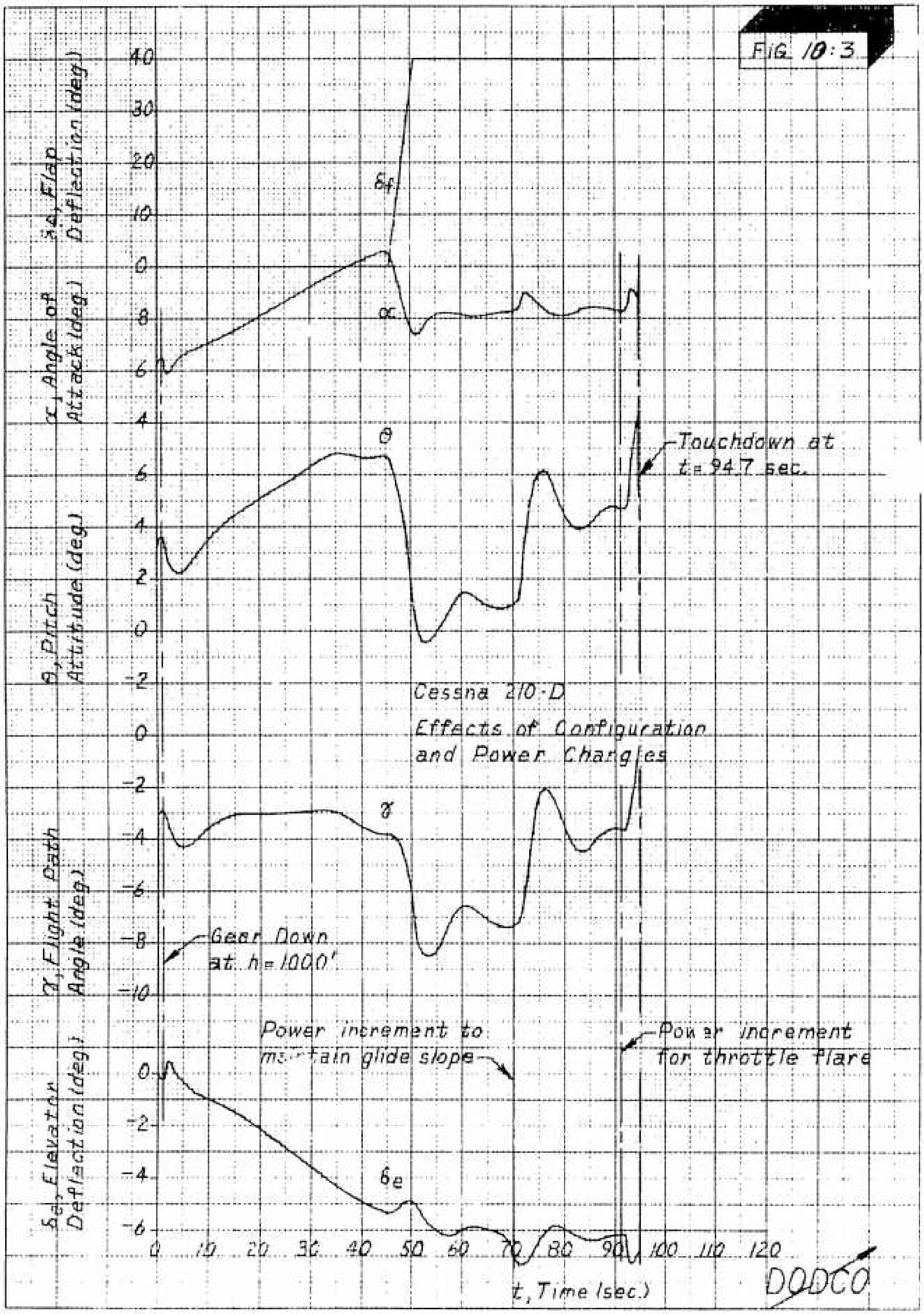


FIG. 10:3
δ_f, Flap Deflection (deg.)
α, Angle of Attack (deg.)
θ, Pitch Attitude (deg.)
γ, Flight Path Angle (deg.)
δ_e, Elevator Deflection (deg.)
δ_f
α
θ
γ
δ_e
Touchdown at $t = 94.7$ sec.
Cessna 210-D
Effects of Configuration and Power Changes
Gear Down at $h = 1000'$
Power increment to maintain glide slope
Power increment for throttle flare
t, Time (sec.)
DODCO

11.) CONCLUDING REMARKS

The modern high speed, relatively low cost digital computing systems are excellent tools for rapid and low cost analysis of aircraft performance, handling qualities and for study of behavior of automatic control logics. They are also useful for design studies, particularly as regards the effects of parameter variations and for examination of nonlinear and cross coupling effects. Applications to structural, weight and balance, flutter and related problems are of equal significance.

Use of this equipment in engineering design is by no means new to the aviation industry as a whole, however fast, low cost computers have only been available for the past five years and just in the past year have there appeared units in the $1,000 a month rental category which are capable of rapid handling of the types of problems involved.

Additionally, until relatively recently the use of executive programming procedures (e.g., FORTRAN, DICTATOR, etc.) which greatly simplify use of computers, has not been wide-spread and either extensive personnel training programs or employment of additional personnel were involved in engineering application of computers. This, plus the earlier high cost of computers, limited aviation applications (particularly of digital units) to design programs on military and large commercial transport equipment having substantial engineering budgets.

The "cost" barrier on digital computers no longer exists, and the presence of "canned" programs of the type presented here eliminates the need for computer specialists for effective utilization of the newer low cost equipment. Proper employment of the computer still requires a rather complete understanding of the problems to be solved however, so that initially a fair amount of study is required on the part of potential users of any set of digital methods and equipment. This report presents methods which were developed in the conduct of research programs under the FAA General Aviation Safety Development Program, and is designed to aid General Aviation activities to evaluate their need for incorporating digital techniques into their engineering operations as well as to encourage such use.

DODCO, INC., will be pleased to answer questions or receive comments concerning this report.

REFERENCES

1. Dommasch, D. O. and Laudeman, C. W., Principles Underlying Systems Engineering, Pitman Publishing Corporation, 1962.

2. Younger, J. E., Advanced Dynamics, Ronald Press, 1958.

3. Dommasch, D. O., Sherby, S. S. and Connolly, T. F., Airplane Aerodynamics, 3rd edition, Pitman Publishing Corporation, 1961.

4. Dommasch, D. O., Control Concepts Applicable to General Aviation Aircraft, DODCO TR #143, March 1963.

5. Dommasch, D. O. and Laudeman, C. W., Some Methods of Modifying the Control Characteristics of G.A. Aircraft to Simplify Flight Handling-Including Simulation of the Mooney Mark 21 (20C) Aircraft with a High Gain Velocity Autopilot, DODCO TR #146, April 1963.

6. Dommasch, D. O. and Panzitta, J. J., Simulation Analysis of a High Gain Velocity Autopilot Controlling a Typical G.A. Aircraft and a Typical Subsonic Jet Transport in the Presence of Air Turbulence and Configuration Changes, DODCO TR #148, June 1963.

7. Dommasch, D. O. and Laudeman, C. W., Equations of Motion and Polynomial Data Representations for Analysis of Autopilot Control of Nonlinear Aircraft, DODCO TR #149, June 1963.

8. Dommasch, D. O., Digital Study of the High Gain Velocity Stabilization Autopilot Installed in a Piper Comanche 250 Aircraft, DODCO TR #150, July 1963.

9. Dommasch, D. O., Parallel Stabilization Systems for General Aviation Aircraft, DODCO TR #151, July 1963.

10. Dommasch, D. O. and Laudeman, C. W., Axis Transformations and Equations of Motion for Flight at Extreme Attitudes, DODCO TR #154, August 1963.

11. Dommasch, D. O. and Laudeman, C. W., Evaluation of Several Roll Stabilizer Control Logics Using the Multi Degree of Freedom Digital Simulation Program, DODCO TR #155, September 1963.

12. Dommasch, D. O., The Effects of Sensor and Actuator Lags on Parallel Velocity Stabilization Systems, DODCO TR #156, October 1963.

13. Dommasch, D. O., Specifications for the "Little Guy" General Aviation Parallel Velocity Stabilization System, DODCO TR #158, October 1963.

14. Dommasch, D. O. and Laudeman, C. W., Interim Report on Complete Air-Data Stability Augmentation and Control of the B-58 Vehicle, DODCO TR #159, October 1963.

15. Dommasch, D. O., Low Cost Electrically Driven Altimeters, Airspeed and Vertical Speed Indicators for General Aviation Aircraft, DODCO TR #160, November 1963.

16. Dommasch, D. O., Feasibility Study of An Automatic Landing System for General Aviation Aircraft, DODCO TR #161, January 1964.

17. Dommasch, D. O., The Possibilities and Problems of a Simplified, Automated General Aviation Control System, DODCO TR #162, January 1964.

18. Dommasch, D. O., Basic Specification for a Full Time Lateral Directional Stability Augmentation System, DODCO TR #164, March 1964.

19. Dommasch, D. O., Periodic Clear Air Turbulence and General Aviation Operations, DODCO TR #166, April 1964.

20. Dommasch, D. O., Preliminary Analysis of Instrumentation, Recording and Analysis Requirements for the Little Guy Flight Test Program, DODCO TR #167, April 1964.

21. Dommasch, D. O., Preliminary Analysis of Re-entry Flight Simulator Data and Equations, DODCO TR #168, June 1964.

22. Dommasch, D. O., Summary of Stability Augmentation System Studies Conducted Under the General Aviation Safety Development Program From February 1963 Through July 1964, DODCO TR #170, July 1964.

23. Neihouse, A. I., Klinar, W. J. and Scher, S. H., Status of Spin Research for Recent Airplane Designs, NASA TR R-57, 1960.

24. Anglin, E. L. and Scher, S. H., Analytical Study of Aircraft-Developed Spins and Determination of Moments Required for Satisfactory Spin Recovery, NASA TN D-2181, February 1964.

APPENDIX 1

THE SPIN PROGRAM

DIGITAL ... INSTRUCTION

PROGRAM Spin (Diff. Eq.)

NAME DSS DATE

REMARKS	Op	Addr		
$\alpha - \alpha_p$	2	2.0.8	8.2.5	0.0.0
TR to 102 if $\alpha - \alpha_p$ max	0	0.1.6	1.0.4	1.0.2
$a_1 \alpha$	3	9.2.2	2.0.8	9.5.0
TR to 407	0	0.1.0	0.0.0	4.0.7
$-K a_1 \alpha$	5	8.2.6	0.0.8	0.0.0
$C_{LW} = K_a - K a_1 \alpha$	1	0.0.0	8.2.5	8.1.2
Set $a_2 = 0$	6	0.0.0	9.0.0	9.2.3
Set 465 to move K_a ...	6	0.0.0	2.4.4	4.6.5
TR to 410	0	0.1.0	0.0.0	4.1.0
$C_c = (1) + [950]$	1	0.0.0	9.5.0	8.2.2
$(pb/2v)^2$	3	8.2.0	8.2.0	8.2.0
$(pb/2v)^3$	3	0.0.0	8.2.0	0.0.0
$(pb/2v)^3/10$	3	0.0.0	8.2.8	8.3.1
$a_2 \sin \alpha$	3	9.5.2	9.2.3	8.3.2
$K_d \cos \alpha$	3	9.5.3	9.2.0	0.0.0
$a_2 \sin \alpha + K_d \cos \alpha$	1	0.0.0	8.3.2	0.0.0
$(pb/2v)^3 (1/10)(a_2 \sin \alpha + K_d \cos \alpha)$	3	0.0.0	8.3.1	0.0.0
$C_c - (1) \to 822$	2	8.2.2	0.0.0	8.2.2
$(pb/2v)^2 \; (rb/2v)$	3	8.3.0	8.2.1	0.0.0
$(1)(1/5)$	3	0.0.0	8.2.4	8.3.0
$2a_2\alpha - a_1 - C_{Dw} + C_{D\alpha}$	1	9.5.1	8.1.6	0.0.0
$2a_2\alpha - a_1 + K_d$	1	0.0.0	9.2.0	8.3.3
$(1) \sin \alpha$	3	0.0.0	9.5.2	8.3.4
$2K_d\alpha - a_2$	2	8.3.5	9.2.3	8.2.6
$(1) \cos \alpha$	3	0.0.0	9.5.3	0.0.0
$(-a_2 + 2K_d\alpha)\cos\alpha + (2a_2\alpha - a_1 - K_d)\sin\alpha$	1	0.0.0	8.3.4	0.0.0
$(1)(830)$	3	0.0.0	8.3.0	[illegible]
TR to 160	0	0.1.0	0.0.0	1.6.0
$a_2 \cos \alpha$	3	9.2.3	9.5.3	8.3.2
$K_d \sin \alpha$	3	9.5.2	9.2.0	0.0.0
$a_2 \cos \alpha - K_d \sin \alpha$	2	8.3.2	0.0.0	[illegible]
$(pv/2v)^3 (1/10)(a_2 \cos \alpha - K_d \sin \alpha)$	3	0.0.0	8.3.1	0.0.0
$C_{nw} + (1)$	1	0.0.0	8.2.3	8.2.3
$(-a_2 + 2K_d\alpha) \sin \alpha$	3	9.5.2	8.3.6	8.3.0
$(2a_2\alpha - a_1 + K_d) \cos \alpha$	3	9.5.3	8.3.3	0.0.0
$[830] - (1)$	2	8.3.0	0.0.0	0.0.0
$(1)(rb/2v)(pb/2v)^2 (5)$	3	0.0.0	8.2.0	0.0.0
$C_{nw} + (1) \to 823$	1	0.0.0	8.2.3	8.2.3
TR to 486	0	0.1.0	0.0.0	4.8.6
$K_2 \ell_2 g/v$	3	9.3.2	9.5.2	5.5.0
$(K_2 \ell_2 g/v)(K_3/K_2)$	3	0.0.0	5.7.4	0.0.0
$(K_3 \ell_2 g/v) \ell_g$	4	0.0.0	7.1.4	0.0.0
$(K_3 \ell_2 /v) \alpha$	3	0.0.0	7.2.4	0.0.0
$(K_3 \ell_2 \alpha/v) + (K_2 \ell_2 g/v)$	1	0.0.0	5.5.0	0.0.0
TR to 440	0	0.1.0	0.0.0	4.4.0

DIGITATOR II INSTR. SHEET

PROGRAM Spin (Diff. E_q)

NAME D.S.S. DATE

LOC	REMARKS	O	O/A	B	C
1.5.0	$\alpha - \alpha_p$	2	7.0.8	9.2.5	9.0.0
1.5.1	TRS – neg 152 pos 154	0	0.1.6	1.5.4	1.5.2
1.5.2	$a_1 \alpha$	3	9.2.2	9.4.1	9.5.1
1.5.3	TR to 234	0	0.1.0	0.0.0	2.3.4
1.5.4	$-Ka_1 \alpha$	5	9.9.1	[illegible]	0.0.0
1.5.5	$C_{Lw} = Ka - Ka_1\alpha$	1	0.5.0	[illegible]	9.5.3
1.5.6	α^2	3	9.4.1	9.4.1	9.5.2
1.5.7	TR to 237	0	0.1.0	0.0.0	2.3.7
1.5.8					
1.5.9					
1.6.0	$C_e = (\uparrow) + [822] \rightarrow 822$	1	0.0.0	8.2.2	8.2.2
1.6.1	$(\delta a)(\partial C_e/\partial \delta a)$	3	8.5.3	8.3.4	0.0.0
1.6.2	$C_e = [\uparrow] + [822]$	1	0.0.0	8.2.2	8.2.2
1.6.3	TR to 128	0	0.1.0	0.0.0	1.2.8
1.6.4					
1.6.5	$Kd\alpha$	3	7.0.6	9.2.0	9.5.5
1.6.6	$Kd\alpha - K_1\alpha$	2	0.0.0	8.7.9	0.0.0
1.6.7	TR to 168 if neg	0	0.1.6	1.6.4	1.6.8
1.6.8	TR to 423	0	0.1.0	0.0.0	4.2.3
1.6.9	move $K_1\alpha/K\alpha$ to 956	6	0.0.0	8.7.8	9.5.6
1.7.0	Set $K\alpha\alpha = 0$	6	0.0.0	9.0.0	9.5.5
1.7.1	TR to 424	0	0.1.0	0.0.0	4.2.4

DICTATOR [illegible] INSTR SHEET

PROGRAM Spin (Initialization)

NAME D.S.S. DATE

REMARKS	O	Ø/L	B	C
$I_z - I_y$	2	917	916	000
$K_1 = (I_z - I_y) I_x \rightarrow 805$	4	000	915	805
$I_z - I_x$	2	917	915	000
$K_2 = (I_z - I_x)/I_y \rightarrow 806$	4	000	916	806
$I_y - I_x$	2	916	915	000
$K_3 = (I_y - I_x)/J_{xz} \rightarrow 807$	4	000	892	807
$b\,S_w \rightarrow 950$	3	911	907	950
$K_4 = b\,S_w / I_x \rightarrow 808$	4	000	915	808
$\bar{c}\,S_w$	3	910	907	000
$K_5 = \bar{c}\,S_w / I_y \rightarrow 809$	4	000	916	809
$K_6 = b\,S_w / J_{xz} \rightarrow 810$	4	950	892	810
$K_7 = J_{xz} / I_x \rightarrow 887$	4	892	915	887
$K_8 = J_{xz} / I_y = 886$	4	892	916	886
$K_9 = I_z / J_{xz} \rightarrow 000$	4	917	892	000
$K_{12} = J_{xz}/I_x - I_z/J_{xz} = K_7 - K_9 \rightarrow 891$	2	887	000	891
$K_{10} = K_1 + 1 \rightarrow 889$	2	805	890	889
$K_{11} = K_7 - K_3 \rightarrow 888$	2	887	807	888
Δt^2	3	943	943	000
$\Delta t^2/2 \rightarrow 944$	3	000	902	944
$S_t/S_w \rightarrow 800$	4	909	907	800
$\ell_t/\bar{c}$	4	913	910	000
$(S_t/S_w)(\ell_t/\bar{c})$	3	000	800	000
$K_g = \eta_t(\;) \rightarrow 801$	3	000	914	801
$W/S_w \rightarrow 802$	4	934	907	802
ℓ_{vt}/b	4	912	911	950
S_{vt}/S_w	4	908	907	000
$(\ell_{vt}/b)(S_{vt}/S_w) \rightarrow 803$	3	950	000	803
$(\ell_{vt}/b)^2(S_{vt}/S_w)$	3	000	950	000
$a_{vt}(\ell_{vt}/b)^2(S_{vt}/S_w)$	3	000	926	000
$2a_{vt}(\ell_{vt}/b)^2(S_{vt}/S_w) \rightarrow 804$	3	000	901	804
Clear 700 to 721 }	6	000	900	700
}	6	021	700	701
set α start	6	000	941	708
set h start	6	000	942	701
set ψ_w start	6	000	898	710
set p start	6	000	897	713
set q start	6	000	937	714
set r start	6	000	938	715
set V start	6	000	885	703
set β start	6	000	882	709
set δ_e start (elevator)	6	000	947	716
set δ_a start (aileron)	6	000	851	865
set δ_r start (rudder)	6	000	949	717
set γ start	6	000	948	707
Set IR #2 6.24	0	062	000	024
K_{13} [804]	3	880	804	804
K_{13}	3	879	879	000
K_{13}/K_{cc}	4	000	920	878
TR to 400	0	010	000	400

PAGE 10 OF

DICTATOR II INSTR. SHEET

PROGRAM Spin (Integration)

NAME D.S.S. DATE

LOC	REMARKS	O	O_2/A	B	C
300	$t = t_n + \Delta t$	1	700	943	700
301	$\Delta t \dot{h}_n$	3	943	702	950
[illegible]	$(\Delta t^2/2)\,\ddot{h}$	3	944	718	000
[illegible]	$\Delta h = (\uparrow) + (301)$	1	000	150	000
[illegible]	$h_{n+1} = h_n + (\uparrow)$	1	000	701	701
[illegible]	No Op	0	009	000	000
[illegible]	$\Delta t \dot{V}_{NS}$	3	943	719	950
[illegible]	$(\Delta t^2/2)\,\ddot{V}_{NS}$	3	944	721	000
[illegible]	Δd_{NS}	1	000	150	000
[illegible]	$d_{NS_{n+1}} = d_{NS} + \Delta d_{NS}$	1	000	705	705
[illegible]	$\Delta t \dot{V}_{EW}$	3	943	720	950
[illegible]	$(\Delta t^2/2)\,\ddot{V}_{EW}$	3	144	722	000
[illegible]	Δd_{EW}	1	000	950	000
[illegible]	$d_{EW_{n+1}} = d_{EW_n} + \Delta d_{EW}$	1	000	706	706
[illegible]	$\Delta t \dot{V}_n$	3	943	704	000
[illegible]	$V_{n+1} = V_n + \Delta t \dot{V}_n$	1	000	703	703
[illegible]	$\Delta t \dot{\gamma}_n$	3	943	712	000
[illegible]	$\gamma_{n+1} = \gamma_n + (\uparrow)$	1	000	707	707
[illegible]	$\Delta t \dot{\alpha}_n$	3	943	724	000
[illegible]	$\alpha_{n+1} = \alpha_n + (\uparrow)$	1	000	708	708
[illegible]	$\Delta t \dot{\beta}_n$	3	943	725	000
[illegible]	$\beta_{n+1} = \beta_n + (\uparrow)$	1	000	709	709
[illegible]	$\Delta t \dot{\varphi}_w$	3	943	723	000
[illegible]	$\varphi_{w_{n+1}} = \varphi_{w_n} + (\uparrow)$	1	000	710	710
[illegible]	$\Delta t \dot{\psi}_n$	3	943	726	000
[illegible]	ψ_{n+1}	1	000	711	711
[illegible]	$\Delta t \dot{p}$	3	943	727	000
[illegible]	p_{n+1}	1	000	713	713
[illegible]	$\Delta t \dot{q}$	3	943	728	000
[illegible]	q_{n+1}	1	000	714	714
[illegible]	$\Delta t \dot{r}$	3	943	729	000
[illegible]	r_{n+1}	1	000	715	715
[illegible]	$\Delta t \dot{\delta}_e$	3	943	730	000
[illegible]	$\delta_{e_{n+1}}$	1	000	716	716
[illegible]	$\Delta t \dot{\delta}_r$	3	943	715	000
[illegible]	$\delta_{r_{n+1}}$	1	000	717	717
[illegible]	TR to 400	0	010	000	400

DIGITAL [illegible] INSTR SHEET

PROGRAM Spin (Diff. Eq.)

NAME D.S.S. DATE

LOC	REMARKS	Op	D/A	B	C
4[illegible]	$-.297h \times 10^{-4}$	3	936	701	000
4[illegible]	e^{η}	0	094	000	000
4[illegible]	$\rho = \rho_0(\uparrow)$	3	000	935	000
4[illegible]	ρV	3	000	703	000
4[illegible]	ρV^2	3	000	703	000
4[illegible]	$q_0 = \rho V^2/2 \rightarrow 811$	3	902	000	811
4[illegible]	TR to 100	0	010	000	100
4[illegible]	$a_2\alpha$	3	923	708	951
4[illegible]	$-a_2\alpha^2$	5	000	708	000
4[illegible]	$C_{Lw} = a_1\alpha - a_2\alpha^2$	1	950	000	812
4[illegible]	$l_t q$	3	913	714	000
4[illegible]	$l_t q/V$	4	000	703	952
4[illegible]	$\alpha + i_t$	1	708	931	953
4[illegible]	$\alpha_t = \alpha + i_t + l_t q/V$	1	000	952	000
4[illegible]	$a_t\alpha_t$	3	000	924	950
4[illegible]	$a_e\delta_e$	3	716	925	954
4[illegible]	$C_{Lt} = a_t\alpha_t + a_e\delta_e$	1	950	000	000
4[illegible]	$C_{Lt}(\eta S_t/S)$	3	000	813	000
4[illegible]	$C_L = C_{Lw} + (\uparrow)$	1	000	812	000
4[illegible]	$\lvert\beta\rvert$	0	096	709	000
4[illegible]	$\lvert\beta\rvert(\partial C_{Dc}/\partial\beta)$	3	000	919	000
4[illegible]	$C_{Dc} = C_{Dc_0} + (\uparrow)$	1	000	918	950
4[illegible]	TR to 165	0	010	000	165
4[illegible]	$K_d\alpha^2$	3	708	955	956
4[illegible]	$C_D = C_{Dc} + K_d\alpha^2$	1	956	950	815
4[illegible]	$C_{Dw} = C_{Do} + K_d\alpha^2$	1	956	921	816
4[illegible]	$C_{L1} = (W/S)/q_0$	4	802	811	817
4[illegible]	$\sin\gamma \rightarrow 956$	0	091	707	956
4[illegible]	$\cos\gamma \rightarrow 957$	0	092	707	957
4[illegible]	C_D/C_{L1}	4	815	817	000
4[illegible]	$(C_D/C_L) + \sin\gamma$	1	000	956	000
4[illegible]	$\dot{V} = -g(\uparrow) \rightarrow 704$	5	000	939	704
4[illegible]	$C_y = -(\partial C_y/\partial\beta)\beta$	5	709	933	818
4[illegible]	$\sin\varphi_w \rightarrow 958$	0	091	710	958
4[illegible]	$C_y \sin\varphi_w$	3	000	818	950
4[illegible]	$\cos\varphi_w$	0	092	710	959
4[illegible]	$C_L \cos\varphi_w$	3	814	000	000
4[illegible]	$C_L\cos\varphi_w - C_y\sin\varphi_w$	2	000	950	000
4[illegible]	$\uparrow/C_{L1}$	4	000	817	000
4[illegible]	$\uparrow - \cos\gamma$	2	000	957	950
4[illegible]	$g/V \rightarrow 960$	4	939	703	960
4[illegible]	$\dot{\gamma} = (g/V)\times(950) \rightarrow 712$	3	000	950	712
4[illegible]	$C_L \sin\varphi_w$	3	958	814	950
4[illegible]	$C_y \cos\varphi_w$	3	959	818	000
4[illegible]	$C_L\sin\varphi_w + C_y\cos\varphi_w$	1	000	950	000
4[illegible]	$(\uparrow)/\cos\gamma$	4	000	957	000
4[illegible]	$(\uparrow)/C_{L1}$	4	000	817	000
4[illegible]	$\dot{\psi} = (\uparrow)(g/V)$	3	000	960	726
4[illegible]	TR to 140	0	010	000	140
4[illegible]	$\alpha + i_t + k_2 l_t q/V$	1	000	953	000

DICTATOR II instr. sheet

PROGRAM Spin (Diff. Eq.)

NAME D.S.S. DATE

LOC	REMARKS	O	A	B	C
4.[illegible]	a_t (↑)	3	0.0.0		
4.[illegible]	$a_t \delta_t$ + (↑)	1	0.0.2	9.[illegible]	[illegible]
4.[illegible]	R_2 (↑)	3	0.0.0	8.0.1	9.5.0
4.[illegible]	sin α → 952	0	0.9.1	7.0.3	9.5.2
4.[illegible]	(Z_{cg}/E) sin α	3	0.0.0	9.2.0	9.5.4
4.[illegible]	cos α → 953	0	0.9.2	7.0.3	9.5.3
4.[illegible]	(X_{cg}/c) cos α	3	0.0.0	9.2.[illegible]	0.0.0
4.[illegible]	(X_{cg}/c) cos α + (Z_{cg}/c) sin α	1	0.0.0	9.5.4	0.0.0
4.[illegible]	C_{LW} (↑)	3	8.1.2	0.0.0	0.0.0
4.[illegible]	C_{mac} + (↑)	1	0.0.0	9.2.[illegible]	0.0.0
4.[illegible]	(↑) − 950 → 819	2	0.0.0	9.5.0	8.1.9
4.[illegible]	$2K_d\alpha$	1	9.5.5	9.5.5	[illegible]
4.[illegible]	$C_{LW} - 2K_d\alpha$ → 955	2	8.1.2	0.0.0	9.5.5
4.[illegible]	(↑) sin α	3	0.0.0	9.5.2	9.5.0
4.[illegible]	$2a_2\alpha$	1	9.5.1	[illegible]	0.0.0
4.[illegible]	$2a_2\alpha - a_1$	2	0.0.0	[illegible]	9.[illegible]
4.[illegible]	$2a_2\alpha - a_1 - C_{DW}$ → 951	2	0.0.0	8.1.6	9.5.1
4.[illegible]	(↑) cos α	3	0.0.0	9.[illegible].3	0.0.0
4.[illegible]	(↑) + 950	1	0.0.0	9.5.0	9.5.0
4.[illegible]	ρb	3	7.1.3	9.1.1	0.0.0
4.[illegible]	ρb/2	3	0.0.0	9.0.2	0.0.0
4.7.[illegible]	ρb/2ν → 820	4	0.0.0	7.0.3	8.2.0
4.7.[illegible]	ρb/16ν	3	0.0.0	9.6.4	9.6.0
4.7.[illegible]	(ρb/16ν)(950)	3	0.0.0	9.5.0	9.5.0
4.[illegible]	$-(\Gamma/4)(a_2 - 2a_1\alpha)$	3	9.6.1	9.4.[illegible]	0.0.0
4.[illegible]	β(↑) = $-(\rho\Gamma/4)(a_1 - 2a_2\alpha)$	3	[illegible]	[illegible]	9.6.1
4.[illegible]	move a_2 to 923	6	0.0.0	9.2.7	9.2.3
4.[illegible]	reset 465	6	0.0.0	8.0.3	4.6.5
4.[illegible]	C_{LW} cos α	3	8.1.2	9.5.3	9.6.2
4.[illegible]	C_{DW} sin α	3	8.1.6	9.5.2	0.0.0
4.[illegible]	C_{DW} sin α + C_{LW} cos α	1	0.0.0	9.6.2	9.6.2
4.[illegible]	rb	3	7.1.5	9.1.1	0.0.0
4.[illegible]	rb/2	3	0.0.0	9.0.2	0.0.0
4.[illegible]	rb/2ν	4	0.0.0	7.0.3	8.2.1
4.[illegible]	rb/6ν	3	0.0.0	9.0.3	0.0.0
4.[illegible]	r[illegible][962]	3	0.0.0	9.6.2	0.0.0
4.[illegible]	(↑) + [961]	1	0.0.0	9.6.1	0.0.0
4.[illegible]	TR to 109	0	0.1.0	0.0.0	1.0.9
4.[illegible]	$(2a_2\alpha - a_1 - C_{DW})$ sin α	3	9.5.1	9.5.2	9.5.1
4.[illegible]	cos α $[-C_{LW} + 2\alpha K_d]$	5	9.5.5	9.5.3	0.0.0
4.[illegible]	(↑) + [951]	1	0.0.0	9.5.0	0.0.0
4.9.1	(↑) ρb/16ν	3	0.0.0	9.6.0	9.5.0
4.[illegible]	C_{DW} cos α	3	9.5.3	8.1.6	9.5.1
4.[illegible]	C_{LW} sin α	3	9.5.2	8.1.2	0.0.0
4.[illegible]	C_{DW} cos α − C_{LW} sin α	2	9.5.1	0.0.0	0.0.0
4.[illegible]	1/3 (↑)	3	9.0.3	0.0.0	0.0.0
4.[illegible]	(↑) + $2a_{[illegible]} l v^2$ [illegible]	1	0.0.0	6.0.4	0.0.0
4.[illegible]	(↑) × rb/2ν	3	0.0.0	8.2.1	0.0.0
4.[illegible]	[950] − (↑)	2	9.5.0	0.0.0	9.5.0
[illegible]	$a_2\delta_t$	3	9.2.7	7.1.7	9.5.1

[illegible] 109 [illegible]

[illegible]

PROGRAM Spin (Diff. Eq.)

NAME D.S.S. DATE

REMARKS	O	A/I	P	Q
β_{ave}	3	709	926	000
$\beta_c\delta_r + \beta C_{n_r}$	1	000	951	000
$(\rho V_c/b)(S r/b)[\ldots]$	3	000	[illegible]	000
$C_n = (1) + [950] \to$ [illegible]	1	000	950	923
$K_4 C_2$	3	809	922	000
$K_5 C_2{}^{*} \to 920$	3	000	911	920
$C_n\,\varepsilon^{*}$	3	923	911	000
$C_n\,\xi_{INC}$	3	000	910	000
$K_4 C_2 \ldots + K_5 C_{n_\xi}$	1	000	920	971
$r_2 \to 972$	3	913	914	972
$[I_{xz}/I_x - (I_y - I_z)/I_{xz}]$	3	000	[illegible]	000
$(1) + [971] \to 971$	1	000	971	971
$\to 923$	3	714	71[illegible]	97[illegible]
$\pm \dot{q} r [(I_z - I_y)/I_x \ldots]$	3	000	951	00[illegible]
$(1) + [971]$	2	000	971	971
$\dot{r} = (1)/[(I_{xz}/I_x) - (I_z/I_{xz})]$	1	000	991	729
pq	1	000	972	100
$[I_{xz}/I_x](p q + \dot{r}) \to 972$	3	000	887	972
TR to 583	0	010	000	583
$\sin\beta$	0	0[illegible]	70[illegible]	154
$\cos\beta$	0	092	70[illegible]	155
$q\cos\beta$	3	955	714	950
$p\sin\beta$	3	954	713	000
$q\cos\beta - p\sin\beta$	2	950	000	950
$\dot\psi\cos\gamma$	3	721	159	960
$\dot\psi\cos\gamma\sin\varphi_w$	3	000	95[illegible]	951
$\dot\gamma\cos\varphi_w$	3	712	95[illegible]	000
$\dot\gamma\cos\varphi_w + \dot\psi\cos\gamma\sin\varphi_w$	1	000	951	000
$\dot\alpha = [950] - (1) \to 724$	2	950	000	724
$\dot\psi\cos\gamma\cos\varphi_w$	3	960	959	000
$[\dot\psi\cos\gamma\cos\varphi_w]\cos\alpha$	3	000	953	000
$\dot\psi\cos\gamma\cos\varphi_w\cos\alpha - r$	2	000	715	950
$\dot\gamma\sin\varphi_w$	3	712	958	000
$[\dot\gamma\sin\varphi_w]\cos\alpha$	3	000	953	000
TR to 630	0	010	000	630
$p\cos\beta$	3	713	955	150
$q\sin\beta$	3	714	954	000
$p\cos\beta + q\sin\beta$	1	950	000	000
$(1)\cos\alpha$	3	000	153	950
$r\sin\alpha$	3	715	952	000
TR to 625	0	010	000	625
$\dot h = V\sin\gamma \to 703$	3	703	956	702
$\dot x = V\cos\gamma$	3	703	952	950
$\cos\psi \to 959$	0	092	711	959
$\dot x_{ns} = \dot x\cos\psi$	3	950	000	719
$\sin\psi \to 958$	0	091	711	958
$V_{ew} = \dot x\sin\psi$	3	000	950	720
$\dot\gamma\sin\gamma$	3	704	956	951
$\dot x\,\dot x$	3	712	950	000
$\dot V = \dot x\,\dot x + \ldots$	1	000	951	718

Revised April 7, 1965

PROGRAM Spin (Diff Eq)

NAME DSS DATE

LOC	REMARKS	OP	A	B	C
5[illegible]	$\dot{\gamma}\cos\gamma$	3	204	959	951
5[illegible]	h	3	712	702	000
5[illegible]	$\dot{X} = V\cos\gamma + \dot{\gamma}h$	1	951	000	951
5[illegible]	$\ddot{X}\cos\Psi$	3	000	959	960
5[illegible]	$\dot{X}\dot{\Psi}$	3	950	726	961
5[illegible]	$\dot{X}\dot{\Psi}\sin\Psi$	3	000	958	000
5[illegible]	$\dot{V}_{ns} = \ddot{X}\cos\Psi + \dot{X}\dot{\Psi}\sin\Psi$	1	000	960	721
5[illegible]	$\ddot{X}\sin\Psi$	3	951	958	960
5[illegible]	$\dot{X}\dot{\Psi}\cos\Psi$	3	961	959	000
5[illegible]	$\dot{V}_{ew} = \dot{X}\dot{\Psi}\cos\Psi + \ddot{X}\sin\Psi$	1	000	960	722
5[illegible]	Test IR #2 : if equal – punch	0	072	089	564
5[illegible]	Add 1 to IR #2	0	042	000	001
5[illegible]	No Op	0	009	000	001
5[illegible]	Sw #3 – if on punch every point	0	013	500	565
5[illegible]	Set IR #2 to zero	0	062	000	000
5[illegible]	Set IR #1 to zero	0	061	000	000
5[illegible]	γ^2 – 57.3? → 607	3	207	906	607
5[illegible]	Inc IR #1 by 1	0	041	000	001
5[illegible]	go to 572 when IR #1 = 11	0	071	011	572
5[illegible]	Inc A address of 566 by 1	0	031	566	001
5[illegible]	Inc C address of 566 by 1	0	033	566	001
5[illegible]	IR to 566	0	010	000	566
5[illegible]	move 700 – 726 to 600 – 6[illegible]	6	007	700	600
5[illegible]	Punch 600 – 617	0	084	600	617
5[illegible]	move 701 to 601	6	000	701	601
5[illegible]	Test for $h<0$	0	014	574	580
5[illegible]	Set A address of 566 to 707	0	037	566	707
5[illegible]	set C address of 566 to 607	0	039	566	607
5[illegible]	Punch CR	0	[illegible]	000	000
5[illegible]	Test sw #2	0	012	[illegible]	[illegible]
5[illegible]	IR to 200	0	012	000	200
5[illegible]	Stop – go to 200 [illegible]	0	000	000	200
5[illegible]	$K_1 q r$	3	173	905	000
5[illegible]	$[922] - K_1 q r$	2	172	000	000
5[illegible]	$\dot{p} = (\uparrow) + [920]^0 \rightarrow 727$	1	000	920	727
5[illegible]	r^2	3	715	715	920
5[illegible]	$-p^2$	5	713	713	000
5[illegible]	$r^2 - p^2$	1	000	920	000
5[illegible]	$[J_{xz}/I_y](r^2-p^2)$	3	000	836	920
5[illegible]	pr	3	713	715	000
5[illegible]	$K_5 pr$	3	000	806	000
5[illegible]	$(\uparrow) + [920]$	1	000	920	920
5[illegible]	C_{mq}	3	819	511	000
5[illegible]	$K_5 C_{mq}$	3	809	205	000
5[illegible]	$\dot{q} = [\uparrow] + 920 \rightarrow 728$	1	000	920	728
5	IR to 519	0	210	000	519

DIGITAL CODING SHEET

PROGRAM Spin (G and I)

NAME D.S.S. DATE

REMARKS	OP	ADDRESS
z		
h		
$\dot{h}$		
v		
$\dot{v}$		
d.u.s		
d.s.u		
γ		
α		
β		
ψ_w		
ψ		
$\dot{\gamma}$		
p		
q		
r		
δc		
δr		
$\psi_? = r \sin \alpha +$ [950] $\rightarrow$ 723	1.0	0.0.9.5.0.7.2.3
$\psi \sin \gamma$	3.9	2.6.7.5.6.0.0.0
$\psi_w = \psi_? \cos \gamma +$ [723]	1.0	0.0.7.2.3.7.2.3
TR to 541	0.0	1.0.0.0.0.5.4.1
[950] − ACC $\rightarrow$ 725	2.9	5.0.0.0.0.7.2.5
$\psi \sin \alpha$	3.9	5.2.7.2.6.0.0.0
$\psi \sin \alpha \sin \gamma$	3.0	0.0.9.5.6.0.0.0
$\beta =$ [725] − (↑) $\rightarrow$ 725	2.7	2.5.0.0.0.7.2.5
TR to 535	0.0	1.0.0.0.0.5.3.5

Revised April 7, 1965

DIGITATOR DATA SHEET

PROGRAM Spin (Output)

NAME D.S.S. DATE

REMARKS

EXPONENT MANTISSA

t

h

$\dot{h}$

V

$\dot{V}$

d_{ns}

d_{sw}

γ

α

β

φ_w ψ

$\dot{\gamma}$

p

q r

δc

δr

$\ddot{h}$

V_{ns}

V_{sw}

$\dot{V}_{ns}$

$\dot{V}_{sw}$ $\dot{\varphi}_w$

$\dot{\alpha}$

$\dot{\beta}$

$\dot{\psi}$

$\dot{p}$

$\dot{q}$ $\dot{r}$

$\dot{\delta c}$

$\dot{\delta r}$

DIGITAL [illegible]

PROGRAM Spin ([illegible] Stage)

NAME D.S.S. [illegible]

REMARKS	VALUE
S_T/S_W	
[illegible]	
W/S	
[illegible]	
[illegible]	
$K_1 = (I_z - I_y)/I_x$	
$K_2 = (I_z - I_x)/I_y$	
$K_3 = (I_y - I_x)/I_z$	
$K_4 = bS/I_x$	
$K_5 = \bar{c}S/I_y$	
$K_6 = bS/I_z$	
[illegible]	
C_{L_W}	
$\eta\, S_t/S$	
C_L	
C_D	
[illegible]	
[illegible]	
C_y	
C_m	
$\rho b/2V$	
$\rho b/2$	
C_ℓ	
C_n	
C_{L_p}	5.1 1.4.0.0.0.0.0.0
α_p	5.0 5.0.0.0.0.0.0.0
α_1	5.1 0.3.2.0.0.0.0.0
α_2	5.2 1.1 3.3.0.0.0.0
V_2	5.0 1.0.0.0.0.0.0.0
V_5	5.3 2.0.0.0.0.0.0.0

GIGO

DIGITATOR [illegible] CODE SHEET

PROGRAM Spin (Constants)

NAME DSS DATE

LOC	REMARKS	[illegible]
	K_{12}/K_1	
	K_{1d}	
	K_{13}	5.1 2.0.0.0.0.0.0.0
	δ_a for start	5.0 1.[illegible].0.0.0.0
	β for Start	5.0 1.5.4.5.0.0.0.0
	δ_a	5.0 1.0.0.0.0.0.0.0
	$\partial C_l/\partial \delta_a$	
	V_s	5.2 3.0.0.0.0.0.0.0
	J_{xz}/I_y	5.2 4.0.0.0.0.0.0.0
	J_{xz}/I_x	
	$(J_{xz}/I_x) - [(I_y - I_x)/J_{xz}]$	
	$[(I_z - I_y)/I_x] + 1$	
	1 (one)	5.1 1.0.0.0.0.0.0.0
	$(J_{xz}/I_x) - (I_z/J_{xz})$	
	I_{xz}	5.3 2.0.0.0.0.0.0.0
	Reset 465	2.0 2.0.4.2.2.7.6.1
	Set 465	4.0 0.0.8.0.6.2.6.1
	$K_a = 4.055$	5.1 4.0.5.5.0.0.0.0
	$K_{a_1} = 1.3065$	5.1 1.3.0.6.5.0.0.0
	P_i	5.[illegible] 5.0.0.0.0.0.0.0
	[illegible]	5.1 1.0.0.0.0.0.0.0
	[illegible]	5.0 3.0.0.0.0.0.0.0

Spir.

D.S.S.

APPENDIX II

THE MULTI DEGREE OF FREEDOM PROGRAM

DIGITATOR

PROGRAM MDOF-GA (Temp Storage)

NAME CLW DATE

REMARKS | MANTISSA

t
h
V
γ°
ψ°
η°

1st line

α°
β°
ϕ_w°

2nd line

$p^{\circ/s}$
$q^{\circ/s}$
$r^{\circ/s}$
δa°
δr°
δe°

3rd line

T
V_i

g
$\dot{h}$
$\dot{V}$
$\dot{\gamma}$
$\dot{\psi}$
C_L
$\dot{\alpha}^{\circ/s}$
$\dot{\beta}^{\circ/s}$
$\dot{\phi}^{\circ/s}$
$\dot{p}^{\circ/s}$
$\dot{q}^{\circ/s}$
$\dot{r}^{\circ/s}$

γ^{r}
ψ^{r}
α^{r}
β^{r}
ϕ_w^{r}
$\dot{p}^{r/s}$
$\dot{q}^{r/s}$
$\dot{r}^{r/s}$
δa^{r}
δr^{r}
δe^{r}

DATA [illegible] SHEET

PROGRAM MDOF - G [illegible] ([illegible] Storage)

NAME CLW

REMARKS

EXP. MANTISSA

γ r/s

ψ r/s

$\dot{\psi}$ r/s

$\dot{\beta}$ r/s

$\dot{\xi}_w$ r/s

$\dot{p}$ r/s

$\dot{q}$ r/s

$\dot{r}$ r/s

HP

h

sin γ

cos γ

sin α

cos α

sin β

cos β

sin ξ_w

cos ξ_w

Δt

$\Delta t/2$

$2t$

550 η

P_3 = Sb/2 / cS

cS

Sb / Ixx

.4 (b/2)

1/4 (b/2)

0.25 sin (2 Λ)

0.25 [illegible]

cS / Iyy

ρ / 2

ℓ_w x_{cg} / c

ℓ_w z_{cg} / c

$K K_1$ [illegible]

ℓ_2 ℓ_3

Sb / Izz

ℓ_{vt} S_{vt} / bS

2 [illegible] ℓ_{vt} [illegible]

b / 2

GIG-0 [illegible]

DICTATOR ... ...

PROGRAM MDOF-6A (Temp Storage)

NAME CLW DATE

REMARKS | SRVANTISSA

C_D

C_{LL}

C_y

C_T

A_n

A_{n-1}

$\dot{A}$

Σ

$\Delta\Sigma$

$\dot{V}_i$

$(\delta_e)_{ref}$

$\int_0^t G_V(\ ) dt$

ϵ_V

$\epsilon_V = ...$

p^*

$\dot{p}^*$

$(\phi)_{ref}$

$\int_0^t G_\phi(\ ) dt$

$\epsilon_p = ...$

a_{yn}

$a_{y\,n-1}$

$\dot{a}_y$

ρ

$1 - 6.875 \times 10^{-6} h$

$(1-6.875 \times 10^{-6} h)^{4.256}$

$q^* S$

δ_a max

δ_r max

δ_e max

$\dot{\delta}_e$ max

Σ max

DICTATOR

PROGRAM MDOF-GA (Initial Conditions)

NAME CLW DATE

LOC	REMARKS	EXP	MANTISSA
	t	00	00000000
	h	54	50000000
	v	53	11100000
	γ	51	20000000
	ψ	00	00000000
	β	50	30000000
	ω_w	52	20000000
	δ_a	00	00000000
	δ_r	00	00000000
	δ_e	00	[illegible]
	$\dot{\psi}$	00	[illegible]
	$\dot{\gamma}$	00	[illegible]
	$\dot{\alpha}$	00	[illegible]
	$\dot{\beta}$	00	[illegible]
	$\dot{\omega}_w$	00	[illegible]
	$\dot{\eta}$	00	[illegible]
	$\Delta\delta_a$ max	45	20000000
	G_c	49	50000000
	G_v	43	25000000
	$\Delta t_{\alpha c}$	51	40000000
	τ_c	51	40000000
	$(e_i)_{x}$	51	20000000
	l_z	50	[illegible]
	G_a	52	20000000
	Δt_{pa}	51	20000000
	τ_a	50	20000000
		54	1765[illegible]
	p [illegible]	55	50000000
	G_y Δt_{py}	52	10000000
	τ	50	20000000

[illegible]

PROGRAM MDOF - GA (Constants)

NAME CLW DATE

REMARKS	CONSTANTS
0	50 0000000000
1	51 1000000000
2	51 2000000000
3	[illegible]
π/180	49 1745329252
180/π	[illegible]
[illegible]	[illegible]
[illegible]	54 [illegible]
[illegible]	[illegible]
[illegible]	[illegible]
0.5 - ½	50 5000000000
6.875 × 10^-?	45 [illegible]
4.25 [illegible]	51 [illegible]
550	53 550000000
5.5 [illegible]	51 5500000000
.25 - ¼	50 25 [illegible]
2.3?6 × 10^-5	46 [illegible]
5.254	51 5254 [illegible]
3.3125 × 10^-?	[illegible]
0.12	50 1200000000
½	[illegible]
⅛	50 1250000000

DICTATOR II data sheet

PROGRAM MDOF-GA (210-D [illegible])

NAME CLW DATE

LOC	REMARKS	EX	MANTISSA
[illegible]	W lbs	5.4	3.1.0.0.0.0.0.0
[illegible]	S ft^2	5.3	1.7.5.5.6.0.0.0
[illegible]	S_t ft^2	5.2	3.8.4.6.0.0.0.0
[illegible]	S_{vt} ft^2	5.2	1.1.5.7.0.0.0.0
[illegible]	b ft	5.2	3.6.5.8.3.3.3.3
[illegible]	c ft	5.1	4.9.0.0.0.0.0.0
[illegible]	l_t ft	5.2	1.5.0.0.0.0.0.0
[illegible]	l_{vt} ft	5.2	1.7.8.3.0.0.0.0
[illegible]	$\partial C_L/\partial\alpha$ rad^{-1}	5.0	3.0.9.[illegible]
[illegible]	a_w rad^{-1}	5.1	4.4.7.0.0.0.0.0
[illegible]	a_t rad^{-1}	5.1	3.6.2.0.0.0.0.0
[illegible]	a_e rad^{-1}	5.1	2.8.[illegible].5.0.0.0.0
[illegible]	a_r rad^{-1}	5.1	1.1.6.0.0.0.0.0
[illegible]	a_{vt} rad^{-1}	5.1	2.0.6.0.0.0.0.0
[illegible]	J_x slug ft^2	5.4	1.2.[illegible].2.0.0.0.0
[illegible]	J_y slug ft^2	5.4	2.0.0.0.0.0.0.0
[illegible]	J_z slug ft^2	5.4	3.2.0.0.0.0.0.0
[illegible]	C_{D_0}	4.8	2.1.0.0.0.0.0.0
[illegible]	$\partial C_{D_0}/\partial\beta$	4.8	7.5.0.0.0.0.0.0
[illegible]	K	4.9	4.8.0.0.0.0.0.0
[illegible]	η	5.0	9.8.0.0.0.0.0.0
[illegible]	K_1	5.1	1.0.0.0.0.0.0.0
[illegible]	K_2	5.1	1.0.0.0.0.0.0.0
[illegible]	C_{mac}	4.9	4.3.0.0.0.0.0.5
[illegible]	z_p ft	5.0	1.6.[illegible]
[illegible]	x_{cg} ft	4.9	5.8.[illegible]
[illegible]	z_{cg} ft	5.1	2.3.8.5.0.0.0.5
[illegible]	Λ°	0.0	0.0.0.0.0.0.0.0
[illegible]	Γ°	5.1	4.7.2.0.0.0.0.0
[illegible]	δ_a max°	5.2	1.6.5.0.0.0.0.0
[illegible]	δ_r max°	5.2	2.4.0.0.0.0.0.0
[illegible]	HP min	0.0	0.0.0.0.0.0.0.0
[illegible]	δ_e max°	5.2	1.9.0.0.0.0.0.0
[illegible]	δ_e max	5.2	1.0.0.[illegible]
[illegible]	HP max	5.3	3.0.0.0.0.0.0.0
[illegible]	$\partial C_L/\partial(HP/[illegible])$	5.0	4.3.7.5.0.0.0.0
[illegible]	i_g	5.2	5.0.0.0.0.0.0.0

[illegible]

PROGRAM MDOF-GA ([illegible])

NAME CLW [illegible]

REMARKS				
Move t, h, V, γ, x	6	005	150	005
γ^r	3	001	[illegible]	030
ψ_r	[illegible]	[illegible]	[illegible]	[illegible]
Move β, φ	[illegible]	002	[illegible]	012
β^r	3	012	[illegible]	042
φ^r	3	012	024	042
Move δa, δr, δe	6	003	[illegible]	012
δa^r	3	017	[illegible]	[illegible]
δr^r	3	[illegible]	204	042
δe^r	3	019	204	042
Move V, ψ	6	002	[illegible]	[illegible]
$\gamma^{r/s}$	3	023	204	050
Move $\dot{\alpha}$, $\dot{\beta}$, $\dot{\psi}$	6	003	[illegible]	021
$\dot{\alpha}^{r/s}$	3	001	204	052
$\dot{\beta}^{r/s}$	3	002	204	[illegible]
$\dot{\psi}^{r/s}$	3	003	204	054
$\dot{\gamma}^{r/s}$	3	015	204	056
δa max	3	[illegible]	404	145
δr max	3	[illegible]	[illegible]	146
δe max	3	[illegible]	[illegible]	147
δe min	3	[illegible]	204	[illegible]
[illegible]	[illegible]	005	[illegible]	[illegible]
δe ref	6	000	[illegible]	111
$\int_0^t G_r(\quad)dt$	6	000	205	112
$\int_0^t G_a(\quad)dt$	6	000	[illegible]	118
Δt	6	000	[illegible]	[illegible]
Δt/2	3	[illegible]	[illegible]	[illegible]
b/2	3	257	212	079
5503	3	[illegible]	020	072
cS	3	255	251	080
St δt	3	252	[illegible]	002
St ℓt/cS	4	000	[illegible]	073
W/S	4	250	251	074
LS	3	254	251	027
LS/I_x	4	000	[illegible]	075
∂Ce/∂([illegible])	3	[illegible]	[illegible]	[illegible]
(1/4)b/2	3	[illegible]	[illegible]	077
Λ^r	3	[illegible]	204	000
$2\Lambda^r$	1	000	002	000
sin $2\Lambda^r$	[illegible]	[illegible]	[illegible]	[illegible]
.25 sin 2Λ	3	[illegible]	[illegible]	[illegible]
Γ^r	3	271	[illegible]	000
$a_w \Gamma$	3	[illegible]	[illegible]	[illegible]
0.25 $a_w \Gamma$	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	4	[illegible]	[illegible]	[illegible]
$c̄S/I_y$	4	[illegible]	[illegible]	[illegible]
a_w/c	4	[illegible]	[illegible]	[illegible]
X_{cg} [illegible]	3	[illegible]	[illegible]	[illegible]
Z_{cg} [illegible]	3	[illegible]	[illegible]	[illegible]
KN	[illegible]	[illegible]	[illegible]	[illegible]

DIGITATOR [illegible]

PROGRAM MDOF-G[illegible] ([illegible])

NAME CLW DATE [illegible]

LOC	REMARKS	Q	[illegible]	[illegible]	C
[illegible]	$K K_1 a_w$	3	0 [illegible] 4	2 5 9	[illegible]
[illegible]	$K_2 l_t$	3	2 [illegible]	[illegible]	0 3 5
[illegible]	bS/J_z	4	[illegible]	[illegible]	0 3 6
[illegible]	$l_{vt} S_{vt}$	3	2 5 2	2 5 7	[illegible]
[illegible]	$l_{vt} S_{vt}/bS$	4	[illegible]	[illegible]	[illegible]
[illegible]	$l_{vt} S_{vt}/b^2S$	4	[illegible]	[illegible]	0 0 [illegible]
[illegible]	$l_{vt}^2 S_{vt}/b^2S$	3	2 5 [illegible]	[illegible]	[illegible]
[illegible]	$a_{vt} l_{vt}^2 S_{vt}/b^2S$	3	[illegible] 2	0 0 0	0 0 0
[illegible]	$3 a_{vt} l_{vt}^2 S_{vt}/b^2S$	4	[illegible]	[illegible]	[illegible]
[illegible]	$6.875 \times 10^{-6} h$	3	[illegible]	[illegible]	[illegible]
[illegible]	$1-(\uparrow)$	[illegible]	[illegible]	[illegible]	1 2 6
[illegible]	$\log_e(\uparrow)$	[illegible]	0 [illegible] 5	0 0 0	0 0 0
[illegible]	$4.2561(\uparrow)$	3	[illegible]	[illegible]	[illegible]
[illegible]	$e^{(\uparrow)}$	0	0 9 4	[illegible]	1 2 7
[illegible]	$\rho = \rho_0(\uparrow)$	3	[illegible]	[illegible]	[illegible] 5
[illegible]	ρV	3	0 0 7	0 0 0	0 0 0
[illegible]	ρV^2	3	0 0 7	[illegible]	[illegible]
[illegible]	$q^* = \rho V^2/2$	3	[illegible]	[illegible]	[illegible] 5
[illegible]	C_{L_L}	4	0 7 4	[illegible] 6	1 0 1
[illegible]	C_y	5	0 4 7	2 5 5	1 0 2
[illegible]	$\sin \gamma$	[illegible]	0 9 1	[illegible]	[illegible]
[illegible]	$\cos \gamma$	0	0 9 2	[illegible]	0 6 1
[illegible]	$\sin \beta$	[illegible]	0 9 1	[illegible]	[illegible] 6 4
[illegible]	$\cos \beta$	0	0 9 2	[illegible]	0 6 5
[illegible]	$\sin \varphi_w$	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	$\cos \varphi_w$	0	[illegible] 2	0 4 3	0 6 7
[illegible]	a_w	[illegible]	[illegible]	2 5 9	0 0 0
[illegible]	C_{L_L}/a_w	[illegible]	1 0 1	[illegible]	[illegible]
[illegible]	$V\dot{\gamma}$	3	0 0 7	[illegible]	0 0 0
[illegible]	$V\dot{\gamma}/g$	4	0 0 0	[illegible]	[illegible]
[illegible]	C_y/C_{L_L}	5	1 0 2	1 0 1	0 9 9
[illegible]	$C_y \sin \varphi_w / C_{L_L}$	3	0 [illegible] 6	0 0 0	0 0 0
[illegible]	$(V\dot{\gamma}/g) - (\uparrow)$	2	[illegible] 1	0 0 0	0 0 0
[illegible]	$(\uparrow) \div \cos \gamma$	1	0 6 1	0 0 0	0 0 0
[illegible]	$\alpha = G_0(\uparrow)$	3	0 [illegible]	[illegible]	[illegible] 1
[illegible]	$\sin \alpha$	0	0 9 1	0 4 1	[illegible] 2
[illegible]	$\cos \alpha$	0	0 9 2	0 5 1	0 6 3
[illegible]	TR to 465	0	[illegible]	[illegible]	4 6 5
[illegible]	$q^* S$	3	0 2 5	[illegible]	1 2 [illegible]
[illegible]	C_L^2	3	0 3 0	0 3 0	0 0 0
[illegible]	$K C_L^2$	2	[illegible] 0 0	[illegible]	0 9 0
[illegible]	$\|\beta\|$	0	0 9 [illegible]	0 4 7	0 0 0
[illegible]	$(\partial C_{D_\beta}/\partial\beta)\|\beta\|$	3	[illegible]	0 0 0	0 0 0
[illegible]	$(\uparrow) + K C_L^2$	1	0 [illegible] 0	0 0 0	0 0 0
[illegible]	C_D	1	0 0 0	[illegible]	1 0 0
[illegible]	D	[illegible]	[illegible]	[illegible]	0 9 2
[illegible]	V/g	4	0 2 7	[illegible]	[illegible]
[illegible]	$\sin \gamma + (\uparrow)$	1	0 [illegible]	[illegible]	[illegible]
[illegible]	$[illegible](\uparrow)$	3	[illegible] 5 0	[illegible]	[illegible]
[illegible]	$T = (\uparrow) + D$	1	[illegible]	0 [illegible] 7	[illegible]

PROGRAM: MDOF - GA (Initialization)

NAME: CLW

REMARKS				
TV	[illegible]	[illegible]	[illegible]	000
$HP = TV/550$	4	[illegible]	[illegible]	[illegible]
[illegible] 434	0	[illegible]	[illegible]	434
(C_y/C_L) [illegible]	3	[illegible]	[illegible]	[illegible]
[illegible]	3	[illegible]	[illegible]	000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C_L/C_y	4	[illegible]	[illegible]	[illegible]
[illegible]	3	[illegible]	[illegible]	000
(1) + [illegible]	1	[illegible]	[illegible]	000
ψ	3	[illegible]	[illegible]	[illegible]
ψ [illegible]	3	[illegible]	[illegible]	[illegible]
[illegible]	3	[illegible]	[illegible]	[illegible]
[illegible]	3	[illegible]	[illegible]	[illegible]
[illegible]	3	[illegible]	[illegible]	[illegible]
ψ [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(1) [illegible]	2	[illegible]	[illegible]	[illegible]
[illegible] (1) $- \beta$	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ψ [illegible]	3	[illegible]	[illegible]	[illegible]
(1) + [illegible]	1	[illegible]	[illegible]	[illegible]
X_1 = [illegible] + (1)	1	[illegible]	[illegible]	[illegible]
[illegible]	3	[illegible]	[illegible]	[illegible]
[illegible]	2	[illegible]	[illegible]	[illegible]
X_2 = (1) / [illegible]	4	[illegible]	[illegible]	[illegible]
$X_1 \sin \beta$	3	[illegible]	[illegible]	[illegible]
$X_1 \cos \beta$	3	[illegible]	[illegible]	[illegible]
$X_2 \sin \beta$	2	[illegible]	[illegible]	[illegible]
$X_2 \cos \beta$	3	[illegible]	[illegible]	[illegible]
p	2	[illegible]	[illegible]	[illegible]
q	1	[illegible]	094	045
[illegible]	[illegible]	[illegible]	007	[illegible]
[illegible]	3	[illegible]	[illegible]	[illegible]
A_{n} = [illegible]	3	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	3	[illegible]	[illegible]	[illegible]
(1) + [illegible]	1	[illegible]	[illegible]	[illegible]
[illegible] (1) [illegible]	3	[illegible]	[illegible]	[illegible]
C_T	4	[illegible]	[illegible]	[illegible]
C_T [illegible]	3	[illegible]	[illegible]	[illegible]
(1) + [illegible]	1	[illegible]	[illegible]	[illegible]
(1) + [illegible]	1	[illegible]	[illegible]	[illegible]
[illegible]	4	[illegible]	025	[illegible]
[illegible]	4	[illegible]	[illegible]	[illegible]
(1) [illegible]	2	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(1) + [illegible]	1	[illegible]	[illegible]	[illegible]
(1) / [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(1) + [illegible]	1	[illegible]	[illegible]	[illegible]
[illegible]	3	[illegible]	[illegible]	[illegible]

DICTATOR [illegible] [illegible]

PROGRAM MDOF - GA (Initialization)

NAME CLW DATE

LOC	REMARKS	C	O.A.	[illegible]	[illegible]
[illegible]	$K = \ell_t\, q / V$	4	0.0.0	[illegible]	[illegible]
	$(1) + C_g \to C_g$	1	0.0.0	[illegible]	[illegible]
	ℓ_t / V	7	[illegible]	[illegible]	[illegible]
	$\ell_t \dot{\alpha} / V$	3	0.5.7	[illegible]	[illegible]
	$\alpha - \ell_t \dot{\alpha} / V$	2	0.4.1	[illegible]	[illegible]
4	$K = K_{aw}\,(1)$	0	[illegible]	[illegible]	[illegible]
	$L_t = (1) - C_g$	2	0.0 [illegible]	[illegible]	[illegible]
	C_y / C_{L}	4	1.0.2	1.0.1	0.0.0
	$\lambda_{y}\, n \ldots C_y / C_L$	2	[illegible]	[illegible]	[illegible]
	TR to 454	0	0.1.0	[illegible]	4.5.4
4					
4	C_L	3	0.4.1	[illegible]	[illegible]
	$C_L \cos \psi_w$	3	0.0.0	[illegible]	[illegible]
	$C_y \sin \psi_w$	3	1.0.7	[illegible]	0.0.0
	$C_L \cos \psi_w + C_y \sin \psi_w$	1	0.0.0	[illegible]	[illegible]
4	$(1) / C_L$	4	0.0 [illegible]	1.1.1	[illegible]
	$(1) \cos \gamma$	2	0. [illegible]	[illegible]	6.0. [illegible]
	$(1) / V$	4	0.0.0	[illegible]	1.0.0
	$\dot{\gamma} = g (1)$	[illegible]	0.0.0	[illegible]	0.5.0
	TR to 3 [illegible]	[illegible]	0.1.0	[illegible]	3.2.3
4					
4					
5	i_a	0	3.8.6	[illegible]	0.4.0
	$\sin (i_a)$	[illegible]	0.9.1	[illegible]	0.0.0
	$r \sin (i_a)$	3	0.4.5	[illegible]	0.9.1
	$\cos (i_a)$	0	0.4.2	[illegible]	0.0.0
	$r \cos (i_a)$	3	0.4.7	[illegible]	[illegible]
	$\Delta d_a = (1) + r \sin (i_a)$	1	0.9.1	[illegible]	1.0.2
5	TR to 550	[illegible]	0.1.0	0.0.0	5.5.0
4	Move HP mix	6	0.0.0	0.5.4	[illegible]
	GTR Alt. [illegible]	[illegible]	2.4.0	0.5.2	[illegible]
	[illegible]	[illegible]	0.7.2	[illegible]	[illegible]
	[illegible]	4	[illegible]	[illegible]	0.2.0
	HP rel	[illegible]	0.0 [illegible]	[illegible]	1.1. [illegible]
	TR	[illegible]	[illegible] 1.0	[illegible]	[illegible]

[illegible] [illegible] — [illegible]

PROGRAM MDOF-9A (Integration)

NAME CLW DATE

REMARKS	Op			
$t + \Delta t$	1	069	005	005
$\dot{h}\,\Delta t/2$	3	020	[illegible]	000
$(h)_n + \bar{h}$	1	026	00[illegible]	000
$(h)'t$	3	069	000	000
h_{n+1}	1	000	[illegible]	[illegible]6
$\dot{V}\Delta t$	3	069	[illegible]7	0[illegible]0
V_{n+1}	1	000	[illegible]7	007
$\dot{\gamma}\,\Delta t$	0	069	050	000
γ_{n+1}	1	000	[illegible]	039
$\dot{\psi}\,\Delta t$	2	069	051	000
ψ_{n+1}	1	000	[illegible]	030
$\dot{\alpha}\,\Delta t$	3	[illegible]	[illegible]	000
α_{n+1}	1	[illegible]	[illegible]	041
$\dot{\beta}\,\Delta t$	3	[illegible]	[illegible]	000
β_{n+1}	1	000	242	042
$\dot{\psi}_w\,\Delta t$	0	031	[illegible]	000
$\psi_{w,n+1}$	1	[illegible]	[illegible]	052
$\dot{p}\,\Delta t$	3	069	[illegible]	000
p_{n+1}	1	000	244	044
$\dot{q}\,\Delta t$	0	061	[illegible]	000
q_{n+1}	1	000	[illegible]	045
$\dot{r}\,\Delta t$	3	068	[illegible]	000
r_{n+1}	1	000	[illegible]	[illegible]
$\Delta\delta\,\Delta t$	3	068	1[illegible]1	000
Add	1	000	132	132
Tr to DE	0	210	000	[illegible]
$\dot{h} = V\sin\gamma$	3	00[illegible]	050	026
$\psi\sin\gamma$	[illegible]	[illegible]	[illegible]	[illegible]
ψ_w	1	[illegible]	[illegible]	[illegible]
Tr to 617	0	210	000	617

DICTATOR II instr. sheet

PROGRAM MDOF - GA (Diff. Eq.)

NAME: CLW DATE: ______

LOC	REMARKS	Q	Q/A	C	C
5	$\sin \gamma$	0	091	039	060
	$\cos \gamma$	0	092	039	061
	$\sin \alpha$	0	091	041	062
	$\cos \alpha$	0	092	041	063
	$\sin \beta$	0	091	042	064
5	$\cos \beta$	0	092	042	065
	$\sin \varphi_w$	0	091	042	066
	$\cos \varphi_w$	0	092	042	067
	$6.575 \times 10^{-6} h$	3	211	006	000
	$1 - (\uparrow)$	2	201	000	126
5	$\log_e (\uparrow)$	0	095	200	000
	$4.25\ldots(\uparrow)$	3	212	000	000
	$e^{(\uparrow)}$	0	094	000	127
	$\rho = \rho_0 (\uparrow)$	3	003	204	125
	ρV	3	002	000	000
5	ρV^2	3	007	000	000
	$q^* = \rho V^2/2$	3	210	000	025
	$q^* S$	3	000	451	128
	$HP(550)(\eta)$	3	258	052	000
	$T = (\uparrow)/V$	4	000	007	020
5	$C_L = a_w \alpha$	3	041	059	030
	C_L^2	3	000	000	000
	$K C_L^2$	3	000	219	090
	$\lvert\beta\rvert$	0	096	042	000
	$(\partial C_{D_\beta}/\partial \beta) \lvert\beta\rvert$	3	2[illegible]	000	000
5	$(\uparrow) + K C_L^2$	1	090	000	000
	$C_D = (\uparrow) + C_{D_{0}}$	1	000	267	100
	$C_{LL} = W/q^* S$	4	250	123	101
	$C_y = -\beta(\partial C_y/\partial \beta)$	5	042	255	102
	$C_T = T/q^* S$	4	020	122	103
5	$C_T - C_D$	2	103	100	000
	$\uparrow / C_{LL}$	4	000	101	000
	$(\uparrow) - \sin \gamma$	2	000	060	000
	$\dot{V} = g(\uparrow)$	3	000	205	027
	$C_L \cos \varphi_w$	3	030	067	070
5	$C_y \sin \varphi_w$	3	102	06[illegible]	000
	$C_L \cos \varphi_w - (\uparrow)$	2	090	000	000
	TR to 647	0	010	000	647
	g/V	4	202	007	092
	$\dot{\gamma}$	3	092	091	050
5	$C_{LL} \cos \gamma$	3	101	041	000
	$g/V\, C_{LL} \cos \gamma$	4	092	002	092
	$C_L \sin \varphi_w$	3	030	066	090
	$C_y \cos \varphi_w$	3	100	067	000
	$(\uparrow) + C_L \sin \varphi_w$	1	090	000	000
5	$\dot{\psi}$	3	000	097	051
	$\dot{\psi} \cos \gamma$	3	051	061	099
	$\dot{\psi} \cos \gamma \sin \varphi_w$	3	000	066	09[illegible]
	$\dot{\gamma} \cos \varphi_w$	3	050	067	000
5	$(\uparrow) + \dot{\psi} \cos \gamma$ [illegible]	1	000	09[illegible]	0[illegible]0

[illegible] INSTRUCTION SHEET

PROGRAM MDOF - GA (Diff Eq)

NAME CLW DATE

REMARKS	O	A	B	C
$q \cos \beta$	3	045	065	091
$p \sin \beta$	3	044	064	000
$q \cos \beta - (1)$	2	091	000	000
$\dot{\alpha} = (1) \cdot G_0$	2	000	090	052
$\gamma \sin \varphi_w$	3	050	066	000
$\gamma \sin \varphi_w \cos \alpha$	3	000	063	092
$\psi \cos \gamma \cos \varphi_w$	3	099	067	000
$\psi \cos \gamma \cos \varphi_w \cos \alpha$	3	063	000	000
$(1) - \gamma \sin \varphi_w \cos \alpha$	2	000	092	000
$\dot{\beta} = (1) - r$	2	000	046	053
$r \sin \alpha$	3	046	062	093
$p \cos \beta$	3	044	065	094
$q \sin \beta$	3	045	064	000
$(1) + p \cos \beta$	1	094	000	000
$\cos \alpha \ (1)$	3	063	000	000
$\dot{\varphi}_w = (1) + r \sin \alpha$	1	000	093	054
TR to 530	0	010	000	530
$V \sin \gamma$	3	027	260	095
$\dot{\gamma} \cos \gamma$	3	050	061	000
$V \dot{\gamma} \cos \gamma$	3	007	000	000
$\dot{h} = (1) + \dot{V} \sin \gamma$	1	000	095	059
TR to 650 for Ball At	0	010	000	650
$(1) / C_{u}$	4	000	101	000
$(1) \cdot \cos \gamma$	3	000	061	091
TR to [illegible]	0	010	000	[illegible]

DICTATOR II instr. sheet

PROGRAM MDOF - GA (CARG Overlay)

NAME CLW DATE

LOC	REMARKS	O	O/A	B	C
600	ig	3	235	204	090
	sin(ig)	0	091	090	000
	r sin(ig)	3	046	000	091
	cos(ig)	0	092	090	000
	p cos(ig)	3	044	000	000
	(↑) + r sin(ig)	1	091	000	130
	$\Delta\delta_a - \Delta\delta_a$	2	000	132	000
	$\overline{\Delta\delta a}$	4	000	195	131
	$\Delta\delta a$ max	1	000	174	090
	$G\Delta\delta a$	3	175	130	191
	LAV	0	099	091	090
	±	0	016	663	667
	$-\Delta\delta a$ max	5	201	091	091
	δa	1	091	047	047
	δa max	6	000	145	090
	LAV	0	097	047	040
	±	0	016	667	667
	$-\delta a$ max	5	201	047	047
	TR to 700	0	010	000	700
	V_i^2	3	021	021	000
	V_i^3	3	000	021	091
	C_y/C_{L}	4	102	101	000
	$a_y = g\,C_y/C_{L}$	3	000	203	120
	Δa_y	2	120	121	000
	$\dot{a}_y$	4	000	067	122
	δr max	6	000	146	040
	$\Delta t\,p_y\,\dot{a}_y$	3	191	122	000
	$a_y + (↑)$	1	120	000	000
	$(↑)/V_i^3$	4	000	091	000
	$\delta r = G_y(↑)$	3	000	190	048
	LAV	0	099	048	090
	±	0	016	687	686
	$-\delta r$ max	5	201	048	048
	a_y n-1	6	000	120	121
	TR to 704	0	010	000	704

DIGITAC II INSTR SHEET

PROGRAM MDOE - GA Velocity A.P.

NAME: CLW DATE

LOC	REMARKS	O	S/A	D	C
7	q^*/p_o	4	0.25	2.05	0.0.0
	$2q^*/p_o$	1	0.0.0	0.0.0	0.0.0
	$V_i = A(1)$	0	0.9.0	0.0.0	0.2.1
	TR to 673	0	0.1.0	0.0.0	6.7.3
	$e_v = V_{id} - V_i$	2	1.8.4	0.2.1	1.1.3
	$h/(1-6.875\times10^{-6})h$	4	0.2.6	1.2.6	0.0.0
	$\dot{\rho}/\rho$	5	0.0.0	2.1.6	0.9.0
	$\dot{V}/V$	4	0.2.7	0.0.7	0.0.0
	$Z\dot{V}/V$	1	0.0.0	0.0.0	0.0.0
	$\dot{q}^*/q^*$	1	0.0.0	0.9.0	0.9.0
	$V_i/2$	3	0.2.1	2.1.0	0.0.0
	$\dot{V}_i$	3	0.0.0	0.9.0	1.1.0
	$\Delta t_{p.r.}(\dot{V}_i)$	3	0.0.0	1.2.1	0.9.0
	$e_v - (1)$	2	1.1.3	0.0.0	1.1.4
	$(1) / \tau_r$	4	0.0.0	1.3.2	0.9.1
	$e(cl)$	6	0.0.0	1.8.3	0.4.7
	larger abs value	0	0.9.9	0.9.1	0.9.2
	$\pm$	0	0.1.6	7.1.8	7.1.8
	$-e(cl)$	5	2.0.1	1.8.3	0.9.1
	$(1) - \dot{V}_i$	2	0.9.1	1.1.0	0.0.0
	$G_r(1)$	3	1.2.0	0.0.0	0.0.0
	$\Delta t(1)$	3	0.4.9	0.0.0	0.0.0
	$\int_0^t(\ )dt$	1	0.0.0	1.1.2	1.1.2
	$G_r \Delta t_{p.r.} \dot{V}_i$	3	1.3.0	0.9.0	0.0.0
	$\delta_x = \int(\ )dt - (2)$	2	1.1.2	0.0.0	0.9.0
	$\delta_{x\,total} = (1) + (2)$ [illegible]	1	1.1.1	0.0.0	0.0.0
	$\Delta\delta_e$	2	0.0.0	[illegible]	[illegible]
	$\Delta\delta_e\,\Delta t$	3	1.4.8	0.4.9	0.9.1
	l.a.v.	0	0.9.9	[illegible]	0.9.1
	$\pm$	0	0.1.6	7.3.1	7.3.0
	$\Delta\delta_e = -\Delta\delta_e\ max$	5	0.6.9	1.4.8	0.0.0
	δe	1	0.9.0	0.4.9	0.4.9
	$\delta e\ max$	6	0.0.0	1.4.7	0.9.0
	l.a.v.	0	0.1.9	0.4.9	0.4.9
	$\pm$	0	0.1.6	7.3.5	7.3.5
	$\delta e = -\delta e\ max$	5	2.0.1	0.4.9	0.4.9
	TR to 800	0	0.1.0	0.0.0	8.0.0

DICTATION [illegible]

PROGRAM MDDE-GA (Dif. Eq.)

NAME CLW DATE [illegible]

LOC	REMARKS	C	[illegible]	[illegible]	[illegible]
[illegible]	p/v	4	044	007	098
[illegible]	r/v	4	046	007	099
	$0.12\,\delta_a$	3	219	047	090
	$0.4\,pb/2v$	3	043	076	091
	$1/4\,(rb/2v)$	3	077	077	000
S	C_L (A)	3	000	030	092
	$0.25\,C_L$ [illegible]	3	[illegible]	[illegible]	[illegible]
	(A) + 0.25 [illegible]	1	09[illegible]	000	[illegible]
	β (A)	3	04[illegible]	000	000
	(A) + 0.4 (pb/2v)	1	0[illegible]1	000	000
S	$(C_L/4)(rb/2v)$ − (A)	2	[illegible]	[illegible]	000
	(A) + 0.12 [illegible]	1	[illegible]	000	000
	(A) (S_b/J_x)	3	025	000	000
	$\dot{p} = p^*$ (A)	3	00[illegible]	[illegible]5	[illegible]
	$a_c\,\delta_c$	3	261	04[illegible]	09[illegible]
S	q/v	4	045	007	000
	$K_2 K_i$ q/v	3	000	0[illegible]	00[illegible]
	α/v	4	05[illegible]	007	000
	[illegible] $\dot{\alpha}$/v	3	25[illegible]	000	000
	α − (A)	3	[illegible]	000	000
	KK_1 [illegible] (A)	3	0[illegible]	000	000
	$(K_2$ [illegible] (v) − (A)	1	[illegible]	000	000
	(A) + [illegible]	1	041	[illegible]	[illegible]
	(A) + [illegible]	1	05[illegible]	[illegible]	[illegible]
	[illegible] (A)	3	[illegible]	[illegible]	[illegible]
	(A) + [illegible]	1	09[illegible]	[illegible]	[illegible]
	[illegible] (A) − [illegible]	3	[illegible]	0[illegible]3	09[illegible]
	C = [illegible] /c	3	10[illegible]	0[illegible]7	09[illegible]
	[illegible] /c	3	[illegible]2	063	091
	[illegible] /c	3	0[illegible]	063	000
	(A) + [illegible] /c	1	091	000	000
	α (A)	3	041	000	000
	(A) + C [illegible]	1	0[illegible]0	0[illegible]	00[illegible]
	(A) + Cm [illegible]	1	273	000	000
	(A) + [illegible]	2	00[illegible]	097	000
	(cS/J_y) (A)	3	030	000	000
	$\dot{q} = q^*$ (A)	3	000	0[illegible]	056
	C_D/2	3	1[illegible]	2[illegible]0	0[illegible]
	(A) + [illegible] /b²S	1	0[illegible]	000	000
	(r/v) [illegible]	3	0[illegible]	000	09[illegible]
	C_L/[illegible]	3	000	221	000
	p/v (A)	3	0[illegible]	000	000
	(A) + [illegible]	1	0[illegible]	000	000
	(b/2) (A)	3	00[illegible]	0[illegible]	099
	$a_r\,\delta_r$	3	2[illegible]2	0[illegible]	090
	TR to [illegible]	[illegible]	[illegible]	[illegible]	89[illegible]
	(A) + [illegible]	1	[illegible]	[illegible]	000
	[illegible]	3	0[illegible]	000	090
	(A) − [illegible]	2	000	09[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	0[illegible]0	00[illegible]

DIGITALOG II INSTR. SHEET

PROGRAM MDOF-GA (Output)

NAME CLW DATE

REMARKS	O	Q/A	A	C
$r = g^{*}(?)$	3	000	025	057
$\eta = CL / C_{LL}$	4	030	101	010
TR to 855	0	010	200	855
$t = t_{print}$	2	005	149	002
=	0	016	[illegible]	[illegible]
Sw #2	0	013	500	[illegible]
$t_{print} = t + \Delta t_{print}$	1	009	149	149
γ°	3	039	[illegible]	[illegible]
ψ°	3	040	205	009
α°	3	041	205	011
β°	3	042	205	012
θ_{w}	3	043	205	013
p°	3	044	205	014
q°	3	045	205	015
r°	3	046	205	016
δ_{e}	3	047	205	017
δ_{a}	3	048	205	018
δ_{r}	3	049	205	019
CP	0	023	000	000
Print	0	022	005	021
Tr	0	010	[illegible]	850
Sw #1	0	011	391	881
ε	3	050	205	028
ψ	3	051	205	029
α	3	052	205	031
β	3	053	205	032
θ_{w}	3	054	205	033
p	3	055	205	034
$\dot{q}$	3	056	205	035
r	3	057	205	036
CP	0	027	000	000
Print	0	024	025	035
Sw #2	0	062	000	500

APPENDIX III

THE LONGITUDINAL DYNAMICS PROGRAM INCLUDING OVERLAYS

DICTATOR ...
PROGRAM Planar (Temp. Storage)
NAME ... DATE
REMARKS | MANTISSA

t
h_G
V
γ^{o}
θ^{o}
α_w^{o}
α_t^{o}
$\dot{h}_G$
V
$\dot{\gamma}^{o/s}$
$\dot{\theta}^{o/s}$
$\dot{\alpha}_w^{o/s}$
δ_e^{o}
X
T
δ_f^{o}
$\ddot{\theta}^{o/s^2}$
$e_v - \Delta t_p V_{i_0}$
V_i
$\dot{V}_i$
V_{i_0}
V_{wv}
V_{wH}
L
D
H
g
$\dot{V}_R$
$g\,S_w$
γ^{r}
θ^{r}
α_w^{r}
α_t^{r}
δ_e^{r}
$\dot{\alpha}_w^{r/s}$
$\dot{\theta}^{r/s}$
$\dot{\gamma}^{r/s}$
$\ddot{\theta}^{r/s^2}$
$\ddot{h}$
$\ddot{X}$
$\dot{X}$
T_0
i_T

DICTATOR II data sheet

PROGRAM Planar (Temp. Storage)

NAME ________ DATE ________

LOC	REMARKS	EXPANTISSA
0	$\sin \alpha_{w}$	
	$\cos \alpha_{w}$	
	$\sin \gamma$	
	$\cos \gamma$	
	$\sin \theta$	
0	$\cos \theta$	
	$\sin \Delta \alpha$	
	$\cos \Delta \alpha$	
	$\sin (\theta - \gamma - i_T)$	
	$\cos (\theta - \gamma - i_T)$	
0	g	
	V_{io}	
	$\alpha_{w} - i_T$	
	$\Delta \alpha$	
	V_{wr}	
0	V_{wH}	
	(ΔC_{m})	
	δ_f	
	δ_f	
	β	
0	V_G	
	γ_G	
	X_w	
	h_w	
	C_{L}	
0	C_{Lw}	
	S_t / S_w	
	$K_1 K_{ap}$	
	$\int (\quad) dt$	
	$(\dot{\theta})_{ref}$	
0	$(\dot{\theta})_{max}$	
	Δt	
	$\Delta t / 2$	
	$\Delta t^2 / 4$	
	t print	
0	V	
	γ	
	θ	
	h	
	X	
0		
	$GIGO_{0 \to ?}$	
0		

DIGITATOR DATA SHEET

PROGRAM Planar (Input Data)

NAME ______ DATE ______

	REMARKS	EXP	MANTISSA
1.	I C t	00	00000000
	N O h_G	54	10000000
	I N V	53	17900000
	T D γ°	51	40000000
	I I α_w° initial guess	51	10000000
1.	A T δ_e°	00	00000000
	L I C_T initial guess	49	30000000
	O ΔC_T initial guess	48	50000000
	N		
	S		
1.	C 0	00	00000000
	O 1	51	10000000
	N 2	51	20000000
	S 3	51	30000000
	T 0.5	50	50000000
1.	A g_0	52	32200000
	N R_e	58	20890875
	T $\pi/180$	49	17453293
	S $\rho_0/2$	48	11884600
	$(\log_e \sigma)/h$	46	29700000
1.	Δt integ	50	10000000
	Δt print	51	10000000
	t_f	53	10000000
	$(f_1 f_2)_{max}$	38	10000000
	$h\delta_f$ rad	00	00000000
1.	$\delta_{f\,max}$ rad/sec	50	69813000
	$\delta_{f\,max}$	50	13962600
	$550\,H_p$	53	46750000
	HP_{max}	53	28500000
	C τ_{filter}	50	15000000
	O $1/\tau$	50	25000000
1.	N c_{cl}	51	20000000
	T V_{id}	53	24450000
	R $\delta_{a\,max}$	52	10000000
	O G	48	25000000
	L Δt_p	51	466[illegible]0000

DIGITATOR II data sheet

PROGRAM Planar (210-D Parameters)

NAME ____________ DATE ____________

LOC	REMARKS	EXP	MANTISSA
	m slugs	52	96276000
	S_w ft^2	53	17550000
	S_t ft^2	52	31070000
	I_y slugs-ft^2	54	[illegible]0000000
	x_{cg} ft	49	55300000
	δ_{cg} ft	51	23250000
	l_t ft	52	17[illegible]30000
	a_w rad^{-1}	51	44000000
	C_{D_e}	49	21000000
	K	49	48000000
	a_t rad^{-1}	51	56200000
	a_e rad^{-1}	51	28650000
	K_1	51	10000000
	K_2	51	10000000
	i_T deg	50	70000000
	δ_p ft	50	16600000
	A ft^2	52	36550000
	l_p ft	51	60000000
	c ft	51	42000000
	$C_{M_{ac}}$	49	43000000
	D_p ft	51	68300000
	$\partial C_{D_e} / \partial \delta_f$ rad^{-1}	49	63800000
	$\partial C_{D_e} / \partial \beta$ rad^{-1}	00	00000000
	$\partial i_w / \partial \delta_f$	49	83000000
	$\partial i_w / \partial \delta_f$	49	83000000
	$\partial C_{M_{ac}} / \partial \delta_f$	50	23750000
	3.75	51	37500000
	σ } Temp Storage		
	V_R / V }		

DIGITATOR — DATA SHEET

PROGRAM Planar (Tabular Data)

NAME ______ DATE ______

	REMARKS	EXPONENT	MANTISSA
2		49	100000000
		52	600000000
		52	600000000
	time(1)	52	850000000
		52	850000000
2		53	110000000
		53	110000000
		55	100000000
2		00	000000000
		00	000000000
		52	100000000
	$V_{WH} = f(time(1))$	52	100000000
		52	100000000
2		52	100000000
		00	000000000
		00	000000000
2		49	100000000
		52	600000000
		52	600000000
	time(2)	52	850000000
		52	850000000
2		53	110000000
		53	110000000
		55	100000000
2		00	000000000
		00	000000000
		52	100000000
	$V_{WV} = f(time(2))$	52	100000000
2		52	100000000
		52	100000000
		00	000000000
		00	000000000
2			
	N.A.		
2			

DICTATOR II data sheet

PROGRAM Planar (Tabular Data)

NAME ______________ DATE ______________

LOC	REMARKS	D	MANTISSA
2			
2			
2		52	10000000
		50	10000000
	$h_{G(1)}$	50	10000000
		55	10000000
2		49	25000000
		49	25000000
	$\Delta C_{D_{eG}} = f(h_{G(1)})$	00	00000000
		00	00000000
2			
2			
2		51	10[illegible]000
		52	15[illegible]000
		52	15[illegible]000
		53	20[illegible]000
	$h_{G(2)}$	53	20000000
?		55	10000000
2		00	00000000
		00	00000000
		00	00000000
		00	00000000
	$\Delta H^P = f(h_{G(2)})$	00	00000000
2		00	00000000

DIGITAL ... INSTRUCTION SHEET

PROGRAM: Planar (Initialization)

NAME ______ DATE ______

	REMARKS	Op			
3	t_0, h, V	6	003	100	005
	γ_r	3	117	103	035
	$\alpha_{i.g.}$	3	117	104	037
	e	3	117	105	039
	$C_{T\,i.g.}$	6	000	106	019
3	Set tr. for Atm.	0	039	569	319
	$\dot{\theta} = 0$	6	000	110	041
	$V_{i_0} = 0$	6	000	000	025
	δ_e ref	6	000	039	079
	δ_e max	3	117	147	080
3	Δt	6	000	120	081
	$\Delta t/2$	3	000	114	082
	$\overline{\Delta t}^2/4$	3	000	000	083
	t print	6	000	005	084
	$\delta(0)$	6	000	110	079
3	θ	1	035	037	036
	X	6	000	110	018
	i_T	3	117	114	048
	tr. to Atm.	0	010	000	550
	set tr. address	0	039	569	570
3	K, K	3	162	159	000
	K, K aw	3	000	157	077
	S_t/S_w	4	157	151	076
	$\dot{\alpha} = 0$	6	000	110	040
	set integ. tr.	0	069	000	001
3	A/S_w	4	166	151	089
	qS_w	3	151	032	034
	mg	3	150	060	086
	mg/qS_w	4	000	034	086
	$mg \sin\gamma / qS_w$	3	052	000	000
3	$X_1 = (f) + C_{D_0}$	1	000	058	085
	$X_2 = mg\cos\gamma / qS_w$	3	086	053	086
	$X_3 = cC_{M_0}$	3	168	169	087
	$l_t X_2$	3	156	086	000
	$X_3 - l_t X_2$	2	087	000	088
3	$\Delta C_{T\,i.g.}$	6	000	107	098
	$\Delta \alpha_{w\,i.g.}$	6	000	117	099
	set tr. address	0	039	368	367
	$C_T/2$	3	019	114	090
3	tr.	0	010	005	343
	$\alpha_w - i_T$	2	037	048	091
	$\sin(\alpha_w - i_T)$	0	091	000	000
3	$C_T \sin(\alpha_w - i_T)$	3	000	019	092
	$\cos(\alpha_w - i_T)$	0	092	091	000
	$C_T \cos(\alpha_w - i_T)$	3	000	019	093
	$X_2 - C_T \sin(\alpha_w - i_T)$	2	086	092	000
	$(\ )^2$	3	000	000	000

DICTATOR II Instr. sheet

PROGRAM Planar (Initialization)

NAME ________ DATE ________

LOC	REMARKS	O	C/A	[illegible]	[illegible]
3	$K(1)$	3	157	000	000
	$c_T \cos(\alpha_w - i_T) - (1)$	2	093	000	000
	$f_1 = (1) - X_1$	2	000	005	093
	$f_p(\alpha_w - i_T)$	3	167	091	000
	$C_{N_{P,S}}$ (1) → G_0	3	000	090	090
3	t_r	0	010	000	415
	$f_t(1)$	3	156	000	000
	$(1) + X_3 - f_t X_2$	1	088	000	000
	$(1) + G_0 \to G_0$	1	000	090	090
	$\sin \alpha_w$	0	091	037	000
3	$z_{cg} \sin \alpha_w$	3	000	155	091
	$\cos \alpha_w$	0	092	037	000
	$x_{cg} \cos \alpha_w$	3	154	000	000
	$(1) + z_{cg} \sin \alpha_w$	1	091	000	000
	$(1) + l_t$	1	156	000	000
3	$\alpha_w(1)$	3	037	000	000
	$a_w(1)$	3	157	000	000
	$f_2 = (1) + G_0$	1	000	090	092
	tr	0	010	000	368
	Move c_T	6	000	019	090
3	Move α_w	6	000	037	091
	print c_T α_w f_2 f_1	0	020	090	093
	$f_1 f_2$	3	092	093	000
	$\|(1)\|$	0	096	000	000
	$f_1 f_2$ min $-(1)$	2	123	000	000
3	t_r t done	0	016	408	376
	$f_1 = a_3$	6	000	093	096
	$f_2 = b_3$	6	000	092	097
	$c_T + \Delta c_T$	1	098	019	019
	set T_r address	0	039	368	381
3	tr	0	010	000	338
	$(f_1)_{i+1} - (f_1)_i$	2	093	096	000
	$\partial f_1 / \partial c_T = b_1$	4	000	092	002
	$(f_2)_{i+1} - (f_2)_i$	2	092	097	000
	$\partial f_2 / \partial c_T = a_1$	4	000	098	001
3	$c_T - \Delta c_T$	2	019	098	019
	$\alpha_w + \Delta\alpha_w$	1	037	099	037
	set T_r address	0	039	368	3[illegible]9
	tr	0	010	000	3[illegible]
	$(f_1)_{i+1} - (f_1)_i$	2	093	096	000
3	$\partial f_1 / \partial \alpha_w = a_2$	4	000	099	003
	$(f_2)_{i+1} - (f_2)_i$	2	092	097	000
	$\partial f_2 / \partial \alpha_w = b_2$	4	000	099	004
	$\alpha_w - \Delta\alpha_w$	2	037	099	037
	$b_2 a_1$	3	004	001	090
3	$b_1 a_2$	3	003	002	000
	$b_2 a_1 - b_1 a_2 = d$	2	090	000	091
	$a_3 b_1$	3	096	002	090
	$b_3 a_1$	3	097	001	000
	$a_3 b_1 - b_3 a_1$	2	090	000	000

PROGRAM Planar (Initialization)

NAME ______ DATE ______

REMARKS			
$\Delta\alpha_w = (f)/d$	4	000 091	099
α_w	1	000 037	037
$b_3 c_2$	3	097 003	090
$b_2 a_3$	3	096 004	000
$b_3 a_2 - b_2 a_3$	2	090 000	000
$\Delta c_T = (f)/d$	4	000 091	098
c_T	1	000 019	019
tr	0	010 000	337
$\alpha_w - i_T$	2	037 048	062
$\sin(\alpha_w - i_T)$	0	091 062	058
$\cos(\alpha_w - i_T)$	0	092 062	059
$\sin\alpha_w$	0	091 037	050
$\cos\alpha_w$	0	092 037	051
θ	1	037 035	036
$\sin\theta$	0	091 036	054
$\cos\theta$	0	092 036	055
$c_T \sin(\alpha_w - i_T)$	3	019 058	091
$a_w \alpha_w$	3	037 157	075
$(f) + c_T \sin(\alpha_w - i_T)$	1	091 000	000
C_{Lt}	2	086 000	074
$a_c \delta_c$	3	111 039	090
$S_w C_{Lt}$	3	151 074	000
$(f)/S_t$	4	000 152	000
$(f) - a_c \delta_c$	2	000 090	000
$C_{Lt} = (f)/a_t$	4	000 160	038
$1 - K_1 K a_w$	2	111 077	000
$\alpha_w (f)$	3	037 000	000
$i_t = \alpha_t - (f)$	2	038 000	049
$T = c_T q S_w$	3	019 034	019
$T(0)$	6	000 019	047
T	6	000 019	096
α_w°	4	037 117	097
α_t°	4	038 117	098
i_t°	4	049 117	099
CR	0	028 000	000
print	0	020 096	099
$\delta_f = 0$	6	000 11[illegible]	067
set Tr address	0	039 587	595
VT	3	007 014	000
VT HP	4	000 127	031
VT	0	090 185	000
HP	4	031 000	031
HP(0)	6	000 031	047
tr	0	010 000	570
$l_t c_T \sin(\alpha_w - i_T)$	3	156 092	092
c_T [illegible]	3	019 165	000
$l_t c_T \sin(\alpha_w - i_T) - c_T$ [illegible]	2	092 000	000
tr	0	010 000	357

DICTATOR II Instr. sheet

PROGRAM Planar (1st Integration)

NAME ____________ DATE ____________

LOC	REMARKS	O	C/A	I	C
4	$\dot{V}_{n-1}$	6	000	013	085
	$\ddot{\gamma}_{n-1}$ $\ddot{\theta}_{n-1}$ $\ddot{h}_{n-1}$ $\ddot{X}_{n-1}$	6	004	047	086
	t_{n+1}	1	081	005	005
	$\ddot{h}\,\Delta t/2$	3	082	044	000
	$1+\dot{h}$	1	012	000	000
4	$\Delta t\,(1)$	3	081	000	000
	$1\ h_{n+1}$	1	000	006	006
	$\dot{V}\,\Delta t$	3	081	013	000
	$1\ V_{n+1}$	1	000	007	007
	$\ddot{\gamma}\,\Delta t$	3	081	047	000
4	$1\ \gamma_{n+1}$	1	000	035	035
	$\ddot{\theta}\,\Delta t/2$	3	082	043	090
	$1+\dot{\theta}$	1	041	000	091
	$\Delta t\,(1)$	3	081	000	000
	$1\ \theta_{n+1}$	1	000	036	036
4	$1\ \dot{\theta}_{n+1}$	1	090	091	041
	$1\ \alpha_{n+1}$	2	036	035	037
	$\ddot{X}\,\Delta t/2$	3	082	045	000
	$1+\dot{X}$	1	046	000	000
	$\Delta t\,(1)$	3	081	000	000
4	$1\ X_{n+1}$	1	000	017	018
	No Op	0	009	000	000
	Set $\Delta\delta_c$	1	063	039	039
	$\Delta t\ \dot{V}_{io}$	3	081	061	000
	$V_{io\ n+1}$	1	000	025	025
4	$\Delta t\ \dot{\delta}_f$	3	081	06[illegible]	000
	$\delta_{f\,n+1}$	1	000	067	067
	tr. to D.E.	0	010	000	550

DIGITAL ... CODING SHEET

PROGRAM Planar (2nd Integration)

NAME

REMARKS			
$\ddot{h}_{n+1} - \ddot{h}_n$	2 044	038	00.0
$\Delta t^2/4$ (i)	3 083	000	00.0
z h_{n+1}	1 000	006	006
$\dot{V}_{n+1} - \dot{V}_n$	2 013	085	000
$\Delta t/2$ (i)	3 082	000	00.0
z V_{n+1}	1 000	00.7	007
$\dot{\gamma}_{n+1} - \dot{\gamma}_n$	2 042	086	000
$\Delta t/2$ (i)	3 082	000	0.0.0
z γ_{n+1}	1 000	035	035
$\ddot{\theta}_{n+1} - \ddot{\theta}_n$	2 043	037	09.0
$\Delta t^2/4$ (i)	3 083	000	00.0
z θ_{n+1}	1 000	036	03.6
$(\Delta t/2)(\ddot{\theta}_{n+1} - \ddot{\theta}_n)$	3 082	090	09.0
z $\dot{\theta}_{n+1}$	1 000	041	041
z α_{n+1}	2 036	035	037
$\ddot{X}_{n+1} - \ddot{X}_n$	2 045	087	000
$\Delta t^2/4$ (i)	3 083	000	00.0
z X_{n+1}	1 000	018	01.8
1S integ ctr = 1 ?	0 079	00.1	550
$\dot{V}_{n+1}$	6 000	013	085
$\dot{\gamma}_{n+1}$ $\ddot{\theta}_{n+1}$ $\ddot{h}_{n+1}$ $\ddot{X}_{n+1}$	6 004	042	086
tr to DE	0 010	000	550

DICTATOR II Instr. sheet

PROGRAM: Planar (Diff. Eq's)

NAME: ______ DATE: ______ O/A R C

LOC REMARKS	O			
$\sin \alpha_w$	0	091	037	050
$\cos \alpha_w$	0	092	037	051
$\sin \gamma$	0	091	035	052
$\cos \gamma$	0	092	035	053
$\sin \theta$	0	091	036	054
$\cos \theta$	0	092	036	055
$\alpha_w - i_T$	2	037	048	062
$\sin(\alpha_w - i_T)$	0	091	062	058
$\cos(\alpha_w - i_T)$	0	092	062	059
h_a	1	006	116	000
dh/dh_G	4	116	000	099
$h = h_G(T)$	3	006	000	098
$(dh/dh_G)^2$	3	099	099	000
$g = g_0(T)$	3	000	115	060
$\log_e \sigma$	3	098	119	000
σ	0	094	000	185
$\rho/z = (\rho_0/z)(T)$	3	000	118	000
$V\rho/z$	3	007	000	000
$\bar{q} = V^2\rho/z$	3	000	007	032
tr	0	010	000	569
$\dot{h} = V \sin \gamma$	3	007	052	012
$\dot{X} = V \cos \gamma$	3	007	053	046
TLU V_{wv}	7	005	220	230
ΔV_{wv}	2	004	003	099
Δt	2	002	001	000
$\dot{V}_{wv}$	4	099	000	064
$t - t_L$	2	005	001	000
$\dot{V}_{wv}(T)$	3	064	000	000
V_{wv}	1	000	003	026
$\dot{V}_{wv}$	6	000	064	064
TLU V_{wH}	7	005	200	210
ΔV_{wH}	2	004	003	099
Δt	2	002	001	00[illegible]
$\dot{V}_{wH}$	4	099	000	065
$t - t_L$	2	005	001	000
$\dot{V}_{wH}(T)$	3	065	000	000
V_{wH}	1	000	003	027
tr	0	010	000	720
$h_{\delta f} - h$	2	124	006	000
t. test	0	016	590	595
$\delta_f - \delta_{f\,max}$	2	067	125	000
t. test	0	016	595	592
$\dot{\delta}_f$	6	000	126	068
set tr address	0	039	589	590
tr	0	010	000	596
$\dot{\delta}_f = 0$	6	000	110	068
TLU $\Delta C_{D_{\delta E}}$	7	006	260	265
$\Delta C_{D_{\delta E}}$	6	000	004	066
TLU ϵ	7	006	770	175
ϵ	6	000	004	069

Planar (Diff. Eq's)

550 K.P.	3 127	031	000
$T = (P)/V$	4 000	007	019
$\dot{X}_w$	1 043	027	072
$\dot{h}_w$	2 012	026	073
$\dot{X}_w^2$	3 072	072	090
$\dot{h}_w^2$	3 073	073	000
V_R^2	1 090	000	000
V_R	0 090	000	000
V_R/V	4 000	007	186
$(V_R/V)^2$	3 000	000	000
$\mathcal{T}$	3 000	032	032
T_{max}	6 000	128	001
τ_r	0 010	000	740
$\tan \gamma_r$	4 073	072	000
γ_r	0 093	000	071
$\Delta\alpha = \gamma - \gamma_r$	2 035	071	099
$\sin \Delta\alpha$	0 091	099	056
$\cos \Delta\alpha$	0 092	099	057
$\alpha_w = \theta - \gamma_R$	2 036	071	037
$\sin \alpha_w$	0 091	037	050
$\cos \alpha_w$	0 092	037	051
l_t/V_R	4 156	070	098
$K_2 l_t/V_R$	3 163	000	000
$(P)\dot{\theta} \rightarrow G_1$	3 000	041	091
$(\partial i_w/\partial \delta_f)\,\delta_f$	3 174	068	000
$(P) + \alpha_w$	1 040	000	000
$(P)\,l_t/V_R \rightarrow G_2$	3 000	098	092
$(\partial i_w/\partial \delta_f)\,\delta_f$	3 173	067	000
$(P) + \alpha_w$	1 037	000	075
$(P) - G_2$	2 000	092	000
$K_1 K\, a_w\, (P)$	3 077	000	000
$G_1 - (P)$	2 091	000	000
$(P) + \alpha_w$	1 037	000	000
$\alpha_t = (P)\,i_t$	1 000	049	038
$a_t\, \alpha_t$	3 038	160	091
$a_e\, \delta_e$	3 039	161	000
$(P) + a_t\, \alpha_t$	1 091	000	000
$C_{L_t} = (P)(S_t/S_w)$	3 076	000	074
$C_{L_w} = a_w[\alpha_w + (\partial i_w/\partial \delta_f)\delta_f]$	3 075	15[illegible]	
C_L	1 000	07[illegible]	
$q S_w$	3 032	151	[illegible]
L	3 071	034	029
C_L^2	3 091	091	000
$K C_L^2 \rightarrow G_2$	3 000	159	092
$(\partial C_{D_c}/\partial \delta_f)\,\delta_f$	3 172	067	000
$(P) + [illegible] \rightarrow G_2$	1 000	092	092
$(\partial C_{D_c}/[illegible]$	3 171	067	000
$(P) + G_2$	1 092	000	000
$(P) + C_{D_0}$	1 15[illegible]	000	000
$C_D = (P) + [illegible]$	1 000	066	092

DICTATOR II Instr Sheet

PROGRAM Planar (Diff. Eq's)

NAME ______ DATE ______

LOC	REMARKS	Q	A	B	C
6	$D = \bar{q} S_w C_D$	3	097	034	030
	$L \sin \Delta\alpha$	3	029	056	091
	$D \cos \Delta\alpha$	3	030	057	092
	No Op	0	009	000	000
	$T\cos(\theta-\gamma-i_T)$	3	019	059	093
6	$g \sin\gamma$	3	060	052	094
	$L\sin\Delta\alpha - D\cos\Delta\alpha$	2	091	092	000
	(P) + $T\cos(\theta-\gamma-i_T)$	1	000	093	000
	(P)/m	4	000	150	000
	$\dot{V}$	2	000	074	013
6	$L\cos\Delta\alpha$	3	029	057	091
	$D\sin\Delta\alpha$	3	030	056	092
	$T\sin(\theta-\gamma-i_T)$	3	019	052	093
	$g\cos\gamma$	3	060	053	094
	$L\cos\Delta\alpha + D\sin\Delta\alpha$	1	091	092	000
6	(P) + $T\sin(\theta-\gamma-i_T)$	1	000	093	000
	(P)/m	4	000	150	000
	(P) $- g\cos\gamma$	2	000	094	000
	$\dot{\gamma} =$ (P)/V	4	000	007	042
	$\dot{\gamma}$ $\dot{X}$	3	042	046	090
6	$\dot{V}\sin\gamma$	3	013	052	000
	$\dot{h}$	1	000	090	044
	$\dot{h}$ $\dot{\gamma}$	3	012	042	090
	$\dot{V}\cos\gamma$	3	013	053	000
	$\dot{X}$	2	000	090	045
6	$\dot{V}_{RV} = \dot{h} - V_{WV}$	2	044	064	090
	$\dot{V}_{RH} = \dot{X} + V_{WH}$	1	045	065	091
	$\sin\gamma_R$	0	091	071	092
	$\cos\gamma_R$	0	092	071	093
	$\dot{V}_{RV} \sin\gamma_R$	3	090	092	094
6	$\dot{V}_{RH}\cos\gamma_R$	3	091	093	000
	$\dot{V}_R$	1	000	094	033
	$\dot{V}_{RV}\cos\gamma_R$	3	090	093	094
	t_n	0	000	000	730
6	$\dot{\alpha} = \theta - \dot{\gamma}_R$	2	041	000	040
	C_T	4	019	034	091
	$C_T/2$	3	000	.14	092
	t_n	0	010	000	692
6					
	$(\partial C_{M_{ac}}/\partial\delta_f)\delta_f$	3	067	175	000
	(P) + $C_{M_{ac}}$	1	167	000	000
	(P) $c \rightarrow G_3$	3	000	168	093
6	$l_p(\alpha_w - i_T)$	3	167	062	094
	3.75 [illegible]	3	176	069	000
	3.75 [illegible]	3	170	000	000
	$l_p(\alpha_w - i_T)$ [illegible]	2	094	000	000
	C_{M} [illegible]	3	000	092	092

[illegible] INSTR. SHEET

PROGRAM Planar (Diff. Eq's)

PAGE ______ DATE ______

	REMARKS	Op.	A	B	C
7	$G_2 + G_3 \to G_2$	1	093	092	092
	x_{cg} cos α_w	3	154	051	094
	z_{cg} sin α_w	3	155	050	000
	x_{cg} cos α_w + z_{cg} sin α_w	1	094	000	000
	C_{Lw} (1)	3	075	000	000
7	(1) + $G_2 \to G_2$	1	000	092	092
	C_T $\bar{z}_T$	3	091	165	000
	$G_{(2)}$ − (1) − G_2	2	092	000	092
	$C_{L_{\alpha_t}}$ $\bar{l}_t$	3	074	156	000
	G_2 − (1)	2	092	000	000
7	$\bar{q}$ S_w (1)	3	034	000	000
	$\dot{\theta}$ = (1) / I_y	4	000	153	043
	integ. ctr −1	0	059	000	001
	= 0?	0	079	000	747
	Tr.	0	010	000	500
7					
7	TLU Δ HP	7	006	280	290
	HP total	1	047	003	031
	Move HP max	6	000	128	070
	g Tr. abs. val.	0	099	031	090
	Tr.	0	0 0	000	588
7					
7	$\dot{V}_{R_w}$ sin γ_R	3	091	092	000
	V_R γ_R	2	094	000	000
	$\dot{\gamma}_R$	4	000	070	000
	Tr.	0	010	000	624
7					
7	$\sqrt{\sigma}$	0	090	185	000
	$\sqrt{\sigma}$ / (V_R / V)	4	000	186	000
	T	3	019	000	019
	Tr.	0	010	000	613
7					
	set integ. ctr = 1	0	064	000	001

DICTATOR II Instr sheet

PROGRAM Planar (Sensor(s))

NAME ______ DATE ______

LOC	REMARKS	O	A	B	C
7	$2g/\rho_0$	4	032	118	000
	$v_i = \sqrt{(r)}$	0	090	000	023
	$\dot V_R / V_R$	4	033	070	000
	$2\dot V_R / V_R$	1	000	000	090
	$-(\text{const})\ h$	3	119	012	000
7	$\dot g/g = (r) + 2\dot V_R/V_R$	1	090	000	000
	$v_i\ (r)$	3	023	000	000
	$\dot v_i = (r)/\tau$	3	000	114	024
	$v_i - v_{i_0}$	2	000	025	000
	$\dot v_{i_0} = (r)/\tau_f$	4	000	143	061
7	τ_r	0	010	000	800

[illegible]

PROGRAM Planar (Control)

NAME

REMARKS				
$e_v = V_{id} - V_i$	2	146	023	099
$\Delta t_p \dot{V}_{io}$	3	149	025	098
e_{cl}	6	003	145	090
$e_v - \Delta t_p \dot{V}_{io}$	2	099	098	022
e_v	6	000	099	000
If = 0, use L.G.	0	015	806	810
$(e_v - \Delta t_p \dot{V}_{io}) / e_v$	4	022	000	000
±, + use L.G.	0	016	210	808
H.G. = G	6	000	146	091
t_r	0	010	000	811
L.G. = G	6	000	148	091
$(1/\tau)(e_v - \Delta t_p \dot{V}_{io})$	3	144	022	092
larg. abs. val.	0	099	090	092
±	0	016	815	814
$-e_{cl}$	5	111	090	090
(7) - $\dot{V}_{io}$	2	090	025	000
G(7)	3	091	000	000
Δt (7)	3	081	000	000
$\int_0^t (\_\_\_) dt$	1	000	078	078
$G \Delta t_p \dot{V}_{io}$	3	091	098	000
$\delta_x = \int -(7)$	2	078	000	000
δ_x total = (7) + δ_{c_0}	1	079	000	000
$\Delta \delta_c$	2	000	039	000
δ_c	4	000	081	090
$\delta_{c\,max}$	6	000	080	091
larg. abs. val.	0	099	090	091
±	0	016	828	827
$-\delta_{c\,max}$	5	111	090	090
$\Delta \delta_c$	3	090	081	063
t_r	0	010	000	850

DICTATOR II Instn sheet

PROGRAM: Planar (Output)

NAME: ______ DATE: ______

REMARKS	O	C/I	F	C
$t - t_{print}$	2	005	084	000
$\pm$	0	016	855	852
sw 3	0	013	855	856
h	6	000	006	000
$\pm$	0	016	450	856
$t_{print} + \Delta t_{print}$	1	121	084	084
γ	4	035	117	008
θ	4	036	117	009
α_w	4	037	117	010
α_t	4	038	117	011
$\dot{\gamma}$	4	042	117	014
$\dot{\theta}$	4	041	117	015
$\dot{\alpha}$	4	040	117	016
δ_e	4	039	117	017
δ_f	4	067	117	020
$\ddot{\theta}$	4	043	117	021
CR	0	028	000	000
h	6	000	006	000
$\pm$	0	016	869	897
print	0	023	005	027
sw 1	0	011	872	871
Op t. print	0	023	029	032
SW2	0	002	000	450
for truncated output: 861 Move	6	010	005	905
862 δ_e	4	039	117	911
863 V_i	6	000	023	913
864 T	6	000	019	915
865 δ_f	4	0[illegible]7	117	916
869 Print	0	023	905	916
CR	0	028	000	000
print	6	020	005	027
halt	0	000	500	849

DIGITAL ... DATA SHEET

PROGRAM Planar (Overlay for Config. & Run Changes)

NAME ____ DATE ____

No.	REMARKS	EXP.	MANTISSA
101	h	54	10100000
102	V	53	17900000
103	γ	51	30000000
124	$h_{\delta f}$	53	60000000
146	V_{id}	53	13200000
261	h_{G1}	54	10000000
262	h_{G1}	54	10000000
201	τ_1	55	10000000
221	τ_2	55	10000000
443	Move Test	60	02883853
444	t_r	00	10000570
853	( ) − h_G	22	50006000
854	±	00	16885450
885	set test ...	00	37855251
886	save temp storage	60	82005917
887	set test	00	38854849
888	t_r	00	16000450
889	set test for 0	00	37853110
890	save temp storage	60	82005917
891	set test	00	38854856
892	t_r	00	10000450
893	( ) − h_G	22	50006000
894	±	00	16000450
900	restart	60	82917005
901	t_r	00	10000450
250	h_G test	53	21000000
251	h_G test	52	20000000
848	truncated print	00	20905916
290	ΔP throttle flare	53	10500000
291	ΔP	53	10500000
292	ΔP maintain glide slope	52	53000000
293	ΔP	52	53000000

PROGRAM: Planar (Overlay for Pr. Clear Air Turb.)

NAME

REMARKS	CONSTANTS
h_G	5420000000
V	5325000000
γ	0000000000
V_{i_d}	5324268000

Planar (Overlay for Pir. Clear Air Turb.)

2	$y = h - h_0$	2	006	254	259
	$x K_2$	3	018	257	260
	$\cos x K_2$	0	092	260	261
	$\sin x K_2$	0	091	260	260
	$M_1 = y - b/2$	2	259	258	000
2	$K_2 M_1$	3	000	257	262
	$-K_2 M_1$	2	110	000	263
	$e^{K_2 M_1}$	0	094	262	270
	$e^{-K_2 M_1}$	0	094	263	271
	$e^{K_2 M_1} + e^{-K_2 M_1}$	1	270	271	000
2	$\cosh K_2 M_1 = (\ )/2$	3	000	114	263
	$e^{K_2 M_1} - e^{-K_2 M_1}$	2	270	271	000
	$\sinh K_2 M_1 = (\ )/2$	3	000	114	262
	$M_2 = y + b/2$	1	259	258	000
	$K_2 M_2$	3	257	000	264
2	$-K_2 M_2$	2	110	000	265
	$e^{K_2 M_2}$	0	094	264	270
	$e^{-K_2 M_2}$	0	094	265	271
	$e^{K_2 M_2} + e^{-K_2 M_2}$	1	270	271	000
	$\cosh K_2 M_2 = (\ )/2$	3	000	114	265
2	$e^{K_2 M_2} - e^{-K_2 M_2}$	2	270	271	000
	$\sinh K_2 M_2 = (\ )/2$	3	000	114	264
	$a/2$	3	114	251	000
	$M_3 = x - a/2$	2	018	000	000
	$K_2 M_3$	3	257	000	266
2	$\cos K_2 M_3$	0	092	000	267
	$\sin K_2 M_3$	0	091	266	266
	$V_1 = \cosh M_1 K_2 \cos x K_2$	2	263	261	268
	$V_2 = \cosh M_2 K_2 \cos M_3 K_2$	2	265	267	269
	$V_3 = \sinh M_1 K_2 / V_1$	4	262	268	270
2	$V_4 = \sinh M_2 K_2 / V_2$	4	264	269	271
	$V_5 = \sin x K_2 / V_1$	4	260	268	272
	$V_6 = \sin M_3 K_2 / V_2$	4	266	269	273
	$V_3 - V_4$	2	270	271	000
	$V_{wH} = K_1 (V_3 - V_4)$	3	000	256	027
2	$V_5 - V_6$	2	272	273	000
	$V_{wV} = K_1 (V_5 - V_6)$	3	000	256	026
	$\dot{y} \sinh M_1 K_2$	3	012	262	274
	$\dot{x} \sin x K_2$	3	046	260	000
	$V_1 / K_2 = (\ ) + \dot{y} \sinh M_1 K_2$	1	274	000	000
2	$V_1 / V_1 K_2$	4	000	263	268
	$\dot{y} \sinh M_2 K_2$	3	012	264	274
	$\dot{x} \sin M_3 K_2$	3	046	266	000
	$V_2 / K_2 = (\ ) + \dot{y} \sinh M_2 K_2$	1	274	000	000
	$V_2 / V_2 K_2$	4	000	264	269
2	$\dot{y} \cosh M_1 K_2$	3	012	263	000
	$(\ ) \sinh M_1 K_2$	4	000	262	000
	$(\ ) - V_1 / V_1 K_2$	2	[illegible]	268	000
	$G_{0} = V_2 \ [illegible]$	3	270	000	274
	$T r$	0	210	000	280

DICTATOR II Instr. Sheet

PROGRAM Planar (Overlay for Per. Clear Air Turb.)

NAME ______ DATE ______

	REMARKS	O	A	B	C
2	$h_0 = 10000$	5	510	000	000
	$a = 625$	5	362	500	000
	$b = 625$	5	362	500	000
	π	5	151	419	927
	$h_0 = 2000$	5	470	000	000
2	V_{WH} comp				
	$K_1 = 3\pi/a$				
	$K_2 = 2\pi/a$				
	$b/2$				
	$y = h - h_0$				
2	xK_2, $\sin xK_2$				
	$\cos xK_2$				
	$\mu_1 K_2 = K_2(y - b/2)$, $\sinh \mu_1 K_2$				
	$-\mu_1 K_2$, $\cosh \mu_1 K_2$				
	$\mu_2 K_2 = K_2(y + b/2)$, $\sinh \mu_2 K_2$				
2	$-\mu_2 K_2$, $\cosh \mu_2 K_2$				
	$\mu_3 K_2 = K_2(x - a/2)$, $\sinh \mu_3 K_2$				
	$\cosh \mu_3 K_2$				
	$\nu_1 = \cosh \mu_1 K_2 - \cos xK_2$, $\nu_1/\mu_1 K_2$				
	$\nu_2 = \cosh \mu_2 K_2 - \cos \mu_3 K_2$, $\nu_2/\mu_2 K_2$				
2	$\nu_3 = \sinh \mu_1 K_2/\mu_1$				
	$\nu_4 = \sinh \mu_2 K_2/\mu_2$				
	$\nu_5 = \sin xK_2/\mu_1$				
	$\nu_6 = \sin \mu_3 K_2/\mu_2$				
	G_{00}				
2	b/a	5	110	000	000
	V_{WH} comp				
	h				
	h				
	x_s	5	393	750	000
2	$y \cosh \mu_2 K_2$	3	012	265	000
	$(P)/\sinh \mu_2 K_2$	4	000	264	000
	$(P) - \nu_2/\mu_2 K_2$	2	000	269	000
	$\nu_4 (P)$	3	271	000	000
	$G_{00} - (P)$	2	274	000	000
2	$K_2 (P)$	3	257	000	000
	$V_{WH} = K_1 (P)$	3	256	000	065
	$x \cos xK_2$	3	046	261	000
	$(P) \sin xK_2$	4	000	260	000
	$(P) - \nu_1/\mu_1 K_2$	2	000	268	000
2	$\nu_5 (P) - G_{00}$	3	000	272	274
	$x \cos \mu_3 K_2$	3	046	267	000
	$(P)/\sin \mu_3 K_2$	4	000	266	000
	$(P) - \nu_2/\mu_2 K_2$	2	000	269	000
	$\nu_6 (P)$	3	273	000	000
2	$G_{00} - (P)$	2	274	000	000
	$K_2 (P)$	3	257	000	000
	$V_{WH} = K_1 (P)$	3	256	000	064
	$V_{WH} + V_{WH}$ comp	1	027	276	027
	tr	0	010	000	785

DICTATOR Instr. Sheet

PROGRAM Planar (Overlay for Pen Clear Air Turb)

NAME ______ DATE ______

	REMARKS	O	A	B	C
316	x_s	6	000	279	018
443	tr	0	010	000	765
477	$\Delta t\ V_{is}$	3	081	798	000
478	$(V_{is})_n = (V_{is})_{n-1} + \Delta V$	1	000	023	023
479	tr	0	010	000	550
	$x - a$	2	018	251	000
	t, if + $x \geq a$	0	016	574	577
	$b = b_0$	6	000	250	277
	V_{wH} comp	6	000	255	276
	tr	0	010	000	580
	$b/b_0 = x/a$	4	018	251	277
	V_{wH} comp	3	000	255	276
	b	3	277	250	277
	$b\pi$	3	277	253	000
	$K_1 = b\pi/a$	4	000	251	256
	tr	0	010	000	200
	No Op	0	009	000	000
	$\Delta C_{D_{CG}} = 0$	6	000	110	066
	$\delta = 0$	6	000	110	069
	tr	0	010	000	600

DIGITATOR ... Instr. sheet

PROGRAM Planar (Overlay for Per. Clear Air Turb.)

NAME ______ DATE ______

REMARKS				
$V_i = \sqrt{(r)}$	0	090	000	799
$V_i - V_{if}$	3	799	023	000
$V_{if} = (r)/\tau_n$	4	000	797	798
V_{if}	6	000	000	024
$V_{if} - V_{io}$	2	000	025	000
$V_{io} = (r)/\tau_f$	4	000	143	061
tr	0	010	000	800
$2g/\rho_o$	4	032	118	000
$V_{i\ell\,max} = \sqrt{(r)}$	0	090	000	023
π/a	4	253	251	257
$b = (b/a)\,a$	3	275	251	252
$K_1 = b\,\pi/a$	3	250	257	256
$K_3 = \pi b/a$	3	252	257	255
$K_2 = 2\pi/a$	1	257	257	257
$b/2$	3	252	114	258
$2K_3$	1	255	255	000
e^{2K_3}	0	094	000	000
$e^{2K_3} - 1$	2	000	111	255
$e^{2K_3} + 1$	1	000	112	000
$\tanh(K_3)$	4	255	000	255
$1/\tanh(K_3)$	4	111	000	000
$(r) + \tanh(K_3)$	1	255	000	000
$V_{iH\,max} = K_1 (r)$	3	000	256	255
CR	0	028	000	000
Print ... , $V_{iH\,max}$	0	024	250	255
Print ... , V_{id}, ...	0	024	145	149
tr	0	010	000	570
$x - a$	2	018	251	000
...	0	016	787	789
... $= 0$	6	000	110	278
tr	0	010	000	791
... $= x/x$	4	046	018	278
NOP	0	009	000	000
(k/k) V_{wH}	3	278	027	000
V_{wH}	1	000	065	065
(k/k) V_{wv}	3	278	026	000
V_{wv}	1	000	064	064
tr	0	010	000	588
τ_{v}	5	050	000	000

Planar (Overlay for Rc (Clear Air Turb.)

t_r	0010 000 875
V_i	6000 779 913
V_{wv}	6000 026 915
V_{wH}	6000 027 916
Print	0023 705 918
$W = mg$	3150 060 000
$N = L/W$	4029 000 911
δ_c	4039 117 907
X	6000 018 917
V_{if}	6000 023 918
t_r	0010 000 863