HRAS3.CSL: Helicopter Recrvery Assist Simulation, level 3
By Harvard Systems, 31 March, 1992

1. Summary

HRAS3.CSL is an ACSL simulation model of the Westland EH101 helicopter being hauled down by Indal Technologies' Recovery Assist (RA) mechanism to a Canadian Patrol Frigate in heavy seas.

2. Model Scope

> Six Degrees Of Freedom (6-DOF) model of EH101 helicopter using Westland supplied stability derivatives

> Stability and Control Augmentation System (SCAS) using Westland supplied loop gains

> Automatic Flight Control System (AFCS), designed by Harvard Systems, provides station keeping and trimming of the Heli/SCAS for any arbitrary wind, cable tension, and helicopter/ship relative position prior to the hauldown phase

> Six degree of freedom ship motion model

> Ship motion model, modularized through use of FORTRAN subroutine, facilitates introduction of user defined ship motion equations of any complexity

> Default ship motion subroutine is simple single frequency sinusoidal model

> RA model, modularized through of "include" file, facilitates introduction of user defined Recovery Assist mechanism equations of any complexity

> Two RA models are provided; user able to select which of them at run time:
- *Idealized model (instant, perfect response to RA input command)*
- *Todorow model (supplied by Indal, as adapted by Harvard Systems)*

> Wind Over Deck (WOD) model having both spatial and temporal variations in wind speed along the three ship axes
- *Spatial variation is a tabular function of helicopter position in ship coordinates*
- *Temporal variation is an exponentially correlated gaussian random variable*

> Man in the loop model allows simple actions of pilot and Landing Safety Officer (LSO)
- *Pilot applies user defined step in collective*
- *LSO applies user defined ramp in cable tension command*

3. Operating Options

The HRAS3.CSL program may be operated in a single flight manner for detailed analysis of the hauldown variables. It may also be operated in a Monte Carlo manner for determining the touchdown statistics, namely, the mean, standard deviation and RMS value of the following terms:

* Radial, longitudinal and lateral components of miss distance of the helicopter probe relative to the RA bellmouth
* Probability (relative frequency) of probe landing within the RA capture area
* Impact velocity resolved along the three ship axes
* Helicopter attitude (Euler angles) with respect to the ship
* Time duration of the hauldown process

Also, a scatter diagram may by plotted at the user's request showing the coordiantes of the probe touchdown point on the ship deck for each of the flights in the Monte Carlo set.

4. Introduction

This program was developed by Harvard Systems under contract to Indal Technologies over the period from 21 January to 29 March, 1992. The purpose of the model is to enable Indal engineers to predict the performance of their RA mechanism in hauling down the EH101 in various sea states and wind conditions. The EH101 is a heavier vehicle than previously experienced by the Indal RA device; hence simulation is the only practical means of obtaining these performance predictions.

The model also enables Indal to determine the effects of pilot and LSO actions; e.g., the timing and magnitude of helicopter collective step and cable tension ramp. One of the first questions of interest is whether the 4000 lb cable tension limit of the existing RA is adequate to haul in the EH101 without any down collective being applied.

The HRAS3.CSL program has the growth potential for predicting the effects of more complex pilot actions; i.e., the handling of the helicopter's lateral and longitudinal cyclic controls. It is also an excellent tool for determining the feasibility and accuracy of an automatic recovery system, in which cable tension is supplemented by special servo loops manipulating the helicopter collective and cyclic.

With minor modifications, the HRAS3.CSL model may be adapted to any other rotorcraft or ship.

5. Run Time Command File

A run time command file, entitled HRAS3.CMD, is provided as part of Harvard Systems' contract with Indal. This file, containing ninety-eight ACSL procedures (PROCEDs), automatically generates a sequence of preprogrammed test cases upon the user typing the command "GO".

The function of this .CMD file is twofold: 1) It illustrates the performance of the model, and 2) It serves as a tutorial to aid the user in gaining a facility with the model. Besides the 98 PROCEDs, this .CMD file includes a number of explanatory paragraphs to further aid the user's understanding.

Invoking the proced "GOWEST", for example automatically produces the entire group of check solutions of Pitkin's flight case 01 (Reference 1, appendix E, pages E1 through E7). Figures 1 and 2, below, correspond to pages E3 and E7 of Reference 1. The agreement is exact, as is the case with the other plots. On this basis the helicopter portion of HRAS3.CSL has been judged valid.

Invoking proced "GOGUST" yields the plots shown in figures 3 and 4. These curves convey an insight into the dynamics of the EH101 helicopter/SCAS system with Harvard Systems' AFCS loops wrapped around it. The AFCS was not designed with any particular stability or speed of response criteria, since its only intended use is as a means of establishing trim, off line. Figures 3 and 4 are thus presented here only for general interest.

Invoking the proced "GOHAULALL" yields the probe trajectory relative to the ship in the ship fixed coordinate frame for seven hauldown cases having different initial conditions, wind models, RA models and cable tensions. Figure 5 is an example of one of these cases.

Invoking the proced "GOMONTEALL" yields the probe touchdown scatter diagrams for seven different 26 flight monte carlo runs. Figure 6 shows the scatter diagram for hauldown case designated 5e. Each touchdown point is identified by its own letter of the alphabet, permitting the user to repeat any particular flight for more detailed analysis if desired. The initial position of the probe is identified by the numeral 9.

In figure 6 it is seen by the position of the 9 that the probe was initially located 7 feet forward and 7 feet to port (and 15 feet above) of the RA bellmouth. The RA bellmouth, or target, lies at the very center of the diagram; the central square of the figure defining the 4ft x 4ft RA capture zone.

It is interesting that the scatter diagram in Figure 6 has a pattern to it, and that the long dimension of the pattern lies not along the initial cable line but more nearly perpendicular to it. This is believed to be caused in part by the helicopter/SCAS being more ringy in roll than in pitch. The helicopter fuselage is initially lined up with its nose pointing toward the ship's bow, hence helicopter rolling swings the probe laterally in the figure.

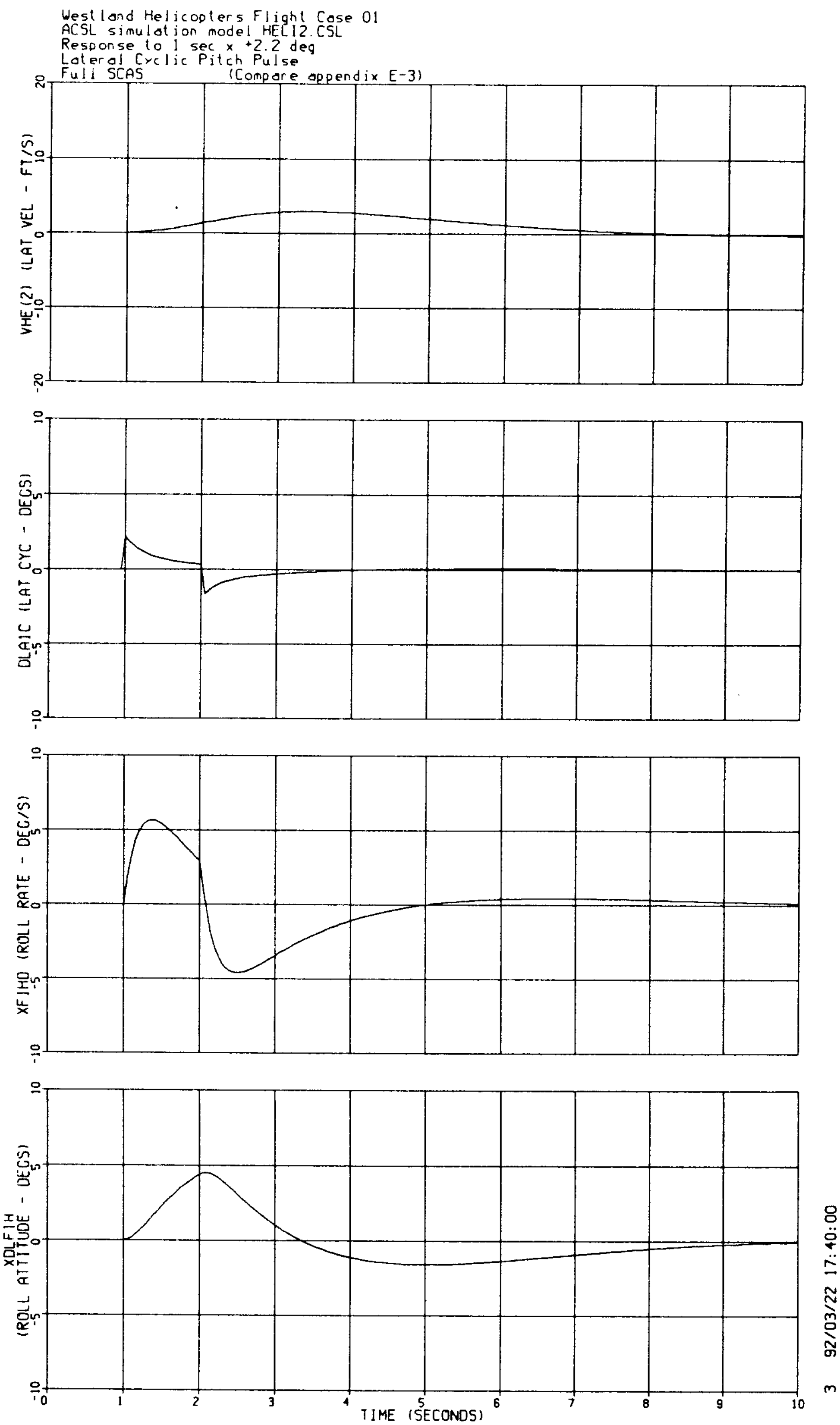
Invoking the proced "GO" causes ACSL to ripple through the above mentioned proceds. The plots and statistical data generated by these proceds illustrate the insights that the user is able to obtain by running the HRAS3.CSL model.

If a new hauldown case is desired it becomes necessary to find the initial conditions which put the helicopter/SCAS in a trimmed state. This is done by invoking the proced "TRIM", which activates the AFCS. Upon invoking this proced the user will see printed out on the monitor screen, in 1 second intervals, the net of the cable and aerodynamic forces on the helicopter resolved in the earth coordinate frame.

If the time allowed for trimming was insufficient the user will note this because the net force has not yet sufficiently approached zero by the time the model stops. ACSL would then be commanded to run longer, continuing from the last state of the system. This process is repeated until the trim is satisfactory (net forces and moments essentially zero). The user then notes the key states of the heli/SCAS for use in the subsequent hauldown experiments.

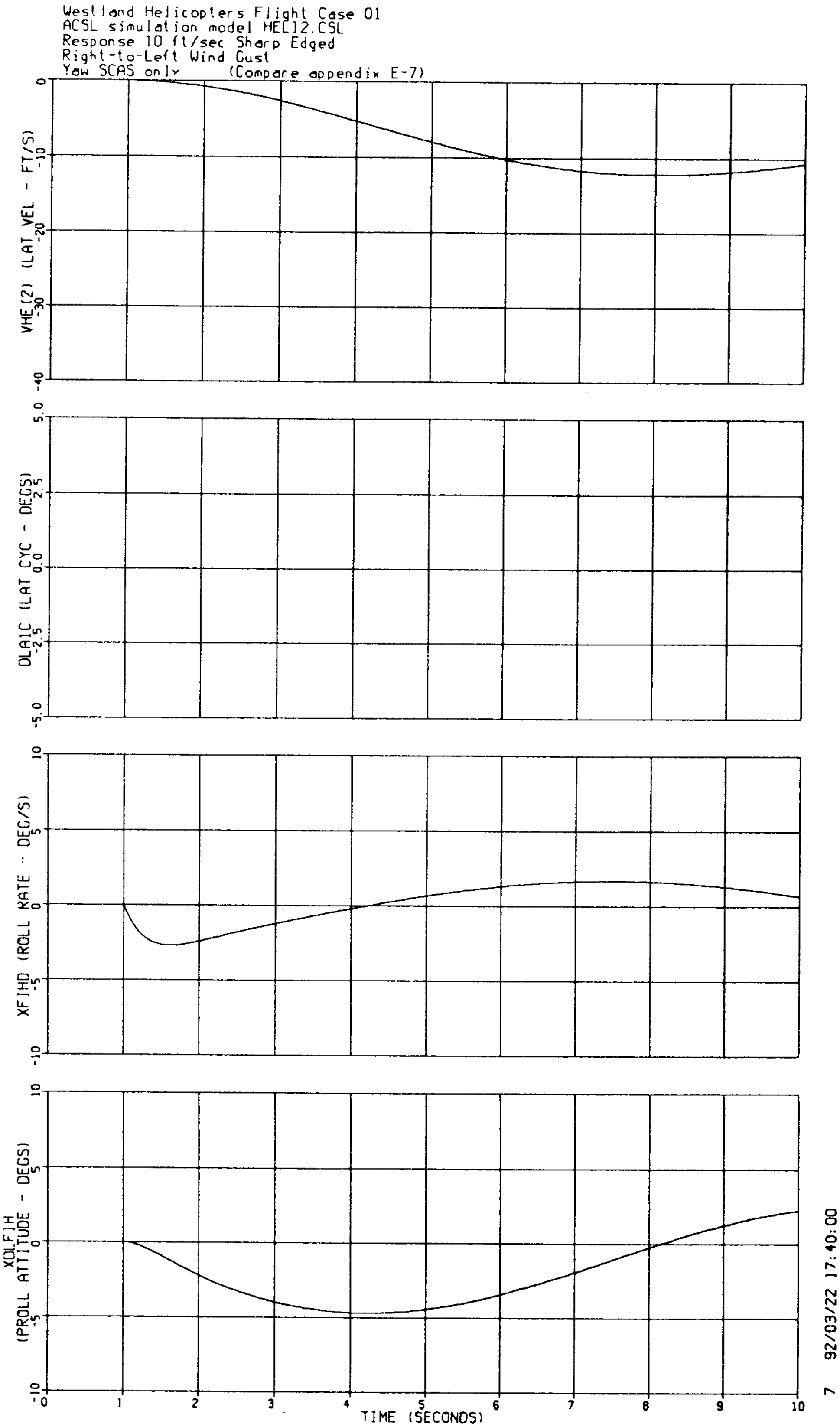
Reference 1: Power Systems Note 244:
"EH101 Stability and Control Data In Support of ITI Studies of the Compatibility of the HHRSD System With the NSA";
dated December, 1991;
by B. Pitkin, Specialist-Flight Mechanics;
Westland Helicopters Limited

Figure 1



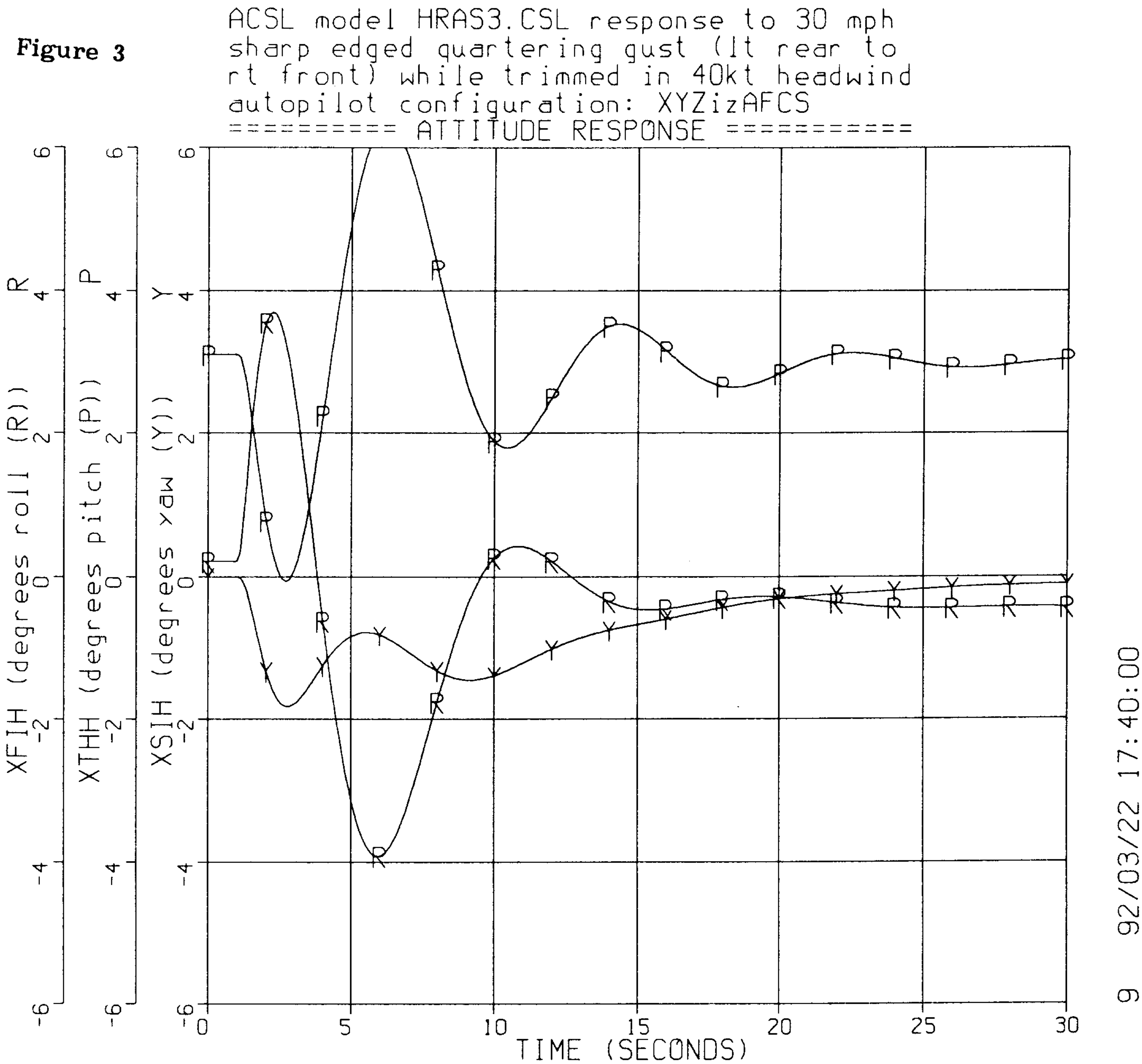
Westland Helicopters Flight Case 01
ACSL simulation model HEL12.CSL
Response to 1 sec x +2.2 deg
Lateral Cyclic Pitch Pulse
Full SCAS (Compare appendix E-3)
VHE(2) (LAT VEL - FT/S)
DLAIC (LAT CYC - DEGS)
XFIHD (ROLL RATE - DEG/S)
XDLFIH (ROLL ATTITUDE - DEGS)
TIME (SECONDS)
92/03/22 17:40:00
3

Figure 2



Westland Helicopters Flight Case 01
ACSL simulation model HELI2.CSL
Response 10 ft/sec Sharp Edged
Right-to-Left Wind Gust
Yaw SCAS only (Compare appendix E-7)
VHE(2) (LAT VEL - FT/S)
0
-10
-20
-30
-40
DLA1C (LAT CYC - DEGS)
5.0
2.5
0.0
-2.5
-5.0
XFIHD (ROLL RATE - DEG/S)
10
5
0
-5
-10
XDLFIH (PROLL ATTITUDE - DEGS)
10
5
0
-5
-10
0
1
2
3
4
5
6
7
8
9
10
TIME (SECONDS)
7 92/03/22 17:40:00

Figure 3



ACSL model HRAS3.CSL response to 30 mph
sharp edged quartering gust (lt rear to
rt front) while trimmed in 40kt headwind
autopilot configuration: XYZizAFCS
========== ATTITUDE RESPONSE ===========
XFIH (degrees roll (R)) R
XTHH (degrees pitch (P)) P
XSIH (degrees yaw (Y)) Y
TIME (SECONDS)
92/03/22 17:40:00
9

Figure 4

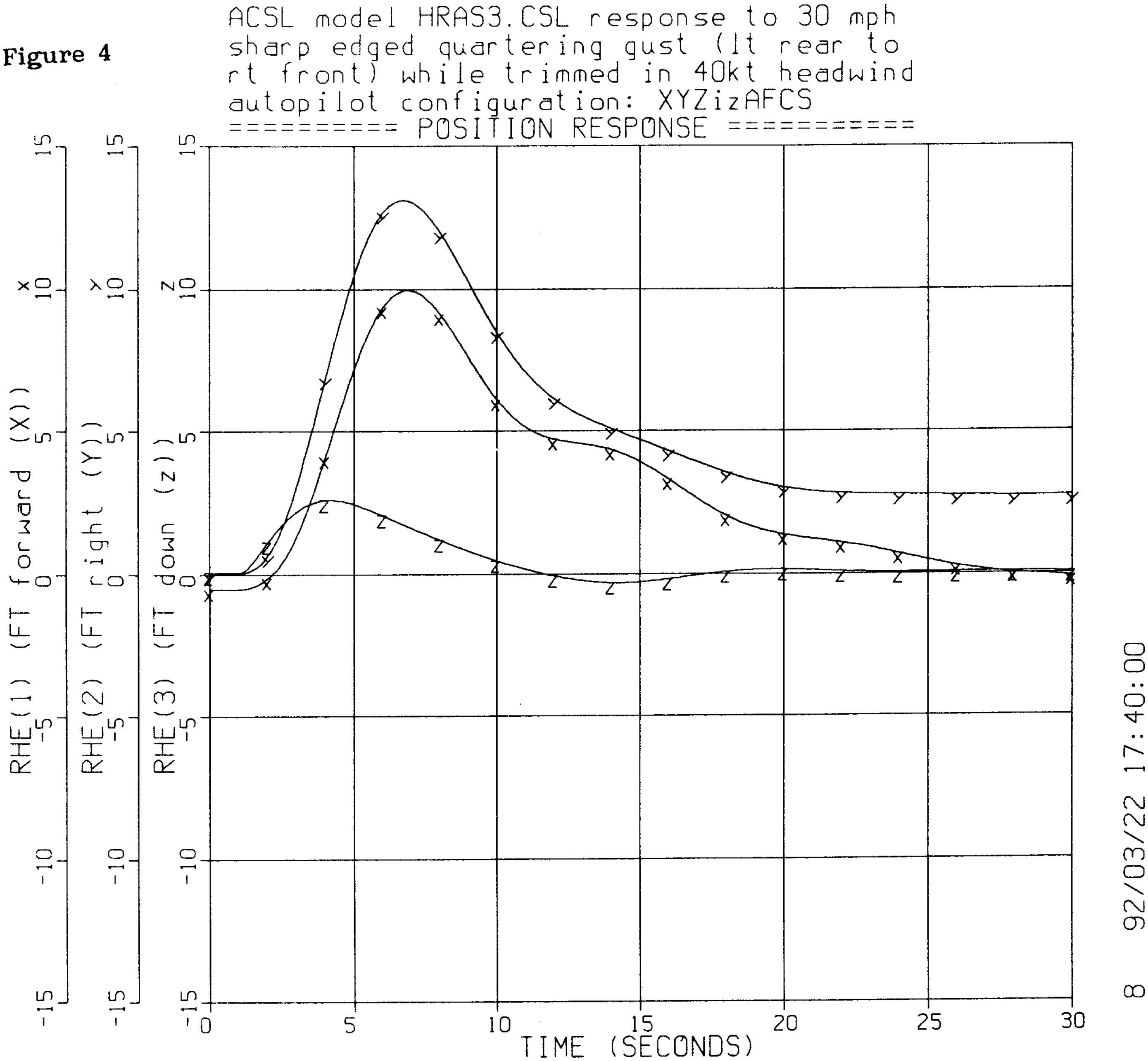

ACSL model HRAS3.CSL response to 30 mph
sharp edged quartering gust (lt rear to
rt front) while trimmed in 40kt headwind
autopilot configuration: XYZizAFCS
========== POSITION RESPONSE ===========
RHE(1) (FT forward (X))
RHE(2) (FT right (Y))
RHE(3) (FT down (z))
x
y
z
15
10
5
0
-5
-10
-15
0
5
10
15
20
25
30
TIME (SECONDS)
8 92/03/22 17:40:00

Figure 5

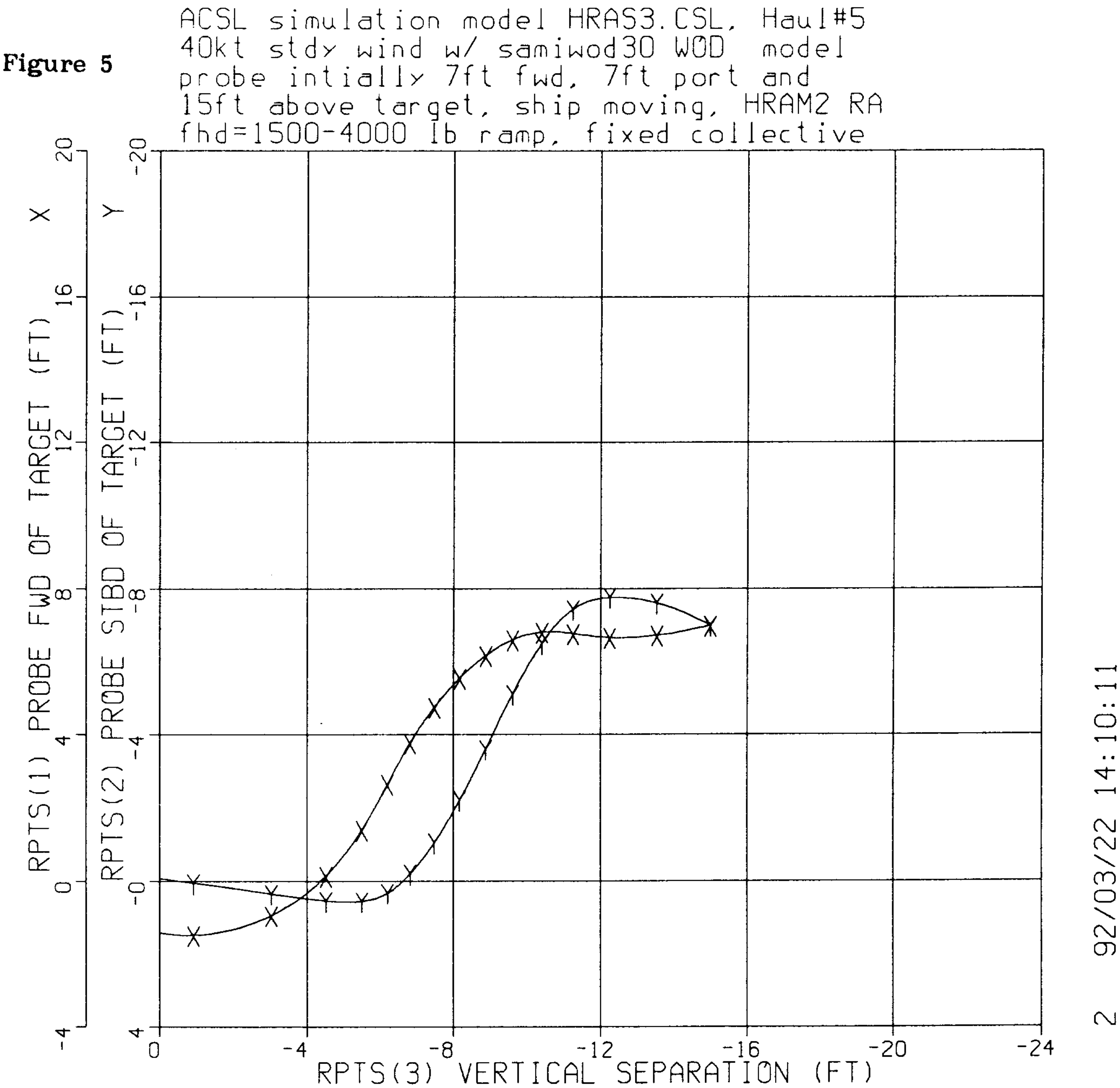
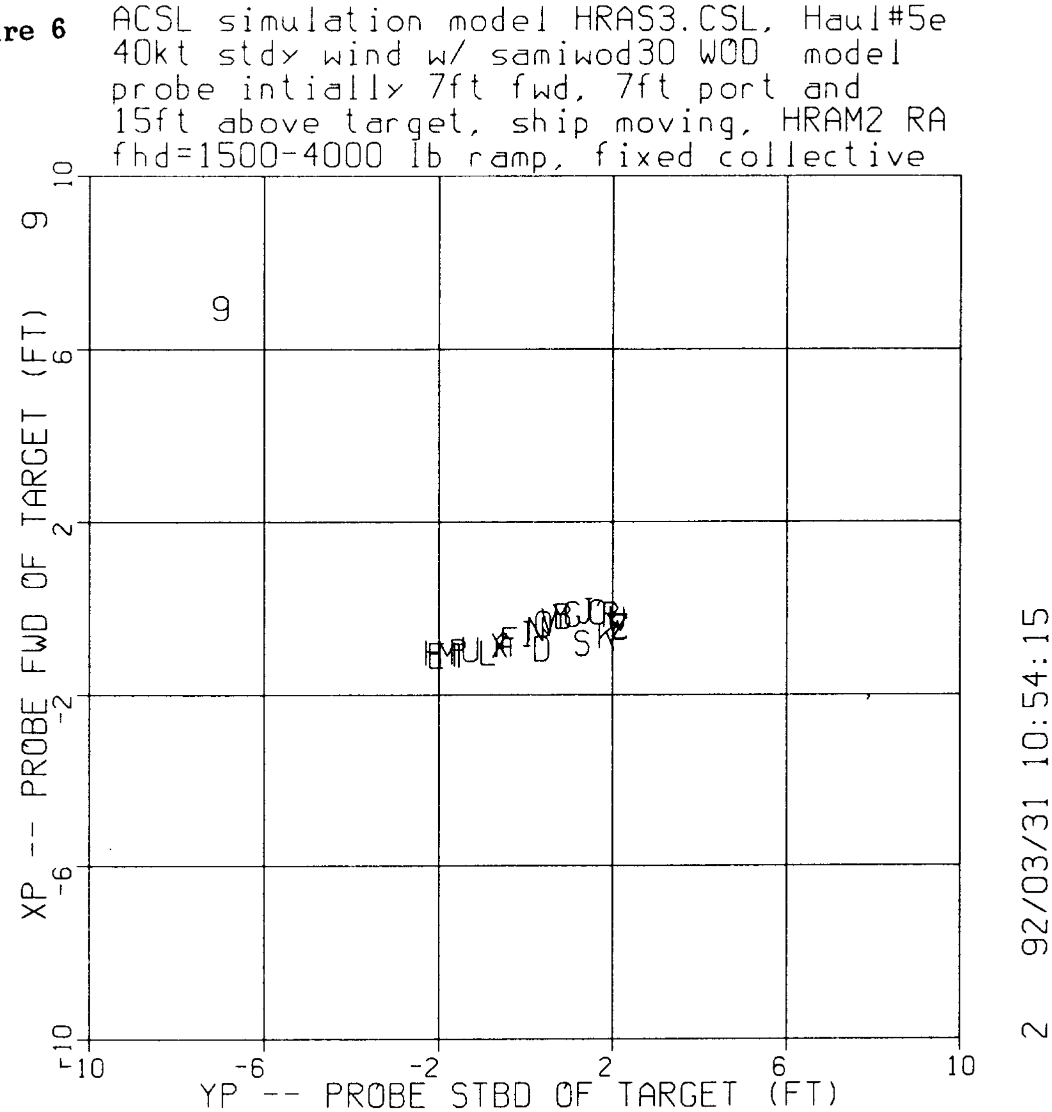
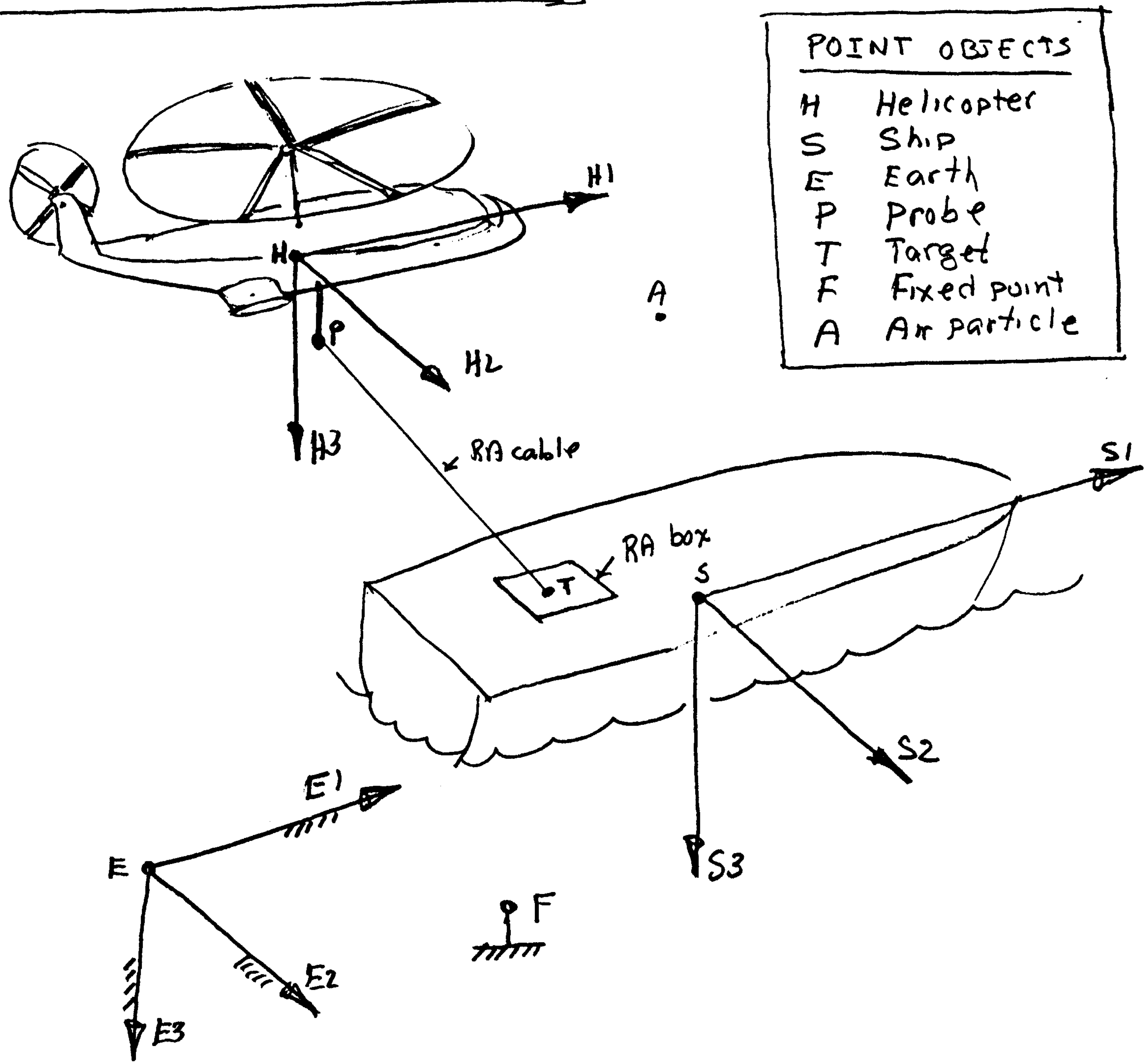

ACSL simulation model HRAS3.CSL, Haul#5
40kt stdy wind w/ samiwod30 WOD model
probe intially 7ft fwd, 7ft port and
15ft above target, ship moving, HRAM2 RA
fhd=1500-4000 lb ramp, fixed collective
RPTS(1) PROBE FWD OF TARGET (FT) X
RPTS(2) PROBE STBD OF TARGET (FT) Y
RPTS(3) VERTICAL SEPARATION (FT)
20
16
12
8
4
0
-4
-20
-16
-12
-8
-4
-0
4
0
-4
-8
-12
-16
-20
-24
92/03/22 14:10:11
2

Figure 6



ACSL simulation model HRAS3.CSL, Haul#5e
40kt stdy wind w/ samiwod30 WOD model
probe intially 7ft fwd, 7ft port and
15ft above target, ship moving, HRAM2 RA
fhd=1500-4000 lb ramp, fixed collective
XP -- PROBE FWD OF TARGET (FT)
YP -- PROBE STBD OF TARGET (FT)
92/03/31 10:54:15
2

FIGURE 2 HRAS3b GEOMETRY



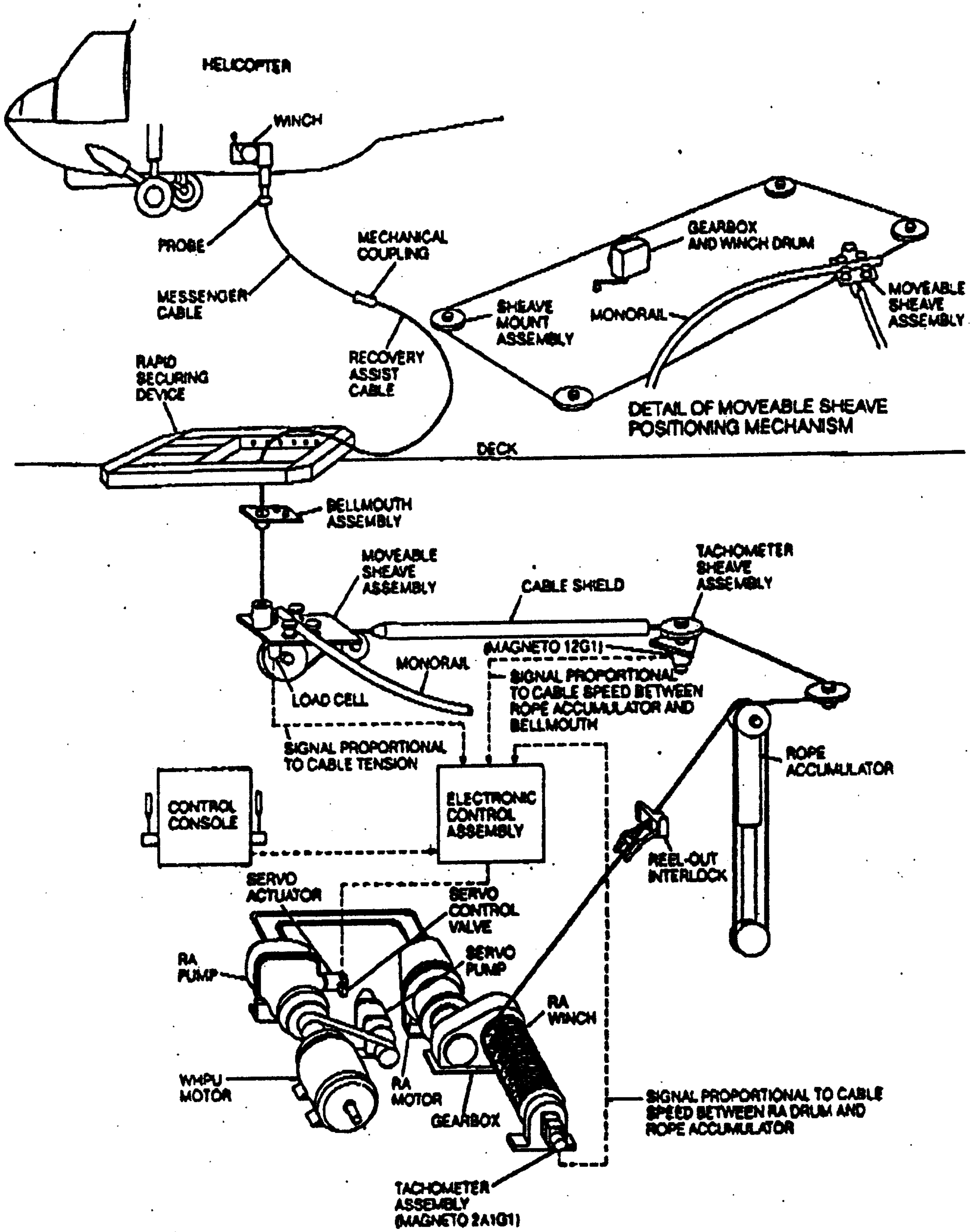


FIGURE 1 SCHEMATIC OF HAULDOWN SYSTEM.

FIGURE 3

HELICOPTER RECOVERY ASSIST SYSTEM SIMULATION, HRAS3b.CSL
OVERALL SYSTEM BLOCK DIAGRAM

5

REV 0: 5 Feb., 1992
REV 1: 17 Feb, 1992
REV 2: 1 Mar, 1992
REV 3: 25 Mar, 1992

D.D. Girard

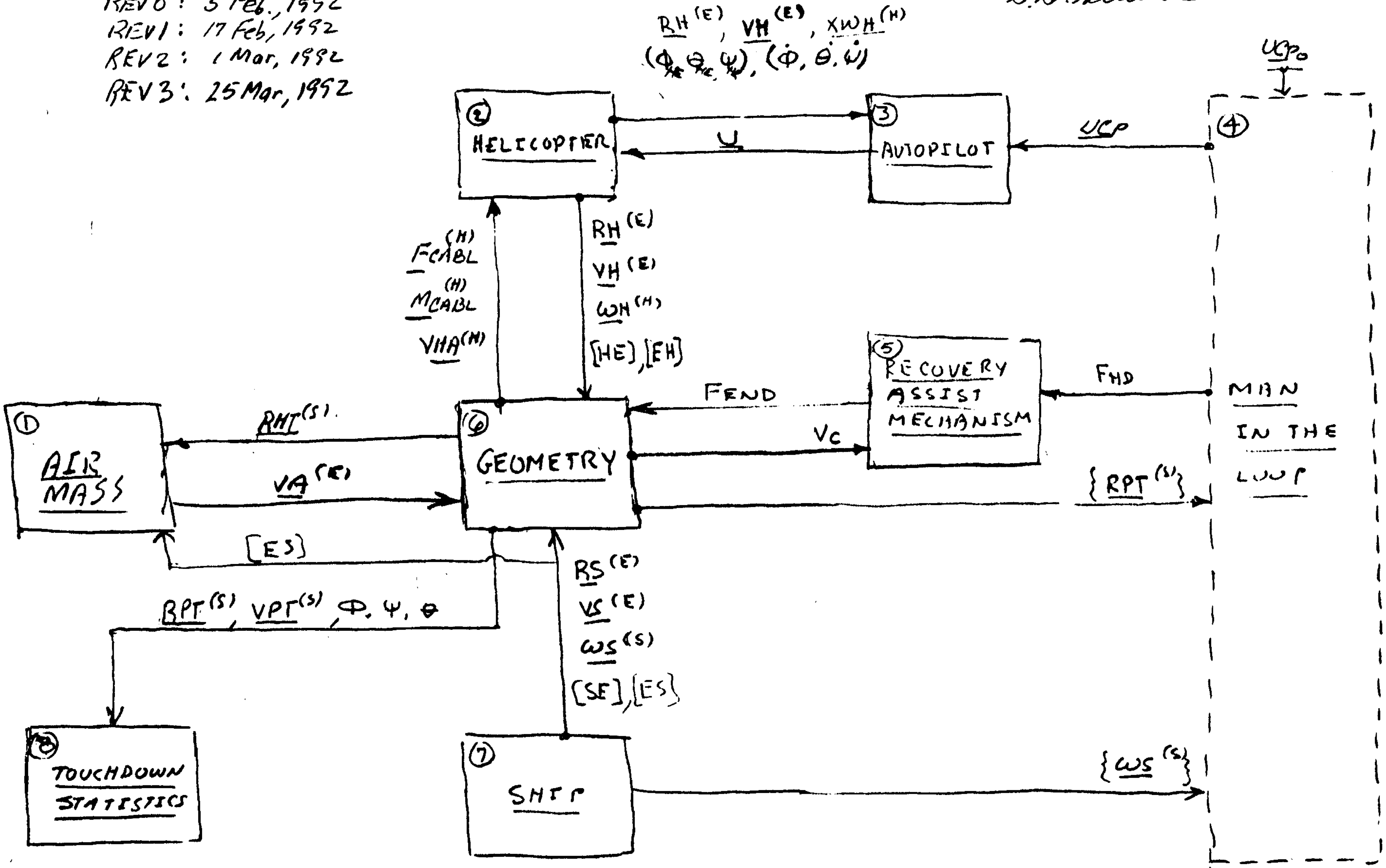
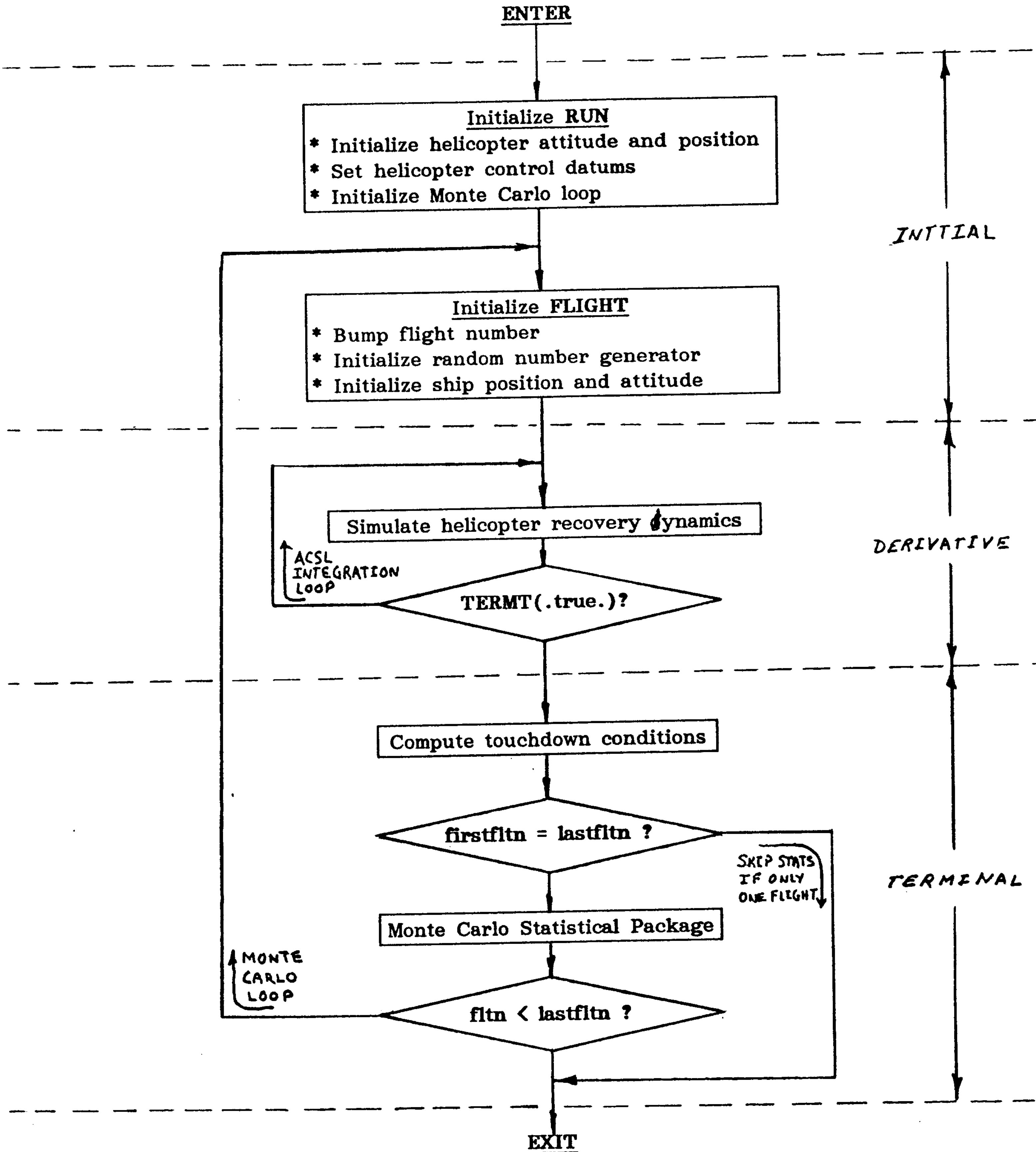
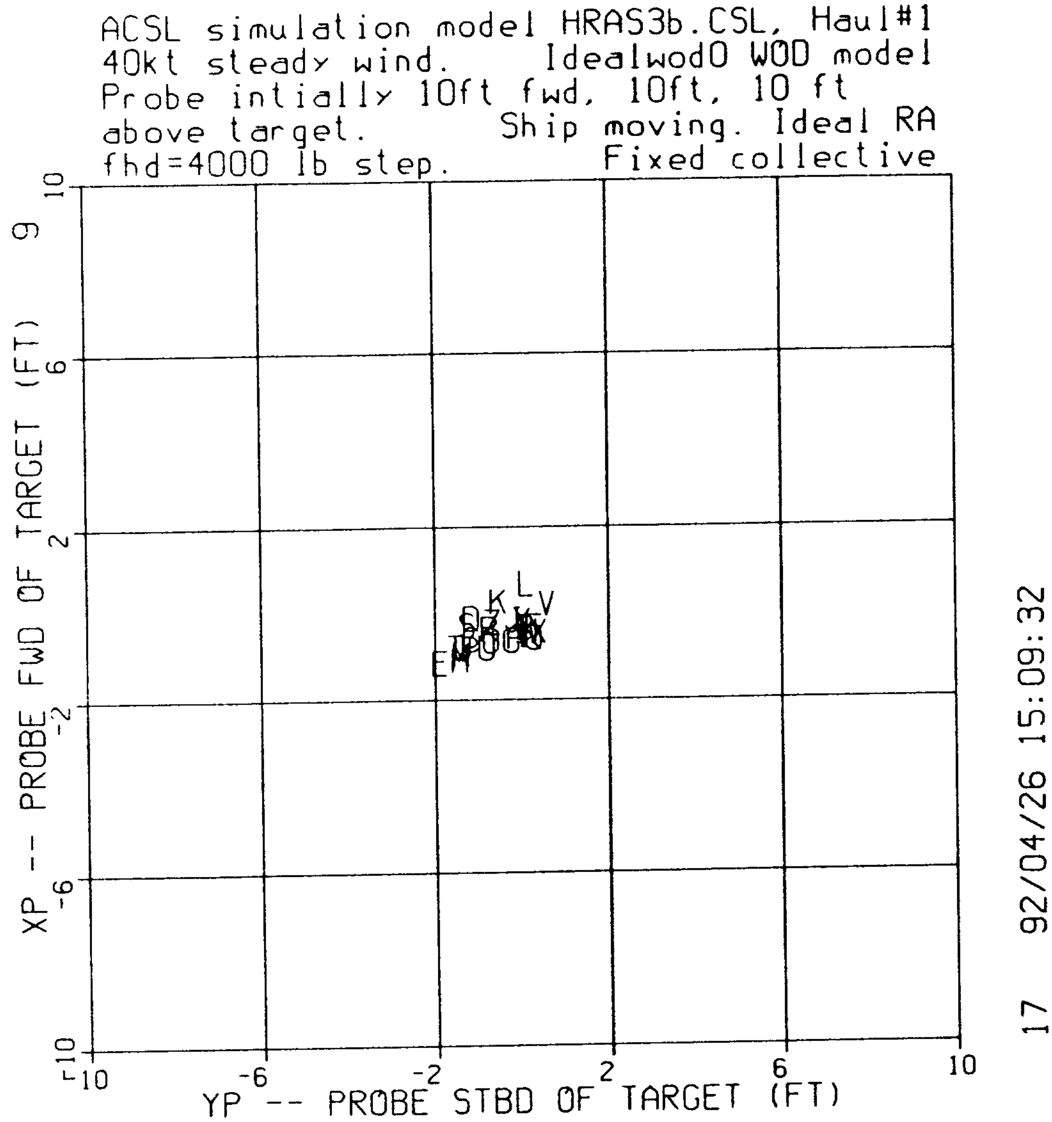
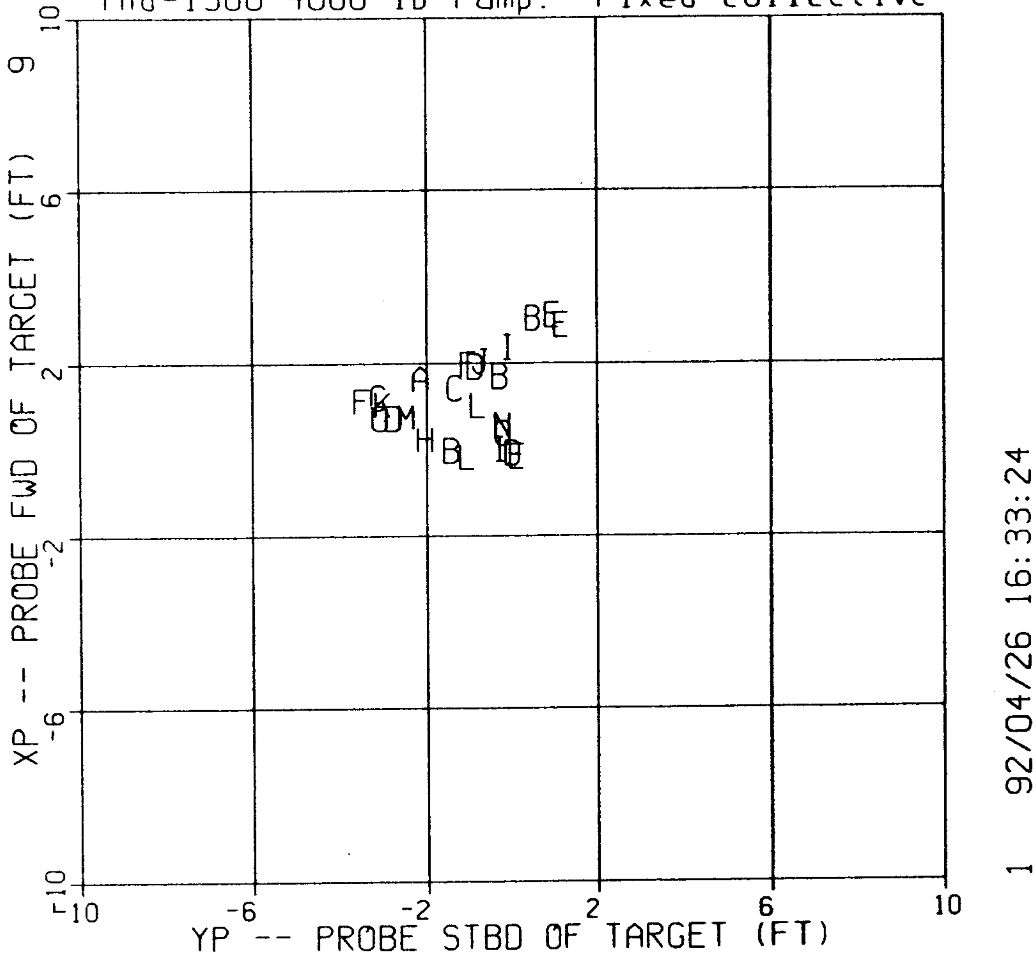


Figure 5 HRAS3b Flow Diagram

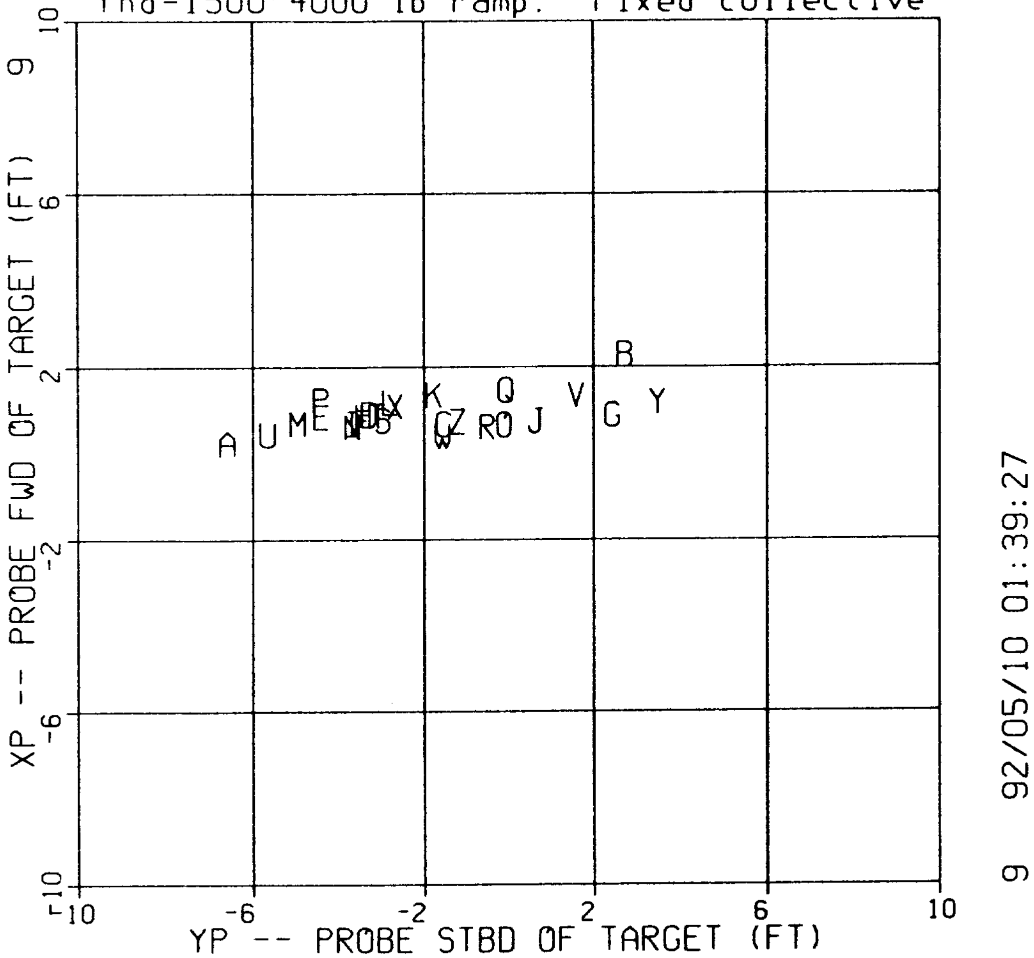


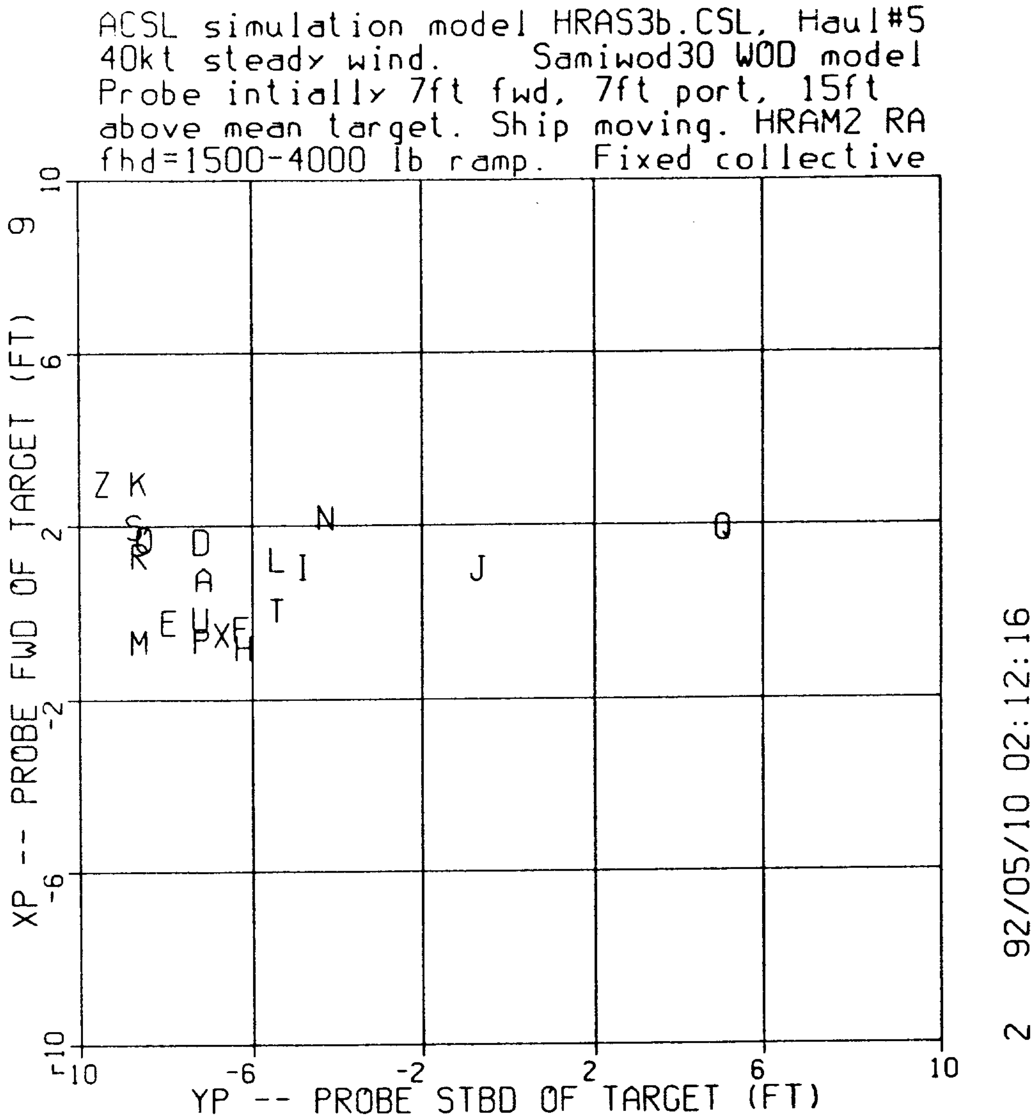

ACSL simulation model HRAS3b.CSL, Haul#1
40kt steady wind. Idealwod0 WOD model
Probe intially 10ft fwd, 10ft, 10 ft
above target. Ship moving. Ideal RA
fhd=4000 lb step. Fixed collective
XP -- PROBE FWD OF TARGET (FT)
YP -- PROBE STBD OF TARGET (FT)
-10
-6
-2
2
6
10
92/04/26 15:09:32
17

ACSL simulation model HRAS3b.CSL, Haul#3
40kt steady wind. Idealwod30 WOD model
Probe intially 7ft fwd, 7ft stbd, 15 ft
above target. Ship moving. Ideal RA
fhd=1500-4000 lb ramp. Fixed collective



ACSL simulation model HRAS3b.CSL, Haul#4
40kt steady wind. Samiwod30 WOD model
probe intially 7ft fwd, 7ft stbd, 15 ft
above mean target. Ship moving. HRAM2 RA
fhd=1500-4000 lb ramp. Fixed collective




ACSL simulation model HRAS3b.CSL, Haul#5
40kt steady wind. Samiwod30 WOD model
Probe intially 7ft fwd, 7ft port, 15ft
above mean target. Ship moving. HRAM2 RA
fhd=1500-4000 lb ramp. Fixed collective
XP -- PROBE FWD OF TARGET (FT)
YP -- PROBE STBD OF TARGET (FT)
92/05/10 02:12:16
2