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FOR
DIGITAL FLIGHT CONTROL AND LANDING SYSTEM

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LIST OF SYMBOLS

SYMBOL	DESCRIPTION	TYPE
k_{r_y}	Cross range error gain	Program Variable
$k_{r_{ymax}}$	Maximum cross range error gain	Input Constant
$k_{r_{ymin}}$	Minimum cross range error gain	Input Constant
$k_{r_{yo}}$	Cross range error gain at zero down range	Input Constant
$k_{r_{y_r}}$	Range gradient on cross range error gain	Input Constant
k_{r_z}	Altitude error gain	Input Constant
k_t	Washout Time gain	Input Constant
k_w	Washout gain	Program Variable
r	Angular rate about z body axis	Input Variable
r_h	Maximum acceptable angular rate about z body axis at hover	Input Constant
r_{cz}^{an}	Commanded altitude in approach navigation frame (ANF)	Program Variable
r_{hh}^{an}	Maximum acceptable horizontal ANF range error at hover	Input Constant
r_x^{an}	Down range in ANF	Input Variable
r_{xsd}^{an}	Down range in ANF at start of level flight deceleration phase	Program Variable
r_{xsf}^{an}	Down range in ANF at start of flare phase	Program Variable
r_{xsg}^{an}	Down range in ANF at start of glide phase	Program Variable

SYMBOL	DESCRIPTION	TYPE
r^{an}_{xsh}	Down range in ANF at start of hover phase	Input Constant
r^{an}_{xslf}	Down range in ANF at start of glide acquisition phase	Program Variable
r^{an}_{xst}	Down range in ANF at start of glide transition phase	Program Variable
r^{an}_{y}	Cross range in ANF	Input Variable
r^{an}_{z}	Altitude in ANF	Input Variable
r^{an}_{zh}	Desired ANF hover altitude	Input Constant
r^{an}_{zo}	Acquisition altitude in ANF	Program Variable
r^{an}_{zsf}	Altitude in ANF at start of flare phase	Program Variable
t	Time	Input Variable
t_s	Time at which velocity error transformation is switched based on speed	Program Variable
V_a	Airspeed	Input Variable
V_{af}	Filtered airspeed	Program Variable
V_{xg}	Desired forward velocity during glide	Input Constant
V_{xo}	Acquisition forward speed	Program Variable
V_{xsh}	Desired forward velocity at start of hover	Input Constant
V_T	Switching value of V'_a	Input Constant
$\dot{V}_{xd}$	Desired forward deceleration rate	Input Constant
$\dot{V}_{zt}$	Desired vertical acceleration during glide transition	Input Constant
V^{an}_{cz}	Commanded vertical velocity in ANF	Program Variable

SYMBOL	DESCRIPTION	TYPE
V_{hh}^{an}	Maximum acceptable horizontal ANF velocity at Hover	Input Constant
V_{x}^{an}	Forward velocity in ANF	Input Variable
V_{y}^{an}	Lateral velocity in ANF	Input Variable
V_{z}^{an}	Vertical velocity in ANF	Input Variable
V_{zh}^{an}	Maximum acceptable vertical ANF velocity at hover	Input Constant
V_{zl}^{an}	Desired vertical velocity for landing	Input Constant
$\dot{V}_{zl}^{an}$	Desired vertical acceleration during landing	Input Constant
V_{x}^{h}	Forward velocity in vertical heading frame (VHF)	Input Variable
V_{a}'	A forward velocity used for switching purposes (either V_{af} or V_{x}^{h})	Program Variable
V_{cx}'	Commanded forward velocity (either V_{cx}^{an} or V_{cx}^{h})	Program Variable
V_{cxl}'	A forward velocity limit on the maximum lateral velocity command	Program Variable
V_{cy}'	Commanded lateral velocity	Program Variable
Δr_{xlf}^{an}	Desired down range increment for glide acquisition	Input Constant
Δr_{zh}^{an}	Maximum acceptable ANF altitude error at hover	Input Constant
ΔV_{x}^{an}	Forward velocity error in ANF	Program Variable

SYMBOL	DESCRIPTION	TYPE
ΔV_y^{an}	Lateral velocity error in ANF	Program Variable
ΔV_x^h	Forward velocity error in VHF	Output Variable
ΔV_{xd}^h	Discontinuity in VHF forward velocity error due to switch in transformation used	Program Variable
$\Delta V_{xt_s}^h$	First value of VHF forward velocity error from transformations used after switch	Program Variable
$\Delta V_{xt_{s-1}}^h$	Last value of VHF forward velocity error from transformation used before switch	Program Variable
ΔV_{xw}^h	Washed out VHF forward velocity error discontinuity	Program Variable
ΔV_y^h	Lateral velocity error in VHF	Output Variable
ΔV_{yd}^h	Discontinuity in VHF lateral velocity error due to switch in transformation used	Program Variable
$\Delta V_{yt_s}^h$	First value of VHF lateral velocity error from transformation used after switch	Program Variable
$\Delta V_{yt_{s-1}}^h$	Last value of VHF lateral velocity error from transformation used before switch	Program Variable
ΔV_{yw}^h	Washed out VHF lateral velocity error discontinuity	Program Variable
ΔV_z^h	Vertical velocity error in VHF	Output Variable
$\Delta V_{at}'$	Switching threshold of V_a'	Input Constant
V_g	Desired glide slope angle	Input Constant
ϕ	Euler roll attitude	Input Variable
ϕ_h	Maximum acceptable Euler roll attitude at hover	Input Constant

SYMBOL	DESCRIPTION	TYPE
τ_{V_a}	Airspeed filter time constant	Input Constant
ψ	Euler yaw attitude	Input Variable
ψ_{max}	Maximum desired heading change for obtaining centerline at high speed	Input Constant

I. INTRODUCTION.

The guidance section of the Digital Flight Control and Landing System for the CH-46C helicopter will have three modes of operation: (1) Disengage, (2) Guidance I, and (3) Guidance II. The guidance laws for the Guidance II mode of operation have been developed by Bell Aerospace Company under NASA/ERC Contract NAS 12-2074. This document describes the software required to mechanize only the Guidance II laws on an airborne digital computer and is submitted in compliance with Item 2 (b) of this contract. The majority of this description is presented in the form of detailed engineering equations and functional block diagrams and only those functions that are peculiar to the digital nature of the system are presented in the form of digital flow diagrams and logic equations. It is believed that this type of description will give the airborne computer programmer a better understanding of the system involved and will enable him to develop the most efficient digital program for the airborne computer that is selected.

II. FUNCTIONAL DESCRIPTION OF GUIDANCE LAWS.

A. Modes.

The Guidance II laws are for the landing mission of the CH-46C helicopter and have been designed to operate in conjunction with a digital flight control system which has several manual modes and an automatic mode of operation. There

are two modes of operation of these laws: (1) an Acquisition to Hover Mode, and (2) a Landing Mode. In each mode, they generate velocity error commands for the flight control system. In the manual modes of flight control, these errors are used by the flight control system to generate command errors for display and the pilot manually controls the helicopter based on these displays. In the automatic mode of flight control, these errors are used by the flight control system to generate automatic commands to control the helicopter.

In the Acquisition to Hover Mode, the laws generate velocity error commands to bring the helicopter from the acquisition conditions to a hover condition over the pad. In the Land Mode, the laws generate velocity error commands to bring the helicopter from hover to touchdown. In the Land Mode, the laws check to determine if the hover conditions are acceptable before starting to generate commands for landing. If the hover conditions are not acceptable for landing, the laws continue to generate hover commands until acceptable conditions are met.

B. Guidance Laws.

1. General Description.

The Guidance II laws generate velocity errors between a velocity landing profile and the sensed helicopter velocities. The profile that is used is a constant speed glide type as shown in Figure 1. As shown in this figure, the flight along this profile is divided into the following phases:

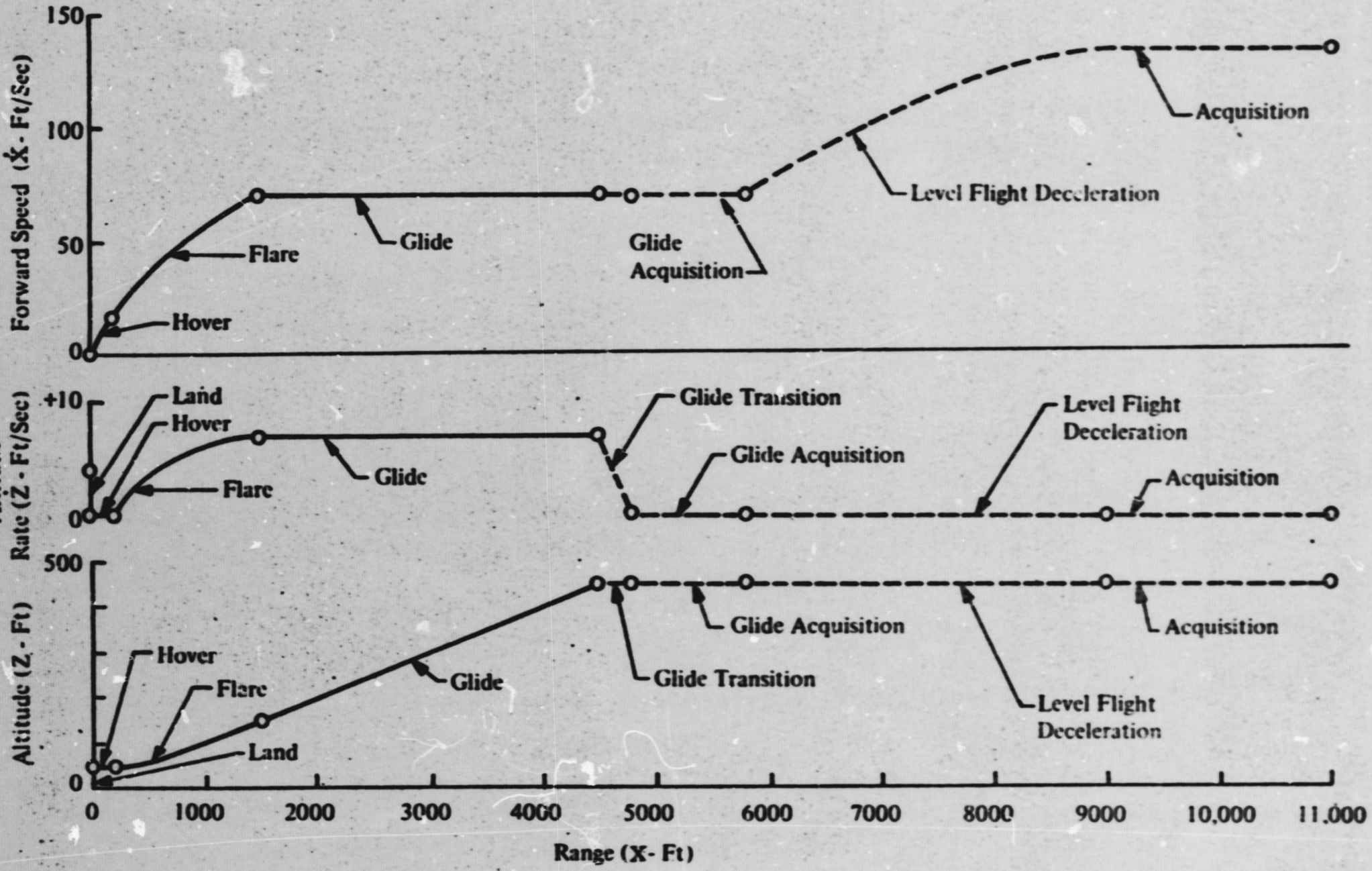


Figure 1. Landing Mission Phases

(1) acquisition, (2) level flight deceleration, (3) glide acquisition, (4) glide transition, (5) glide, (6) flare, (7) hover, and (8) land. In each phase, separate longitudinal guidance laws are used to generate total forward and vertical velocity commands along the profile. A single lateral guidance law is used to generate a total lateral velocity command. These total velocity commands are then differenced with the sensed helicopter velocities and transformed into velocity errors in the vertical heading frame. These errors form the command inputs to the flight control system.

2. Longitudinal Guidance II Laws.

a. Initial Acquisition Phase.

The commands during the initial acquisition phase are those required to hold the aircraft at the acquisition forward velocity and altitude.

$$V_{cx}' = V_{xo}$$

$$r_{cz}^{an} = r_{zo}^{an}$$

$$V_{cz}^{an} = 0$$

b. Level Flight Deceleration Phase.

The commands during the level flight deceleration phase are those for decelerating the aircraft's forward speed to a specified glide value (nominally 42 knots) before intercepting the glide slope.

$$V_{cx}' = \sqrt{2\dot{V}_{xd}\left(\left|r_x^{an}\right| - r_{xslf}^{an}\right) + \left(V_{xg}\right)^2}$$

where $\dot{V}_{xd}$ is the desired deceleration rate

r_{xslf}^{an} is the down range at which the deceleration phase is to be completed and the constant speed level flight to glide slope interception phase is to be started

V_{xg} is the desired forward glide velocity

$r_{cz}^{an} = r_{zo}^{an}$

$V_{cz}^{an} = 0$

c. Glide Slope Acquisition Phase.

The commands for this phase are those required to hold the aircraft in level flight at the desired forward glide velocity until it is time to transition to the glide slope.

$V_{cx}' = V_{xg}$

$r_{cz}^{an} = r_{zo}^{an}$

$V_{cz}^{an} = 0$

d. Glide Transition Phase.

The commands for this phase are those required to accelerate the aircraft downward until the desired glide slope is intercepted at the required vertical rate of descent.

$$V_{cx}' = V_{xg}$$

$$r_{cz}^{an} = r_{zb}^{an}$$

$$V_{cz}^{an} = \left[\frac{r_{xst}^{an} - \left| r_{x}^{an} \right|}{\Delta r_{xt}^{an}} \right] V_{xg} \tan \gamma_g$$

where r_{xst}^{an} is the down range at which the transition phase is to be started

Δr_{xt}^{an} is the down range from the glide interception point over which the transition is to be performed

γ_g is the desired glide path angle.

e. Glide Phase.

The commands during the glide phase are those required to fly down the desired glide slope.

$$V_{cx}' = V_{xg}$$

$$r_{cz}^{an} = -\left(\left| r_{x}^{an} \right| - r_{xsf}^{an} \right) \tan \gamma_g + r_{zsf}^{an}$$

where r_{xsf}^{an} is the down range at which the flare phase is to be started

r_{zsf}^{an} is the altitude at which the flare phase is to be started

$V_{cz}^{an} = V_{xg} \tan \gamma_g$.

f. Flare Phase.

The commands during the flare phase are those required to decelerate the aircraft's forward speed to a specified value for starting the hover phase (nominally 10 knots)

and to brake the aircraft's vertical rate of descent to zero by the time the desired hover altitude is reached.

$$V_{cx}' = \sqrt{2\dot{V}_{xd}\left(\left|r_x^{an}\right| - r_{xsh}^{an}\right) + \left(V_{xsh}\right)^2}$$

$$r_{cz}^{an} = \frac{-.5\, V_{xg} \tan\gamma_g \left(V_{cx}' - V_{xsh}\right)^2}{\dot{V}_{xd}\left(V_{xg} - V_{xsh}\right)} + r_{zh}^{an}$$

$$V_{cz}^{an} = \frac{V_{xg} \tan\gamma_g \left(V_{cx}' - V_{xsh}\right)}{\dot{V}_{xd}\left(V_{xg} - V_{xsh}\right)}$$

where r_{xsh}^{an} is the down range at which the flare phase is completed and the hover phase is started

V_{xsh} is the desired forward speed at the start of the hover phase

r_{zh}^{an} is the desired hover phase altitude.

g. Hover Phase.

The commands during this phase are those required to bring the vehicle to and hold it at a hover condition over the pad.

$$V_{cx}' = \frac{-r_x^{an}}{r_{xsh}^{an}} V_{xsh}$$

$$r_{cz}^{an} = r_{zh}^{an}$$

$$V_{cz}^{an} = 0.$$

h. Landing Mode.

The commands for this mode are those required to accelerate downward to a desired vertical sink rate and then hold this sink rate until touchdown.

$$V_{cx}' = \frac{-r_x^{an}}{r_{xsh}^{an}} \; V_{xsh}$$

$$V_{cz}^{an} = \frac{\dot{V}_{zl}^{an}}{s} \; dt \leq V_{zl}^{an}$$

3. Lateral Guidance Law.

The lateral guidance law for all phases is,

$$V_{cy}' = k_{r_y} \; r_y^{an}$$

where $k_{r_y} = k_{r_{yo}} - k_{r_{yr}} \left| r_x^{an} \right|$

$$k_{r_{ymin}} \leq k_{r_y} \leq k_{r_{ymax}}$$

The lateral velocity command is limited as follows to prevent orbiting.

$$-V_{cxl}' \sin \gamma_{max} \leq V_{cy}' \leq V_{cxl}' \sin \gamma_{max}$$

where: $V_{cxl}' = \left| V_{cx}' \right|$, if $\left| V_{cx}' \right| > V_{xsh}$

$= V_{xsh}$, if $\left| V_{cx}' \right| \leq V_{xsh}$

ψ_{max} = maximum desired heading change for obtaining centerline at high speed.

4. Transformation to Velocity Errors.

At high speeds, (high V_a'), the commanded forward and lateral velocities are transformed directly into velocity errors in the vertical heading frame as follows:

$$\Delta V_x^h = V_{cx}' - V_x^h$$

$$\Delta V_y^h = V_{cy}' - V_x^h \sin \psi$$

At low speeds (low V_a'), the commanded forward and lateral velocities are first converted to velocity errors in the approach navigation frame and then transformed to velocity errors in the vertical heading frame as follows:

$$\Delta V_x^{an} = V_{cx}' - V_x^{an}$$

$$\Delta V_y^{an} = V_{cy}' - V_y^{an}$$

$$\Delta V_x^h = \Delta V_x^{an} \cos \psi + \Delta V_y^{an} \sin \psi$$

$$\Delta V_y^h = -\Delta V_x^{an} \sin \psi + \Delta V_y^{an} \cos \psi$$

To eliminate the finite discontinuities which will result in the velocity errors when a switch is made from one transformation to the other, washout terms must be added to velocity errors. These terms are defined as:

$$\Delta V^h_{xw} = \Delta V^h_{xd}\ k_w$$

$$\Delta V^h_{yw} = \Delta V^h_{yd}\ k_w$$

where ΔV^h_{xd} and ΔV^h_{yd} are the velocity error discontinuities

k_w is the washout gain.

The velocity error discontinuities are defined as:

$$\Delta V^h_{xd} = \Delta V^h_{xt_{s-1}} - \Delta V^h_{xt_s}$$

$$\Delta V^h_{yd} = \Delta V^h_{yt_{s-1}} - \Delta V^h_{yt_s}$$

where $\Delta V^h_{xt_{s-1}}$ and $\Delta V^h_{yt_{s-1}}$ are the last velocity errors resulting from the transformation used before a switch occurs

$\Delta V^h_{xt_s}$ and $\Delta V^h_{yt_s}$ are the first velocity errors resulting from the transformation used after a switch occurs.

The washout gain is defined as

$$k_w = \left[1 - k_t\ (t - t_s)\right]$$

where: t_s is the time when the switch occurs.

The vertical velocity error in all phases of the Acquisition to Hover Mode is defined as follows.

$$\Delta V^h_z = (V^{an}_{cz} - V^{an}_z) + k_{r_z}\ (r^{an}_{cz} - r^{an}_z)\ .$$

$$\Delta V^h_{xw} = \Delta V^h_{xd}\ k_w$$

$$\Delta V^h_{yw} = \Delta V^h_{yd}\ k_w$$

where ΔV^h_{xd} and ΔV^h_{yd} are the velocity error discontinuities

k_w is the washout gain.

The velocity error discontinuities are defined as:

$$\Delta V^h_{xd} = \Delta V^h_{xt_{s-1}} - \Delta V^h_{xt_s}$$

$$\Delta V^h_{yd} = \Delta V^h_{yt_{s-1}} - \Delta V^h_{yt_s}$$

where $\Delta V^h_{xt_{s-1}}$ and $\Delta V^h_{yt_{s-1}}$ are the last velocity errors resulting from the transformation used before a switch occurs

$\Delta V^h_{xt_s}$ and $\Delta V^h_{yt_s}$ are the first velocity errors resulting from the transformation used after a switch occurs.

The washout gain is defined as

$$k_w = \left[1 - k_t\ (t - t_s)\right]$$

where: t_s is the time when the switch occurs.

The vertical velocity error in all phases of the Acquisition to Hover Mode is defined as follows.

$$\Delta V^h_z = (V^{an}_{cz} - V^{an}_z) + k_{r_z}\ (r^{an}_{cz} - r^{an}_z)\ .$$

For the Landing Mode, the command is defined as follows:

$$\Delta V_z^h = (V_{cz}^{an} - V_z^{an})$$

The velocity, V_a', which is used to determine the method of generating the incremental forward and lateral velocity commands, is defined as,

$$V_a' = V_x^h \quad , \quad \text{if } V_{af} > V_x^h$$

$$= V_{af} \quad , \quad \text{if } V_{af} \leq V_x^h$$

where $V_{af} = \dfrac{V_a}{T_{V_a} s + 1}$

C. Mode Control.

The Acquisition to Hover Mode and the Land Mode of operation of the Guidance II laws are controlled directly by the pilot. In the Acquisition to Hover Mode, the flight phase is based solely on the down range to the touchdown point as follows.

DOWNRANGE	PHASE
$\left\|r_x^{an}\right\| > r_{xsd}^{an}$	Acquisition
$r_{xslf}^{an} < \left\|r_x^{an}\right\| \leq r_{xsd}^{an}$	Level Flight Deceleration
$r_{xst}^{an} < \left\|r_x^{an}\right\| \leq r_{xslf}^{an}$	Glide Acquisition

DOWNRANGE	PHASE
$r^{an}_{xsg} < \left\lvert r^{an}_{x} \right\rvert \leq r^{an}_{xst}$	Glide Transition
$r^{an}_{xsf} < \left\lvert r^{an}_{x} \right\rvert \leq r^{an}_{xsg}$	Glide
$r^{an}_{xsh} < \left\lvert r^{an}_{x} \right\rvert \leq r^{an}_{xsf}$	Flare
$\left\lvert r^{an}_{x} \right\rvert \leq r^{an}_{xsh}$	Hover

The down ranges that control when each flight phase starts are computed when the system is initialized as discussed in Section II.D.

When the system is in the Hover Phase of the Acquisition to Hover Mode, a series of tests are made to determine if the aircraft flight conditions are acceptable for landing. If they are, a ready to land output signal is set. This signal is to be used to light the "Ready to Land" indicator in the cockpit. If the pilot selects the Landing Mode when this indicator is lit, the laws will generate commands for landing. However, if the pilot selects the Landing Mode before this indicator is lit, the laws will continue to generate commands to hold the aircraft in hover until the flight conditions are acceptable for landing. The flight conditions that must be met at hover for landing are as follows:

$$\sqrt{(r^{an}_{x})^2 + (r^{an}_{y})^2} \leq r^{an}_{hh}$$

$$\left| r_z^{an} - r_{zh}^{an} \right| \leq \Delta r_{zh}^{an}$$

$$\sqrt{(V_x^{an})^2 + (V_y^{an})^2} \leq V_{hh}^{an}$$

$$V_z^{an} \leq V_{zh}^{an}$$

$$\phi \leq \phi_h$$

$$r \leq r_h$$

D. Initialization.

Any time that the Guidance II Mode is engaged from either the Disengage or Guidance I Modes, certain parameters in the Guidance II laws must be initialized. These include the initial acquisition flight conditions, the down ranges that control the various flight phases in the Acquisition to Hover Mode, and other initial conditions. The initial acquisition flight conditions are initialized as follows:

$$r_{zo}^{an} = r_z^{an}$$

$$V_{xo} = V_x^h$$

The down ranges that control when each flight phase starts are computed based on the desired characteristics of the landing profile. They are computed as:

$$r^{an}_{xsf} = r^{an}_{xsh} + \frac{V_{xg}\ (V_{xg} - V_{xsh})}{\dot{V}_{xd}} - \frac{.5(V_{xg} - V_{xsh})^2}{\dot{V}_{xd}}$$

$$r^{an}_{zsf} = r^{an}_{zh} - \frac{.5\ V_{xg}\ \tan \gamma_g\ (V_{xg} - V_{xsh})}{\dot{V}_{xd}}$$

$$r^{an}_{xsg} = r^{an}_{xsf} - (r^{an}_{zo} - r^{an}_{zsf})/\tan \gamma_g$$

$$r^{an}_{xst} = r^{an}_{xsg} + V_{xg}^2 \tan \gamma_g/\dot{V}_{zt}$$

$$r^{an}_{xslf} = r^{an}_{xst} + \Delta r^{an}_{xlf}$$

$$r^{an}_{xsd} = r^{an}_{xst} + \frac{V_{xo}\ (V_{xo} - V_{xg})}{\dot{V}_{xd}} - \frac{.5\ (V_{xo} - V_{xg})^2}{\dot{V}_{xd}}.$$

where: r^{an}_{xsh} is the desired downrange at which hover is started

r^{an}_{zh} is the desired hover altitude

V_{xsh} is the desired forward velocity at the start of hover

$\dot{V}_{xd}$ is the desired deceleration rate

γ_g is the desired glide angle

V_{xg} is the desired glide velocity

$\dot{V}_{zt}$ is the desired vertical acceleration during glide transition

Δr_{xlf} is the desired down range increment for glide acquisition.

Although these down ranges could be precomputed and inputted into the airborne computer during pre-flight operations, computing them in the guidance initialization section allows for in flight updating of the desired landing profile

characteristics from a Manual Communications Unit which addresses the computer in flight.

In addition to computing the down ranges, the previous inputs and outputs of the integrator difference equations used in the Landing Mode guidance laws and the velocity discontinuities (ΔV^h_{xd} and ΔV^h_{yd}) must all be set to zero when the Guidance II laws are initialized.

In addition to initialization, the Guidance II laws are to be locked in the Landing Mode of operation whenever the Land Mode is selected and the flight conditions first become acceptable for landing. This "lock" is to be unlocked whenever the Guidance I or Disengage Mode of guidance is selected.

E. Inputs and Outputs.

1. Inputs.

a. Variable.

The variable inputs required by the Guidance II laws are listed in Table 1.

b. Discrete.

Only one discrete input is required to select the mode of operation of the Guidance II laws. This discrete will be externally coded into an input data word for the airborne computer and must be decoded in the airborne computer. To enable a coded bit pattern for this word and the decoded modes to be specified, it is assumed that, subject to final hardware specification; (1) from right to left, the sixth[1] bit of this

---

[1] The assumed use of the first five bits of this word are discussed in the Final Flight Control Software Package, Reference 1.

TABLE 1 VARIABLE INPUTS

INPUT	DESCRIPTION	SOURCE	UNITS
r	Angular rate about the z body axis	Navigation System	Rad/Sec.
ψ	Euler yaw attitude relative to x axis of approach navigation frame	Navigation System	Rad.
ϕ	Euler roll attitude	Navigation System	Rad.
V_x^h	Forward velocity in the vertical heading frame	Navigation System	Ft/sec.
V_y^h	Lateral velocity in the vertical heading frame	Navigation System	Ft/sec
V_z^h or V_z^{an}	Vertical velocity in the vertical heading or approach navigation frame	Navigation System	Ft/sec
r_x^{an}	Down range to touchdown point in approach navigation frame	Navigation System	Ft.
r_y^{an}	Cross range to touchdown point in approach navigation frame	Navigation System	Ft.
r_z^{an}	Altitude to touchdown point in approach navigation frame	Navigation System	Ft.

input data word will be used for the Guidance II Mode discrete and (2) the coded pattern of this bit and the decoded mode will be as illustrated below

TABLE 2
INPUT DATA WORD CODE

CODED PATTERN			DECODED MODE
Spares	Guid. II bit	Bits used by Flight Control	
	0		Acquisition to Hover Mode
	1		Land Mode

c. Constant.

The description and values of the constant inputs required by the Guidance II laws are given in Table 2.

2. Outputs.

a. Variable.

There are only three variable outputs from the Guidance II laws. These are the three velocity errors (ΔV_x^h, ΔV_y^h, and ΔV_z^h) in the vertical heading frame and they are all in units of ft/sec.

b. Discrete.

The ready to land signal is the only discrete output of the Guidance II laws. This discrete will be coded into

TABLE 3 CONSTANT INPUTS

INPUT	DESCRIPTION	VALUE AND UNITS
$k_{r_{y\ max}}$	Maximum cross range error gain	0.2 ft/sec/ft
$k_{r_{y\ min}}$	Minimum cross range error gain	0.1 ft/sec/ft
$k_{r_{yo}}$	Cross range error gain at zero down range	0.3 ft/sec/ft
$k_{r_{yr}}$	Range gradient on cross range error gain	0.00002 ft/sec/ft^2
k_{r_z}	Altitude error gain	0.2 ft/sec/ft
r_h	Maximum acceptable angular rate about z body axis at hover.	0.0349 rad/sec
r^{an}_{hh}	Maximum acceptable horizontal range error at hover	50.0 ft
r^{an}_{xsh}	Desired down range at start of hover phase	200.0 ft
r^{an}_{zh}	Desired hover altitude	-50.0 ft
V^{an}_{hh}	Maximum acceptable horizontal velocity at hover	4.0 ft/sec
V_{xg}	Desired forward velocity during glide	71.0 ft/sec
V_{xsh}	Desired forward velocity at start of hover	17.0 ft/sec
$\dot{V}_{xd}$	Desired forward deceleration rate	2.0 ft/sec^2

TABLE 3 (CONTINUED)

INPUT	DESCRIPTION	VALUE AND UNITS
V_{zh}^{an}	Maximum acceptable vertical velocity at Hover	2.0 ft/sec
V_{zl}^{an}	Desired vertical velocity for landing	4.0 ft/sec
$\dot{V}_{zl}^{an}$	Desired vertical acceleration during landing	2.0 ft/sec^2
$\Delta\dot{V}_{zt}$	Desired vertical acceleration during glide transition	2.0 ft/sec^2
Δr_{xlf}^{an}	Desired down range increment for glide acquisition	1000.0 ft
Δr_{zh}^{an}	Maximum acceptable altitude error at hover	5.0 ft
$\Delta V_{at}'$	Threshold on speed used for switching purposes	5.0 ft/sec
γ_g	Desired glide slope	0.1048 rad
ϕ_h	Maximum acceptable Euler roll attitude at hover	0.0436 rad
τ_{V_a}	Airspeed filter time constant	2.5 sec
ψ_{max}	Maximum desired heading change for obtaining center-line at high speed	0.523 rad

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

airborne computer and externally

light the "Ready to Land" indicator in the

ding procedure to be specified, it is

final hardware specifications: (1) from

bit of the output data word will be

discrete and (2) the conditions for

pattern will be as illustrated below.

TABLE 4

DATA WORD FORMAT

CODING	CODED PATTERN		
	Spares	Ready to Land Bit	Bits used by Flight Control
Mode is Beware or Caution		0	
Mode is Acceptable		1	

Report

the first six bits of this word are
Final Flight Control Software Package,

III. DIGITAL DESCRIPTION OF GUIDANCE LAWS.

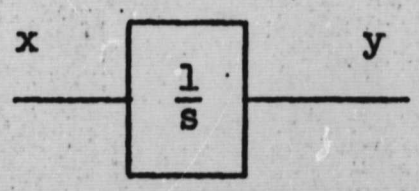
A. General Requirements.

A main program must be provided to control entry to the guidance subroutine and to generate certain inputs needed by the guidance subroutine. The main program is responsible for calling the guidance subroutine at a recommended frequency of 3 times per second and for providing the value of time at each entry. Time is needed in the difference equations. The main program must read and decode an input discrete word containing the the guidance mode and the Guidance II Flight Phase Mode (Acquisition to Hover or Land). If the Guidance II mode is selected, the main program calls the Guidance II subroutine. The main program also must encode and transmit an output discrete word containing the guidance mode and the Guidance II Ready to Land Indicator bit.

B. Difference Equations.

Whenever a transfer function in the Laplacian operator, s, domain is encountered in the guidance laws, a difference equation derived by Tustin's method should be used as described below.

1. Integrator.



$$y_i = y_{i-1} + \frac{\Delta t}{2}(x_i + x_{i-1})$$

where y_i = current output of integrator

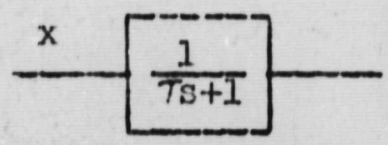
y_{i-1} = previous output of integrator

x_i = current input to integrator

x_{i-1} = previous input to integrator

Δt = elapsed time between this update and previous update (seconds)

2. Filter.



$$y_i = \frac{x_i + x_{i-1} + (a-1)\, y_{i-1}}{a + 1}$$

where a = $2\tau/\Delta t$

τ = filter time constant (seconds)

Δt = elapsed time (seconds)

y_i = current output of filter

y_{i-1} = previous output of filter

x_i = current input to filter

x_{i-1} = previous input to filter

C. Flow Diagrams.

A flow diagram of the Guidance II Subroutine is shown in Figure 2. The logic codes used in this diagram are defined in Table 3.

FIGURE 2 GUIDANCE SUBROUTINE

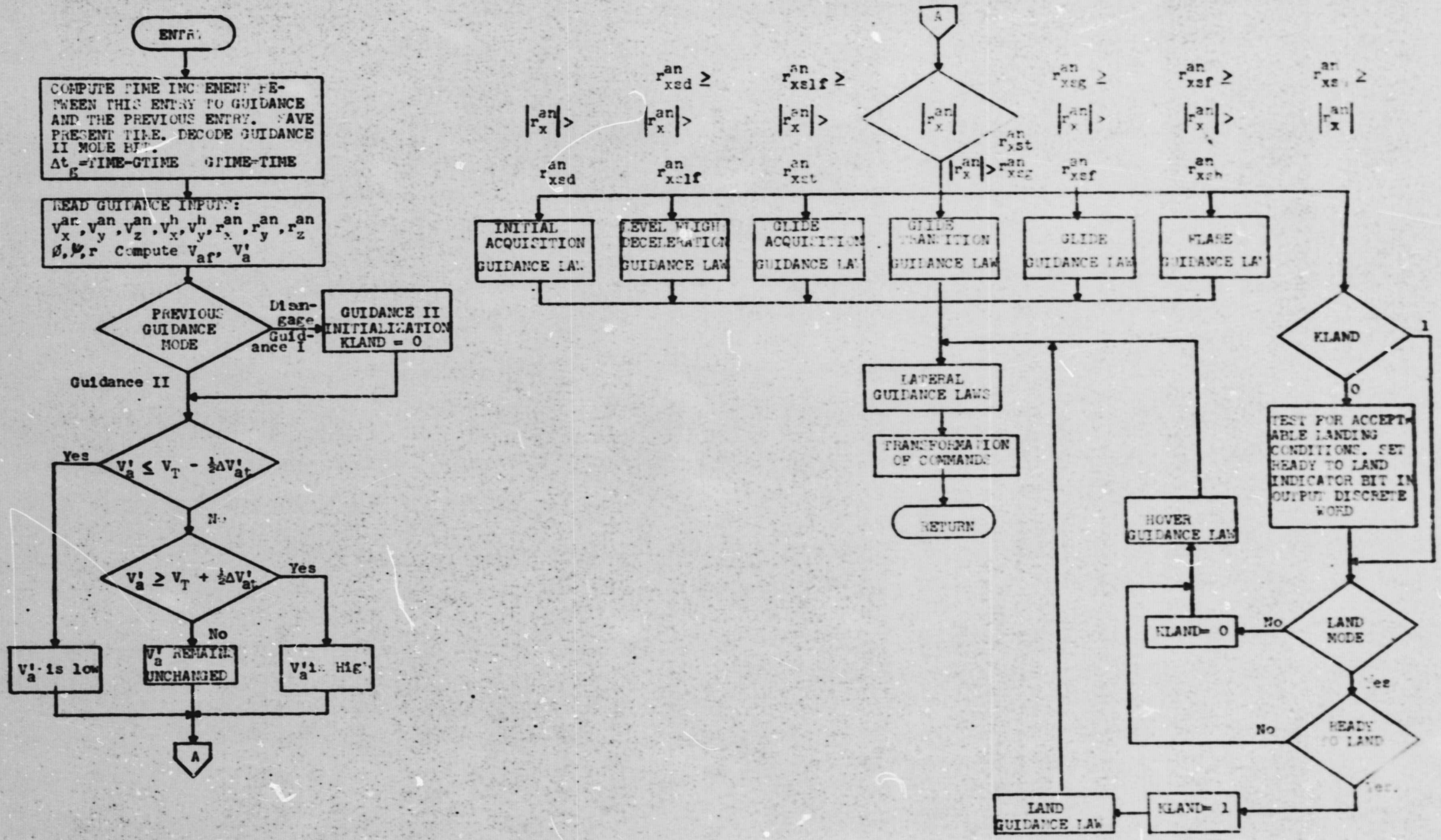


TABLE 5

DEFINITION OF SYMBOLS USED IN FLOW DIAGRAMS

CODE	DEFINITION
XLAND	Set to 1 when acceptable landing conditions have been met and land mode is engaged. Set to 0 if not.
MODE	Guidance Mode as decoded from input discrete word. Disengage, Guidance I, Guidance II.
TIME	Current value of time provided by main program.
GTIME	Time at the beginning of each entry to the guidance subroutine
ΔT_g	Incremental time between successive updates of the guidance subroutine.

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