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INVESTIGATION OF THE CONCEPT OF DIRECT FLIGHT CONTROL

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I. SUMMARY

A system which provides direct and independent control of flight path speed, heading, and angle with the horizon was synthesized and evaluated in an analog computer simulation. Performance by subjects whose piloting experience varied from zero flight hours to four thousand flight hours was compared using direct control and conventional control systems. Two primary results were obtained: first, the performance of a subject with no flight experience using direct control was equal or superior to the performance of a subject of 4,000 hours experience using conventional controls, performance being measured in terms of mean square deviation from a proscribed flight path; second, performance improvement varied inversely with pilot experience. The resulting control scheme utilized closed-loop devices with emphasis placed on simplicity and reliability.

SYMBOLS

α	airplane angle of attack
γ	flight path angle measured from the horizontal
$\delta_{a,r}$	deflection of aileron and/or rudder
δ_e	deflection of the elevator
δ_F	deflection of the wing flap
δ_T	displacement of the engine throttle
$\Delta\gamma$	increment in γ
ρ	atmospheric density
ϕ	airplane bank angle
ψ	angle of heading

C_D	airplane drag coefficient
C_L	airplane lift coefficient
C_T	thrust coefficient
$f_i(x)$	the i^{th} function whose argument is x
F	a matrix
g	gravitational acceleration
M	test mass of a linear accelerometer
q	angular rate about airplane body axis y
$\bar{q}$	dynamic pressure $\left(\frac{1}{2}\ \rho V^2\right)$
r	angular rate about airplane body axis z
V	flight path speed
$\dot{x}$	$\frac{\partial x}{\partial t}$

II. INTRODUCTION

The task of piloting a conventional aircraft consists of two separate portions: decision-making or exercising judgement as to a desired flight path, and proper mixing of the available flight controls to achieve the desired path. It is postulated that if the pilot could be relieved of the second part of the task, concentration on decision-making would result in a shorter training period for learning to fly and better performance for experienced pilots. A constraint on the solution to accomplish this is that the goal is to be realized as a primary control system for a low-cost (under $10,000) personal aircraft. This means minimization of complexity and maximization of reliability.

The Problem

The path of an aircraft is defined by the time history of the velocity vector associated with the airplane motion. From a pilot's viewpoint it is convenient and useful to specify three quantities to determine a flight path: path angle measured above or below the horizon (γ), azimuthal path angle measured with respect to north (ψ), and path speed (V). As a system for controlling these variables, the conventional aircraft uses (1) an aerodynamic surface to introduce motion about the pitch axis, thus changing angle of attack (α) of the wing to alter lift and drag forces; (2) other aerodynamic surfaces to cause rolling motion which tilts the wing lift force, thus introducing a turning rate; and (3) a throttle for changing longitudinal force, thus causing changes in the major component of path speed. If a vector matrix mathematical model is constructed for illustration, we might write

$$\begin{vmatrix} \alpha \\ \psi \\ V \end{vmatrix} = [F] \begin{vmatrix} \delta_e \\ \delta_{a,r} \\ \delta_T \end{vmatrix} \qquad (1)$$

The path variables on the left are related to control actions (represented by the vector on the right whose elements are elevator deflection, δ_e, aileron and rudder deflection, $\delta_{a,r}$, and throttle position, δ_T) by the matrix F*. If the matrix F was composed of only elements on the diagonal, the pilot's task would be simple in that one of the control elements would effect one and only one of the path variables. Unfortunately, such is not the case for a real airplane. In fact, learning to fly a real airplane consists of learning to develop the proper values for all the elements of F. The elements of F vary somewhat from airplane to airplane, which is what pilots mean by saying that a B-52 "handles differently" from a Cessna 180. The task at hand is to provide a control scheme which

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*This presumes the variables are linearly related to the control inputs, which may or may not be so. This notation is to be used only to illustrate the problem and not for any computation.

effectively diagonalizes F and controls γ rather than α. The pilot is to be given a separate control to change γ, a separate control to change ψ, and a separate control to change V. These controls will replace those which comprise the control vector in Eq. (1).

The Method of Attack

Because of the constraint of requiring simplicity and reliability of the control scheme, open-loop control will be utilized wherever possible. If the attendant performance is unsatisfactory, closed-loop control methods will be sought, using as a priority those systems which depend on variables which are most easily measured. In modern control system theory this corresponds to designing a control by commencing with "the observable state variables."

Should closed-loop controls be required to provide adequate performance, use of the pilot's judgment will be included in the feedback loop to simplify the control. As an example, calibrated controls--those where a given position of a control lever is labeled with a specific value of the variable it controls--will be avoided. Instead, suppose a velocity control is mechanized which, when its position is changed, alters only V. We seek to make this control function so that control movement in one direction causes monotonic changes in V, but not necessarily in a specific or linearly proportional amount. For a desired value of V, the pilot would monitor an airspeed indicator to determine a match between control position and V in the steady state. It is in this sense that the pilot would serve to assist in closing the control loop. For a fixed control lever position the last value of the variable being controlled will be maintained.

Finally, the problem will be considered in two parts: control of γ and V (motion in the vertical plane) in one section, and control of ψ (motion in the horizontal plane) in another section. Coupling of the two control modes will complete the analysis.

III. DEVELOPMENT

Control of γ and V

For analysis of motion in the vertical plane, ψ will be considered constant and the airplane assumed to be in a wings-level, zero sideslip condition at all times. Then the locus of points which constitute equilibrium flight condition for combinations of γ and V define the shaded surface shown in Figure 1.* We wish a control scheme which permits movement on this surface in any desired direction. If direct, independent control is to be realized, movement of the γ-control must cause the aircraft operating point to move on a particular line belonging to the surface; namely, the line

*At a given aircraft gross weight and for V measured in indicated airspeed at any density altitude.

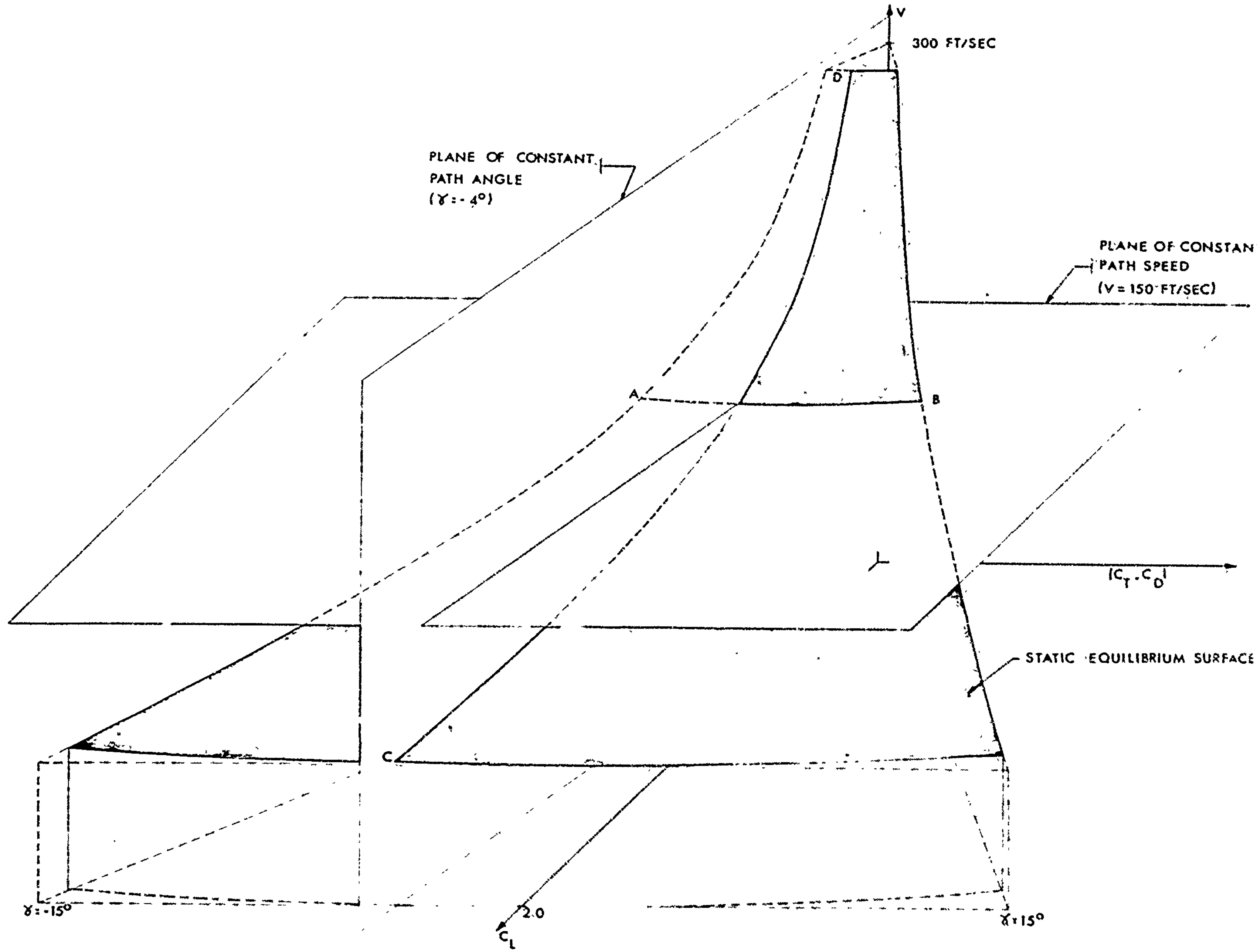

FIG 1 STATIC OPERATING SURFACE

resulting as the intersection of a horizontal plane (representing some constant value of V) and the shaded surface. A-B is such a line. Similarly a velocity control must alter V at a constant value for γ, such as the locus represented by the curve C-D.

During periods of accelerated flight the instantaneous operating point departs from the shaded surface. An acceptable control system must provide satisfactory aircraft behavior during the period of returning to equilibrium flight, that is, while moving from one point to another on the surface.

The equations defining the shaded surface are

$$\gamma = \tan^{-1} \frac{C_T - C_D}{C_L} = \frac{C_T - C_D}{C_L} \qquad (2)$$

$$V = \left(\frac{W \cos \gamma}{\rho/2 \; S \; C_L} \right)^{1/2} \qquad (3)$$

Elements in Eqs. (2) and (3) which determine γ and V are functions of these flight and control parameters:

$C_T = f_1$ (engine-propeller combination, i.e., power controls settings, and density altitude)

$C_D = f_2$ (airplane angle of attack, α, and wing flap deflection, δ_F)

$C_L = f_3$ (α, δ_F)

$\rho = f_4$ (altitude)

$W = f_5$ (payload, fuel)

Considering for the moment ρ and W to be constants, Eqs. (2) and (3) can be written

$$\gamma = \frac{f_1 (\delta_T) - f_2 (\alpha, \delta_F)}{f_3 (\alpha, \delta_F)} \tag{4}$$

$$V = K\left[\frac{\cos \gamma}{f_3 (\alpha, \delta_F)}\right]^{1/2} = K\left[\frac{\cos\left(\frac{f_1 - f_2}{f_3}\right)}{f_3}\right]^{1/2} \tag{5}$$

Neither γ nor V appear to be affected separately by just one of the functions f_i. The interrelation of the functions infer that any mixing scheme will need to be somewhat complex to accomplish independent control. However, it is reasonable to restrict the total range of γ to $\pm$ 10°* and as a consequence changes in the value of f_1 while holding f_2 and f_3 constant cause significant bipolarity changes in γ while affecting V only slightly. This suggests the use of throttle as a path control and α and/or δ_F as a velocity control. If this is to be done, keeping γ constant while changing V will necessitate coupling δ_T with α and δ_F to counteract changes in f_2 and f_3 in Eq. (4). Another difficulty occurs, caused by the need to maintain constant α while varying γ: this virtually requires sensing and closed-loop control of α.

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*As shown for even STOL aircraft in Ref. 1, 2.

To see if these complexities are justified by the performance this scheme produces, an analog computer simulation was mechanized according to the block diagram shown in Fig. 2.

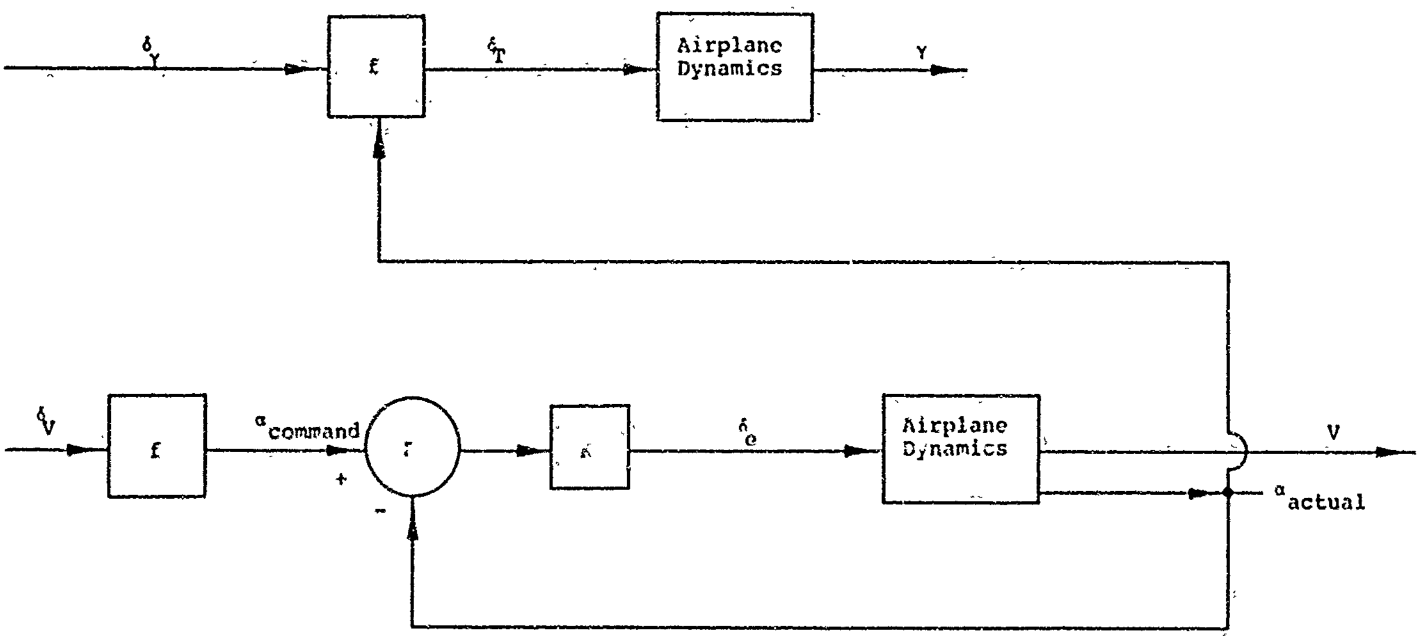

FIG. 2 - PROPOSED CONTROL SCHEME UTILIZING α-COMMAND AND THROTTLE

Flight test data for a Cessna 180 was used to construct a non-linear mathematical model. Compensation of δ_T to maintain constant γ as described above was done by incorporating a model of the airplane drag polar into the control scheme. Not only was this method involved but an additional difficulty was revealed. Although the static solutions afforded were satisfactory, an attempt to change status invariably excited the long-period, poorly-damped longitudinal oscillation (phugoid mode) characteristic of this type of aircraft. Sample time histories which demonstrate this behavior are shown in Fig. 3. In consideration of these shortcomings, this scheme was discarded.

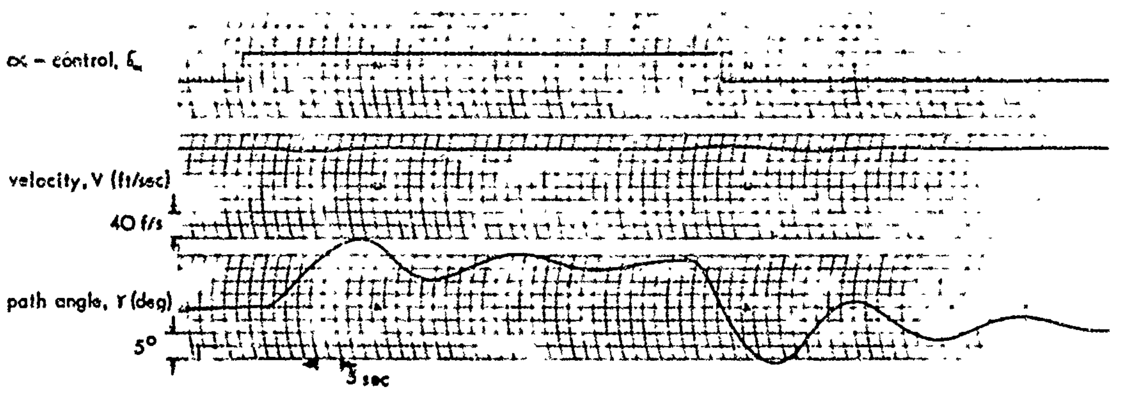

FIG. 3 - DYNAMIC BEHAVIOR OF PROPOSED α-THROTTLE CONTROL SCHEME

Returning to the equations, it is worthwhile to consider attempting what is apparently the most difficult method of control--use of closed-loop systems which command γ and V. To begin with, measurement of γ is not easily accomplished. Path angle can be measured either by

$$\gamma = \theta - \alpha \tag{6}$$

or by

$$\gamma \cong \frac{\text{vertical speed}}{\text{path speed}} \tag{7}$$

If the relationship of Eq. (6) is used, both pitch attitude and angle of attack must be measured and their difference formed to determine γ. In Eq. (7), vertical path speed is not quickly measured plus a quotient must be formed. Such complexities are what we wish to avoid. As to measuring velocity, true airspeed requires computation based upon dynamic pressure measurement and air density measurement.

As a compromise solution, we might provide control of two variables slightly removed from γ and V: $\dot{\gamma}$ and q, dynamic pressure. If we are successful, this will mean a change in the way a pilot uses the controls. First, a lever which controls $\dot{\gamma}$ rather than γ would be displaced from a neutral position only while the pilot was changing path angle. When this lever is returned to a neutral position, $\dot{\gamma}$ would be maintained at zero thus sustaining the last value of γ. The pilot would be required to do something only when he wished to change path. Second, a lever to control q rather then V would provide a command for indicated airspeed instead of true airspeed. The merits and demerits of this subsitution are largely subjective and dependent upon pilot opinion. Certainly it could be no worse than the conventional control system where the pilot flies by indicated airspeed completely.

Both $\dot{\gamma}$ and q are relatively simple to measure. For q, a spring bellows will produce a displacement proportional to q. For $\dot{\gamma}$, an accelerometer mounted to be sensitive to acceleration normal to the flight path will measure something which includes $\dot{\gamma}$:

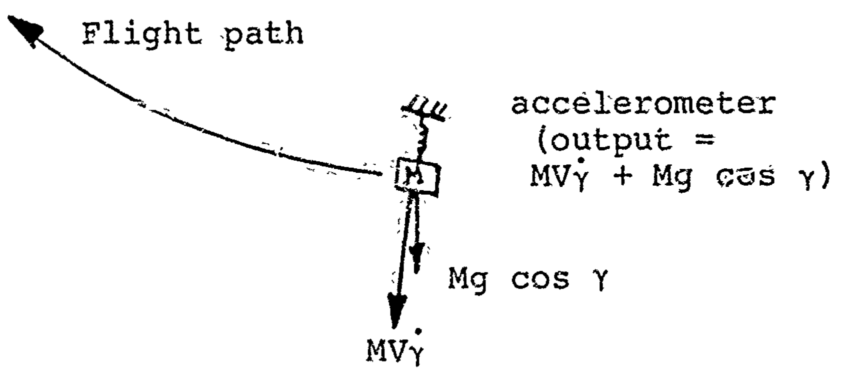

FIG. 4 - ACCELERATED FLIGHT MEASUREMENT

If level flight load factor of one is subtracted from the accelerometer output, the difference between the output and $MV\dot{\gamma}$ is Mg $(1 - \cos\gamma)$. Consequently, the accelerometer measures true normal acceleration only when $\gamma = 0$. Seriousness of this error can be ascertained by integrating the equation

$$V \frac{d\gamma}{dt} = + g\ (1 - \cos\gamma) \qquad (9)$$

Bounds on the error are seen to occur where γ @ $t = 0$ is greatest and V is least, as in a landing approach or takeoff climb. For $\gamma_{t=0} = 0.1$ RAD and $V = 100$ ft/sec., $\Delta\gamma = .03$ RAD after 15 seconds. Since it is unlikely that a pilot would fly "hands-off" for 15 seconds during this type of maneuver, the error is not serious. A more representative test case is cruising flight conditions where it is desirable to pay little attention to controlling the aircraft. Then, for $\gamma_{t=0}$ = .06 RAD and V = 250 ft/sec, $\Delta\gamma$ = .003 RAD after 30 seconds. Of course the nearer level flight the aircraft is initially the less the cumulative error.

It is better to command a value of the product $V\dot{\gamma}$ than a value of $\dot{\gamma}$ alone because the need for a large size $\dot{\gamma}$ occurs only at low V while at high V small $\dot{\gamma}$ values suffice. Furthermore, this product represents load factor normal to the flight path, a quantity to which pilot, passengers, and the aircraft structure is sensitive. Since the control scheme provides control of $V\dot{\gamma}$ at constant V, it actually functions as a $\dot{\gamma}$ control with a sensitivity inversely proportional to velocity.

A system based upon controlling these two variables was synthesized in an analog simulation according to the block diagram of Fig. 5. As a test of this system, control inputs were applied one at a time to determine the degree of separation between γ and V changes. The sequence of operation was this:

Part A - From an initial condition of level flight at 250 ft/sec, step function movement of the $\mathcal{J}$-control to reduce speed while maintaining level flight (γ = 0).

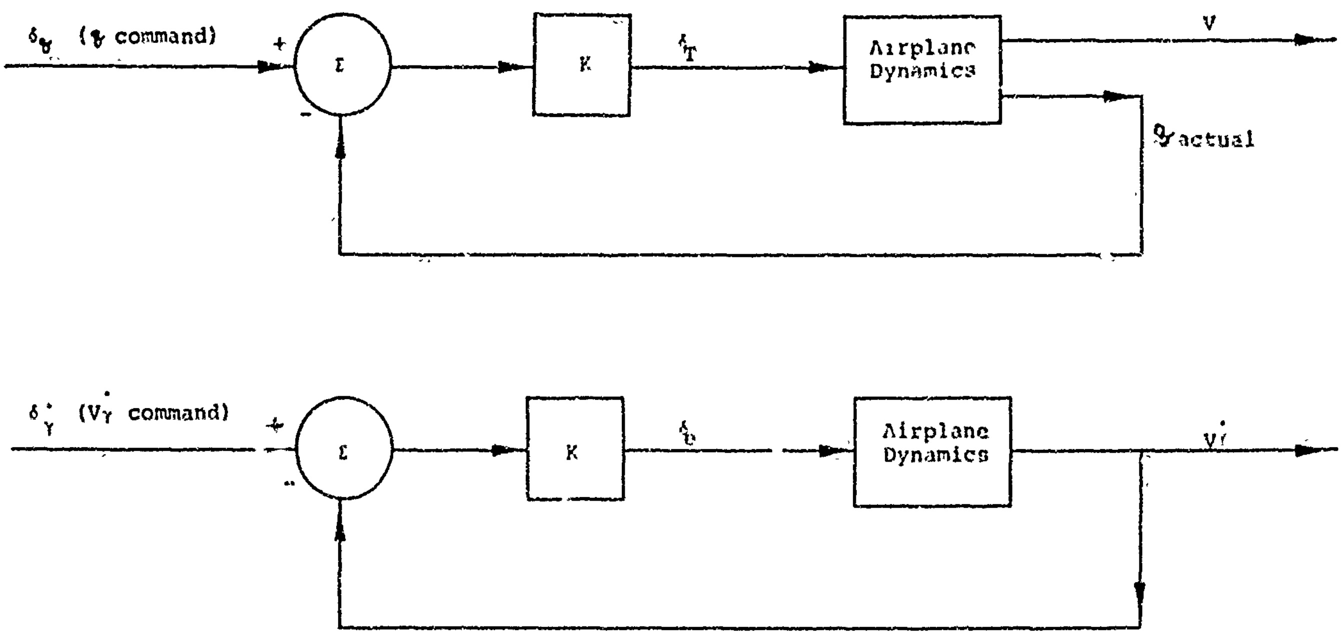

FIG. 5 - PROPOSED $V\dot{\gamma}$-γ CONTROL SCHEME

Part B - A pulse displacement of the $\dot{\gamma}$ control to transition from level flight to a descent angle while maintaining constant V.

Part C - A reverse pulse displacement of the $\dot{\gamma}$ control to return the path angle to zero.

Part D - A period of level flight with no control action

Part E - Transition to a climb angle

Part F - Return to level flight

Part G - Acceleration to original velocity during level flight.

Figure 6 presents time histories of V, h, δ , and $\delta_{\dot{\gamma}}$. The second trace is altitude, a measure of the integral of γ:

$$h = \int_0^t \gamma \, V \, dt$$

Moderate values of forward loop gain in both the $\dot{\gamma}$ and systems were used, with the result in a maximum excursion of V from the desired value at any time of $\pm$ 6 ft/sec and an excursion of 50 ft in h while $\dot{\gamma}$ was held at zero. The error in h reflects the difficulty in estimating when $\gamma = 0$ is reached by using an altimeter for information and a $\dot{\gamma}$ control. A sensitive, fast-acting rate of climb instrument produced better results.

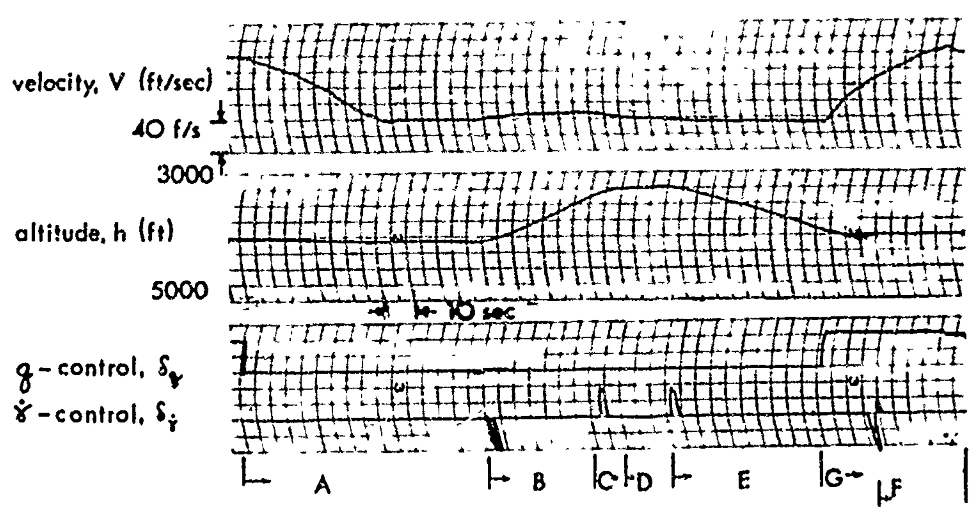

FIG. 6 – DYNAMIC RESPONSE TO INDIVIDUAL INPUTS IN $\dot{\gamma}$-γ CONTROL SYSTEM

The scheme was considered good enough to test with a more elaborate simulation and three test subjects: a person with no flight experience, a pilot with 100 hours total time, and a pilot with 4,000 hours total time. Results are presented in detail in Section IV.

Control of ψ

For fixed-wing aircraft, the only method of producing a turning flight path is to tilt the largest aerodynamic force vector, lift, so as to produce a lateral force component of sufficient size. This means tilting the entire aircraft, that is, banking the airplane. The dynamics of turning flight lead to spiral maneuvers, and problems with providing inherent spiral stability for personal aircraft have long been troublesome to the designer. Compromises in either performance or cost and complexity appear to be necessary to achieve stability in turning maneuvers. The Mooney Aircraft Company recently adopted full-time automatic stabilization of the roll axis as standard equipment on one of their aircraft. A closed-loop control system with rate gyro sensing is used in their method with a demonstrated reliability sufficient to win Federal Aviation Agency approval as a primary control system.

In this study an open-loop method of controlling heading was attempted with no success. It is believed that the merits of a system such as that of the Mooney Company outweigh the cost* and complexity of the device. Consequently a rate gyro sensed, aileron actuated control which commands $\dot{\psi}$ was investigated. No difficulties were encountered in achieving

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*Interestingly, Mooney incorporated the control system at no increase in retail cost of the airplane.

excellent performance by application of standard control system design techniques. The resulting scheme is diagrammed in Fig. 7.

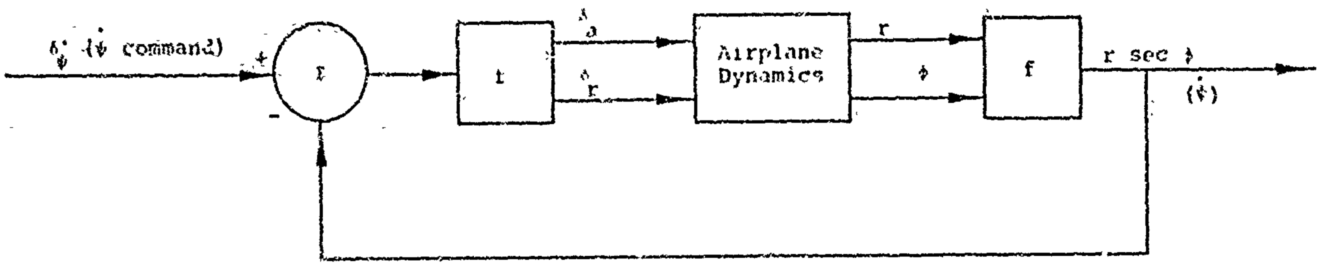


FIG. 7 - PROPOSED $\dot{\psi}$ CONTROL SCHEME

Coupling the Two Controls

Coupling of the equations of motion for longitudinal dynamics and lateral-directional dynamics resolves into a single problem for the class of aircraft being studied: equilibrium in steady state turns. In Fig. 8, angular motion about a body axis coordinate system is measured by the accelerometer output used in the $\dot{\gamma}$ control (which is constrained to tilt with the aircraft in roll), along with the rate gyro used to sense r in controlling $\dot{\psi}$. These angular rates can be expressed in components along the local earth vertical and along a horizontal axis perpendicular to the flight path:

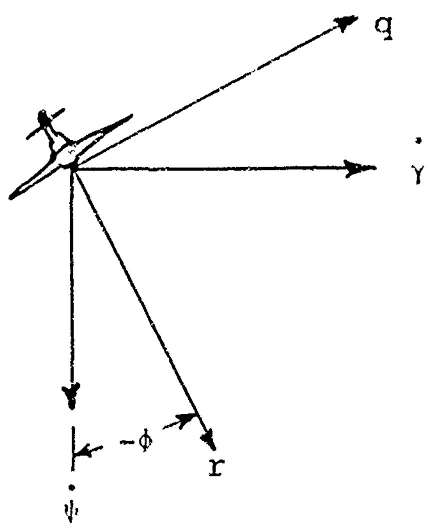


FIG. 8 - TURNING FLIGHT ANGULAR RATES

$$\dot{\psi} = r \cos \phi + q \sin \phi \qquad (10)$$

$$\dot{\gamma} = -r \sin \phi + q \cos \phi \qquad (11)$$

r is measured by rate gyro

$$q \cong \frac{\text{accelerometer output}}{V}$$

Since we wish to not cause a change in γ when changing ψ, we couple the two parts of the control scheme by sending the $\dot{\gamma}$ control a compensating signal during turning flight. This signal is determined by equating $\dot{\gamma} = 0$

$$\dot{\gamma} = 0 = -r \sin \phi + q \cos \phi \qquad (12)$$

so

$$q_{correction} = r \tan \phi \qquad (13)$$

$$V\dot{\gamma}_{correction} = V r \tan \phi \qquad (14)$$

Under the constraint of $\dot{\gamma} = 0$, turning rate becomes

$$\dot{\psi} = r \sec \phi \qquad (15)$$

which was the reason for the appearance of that term in the $\dot{\psi}$ control.

Now and in the $\dot{\psi}$ control system we have presumed that information about bank angle, ϕ, was available. Even in the lowest cost aircraft, attitude gyros are generally installed and are likely to become more common in the future.

If the added complexity of multiplying the V in correcting $\dot{\gamma}$ is considered too elaborate, a good compromise can be made by assuming a value for V in the most critical range, probably in cruising flight, and using it as a multiplicative constant.

Thus the total control system diagram would be as shown in Fig. 9. The original task of having three inputs to command directly the three outputs is indicated in the block diagram.

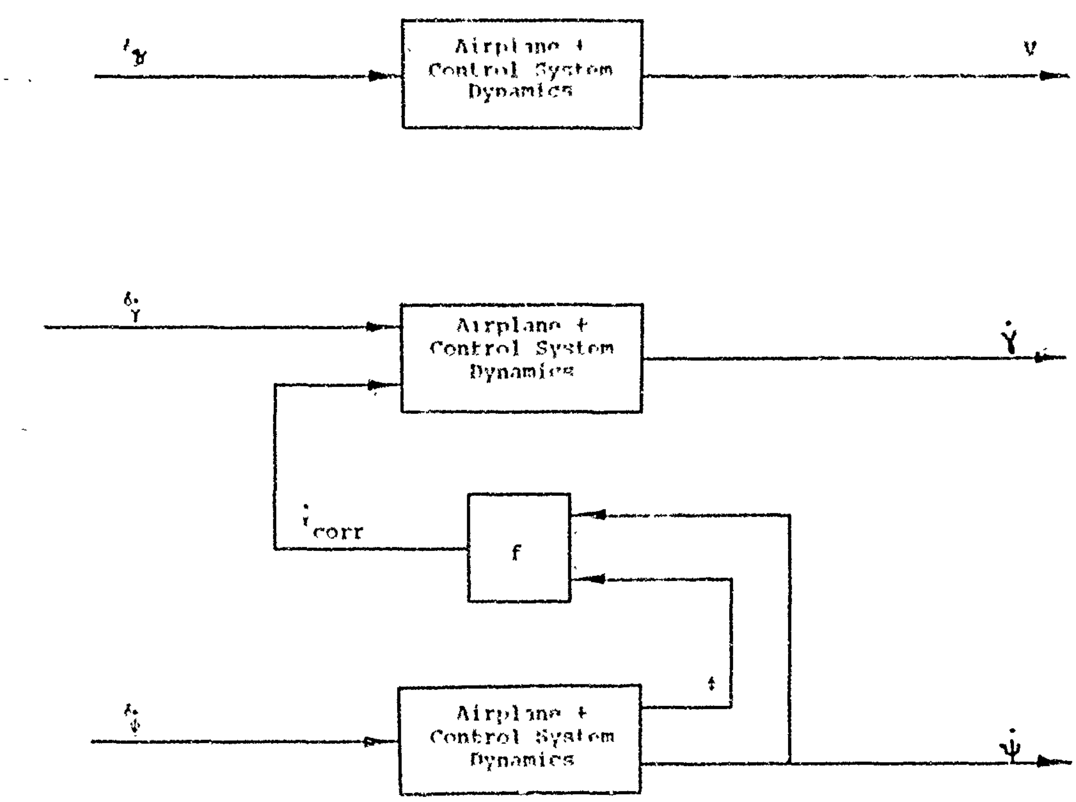


FIG. 9 - COUPLING OF THE $\dot{\gamma}$-q AND $\dot{\psi}$ CONTROL SYSTEMS

Summary Features of the Scheme

A. Separation of Control Functions - excellent, can be improved with increased loop gains, requires no compensation in forward or feedback loops.

B. Complexity

1. Sensing Devices Required

a. Spring bellows for q-sensing, can also be made large enough to actuate the throttle without amplification devices.

b. Accelerometer for $\dot{V}_\gamma$ sensing, mounted on a vane device to sense along wind axes.

c. Rate gyro, mounted to sense along body axis z

d. Attitude gyro - presumed already in aircraft, used to obtain ϕ information.

2. Computation Required

a. Determination of the product r tan ϕ and r sec ϕ, possibly available simply with non-linear resistance pickoffs on ϕ-gyro.

b. Summing devices to form error signals in the closed loops.

3. Servo Amplification and Actuation Required

a. One for elevator actuation

b. One for aileron actuation, probably with interconnected rudder actuation to counteract yaw.

C. <u>Reliability as a Primary Control System</u> - Dependent upon the degree of redundancy incorporated, which is dependent upon the desired cost-safety compromise. Could also be backed up by conventional mechanical linkage during emergencies.

D. <u>Performance</u> - described in the following section.

IV. RESULTS

An analog simulation* incorporating a point source visual projector for horizon presentation and cockpit instruments to present airspeed, altitude, and engine power was mechanized to measure pilot performance. Limitations in the quantity of servo equipment available prevented simultaneous simulation of both longitudinal and lateral-directional modes of motion. Since longitudinal motion represents the larger portion of the task of the pilot and since it requires much more learning or skill on the part of the pilot, efforts to measure performance were concentrated on this part. A sketch of the physical arrangement is shown in Fig. 10.

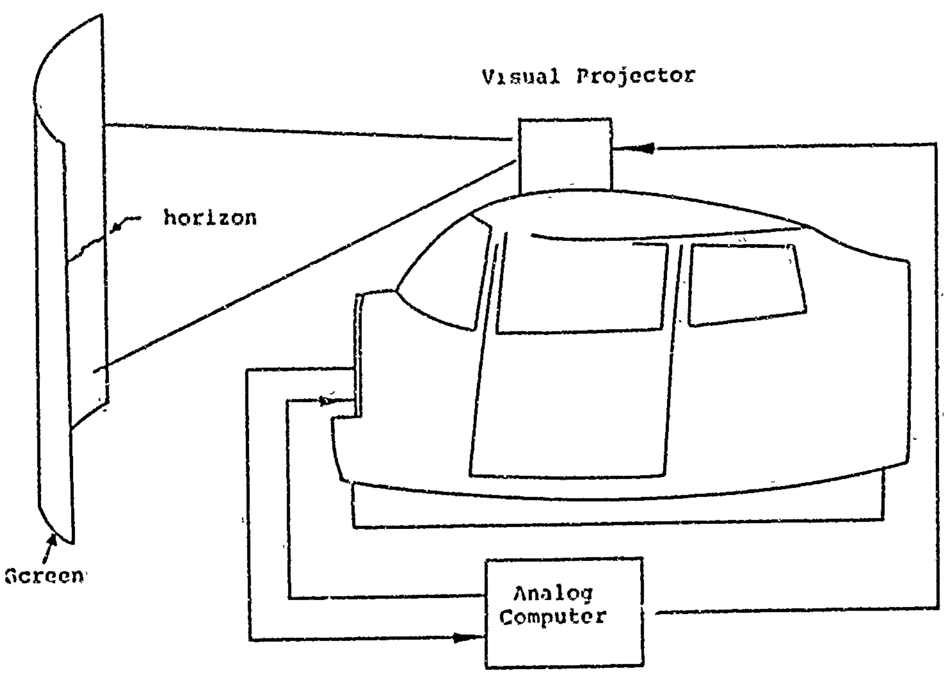


FIG. 10 - SIMULATOR SCHEMATIC

*Described in the Appendix

The task was organized to compare the performance of three test subjects when using a conventional control system (throttle, control column to deflect elevator, and flap deflection lever) and when using the proposed scheme of $\dot{\gamma}$ and γ control. The flight profile specified as the test maneuver was as follows:

A. From a cruising flight condition of level flight at 4,000 ft altitude and 150 MPH, reduce speed to 120 MPH while maintaining altitude. Stabilize in this configuration.

B. Establish a climb at 120 MPH and climb to 5,000 ft altitude, maintaining airspeed and pitch attitude.

C. Level off at 5,000 ft; then, maintaining 120 MPH, establish a steady descent at approximately the same magnitude of vertical speed as was used in the climb.

D. Halt the descent at either 4,000 or 3,000 ft, at the pilot's discretion.

E. When established in level flight, increase speed to 150 MPH, maintaining altitude.

Test subjects were given several practice runs, and when they stated they were ready, three data runs were recorded in the form of time histories of V and h and sometimes additional parameters such as α, θ, and γ. The resulting data are not intended to be a complete statistical sample, simply enough to obtain consistency among the three test runs for each subject to indicate comparative performance.

We will call the subjects 0, 1 and 40, indicating zero flight experience, 100 hours flight experience, and 4,000 hours flight experience. Figures 11a, b, c show representative performance by subjects 0, 1 and 40 respectively while using the conventional control system. Figures 12a, b, c show performance using the $\dot{\gamma}-q$ system. As a measure of pilot effort, time histories of pitch attitude using the conventional and proposed control scheme are compared in Fig. 13. Significant results indicated by the data are:

A. The performance of subject 0 using the proposed control scheme is equal or superior to the performance of subject 40 using a conventional control system, in terms of mean square deviation from the desired flight profile.

B. Pilot effort decreased sharply using the proposed scheme.

C. Performance improvement varied inversely with flight experience.

Subjective evaluation of the $\dot{\gamma}-q$ control system can be determined by pilot comment:

<u>Subject 0</u> - "I'm sure my performance was much better on this airplane than the previous one. I was able most of the time to execute the maneuver with only one handle. On climb and descents I could easily set up the climb angle and then make minute adjustments to hold the airspeed. At no time did I worry about the airspeed getting out of hand due to a pitch change and conversely. At no time did I get disoriented and attempt a correction in the wrong direction. I did this several times on the previous airplane. I think I could do better with a smoother $\dot{\gamma}$ lever. Several times I thought I was against a stop,

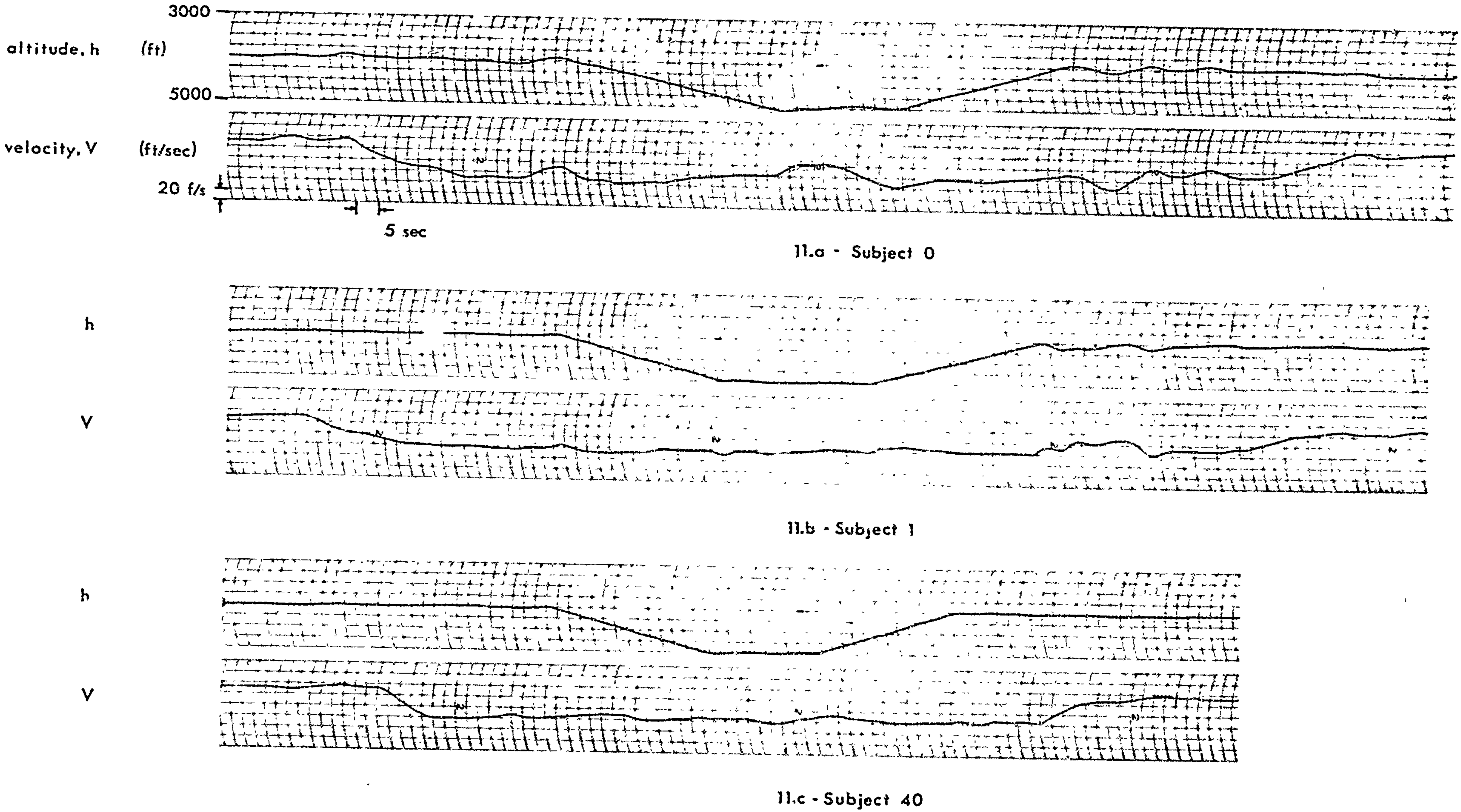
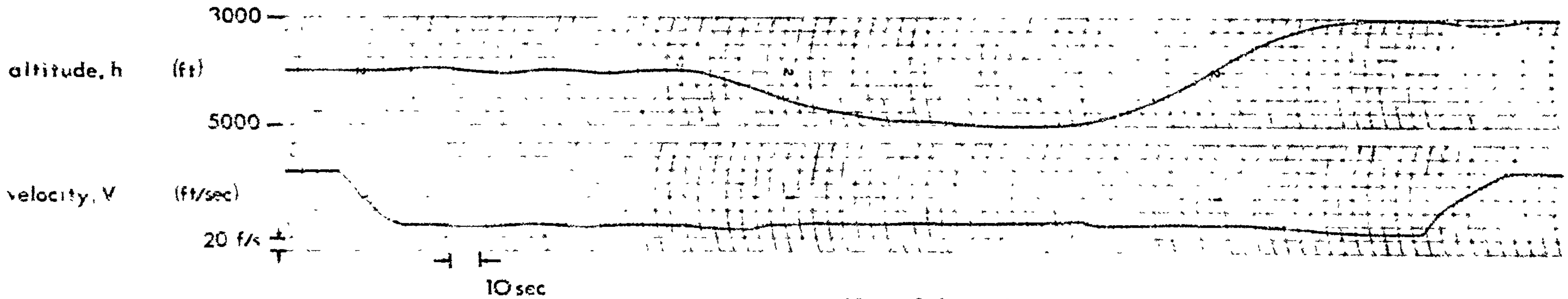
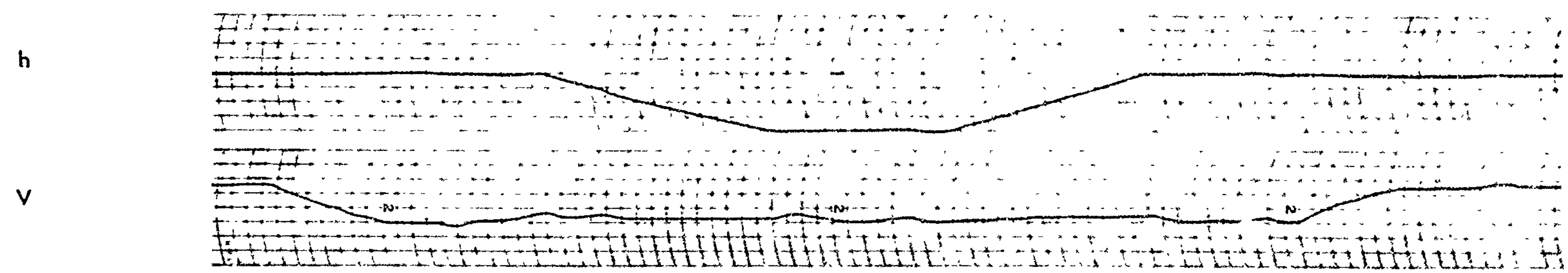


FIG. 11 — PERFORMANCE WITH CONVENTIONAL CONTROL SYSTEM



12.a - Subject 0

12.b - Subject 1



12.c - Subject 40

FIG. 12 — PERFORMANCE WITH $\dot{\gamma} - q$ CONTROL

then 'broke over' as the spring buckled. Airspeed control was extremely easy requiring only fingertip positioning. Altitude control was not quite as easy, but far superior to the previous airplane. It was several minutes before I began to really use the horizon display in flying. It was helpful when I began to use it. I had some difficulty getting accustomed to the horizon changes with airspeed at constant altitude."

Subject 1 - "I think my performance was better. It is easier to fly, but I don't have the 'feel' of the airplane and I don't think I would get any 'feel'."

Subject 40- "The work load is down--it flies like a 180 with a L-2 (autopilot)."

Miscellaneous other comment was given with a summary statement from all the pilots that the proposed scheme was much easier to fly and mini~ized the amount of concentration required. It is emphasized that these tests are not intended to be exhaustive statistical samples, only sufficient data to indicate the potential of the concept of direct flight control.

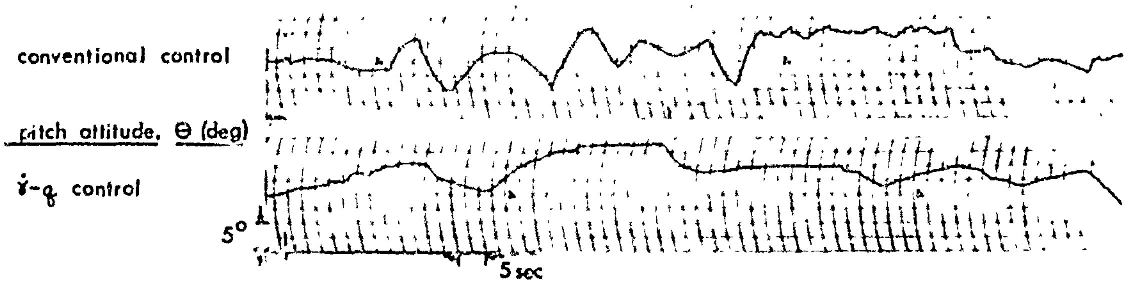


FIG 13 - PITCH ATTITUDE COMPARISON AS A MEASURE OF PILOT EFFORT

(SUBJECT O)

V. CONCLUSION

While the simulation results are encouraging, actual flight evaluation is the only way to verify the apparent merits of direct flight control. In the opinion of the principal investigator, the most fruitful extension of this work would consist of a flight program with two major goals: First, verification of performance improvement obtained with $\dot{\gamma} - \phi - \dot{\psi}$ controls; second, experimentation with various schemes which can act upon the information most easily measured in flight. The latter part would help establish the simplest, most reliable methods of providing flight control--a task where it is easy to be mislead when a purely theoretical approach is used. Certain simple theoretical concepts are quite difficult to implement while certain elaborate theorems are readily transferred to reality.

If the results obtained here are correct, extension to other or more sophisticated vehicles is readily achievable since nothing in the synthesis of this approach requires a certain range of aerodynamic or dynamic parameters. For example extension to a rotary-winged vehicle is possible; in fact, a helicopter embodies a measure of direct flight control already. The collective pitch control governs the magnitude of a force vector, the cyclic pitch control governs the direction of the force vector, and the pedals provide yaw motion. These controls must be coupled however and thus the task would resemble the one undertaken here.

Also, if the results obtained here are correct, additional sophistication of the $\dot{\gamma} - \varphi - \dot{\psi}$ scheme could provide extra features such as pressure altitude hold. Ground command of flight path and speed via a radio link could achieve traffic control for instrument flight.

It is believed that the greatest potential benefit of direct flight control as evaluated here would be the ease in learning to fly afforded by this scheme. This also infers an ease in maintaining a desired level of proficiency for the experienced pilot.

References

1. Craig, A. J., "Achieving Consistency in Maximum Performance STOL Landings," UWER Report No. 351, Univ. of Wichita, January, 1961.

2. Craig, A. J., "Evaluation of the Performance, Stability and Control of the Helio Courier Airplane," Report No. 264, Univ. of Wichita.

3. Crawshaw, R. L. and Mooney, J. M., "Determination of Aerodynamic Characteristics from Glide Sawtooth Data," Report No. 795, Cessna Aircraft Company, Wichita, Kansas, September 1, 1953.

4. Leisher, L. L. and Walter, H. L., "Stability Derivatives of Cessna Aircraft," Report No. 1356, Cessna Aircraft Company, Wichita, Kansas, May 22, 1957.

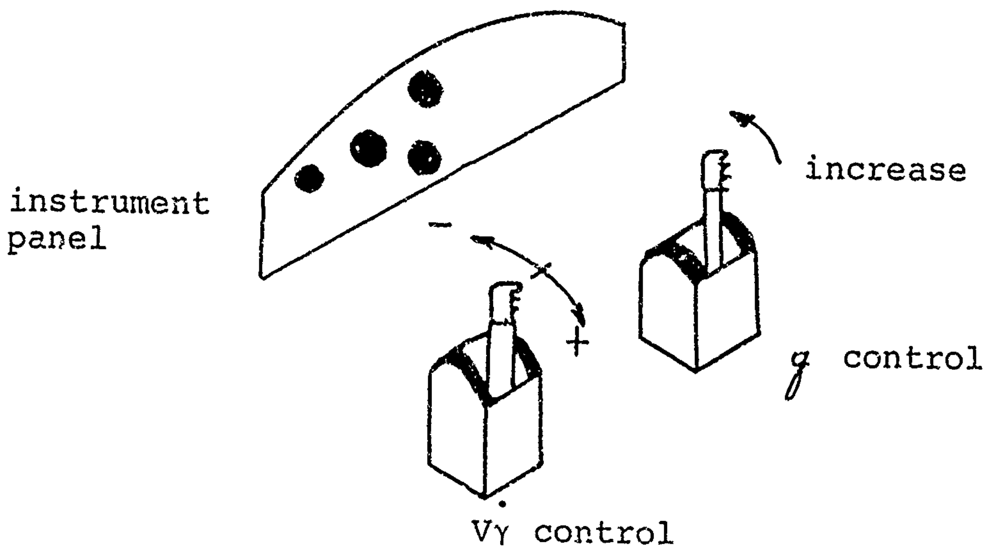
APPENDIX

A. Mathematical Model Used for Simulation

So as to insure accurate simulation of the flight dynamics of the airplane being simulated (a Cessna 180), a non-linear force and moment model was used rather than a small-perturbation-from-equilibrium, linearized model. This method afforded the retention of dimensional variables and permitted a range of flight velocities of from 10 ft/sec to 300 ft/sec. Aerodynamic derivatives and mass and inertia parameters were obtained from Cessna Aircraft Company as presented in company reports (Ref. 3, 4).

B. Visual Presentation and Cockpit Equipment

A point source projector mounted in a gimbal frame atop the cockpit presented a horizon which tilted with the aircraft motion. A blue sky--green and brown earth picture which did not show translation was deemed realistic enough for this project. Within the cockpit an instrument panel included an airspeed indicator, an altimeter, and an engine power gage. For the conventional control scheme a standard control wheel and throttle were used, while for the proposed scheme two levers were mounted in front of the pilot, as shown below. The right-hand lever functioned as the γ-control and friction was incorporated in the mechanism to make the lever stay where it was placed. On the left the lever which controlled $V\dot{\gamma}$ was spring loaded to maintain a center position when released. A dead zone was synthesized about this position so as to insure the ability to return to $\dot{\gamma} = 0$ in the presence of system friction. Outside the dead zone a force proportional to lever deflection--hence proportional to $|\dot{\gamma}|$--existed.



Cockpit Arrangement of the $\dot{\gamma}$-g Control System