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(NASA-CR-176355) AN INVESTIGATION INTO THE VERTICAL AXIS CONTROL POWER REQUIREMENTS FOR LANDING VTOL TYPE AIRCRAFT ONBOARD NONAVIATION SHIPS IN VARIOUS SEA STATES (Kansas Univ. Center for Research, Inc.)

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Report on Research
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"V/STOL Handling and Control Power Requirements"

AN INVESTIGATION INTO THE VERTICAL AXIS CONTROL POWER REQUIREMENTS FOR LANDING VTOL TYPE AIRCRAFT ONBOARD NON-AVIATION SHIPS IN VARIOUS SEA STATES

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ABSTRACT

The problem of determining the vertical axis control requirements for landing a VTOL aircraft on a moving ship deck in various sea states is examined. Both a fixed-base piloted simulation and a non-piloted simulation were used to determine the landing performance as influenced by thrust-to-weight ratio, vertical damping, and engine lags.

The piloted simulation was run using a fixed-base simulator at N.A.S.A. Ames Research Center. Simplified versions of an existing AV-8A Harrier model and an existing head-up display format were used. The ship model used was that of a DD963 class destroyer.

Simplified linear models of the pilot, aircraft, ship motion, and ship air-wake turbulence were developed for the non-piloted simulation. A unique aspect of the non-piloted simulation was the development of a model of the piloting strategy used for shipboard landing. This model was refined during the piloted simulation until it provided a reasonably good representation of observed pilot behavior. Further refinement could lead to a model suitable for prediction of landing performance of VTOL aircraft on ships and as the basis of control logic for automatic landing.

A surprising result of this simulation was that, with a good station keeping control system and with statistical ship motion displayed on the head-up display, pilots could consistently perform safe landings in sea state 6, with handling qualities that were adequate at thrust-to-weight ratios greater than 1.03 and even

marginally adequate down to thrust-to-weight ratios of 1.01. These results should hold quite generally provided that a thrust-to-weight ratio of 1 + Δ is interpreted as meaning that the pilot always has the capability of accelerating the aircraft at Δg upward even in the presence of ground effect and hot gas reingestion.

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AC	Aircraft transfer function
A_n	Amplitude
A_R	Acceleration magnitude
cos	Cosine
cmd	Command
deg	Degree
ENG	Engine transfer function
ELC	Engine lag time constant
E_n	Random phase angle
ft	Foot, feet
g	Gravitational constant
h	Altitude
H_s	Significant wave height
in	Inches
i(t)	Ship motion component
K_p	Pilot gain
knts	Nautical miles per hour
m	Meters
msec	Millisecond
n	Random number
s	Laplace variable
s	Second
sec	Second

LIST OF SYMBOLS, continued

Symbol	Definition
t	Time (seconds)
T	Thrust
TC	Time increment
TG	Lag time constant
TL	Lead time constant
T_o	Modal period
V	Velocity
W	Weight
X	Position along the X axis
$\ddot{X}$	True longitudinal acceleration
$\hat{\ddot{X}}$	Estimated true acceleration
$\hat{\ddot{X}}_1$	Estimate of high frequency acceleration
Y_p	Pilot transfer function
Z_w	Vertical velocity damping coefficient

Greek Symbol	
Δ	Increment
ω	Frequency
σ	Statistical variance
τ	Time constant
Δ	Component of the ship motion spectrum

LIST OF SYMBOLS, continued

Greek Symbol	Definition
ϕ	Roll angle (deg)
θ	Pitch angle (deg)
ψ	Yaw angle (deg)
ψ	Ship heading (deg)
ζ	Laplace variable

Subscript	
c	Command
cg	Center of gravity
en	Encounter
eng	Engine
ℓ_p	Landing pad
long	Longitudinal
v	Velocity
w	Wind
wod	Wind over deck
x	Position along x axis
y	Position along y axis
z	Position along x axis
ϕ	Roll axis
θ	Pitch axis
ψ	Yaw axis

LIST OF SYMBOLS, continued

Abbreviation	Definition
A.I.L.	Approximate inverse Laplace transform
HUD	Head-up display
N.A.S.A.	National Aeronautics and Space Administration
V/STOL	Vertical/short takeoff and landing
VTOL	Vertical takeoff and landing
A.C.	Attitude command control system
V.C.	Translational velocity command control system

I. INTRODUCTION

The problem of landing V/STOL aircraft aboard destroyer class ships has been investigated in the past (References 1-3). Several methods have been used to determine the feasibility of, and the control/display systems needed, to accomplish this task.

Many of the researchers in this area began with the premise that for the successful completion of this task, it would be necessary for the pilot/aircraft system to have the capability of in-phase chasing of the ship deck. The vertical task then was to start at a specified altitude, descend at a reasonable rate and begin to match the vertical motion of the ship deck. If the ship deck motion can be matched in both phase and amplitude, then it is only a matter of establishing a small relative descent rate and a reasonable landing can be made. There are, of course, problems with this technique. In high sea states (5-6) the frequency of the ship motion is near the maximum piloting frequency (~4 rad/sec). In attempting to match both the phase and amplitude of the ship motion, the pilot is forced to operate at close to his break frequency and at fairly high gain. The aircraft must incorporate a high thrust-to-weight ratio to achieve the maximum amplitudes in the time required. The combination of high piloting frequency and gain with high thrust-to-weight ratio can cause lags and a tendency to overshoot. If in addition there is a large system lag due to engine spool time, display lags, and pilot delay times, the phase lag can become excessive to the point of producing large touchdown velocities and an unstable system. This has been demonstrated in computer simulations (Reference 1). As a result it is generally concluded that deck chasing is not a reliable method for landing an aircraft with reasonable accuracies or consistently low touchdown velocities. This conclusion is confirmed in helicopter operations onto small ships.

A second approach was based on the idea that the pilot could loiter until a lull in the ship motion occurred. Some of the research indicates that adequate lulls are not frequent occurrences or are too short in duration to be useful. For example Reference 1, which investigated results for the two lull criteria given in Table 1, determined that for the more conservative criterion no lulls occurred in the DD963 ship motion model over a period of 1800 seconds. For the less stringent criterion, 52 lulls occurred in this time period, or the average of 1 every 33 seconds. This indicates lulls of very short duration.

Reference 1 concludes that looking for lull conditions under high sea states in order to make a landing is not very feasible. Other research conducted in the area of lull prediction (Reference 2) indicates that lull conditions (defined as the time from which there are 2 successive peaks under the mean value of the positive peak amplitude envelope until 2 successive peaks over that value) occurs at the rate of 1 every 70 seconds and are of 10 to 60 seconds duration. Another consideration is found in Reference 3 where a

Table 1: Example Lull Criteria

Reference 1 LULL CRITERIA		
Motion Component Limit	Criteria 1	Criteria 2
Longitudinal Vel.	2 ft/sec	3 ft/sec
Lateral Velocity	2 ft/sec	3 ft/sec
Vertical Velocity	2 ft/sec	3 ft/sec
Pitch	1°	1.5°
Roll	2°	3°
Pitch Rate	2 $^{\circ}$/sec	8 $^{\circ}$/sec
Roll Rate	2 $^{\circ}$/sec	8 $^{\circ}$/sec
No. of Occurrances Based on 1800 sec. of DD963 ship model motion for Sea State 5.	0	52

description of sea trials performed using a SH-2F helicopter indicated that pilots were often unable to determine visually when a lull was occurring. The above information indicates that in general it is not practical for fixed wing VTOL aircraft to loiter for the required time periods in the high fuel use state of hovering while waiting for optimum landing conditions.

Another area of research involved the use of ship motion prediction schemes. Research in this area has shown some promising results. Computer studies have shown that ship motion can be predicted with reasonable accuracies for 10-15 seconds in advance (Reference 4). Given this capability, it has been demonstrated in computer studies using optimal control modeling techniques, that autopilot landings can be made with touchdown velocities on the order of 1 ft/sec in sea state 5 conditions (Reference 5). The advantage to using a system in which the ship position is predicted in advance and updated as the approach progresses comes from being able to adopt a control strategy in which the aircraft is chasing a slower moving prediction point rather than the real time deck motion. This adds lead, thereby requiring less effort on the part of the system as demonstrated by adequate performance at thrust-to-weight ratios of 1.05. The major problem here is that motion prediction for destroyer class ships in high seas has not been demonstrated.

The research conducted for this report is directed at the question of what thrust-to-weight ratios, and vertical velocity damping are required to allow a pilot to make an acceptable landing given adequate situational information.

It is clear that it is desirable to land with low touchdown velocities using low thrust-to-weight ratios, and without wasting time in the high fuel consumption state of a hovering loiter waiting for lulls in the ship motion.

II. ANALYSIS OF HOVER HEIGHT CONTROL

To provide some insight into the problem and the models being used in this research, the following facts are presented: 1) The current AV-8A Harrier aircraft has a maximum touchdown velocity limit of 12 ft/sec. 2) The DD963 ship motion model has a maximum ship deck heave velocity (3 sigma value) of 17.5 ft/sec. 3) In sea state 6, the ship has a heave velocity equal to or greater than 12 ft/sec for less than 0.6% of the time. 4) The maximum heave velocity values occur in a region close to the ship motion mean position. 5) The lower velocities occur in the peak and trough regions of the motions. The above facts in conjunction with the ship motion histogram for sea state 6 would indicate that if the pilot did nothing but maintain a descent velocity of less than 2 ft/sec, he would touch down within the AV-8A gear limits approximately 97% of the time. The ship motion statistics show that a maximum heave velocity of 12.5 ft/sec is encountered at the 2 sigma heave amplitude for sea state 6 conditions. These same statistics show that the 2 sigma heave amplitude values are reached at reasonable time intervals of approximately 1 per minute. This frequency increases to 1 every 40 seconds for amplitudes of 1 foot below the 2 sigma value. These facts suggest a landing strategy differing from both the "deck chasing" and "lull waiting." This strategy has the pilot descend to the 2 sigma height above the mean deck position. At this height the pilot waits and watches the ship motion. If it appears that a 3 sigma amplitude (high velocity) deck motion is imminent, the pilot has enough height, and therefore lead time to begin an ascent, landing at the more desirable higher altitude (lower ship and relative velocity) as the deck catches up to him. If it appears that the deck position is going to peak somewhat below his present altitude, there is again enough lead time to begin a slow descent and land near the crest (low ship velocity position) of the deck motion. The 2 sigma height above mean deck position meets the desired criteria for the strategy. It offers an easily obtained position without continous deck chasing, provides the buffer needed to escape the high velocity portions of the deck motion, and presents the pilot with numerous landing opportunities without a lengthy loiter period. To accomplish this, the pilot must be presented with a suitable indication of mean deck position and the 2 and 3 sigma values of deck position relative to the aircraft's landing gear. This information requires measurement of the ship motion for several minutes prior to the arrival of the aircraft and the transmission of this information to the aircraft for use in the head-up display. Real time information is also required to show the pilot where the deck is currently positioned within the bounds of the probable travel. The pilot can then monitor the ship motion, obtain an accurate deck position relative to the mean, and make his prediction as to how fast it is moving and where its position will be in a couple of seconds.

An investigation of the proposed landing strategy was conducted along two lines: namely, a non-piloted simulation and a piloted simulation. The non-piloted simulation incorporates a linear pilot model and vertical axis aircraft model. In addition there is a flight path command logic section, a command flight path subroutine, a ship motion subroutine, and a turbulence modeling subroutine. Input variables are pilot gain, maximum thrust-to-weight ratio, sea state, vertical velocity damping coefficient, pilot time delay, and engine lag.

The piloted simulation used the chair 6 simulator at the N.A.S.A. Ames Research Center. This fixed-base simulator consists of a cab containing the normal cockpit controls and a single forward looking window through which a visual image of the outside environment can be obtained. The visual image is provided by a camera-terrain board imaging system. A head-up display can be superimposed on the outside scene to provide flight situation information to the pilot. The cockpit also contains a unique throttle/nozzle control quadrant used for V/STOL simulation. Slightly modified versions of an existing math model of the AV-8A (Reference 6) and an existing head-up display format were used. The math model was linearized in the vertical axis and the display format simplified to represent only information needed to fly the vertical axis.

A. CONTROL TASK

The task to be flown begins with the aircraft at an initial altitude of 45 ft above the mean deck position in a stabilized hover directly over the bull's-eye on the ship deck landing pad. The pilot uses the throttle to control altitude and vertical velocity to descend to an initial hover altitude. This initial hover altitude is the 2 sigma value of ship deck position above the mean, as designated by a line on the head-up display (HUD). The pilot then lands at his discretion, based on the ship deck motion information presented on the HUD.

There are two variations of this task. In the first variation, the ship deck motion boundaries and reference lines are not displayed on the HUD and the pilot makes the landing without the 2 sigma reference. In the second variation, an attitude command control system replaces the translational velocity command control system which creates an effective sidetask in that the pilot must actively maintain the aircraft position over the bull's-eye, using the control stick, while performing the vertical task.

B. THE NON-PILOTED SIMULATION

The non-piloted simulation was run through a control program which links the main program with flight path, ship motion, and turbulence subroutines, data files, and subroutines for output of statistical and plotted data. Figure 1 shows the flow path diagram

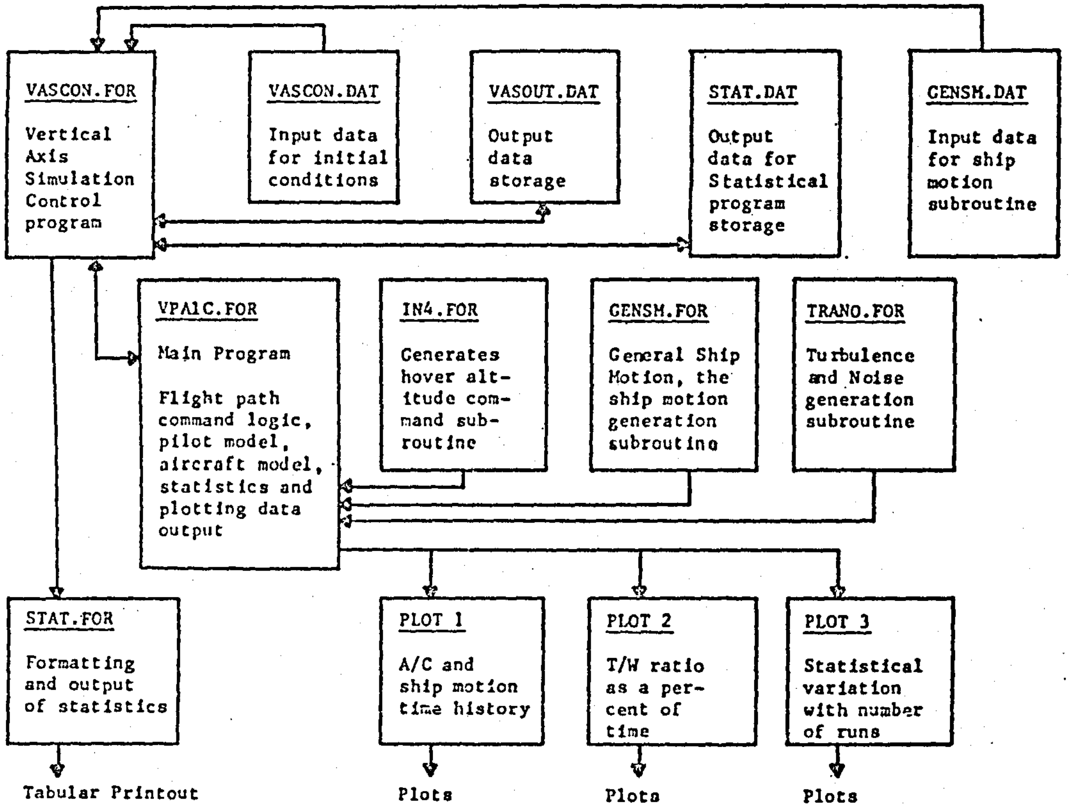


Figure 1: Non-Piloted Simulation Computer Program Flow Path

between the various programs and files. The main program contains the flight path command logic, pilot neuromuscular model, and aircraft models. A block diagram showing the model transfer functions is shown in Figure 2.

The rationale for developing a non-piloted simulation was that it provided a relatively low cost test of the feasibility of the proposed landing strategy and its ability to minimize the required T/W. In addition it was conjectured that comparison of the results of such a simulation with the piloted simulation would provide a test of the validity of the intuitive notions underlying the assumed way the pilot would implement the strategy. Perhaps not too surprisingly, the task turned out to be much more invloved than originally thought, and refinements to incorporate additional features suggested by the piloted simulation was a continous process. Nonetheless, the insight gained by the exercise was invaluable.

The Approximate Inverse Laplace Transform (A.I.L.) method (see Appendix A), was used to solve the differential equations describing the pilot and aircraft transfer functions. From a review of the literature and looking at the task to be flown, it appeared from the beginning that the pilot transfer function would be the major problem. For the type of problem being looked at, a generic aircraft transfer function could be used, but because of the amplitudes and frequencies involved in the ship motion, it was apparent that the time constants used in the pilot transfer function

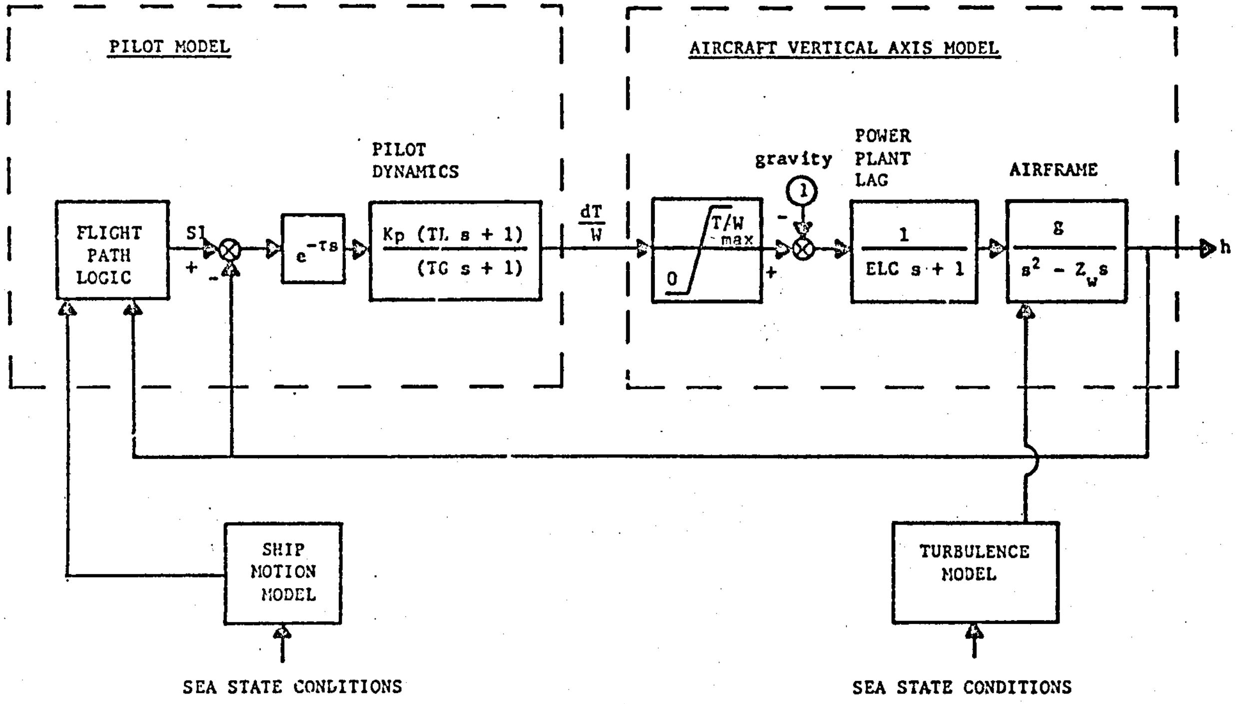


Figure 2: Block Diagram of the Original Non-Piloted Simulation Model

would be more critical. It was also desired to keep the pilot transfer function separated from the aircraft transfer function as much as possible, so that either the pilot or aircraft portion of the program could be moved as a block, either for use in other programs or to facilitate looking at other systems in the current program. This need to separate the transfer functions complicated the A.I.L. equation set-up.

C. ANALYTICAL MODELS.

1. Aircraft Model

The dynamics of the aircraft vertical axis are represented by two first order cascaded transfer functions (Figure 2), one representing the airframe vertical velocity response to a thrust change, and the second representing the engine response to a power lever input. The feedback from the aircraft to the pilot is assumed to be aircraft altitude only.

Only the vertical axis of the aircraft is modeled. The first order powerplant transfer function representing powerplant lags is

$$\frac{dT/W}{dT/W_c} = \frac{1}{(ELC\ s + 1)} \qquad (1)$$

Cascaded to this is the aircraft transfer function:

$$\frac{h}{dT/W} = \frac{g}{(s^2 + Z_w\ s)} \qquad (2)$$

To give a total vertical axis transfer function of

$$\frac{h}{dT/W_c} = \frac{(g/ELC)}{[s^3 + (1/ELC + Z_w)s^2 + (Z_w/ELC)s]} \qquad (3)$$

A limiter is put on the pilot output of T/W to prevent any input above the maximum T/W ratio or below 0; i.e., the pilot can not command a negative thrust.

The engine lag constant, ELC, is one of the parameters on which the control requirements depend.

2. Pilot Model

The pilot transfer function was first set up using a first order lead-lag multiplied by the Padé approximation (Figure 2). This transfer function was looked at using the Linear Systems Analysis Program (LSAP). Bode plots, root locus plots, and time history plots were looked at to determine values for lead and lag time constants which gave the best results for both a step input and a sine-wave input. The values which subjectively produced outputs similiar to those expected from a piloted simulation were then used in the non-piloted simulation. Because the computer program is nonlinear, several runs were made to determine which values for lead and lag still gave a good combination of rise time for step inputs and small phase and position errors in following a sine-wave. Values for the lag time constant, TG, of 0.1 secs and for the lead time constant, TL, of 0.5 secs were finally selected. These values are within the range of values usually quoted for pilot models (Reference 7).

Because a pure time delay could be programmed into the non-piloted simulation, the Padé approximation, which was needed in the analysis using LSAP, was replaced.

The pilot transfer function is

$$Y_p = K_p \frac{(TL\ s + 1)}{(TG\ s + 1)} \tag{4}$$

The pilot's logic is represented by a logic section in the simulation. The logic section consists of 4 basic sections. The first section is a series of logic statements which determine which of the other 3 sections will be used to provide the commanded flight path. These sections will be referred to subsequently as ABORT TO HOVER HEIGHT, CHASE, and RUN FROM.

If the aircraft is more than 6 ft above the ship deck, or has followed the ship deck below a specified abort chase altitude, or has exceeded a specified vertical velocity (a function of the maximum available T/W), the flight path command logic enters the ABORT TO HOVER HEIGHT section. The hover height is the 2 sigma value of the ship deck heave above the ship deck mean position. The CHASE sequence is entered if the ship deck is within 6 ft of the aircraft and the ship deck velocity is less than 2 ft/sec (approaching the aircraft) and decreasing. When the CHASE sequence is entered, the aircraft flight path is commanded to match the ship motion. The RUN FROM sequence is entered if the ship deck velocity is greater than 2 ft/sec or if the velocity is increasing; i.e., the ship is accelerating toward the aircraft. In the RUN FROM sequence, the commanded altitude is the ship position plus an exponential smoothing function (a function of time, based on when the sequence was entered). Because the exponential function dies out with time, the aircraft is prevented from climbing to excessive altitudes before one of the other sequences is initiated. A block diagram and example time history of the flight path command logic prior to the piloted simulation are presented in Figure 3.

After results were obtained from the piloted simulation, models representing the time the pilot spends flying a particular portion of the task and delays in perception were added. Since the pilot scans the situation and instruments and corrects errors in a sequence rather than in parallel, the time delay was divided into a combination of the pure delay and a gap where the input was maintained at a given value for the time a pilot could be considered flying another axis or scanning other instruments and therefore not activily flying the vertical task. The length of the time delay, the length of the gap, and how often the gap occurs are variables that can be initialized at the beginning of a run. In addition there are inputs for pilot preception error noise and pilot internal noise. These are discussed in more detail later.

3. Ship Model

An understanding of sea state can be gained by referring to the chart in Figure 4. Sea state is shown with the associated wind, wave heights, lengths, and periods. Sea state 6 is considered significant in that it is estimated that operational capability under these conditions would provide for use of aircraft 67% of the

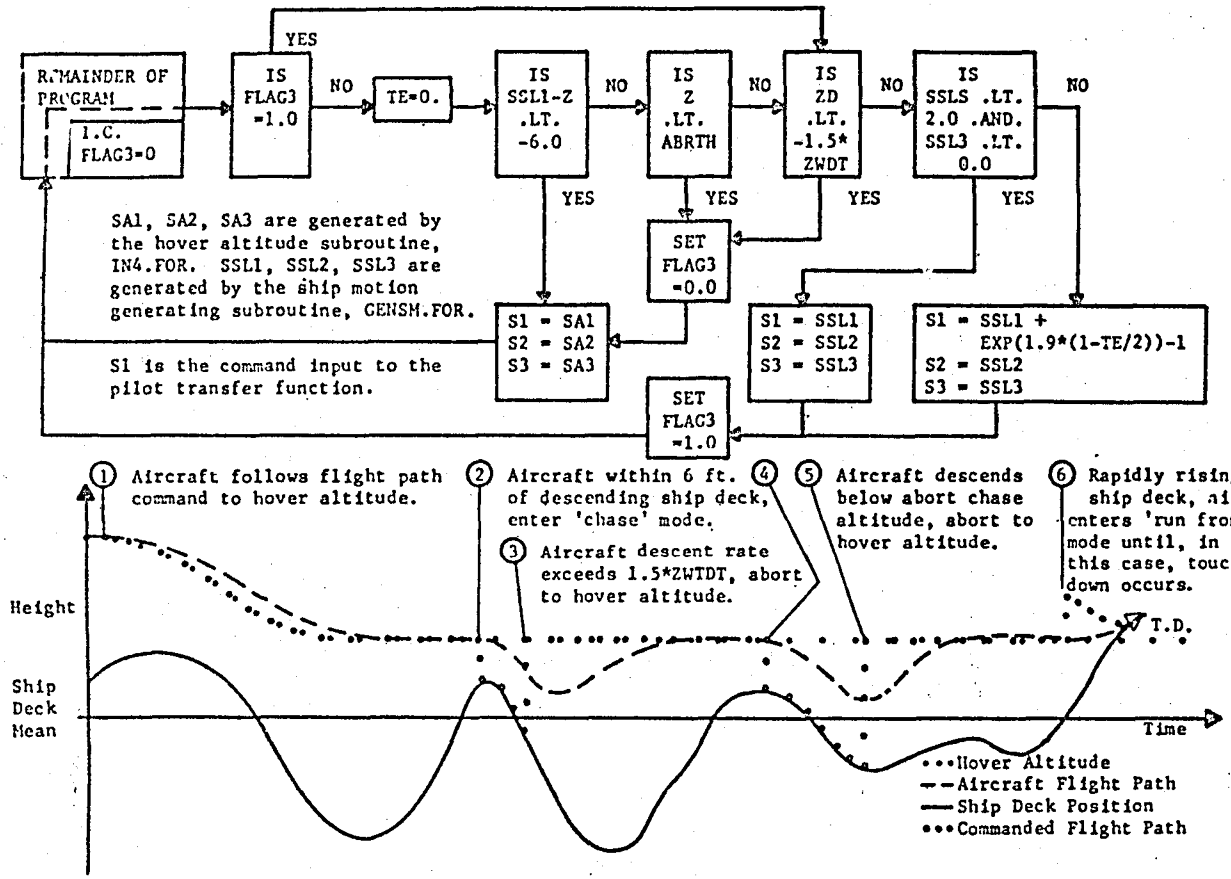
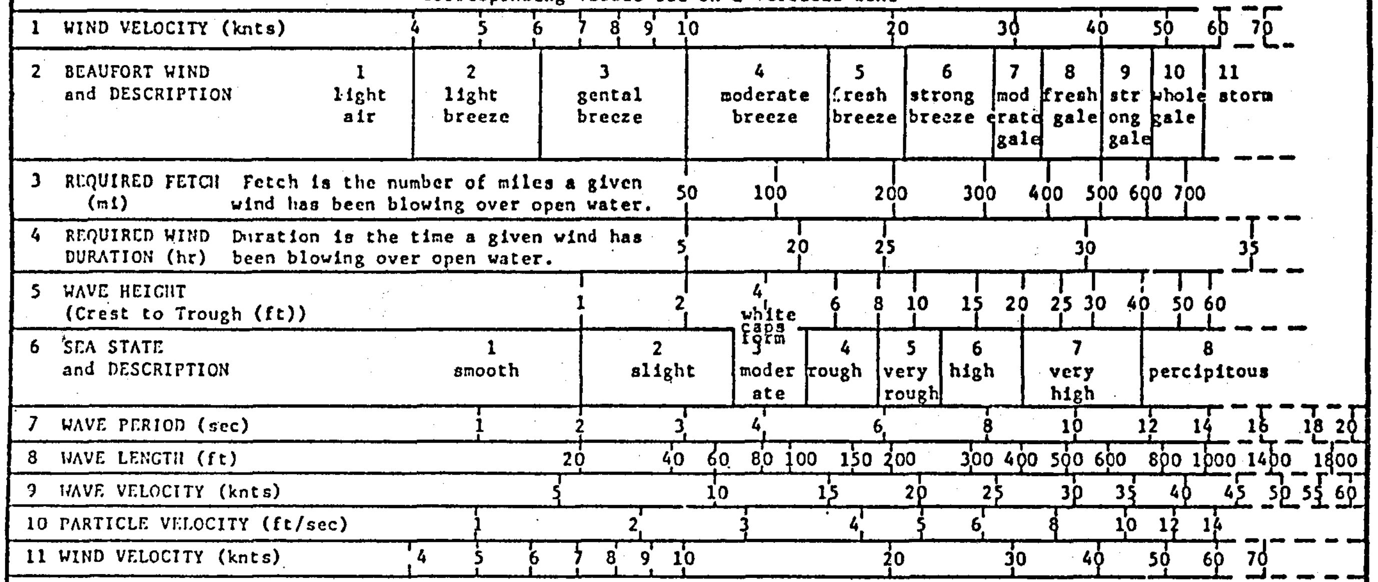


Figure 3: Block Diagram and Example Time History of the Original Flight Path Command Logic

WIND WAVES AT SEA

Corresponding values lie on a vertical line



This table applies to waves generated by the local wind and dows not apply to swell orginating elsewhere.

WARNING NOTE: Presence of swell makes accurate wave observations exceedingly difficult.

a. The height of waves is arbitrarily choosen as the height of the highest 1/3 of the waves. Occasional waves by interference between waves or between waves and swell may be considerably larger.

b. The above values are only approximate due to lack of precise data and to the difficulty in expressing it in a single easy way.

c. Below the surface the wave motion decreases by 1/2 for every 1/9 of a wave length of depth increase.

Figure 4: Wind Waves at Sea

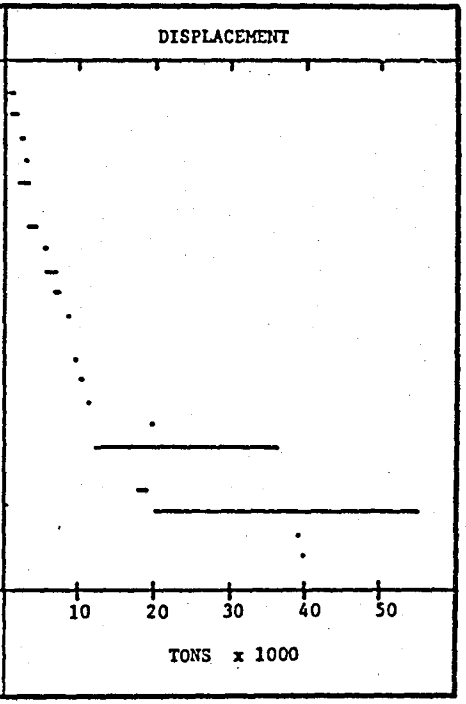
time, in the North Atlantic during January. If operations can be conducted only under sea state 3 conditions, operations would be limited to 31% of the time.

It should be noted that ship motion may be considerably greater than indicated by the wave amplitude values. For example in sea state 6 the wave height maximum is 20 ft from crest to trough. The heave motion for the DD963 class destroyer can approach 40 ft from crest to trough under sea state 6 conditions.

The DD963 Spruance class destroyer model was used for both the piloted and non-piloted simulation. This ship was chosen because a motion program for use with the piloted simulation was already available. The DD963 is considered to be typical of the type of ship from which VTOL operations could be conducted. The non-piloted simulation was set up so that data for other ships, as contained in Reference 8, could also be used. To provide some perspective of the ship used, Figure 5 shows a listing of ships according to type and class, information on the number of helicopters (assumed replaceable by VTOL aircraft) that can be carried, dimensional information, and a chart showing displacement.

A single degree of freedom ship model was programmed using the method outlined in Reference 9. The data for the DD963 class destroyer were obtained from Reference 8. The model consists of the superposition of twelve sine waves, six representing the heave motion at the ships center of gravity and six representing the pitch motion. The pitch motion is multiplied by the appropriate moment

SHIP	TYPE	CLASS	HELI-COPTER	DIMENSIONS		
				L (ft)	W (ft)	H (ft)
RELIANCE	C. G. CUTTER	WMEC 615	1	210.5	34	10.5
BEAR	C. G. CUTTER	WMEC 901	1	270	38	13.5
GARCIA	FRIGATE	FF 1040 *	1	414	44	24
WEST WIND	ICE BREAKER	WAGB 83	2	269	63.5	29
O.H. PERRY	FRIGATE	FFG 7 *	2	445	45	24.5
KNOX	FRIGATE	FF 1052 *	1	438	46.8	24.8
MACKINAW	ICE BREAKER	WAGB 83	1	290	74	19
SPRUANCE	DESTROYER	DD 963 **	2	563.2	55.1	29
BELKNAP	G. MISSLE CRUISER	CG 26	1	547	54.8	28.8
GLACIER	ICE BREAKER	WAGB	2	309.6	74	29
AUSTIN	AMPHIB. TRANS. DOCK	LPD 4	6	570	100	23
MARS	COMBAT STORES	AFS 1	2	581	79	24
IWO JIMA	AMPHIBIOUS ASSUALT	LPH 2 ***	11-20	602	84	26
KILAUEA	AMMUNITION	T-AE 26	2	564	81	28
WICHITA	REPLENISHMENT OILER	AOR 1	2	659	96	33.3
BLUE RIDGE	AMPHIBIOUS COMMAND	LCC 19	1	620	82	29
SACRAMENTO	FAST COMBAT SUPPORT	AOE 1	2	793	107	39.3
SAIPAN	AMPHIBIOUS ASSUALT	LHA 2	19-26	820	106	26
---	AMPHIBIOUS ASSUALT	LHD 1	19-26	840	106	26



* OTHER SHIPS CONTAINED IN REF. 4 DATA BASE
** SHIP MODELED IN THIS SIMULATION
*** THIS SHIP IS ALSO MODELED AT N.A.S.A. AMES

Figure 5: U. S. Non-Aviation Ships

arm and the vertical component is extracted and added to the heave motion to obtain the heave motion at the landing pad. Reference 9 reports that this method gives ship motion accuracies to within 5% of a model containing 30 superimposed sine waves per axis.

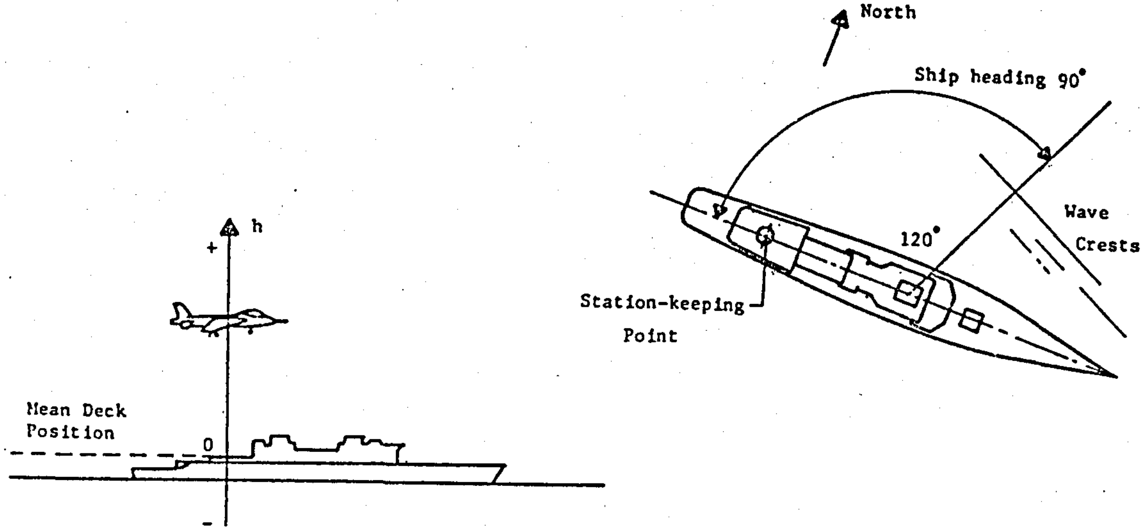
This ship motion program uses the Bretschneider wave spectrum, transformed based on ship velocity and heading relative to the waves. The ship motion spectrum is then obtained by combining the wave spectrum with the ship response functions and phase differences, ϕ_{ii}, and the six amplitudes, A_n, and frequencies, ω_{en}, are extracted. The appendix contains more information on how this is accomplished. A component of the ship motion is then represented by

$$i(t) = \sum_{n=1}^{6} A_n \cos(\omega_{en} t - \phi_{ii} + E_n) \qquad (5)$$

The phase differences are directly available from the ship motion data base information contained in Reference 8. E_n is a random phase angle which is obtained from a random number generator with an output scaled to give valued between 0 an 6.242 radians. Figure 6 shows a graphical definition of the axis system used in the simulation.

4. Turbulence Model

The turbulence model (Reference 9) consists of white noise, shaped by the following filters:



NON-PILOTED SIMULATION
AXIS DEFINITION

NON-PILOTED SIMULATION SHIP
OREINTATION TO WAVES

Figure 6: Axis Definitions for the Non-Piloted Simulation Model

$$\dot{A}_R = \omega_n A_R + \sigma_v (2\omega_n)^2 n(1/TC^{1/2})$$

$$A_R = A_R + TC\ \dot{A}_R \tag{6}$$

Where A_R is turbulence induced accelerations on the aircraft in g's. The bandwidth, ω_n, was obtained from Reference 9. Values of the variance, σ_v, were obtained from a strip-chart recording of the turbulence induced vertical acceleration for the AV-8A during a fixed-based simulation. The term containing the simulation time increment, TC, is a correction to the power spectrum to allow for digitization. The quantity, n, is a random number from a Guasian distributed sequence with zero mean and unity variance.

D. RESULTS FOR NON-PILOTED SIMULATION

Touchdown velocities obtained from the non-piloted simulation incorporating the flight path command logic devised prior to the piloted simulation are shown in Figure 7. This figure shows the average over many runs during which damping constants, and various parameters in the flight path command logic, as well as pilot gain, were being manipulated to roughly determine the range of values that could be expected for touchdown velocities. These runs were also monitored as they were occurring to determine (subjectively) which values provided realistic piloting responses. As such, the results should be interpreted as a rough indication of the trends.

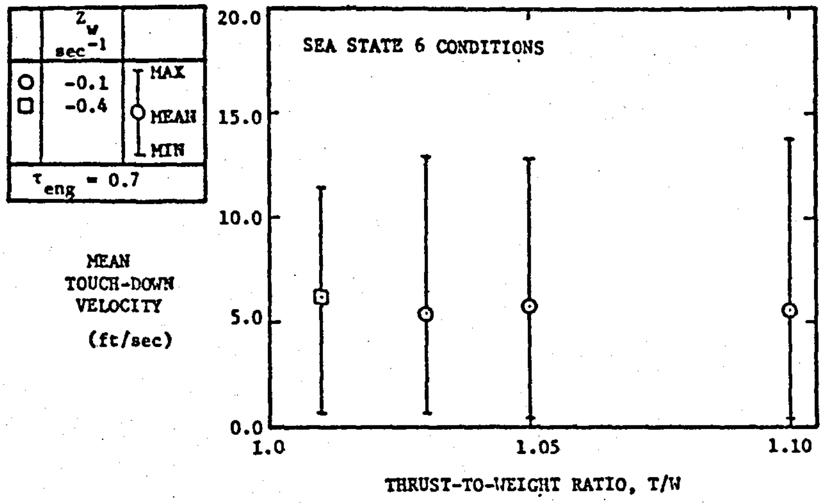


Figure 7: Non-Piloted Simulation Touchdown Velocity Results

Figure 7 shows that in sea state 6 conditions, the orginal flight path command logic suggested the very surprising result that the landing task could be accomplished without ever exceeding a touchdown velocity of 12 ft/sec, for T/W values down to 1.01 and with engine lags as high as 0.7 sec. Moreover, the mean value of touchdown velocity was only mildly dependent on T/W and engine lag, ranging between 5.5 ft/sec and 6.5 ft/sec. Flight times from the initial altitude of 20 ft above the mean deck height were again only mildly dependent on T/W and engine lag, ranging from 20 to 30 sec.

The unexpected nature of the preliminary non-piloted simulation results strongly indicated the need for experimental verification. This experiment was performed on a fixed-base simulator at N.A.S.A.

Ames Research Center using an existing model of the AV-8A. It was recognized from the outset that an important requirement of this experiment was the need to supply the pilot with exactly the same information assumed in the construction of the command logic in the non-piloted simulation. Fortunately, an existing head-up display format termed SUPAR HUD (Reference 10) was available and was modified by removing all augmented information and adding the basic situation information of mean deck position, and the 2 sigma and 3 sigma deck positions relative to the mean.

III. SIMULATION EXPERIMENT

A description of the test matrix, aircraft and ship models, simulation cab, and results obtained for the piloted simulation are presented in the following sections.

A. TEST MATRIX

Based on the information gained from the non-piloted simulation, the test matrix shown in Figure 8 was set up. Sea state, thrust-to-weight ratio, vertical velocity damping through thrust, pilot, and HUD format were the variables. The task was then simulated using the fixed-base simulation facilties as further descibed below.

B. AIRCRAFT MODEL

1. Basic Aircraft

The AV-8A model used in the piloted simulation is described in Reference 6. It is a real time digital computer program developed to simulate the take-off and landing of V/STOL aircraft aboard ship. The unmodified aircraft model includes nonlinear aerodynamics, engine and reaction control systems, stability augmentation and actuator dynamics, and a landing gear model.

	HUD FORMAT	HUD1 VEL. COM. SYS.										HUD3 VEL. COM. SYS.										HUD3 ATT. COM. SYS.									
SEA STATE	ENGINE LAG	0.3					0.7					0.3					0.7					0.3					0.7				
	T/W Z_w	1.01	1.03	1.05	1.07	1.10	1.01	1.03	1.05	1.07	1.10	1.01	1.03	1.05	1.07	1.10	1.01	1.03	1.05	1.07	1.10	1.01	1.03	1.05	1.07	1.10	1.01	1.03	1.05	1.07	1.10
0	-0.0											○	○	○	○	○	○	○	○	○	○										
	-0.2											○	○	○	○	○	○	○	○	○	○										
	-0.4											○	○	○	○	○	○	○	○	○	○										
4	-0.0											○	○	○	○	○	○	○	○	○	○										
	-0.2											○	○	○	○	○	○	○	○	○	○										
	-0.4											○	○	○	○	○	○	○	○	○	○										
6	-0.0	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		○		○	○		○		○
	-0.2	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		○		○	○		○		○
	-0.4	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		○		○	○		○		○

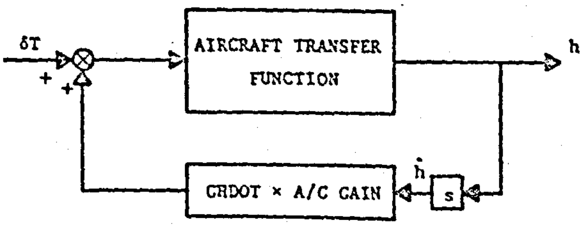
○ INDICATES AREAS OF MATRIX TESTED

Figure 8: Test Matrix for the Piloted Simulation

2. Modifications to the Simulation Model

Only the turbulence portion of the airwake simulation was used. In order to create a simulation environment as close as possible to that assumed in the non-piloted simulation, the mean wind and its variation with height above deck were not used. In addition, the ground effects inherent in the AV-8A were deleted from the simulation to match the non-piloted simulation, and to more effectively isolate the parameters being studied.

A block diagram of the vertical velocity damping through thrust is presented in Figure 9, along with a definition of the variables used.



GHDOT - POWER LEVER ANGLE (deg)/(ft/sec)
A/C GAIN - 0.45 (ft/sec^2)/POWER LEVER ANGLE (deg)

Figure 9: Block Diagram of Vertical Velocity Damping through Thrust as Implemented in the Simulations

3. Control Augmentation System

In running the simulation, the throttle quadrant was used with a fixed range of travel throughout the test matrix. As a result, the throttle sensitivity (vertical acceleration per degree of throttle) varied with thrust-to-weight ratio. A plot of commanded g per degree of throttle travel may be found in Figure 10.

Two control systems were used for the fixed-based simulation. For the portion of the simulation in which only the vertical axis was being flown, a translational velocity command system was used. With this system the stick controls velocity in the longitudinal and lateral directions. When the pilot leaves the stick centered, the aircraft maintains position (zero velocity). The pilot only had to control the throttle to perform the task.

The second control system was an attitude command system. It was used to provide a positioning sidetask for the pilot. Using this system, the pilot flew the vertical task using throttle and had to actively maintain position over the ship deck by commanding attitude through the stick.

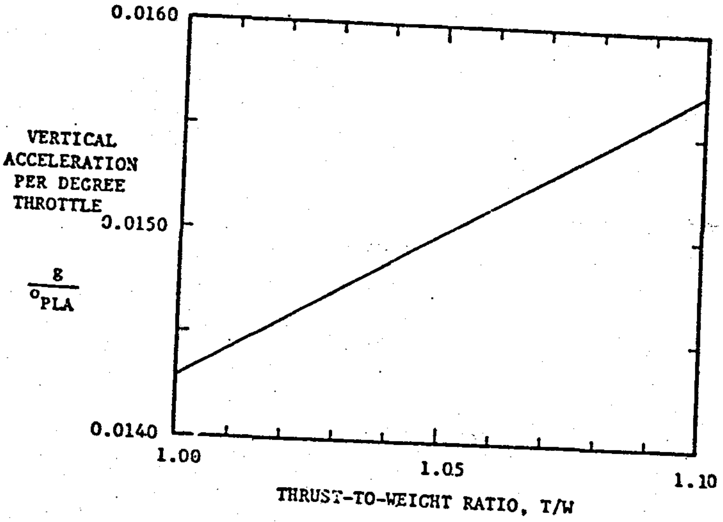


Figure 10: Throttle Control Sensitivity

The transfer functions for the control systems are as follows:

Translational velocity command system:

$$V_x = \frac{1.25}{s + 1.25} \qquad V_y = \frac{1.25}{s + 1.25}$$

$$\frac{V_{x_{cmd}}}{V_{stick}} = 7 \, \frac{ft/s}{in} \qquad \frac{V_{y_{cmd}}}{V_{stick}} = 7 \, \frac{ft/s}{in} \qquad (7)$$

Attitude command system:

$$\frac{\phi}{\phi_{cmd}} = \frac{4}{(s^2 + 3s + 4)} \qquad \frac{\theta}{\theta_{cmd}} = \frac{4}{(s^2 + 3s + 4)}$$

$$\frac{\phi_{cmd}}{\phi_{lat\ stick}} = 11°/in \qquad \frac{\theta_{cmd}}{\theta_{long\ stick}} = 11°/in \qquad (8)$$

More information on the control systems being used in fixed-based simulations may be found in Reference 11.

4. Head-Up Display

Two HUD displays were used in the piloted simulation. These are referred to as HUD1, and HUD3, and are shown in Figure 11. HUD3 was used most extensively in the testing. HUD3 contains the ship position reference lines and aircraft hover height and "abort chase" altitude lines. HUD1 contains only the symbol indicating current ship deck position. HUD1 was used to determine how much (if any) advantage there was to displaying the extra information on ship motion boundaries. It should be noted that the HUD3 format collapses into the HUD1 format for calm seas (sea state 0).

The head-up display superimposes vertical and horizontal situation information. The trident symbol is fixed in the center of the display and shows the aircraft's vertical position as the distance of the three 'pads' of the trident from the top of the ship deck reference symbol. In addition, the trident provides horizontal situation indications to the pilot when actively flying the sidetask with the attitude command control system. When the sidetask is flown, a dagger is added to the display to indicate the undisturbed position of the deck bull's-eye. The distance between the trident and the dagger shows the error in lateral and longitudinal position. The HUD format also contains symbols showing a horizon line, pitch bars, pitch reference, and side slip. The lines added for the experiment show the 3 sigma, 2 sigma, abort chase height, and mean deck positions.

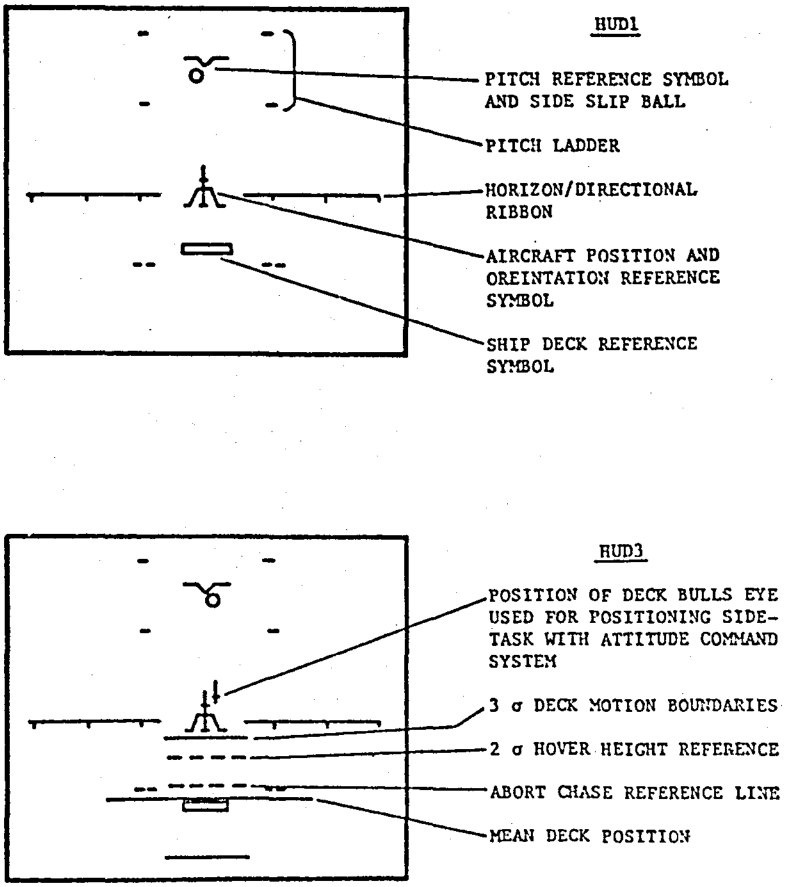


Figure 11: Head-up Display Format and Symbology Definitions

The equations describing the transfer function for moving the dagger relative to the trident are described in appendix B. To assist the pilot in performing the station keeping task the dagger motion is augmented with input of aircraft true velocity, the estimated acceleration, and stick position. The HUD symbology was driven by a Digital Corperation PDP-1VES computer at an update frame time of 110 msec.

C. SHIP MODEL

Ship dynamics are modeled as six degree of freedom sinusodial motion. The ship is assumed to have a fixed mean position about which it oscillates. Wind over the deck is composed of a steady induced wind equal to the ship speed plus a separate North or East component of natural wind which can be specified. At present a turbulence model developed for the DD963 class destroyer is used (Reference 8). This subroutine calculates the free air turbulence as well as ship wake turbulence. The latter varies with position relative to the landing pad. Table 2 gives an indication of the environmental conditions for the simulation.

D. SIMULATION FACILITIES

1. Simulator

The fixed-base chair (Ch. 06), is used primarily to develop controls and head-up displays for use in VTOL aircraft and

Table 2: Simulation Environmental Conditions for the DD963 Class Destroyer

CONDITION NUMBER	SEA STATE	V_s (knts)	μ_s (deg)	ψ_w (deg)	ψ_{wod} (deg)	V_w (knts)	V_{wod} (knts)	H_s (m)	T_o (sec)
1 7 14	6 4 0	25 25 10	120 105 -	-60 -75 -68.6	-30 -30 -30	25.00 17.68 8.07	43.30 34.15 15.00	5.49 2.10 0	15.13 10.60 -
	σ_ϕ (deg)	σ_θ (deg)	σ_ψ (deg)	$\sigma_{x_{cg}}$ (m)	$\sigma_{y_{cg}}$ (m)	$\sigma_{z_{cg}}$ (m)	σ_{x_ℓ} (m)	$\sigma_{y_{\ell p}}$ (m)	$\sigma_{z_{\ell p}}$ (m)
1 7 14	3.13 1.11 0	1.05 0.34 0	0.45 0.17 0	0.24 0.05 0	0.71 0.27 0	1.51 0.60 0	0.45 0.12 0	0.63 0.18 0	1.67 0.65 0
	$\sigma_{\dot\phi}$ (deg/sec)	$\sigma_{\dot\theta}$ (deg/sec)	$\sigma_{\dot\psi}$ (deg/sec)	$\sigma_{\dot x_{cg}}$ (m/sec)	$\sigma_{\dot y_{cg}}$ (m/sec)	$\sigma_{\dot z_{cg}}$ (m/sec)	$\sigma_{\dot x_{\ell p}}$ (m/sec)	$\sigma_{\dot y_{\ell p}}$ (m/sec)	$\sigma_{\dot z_{\ell p}}$ (m/sec)
1 7 14	2.00 0.88 0	0.90 0.32 0	0.36 0.18 0	0.15 0.04 0	0.41 0.21 0	1.10 0.53 0	0.32 0.10 0	0.46 0.20 0	1.31 0.59 0

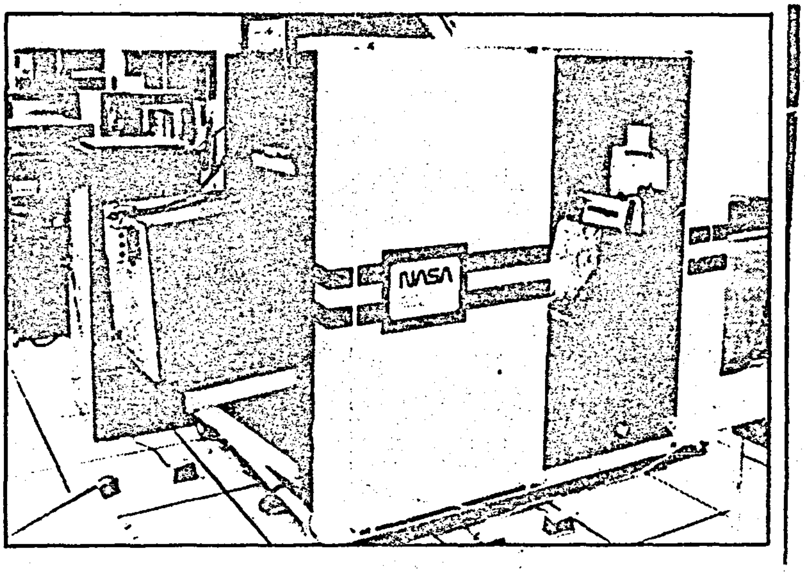
helicopters (Figure 12). Configured as a single-seat cockpit, it is equipped with a conventional stick and rudder pedals with adjustable trim. The chair is provided with a virtual image TV display, on a single forward looking window. The outside scene is provided by a camera-terrain board system. A head-up display can be superimposed on the outside scene to provide flight information to the pilot. The cockpit also contains a unique throttle/nozzle control quadrant used for V/STOL simulation. Aircraft dynamics are provided by a Xerox Sigma 9 digital computer. The aircraft dynamics are updated at a frame time of 55 msec for the AV-8A model.

2. Pilots

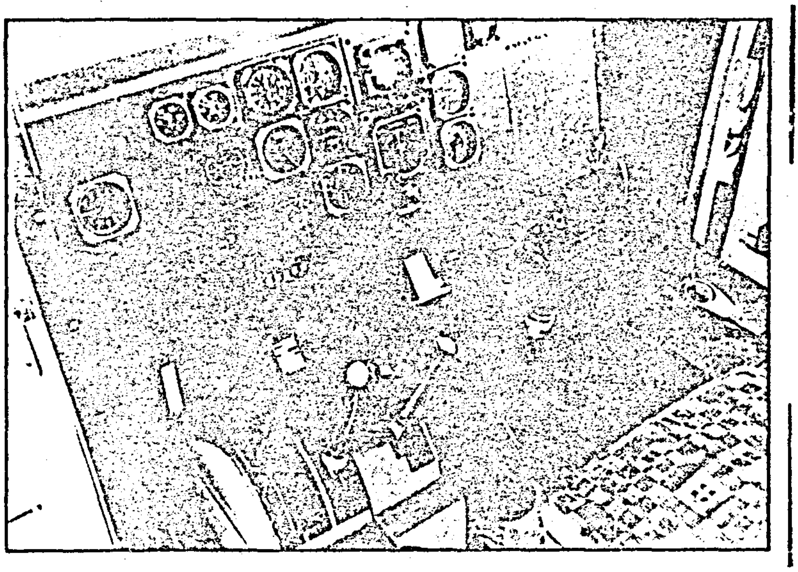
Two pilots were used for the simulation. Both pilots were used in the sea state 6 portion of the test matrix. Pilot B filled in the remaining tested portions of the test matrix.

Pilot A is a research engineer at NASA Ames Research Center. He has been flying both the fixed and moving base simulators for 15 years. Most of this time has been spent using the AV-8A and YAV-8B simulation models. He was also heavily involved in simulations of advanced lift-fan transport (ALFT) aircraft and the Navy research and technology aircraft (RTA).

Pilot B is also a research engineer at NASA Ames Research Center. He has been flying both the fixed and moving base simulators for over 4 years. Most of his simulation time has also been with the AV-8A and YAV-8B models. He also has some helicopter simulation time.



a. Outside View of the Cab



b. Inside View of the Cab

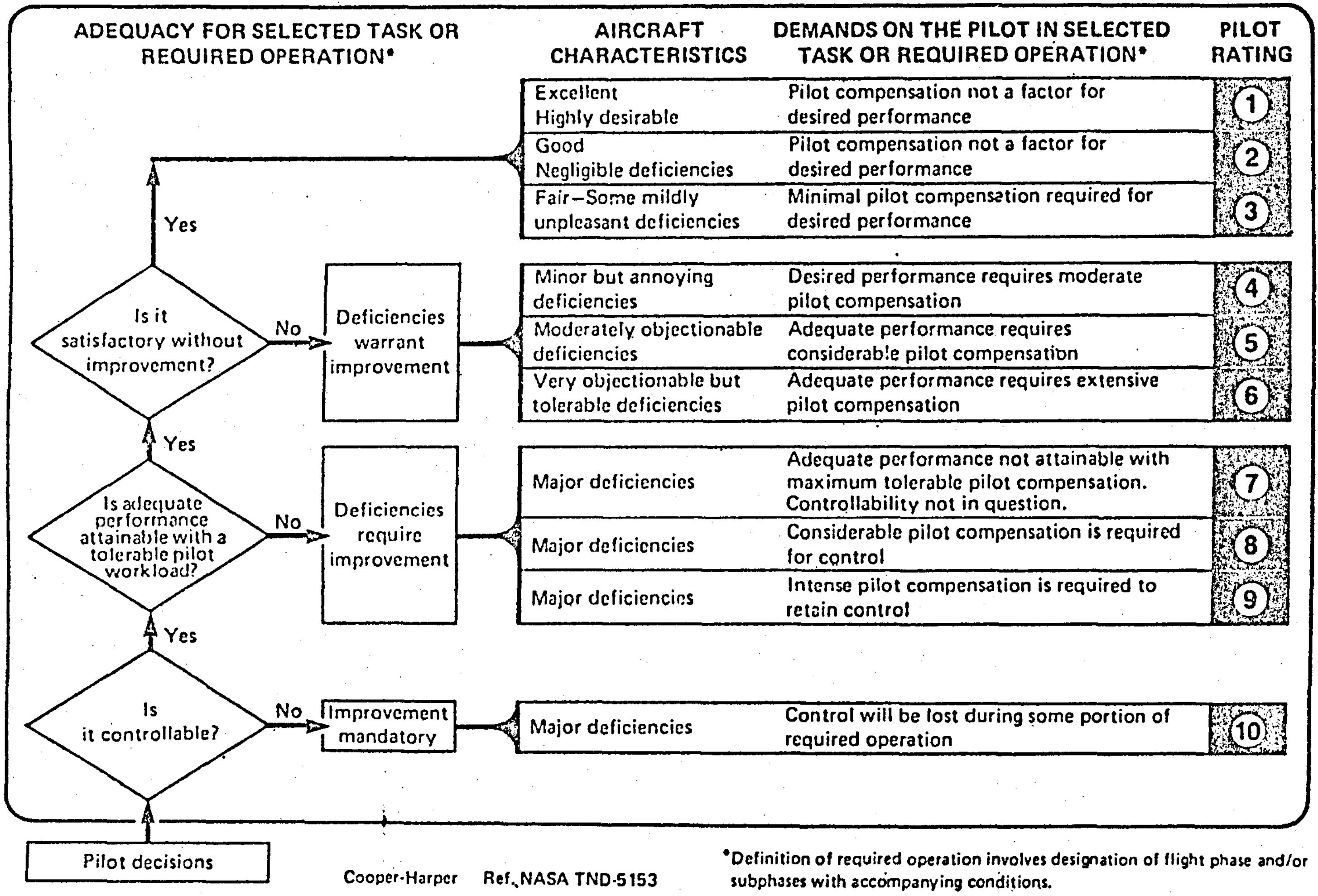
Figure 12: The Chair 6 Fixed-Base Simulator

The pilots were asked for comments and a pilot rating following each series of the five runs that made up a data point. The pilot rating is based on the Cooper-Harper rating scale (Figure 13). More information on the Cooper-Harper scale may be found in Reference 12.

E. OPERATIONAL TASK

The task to be flown was the same as described in the non-piloted simulation. The aircraft was positioned at an initial altitude of 45 ft above the mean deck position, in a stabilized hover, directly over the bull's-eye on the ship deck landing pad. The pilot, through use of throttle, was then to control altitude and vertical velocity in descending to an initial hover altitude. The intial hover altitude was the 2 sigma value of the ship deck position, above the ship deck position mean, as designated by a line on the HUD (HUD3). The pilot was then to land at his descretion, aided by the ship deck motion information presented on the HUD.

There were two variations of the task. In the first, the HUD was reconfigured so that the ship deck motion boundaries and position reference lines were not displayed (HUD1). The pilot was then to complete the task with only the deck position symbol as a reference. In the second variation, the control system was changed from the translational velocity command system to an attitude command system. This was done to provide the pilot with the sidetask of actively using the stick to maintain the aircraft position over the deck bull's-eye while performing the vertical task.



AIRCRAFT CHARACTERISTICS	DEMANDS ON THE PILOT IN SELECTED TASK OR REQUIRED OPERATION*	PILOT RATING
Excellent Highly desirable	Pilot compensation not a factor for desired performance	1
Good Negligible deficiencies	Pilot compensation not a factor for desired performance	2
Fair—Some mildly unpleasant deficiencies	Minimal pilot compensation required for desired performance	3
Minor but annoying deficiencies	Desired performance requires moderate pilot compensation	4
Moderately objectionable deficiencies	Adequate performance requires considerable pilot compensation	5
Very objectionable but tolerable deficiencies	Adequate performance requires extensive pilot compensation	6
Major deficiencies	Adequate performance not attainable with maximum tolerable pilot compensation. Controllability not in question.	7
Major deficiencies	Considerable pilot compensation is required for control	8
Major deficiencies	Intense pilot compensation is required to retain control	9
Major deficiencies	Control will be lost during some portion of required operation	10

Cooper-Harper Ref. NASA TND-5153

*Definition of required operation involves designation of flight phase and/or subphases with accompanying conditions.

Figure 13: Handling-Qualities Rating Scale

F. RESULTS FOR THE PILOTED SIMULATION

1. Task Performance and Pilot Ratings

A record of the test matrix and runs completed may be found in Appendix B.

As might be expected from the random nature of the ship motion, the time to complete the task was the most variable parameter. The average time over each series of 5 runs as a function of sea state, HUD, and T/W (Figure 14) lies in a band from 19 to 36 seconds.

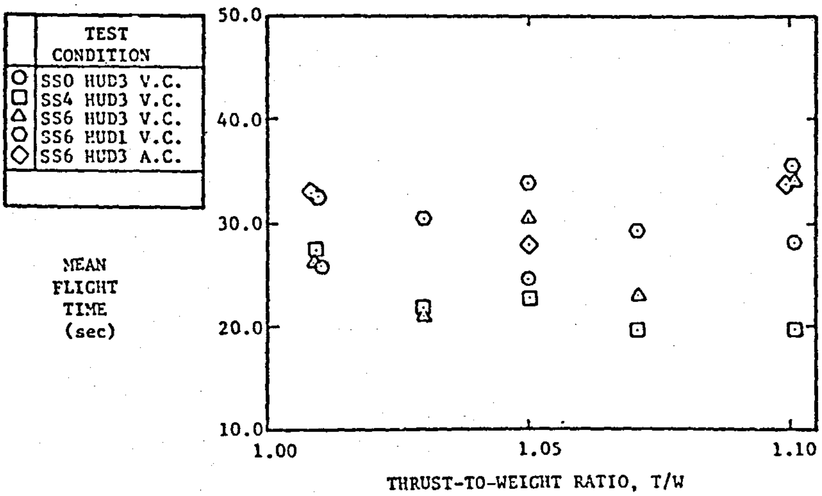


Figure 14: Mean Flight Times for the Piloted Simulation

Individual times varied from a low of 7.2 seconds for a particular sea state 4, HUD3 run, to a high of 79.0 seconds for a sea state 6, HUD1 run. It should be noted that the addition of the sidetask does not appear to change the amount of time the pilot takes to complete the task.

The non-piloted simulation showed that the mean time and standard deviation for flight time did not approach a steady value until after approximately 40 runs, indicating why such a large variation exits for the piloted simulation groups of 5 runs each.

Average touchdown velocity as a function of T/W for HUD1, sea state 6 conditions are presented in Figure 15 for two values of engine response. The following points should be noted: 1) In general there is a less than expected change in touchdown velocity with change in T/W ratio (less than 4.0 ft/sec for the T/W ratio range tested), 2) The faster engine time response (0.3 secs) produce touchdown velocities of 0.5 to 1.5 ft/sec less than the slower responding engine (0.7 secs) and 3) The greater vertical velocity damping the lower the touchdown velocity (as much as 4 ft/sec).

Pilot ratings as a function of T/W for HUD1, sea state 6 conditions are presented in Figure 16 for two values of engine response. The following items should be noted: 1) The pilot rating is higher (worse) as T/W ratio goes down over the range tested, 2) Pilot rating is higher (worse) as engine lag is increased and as vertical velocity damping is decreased (as much as 2.5 points difference) 3) With the HUD1 system and low vertical damping there are ratings in the Inadequate range even for T/W ratios of 1.1.

Average touchdown velocity and pilot ratings as a function of the control system and HUD format are presented in Figure 17.

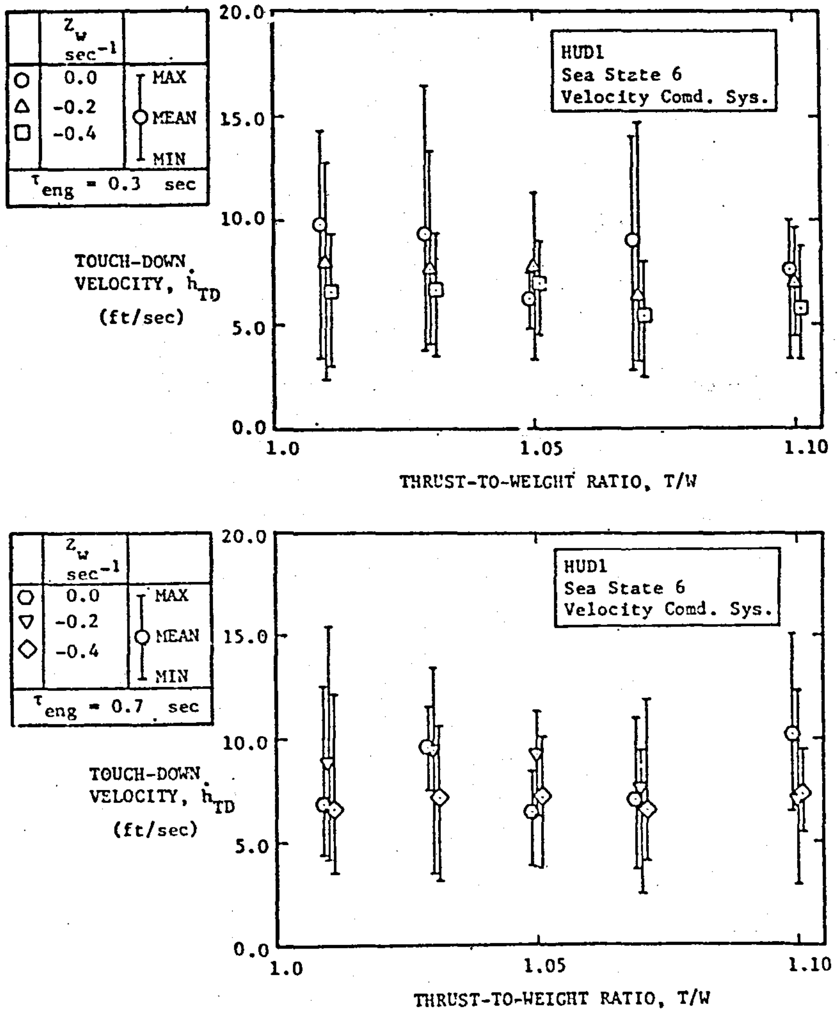


Figure 15: Influence of Thrust-to-Weight Ratio, Engine and Airframe Dynamics on Touchdown Sink Rate--Baseline HUD with Velocity Command Control System

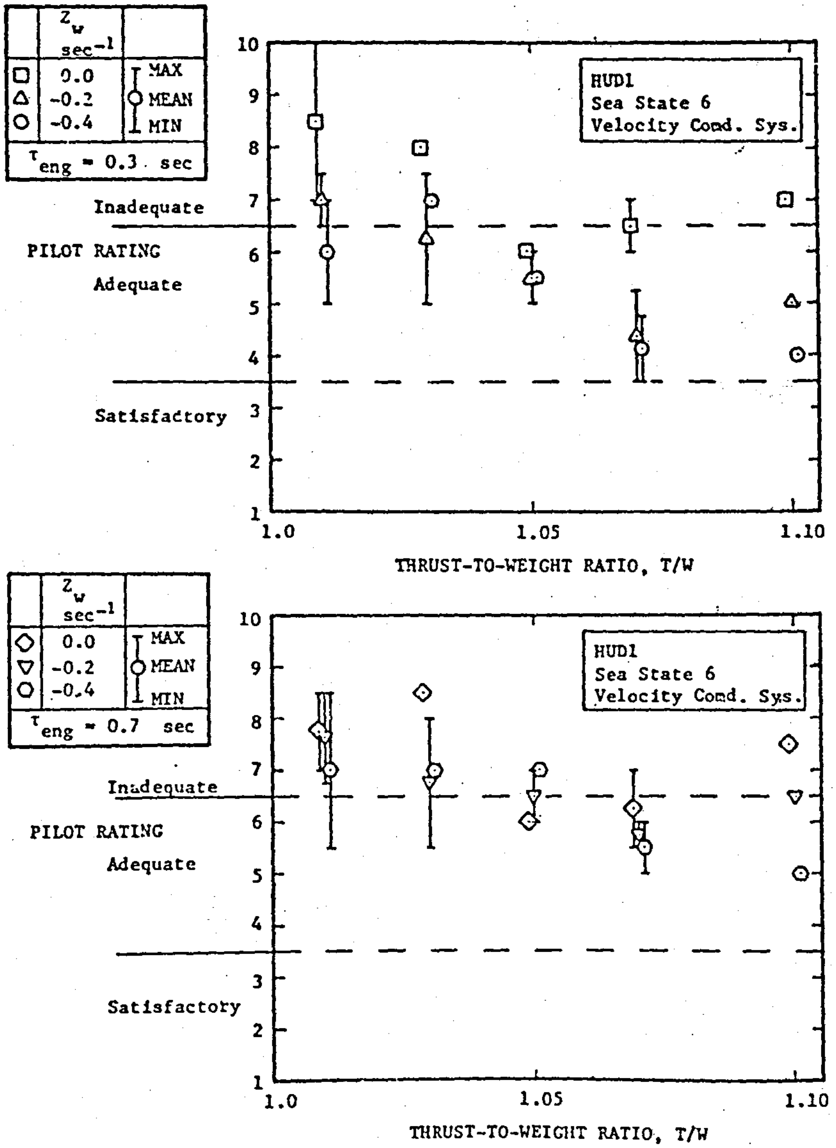


Figure 16: Influence of Thrust-to-Weight Ratio, Engine and Airframe Dynamics on Pilot Ratings--Baseline HUD with Velocity Command Control System

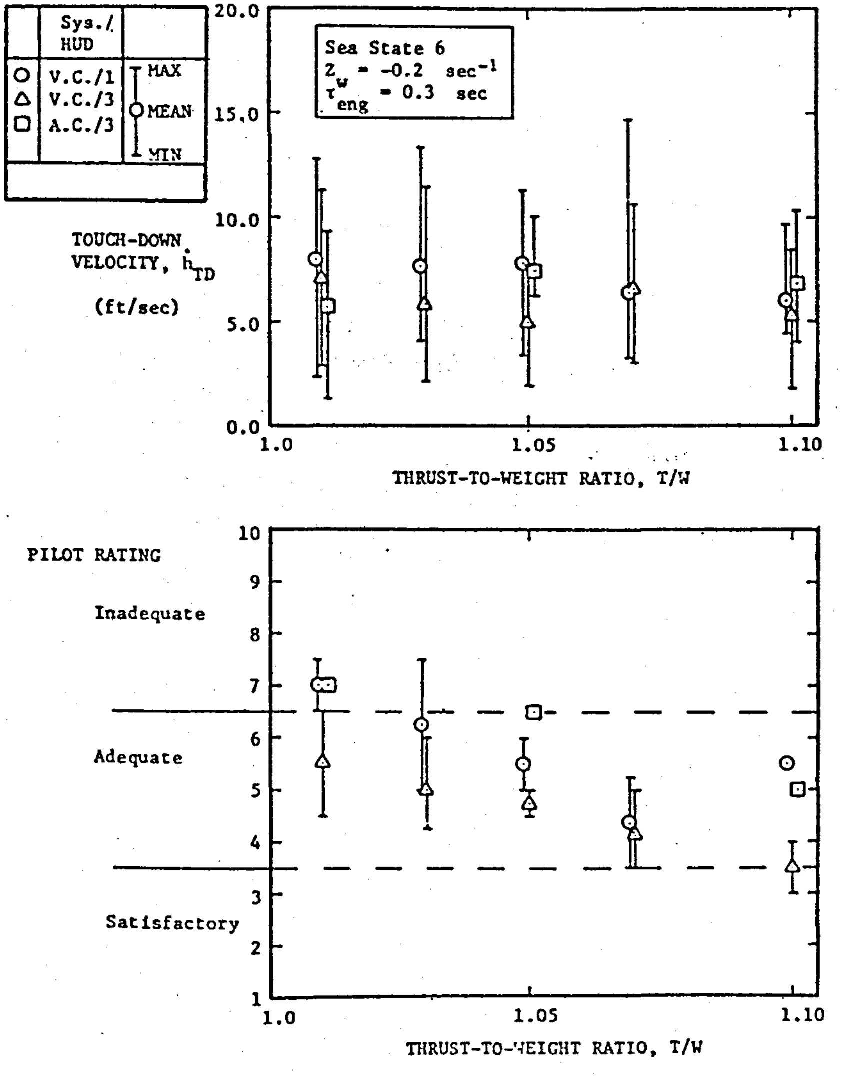


Figure 17. Comparison of Touchdown Sink Rate and Pilot Rating as Influenced by Thrust-to-Weight Ratio for a Selected Condition--Baseline HUD with Velocity and Attitude Control Systems

As shown, the touchdown velocity and pilot ratings are both improved with the additional information of the HUD3 format. There is as much as a 2.5 ft/sec improvement in average touchdown velocity in going from HUD1 to HUD3. It should also be noted that HUD3 produced an Adequate pilot rating throughout the range of T/W ratio tested for the stated engine response and vertical damping (Figure 17). The addition of the sidetask did not seem to influence the result in any systematic manner.

Average touchdown velocity as a function of T/W for HUD3, sea state 6 conditions are presented in Figure 18. Again note that there is little change in average touchdown velocity over the T/W ratio range tested (less than 3 ft/sec for the worse case). Average touchdown velocities are 0.5 to 3 ft/sec better with the HUD3 format than for the HUD1 format (Figures 15 and 18). The engine time constant and vertical velocity time constant have a much smaller and less consistent effect on average touchdown rate for the HUD3 format (Figures 15 and 18).

Pilot rating as a function of T/W for HUD3, sea state 6 conditions are presented in Figure 19. The most interesting thing to note here is that the average ratings are Adequate for all conditions tested throughout the T/W ratio range tested. The pilot ratings also show more clearly that the faster responding engine and greater vertical velocity damping are important to the pilot as evidenced by the consistent effect they have on pilot rating. There is as much as one pilot rating improvement attributable to either a fast responding engine or good damping.

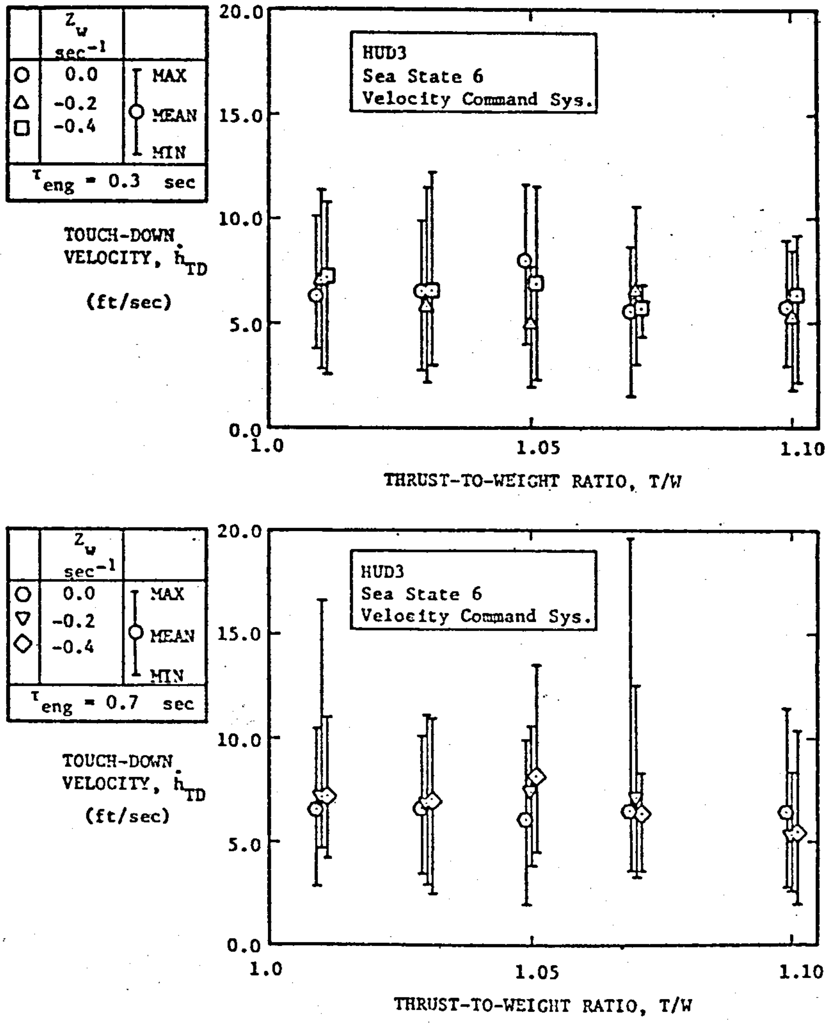


Figure 18: Influence of Thrust-to-Weight Ratio, Engine and Airframe Dynamics on Touchdown Sink Rate--Augmented HUD with Velocity Command Control System

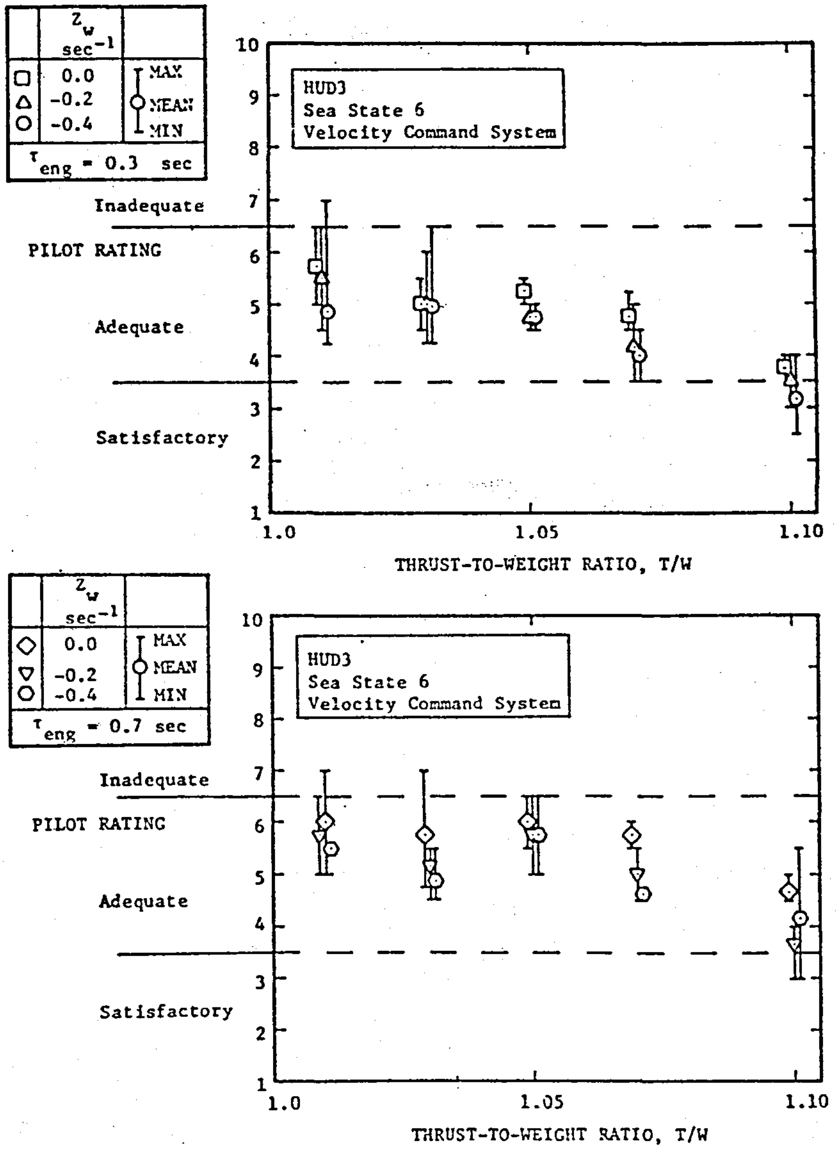


Figure 19: Influence of Thrust-to-Weight Ratio, Engine and Airframe Dynamics on Pilot Ratings--Augmented HUD with Velocity Control System

Figure 20 provides some perspective on the effect of sea state on average touchdown velocity and pilot rating, for a selected, condition using the HUD3 format. Note the relatively small change in touchdown velocity over the range of sea state, the greatest change occurring for T/W ratio of 1.01 (an increase of 5.0 ft/sec from calm sea to sea state 6). The pilot ratings show Satisfactory ratings for sea state 0 and 4 and Adequate ratings at sea state 6 for all T/W ratios for the selected condition.

The miss distance when performing the sidetask associated with the attitude command system is presented in Figure 21 for various values of T/W. The miss distance is the horizontal distance from the aircraft center of gravity to the center of the bull's-eye on the ship deck at the time of landing. It is interesting to note that the average miss distance changes less than a foot with the fast responding engine while changing 5.5 feet for the slow responding engine over the T/W ratio range tested. In both cases the miss distance decreases with decreasing T/W ratio. Possible reasons for this result would include; too much control sensitivity at higher T/W, or a change in piloting technique; i.e., the pilot may be spending a different percentage of time, or changing the frequency with which he samples the information at the different T/W ratios.

A better understanding of the relative performance of HUD1 and HUD3 can be gained from Figure 22, which shows a histogram of the landing performance for HUD1 and HUD3 with a histogram of the ship deck motion for sea state 6 conditions.

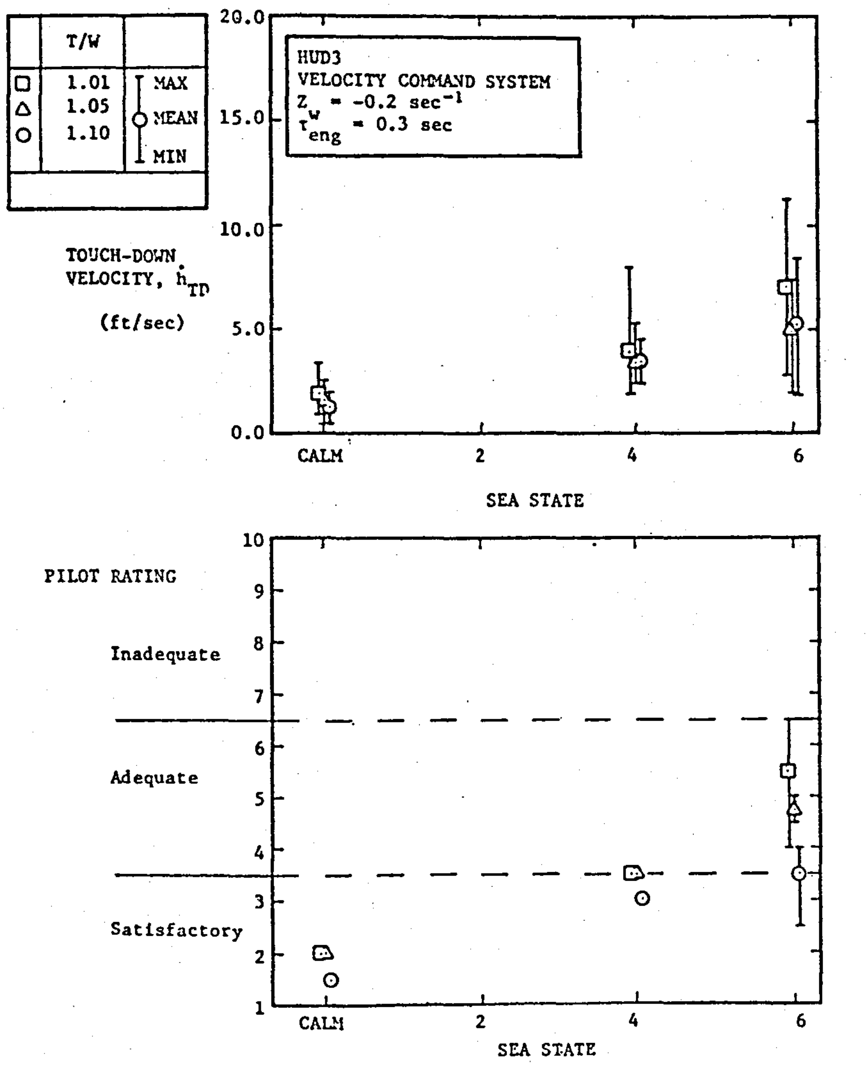


Figure 20: Comparison of Touchdown Sink Rate and Pilot Rating as Influenced by Sea State for a Selected Test Condition--Augmented HUD with Velocity Command Control System

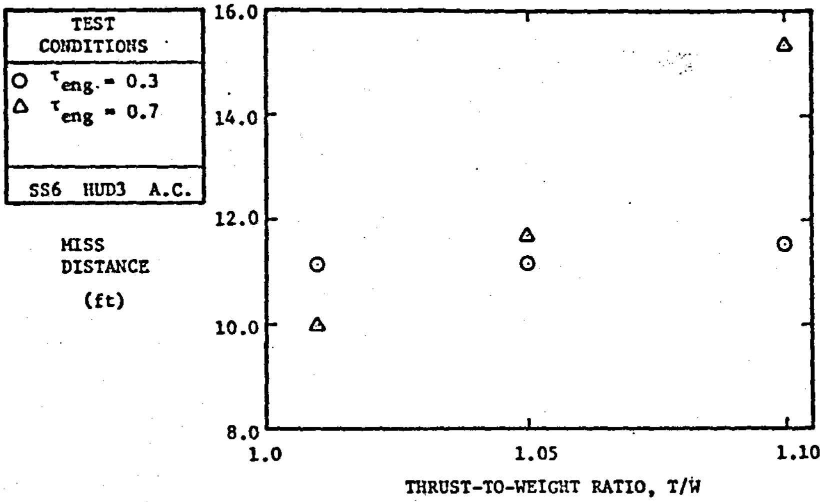


Figure 21: Influence of Thrust-to-Weight Ratio on the Positioning Side Task--Augmented HUD with Attitude Command System

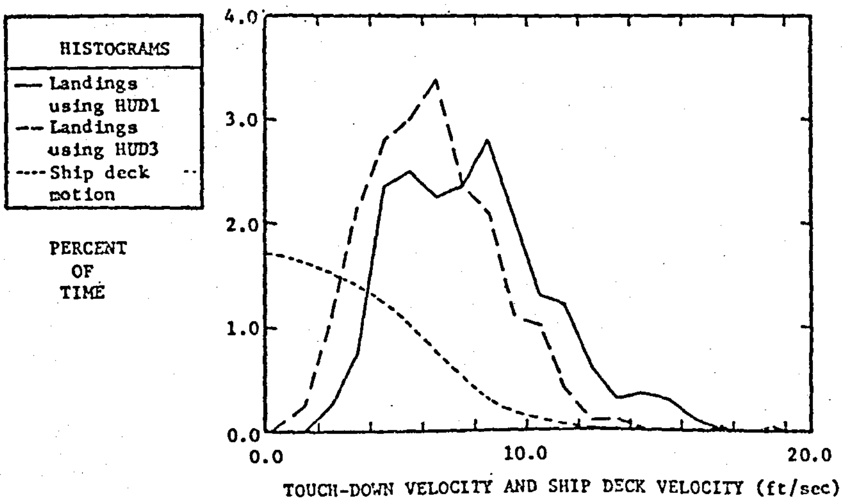


Figure 22: Distribution of Touchdown Sink Rate and Ship Deck Velocity--Baseline and Augmented HUD Breakdown for all Landings Completed for the Simulation

The velocity histogram for HUD1 peaks at 8.5 ft/sec, which is just above the 1 sigma value for the ship motion velocity for sea state 6. The touchdown velocity for HUD3 peaks at 6.5 ft/sec or 2 ft/sec less than HUD1. The histogram also shows the HUD3 data to have a smaller standard deviation.

Table 3 indicates the precentage and number of landings over 12 ft/sec which occurred overall and for several sets of test conditions.

Table 3: Touchdown Velocity Statistics Indicating Number of Landings with Sink Rates Greater Than 12 ft/s for Selected Test Conditions.

CONDITION	NUMBER OF LANDINGS	NUMBER OF LANDINGS > 12 ft/sec	% LANDINGS > 12 ft/sec
Total Simulation	995	28	2.81
S.S.0, S.S.4 Overall	260	0	0.0
S.S.6 Overall	735	28	3.81
S.S.6, HUD1 Vel. Cmd. Sys.	212	18	8.49
S.S.6, HUD3 Vel. Cmd. Sys.	419	7	1.67
S.S.6, HUD3 Atd. Cmd. Sys.	104	3	2.89
S.S.6, HUD3 V.C. $\tau_{eng}=0.3$	216	1	0.46
S.S.6, HUD3 A.C. $\tau_{eng}=0.3$	60	1	1.67

A series of T/W ratio histograms are presented in Figures 23 through 27. Most of these curves show a fairly sharp spiked peak. In observing the simulation and through pilot comments, it is concluded that this shape of curve can be attributed to the pilots technique of setting up an initial descent rate and holding it either until near the ship deck for the HUD1 system, or until the 3 sigma line on the HUD3 system was approached, and then slowing or arresting the descent. The initial descent phase, which takes 90 to 95% of the total time produces the predominant peak in the histogram.

The histograms for HUD1, sea state 6 conditions are presented in Figure 23.

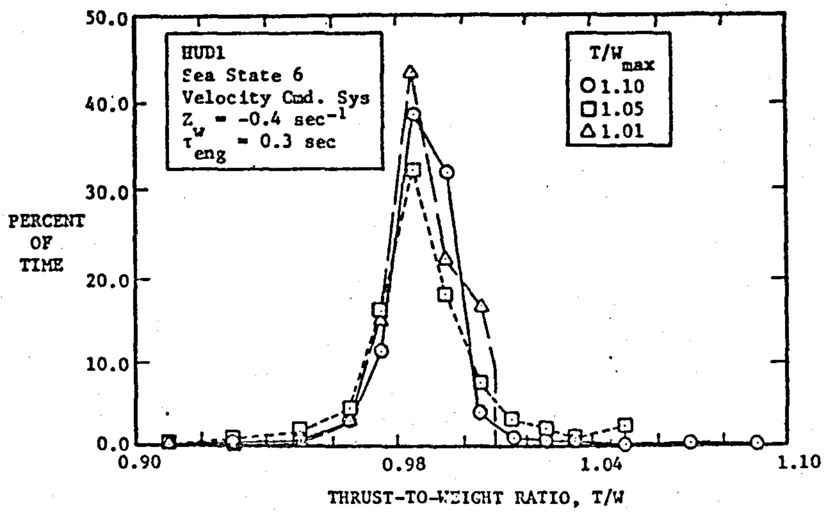


Figure 2: Influence of Thrust-to-Weight Ratio on Thrust-to-Weight Ratio Use Histograms--Baseline HUD with Velocity Command Control System

The peak occurs at the T/W ratio used most often in the initial descent. The peak is somewhat broader for T/Wmax of 1.1 probably indicating that the pilot is operating with lower gains. The base of the peak is fairly narrow and corresponds to the observed pilot behavior, with the HUD1 format, of chasing the deck less, possibly due to lack of positional cues. Landings, using the HUD1 format generally occurred as the deck caught the aircraft. The area under the curves tends to bunch up at the high end of the available T/W as T/Wmax is decreased. This is due to the pilot tending to fly more conservatively (lower descent velocities).

The histograms for HUD3, sea state 6 conditons are shown in Figure 24.

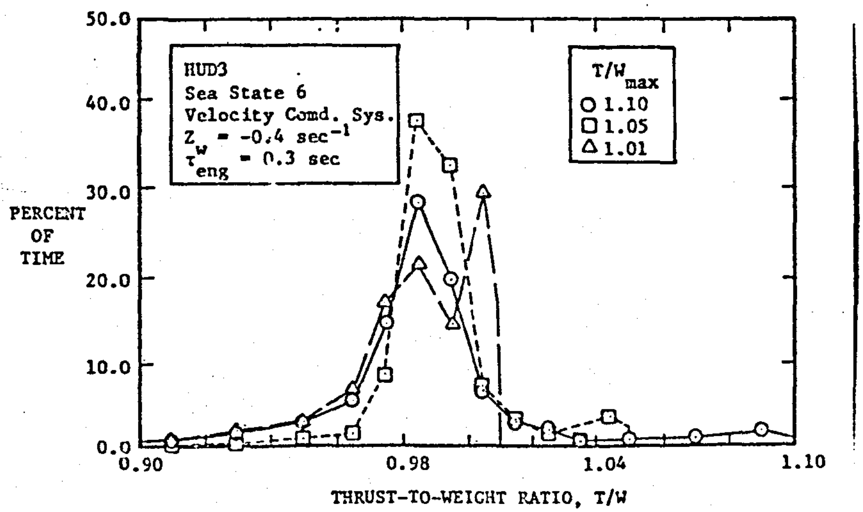


Figure 24: Influence of Thrust-to-Weight Ratio on Thrust-to-Weight Ratio Use Histograms--Augmented HUD with Velocity Command Control System

Notice that the curves broaden somewhat in comparison to those for the HUD1 format. Because of the positional information available to the pilot with the HUD3 format, pilot gains are somewhat lower, and the pilot has more opportunity to chase or run from the ship deck. This tends to broaden the peak and base of the curves. The area under the curve for T/Wmax = 1.01 is much more bunched up at the high end, than for the HUD1 case. This is due to, the pilot's tendency to fly more conservatively (lower descent velocities, higher thrust settings), since the HUD3 format makes him more aware of the limitations of the available control power.

The effects of vertical velocity and engine time lag for HUD3, sea state 6 conditions are presented in Figure 25.

With zero vertical damping, the pilot had a much more difficult time controlling vertical velocity, and this is compounded with a slow responding engine. The curve becomes much less peaked and is spread out over a larger range of available T/W. This is in contrast to the curve for higher damping and faster responding engine where the pilot is able to control vertical velocity with much less throttle movement (i.e., the throttle becomes a vertical velocity command control).

The effects of HUD format and type of control system on T/W histograms is presented in Figure 26. An interesting thing to note here is that the peak for the attitude command system occurs at a higher T/W ratio than for the velocity command system using either HUD. Also the curves for the attitude command system tend to be

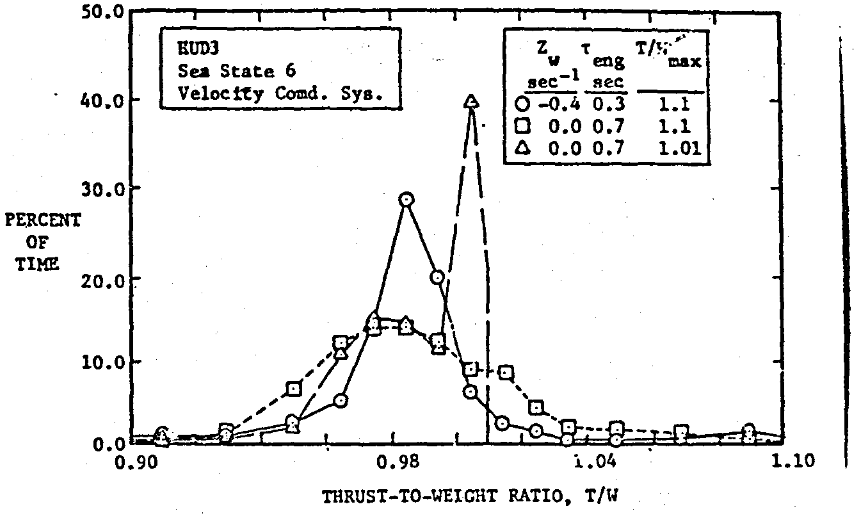


Figure 25: Influence of Engine and Airframe Dynamics, and Thrust-to-Weight Ratio on Thrust-to-Weight Use--Augmented HUD with Velocity Command Control System

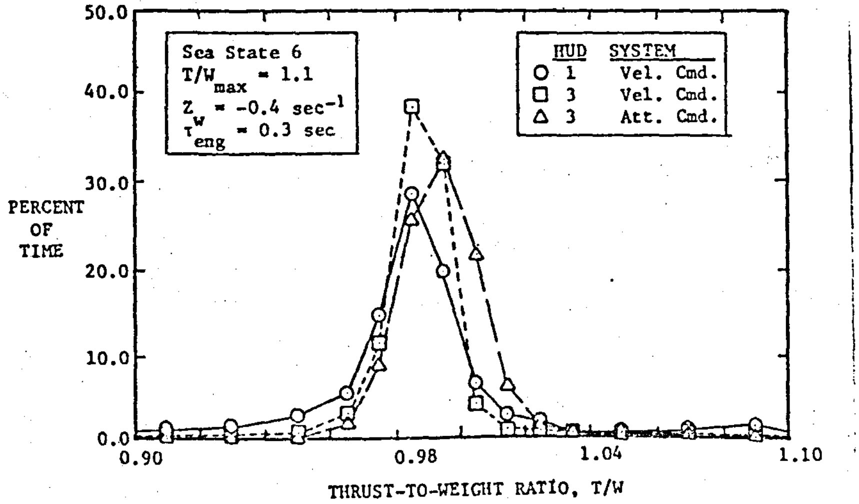


Figure 26: Influence of HUD Format and Control System on Thrust-to-Weight Use for a Selected Test Condition

much more symmetrical about the peak. The explaination for this is that the pilot was observed to spend at least as much time on the positioning sidetask as with the vertical task. As a result, he tended to fly more conservatively (at a higher thrust, slower descent rate) and the errors in desired vertical position/velocity are therefore more likely to occur randomly rather than only on a conservative side as when flying only a vertical task.

The effect of sea state on T/W histograms for a selected condition is presented in Figure 27.

As expected, at the low sea states the pilot spends more time in the initial descent and less time correcting for deck position. As a result, lower sea states produce a histogram with a sharper peak and with a smaller base.

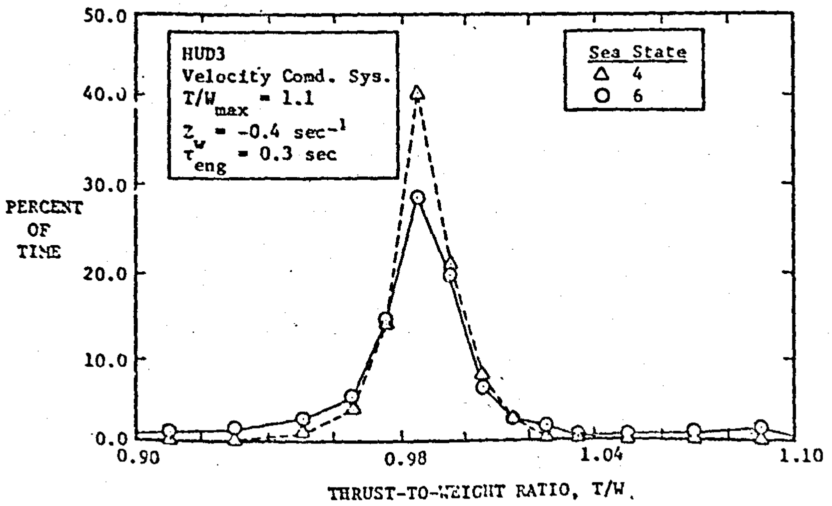


Figure 27: Influence of Sea State on Thrust-to-Weight Ratio Use--Augmented HUD with Velocity Command System

2. Pilot Comments

The pilots were given an explanation of the task and discription of the HUD symbology. From this they developed some individual techniques. Pilot A, especially for the higher values of T/W with fast responding engine, often waited for the deck symbol to crest just below the 2 sigma line, and then smoothly rolled off the throttle providing a quick descent in which the aircraft would catch the deck on its downward motion with a usually low value of relative descent rate. Pilot B used this technique also although, not as often.

Both pilots became more adept at picking out "lulls" in the ship motion as the simulation progressed. It was often possible to tell that the deck was in a lull condition when its motion was slow and position was a couple of feet above the mean line. The pilots would make a quick descent and attempt to catch the deck before the more extreme motions reoccurred.

The pilots also understood that if they chased the deck below the mean line (or were unable to arrest a descent until below the mean line), then in most cases it was better to continue and attempt to catch the deck near its lowest position (and therefore low velocity) than attempt to climb back to the 2 sigma line. When the attempt to pull up was made, especially with low T/W, the deck tended to catch the aircraft near the mean deck position, often with a high velocity, and therefore, high relative velocity.

The most general comment expressed about technique was, "always be in a position to gradually take off power, and don't get caught needing it."

Pilot comments indicated the following:

1) The greater the T/W, the more controllable and easier it is to perform the task (through the range tested).

2) The higher the value of T/W, the less sensitive the pilot workload is to engine lag and vertical damping.

3) The higher values of damping provided better control of vertical velocity, which in turn aided the initial descent to the 2 sigma line. The lower values of damping provide quicker vertical response and therefore greater agility during the final phase of descent.

4) The slow responding engine was considered unfavorable, even though a few cases occurred when the engine compensated for an overcontrol by the pilot.

5) Both pilots commented on the importance of engine noise as a cue.

6) HUD3 was perferred over HUD1. The pilots commented favorably on having the ship motion boundaries and 2 sigma lines as references in giving precise situation information.

7) Comments concerning HUD1 generally focused on the feeling of not knowing either the position or vertical velocity of the aircraft relative to the mean deck position.

8) When using HUD1, the effects of damping and engine lag were less evident, since errors were not as easily detected due to the lack of references. One of the pilots commented that the task workload was less using HUD1 because of the lack of references, but gave it a higher (worse) pilot rating because of the greater uncertainty involved.

IV. REVISED ANALYTICAL PREDICTIONS

After the piloted simulation was run, the non-piloted simulation was modified in an attempt to match the measured $T/\dot{W}$ histograms, as well as to better represent the observed piloting technique.

A. MODIFIED ANALYTICAL MODEL

The following modifications were made to the program:

1) A feed back loop was added to provide vertical velocity damping through thrust, and the coefficient for vertical velocity damping through airframe was reduced to more closely match the fixed-based simulation model.

2) The flight path command logic was rewritten to provide a better match to the observed landing strategy adopted by the pilots. Details of the logic are given in the next section.

3) Two additional noise sources were added to account for pilot perception error and internal pilot noise.

4) The pure time lag, used to represent the pilot's information processing time interval, was divided into a pure lag and a secondary time in which the input to the pilot's neuromuscular dynamics was held constant for a specified time. The purpose here was to simulate the pilots concentration on a sidetask. A block diagram of the modified model set-up is shown in Figure 28.

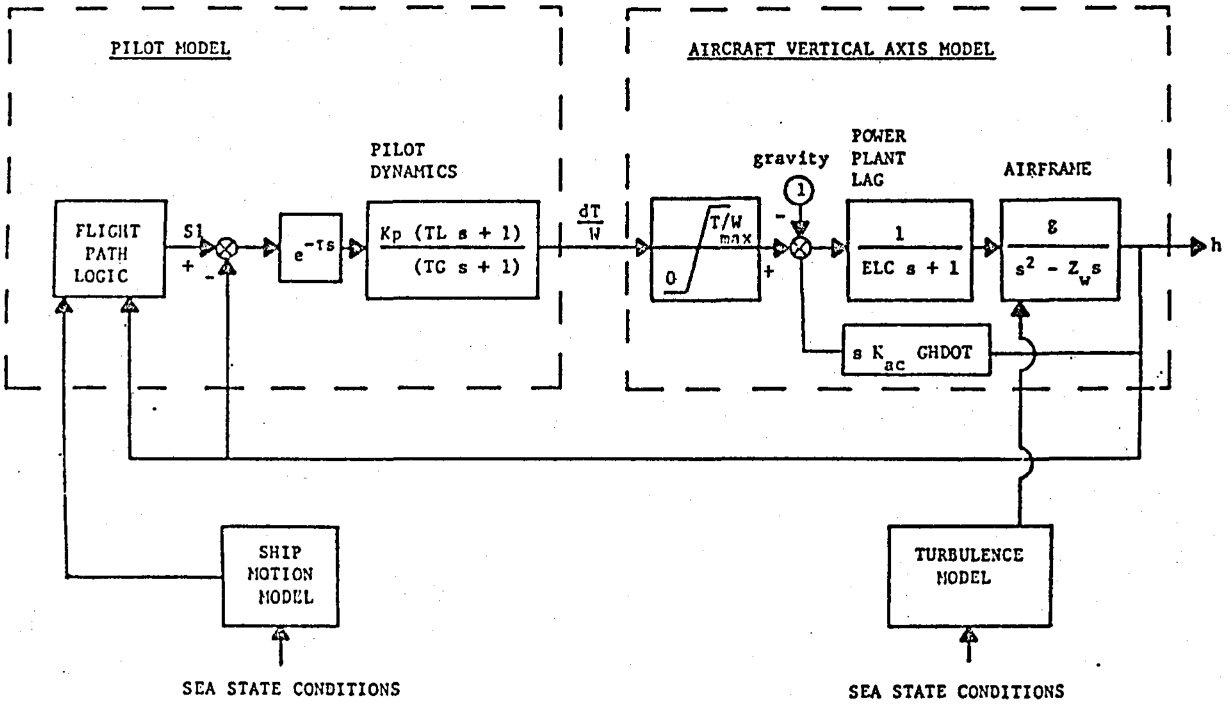


Figure 28: Block Diagram for the Modified Non-Piloted Simulation Model

The modified version of the flight path command logic consists of 6 basic sections. The first section determines which of five defined regions of relative position and velocity that the aircraft is currently in. This section then specifies which of the remaining 5 sections is to be used to supply the commanded flight path information to the pilot transfer function. These sections are referred to according to their basic strategy: RUN FAST, RUN, CHASE, ABORT TO HOVER HEIGHT, and CHOP THROTTLE. The RUN FAST sequence is initiated whenever the relative velocity of the aircraft and ship exceeds a given value, typically 5.5 ft/sec. The RUN FAST logic commands an altitude of 12 ft above the present altitude using a cosine smoothing function. This command causes the simulated pilot to apply full throttle. If the relative position is less than 9 ft and the relative velocity exceeds 4.5 ft/sec the RUN sequence is initiated. The RUN logic commands an altitude of 6 ft above the present altitude through a cosine smoothing function, causing the simulated pilot to apply approximately 95% of full throttle. If the aircraft was in the RUN FAST sequence and then switches to the RUN sequence, the commanded altitude is lowered 6 ft from the previously commanded altitude, thus causing the throttle to be reduced from full to approximately 90%. If the relative position of the aircraft and ship deck is less than 3 ft and the relative velocity hasn't exceeded 4.5 ft/sec then the CHASE sequence is initiated. The CHASE logic commands a cosine function descent, modulated by the ship deck motion, starting at the previously commanded altitude and ending at the ship deck. If the aircraft position descends below a designated abort height, the ABORT TO HOVER HEIGHT sequence is initiated. The abort height is the height above the ship deck mean position which, if a descent is continued, will not provide enough time to gain the necessary height to prevent a hard landing in the event the next segment of the motion is around the 3 sigma value. This height, of course, varies with sea state. Up to sea state 4 the abort height is zero because the relative velocity can be maintained below the gear limits anywhere in the ship motion boundaries. The hover height is the 2 sigma height above the ship deck mean. The ABORT TO HOVER HEIGHT logic commands the hover height altitude through a cosine smoothing function from the altitude in the previous sequence. The hover height altitude is then maintained until conditions require use of another logic section. The CHOP THROTTLE sequence is designed to mimick a normal pilot landing technique. It is initiated when the relative aircraft to ship position is less than the Chop Throttle Now Height (CTNH), which is another adjustable variable. Unlike the other sequences, which can be abandoned for a more apporpriate one at any time during the sequence, once the CHOP THROTTLE sequence is initiated it continues until a landing occurs or a specified time has elasped The CHOP THROTTLE logic commands a 12 ft descent in altitude through a cosine smoothing function. This command effectively produces near zero thrust output. The sequence maintains this reduced altitude for a specified period of time. If during this time period a landing has not occurred, the sequence commands an ascent back to the hover altitude. This logic models the pilot behavior after he sees a landing opportunity; i.e., the aircraft is 0.5 ft off the deck but with the deck beginning to descend.

The modified analytical model produced a much more accurate representation of observed piloting technique. For example, it was observed in the piloted simulation that with the slow responding engine, more landings were made running from the ship than chasing it, whereas with the fast responding engine, approximately the same number of landings were made chasing the ship as running from it. A series of computer runs were made which duplicated this result (Table 4).

Table 4: Influence of Thrust-to-Weight Ratio and Engine and Airframe Dynamics on Flight Path Command Logic Sequence Use

TEST CONDITION			PERCENT OF LANDINGS			
T/W	τ_{eng} sec	Z_w sec^{-1}	Flight Path Logic Section 1	2	6	7
1.07	0.7	0.4	52.5	10.0	35.0	2.5
1.05	0.7	0.4	55.0	10.0	15.0	20.0
1.03	0.7	0.4	55.0	5.0	27.5	12.5
1.01	0.7	0.4	50.0	15.0	30.0	5.0
	Average		63.1		36.9	
1.01	0.3	0.4	42.5	10.0	27.5	20.0
1.07	0.3	0.4	42.5	5.0	32.5	20.0
1.05	0.3	0.4	40.0	12.5	30.0	17.5
1.03	0.3	0.4	45.0	2.5	45.0	7.5
	Average		50.0		50.0	

Flight Path Logic Sections:

1 - Run Fast Sequence
2 - Run Sequence
6 - First section of the Chop Throttle Sequence
7 - Second section of the Chop Throttle Sequence

The original flight path command logic did not provide a chop throttle sequence, and the landing nearly always occurred while in the RUN FROM sequence. A schematic diagram of the modified flight path command logic is shown in Figure 29. An example time history showing some of the flight path command logic aspects is shown in Figure 30. In addition, two representive time histories are presented in Figures 31 and 32.

B. COMPARISON OF ANALYTICAL AND SIMULATION RESULTS

A comparison of touchdown velocities for the non-piloted simulation and the piloted simulation are shown in Figure 33. The non-piloted simulation results, using either the original or modified flight path command logic, produced lower touchdown velocities than were achieved in the piloted simulation. The modified logic generally produced the lowest touchdown velocities. Further adjustment of the parameters in the non-piloted simulation to produce a closer match to the piloted simulation results could provide further insight into the pilot's capabilities.

The results for the modified version of the flight path command logic when compared to the piloted simulation data show a good correspondance in average flight time for the lower T/W ratios, but a large gap is evident for T/W = 1.1 as shown in Figure 34.

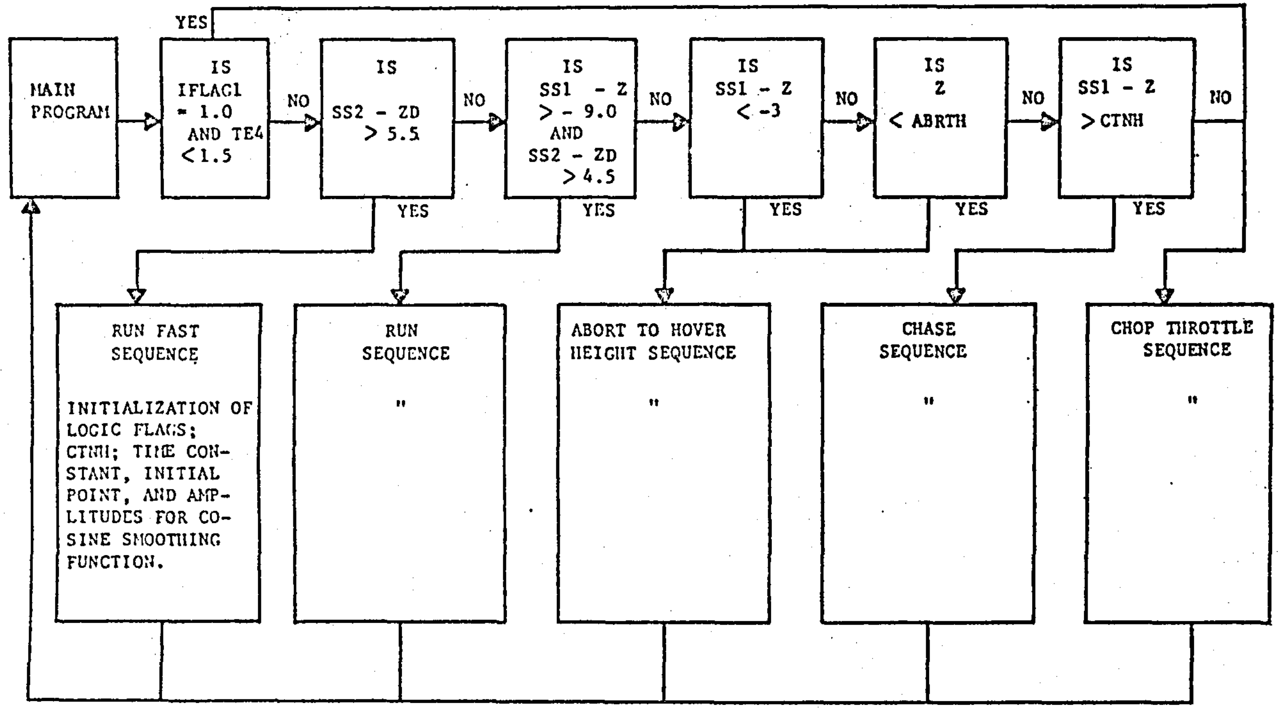


Figure 29: Block Diagram of the Modified Flight Path Command Logic

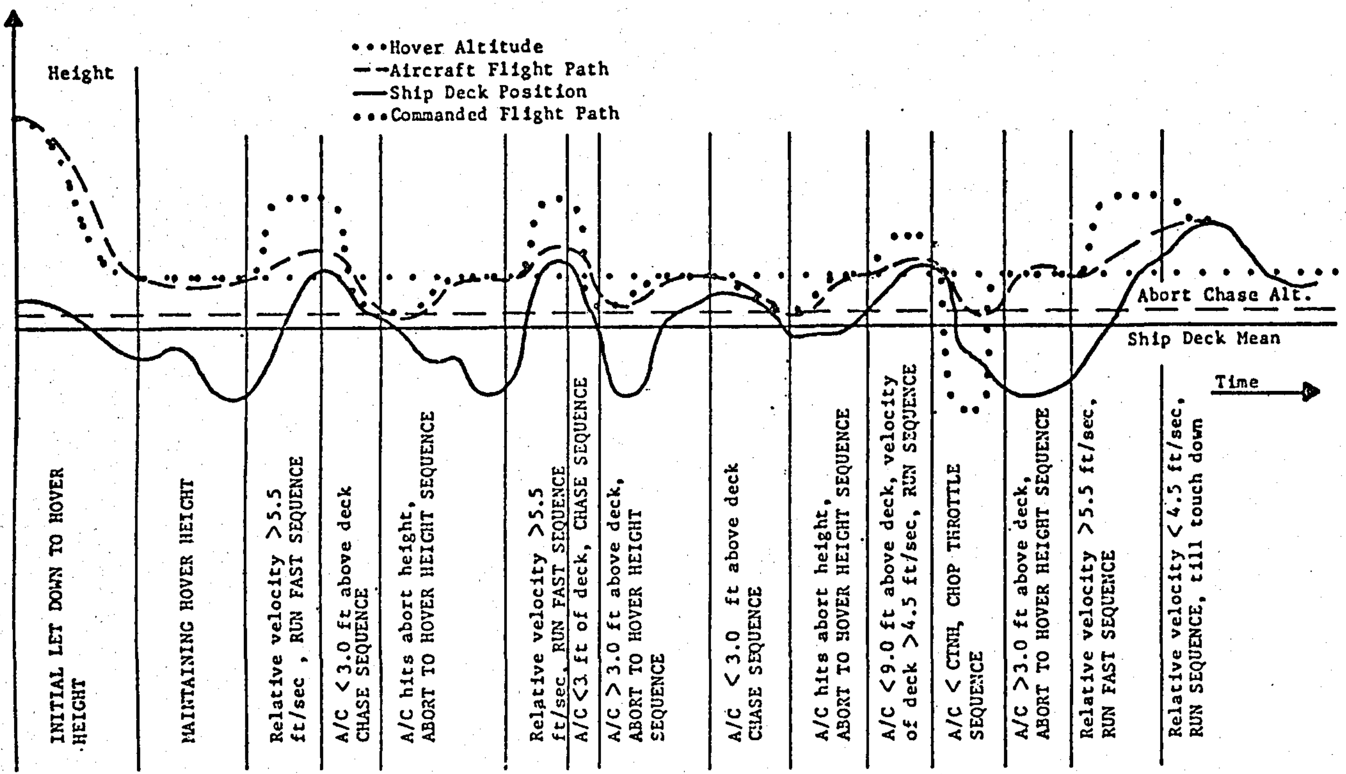


Figure 30: Example Time History for the Modified Flight Path Command Logic

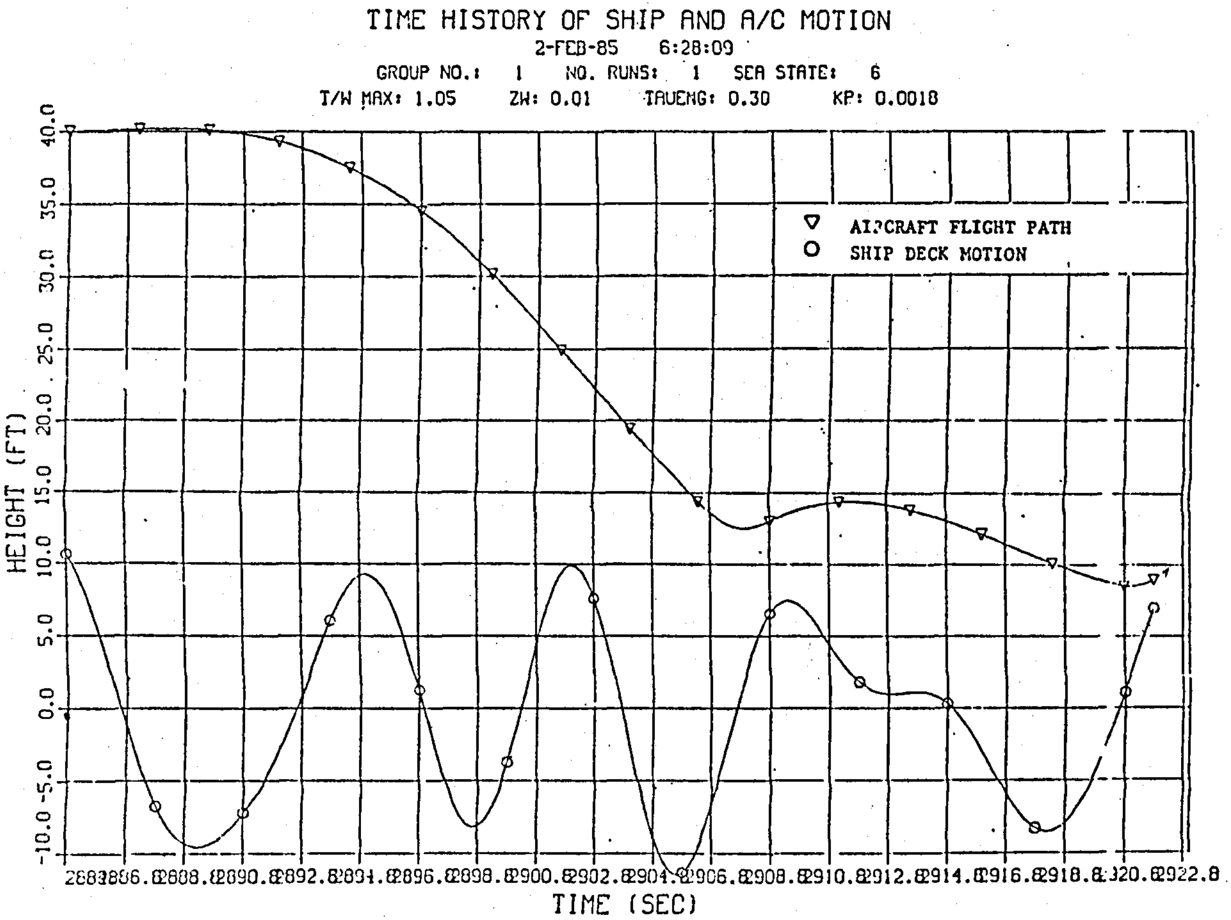


Figure 31: Aircraft and Ship Motion Time History as Output from the Non-Piloted Simulation

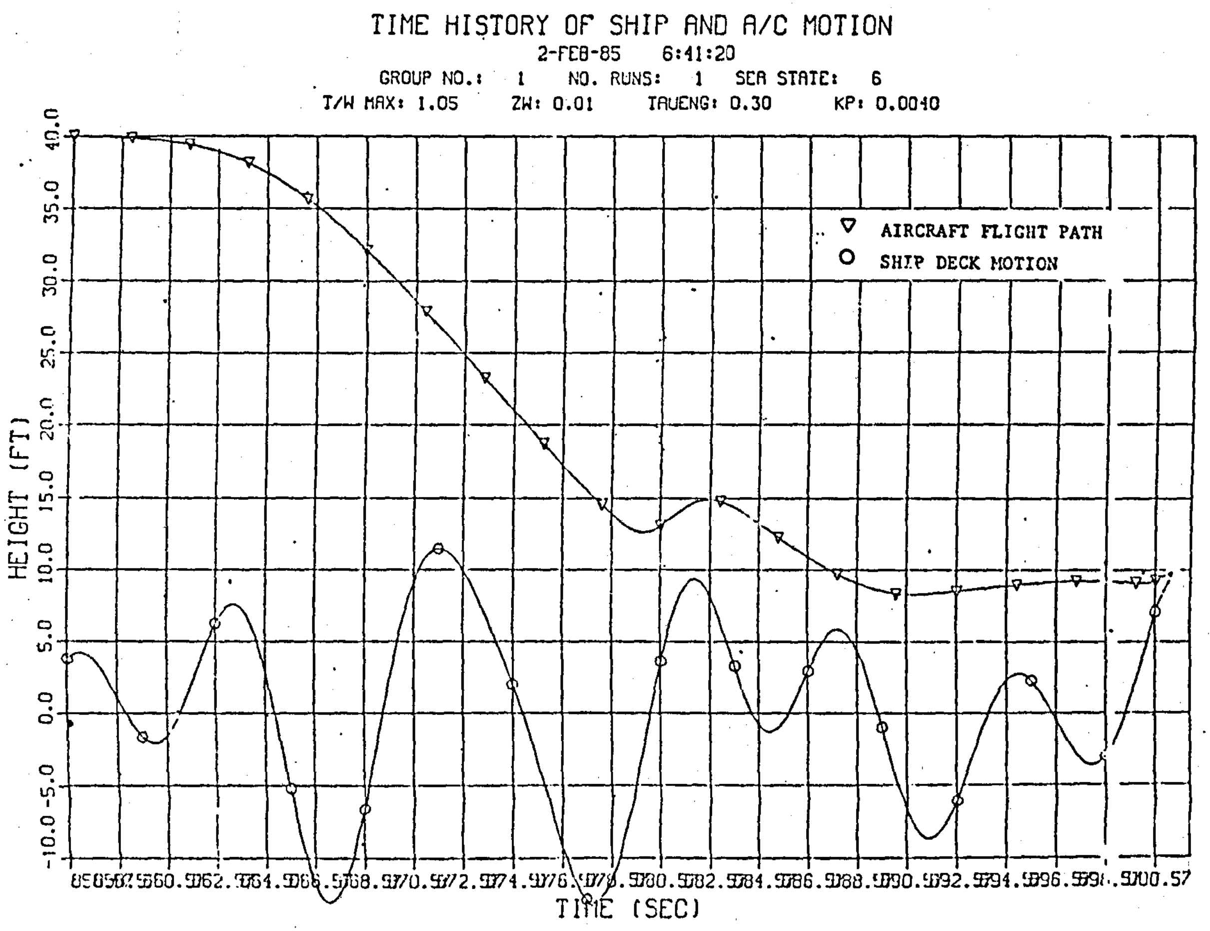


Figure 32: Aircraft and Ship Motion Time History as Output from the Non-Piloted Simulation

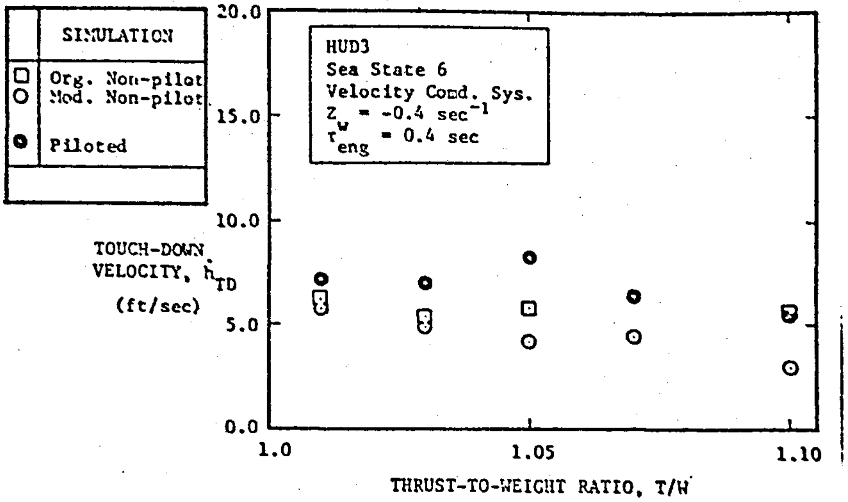


Figure 33: Comparison of the Influence of Thrust-to-Weight Ratio on Touchdown Sink Rate--Augmented HUD Velocity Command System of Piloted Simulation with Non-Piloted System

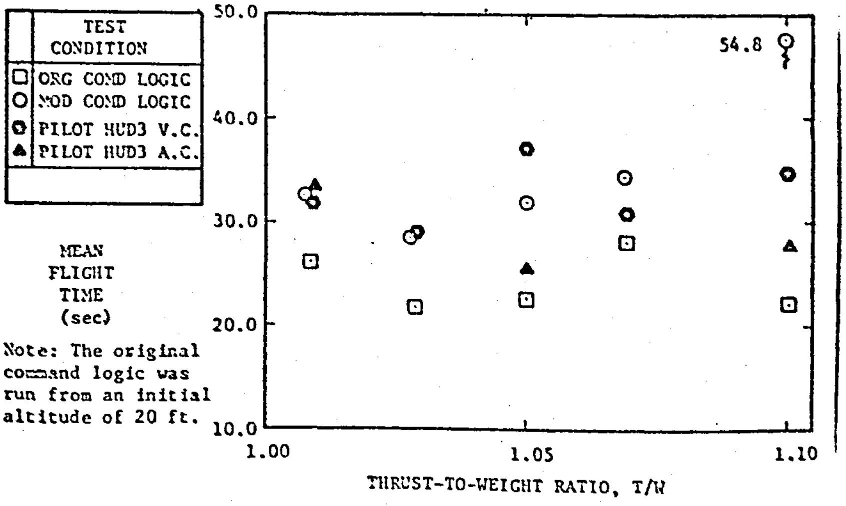


Figure 34: Comparison of the Influence of Thrust-to-Weight Ratio on Flight Time--Augmented HUD with Velocity and Attitude Command Systems of Piloted Simulation and the Original and Modified Flight Path Command Logic of Non-Piloted Simulation

A comparison of average touchdown velocities for a selected condition is shown in Figure 35.

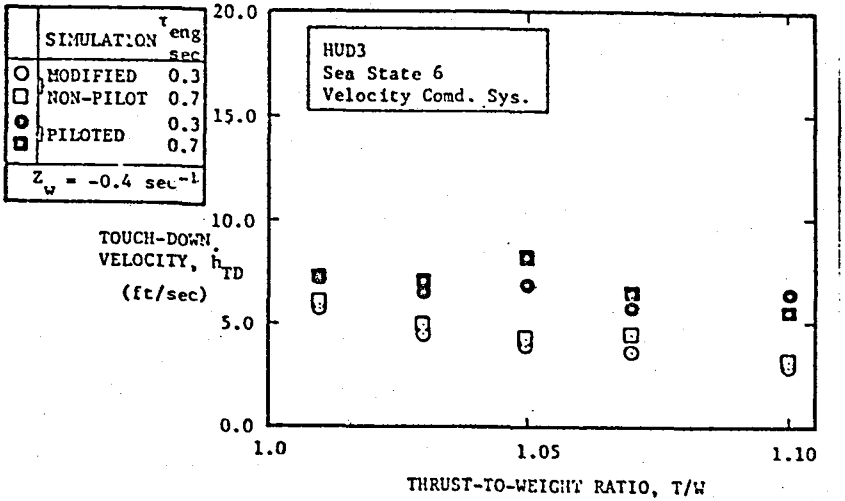


Figure 35: Comparison of the Influence of Thrust-to-Weight Ratio and Engine Dynamics on Touchdown Sink Rate--Augmented HUD with Velocity Command System and Modified Flight Path Command System.

As can be seen the trends are roughly correct for either command logic. However, there is still a fairly large bias that is unaccounted for. It should be noted that the data shown for the non-piloted simulation is a composite of data in which the pilot gains, aircraft vertical velocity damping, and variables mentioned in the T/W histogram section were being manipulated in an attempt to find optima (touchdown velocity and flight time) for each T/W ratio. Most of these runs were made shortly after the piloted simulations began, but before the data from the piloted simulation were analyzed. A more precise comparison requires another series of non-piloted simulations to be run with variables similiar to those used in the piloted simulations.

Initially, there was only interest in obtaining an indication from the non-piloted simulation as to whether or not the lower thrust-to-weight values were practical for landing in high sea states. In the early stages the program was used to provide estimates of touchdown velocity means and standard deviation and the time required to land. As the work progressed it became clear that the fixed-base simulation output data used to construct thrust-to-weight ratio histograms, could then be used as another matching variable in determining the accuracy of the non-piloted simulation.

There are 17 variables whose values determine in some way the shape of the histogram. These are:

1. The initial starting altitude.
2. The letdown time.
3. The hover height altitude.
4. The abort height altitude.
5. The chop throttle height.

6-8. Pilot gains.

9. The pilot pure lag time.
10. The pilot sidetask time.
11. The ratio of 9. and 10.
12. The pilot preception error noise amplitude.
13. The pilot preception error noise frequency.
14. The pilot internal noise amplitude.

15. The pilot internal noise frequency.

16. Pilot lead time time constant.

17. Pilot lag time constant.

Some of these non-piloted simulation variables are easily fixed. Initial height, hover height, and abort heights are all displayed for the pilot and so are the same in both piloted and non-piloted simulations. Pilot internal noise amplitude was based on having each pilot, and any other observers present, guess the velocity at which the pilot touched down as viewed on the head-up display monitors. The error was then determined and the noise standard deviation was set at 1.5 ft/sec after averaging over the number of observers approximately 180 landings. The rest of the variables were set by making an initial guess and then making 5 runs and looking to determine how the variable had changed the histogram. This process was repeated by either changing the variable again, or going to the next one. In this way a good match to the histogram was made for one of the cases (Figure 36). It should be noted that there may be as much as 20-30% change in any one point on the histogram for a given set of 5 runs (as can be seen in Figure 37). This is because 5 runs are not enough to get a good statistical representation, thus aggravating the difficulty of trying to obtain a good match. The non-piloted simulation showed that approximately 40 runs (depending on the T/W ratio being used) is needed to provide adequate statistics. When histograms representing only 5 runs are constructed based on 10 unknown variables, there is some difficulty in producing a good match. Another problem occurs when trying to

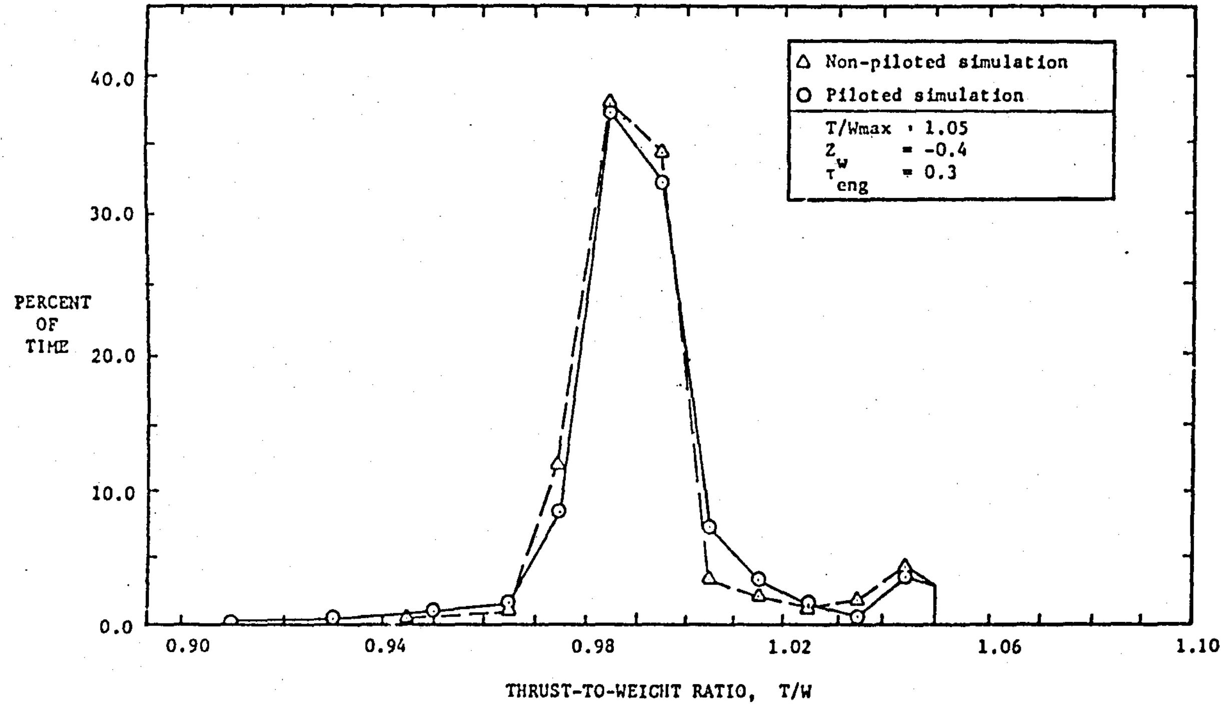


Figure 36: Comparison of Thrust-to-Weight Use Histograms as Obtained from the Piloted and Non-Piloted Simulations

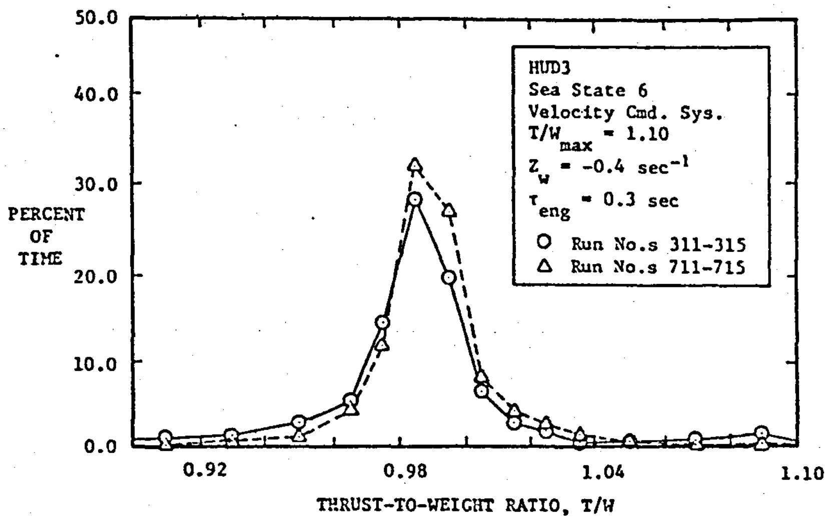


Figure 37: Variation of Thrust-to-Weight Ratio Use Histograms Due to a Statistically Small Number of Runs Used Per Data Point

match the touchdown velocity and flight time averages for the same cases. It was found that once the major influence of variable changes on the histogram shape was obtained, it was fairly easy to get a rough match of histograms. The T/W ratio for which the histogram peaks can be obtained through selection of the initial letdown velocity of the aircraft. The base can be broadened by selecting higher values for the pilot gains. The sharpness of the fillets between the base and peak were found to change somewhat with the selection of pilot gains and the values used for frequency and magnitude in the pilot internal and preception noise models. The shape of the base; i.e., the number and size of the peaks appeared to be mainly dependant on the ratio of three pilot gains used. It is also fairly easy to get a reasonable match of touchdown velocities and flight times. It is not easy to get all three of these results to give a reasonable match simultaneously. This may be due to something inherent in either the piloting technique or aircraft model being flown on the fixed-base simulation that is not being modeled accurately in the non-piloted simulation, or that the right combination of values for the variables has not been found. The latter should be explored further using parameter identification techniques. It would ultimately be hoped that all three could be matched for a couple of cases and then the values of the variables be determined analytically to produce matching values for other cases. This pilot model would then be a good tool for predicting the landing performance of any VTOL aircraft onto any type of ship.

V. CONCLUSIONS

The problem of determining the vertical axis control requirements for landing a VTOL aircraft on a moving ship deck in various sea states is examined. Both a fixed-base piloted simulation and a non-piloted batch simulation were used to determine the landing performance as influenced by thrust-to-weight ratio, vertical damping, and engine lags.

The piloted simulation was run using a fixed-base simulator at N.A.S.A. Ames Research Center. Simplified versions of an existing AV-8A Harrier model and an existing head-up display format were used. The ship model used was that of a DD963 class destroyer. Two pilots were used to obtain data and to give pilot ratings based on the Cooper-Harper pilot rating scale.

A surprising result of this simulation was that, with a good station keeping control system and with statistical ship motion displayed on the head-up display, pilots could consistently perform safe landings in sea state 6, with handling qualities that were adequate at thrust-to-weight ratios greater than 1.03 and even marginally adequate down to thrust-to-weight ratios of 1.01. These results should hold quite generally provided that a thrust-to-weight ratio of $1 + \Delta$ is interpreted as meaning that the pilot always has the capability of accelerating the aircraft at Δg upward even in the presence of ground effect and hot gas reingestion.

Preliminary work with a non-piloted simulation showed that with a good strategy and the right information, a pilot should be able to land a VTOL type aircraft vertically aboard a DD963 class destroyer under sea state 6 conditions, in an adequately controllable manner, with thrust-to-weight ratios as low as 1.01, engine lags as high as 0.7 sec, and vertical velocity damping of 0.2 secs, without exceeding a 12 ft/sec landing gear limit. This non-piloted simulation showed an overall average touchdown velocity of 5.8 ft/sec and an average flight time of 32.5 seconds. Results were then obtained from a piloted fixed-base simulation in order to verify the non-piloted results. Similiar results were obtained, with an average touchdown velocity of 6.7 ft/sec and flight time average of 33 seconds. In addition, the pilot ratings indicate satisfactory (level 1) handling qualities for sea state 6 conditons and thrust-to-weight ratios as low as 1.03 and adequate (level 2) handling qualities for thrust-to-weight ratios as low as 1.01.

Pilot ratings showed the expected results of being more favorable as T/W ratio increased, up to the maximum tested of 1.1, and with increasing vertical velocity damping, up to the maximum of -0.4 $\sec^{-1}$ tested, and with the faster responding engine, engine lag of 0.3 secs. The pilots also demonstrated lower touchdown velocities when presented with the ship motion boundaries, and aircraft hover and abort chase height lines on the head-up display, then when presented only with the ship deck position symbol. The simulation also showed that the pilot was capable of obtaining similiar results when flying either the translational velocity command system or attitude command system. Pilot ratings indicate that the translational velocity command system was perferred however.

Based on the current non-piloted simulation, it is believed that an extension can be made to determine piloted results for other T/W ratios, engine lags, vertical velocity damping, and ship classes, under various sea state conditions. This is based on the assumption that, using parameter indentification techniques, touchdown velocities, flight times, and T/W use histograms can be made to match the current piloted simulation data.

Although the simulation indicates that aircraft can be landed vertically at much lower T/W ratios than previously suspected, even with the positioning sidetask, it remains to be seen how well low thrust-to-weight ratios will work when a full range of sidetasks inherent in flying actual aircraft are employed. In addition, more work should be done to determine the effects on minimum T/W ratio of non-linear elements which were not examined in this simulation. The effects of suckdown, fountains, hot gas ingestion, and height dependant mean winds can all significantly effect minimum T/W.

As a practical point regarding the simulation, additional research would have to be conducted to ascertain how well instrumentation aboard ship can determine the mean ship position and the motion boundaries, how long in advance of the aircraft arrival the motion would have to be monitored to provide accurate results, and how well the aircraft/ship systems can determine real time deck position.

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VII. APPENDIX A

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The computer program for the non-piloted simulation was discussed in general in the main body of the report. Some more detailed information regarding certain aspects of the program are described below.

A. APROXIMATE INVERSE LAPLACE TRANSFORM METHOD.

The numerical iteration method used for solving the differential equations used in the computer program is the Approximate Inverse Laplace (A.I.L.) method (Reference 13). It is assumed that the equations for the transfer functions are in the form:

$$X(s) = \frac{N(s)}{D(s)} = \frac{A_n s^n + A_{n-1} s^{n-1} + \ldots + A_0}{B_m s^m + B_{m-1} s^{m-1} + \ldots + B_0} \quad \text{(A1)}$$

where $m > n$ and B_m is not equal to zero.

Then using the following recurrence formula:

$$C_i = \frac{1}{B_m} [A_{n-i+1} - \sum_{j=0}^{m-1} B_j C_{i-m+j}] \quad \text{(A2)}$$

where $A_x = B_x = 0$ for $x < 0$, and $C_x = 0$ for $x < 0$.

X(s) can be rewritten as

$$X(s) = C_1 s^{n-m} + C_2 s^{n-m-1} + C_3 s^{n-m-2} + \ldots \quad \text{(A3)}$$

The inverse transform of equation (A3) is

$$X(t + dt)_1 = C_1 + C_2 dt + C_3 \frac{dt^2}{2!} + \ldots \qquad (A4)$$

The derivatives can then be found from differentiation:

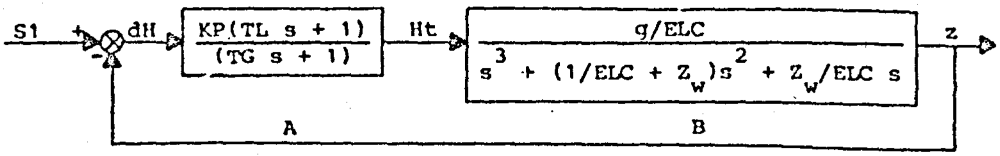
$$\dot{X}(t + dt) = C_2 + C_3 dt + C_4 \frac{dt^2}{2!} \ldots \qquad (A5)$$

$$\ddot{X}(t + dt) = C_3 + C_4 dt + C_5 \frac{dt^2}{2!} \ldots \qquad (A6)$$

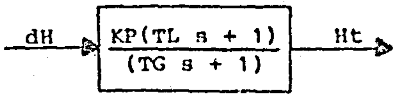
The A.I.L. method allows the use of time varying coefficients in the transfer function. The method is based on the assumption that a time interval, Δt, can be found during which all of the coefficients can be considered as constant. A set of points calculated in one interval of time is then used as the initial conditions for the next calculation, and the process is repeated. More information on the A.I.L. method may be obtained from Reference 13.

B. A.I.L. IMPLEMENTATION

The specific equations used for the non-piloted simulation were derived as follows:



A)



Can be expressed as

Then

$$\dot{\gamma} + \frac{1}{TG}\gamma = dH \qquad (A7)$$

Using Laplace transformation,

$$\gamma = \Gamma$$

$$\dot{\gamma} = s\Gamma - \gamma(0) \qquad (A8)$$

Therefore,

$$s\Gamma - \gamma(0) + \frac{1}{TG}\Gamma = \frac{dH}{s}$$

or $$\Gamma = \frac{\gamma(0)s + dH}{s^2 + 1/TG\ s}$$

Where dH is considered a constant for the time interval under consideration. (A9)

Using the A.I.L. method:

A0 = 1
A1 = γ(0)

(dH will be reintroduced at a later point)

B0 = 0.0
B1 = 1/TG
B2 = 1.0

(A10)

And from the reversion forumula:

$$C_i = \frac{1}{B2}\left[A_{2-i} - \sum_{j=0}^{1} B_j C_{(i-j)-2}\right] \qquad (A11)$$

C1 = A1

C2 = A0 -B1 * C1

C2A = A0

C3A = -B1 * C2A

C2B = -B1 * C1

C3B = -B1 * C2B

$$C4A = -B1 * C3A \qquad\qquad C4B = -B1 * C3B$$

$$\vdots \qquad\qquad\qquad\qquad \vdots$$

Then

$$\gamma A = C1 + C2A * IT1 + C3A * IT2 + \dots$$

$$\gamma B = \quad C2B * IT1 + C3B * IT2 + \dots \qquad (A13)$$

$$\dot{\gamma} A = C2A + C3A * IT1 + C4A * IT2 + \dots$$

$$\dot{\gamma} B = C2B + C3B * IT1 + C4B * IT2 + \dots$$

For the next iteration

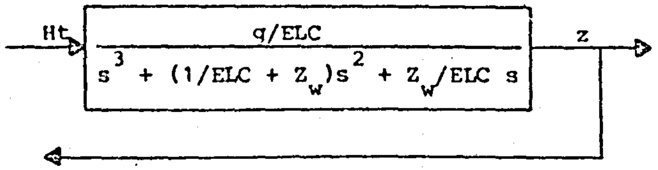
$$\gamma(0)_n = \gamma_{n-1}$$

$$\dot{\gamma}(0)_n = \dot{\gamma}_{n-1} \qquad (A14)$$

And

$$KP \frac{TL}{TG} [(\dot{\gamma} A * dH + \dot{\gamma} B) + \frac{1}{TL} (\gamma A * dH + \gamma B)] = Ht \qquad (A15)$$

B)



Or

$$\dddot{z} + (1/ELC + Z_w)\ddot{z} + \frac{Z_w}{ELC} \dot{z} = \frac{g}{ELC} Ht \qquad (A16)$$

Substituting (A15) for Ht:

$$\dddot{z} + \left(\frac{1}{ELC} + Z_w\right)\ddot{z} + \frac{Z_w}{ELC}\dot{z} = \frac{g}{ELC}\{KP\,\frac{TL}{TG}\,[(\dot{\gamma}A * dH + \dot{\gamma}B)$$

$$+ \frac{1}{TL}(\gamma A * dH + \gamma B)]\} \qquad (A17)$$

But $dH = S1 - z$;

Therefore, (A17) can be rewritten as

$$\dddot{z} + (1/ELC + Z_w)\ddot{z} + \frac{Z_w}{ELC}\dot{z} + \overbrace{\frac{g}{ELC}\{KP\,\frac{TL}{TG}\,[\dot{\gamma}A + \frac{1}{TL}(\gamma A)]\}}^{B}\,z$$

$$= \underbrace{\frac{g}{ELC}\{KP\,\frac{TL}{TG}\,[(\dot{\gamma}A * S1 + \dot{\gamma}B) + \frac{1}{TL}(\gamma A * S1 + \gamma B)]\}}_{A} \qquad (A18)$$

Or

$$\dddot{z} + \left(\frac{1}{ELC} + Z_w\right)\ddot{z} + \frac{Z_w}{ELC}\dot{z} + B = A \qquad (A19)$$

Using Laplace transform:

$$z = \zeta$$

$$\dot{z} = s\zeta - z(0)$$

$$\ddot{z} = s^2\zeta - sz(0) - \dot{z}(0)$$

$$\dddot{z} = s^3\zeta - s^2z(0) - s\dot{z}(0) - \ddot{z}(0)$$

And therefore

$$s^3\zeta - s^2z(0) - s\dot{z}(0) - \ddot{z}(0) + \left(\frac{1}{ELC} + Z_w\right)[s^2\zeta - sz(0) - \dot{z}(0)] +$$

$$+ \frac{Z_w}{ELC}[s\zeta - z(0)] + B\zeta = \frac{A}{s} \qquad (A21)$$

where B is considered a constant for the time interval under consideration.

Or

$$\zeta = \frac{z(0)s^3 + [\frac{1}{ELC} + Z_w)z(0) + \dot{z}(0)]s^2}{s^4 + (\frac{1}{ELC} + Z_w)s^3 + \frac{Z_w}{ELC}s^2 + Bs} + \frac{[\frac{Z_w}{ELC}z(0) + (\frac{1}{ELC} + Z_w)\dot{z}(0) + \ddot{z}(0)]s + A}{s^4 + (\frac{1}{ELC} + Z_w)s^3 + \frac{Z_w}{ELC}s^2 + Bs} \qquad \text{(A22)}$$

Using the A.I.L. method:

$AA0 = A$

$AA1 = \frac{Z_w}{ELC}z(0) + (\frac{1}{ELC} + Z_w)\dot{z}(0) + \ddot{z}(0)$

$AA2 = (\frac{1}{ELC} + Z_w)z(0) + \dot{z}(0)$

$AA3 = z(0)$

$B0 = 0.0$

$B1 = B$

$B2 = \frac{Z_w}{ELC}$

$B3 = (\frac{1}{ELC} + Z_w)$

$B4 = 1.0$ (A23)

And from the recursion formula:

$$C_i = \frac{1}{B^4}[A_{4-i} - \sum_{j=0}^{3} B_j C_{(i-j)-4}] \qquad \text{(A24)}$$

$$
\begin{aligned}
&C1 = A3 \\
&C2 = A2 - B3 * C1 \\
&C3 = A1 - B2 * C1 - B3 * C2 \\
&C4 = A0 - B1 * C1 - B2 * C2 - B3 * C3 \\
&C5 = -B1 * C2 - B2 * C3 - B3 * C4 \qquad \text{(A25)} \\
&\vdots
\end{aligned}
$$

Then,

$$
\begin{aligned}
&z = C1 + C2 * IT1 + C3 * IT2 + \ldots \\
&\dot{z} = C2 + C3 * IT1 + C4 * IT2 + \ldots \\
&\ddot{z} = C3 + C4 * IT1 + C5 * IT2 + \ldots \qquad \text{(A26)}
\end{aligned}
$$

For the next iteration,

$$
\begin{aligned}
&z(0)_n = z_{n-1} \\
&\dot{z}(0)_n = \dot{z}_{n-1} \\
&\ddot{z}(0)_n = \ddot{z}_{n-1} \qquad \text{(A27)}
\end{aligned}
$$

A block-type diagram showing how the A.I.L. equations are implemented in the computer program for the pilot servo and aircraft transfer functions is shown in Figure A1.

A series of runs were made to determine the number of A.I.L. coefficients and size of time step required to obtain accurate results and a stable program. It was found that 6 terms and a time step of 0.01 seconds provided good results.

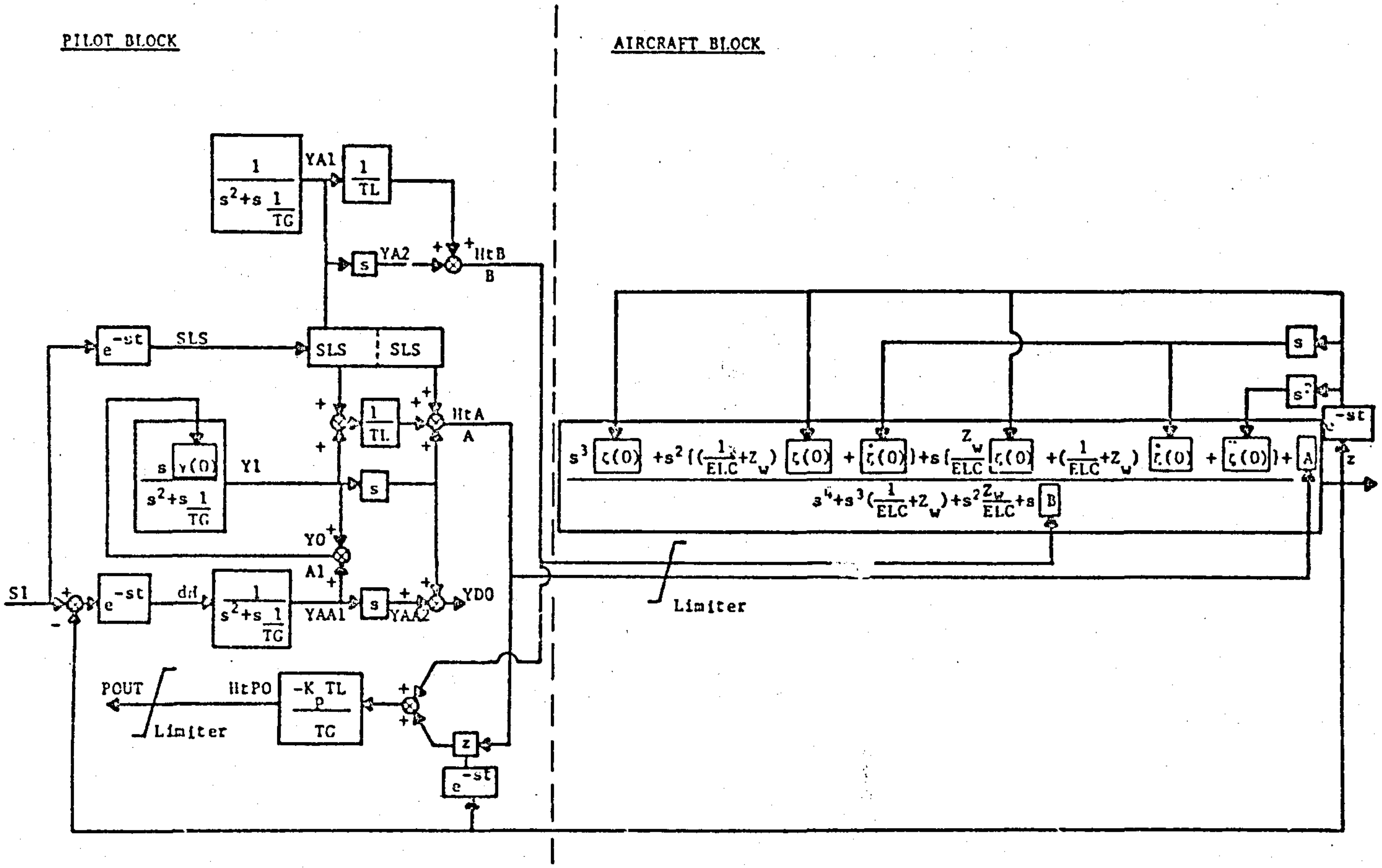


Figure A1: Block Diagram of the A.I.L. Implementation in the Non-Piloted Simulation

C. DEVELOPMENT OF THE SHIP MOTION MODEL

To obtain the amplitudes for the individual sinusoidal components, the following method was employed. First, the two-parameter Bretschneider wave spectrum is used to obtain the wave spectrum:

$$S_w(\omega) = \frac{483.5\ H_s^{\,2}\ e^{-1944.5/(\omega\ T_o)^4}}{T_o^{\,4}\ \omega^5} \tag{A28}$$

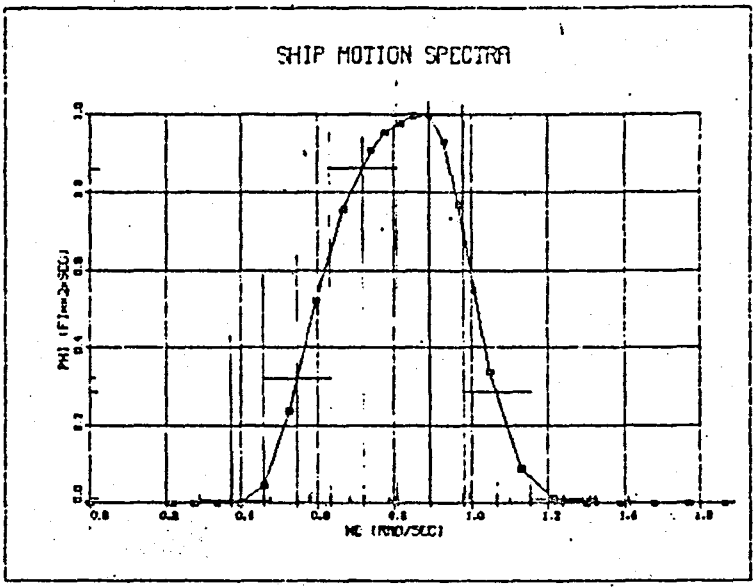
This is transformed using the following relationship:

$$\omega_e = \omega - \frac{\omega^2\ V_s\ \cos(\mu_s)}{g} \tag{A29}$$

To obtain the effective frequency based on ship velocity and heading relative to the waves. The ship motion spectrum can then be obtained as follows.

$$\Phi_{ii}(\omega_e) = S_w(\omega_e)\ \frac{\delta\omega}{\delta\omega_e}\ \mathrm{RAO}_i(\omega_e) \tag{A30}$$

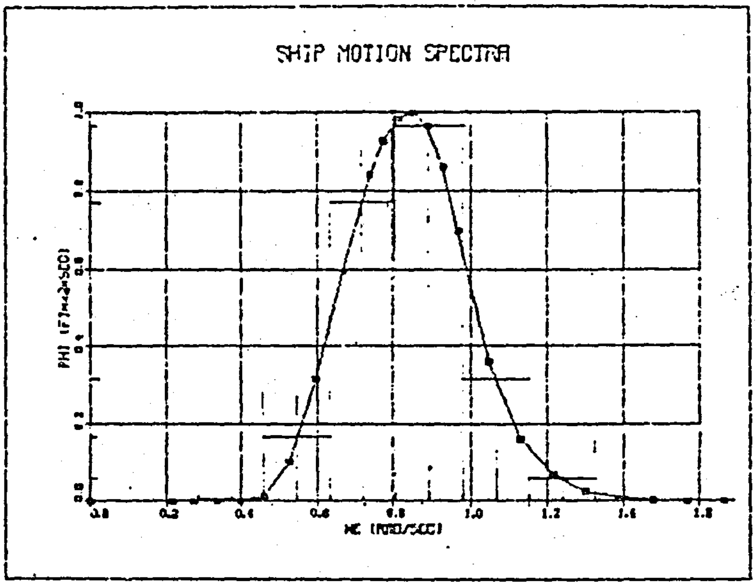
A computer program, SHPREF.FOR, was developed to accept a table of RAO values corresponding to a set of values, and then store the information in a data file. This table is then read by the program, and the above calculations are made. A numerical table and a plot of Φ versus ω_e is then output as the finished result; see Figures A2 and A3. The plot was then sectioned by hand into six components and the amplitudes for these six frequencies were determined by the following relationship:



```
WE=   0.2155281        PHI=  0.0000000E+00     SW(I)=  0.0000000E+00
WE=   0.2742626        PHI=  1.5390024E-15     SW(I)=  1.4029235E-14
WE=   0.3349382        FHI=  4.5292239E-07     SW(I)=  4.1409426E-06
WE=   0.3975548        PHI=  1.3130214E-03     SW(I)=  1.2105345E-02
WE=   0.4621124        PHI=  4.6292055E-02     SW(I)=  0.4341457
WE=   0.5286109        FHI=  0.2380974         SW(I)=   2.309751
WE=   0.5970505        PHI=  0.5212409         SW(I)=   4.963209
WE=   0.6674311        PHI=  0.7592450         SW(I)=   6.730645
WE=   0.7397528        PHI=  0.9081539         SW(I)=   7.144627
WE=   0.7766414        PHI=  0.9543847         SW(I)=   6.967761
WE=   0.8140153        PHI=  0.9798968         SW(I)=   6.630970
WE=   0.8518746        PHI=  0.9986890         SW(I)=   6.196284
WE=   0.8902190        FHI=   1.000000         SW(I)=   5.711943
WE=   0.9290487        PHI=  0.9313180         SW(I)=   5.212773
WE=   0.9683636        PHI=  0.7695953         SW(I)=   4.722323
WE=    1.048449        PHI=  0.3381195         SW(I)=   3.820434
WE=    1.130476        PHI=  8.9954354E-02     SW(I)=   3.059384
WE=    1.214444        PHI=  1.4484011E-02     SW(I)=   2.441777
WE=    1.300352        PHI=  1.2603654E-03     SW(I)=   1.950421
WE=    1.388202        PHI=  1.7391144E-04     SW(I)=   1.563076
WE=    1.477993        PHI=  3.7044092E-04     SW(I)=   1.258616
WE=    1.569724        FHI=  2.8305821E-04     SW(I)=   1.019108
WE=    1.663397        PHI=  1.3718315E-04     SW(I)=  0.8301120
WE=    1.759011        PHI=  5.8686554E-05     SW(I)=  0.6803094
FHIMAX=    7.771437     MUS=   2.094400     HS=   6.900000     TO=    10.60000
```

DD963H.DAT

Figure A2: Example Output from SHPREF.FOR with Plot of Ship Motion Specturm for the DD962 in Heave



```
WE=  0.2155281       PHI=  0.0000000E+00     SW(I)=  0.0000000E+00
WE=  0.2742626       PHI=  1.0081215E-16     SW(I)=  1.4029235E-14
WE=  0.3349382       PHI=  4.7250222E-08     SW(I)=  4.1409426E-06
WE=  0.3975546       PHI=  2.2123220E-04     SW(I)=  1.2105345E-02
WE=  0.4621124       PHI=  1.2612537E-02     SW(I)=  0.4341457
WE=  0.5286109       PHI=  0.1025751         SW(I)=   2.309751
WE=  0.5970505       PHI=  0.3154627         SW(I)=   4.963209
WE=  0.6674311       PHI=  0.5932509         SW(I)=   6.730645
WE=  0.7397528       PHI=  0.8416853         SW(I)=   7.144627
WE=  0.7766414       PHI=  0.9302165         SW(I)=   6.907761
WE=  0.8140153       PHI=  0.9839358         SW(I)=   6.630970
WE=  0.8518746       PHI=   1.000000         SW(I)=   6.196284
WE=  0.8902190       PHI=  0.9649336         SW(I)=   5.711943
WE=  0.9290487       PHI=  0.8602818         SW(I)=   5.212773
WE=  0.9683636       PHI=  0.6967936         SW(I)=   4.722323
WE=   1.048449       PHI=  0.3589893         SW(I)=   3.820434
WE=   1.130476       PHI=  0.1623948         SW(I)=   3.059384
WE=   1.214444       PHI=  6.8711556E-02     SW(I)=   2.441777
WE=   1.300352       PHI=  2.5693722E-02     SW(I)=   1.950421
WE=   1.388202       PHI=  8.2251765E-03     SW(I)=   1.563076
WE=   1.477993       PHI=  1.2260162E-03     SW(I)=   1.258616
WE=   1.569724       PHI=  8.9359164E-05     SW(I)=   1.019108
WE=   1.663397       PHI=  7.9859157E-05     SW(I)=  0.8301120
WE=   1.759011       PHI=  7.7392666E-05     SW(I)=  0.6803094
PHIMAX=  0.5683722    MUS=   2.094400     HS=   6.900000       TO=    10.60000
DD963P.DAT
```

Figure A3: Example Output from SHPREF.FOR with Plot of Ship Motion Spectrum for the DD962 in Pitch

$$A_n = [2\Phi_{ii}(\omega_e)\ \Delta\omega_e]^{1/2} \qquad \text{(A31)}$$

A component of the ship motion could then be calculated as:

$$i(t) = \sum_{n=1}^{6} A_n \cos(\omega_{e_n} t - \Phi_{ii} + E_n) \qquad \text{(A32)}$$

where Φ_{ii} is directly available from the ship data base information contained in Reference 8. E_n is a random phase angle which is calculated from a random number generator with the output scaled to give values between 0 and 6.242 radians.

In the computer-run simulation the ship motion is calculated in the GENeral Ship Motion, GENSM.FOR, subroutine. This subroutine uses the associated amplitudes and phase angles corresponding to a particular sea state as stored in the data file, GENSM.DAT.

D. TURBULENCE MODEL

The turbulence model for the computer-run simulation is located in the subroutine TURB3.FOR. It consists of a random number generator and the following principle equations:

$$\dot{A}_R = \omega_n A_R + \sigma_v (2\omega_n)\ n\ (1/TC^{1/2})$$

$$A_R = A_R + TC\ \dot{A}_R \qquad \text{(A33)}$$

The bandwidth, ω_n, was obtained from page 10, Figure 15, of Reference 9. The sigma values were obtained from a strip-chart recording of the acceleration of the vertical axis for the AV8-B during a fixed-base simulation, as presented in Figure A4. The (1/TC ** 0.5) term is a correction for the effects of using digital computation. The random number input is represented by n. Becuase this is a filter acting to shape white-noise, it is necessary to precycle it initially before inputing values into the simulation. This is also accomplished as part of the subroutine.

E. HOVER HEIGHT INPUT

The subroutine IN4.FOR provides the values for the flight path command logic hover height. The sequence starts at an initial altitude and follows a shallow cosine path to a selected hover altitude as a function of time. The hover altitude is then maintained as a constant for the remainder of the run. It is also possible to configure the subroutine to change to a second hover height during the run, although this function was not used other than for initial testing of pilot lead and lag time constants. Variables which can be adjusted before running a simulation are, the initial altitude, AMPA + AMPB, the hover altitude, AMPA, and the rate of descent, through the frequency term of the cosine function, WNS.

F. DATA PLOTTING

The subroutine MPLT2.FOR provides the instruction to the system library and DISSPLA software to produce a plot of the desired data

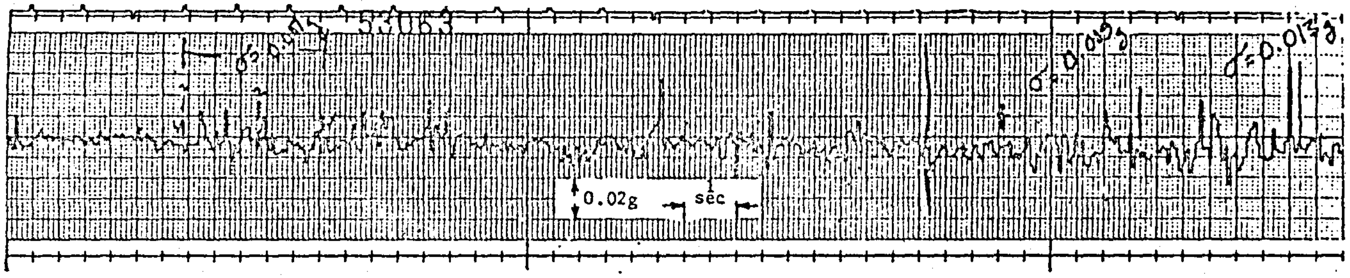


Figure A4: Strip Chart Recording of Vertical Acceleration Due to Turbulence as Obtained from the AV-8A Fixed-Base Simulation Facilities and Used to Determine Magnitude of Turbulence Values for the Turbulence Modeling in the Non-Piloted Simulation at the end of program execution. Currently, plots of the T/W ratio used as a percentage of time, and statistical variations as a function of the number of runs made are output (for examples see Figures A5-A7). A plot of the aircraft flightpath and ship deck position time history can also be set up with small changes in program configuration (for examples see Figures 31 and 32). A tabular listing of the runs made for each test configuration is also output, an example is given in Figure A8.

The following table is a listing of variable names and their appropriate values which must be edited into the indicated programs when a change in sea state is made.

Table A1: Valued for Variable Which Must Be Edited into Program with Change in Sea State

VARIABLES WHICH ARE FUNCTION OF SEA STATE					
Subroutine	Variable Name	Sea State			
		0	4	5	6
TRANO.FOR	WN	2.70	6.15	7.79	7.79
	SIGMA	0.001	0.007	0.01	0.01
IN4.FOR	AMPA	0.0	5.0	7.0	9.0
	AMPB	40.0	35.0	33.0	31.0
VPA1C	ABRTHT	0.0	1.5	3.0	6.0
GENSM.DAT (Version No.	-	-	;4	;5	;6
VASCON.DAT	Supplies the input data for the test conditions and is also changed as apporpriate.				

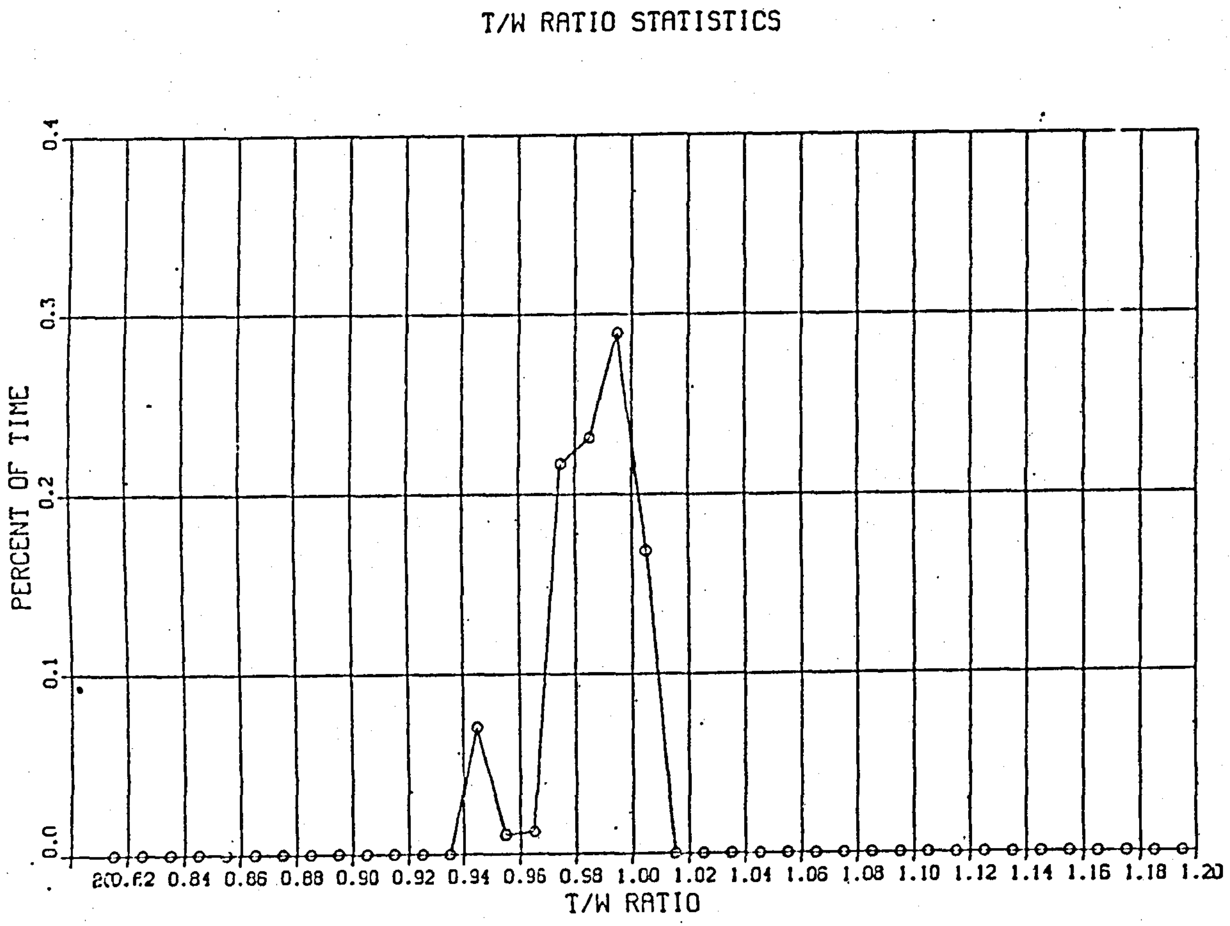


Figure A5: Example Plot of Thrust-to-Weight Ratio Use as Output from the Non-Piloted Simulation

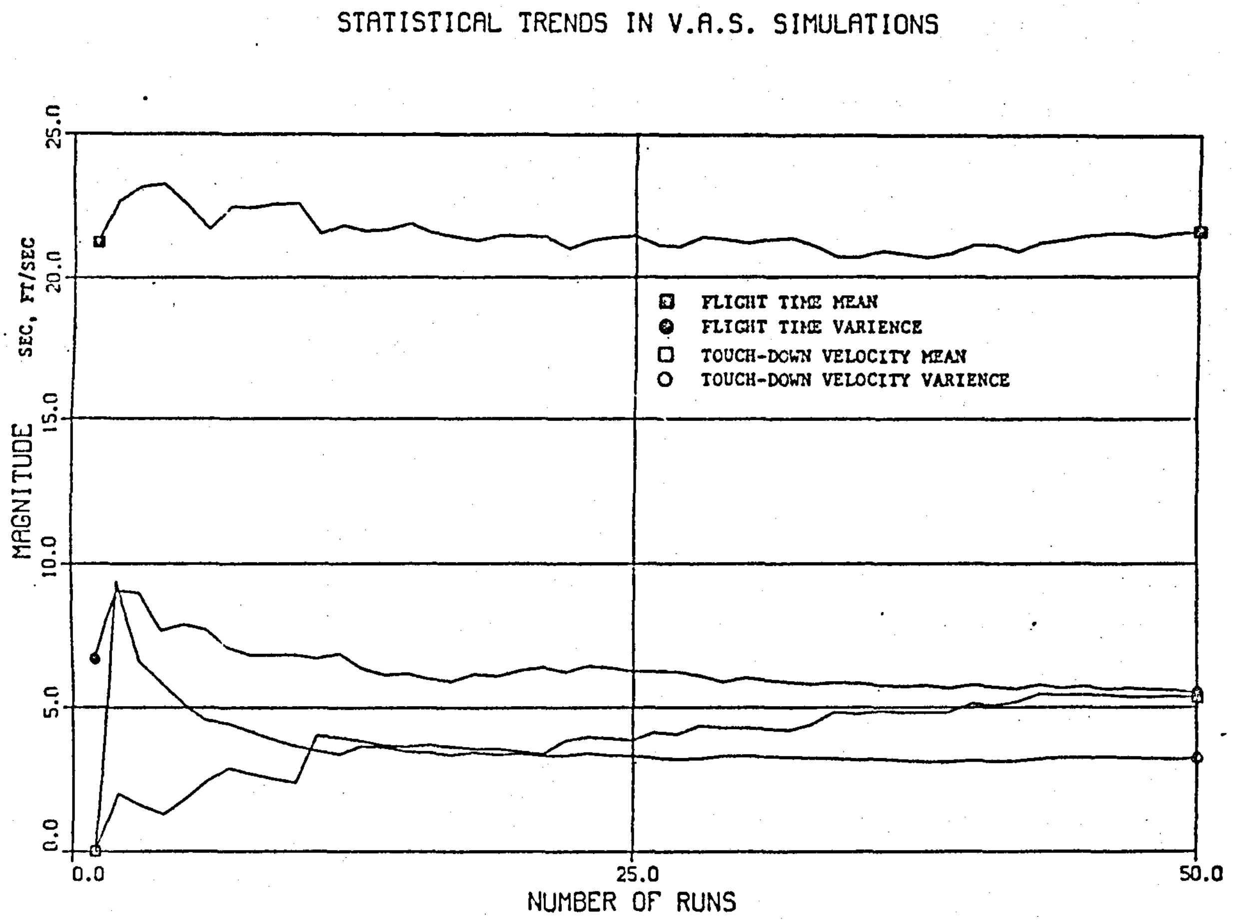


Figure A6: Example Plot Showing the Variation in Variance and Means for Flight Time and Touchdown Velocity as Influenced by the Number of Runs Made in the Non-Piloted Simulation

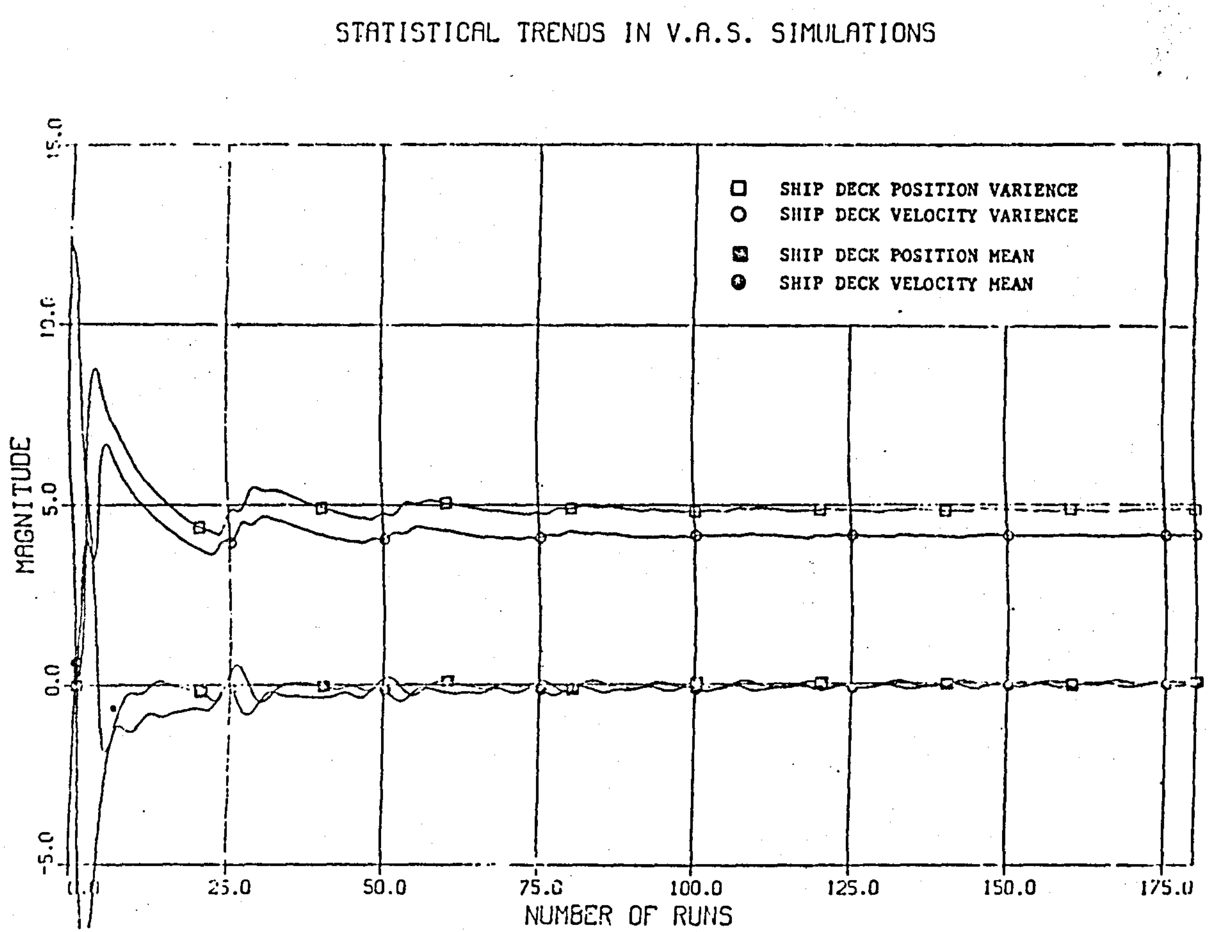


Figure A7: Example Plot Showing the Variation in Variance and Means for Ship Motion as Influenced by the Number of Runs Made, Where Number of Runs is Seconds in This Case

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( ILP NO.:                1

TAL=  0.1500000     ELC=  0.7000000     TW=    1.010000      ZW=  0.1000000
SEE S.=            6 KF=  7.0000002E-03

~~~~~~~~~~~~~

  RUN     I.T.      F.T.     TCVEL     MIVRD    THMEAN    THMAX    THMIN
 -----   ------    ------   -------   -------  --------  -------  -------
   1     2969.7     21.2      5.7       7.9     0.988     1.010    0.977
   2      121.4     24.1     11.4      11.6     0.986     1.010    0.950
   3     2026.6     24.2      9.8       9.1     0.991     1.010    0.950
   4      384.2     23.4      3.8       6.9     0.985     1.010    0.950
   5     2524.8     19.7      8.8      10.8     0.987     1.010    0.950
   6      774.4     17.6      6.9       8.4     0.987     1.010    0.977
   7     2825.2     27.0      3.3       8.8     0.988     1.010    0.950
   8      262.6     22.3      5.1       9.8     0.936     1.010    0.950
   9     2729.8     23.5      6.7       6.7     0.985     1.010    0.950
  10     3491.9     22.8      6.9       9.7     0.985     1.010    0.950
  11     2404.7     11.0      5.6      10.7     0.987     1.010    0.977
  12      945.4     24.9      8.7       9.3     0.987     1.010    0.950
  13     1816.2     19.4      0.4      11.1     0.989     1.010    0.950
  14      672.8     22.3      3.4       6.5     0.990     1.010    0.950
  15     3490.0     24.6      6.9       9.9     0.986     1.010    0.950
  16      962.4     16.9      3.2       8.6     0.987     1.010    0.977
  17     3467.7     19.2      4.2       6.5     0.988     1.010    0.977
  18      543.1     18.9     10.9      11.8     0.986     1.010    0.950
  19     3075.1     24.9      4.6       9.3     0.991     1.010    0.977
  20     3225.8     20.7     10.2      10.2     0.985     1.010    0.950
  21     2802.3     21.1      8.2       8.7     0.984     1.010    0.950
  22     1931.2     12.0      3.1       9.5     0.994     1.010    0.950
  23     1901.3     27.4     11.0      11.0     0.983     1.010    0.950
  24     1974.7     24.2      4.8      11.7     0.991     1.010    0.950
  25     2514.5     22.6      3.5       6.3     0.989     1.010    0.977
  26     2255.3     12.8      6.3       9.0     0.986     1.010    0.977
  27     3116.8     19.9      5.5       7.6     0.988     1.010    0.977
  28     1216.4     30.6      2.3       9.0     0.993     1.010    0.950
  29     1298.2     19.1      0.6       7.4     0.988     1.010    0.950
  30     2666.2     17.4      9.6      10.6     0.987     1.010    0.977
  31     2999.0     24.4      3.7       7.3     0.986     1.010    0.950
  32     1157.0     23.2      3.3       5.0     0.989     1.010    0.977
  33      165.6     12.4      3.5       9.5     0.987     1.010    0.977
  34     2190.3      8.3      8.6      14.6     0.990     1.010    0.978
  35      866.7     20.2      5.0       9.8     0.984     1.010    0.950
  36     3417.2     28.2      2.3       8.9     0.992     1.010    0.950
  37     2984.7     17.2      5.2       8.5     0.988     1.010    0.950
  38      615.9     16.1      6.5       9.0     0.986     1.010    0.977
  39      521.1     25.8      2.6      12.1     0.990     1.010    0.950
  40     2124.9     33.2     10.3      10.3     0.991     1.010    0.950
  41     1051.6     20.5      3.1       5.9     0.989     1.010    0.950
  42      165.8     12.2      2.8       9.5     0.987     1.010    0.977
  43     3314.5     33.4     10.9      11.5     0.991     1.010    0.950
  44     2679.8     24.7      0.7      10.4     0.989     1.010    0.950
  45     2616.7     27.7      8.6       8.6     0.987     1.010    0.950
  46     2302.2     25.9      1.4      10.6     0.989     1.010    0.950
  47     2956.3     21.2      7.7       7.7     0.984     1.010    0.950
```

Figure A8: Example Output of Run Conditions and Results for the Non-Piloted Simulation

```
 48    1083.0     16.0      3.4      8.6      0.986     1.010     0.977
 49    1784.8     27.9      4.2      6.8      0.991     1.010     0.950
 50    2304.6     23.7      1.1     10.4      0.968     1.010     0.950
-------------

FT MEAN(SEC):    21.55800     FT SIG(SEC):    5.464322
FTMAX:    33.40000     FTMIN:    8.300000

TDVEL MEAN(FT/S):    5.526001    TDVEL SIG(FT/S):    3.060933
TDVELMAX:    11.40000    TDVELMIN:  0.4000000

MTOUT MEAN:  0.9879200    MTOUT SIG:  2.3633221E-03
MTOUTMAX:  0.9940000    MTOUTMIN:  0.9840000

TIME:11:11:54   DATE: 4-JAN-85

**********************************************
FORTRAN STOP
```

Figure A8, continued: Example Output of Run Conditions and Results for the Non-Piloted Simulation

G. LISTING OF NON-PILOTED SIMULATION COMPUTER VARIABLE DEFINITIONS AND PROGRAM LISTINGS

LIST OF VARIABLES FOR VPA1C.FOR PROGRAM

NAME	DESRIPTION
A0	CONSTANT FOR THE ZEROTH ORDER NUMERATOR TERM OF THE PILOT TRANSFER FUNCTION.
A1	CONSTANT FOR THE FIRST ORDER NUMERATOR TERM OF THE PILOT TRANSFER FUNCTION.
AA0	CONSTANT FOR THE ZEROTH ORDER NUMERATOR TERM OF THE AIRCRAFT TRANSFER FUNCTION.
AA0P	MAGNITUDE OF THE PILOT OUTPUT SIGNAL ATTRIBUTED TO THE NUMERATOR OF THE PILOT TRANSFER FUNCTION.
AA1	CONSTANT FOR THE FIRST ORDER NUMERATOR TERM OF THE AIRCRAFT TRANSFER FUNCTION.
AA2	CONSTANT FOR THE SECOND ORDER NUMERATOR TERM OF THE AIRCRAFT TRANSFER FUNCTION.
AA3	CONSTANT FOR THE THIRD ORDER NUMERATOR TERM OF THE AIRCRAFT TRANSFER FUNCTION.
ABRTHT	ALTITUDE ABOVE THE DECK MOTION MEAN AT WHICH THE PILOT IS TO ABORT 'CHASING' THE SHIP DECK AND RETURN TO THE ASSIGNED HOVER ALTITUDE.
B1	CONSTANT FOR THE FIRST ORDER DENOMINATOR TERM OF THE PILOT TRANSFER FUNCTION.
B2	CONSTANT FOR THE SECOND ORDER DENOMINATOR TERM OF THE PILOT TRANSFER FUNCTION. SET = 0.0 IN CURRENT PROGRAM BECAUSE NOT IN CURRENT USE.
BA1	CONSTANT FOR THE FIRST ORDER DENOMINATOR TERM OF THE AIRCRAFT TRANSFER FUNCTION.
BA1P	MAGNITUDE OF THE PILOT OUTPUT SIGNAL ATTRIBUTED TO THE DENOMINATOR TERM OF THE PILOT TRANSFER FUNCTION.
BA2	CONSTANT FOR THE SECOND ORDER DENOMINATOR TERM OF THE AIRCRAFT TRANSFER FUNCTION.
BA3	CONSTANT FOR THE THIRD ORDER DENOMINATOR TERM OF THE AIRCRAFT TRANSFER FUNCTION.

BEG	INSTRUCTION TO PLOT3.FOR SUBROUTINE INDICATING BEGINNING POINT OF THE GRAPH X-AXIS.
BUF	DIMENSIONAL DUMMY VARIABLE USED IN THE TIME SUBROUTINE.
BUFF	DIMENSIONAL DUMMY VARIABLE USED IN THE DATE SUBROUTINE.
C1	FIRST RECURSION CONSTANT USED IN A.I.L. CALCULATION OF PILOT MODEL OUTPUT.
C1A	FIRST RECURSION CONSTANT USED IN A.I.L. CALCULATION OF AIRCRAFT MODEL OUTPUT.
C2	REMNANT FROM EARLIER PROGRAM. NOT USED IN THIS VERSION.
C2A	SECOND RECURSION CONSTANT USED IN A.I.L. CALCULATION. SAME VARIABLE NAME IS USED FOR BOTH PILOT AND A/C MODELS.
C2B	SECOND RECURSION CONSTANT USED IN A.I.L. CALCULATION OF PILOT MODEL OUTPUT USED AS INITIAL CONDITION INPUT TO PILOT MODEL.
C3A	THIRD RECURSION CONSTANT USED IN A.I.L. CALCULATION. SAME VARIABLE NAME IS USED FOR BOTH PILOT AND A/C MODELS.
C3B	THIRD RECURSION CONSTANT USED IN A.I.L. CALCULATION OF PILOT MODEL OUTPUT USED AS INITIAL CONDITION INPUT TO PILOT MODEL.
C4A	FOURTH RECURSION CONSTANT USED IN A.I.L. CALCULATION. SAME VARIABLE NAME IS USED FOR BOTH PILOT AND A/C MODELS.
C4B	FOURTH RECURSION CONSTANT USED IN A.I.L. CALCULATION OF PILOT MODEL OUTPUT USED AS INITIAL CONDITION INPUT TO PILOT MODEL.

C5A,C5B,C6A,C6B,C7A,C7B,C8A,C8B ARE SIMIALAR TO THE ABOVE.

CKPB	REMNANT FROM EARLIER PROGRAM. NOT USED IN THIS VERSION.
CTNH	'CHOP THROTTLE NOW HEIGHT'; HEIGHT ABOVE THE DECK AT WHICH THE PILOT IS TO QUICKLY REDUCE THRUST FOR LANDING.
D1	REMNANT FROM EARLIER PROGRAM. NOT USED IN THIS VERSION.
D2	REMNANT FROM EARLIER PROGRAM. NOT USED IN THIS VERSION.
D3	AN OFTEN USED COMBINATION OF OTHER VARIABLES.

DAMP	MAGNITUDE OF VERTICAL VELOCITY DAMPING THROUGH THRUST TERM.
DH	PILOT PRECIEVED ERROR IN HEIGHT (COMMANDED HEIGHT - ACTUAL HEIGHT + NOISE).
DHD	PILOT PRECIEVED ERROR IN VERTICAL VELOCITY.
DHDD	PILOT PRECIEVED ERROR IN VERTICAL ACCELERATION.
DHDTR	TRUE ERROR IN VERTICAL VELOCITY.
DHTR	TRUE ERROR IN HEIGHT.
ELC	ENGINE LAG TIME CONSTANT.
EN	RANDOM PHASE ANGLE GENERATED AND USED IN THE GENSM.FOR SUBROUTINE.
ERR	ERROR TERM (RANDOM NOISE WITH MAGNITUDE FROM -0.5 TO 0.5).
ERROR	ERROR TERM (RANDOM NOISE WITH MAGNITUDE FROM 0 TO 1).
FLAG2	REMNANT FROM EARLIER PROGRAM. NOT USED IN THIS VERSION.
FLT	FLIGHT TIME (INITIAL TIME MINUS TIME AT TOUCHDOWN).
FLT1	PREVIOUS FLIGHT TIME VALUE, HELD FOR USE IN STATISTIC CALCULATIONS.
FPLS	'FLIGHT PATH LOGIC SLOT'; INTEGER USED TO SHOW SECTION OF FLIGHT PATH COMMAND LOGIC IN USE WHEN MONITERING SIMULATION.
FPLS1	VARIABLE USED IN FINAL PRINTOUT TO INDICATE IF THE FLIGHT PATH COMMAND LOGIC HAD CYCLED THROUGH THE 'CHOP THROTTLE' SEQUENCE AT LEAST ONCE.
GAP	VARIABLE WHICH DETERMINES THE AMPLITUDE FOR A COSINE SMOOTHING FUNCTION IN THE FLIGHT PATH COMMAND LOGIC.
GAPP	VARIABLE WHICH DETERMINES THE AMPLITUDE FOR A COSINE SMOOTHING FUNCTION IN THE FLIGHT PATH COMMAND LOGIC.
GD	DUMMY VARIABLE USED TO TRANSFER THE VALUE OF GHDOT BETWEEN VASCON.FOR AND VA1C.FOR.
GHDOT	GAIN USED IN CALUCULATING THE VERTICAL VELOCITY DAMPING THROUGH THRUST VALUE.

GPP	VARIABLE WHICH DETERMINES THE AMPLITUDE FOR A COSINE SMOOTHING FUNCTION IN THE FLIGHT PATH COMMAND LOGIC.
HLIM	VARIABLE WHICH CAN BE USED TO SET A LIMIT ON THE LOWER BOUNDS OF COMMANDED THRUST.
HTA	THE NUMERATOR PORTION OF THE PILOT MODEL OUTPUT USED AS THE INPUT CONSTANT FOR THE ZEROTH TERM IN THE NUMERATOR OF THE AIRCRAFT TRANSFER FUNCTION AFTER ADDITION OF NOISE AND LIMITS.
HTB	THE DENOMINATOR PORTION OF THE PILOT MODEL OUTPUT USED AS THE INPUT CONSTANT FOR THE ZEROTH TERM IN THE DENOMINATOR OF THE AIRCRAFT TRANSFER FUNCTION AFTER ADDITON OF NOISE AND LIMITS.
HTPO	MAGNITUDE OF THE PILOT MODEL OUTPUT BEFORE THE ADDITION OF NOISE OR LIMITS.
HTPOA	FIRST PORTION OF EQUATION USED TO CALCULATE HTPO.
HTPOB	SECOND PORTION OF EQUATION USED TO CALCULATE HTPO.
I	DUMMY VARIABLE FOR DO STATEMENT.
IDO	DUMMY VARIABLE FOR DO STATEMENT.
IFLAG10	LOGIC SWITCH USED TO CONTINUE 'CHOPPED THROTTLE' SEQUENCE IN THE FLIGHT PATH COMMAND LOGIC AFTER ITS INITIALIZATION.
IFLAG11	LOGIC SWITCH TURNED ON IN THE 'RUN FAST' SEQUENCE OF THE FLIGHT PATH COMMAND LOGIC AND USED TO DETERMINE THE INITIAL AMPLITUDE FOR THE COSINE SMOOTHING FUNCTION IN THE 'RUN' SEQUENCE OF THE FLIGHT PATH COMMAND LOGIC.
IFLAG12	LOGIC SWITCH TURNED ON IN THE 'RUN' SEQUENCE OF THE FLIGHT PATH LOGIC AFTER INITIALIZATION OF TIME CONSTANT FOR THE COSINE SMOOTHING FUNCTION, TO PREVENT REINITIALIZATION ON CONSECUTIVE PASSES.
IFLAG13	LOGIC SWITCH TURNED ON IN THE 'ABORT TO HOVER ALTITUDE' SEQUENCE OF THE FLIGHT PATH LOGIC AFTER INITIALIZATION OF TIME CONSTANT FOR THE COSINE SMOOTHING FUNCTION, TO PREVENT REINITIALIZATION ON CONSECUTIVE PASSES.

IFLAG3	LOGIC SWITCH TURNED ON IN THE 'ABORT TO HOVER ALTITUDE' SEQUENCE OF THE FLIGHT PATH COMMAND LOGIC AFTER INITIALIZATION OF A TIME CONSTANT FOR THE COSINE SMOOTHING FUNCTION TO PREVENT REINITIALIZATION ON CONSECUTIVE PASSES.
IFLAG5	DATA OUTPUT SWITCH, IF IFLAG5=1 THEN THE STATISTICAL INFORMATION IS CALCULATED AND OUTPUT.
IFLAG7	LOGIC SWITCH TURNED ON IN THE 'CHOP THROTTLE SEQUENCE' OF THE FLIGHT PATH COMMAND LOGIC AND USED IN THE 'CHASE' SEQUENCE OF THE FLIGHT PATH COMMAND LOGIC TO DETERMINE THE INITIAL AMPLITUDE FOR THE COSINE SMOOTHING FUNCTION.
IFLAG8	LOGIC SWITCH TURNED ON IN THE IN4.FOR SUBROUTINE AFTER INITIAL COMMANDED LETDOWN FLIGHTPATH REACHES THE CONSTANT HOVER ALTITUDE VALUE, PREVENTS REINITIALIZATION OF LETDOWN SEQUENCE DURING A RUN.
IFLAG9	LOGIC SWITCH TURNED ON IN THE 'CHOP THROTTLE' SEQUENCE OF THE FLIGHT PATH COMMAND LOGIC, WHICH CAN BE USED TO CHANGE THE THRUST LOWER LIMITS FROM THE NOMINAL VALUE USED FOR THE REST OF FLIGHT PATH COMMAND SEQUENCES.
INT	DUMMY VARIABLE USED IN DO LOOP.
ISEAS	INTEGER VALUE OF SEA STATE BEING SIMULATED. IT IS PASSED TO VARIOUS SUBROUTINES AS A SIMULATION PARAMETER AND FOR PARAMETER PRINTOUT FOR THE SIMULATION ON DATA OUTPUT.
IT	DUMMY VARIABLE USED IN VARIABLE DIMENSION STATEMENTS.
IT1	TIME INCREMENT USED IN THE A.I.L. CALCULATIONS
IT2 THROUGH IT8	ARE TIME INCREMENTS USED IN THE A.I.L. CALCULATIONS. IT2=IT1**2/2!, IT3=IT1**3/3!, ETC.
IT9 THROUGH IT12	ARE REMNANTS FROM EARLIER PROGRAMING. NOT USED IN THIS VERSION.
ITOT	TOTAL NUMBER OF ENTRIES USED IN DETERMING A HISTOGRAM OF STATISTICAL DATA.
J	INITIAL SEED FOR USE IN THE RANDOM NUMBER GENERATING SUBROUTINE.
JAY	DUMMY VARIABLE FOR PASSING THE NUMBER OF GROUPS BEING RUN IN A GIVEN SIMULATION SESSION TO VARIOUS SUBROUTINES.

JRAN	INITIAL SEED FOR USE IN THE RANDOM NUMBER GENERATING SUBROUTINE.
K	NUMBER OF RUNS/GROUP OF A SIMULATION SESSION.
KAY	DUMMY VARIABLE, NUMBER OF RUNS/GROUP OF A SIMULATION SESSION.
KDOO	INCREMENTED VARIABLE USED AS A DIMENSION IN A DO LOOP.
KMEAN	NUMBER OF ENTRIES IN A STATISTICAL MEAN CALCULATION.
KMN	NUMBER OF ENTRIES IN A STATISTICAL MEAN CALCULATION.
KP	NOMINAL PILOT GAIN.
KPA	MODIFIED PILOT GAIN.
KPB	MODIFIED PILOT GAIN.
KPC	MODIFIED PILOT GAIN.
L	INTEGER VALUE OF THE PILOTS PURE LAG TIME MULTIPLIED BY 100.
LIM	CALCULATED VARIABLE WHICH MODIFIES THE dT/W VALUE OUTPUT FROM THE PILOT MODEL TO KEEP IT IN PHYSICALLY REALIZABLE LIMITS.
MIVRD	VALUE OF THE MAXIMUM INSTANTANEOUS VELOCITY RELATIVE TO DECK ENCOUNTERED DURING A SIMULATION RUN.
MTOUT	MEAN THRUST/WEIGHT RATIO OUTPUT DURING A SIMULATION RUN.
POUT	VALUE OF THE PILOT MODEL OUTPUT, AFTER ADDITION OF NOISE AND LIMITS.
PRECYC	NUMBER OF CYCLES THE SUBROUTINE TRANO.FOR IS TO RUN THROUGH TO OBTAIN STEADY STATE OUTPUT BEFORE VALUES FOR NOISE AND TURBULENCE INPUTS ARE RETURNED TO THE MAIN PROGRAM.
RNP	VALUE OF NOISE CALCULATED IN TRANO.FOR INSERTED INTO THE PILOT MODEL AS INTERNAL PILOT NOISE.
RNQ	VALUE OF NOISE CALCULATED IN TRANO.FOR ADDED TO THE POSITON ERROR (PILOT PRECEPTION NOISE).
S1	COMMANDED FLIGHT PATH ALTITUDE.

S2	COMMANDED FLIGHT PATH VELOCITY.
S3	COMMANDED FLIGHT PATH ACCELERATION.
SA1	COMMANDED HOVER ALTITUDE.
SA2	COMMANDED HOVER VELOCITY.
SA3	COMMANDED HOVER ACCELERATION.
SGAPP	INITIAL POINT FOR A COSINE SMOOTHING FUNCTION IN THE 'RUN FAST' SEQUENCE OF THE FLIGHT PATH LOGIC.
SGP	INITIAL POINT FOR A COSINE SMOOTHING FUNCTION IN THE 'CHASE' SEQUENCE OF THE FLIGHT PATH LOGIC.
SGPP	INITIAL POINT FOR A COSINE SMOOTHING FUNCTION IN THE 'RUN' SEQUENCE OF THE FLIGHT PATH LOGIC.
SS1	SHIP DECK POSITION.
SS1Z	RELATIVE DISTANCE BETWEEN SHIP DECK AND A/C DELAYED BY THE VALUE OF THE PURE PILOT LAG TIME.
SS2	SHIP DECK VELOCITY.
SS2ZD	RELATIVE VELOCITY OF THE SHIP DECK AND A/C DELAYED BY THE VALUE OF THE PURE PILOT LAG TIME.
SS3	SHIP DECK ACCELERATION.
SSAMP	AMPLITUDE OF THE COSINE SMOOTHING FUNCTION IN THE 'ABORT TO HOVER ALTITUDE' SEQUENCE OF THE FLIGHT PATH COMMAND LOGIC.
SSGAP	INITIAL POSITION FOR THE START OF THE COSINE SMOOTHING FUNCTION IN THE 'ABORT TO HOVER ALTITUDE' SEQUENCE OF THE FLIGHT PATH COMMAND LOGIC.
SX	DUMMY VARIABLE IN CALL TO INPUT1.FOR, NOT USED IN THIS VERSION.
T	TIME (SECONDS).
T1	MODIFIED VALUE OF T2, NOT USED IN THIS VERSION.
T2	REMNANT FROM EARLIER PROGRAM, NOT USED IN THIS VERSION.
T4	MODIFIED VALUE OF T2, NOT USED IN THIS VERSION.

TC	TIME INCREMENT FOR RUNNING THE SIMULATION.
TE THROUGH TE4	TIME INITIALIZED AT THE BEGINING OF A SET OF CONSECUTIVE RUNS THROUGH ONE OF THE FLIGHT PATH COMMAND LOGIC SEQUENCES FOR TIMING OF THE COSINE SMOOTHING FUNCTIONS.
TF	FINAL TIME FOR WHICH THE SIMULATION ABORTS A RUN IF TOUCHDOWN HAS NOT BEEN ACHEIVED.
TFIN	DUMMY VARIABLE USED IN GRAPHICS SUBROUTINE TO INDICATE X-AXIS MAXIMUM VALUE FOR GRAPH.
TG	PILOT LAG TIME CONSTANT.
TGEE	VALUE CALCULATED IN TRANO.FOR FOR INPUT AS TURBULENCE INTO THE A/C TRANSFER FUNCTION.
TII	THE INITIAL TIME A RUN WAS STARTED AT AS OUTPUTTED FROM A RANDOM NUMBER GENRATION SEQUENCE WITH BOUNDS FROM 0 TO 3600 SECONDS.
TL	PILOT LEAD TIME CONSTANT.
TOUT	THRUST-TO-WEIGHT RATIO.
TOUTMAX	MAXIMUM THRUST-TO-WEIGHT RATIO COMMANDED BY PILOT (WITH A/C LIMITS) DURING A GIVEN RUN.
TOUTMIN	MINIMUM THRUST-TO-WEIGHT RATIO COMMANDED BY PILOT (WITH A/C LIMITS) DURING A GIVEN RUN.
TSDA	PART OF THE SEQUENTIAL CALCULATION OF STANDARD DEVIATION FOR FLIGHT TIMES IN A GROUP OF RUNS.
TW	THE MAXIMUM THRUST-TO-WEIGHT RATIO ALLOWED FOR A GROUP OF RUNS.
VSDA	PART OF THE SEQUENTIAL CALCULATION OF STANDARD DEVIATION FOR TOUCH DOWN VELOCITIES IN A GROUP OF RUNS.
VTD	RELATIVE VELOCITY OF SHIP AND A/C AT TOUCHDOWN.
VTD1	TOUCHDOWN VELOCITY FOR PREVIOUS RUN USED IN STATISTICAL CALCULATIONS.
VTZ	DUMMY VARIABLE PASSED TO SUBROUTINE TRANO.FOR. NOT USED IN THIS VERSION.

Y0	AN INITIAL CONDITION OF POSITION FOR THE A.I.L. CALCULATION OF THE DIFFERIENTIAL EQUATION DESCRIBING THE PILOT TRANSFER FUNCTION.
Y1	POSITION OUTPUT OF THE PILOT TRANSFER FUNCTION.
Y1A	FIRST PART OF POSITION CALCULATION FOR OUTPUT OF PILOT TRANSFER FUNCTION.
Y1B	SECOND PART OF POSITION CALCULATION FOR OUTPUT OF PILOT TRANSFER FUNCTION.
Y2	VELOCITY OUTPUT OF THE PILOT TRANSFER FUNCTION.
Y2A	FIRST PART OF VELOCITY CALCULATION FOR OUTPUT OF PILOT TRANSFER FUNCTION.
Y2B	SECOND PART OF VELOCITY CALCULATION FOR OUTPUT OF PILOT TRANSFER FUNCTION.
Y3	ACCELERATION OUTPUT OF THE PILOT TRANSFER FUNCTION.
Y3A	FIRST PART OF ACCELERATION CALCULATION FOR OUTPUT OF PILOT TRANSFER FUNCTION.
Y3B	SECOND PART OF ACCELERATION CALCULATION FOR OUTPUT OF PILOT TRANSFER FUNCTION.
YA1	POSITION OUTPUT OF THE PILOT TRANSFER FUNCTION AS USED FOR INPUT TO A/C TRANSFER FUNCTION.
YA1A	FIRST PART OF POSITION CALCULATION FOR OUTPUT OF THE PILOT TRANSFER FUNCTION AS USED FOR INPUT TO A/C TRANSFER FUNCTION.
YA1B	SECOND PART OF POSITION CALCULATION FOR OUTPUT OF THE PILOT TRANSFER FUNCTION AS USED FOR INPUT TO A/C TRANSFER FUNCTION.
YA2	VELOCITY OUTPUT OF THE PILOT TRANSFER FUNCTION AS USED FOR INPUT TO A/C TRANSFER FUNCTION.
YA3	ACCELERATION OUTPUT OF THE PILOT TRANSFER FUNCTION AS USED FOR INPUT TO THE A/C TRANSFER FUNCTION.
YAA1	POSITION OUTPUT OF THE PILOT TRANSFER FUNCTION USED FOR MONITERING PILOT TRANSFER FUNCTION OUTPUT.
YAA1A	FIRST PART OF POSITION OUTPUT OF PILOT TRANSFER FUNCTION CALCULATION.

YAA1B	SECOND PART OF POSITION OUTPUT OF PILOT TRANSFER FUNCTION CALCULATION.
YAA2	VELOCITY OUTPUT OF THE PILOT TRANSFER FUNCTION USED FOR MONITERING PILOT TRANSFER FUNCTION OUTPUT.
YAA3	ACCELERATION OUTPUT OF THE PILOT TRANSFER FUNCTION USED FOR MONITERING PILOT TRANSFER FUNCTION OUTPUT.
YD0	INITIAL CONSTANT FOR VELOCITY USED IN THE A.I.L. CALCULATION OF THE DIFFERIENTIAL EQUATION REPERSENTING THE PILOT TRANSFER FUNCTION.
Z	AIRCRAFT HEIGHT ABOVE MEAN DECK POSITION.
ZA1	FIRST PART OF THE POSITON CALCULATION FOR A/C TRANSFER FUNCTION OUTPUT.
ZA2	SECOND PART OF THE POSITION CALCULATION FOR A/C TRANSFER FUNCTION OUTPUT.
ZB1	FIRST PART OF THE VELOCITY CALCULATION FOR A/C TRANSFER FUNCTION OUTPUT.
ZB2	SECOND PART OF THE VELOCITY CALCULATION FOR A/C TRANSFER FUNCTION OUTPUT.
ZC1	FIRST PART OF THE ACCELERATION CALCULATION FOR A/C TRANSFER FUNCTION OUTPUT.
ZC2	SECOND PART OF THE ACCELERATION CALCULATION FOR A/C TRANSFER FUNCTION OUTPUT.
ZD	A/C VELOCITY OUTPUT.
ZDD	A/C ACCELERATION OUTPUT.
ZW	VERTICAL VELOCITY DAMPING DUE TO AIRFRAME TIME CONSTANT.
ZWDTDT	NUMERATOR CONSTANT FOR THE A/C TRANSFER FUNCTION.

LIST OF VARIABLES FOR IN4.FOR

NAME	DESCRIPTION
A	THE INITIAL TIME FOR THE 'A' SEQUENCE OF THE HOVER ALTITUDE COMMAND LOGIC.
AMPA	FINAL HOVER COMMAND HEIGHT. ALSO THE AMPLITUDE FOR THE 'A' SEQUNCE OF THE HOVER COMMAND HEIGHT LOGIC (THE COSINE FUNCTION OF 'A' SEQUENCE IS NOT USED IN THIS VERSION).
AMPB	THE AMPLITUDE FOR THE COSINE FUNCTION OF THE 'B' SEQUENCE OF THE HOVER HEIGHT LOGIC. AMPA+AMPB GIVES THE INITIAL STARTING HEIGHT ABOVE THE SHIP DECK MEAN IN THIS VERSION.
B	THE INITIAL TIME FOR THE 'B' SEQUENCE OF THE HOVER ALTITUDE COMMAND LOGIC.
IFLAG5	LOGIC SWITCH TURNED ON AFTER THE INITIAL COMMANDED LETDOWN FLIGHTPATH ('B' SEQUENCE) REACHES THE CONSTANT HOVER ALTITUDE VALUE (AMPA) TO PREVENT REINITIALIZATION OF THE 'B' SEQUENCE DURING A GIVEN RUN. THIS VARIABLE CORRESPONDS TO IFLAG8 IN THE IN4.FOR CALL STATEMENT FROM VPAIC.FOR.
ISFLAG1	LOGIC SWITCH TURNED ON AFTER THE TIME INITIALIZATION IN THE 'A' SEQUENCE TO PREVENT REINITIALIZATION OF THE TIME DURING A GIVEN RUN.
S1	COMMANDED HOVER FLIGHT PATH ALTITUDE.
S2	COMMANDED HOVER FLIGHT PATH VELOCITY.
S3	COMMANDED HOVER FLIGHT PATH ACCELERATION.
SX	DUMMY VARIABLE USED IN CALL STATEMENT TO IN4.FOR, NOT USED IN THIS VERSION.
T	TIME (SECONDS).
TAU	TIME MINUS THE TIME OF INITIALIZATION OF EITHER THE 'A' OR 'B' SEQUENCE.
TI	THE INITIAL TIME A RUN WAS STARTED AT, AS OUTPUTTED FROM A RANDOM NUMBER GENERATION SEQUENCE WITH BOUNDS FROM 0 TO 3600 SECONDS.

TIMA	VARIABLE USED IN THE INITIALIZING THE TIME FOR THE 'A' SEQUENCE.
WNS	FREQUENCY OF THE COSINE FUNCTION IN THE 'A' SEQUENCE.
WNS1	FREQUENCY OF THE COSINE FUNCTION IN THE 'B' SEQUENCE.

LIST OF VARIABLES FOR TRANO.FOR

NAME	DESCRIPTION
FLAG	REMNANT FROM EARLIER PROGRAM, NOT USED IN THIS VERSION.
I	DUMMY VARIABLE USED IN DO LOOPS.
IB	IFIXED VALUE OF XB.
IS	IFIXED VALUE OF S.
M	THE NONINTEGER PART OF THE TIME (IN SECONDS) OF THE SYSTEM CLOCK.
PRECYC	NUMBER OF CYCLES THE TRANO.FOR SUBROUTINE IS TO RUN THROUGH TO OBTAIN STEADY STATE OUTPUT BEFORE VALUES FOR NOISE AND TURBULENCE INPUTS ARE RETURNED TO THE MAIN PROGRAM.
RNO	OUTPUT OF THE FIRST ORDER FILTER USED AS INTERNAL PILOT NOISE.
RNOD	FIRST DERIVATIVE OF RNO.
RNP	RNO MODIFIED BY A GAIN.
RNQ	OUTPUT OF THE FIRST ORDER FILTER USED AS PILOT PRECEPTION ERROR.
RNQD	FIRST DERIVATIVE OF RNQ.
RT	SYSTEM TIME MINUS THE NONINTEGER PART OF THE SYSTEM TIME, IN SECONDS.
S	INDICATES IF XM IS EVEN OR ODD.

SIGMA	THE SIGMA VALUE FOR THE FILTER USED IN GENERATING RANDOM TURBULENCE.
SIGMAN	THE SIGMA VALUE FOR THE FILTER USED IN GENERATING THE INTERNAL PILOT NOISE.
SIGMAQ	THE SIGMA VALUE FOR THE FILTER USED IN GENERATING THE PILOT PRECEPTION NOISE.
TC	THE PROGRAM TIME INCREMENT.
TGEE	OUTPUT OF THE FRIST ORDER FILTER USED TO GENERATE RANDOM TURBULENCE.
TM	SYSTEM TIME IN SECONDS.
VTZ	SAME AS TGEE.
WN	FREQUENCY TERM FOR THE TURBULENCE SHAPING FILTER.
WNN	FREQUENCY TERM FOR THE INTERNAL PILOT NOISE SHAPING FILTER.
WNQ	FREQUENCY TERM FOR THE PILOT PERCEPTION ERROR SHAPING FILTER.
XB	MODIFIED VALUE OF RT.
XM	FLOATED VALUE OF M.
XS	FLOATED VALUE OF IS.
Y	VALUE OF 12 RANDOM NUMBERS ADDED TOGETHER IN THE PROCESS OF CREATING A GAUSSIAN DISTRIBUTION FROM A WHITE NOISE SOURCE.
YA	A RANDOM NUMBER GENERATED FROM A WHITE NOISE SOURCE.
YB	A RANDOM NUMBER GENERATED FROM A GAUSSIAN DISTRIBUTION SOURCE.

VARIABLES FOR GENSM.FOR

NAME	DESCRIPTION
EN	RANDOM PHASE ANGLE.
H1 THROUGH H6	ARE THE CONTRIBUTIONS TO THE SHIP HEAVE IN FEET, FROM EACH OF THE SIX SINE CONPONENTS TO THE SHIP HEAVE MOTION APPROXIMATION.
HD1 THROUGH HD6	ARE THE CONTRIBUTIONS TO THE SHIP HEAVE VELOCITY IN FEET/SEC, FROM EACH OF THE SIX SINE CONPONENTS TO THE SHIP HEAVE MOTION APPROXIMATION.
HDD1 THROUGH HDD6	ARE THE CONTRIBUTIONS TO THE SHIP HEAVE ACCELERATION IN FEET/SEC**2, FROM EACH OF THE SIX SINE CONPONENTS OF THE SIX SINE CONPONENTS TO THE SHIP HEAVE MOTION APPROXIMATION.
IB	IFIXED VALUE OF XB.
M	IFIXED VALUE OF S.
P1 THROUGH P6	ARE THE CONTRIBUTIONS TO THE SHIP PITCH POSITION IN RADIANS, FROM EACH OF THE SIX SINE CONPONENTS TO SHIP PITCH MOTION APPROXIMATION.
PD1 THROUGH PD6	ARE THE CONTRIBUTIONS TO THE SHIP PITCH VELOCITY IN RADIANS/SEC, FROM EACH OF THE SIX SINE CONPONENTS TO SHIP PITCH MOTION APPROXIMATION.
PDD1 THROUGH PDD6	ARE THE CONTRIBUTIONS TO THE SHIP PITCH ACCELERATION IN RADIANS/SEC**2, FROM EACH OF THE SIX SINE CONPONENTS TO SHIP PITCH MOTION APPROXIMATION.
RT	SYSTEM TIME MINUS THE NONINTEGER PART OF THE SYSTEM TIME IN SECONDS.
S	INDICATES IF XM IS EVEN OR ODD.
S1	SHIP DECK POSITION RELATIVE TO THE MEAN DECK POSITION.
S2	SHIP DECK VELOCITY.
S2A	SUM OF THE SHIP HEAVE VELOCITY CONTRIBUTIONS TO THE SHIP HEAVE MOTION.

S2B	SUM OF THE SHIP PITCH VELOCITY CONTRIBUTIONS, MULTIPLIED BY THE DISTANCE FROM THE SHIP C.G. TO THE SHIP LANDING PAD BULLSEYE TO OBTAIN THE CONTRIBUTION OF THE SHIP PITCHING MOTION TO HEAVE AT THE LANDING PAD BULLSEYE.
S3	SHIP DECK ACCELERATION.
S3A	SUM OF THE SHIP HEAVE ACCELERATION CONTRIBUTIONS TO THE SHIP HEAVE ACCELERATION.
S3B	SUM OF THE SHIP PITCH ACCELERATION CONTRIBUTIONS, MULTIPLIED BY THE DISTANCE FROM THE SHIP C.G. TO THE SHIP LANDING PAD BULLSEYE TO OBTAIN THE CONTRIBUTION OF THE SHIP PITCHING MOTION TO HEAVE AT THE LANDING PAD BULLSEYE.
T	TIME (SECONDS).
T1	THE INITIAL TIME A RUN WAS STARTED AT, AS OUTPUTTED FROM A RANDOM NUMBER GENERATION SEQUENCE WITH BOUNDS FROM 0 TO 3600 SECONDS.
TM	SYSTEM TIME IN SECONDS.
XB	MODIFIED VALUE OF RT.
XM	FLOATED VALUE OF M.
XS	FLOATED VALUE OF IS.
Y	RANDOM NUMBER WITH MAGNITUDE OF -0.5 TO 0.5.

```
******************************   2-FEB-1985 13:38:24.07   FSD0:[STEVENS.SHIPSTUFF]SHPREFLIN.COM;1   **********
*
******************************   2-FEB-1985 13:38:24.07   FSD0:[STEVENS.SHIPSTUFF]SHPREFLIN.COM;1   **********
*
******************************   2-FEB-1985 13:38:24.07   FSD0:[STEVENS.SHIPSTUFF]SHPREFLIN.COM;1   **********
```

```
SHPREFLIN.COM;1
```

```
*****************************   2-FEB-1985 13:38:24.07   FSD0:[STEVENS.SHIPSTUFF]SHPREFLIN.COM;1   ***********
```

```
$ SET VERIFY
$ ASSIGN/USER SYS$COMMAND SYS$INPUT
$ LINK SHPREF,DISPLOT,SYS$LIBRARY:INTLIB/LIB,DISSPLA/LIB,INTLIB/LIB
$ SET NOVERIFY
```

```
******************************  2-FEB-1985 13:23:47.97  FSD0:[STEVENS.SHIPSTUFF]SHPREF.LIS;1  ******************************
******************************  2-FEB-1985 13:23:47.97  FSD0:[STEVENS.SHIPSTUFF]SHPREF.LIS;1  ******************************
******************************  2-FEB-1985 13:23:47.97  FSD0:[STEVENS.SHIPSTUFF]SHPREF.LIS;1  ******************************
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SHPREF.LIS;1

```
******************************  2-FEB-1985 13:23:4 .97  A40       SHIPSTUFF]SHPREF.LIS;1  ******************************
******************************  2-FEB-1985 13:23:47.97             HIPSTUFF]SHPREF.LIS;1  ******************************
******************************  2-FEB-1985 13:23:47.97  FSD0:[STEVENS.SHIPSTUFF]SHPREF.LIS;1  ******************************
```

```
                                        2-Feb-1985 13:21:49    VAX-11 FORTRAN V3.5-62          Page  1
                                        10-Dec-1984 13:18:18   FS00:[STEVENS.SHIPSTUFF]SHPREF.FOR;23

C23456789012345678901...etc.

      DIMENSION H(30),HE(30),PHI(30),SH(30)
      REAL MUS
      CHARACTER*12 FLNM
C     VS=42.17  !42.17     !FT/SEC
C     MUS=2.0944    !RAD
C     HS=12.0       !FT
      PRINT*,'DO YOU WISH TO ENTER DATA IN NEW FILE? 1=YES'
      ACCEPT*,FLAGA
      PRINT*,'DO YOU WISH A PLOT OF THE DATA?  1=YES'
      ACCEPT*,FLAGB
      PRINT*,'ENTER TO,VS,MUS,HS'
      ACCEPT*,TO,VS,MUS,HS
C     TO=13.1       !SEC

C *** ENTER FILENAME IN ACCEPT STATEMENT IN FORM OF 'filename',
C     i.e., IF YOU NAME IT STUFF.DAT, INPUT IT AS 'STUFF.DAT'
      TYPE*,'ENTER FILE NAME'    ! INPUT FILENAME AS 'filename'
      ACCEPT*, FLNM
      IF (FLAGA .EQ. 1) GO TO 5
      OPEN (UNIT=1,FILE=FLNM,TYPE='OLD')
      GO TO 10
5     OPEN (UNIT=1,FILE=FLNM,TYPE='NEW')
10    J=50
      L=200
      M=600
      K=1
15     DO 50 I=L,M,J
        H(K)=FLOAT(I)/1000.
        IF (FLAGA .EQ. 1.0) GO TO 30
20       READ (1,25) RAO
25       FORMAT(1X,F10.7)
        GO TO 40
30       TYPE*,'H=',H(K)
        PRINT*,'INPUT CORRESPONDING RAO VALUE'
        ACCEPT*,RAO
        WRITE (1,35) RAO
35       FORMAT(1X,F10.7)
40      HE(K)=H(K)-H(K)**2*VS*COS(MUS)/32.2
        SHA=((483.5*HS**2)/((TO**4)*(H(K)**5)))
        SHB=EXP(-1944.5/((H(K)*TO)**4))
        SH(K)=SHA*SHB
C       SH(K)=SHA*SHB
        RCHK=4*VS*COS(MUS)*HE(K)/32.2
C       PRINT*,'#########',RCHK
        IF (RCHK .LT. 1.0) GO TO 45
        DWOWE=1.0/((ABS(RCHK)-1)**0.5)
        GO TO 47
45      DWOWE=1.0/((1-RCHK)**0.5)
C47     PRINT*,DWOWE
47      PHI(K)=SH(K)*DWOWE*RAO
        IF (PHI(K) .GT. PHIMAX) PHIMAX=PHI(K)
C       PRINT*,PHI(K),PHIMAX
        K=K+1
50    CONTINUE
      IF (K .GT. 24) GO TO 60
```

```
0058          IF (K .GT. 15) GO TO 55
0059          L=625
0060          M=750
0061          J=25
0062          GO TO 15
0063    55     L=800
0064          M=1200
0065          J=50
0066          GO TO 15
0067    60     DO 65 I=1,24
0068            PHI(I)=PHI(I)/PHIMAX
0069    65    CONTINUE
0070          IF (FLAGB .NE. 1.0) GO TO 66
0071          CALL MARKPLT(HE,PHI,K)
0072    66    PRINT*,'    H              HE             PHI',
0073         1'            SH'
0074          TYPE*,'---------------------------------------------'
0075          DO 70 I=1,24
0076            TYPE*,H(I),HE(I),PHI(I),SH(I)
0077    C       TYPE*,'HE=',HE(I),' PHI=',PHI(I),' SH(I)=',SH(I)
0078    70    CONTINUE
0079          PRINT*,'PHIMAX=',PHIMAX,' HUS=',HUS,' HS=',HS,' TO=',TO
0080          PRINT*,FLNM
0081          CLOSE(1)
0082          STOP
0083          END
```

```
PROGRAM SECTIONS

    Name                                   Bytes   Attributes

  0 $CODE                                   1208   PIC CON REL LCL   SHR   EXE   RD NOWRT LONG
  1 $PDATA                                   279   PIC CON REL LCL   SHR NOEXE   RD NOWRT LONG
  2 $LOCAL                                   752   PIC CON REL LCL NOSHR NOEXE   RD   WRT LONG

    Total Space Allocated                   2239


ENTRY POINTS

    Address  Type  Name                        References

  0-00000000       SHPREF$MAIN


VARIABLES

    Address  Type  Name         Attributes  References

  2-00000228  R*4  DONE                        48=        50=        52
  2-000001F0  R*4  FLAGA                       10=        21         31
  2-000001F4  R*4  FLAGB                       12=        70
  2-000001E0  CHAR FLNM                         5         20=        22A        24A        83
  2-00000200  R*4  HS                          14=        41         79
```

```
  2-00000214  I*4  I                    29=     30      67=     68(2)   75=     76(4)
  2-00000204  I*4  J                    25=     29      61=     65=
  2-00000210  I*4  K                    28=     30      35      40(3)   41      42      43      45
                                        52(2)   53(2)   55(2)=  57      58      71A
  2-00000208  I*4  L                    26=     29      59=     63=
  2-0000020C  I*4  M                    27=     29      60=     64=

  2-000001EC  R*4  MUS                   4      14=     40      45      79
  2-0000022C  R*4  PHIMAX               53(2)=  68      79
  2-00000218  R*4  RAD                  32=     37=     38      52
  2-00000224  R*4  RCHK                 45=     47      48      58
  2-0000021C  R*4  SWA                  41=     43

  2-00000220  R*4  SWB                  42=     43
  2-000001F8  R*4  TO                   14=     41      42      79
  2-000001FC  R*4  VS                   14=     40      45

ARRAYS

   Address  Type  Name        Attributes       Bytes  Dimensions       References

  2-000000F0  R*4  PHI                          120  (30)               3      52=     53(2)   68(2)=  71A
                                                                       76
  2-00000168  R*4  SH                           120  (30)               3      43=     52      76
  2-00000000  R*4  W                            120  (30)               3      30=     35      40(2)   41
                                                                       42      76
  2-00000078  R*4  WE                           120  (30)               3      40=     45      71A     76

LABELS

   Address   Label                        References

  0-0000010E  5                            21      24#
  0-00000117  10                           23      25#
  0-0000012A  15                           29#     62      66
      **      20                           32#
  1-00000108  25'                          32      33#

  0-000001B8  30                           31      35#
  1-00000111  35'                          38      39#
  0-0000023E  40                           34      40#
  0-000002E3  45                           47      50#
  0-000002F1  47                           49      52#

      **      50                           29      56#
  0-00000356  55                           58      63#
  0-00000369  60                           57      67#
      **      65                           67      69#
  0-0000039C  66                           70      72#

      **      70                           75      78#
```

```
SHPREF$MAIN                                            2-Feb-1985 13:21:49    VAX-11 FORTRAN V3.5-62          Page   4
                                                       18-Dec-1984 13:18:18   FS00:[STEVENS.SHIPSTUFF]SHPREF.FOR;23

FUNCTIONS AND SUBROUTINES REFERENCED

 Type  Name                          References

       FOR$CLOSE                        81
       FOR$OPEN                         22        24
       MARKPLT                          71
  R*4  MTH$COS                          40        45
  R*4  MTH$EXP                          42


 +------------------------------------------+
 |          KEY TO REFERENCE FLAGS          |
 |   *   - Value Modified                   |
 |   #   - Defining Reference               |
 |   A   - Actual Argument, possibly modified |
 |   D   - Data Initialization              |
 |  (n)  - Number of occurrences on line    |
 +------------------------------------------+


COMMAND QUALIFIERS

  FORTRAN /CRO/LIS SHPREF.FOR

  /CHECK=(NOBOUNDS,OVERFLOW,NOUNDERFLOW)
  /DEBUG=(NOSYMBOLS,TRACEBACK)
  /STANDARD=(NOSYNTAX,NOSOURCE_FORM)
  /SHOW=(NOPREPROCESSOR,NOINCLUDE,MAP)
  /F77  /NOG_FLOATING  /I4  /OPTIMIZE  /WARNINGS  /NOD_LINES  /CROSS_REFERENCE  /NOMACHINE_CODE  /CONTINUATIONS=19

COMPILATION STATISTICS

  Run Time:           4.57 seconds
  Elapsed Time:       5.47 seconds
  Page Faults:        248
  Dynamic Memory:     150 pages
```

```
******************************   2-FEB-1985 13:30:33.32   FS00:[STEVENS.SHIPSTUFF]GNSMINFIL.FOR;3   ****************************
**
******************************   2-FEB-1985 13:30:33.32   FS00:[STEVENS.SHIPSTUFF]GNSMINFIL.FOR;3   ****************************
**
******************************   2-FEB-1985 13:30:33.32   FS00:[STEVENS.SHIPSTUFF]GNSMINFIL.FOR;3   ****************************
**
```

GNSMINFIL.FOR;3

```
******************************   2-FEB-1985 13:30:33.32   FS00:[STEVENS.SHIPSTUFF]GNSMINFIL.FOR;3   ****************************
**
******************************   2-FEB-1985 13:30:33.32   FS00:[STEVENS.SHIPSTUFF]GNSMINFIL.FOR;3   ****************************
```

```
C234567890234567890...etc.

      CHARACTER*12,FLNM
      TYPE*,'INPUT FILENAME '
      ACCEPT*,FLNM
      OPEN (UNIT=4,FILE=FLNM,TYPE='NEW')
      TYPE*,'INPUT VALUE FOR ISEAS, THE SEA STATE'
      ACCEPT*,J
      WRITE (4,5) J
5     FORMAT (1X,I4)
      TYPE*,'INPUT VALUES FOR WE,AZ,PHIZ,ATH, AND PHIO'
      TYPE*,'TYPE NUMBERS .GE. 50 TO QUIT'
7         TYPE*,'INPUT WE,AZ,PHIZ,ATH,PHIO'
          ACCEPT*,WE,AZ,PHIZ,ATH,PHIO
          IF (AZ .GE. 50) GO TO 50
          WRITE (4,10) WE,AZ,PHIZ,ATH,PHIO
10        FORMAT (1X,5(F8.4))

          GO TO 7
50    CLOSE(4)
      STOP
      END
```

```
******************************    2-FEB-1985 11:57:54.13    FSD0:[STEVENS.SHIPSTUFF]VASINFIL.LIS;1    ******************************
*
******************************    2-FEB-1985 11:57:54.13    FSD0:[STEVENS.SHIPSTUFF]VASINFIL.LIS;1    ******************************
*
******************************    2-FEB-1985 11:57:54.13    FSD0:[STEVENS.SHIPSTUFF]VASINFIL.LIS;1    ******************************
*
```

```
VASINFIL.LIS;1
```

```
******************************    2-FEB-1985 11:57:54.13    FSD0:[STEVENS.SHIPSTUFF]VASINFIL.LIS;1    ******************************
*
******************************    2-FEB-1985 11:57:54.13    FSD0:[STEVENS.SHIPSTUFF]VASINFIL.LIS;1    ******************************
```

```
                                                          2-Feb-1985 11:49:89   VAX-11 FORTRAN V3.5-62              Page  1
                                                          10-Dec-1984.16:23:10  FS00:[STEVENS.SHIPSTUFF]VASINFIL.FOR;9

0001    C234567890234567890...etc.
0002
0003          REAL KP
0004          CHARACTER*12,FLNM
0005          TYPE*,'INPUT FILENAME '
0006          ACCEPT*,FLNM
0007          OPEN (UNIT=1,FILE=FLNM,TYPE='NEW')
0008          TYPE*,'INPUT VALUES FOR J, THE NUMBER OF CONDITIONS,'
0009          TYPE*,'AND K, THE NUMBER OF RUNS FOR EACH CONDITION.'
0010          ACCEPT*,J,K
0011          WRITE (1,5) J,K
0012    5     FORMAT (1X,2(I4))
0013          TYPE*,'INPUT VALUES FOR LAG,ELC,TH,ZH, AND KP'
0014          TYPE*,'TYPE NUMBERS .GE. 50 TO QUIT'
0015    7        TYPE*,'INPUT LAG.ELC.TH.ZH,KP'
0016             ACCEPT*,LAG,ELC,TH,ZH,KP
0017             IF (LAG .GE. 50) GO TO 50
0018             WRITE (1,10) LAG.ELC,TH,ZH,KP
0019    10       FORMAT (1X,I4,4(F10.6))
0020
0021             GO TO 7
0022    50    CLOSE(1)
0023          STOP
0024          END


PROGRAM SECTIONS

    Name                                   Bytes  Attributes

  0 $CODE                                    446  PIC CON REL LCL    SHR   EXE   RD NOWRT LONG
  1 $PDATA                                   216  PIC CON REL LCL    SHR NOEXE   RD NOWRT LONG
  2 $LOCAL                                   128  PIC CON REL LCL NOSHR NOEXE   RD   WRT LONG

    Total Space Allocated                    790

ENTRY POINTS

    Address  Type  Name                       References

  0-00000000       VASINFIL$MAIN

VARIABLES

    Address  Type  Name          Attributes  References

  2-0000001C  R*4  ELC                          16=       18
  2-00000000  CHAR FLNM                          4         6=        7A
  2-00000010  I*4  J                            10=       11
  2-00000014  I*4  K                            10=       11
  2-0000000C  R*4  KP                            3        16=        18

  2-00000018  I*4  LAG                          16=       17         18
```

```
VASINFIL$MAIN                                         2-Feb-1985 11:49:09    VAX-11 FORTRAN V3.5-62           Page  2
                                                      10-Dec-1984 16:23:10   FSD0:[STEVENS.SHIPSTUFF]VASINFIL.FOR;9

  2-00000020  R*4  TW                         16*      18
  2-00000024  R*4  ZW                         16*      18


LABELS

    Address   Label                       References

  1-000000C1  5'                              11       12#
  0-00000102  7                               15#      21
  1-000000C8  10'                             18       19#
  0-000001AF  50                              17       22#


FUNCTIONS AND SUBROUTINES REFERENCED

  Type  Name                              References

        FOR$CLOSE                             22
        FOR$OPEN                               7


  +------------------------------------------+
  |           KEY TO REFERENCE FLAGS          |
  |   *   - Value Modified                    |
  |   #   - Defining Reference                |
  |   A   - Actual Argument, possibly modified |
  |   D   - Data Initialization               |
  |  (n)  - Number of occurrences on line     |
  +------------------------------------------+


COMMAND QUALIFIERS

  FORTRAN /LIS/CRO VASINFIL.FOR

  /CHECK=(NOBOUNDS,OVERFLOW,NOUNDERFLOW)
  /DEBUG=(NOSYMBOLS,TRACEBACK)
  /STANDARD=(NOSYNTAX,NOSOURCE_FORM)
  /SHOW=(NOPREPROCESSOR,NOINCLUDE,MAP)
  /F77  /NOG_FLOATING  /I4  /OPTIMIZE  /WARNINGS  /NOD_LINES  /CROSS_REFERENCE  /NOMACHINE_CODE  /CONTINUATIONS=19

COMPILATION STATISTICS

  Run Time:           1.68 seconds
  Elapsed Time:       2.53 seconds
  Page Faults:        139
  Dynamic Memory:     125 pages
```

```
********************************     2-FEB-1985 13:31:47.17    FSD0:[STEVENS.SHIPSTUFF]GNSMINFIL.LIS;1     ******************************
**
********************************     2-FEB-1985 13:31:47.17    FSD0:[STEVENS.SHIPSTUFF]GNSMINFIL.LIS;1     ******************************
**
********************************     2-FEB-1985 13:31:47.17    FSD0:[STEVENS.SHIPSTUFF]GNSMINFIL.LIS;1     ******************************
**




                    GNSMINFIL.LIS;1




********************************     2-FEB-1985 13:31:47.17    FSD0:[STEVENS.SHIPSTUFF]GNSMINFIL.LIS;1     ******************************
**
********************************     2-FEB-1985 13:31:47.17    FSD0:[STEVENS.SHIPSTUFF]GNSMINFIL.LIS;1     ******************************
```

```
                                                2-Feb-1985 13:21:30    VAX-11 FORTRAN V3.5-62          Page   1
                                               10-Dec-1984 15:54:03    FS00:[STEVENS.SHIPSTUF]GHSMINFIL.FOR;3

0001    C234567890234567890...etc.
0002
0003          CHARACTER*12,FLNM
0004          TYPE*,'INPUT FILENAME '
0005          ACCEPT*,FLNM
0006          OPEN (UNIT=4,FILE=FLNM,TYPE='NEW')
0007          TYPE*,'INPUT VALUE FOR ISEAS, THE SEA STATE'
0008          ACCEPT*,J
0009          WRITE (4,5) J
0010    5     FORMAT (1X,I4)
0011          TYPE*,'INPUT VALUES FOR WE,AZ,PHIZ,ATH, AND PHIO'
0012          TYPE*,'TYPE NUMBERS .GE. 50 TO QUIT'
0013    7         TYPE*,'INPUT WE,AZ,PHIZ,ATH,PHIO'
0014              ACCEPT*,WE,AZ,PHIZ,ATH,PHIO
0015              IF (AZ .GE. 50) GO TO 50
0016              WRITE (4,10) WE,AZ,PHIZ,ATH,PHIO
0017    10        FORMAT (1X,5(F8.4))
0018
0019              GO TO 7
0020    50    CLOSE(4)
0021          STOP
0022          END


PROGRAM SECTIONS

  Name                                  Bytes   Attributes

 0 $CODE                                  403   PIC CON REL LCL   SHR   EXE   RD NOWRT LONG
 1 $PDATA                                 161   PIC CON REL LCL   SHR NOEXE   RD NOWRT LONG
 2 $LOCAL                                 116   PIC CON REL LCL NOSHR NOEXE   RD   WRT LONG

   Total Space Allocated                  680

ENTRY POINTS

   Address  Type  Name                               References

 0-00000000       GHSMINFIL$MAIN

VARIABLES

   Address  Type  Name                         Attributes  References

 2-0000001C  R*4  ATH                                         14=       16
 2-00000014  R*4  AZ                                          14=       15         16
 2-00000000  CHAR FLNM                                         3         5=         6A
 2-0000000C  I*4  J                                            8=        9
 2-00000020  R*4  PHIO                                        14=       16

 2-00000018  R*4  PHIZ                                        14=       16
 2-00000010  R*4  WE                                          14=       16
```

```
LABELS

  Address   Label                                 References

 1-00000091  5'                                      9        10#
 0-00000001  7                                      13#       19
 1-00000096  10'                                    16        17#
 0-00000104  50                                     15        20#


FUNCTIONS AND SUBROUTINES REFERENCED

 Type  Name                                       References

       FOR$CLOSE                                     20
       FOR$OPEN                                       6


 +-----------------------------------------------+
 |          KEY TO REFERENCE FLAGS               |
 |   *    - Value Modified                       |
 |   #    - Defining Reference                   |
 |   A    - Actual Argument, possibly modified   |
 |   D    - Data Initialization                  |
 |  (n)   - Number of occurrences on line        |
 +-----------------------------------------------+


COMMAND QUALIFIERS

  FORTRAN /CRO/LIS GNSMINFIL.FOR

  /CHECK=(NOBOUNDS,OVERFLOW,NOUNDERFLOW)
  /DEBUG=(NOSYMBOLS,TRACEBACK)
  /STANDARD=(NOSYNTAX,NOSOURCE_FORM)
  /SHOW=(NOPREPROCESSOR,NOINCLUDE,MAP)
  /F77  /NOG_FLOATING  /I4  /OPTIMIZE  /WARNINGS  /NOD_LINES  /CROSS_REFERENCE  /NOMACHINE_CODE  /CONTINUATIONS=19

COMPILATION STATISTICS

  Run Time:          1.56 seconds
  Elapsed Time:      2.33 seconds
  Page Faults:       128
  Dynamic Memory:    125 pages
```

```
******************************    2-FEB-1985 13:12:50.45    FSD0:[STEVENS.STORAGE]GENSM.DAT;4    ******************************
******************************    2-FEB-1985 13:12:50.45    FSD0:[STEVENS.STORAGE]GENSM.DAT;4    ******************************
```

GENSM.DAT;4

```
******************************    2-FEB-1985 13:12:50.45    FSD0:[STEVENS.STORAGE]GENSM.DAT;4    ******************************
******************************    2-FEB-1985 13:12:50.45    FSD0:[STEVENS.STORAGE]GENSM.DAT;4    ******************************
******************************    2-FEB-1985 13:12:50.45    FSD0:[STEVENS.STORAGE]GENSM.DAT;4    ******************************
```

```
  DATA FOR DD963 CLASS, SEA STATE 4
  WE       AZ      PHIZ     ATH     PHIO
------  ------  ------  -------  -------
 4
0.3714  0.1234  0.0035  0.0004 -1.1447
0.5485  0.5654  0.0035  0.0031 -1.1161
0.7200  1.5111  0.0132  0.0068 -0.9926
0.8914  1.6322  0.1242  0.0076 -0.7348
1.0629  0.8724  0.5887  0.0043 -0.2552
1.2400  0.1511  1.4188  0.0018  0.2711
```

```
******************************    2-FEB-1985 13:14:50.21    FSD0:[STEVENS.STORAGE]GENSM.DAT;5    ******************************
******************************    2-FEB-1985 13:14:50.21    FSD0:[STEVENS.STORAGE]GENSM.DAT;5    ******************************
******************************    2-FEB-1985 13:14:50.21    FSD0:[STEVENS.STORAGE]GENSM.DAT;5    ******************************
```

```
GENSM.DAT;5
```

```
******************************    2-FEB-1985 13:14:50.21    FSD0:[STEVENS.STORAGE]GENSM.DAT;5    ******************************
******************************    2-FEB-1985 13:14:50.21    FSD0:[STEVENS.STORAGE]GENSM.DAT;5    ******************************
******************************    2-FEB-1985 13:14:50.21    FSD0:[STEVENS.STORAGE]GENSM.DAT;5    ******************************
```

```
   DATA FOR DD963 CLASS, SEA STATE 5
  WE      AZ      PHIZ     ATH    PHIO
------  ------  ------  ------  ------

 5
0.3543  0.9917 -0.0035  0.0019 -1.1439
0.5134  2.7355 -0.0035  0.0086 -1.1467
0.7029  2.4986  0.0093  0.0108 -1.0109
0.8743  2.1737  0.1031  0.1000 -0.7674
1.0457  1.1326  0.5180  0.0052 -0.3152
1.2229  0.2533  1.3551  0.0019  0.2378
```

```
******************************    2-FEB-1985 13:15:35.98    FSD0:[STEVENS.STORAGE]GENSM.DAT;6    ******************************
******************************    2-FEB-1985 13:15:35.98    FSD0:[STEVENS.STORAGE]GENSM.DAT;6    ******************************
******************************    2-FEB-1985 13:15:35.98    FSD0:[STEVENS.STORAGE]GENSM.DAT;6    ******************************
```

```
GENSM.DAT;6
```

```
******************************    2-FEB-1985 13:15:35.98    FSD0:[STEVENS.STORAGE]GENSM.DAT;6    ******************************
******************************    2-FEB-1985 13:15:35.98    FSD0:[STEVENS.STORAGE]GENSM.DAT;6    ******************************
******************************    2-FEB-1985 13:15:35.98    FSD0:[STEVENS.STORAGE]GENSM.DAT;6    ******************************
```

```
  DATA FOR DD963 CLASS, SEA STATE 6
   WE      AZ     PHIZ     ATH     PHID
 ------  ------  ------  ------  -------
  6
0.3486  1.0005 -0.0035  0.0019 -1.1448
0.4686  4.4116 -0.0035  0.0113 -1.1492
0.6343  3.6532  0.0002  0.0143 -1.0748
0.8143  2.8688  0.0546  0.0135 -0.8560
0.9829  2.0422  0.2984  0.0094 -0.5174
1.1257  0.5776  0.8894  0.0033 -0.0384
```

```
******************************    2-FEB-1985 13:40:23.90    FSD0:[STEVENS.SHIPSTUFF]VASLNK5.COM;3    ******************************
******************************    2-FEB-1985 13:40:23.90    FSD0:[STEVENS.SHIPSTUFF]VASLNK5.COM;3    ******************************
******************************    2-FEB-1985 13:40:23.90    FSD0:[STEVENS.SHIPSTUFF]VASLNK5.COM;3    ******************************
```

VASLNK5.COM;3

```
******************************    2-FEB-1985 13:40:23.90    FSD0:[STEVENS.SHIPSTUFF]VASLNK5.COM;3    ******************************
******************************    2-FEB-1985 13:40:23.90    FSD0:[STEVENS.SHIPSTUFF]VASLNK5.COM;3    ******************************
******************************    2-FEB-1985 13:40:23.90    FSD0:[STEVENS.SHIPSTUFF]VASLNK5.COM;3    ******************************
```

```
$ SET VERIFY
$ LINK VASCON.VPA1C,IN4.GENSM.TRANO.VASSTAT,MPLT2,PLOT3,SYS$LIBRARY:INTLIB/LIB.D
$ SET NOVERIFY
```

```
******************************    2-FEB-1985 11:05:18.68    FSD0:[STEVENS.SHIPSTUFF]VPA1C.LIS;1    ******************************
******************************    2-FEB-1985 11:05:18.68    FSD0:[STEVENS.SHIPSTUFF]VPA1C.LIS;1    ******************************
******************************    2-FEB-1985 11:05:18.68    FSD0:[STEVENS.SHIPSTUFF]VPA1C.LIS;1    ******************************




                         VPA1C.LIS;1




******************************    2-FEB-1985 11:05:18.68    FSD0:[STEVENS.SHIPSTUFF]VPA1C.LIS;1    ******************************
******************************    2-FEB-1985 11:05:18.68    FSD0:[STEVENS.SHIPSTUFF]VPA1C.LIS;1    ******************************
******************************    2-FEB-1985 11:05:18.68    FSD0:[STEVENS.SHIPSTUFF]VPA1C.LIS;1    ******************************
```

```
C12345678901234567890...etc
C
      SUBROUTINE VASMP(ISEAS,K,JRAN,L,ELC,TH,GD,KP,WE,AZ,PHIZ,
     1 ATH,PHIO,JAY)

      DIMENSION SLS(30),SLV(50),SLA(50),ZL(50),ZDL(50),ZDDL(50)
      DIMENSION WE(10),AZ(10),PHIZ(10),ATH(10),PHIO(10),SM(500)
      DIMENSION AC(500),TIMEE(500)
      DIMENSION SLOT(50),THRTR(50),IS(50),DUMB(50)
      DIMENSION VMN(500),VSD(500),THN(500),TSD(500),TIMA(500)

      REAL KP,IT1,IT2,IT3,IT4,IT5,IT6,IT7,IT8,IT9,IT10,IT11
      REAL IT12,IT13,LIM,HTOUT,HIVRD
      REAL KPA,KP8,KPC
      CHARACTER*8,BUF
      CHARACTER*9,BUFF

      PRINT*,'RUNNING VPA1B AS MAIN PROGRAM'
      PRINT*,'SEASTATE=',ISEAS
      PRINT*,'KP=',KP
      KPA=KP
      KPB=KP*1.3
      KPC=KP*2.0

      GD=GHDOT
      ZH=0.01
      IFLAG5=0
      KAY=K
      DO 1 INT=1,50
         IS(INT)=0
         DUMB(INT)=0
1     CONTINUE
      DO 175 IDO=1,K


C*    TYPE*,'DO YOU WANT A PLOT? NO=0'
C*    ACCEPT*,FLAG4
C*    TYPE*,'INPUT INITIAL TIME'
C*    ACCEPT*,t
C*    TYPE*,'INPUT T/H, ELC, ZH,TLAGh'
C*    ACCEPT*,TH,ELC,ZH,L

       t=3600*RAN(JRAN)

       tII=t
       TC=0.01
        dHO=0.0
        dHOD=0.0
        dHTR=0.0
        dHOTR=0.0
CH      Ht=T
CH      Wh=0.25
                                  TF=tII+360
C*        GRPHT=t
C*        GRPHh=0.2
        ABRTHT=6.0  !4.5
        CTNH=-1.0
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        Y1=0.0
        Y2=0.0
        Y3=0.0
        Y0=0.0
        YD0=0.0
        T2=0.01
CXP     KP=0.01
                TL=0.75
               TG=0.01  !0.01
        FLAG2=1.0      ! 1=TURBULENCE IS ON
        IFLAG3=0
        IFLAG7=1
        IFLAG8=0
        IFLAG9=0
        IFLAG10=0
        IFLAG11=0
        IFLAG12=0
        IFLAG13=1

        TE=0.0
        FPLS1=0.0
        ZWDTDT=32.2
        S1=40
        S2=0.0
        S3=0.0


        T1=T2*2
        T4=T2**2
        IT1=TC
        IT2=TC*TC/2
        IT3=TC**3/6
        IT4=TC**4/24
        IT5=TC**5/120
        IT6=TC**6/720
        IT7=TC**7/5040
        IT8=TC**8/40320.0
        dHTR=0.0
        dH=0.0
        Z=40.0
        ZD=0.0
        ZDD=0.0
        IT=1
        KMEAN=1
        TOUTMAX=0.0
        TOUTMIN=10.0
        MIVRD=0.0
        J=79856423
        DO 5 I=1,50
              SLS(I)=40.0
              SLV(I)=0.0
              SLA(I)=0.0
              ZL(I)=40.0
              ZDL(I)=0.0
              ZDDL(I)=0.0
                SLOT(I)=0.0
                TWRTR(I)=0.0
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5       CONTINUE
        DO 6 I=1,500
          AC(I)=0
          TIMEE(I)=0
6       CONTINUE

CH      WRITE(5,10)
CH10    FORMAT (5X,'t',8X,'S1',8X,'Ht',8X,'dH',8X,'TG',8X,'TL',
CH   1   8X,'KP')
CH      WRITE(6,15)
CH15    FORMAT (1X,10('_____'),//)


        CALL INPUT1(SA1,SA2,SA3,t,tII,IFLAG8,SX)
        CALL INPUT2(SS1,SS2,SS3,t,tII,EN,WE,AZ,PHIZ,ATH,PHI0)
        CALL TURBULENCE(TGEE,TC,VTZ,PRECYC,RNP,RNQ)

        GO TO 140

20      CALL INPUT1(SA1,SA2,SA3,t,tII,IFLAG8,SX)
        CALL INFUT2(SS1,SS2,SS3,t,tII,EN,WE,AZ,PHIZ,ATH,PHI0)
        CALL TURBULENCE(TGEE,TC,VTZ,PRECYC,RNP,RNQ)

C        ********** FLIGHTPATH COMMAND LOGIC **********

30      SS1Z=SS1-Z
        SS2ZD=SS2-ZD
        IF (IFLAG10 .EQ. 1 .AND. TE4 .LT. 1.5) GO TO 50
        IF (SS2 .GT. 5.5) GO TO 35
        IF (SS1Z .GT. -9.0 .AND. SS2 .GT. 4.5) GO TO 40
        IF (SS1Z .LT. -3.0) GO TO 45
        IF (Z .LT. ABRTH) GO TO 45
        IF (SS1Z .GT. CTNH) GO TO 50

        IF (IFLAG3 .EQ. 0) THEN
          TE1=0.0
          IFLAG3=1
           IFLAG7=0
           IFLAG9=0
           IFLAG10=0
           IFLAG11=0
           IFLAG12=0
           IFLAG13=0
           SGP=S1
           CTNH=-1.0
        END IF

        S1=SS1+((SGP-SS1)+(SGP-SS1)*COS(6.2832*TE1))/2.0
        S2=SS2
        S3=SS3
          KP=KPB
          IF (CKPB .EQ. 1) KP=KPA
        TE1=TE1+TC
        IF (TE1 .GT. 0.5) TE1=0.5
        FPLS=3
        GO TO 65
35     IF (IFLAG11 .EQ. 0) THEN
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        TE3=0.0
        IFLAG3=0
        IFLAG7=0
        IFLAG9=0
        IFLAG10=0
          IFLAG11=1
          IFLAG12=0
          IFLAG13=0
        SGAPP=S1
        GAPP=6.0
        CTNH=-1.0
      END IF
      S1=SGAPP+(GAPP-GAPP*COS(6.2832*TE3))/2.0
      S2=SS2
      S3=SS3
      KP=KPC
      TE3=TE3+TC
      IF (TE3 .GT. 0.5) TE3=0.5
      FPLS=1
      GO TO 65

40   IF (IFLAG12 .EQ. 0) THEN
        TE=0.0
        IFLAG3=0
        IFLAG7=0
         IFLAG9=0
         IFLAG10=0
       IF (IFLAG11 .EQ. 1) THEN
          SGPP=S1
          GPP=-3.0
       ELSE IF (IFLAG11 .EQ. 0) THEN
          SGPP=S1
          GPP=3.0
       END IF
          IFLAG11=0
          IFLAG12=1
          IFLAG13=0
        CTNH=-1.0
      END IF
      S1=SGPP+(GPP-GPP*COS(6.2832*TE))/2.0
      S2=SS2
      S3=SS3
      KP=KPB
      TE=TE+TC
      IF (TE .GT. 0.5) TE=0.5
      FPLS=2
      GO TO 65

45    IF (IFLAG13 .EQ. 0) THEN
         TE2=0.0
         SSGAP=S1
         SSAMP=SA1-SSGAP
         IFLAG3=0
         IFLAG9=0
         IFLAG10=0
          IFLAG11=0
          IFLAG12=0
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           IFLAG13=1
           CTNH=-1.0
        END IF

        IF (IFLAG7 .EQ. 1) GO TO 46
        S1=SSGAP+(SSAMP-SSAMP*COS(6.2832*TE2))/2.0
        GO TO 47
46      S1=SA1
47      S2=SA2
        S3=SA3
        IF (Z+0.5 .LT. S1) THEN
          KP=KPB
        ELSE IF (Z+0.5 .GE. S1) THEN
          KP=KPA
        END IF
        TE2=TE2+TC
        IF (TE2 .GT. 0.5) THEN
            TE2=0.5
            IFLAG7=1
        END IF
        FPLS=0
        GO TO 65

50       IF (IFLAG10 .EQ. 0) THEN
         KP=KPA
         FPLS=5
          IFLAG3=8
          IFLAG7=1
          IFLAG9=1
          IFLAG10=1
            IFLAG11=0
            IFLAG12=0
            IFLAG13=0
           CTNH=-1.7
           TE4=0.0
          GAP=S1
         END IF
        HLIM=-1.0
        IF (TE4 .LT. 0.25) THEN
           S1=GAP+(9.0*COS(12.5664*TE4)-9.0)/2.0
            FPLS=6
        ELSE IF (TE4 .GE. 0.25 .AND. TE4 .LT. 1.25) THEN
           S1=GAP-9.0
             FPLS=7
        ELSE IF (TE4 .GE. 1.25) THEN
           S1=GAP+(9.0*COS(12.5664*(TE4-1))-9.0)/2.0
              FPLS=8
        END IF
        TE4=TE4+TC

65      IF ((SS1-Z) .GE. 0.0) GO TO 150

         DO 70 I=L,2,-1
              SLS(I)=SLS(I-1)
              SLV(I)=SLV(I-1)
              SLA(I)=SLA(I-1)
70       CONTINUE
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      SLS(1)=S1
      SLV(1)=S2
      SLA(1)=S3

C     ********** PILOT T.F.F. **********

      A0=dH
      A1=Y0
      B1=1/TG
      B2=0.0

      C1=A1
      C2B=-B1*C1
      C3B=-B1*C2B-B2*C2
      C4B=-B1*C3B-B2*C3B
      C5B=-B1*C4B-B2*C4B
      C6B=-B1*C5B-B2*C5B
      C7B=-B1*C6B-B2*C6B
      C8B=-B1*C7B-B2*C7B

      C2A=1.0
      C3A=-B1*C2A
      C4A=-B1*C3A
      C5A=-B1*C4A-B2*C4A
      C6A=-B1*C5A-B2*C5A
      C7A=-B1*C6A-B2*C6A
      C8A=-B1*C7A-B2*C7A

      Y1A=C1+C2B*IT1+C3B*IT2+C4B*IT3+C5B*IT4+C6B*IT5
      Y1B=C7B*IT6+C8B*IT7
      Y2A=C2B+C3B*IT1+C4B*IT2+C5B*IT3+C6B*IT4
      Y2B=C7B*IT5+C8B*IT6
      Y3A=C3B+C4B*IT1+C5B*IT2+C6B*IT3
      Y3B=C7B*IT4+C8B*IT5
C     Y4A=C4B+C5B*IT1+C6B*IT2+C7B*IT3+C8B*IT4

      YA1A=C2A*IT1+C3A*IT2+C4A*IT3+C5A*IT4+C6A*IT5+C7A*IT6
      YA1B=C8A*IT7
      YA1=YA1A+YA1B
      YA2=C2A+C3A*IT1+C4A*IT2+C5A*IT3+C6A*IT4+C7A*IT5+C8A*IT6
      YA3=C3A+C4A*IT1+C5A*IT2+C6A*IT3+C7A*IT4+C8A*IT5
C     YA4=C4A+C5A*IT1+C6A*IT2+C7A*IT3+C8A*IT4

      C2A=A0
      C3A=-B1*C2A
      C4A=-B1*C3A
      C5A=-B1*C4A-B2*C4A
      C6A=-B1*C5A-B2*C5A
      C7A=-B1*C6A-B2*C6A
      C8A=-B1*C7A-B2*C7A

      YAA1A=C2A*IT1+C3A*IT2+C4A*IT3+C5A*IT4+C6A*IT5+C7A*IT6
      YAA1B=C8A*IT7
      YAA1=YAA1A+YAA1B
      YAA2=C2A+C3A*IT1+C4A*IT2+C5A*IT3+C6A*IT4+C7A*IT5+C8A*IT6
      YAA3=C3A+C4A*IT1+C5A*IT2+C6A*IT3+C7A*IT4+C8A*IT5
C     YAA4=C4A+C5A*IT1+C6A*IT2+C7A*IT3+C8A*IT4
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      Y1=Y1A+Y1B
      Y2=Y2A+Y23
      Y3=Y3A+Y3B
C     Y4=Y4A+YA4

      D1=(1/TL-1/T2)
      D2=1/(TL*T2)
      D3=(KP*TL/TG)
      HtB=YA2+(1/TL)*YA1
C     HtB=(YA3+D1*YA2-D2*YA1)
      HtA=(Y2+SLS(L)*YA2)+(1/TL)*(Y1+SLS(L)*YA1)
C     HtA=(Y3+SLS(L)*YA3)+D1*(Y2+SLS(L)*YA2)-D2*(Y1+SLS(L)*YA1)
C     HtPOB=-D2*(Y1+YAA1)
C     HtPOA=(Y3+YAA3)+D1*(Y2+YAA2)
      HtPOB=(1/TL)*(Y1+(SLS(L)-ZL(L))*YA1)
C     HtPOB=-D2*(Y1+(SLS(L)-ZL(L))*YA1)
      HtPOA=Y2+(SLS(L)-ZL(L))*YA2
C     HtPOA=(Y3+(SLS(L)-ZL(L))*YA3)+D1*(Y2+(SLS(L)-ZL(L))*YA2)
      HtPO=D3*(HtPOA+HtPOB)

      Y0=Y1+YAA1+RNP
      YD0=Y2+YAA2


      LIM=1.0
      IF (HtPO .EQ. 0.0) HtPO=0.00001
      IF (IFLAG9 .EQ. 1) GO TO 74
C     HLIM=-((TH-1)*1.5)
C     IF (HLIM .GT. -0.05) HLIM=-0.05
      HLIM=-1.0
 74   IF (HtPO .GT. HLIM) GO TO 75
      LIM=HLIM/HtPO
      GO TO 80
 75   IF (HtPO .LT. (TH-1))  GO TO 80
      LIM=(TH-1)/HtPO


C         ************ A/C T.F.F. ***********

 80   AA0=((ZHDTDT+((TGEE+DAMP)/LIM))/ELC)*LIM*D3*HtA
      AA1=Z*ZH/ELC+ZD*(1/ELC+ZH)+ZDD
      AA2=Z*(1/ELC+ZH)+ZD
      AA3=Z
      BA1=((ZHDTDT+((TGEE+DAMP)/LIM))/ELC)*LIM*D3*HtB
      BA2=ZH/ELC
      BA3=ZH+1/ELC

      AA0P=LIM*D3*HtA
      BA1P=LIM*D3*HtB
      POUT=AA0P+BA1P*(-ZL(L))
      TOUT=POUT+1
      MTOUT=((KMEAN-1)*MTOUT+TOUT)/KMEAN
      IF (TOUT .GT. TOUTMAX) TOUTMAX=TOUT
      IF (TOUT .LT. TOUTMIN) TOUTMIN=TOUT
C     IF (TOUT .LE. 1.21 .AND. TOUT .GT. 1.101) THEN
C         GO TO 85
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         IF (TOUT .LE. 1.101 .AND. TOUT .GT. 1.001) THEN
            GO TO 90
        ELSE IF (TOUT .LE. 1.001 .AND. TOUT .GT. 0.901) THEN
            GO TO 95
        ELSE IF (TOUT .LE. 0.991 .AND. TOUT .GT. 0.800) THEN
            GO TO 100
        END IF
        GO TO 105
C85     IF (TOUT .LE. 1.201 .AND. TOUT .GT. 1.191) THEN
C          IS(1)=IS(1)+1
C       ELSE IF (TOUT .LE. 1.191 .AND. TOUT .GT. 1.181) THEN
C          IS(2)=IS(2)+1
C       ELSE IF (TOUT .LE. 1.181 .AND. TOUT .GT. 1.171) THEN
C          IS(3)=IS(3)+1
C       ELSE IF (TOUT .LE. 1.171 .AND. TOUT .GT. 1.161) THEN
C          IS(4)=IS(4)+1
C       ELSE IF (TOUT .LE. 1.161 .AND. TOUT .GT. 1.151) THEN
C          IS(5)=IS(5)+1
C       ELSE IF (TOUT .LE. 1.151 .AND. TOUT .GT. 1.141) THEN
C          IS(6)=IS(6)+1
C       ELSE IF (TOUT .LE. 1.141 .AND. TOUT .GT. 1.131) THEN
C          IS(7)=IS(7)+1
C       ELSE IF (TOUT .LE. 1.131 .AND. TOUT .GT. 1.121) THEN
C          IS(8)=IS(8)+1
C       ELSE IF (TOUT .LE. 1.121 .AND. TOUT .GT. 1.111) THEN
C          IS(9)=IS(9)+1
C       ELSE IF (TOUT .LE. 1.111 .AND. TOUT .GT. 1.101) THEN
C          IS(10)=IS(10)+1
C       END IF
C       GO TO 105
90       IF (TOUT .LE. 1.101 .AND. TOUT .GT. 1.091) THEN
           IS(11)=IS(11)+1
        ELSE IF (TOUT .LE. 1.091 .AND. TOUT .GT. 1.081) THEN
           IS(12)=IS(12)+1
        ELSE IF (TOUT .LE. 1.081 .AND. TOUT .GT. 1.071) THEN
           IS(13)=IS(13)+1
        ELSE IF (TOUT .LE. 1.071 .AND. TOUT .GT. 1.061) THEN
           IS(14)=IS(14)+1
        ELSE IF (TOUT .LE. 1.061 .AND. TOUT .GT. 1.051) THEN
           IS(15)=IS(15)+1
        ELSE IF (TOUT .LE. 1.051 .AND. TOUT .GT. 1.041) THEN
           IS(16)=IS(16)+1
        ELSE IF (TOUT .LE. 1.041 .AND. TOUT .GT. 1.031) THEN
           IS(17)=IS(17)+1
        ELSE IF (TOUT .LE. 1.031 .AND. TOUT .GT. 1.021) THEN
          IS(18)=IS(18)+1
        ELSE IF (TOUT .LE. 1.021 .AND. TOUT .GT. 1.011) THEN
          IS(19)=IS(19)+1
        ELSE IF (TOUT .LE. 1.011 .AND. TOUT .GT. 1.001) THEN
           IS(20)=IS(20)+1
        END IF
        GO TO 105
95      IF (TOUT .LE. 1.001 .AND. TOUT .GT. 0.991) THEN
           IS(21)=IS(21)+1
        ELSE IF (TOUT .LE. 0.991 .AND. TOUT .GT. 0.981) THEN
           IS(22)=IS(22)+1
        ELSE IF (TOUT .LE. 0.981 .AND. TOUT .GT. 0.971) THEN
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             IS(23)=IS(23)+1
           ELSE IF (TOUT .LE. 0.971 .AND. TOUT .GT. 0.961) THEN
             IS(24)=IS(24)+1
           ELSE IF (TOUT .LE. 0.961 .AND. TOUT .GT. 0.951) THEN
             IS(25)=IS(25)+1
           ELSE IF (TOUT .LE. 0.951 .AND. TOUT .GT. 0.941) THEN
             IS(26)=IS(26)+1
           ELSE IF (TOUT .LE. 0.941 .AND. TOUT .GT. 0.931) THEN
             IS(27)=IS(27)+1
           ELSE IF (TOUT .LE. 0.931 .AND. TOUT .GT. 0.921) THEN
             IS(28)=IS(28)+1
           ELSE IF (TOUT .LE. 0.921 .AND. TOUT .GT. 0.911) THEN
             IS(29)=IS(29)+1
           ELSE IF (TOUT .LE. 0.911 .AND. TOUT .GT. 0.901) THEN
             IS(30)=IS(30)+1
           END IF
           GO TO 105
   100      IF (TOUT .LE. 0.901 .AND. TOUT .GT. 0.891) THEN
             IS(31)=IS(31)+1
           ELSE IF (TOUT .LE. 0.891 .AND. TOUT .GT. 0.881) THEN
             IS(32)=IS(32)+1
           ELSE IF (TOUT .LE. 0.881 .AND. TOUT .GT. 0.871) THEN
             IS(33)=IS(33)+1
           ELSE IF (TOUT .LE. 0.871 .AND. TOUT .GT. 0.861) THEN
             IS(34)=IS(34)+1
           ELSE IF (TOUT .LE. 0.861 .AND. TOUT .GT. 0.851) THEN
             IS(35)=IS(35)+1
           ELSE IF (TOUT .LE. 0.851 .AND. TOUT .GT. 0.841) THEN
             IS(36)=IS(36)+1
           ELSE IF (TOUT .LE. 0.841 .AND. TOUT .GT. 0.831) THEN
             IS(37)=IS(37)+1
           ELSE IF (TOUT .LE. 0.831 .AND. TOUT .GT. 0.821) THEN
             IS(38)=IS(38)+1
           ELSE IF (TOUT .LE. 0.821 .AND. TOUT .GT. 0.811) THEN
             IS(39)=IS(39)+1
           ELSE IF (TOUT .LE. 0.811 .AND. TOUT .GT. 0.801) THEN
             IS(40)=IS(40)+1
           END IF

   105     C1A=AA3
           C2A=AA2-BA3*C1A
           C3A=AA1-BA2*C1A-BA3*C2A
           C4A=AA0-BA1*C1A-BA2*C2A-BA3*C3A
           C5A=-BA1*C2A-BA2*C3A-BA3*C4A
           C6A=-BA1*C3A-BA2*C4A-BA3*C5A
           C7A=-BA1*C4A-BA2*C5A-BA3*C6A
           C8A=-BA1*C5A-BA2*C6A-BA3*C7A

           ZA1=C1A+C2A*IT1+C3A*IT2+C4A*IT3+C5A*IT4+C6A*IT5
           ZA2=C7A*IT6+C8A*IT7
           ZB1=C2A+C3A*IT1+C4A*IT2+C5A*IT3+C6A*IT4
           ZB2=C7A*IT5+C8A*IT6
           ZC1=C3A+C4A*IT1+C5A*IT2+C6A*IT3
           ZC2=C7A*IT4+C8A*IT5

           Z=ZA1+ZA2
           ZD=ZB1+ZB2
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0514          ZDD=ZC1+ZC2
0515
0516          DO 110 I=L,2,-1
0517              ZL(I)=ZL(I-1)
0518              ZDL(I)=ZDL(I-1)
0519              ZDDL(I)=ZDDL(I-1)
0520     110  CONTINUE
0521          ZL(1)=Z
0522          ZDL(1)=ZD
0523          ZDDL(1)=ZDD
0524          DAMP=(ZD*0.45*GHDOT)
0525
0526          dHTR=SLS(L)-ZL(L)
0527          ERROR=RAN(J)
0528          ERR=0.5-ERROR
0529          dH=dHTR+RNP
0530     C    dH=dHTR+0.1*ERR
0531
0532          dHDTR=(SLV(L)-ZDL(L))
0533          dHD=dHDTR
0534     C    dHD=dHDTR+0.12*ERR
0535
0536     C    dHDD=(S3-HtDD)
0537
0538     CCH   WHEN CHANGING TO THE CONTINOUS PRINTOUT MODE
0539     CCH   SUBSTITUTE BLANKS FOR THE CH'S AND CHANGE 69
0540     CCH   ON LINE 99 TO 71, AND THE 69 ON LINE 296 TO 71
0541     CH120 IF (t .LT. HT)  GO TO 71
0542     CH125  TYPE 130, t,S1,Z,SS1,TGEE,POUT,HtPO
0543     CH130  FORMAT (1X,7(F10.5,X))
0544     CH    HT=HT+Hh
0545
0546     C*135 IF (t .LT. GRPHT) GO TO 71
0547     C*     SH(IT)=SS1
0548     C*     AC(IT)=Z
0549     C*     TIMEE(IT)=t
0550     C*     IT=IT+1
0551     C*     GRPHT=GRPHT+GRPHh
0552     140    t=t+TC
0553            KMEAN=KMEAN+1
0554            IF ((SS2-ZD) .GT. MIVRD) MIVRD=(SS2-ZD)
0555            IF ((t-TC) .GE. TF) GO TO 150
0556     145    GO TO 20
0557     150    PRINT*,'T/H =',TH,' ELC =',ELC,' ZH =',ZH
0558            PRINT*,'T.D. VEL =',(SS2-ZD),'TIME =',(t-tII)
0559            PRINT*,'MTOUT=',MTOUT,' FPLS=',FPLS,'  RUN NO.:',IDO
0560            PRINT*,'IS(21)=',IS(21),'  FPLS1=',FPLS1
0561     C*     IF (FLAG4..EQ. 0.0) GO TO 180
0562     C*     TFIN=TII+30
0563     CC*    TFIN=IFIX(t+1)
0564            WRITE (2,155) TII,T-TII,(SS2-ZD),MIVRD,MTOUT,TOUTMAX,
0565           1 TOUTMIN
0566     155    FORMAT (1X,2(2X,F8.1),2(2X,F5.1),3(2X,F6.3))
0567            IF (IFLAG5 .EQ. 0) GO TO 175
0568            FLT=T-TII
0569            VTD=(SS2-ZD)
0570
```

```
      KMN=IDO
      TMN(KMN)=((KMN-1)*TMN(KMN-1)+FLT)/KMN
      VMN(KMN)=((KMN-1)*VMN(KMN-1)+VTD)/KMN

      IF (KMN .EQ. 1) GO TO 165
      IF (KMN .GT. 2) GO TO 160
      TSD(KMN)=((FLT1-TMN(KMN))**2+(FLT-TMN(KMN))**2)**0.5
      VSD(KMN)=((VTD1-VMN(KMN))**2+(VTD-VMN(KMN))**2)**0.5
      GO TO 165

160   TSDA=((TSD(KMN-1)**2)*(KMN-2)+(FLT-TMN(KMN))**2)
      TSD(KMN)=(TSDA/(KMN-1))**0.5
      VSDA=((VSD(KMN-1)**2)*(KMN-2)+(VTD-VMN(KMN))**2)
      VSD(KMN)=(VSDA/(KMN-1))**0.5

165    TIMA(KMN)=KMN
      FLT1=FLT

      WRITE (3,170) KMN,TMN(KMN),TSD(KMN),VMN(KMN),VSD(KMN)
170   FORMAT (1X,I5,4(2X,F8.4))
175   CONTINUE
      IF (IFLAGS .EQ. 0) GO TO 180
      BEG=0
      TFIN=FLOAT(K)
      IT=K
      CALL PLOT3(TIMA,TMN,TSD,VMN,VSD,BEG.TFIN,IT,JAY,KAY)
180   KDOO=1
      DO 185 I=1195,795,-10
         THRTR(KDOO)=FLOAT(I)/1000
         KDOO=KDOO+1
185    CONTINUE
      ITOT=0.0
      DO 190 I=1,40
           ITOT=ITOT+IS(I)
190   CONTINUE
      DO 195 I=1,40
           SLOT(I)=FLOAT(IS(I))/FLOAT(ITOT)
195   CONTINUE
      TFIN=1.2
      TII=0.8
      IT=40
      CALL PLOT2(THRTR,SLOT,SLOT,TII,TFIN,IT,JAY,KAY,TH,ZH,ELC,
     7 KPA,ISEAS)
C*     CALL PLOT1(TIMEE,SM,AC,TII,TFIN,IT)
       CALL TIME(BUF)
       CALL DATE(BUFF)

       WRITE (2,200) BUF,BUFF
200    FORMAT (1X,2(A12))
       RETURN
       END
```

```
PROGRAM SECTIONS

   Name                          Bytes   Attributes

 0 $CODE                          5759   PIC CON REL LCL   SHR   EXE   RD NOWRT LONG
 1 $PDATA                          168   PIC CON REL LCL   SHR NOEXE   RD NOWRT LONG
 2 $LOCAL                        19116   PIC CON REL LCL NOSHR NOEXE   RD   WRT LONG

    Total Space Allocated        25042


ENTRY POINTS

    Address   Type  Name                 References

  G-00000000        VASHP                    3


VARIABLES

    Address   Type  Name         Attributes  References

  2-000047A8  R*4   A0                       292=    329
  2-000047AC  R*4   A1                       293=    297
  2-00004853  R*4   AA0                      383=    499
  2-00004878  R*4   AA0P                     391=    393
  2-00004860  R*4   AA1                      384=    498

  2-00004864  R*4   AA2                      385=    497
  2-00004868  R*4   AA3                      386=    496
  2-0000476C  R*4   ABRTH                    146
  2-00004698  R*4   ABRTHT                    56=
  2-00004780  R*4   B1                       294=    298     299     300     301     302     303     304
                                             307     308     309     310     311     312     330     331
                                             332     333     334     335

  2-00004784  R*4   B2                       295=    299     300     301     302     303     304     309
                                             310     311     312     332     333     334     335
  2-0000486C  R*4   DA1                      387=    499     500     501     502     503
  2-0000487C  R*4   BA1P                     392=    393
  2-00004870  R*4   BA2                      368=    498     499     500     501     502     503
  2-00004874  R*4   BA3                      389=    497     498     499     500     501     502     503

  2-000048C8  R*4   BEG                      593=    596A
  2-00004600  CHAR  BUF                       15     615A    618
  2-00004608  CHAR  BUFF                      16     616A    618
  2-000047B8  R*4   C1                       297=    298     314
  2-00004888  R*4   C1A                      496=    497     498     499     505

  2-000047C4  R*4   C2                       299
                                             306=    307     322     325     329=    330     337     340
  2-000047DC  R*4   C2A                      497=    498     499     500     505     507

  2-000047BC  R*4   C2B                      298=    299     314     316
  2-000047E0  R*4   C3A                      307=    308     322     325     326     330=    331     337
                                             340     341     498=    499     500     501     505     507
                                             509
  2-000047C0  R*4   C3B                      299=    300(2)  314     316     318
```

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  2-000047E4  R*4  C4A              308=   309(2)  322     325     326     331=    332(2)  337
                                    340    341     499=    500     501     502     505     507
                                    509
  2-000047C8  R*4  C4B              300=   301(2)  314     316     318
  2-000047E8  R*4  C5A              309=   310(2)  322     325     326     332=    333(2)  337
                                    340    341     500=    501     502     503     505     507
                                    509
  2-000047CC  R*4  C5B              301=   302(2)  314     316     318
  2-000047EC  R*4  C6A              310=   311(2)  322     325     326     333=    334(2)  337
                                    340    341     501=    502     503     505     507     509

  2-000047D0  R*4  C6B              302=   303(2)  314     316     318
  2-000047F0  R*4  C7A              311=   312(2)  322     325     326     334=    335(2)  337
                                    340    341     502=    503     506     508     510
  2-000047D4  R*4  C7B              303=   304(2)  315     317     319
  2-000047F4  R*4  C8A              312=   323     325     326     335=    338     340     341
                                    503=   506     508     510
  2-000047D8  R*4  C8B              304=   315     317     319

  2-00004778  R*4  CKPB             166
  2-0000469C  R*4  CTNH              57=   147     159=    182=    209=    230=    262=
  2-00004838  R*4  D1               349=
  2-0000483C  R*4  D2               350=
  2-00004840  R*4  D3               351=   362     383     387     391     392

  2-0000485C  R*4  DAMP             383    387     524=
  2-00004704  R*4  DM                96=   292     529=
  2-00004684  R*4  DHD               47=   533=
  2-00004688  R*4  DHDD              48=
  2-00004690  R*4  DHOTR             50=   532=    533

  2-0000468C  R*4  DHTR              49=    95=    526=    529
 AP-00000014@ R*4  ELC                3    383     384(2)  385     387     388     389     557
                                    612A
  2-00004748  R*4  EN               129A   135A
  2-000048A8  R*4  ERR              528=
  2-000048A4  R*4  ERROR            527=   529

  2-000046C0  R*4  FLAG2             67=
  2-000048AC  R*4  FLT              568=   572     577     581     587
  2-00004688  R*4  FLT1             577    587=
  2-0000477C  R*4  FPLS             169=   190=    217=    249=    254=    269=    272=    275=
                                    559
  2-000046E8  R*4  FPLS1             78=   560

  2-000047A0  R*4  GAP              264=   268     271     274
  2-00004788  R*4  GAPP             181=   184(2)
 AP-0000001C@ R*4  GD                 3     25=
  2-00004660  R*4  GHDOT             25    524
  2-00004790  R*4  GPP              201=   204=    211(2)

  2-000047A4  R*4  HLIM             266=   373=    374     375
  2-00004848  R*4  HTA              354=   383     391
  2-00004844  R*4  HTB              352=   387     392
  2-00004854  R*4  HTPO             362=   369(2)= 374     375     377     378
  2-00004850  R*4  HTPOA            360=   362
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  2-0000484C  R*4  HTP08             358=    362
  2-00004728  I*4  I                 106=    107     108     109     110     111     112     113
                                     114     116=    117     118     281=    282(2)  283(2)  284(2)
                                     516=    517(2)  518(2)  519(2)  598=    599     603=    604
                                     606=    607(2)
  2-00004674  I*4  IDO                33=    559     571
  2-000046D4  I*4  IFLAG10            72=    142     154=    176=    198=    226=    252     258=
  2-000046D8  I*4  IFLAG11            73=    155=    171     177=    199     202     206=    227=
                                     259=

  2-000046DC  I*4  IFLAG12            74=    156=    178=    193     207=    228=    260=
  2-000046E0  I*4  IFLAG13            75=    157=    179=    208=    220     229=    261=
  2-000046C4  I*4  IFLAG3             68=    149     151=    173=    195=    224=    255=
  2-00004668  I*4  IFLAG5             27=    567     592
  2-000046C8  I*4  IFLAG7             69=    152=    174=    196=    233     247=    256=

  2-000046CC  I*4  IFLAG8             70=    120A    134A
  2-000046D0  I*4  IFLAG9             71=    153=    175=    197=    225=    257=    370
  2-00004670  I*4  INT                29=     30      31
 AP-00000004@ I*4  ISEAS               3      19     612A
  2-00004714  I*4  IT                100=    595=    596A    611=    612A

  2-00004614  R*4  IT1                12      87=    314     316     318     322     325     326
                                     337     340     341     505     507     509
  2-00004638  R*4  IT10               12
  2-0000463C  R*4  IT11               12
  2-00004640  R*4  IT12               13
  2-00004644  R*4  IT13               13

  2-00004618  R*4  IT2                12      88=    314     316     318     322     325     326
                                     337     340     341     505     507     509
  2-0000461C  R*4  IT3                12      89=    314     316     318     322     325     326
                                     337     340     341     505     507     509
  2-00004620  R*4  IT4                12      90=    314     316     319     322     325     326
                                     337     340     341     505     507     510
  2-00004624  R*4  IT5                12      91=    314     317     319     322     325     326
                                     337     340     341     505     508     510
  2-00004628  R*4  IT6                12      92=    315     317     322     325     337     340
                                     506     508

  2-0000462C  R*4  IT7                12      93=    315     323     338     506
  2-00004630  R*4  IT8                12      94=
  2-00004634  R*4  IT9                12
  2-00004804  I*4  ITOT              602=    604(2)= 607
  2-00004724  I*4  J                 105=    527A

 AP-00000030@ I*4  JAY                 3     596A    612A
 AP-0000000C@ I*4  JRAN                3      43A
 AP-00000008@ I*4  K                   3      28      33     594     595
  2-0000466C  I*4  KAY                28=    596A    612A
  2-000048D0  I*4  KDOO              597=    599     600(2)=

  2-00004718  I*4  KMEAN             101=    395(2)  553(2)=
  2-00004884  I*4  KHN               571=    572(4)  573(4)  575     576     577(3)  578(3)  581(3)
                                     582(2)  583(3)  584(2)  586(2)  589(5)
 AP-00000020@ R*4  KP                  3      12      20      21      22      23     165=    166=
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                                    187=    214=    240=    242=    253=    351
  2-00004654  R*4  KPA               14      21=    166     242     253     612A
  2-00004658  R*4  KPB               14      22=    165     214     240

  2-0000465C  R*4  KPC               14      23=    187
 AP-00000010@ I*4  L                  3     281     354(2)  358(2)  360(2)  393     516     526(2)
                                    532(2)
  2-00004648  R*4  LIM               13     368=    375=    378=    383(2)  387(2)  391     392
  2-00004650  R*4  MIVRD             13     104=    554(2)= 564
  2-0000464C  R*4  MTOUT             13     395(2)= 559     564

  2-00004690  R*4  POUT             393=    394
  2-00004754  R*4  PRECYC           130A    136A
  2-00004758  R*4  RNP              130A    136A    364     529
  2-0000475C  R*4  RNQ              130A    136A
  2-000046F0  R*4  S1                80=    158     162=    180     184=    200     203     211=
                                    222     234=    236=    239     241     264     268=    271=
                                    274=    286

  2-000046F4  R*4  S2                81=    163=    185=    212=    237=    287
  2-000046F8  R*4  S3                82=    164=    186=    213=    238=    288
  2-0000472C  R*4  SA1              128A    134A    223     236
  2-00004730  R*4  SA2              128A    134A    237
  2-00004734  R*4  SA3              128A    134A    238

  2-00004784  R*4  SGAPP            180=    184
  2-00004774  R*4  SGP              158=    162(2)
  2-0000478C  R*4  SGPP             200=    203=    211
  2-0000473C  R*4  SS1              129A    135A    140     162(3)  279
  2-00004760  R*4  SS1Z             140=    144     145     147

  2-00004740  R*4  SS2              129A    135A    141     143     144     163     185     212
                                    554(2)  558     564     569
  2-00004764  R*4  SS2ZD            141=
  2-00004744  R*4  SS3              129A    135A    164     186     213
  2-0000479C  R*4  SSAMP            223=    234(2)
  2-00004798  R*4  SSGAP            222=    223     234

  2-00004738  R*4  SX               128A    134A
  2-00004678  R*4  T                 43=     45     128A    129A    134A    135A    552(2)= 555
                                    558     564     568
  2-000046FC  R*4  T1                85=
  2-00004684  R*4  T2                63=     85      86     349     350
  2-00004700  R*4  T4                86=

  2-00004680  R*4  TC                46=     87      88(2)   89      90      91      92      93
                                     94     130A    136A    167     188     215     244     277
                                    552     555
  2-000046E4  R*4  TE                77=    194=    211     215(2)= 216(2)=
  2-00004770  R*4  TE1              150=    162     167(2)= 168(2)=
  2-00004794  R*4  TE2              221=    234     244(2)= 245     246=
  2-00004780  R*4  TE3              172=    184     188(2)= 189(2)=

  2-00004768  R*4  TE4              142     263=    267     268     270(2)  273     274     277(2)=
  2-00004694  R*4  TF                53=    555
  2-000048CC  R*4  TFIN             594=    596A    609=    612A
  2-0000466C  R*4  TG                66=    294     351
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  2-0000474C  R*4  TGEE          130A    136A    383     387

  2-0000467C  R*4  TII            45=     53     128A    129A    134A    135A    558     564(2)
                                 568     610=    612A
  2-00004688  R*4  TL             65=    349     350     351     352     354     358
  2-00004884  R*4  TOUT          394=    395     396(2)  397(2)  400(2)  402(2)  404(2)  430(2)
                                 432(2)  434(2)  436(2)  438(2)  440(2)  442(2)  444(2)  446(2)
                                 448(2)  452(2)  454(2)  456(2)  458(2)  460(2)  462(2)  464(2)
                                 466(2)  468(2)  470(2)  474(2)  476(2)  478(2)  480(2)  482(2)
                                 484(2)  486(2)  488(2)  490(2)  492(2)
  2-0000471C  R*4  TOUTMAX       102=    396(2)= 564
  2-00004720  R*4  TOUTMIN       103=    397(2)= 564

  2-000048C0  R*4  TSDA          581=    582
 AP-00000018@ R*4  TW              3     377     378     557     612A
  2-000048C4  R*4  VSDA          583=    584
  2-000048B8  R*4  VTD           569=    573     578     583
  2-000048BC  R*4  VTD1          578

  2-00004750  R*4  VTZ           130A    136A
  2-000046AC  R*4  Y0             61=    293     364=
  2-000046A0  R*4  Y1             58=    344=    354     358     364
  2-000047F8  R*4  Y1A           314=    344
  2-000047FC  R*4  Y1B           315=    344

  2-000046A4  R*4  Y2             59=    345=    354     360     365
  2-00004800  R*4  Y2A           316=    345
  2-00004804  R*4  Y2B           317=    345
  2-000046A8  R*4  Y3             60=    346=
  2-00004808  R*4  Y3A           318=    346

  2-0000480C  R*4  Y3B           319=    346
  2-00004818  R*4  YA1           324=    352     354     358
  2-00004810  R*4  YA1A          322=    324
  2-00004814  R*4  YA1B          323=    324
  2-0000481C  R*4  YA2           325=    352     354     360

  2-00004820  R*4  YA3           326=
  2-0000482C  R*4  YAA1          339=    364
  2-00004824  R*4  YAA1A         337=    339
  2-00004828  R*4  YAA1B         338=    339
  2-00004830  R*4  YAA2          340=    365

  2-00004834  R*4  YAA3          341=
  2-000046B0  R*4  YD0            62=    365=
  2-00004708  R*4  Z              97=    140     146     239     241     279     384     385
                                 386     512=    521
  2-0000488C  R*4  ZA1           505=    512
  2-00004890  R*4  ZA2           506=    512

  2-00004894  R*4  ZB1           507=    513
  2-00004898  R*4  ZB2           508=    513
  2-0000489C  R*4  ZC1           509=    514
  2-000048A0  R*4  ZC2           510=    514
  2-0000470C  R*4  ZD             98=    141     384     385     513=    522     524     554(2)
                                 558     564     569
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  2-00004710  R*4  ZDD                          99=     384      514=     523
  2-00004664  R*4  ZH                           26=     384(2)   385      388      389      557      612A
  2-000046EC  R*4  ZHOTDT                       79=     383      387

ARRAYS

    Address  Type  Name          Attributes       Bytes  Dimensions       References

  2-00000C30  R*4  AC                            2000  (500)           8        117=
 AP-00000030@ R*4  ATH                             40  (10)            3        7        129A     135A
 AP-00000028@ R*4  AZ                              40  (10)            3        7        129A     135A
  2-00001E28  R*4  DUMB                           200  (50)            9        31=
  2-00001D60  I*4  IS                             200  (50)            9        30=      431(2)=  433(2)=  435(2)=
                                                                     437(2)=  439(2)=  441(2)=  443(2)=  445(2)=
                                                                     447(2)=  449(2)=  453(2)=  455(2)=  457(2)=
                                                                     459(2)=  461(2)=  463(2)=  465(2)=  467(2)=
                                                                     469(2)=  471(2)=  475(2)=  477(2)=  479(2)=
                                                                     481(2)=  483(2)=  485(2)=  487(2)=  489(2)=
                                                                     491(2)=  493(2)=  560      604      607

 AP-00000034@ R*4  PHIO                            40  (10)            3        7        129A     135A
 AP-0000002C@ R*4  PHIZ                            40  (10)            3        7        129A     135A
  2-00000140  R*4  SLA                            200  (50)            6        109=     284(2)=  288=
  2-00001BD0  R*4  SLOT                           200  (50)            9        113=     607=     612(2)A
  2-00000000  R*4  SLS                            120  (30)            6        107=     282(2)=  286=     354(2)
                                                                     358      360      526

  2-00000078  R*4  SLV                            200  (50)            6        108=     283(2)=  287=     532
  2-00000460  R*4  SM                            2000  (500)           7
  2-00003E30  R*4  TIMA                          2000  (500)          10        586=     596A
  2-00001400  R*4  TIMEE                         2000  (500)           8        118=
  2-00002E90  R*4  THN                           2000  (500)          10        572(2)=  577(2)   581      589
                                                                     596A

  2-00003660  R*4  TSD                           2000  (500)          10        577=     581      582=     589
                                                                     596A
  2-00001C98  R*4  THRTR                          200  (50)            9        114=     599=     612A
  2-00001EF0  R*4  VHN                           2000  (500)          10        573(2)=  578(2)   583      589
                                                                     596A
  2-000026C0  R*4  VSD                           2000  (500)          10        578=     583      584=     589
                                                                     596A
 AP-00000024@ R*4  WE                              40  (10)            3        7        129A     135A

  2-00000398  R*4  ZDDL                           200  (50)            6        112=     519(2)=  523=
  2-000002D0  R*4  ZDL                            200  (50)            6        111=     518(2)=  522=     532
  2-00000208  R*4  ZL                             200  (50)            6        110=     358      360      393
                                                                     517(2)=  521=     526

LABELS

    Address   Label                      References

      **      1                             29       32#
      **      5                            106      115#
      **      6                            116      119#
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 0-00000300  20                   134#     556
     **      30                   140#

 0-00000434  35                   143      171#
 0-000004B0  40                   144      193#
 0-00000569  45                   145      146      220#
 0-000005D1  46                   233      236#
 0-000005D6  47                   235      237#

 0-00000622  50                   142      147      252#
 0-000006F4  65                   170      191      218      250      279#
     **      70                   261      285#
 0-00000BB5  74                   370      374#
 0-00000BC9  75                   374      377#

 0-00000BE2  80                   376      377      383#
 0-00000D17  90                   401      430#
 0-00000E11  95                   403      452#
 0-00000F08  100                  405      474#
 0-00001002  105                  407      451      473      496#

     **      110                  516      520#
 0-00001229  140                  132      552#
     **      145                  556#
 0-00001254  150                  279      555      557#
 1-0000006E  155'                 564      566#

 0-00001491  160                  576      581#
 0-00001518  165                  575      579      586#
 1-0000008F  170'                 589      590#
 0-00001580  175                   33      567      591#
 0-000015A0  180                  592      597#

     **      185                  598      601#
     **      190                  603      605#
     **      195                  606      608#
 1-0000009E  200'                 618      619#


FUNCTIONS AND SUBROUTINES REFERENCED

 Type  Name                       References

       FOR$DATE_T_DS              616
       FOR$TIME_T_DS              615
       INPUT1                     128      134
       INPUT2                     129      135
 R*4   MTH$COS                    162      184      211      234      268      274

 R*4   MTH$RANDOM                  43      527
       PLOT2                      612
       PLOT3                      596
       TURBULENCE                 130      136
```

```
                                                  21-Jan-1985 12:09:35   VAX-11 FORTRAN V3.5-62          Page 19
                                                  19-Jan-1985 21:06:48   FSD0:[STEVENS.SHIPSTUFF]VPA1C.FOR;17

0001


  +------------------------------------------+
  |           KEY TO REFERENCE FLAGS         |
  |   *   - Value Modified                   |
  |   #   - Defining Reference               |
  |   A   - Actual Argument, possibly modified |
  |   D   - Data Initialization.             |
  |  (n)  - Number of occurrences on line    |
  +------------------------------------------+


COMMAND QUALIFIERS

  FORTRAN /LIS/CRO VPA1C.FOR

  /CHECK=(NOBOUNDS,OVERFLOW,NOUNDERFLOW)
  /DEBUG=(NOSYMBOLS,TRACEBACK)
  /STANDARD=(NOSYNTAX,NOSOURCE_FORM)
  /SHOW=(NOPREPROCESSOR,NOINCLUDE,MAP)
  /F77  /NOG_FLOATING  /I4  /OPTIMIZE  /WARNINGS  /NOD_LINES  /CROSS_REFERENCE  /NOMACHINE_CODE  /CONTINUATIONS=19


COMPILATION STATISTICS

  Run Time:           26.45 seconds
  Elapsed Time:       29.38 seconds
  Page Faults:        492
  Dynamic Memory:     333 pages
```

```
******************************    2-FEB-1985 11:37:52.93    FSD0:[STEVENS.SHIPSTUFF]IN4.LIS;1    ******************************
******************************    2-FEB-1985 11:37:52.93    FSD0:[STEVENS.SHIPSTUFF]IN4.LIS;1    ******************************
******************************    2-FEB-1985 11:37:52.93    FSD0:[STEVENS.SHIPSTUFF]IN4.LIS;1    ******************************
```

IN4.LIS;1

```
******************************    2-FEB-1985 11:37:52.93    FSD0:[STEVENS.SHIPSTUFF]IN4.LIS;1    ******************************
******************************    2-FEB-1985 11:37:52.93    FSD0:[STEVENS.SHIPSTUFF]IN4.LIS;1    ******************************
******************************    2-FEB-1985 11:37:52.93    FSD0:[STEVENS.SHIPSTUFF]IN4.LIS;1    ******************************
```

```
        SUBROUTINE INPUT1(S1,S2,S3,t,tI,IFLAG5,SX)

         AMPA=9.0
         AMPB=31.0

         WNS=1.0
         WNS1=0.12  !0.14
         S1=0.0
                          S2=0.0

        IF  (IFLAG5 .EQ. 0) GO TO 20

        IF (ISFLAG1 .EQ. 0) TIMA=t
        A=TIMA
        IF (t .GE. A+3.14159/WNS) GO TO 10
        TAU=T-A
        S1=AMPA*(0.5+0.5*COS(WNS*TAU+3.14159))
        S2=-AMPA*0.5*WNS*SIN(WNS*TAU+3.14159)
        S3=-AMPA*0.5*WNS**2*COS(WNS*TAU+3.14159)
        ISFLAG1=1
        GO TO 30
 10      S1=AMPA
         S2=0.0
         S3=0.0
         GO TO 30

 20      B=tI
         IF (t .GE. B+3.14159/WNS1) GO TO 25
         TAU=+(T-B)
         S1=AMPA+AMPB*(0.5+0.5*COS(WNS1*TAU))
         S2=-AMPB*0.5*WNS1*SIN(WNS1*TAU)
         S3=-AMPB*0.5*WNS1**2*COS(WNS1*TAU)
         ISFLAG1=0
         GO TO 30
 25      S1=AMPA
         S2=0
         S3=0
          ISFLAG1=0
 30      RETURN
          END
```

```
INPUT1                                        2-Feb-1985 11:27:41    VAX-11 FORTRAN V3.5-62            Page  2
                                              2-Feb-1985 10:52:12    FSD0:[STEVENS.SHIPSTUFF]IN4.FOR;44

PROGRAM SECTIONS

    Name                                Bytes  Attributes

  0 $CODE                                 292  PIC CON REL LCL   SHR   EXE   RD NOWRT LONG
  2 $LOCAL                                 36  PIC CON REL LCL NOSHR NOEXE   RD   WRT LONG

    Total Space Allocated                 328

ENTRY POINTS

    Address   Type  Name                    References

  0-00000000        INPUT1                    1

VARIABLES

    Address   Type  Name        Attributes  References

  2-00000018  R*4  A                          14=     15      16
  2-00000000  R*4  AMPA                        3=     17      18      19      22      30      35
  2-00000004  R*4  AMPB                        4=     30      31      32
  2-00000020  R*4  B                          27=     28      29
 AP-00000018@ I*4  IFLAG5                      1      11

  2-00000010  I*4  ISFLAG1                    13      20=     33=     38=
 AP-00000004@ R*4  S1                          1       8=     17=     22=     30=     35=
 AP-00000008@ R*4  S2                          1       9=     18=     23=     31=     36=
 AP-0000000C@ R*4  S3                          1      19=     24=     32=     37=
 AP-0000001C@ R*4  SX                          1

 AP-00000010@ R*4  T                           1      13      15      16      28      29
  2-0000001C  R*4  TAU                        16=     17      18      19      29=     30      31      32
 AP-00000014@ R*4  TI                          1      27
  2-00000014  R*4  TIMA                       13=     14
  2-00000008  R*4  WNS                         6=     15      17      18(2)   19(2)

  2-0000000C  R*4  WNS1                        7=     28      30      31(2)   32(2)

LABELS

    Address   Label                         References

  0-000000A3  10                              15      22#
  0-000000AF  20                              11      27#
  0-00000116  25                              28      35#
  0-00000123  30                              21      25      34      39#
```

```
FUNCTIONS AND SUBROUTINES REFERENCED

  Type Name                                References

   R*4  MTH$COS                               17        19        30        32
   R*4  MTH$SIN                               18        31


  +-----------------------------------------+
  |           KEY TO REFERENCE FLAGS        |
  |   =   - Value Modified                  |
  |   #   - Defining Reference              |
  |   A   - Actual Argument, possibly modified |
  |   D   - Data Initialization             |
  |  (n)  - Number of occurrences on line   |
  +-----------------------------------------+


COMMAND QUALIFIERS

  FORTRAN /LIS/CRO IN4.FOR

  /CHECK=(NOBOUNDS,OVERFLOW,NOUNDERFLOW)
  /DEBUG=(NOSYMBOLS,TRACEBACK)
  /STANDARD=(NOSYNTAX,NOSOURCE_FORM)
  /SHOW=(NOPREPROCESSOR,NOINCLUDE,MAP)
  /F77  /NOG_FLOATING  /I4  /OPTIMIZE  /WARNINGS  /NOD_LINES  /CROSS_REFERENCE  /NOMACHINE_CODE  /CONTINUATIONS=19


COMPILATION STATISTICS

  Run Time:           2.16 seconds
  Elapsed Time:       2.84 seconds
  Page Faults:        127
  Dynamic Memory:     117 pages
```

```
*****************************   2-FEB-1985 11:32:46.87   FSD0:[STEVENS.SHIPSTUFF]GENSM.LIS;1   *****************************
*****************************   2-FEB-1985 11:32:46.87   FSD0:[STEVENS.SHIPSTUFF]GENSM.LIS;1   *****************************
*****************************   2-FEB-1985 11:32:46.87   FSD0:[STEVENS.SHIPSTUFF]GENSM.LIS;1   *****************************
```

GENSM.LIS;1

```
*****************************   2-FEB-1985 11:32:46.87   FSD0:[STEVENS.SHIPSTUFF]GENSM.LIS;1   *****************************
*****************************   2-FEB-1985 11:32:46.87   FSD0:[STEVENS.SHIPSTUFF]GENSM.LIS;1   *****************************
*****************************   2-FEB-1985 11:32:46.87   FSD0:[STEVENS.SHIPSTUFF]GENSM.LIS;1   *****************************
```

```
        SUBROUTINE INPUT2(S1,S2,S3,t,t1,EN,WE,AZ,PHIZ,ATH,PHI0)
        DIMENSION WE(10),AZ(10),PHIZ(10),ATH(10),PHI0(10)

        IF (t .GT.t1) GO TO 10



C     ***RANDOM PHASE ANGLE GENERATED***

        TM = SECNDS(0.0)
        M = NINT(TM)
        XM = FLOAT(M)
        RT = TM - XM
        S = MOD(XM,2.)
        IF ( S  .EQ.  0.0 ) THEN
             XM = XM + 1.
        END IF
        M = IFIX(XM)
        XB = -2147483648.0 * RT
        S = XB / 2.
        IS = IFIX(S)
        XS = FLOAT(IS)
        S = S - XS
        IF ( S  .NE.  0.0 ) THEN
             XB = XB + 1.
        END IF
        IB = IFIX(XB)
        M = IB - M
              Y = RAN(M) - 0.5
              EN=6.2832*Y
              EN=0.0

C    ***SHIP HEAVE (FT.)***

10      H1=AZ(1)*COS(WE(1)*t+PHIZ(1)+EN)
        H2=AZ(2)*COS(WE(2)*t+PHIZ(2)+EN)
        H3=AZ(3)*COS(WE(3)*t+PHIZ(3)+EN)
        H4=AZ(4)*COS(WE(4)*t+PHIZ(4)+EN)
        H5=AZ(5)*COS(WE(5)*t+PHIZ(5)+EN)
        H6=AZ(6)*COS(WE(6)*t+PHIZ(6)+EN)

C       ***SHIP PITCH (RAD)***

        P1=ATH(1)*COS(WE(1)*t+PHI0(1)+EN)
        P2=ATH(2)*COS(WE(2)*t+PHI0(2)+EN)
        P3=ATH(3)*COS(WE(3)*t+PHI0(3)+EN)
        P4=ATH(4)*COS(WE(4)*t+PHI0(4)+EN)
        P5=ATH(5)*COS(WE(5)*t+PHI0(5)+EN)
        P6=ATH(6)*COS(WE(6)*t+PHI0(6)+EN)



C       ***HEAVE AT LANDING PAD***

        S1=H1+H2+H3+H4+H5+H6+(160.0*SIN(P1+P2+P3+P4+P5+P6))
C       S1=-S1

C       ***SHIP HEAVE VELOCITY (FT/S)***
```

```

      HD1=-AZ(1)*WE(1)*SIN(WE(1)*t+PHIZ(1)+EN)
      HD2=-AZ(2)*WE(2)*SIN(WE(2)*t+PHIZ(2)+EN)
      HD3=-AZ(3)*WE(3)*SIN(WE(3)*t+PHIZ(3)+EN)
      HD4=-AZ(4)*WE(4)*SIN(WE(4)*t+PHIZ(4)+EN)
      HD5=-AZ(5)*WE(5)*SIN(WE(5)*t+PHIZ(5)+EN)
      HD6=-AZ(6)*WE(6)*SIN(WE(6)*t+PHIZ(6)+EN)

C     ***SHIP PITCH VELOCITY (RAD/S)***

      PD1=-ATH(1)*WE(1)*SIN(WE(1)*t+PHI0(1)+EN)
      PD2=-ATH(2)*WE(2)*SIN(WE(2)*t+PHI0(2)+EN)
      PD3=-ATH(3)*WE(3)*SIN(WE(3)*t+PHI0(3)+EN)
      PD4=-ATH(4)*WE(4)*SIN(WE(4)*t+PHI0(4)+EN)
      PD5=-ATH(5)*WE(5)*SIN(WE(5)*t+PHI0(5)+EN)
      PD6=-ATH(6)*WE(6)*SIN(WE(6)*t+PHI0(6)+EN)

C     ***SHIP LANDING PAD HEAVE VELOCITY (FT/S)***

      S2A=HD1+HD2+HD3+HD4+HD5+HD6
      S2B=160.8*SIN(PD1+PD2+PD3+PD4+PD5+PD6)

      S2=S2A+S2B
C     S2=-S2

C      ***SHIP HEAVE ACCELERATION (FT/S**2)***


      HDD1=-WE(1)**2*AZ(1)*COS(WE(1)*t+PHIZ(1)+EN)
      HDD2=-WE(2)**2*AZ(2)*COS(WE(2)*t+PHIZ(2)+EN)
      HDD3=-WE(3)**2*AZ(3)*COS(WE(3)*t+PHIZ(3)+EN)
      HDD4=-WE(4)**2*AZ(4)*COS(WE(4)*t+PHIZ(4)+EN)
      HDD5=-WE(5)**2*AZ(5)*COS(WE(5)*t+PHIZ(5)+EN)
      HDD6=-WE(6)**2*AZ(6)*COS(WE(6)*t+PHIZ(6)+EN)

C    SHIP PITCH ACCELERATION RAD/S**2

      PDD1=-WE(1)**2*ATH(1)*COS(WE(1)*t+PHI0(1)+EN)
      PDD2=-WE(2)**2*ATH(2)*COS(WE(2)*t+PHI0(2)+EN)
      PDD3=-WE(3)**2*ATH(3)*COS(WE(3)*t+PHI0(3)+EN)
      PDD4=-WE(4)**2*ATH(4)*COS(WE(4)*t+PHI0(4)+EN)
      PDD5=-WE(5)**2*ATH(5)*COS(WE(5)*t+PHI0(5)+EN)
      PDD6=-WE(6)**2*ATH(6)*COS(WE(6)*t+PHI0(6)+EN)

C     ***SHIP LANDING PAD HEAVE ACCELERATION (FT/S**2)***

      S3A=HDD1+HDD2+HDD3+HDD4+HDD5+HDD6
      S3B=160.8*SIN(PDD1+PDD2+PDD3+PDD4+PDD5+PDD6)

      S3=S3A+S3B
C     S3=-S3

      RETURN
      END
```

```
PROGRAM S""TIONS

    Name                                 Bytes  Attributes

  0 $CODE                                 1667  PIC CON REL LCL   SHR   EXE    RD NOWRT LONG
  1 $PDATA                                   8  PIC CON REL LCL   SHR NOEXE    RD NOWRT LONG
  2 $LOCAL                                 368  PIC CON REL LCL NOSHR NOEXE    RD   WRT LONG

    Total Space Allocated                 2043


ENTRY POINTS

    Address  Type  Name                     References

  0-00000000       INPUT2                        1


VARIABLES

    Address  Type  Name          Attributes  References

 AP-0000001C@ R*4  EN                            1      30*     31*     35      36      37      38      39
                                                40      44      45      46      47      48      49      59
                                                60      61      62      63      64      68      69      70
                                                71      72      73      86      87      88      89      90
                                                91      95      96      97      98      99     100
  2-00000028  R*4  H1                           35*     54
  2-0000002C  R*4  H2                           36*     54
  2-00000030  R*4  H3                           37*     54
  2-00000034  R*4  H4                           38*     54

  2-00000038  R*4  H5                           39*     54
  2-0000003C  R*4  H6                           40*     54
  2-00000058  R*4  HD1                          59*     77
  2-0000005C  R*4  HD2                          60*     77
  2-00000060  R*4  HD3                          61*     77

  2-00000064  R*4  HD4                          62*     77
  2-00000068  R*4  HD5                          63*     77
  2-0000006C  R*4  HD6                          64*     77
  2-00000090  R*4  HDD1                         86*    104
  2-00000094  R*4  HDD2                         87*    104

  2-00000098  R*4  HDD3                         88*    104
  2-0000009C  R*4  HDD4                         89*    104
  2-000000A0  R*4  HDD5                         90*    104
  2-000000A4  R*4  HDD6                         91*    104
  2-00000020  I*4  IB                           27*     28

  2-00000018  I*4  IS                           21*     22
  2-00000004  I*4  M                            11*     12      18*     26(2)*  29A
  2-00000040  R*4  P1                           44*     54
  2-00000044  R*4  P2                           45*     54
  2-00000048  R*4  P3                           46*     54

  2-0000004C  R*4  P4                           47*     54
```

```
  2-00000050  R*4  P5                       48=     54
  2-00000054  R*4  P6                       49=     54
  2-00000070  R*4  PD1                      68=     78
  2-00000074  R*4  PD2                      69=     78

  2-00000078  R*4  PD3                      70=     78
  2-0000007C  R*4  PD4                      71=     78
  2-00000080  R*4  PD5                      72=     78
  2-00000084  R*4  PD6                      73=     78
  2-000000A8  R*4  PDD1                     95=     105

  2-000000AC  R*4  PDD2                     96=     105
  2-000000B0  R*4  PDD3                     97=     105
  2-000000B4  R*4  PDD4                     98=     105
  2-000000B8  R*4  PDD5                     99=     105
  2-000000BC  R*4  PDD6                    100=     105

  2-0000000C  R*4  RT                       13=     19
  2-00000010  R*4  S                        14=     15      20=     21      23(2)=  24
 AP-00000004@ R*4  S1                        1      54=
 AP-00000006@ R*4  S2                        1      80=
  2-00000088  R*4  S2A                      77=     80

  2-0000008C  R*4  S2B                      78=     80
 AP-0000000C@ R*4  S3                        1      107=
  2-000000C0  R*4  S3A                     104=     107
  2-000000C4  R*4  S3B                     105=     107
 AP-00000010@ R*4  T                         1       4      35      36      37      38      39      40
                                            44      45      46      47      48      49      59      60
                                            61      62      63      64      68      69      70      71
                                            72      73      86      87      88      89      90      91
                                            95      96      97      98      99      100

 AP-00000014@ R*4  TI                        1       4
  2-00000000  R*4  TM                       10=     11      13
  2-00000014  R*4  XB                       19=     20      25(2)=  27
  2-00000008  R*4  XM                       12=     13      14      16(2)=  18
  2-0000001C  R*4  XS                       22=     23

  2-00000024  R*4  Y                        29=     30

ARRAYS

    Address  Type  Name          Attributes        Bytes  Dimensions      References

 AP-00000028@ R*4  ATH                               40  (10)             1       2       44      45      46
                                                                         47      48      49      68      69
                                                                         70      71      72      73      95
                                                                         96      97      98      99      100
 AP-00000020@ R*4  AZ                                40  (10)             1       2       35      36      37
                                                                         38      39      40      59      60
                                                                         61      62      63      64      86
                                                                         87      88      89      90      91
 AP-0000002C@ R*4  PHIO                              40  (10)             1       2       44      45      46
                                                                         47      48      49      68      69
                                                                         70      71      72      73      95
```

```
                                                     96      97      98      99      100
 AP-00000024@ R*4  PHIZ                   40  (10)    1       2      35      36       37
                                                     38      39      40      59       60
                                                     61      62      63      64       86
                                                     87      88      89      90       91
 AP-0000001C@ R*4  WE                     40  (10)    1       2      35      36       37
                                                     38      39      40      44       45
                                                     46      47      48      49       59(2)
                                                     60(2)   61(2)   62(2)   63(2)    64(2)
                                                     68(2)   69(2)   70(2)   71(2)    72(2)
                                                     73(2)   86(2)   87(2)   88(2)    89(2)
                                                     90(2)   91(2)   95(2)   96(2)    97(2)
                                                     98(2)   99(2)  100(2)


LABELS

   Address   Label                     References

  0-000000CF  10                          4      35#


FUNCTIONS AND SUBROUTINES REFERENCED

  Type  Name                           References

   R*4  FOR$SECNDS                       10
   R*4  MTH$AMOD                         14
   R*4  MTH$COS                          35      36      37      38      39      40      44      45
                                         46      47      48      49      86      87      88      89
                                         90      91      95      96      97      98      99     100
   R*4  MTH$RANDOM                       29
   R*4  MTH$SIN                          54      59      60      61      62      63      64      68
                                         69      70      71      72      73      78     105
```

```
0001


  +------------------------------------------------+
  |           KEY TO REFERENCE FLAGS               |
  |   *   - Value Modified                         |
  |   #   - Defining Reference                     |
  |   A   - Actual Argument, possibly modified     |
  |   D   - Data Initialization                    |
  |  (n)  - Number of occurrences on line          |
  +------------------------------------------------+


COMMAND QUALIFIERS

  FORTRAN /LIS/CRO GENSM.FOR

  /CHECK=(NOBOUNDS,OVERFLOW,NOUNDERFLOW)
  /DEBUG=(NOSYMBOLS,TRACEBACK)
  /STANDARD=(NOSYNTAX,NOSOURCE_FORM)
  /SHOW=(NOPREPROCESSOR,NOINCLUDE,MAP)
  /F77  /NOG_FLOATING  /I4  /OPTIMIZE  /WARNINGS  /NOD_LINES  /CROSS_REFERENCE  /NOMACHINE_CODE  /CONTINUATIONS=19


COMPILATION STATISTICS

  Run Time:          8.42 seconds
  Elapsed Time:      9.33 seconds
  Page Faults:       244
  Dynamic Memory:    178 pages
```

```
******************************   2-FEB-1985 11:40:26.97   FSD0:[STEVENS.SHIPSTUFF]TRANO.LIS;1   ******************************
******************************   2-FEB-1985 11:40:26.97   FSD0:[STEVENS.SHIPSTUFF]TRANO.LIS;1   ******************************
******************************   2-FEB-1985 11:40:26.97   FSD0:[STEVENS.SHIPSTUFF]TRANO.LIS;1   ******************************
```

TRANO.LIS;1

```
******************************   2-FEB-1985 11:40:26.97   FSD0:[STEVENS.SHIPSTUFF]TRANO.LIS;1   ******************************
******************************   2-FEB-1985 11:40:26.97   FSD0:[STEVENS.SHIPSTUFF]TRANO.LIS;1   ******************************
******************************   2-FEB-1985 11:40:26.97   FSD0:[STEVENS.SHIPSTUFF]TRANO.LIS;1   ******************************
```

```
C234567890123456789 0...etc.
      SUBROUTINE TURBULENCE(TGEE,TC,VTZ,PRECYC,RNP,RNQ)
      HN=7.79
      SIGMA=0.032

      HNN=2.8  !1.8  !2.8
      SIGMAN=0.0003  !0.005  !.0003
      HNQ=0.0  !1.6  !2.6
      SIGMAQ=0.0  !24.0  !8.6

5     PRECYC=PRECYC+1
      TM = SECNDS(0.0)
      M = NINT(TM)
      XM = FLOAT(M)
      RT = TM - XM
      S = MOD(XM,2.)
      IF ( S  .EQ.  0.0 ) THEN
         XM = XM + 1.
      END IF
      M = IFIX(XM)
      XB = -2147483648.0 * RT
      S = XB / 2.
      IS = IFIX(S)
      XS = FLOAT(IS)
      S = S - XS
      IF ( S  .NE.  0.0 ) THEN
         XB = XB + 1.
      END IF
      IB = IFIX(XB)
      M = IB - M
      FLAG=0.0
      YB=0.0
      Y=0.0
      DO 10 I=1,12
         YA=RAN(M)
         Y=Y+YA
10    CONTINUE
      YB=(Y-6.0)
      VTZD=-HN*VTZ+SIGMA*(2*HN)**2*(1/(TC**0.5))*YB
      VTZ=(VTZ+TC*VTZD)
      TGEE=VTZ

      YB=0.0
      Y=0.0

      DO 15 I=1,12
         YA=RAN(M)
         Y=Y+YA
15    CONTINUE
      YB=(Y-6.0)
      RNOD=-HNN*RNO+SIGMAN*(2*HNN)**2*(1/(TC**0.5))*YB
      RNO=(RNO+TC*RNOD)
      RNP=RNO*0.066

      YB=0.0
      Y=0.0

```

```
0058            DO 20 I=1,12
0059                  YA=RAN(M)
0060                  Y=Y+YA
0061     20     CONTINUE
0062            YB=(Y-6.0)
0063            RNQD=-WNN*RNQ+SIGMAQ*(2*WNN)**2*(1/(TC**0.5))*YB
0064            RNQ=(RNQ+TC*RNQD)
0065            RNQ=RNQ*0.066
0066
0067
0068            IF (PRECYC .LT. 100) GO TO 5
0069     50     RETURN
0070            END



PROGRAM SECTIONS

    Name                                    Bytes  Attributes

  0 $CODE                                     437  PIC CON REL LCL   SHR  EXE   RD NOWRT LONG
  1 $PDATA                                      8  PIC CON REL LCL   SHR NOEXE  RD NOWRT LONG
  2 $LOCAL                                    124  PIC CON REL LCL NOSHR NOEXE  RD   WRT LONG

    Total Space Allocated                     569


ENTRY POINTS

    Address  Type  Name                  References

  0-00000000       TURBULENCE                2


VARIABLES

    Address  Type  Name          Attributes  References

  2-0000003C  R*4  FLAG                        31=
  2-00000048  I*4  I                           34=       46=       58=
  2-00000038  I*4  IB                          29=       30
  2-00000030  I*4  IS                          23=       24
  2-0000001C  I*4  M                           13=       14        20=       30(2)=    35A       47A       59A

 AP-00000010@ R*4  PRECYC                       2        11(2)=    68
  2-00000058  R*4  RNO                         51        52(2)=    53
  2-00000054  R*4  RNOD                        51=       52
 AP-00000014@ R*4  RNP                          2        53=
 AP-00000018@ R*4  RNQ                          2        63        64(2)=    65(2)=

  2-0000005C  R*4  RNQD                        63=       64
  2-00000024  R*4  RT                          15=       21
  2-00000028  R*4  S                           16=       17        22=       23        25(2)=    26
  2-00000004  R*4  SIGMA                        4=       39
  2-0000000C  R*4  SIGMAN                       7=       51
```

```
  2-00000014  R*4  SIGMAQ                        9=     63
 AP-00000008@ R*4  TC                            2      39       40       51       52       63       64
 AP-00000004@ R*4  TGEE                          2      41=
  2-00000018  R*4  TM                           12=     13       15
 AP-0000000C@ R*4  VTZ                           2      39       40(2)=   41

  2-00000050  R*4  VTZD                         39=     40
  2-00000000  R*4  WN                            3=     39(2)
  2-00000008  R*4  WNN                           6=     51(2)    63(2)
  2-00000010  R*4  WNQ                           8=
  2-0000002C  R*4  XB                           21=     22       27(2)=   29

  2-00000020  R*4  XM                           14=     15       16       18(2)=   20
  2-00000034  R*4  XS                           24=     25
  2-00000044  R*4  Y                            33=     36(2)=   38       44=      48(2)=   50       56=      60(2)=
                                                62
  2-0000004C  R*4  YA                           35=     36       47=      48       59=      60
  2-00000040  R*4  YB                           32=     39=      39       43=      50=      51       55=      62=
                                                63


LABELS

   Address   Label                            References

 0-0000002E  5                                  11#     69
     **      10                                 34      37#
     **      15                                 46      49#
     **      20                                 58      61#
     **      50                                 69#


FUNCTIONS AND SUBROUTINES REFERENCED

 Type Name                                    References

  R*4  FOR$SECNDS                               12
  R*4  MTH$AMOD                                 16
  R*4  MTH$RANDOM                               35      47       59

 +--------------------------------------------+
 |           KEY TO REFERENCE FLAGS           |
 |   =   - Value Modified                     |
 |   #   - Defining Reference                 |
 |   A   - Actual Argument, possibly modified |
 |   D   - Data Initialization                |
 |  (n)  - Number of occurrences on line      |
 +--------------------------------------------+
```

```
                                          2-Feb-1985 10:48:16    FSD0:[STEVENS.SHIPSTUFF]TRANO.FOR:56

COMMAND QUALIFIERS

  FORTRAN /LIS/CRO TRANO.FOR

  /CHECK=(NOBOUNDS,OVERFLOW,NOUNDERFLOW)
  /DEBUG=(NOSYMBOLS.TRACEBACK)
  /STANDARD=(NOSYNTAX,NOSOURCE_FORM)
  /SHOW=(NOPREPROCESSOR,NOINCLUDE,MAP)
  /F77  /NOG_FLOATING  /I4  /OPTIMIZE  /WARNINGS  /NOD_LINES  /CROSS_REFERENCE  /NOMACHINE_CODE  /CONTINUATIONS=19


COMPILATION STATISTICS

  Run Time:           3.09 seconds
  Elapsed Time:       3.84 seconds
  Page Faults:        133
  Dynamic Memory:     137 pages
```

```
******************************    2-FEB-1985 11:54:35.32    FSD0:[STEVENS.SHIPSTUFF]MPLT2.LIS;1    ******************************
******************************    2-FEB-1985 11:54:35.32    FSD0:[STEVENS.SHIPSTUFF]MPLT2.LIS;1    ******************************
******************************    2-FEB-1985 11:54:35.32    FSD0:[STEVENS.SHIPSTUFF]MPLT2.LIS;1    ******************************
```

```
MPLT2.LIS;1
```

```
******************************    2-FEB-1985 11:54:35.32    FSD0:[STEVENS.SHIPSTUFF]MPLT2.LIS;1    ******************************
******************************    2-FEB-1985 11:54:35.32    FSD0:[STEVENS.SHIPSTUFF]MPLT2.LIS;1    ******************************
******************************    2-FEB-1985 11:54:35.32    FSD0:[STEVENS.SHIPSTUFF]MPLT2.LIS;1    ******************************
```

```
C2345678901234567890...etc.
      SUBROUTINE PLOT2(X,Y,R,XI,XF,IDI,JAY,KAY,TH,ZH,ELC,KP,ISE)
      DIMENSION X(IDI),Y(IDI),R(IDI)
      REAL KP
      CHARACTER*9, BUF
      CHARACTER*8,BUFF
      CHARACTER*1 LABEL(20)
      CHARACTER*1 LBL2(48), LBL3(59)
      CHARACTER*48 LABEL2
      CHARACTER*59 LABEL3
      EQUIVALENCE (LABEL2,LBL2(1))
      EQUIVALENCE (LABEL(1),BUF)
      EQUIVALENCE (LABEL(10),SPACE)
      EQUIVALENCE (LABEL(13),BUFF)
      EQUIVALENCE (LABEL3,LBL3(1))


      DATA LABEL2/'GROUP NO.:        NO. RUNS:       SEA
     1 STATE:     '/
      DATA LABEL3/'T/H MAX:          ZH:           TAUENG:
     1            KP:        '/
      ENCODE (3,5,LBL2(12))JAY
      ENCODE (3,5,LBL2(29))KAY
      ENCODE (3,5,LBL2(46))ISE
    5 FORMAT (I3)

      ENCODE (4,10,LBL3(10))TH
      ENCODE (4,10,LBL3(23))ZH
      ENCODE (4,10,LBL3(40))ELC
      ENCODE (6,15,LBL3(54))KP

   10 FORMAT (F4.2)
   15 FORMAT (F6.4)
      CALL TIME(BUFF)
      CALL DATE(BUF)
      SPACE='   '


      ID=IDI-1
      CALL COMPRS
      CALL PAGE (11.,8.5)
      CALL XNAME ('T/H RATIO$',100)
C     CALL XNAME ('TIME (SEC)$',100)
      CALL YNAME ('PERCENT OF TIME$',100)
C     CALL YNAME ('HEIGHT (FT)$',100)
      CALL AREA2D (9.,5.75)
      CALL HEADIN ('T/H RATIO STATISTICS$',20,1.,4)
      CALL HEADIN (%REF(LABEL),20,0.7,4)
      CALL HEADIN (%REF(LABEL2),48,0.7,4)
      CALL HEADIN (%REF(LABEL3),59,0.7,4)
C     CALL HEADIN ('TIME HISTORY OF SHIP AND A/C MOTIONS$',35,1.,1)
      CALL THKFRM (0.01)
C     CALL GRAF (XI,2.,XF,-10.,5.,20.)
C  FOLLOWING GRAPH CALL IS FOR VPAIC.FOR
      CALL GRAF (XI,.02,XF,0.,.1,0.4)
      CALL GRID (1,1)
      CALL MARKER(16)
```

```
0058            CALL CURVE (X,Y,ID,1)
0059     C      CALL MARKER(6)
0060     C      CALL CURVE (X,R,ID,10)
0061            CALL ENDPL(0)
0062            CALL DONEPL
0063            PRINT*,'IDI=',IDI
0064            RETURN
0065            END



PROGRAM SECTIONS

   Name                             Bytes   Attributes

 0 $CODE                              548   PIC CON REL LCL   SHR   EXE   RD NOWRT LONG
 1 $PDATA                             141   PIC CON REL LCL   SHR NOEXE   RD NOWRT LONG
 2 $LOCAL                             528   PIC CON REL LCL NOSHR NOEXE   RD   WRT LONG

   Total Space Allocated             1217


ENTRY POINTS

   Address  Type  Name                  References

 0-00000000       PLOT2                     2


VARIABLES

   Address  Type  Name          Attributes  References

  2-00000038  CHAR BUF             EQUIV      5         12        35A
  2-00000047  CHAR BUFF            EQUIV      6         14        34A
 AP-0000002C@ R*4  ELC                        2         29
  2-00000080  I*4  ID                        39=        58A
 AP-00000018@ I*4  IDI                        2          3(3)     39         63

 AP-00000034@ I*4  ISE                        2         24
 AP-0000001C@ I*4  JAY                        2         22
 AP-00000020@ I*4  KAY                        2         23
 AP-00000030@ R*4  KP                         2          4        30
  2-0000004F  CHAR LABEL2          EQUIV      9         11        180        49A

  2-00000000  CHAR LABEL3          EQUIV     10         15        200        50A
  2-00000044  R*4  SPACE           EQUIV     13         36=
 AP-00000024@ R*4  TH                         2         27
 AP-00000014@ R*4  XF                         2         55A
 AP-00000010@ R*4  XI                         2         55A

 AP-00000028@ R*4  ZH                         2         28
```

```
PLOT2                                              2-Feb-1985 11:48:33   VAX-11 FORTRAN V3.5-62         Page  3
                                                  29-Jan-1985 18:09:55   FS00:[STEVENS.SHIPSTUFF]MPLT2.FOR;43

ARRAYS

   Address  Type Name          Attributes      Bytes  Dimensions      References

  2-0000A03B  CHAR LABEL           EQUIV         20  (20)              7        12        13        14        40A
  2-0000004F  CHAR LBL2            EQUIV         48  (48)              8        11        22        23        24
  2-00000080  CHAR LBL3            EQUIV         59  (59)              8        15        27        28        29
                                                                      30
 AP-0000008C@ R*4  R                             **  (*)               2         3
 AP-00000004@ R*4  X                             **  (*)               2         3        50A

 AP-0000000C@ R*4  Y                             **  (*)               2         3        50A

LABELS

   Address   Label                     References.

  1-00000082  5'                         22        23        24        25#
  1-00000085  10'                        27        28        29        [illegible]
  1-00000089  15'                        30        33#

FUNCTIONS AND SUBROUTINES REFERENCED

  Type  Name                           References

        AREA2D                           46
        COMPRS                           40
        CURVE                            58
        DONEPL                           62
        ENDPL                            61

        FOR$DATE_T_DS                    35
        FOR$TIME_T_DS                    34
        GRAF                             55
        GRID                             56
        HEADIN                           47        48        49        50

        MARKER                           57
        PAGE                             41
        THKFRM                           52
        XNAME                            42
        YNAME                            44


  +------------------------------------------------+
  |           KEY TO REFERENCE FLAGS               |
  |   *   - Value Modified                         |
  |   #   - Defining Reference                     |
  |   A   - Actual Argument, possibly modified     |
  |   D   - Data Initialization                    |
  |  (n)  - Number of occurrences on line          |
  +------------------------------------------------+
```

C-3

```
PLOT2                                              2-Feb-1985 11:48:38    VAX-11 FORTRAN V3.5-62               Page   4
                                                   29-Jan-1985 18:00:55   FSC0:[STEVENS.SHIPSTUFF]MPLT2.FOR;43

COMMAND QUALIFIERS

  FORTRAN /LIS/CRO MPLT2.FOR

  /CHECK=(NOBOUNDS,OVERFLOW,NOUNDERFLOW)
  /DEBUG=(NOSYMBOLS,TRACEBACK)
  /STANDARD=(NOSYNTAX,NOSOURCE_FORM)
  /SHOW=(NOPREPROCESSOR,NOINCLUDE,MAP)
  /F77  /NOG_FLOATING  /I4  /OPTIMIZE  /WARNINGS  /NOD_LINES  /CROSS_REFERENCE  /NOMACHINE_CODE  /CONTINUATIONS=19


COMPILATION STATISTICS

  Run Time:          2.67 seconds
  Elapsed Time:      3.45 seconds
  Page Faults:       145
  Dynamic Memory:    125 pages
```

```
********************************    2-FEB-1985 11:52:08.88    FSD0:[STEVENS.SHIPSTUFF]PLOT3.LIS;1    ********************************
********************************    2-FEB-1985 11:52:08.88    FSD0:[STEVENS.SHIPSTUFF]PLOT3.LIS;1    ********************************
********************************    2-FEB-1985 11:52:08.88    FSD0:[STEVENS.SHIPSTUFF]PLOT3.LIS;1    ********************************
```

```
PLOT3.LIS;1
```

```
********************************    2-FEB-1985 11:52:08.88    FSD0:[STEVENS.SHIPSTUFF]PLOT3.LIS;1    ********************************
********************************    2-FEB-1985 11:52:08.88    FSD0:[STEVENS.SHIPSTUFF]PLOT3.LIS;1    ********************************
********************************    2-FEB-1985 11:52:08.88    FSD0:[STEVENS.SHIPSTUFF]PLOT3.LIS;1    ********************************
```

```
                                                  2-Feb-1985 11:48:25    VAX-11 FORTRAN V3.5-62              Page   1
                                                  3-Jan-1985 15:22:46    FSD0:[STEVENS.SHIPSTUFF]PLOT3.FOR;3

C234567890123456789...etc.
      SUBROUTINE PLOT3(X,Y,R,S,U,XI,XF,IDI)
      DIMENSION S(IDI),U(IDI),X(IDI),Y(IDI),R(IDI)

      ID=IDI
      CALL COMPRS
      CALL PAGE (11.,8.5)
      CALL XNAME ('NUMBER OF RUNS$',100)
      CALL YNAME ('MAGNITUDES$',100)
      CALL AREA2D (9.,5.75)
      CALL HEADIN ('STATISTICAL TRENDS IN V.A.S. SIMULATIONS$',40,1.,1)
      CALL THKFRM (0.01)
C     CALL GRAF (XI,25.,XF,-0.5,.2,3.5)
      CALL GRAF (XI,25.,XF,0.,5.,25.)
      CALL GRID (1,1)
      CALL MARKER(18)
      CALL CURVE (X,Y,ID,100)
      CALL MARKER(17)
      CALL CURVE (X,R,ID,100)
      CALL MARKER(15)
      CALL CURVE (X,S,ID,125)
      CALL MARKER(16)
      CALL CURVE (X,U,ID,125)
      CALL ENDPL(0)
      CALL DONEPL
      PRINT*,'IDI=',IDI
      CLOSE(3)
      RETURN
      END
```

```
PLOT3                                               2-Feb-1985 11:48:25    VAX-11 FORTRAN V3.5-62         Page  2
                                                    3-Jan-1985 15:22:46    FS00:[STEVENS.SHIPSTUFF]PLOT3.FOR;3

PROGRAM SECTIONS

    Name                                 Bytes  Attributes

  0 $CODE                                  394  PIC CON REL LCL   SHR   EXE   RD NOWRT LONG
  1 $PDATA                                 145  PIC CON REL LCL   SHR NOEXE   RD NOWRT LONG
  2 $LOCAL                                 440  PIC CON REL LCL NOSHR NOEXE   RD   WRT LONG

    Total Space Allocated                  979


ENTRY POINTS

    Address   Type  Name                      References

  0-00000000        PLOT3                        2


VARIABLES

    Address   Type  Name         Attributes  References

  2-00000000  I*4   ID                           5=        17A        19A        21A        23A
 AP-00000020@ I*4   IDI                          2          3(5)      5          26
 AP-0000001C@ R*4   XF                           2         14A
 AP-00000018@ R*4   XI                           2         14A


ARRAYS

    Address   Type  Name         Attributes         Bytes  Dimensions        References

 AP-0000000C@ R*4   R                                  **  (*)                  2          3          19A
 AP-00000010@ R*4   S                                  **  (*)                  2          3          21A
 AP-00000014@ R*4   U                                  **  (*)                  2          3          23A
 AP-00000004@ R*4   X                                  **  (*)                  2          3          17A        19A        21A
                                                                                23A
 AP-00000008@ R*4   Y                                  **  (*)                  2          3          17A


FUNCTIONS AND SUBROUTINES REFERENCED

  Type  Name                              References

        AREA2D                               10
        COMPRS                               6
        CURVE                                17         19         21         23
        DONEPL                               25
        ENDPL                                24

        FOR$CLOSE                            27
        GRAF                                 14
        GRID                                 15
        HEADIN                               11
        MARKER                               16         18         20         22
```

```
      PAGE                                  7
      THKFRM                               12
      XNAME                                 8
      YNAME                                 9

  +-----------------------------------------+
  |             KEY TO REFERENCE FLAGS      |
  |   *    - Value Modified                 |
  |   #    - Defining Reference             |
  |   A    - Actual Argument, possibly modified |
  |   D    - Data Initialization            |
  |  (n)   - Number of occurrences on line  |
  +-----------------------------------------+


COMMAND QUALIFIERS

  FORTRAN /LIS/CRO PLOT3.FOR

  /CHECK=(NOBOUNDS,OVERFLOW,NOUNDERFLOW)
  /DEBUG=(NOSYMBOLS,TRACEBACK)
  /STANDARD=(NOSYNTAX,NOSOURCE_FORM)
  /SHOW=(NOPREPROCESSOR,NOINCLUDE,MAP)
  /F77  /NOG_FLOATING  /I4  /OPTIMIZE  /WARNINGS  /NOD_LINES  /CROSS_REFERENCE  /NOMACHINE_CODE  /CONTINUATIONS=19


COMPILATION STATISTICS

  Run Time:          1.83 seconds
  Elapsed Time:      2.58 seconds
  Page Faults:       128
  Dynamic Memory:    124 pages
```

```
****************************
*                          *
*    VIII. APPENDIX  B     *
*                          *
****************************
```

A. TEST VARIABLES

The following table gives a listing of the variables used in the test matrix.

Table B1: Fixed-Base Simulation Computer Variables and Related Variables and Values

LIST OF VARIABLES USED IN FIXED-BASE SIMULATION

TEST VARIABLES

Sea State	0, 4, 6	
HUD	1, 3	
T/W	1.1, 1.07, 1.05, 1.03, 1.01	
Damping	0.0, -0.2, -0.4	sec^{-1}
Engine Lag	0.3, 0.7	sec

ITEM	RELATED ITEMS		COMPUTER VARIABLE	
Engine Lag				
τ_{eng} (sec)			TAUENG (sec)	
0.3			0.3	
0.7			0.7	
Vertical Velocity Damping				
Z_w (sec^{-1})	τ (sec)	A/C GAIN (ft/sec^2)/°PLA	GHDOT °PLA/(ft/sec)	
0.0	-	≈ 0.45	0.0	
-0.2	5.0	≈ 0.45	0.43	
-0.4	2.5	≈ 0.45	0.87	
THRUST/WEIGHT			WAIT* (lb)	
T/W			S.S.0	S.S.4-6
1.00			18974	18739
1.01			18786	18554
1.03			18422	18193
1.05			18071	17847
1.07			17733	17513
1.10			17249	17036

* Different weights are used, due to the changing mean wind as a function of sea state, in order to eliminate the effects of the aerodynamic forces.

The mean aerodynamic force for a given sea state was determined by:

$$FAZN = \frac{WAIT}{HKTW} - FGS \qquad \text{(B1)}$$

Where:
FAZN - Mean aerodynamic force
WAIT - Aircraft weight
HKTW - Scale factor
FGS - Gross thrust

The following table shows the values used for the above variables as a function of sea state.

Table B2: Variable Values Used in Correcting for the Mean Aerodynamic Forces

TRIM FOR T/W = 1.0				
Sea State	HKTW	WAIT	FGS	FAZN
0	0.99046	17036	17530.3	-330.25
4	0.99046	17036	17363.3	-163.23
5	0.98734	17249	17509.7	- 39.48

B. HUD DYNAMICS

The following equations describe the hover point dynamics used in the HUD system:

$$e_x = (\text{s.f.})\, K_{pos}(X_{position}) - K_{vel}[(\tau_h \hat{\ddot{X}} + V_x) + K_\delta \delta_{long\ stick}] \qquad \text{(B2)}$$

(Expressions for e_y are similar to those for e_x.)

Where:
s.f. = Scale factor
$K_\delta = 1.0$
$K_{pos} = 1°/17$ ft
X = True X position

$K_{vel} = 0.29°/(ft/sec)$

$\tau_h = 1.1$ sec

V_x = True longitudinal velocity

(B3)

$$\hat{\ddot{X}} = \frac{\tau_1 \hat{\ddot{X}}_1 + \ddot{X}}{(\tau_1 s + 1)} \qquad \hat{\ddot{X}}_1 = \frac{-g\ \tau_2 s \theta}{(\tau_2 s + 1)}$$

(B4)

Where:

$\ddot{X}$ = True longitudinal acceleration

$\hat{\ddot{X}}$ = Estimated true acceleration

$\hat{\ddot{X}}_1$ = Estimate of high frequency acceleration

Figure B1 shows a graphical definition of the error e_x and e_y.

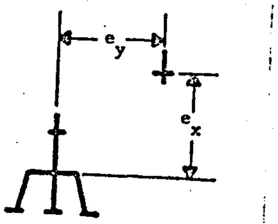


Figure B1: HUD Hover Point Dynamics

C. DATA OUTPUT OF THE PILOTED SIMULATION

Figure B2 is an example of the output data from the fixed-base simulation. Information used includes the following:

Page 1 - All of the title information
Page 2 - Start and stop times, and T/W information
Page 3 - Maximum gear z velocity, and the position error when the side task (attitude command system) was being flown.

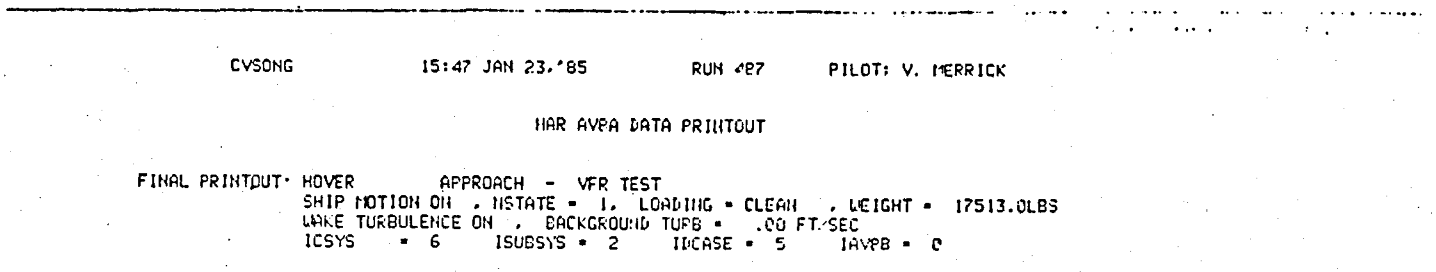
NOTE:

Since the simulation was primarily concerned with the vertical axis, the highest main gear, designated N (nose) or T (tail), z velocity was used, and the outrigger readings were ignored.

D. PILOTS

Pilot A - Vernon K. Merrick

Pilot B - Glenn G. Ferris



```
          CVSONG            15:47 JAN 23,'85          RUN 407      PILOT: V. MERRICK

                                          NAR AVRA DATA PRINTOUT

    FINAL PRINTOUT: HOVER        APPROACH  -  VFR TEST
                    SHIP MOTION ON  , NSTATE =  1.  LOADING = CLEAN   , WEIGHT =  17513.0LBS
                    WAKE TURBULENCE ON  ,  BACKGROUND TURB =   .00 FT/SEC
                    ICSYS    =  6     ISUBSYS =  2     IDCASE =  5     IAVRB =  0
```

Figure B2: Example Data Output from the Piloted Simulation

```
 PHASE III: VERTICAL DESCENT

TIME:   START AT     .00     END AT   28.41     DURATION OF   28.48 SECS
                                                                    ALTITUDE    AIRSPEED    ALTITUDE    AIRSPEED
  DESCRIPTION     UNITS     MEAN       STD DEV       MIN         MAX       (FT)  MIN   (F/S) MIN   (FT)  MAX   (F/S) MAX
  -----------     -----     ----       -------       ---         ---       ---------   ---------   ---------   ---------
HORZ VEL          F/S    -.7796E-03  .3918E-01  -.1804E 00   .1610E 00   .5714E 02   .4495E 02   .4174E 02   .6019E 02
VERT VEL          F/S    -.1504E 01  .1062E 01  -.3493E 01   .1156E 01   .5998E 02   .3164E 02   .5063E 02   .5010E 02

X PILOT ACCEL.    G        .1129E 00  .8118E-02   .6923E-01   .1404E 00   .5759E 02   .5253E 02   .5714E 02   .4495E 02
Y PILOT ACCEL.    G        .1564E-02  .2276E-01  -.5983E-01   .6765E-01   .4520E 02   .5545E 02   .4302E 02   .4685E 02
Z PILOT ACCEL.    G       -.9910E 00  .4844E-01  -.1121E 01  -.7716E 00   .5024E 02   .5347E 02    4009E 02   .4264E 02

PC DEFLECTION     %        .2271E 02  .3267E 01   .1165E 02   .3462E 02   .5976E 02   .3872E 02   .4044E 02   .2862E 02
RC DEFLECTION     %        .1550E 00  .1254E 02  -.4679E 02   .5191E 02   .4288E 02   .5027E 02   .4491E 02   .5700E 02
YC DEFLECTION     %        .1869E 01  .1269E 02  -.3888E 02   .3736E 02   .5549E 02   .3838E 02   .5141E 02   .3816E 02

PC AERO           R/S2     .5195E-01  .2010E-01   .1502E-01   .1916E 00   .4920E 02   .3896E 02   .5759E 02   .5253E 02
RC AERO           R/S2    -.2091E-04  .1798E-01  -.8363E-01   .8653E-01   .5774E 02   .7114E 02   .4491E 02   .5700E 02
YC AERO           R/S2    -.3597E-03  .1945E-02  -.6397E-02   .1091E-01   .5125E 02   .4266E 02   .5759E 02   .5253E 02
PC ENGINE         R/S2    -.1028E 00  .3505E-01  -.2171E 00   .5191E-01   .4043E 02   .4220E 02   .5954E 02   .5074E 02
RC ENGINE         R/S2     .4820E-02  .2571E 00  -.7964E 00   .8099E 00   .4274E 02   .3900E 02   .4476E 02   .4795E 02
YC ENGINE         R/S2    -.7042E-02  .4638E-01  -.1639E 00   .1750E 00   .5140E 02   .4220E 02   .5544E 02   .3437E 02

TOT ENGINE BLEED  LB/S     .3948E 01  .1894E 01   .7099E 00   .1214E 02   .5042E 02   .2957E 02   .5141E 02   .3016E 02

RPM               PCT      .1002E 03  .1180E 01   .9157E 02   .1025E 03   .3994E 02   .4476E 02   .4038E 02   .4506E 02

T/W                        .9334E 00  .3284E-01   .7396E 00   .1048E 01   .3994E 02   .4476E 02   .4038E 02   .5147E 02

NOZZLE ANGLE      DEG      .7887E 02  .3578E 00   .7738E 02   .8002E 02   .5714E 02   .4495E 02   .4174E 02   .6013E 02

THETA             DEG      .6500E 01  .3220E-01   .6428E 01   .6610E 01   .4053E 02   .4128E 02   .4044E 02   .2862E 02
PHI               DEG     -.9468E-01  .6865E 00  -.1634E 01   .1869E 01   .4491E 02   .5700E 02   .4797E 02   .4262E 02

FLAP DEFL         DEG      .5008E 02  .5840E-06   .5000E 02   .5000E 02   .8250E 02   .4330E 02   .8250E 02   .4330E 02

T/W                          .00        .18         .34         .48         .60         .70         .79         .84
TIME ABOVE T/W    SEC      .2835E 02  .2835E 02   .2835E 02   .2835E 02   .2835E 02   .2835E 02   .2822E 02   .2803E 02
T/W                          .88        .90         .92         .94         .96         .97         .98         .99
TIME ABOVE T/W    SEC      .2790E 02  .2784E 02   .2778E 02   .2745E 02   .2592E 02   .2035E 02   .1440E 02   .9856E 01
T/W                         1.00       1.01        1.02        1.03        1.04        1.06        1.08        1.10
TIME ABOVE T/W    SEC      .6400E 01  .4864E 01   .3264E 01   .2112E 01   .7680E 00   .0000E 00   .0000E 00   .0000E 00

RELATIVE DESCENT RATE
    TO DECK       F/S      .1532E 01  .6356E 01  -.9101E 02   .1193E 02   .8250E 02   .4618E 02   .6275E 02   .3849E 02
    TO SEA LEVEL  F/S      .1504E 01  .1062E 01  -.1156E 01   .3493E 01   .5063E 02   .5010E 02   .5993E 02   .3164E 02

WATER USED =    .0 LBS.   FUEL USED =  113.3 LBS.   WEIGHT =  17399.1LBS
```

Figure B2, continued: Example Data Output from the Piloted Simulation

```
TOUCHDOWN          AT TIME =   20.41

  VEL - DECK AXES       POSITION ERROR        A/C ATTITUDE            SHIP ATTITUDE          SHIP VELOCITY
  ---------------       --------------        ------------            -------------          -------------
  X=  .2745E 00 F/S     X=  .4945E 00 FT     PHI=  .1144E 01 DEG     PHI=  .2706E 01 DEG    X=  .2107E 02 F/S
  Y=  .2459E-02         Y= -.3932E 01        THT=  .6660E 01         THT=  .6857E 00        Y=  .1127E 02
  Z=  .1971E 01      DIST=  .3963E 01        PSI= -.3013E 02         PSI=  .4500E 00        Z= -.3444E 02

  MAX OLEO FORCES       ATTITUDE-REL. DECK      MAX GEAR X VEL.         MAX GEAR Y VEL.        MAX GEAR Z VEL
  ---------------       ------------------      ---------------         ---------------        ---------------
  N=  .7701E 04 LBS     PHI= -.9319E 00 DEG     N=  .3067E 00 F/S       N=  .1103E 01 F/S      N=  .3567E 01 F/S
  R=  .1653E 04         THT=  .4635E 01         R=  .2202E 00           R=  .8154E 00          R=  .62[illegible]E 01
  L=  .1864E 03         PSI= -.3074E 02         L=  .1159E 00           L=  .8154E 00          L=  .2[illegible]E 01
  T=  .1115E 05                                 T=  .2280E 00           T=  .9976E 00          T=  .4153E 01

THE MINIMUM MISS DISTANCE WAS LOMY EQUAL TO  11.4 FT.
```

Figure B2, continued: Example Data Output from the Piloted Simulation

E. LISTING OF PILOTED SIMULATION RUNS AND RESULTS

PILOTED SIMULATION TEST MATRIX

T/W = 1.10

Z_w \ τ_{eng}	0.3	0.7
0.0	○ 5-B △ 5-B □ 5-A, 10-B ○ 5-B ◇ 10-B	○ 5-B △ 5-B □ 5-A, 10-B ○ 5-B ◇ 5-B
-0.2	○ 5-B △ 5-B □ 5-A, 10-B ○ 5-B ◇ 10-B	○ 5-B △ 5-B □ 5-A, 10-B ○ 6-B ◇ 5-B
-0.4	○ 5-B △ 5-B □ 5-A, 10-B ○ 5-B ◇ 10-B	○ 5-B △ 5-B □ 5-A, 10-B ○ 5-B ◇ 5-B

T/W = 1.07

Z_w \ τ_{eng}	0.3	0.7
0.0	△ 5-B □ 5-A, 10-B ○ 5-A, 5-B	△ 5-B □ 5-A, 5-B ○ 5-A, 5-B
-0.2	△ 5-B □ 5-A, 10-B ○ 5-A, 5-B	△ 5-B □ 5-A, 5-B ○ 5-A, 5-B
-0.4	△ 5-B □ 5-A, 5-B ○ 5-A, 5-B	△ 5-B □ 5-A, 5-B ○ 5-A, 5-B

T/W = 1.05

Z_w \ τ_{eng}	0.3	0.7
0.0	○ 6-B △ 5-B □ 5-A, 5-B ○ 5-B ◇ 5-B	○ 5-B △ 5-B □ 5-A, 5-B ○ 5-B ◇ 5-B
-0.2	○ 5-B △ 5-B □ 5-A, 5-B ○ 5-B ◇ 5-B	○ 5-B △ 5-B □ 5-A, 5-B ○ 5-B ◇ 4-B
-0.4	○ 5-B △ 5-B □ 6-A, 5-B ○ 5-B ◇ 5-B	○ 5-B △ 5-B □ 5-A, 5-B ○ 5-B ◇ 5-B

T/W = 1.03

Z_w \ τ_{eng}	0.3	0.7
0.0	△ 5-B □ 15-A, 10-B ○ 6-B	△ 5-B □ 11-A, 10-B ○ 5-B
-0.2	△ 5-B □ 15-A, 15-B ○ 5-A, 10-B	△ 5-B □ 15-A, 15-B ○ 5-A, 10-B
-0.4	△ 5-B □ 15-A, 10-B ○ 5-B	△ 5-B □ 10-A, 10-B ○ 5-B

T/W = 1.01

Z_w \ τ_{eng}	0.3	0.7
0.0	○ 5-B △ 5-B □ 5-A, 5-B ○ 5-A, 5-B ◇ 5-B	○ 5-B △ 5-B □ 5-A, 5-B ○ 5-A, 5-B ◇ 5-B
-0.2	○ 5-B △ 5-B □ 5-A, 5-B ○ 5-A, 5-B ◇ 5-B	○ 5-B △ 5-B □ 6-A, 6-B ○ 5-A, 5-B ◇ 5-B
-0.4	○ 5-B △ 5-B □ 5-A, 5-B ○ 4-A, 5-B ◇ 5-B	○ 5-B △ 5-B □ 5-A, 5-B ○ 5-A, 5-B ◇ 5-B

○	n-ℓ	S.S.0	HUD3	V.C.
△	n-ℓ	S.S.4	HUD3	V.C.
□	n-ℓ	S.S.6	HUD3	V.C.
○	n-ℓ	S.S.6	HUD1	V.C.
◇	n-ℓ	S.S.6	HUD3	A.C.

n- Number of runs
ℓ- Pilot

Figure B3: Piloted Simulation Test Matrix

PILOTED SIMULATION RUN LISTING

τ_{eng} - (sec)
Z_w - (sec^{-1})
$\overline{T.D.}_{vel}$ - (ft/sec)
$\overline{\text{Flight Time}}$ - (sec)

SEA STATE 0
HUD3
VELOCITY COMMAND SYSTEM

T/W_{max}	τ_{eng}	Z_w	Pilot	Run No.s	$\overline{T.D.}_{vel}$	$\overline{\text{FLIGHT TIME}}$	P.R.
1.01	0.3	0.0	B	916-920	1.87	26.0	3
"	"	0.2	"	911-915	1.70	22.9	2
"	"	0.4	"	906-910	2.17	25.0	1 1/2
"	0.7	0.0	"	891-895	3.15	20.2	3 1/2
"	"	0.2	"	896-905	1.42	27.8	2 1/2
"	"	0.4	"	901-905	1.58	31.5	1 1/2
1.05	0.3	0.0	"	921-925	2.04	23.3	3
"	"	0.2	"	926-930	1.61	21.6	2
"	"	0.4	"	931-935	1.36	28.0	1
"	0.7	0.0	"	946-950	2.04	17.5	3 1/2
"	"	0.2	"	941-945	1.14	28.4	2 1/2
"	"	0.4	"	936-940	1.57	28.0	1 1/2
1.10	0.3	0.0	"	976-980	1.95	15.1	3
"	"	0.2	"	971-975	1.26	23.8	1 1/2
"	"	0.4	"	966-970	0.68	42.1	1
"	0.7	0.0	"	951-955	1.49	24.2	3 1/2
"	"	0.2	"	956-960	1.29	33.2	3
"	"	0.4	"	961-965	1.21	28.4	2

SEA STATE 4
HUD3
VELOCITY COMMAND SYSTEM

T/W_{max}	τ_{eng}	Z_w	Pilot	Run No.s	$\overline{T.D.}_{vel}$	$\overline{\text{FLIGHT TIME}}$	P.R.
1.01	0.3	0.0	"	861-865	2.9	26.1	4 1/2
"	"	0.2	"	866-870	4.0	23.2	3 1/2
"	"	0.4	"	871-875	2.8	30.0	3
"	0.7	0.0	"	886-890	3.5	27.2	6
"	"	0.2	"	881-885	3.7	24.1	5
"	"	0.4	"	876-880	3.4	33.1	4
1.03	0.3	0.0	"	856-860	3.0	27.7	3 1/2
"	"	0.2	"	851-855	2.3	24.0	3 1/2
"	"	0.4	"	846-850	1.9	20.1	2 1/2
"	0.7	0.0	"	831-835	3.9	17.2	4 1/2
"	"	0.2	"	836-840	2.8	19.7	3 1/2
"	"	0.4	"	841-845	3.5	23.0	3 1/2
1.05	0.3	0.0	"	801-805	4.6	14.7	3 1/2
"	"	0.2	"	806-810	3.4	17.0	3 1/2
"	"	0.4	"	811-815	5.3	23.3	4
"	0.7	0.0	"	826-830	5.4	17.3	5
"	"	0.2	"	821-825	4.0	27.7	4 1/2
"	"	0.4	"	816-820	3.7	21.9	4

PILOTED SIMULATION RUN LISTING Cont.

SEA STATE 4 Cont.
HUD3
VELOCITY COMMAND SYSTEM

T/W_{max}	τ_{eng}	Z_w	Pilot	Run No.s	$\overline{T.D.}_{vel}$	$\overline{\text{FLIGHT}}$ TIME	P.R.
1.07	0.3	0.0	B	796-800	2.8	15.9	3
"	"	0.2	"	786-790	2.8	17.3	3
"	"	0.4	"	791-795	3.0	20.9	2 1/2
"	0.7	0.0	"	771-775	4.2	21.3	5
"	"	0.2	"	776-780	3.7	20.5	4
"	"	0.4	"	781-785	4.4	21.2	4
1.10	0.3	0.0	"	741-745	3.5	14.7	4
"	"	0.2	"	746-759	3.5	18.3	3
"	"	0.4	"	751-755	3.5	21.3	1 1/2
"	0.7	0.0	"	766-770	3.6	18.6	4
"	"	0.2	"	761-765	4.0	22.3	3
"	"	0.4	"	756-760	3.7	22.6	2

SEA STATE 6
HUD1
VELOCITY COMMAND SYSTEM

1.01	0.3	0.0	A	506-510	8.0	26.2	7
"	"	"	B	616-620	11.6	26.0	10
"	"	0.2	A	511-515	6.6	29.3	6 1/2
"	"	"	B	611-615	9.4	22.7	7 1/2
"	"	0.4	A	431-435	6.2	39.0	5
"	"	"	B	606-610	6.9	31.0	7
"	0.7	0.0	A	526-530	6.5	24.9	7
"	"	"	B	591-595	7.2	18.2	8 1/2
"	"	0.2	A	521-525	8.6	25.1	6 3/4
"	"	"	B	596-600	9.1	15.4	8 1/2
"	"	0.4	A	516-520	5.3	29.0	5 1/2
"	"	"	B	601-605	7.9	24.5	8 1/2
1.03	0.3	0.0	B	561-565B	9.3	15.4	8
"	"	0.2	A	411-415	6.2	23.0	5
"	"	"	B	416-420	8.1	24.1	5
"	"	"	"	566-570	8.7	18.9	7 1/2
"	"	0.4	"	571-575	6.7	29.9	7
"	0.7	0.0	"	586-590	9.6	25.9	8 1/2
"	"	0.2	"	421-415	8.6	20.5	5 1/2
"	"	"	A	426-430	9.1	20.9	6
"	"	"	B	581-585	9.5	17.7	8
"	"	0.4	"	576-580	7.2	16.7	7

PILOTED SIMULATION RUN LISTING Cont.

SEA STATE 6 Cont.
HUD3
VELOCITY COMMAND SYSTEM

T/W_{max}	τ_{eng}	Z_w	Pilot	Run No.s	$\overline{T.D.}_{vel}$	$\overline{\text{Flight}}$ Time	P.R.
1.05	0.3	0.0	B	621-625	6.2	30.0	6
"	"	0.2	"	626-630	7.8	32.3	6
"	"	0.4	"	631-635	7.0	34.3	5 1/2
"	0.7	0.0	"	636-640	6.4	22.7	6
"	"	0.2	"	641-645	9.2	39.8	7
"	"	0.4	"	646-650	7.2	24.1	7
1.07	0.3	0.0	A	501-505	8.2	27.9	6
"	"	"	B	661-665	10.0	16.8	7
"	"	0.2	A	496-500	8.2	21.2	5 1/4
"	"	"	B	656-660	4.5	28.7	3 1/2
"	"	0.4	A	491-495	5.5	32.5	4 3/4
"	"	"	B	651-655	5.3	22.5	3 1/2
"	0.7	0.0	A	476-480	6.2	20.5	5 1/2
"	"	"	B	666-670	8.1	13.1	7
"	"	0.2	A	481-485	7.2	17.0	5 1/2
"	"	"	B	671-675	8.1	20.4	6
"	"	0.4	A	486-490	5.3	23.0	5
"	"	"	B	676-680	7.9	34.5	6
1.10	0.3	0.0	B	696-700	7.6	19.1	7
"	"	0.2	"	701-705	7.0	35.4	5 1/2
"	"	0.4	"	706-710	5.7	38.1	4
"	0.7	0.0	"	691-695	10.2	22.3	7 1/2
"	"	0.2	"	686-690	7.1	43.4	6 1/2
"	"	0.4	"	681-685	7.3	43.8	5

SEA STATE 6
HUD3
VELOCITY COMMAND SYSTEM

1.01	0.3	0.0	A	156-160	6.1	33.3	5
"	"	"	B	186-190	6.5	24.2	6 1/2
"	"	0.2	A	151-155	5.7	34.1	4 1/2
"	"	"	B	181-185	8.5	34.9	6 1/2
"	"	0.4	A	146-150	5.6	31.2	4 1/4
"	"	"	B	176-180	9.4	18.3	5 1/2
"	0.7	0.0	A	171-175	6.7	28.5	5
"	"	"	B	201-205	6.4	35.4	6 1/2
"	"	0.2	A	166-170	6.5	26.1	5
"	"	"	B	196-200	7.9	29.6	7
"	"	0.4	A	161-165	7.7	34.2	5 1/2
"	"	"	B	191-195	6.7	38.6	5 1/2

PILOTED SIMULATION RUN LISTING Cont.

SEA STATE 6 Cont.
HUD3
VELOCITY COMMAND SYSTEM

T/W_{max}	τ_{eng}	Z_w	Pilot	Run No.s	$\overline{T.D.}_{vel}$	$\overline{\text{Flight}}$ Time	P.R.
1.03	0.3	0.0	A	96-100	7.0	37.7	4 1/2
"	"	"	"	131-135	7.1	28.7	5
"	"	"	"	271-275	6.7	22.0	5
"	"	"	B	291-295	5.5	21.2	5 1/2
"	"	"	"	556-560	6.0	23.8	5
"	"	0.2	A	91-95	6.6	32.3	4 1/4
"	"	"	"	136-140	4.2	32.2	4 1/2
"	"	"	B	286-290	6.5	26.6	5
"	"	"	A	401-405	6.5	33.1	5 1/4
"	"	"	B	406-410	5.3	44.0	5
"	"	"	"	551-555	5.1	19.1	6
"	"	0.4	A	86-90	7.4	38.3	4 1/2
"	"	"	"	141-145	6.5	24.5	4 1/4
"	"	"	"	266-270	7.1	42.4	5 1/4
"	"	"	B	281-285	5.4	26.8	4 1/2
"	"	"	"	546-550	7.5	29.8	6 1/2
"	0.7	0.0	A	111-115	6.5	38.9	4 3/4
"	"	"	"	116-120	6.3	37.1	4 3/4
"	"	"	B	306-310	7.2	17.1	6 1/2
"	"	"	"	531-535	7.6	23.3	7
"	"	0.2	A	106-110	8.0	36.7	4 3/4
"	"	"	"	121-125	6.3	25.6	4 1/2
"	"	"	"	276-280	7.7	22.6	5 1/2
"	"	"	B	301-305	5.2	19.9	5 1/2
"	"	"	"	536-540	4.7	24.5	5 1/2
"	"	"	A	101-105	8.1	35.8	4 1/2
"	"	"	"	126-130	7.1	33.7	4 1/2
"	"	"	B	296-300	5.8	24.6	5 1/2
"	"	"	"	541-545	4.9	25.7	5
1.05	0.3	0.0	A	216-220	8.9	24.2	5 1/2
"	"	"	B	251-255	7.0	30.7	5
"	"	0.2	A	211-215	4.4	26.6	4 1/2
"	"	"	B	256-260	5.5	33.6	5
"	"	0.4	A	206-210	6.6	27.7	5
"	"	"	B	261-265	7.1	42.4	4 1/2
"	0.7	0.0	A	221-225	7.1	31.5	5 1/2
"	"	"	B	246-250	5.0	44.5	6 1/2
"	"	0.2	A	226-230	7.0	38.3	5
"	"	"	B	241-245	8.0	37.2	6 1/2
"	"	0.4	A	231-235	6.5	30.9	5
"	"	"	B	236-240	9.8	39.9	6 1/2

PILOTED SIMULATION RUN LISTING Cont.

SEA STATE 6 Cont.
HUD3
VELOCITY COMMAND SYSTEM

T/W_{max}	τ_{eng}	Z_w	Pilot	Run No.s	$\overline{T.D.}_{vel}$	$\overline{\text{Flight}}$ Time	P.R.
1.05	0.3	0.0	A	216-220	8.9	24.2	5 1/2
"	"	"	B	251-255	7.0	30.7	5
"	"	0.2	A	211-215	4.4	26.6	4 1/2
"	"	"	B	256-260	5.5	33.6	5
"	"	0.4	A	206-210	6.6	27.7	5
"	"	"	B	261-265	7.1	42.4	4 1/2
"	0.7	0.0	A	221-225	7.0	31.5	5 1/2
"	"	"	B	246-250	5.0	44.5	6 1/2
"	"	0.2	A	226-230	7.0	38.3	5
"	"	"	B	241-245	8.0	37.2	6 1/2
"	"	0.4	A	231-235	6.5	30.9	5
"	"	"	B	236-240	9.8	39.9	6 1/2
1.07	0.3	0.0	B	386-390	5.0	24.7	4 1/2
"	"	"	"	436-440	5.8	29.5	4 1/2
"	"	"	A	446-450	5.9	25.2	5 1/4
"	"	0.2	B	391-395	7.8	22.2	4
"	"	"	"	441-445	6.1	26.7	3 1/2
"	"	"	A	451-455	5.9	31.3	5
"	"	0.4	B	396-400	5.5	26.2	3 1/2
"	"	"	A	456-460	6.0	30.3	4 1/2
"	0.7	0.0	B	381-385	7.4	23.5	5 1/2
"	"	"	A	471-475	5.4	39.9	6
"	"	0.2	B	376-380	7.0	27.7	4 1/2
"	"	"	A	466-470	7.4	35.6	5 1/2
"	"	0.4	B	371-375	7.1	24.7	4 1/2
"	"	"	A	461-465	5.7	35.4	4 3/4
1.10	0.3	0.0	B	321-325	6.7	33.2	3 1/2
"	"	"	A	356-360	5.3	32.5	3 3/4
"	"	"	B	721-725	5.2	26.9	4
"	"	0.2	"	316-320	5.3	25.8	3
"	"	"	A	361-365	5.9	29.3	4
"	"	"	B	716-720	4.5	52.1	3 1/2
"	"	0.4	"	311-315	8.2	40.2	3
"	"	"	A	366-370	6.2	26.2	4
"	"	"	B	711-715	4.7	53.9	2 1/2
"	0.7	0.0	"	336-340	6.9	32.6	5
"	"	"	A	351-355	6.9	34.4	4 1/2
"	"	"	B	726-730	5.6	39.0	4 1/2
"	"	0.2	"	331-335	4.4	29.2	3
"	"	"	A	346-350	6.1	35.0	4
"	"	"	B	731-735	5.4	22.3	4
"	"	0.4	"	326-330	6.4	40.1	3
"	"	"	A	341-345	5.2	48.9	4
"	"	"	B	736-740	5.0	33.7	5 1/2

PILOTED SIMULATION RUN LISTING Cont.

SEA STATE 6
HUD3
ATTITUDE COMMAND SYSTEM

T/W_{max}	τ_{eng}	Z_w	Pilot	Run No.s	$\overline{T.D.}_{vel}$	$\overline{\text{Flight}}$ Time	P.R.
1.01	0.3	0.0	B	1051-1055	8.7	36.9	8
"	"	0.2	"	1046-1050	5.7	30.0	7
"	"	0.4	"	1041-1045	6.6	29.6	6
"	0.7	0.0	"	1056-1060	6.3	25.3	8
"	"	0.2	"	1061-1065	5.9	35.3	6 1/2
"	"	0.4	"	1066-1070	6.9	39.6	6
1.05	0.3	0.0	"	1026-1030	9.5	24.8	8
"	"	0.2	"	1031-1035	7.5	29.6	6 1/2
"	"	0.4	"	1036-1040	4.8	35.9	5 1/2
"	0.7	0.0	"	1021-1025	8.7	27.9	8
"	"	0.2	"	1016-1020	9.9	22.2	7
"	"	0.4	"	1011-1015	6.3	27.3	6
1.10	0.3	0.0	"	1081-1085	5.0	33.4	5
"	"	0.2	"	1076-1080	6.8	34.8	5
"	"	0.0	"	1071-1075	5.4	49.2	4 1/2
"	0.7	0.0	"	996-1000	7.3	23.0	7 1/2
"	"	0.2	"	1001-1005	6.7	31.6	6 1/2
"	"	0.4	"	1006-1010	6.7	29.0	6

ABSTRACT

The problem of determining the vertical axis control requirements for landing a VTOL aircraft on a moving ship deck in various sea states is examined. Both a fixed-base piloted simulation and a non-piloted simulation were used to determine the landing performance as influenced by thrust-to-weight ratio, vertical damping, and engine lags.

The piloted simulation was run using a fixed-base simulator at N.A.S.A. Ames Research Center. Simplified versions of an existing AV-8A Harrier model and an existing head-up display format were used. The ship model used was that of a DD963 class destroyer.

Simplified linear models of the pilot, aircraft, ship motion, and ship air-wake turbulence were developed for the non-piloted simulation. A unique aspect of the non-piloted simulation was the development of a model of the piloting strategy used for shipboard landing. This model was refined during the piloted simulation until it provided a reasonably good representation of observed pilot behavior. Further refinement could lead to a model suitable for prediction of landing performance of VTOL aircraft on ships and as the basis of control logic for automatic landing.

A surprising result of this simulation was that, with a good station keeping control system and with statistical ship motion displayed on the head-up display, pilots could consistently perform safe landings in sea state 6, with handling qualities that were adequate at thrust-to-weight ratios greater than 1.03 and even

marginally adequate down to thrust-to-weight ratios of 1.01. These results should hold quite generally provided that a thrust-to-weight ratio of $1 + \Delta$ is interpreted as meaning that the pilot always has the capability of accelerating the aircraft at Δg upward even in the presence of ground effect and hot gas reingestion.

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