10-20

AR-007-005

DEPARTMENT OF DEFENCE

DSTO

Information Technology Division

RESEARCH REPORT
ERL-0656-RR

A PC-BASED INTERACTIVE SIMULATION OF THE F-111C PAVE TACK SYSTEM AND RELATED SENSOR, AVIONICS AND AIRCRAFT ASPECTS

by

David A.B. Fogg, Mike Davies, Fred D.J. Bowden and Ray Janus

2178

8

APPROVED FOR PUBLIC RELEASE

ELECTRONICS AND SURVEILLANCE RESEARCH LABORATORY

AR-007-005

DSTO
AUSTRALIA

ELECTRONICS & SURVEILLANCE RESEARCH LABORATORY

Information Technology Division

RESEARCH REPORT
ERL-0656-RR

A PC-BASED INTERACTIVE SIMULATION OF THE F-111C PAVE TACK SYSTEM AND RELATED SENSOR, AVIONICS AND AIRCRAFT ASPECTS

by

David A.B. Fogg, Mike Davies, Fred D.J. Bowden and Ray Janus

Accesion For
NTIS CRA&I ☒
DTIC TAB ☐
Unannounced ☐
Justification ______
By ______
Distribution /
Availability Codes

Dist	Avail and / or Special
A-1	

SUMMARY

Pave Tack is an all weather, day and night, navigation and weapon delivery system fitted to the F-111C aircraft. A PC-based, interactive digital computer simulation has been written which can be used to assess the performance of the Pave Tack system and also as a computer-aided training device. In forming the simulation, it was necessary to model a number of avionics and sensor aspects and an F-111C flight path generator was used to produce accurate data off-line. This report details the history, structure and general capabilities of the F-111C Pave Tack Simulation (FPTS).

MAR 94

APPROVED FOR PUBLIC RELEASE

POSTAL ADDRESS: Director, Electronics & Surveillance Research Laboratory, PO Box 1500,
Salisbury, South Australia, 5108.

CONTENTS

ABBREVIATIONS vii

1 INTRODUCTION 1

2 FPTS MODELLING CONCEPTS 2

3 THE PAVE TACK POD 2
- 3.1 Pod location and structure 3
- 3.2 Pod dynamics 3

4 PAVE TACK SYSTEM MODES OF OPERATION 3
- 4.1 Pave Tack search modes (target acquisition) 3
- 4.2 Pave Tack track modes (target designation and navigation updates) 4
- 4.3 Pave Tack navigation and navigation updates 5
- 4.4 Weapon delivery 6
- 4.5 Damage assessment 7

5 PAVE TACK SYSTEM PROCESSING AND POSITION UPDATING 7
- 5.1 Processing in cue mode and position updating using the radar 8
- 5.2 Processing in track mode and position updating using the pod 8

6 THE ANALOGUE INTERFACE UNIT 10

7 AVIONICS SYSTEMS 10
- 7.1 The Central Air Data Computer 10
- 7.2 The Inertial Bomb Navigation System 10
  - 7.2.1 The Inertial Navigation System 11
- 7.3 The Terrain Following Radar computer 11

8 AIRCRAFT FLIGHT SIMULATION 12
- 8.1 Point mass models 12
- 8.2 Six degrees of freedom models 13
- 8.3 Aircraft model for use in the terrain screening mode 14

9 AIRCRAFT SENSORS 15
- 9.1 Attack Radar 15
- 9.2 Altimeters 15

10 TERRAIN TOPOGRAPHIC MODEL AND MOTION SIMULATOR 15
- 10.1 Terrain display options 15
- 10.2 Airborne surrogate travel visualisation 16

11 THE HUMAN OPERATOR 16

12 DESCRIPTION OF THE BASE MODEL 16
- 12.1 Coordinate systems 17
- 12.2 Program language and structure 17
- 12.3 Model time sequencing 18
- 12.4 FPTS baseline assumptions 18

13 WEAPON DELIVERY MODELS 19

14 DISCUSSION 19

15 CONCLUSIONS 23

REFERENCES 25

FIGURES

1 F-111C Pave Tack simulation overview 28
2 Pave Tack pod deployment 29
3 Pave Tack pod configuration 30
4 F-111C PT/GW cursor control mechanism; radar prime, cue mode, GND AUTO or GND VEL 31
5 F-111C PT/GW cursor control mechanism; Pave Tack prime, cue mode, GND AUTO or GND VEL 32
6 Position updating logic (Pave Tack, Track mode) 33
7 AIS electrical interface 34
8 Figure relating to 'Terrain Display Options' - Section 10.1. 35
9 Variation in error in vertical range to target (cue mode) 36
10 Variation in precise and system north range components (cue mode) 36
11 Variation in error in north range to target (cue mode) 37
12 Variation in error in east range to target (cue mode) 37
13 Variation in north range error and pod correction signal (track mode, no laser) . . . 38
14 Variation in east range error and pod correction signal (Track mode, no laser) 38
15 Variation in vertical range error and pod correction signal (track mode with laser) 39
16 Variation in north range error and pod correction signal (track mode with laser) . . 39
17 Variation in east range error and pod correction signal (track mode with laser) . . . 40
18 Variation in vertical range error (track mode, no laser, deliberate navigation error) 40
19 Variation in north range error and pod correction signal (track mode, no laser, deliberate navigation error) 41
20 Variation in east range error and pod correction signal (track mode, no laser, deliberate navigation error) 41
21 Variation in vertical range error and pod correction signal (track mode with laser, deliberate navigation error) 42
22 Variation in north range error and pod correction signal (track mode with laser, deliberate navigation error) 42
23 Variation in east range error and pod correction signal (track mode with laser, deliberate navigation error) 43

TABLES

1 Timing references 18

APPENDICES

I COORDINATE SYSTEMS 45
II FPTS: STRUCTURE 55
III FPTS: INITIALISATION (MODULE 1) 65
IV FPTS: NAVIGATION (MODULE 2) 81

V FPTS: RADAR SIGHTING (MODULE 3) 93
VI FPTS: PAVE TACK POD SIGHTING (MODULE 4) 105
VII FPTS: WEAPON DELIVERY (MODULE 5) 123
VIII FPTS: RADAR POSITION UPDATING (MODULE 6) 135
IX FPTS: PT POD SIGHTLINE VECTOR POSITIONING (MODULE 7) 147
X FPTS: PAVE TACK POSITION UPDATING (MODULE 8) 167
XI FPTS: PAVE TACK ALTITUDE CALIBRATION (MODULE 9) 187
XII FPTS: POSITION OF TARGET RELATIVE TO AIRCRAFT (MODULE 10) 199
XIII FPTS: OPERATOR INTERACTION (MODULE 11) 215

THIS IS A BLANK PAGE

ABBREVIATIONS

ACU	Antenna Control Unit
AIC	Antenna Indicator Control
AIS	Analog Interface Set
AIU	Analog Interface Unit
ARDU	Air Force Research and Development Unit
ARL	Aeronautical Research Laboratory
ARS	Attack Radar Set
BCU	Ballistics Computer Unit
c of g	Centre of gravity
CADC	Central Air Data Computer
CAI	Inertial-to-aircraft transformation matrix
CSA	Aircraft-to-sightline transformation matrix
CSD	Combat Systems Division
CSI	Inertial-to-sightline transformation matrix
DPC	Data Processor Computer
FLIR	Forward Looking Infrared
FPTS	F-111C Pave Tack Simulation
HAT	Height Above Target
HCP	Harpoon Control Panel
HIU	Harpoon Interface Unit
H_J	Sightline pitch acceleration signal (derotated operator input)
H_K	Sightline yaw acceleration signal (derotated operator input)
H_X	Operator-input angular acceleration along X axis of Pave Tack VID
H_Y	Operator-input angular acceleration along Y axis of Pave Tack VID
IBNS	Inertial Bombing Navigation System
IJK	PT pod sightline right-handed axis system
INS	Inertial Navigation System
IR	Infrared
IRDS	Infrared Detection Set
KTAS	Knots, true air speed
LARA	Low altitude radar altimeter
LCOSS	Lead Computing Optical Sight Set
LCP	Laser Control Panel
LGB	Laser Guided Bomb
LOS	Line-of-sight
LRU	Line Replaceable Unit
LTI	Linear time invariant
MOAP	Multiple Offset Aimpoint Panel
MPT	Memory Point Track
NCU	Navigation Computer Unit
NEV	Inertial axis system (north, east and downward vertical)
OFP	Operational Flight Program
PC	Personal computer
PT	Pave Tack
PTAP	Pave Tack Auxiliary Panel
PTCP	Pave Tack Control Panel
PT/GW	Pave Tack / Guided Weapons program
RAI	Radar Altitude Indicator
RCP	Radar Control Panel

R_N, R_E, R_V	System inertial range components to target
R_{NP}, R_{EP}, R_{VP}	Precise inertial range components to target
R_S	System slant range to target
SDC	Signal Data Converter
SDU	Signal Distribution Unit
SMS	Stores Management Set
SPU	Stabilised Platform Unit
SSA	Systems Simulation and Assessment group
T	Column matrix used in sightline location for perfect operator
TCU	Tracking Control Unit
TFR	Terrain Following Radar
VDU	Visual Display Unit
VID	Virtual Image Display
WSO	Weapons System Officer
3DF	three degrees of freedom
6DF	six degrees of freedom
Θ	Pitch matrix (general)
θ	Pitch angle (general)
Θ_A	Aircraft pitch matrix
θ_A	Aircraft pitch angle
Θ_I	Pod inner pitch matrix
θ_I	Pod inner pitch angle
Θ_O	Pod outer pitch matrix
θ_O	Pod outer pitch angle
τ_{HN}	Derotation angle
Φ	Roll matrix (general)
ϕ	Roll angle (general)
Φ_A	Aircraft roll matrix
ϕ_A	Aircraft roll angle
Φ_O	Pod outer roll matrix
ϕ_O	Pod outer roll angle
Ψ	Yaw matrix (general)
ψ	Yaw angle (general)
Ψ_A	Aircraft yaw matrix
ψ_A	Aircraft yaw angle
Ψ_I	Pod inner yaw matrix
ψ_I	Pod inner yaw angle

1 INTRODUCTION

The Pave Tack System (AN/AVQ-26), installed on the RAAF F-111C aircraft, is a 24-hour weapon delivery system and navigation aid with electro-optical target acquisition and a laser designator. It consists of a pod, mounted in the weapons bay, which is capable of being lowered below the fuselage with controls and displays used by the Weapons Systems Officer (WSO) in the cockpit. It incorporates an Infrared Detection Set (IRDS), also known as Forward Looking Infrared (FLIR), which in addition to improving day and night operability, can be used in relatively adverse weather conditions. A model capable of predicting the performance of Pave Tack, both in the navigation mode and as an aid to the delivery of weapons was required. The work began under Air Force task AIR 86/166 "F-111C Pave Tack Modelling", and continued under AIR 90/096, "Pave Tack Pre-mission Simulation". There were a number of aspects to this work. First, information describing the physical characteristics of the Pave Tack system and the details of operation of its components, particularly the logic embodied in its computer, was collected and assessed. The expertise of engineers at British Aerospace Australia (BAe (Aust)) who had been involved with the system prior to and during the purchase and initial acceptance trials, was called upon to identify the interaction with aircraft sensors and avionics systems. The analog interface unit, unique to the F-111C, was given special attention. Existing studies such as the Pave Tack error propagation study by General Dynamics[12] and models of weapon trajectories, the ballistic computer unit and the atmosphere developed by the RAAF Pave Tack Office at McClellan Airforce Base, California[20] were examined to determine whether they could be incorporated directly or conceptually into the proposed simulation. Although a great deal was learned from these models, their philosophies were not compatible and computer code, where available, was not readily transferable. IRDS studies done at the DSTO were also examined to ascertain their possible incorporation into the simulation.

It was determined that a new model, referred to as the "F-111C Pave Tack Simulation (FPTS)", should be developed in the then Combat Systems Division (CSD), and was to be a simulation in time of the Pave Tack system and other relevant associated processes. Pave Tack performance is critically affected by a number of factors including the human operator, sensors, aircraft avionics, the aircraft's flight path and the environment. Decisions on what subsystems to include had to be made, and methods for incorporating them into a simulation model had to be determined. The size and complexity of the simulation also had to be kept at a level enabling the overall simulation model to run in a reasonable time, while maintaining the accuracy of the sub-model results commensurate with the desired overall accuracy of the study. To achieve this trade-off, it was necessary in a number of cases to deviate from the simple expedient of simulating the actual avionics system in an appropriate amount of detail, and instead to simulate something like it, ie a system which was partially or wholly generic.

In deciding what was a true representation of the systems to be modelled, many sources were used, numerous errors had to be corrected and many ambiguities and conflicting statements had to be examined carefully and resolved. This report as well as providing an overview of the model, represents the only definitive statement of the ratified versions of equations and procedures governing the precise operation of the model. A number of systems were dealt with separately, including the inertial navigation system[10,37], the manoeuvre controller[24,25,26], the aircraft flight model, the human operator[36], the terrain following radar[14] and the terrain model[4,15].

During the early stages of the study, information on the performance of Pave Tack was required for the System Segment Specification for the F-111C Avionics Update Study being conducted by the RAAF. This work was done under the auspices of AIR 86/166 by BAe(Aust) under the direction of the DSTO. That aspect of the work is published in references 7 and 8.

2 FPTS MODELLING CONCEPTS

When formulating a concept for modelling the Pave Tack system, it very rapidly became evident that it would not be sufficient to concern ourselves with only the contents of the pod. The number of factors and subsystems to be simulated quickly escalated following deliberation on parameters which needed to be considered (see Figure 1). There is a constant interchange of data between the pod and the aircraft's on-board computers, in particular the Inertial Bomb Navigation System (IBNS) and the Central Air Data Computer (CADC). Since Pave Tack is a digital piece of equipment and the aircraft systems are analogue, these interchanges must be done via an Analogue-to-digital/digital-to-analogue Interface Unit (AIU). The motion of the aircraft also must be considered. Because of program size and run-time considerations this required an off-line flight and manoeuvre controller simulation. Information from a number of sensors is used and these, listed in the second column of Figure 1, include:

(a) Imaging devices: radar, passive infrared and visual sensing,

(b) Position sensing devices: the inertial navigation system, the infrared laser range finder, the terrain following radar and the low altitude radar altimeter,

(c) Atmospheric parameter sensors: pressure altimeter and wind speed sensor.

The simulation of these sensors calls for models of environmental and cultural parameters including the atmosphere, terrain elevation, vegetation, targets used for navigation updates (referred to as offset aimpoints) and weapon targets (referred to as mission targets). During target tracking prior to weapon delivery and when the Pave Tack system is used for navigation updating, the F-111C Weapons Systems Officer (WSO) is required to position and maintain cross hairs on the target. Although the system provides rate assistance, the human performance must be simulated. In order to provide a measure of the effectiveness of weapon delivery using Pave Tack, it is necessary to use weapon delivery models. These can vary from six degree of freedom flight models[14], through to quite simple point-mass trajectory estimates such as that in [8]. The resultant model, although designed to predict the performance of the Pave Tack system, encompasses a number of subsystems, some of which are useful in their own right and can be extracted as separate modules. Details of the program philosophy and structure are given in Section 12.

3 THE PAVE TACK POD

The Pave Tack system, manufactured by Ford Aerospace, consists of a pod mounted on the aircraft fuselage and associated cockpit displays and controls. It includes or incorporates the following:

SDU - Signal Distribution Unit
LCP - Laser Control Panel
PT Pod - Pave Tack Pod
PTCP - Pave Tack Control Panel

The system includes the Pave Tack Operational Flight Program (OFP) used by the digital computer resident in the pod base[30]. When referring to the pod in this simulation we will generally be concerned with its mode of operation, viewing direction and the flow of information to and from its digital computer. To put these into perspective it is necessary also to have some understanding of the physical layout and the relevant components. The F-111C Pave Tack system is complex and the reader is referred to Appendices II through to XII for details of the aspects that were included in the simulation and the equations and procedures which define its operations.

3.1 Pod location and structure

In the F-111C, the pod is fitted into the fuselage weapons bay. It is completely contained within this bay during take-off or landing or when not in use, but is lowered to a position just outside the fuselage for use. The deployment sequence of the pod is illustrated in Figure 2. The double gimballed turret is at the rear of the pod. Problems relating to the strain of the pod and the aircraft (which can be considerable) have been omitted since a "g-load patch" to the OFP to counteract the effects of bending under load is available, although it is not yet installed on the aircraft. A detailed description of the Pave Tack system can be found in references 1 and 2. Figure 3 shows the Pave Tack pod indicating the arrangement of its main components. It is divided into a Base Section Assembly[1] and a Head Section Assembly. A turret in the Head Section contains an optical bench on which are mounted the FLIR, laser designator, laser range receiver, and the stabilised sight.

3.2 Pod dynamics

When the pod is operational, the base is fixed with respect to the aircraft and the head can rotate in roll with respect to this base and the turret can rotate in pitch with respect to the head. These two forms of rotation are known as *outer roll* and *outer pitch* or rotations through outer gimbal angles and provide full lower hemisphere line-of-sight (LOS) coverage. They are used as coarse aiming devices for placing the pod sightline on the target. The mirror in the stabilised sight is free to rotate in azimuth and elevation. These two forms of rotation are known as *inner pitch* and *inner yaw* or rotations through inner gimbal angles and are used to provide fine adjustments to the pod sightline. Positioning of the pod sightline is therefore achieved by at most four rotations - outer roll and pitch and inner yaw and pitch. These coarse and fine motions are represented in the model. The "optical bench" is stable and accurate enough to warrant not modelling it explicitly; its small alignment errors are represented statistically.

4 PAVE TACK SYSTEM MODES OF OPERATION

It is advantageous to understand the typical modes of operation that are used in an F-111C flight mission and how such modes are processed, both in the actual system and in the FPTS. There are two distinct stages of operation that can occur repeatedly during a mission, namely target (or any other aimpoint) acquisition and navigation updating. The two modes of pod operation that correspond to these stages are the search and track modes respectively. Track mode is also used to maintain target designation during weapon delivery. These modes are discussed in the following sections. It will be apparent that the effectiveness of the Pave Tack system is considerably influenced by the WSO's ability to carry out a number of duties[36]. It is also important to note that the Virtual Image Display (VID) unit has two screens: the primary and the secondary; the primary screen is the larger. This allows the operator to view both the return of the attack radar and the infrared image from the PT pod simultaneously. PT is said to be *prime* if the pod display occupies the primary screen and the radar the secondary. Similarly radar is prime if this screen allocation is reversed.

4.1 Pave Tack search modes (target acquisition)

There are five search modes which are operator selectable. These are forward acquire, left acquire, snow plow, terrain monitor and cue modes. These modes are used in the visual acquisition of the target and other landmarks and are selected via push-button switches on the Pave Tack Control Panel (PTCP).

In *forward and left acquire modes* the pod sightline is electrically caged to the aircraft reference frame. In forward acquire mode the pod sightline is pointed directly ahead of the aircraft and at some depression angle relative to the aircraft longitudinal (Y) axis. This differs from the standard use of axes to conform with the pod usage. If PT is prime then the operator can make adjustments to this depression angle via the thumbtracker control on the Antenna Indicator Control (AIC). Left acquire is a similar mode where the pod sightline is now directed along the left wing of the aircraft and at some operator-adjustable depression angle relative to the negative X axis of the aircraft reference frame.

In *snow plow mode* the pod sightline is fixed in inertial space and is particularly useful for searching along straight roads and similar terrain features. With PT prime, the inertial position of the sightline can be altered by the operator depressing the enable switch on the AIC to half-action and moving the AIC handle. When in *terrain monitor mode,* the sightline of the pod is coincident with the velocity vector of the aircraft. The sightline location is not adjustable by the operator in this mode of operation.

In *cue mode* the pod sightline is slaved to a specific ground-based position determined by the navigation system. This position can be either that of the target or an offset aimpoint. The aimpoint can be selected in-flight by the operator. The position of the target (mission destination) is described by latitude and longitude, and offset aimpoints are characterised by their positions relative to the target. Alteration of the sightline position when in cue mode can be achieved by the operator depressing the enable switch on the AIC to half-action and moving the AIC handle. This mode of operation is known as *coarse cue* and is generally used prior to placing the pod in track mode and achieving navigation updates.

Manual repositioning of the pod sightline when in a search mode is achieved through outer gimbal rotations of the pod head and turret. The operator must manually compensate for any aircraft motion when moving the sightline to the desired position; he is not automatically assisted in any way during this task. For this reason such adjustments are referred to as coarse.

4.2 Pave Tack track modes (target designation and navigation updates)

There are two modes of operation associated with target designation and navigation updating, namely track and memory point track (MPT) modes.

Track mode can be entered only if Pave Tack is prime and is selected by momentarily depressing the enable switch on the AIC to full action and then completely releasing it. Track mode must be entered in order to generate navigation updates to the stored destination (target) or present position (aircraft). It is also a crucial stage in the weapon delivery process. Both navigation updating and weapon delivery are discussed later. When in track mode the operator must endeavour to keep the pod sightline on the target by making fine adjustments to the pod inner gimbal angles via the thumb joystick on the AIC. The operator is rate-assisted in this task by signals generated in the pod which attempt to nullify sightline drift caused by aircraft motion. When in track mode the laser range finder can be fired and is used to give a precise value for aircraft-to-target range and an invaluable aid in the navigation update and weapon delivery processes.

Memory point track mode is automatically entered if during track mode the pod sightline attempts to pass through some part of the aircraft fuselage or a region where the laser is not permitted to fire. MPT can also be manually selected if for example the target image is obscured by terrain or some terrain feature. Manual selection is achieved by momentarily depressing the enable switch of the AIC to half-action. Track mode is reselected automatically with use of the thumb joystick. When in MPT mode the pod computes sightline position in a similar manner to that inherent in track mode. MPT is also invoked when the radar is made prime whilst in track mode.

The attack radar can also take on a number of modes for navigation purposes. Generally the radar cursors locate the same ground point as that viewed by the PT pod. However, if the target does not provide a satisfactory radar return, differential sighting can be selected where the radar cursors are slaved to some offset position while the pod sightline continues to be directed at the target. Navigation updates (using target or offset returns) can also be generated by using the AIC with the radar prime.

4.3 Pave Tack navigation and navigation updates

The mission destination or target coordinates are stored prior to the mission in the Navigation Computer Unit (NCU). The coordinates used are latitude and longitude. The positions of up to six offset aimpoints can also be stored. There is also the facility for a manual offset which can be input by the WSO during the mission. An offset is generally a distinct landmark either in the vicinity of the target or en route to the target. An offset close to the target may be known to provide a better radar or infrared return than the target itself and can therefore serve to assist weapon delivery and navigation in the final stages of the mission. During flight the aircraft's present position (latitude and longitude also) is calculated by the Inertial Navigation System (INS). In the FPTS the present position is calculated by integrating the inertial velocity components of the aircraft.

Navigation is achieved by either great circle or short range navigation procedures. The solution to the navigation problem gives the desired aircraft heading, components of aircraft-to-target range and time-to-go. Great circle navigation is used for distances exceeding 200 nautical miles and uses spherical geometry to give the great circle route between the aircraft and target. This gives the route of shortest distance but, due to meridional convergence, necessitates that the aircraft continually change heading. For distances less than 200 nautical miles, short range navigation is employed which solves the navigation problem by considering a rhumb line on the earth's surface which makes the same angle with each meridian. Aircraft heading is therefore kept constant in this mode of navigation. The effect of earth curvature between the aircraft and target is also considered.

Navigation errors can result from a number of sources including inaccuracy in the stored target or offset positions, instrumentation errors and INS imprecision. Such errors can accumulate throughout a mission. The use of navigation updates is therefore critical to the overall mission effectiveness. Updates can be applied to destination and present position, aircraft altitude and aircraft and wind velocity. As an illustrative example, position updating is discussed below.

A position update can be applied to either the stored destination (ie the target) or the present position of the aircraft and the selection is made via a switch on the Radar Control Panel (RCP). The need for a position update will be most apparent when the cursors of the PT or radar display are not satisfactorily superimposed over the return of the target or offset viewed (when in cue mode). The navigation update process essentially adjusts either the stored target or aircraft position such that the above condition is satisfied. The use of the PT system in navigation updating is outlined below where landmark is used to refer to either the target or offset.

(a) The position to be updated is selected as either the destination or present position.

(b) Pave Tack is made prime.

(c) The pod is put into coarse cue mode and the pod sightline is coarse aimed at the landmark.

(d) When the WSO is satisfied with the coarse aiming, the pod is placed in track mode and the operator then makes fine adjustments via inner gimbals to the sightline in order to maintain the PT crosshairs over the landmark or a specific part of that landmark. The inner gimbals of the optical mirror have limited travel and for this reason the pod is continually adjusted in outer roll and pitch. These adjustments are such that the pod constantly attempts to nullify the inner gimbal angles so that the limits of travel are not reached.

(e) To achieve the best update the laser is fired at the designated aimpoint. The returned signal of the laser gives the range between the aircraft and the aimpoint.

(f) The position of the pod sightline relative to the aircraft reference frame and velocity vector determines the method used to compute correction signals for navigation updating. For example, if the sightline is at too shallow a depression angle with the horizontal inertial plane then the laser range is considered unreliable and correction signals are generated by other means. The numerous checks that are carried out are described when discussing the FPTS. The operator must track the landmark for a number of seconds before the navigation update is regarded as satisfactory. The navigation update is directed to the stored target or aircraft position as selected in step (a) above.

It is possible to achieve navigation updates using the attack radar as follows:

(i) The position to be updated is selected as either destination or present position.

(ii) Radar is made prime.

(iii) The enable switch on the AIC handle is held at half-action and the handle moved such that the radar cursors are superimposed over the desired position. Correction signals are then generated based on the new cursor positions which are used to update the required position selected in step (i).

Use of the Pave Tack system is considered more accurate owing to the availability of the laser range finder. Aircraft and wind velocity updating is conducted in a similar manner to that for position updating. The aircraft altitude above the target is continually computed in the NCU throughout the mission by using information from the pressure altimeter which is calibrated using data provided by the Low Altitude Radar Altimeter (LARA). This altitude is also corrected further by conducting an altitude update in an identical manner to position updating where the approach is then known as HAT (Height Above Target) calibration. HAT calibration involves comparing the altitude obtained from the laser range with that of the pressure altimeter to give the appropriate correction signals to the aircraft altitude.

4.4 Weapon delivery

The NCU can be set to one of three weapon delivery or bomb modes. These are referred to as the trail, range and auto bomb modes. For each mode the NCU computes the weapon release point for a ballistic missile based on navigation information (aircraft altitude, heading and distance from target) and the expected ballistic time or range of fall to target impact for the selected weapon type.

If trail mode is selected then the expected time of fall and trail of the missile is manually inserted by the operator. Similarly, if range mode is used then the operator specifies the anticipated range of travel of the missile between weapon release and impact. In the auto weapon delivery mode the ballistic information is calculated automatically within the Ballistics Computer Unit (BCU).

It is very important that a navigation update (particularly in aircraft altitude) has been achieved prior to weapon delivery. In the case of laser guided bombs (LGB), target designation must be maintained by using the pod in track mode with laser fire.

4.5 Damage assessment

The rotational dynamics of the pod, as discussed in Section 3.2, are such that the Weapons Officer can continue to view the mission target after weapon impact. This fea particularly useful for damage assessment purposes which can be carried out aircraft egresses from the mission target area.

5 PAVE TACK SYSTEM PROCESSING AND POSITION UPDATING

When the pod is in track mode, operator adjustments are required to update the position of either the destination or the aircraft and the resultant accuracy of the update is therefore dependent upon the operator's ability to maintain target designation during this mode of operation. However, it is necessary for the analyst to know with high accuracy the actual positions of the aircraft and destination at any time. The formulae used in the calculation of precise aircraft position are detailed in module 10.5 of the FPTS. It should be noted that the *precise* quantities can still be subject to some level of inaccuracy. The formulae for such quantities utilise inertial velocity components and pressure altitude rate which are sampled in a discrete fashion and therefore typical time-related errors can result. The actual position of the target is currently taken to be the position stored at the outset of the mission. From these positions are calculated precise inertial range and range components between the aircraft and target. Apart from providing an invaluable tool for assisting program debugging, there are currently two uses for these parameters.

(a) Target image: the positioning of the target image within the FOV of the PT display is a function of the exact relative positions of the aircraft and target and is not susceptible to any system error. The precise positions of the aircraft and target are therefore used for this purpose. The image display aspects of this simulation are detailed in reference 36.

(b) Laser range: the laser is only fired when Pave Tack is prime and the pod is in track mode ie when the operator is providing target designation. In the case of a perfect operator, the laser range is the most accurate value of aircraft-to-target range available. In this situation therefore the range between the precise positions of aircraft and target is taken as the laser range. The precise value for aircraft altitude is also used with a manual operator to give the range between the aircraft and the point on the ground designated by the pod sightline ie the laser range to the designated aimpoint. The nature of the terrain at the aimpoint will also affect the returned laser range; the simulation currently assumes level terrain in the immediate vicinity of the target or any offset.

It should be noted that there is no time delay between laser range or target image calculations and the application of these computations. Although the individual precise values of the aircraft and target parameters can have some inaccuracy, no additional time-related errors are introduced.

The terms *precise* and *system* will be used to distinguish between the above mentioned parameters and the equivalent terms in the actual F-111C system and the simulation. For example, system range components will refer to the range between the aircraft and target positions as perceived by the system ie of variable accuracy. Precise range components describe the distance between the precise positions of the aircraft and target: known to the analyst but not the system. The use of precise quantities will also greatly assist any studies of system performance.

5.1 Processing in cue mode and position updating using the radar

When in cue mode the sightline of the PT pod is directed at either the stored destination or one of the stored offset aimpoints. The cursors of the attack radar screen are also superimposed over the same point unless differential sighting is selected. The NCU computes information concerning navigation to the stored destination and data describing the geometry between the aircraft and the aimpoint (destination or offset) viewed at any particular instant. This information includes present position latitude and longitude, ground track, ground speed, slant range to aimpoint, altitude above aimpoint, relative bearing of aimpoint and time or range to weapon release.

To obtain position updates using the radar the operator adjusts the position of the radar cursors by depressing the enable switch on the AIC handle to half-action and moving the handle. A schematic representation of the control mechanism for this mode of operation is illustrated in Figure 4 where the VID shows the necessary condition of radar prime. Operator adjustments are interpreted by the SDU and AIU as along track and cross-track signals which are fed into the NCU. The NCU uses this information to compute new values of slant range, relative bearing, altitude etc. which relate to the new aimpoint dictated by the operator. This analog information is converted to digital by the AIU and, via the SDC (for radar) and SDU (for PT), is used to alter the cursor positions and alphanumeric data on the radar and PT displays. A detailed report on the display aspects of the FPTS can be found in reference 36. The NCU also uses this information to update the position indicated by the RCP (ie destination or present position). The operator ends the navigation update by releasing the enable switch.

The pod is put in coarse cue mode if PT is prime and the enable switch held at half action. Movement of the AIC handle in this mode adjusts the position of the pod sightline and the display features are modified in a similar manner to that in the radar procedure above. It is important to note that no navigation updates are carried out in the coarse cue mode. However, range trims are calculated and these and the corresponding ranges to the aimpoint are used as initial values in the navigation update procedures if track mode is selected immediately after coarse cue. Also sightline slewing signals from the AIC handle are processed immediately after entering coarse cue mode; there are no time delays inherent in the control mechanism for this mode of operation.

The operator may revert back to cue mode from coarse cue by releasing the enable switch on the AIC handle. However, the PT pod and radar are still directed at the aimpoint designated prior to leaving coarse cue mode. The system attempts to maintain this designation by applying rate signals to the pod sightline in a similar manner to that used in MPT mode. Coarse cue can be re-selected by the usual procedure. Pressing the CUE button on the PTCP redirects the PT pod and radar to the stored position of the destination or offset originally viewed.

5.2 Processing in track mode and position updating using the pod

Navigation updates are achieved by first depressing the AIC enable switch to full action and then releasing it, placing the pod in track mode. When in this mode, the operator adjusts the position of the pod sightline by movement of the thumb tracker or thumb joystick on the AIC. The control mechanism for this mode of operation is shown schematically in Figure 5. PT must be prime in order to select track mode and this is illustrated by the PT pod display being the primary VID screen in this figure.

The pod sightline is adjusted by velocity trims computed by the OFP in the pod. These trims are calculated using aircraft velocity and altitude. slant range, pod sightline directional cosines and the manual inputs from the thumb tracker. Within these trims are also incorporated rate-aiding components which assist the operator in target designation by automatically compensating for aircraft motion.

The pod also translates the sightline repositioning signals into range trims for use in navigation updating. These range trims are converted to along track and cross track correction signals which are referred to as pseudo cursor commands. These correction signals are then used by the NCU to compute slant range, relative bearing, altitude etc. to the aimpoint in an identical manner to that used in position updating with the radar and coarse cue mode. Similarly this data is used to modify the features of the PT and radar displays on the VID. The NCU also uses this information to update the present position of the aircraft or the stored destination. The position to be updated is determined by settings on the RCP.

If conditions permit, the laser can be fired when in track mode. The returned laser range to the aimpoint is used in calculations of sightline velocity signals and the pod range trims. Operator adjustments are filtered in the OFP and hence there are subsequent time delays between manual movements of the thumb tracker and the acceptance and use of these signals for navigation updating. The operator has to therefore track for some time (nominally 16 s) in order to achieve a satisfactory update. The inherent time delays and different forms of position updating are shown in Figure 6 and discussed below. Details of the filters used in the processing of operator correction signals can be found in the relevant modules of Appendices II through to XII.

The following methods of navigation updating are listed in order of increasing priority.

(a) Azimuth only updating

Range trims are considered to be not available if the pod sightline is within a cone of 15° half-angle about the aircraft's velocity vector. If this case arises then navigation updating is achieved in azimuth only. Pod range trims are calculated by considering the azimuth component of adjustments to the sightline such that the pod slant range is maintained at a constant value. These range trims are then fed to the NCU to achieve the corresponding position update. This method of updating is also used when range trims are available but the sightline is at a depression angle of less than 15° with the horizontal inertial plane. There is approximately a 1.5 s delay between entering track mode and the initiation of azimuth only updating.

(b) Updating using geometric and kinematic ranges

If range trims are available but the laser range is not and the depression angle of the pod sightline is greater than 15° then updating is achieved by using geometric and kinematic range components to the aimpoint. Geometric range components are initialised to those calculated in cue or coarse cue modes. Kinematic ranges are derived from the slewing rates of the pod sightline. Both geometric and kinematic ranges are used to generate the range trims for navigation updating. As the target or offset is tracked, the geometric ranges are weighted less and the kinematic range components are given more loading. If track mode is entered after coarse cue then the range trim computations are initialised using those trims computed in coarse cue mode. Pod range trims are available for position updating approximately 1.25 s after entry into track mode with an additional delay of about 1 s within the AIU.

(c) Updating using the laser range

If both range trims and laser range are available then navigation updating is achieved by using the pointing angles of the pod sightline and the laser range to the aimpoint. X, Y and Z range trims are computed by the pod and are available for position updating about 1.3 s after entering track mode and after the laser range is deemed reasonable. This method of updating is given the highest status.

The operator can exit track mode by momentarily depressing to full action and then releasing the enable switch or by selecting a different search mode on the PTCP. If the former is used then the system will revert back to the search mode (ie cue mode in the case of the FPTS) that was previously active.

6 THE ANALOGUE INTERFACE UNIT

The Analog Interface Set (AIS) on the F-111C was developed by General Dynamics and consists of two Line Replaceable Units (LRU) namely the Pave Tack Auxiliary Panel (PTAP) and the Analog Interface Unit (AIU). The PTAP provides controls which enable the operator to select a number of functions in the AIU. The AIU provides the data conversion, processing and retransmission necessary to facilitate coherent information transfer between the F-111 analog avionics and the digital Pave Tack and Harpoon weapon systems. The AIU processes and directs the signals between the numerous units as illustrated in Figure 7 and maintains the correct system response between the analog avionics and the PT and Harpoon systems[2].

7 AVIONICS SYSTEMS

To understand the F-111C Pave Tack system it is necessary to have knowledge of the numerous analog and digital units that were included as part of the Pave Tack fit or that already existed in the F-111C aircraft and are used by the Pave Tack system. The timeliness and accuracy of the transferral of information between these units must also be considered.

7.1 The Central Air Data Computer

The Central Air Data Computer is not modelled explicitly but its functions are implicit in numerous calculations and operations throughout the FPTS.

7.2 The Inertial Bomb Navigation System

The F-111 is fitted with the AN/AJQ-20A Inertial Bomb Navigation Set (IBNS), reference 11, which is a dead reckoning analogue inertial system in which the stabilised platform, navigation computer and automatic ballistics computer are relevant to this simulation. The stabilised platform is a four-gimbal, all attitude inertially stabilised system supplying pitch, roll, true heading, vertical acceleration, and north and east components of groundspeed. It also indicates reliability of its output data.

The IBNS has the following Line Replaceable Units (LRU):

SPU - Stabilised Platform Unit
NCU - Navigation Computer Unit

BCU - Ballistics Computer Unit
MOAP - Multiple Offset Aimpoint Panel

Prior to flight the system can be aligned using a number of methods, the most common of which is gyrocompass alignment. The navigation computer is a self contained navigation steering, radar sighting and bombing computer, utilising inputs from the stabilised platform and true airspeed and pressure altitude from the CADC.

The F-111C Pave Tack/Guided Weapons (PT/GW) system provides improved navigation and weapon delivery capabilities by using the existing IBNS. It was necessary to decide how this system should be incorporated into the overall model. After an examination of information on the IBNS system it was concluded that a detailed model of it was beyond the scope of the task. The problem was dealt with by splitting the IBNS into an inertial system, which was modelled generically, and aspects of the bombing computer which were incorporated more specifically.

7.2.1 The Inertial Navigation System

There was a considerable amount of manufacturer and acceptance trials data (see reference 13, for instance) available about INS under cruise conditions but almost none on what happened to INS errors when the aircraft was accelerating. A study[10] was carried out to determine a suitable generic model to represent the stabilised platform and navigation computer with a fidelity commensurate with the requirements of this study.

Three generic models, ranging from a simple forced harmonic oscillator model to a 3-gyro, 3-accelerometer model, were compared. Programmes were developed for the two simpler models and the output from these was compared to results published for the more complex model. Both position and platform (attitude) errors were considered under cruise and accelerated conditions and considered the trade-off between detail of representation (accuracy) on one hand and development effort and run time of the computer models on the other.

The intermediate model was found to give suitably reliable predictions of INS position and orientation errors for up to 2 hours flight time under cruise conditions, while satisfying time and complexity restrictions imposed by its intended role in the overall Pave Tack effectiveness model. In addition the model was able to predict the effect of linear and centripetal accelerations on these errors. The latter have not been verified because of the lack of available trials data.

7.3 The Terrain Following Radar computer

The missions with which we were concerned included low level segments utilising Terrain Following Radar(TFR), particularly in the vicinity of the weapon release area. This model is based on the AN/APQ-110 TFR set in the F-111C aircraft. The TFR computer is an analogue control system. Its objective is to generate commands to the aircraft autopilot which ensure that the aircraft flies at a selected altitude h_0 above the terrain, subject to specified smoothing or "ride hardness" constraints. The data used for the command calculation consist mainly of the angular position of the terrain referred to the aircraft longitudinal (roll) axis, and the associated range supplied by the TFR. However, when the terrain is relatively flat, information from the altimeter, ie the AN/APQ-167 Low Altitude Radar Altimeter (LARA), is used, see Section 9.2.

The TFR command computation uses only the pitch plane. (see reference 21 for details) The algorithm by itself effectively commands the aircraft to fly directly at a point which is a height h_0 above the highest terrain in the radar field of view. It does not produce a path which follows the terrain at a height h_0 above it. In the AN/APQ-128 computer, the procedure is modified and has a range dependent function which also incorporates a "ride hardness" coefficient.

The attack radar is used as the TFR sensor and its antenna scans up and down through the range (-32°, 8°) relative to the aircraft longitudinal axis. The antenna scan cycle time is 1.33 seconds. The command computations are performed on each transmitted return (ie for each range and elevation scan angle.) If the TFR does not receive range information in the interval (3500,4500) ft, which could occur in terrain with poor radar reflectivity or inappropriate geometry, then a quantity referred to as the "altimeter override command" based on information from the altimeter is calculated.

If the radar altitude drops below 68% of the set terrain clearance height, information is passed to the autopilot to indicate a maximum (2g) pull up. This situation should never occur with the model but a check is made and an error would be flagged for this case.

The Harpoon Weapon System was not specifically implemented, but could be incorporated without extensive remodelling and involves the following LRUs:

HIU - Harpoon Interface Unit,
DPC - Data Processor Computer,
HCP - Harpoon Control Panel,
HM - Harpoon Missile.

8 AIRCRAFT FLIGHT SIMULATION

The flight of an aircraft can be quantified by specifying the values of a selected set of parameters describing the state of the aircraft at discrete intervals of time. The set of parameters chosen can be ordered to form the elements of a vector $\underline{x}$ known as the state vector. The desired accuracy of representation determines how many, and which parameters are used and the observation interval. The models selected for generating flight path data were required to be suitably accurate while fast enough to be used as part of the overall Pave Tack performance model.

8.1 Point mass models

If the mass of the aircraft is considered to be concentrated at its centre of gravity, its state vector can be completely specified by its position (x_E, y_E, z_E), velocity $(\dot{x}_E, \dot{y}_E, \dot{z}_E)$ and acceleration $(\ddot{x}_E, \ddot{y}_E, \ddot{z}_E)$ known as a three degrees of freedom or point-mass model described by a nine-element state vector.

Essentially the aircraft, with its mass considered to act at its c of g, is assumed to follow the applicable laws of motion and in addition is considered to be subjected to an aerodynamic drag force which is dependent on speed, and of a magnitude appropriate to the aircraft under consideration. The forces acting on this point are therefore gravity, aerodynamic forces and the thrust exerted by the aircraft's engine.

A study of point-mass models was needed to establish their accuracy, in particular for representing the F-111C aircraft. Detailed empirical aircraft flight parameter data against which such models could be tested were not available. A six degrees of freedom (6DF) model of the F-111C was available at the Aeronautical Research Laboratory (ARL) but it is necessary to specify commands which emulate a pilot's manipulation of the aircraft controls in order to "fly" the aircraft model. The manoeuvre controller model required to do this was not available in the case of the F-111C. However, an ARL 6DF Mirage III model and a manoeuvre controller, produced by the Department of Electrical and Computer Engineering at the University of Newcastle for the Aeronautical Engineering

Laboratory, was available and was considered to be suitable for determining the feasibility of using point-mass models in the Pave Tack performance study. The Mirage manoeuvre controller was capable of simulating a number of standard manoeuvres, including: step change in thrust, altitude change, pushover, pull up, and turn at constant speed and altitude. It was decided to use altitude change as the initial basis for comparison of the predictions of the point-mass models and the Mirage III 6DF model.

Of the various propositions for models, the most promising were the "constant nett thrust" type, in which it is assumed that the nett effect of the thrust minus the drag is constant, and "balanced power" category in which the engine is assumed to maintain a constant power output, and that energy losses are due to overcoming the aerodynamic drag and gravity. These types of model are discussed in reference 14.

The conclusions from the point mass study were that at least one parameter can be matched to any desired accuracy, but this may involve a long and intricate sequence of control selections, which can only be determined empirically, ie by comparison with a model such as the Mirage III 6DF model and that no simple rules could be determined for predicting the control sequence of values. Furthermore while optimising one such parameter to obtain a good match some or all of the other relevant parameters were invariably grossly inaccurate. It was therefore necessary to reject point-mass models as a means for deriving flight path data in combat systems performance models for the Mirage III, and by implication for the F-111C, in all but the most elementary applications.

8.2 Six degrees of freedom models

Considering the aircraft to be an extended object we can incorporate three new degrees of freedom, yaw, pitch and roll (ψ,θ,ϕ), and the related aircraft angular velocities (p,q,r) and aircraft angular accelerations $(\dot{p},\dot{q},\dot{r})$, see reference 19. This is known as a six degrees of freedom model. Some, or all, of these eighteen quantities are used to specify aircraft flight path in combat systems performance models.

Since the study in reference 14 had indicated that point mass models were not adequate, a contract was let to the University of Newcastle's Department of Electrical Engineering and Computing Science, to produce a manoeuvre controller for the ARL 6DF F-111C aircraft model. The resulting combination is a full nonlinear six degrees of freedom aircraft model, which includes the full flight control system, and allows the following ten manoeuvres:

(i) Step change in thrust,
(ii) Level flight acceleration / deceleration,
(iii) Push-over, pull-up,
(iv) Pull-up,
(v) Turn at constant velocity and altitude: bank angle or acceleration specified (the latter as a constant times g),
(vi) Turn at constant speed and altitude: angle of attack specified,
(vii) Altitude change,
(viii) Dive and climb,
(ix) Altitude change and turn,
(x) Full turn.

Manoeuvres (iii), (iv) and (vii) can be performed at either constant speed or constant thrust settings.

Simulated flight is determined by selecting the setting and duration of the following controls; thrust-lever, longitudinal and lateral stick, and rudder pedal position (defined as fractions of full travel). The user selects a manoeuvre and nominates values for the appropriate options. The software computes a sequence of controls which will produce the desired manoeuvre, and then implements these controls, recording the position, orientation and the values of a number of aircraft parameters at specified intervals of time. This information can be recorded for use in a Pave Tack simulation or displayed in numerical or graphical form.

The aircraft model can be flown with a wingsweep of 16°,26°,35° or 45°. Because of the high speed dynamics inherent in the flight control system, the simulation time step can be varied and is currently given by a cycle time of 160 Hz. A database of aerodynamic derivatives specified as functions of Mach number, altitude and aircraft angle of attack is sampled at 0.5 s intervals, with interpolation and filtering as appropriate. Atmospheric conditions are updated at every time interval and are based on the International Standard Atmosphere.

A desired flight plan can be split into a sequence of standard manoeuvres. The path data generated by the model for each manoeuvre can be used to determine the initial conditions for the next one and the resulting output files combined to form a continuous record of relevant data for the complete flight path. Manoeuvres are currently limited to 320 s, but this value can be extended if necessary. A further constraint is the need to separately maintain a record of the estimated fuel usage as this affects the aircraft weight and therefore has a significant effect on the computed path and aerodynamic data. Tables of fuel usage rates have been supplied by ARDU. A number of typical flight paths have been processed, including some used in references 7 and 18 to enable comparison with navigation and weapon delivery results published in those references.

8.3 Aircraft model for use in the terrain following mode

Since the F-111C's terrain following mode is an option which must be considered, and the model described above could not be used for this purpose, it was necessary to develop a specific flight model for use in the terrain following radar mode. A lateral/longitudinal decoupled, generic flight model operating only in the longitudinal plane, and made specific to the F-111C by adjusting its parameters to match the output from an F-111C aerodynamic model at Aeronautical Research Laboratory, was developed.

The aerodynamic equations are readily integrated numerically, and this was done initially, using the non-procedural system simulation language SYSL[27,29]. The trade-off between accuracy and computing time, bearing in mind the intended use of the TFR model, can readily be established. Although direct integration is reasonable for studying the problem, when incorporating this F-111C TFR model into the Pave Tack system performance model, solution speed was improved by first integrating the equations analytically, reducing them to a set of discrete convolution equations, for which a solution in the form of a set of recursive relations exist. A description of the analysis can be found in reference 14. Dynamical systems described by state models can be assessed, by determining a number of system properties including its reachability, controllability, stability and reconstructability. Brief descriptions are given in reference 14 and were used to ensure the appropriateness of the solutions proposed in this section.

The overall TFR model consisted of the combination of elements described in Sections 7.3 and 10. At each cycle of the TFR model the demanded elevator deflection was calculated and used in the aircraft aerodynamics equations. The aircraft position was then computed, allowing a further calculation of demanded elevator deflection. Examples demonstrating the performance of the TFR model can be found in references 14 and 27.

9 AIRCRAFT SENSORS

9.1 Attack Radar

The F111-C aircraft's Attack Radar Set (ARS) is used for navigation and fixtaking. It consists of the following LRUs:

VID -	Virtual Image Display
SDC -	Signal Data Converter
- -	Radar Synchroniser
RCP -	Radar Control Panel
AIC -	Antenna Indicator Control
ACU -	Antenna Control Unit

The radar antennas scans in azimuth, either ±45° about the longitudinal axis of the *aircraft, or ±10° about the azimuth cursor and is stabilised* in pitch and roll. The VID presentation is stabilised with drift angle from the NCU, so the direction of ground-track is displayed vertically in the centre of the display. The VID and AIC are represented in the interactive model [36].

9.2 Altimeters

The aircraft obtains height information from the AN/ APQ 167 Low Altitude Radar Altimeter (LARA) and a pressure altimeter. The former is taken into account in the TFR mode [14], see Section 7.3. It was intended that a model of the pressure altimeter be developed and incorporated into FPTS. However a deterministic model was seen to be inappropriate, even if the information to produce one had been available, and the available trials data was insufficient to produce a viable stochastic model.

10 TERRAIN TOPOGRAPHIC MODEL AND MOTION SIMULATOR

To fill a requirement for a PC-based terrain topography model capable of high resolution display, a software package producing multicoloured displays of digital elevation data was developed under contract[4] to run on an IBM PC/AT with a floating point co-processor and an Ω/PC colour graphics display processor by Metheus. The latter has a 1024 X 1024 pixel screen memory of which 1024 X 768 pixels can be displayed to provide isotropic screen scaling. The screen RAM is four "layers" deep, having four bit planes in which a pixel is represented by one bit. The bit planes can be enabled or disabled allowing rapid screen swapping under host control. The planes can be shown separately as monochrome images or grouped to give 4, 8 or 16 values used for colour representation. The Ω/PC has a 256 byte memory-mapped ring buffer (circular queue) which stores display instructions from the host. These instructions are automatically implemented by the display processor when the buffer is full or by host command. A 'C' language utility library provides the software interface to the display processor.

The topography model evolved from a previous DSTOS terrain display processor designed on a PDP 11/34 computer using a Vectorix display system. The algorithms used are of DSTOs origin with the exception of the masked plot (hidden line) algorithm which is the Association for Computing Machinery "Algorithm 483"[3].

10.1 Terrain display options

The software package allows the following displays:

(i) Height contours (with or without coordinate grid lines),
(ii) Line of sight visibility "fan",

(iii) Oblique view,
(iv) Perspective view, and
(v) Point-to-point terrain height profile.

These displays are selected through a series of menus and can be saved in either pixel or plot command form for future retrieval and display. The oblique and perspective views consist of lateral cross sections taken at regular intervals to the chosen viewing direction (see Figure 8). This is unusual; most "line" terrain height displays utilise cross sections in two orthogonal directions. The form of the display chosen is implemented much faster.

10.2 Airborne surrogate travel visualisation

The lateral cross section representation was of particular importance in producing the next phase of the work in which the appearance of motion over the terrain as seen from the cockpit was simulated by retrieving and displaying a sequence of previously computed full frames in rapid succession, each one generated from a position slightly in front of the previous one. The frame rate had to be sufficiently fast to allow small increments in viewing position, for smoothness while maintaining the correct speed of apparent forward motion. Two options for generating each frame were available. First, storing each pixel (approx ¾ million) in a frame and simply reading and displaying them, and secondly storing the plot commands and redrawing each frame as required. The latter was found to be significantly faster and required less data storage.

In order to achieve the type of rapid screen swapping necessary to avoid a ragged transition from one frame to another, screen double-buffering can be simulated on the Ω/PC by representing two identical sets of colours on the two most significant and two least significant bits respectively of the 4 bit planes. Disabling the current set and enabling the other produces a frame rate of 2/s, which was not adequate because the draw commands produced line segments which were all 5 pixels long, chosen to optimise curve smoothness. A post processing procedure was incorporated to modify the command data file to remove superfluous plot commands, ie representing straight lines longer than 5 pixels by one command instead of several. This resulted in compression of the command data file by at least a factor of two and up to a factor of 12, thereby improving retrieval time. The display frame rate time was improved to approximately 6/s.

11 THE HUMAN OPERATOR

Despite the high degree of sophistication of the Pave Tack system, it is evident that the full capabilities of the system are very much reliant on the WSO's ability to carry out a number of duties. Modelling the human operator was therefore mandatory. This work covered the major recent thrust called for by the Sponsor. It involved the addition of a microprocessor to the standard 486 PC to enable rapid handling of the graphics tasks associated with the real time interactive display of the PT VID data and simulated scenes. This topic is too large to be included as an appendix in this report. The reader is referred to reference 36, although some of the functions of the human operator can be clearly seen from the modes of operation and navigation updating procedures discussed in Sections 4 and 5.

12 DESCRIPTION OF THE BASE MODEL

This model differs from error propagation models such as the one described in reference 18, in that it is a deterministic, time sequenced model which attempts to simulate specific flights. This type of model can be implemented by adopting a standard small time increment and interrogating and advancing all time dependent functions at each increment, which gives rise to problems when the order of events is important and they can be separated in time by amounts less than the standard time increment. It can also be very inefficient when many of the time dependent processes vary only slowly in time. The alternative is to compute event times in advance, arrange them in a time sequence (calendar) and allow time to progress irregularly from one event time to the next. This is referred to as event stepping and also has its problems, namely overheads in computing and maintaining the calendar, and sometimes, difficulties in predicting the time of occurrence of an event. Having examined the trade-offs it was decided to make FPTS an event-stepped model. External stimulation comes from the input of aircraft flight path data, previously computed off-line, and a Pave Tack mode selection sequence. Sensor information is generated from a knowledge of true aircraft position and is input to the sensor modules as required. At this stage in the model development the human operator interface was not included.

Information on Pave Tack procedures, and details of the interchange of data with other avionics systems via the AIU was provided by BAe Aust.[5,6]. The FPTS consists of models of the Pave Tack system, aspects of the OFP, the AIU, relevant sensors and avionics systems on which the operation of the Pave Tack system depends. The following sections provide an overview of basic information, modes of operation, and constraints considered in, or pertinent to, the FPTS. Detailed discussions can be found in Appendices I through to XIII.

12.1 Coordinate systems

A number of right-handed Cartesian coordinate systems are used in the aircraft. They have different origins and orientations. These conventions were also adopted for use in the FPTS and are detailed in Appendix I including the relationship between each system and how such transformations are used in the numerous modes of operation of the simulated Pave Tack system. For rotations from one frame of reference to another, the Eulerian angles, direction cosines and angular transformation matrices are as defined in reference 19.

12.2 Program language and structure

The model was initially coded in SIMSCRIPT because of its many built-in simulation features, including a general purpose event scheduler for implementing the event stepped type of simulation. It was found however that the graphics capabilities of SIMSCRIPT fell short of the requirement. It was a relatively straight forward task to devise a simple event scheduler in Turbo Pascal and rewrite the model in that language, giving access to a number of recently developed graphics packages.

Since the model is based on the event stepping concept, simulation time progresses in discrete, variable length steps from the time of execution of the current event to the next time at which an event is scheduled. Each event corresponds to a group of computations or procedures in the physical system described in the Appendices as a module. The event scheduler under which the model operates consists of three procedures:

(a) Activate(Event,Event_Time), which schedules an Event to occur at the specified Event_Time.

(b) Event_Handler, which, at the completion of the current event, looks at the times of all scheduled events (stored in an array according to when they were created rather than in the chronological sequence in which they were scheduled to occur) and indicates which event is scheduled to occur next. If two or more events are scheduled for precisely that time an event priority table is used to determine the sequence of executing the procedures associated with the multiple simultaneous events.

(c) Get_Event, which is used by the Event_Handler to extract the relevant information and execute the procedure corresponding to the event.

Events may be caused (scheduled to occur at some time in the future) by external processes, eg the stepping of the aircraft along its pre-defined flightpath, or by event generating circumstances within an executing event. Information is exchanged by global and local variables.

12.3 Model time sequencing

In order to achieve efficient interchange of data between the digital pod and the analog avionics systems, the AIU divides its input, output and computations into appropriate "rate groups" based on a 32 Hz main loop cycle. Five rate groups namely, 32, 16, 8, 4 and 1 Hz are used. Within the Pave Tack pod input processing and computations are performed at a main loop cycle rate of 40 Hz. The pod output processing is at a rate of approximately 240 Hz. Processing in the pod, AIU and avionics subsystems is asynchronous. Time references for the various rate groups and processes (input, output and computation) are shown in Table 1, where ∞ represents analog processing.

Since FPTS is a digital simulation, the rate group structure is readily emulated, but the analog computations and I/O procedures must be represented as discrete events occurring at rates determined by the maximum rate requirement in other areas or by accuracy considerations. Because of the AD/DA conversion and the lack of synchronisation it is possible for a spurious time lag of up to one period to occur in data transmission between different rate groups.

Table 1 Timing references

MODE	FREQUENCY IN HZ							
	∞	240*	40	32	16	8	4	1
IN				t_1	t_2	t_7	t_8	t_{13}
COMP	t_0		t_{20}	t_3	t_4	t_9	t_{10}	
OUT		t_{21}		t_5	t_6	t_{11}	t_{12}	t_{13}

* the actual frequency is 3125/13 = 240.3846

12.4 FPTS baseline assumptions

The F-111C Pave Tack Simulation (FPTS) is written with a number of baseline assumptions, viz:

(a) All avionics equipments are considered to be functional and hence procedures that are carried out in the event of any equipment failure are not included in the simulation.

(b) The operational boundaries of any piece of equipment are not exceeded.

(c) Only takes the cue search mode and coarse cue mode are used. It should be noted, however, that it would be a simple task to incorporate the other four search modes. However, these modes where not requested by the Sponsor.

(d) Great circle navigation is not used in the model and the Navigation Computer Unit (NCU) is therefore either set to short range navigation or one of the weapon delivery modes.

(e) The facility for manual offsets is not included.

(f) Memory point track mode is not considered. It should be noted that only a simple laser inhibit region, consisting of the upper hemisphere relative to the aircraft reference frame, is considered.

(g) Velocity updates are not considered.

(h) Only conventional dumb bombs or laser guided bombs (LGB) are considered as weapons.

(i) The attack radar is considered to be in GND VEL or GND AUTO modes only. The use of these modes makes it possible to select Pave Tack as prime at any time.

It can be seen that the effects of these assumptions is to limit the range of operations possible but not the accuracy of representation of those aspects simulated.

13 WEAPON DELIVERY MODELS

The types of weapon could include simple bombs, laser guided bombs and Harpoon. A number of good weapon delivery models exist for both simple and laser guided bombs. The Texas Instruments, fully validated six-degree-of-freedom model for the GBU-12B/B and GBU-10C/B laser guided bomb is available on the DSTOS, IBM ES/9000 mainframe computer[31]. In addition, a simplified version has been developed for use on either the mainframe or on an IBM PC compatible[32]. This model has been validated against the Texas Instruments model. Another faster running, simpler model was developed as part of the AIR 86/166, Pave Tack modelling task[7] and can also be used on a PC. The models also can be used for unguided simple bombs. Reference 32 deals mainly with the Mk 82/GBU 12, 500 lb bombs. It also should be possible to deal readily with the Mk 84/GBU 10 bombs and the BDU 33 practice bomb. The initial conditions necessary to use the weapon delivery models include aircraft position, orientation and motion descriptors, provided by FPTS, bomb characteristics and these models assume the bomb ejection velocities are known and no attempt is made to modify these to account for post release turbulence. A method for dealing with this is described in references 34 and 35. Launch-time information derived from FPTS can also be used as input to the HAMA software[33] for predicting the performance of the Harpoon missile.

14 DISCUSSION

The F-111C Pave Tack Simulation reported in this document was originally developed from conceptual guidelines laid down in reference 6. This base model was subsequently refined during a process of ratification, cross-checking with available literature and assessment of requirements. This process involved much communication with British Aerospace Australia and General Dynamics and Loral Aerospace of the US. The simulation has therefore become considerably refined, particularly in the areas of graphical display features and human operator interaction[36].

As well as the comprehensive work required to incorporate the manual interaction of the human operator, enhancements were made to the FPTS allowing the inclusion of a perfect operator ie one that results in zero target designation and tracking errors. This facility is very important to the analyst. The F-111C flight model is discussed in Section 8.2 and is used off-line from the FPTS to generate an aircraft flight path and provide associated information on the aircraft orientation throughout this profile. Considerable work had to be undertaken in order that the FPTS could accept and utilise this data. To incorporate the effects of aircraft orientation on the Pave Tack display, for example, required an understanding of the dynamics of the pod and representation of the numerous coordinate systems associated with the aircraft and the Pave Tack pod systems.

As an illustration of the current status and capabilities of the main FPTS, a number of sample results will be presented. These results will serve to illustrate many of the features of the FPTS that have been discussed throughout this document. For the purpose of this discussion, the results will concern the vertical, northern and eastern components of aircraft-to-target range and the system generated corrections (to perceived errors in navigation) in these directions. Errors in these range components are expressed as the difference between the system and the precise range components mentioned earlier.

It is important to note that inertial velocity components are provided by the F-111C flight path model. These components are fed to the FPTS at a rate of 32 Hz where they are integrated and used to give range components to the target or selected aimpoint. (The reader is referred to module 2.4 of Appendix IV for details of this process.) Use of these inertial velocity components can therefore result in range errors due to the discrete nature of the numerical integration. Such errors do not occur in the sample results illustrated in this section since the aircraft is considered to be flying in cruise conditions. The use of the F-111C flight path model in this manner is temporary pending the incorporation of a sophisticated INS model[37]. Cruise conditions were therefore considered so that unrealistic (ie not occurring in the true system) INS errors do not mask the inherent characteristics of the Pave Tack and associated systems.

The results presented in this section relate to a simple scenario with the following conditions:

(a) A perfect operator is assumed ie any errors traces that are illustrated are inherent in the system and not introduced by external sources.

(b) Initial aircraft latitude: 0.624145 and longitude: 2.055815 radians

(c) Altitude: 1000 ft

(d) Target latitude: 0.626600 and longitude: 2.055700 radians

(e) Aircraft speed: 984 feet/s (approximately 300 ms^{-1})

(f) Aircraft heading: 0 degrees

It should be noted that the aircraft is flying due north along a line of constant longitude such that it will fly by the target.

Figures 9 to 17 pertain to the above scenario with the assumption that, throughout the mission, there are no actual navigation errors. The simplicity of the above scenario (that of cruise conditions, zero target designation or tracking errors and actual navigation errors of zero) was purposely selected in order to illustrate the basic characteristics that are inherent in the Pave Tack configuration. The effect of actual navigation errors and how the system can be used to compensate for these, are discussed later in this section. What is illustrated in the results of this first scenario is the vertical, north and east ranges to the target as perceived by the aircraft's navigation system. It should be noted that the actual vertical range is not constant but takes into account earth curvature between the aircraft and target and hence varies during flight. Only when the aircraft is immediately above the target is the actual vertical range equated to pressure altitude.

Figures 9 to 12 correspond to the system in Cue mode. Figure 9 shows the variation with time of the error in vertical range to the target (ie the inaccuracy of the aircraft's representation of this range). It can be seen from this figure that the error in the system vertical range does not exceed 5 ft (ie a percentage error of about 0.5 %).

Figure 10 illustrates the variation in the precise and system range components in the north direction, this variation is shown over a relatively small time interval to illustrate the characteristics of these profiles. North range is calculated at a rate of 16 Hz. This range is then sampled at a rate of 40 Hz and used by the pod to determine such information as pointing direction. Since, in this scenario, the aircraft's velocity vector is purely northern, the sampled range north can be somewhat *stale*. This staleness, caused by the difference in the rate at which the north range is calculated and the rate at which it is used, gives the jagged appearance shown in Figure 10. The profiles shown in Figure 10 exhibit the same features throughout the selected mission except in the vicinity of zero north range; the characteristics of the north range error in this vicinity are addressed later when discussing Figure 11. Inherent in the Pave Tack system equations are a number of empirical adjustment terms which serve to enhance system performance. One such term is found in Module 3.6 (equation (a)) and is used to adjust the slant range to the target. Referring to Figure 10, it is important to note that the presence of this term results in the system north range profile being superimposed over the precise range profile. Omitting this particular empirical correction term causes the system range contour to lie continually above the precise profile such that the system error is approximately doubled. This illustrates the significance of such correction terms and further emphasises the importance of the ratification process that had to be conducted in developing the FPTS and associated software.

In Figure 11 is shown the variation with time of the north range error (ie the difference between the two profiles shown in Figure 10). The five bands result from the jagged nature of the system north range and indicate the coverage of the range of values of north error that occur due to the discrete system. Any one error band rises to a peak when the aircraft is at zero north range from the target. This feature results from the empirical adjustment term, discussed above, losing its significance (ie tending to zero) when the bearing to the target is close to 90°. It is important to note that the slant range to the target is used to calculate ground range which in turn gives the north and east components of this range. The effect, shown in Figure 10, of the correction term discussed above has therefore to be shared between the north and east ranges. The gradual rise and fall either side of the peak in any one error band shown in Figure 11, results from an increasing and decreasing proportion of the correction term being used on the east range. In Figure 12 is shown the variation in the inaccuracy of the east range representation where the influence of this correction term is seen to become more evident as the aircraft nears the target where the east range becomes considerably greater than the north. Since, in this simple scenario, the actual east range to the target is constant, the effect of the correction term (which serves to compensate for errors introduced by discrete sampling) is to make the system east range diverge from the actual east range.

Figures 13 and 14 correspond to the system in Track mode without the laser firing. Track mode is entered after approximately 7.3 s into the mission and the aircraft is directly alongside (zero north range) the target at approximately 52 s into the mission. It is important to note that short range navigation mode is also selected, this is an essential requirement if any navigation updates are to occur in this mode of Track. When in this mode (and similarly when the laser is firing) the system will attempt to correct for any perceived errors in navigation. When in this mode, the variation with time of the vertical range error is almost identical to that shown in Figure 9 for Cue mode. The magnitude of the correction signals to vertical range, generated in Track mode, is minuscule in comparison with the vertical range at any instant. This can be clearly explained by referring to specific equations in numerous components of the Pave Tack system. Any correction signals to the vertical range are not used by the system, in this mode, to update *vertical range*. Such updates occur in Track mode only when the laser is firing. Correction signals generated in non-laser Track serve as initial values to any update processes conducted on vertical range when the laser is firing.

The variation in north range error and north range correction is shown in Figure 13. The oscillatory nature of the pod correction signal prior to entering Track mode is caused from the discrete sampling of initial correction signals generated when in Coarse Cue mode. When in non-laser Track mode, the vertical range to the target is used to determine slant range and hence components of ground range to the target. That is, the vertical range is assumed to be exact. As mentioned earlier, small errors exist in the vertical range which decrease as the aircraft approaches the target. The use of this inaccurate range component gives rise to the initial characteristics of the pod correction signal shown in Figure 13. The small errors in vertical range are initially manifested as relatively large north range correction signals due to the shallow depression angle of the pod at the ranges concerned. It is important to note that these relatively large correction signals are not used for navigation updating because they are considered unrediable. This is due to the shallow depression angle of the pod. Three corrections ate accepted and used in the Navigation Computer Unit for navigation updating. These occur approximately at times 50, 55 and 58 s and the effect of these updates, on the north range error, can be clearly seen in Figure 13. Overall the system representation of the north range to the target has been worsened by the navigation updates. This is a consequence of tracking at high speed and low altitude where any errors that are inherent in a discrete system are accentuated. Figure 14 shows the east range profiles which exhibit, for the same reasons, similar characteristics to those of Figure 13.

Figures 15 to 17 correspond to the system in Track mode with the laser firing; track mode again entered at approximately 7.3 s and the laser fired after about 9.2 s into the mission. In this mode of operation, the pod no longer relies on the vertical range being exact since the laser range gives an accurate measure of the slant range to the target. Owing to the reliability of the laser range, navigation updates are more frequent and in the mission discussed here 12 updates were made. Updates are also made to the vertical range to the target.

Figure 15 shows the variation in the error in the vertical range and the pod-generated correction signal to this range component. The effect of the correction signals can be clearly seen after the laser has been fired. Prior to laser fire the variation in the error is as shown in Figure 9. The large errors exhibited in the vicinity of the target are the result of discrete sampling and range comparisons made over a period where the slant range to the target is changing rapidly. This can be explained with reference to the equations in Module 7.6. Similar features to those of Figure 15 are present in the north range and east range profiles of Figures 16 and 17. Overall the effect of navigation updating can be seen to have a minimal effect on the system vertical, north and east range components. This is bacause the system is responding to perceived navigation errors in a scenario where the actual navigation errors are zero.

Figures 18 to 23 relate to the same scenario as Figures 9 to 17 but with the following initial navigation errors:

(a) A 100 ft error in the vertical range to the target

(b) An error of 0.000050 radians in the aircraft latitude (ie the navigation system has the aircraft initially at latitude 0.624095 radians). This translates to an approximate error of 1044 ft in the north range to the target.

(c) An error of 0.000020 radians in the aircraft longitude (ie the navigation system has the aircraft initially at longitude 2.055795 radians). This translates to an approximate error of 340 ft in the east range to the target.

When in Cue mode, the vertical, north and east errors for this scenario have exactly the same characteristics as those profiles shown in Figures 9 to 12 except that, in this case, the magnitude of the errors are increased to reflect the actual navigation errors that are present.

Figures 18 to 20 relate to the vertical, north and east range components respectively when the pod is in Track mode without the laser firing. Track mode was entered at approximately 7.3 s. It is important to recall that, in this mode of operation, the vertical range is assumed to be exact and is used to determine the correction signals or range trims that need to be applied to the north and east range components. No corrections are made to the vertical range. In Figure 18 is shown the variation with time of the vertical range to the target. As mentioned earlier, the vertical range is a function of the aircraft altitude and the curvature of the earth between the aircraft and the target. Earth curvature is expressed in terms of the ground range to the target (ie a function of the north and east range components). As illustrated in later figures, corrections are made to the north and east range components and, although navigation updates to the vertical range are not made, these corrections affect the vertical range via the earth curvature term. This is illustrated in Figure 18 by the distinct kink in the vertical range profile.

In this mode ten correction signals were accepted and passed to the NCU for navigation updating. The effect of these signals, on the system north and east range components, can be clearly seen in Figures 19 and 20. It should be noted that the overall effect of the corrections is minimal and this is a direct consequence of the assumption of exact vertical range. (As an aside, running this scenario with an actual vertical range error of zero results in successful navigation updating in that the errors in the north and east range components gets reduced to minimal values.)

In Figures 21 to 23 are shown the errors in the range components, and the pod generated correction signals to these errors, when in Track mode with the laser firing. Track mode was again entered after approximately 7.3 s and the laser was fired after about 9.3 s into the mission. In this case 23 corrections were used by the NCU for navigation updating of each of the range components. It is quite evident from these figures that navigation updating is successful in that what were large errors in the vertical, north and east range components have been reduced to relatively very small values.

The results illustrate the navigation capabilities of the Pave Tack and associated systems under the chosen conditions. Running other scenarios, but maintaining the assumptions of cruise conditions and a perfect operator, would give very similar results. For reasons already mentioned, the effect of a manoeuvring aircraft can only be considered after the incorporation in the FPTS of a sophisticated representation of the Inertial Navigation System. This aspect is addressed in reference 37. The affect of the tracking capability of the Weapons Officer has been studied and is reported in reference 36.

15 CONCLUSIONS

An F-111C Pave Tack Simulation (FPTS) has been developed which encompasses the Pave Tack system itself and many of the associated avionic and sensor systems in the F-111C. The simulation has a wealth of potential applications and the modular structure of the FPTS greatly facilitates the modification or replacement of existing components, and the addition of new modules to the system.

Owing to its interactive nature, the FPTS has obvious scope as a part task trainer or some other form of computer-aided training. The simulation could be used as a classroom training device for familiarising trainees with such aspects as pod imagery orientation for particular scenarios, and also as a support system to an F-111C cockpit simulator. The FPTS is sufficiently sophisticated to be used in such studies as post and pre avionics update performance comparisons. The simulation could also be used as a tool for mission planning and post mission analysis; for which it was originally intended.

The present simulation forms a firm foundation upon which further analyses can be carried out. The overall system is largely generic and therefore the tools and the knowledge base developed from this task will greatly assist any studies relating to other aircraft and/or aircraft systems.

REFERENCES

1. - "AN/AVQ-26 Pave Tack System Description Part I". Ford Aerospace and Communications Corporation, PT-78-FS-001, February 1978.

2. - "AN/AVQ-26 Pave Tack System Description Part II". Ford Aerospace and Communications Corporation, PT-78-FS-001, Confidential , February 1978.

3. M.D. Burns "Aircraft Flight Path Plotting Software". Combat Systems Effectiveness Group, Working Paper, CSF/A25, February 1987.

4. - "Fast Colour Displays of Digital Terrain Elevation Data, User Handbook". CSA SED/5347/0800/0010, September 1988.

5. - "Report on the Pave Tack System Accuracy". BAe Aust 20931, October 1988.

6. M.A. Hue "F-111C Pave Tack Flight Test Model Conceptual Outline". BAe Aust 21046, November 1988.

7. D.A.B. Fogg, S. Lukacs "An Analysis of Navigation and Weapon Delivery Accuracies for the F-111C Avionics Update, Part I, Procedures and Summary of Results". WSRL Technical Report WSRL-TR-17/89, March 1989.

8. D.A.B. Fogg, S. Lukacs "An Analysis of Navigation and Weapon Delivery Accuracies for the F-111C Avionics Update, Part II, Detailed Results". WSRL Technical Report WSRL-TR-17/89, March 1989.

9. - "F-111C Manoeuvre Controller Programme F-111C PILOT User Information". Department of Electrical and Computer Engineering, University of Newcastle, June 1989.

10. D.A.B. Fogg, R. Janus "A Generic Inertial Navigation System Model for Computer Simulation Studies". WSRL Technical Memorandum, WSRL TM-30/90, September 1990.

11. - "AN/AJQ-20A Inertial Bomb Navigation Set". Section 1, Discription and Operation, F-111C Flight Manual.

12. - "F-111C Pave Tack / Guided Weapons Accuracy Prediction Document". FZM-12-26604, General Dynamics, Fort Worth Division, 15 February 1985.

13. - "Ground and Flight Testing of Litton LTN-72R Inertial Navigation System Integration with C130H Installed equipment - Phase Two - Analysis of Operational Performance Between July 1979 and May 1980". Aircraft

		Research Development Unit Report No ARDU-TS-1652, January 1981.
14.	D.A.B. Fogg	"F-111C Flight Models for Combat Systems Performance Studies". WSRL Technical Report WSRL-TR-6/91, January 1991.
15.	D.A.B. Fogg, J.M. Dunn	"A Terrain Model for Analysis, Display and Motion Simulation in Combat Systems performance models." ERL Technical Report (to be published).
16.	-	"Prime Item Development Specification for Radar Set AN/APQ -165"
17.	-	"System Segment Specification for the F111 A/E Avionics Modernisation Program". 32SSV001,3, April 1986.
18.	-	"F111 A/E AMP Navigation and Weapon System Error Analysis". Grumman Aerospace Corporation: AMPRPT-86-003, 12 April 1986.
19.	D.A.B. Fogg	"Transformation Matrices for Aerodynamic problems". Weapons Research Establishment Technical Memorandum, WRE-TM-721(AP), July 1972.
20.	-	F-111C Pave Tack Guided Weapons Program. Performance Evaluation Phase Flight Test Report Vols I-V, RAAF Pave Tack Office McClellan AFB, CA USA, January 1986.
21.	-	"TFR AN/APQ 110/AN/APQ-128 Specifications"
22.	J.G. Gardner	"A Mathematical Model of Manoeuvring Aircraft in a Turbulent Atmosphere". Technical Note SAD 283, March 1970.
23.	-	"Effects of Weather on the F-111 Terrain Following Radar System". General Dynamics Convair Aerospace Division, FZM-12-13551, 12 February 1973.
24.	V. Wertz, G.C. Goodwin, C.E. De Souza, M.J. Loveridge	"Design of a Manoeuvre Autopilot". Technical Report EE8703, Department of Electrical and Computer Engineering, University of Newcastle, NSW Australia, January 1987.
25.	C.E. De Souza	"Further Considerations on the Design of Manoeuvre Controller Model". Technical Report EE8746, Department of Electrical and Computer Engineering, University of Newcastle, NSW Australia, December 1987.
26.	P.W. Gibbens	"F-111C Manoeuvre Controller Programme F111CPILOT User Information". Department of Electrical and Computer Engineering, University of Newcastle, NSW Australia, July 1989.

27.	W.J.J. Roberts	"The Terrain Following Radar and the Aerodynamic Differential Equations". Combat Systems Effectiveness Working Paper CSF/A29, February 1989.
28.	G.A. Korn, T.A. Korn	"Mathematical Handbook for Scientists and Engineers", Mc Graw-Hill, New York, 1968.
29.	-	"SYSL Simulation Language User's Guide". SYSL/M Version 1.0, E^2 Consulting, Poway, California, September 1985.
30.	-	"Computer Program Development Specification for Program, Operational Flight". CI No.A000011, Spec. No AS14192E, Ford Aerospace.
31.	-	"Six-degrees-of freedom computer simulation for the GBU-12B/B and GBU-10C/B Laser Guided Bombs". Missile Ordnance Division Report No. C1-776546-F, Texas Instruments Corporation, Dallas Texas, 4th April, 1980.
32.	R.D. Anderson	"A Simplified Version of the Texas Instruments' Model of the GBU-12 Laser Guided Bomb". Weapons Systems Research Laboratory Technical Report WSRL-0559-TR, November 1987.
33.	P. Rogers	"The Harpoon Attack Mission Analyser (HAMA)". Advanced Engineering Laboratory Special Document, AEL-0295-SD, November 1987.
34.	G. Readett	"Expanded Ballistic Tables for Mk 82 Bombs and BDU-33 CB (Aust) Practice Bombs released from Mirage Aircraft". Report No. ARDU TI-677, RESTRICTED, November 1980.
35.	G. Readett	"Development of Ballistic Tables for F-111C Bombing System, Employing BDU-33 CB Practice Bombs". Report No ARDU TI-607, January 1979.
36.	Fred D.J. Bowden, Mike Davies	"The Man-in-the-Loop Aspects of the F-111C Pave Tack Simulation". Research Report, ERL-0658-RR, FEB 1993.
37.	Mike Davies, Fred D.J. Bowden, David A.B. Fogg, John M. Dunn	"A Study of F-111C Navigation". Research Report, ERL-0772-RR, (to be published).
38.	-	"F-111 ARS Update Error Loss Budget" General Electric Document N0. 52585-058, 15 November 1984.

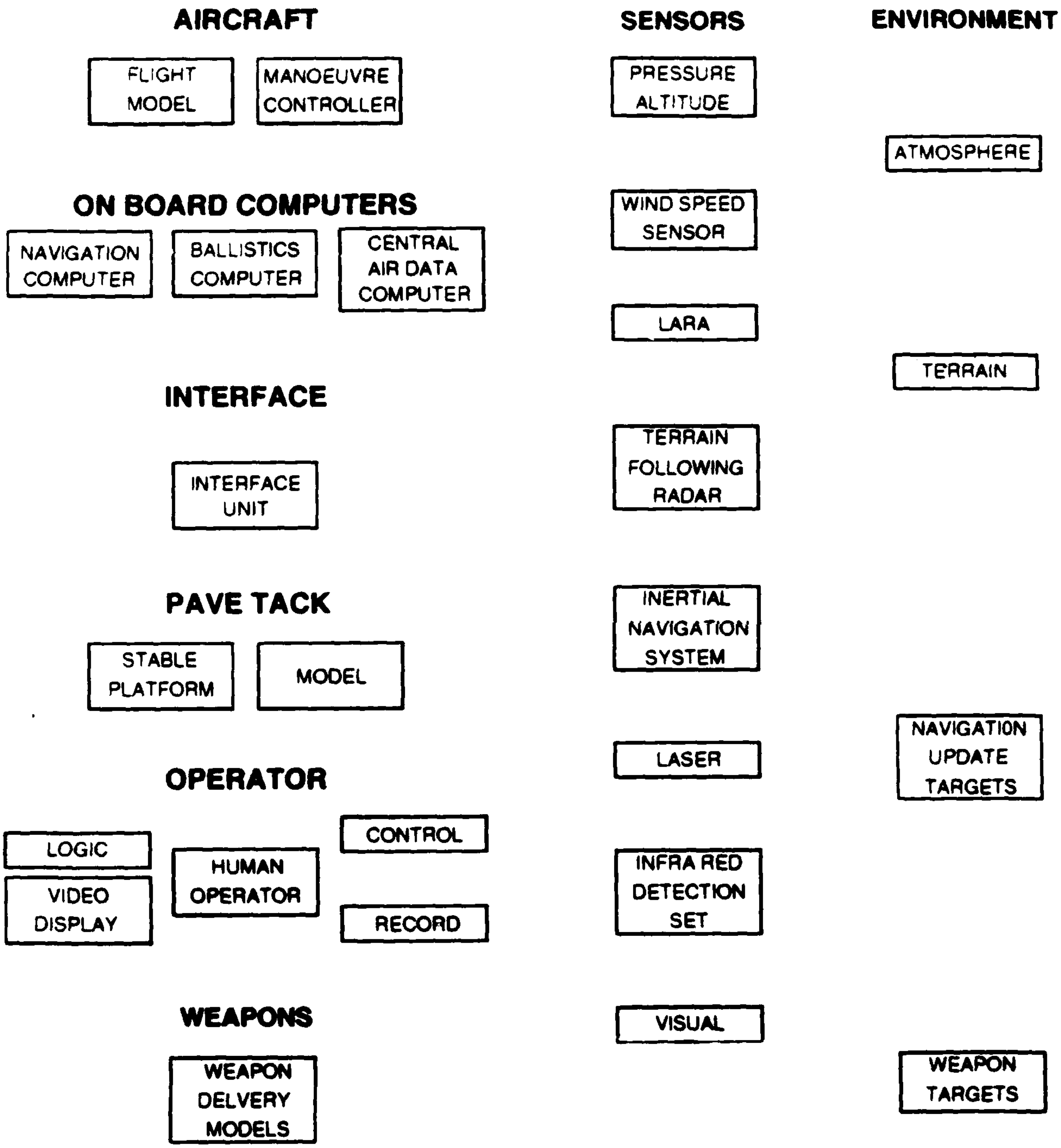

Figure 1 F-111C Pave Tack simulation overview

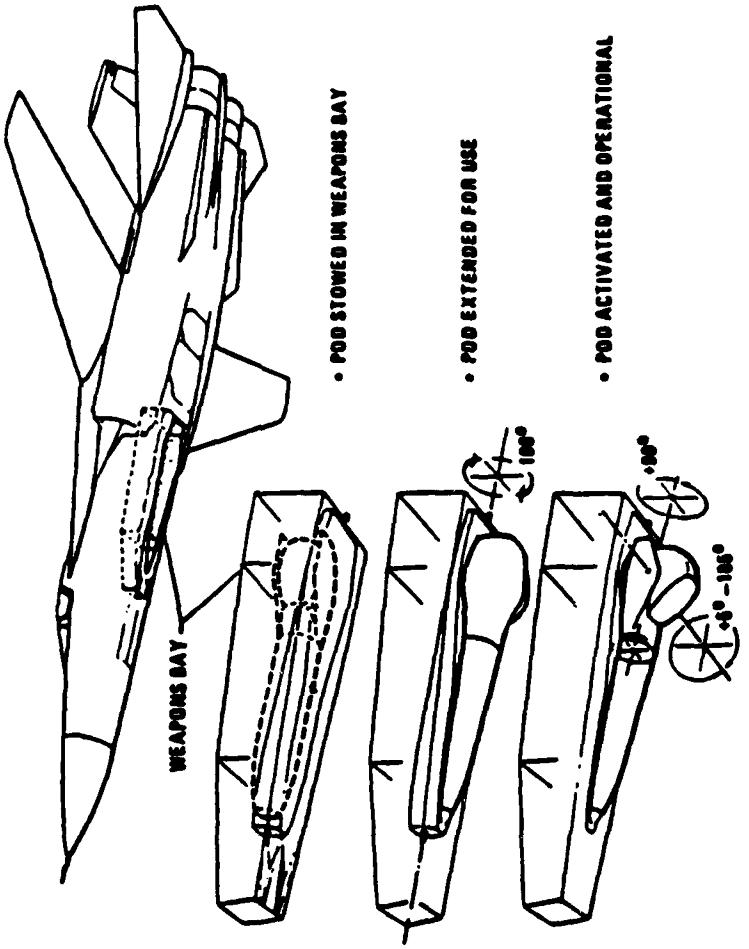

Figure 2 Pave Tack pod deployment

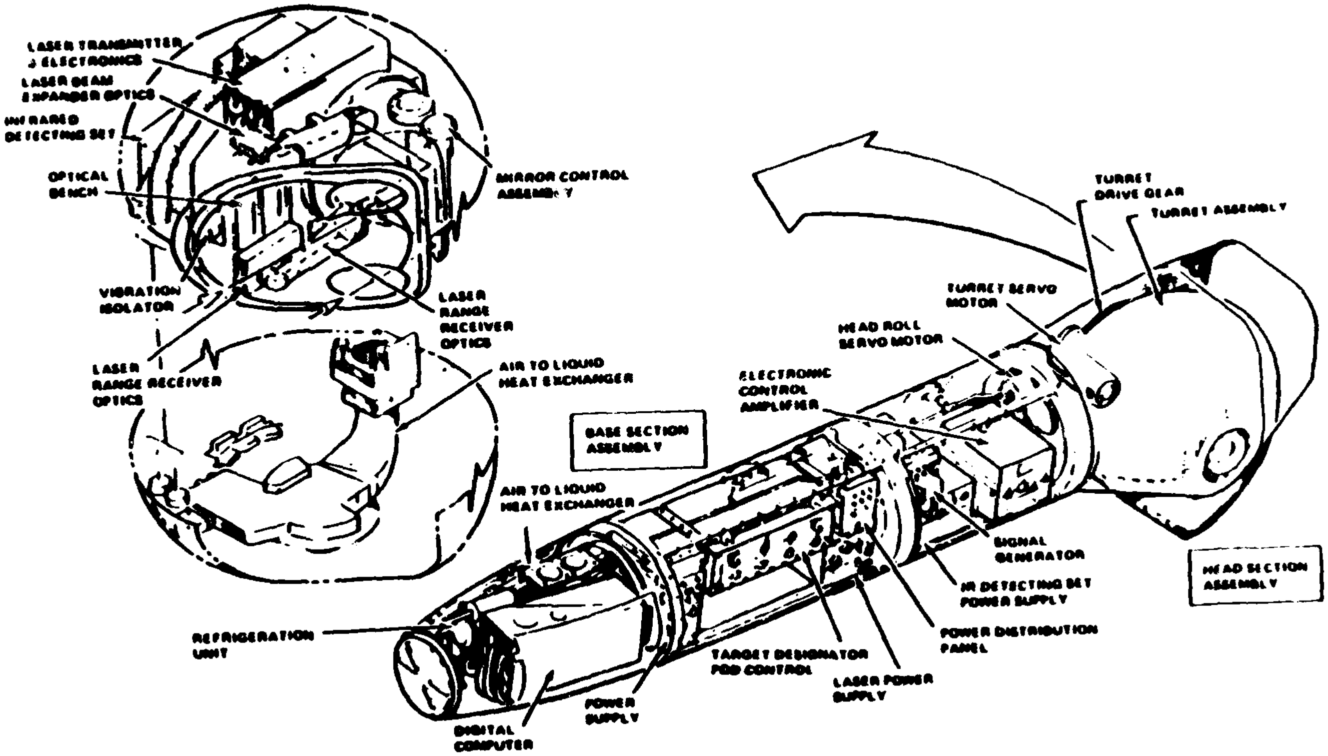

Figure 3 Pave Tack pod configuration

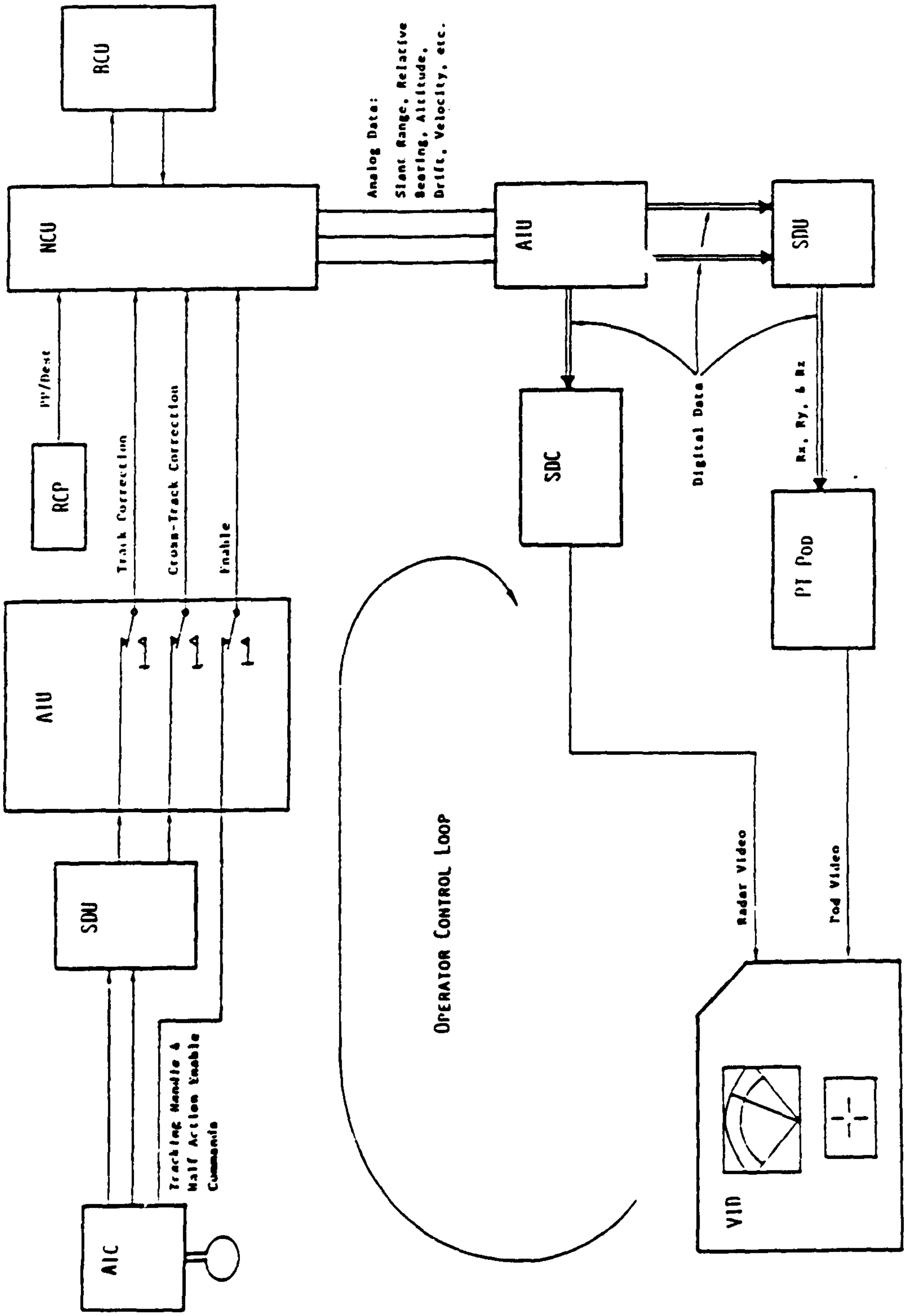

Figure 4 F-111C PT/GW cursor control mechanism; radar prime, cue mode, GND AUTO or GND VEL

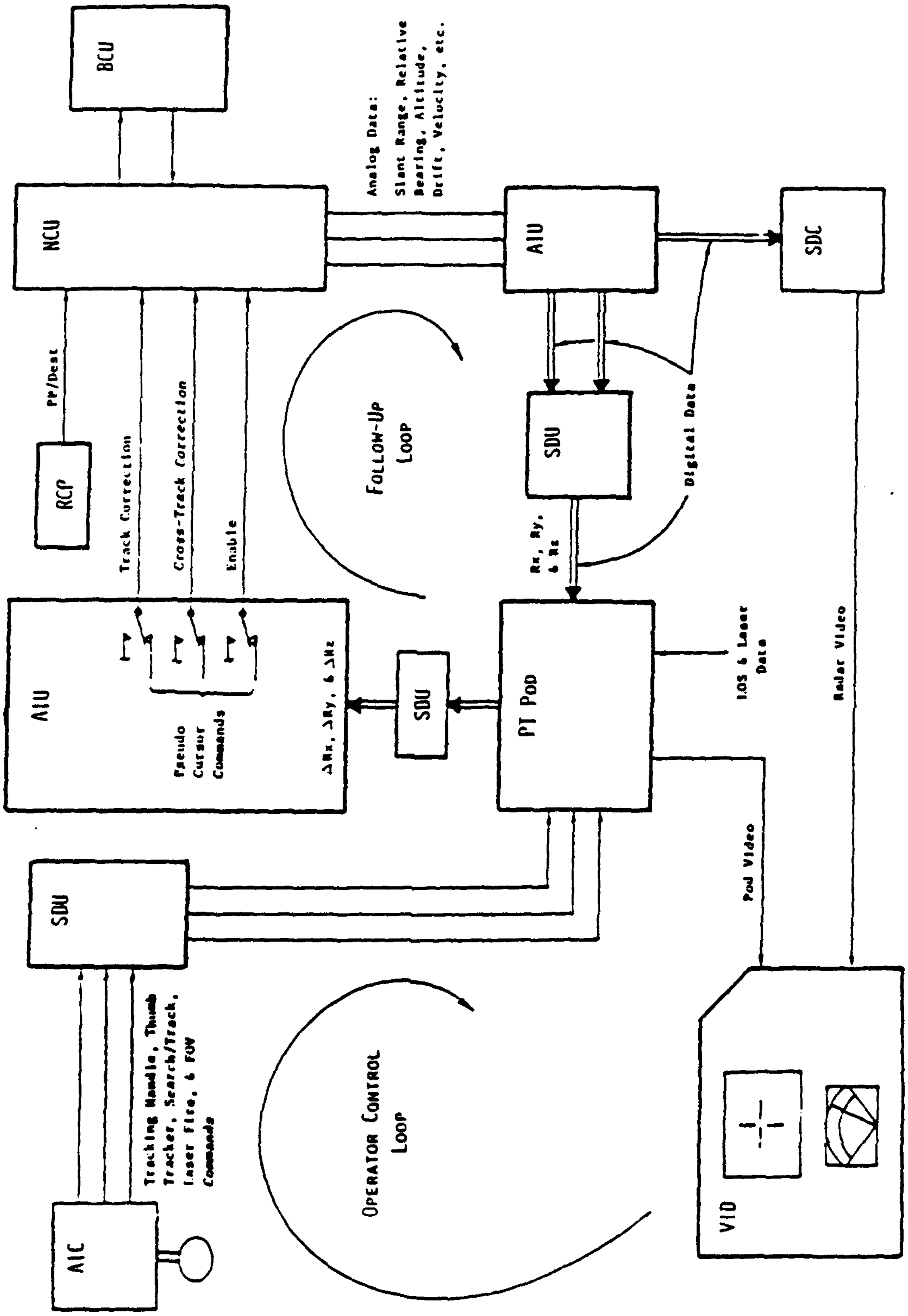

Figure 5 F-111C PT/GW cursor control mechanism; Pave Tack prime, cue mode, GND AUTO or GND VEL

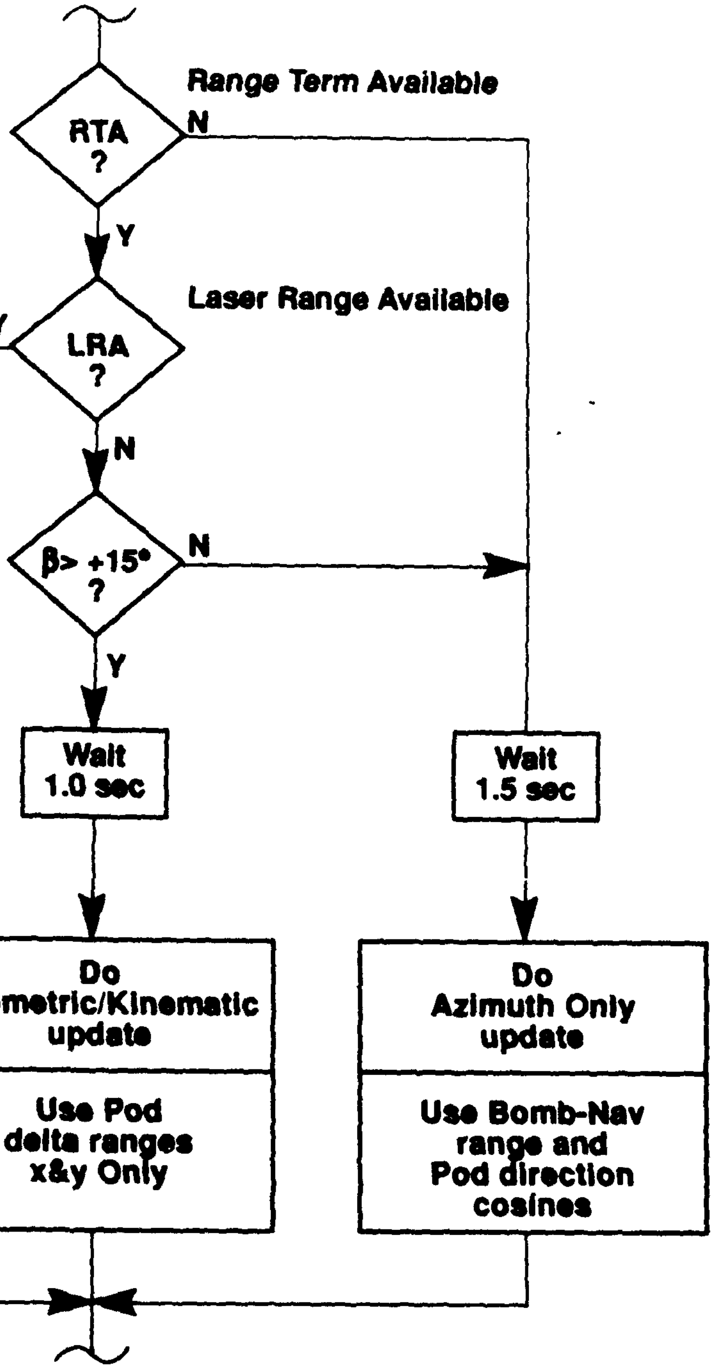

Figure 6 Position updating logic (Pave Tack, Track mode)

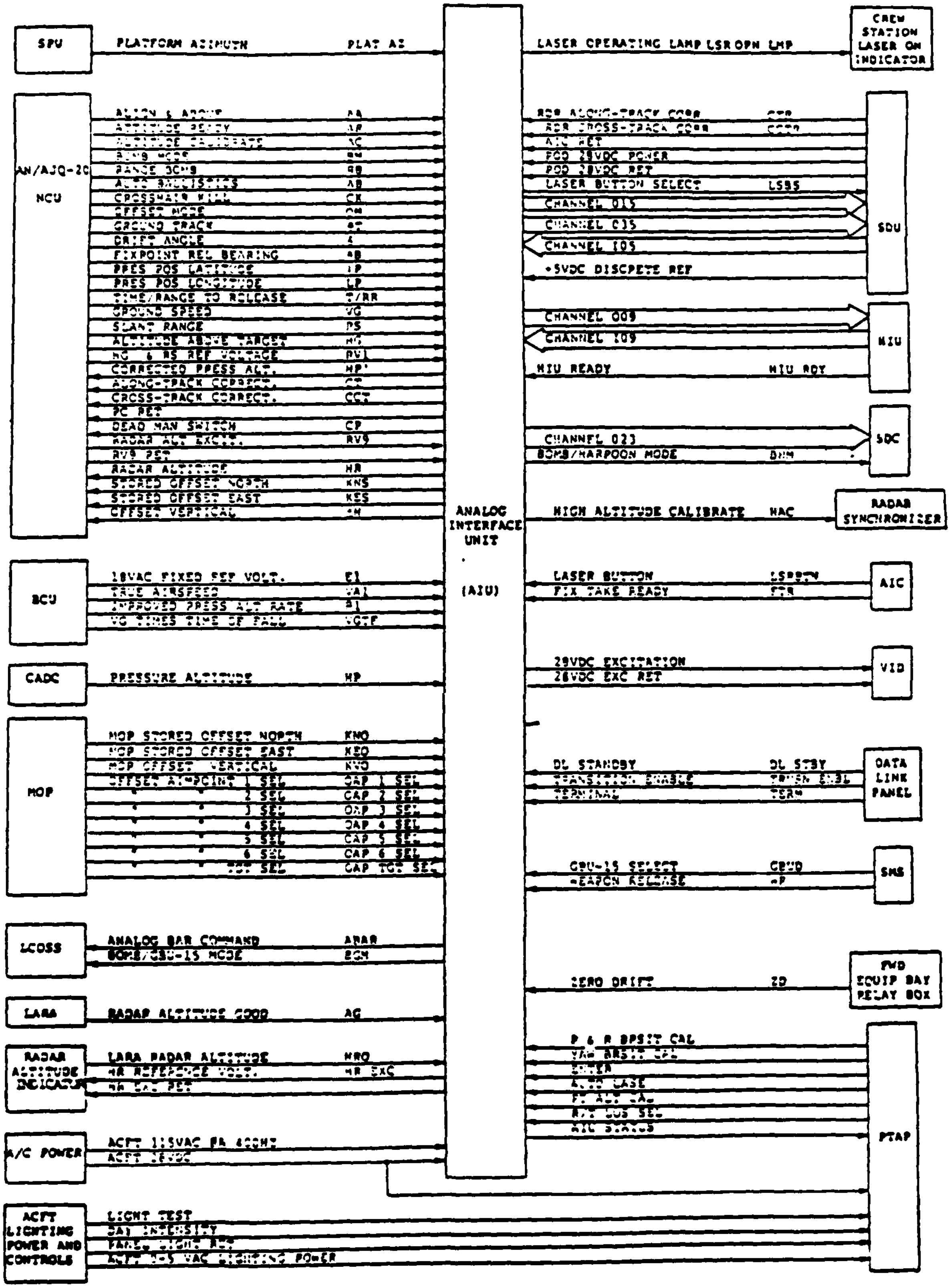

Figure 7 AIS electrical interface

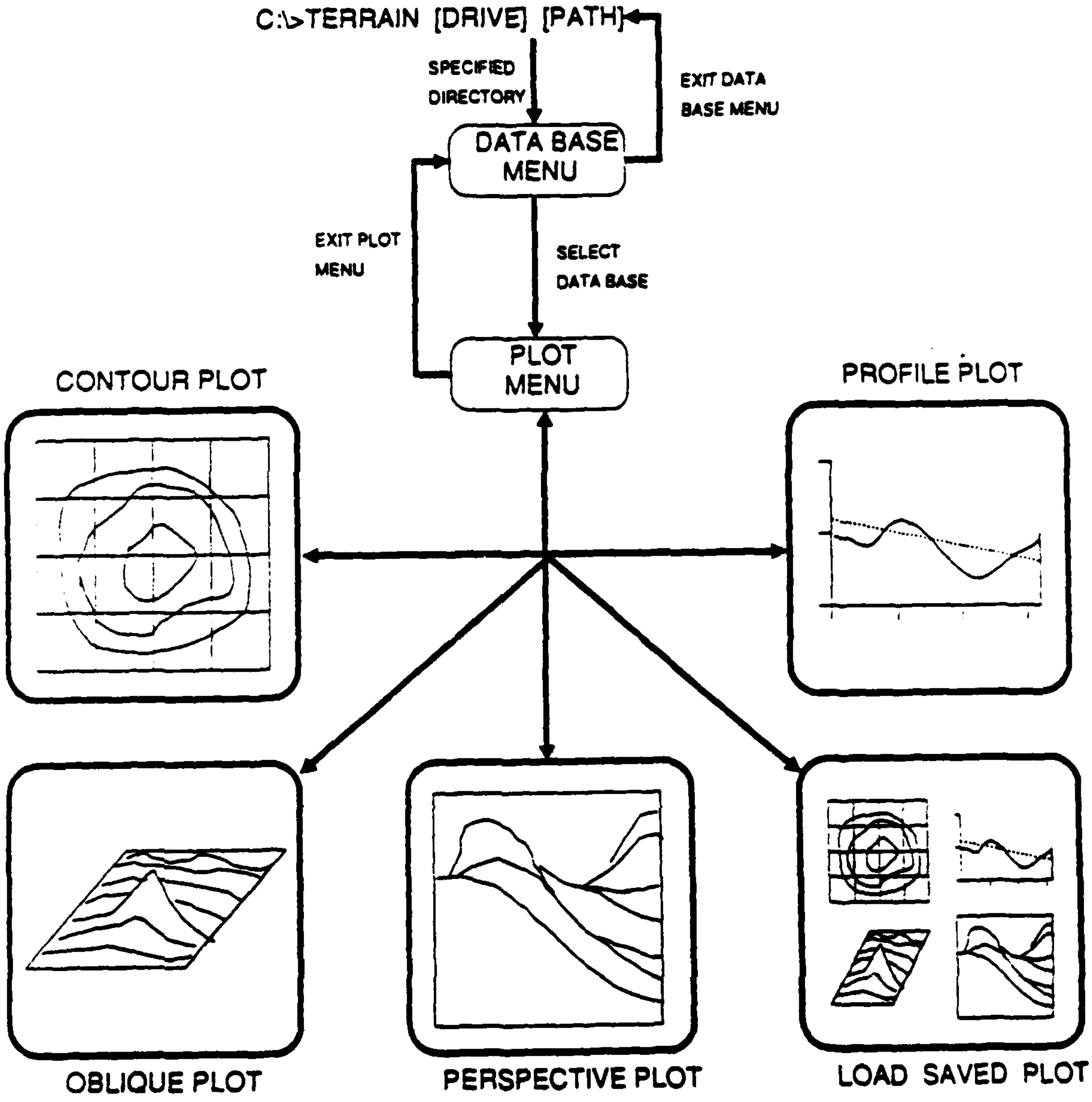

Figure 8 Figure relating to 'Terrain Display Options' - Section 10.1.

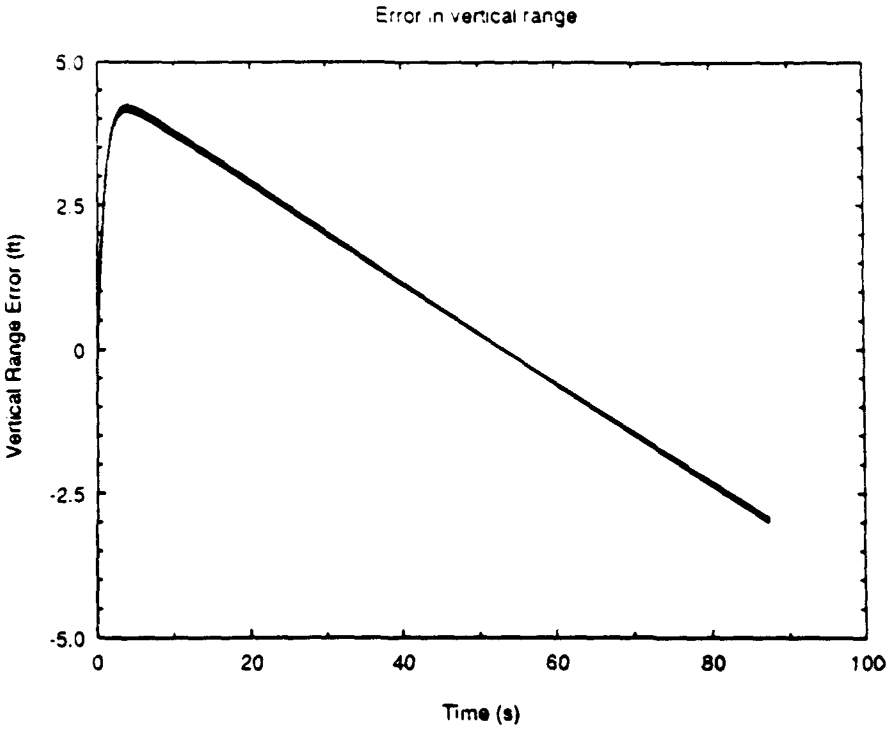

Figure 9 Variation in error in vertical range to target (cue mode)

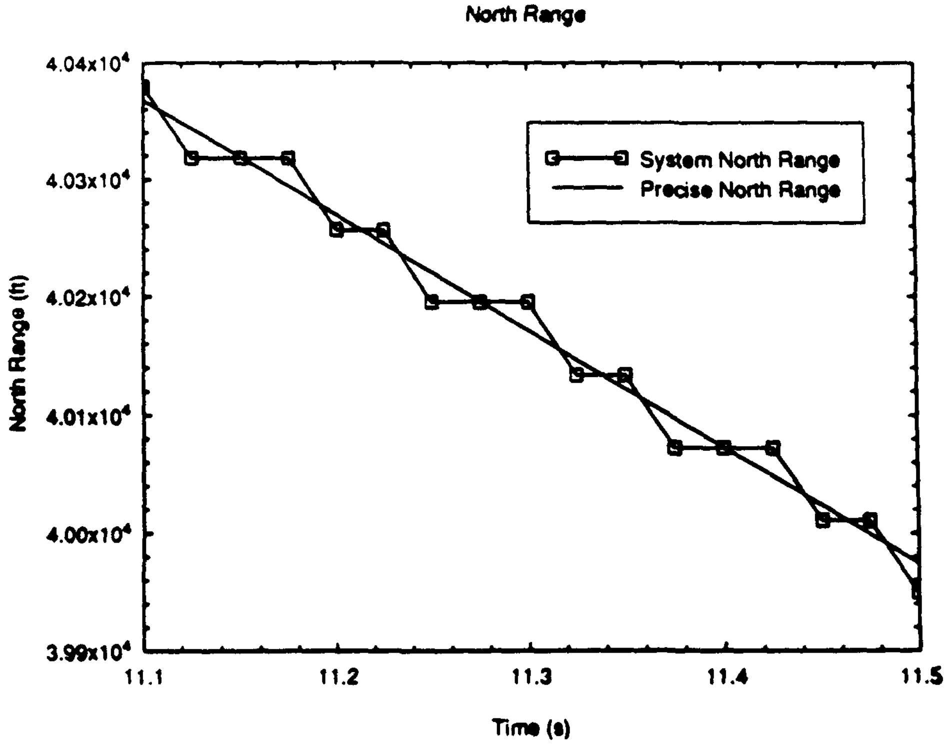

Figure 10 Variation in precise and system north range components (cue mode)

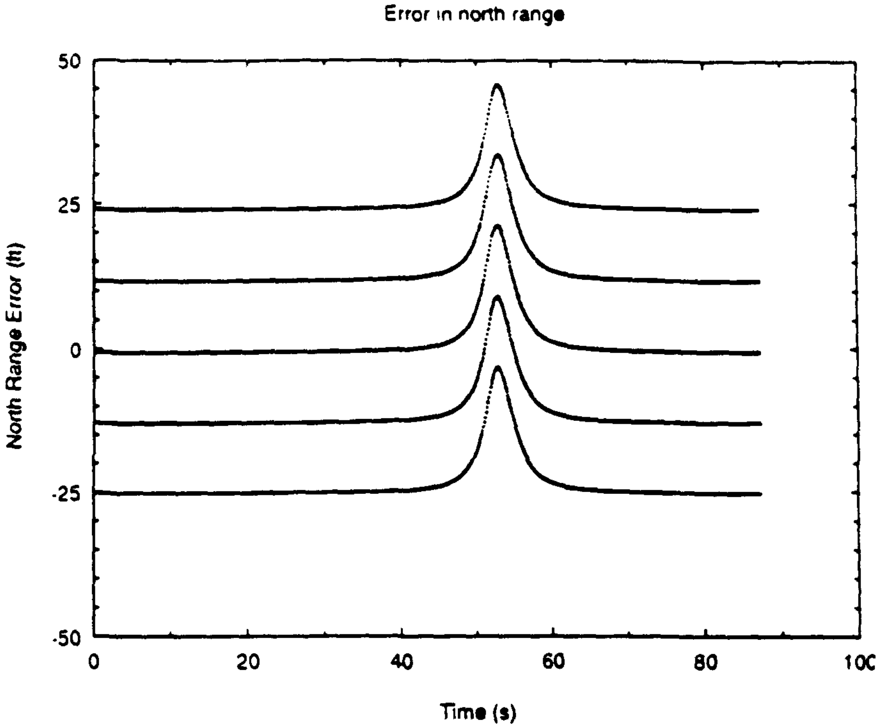

Figure 11 Variation in error in north range to target (cue mode)

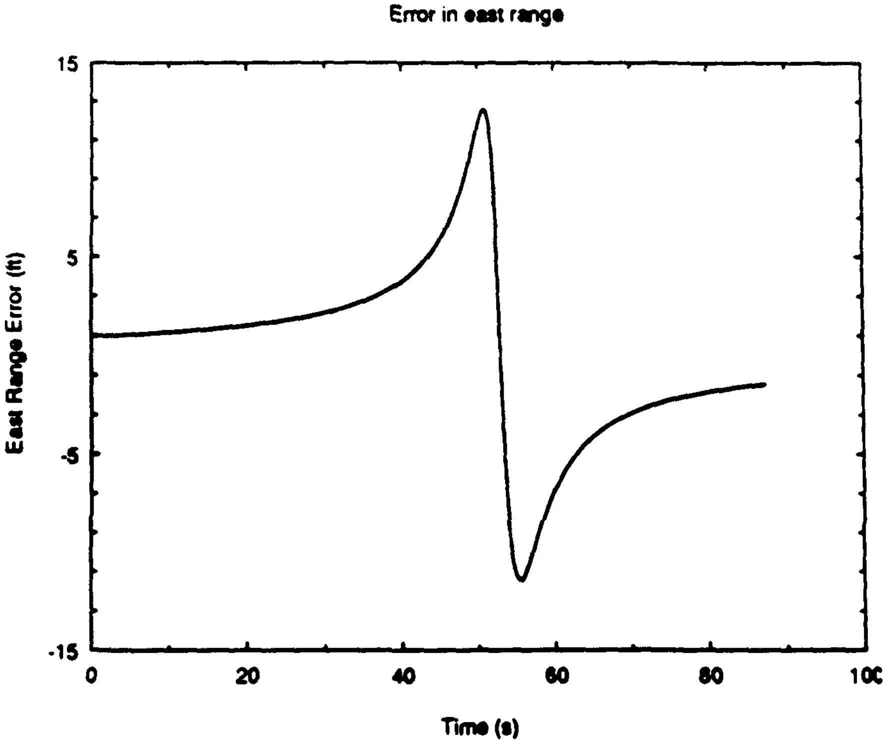

Figure 12 Variation in error in east range to target (cue mode)

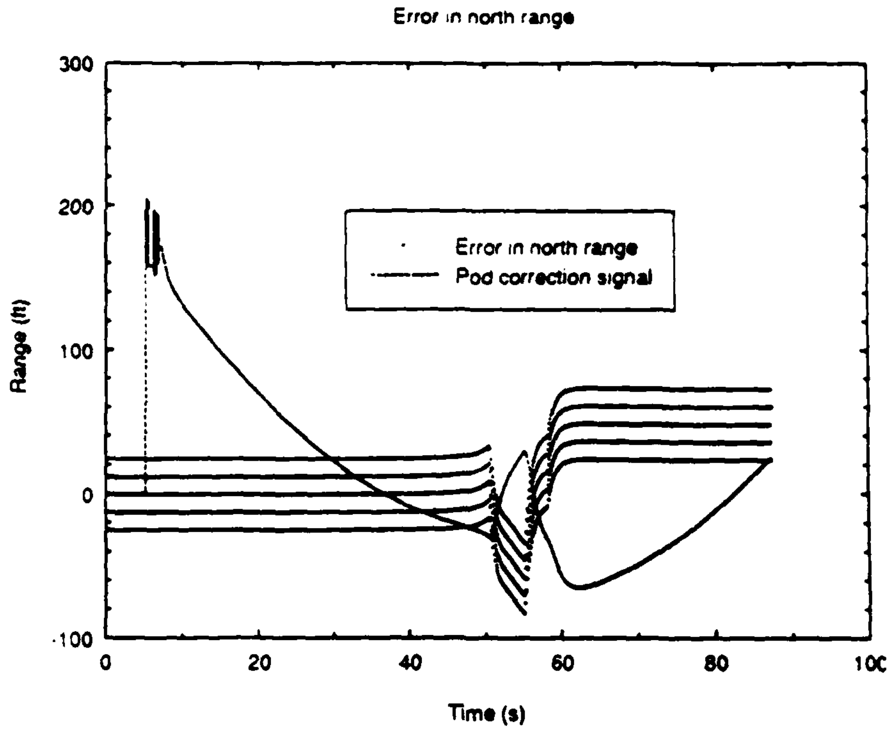

Figure 13 Variation in north range error and pod correction signal (track mode, no laser)

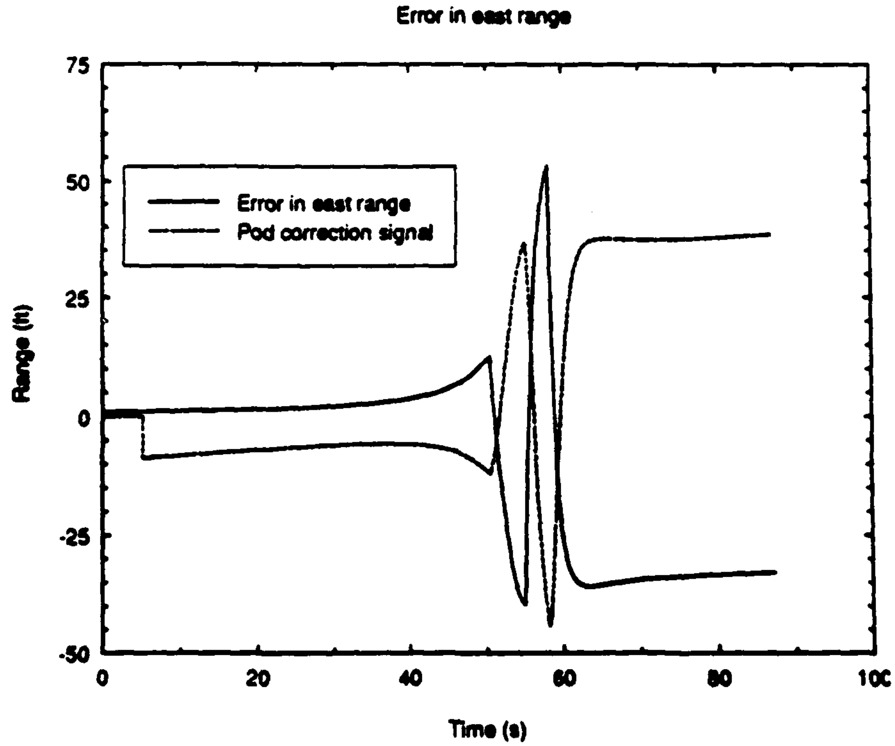

Figure 14 Variation in east range error and pod correction signal (Track mode, no laser)

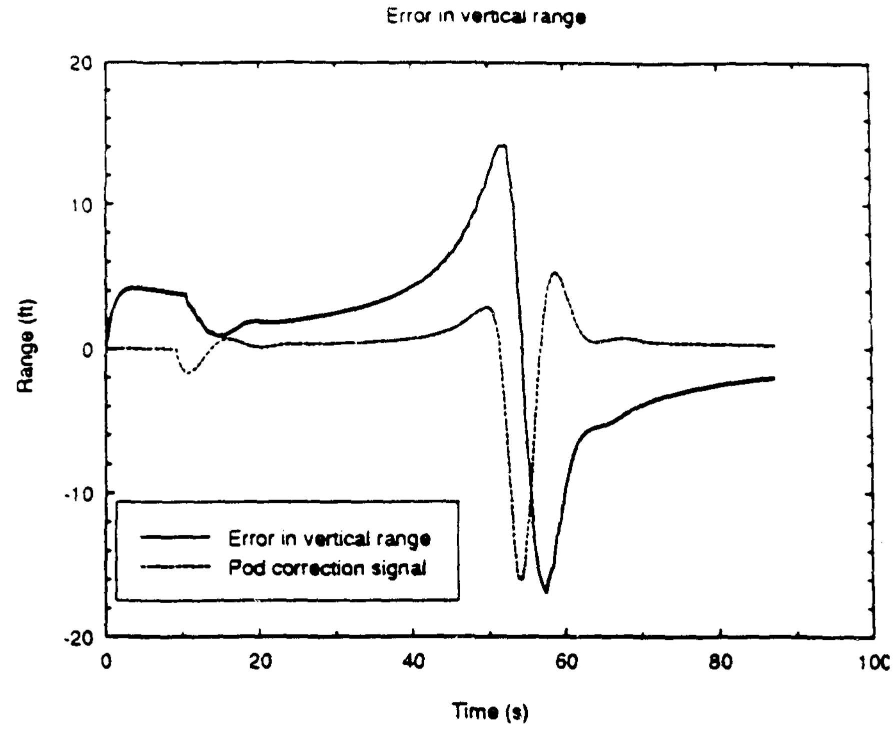

Figure 15 Variation in vertical range error and pod correction signal (track mode with laser)

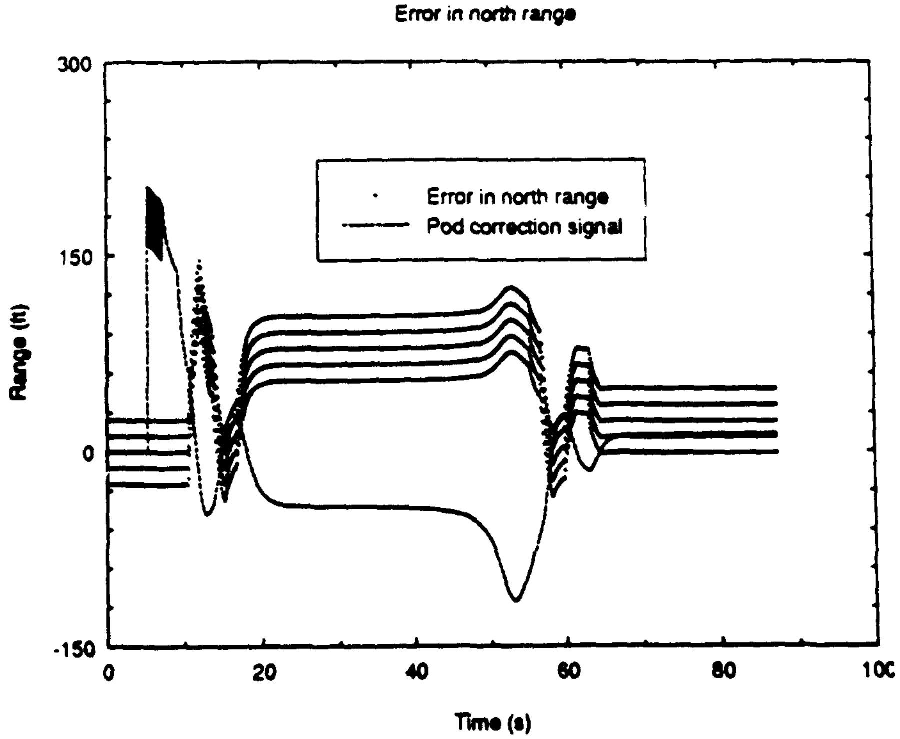

Figure 16 Variation in north range error and pod correction signal (track mode with laser)

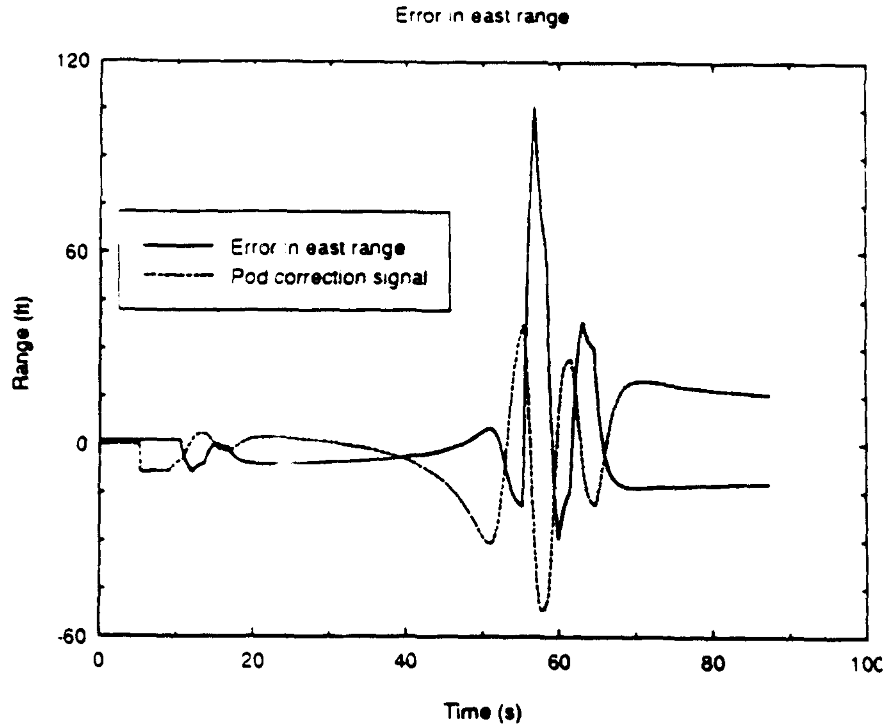

Figure 17 Variation in east range error and pod correction signal (track mode with laser)

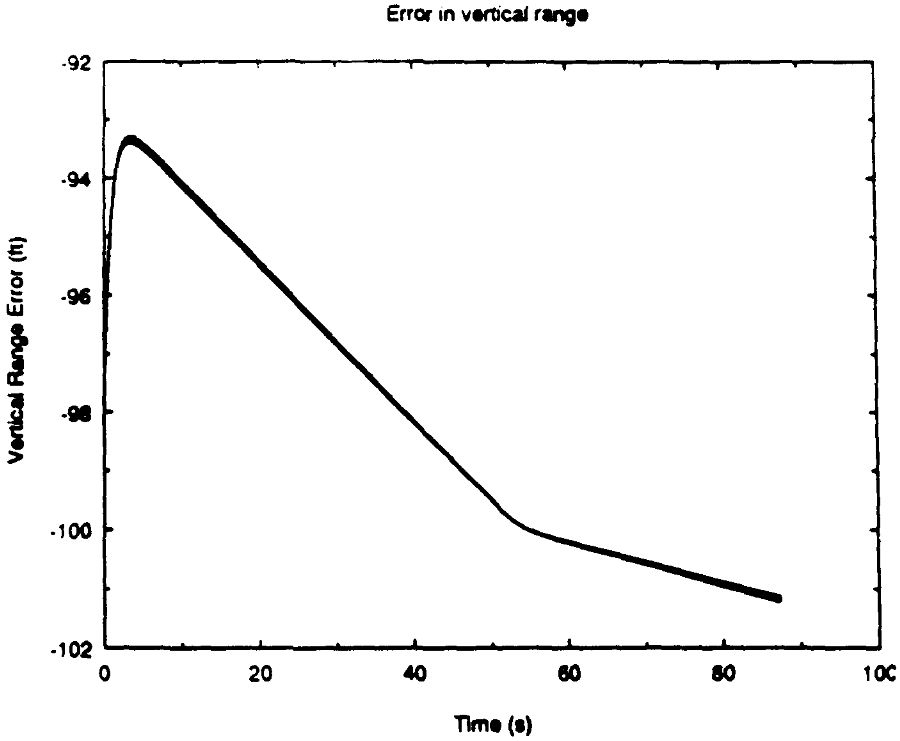

Figure 18 Variation in vertical range error (track mode, no laser, deliberate navigation error)

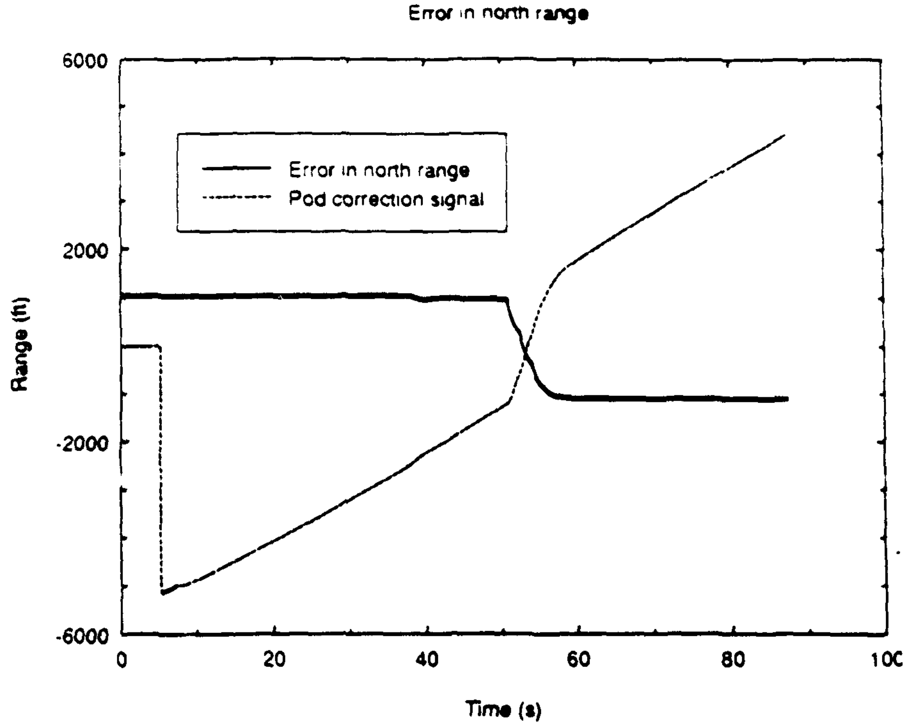

Figure 19 Variation in north range error and pod correction signal (track mode, no laser, deliberate navigation error)

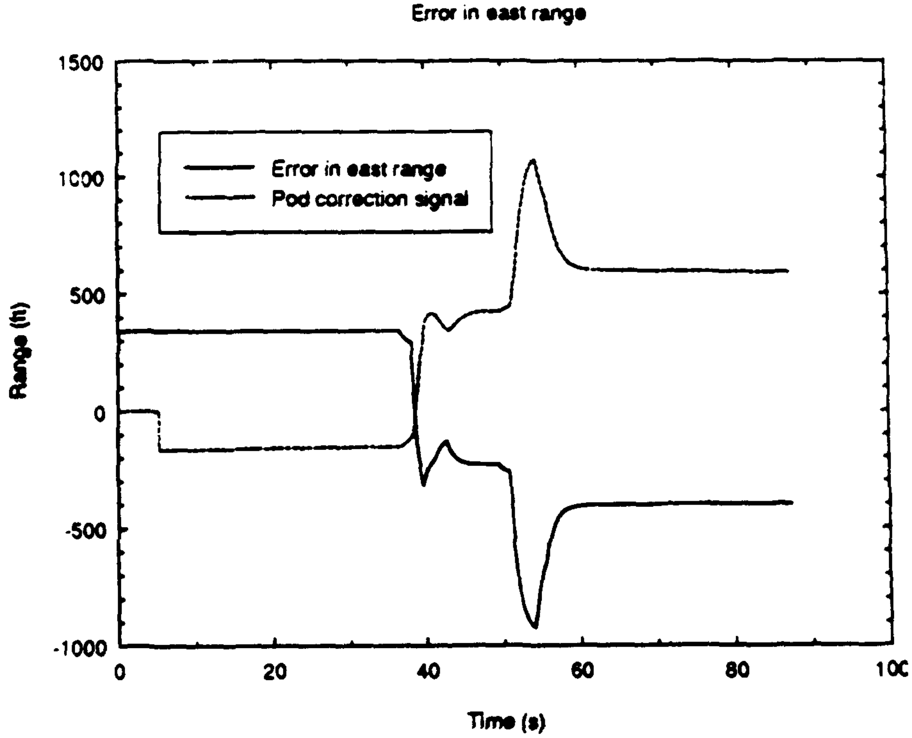

Figure 20 Variation in east range error and pod correction signal (track mode, no laser, deliberate navigation error)

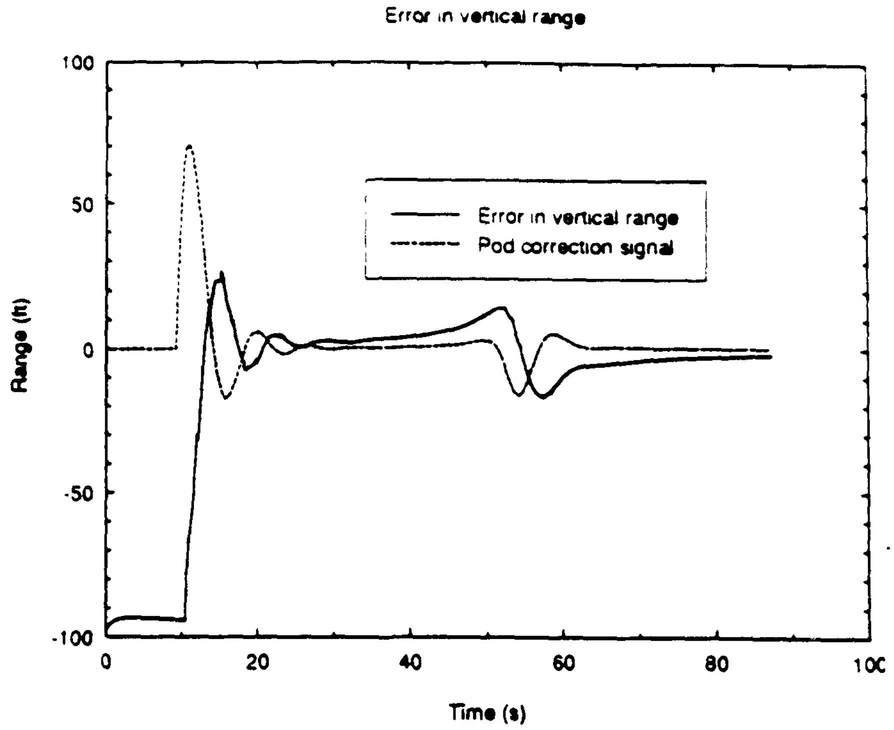

Figure 21 Variation in vertical range error and pod correction signal (track mode with laser, deliberate navigation error)

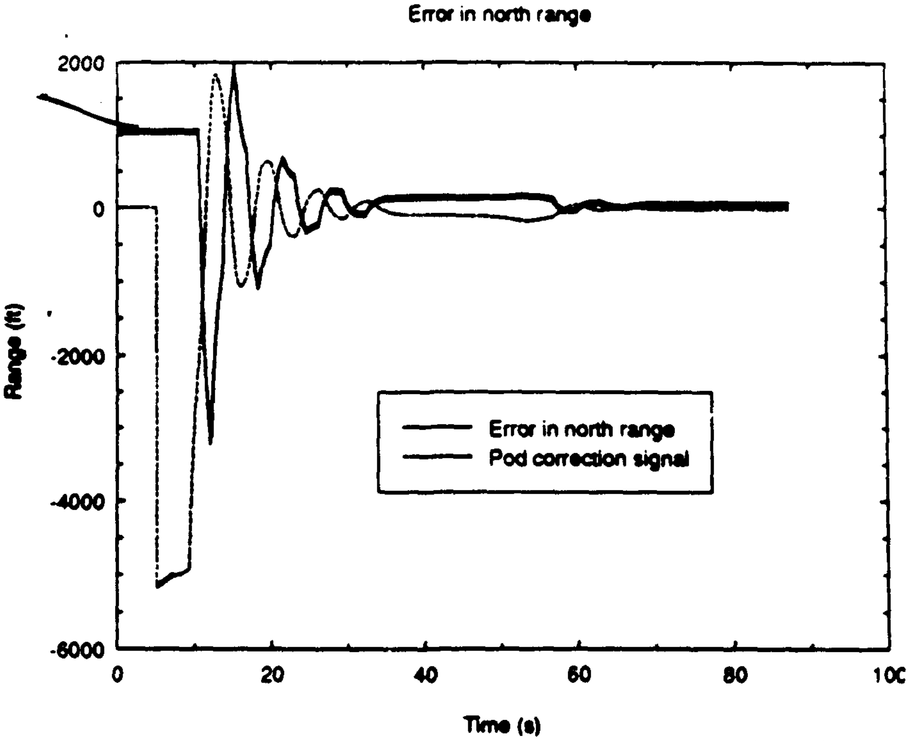

Figure 22 Variation in north range error and pod correction signal (track mode with laser, deliberate navigation error)

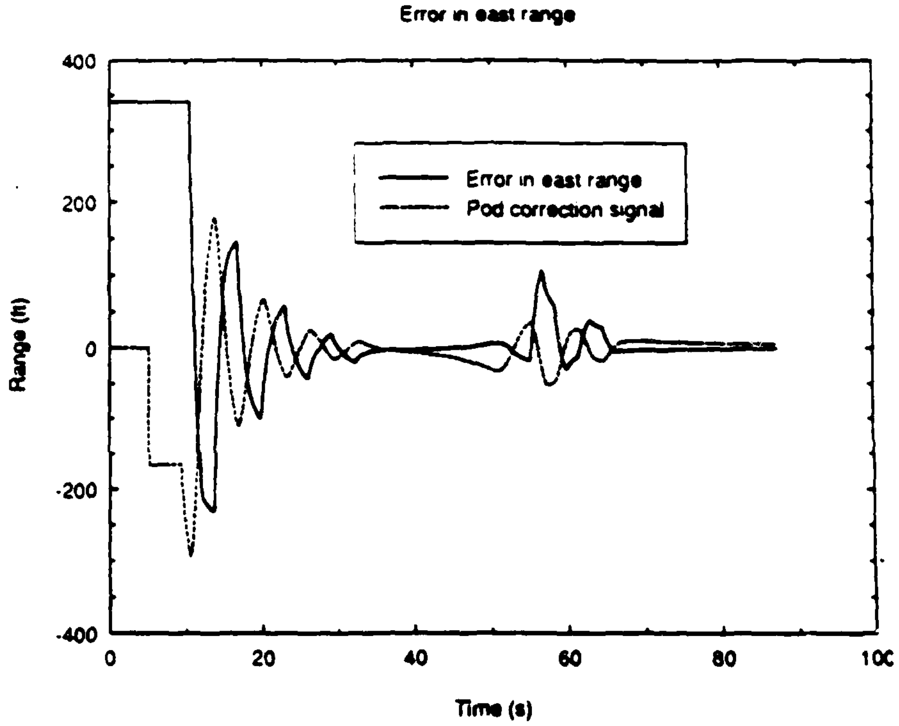

Figure 23 Variation in east range error and pod correction signal (track mode with laser, deliberate navigation error)

THIS IS A BLANK PAGE

APPENDIX I

COORDINATE SYSTEMS

THIS IS A BLANK PAGE

CONTENTS

I.1 NOTATION 49

I.2 TRANSFORMATIONS: THEORY AND TERMINOLOGY 49
  I.2.1 The roll matrix 50
  I.2.2 The pitch matrix 50
  I.2.3 The yaw matrix 50

I.3 TRANSFORMATIONS USED IN THE FPTS 50

I.4 APPLICATIONS OF MATRIX TRANSFORMATIONS 51
  I.4.1 Cue mode 52
  I.4.2 Coarse cue mode: incorporating the human operator 53
  I.4.3 Track mode: incorporating the human operator 53
  I.4.4 Coarse cue and track modes: perfect operator 53

FIGURES

1 Inertial reference frame 54
2 Aircraft reference frame 54
3 Analog interface unit reference frame 54
4 Pave Tack pod reference frame 54
5 Pod sightline reference frame 54
6 Pave Tack image display coordinate system 54

THIS IS A BLANK PAGE

I.1 NOTATION

Within this appendix is a series of figures which illustrate the coordinate system conventions adopted in the F-111C Pave Tack Simulation and associated software. It should be noted that the conventions described are not necessarily identical to those utilised in the guidance material used as references throughout this work. In Figures I.1 to I.6 are illustrated the conventions adopted for the inertial, aircraft, analog interface unit (AIU), pod and pod sightline Cartesian reference frames and also the coordinate system relating to the Pave Tack image display.

The origin of each of the reference frames is taken to be at aircraft centre-of-mass. The position at any given time of each of the axis systems in Figures I.2 to I.5 can be expressed relative to the inertial frame of Figure I.1. The position in space of the aircraft axis system (Figure I.2) is a function of aircraft roll, pitch and yaw. The X and Y axes of both the AIU and pod axis systems remain in the inertial NE plane at all times with the Y axis of these systems being in the direction of aircraft heading.

The pod sightline reference frame is generally displaced with respect to the aircraft frame. The initial position of the IJK axis system is taken such the I, J and K axes are aligned with the Y, X and Z axes respectively of the aircraft system. The general position of the sightline axis system is described by rotations with respect to this initial position. These rotations are given by the outer and inner gimbal angles of the pod. Details of such coordinate system transformations can be found in Sections I.2 and I.3 of this appendix. Since the I axis represents the actual pod sightline then the associated pod image display is taken to lie in the JK plane where, with respect to this image, J is the horizontal axis and K the vertical. The image display portrayed to the weapons officer is generally a rotation of this pod image giving the XY system illustrated in Figure I.6. Such a rotation puts the image in *horizon natural* mode such that the true horizon is always displayed horizontally. In this mode, the image is said to be *derotated*[36].

The position of an offset aimpoint is described by its range components relative to the target in the north, east and vertical directions. These range components are each positive if the offset aimpoint is west of, south of and above the target.

I.2 TRANSFORMATIONS: THEORY AND TERMINOLOGY

Before discussing the coordinate system transformations used in the FPTS, some basic theory and terminology will be introduced. In the simulation, as will be illustrated later, transformations are only applied to right-handed axis systems and it is to this type of system that the following discussion applies.

The orientation of any one reference frame relative to another can be specified by three rotations or angular coordinates, namely: roll, pitch and yaw. Each rotation can be described by an appropriate 3x3 matrix and the characteristics of each matrix will be introduced below. The reader is referred to reference 19 for details concerning the derivation of these matrices.

For the purposes of this introduction, the right-handed axis system shall be labelled OXYZ where roll, pitch and yaw are rotations about the X, Y and Z axes respectively and O is the origin of the system. (Direction of positive rotation is given by the 'right-hand grip rule' where the thumb points along the positive direction of the appropriate axis and the gripping fingers indicate positive rotation.) Any rotation will be said to give a new axis system OX'Y'Z'. A general point shall be considered to have Cartesian coordinates x, y, z with respect to axis system OXYZ and coordinates x', y', z' with respect to OX'Y'Z'.

I.2.1 The roll matrix

A rotation of the OXYZ axis system through a roll angle ϕ results in a new axis system where:

$$[x', y', z']^T = \Phi\, [x, y, z]^T \tag{I.1}$$

where a superscript T denotes the matrix transpose and Φ is the roll matrix given by:

$$\Phi = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix}. \tag{I.2}$$

I.2.2 The pitch matrix

A rotation of the OXYZ axis system through a pitch angle θ results in a new axis system where:

$$[x', y', z']^T = \Theta\, [x, y, z]^T \tag{I.3}$$

where Θ is the pitch matrix given by:

$$\Theta = \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix}. \tag{I.4}$$

I.2.3 The yaw matrix

A rotation of the OXYZ axis system through a yaw angle ψ results in a new axis system where:

$$[x', y', z']^T = \Psi\, [x, y, z]^T \tag{I.5}$$

where Ψ is the yaw matrix given by:

$$\Psi = \begin{bmatrix} \cos\psi & \sin\psi & 0 \\ -\sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix}. \tag{I.6}$$

The above matrices will be used for reference purposes in the following section. For example, Θ_A will denote a pitch matrix with the same appearance as matrix Θ but with the pitch angle θ_A used in lieu of θ.

I.3 TRANSFORMATIONS USED IN THE FPTS

At any instant in time, the relative orientations of the aircraft, inertial and sightline axis systems form important features of the FPTS. There are three transformation matrices that are used to describe the relative positioning of these three systems, namely:

CAI - the inertial-to-aircraft transformation matrix,

CSA - the aircraft-to-sightline transformation matrix and

CSI - the inertial-to-sightline transformation matrix.

The aircraft axis system (Figure I.2) is generally at some orientation given by aircraft roll, pitch and yaw angles relative to the inertial reference frame (Figure I.1). If ϕ_A, θ_A and ψ_A denote aircraft roll, pitch and yaw respectively then the inertial-to-aircraft transformation matrix CAI is given by:

$$CAI = \Phi_A \, \Theta_A \, \Psi_A \tag{I.7}$$

where Φ_A, Θ_A and Ψ_A are the aircraft roll, pitch and yaw matrices. It should be noted that aircraft roll, pitch and yaw are rotations about the Y (through nose), X (through right wing) and Z (downward vertical) axes respectively (see Figure I.2). It is also important to note the order of the matrix operations.

The orientation of the sightline axis system relative to the aircraft reference frame can be described by the outer and inner gimbal angles of the pod since these angles are referenced to the aircraft frame. The sightline system can therefore be generally regarded as being at outer roll ϕ_O, outer pitch θ_O, inner yaw ψ_I and inner pitch θ_I with respect to the aircraft. The aircraft-to-sightline transformation matrix CSA is given by:

$$CSA = \Theta_I \, \Psi_I \, \Theta_O \, \Phi_O \tag{I.8}$$

where Θ_I, Ψ_I, Θ_O and Φ_O are the inner pitch, inner yaw, outer pitch and outer roll matrices respectively.

The inertial-to-sightline transformation matrix CSI can be derived from CAI and CSA by:

$$CSI = CSA \; CAI \, . \tag{I.9}$$

The methods used to calculate each of the above transformation matrices are discussed in the following section.

I.4 APPLICATIONS OF MATRIX TRANSFORMATIONS

The need for and applications of the FPTS transformation matrices vary with the mode of operation of the Pave Tack system at any given time.

Aircraft roll, pitch and yaw are external inputs to the simulation and are pre-generated as part of the aircraft flight profile data. These quantities are available in any operation mode and therefore the inertial-to-aircraft transformation matrix CAI can be directly constructed at any time.

Matrices CSA and CSI are functions of the position of the pod sightline relative to the aircraft. The methods used in the construction of these matrices depend upon the mode of operation of the Pave Tack pod. Also, in the case of the model, matrix construction techniques will depend on whether or not the effects of the human operator are considered. The appropriate pod modes and the corresponding methods used to construct the transformation matrices are addressed below.

I.4.1 Cue mode

When the Pave Tack pod is in cue mode, the pod sightline is slave to either the location of the stored target position (latitude, longitude and altitude) or that of a stored offset. The stored position of the desired aimpoint and the current system position of the aircraft are used to give the inertial range components to the stored position.

Let the stored aimpoint have system coordinates (R_N, R_E, R_V) with respect to the inertial reference frame and system coordinates (R_I, R_J, R_K) relative to the sightline IJK axis system. Since the sightline is directed through the stored position then both R_J and R_K are zero and:

$$R_I = R_S = \sqrt{R_N^2 + R_E^2 + R_V^2} \tag{I.10}$$

where R_S is the system slant range to the stored aimpoint. The matrix CAI is known and therefore the aircraft-to-sightline transformation matrix CSA is given by the solution of:

$$\begin{bmatrix} R_S \\ 0 \\ 0 \end{bmatrix} = CSA\ CAI \begin{bmatrix} R_N \\ R_E \\ R_V \end{bmatrix} \tag{I.11}$$

where CSA describes the position of the pod sightline relative to the aircraft. As described by equation (I.8), CSA is a function of the inner and outer gimbal angles of the pod. When the pod is in cue mode the sightline is coarse aligned to the stored position via outer gimbal angles only ie inner pitch and yaw angles are both taken as zero and the correspondingly Θ_I and Ψ_I are unit matrices. CSA is therefore a function of outer roll and outer pitch only. In this situation, equation (I.11) can be shown to be:

$$\begin{bmatrix} R_S \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} \cos\theta_O & \sin\phi_O \sin\theta_O & -\cos\phi_O \sin\theta_O \\ 0 & \cos\phi_O & \sin\phi_O \\ \sin\theta_O & -\sin\phi_O \cos\theta_O & \cos\phi_O \cos\theta_O \end{bmatrix} CAI \begin{bmatrix} R_N \\ R_E \\ R_V \end{bmatrix} . \tag{I.12}$$

The problem is now to solve equation (I.12) to give ϕ_O and θ_O in terms of the known quantities R_N, R_E, R_V and elements of matrix CAI. An algebraic task gives:

$$\tan\phi_O = -\frac{T_2}{T_3} \tag{I.13}$$

and

$$\tan\theta_O = -\frac{\sqrt{T_2^2 + T_3^2}}{T_1} \tag{I.14}$$

where T_1, T_2 and T_3 are elements of the column matrix T formed by:

$$T = CAI \left[R_N, R_E, R_V\right]^T . \tag{I.15}$$

The corresponding outer roll Φ_O and pitch Θ_O matrices can now be formed which in turn give the aircraft-to-sightline matrix CSA where CSA = $\Theta_O \Phi_O$. The inertial-to-sightline matrix CSI can now be formed from equation (I.9). Thus all the necessary transformation matrices are made available in this mode of operation.

I.4.2 Coarse cue mode: incorporating the human operator

When the pod is in coarse cue mode then the operator maintains target designation by adjustment of the pod sightline using the handle of the Antenna Indicator Control (AIC) (or Target Control Unit (TCU)). Adjustments of the AIC handle result in alterations to the outer roll ϕ_O and pitch θ_O gimbal angles of the pod sightline; thus sightline alignment is again achieved by coarse means. From these outer gimbal angles can be formed matrices Θ_O and Φ_O which give the aircraft-to-sightline transformation matrix CSA. Hence, with the readily available CAI matrix, the inertial-to-sightline matrix CSI can be formed via equation (I.9).

I.4.3 Track mode: incorporating the human operator

Entering coarse cue mode is generally a prerequisite to placing the pod in track. When the pod is set in track mode then the operator attempts to align the pod sightline with the desired aimpoint by making fine adjustments to the inner gimbal angles. This is carried out via a thumb joystick attached to the AIC handle. In the true system the outer pitch and roll of the pod are configured electronically such that they continually attempt to nullify any inner pitch and yaw. For the purposes of this model, inner pitch is always zero and the operator affects outer pitch directly. Also the inner yaw angles are taken as unbounded since gimbal limits for such rotations in practice are unlikely to be attained. Thus operator adjustments give the values of outer pitch and inner yaw and the matrix CSA can be formed from equation (I.8) where Θ_I is the unit matrix. Transformation matrices CAI and CSI can therefore be formed in an identical manner to that used in coarse cue mode.

I.4.4 Coarse cue and track modes: perfect operator

A human operator is inherently limited in his ability to conduct a given task and therefore the introduction of a human to the system immediately produces another contribution to overall system accuracy. The magnitude and effect of this contributing error, and the sensitivity to different scenarios, are areas of analysis that can be carried out with the flight model reported herein. In order to assess the effect of an human operator on the system it is important to also consider system performance with an operator who is perfect at conducting the associated tasks.

A perfect operator functioning with the pod in track or coarse cue mode will result in the pod sightline always being directed along the line-of-sight (LOS) to the required aimpoint (stored target or offset). The appropriate coordinate transformation matrices must be set up such that they reflect this positioning of the sightline. Since a perfect operator is considered to position the sightline based on the visual image of the *actual* target or offset then the subsequent aircraft-to-sightline and inertial-to-sightline transformation matrices are constructed from precise range components to the target (see Section 5 of main text). The method used to form matrices CAI, CSA and CSI is therefore identical to that used in Section I.4.1 except that here precise inertial range components R_{NP}, R_{EP} and R_{VP} are used in place of system ranges.

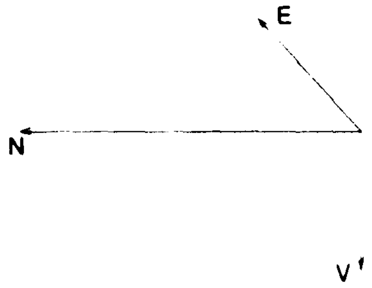

Figure I.1 Inertial reference frame

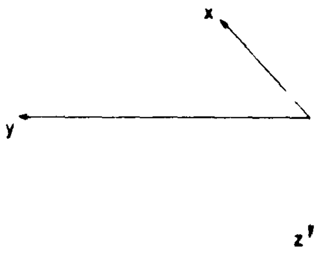

Figure I.2 Aircraft reference frame

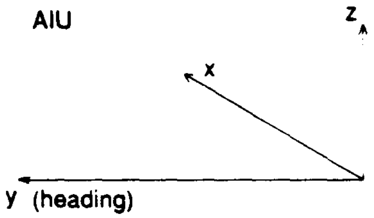

Figure I.3 Analog interface unit reference frame

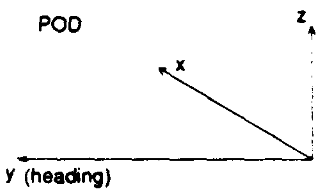

Figure I.4 Pave Tack pod reference frame

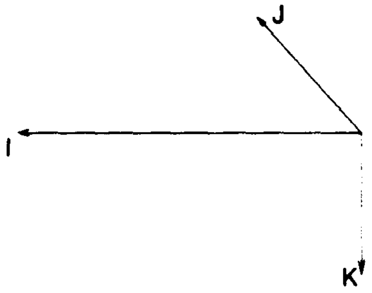

Figure I.5 Pod sight line reference frame

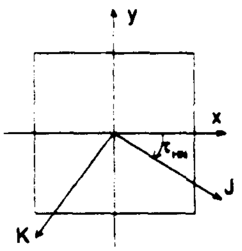

Figure I.6 Pave Tack image display coordinate system

APPENDIX II

FPTS: STRUCTURE

THIS IS A BLANK PAGE

CONTENTS

II.1 INTRODUCTION 59

II.2 INPUT, OUTPUT AND TIMING REFERENCES 59

FIGURES

II.1: Baseline sequence of events for FPTS 62
II.2: Template for layout of FPTS modules 63

THIS IS A BLANK PAGE

II.1 INTRODUCTION

The F-111C Pave Tack Simulation (FPTS) is written in a modular fashion; the layout of the main sequence of events being illustrated in Figure II.1. The main part of the model is associated with navigation and weapon delivery; the individual modules (1 to 9) and submodules therein of the main structure shown in Figure II.1 are discussed in considerable detail in Appendices III through to XIII. The contents and structure of these modules are derived from guidelines laid down in reference 6 and information held in other references. Many equations and features have been incorporated in addition to those given in the references.

The baseline assumptions of the FPTS are discussed in Section 12.4 of the main text. When detailing a particular module, a standard layout is adopted and is illustrated in Figure II.2. Some features of this layout are discussed in the following section; any other parts are quite self-explanatory. Each of Appendices III through to XIII also has an illustration, similar to Figure II.1, of the sequence of events associated with the module for that appendix. To circumvent reading the detailed equations, the reader is referred to such figures for a quick guide to the timing or processing rates of each submodule.

Many of the equations have empirically derived numerical terms, the sources and functions of which are generally unknown. Numerical terms with a known function are explained with appropriate comments.

II.2 INPUT, OUTPUT AND TIMING REFERENCES

Each module identifies the source and destination modules of each parameter as it propagates through that subsystem of the avionics system described by the current module. The interdependence of parameters is therefore identified. An output destination of 'external' indicates that the information is used for display purposes (eg the positioning of the radar cursors). If an input or output parameter is binary (ie can take the values 0 or 1 (false or true) only) then this is indicated in the input and output lists. Input parameters are sampled and output parameters are fed on at the rate of the associated module. This rate is indicated alongside the input and output section headings of the module description (eg in Figure II.2 this rate is 40 Hz).

The input parameters are generally set in other modules which, owing to the discrete nature of the system, are not necessarily processed at the same rate as the current module. For this reason, although input parameters are sampled at a given rate the values of these parameters can be subject to some time-related inaccuracy: the value of the input parameters can be somewhat *stale*. So that the reader or analyst is made aware of any parameters which may have some inherent staleness, the update rate of each input parameter (ie the processing rate of the module from which this parameter comes) is indicated under the column headed 'Update'.

Processing within individual modules may be either continuous, as will occur for analog computations, or may be undertaken periodically within defined rates groups, as will occur for digital computations. Modules which are processed at a continuous rate will be indicated by the abbreviation 'cs'. (Within the flight model, variables which are processed in a continuous manner in the actual system are set up such that their values are readily available to any subsystem requiring them. That is, although continuous processing of these parameters is impractical, the model is never aware of any time-related errors or staleness in these terms.)

It is very difficult in a system such as this to illustrate pictorially the timing relationships between the numerous subsystems. In order to provide some additional clarity when detailing such a complex system, some subsystems have been arranged in time-related groups which are discussed below.

(a) Those computations which are performed 'continuously' in real time (analog computations) are referenced to time t_0.

(b) The AIU computations, input and output processing are based on a 32 Hz main loop cycle, with individual sub-tasks being undertaken in 32, 16, 8, 4, 2, and 1 Hz rate groups. These different groups are:

  (i) AIU 32 Hz rate group input processing referenced to time t_1.

  (ii) AIU 16 Hz rate group input processing referenced to time t_2.

  (iii) AIU 32 Hz rate group computational processing referenced to time t_3.

  (iv) AIU 16 Hz rate group computational processing referenced to time t_4.

  (v) AIU 32 Hz rate group output processing referenced to time t_5.

  (vi) AIU 16 Hz rate group output processing referenced to time t_6.

  (vii) AIU 8 Hz rate group input processing referenced to time t_7.

  (viii) AIU 4 Hz rate group input processing referenced to time t_8.

  (ix) AIU 8 Hz rate group computational processing referenced to time t_9.

  (x) AIU 4 Hz rate group computational processing referenced to time t_{10}.

  (xi) AIU 8 Hz rate group output processing referenced to time t_{11}.

  (xii) AIU 4 Hz rate group output processing referenced to time t_{12}.

  (xiii) AIU 1 Hz rate group input processing referenced to time t_{13}.

(c) PT pod computations and input processing are performed at a main loop cycle rate of 40 Hz and are referenced to time t_{20}.

(d) Data is output from the PT Pod at a rate of 3125/13 Hz (approximately 240 Hz) and is referenced to time t_{21}.

(e) Data that is output by the laser module to the pod is done at a rate of 10 Hz and is referenced to time t_{22}.

The timing reference of each module or subsystem is stated, when appropriate, in the first line of the processing section of the module description (eg the timing reference in Figure II.2 is t_4).

Where AIU computations are dependent on the prior value of a parameter determined during the last rate group cycle, n_i represents the parameter value determined during the current cycle and $(n_i - 1)$ represents the parameter value determined during the previous cycle where i identifies the timing reference for the rate group concerned.

Where PT pod computations are dependent on the prior value of the parameter determined during the last main loop cycle, (i) identifies the parameter value determined during the current cycle, and (i-1) represents the parameter value determined during the previous main loop cycle. The main loop cycle being t_{20} and carried out at 40 Hz.

```
                              ENTRY
                                |
                                V
                               1.0
                         INITIALISE (cs)
                                |
                                V
                               2.0
                DETERMINE NAVIGATION SOLUTION (cs)
                                |
                                V
                               3.0
          DETERMINE RADAR SIGHTING POINT (cs, @32 and 16 Hz)
                                |
                                V
                               4.0
         DETERMINE PT POD SIGHTING POINT (@32, 16, 8 and 4 Hz)
                                |
                                V
                               5.0
                 DETERMINE BOMBING SOLUTION (cs)
                                |
                                V
                               6.0
                PERFORM RADAR POSITION UPDATE (cs)
                                |
                                V
                               7.0
     DETERMINE PT POD SIGHTLINE VECTOR POSITIONING (@40, 3125/13 Hz)
                                |
                                V
                               8.0
                PERFORM PT POSITION UPDATE (@16, 1 Hz)
                                |
                                V
                               9.0
       PERFORM PT ALTITUDE CALIBRATION AND HAT (@32 and 16 Hz)
                                |
                                V
                               10.0
 DETERMINE POSITION OF TARGET RELATIVE TO AIRCRAFT (cs, @40 and 10 Hz)
                                |
                                V
                               11.0
             DETERMINE OPERATOR INTERACTION (cs, @40 Hz)
                                |
                                V
                               EXIT
```

Figure II.1: Baseline sequence of events for FPTS

Module #.#: title

PURPOSE:

Description ....

INPUTS ((@40 Hz)):

	Parameter	Source	Update
Input parameter 1 (Binary)	INPUT_PARM_1	1.5	cs
Input parameter 2	INPUT_PARM_2	4.6	@8 Hz
Input parameter 3	INPUT_PARM_3	O.2	@32 Hz

PROCESSING:

Timing reference t_4:

(a) Processing step 1.

(b) Processing step 2.

OUTPUTS (@40 Hz):

	Parameter	Destination
Output parameter 1	OUTPUT_PARM_1	6.3
Output parameter 2 (Binary)	OUTPUT_PARM_2	4.5
Output parameter 3	OUTPUT_PARM_3	3.1

COMMENTS:

(a) Comment 1.

(b) Comment 2.

Figure II.2: Template for layout of FPTS modules

THIS IS A BLANK PAGE

APPENDIX III

FPTS: INITIALISATION (MODULE 1)

THIS IS A BLANK PAGE

CONTENTS

III.1 INTRODUCTION 69

III.2 MODULE 1.1: PRE-SET PARAMETERS 69

III.3 MODULE 1.2: MISSION PROFILE OR EVENT DEPENDENT PARAMETERS 70

III.4 MODULE 1.3: FLIGHT DEPENDENT PARAMETERS 71

III.5 MODULE 1.4: FLIGHT INDEPENDENT PARAMETERS 72

III.6 MODULE 1.5: MODE IDENTIFIERS 72

III.7 MODULE 1.6: FLIGHT DEPENDENT PARAMETERS (EXTERNAL INPUT) 77

FIGURES

III.1: Sequence of events for initialisation (module 1) 79

THIS IS A BLANK PAGE

III.1 INTRODUCTION

The events associated with module 1 are illustrated in Figure III.1. Each of the submodules of this event sequence is detailed below.

III.2 MODULE 1.1: PRE-SET PARAMETERS

PURPOSE:

> To initialise those navigation and weapon delivery parameters required at the beginning of each flight or mission. These are determined by pre-set positions of switches and counters which are not operator selectable in flight.

INPUTS (cs):

	Parameter	Source	Update
Initial value of present position latitude	λ_{P0}	External	cs
Initial value of present position longitude	L_{P0}	External	cs
Stored offset north (#1, #2, #3, #4, #5, #6)	K_{NO}(#1,#2,#3,#4,#5,#6)	External	cs
Stored offset east (#1, #2, #3, #4, #5, #6)	K_{EO}(#1,#2,#3,#4,#5,#6)	External	cs
Stored offset vertical (#1, #2, #3, #4, #5, #6)	K_{VO}(#1,#2,#3,#4,#5,#6)	External	cs
Target latitude	λ_T	External	cs
Weapon trajectory (X,Y,Z settings)	Weapon Type	External	cs
Weapon ejection velocity	V_{EJ}	External	cs

PROCESSING:

Load initial parameter values.

OUTPUTS (cs):

	Parameter	Destination
Initial present position latitude	$\lambda_P(t=0)$	2.4, 10.5
Initial present position longitude	$L_P(t=0)$	2.4, 10.5
Stored offset north	K_{NO} (#1,#2,#3,#4,#5,#6)	2.1
Stored offset east	K_{EO} (#1,#2,#3,#4,#5,#6)	2.1
Stored offset vertical	K_{VO} (#1,#2,#3,#4,#5,#6)	2.1
Target latitude	λ_T	5.3
Weapon type	Weapon Type	5.3
Weapon ejection velocity	V_{EJ}	5.3

COMMENTS:

(a) A change in parameter value of any of the above inputs represents the start of a new mission.

(b) Note that X, Y, Z settings are pre-set prior to commencement of flight for the particular weapon type and hence for the particular set of weapons ballistics equations.

III.3 MODULE 1.2: MISSION PROFILE OR EVENT DEPENDENT PARAMETERS

PURPOSE:

To initialise, at the beginning of each mission profile or event, those navigation and weapon delivery parameters determined by set positions of switches and counters which are operator selectable during flight.

INPUTS (cs):

	Parameter	Source	Update
Destination latitude	λ_{D0}	Operator	cs
Destination longitude	L_{D0}	Operator	cs
Fixpoint elevation	H_F	Operator	cs
Bomb range to target	R_B	Operator	cs
Weapon trail	L	Operator	cs
Weapon time of fall	T_F	Operator	cs
Burst altitude above target	H_{BACL}	Operator	cs
Number of weapons	n_W	Operator	cs
Ripple interval	t_{RI}	Operator	cs
Number of weapons left	n_{WL}	11.12, Operator	cs
Release switch selected (Binary)	REL SWT	11.12, Operator	cs

PROCESSING:

Load initial parameter values.

OUTPUTS (cs):

	Parameter	Destination
Destination latitude	λ_{D0}	2.5, 10.5
Destination longitude	L_{D0}	2.5, 10.5
Fixpoint elevation	H_F	3.2, 10.5
Bomb range to target	R_B	5.1
Weapon trail	L	5.2
Weapon time of fall	T_F	5.2
Burst altitude above target	H_{BACL}	5.3
Number of weapons	n_W	5.3, 5.5
Ripple interval	t_{RI}	5.3
Number of weapons left	n_{WL}	5.5
Release switch selected (Binary)	REL SWT	5.5

COMMENTS:

(a) A change in parameter value of any of the above inputs represents the start of a new event.

(b) Fixpoint elevation is the height of the stored target above sea level.

III.4 MODULE 1.3: FLIGHT DEPENDENT PARAMETERS

PURPOSE:

To define the operating point of the avionics systems at the start of each event for those parameter values which are dependent on the prior history of flight.

INPUTS (cs):

	Parameter	Source
PT pod altitude correction	ALTRIM	None
Along track correction	C_T	None
Cross track correction	C_{CT}	None
Pressure altitude correction term	ΔH_P	None
LARA altitude calibration term	H_C	None

PROCESSING:

(a) $H_C = 0$

(b) $C_T = C_{CT} = 0$

(c) $\Delta H_P = 0$

(d) ALTRIM = 0

OUTPUTS (cs):

	Parameter	Destination
PT pod altitude correction	ALTRIM	7.5
Along track correction	C_T	6.3
Cross track correction	C_{CT}	6.3
Pressure altitude correction term	ΔH_P	2.6
LARA altitude calibration term	H_C	3.2

COMMENTS:

(a) Parameter values are dependent on prior history of flight.

(b) Parameter values are reset to zero prior to commencement of a new mission.

(c) During a navigation update, the operator correction signals are resolved into along track and cross track components. Along track correction refers to that component along the ground track to the target and cross track correction is the component in the ground plane orthogonal to this.

(b) Altrim varies as a function of operator AIC thumbtracker movement while the PT pod is in track mode. Altrim compensates for vertical error in the PT pod sightline when the pod is in this mode and the laser is not firing.

III.5 MODULE 1.4: FLIGHT INDEPENDENT PARAMETERS

PURPOSE:

To define the operating point of the avionics systems at the start of each event for those parameters which are independent of the prior history of flight during the mission.

INPUTS (cs):

	Parameter	Source	Update
Inertial velocity north	V_{IN}	External	cs
Inertial velocity east	V_{IE}	External	cs
Pressure altitude rate	$\dot{H}_I$	External	cs
Calibrated airspeed	V_C	External	cs
Pressure altitude	H_p	External	cs
Radar return absolute latitude	λ_{PPABS}	11.18	cs
Radar return absolute longitude	L_{PPABS}	11.18	cs
Radar return latitude	λ_{RDRRET}	11.18	cs
Radar return longitude	L_{RDRRET}	11.18	cs

PROCESSING:

Input all parameters

OUTPUTS (cs):

	Parameter	Destination
Inertial velocity north	V_{IN}	2.2, 2.3, 10.5
Inertial veocity east	V_{IE}	2.2, 2.3, 5.3, 10.5
Pressure altitude rate	$\dot{H}_I$	4.1, 5.3, 10.5
Calibrated airspeed	V_C	5.4
Pressure altitude	H_p	2.6, 10.5
Radar return absolute latitude	λ_{PPABS}	6.2
Radar return absolute longitude	L_{PPABS}	6.2
Radar return latitude	λ_{RDRRET}	6.1
Radar return longitude	L_{RDRRET}	6.1

COMMENTS:

(a) Parameter values are independent of the prior history of flight.

III.6 MODULE 1.5: MODE IDENTIFIERS

PURPOSE:

To initialise the status of switches and control settings which are operator selectable or adjustable, and which affect parameter determination during flight.

INPUTS (Binary) (cs):

	Parameter	Source	Update
Navigation or weapon delivery mode (One of)	SR BM RB AB	11.9	cs
Offset mode selected	OS	11.10	cs
Stored offset mode selected (One of)	OFFSET#1 OFFSET#2 OFFSET#3 OFFSET#4 OFFSET#5 OFFSET#6	11.10	cs
Laser firing	LSR FIRE	11.1, 11.3, 11.8 11.10, 11.15	cs
Laser armed	LSR ARM	11.1, 11.3, 11.8 11.10, 11.15	cs
Time Laser Fired	LSR TIME	11.3	cs
Destination (or present position) selected	PP/DEST	11.7	cs
Dead-man switch	C_P	see notes	cs
Weapon release	W_R	11.12	cs
PT or radar prime (One of)	RDR PRM PT PRM	11.1	cs
Cue mode status indicator	CueButton	10.2, 11.8, 11.10 11.14, 11.15 11.16	cs
Pod in track	PIT	11.1, 11.8,11.10 11.15	cs
Dead-man switch at 1/2 action	1/2 ACTION	11.1, 11.8,11.10 11.14, 11.15	cs
PT altitude calibration	PT ALT CAL	11.4	cs
LARA altitude calibration	AC	11.6	cs
PT pod differential sighting selected	R/T LOS SEL	11.8	cs
Horizon natural selected (Binary)	HorNat	11.13	cs
Pave tack pos view selected (Binary)	PV	11.13	cs

PROCESSING:

(a) Set default values:

LSR ARM = 0 (ie laser is not armed)
LSR FIRE = 0 (ie laser is not firing)
GREAT CIRCLE = 0 (ie no Great Circle navigation)
VISUAL CCIP = 0 (ie no Visual CCIP selected)
SR = 0 (ie short range navigation not selected)
BM = 1
RB = 0 (ie auto bomb mode currently selected)
AB = 1
PP/DEST = 1 (ie for destination position update)
OS = 0 (ie no offsets currently selected)
OFFSET#1 = 0 (ie Offset Aimpoint No. 1 is not selected)

OFFSET#2 = 0	(ie Offset Aimpoint No. 2 is not selected)
OFFSET#3 = 0	(ie Offset Aimpoint No. 3 is not selected)
OFFSET#4 = 0	(ie Offset Aimpoint No. 4 is not selected)
OFFSET#5 = 0	(ie Offset Aimpoint No. 5 is not selected)
OFFSET#6 = 0	(ie Offset Aimpoint No. 6 is not selected)
$C_P = 0$	(ie no position updating currently under way)
$W_R = 0$	(ie no weapon release)
WPNST = 0	
PT PRM = 1	(ie PT is prime)
RDR PRM = 0	(ie radar is not prime)
1/2 ACTION = 0	(ie PT pod is in cue mode)
CueButton = 1	
PIT = 0	
MPT = 0	(ie PT pod is not in memory point track)
PT ALT CAL = 1	(ie PT altitude calibration selected)
AC = 0	
R/T LOS SEL = 0	(ie PT pod differential sighting is not selected)
HorNat = 1	(ie PT pod horizon natural mode is selected)
PV = 0	

(b) Determine navigation or weapon delivery mode (see module 2.1)

(c) Determine offset mode selected (see module 2.2)

(d) Determine differential sighting mode

(i) If differential sighting mode is not selected, then:

R/T LOS SEL = 0

(ii) If differential sighting mode is selected, then:

R/T LOS SEL = 1

(e) Determine if updates apply to present or destination position

(i) If present position is to be updated, then:

PP/DEST = 0

(ii) If destination position is to be updated, then:

PP/DEST = 1

(f) Determine PT altitude calibration mode selected:

(i) If PT HAT mode is selected, then:

PT ALT CAL = 0

(ii) If PT altitude calibration mode is selected, then:

PT ALT CAL = 1

(g) Determine if PT or radar is selected prime

(i) If radar is selected prime, then:

PT PRM = 0
RDR PRM = 1

(ii) If PT pod is selected prime, then:

PT PRM = 1
RDR PRM = 0

(h) Determine if dead-man switch is depressed to 1/2 ACTION, or ACTION, these are operator input from 11.14 and 11.15

(i) If dead-man switch is not depressed, and RDR PRM = 1, then:

$C_P = 0$
1/2 ACTION = 0
PIT = 0

(ii) If dead-man switch is depressed to 1/2 ACTION (for time t_{AIC}, determined in 11.18). and RDR PRM = 1, then:

$C_P = 1$ (for time t_{AIC})
1/2 ACTION = 1 (for time t_{AIC})
PIT = 0

(iii) If dead-man switch is depressed to ACTION, and RDR PRM = 1, then :

$C_P = 0$
1/2 ACTION = 0
PIT = 0

(iv) If dead-man switch is not depressed, and PT PRM = 1, then:

$C_P = 0$
1/2 ACTION = 0
PIT = 0

(v) If dead-man switch is depressed to 1/2 ACTION, and PT PRM = 1, then :

$C_P = 0$
1/2 ACTION = 1
PIT = 0

(i) Determine if laser is firing or not

(i) If laser is firing, then:

LSRFIRE = 1

(ii) If laser is not firing, then:

LSRFIRE = 0

OUTPUTS (Binary) (cs):

	Parameter	Destination
Bomb mode selected	BM	4.1, 5.2, 5.5
Range bomb selected	RB	5.1, 5.2, 5.5
Auto bomb selected	AB	4.1, 5.2, 5.3, 5.4, 5.5
Destination (or present position) update selected	PP/DEST	2.4, 2.5, 6.1, 6.2
Offset mode selected	OS	2.1, 10.5
Stored offset number 1 selected	OFFSET#1	2.1
Stored offset number 2 selected	OFFSET#2	2.1
Stored offset number 3 selected	OFFSET#3	2.1
Stored offset number 4 selected	OFFSET#4	2.1
Stored offset number 5 selected	OFFSET#5	2.1
Stored offset number 6 selected	OFFSET#6	2.1
PT pod differential sighting selected	R/T LOS SEL	4.1, 10.5, 11.10
Dead-man switch selected	C_P	2.4, 2.5, 6.3
Weapon released	W_R	4.1
Weapon release flag	WPNST	4.3
Cue mode status indecator	CueButton	7.2, 7.3, 10.2
Pod in track	PIT	7.2, 7.3, 7.4, 7.5, 7.6, 8.3, 10.1, 10.2, 10.3, 10.4, 11.3, 11.15, 11.17
Laser firing	LSR FIRE	7.5, 7.6, 11.3
Laser armed	LSR ARM	11.3
Time Laser Fired	LSR TIME	7.6
PT altitude calibration selected	PT ALT CAL	9.1
LARA altitude calibration selected	AC	9.1
Pave tack is primary	PT PRM	7.2, 7.3, 7.4, 7.5, 7.6, 10.1, 10.2, 10.3, 10.4, 11.1, 11.3, 11.4, 11.10, 11.15, 11.17
Radar is primary	RDR PRM	6.1, 6.2, 10.5, 11.1, 11.11, 11.14, 11.18
Dead-man switch depressed to 1/2 action	1/2 ACTION	6.1, 6.2, 7.2, 7.3, 7.4, 7.5, 7.6, 8.3, 10.1, 10.3, 10.4, 11.14, 11.17, 11.18
Horizon natural selected (Binary)	HorNat	7.2, 7.3, 10.3, 10.4
Pave tack pos view selected (Binary)	PV	7.2, 7.3, 10.3, 10.4

COMMENTS:

(a) The above parameters represent the states of switch positions as a result of operator initiated actions (with the exception of LSRFIRE, W_R, C_P, and MPT which have automatic or manual select) and may be either true or false. Parameters may change at random, at any point in real time due to operator selection.

(b) States PT PRM and RDR PRM are mutually exclusive. PT prime indicates that the PT display occupies the primary screen on the VID. Similarly for radar prime.

(c) Modes Range, Trail and Autobomb are mutually exclusive. It should be noted that Trail Bomb mode is assumed if Range and Autobomb modes are not selected (see Module 5.2).

(d) Stored offset mode may only be selected if offset mode is also selected.

(e) LSRFIRE may be set true or false either from external operator input, or automatically if autolase function is selected. The autolase mechanisation is not currently implemented in this flight model.

(f) A change in states of any of the above parameters (except C_P) signifies the boundary between two events.

(g) The dead man switch may be set true either from external operator input, or automatically if the particular requirements are met for PT position updating.

(h) Differential sighting is the process where the radar is slave to a stored offset aimpoint while the PT pod is directed to the stored target position.

III.7 MODULE 1.6: FLIGHT DEPENDENT PARAMETERS (EXTERNAL INPUT)

PURPOSE:

To define parameter values during each event for those parameters which change dynamically during flight, and hence are dependent on the prior history of flight.

INPUTS (cs):

	Parameter	Source	Update
PT pod laser slant range	R_{SL}	10.6	@40 Hz
Inertial-to-sightline transformation matrix	CSI	7.2,7.2,10.3,10.4	@40 Hz
AIC dead-man switch depression time	t_{AIC}	11.17	cs
WR switch depression time	t_{WR}	External	cs
Range data staleness	δR_{SYNC}	External	cs
Velocity data staleness	δV_{SYNC}	External	cs

PROCESSING:

(a) Input R_{SL}

(b) Input CSI

(c) Input δR_{SYNC}

(d) Input δV_{SYNC}

(e) Input t_{AIC}

(f) Input t_{WR}

OUTPUTS (cs):

	Parameter	Destination
PT pod laser slant range	R_{SL}	7.6
Inertial-to-sightline transformation matrix	CSI	7.3, 7.4, 7.5, 7.6
AIC dead-man switch depression time	t_{AIC}	2.4, 2.5, 6.1, 6.2
WR switch depression time	t_{WR}	5.5
Range data staleness	δR_{SYNC}	7.1
Velocity data staleness	δV_{SYNC}	7.1

COMMENTS:

(a) Parameter values are dependent on prior history of flight.

(b) CSI, a 3x3 matrix, identifies the direction cosines of the current position of the PT pod sightline with respect to the inertial reference frame.

(c) Range and data staleness represent input data staleness incurred due to the difference in main loop cycle rate of the PT pod with respect to the output data transmission rate of the originating subsystem.

(d) The nominal AIC dead-man switch depression time is 0.5 s.

(e) Nominal weapon release switch depression time is 0.125 s.

```
ENTRY
  |
  V
 1.1
INITIALISE PRE-SET PARAMETERS (cs)
  |
  V
 1.2
INITIALISE MISSION PROFILE DEPENDENT PARAMETERS (cs)
  |
  V
 1.3
INITIALISE FLIGHT DEPENDENT PARAMETERS (cs)
  |
  V
 1.4
INITIALISE FLIGHT INDEPENDENT PARAMETERS (cs)
  |
  V
 1.5
INITIALISE MODE IDENTIFIERS (cs)
  |
  V
 1.6
INPUT FLIGHT DYNAMIC PARAMETERS FROM EXTERNAL SOURCES (cs)
  |
  V
EXIT
```

Figure III.1: Sequence of events for initialisation (module 1)

THIS IS A BLANK PAGE

APPENDIX IV

FPTS: NAVIGATION (MODULE 2)

THIS IS A BLANK PAGE

CONTENTS

IV.1 INTRODUCTION 85

IV.2 MODULE 2.1: OFFSET AIMPOINT MODE SELECTION 85

IV.3 MODULE 2.2: SPEED AND GROUND TRACK DETERMINATION 87

IV.4 MODULE 2.3: HEADING AND DRIFT ANGLE DETERMINATION 87

IV.5 MODULE 2.4: AIRCRAFT PRESENT POSITION 88

IV.6 MODULE 2.5: AIRCRAFT DESTINATION POSITION 89

IV.7 MODULE 2.6: AIRCRAFT PRESSURE ALTITUDE 90

FIGURES

IV.1: Sequence of events for navigation processing (module 2) 92

THIS IS A BLANK PAGE

IV.1 INTRODUCTION

The events associated with module 2 are illustrated in Figure IV.1. Each of the submodules of this event sequence is detailed below.

IV.2 MODULE 2.1: OFFSET AIMPOINT MODE SELECTION

PURPOSE:

To allow operator to select and reselect offset aimpoint mode at any point in real time

INPUTS (cs):

	Parameter	Source	Update
Offset mode selected	OS	1.5	cs
Stored offset mode selected (One of)	OFFSET#1 OFFSET#2 OFFSET#3 OFFSET#4 OFFSET#5 OFFSET#6	1.5	cs
Stored offset north	K_{N0}(#1,#2,#3,#4,#5,#6)	1.1	cs
Stored offset east	K_{E0}(#1,#2,#3,#4,#5,#6)	1.1	cs
Stored offset vertical	K_{V0}(#1,#2,#3,#4,#5,#6)	1.1	cs

PROCESSING:

Timing reference t_0:

(a) If OS = 0, then set:

$K_{N0} = 0$
$K_{E0} = 0$
$K_{V0} = 0$

(b) If OS = 1 and:

(i) If OFFSET#1 = 1, then set:

$K_{N0} = K_{N0}$ (#1)
$K_{E0} = K_{E0}$ (#1)
$K_{V0} = K_{V0}$ (#1)

(ii) If OFFSET#2 = 1, then set:

$K_{N0} = K_{N0}$ (#2)
$K_{E0} = K_{E0}$ (#2)
$K_{V0} = K_{V0}$ (#2)

(iii) If OFFSET#3 = 1, then set:

$K_{N0} = K_{N0}$ (#3)

$K_{E0} = K_{E0}$ (#3)
$K_{V0} = K_{V0}$ (#3)

(iv) If OFFSET#4 = 1, then set:

$K_{N0} = K_{N0}$ (#4)
$K_{E0} = K_{E0}$ (#4)
$K_{V0} = K_{V0}$ (#4)

(v) If OFFSET#5 = 1, then set:

$K_{N0} = K_{N0}$ (#5)
$K_{E0} = K_{E0}$ (#5)
$K_{V0} = K_{V0}$ (#5)

(vi) If OFFSET#6 = 1, then set:

$K_{N0} = K_{N0}$ (#6)
$K_{E0} = K_{E0}$ (#6)
$K_{V0} = K_{V0}$ (#6)

(c) If OS = 1, OFFSET#1 = 0,
OFFSET#2 = 0,
OFFSET#3 = 0,
OFFSET#4 = 0,
OFFSET#5 = 0 and
OFFSET#6 = 0 then set:

$K_{N0} = 0$
$K_{E0} = 0$
$K_{V0} = 0$

OUTPUTS (cs):

	Parameter	Destination
Offset selected (Binary)	OS	3.3, 4.1
Stored offset north	K_{N0}	3.3, 4.2, 10.5, 11.18
Stored offset east	K_{E0}	3.3, 4.2, 10.5, 11.18
Stored offset vertical	K_{V0}	3.3, 4.2, 10.5
Offset No.1 selected (Binary)	OFFSET#1	4.1
Offset No.2 selected (Binary)	OFFSET#2	4.1
Offset No.3 selected (Binary)	OFFSET#3	4.1
Offset No.4 selected (Binary)	OFFSET#4	4.1
Offset No.5 selected (Binary)	OFFSET#5	4.1
Offset No.6 selected (Binary)	OFFSET#6	4.1

COMMENTS:

(a) Offset mode is operator selectable during flight.

(b) Change of parameter value during flight represents the start of a new event.

IV.3 MODULE 2.2: SPEED AND GROUND TRACK DETERMINATION

PURPOSE:

To determine ground speed and ground track for navigation purposes.

INPUTS (cs):

	Parameter	Source	Update
Inertial velocity north	V_{IN}	1.4	cs
Inertial velocity east	V_{IE}	1.4	cs

PROCESSING:

Timing reference t_0:

(a) $V_N = V_{IN}$

(b) $V_E = V_{IE}$

(c) $V_G = (V_{IE}^2 + V_{IE}^2)^{1/2}$

(d) $\theta_T = \tan^{-1} (V_{IE}/V_{IN})$

OUTPUTS (cs):

	Parameter	Destination
North velocity	V_N	2.4
East velocity	V_E	2.4
Ground speed	V_G	3.4, 4.1, 5.2, 5.3
Ground track	θ_T	2.3, 4.1, 6.1, 6.2, 6.3, 11.18

COMMENTS:

(a) Parameters are computed independent of prior history of flight.

IV.4 MODULE 2.3: HEADING AND DRIFT ANGLE DETERMINATION

PURPOSE:

To determine aircraft heading and drift angle.

INPUTS (cs):

	Parameter	Source	Update
Inertial velocity north	V_{IN}	1.4	cs
Inertial velocity east	V_{IE}	1.4	cs
Ground track	θ_T	2.2	cs

PROCESSING:

Timing reference t_0:

(a) Plat Az = $\tan^{-1}(V_{IE}/V_{IN})$

(b) θ_H = Plat Az

(c) $\delta = \theta_T$ - Plat Az

OUTPUTS (cs):

	Parameter	Destination
Aircraft heading	Plat Az	4.1
Aircraft heading	θ_H	3.3, 5.5
Drift angle	δ	3.4

COMMENTS:

(a) Parameters are computed independent of prior history of flight.

IV.5 MODULE 2.4: AIRCRAFT PRESENT POSITION

PURPOSE:

To determine aircraft present position, extrapolated as a function of velocity and radar fix magnitude, for navigation purposes.

INPUTS (cs):

	Parameter	Source	Update
Present position latitude	λ_{P0}	1.1	cs
Present position longitude	L_{P0}	1.1	cs
Velocity north	V_N	2.2	cs
Velocity east	V_E	2.2	cs
North correction signal	C_N	6.3	cs
East correction signal	C_E	6.3	cs
Destination (or present position) selected (Binary)	PP/DEST	1.5	cs
Dead-man switch depressed (Binary)	C_P	1.5,6.1 6.2,8.8	See note a
Dead-man switch depressed duration	t_{AJC}	1.6,8.8	See note a

PROCESSING:

Timing reference t_0:

(a) If PP/DEST = 1 or $C_P = 0$, then set:

(i) $C_N = 0$

(ii) $C_E = 0$

Otherwise:

(b)
$$\lambda_P = \frac{1}{20.8961 \times 10^6} \int V_N \, dt + \lambda_{PO} - \int_{t=0}^{t=t_{AIC}} C_N \, dt$$

(c)
$$L_P = \frac{1}{20.9667 \times 10^6} \int V_E \sec\lambda_P \, dt + L_{PO} - \int_{t=0}^{t=t_{AIC}} C_E \, dt$$

OUTPUTS (cs):

	Parameter	Destination
Present position latitude	λ_P	3.1, 6.1, 6.2, 8.2
Present position longitude	L_P	3.1, 6.1, 6.2

COMMENTS:

(a) The output rate from module 8.8 is 16 Hz. The output rate from modules 1.5, 1.6, 6.1 and 6.2 can be taken as continuous.

(b) This module is only carried out if PP/DEST equals 0 which indicates that the position update is applied to the present position of the aircraft and not the stored destination.

(c) Present position latitude and longitude are developed from inertial velocities integrated over time with respect to initial position at commencement of flight. The numerical quantities used in equations (b) and (c) are approximations to the earth's radius (in feet) in the latitude and longitudinal directions.

(d) Correction signals are integrated for period t_{AIC}, measured from when C_P changes from 0 to 1 until C_P changes back to 0. When the pod is in track mode C_P is reset to 0 immediately after the update has been preformed.

IV.6 MODULE 2.5: AIRCRAFT DESTINATION POSITION

PURPOSE:

To determine aircraft destination position, extrapolated as a function of radar fix magnitude, for navigation purposes.

INPUTS (cs):

	Parameter	Source	Update
Present position latitude	λ_{DO}	1.2	cs
Present position longitude	L_{DO}	1.2	cs
North correction signal	C_N	6.3	cs
East correction signal	C_E	6.3	cs
Destination (or present position) selected (Binary)	PP/DEST	1.5	cs

Dead-man switch depressed (Binary)	C_P	1.5, 6.1 6.2, 8.8	See note a
Dead-man switch depressed duration	t_{AIC}	1.6, 8.8	See note b

PROCESSING:

Timing reference t_0:

(a) If PP/DEST = 0 or $C_P = 0$, then set:

(i) $C_N = 0$

(ii) $C_E = 0$

Otherwise:

$$(b)\quad \lambda_D = \lambda_{D0} + \int_{t=0}^{t=t_{AIC}} C_N \, dt$$

$$(c)\quad L_D = L_{D0} + \int_{t=0}^{t=t_{AIC}} C_E \, dt$$

OUTPUTS (cs):

	Parameter	Destination
Destination position latitude	λ_D	3.1, 11.18
Destination position longitude	L_D	3.1, 11.18

COMMENTS:

(a) The output rate from module 8.8 is 16 Hz. The output rate from modules 1.5, 6.1 and 6.2 can be taken as continuous.

(b) The output rate from module 8.8 is 16 Hz. The output rate from modules 1.6 can be taken as continuous.

(c) This module is only carried out if PP/DEST equals 1 which indicates that the position update is applied to the mission destination or target and not the aircraft's present position.

(d) Correction signals are integrated for period t_{AIC}, measured from when C_P changes from 0 to 1 until C_P changes back to 0. When the pod is in track mode C_P is reset to 0 immediately after the update has been preformed.

IV.7 MODULE 2.6: AIRCRAFT PRESSURE ALTITUDE

PURPOSE:

To determine aircraft corrected pressure altitude for navigation purposes.

INPUTS (cs):

	Parameter	Source	Update
Pressure altitude	H_P	1.4	cs
Pressure altitude calibration term	ΔH_P	1.3, 9.5	See note a

PROCESSING:

Timing reference t_0:

(a) $H'_P = H_P + \Delta H_P$

OUTPUTS (cs):

	Parameter	Destination
Improved pressure altitude	H'_P	3.2

COMMENTS:

(a) The output rate from module 9.5 is 16 Hz. The output rate from module 1.3 can be taken as continuous.

(b) Pressure altitude calibration term is initially set to zero prior to first position update.

(c) Parameter value is dependent on prior history of flight. A discrete change in parameter value represents the start of a new event.

```
                  ENTRY
                    |
                    V
                   2.1
      DETERMINE OFFSET MODE SELECTED (cs)
                    |
                    V
                   2.2
     DETERMINE SPEED AND GROUND TRACK (cs)
                    |
                    V
                   2.3
DETERMINE AIRCRAFT HEADING AND DRIFT ANGLE (cs)
                    |
                    V
                   2.4
       DETERMINE PRESENT POSITION (cs)
                    |
                    V
                   2.5
     DETERMINE DESTINATION POSITION (cs)
                    |
                    V
                   2.6
   DETERMINE AIRCRAFT PRESSURE ALTITUDE (cs)
                    |
                    V
                  EXIT
```

Figure IV.1: Sequence of events for navigation processing (module 2)

APPENDIX V

FPTS: RADAR SIGHTING (MODULE 3)

THIS IS A BLANK PAGE

CONTENTS

V.1 INTRODUCTION 97

V.2 MODULE 3.1: TARGET POSITION 97

V.3 MODULE 3.2: ALTITUDE ABOVE TARGET 98

V.4 MODULE 3.3: RADAR SIGHTING POINT 98

V.5 MODULE 3.4: INPUT PROCESSING FOR LAYING OF RADAR CURSOR (@32 Hz) 100

V.6 MODULE 3.5: INPUT PROCESSING FOR LAYING OF RADAR CURSOR (@16 Hz) 100

V.7 MODULE 3.6: COMPUTATIONS FOR LAYING OF RADAR CURSOR (@32 Hz) . . 101

V.8 MODULE 3.7: COMPUTATIONS FOR RADAR CURSOR LAYING (@16 Hz) 101

V.9 MODULE 3.8: OUTPUT PROCESSING FOR RADAR CURSOR LAYING (@32 Hz) 102

V.10 MODULE 3.9: OUTPUT PROCESSING FOR RADAR CURSOR LAYING (@16 Hz) 102

FIGURES

V.1: Sequence of events for radar sighting (module 3) 104

THIS IS A BLANK PAGE

V.1 INTRODUCTION

The events associated with module 3 are illustrated in Figure V.1. Each of the submodules of this event sequence is detailed below.

V.2 MODULE 3.1: TARGET POSITION

PURPOSE:

To determine the range to the target for navigation purposes.

INPUTS (cs):

	Parameter	Source	Update
Destination latitude	λ_D	2.5	cs
Destination longitude	L_D	2.5	cs
Present position latitude	λ_P	2.4	cs
Present position longitude	L_P	2.4	cs

PROCESSING:

Timing reference t_0:

(a) $\Delta\lambda = \lambda_D - \lambda_P$

(b) $\Delta L = L_D - L_P$

(c) $h_1 = (\Delta L/2) \sin\Delta L \cos\lambda_P \sin\lambda_D$

(d) $R_{TN} = 20.8961 \times 10^6 (\Delta\lambda + h_1)$

(e) $R_{TE} = 20.9667 \times 10^6 (\Delta L \cos\lambda_D)$

(f) $R_T = (R_{TN}^2 + R_{TE}^2)^{1/2}$

OUTPUTS (cs):

	Parameter	Destination
Ground range to target, north	R_{TN}	3.3, 5.5
Ground range to target, east	R_{TE}	3.3, 5.5
Ground range to target	R_T	5.5

COMMENTS:

(a) Parameter values are dependent on prior history of flight. A discrete change in parameter value of outputs represents the start of a new event, eg due to selection of new target attitude and longitude.

(b) The numerical quantities used in equations (d) and (e) are approximations to the earth's radius in the latitude and longitudinal directions.

V.3 MODULE 3.2: ALTITUDE ABOVE TARGET

PURPOSE:

To determine aircraft height above target.

INPUTS (cs):

	Parameter	Source	Update
Improved pressure altitude	H'_P	2.6	cs
LARA altitude correction term	H_C	1.3	cs
Fixpoint elevation	H_F	1.2	cs

PROCESSING:

Timing reference t_0:

(a) $H_G = H'_P - (H_F - H_C)$

OUTPUTS (cs):

	Parameter	Destination
Altitude above target	H_G	3.3, 3.6, 4.1, 5.3

COMMENTS:

(a) The value of H_G is dependent on prior history of flight.

(b) A discrete change in H_C represents the start of a new event, eg due to selection of a new target fixpoint elevation.

(c) The initial value of H_P' is set to H_P, prior to first PT or HAT altitude calibration update.

V.4 MODULE 3.3: RADAR SIGHTING POINT

PURPOSE:

To determine aircraft range to the offset sighting point.

INPUTS (cs):

	Parameter	Source	Update
Offset selected (Binary)	OS	2.1	cs
Stored offset north	K_{N0}	2.1	cs
Stored offset east	K_{E0}	2.1	cs
Stored offset vertical	K_{V0}	2.1	cs
Altitude above target	H_G	3.2	cs
Range to target north	R_{TN}	3.1	cs
Range to target east	R_{TE}	3.1	cs
Aircraft heading	θ_H	2.3	cs

PROCESSING:

Timing reference t_0:

(a) OS = 0 then set:

$K_{NS} = 0$
$K_{ES} = 0$
$\Delta H = 0$

(b) If OS = 1, then set:

$K_{NS} = K_{N0}$
$K_{ES} = K_{E0}$
$\Delta H = K_{V0}$

(c) If OS = 0, then set:

$R_{GN} = R_{TN}$
$R_{GE} = R_{TE}$

(d) If OS = 1, then set:

(i) $R_{GN} = R_{TN} - K_{NS}$

(ii) $R_{GE} = R_{TE} - K_{ES}$

(e) $R_G = (R_{GN}^2 + R_{GE}^2)^{1/2}$

(f) $\theta_F = \tan^{-1}(R_{GE}/R_{GN})$

(g) If OS = 0, then set:

$R_S = [-H_G^2 + R_G^2]^{1/2}$

(h) If OS = 1, then set:

$R_S = [(-H_G + \Delta_H)^2 + R_G^2]^{1/2}$

(i) $\theta_B = \theta_F - \theta_H$

OUTPUTS (cs):

	Parameter	Destination
Slant range to radar sighting point	R_S	3.4
Fixpoint relative bearing	θ_B	3.5

COMMENTS:

(a) Parameter values are dependent on prior history of flight.

(b) A discrete change in any parameter value represents the start of a new event, eg selection of a new target or offset aimpoint.

V.5 MODULE 3.4: INPUT PROCESSING FOR LAYING OF RADAR CURSOR (@32 Hz)

PURPOSE:

To sample input parameters used in the positioning of the radar cursor.

INPUTS (@32 Hz):

	Parameter	Source	Update
Slant range	R_S	3.3	cs
Groundspeed	V_G	2.2	cs
Drift angle	δ	2.3	cs

PROCESSING:

Timing reference t_1:

(a) Input R_S

(b) Input V_G

(c) Input δ

OUTPUTS (@32 Hz):

	Parameter	Destination
Sampled slant range	R_S	3.6, 4.4
Sampled groundspeed	V_G	3.6, 4.4
Sampled drift angle	δ	3.6

V.6 MODULE 3.5: INPUT PROCESSING FOR LAYING OF RADAR CURSOR (@16 Hz)

PURPOSE:

To sample input parameters used in the positioning of the radar cursor.

INPUTS (@16 Hz):

	Parameter	Source	Update
Fixpoint relative bearing	θ_B	3.3	cs

PROCESSING:

Timing reference t_2:

(a) Input θ_B

OUTPUTS (@16 Hz):

	Parameter	Destination
Sampled fixpoint relative bearing	θ_B	3.6, 3.7

V.7 MODULE 3.6: COMPUTATIONS FOR LAYING OF RADAR CURSOR (@32 Hz)

PURPOSE:

To determine slant range to the radar fixpoint, as required for radar range cursor laying.

INPUTS (@32 Hz):

	Parameter	Source	Update
Sampled slant range	$R_S(t_1)$	3.4	@32 Hz
Sampled groundspeed	$V_G(t_1)$	3.4	@32 Hz
Sampled drift angle	$\delta(t_1)$	3.4	@32 Hz
Sampled fixpoint relative bearing	$\theta_B(t_2)$	3.5	@16 Hz
Altitude above target	H_G	3.2	cs

PROCESSING:

Timing reference t_3:

(a) $R_{S1} = R_S - 0.0255\ V_G \cos(\theta_B - \delta)$

(b) If $R_{S1} < H_G$ then $R_{S1} = H_G$

(c) $R_{SR} = R_{S1}$

OUTPUTS (@32 Hz):

	Parameter	Destination
Corrected slant range	R_{S1}	4.4, 8.3
Radar slant range	R_{SR}	3.8, 11.18

(a) The second term in equation (a) represents an empirical adjustment to the sampled stant range, this is done to correct for errors caused by time delays resulting from the discrete nature of the system. Figure V.2 shows the effect of this on the north range that is passed to module 7.1. From the figure it can be seen that the correction results in the range being passed lying on either side of the percise range, thus minimising the overall effect of the discrete time delays.

V.8 MODULE 3.7: COMPUTATIONS FOR RADAR CURSOR LAYING (@16 Hz)

PURPOSE:

To determine fixpoint relative bearing to the radar fixpoint, for radar azimuth cursor laying.

INPUTS (@16 Hz):

	Parameter	Source	Update
Sampled fixpoint relative bearing	$\theta_B(t_2)$	3.5	@16 Hz

PROCESSING:

Timing reference t_4:

(a) $\theta_{BR} = \theta B$

OUTPUTS (@16 Hz):

	Parameter	Destination
Radar fixpoint relative bearing	θ_{BR}	3.9, 11.18

V.9 MODULE 3.8: OUTPUT PROCESSING FOR RADAR CURSOR LAYING (@32 Hz)

PURPOSE:

To output slant range to the radar for radar range cursor laying.

INPUTS (@32 Hz):

	Parameter	Source	Update
Radar slant range	$R_{SR}(t_3)$	3.6	@32 Hz

PROCESSING:

Timing reference t_5:

(a) ARSRS = R_{SR}

OUTPUTS (@32 Hz):

	Parameter	Destination
Radar slant range	ARSRS	External

V.10 MODULE 3.9: OUTPUT PROCESSING FOR RADAR CURSOR LAYING (@16 Hz)

PURPOSE:

To output fixpoint relative bearing to the radar for radar cursor laying.

INPUTS (@16 Hz):

	Parameter	Source	Update
Radar fixpoint relative bearing	$\theta_{BR}(t_4)$	3.7	@16 Hz

PROCESSING:

Timing reference t_6:

(a) ARSRB = θ_{BR}

OUTPUTS (@16 Hz):

	Parameter	Destination
Radar fixpoint relative bearing	ARSRB	External

ENTRY
|
V
3.1
DETERMINE TARGET POSITION (cs)
|
V
3.2
DETERMINE ALTITUDE ABOVE TARGET (cs)
|
V
3.1
DETERMINE RADAR SIGHTING POINT (cs)
|
V
3.4
PROCESS INPUT FOR RADAR CURSOR LAYING (@32 Hz)
|
V
3.5
PROCESS INPUT FOR RADAR CURSOR LAYING (@16 Hz)
|
V
3.6
PERFORM COMPUTATIONS FOR RADAR CURSOR LAYING (@32 Hz)
|
V
3.7
PERFORM COMPUTATIONS FOR RADAR CURSOR LAYING (@16 Hz)
|
V
3.8
PROCESS OUTPUT FOR RADAR CURSOR LAYING (@32 Hz)
|
V
3.9
PROCESS OUTPUT FOR RADAR CURSOR LAYING (@16 Hz)
|
V
EXIT

Figure V.1: Sequence of events for radar sighting (module 3)

APPENDIX VI

FPTS: PAVE TACK POD SIGHTING (MODULE 4)

THIS IS A BLANK PAGE

CONTENTS

VI.1 INTRODUCTION 109

VI.2 MODULE 4.1: INPUT PROCESSING FOR PT POD SIGHTING (@32 Hz) 109

VI.3 MODULE 4.2: INPUT PROCESSING FOR PT POD SIGHTING (@4 Hz) 110

VI.4 MODULE 4.3: COMPUTATIONS FOR SIGHTING OF PT POD (@32 Hz) 111

VI.5 MODULE 4.4: COMPUTATIONS FOR SIGHTING OF PT POD (@16 Hz) 113

VI.6 MODULE 4.5: COMPUTATIONS FOR SIGHTING OF PT POD (@8 Hz) 115

VI.7 MODULE 4.6: COMPUTATIONS FOR SIGHTING OF PT POD (4 Hz) 117

VI.8 MODULE 4.7: PROCESS OUTPUT FOR PT POD SIGHTING (@32 Hz) 119

VI.9 MODULE 4.8: PROCESS OUTPUT FOR PT POD SIGHTING (@16 Hz) 119

VI.10 MODULE 4.9: PROCESS OUTPUT FOR PT POD SIGHTING (@8 Hz) 120

FIGURES

VI.1: Sequence of events for PT pod sighting (module 4) 121

THIS IS A BLANK PAGE

VI.1 INTRODUCTION

The events associated with module 4 are illustrated in Figure VI.1. Each of the submodules of this event sequence is detailed below.

VI.2 MODULE 4.1: INPUT PROCESSING FOR PT POD SIGHTING (@32 Hz)

PURPOSE:

To sample input parameters used in the sighting of the PT pod.

INPUTS (@32 Hz):

	Parameter	Source	Update
Altitude above target	H_C	3.2	cs
Improved pressure altitude rate	$\dot{H}_I$	1.4	cs
Groundspeed	V_G	2.2	cs
Groundspeed times time of fall	V_GT_{FI}	5.4	cs
Ground track	θ_T	2.2	cs
Platform azimuth	Plat Az	1.4	cs
Offset selected (Binary)	OS	2.1	cs
Differential sighting selected (Binary)	R/T LOS SEL	1.5	cs
Offset no. 1 selected (Binary)	OFFSET#1	2.1	cs
Offset no. 2 selected (Binary)	OFFSET#2	2.1	cs
Offset no. 3 selected (Binary)	OFFSET#3	2.1	cs
Offset no. 4 selected (Binary)	OFFSET#4	2.1	cs
Offset no. 5 selected (Binary)	OFFSET#5	2.1	cs
Offset no. 6 selected (Binary)	OFFSET#6	2.1	cs
Weapon released (Binary)	W_R	1.5, 5.5	cs
Bomb mode (Binary)	BM	1.5	cs
Auto bomb mode (Binary)	AB	1.5	cs

PROCESSING:

Timing reference t_1:

(a) Input H_C

(b) Input $\dot{H}_I$

(c) Input V_G

(d) Input V_GT_{FI}

(e) Input θ_T

(f) Input Plat Az

(g) Input OS

(h) Input R/T LOS SEL

(i) Input OFFSET#1

(j) Input OFFSET#2

(k) Input OFFSET#3

(l) Input OFFSET#4

(m) Input OFFSET#5

(n) Input OFFSET#6

(o) Input W_R

(p) Input BM

(q) Input AB

OUTPUTS (@32 Hz):

	Parameter	Destination
Altitude above target	$H_G(t_1)$	4.3, 4.4, 4.5, 8.3
Improved pressure altitude rate	$\dot{H}_1(t_1)$	4.3, 4.4, 4.5, 8.3
Groundspeed	$V_G(t_1)$	4.3, 8.3
Groundspeed times time of fall	$V_G T_{F1}(t_1)$	4.3
Ground track	$\theta_T(t_1)$	4.3, 4.4, 8.3, 8.6
Platform azimuth	Plat Az(t_1)	4.4
Offset selected (Binary)	OS(t_1)	4.6
Differential sighting selected (Binary)	R/T LOS SEL(t_1)	4.6
Offset no. 1 selected (Binary)	OFFSET#1(t_1)	4.6
Offset no. 2 selected (Binary)	OFFSET#2(t_1)	4.6
Offset no. 3 selected (Binary)	OFFSET#3(t_1)	4.6
Offset no. 4 selected (Binary)	OFFSET#4(t_1)	4.6
Offset no. 5 selected (Binary)	OFFSET#5(t_1)	4.6
Offset no. 6 selected (Binary)	OFFSET#6(t_1)	4.6
Weapon released (Binary)	$W_R(t_1)$	4.3
Bomb mode (Binary)	BM(t_1)	4.3, 4.5, 9.4
Auto bomb mode (Binary)	AB(t_1)	4.3, 9.4

VI.3 MODULE 4.2: INPUT PROCESSING FOR PT POD SIGHTING (@4 Hz)

PURPOSE:

To sample input parameters used in the sighting of the PT pod.

INPUTS (@4 Hz):

	Parameter	Source	Update
Stored offset north	K_{N0}	2.1	cs
Stored offset east	K_{E0}	2.1	cs
Stored offset vertical	K_{V0}	2.1	cs

PROCESSING:

Timing reference t_8:

(a) Input K_{N0}

(b) Input K_{E0}

(c) Input K_{V0}

OUTPUTS (@4 Hz):

	Parameter	Destination
Sampled stored offset north	$K_{N0}(t_8)$	4.6
Sampled stored offset east	$K_{E0}(t_8)$	4.6
Sampled stored offset vertical	$K_{V0}(t_8)$	4.6

VI.4 MODULE 4.3: COMPUTATIONS FOR SIGHTING OF PT POD (@32 Hz)

PURPOSE:

To conduct computations required to position PT pod sightline.

INPUTS (@32 Hz):

	Parameter	Source	Update
Altitude above target	$H_C(t_1)$	4.1	@32 Hz
Improved pressure altitude rate	$\dot{H}_I(t_1)$	4.1	@32 Hz
Groundspeed	$V_G(t_1)$	4.1	@32 Hz
Groundspeed times time of fall	$V_G T_{FT}(t_1)$	4.1	@32 Hz
Ground track	$\theta_T(t_1)$	4.1	@32 Hz
Weapon released (Binary)	$W_R(t_1)$	4.1	@32 Hz
Weapon release flag	WPNST(n_{32}-1)	1.5, 4.3	See note (a)
Countdown in progress flag	CDIP(n_8)	4.3, 4.5	See note (b)
Bomb mode (Binary)	BM(t_1)	4.1	@32 Hz
Autobomb mode (Binary)	AB(t_1)	4.1	@32 Hz

PROCESSING:

Timing reference t_3:

(a) $H'_{G1} = H_G$

(b) $H_{G1} = H'_{G1} + \dot{H}_I$

(c) $V_{X1} = V_G \sin\theta_T$

(d) $V_{Y1} = V_G \cos\theta_T$

(e) $V_{Z1} = -\dot{H}_I$

(f) $V_{XP} = V_{X1}$

(g) $V_{YP} = V_{YI}$

(h) $V_{ZP} = V_{ZI}$

(i) If BM = 1 and AB = 1, and WPNST(n_{32}-1) = 0 and W_R = 0, then set:

- (i) WPNST (n_{32}) = 0
- (ii) FTFG = 0
- (iii) CDIP = 0

(j) If BM = 1, and AB = 1, and WPNST(n_{32}-1) = 0 and W_R = 1, then set:

- (i) WPNST(n_{32}) = 1
- (ii) FTFG = 0
- (iii) CDIP = 0

(k) If BM = 1, and AB = 1, and WPNST(n_{32}-1) = 1 and W_R = 0, then set:

- (i) WPNST = 0
- (ii) FTFG = 0
- (iii) CDIP = 0

(l) If BM = 1, and AB = 1, and WPNST(n_{32}-1) = 1 and W_R = 1, then set:

- (i) WPNST(n_{32}) = 2
- (ii) $V_C T_{FS} = V_C T_{FI}$
- (iii) $V_{CS} = V_C$
- (iv) CDIP = 1
- (v) FTFG = 1

(m) If BM = 1, and AB = 1, and WPNST(n_{32}-1) = 2, then:

- (i) If W_R = 0 and CDIP = 0 then set:
  - WPNST(n_{32}) = 0
- (ii) Otherwise set:
  - WPNST(n_{32}) = 2

OUTPUTS (@32 Hz):

	Parameter	Destination
Corrected altitude above target	H_{G1}	4.4
X velocity	V_{XP}	4.7
Y velocity	V_{YP}	4.7
Z velocity	V_{ZP}	4.7
Countdown in progress	CDIP	4.3, 4.5
Weapon release flag	WPNST(n_{32})	4.3
First time flag	FTFG	4.5
Sampled groundspeed times time of fall	$V_G T_{PS}$	4.5
Sampled groundspeed	V_{GS}	4.5

COMMENTS:

(a) Inputs from module 1.5 can be considered to be continuously updated whilst parameters from module 4.3 itself are output at a rate of 32 Hz.

(b) Inputs from module 4.5 are updated at 8 Hz, parameters from module 4.3 itself are output at a rate of 32 Hz.

(c) Weapon release signal duration is assumed to be less than computed value of weapon time of fall.

(d) W_R must be set true for two successive rate group cycles before $V_G T_{FI}$ may be sampled.

(e) CDIP is set true in this module if W_R is true for two successive cycles of this rate group and *is reset to zero in the 8 Hz rate group of module 4.5.*

(f) The use of $\dot{H}_1$ in equation (b) to calculate H_{G1} is an empirical adjustment which takes into account the phisical nature of the pressure altimeter. This was left in the equations for the simulation for completeness.

VI.5 MODULE 4.4: COMPUTATIONS FOR SIGHTING OF PT POD (@16 Hz)

PURPOSE:

To conduct computations required to position PT pod sightline.

INPUTS (@16 Hz):

	Parameter	Source	Update
Altitude above target	$H_G(t_1)$	4.1	@32 Hz
Corrected altitude above target	$H_{G1}(t_3)$	4.3	@32 Hz
Groundspeed	$V_G(t_1)$	3.4	@32 Hz
Slant range	$R_S(t_1)$	3.4	@32 Hz
Normalised stored offset north	$K_{NSZ}(t_{10})$	4.6	@4 Hz
Normalised stored offset east	$K_{ESZ}(t_{10})$	4.6	@4 Hz
Normalised stored offset vertical	$K_{VZ}(t_{10})$	4.6	@4 Hz
Offset selected (Binary)	OS(t_{10})	4.6	@4 Hz
Differential sighting selected (Binary)	R/T LOS SEL(t_{10})	4.6	@4 Hz
Aircraft heading	Plat Az (t_1)	4.1	@32 Hz

Ground track	$\theta_T(t_1)$	4.1	@32 Hz
Slant range	$R_{S1}(t_3)$	3.6	@32 Hz
X aimpoint range	$R_{X1}(n_{16}-1)$	4.4	@16 Hz
Y aimpoint range	$R_{Y1}(n_{16}-1)$	4.4	@16 Hz
Z aimpoint range	$R_{Z1}(n_{16}-1)$	4.4	@16 Hz
Improved pressure altitude rate	$\dot{H}_1(t_1)$	4.1	@32 Hz

PROCESSING:

Timing reference t_4:

(a) $H'_{G1} = H_G$

(b) $\theta_F(t_4) = \theta_T + \text{Plat Az}$

(c) (i) If OS = 0, then set:

$$R_G = [R_{S1}^2 - (H'_{G1})^2]^{1/2}$$

(ii) If OS = 1, and R/T LOS SEL = 0 then set:

$$R_G = [R_{S1}^2 - (H'_{G1} + K_{V2})^2]^{1/2}$$

(iii) If OS = 1, and R/T LOS SEL = 1 then set:

$$R_G = [R_{S1}^2 - (H'_{G1})^2]^{1/2}$$

(d) $R_{X0} = R_G \sin\theta_F$

(e) $R_{Y0} = R_G \cos\theta_F$

(f) $R_{Z0} = H_{G1} + 2.39\text{x}10^{-8} [R_{X0}^2 + R_{Y0}^2]$

(g) (i) If OS = 0, then set:

$$R_{X1}(t_4) = R_{X0}$$

$$R_{Y1}(t_4) = R_{Y0}$$

$$R_{Z1}(t_4) = R_{Z0}$$

(ii) If OS = 1, and R/T LOS SEL = 0 then set:

$$R_{X1}(t_4) = R_{X0}$$

$$R_{Y1}(t_4) = R_{Y0}$$

$$R_{Z1}(t_4) = R_{Z0} - K_{V2}$$

(iii) If OS = 1, and R/T LOS SEL = 1 then set:

$$R_{X1}(t_4) = R_{X0} + K_{ES2}$$

$$R_{Y1}(t_4) = R_{Y0} + K_{NS2}$$

$$R_{Z1}(t_4) = R_{Z0}$$

(h) $R_{X1}(n_{16}) = R_{X1}(n_{16} - 1) + 1/16\ [R_{X1}(t_4) - R_{X1}(n_{16} - 1)] - 0.05859375\ V_G \sin\theta_T$

(i) $R_{Y1}(n_{16}) = R_{Y1}(n_{16} - 1) + 1/16\ [R_{Y1}(t_4) - R_{Y1}(n_{16} - 1)] - 0.05859375\ V_G \cos\theta_T$

(j) $R_{Z1}(n_{16}) = R_{Z1}(n_{16}-1)+1/16\ [R_{Z1}(t_4)-R_{Z1}(n_{16}-1)] - 0.05859375(\dot{H}_1)$

(l) $R_{XP} = R_{X1}(n_{16})$

(m) $R_{YP} = R_{Y1}(n_{16})$

(n) $R_{ZP} = R_{Z1}(n_{16})$

(o) $\theta_F(n_{16}) = \theta_F(t_4)$

OUTPUTS (@16 Hz):

	Parameter	Destination
Fixpoint true bearing	$\theta_F(n_{16})$	8.3
X aimpoint range	$R_{X1}(n_{16})$	4.4
Y aimpoint range	$R_{Y1}(n_{16})$	4.4
Z aimpoint range	$R_{Z1}(n_{16})$	4.4
X aimpoint range	R_{XP}	4.8, 8.5
Y aimpoint range	R_{YP}	4.8, 8.5
Z aimpoint range	R_{ZP}	4.8, 8.5
Ground range	R_G	8.3

COMMENTS:

(a) The numerical quantity used in equations (f) and (k) compensates for the curvature of the earth between the aircraft and aimpoint. The units of this quantity are ft^{-1}.

VI.6 MODULE 4.5: COMPUTATIONS FOR SIGHTING OF PT POD (@8 Hz)

PURPOSE:

To conduct computations required to position PT pod sightline.

INPUTS (@8 Hz):

	Parameter	Source	Update
Altitude above target	$H_G(t_3)$	4.1	@32 Hz
Groundspeed times time of fall	$V_G T_{PS}(t_3)$	4.3	@32 Hz
Groundspeed	$V_{GS}(t_3)$	4.3	@32 Hz
Bomb mode (Binary)	$BM(t_1)$	4.1	@32 Hz
Count down in progress	$CDIP(t_3)$	4.3, 4.5	@32 Hz
First time flag	FTFG	4.3, 4.5	See note (a)
Improved pressure altitude rate	$\dot{H}_1(t_1)$	4.1	@32 Hz
Time to impact	$T_I(n_8-1)$	4.5	@8 Hz

PROCESSING:

Timing reference t_9:

(a) If FTFG = 1, then:

(i) FTFG = 0

(ii) If $\dot{H}1 > 0$ then set:

$$T_{FI} = V_G T_{PS}/V_{GS} - 6.5x10^{-5} V_G T_{PS} \dot{H}_1/V_{GS} + 1.25x10^{-4} H_G$$

(iii) If $\dot{H}_1 \leq 0$ then set:

$$T_{FI} = V_G T_{PS}/V_{GS} + 1.25x10^{-4} H_G$$

(iv) $T_I(n_8) = 8\ T_{FI}$

Otherwise:

(i) $T_I(n_8) = T_I(n_8 - 1) - 1$

(ii) If $T_I(n_8) = 0$ then set:

CDIP = 0

(iii) If $T_I(n_8) > 0$ then set:

CDIP = 1

(b) (i) If BM = 1 or if CDIP = 1 then set:

WDIP = 1

Otherwise set:

WDIP = 0

OUTPUTS (@8 Hz):

	Parameter	Destination
Time to impact	$T_I(n_8)$	4.5
Count down in progress	CDIP	4.3,4.5
First time flag	FTFG	4.5
Weapon delivery in progress (Binary)	WDIP	4.9

COMMENTS:

(a) Input from module 4.3 is updated at 32 Hz; parameters from module 4.5 itself are output at a rate of 8 Hz.

(b) FTFG is set when the initial time of fall value is computed, and is reset to zero after time to impact commences counting down towards zero.

(c) CDIP flag is set when initial time of fall value is computed, and is reset when time to impact has counted down to zero.

(d) Initial value of time of fall is computed in seconds, and is decremented in 0.125 s increments towards zero.

VI.7 MODULE 4.6: COMPUTATIONS FOR SIGHTING OF PT POD (4 Hz)

PURPOSE:

To conduct computations required to position PT pod sightline.

INPUTS (@4 Hz):

	Parameter	Source	Update
Stored offset north	$K_{NS1}(n_4-1)$	4.6	@4 Hz
Stored offset east	$K_{ES1}(n_4 - 1)$	4.6	@4 Hz
Stored offset vertical	$K_{V1}(n_4 - 1)$	4.6	@4 Hz
Stored offset north	$K_{N0}(t_8)$	4.2	@4 Hz
Stored offset east	$K_{E0}(t_8)$	4.2	@4 Hz
Stored offset vertical	$K_{V0}(t_8)$	4.2	@4 Hz
Offset selected (Binary)	$OS(t_1)$	4.1	@32 Hz
Differential sighting selected (Binary)	R/T LOS SEL(t_1)	4.1	@32 Hz
Offset No. 1 Selected (Binary)	OFFSET#1(t_1)	4.1	@32 Hz
Offset No. 2 Selected (Binary)	OFFSET#2(t_1)	4.1	@32 Hz
Offset No. 3 Selected (Binary)	OFFSET#3(t_1)	4.1	@32 Hz
Offset No. 4 Selected (Binary)	OFFSET#4(t_1)	4.1	@32 Hz
Offset No. 5 Selected (Binary)	OFFSET#5(t_1)	4.1	@32 Hz
Offset No. 6 Selected (Binary)	OFFSET#6(t_1)	4.1	@32 Hz

PROCESSING:

Timing reference t_{10}:

(a) $K_{NS1}(n_4) = K_{N0}$

(b) $K_{ES1}(n_4) = K_{E0}$

(c) $K_{VS1}(n_4) = K_{V0}$

(d) $OS(n_4) = OS(t_1)$

(e) R/T LOS SEL(n_4) = R/T LOS SEL (t_1)

(f) If either $OS(n_4)$ has changed state from 1 to 0 since last sample, or,
If $OS(n_4)$ has changed state from 0 to 1 since last sample, or

If $OS(n_4) = 1$, and (i) OFFSET#n (n =1 ,6) has changed from 0 to 1 since last sample, or

(ii) OFFSET#n (n = 1,6) has changed state from 1 to 0 since last sample,

or

If $OS(n_4) = 1$, and (i) R/T LOS SEL(n_4) has changed state from 0 to 1 since last sample,

or

(ii) R/T LOS SEL(n_4) has changed state from 1 to 0 since last sample,

then set:

OAPCHANGE = 1

Otherwise set:

OAPCHANGE = 0

(g) If OAPCHANGE = 0, then set:

(i) $K_{NS2} = \overline{K}_{NS1}(n_4) = \overline{K}_{NS1}(n_4 - 1) + 1/8\ [K_{N0}(t_8) - \overline{K}_{NS1}(n_4 - 1)]$

(ii) $K_{ES2} = \overline{K}_{ES1}(n_4) = \overline{K}_{ES1}(n_4 - 1) + 1/8\ [K_{E0}(t_8) - \overline{K}_{ES1}(n_4 - 1)]$

(iii) $K_{V2} = \overline{K}_{V1}(n_4) = \overline{K}_{V1}(n_4 - 1) + 1/8\ [K_{V0}(t_8) - \overline{K}_{V1}(n_4 - 1)]$

(h) If OAPCHANGE = 1, then set:

(i) $K_{NS2} = K_{NS1}(n_4)$

(ii) $K_{ES2} = K_{ES1}(n_4)$

(iii) $K_{V2} = K_{V1}(n_4)$

OUTPUTS (@4 Hz):

	Parameter	Destination
Normalised stored offset north	$K_{NS2}(n_4)$	4.4
Normalised stored offset east	$K_{ES2}(n_4)$	4.4
Normalised stored offset vertical	$K_{V2}(n_4)$	4.4
Stored offset north	$K_{NS1}(n_4)$	4.6
Stored offset east	$K_{ES1}(n_4)$	4.6
Stored offset vertical	$K_{V1}(n_4)$	4.6
Offset selected (Binary)	$OS(n_4)$	4.4
Differential sighting selected (Binary)	R/T LOS SEL(n_4)	4.4

COMMENTS:

(a) If a different stored offset is selected, the initial value of the normalised stored offset is set equal to the first sampled value.

VI.8 MODULE 4.7: PROCESS OUTPUT FOR PT POD SIGHTING (@32 Hz)

PURPOSE:

To output aircraft X, Y, Z velocities to the PT pod for sightline positioning.

INPUTS (@32 Hz):

	Parameter	Source	Update
X velocity	V_{XP}	4.3	@32 Hz
Y velocity	V_{YP}	4.3	@32 Hz
Z velocity	V_{ZP}	4.3	@32 Hz

PROCESSING:

Timing reference t_5:

(a) $V_{XP}(t_5) = V_{XP}$

(b) $V_{YP}(t_5) = V_{YP}$

(c) $V_{ZP}(t_5) = V_{ZP}$

OUTPUTS (@32 Hz):

	Parameter	Destination
X velocity	$V_{XP}(t_5)$	7.1
Y velocity	$V_{YP}(t_5)$	7.1
Z velocity	$V_{ZP}(t_5)$	7.1

VI.9 MODULE 4.8: PROCESS OUTPUT FOR PT POD SIGHTING (@16 Hz)

PURPOSE:

To output X, Y, Z aimpoint ranges to the PT pod for cursor positioning.

INPUTS (@16 Hz):

	Parameter	Source	Update
X aimpoint range	R_{XP}	4.4	@16 Hz
Y aimpoint range	R_{YP}	4.4	@16 Hz
Z aimpoint range	R_{ZP}	4.4	@16 Hz

PROCESSING:

Timing reference t_5:

(a) $R_{XP}(t_5) = R_{XP}$

(b) $R_{YP}(t_5) = R_{YP}$

(c) $R_{ZP}(t_5) = R_{ZP}$

OUTPUTS (@16 Hz):

	Parameter	Destination
X aimpoint range	$R_{XP}(t_5)$	7.1
Y aimpoint range	$R_{YP}(t_5)$	7.1
Z aimpoint range	$R_{ZP}(t_5)$	7.1

VI.10 MODULE 4.9: PROCESS OUTPUT FOR PT POD SIGHTING (@8 Hz)

PURPOSE:

To output PT mode word to the PT pod.

INPUTS (@8 Hz):

	Parameter	Source	Update
Weapon delivery in progress	$WDIP(t_9)$	4.5	@8 Hz

PROCESSING:

Timing reference t_{11}:

(a) Set bit 14 of PT MODE = WDIP

OUTPUTS (@8 Hz):

	Parameter	Destination
PT mode	PT MODE	7.1

```
                              ENTRY
                                |
                                V
                               4.1
              PROCESS INPUT FOR PT POD SIGHTING (@32 Hz)
                                |
                                V
                               4.2
              PROCESS INPUT FOR PT POD SIGHTING (@4 Hz)
                                |
                                V
                               4.3
         PERFORM COMPUTATIONS FOR PT POD SIGHTING (@32 Hz)
                                |
                                V
                               4.4
         PERFORM COMPUTATIONS FOR PT POD SIGHTING (@16 Hz)
                                |
                                V
                               4.5
         PERFORM COMPUTATIONS FOR PT POD SIGHTING (@8 Hz)
                                |
                                V
                               4.6
         PERFORM COMPUTATIONS FOR PT POD SIGHTING (@4 Hz)
                                |
                                V
                               4.7
              PROCESS OUTPUT FOR PT POD SIGHTING (@32 Hz)
                                |
                                V
                               4.8
              PROCESS OUTPUT FOR PT POD SIGHTING (@16 Hz)
                                |
                                V
                               4.9
              PROCESS OUTPUT FOR PT POD SIGHTING (@8 Hz)
                                |
                                V
                               EXIT
```

Figure VI.1: Sequence of events for PT pod sighting (module 4)

THIS IS A BLANK PAGE

APPENDIX VII

FPTS: WEAPON DELIVERY (MODULE 5)

THIS IS A BLANK PAGE

CONTENTS

VII.1 INTRODUCTION 127

VII.2 MODULE 5.1: RANGE BOMB WEAPON DELIVERY 127

VII.3 MODULE 5.2: TRAIL BOMB WEAPON DELIVERY 127

VII.4 MODULE 5.3: AUTOBOMB WEAPONS CHARACTERISTICS 128

VII.5 MODULE 5.4: AUTOBOMB BALLISTICS COMPUTATIONS 130

VII.6 MODULE 5.5: DETERMINATION OF THE WEAPON RELEASE POINT 131

FIGURES

VII.1: Sequence of events for weapon delivery (module 5) 134

THIS IS A BLANK PAGE

VII.1 INTRODUCTION

The events associated with module 5 are illustrated in Figure VII.1. Each of the submodules of this event sequence is detailed below.

VII.2 MODULE 5.1: RANGE BOMB WEAPON DELIVERY

PURPOSE:

To determine values of weapon ballistics parameters utilised during RANGE BOMB mode.

INPUTS (cs):

	Parameter	Source	Update
Range bomb mode selected (Binary)	RB	1.5	cs
Bomb range to target	R_B	1.2	cs

PROCESSING:

Timing reference t_0:

(a) If RB = 0 then:

exit from module

(b) If RB = 1 then set:

$R_I = R_B$

OUTPUTS (cs):

	Parameter	Destination
Bomb range to impact	R_I	5.5

COMMENTS:

(a) Range to impact is only computed in RANGE BOMB mode.

VII.3 MODULE 5.2: TRAIL BOMB WEAPON DELIVERY

PURPOSE:

To determine values of weapon ballistics parameters utilised during TRAIL BOMB mode.

INPUTS (cs):

	Parameter	Source	Update
Navigation or weapon delivery mode (One of - Binary)	BM RB AB	1.5 1.5 1.5	cs cs cs
Groundspeed	V_G	2.2	cs

Weapon trail	L	1.2	cs
Weapon time of fall	T_F	1.2	cs

PROCESSING:

Timing reference t_0:

(a) If BM = 1 and RB = 0 and AB = 0 then set:

$$V_GT_F = V_G\,T_F$$

(b) Otherwise:

exit from module

OUTPUTS (cs):

	Parameter	Destination
Weapon trail	L	5.5
Groundspeed times time of fall	V_GT_F	5.5

COMMENTS:

(a) Weapon trail and V_GT_F are only computed if TRAIL BOMB mode is selected (for the purposes of the FPTS, Trail Bomb mode is active if neither Range Bomb or Autobomb is selected).

VII.4 MODULE 5.3: AUTOBOMB WEAPONS CHARACTERISTICS

PURPOSE:

To determine the value of weapon ballistics parameters utilised during AUTO BOMB mode.

INPUTS (cs):

	Parameter	Source	Update
Weapon type	See table below	1.1	cs
Weapon ejection velocity	V_{EJ}	1.1	cs
Number of weapons to be released	n_W	1.2	cs
Ripple interval selected	t_{RI}	1.2	cs
Target latitude	λ_T	1.1	cs
Burst altitude above ground	H_{BAGL}	1.2	cs
Groundspeed	V_G	2.2	cs
Improved pressure altitude rate	$\dot{H}_I$	1.4	cs
Inertial east velocity	V_{IE}	1.4	cs
Auto bomb selected	AB	1.5	cs
Altitude above target	H_G	3.2	cs

PROCESSING:

Timing reference t_0:

(a) If AB = 0 then:

exit from module

(b) If AB = 1 then:

(i) Determine C_1 value from table according to weapon type

Weapon Type	$C_1 (10^{-6} s^2/ft^2)$
BDU-23(MK-2)	0.2598
BDU-33(MK-76)	0.5089
BLU-1/B f	0.2879
BLU-27/B f	0.2837
BLU-31/B	0.5089
BLU-34/B	0.4318
M-117	0.1856
M-118	0.1123
MK-81	0.2282
K-82	0.1755
MK-83	0.1123
MK-84	0.0912

(ii) $\dot{H}_2 = \dot{H}_1 - V_{ej}$

(iii) $H_{AB} = H_G - H_{BAGL}$

(iv) $g' = 32.0996 - 44.64 \times 10^{-6} V_G - 145.8 \times 10^{-6} V_{IE} \cos\lambda_T \quad ft/s^2$

(v) If $\dot{H}_2 < 0$ then set:

$C_2 = 3.0 \; s^{½}$

(vi) If $\dot{H}_2 \geq 0$ then set:

$C_2 = 6.0 \; s^{½}$

(vii) $T_L = (n_W - 1) \, t_{RI}/2$

OUTPUTS (cs):

	Parameter	Destination
Weapon vertical velocity	$\dot{H}_2$	5.4
Weapon constant	C_1	5.4
Weapon constant	C_2	5.4
Trail lead time	T_L	5.4
Corrected gravity constant	g'	5.4
Height above burst	H_{AB}	5.4

COMMENTS:

(a) Parameter values for $\dot{H}_2$, g', and C_2 are independent on prior history of flight.

(b) A discrete change in value of λ_T or g' represents the start of a new mission.

(c) A discrete change in any of the other parameter values represents the start of a new event, eg selection of a different weapon type.

(d) Autobomb weapon delivery characteristics are only computed in AUTO BOMB mode.

VII.5 MODULE 5.4: AUTOBOMB BALLISTICS COMPUTATIONS

PURPOSE:

To conduct weapon ballistics computations in AUTO BOMB mode.

INPUTS (cs):

	Parameter	Source	Update
Weapon vertical velocity	$\dot{H}_2$	5.3	cs
Height above burst	H_{AB}	5.3	cs
Corrected gravity constant	g'	5.3	cs
Calibrated airspeed	V_C	1.4	cs
Trail lead time	T_L	5.3	cs
Weapon constant	C_1	5.3	cs
Weapon constant	C_2	5.3	cs
Autobomb mode selected	AB	1.5	cs

PROCESSING:

Timing reference t_0:

(a) If AB = 0 then:

exit from module

(b) If AB = 1 then set:

(i) $T_V = \dot{H}_2/g' + [(\dot{H}_2/g')^2+2H_{AB}/g']^{1/2}$

(ii) $V_G T_{FI} = V_G\, T_V + V_G\, T_L + 0.04\, V_G + 36$ ft

(iii) $L_1 = C_1\, V_C^2\, [H_{AB} + C_2\, \dot{H}_2\, (T_V)^{1/2}]$

OUTPUTS (cs):

	Parameter	Destination
Autobomb groundspeed times time of fall	$V_G T_{FI}$	4.1, 5.5
Autobomb trail	L_1	5.5

COMMENTS:

(a) Parameter values are dependent on prior history of flight.

(b) A discrete change in parameter value represents the start of a new event, eg selection of a different weapon type.

(c) Autobomb ballistics computations are only computed in AUTOBOMB mode.

VII.6 MODULE 5.5: DETERMINATION OF THE WEAPON RELEASE POINT

PURPOSE:

To determine weapon release point during navigation to the target.

INPUTS (cs):

	Parameter	Source	Update
Range to target	R_T	3.1	cs
Range to target east	R_{TE}	3.1	cs
Range to target north	R_{TN}	3.1	cs
Auto bomb mode ground speed times time of fall	$V_G T_{F1}$	5.4	cs
Auto bomb mode trail	L_1	5.4	cs
Trail bomb mode trail	L	5.2	cs
Range bomb mode bomb range to target	R_I	5.1	cs
Trail ground speed times time of fall	$V_G T_F$	5.2	cs
Aircraft heading	θ_H	2.3	cs
Bomb mode selected	BM	1.5	cs
Autobomb mode selected	AB	1.5	cs
Range bomb mode selected	RB	1.5	cs
Weapon release switch depression duration	t_{WR}	1.6	cs
Number of weapons	n_W	1.2	cs
Number of bombs left	n_{WL}	1.2, 5.5	cs
Release switch selected (Binary)	REL SWT	1.2	cs

PROCESSING:

Timing reference t_0:

(a) If BM = 0 then:

exit from module

(b) If BM = 1 then:

(i) If RB = 1 then set:

$$R_R = R_T - R_I$$

(ii) If RB = 0 and AB = 0 then set:

$L_N = L \cos\theta_H$

$L_E = L \sin\theta_H$

$(R_T + L)_E = R_{TE} + L_E$

$(R_T + L)_N = R_{TN} + L_N$

$(R_T + L) = [(R_T + L)_E^2 + (R_T + L)_N^2]^{1/2}$

$V_C T_G = (R_T + L) - V_C T_F$

$R_R = V_C T_G$

(iii) If AB = 1 then set:

$L_N = L_1 \cos\theta_H$

$L_E = L1 \sin\theta_H$

$(R_T + L)_E = R_{TE} + L_E$

$(R_T + L)_N = R_{TN} + L_N$

$(R_T + L) = [(R_T + L)_E^2 + (R_T + L)_N^2]^{1/2}$

$V_C T_G = (R_T + L) - V_C T_{F1}$

$R_R = V_C T_G$

(iv) If $R_R \leq 0$ or REL SWT = 1 then:

If $n_{WL} \geq 0$, then set:

$W_R = 1$ for time t_{WR} before returning to 0

$n_{WL} = n_{WL} - n_W$

REL SWT = 1

Otherwise set:

$W_R = 0$

Output (cs):

	Parameter	Destination
Range to weapon release	R_R	External
Weapon release	W_R	4.1
Number of weapons left	n_{WL}	5.5, 11.12
Release switch selected (Binary)	REL SWT	11.12

COMMENTS:

(a) Weapon release occurs when R_R decreases to zero.

(b) Value of R_R increases negatively if aircraft moves closer towards the target after weapon release, and increases positively as aircraft moves away from the weapon release point after weapon release.

```
                              ENTRY
                                |
                                V
                               5.1
   DETERMINE PARAMETER VALUES FOR RANGE BOMB BALLISTICS (cs)
                                |
                                V
                               5.2
   DETERMINE PARAMETER VALUES FOR TRAIL BOMB BALLISTICS (cs)
                                |
                                V
                               5.3
       DETERMINE AUTO BOMB WEAPONS CHARACTERISTICS (cs)
                                |
                                V
                               5.4
         PERFORM AUTOBOMB BALLISTICS COMPUTATIONS (cs)
                                |
                                V
                               5.5
               DETERMINE WEAPON RELEASE POINT (cs)
                                |
                                V
                               EXIT
```

Figure VII.1: Sequence of events for weapon delivery (module 5)

APPENDIX VIII

FPTS: RADAR POSITION UPDATING (MODULE 6)

THIS IS A BLANK PAGE

CONTENTS

VIII.1 INTRODUCTION . . . 139

VIII.2 MODULE 6.1: RADAR FIX MAGNITUDE (DESTINATION POSITION UPDATING) . . . 139

VIII.3 MODULE 6.2: RADAR FIX MAGNITUDE (PRESENT POSITION UPDATING) 141

VIII.4 MODULE 6.3: BOMB AND NAVIGATION SYSTEM POSITION UPDATING 143

FIGURES

VIII.1: Sequence of events for radar position updating (module 6) . . . 145

THIS IS A BLANK PAGE

VIII.1 INTRODUCTION

The events associated with module 6 are illustrated in Figure VIII.1. Each of the submodules of this event sequence is detailed below.

VIII.2 MODULE 6.1: RADAR FIX MAGNITUDE (DESTINATION POSITION UPDATING)

PURPOSE:

To determine error magnitude between the target return indicated on the VID radar display and the position of the intersection point of the range and azimuth cursor, for Bomb/Nav system destination position updating.

INPUTS (cs):

	Parameter	Source	Update
Radar prime (Binary)	RDR PRM	1.5	cs
Destination (or present position) selected (Binary)	PP/DEST	1.5	cs
Radar return latitude	λ_{RDRRET}	1.4	cs
Radar return longitude	L_{RDRRET}	1 [illegible]	cs
Present position latitude	λ_P	2.4	cs
Present position longitude	L_P	2.4	cs
AIC dead-man switch depressed to 1/2 ACTION (Binary)	1/2 ACTION	1.5	cs
AIC dead-man switch depressed duration	t_{AIC}	1.6	cs
Ground track	θ_T	2.2	cs

PROCESSING:

Timing reference t_0:

(a) If RDR PRM = 0, then:

exit from module

(b) If RDR PRM = 1 and 1/2 ACTION = 0 then set:

$C_T = 0$
$C_{CT} = 0$
$C_P = 0$

exit from module

(c) If RDR PRM = 1 and PP/DEST = 0 and 1/2 ACTION = 1 then:

exit from module

(d) If RDR PRM = 1 and PP/DEST = 1 and 1/2 ACTION = 1 then set:

(i) $\Delta\lambda_{RDRRET} = \lambda_{RDRRET} - \lambda_P$

(ii) $\Delta L_{RDRRET} = L_{RDRRET} - L_P$

(iii) $h_{TRDRRET} = (\Delta L_{RDRRET}/2) \sin\Delta L_{RDRRET} \cos\lambda_P \sin\lambda_{RDRRET}$

(iv) $R_{TNRDRRET} = 20.8961\text{x}10^6 (\Delta\lambda_{RDRRET} + h_{TRDRRET})$

(v) $R_{TERDRRET} = 20.9667\text{x}10^6 (\Delta L_{RDRRET} \cos\lambda_{RDRRET})$

(vi) $\varepsilon_N = R_{TNRDRRET} - R_{TN}$

(vii) $\varepsilon_E = R_{TERDRRET} - R_{TE}$

(viii) $\varepsilon_T = \varepsilon_N \cos\theta_T + \varepsilon_E \sin\theta_T$

(ix) $\varepsilon_{CT} = -\varepsilon_N \sin\theta_T + \varepsilon_E \cos\theta_T$

(x) $C_{TR} = \varepsilon_T/t_{AIC}$

(xi) $C_{CTR} = \varepsilon_{CT}/t_{AIC}$

(xii) Set $C_P = 1$ for duration t_{AIC}

(e) $C_T = C_{TR}$

(f) $C_{CT} = C_{CTR}$

OUTPUTS (cs):

	Parameter	Destination
Radar along track correction	C_T	6.3
Radar cross track correction	C_{CT}	6.3
Dead-man switch	C_P	6.3, 2.4, 2.5

COMMENTS:

(a) Target return position is identified in terms of absolute latitude and longitude.

(b) If position error is due to error in NCU destination latitude and longitude, then fix magnitude is the difference between radar return latitude and longitude with respect to destination latitude and longitude.

(c) If position error is due to error in NCU present position latitude and longitude, then the net effect will be the same disparity between the intersection point of the cursors with respect to the target radar return. Either the present position or the destination may be updated to correct the navigation solution, regardless of the error source.

(d) Magnitude of radar correction applied is dependent on magnitude of AIC displacement caused by the operator, and duration the dead-man switch is depressed.

(e) C_{TR}, and C_{CTR} are slewing signals (ft/s) with magnitude proportional to fore or aft and lateral displacement of the AIC by the operator .

(f) The AIC dead-man switch is usually depressed by the operator in short bursts (known as "beeps"), of duration t_{AIC}, with fixed AIC displacement. During each "beep", the NCU recomputes a new navigation solution to reposition the radar cursors by an amount proportional to the displacement of the AIC. Correction signals C_{TR} and C_{CTR} are only applied to the NCU to change the navigation solution while the AIC dead-man switch is depressed. However, corrections may also be applied with the dead-man switch depressed for a longer period of time, where the AIC displacement is varied by the operator in response to the change in cursor positioning with respect to the radar target return while the dead-man switch is depressed.

(g) The numerical quantities used in steps (iv) and (v) of (d) are approximations to the earth's radius in the latitude and longitudinal directions.

VIII.3 MODULE 6.2: RADAR FIX MAGNITUDE (PRESENT POSITION UPDATING)

PURPOSE:

To determine error magnitude between the target return indicated on the VID Radar Display and the position of the intersection point of the range and azimuth cursor, for Bomb/Nav System present position updating.

INPUTS (cs):

	Parameter	Source	Update
Radar prime (Binary)	RDR PRM	1.5	cs
Aircraft absolute present position latitude	λ_{PPABS}	1.4	cs
Aircraft absolute present position longitude	L_{PPABS}	1.4	cs
Present position latitude	λ_P	2.4	cs
Present position longitude	L_P	2.4	cs
Destination (or present position) selected (Binary)	PP/DEST	1.5	cs
AIC dead-man switch depressed to 1/2 ACTION (Binary)	1/2 ACTION	1.5	cs
AIC dead-man switch depressed duration	t_{AIC}	1.6	cs
Ground track	θ_T	2.2	cs

PROCESSING:

Timing reference t_0:

(a) If RDR PRM = 0, then:

exit from module

(b) If RDR PRM = 1 and 1/2ACTION = 0 then set:

$C_{TR} = 0$

$C_{CTR} = 0$

exit from module

(c) If RDR PRM = 1 and PP/DEST = 1 and 1/2 ACTION = 1 then:

exit from module

(d) IF RDR PRM = 1 and PP/DEST = 0 and 1/2 ACTION = 1 then set:

(i) $\Delta\lambda_{PPABS} = \lambda_{PPABS} - \lambda_P$

(ii) $\Delta L_{PPABS} = L_{PPABS} - L_P$

(iii) $h_{1PPABS} = (\Delta L_{PPABS}/2) \sin\Delta L_{PPABS} \cos\lambda_P \sin\lambda_{PPABS}$

(iv) $R_{TNPPABS} = 20.8961\mathrm{x}10^6 (\Delta\lambda_{PPABS} + h_{1PPABS})$

(v) $R_{TEPPABS} = 20.9667\mathrm{x}10^6 (\Delta L_{PPABS} \cos\lambda_{PPABS})$

(vi) $\varepsilon_N = R_{TNPPABS} - R_{TN}$

(vii) $\varepsilon_E = R_{TEPPABS} - R_{TE}$

(viii) $\varepsilon_T = \varepsilon_N \cos\theta_T + \varepsilon_E \sin\theta_T$

(ix) $\varepsilon_{CT} = -\varepsilon_N \sin\theta_T + \varepsilon_E \cos\theta_T$

(x) $C_{TR} = \varepsilon_T/t_{AIC}$

(xi) $C_{CTR} = \varepsilon_{CT}/t_{AIC}$

(xii) Set $C_P = 1$ for duration t_{AIC}

(e) $C_T = C_{TR}$

(f) $C_{CT} = C_{CTR}$

OUTPUTS (cs):

	Parameter	Destination
Radar along track correction	C_T	6.3
Radar cross track correction	C_{CT}	6.3
Dead-man switch	C_P	6.3, 2.4, 2.5

COMMENTS:

(a) Aircraft true present position is identified in terms of absolute latitude and longitude of the aircraft present position.

(b) If position error is due to error in NCU present position latitude and longitude, then fix magnitude is the difference between absolute present position latitude and longitude with respect to NCU present position latitude and longitude.

(c) Magnitude of radar correction applied is dependent on magnitude of AIC displacement caused by the operator, and the duration t_{AIC} that the dead-man switch is depressed.

(d) C_{TR}, and C_{CTR} are slewing signals (ft/s) with magnitude proportional to fore or aft and lateral displacement of the AIC by the operator .

(e) The numerical quantities used in steps (iv) and (v) of (d) are approximations to the earth's radius in the latitude and longitudinal directions.

VIII.4 MODULE 6.3: BOMB AND NAVIGATION SYSTEM POSITION UPDATING

PURPOSE:

To determine the magnitude of correction signals north and east to be applied to the NCU navigation solution, derived from position corrections determined using the radar or the PT pod as position sensors.

INPUTS (cs):

	Parameter	Source	Update
Dead-man switch (Binary)	C_P	1.5,6.1,6.2,8.8	See note (a)
Radar along track correction	C_T	1.3,6.1,6.2,8.8	See note (a)
Radar cross track correction	C_{CT}	1.3,6.1,6.2,8.8	See note (a)
Ground track	θ_T	2.2	cs

PROCESSING:

Timing reference t_0:

(a) If $C_P = 0$ then set:

(i) $C_N = O$

(ii) $C_E = O$

exit from module

(b) If $C_P = 1$ then set:

(i) $C_N = C_T \cos\theta_T - C_{CT} \sin\theta_T$

(ii) $C_E = C_T \sin\theta_T + C_{CT} \cos\theta_T$

OUTPUTS (cs):

	Parameter	Destination
North correction signal	C_N	2.4, 2.5
East correction signal	C_E	2.4, 2.5

COMMENTS:

(a) Input from submodules of module 1 and 6 can be regarded as updated continuously; parameters from module 8.8 are updated at a rate of 16 Hz.

(b) Correction signals slew the present position or destination position counters on the NCU, dependent on selection of PP/DEST switch.

(c) If RDR PRM = 1, position updating will utilise radar position corrections.

(d) If RDR PRM = 0, position updating will utilise PT pod position corrections.

(e) Dead-man switch is set true for time t_{AIC}, determined by length of depression by operator for radar position updating and determined by AIU computations for PT position updating.

ENTRY
|
V
6.1
DETERMINE RADAR FIX MAGNITUDE
(DESTINATION UPDATING) (cs)
|
V
6.2
DETERMINE RADAR FIX MAGNITUDE
(PRESENT POSITION UPDATING) (cs)
|
V
6.3
DETERMINE BOMB AND NAVIGATION SYSTEM POSITION CORRECTIONS (cs)
|
V
EXIT

Figure VIII.1: Sequence of events for radar position updating (module 6)

THIS IS A BLANK PAGE

APPENDIX IX

FPTS: PT POD SIGHTLINE VECTOR POSITIONING (MODULE 7)

THIS IS A BLANK PAGE

CONTENTS

IX.1 INTRODUCTION 151

IX.2 MODULE 7.1: PT POD INPUT PROCESSING FOR SIGHTLINE CONTROL (@40 Hz) 151

IX.3 MODULE 7.2: PT POD SIGHTLINE VECTOR IN CUE MODE 152

IX.4 MODULE 7.3: PT POD SIGHTLINE VECTOR IN COARSE CUE MODE 155

IX.5 MODULE 7.4: PT POD VELOCITY VECTOR IN TRACK MODE 158

IX.6 MODULE 7.5: PT POD SIGHTLINE VECTOR IN TRACK MODE (WITHOUT LASER FIRE) 159

IX.7 MODULE 7.6: PT SIGHTLINE VECTOR IN TRACK MODE (WITH LASER FIRE) . 162

IX.8 MODULE 7.7: PT POD OUTPUT PROCESSING (@3125/13 Hz) 164

FIGURES

IX.1: Sequence of events for PT pod sightline vector positioning (module 7) 166

THIS IS A BLANK PAGE

IX.1 INTRODUCTION

The events associated with module 7 are illustrated in Figure IX.1. Each of the submodules of this event sequence is detailed below.

IX.2 MODULE 7.1: PT POD INPUT PROCESSING FOR SIGHTLINE CONTROL (@40 Hz)

PURPOSE:

To synchronise aircraft input data to the PT pod main loop cycle time.

INPUTS (@40 Hz):

	Parameter	Source	Update
Aircraft X velocity	$V_{XP}(t_5)$	4.7	@32 Hz
Aircraft Y velocity	$V_{YP}(t_5)$	4.7	@32 Hz
Aircraft Z velocity	$V_{ZP}(t_5)$	4.7	@32 Hz
Aircraft X aimpoint range	$R_{XP}(t_6)$	4.8	@16 Hz
Aircraft Y aimpoint range	$R_{YP}(t_6)$	4.8	@16 Hz
Aircraft Z aimpoint range	$R_{ZP}(t_6)$	4.8	@16 Hz
Range staleness	δR_{SYNC}	1.6	cs
Velocity staleness	δV_{SYNC}	1.6	cs
PT mode	PT MODE(t_{11})	4.9	@8 Hz

PROCESSING:

Timing reference t_{20}:

(a) Input parameters

(b) $R_{EA} = R_{XP} + \delta R_{SYNC}$

(c) $R_{NA} = R_{YP} + \delta R_{SYNC}$

(d) $R_{VA} = R_{ZP} + \delta R_{SYNC}$

(e) $V_{EA} = V_{XP} + \delta V_{SYNC}$

(f) $V_{NA} = V_{YP} + \delta V_{SYNC}$

(g) $V_{VA} = V_{ZP} + \delta V_{SYNC}$

(h) $R_Z = R_{ZP}$

(i) Input WDIP (Bit 14 of word PT MODE)

OUTPUTS (@40 Hz):

	Parameter	Destination
Untrimmed aircraft north range	R_{NA}	7.2, 7.3, 7.5, 7.6
Untrimmed aircraft east range	R_{EA}	7.2, 7.3, 7.5, 7.6

Untrimmed aircraft vertical range	R_{VA}	7.2, 7.5, 7.6
Untrimmed aircraft north velocity	V_{NA}	7.3, 7.4, 7.6
Untrimmed aircraft east velocity	V_{EA}	7.3, 7.4, 7.6
Untrimmed aircraft vertical velocity	V_{VA}	7.3, 7.4, 7.6
Unsynchronised aircraft vertical range	R_Z	7.3, 7.5
Weapon delivery in progress (Binary)	WDIP	7.5

COMMENTS:

(a) PT pod compensates for data staleness incurred due to difference in processing rates between the external data source and the PT pod main loop cycle rate.

IX.3 MODULE 7.2: PT POD SIGHTLINE VECTOR IN CUE MODE

PURPOSE:

To determine the PT pod sightline vector in CUE mode, prior to entering into COARSE CUE or TRACK mode.

INPUTS (@40 Hz):

	Parameter	Source	Update
Pave tack prime (Binary)	PT PRM	1.5	cs
cue mode status indicator (Binary)	CueButton	1.5	cs
Pod in track (Binary)	PIT	1.5	cs
Horizon natural selected (Binary)	Hor Nat	1.5	cs
Pave tack pod view selected (Binary)	PV	1.5	cs
Untrimmed north range	R_{NA}	7.1	@40 Hz
Untrimmed east range	R_{EA}	7.1	@40 Hz
Untrimmed vertical range	R_{VA}	7.1	@40 Hz

PROCESSING:

Timing reference t_{20}:

If PT PRM = 0 or PT PRM = 1 and CueButton = 1 and PIT = 0 then set:

(a) $R_E = R_{EA}$

(b) $R_N = R_{NA}$

(c) $R_V = R_{VA}$

(d) $R_{SPTCP} = [R_E^2 + R_N^2 + R_V^2]^{1/2}$

(e) $R_{SPTSP} = R_{SPTCP}$

(f) $\delta R_E(i) = 0$

(g) $\delta R_N(i) = 0$

(h) $\delta R_V(i) = 0$

(i) $CSII_{11} = R_N / R_{SPTCP}$

(j) $CSII_{12} = R_E / R_{SPTCP}$

(k) $CSII_{13} = R_V / R_{SPTCP}$

(l) RTA = 0

(m) LRA = 0

(n) $R_1 = R_N$

(o) $R_2 = R_E$

(p) $R_3 = R_V$

(q) T = CAI R

(r) Outer Roll = $\tan^{-1}(-T_2/T_3)$

(s) Outer Pitch = $\tan^{-1}(-(T_2^2 + T_3^2)^{1/2} / T_1)$

(t) Inner Yaw = 0

(u) (i) Translate Outer Roll into 3 x 3 Roll transfer matrix Phi

  (ii) Translate Outer Pitch into 3 x 3 Pitch transfer matrix Theta

  (iii) Translate Inner Yaw into 3 x 3 Yaw transfer matrix Psi

(v) (i) CSI = Phi Theta Psi CAI

  (ii) CSA = Phi Theta Psi

(w) Theta LoS = $|\sin^{-1}(CSA_{1,3})|$

(x) Psi LoS = $\tan^{-1}(CSA_{1,2}/CSA_{1,1})$

(y) $ZTheta_1 = \cos^{-1}(CSI_{1,3})$

(z) If $ZTheta_1 > \pi/2$ then $ZTheta_1 = ZTheta_1 - \pi$

(aa) If PV = 1 then set:

  $\tau = 0$

 Otherwise:

  (i) If HorNat = 1 then set:

   $\tau = \tan^{-1}[\sin(\text{Outer Roll})/(\cos(\text{Outer Pitch}) \cos(\text{Outer Roll}))]$

Otherwise:

(ii) $\tau = \tan^{-1}[\sin(\text{Outer Roll})/(\cos(\text{Outer Pitch})\cos(\text{Outer Roll}))] - \text{Psi LoS}$

(bb) $\text{LoS} = \text{CSI}\,(R_{SPTSP},0,0)^T$

Otherwise:

exit from module

OUTPUTS (@40 Hz):

	Parameter	Destination
North correction	$\delta R_N(i)$	7.7
East correction	$\delta R_E(i)$	7.7
Vertical correction	$\delta R_V(i)$	7.7
Inerital-to-sightline transformation matrix	CSI	1.6
North direction cosine	$CSII_{11}$	7.7
East direction cosine	$CSII_{12}$	7.7
Vertical direction cosine	$CSII_{13}$	7.7
Slant range to PT pod sighting point	R_{SPTSP}	7.3, External
Range trim available (Binary)	RTA	7.7
Laser range available (Binary)	LRA	7.7
Depression angle	$ZTheta_1$	External
Pod outer pitch	Outer Pitch	10.4
Depression angle line-of-sight marker	Theta LoS	External
Azimuth angle line-of-sight marker	Psi Los	External
Derotation angle	τ	11.17, External
Arbitrary point on sight line vector	LoS	10.2

COMMENTS:

(a) PT pod sightline is cued to aircraft X,Y,Z aimpoint in CUE mode.

(b) R_{SPTCP} is length of the PT pod sightline vector in CUE mode.

(c) PT pod Cue point is the intersection point of the azimuth and elevation cursors as seen on the PT VID display, defined by (R_{SPTCP}, $CSII_{11}$, $CSII_{12}$, $CSII_{13}$)

(d) PT pod recomputes N, E, V corrections and N, E, V direction cosines at 40 Hz.

(e) R_N, R_E, and R_V are PT pod synchronised aircraft ranges to the PT pod sighting point.

(f) For details of the construction of the roll, pitch and yaw transformation matrices refer to Appendix I.

(g) T_1, T_2 and T_3 are the elements of the array T.

IX.4 MODULE 7.3: PT POD SIGHTLINE VECTOR IN COARSE CUE MODE

PURPOSE:

To determine PT Pod sightline vector in COARSE CUE mode, prior to entering into TRACK mode.

INPUTS (@40 Hz):

	Parameter	Source	Update
Pave tack prime (Binary)	PT PRM	1.5	cs
Dead-man switch depressed to 1/2 ACTION (Binary)	1/2 ACTION	1.5	cs
Cue mode status indecator (Binary)	CueButton	1.5	cs
Pod in track (Binary)	PIT	1.5	cs
Horizon natural selected (Binary)	Hor Nat	1.5	cs
Pave tack pod view selected (Binary)	PV	1.5	cs
PT pod sightline transformation matrix	CSI	1.6	cs
Untrimmed east range	R_{EA}	7.1	@40 Hz
Untrimmed north range	R_{NA}	7.1	@40 Hz
Z aimpoint range	R_Z	7.1	@40 Hz
Slant range to PT pod sighting point	R_{SPTSP}	7.2, 7.3, 7.5, 7.6	@40 Hz
Untrimmed aircraft north velocity	V_{NA}	7.1	@40 Hz
Untrimmed aircraft east velocity	V_{EA}	7.1	@40 Hz
Untrimmed aircraft vertical velocity	V_{VA}	7.1	@40 Hz
Inertial to aircraft transformation matrix	CAI	10.2	@40 Hz

PROCESSING:

Timing reference t_{20}:

If PT PRM = 1 and CueButton = 0 and PIT = 0 then set:

(a) If 1/2 ACTION = 1 then:

(i) $R_{SCC} = R_Z / CSI_{1,3}$

(ii) $R_{SPTSP} = R_{SCC}$

(iii) $CSII_{11} = CSI_{1,1}$

(iv) $CSII_{12} = CSI_{1,2}$

(v) $CSII_{13} = CSI_{1,3}$

(vi) $R_{NCCPTSP} = R_{SCC}\ CSI_{11}$

(vii) $R_{ECCPTSP} = R_{SCC}\ CSII_{12}$

(viii) $R_{VCCPTSP} = R_Z$

(ix) $\delta R_N(i) = R_{NCCPTSP} - R_{NA}$

(x) $\delta R_E(i) = R_{ECCPTSP} - R_{EA}$

(xi) $\delta R_V(i) = 0$

(xii) $RTA = 0$

(xiii) $LRA = 0$

(xiv) $R_N(i) = R_{NV} + \delta R_N(i)$

(xv) $R_E(i) = R_{EA} + \delta_{RE}(i)$

(xvi) $R_V(i) = R_{VA} + \delta R_V(i)$

Otherwise:

(i) $R_{NP} = R_{SPTCP}\, CSI_{1,1}$

(ii) $R_{EP} = R_{SPTCP}\, CSI_{1,2}$

(iii) $R_{VP} = R_{SPTCP}\, CSI_{1,3}$

(iv) $R_N(i) = R_{NP} - V_{NA}/40$

(v) $R_E(i) = R_{EP} - V_{EA}/40$

(vi) $R_V(i) = R_{VP} - V_{VA}/40$

(vii) $R_{SPTSP} = (R_N^2 + R_E^2 + R_V^2)^{\frac{1}{2}}$

(viii) Set up array Ranges of length 3 by setting

$\text{Ranges}_1 = R_N(i)$

$\text{Ranges}_2 = R_E(i)$

$\text{Ranges}_3 = R_V(i)$

(ix) T = CAI Ranges

(x) Outer Roll = $\tan^{-1}(-T_2/T_3)$

(xi) Outer Pitch = $\tan^{-1}(-(T_2^2+T_3^2)^{\frac{1}{2}}/T_1)$

(xii) Inner Yaw = 0

(xiii) Construct yaw transformation matrix Ψ from yaw angle Inner Yaw(n)

(xiv) Construct pitch transformation matrix Θ from pitch angle Outer Pitch(n)

(xv) Construct roll transformation matrix Φ from roll angle Outer Roll(n)

(xvi) $CSA = \Psi\, \Theta\, \Phi$

(xvii) $CSI = CSA\ CAI$

(xviii) $ThetaLoS = |\sin^{-1}CSA_{1,3}|$

(xix) $PsiLoS = \tan^{-1}(CSA_{1,2}/CSA_{1,1})$

(xx) $ZTheta_1 = \cos^{-1}(CSI_{1,3})$

(xxi) If $ZTheta_1 > \pi/2$ then $ZTheta_1 = ZTheta_1 - \pi$

(b) If PV = 1 then set:

$\tau = 0$

Otherwise:

(i) If HorNat = 1 then set:

$\tau = \tan^{-1}[\sin(\text{Outer Roll})/(\cos(\text{Outer Pitch})\cos(\text{Outer Roll}))]$

Otherwise:

(ii) $\tau = \tan^{-1}[\sin(\text{Outer Roll})/(\cos(\text{Outer Pitch})\cos(\text{Outer Roll}))] - \text{Psi LoS}$

Otherwise:

exit from module

OUTPUTS (@40 Hz):

	Parameter	Destination
North range trim	$\delta R_N(i)$	7.5, 7.7
East range trim	$\delta R_E(i)$	7.5, 7.7
Vertical range trim	$\delta R_V(i)$	7.5, 7.7
Inerital-to-sightline transformation matrix	CSI	1.6
North direction cosine	$CSII_{11}$	7.7
East direction cosine	$CSII_{12}$	7.7
Vertical direction cosine	$CSII_{13}$	7.7
Slant range to PT sighting point	R_{SPTSP}	7.3, External
Range trim available (Binary)	RTA	7.7
Laser range available (Binary)	LRA	7.7
North range to sighting point	$R_N(i)$	7.5
East range to sighting point	$R_E(i)$	7.5
Vertical range to sighting point	$R_V(i)$	7.5
Pod pitch angle	Outer Pitch(n)	10.4
Depression angle	$ZTheta_1$	External
Depression angle line-of-sight marker	Theta LoS	External
Azimuth angle line-of-sight marker	Psi Los	External
Derotation angle	τ	11.17, External

COMMENTS:

(a) R_{SCC} is length of the PT pod sightline vector in Coarse Cue mode.

(b) PT pod Coarse Cue sighting point is the intersection point of the azimuth and elevation cursors as seen on the PT VID display, defined by (R_{SCC}, $CSII_{11}$, $CSII_{12}$, $CSII_{13}$).

(c) R_N, R_E and R_V are PT Pod synchronised aircraft ranges to the PT Pod sighting point

IX.5 MODULE 7.4: PT POD VELOCITY VECTOR IN TRACK MODE

PURPOSE

To determine the PT Pod velocity vector when the pod is in track mode.

INPUTS (@40 Hz):

	Parameter	Source	Update
Pave tack prime (Binary)	PT PRM	1.5	cs
Dead-man switch depressed to 1/2 ACTION (Binary)	1/2 ACTION	1.5	cs
Pod in track (Binary)	PIT	1.5	cs
PT pod sightline transformation matrix	CSI	1.6	cs
Untrimmed north velocity	V_{NA}	7.1	@40 Hz
Untrimmed east velocity	V_{EA}	7.1	@40 Hz
Untrimmed vertical velocity	V_{VA}	7.1	@40 Hz

PROCESSING:

Timing reference t_{20}

If PT PRM = 1 and 1/2 ACTION = 0 and PIT = 1 then set:

(a) $V_N = V_{NA}$

(b) $V_E = V_{EA}$

(c) $V_V = V_{VA}$

(d) $CSII_{ij} = CSI_{ij}$ (i = 1-3, j = 1-3)

(e) $V_I = V_N\, CSII_{11} + V_E\, CSII_{12} + V_V\, CSII_{13}$

(f) $V_J = V_N\, CSII_{21} + V_E\, CSII_{22} + V_V\, CSII_{23}$

(g) $V_K = V_N\, CSII_{31} + V_E\, CSII_{32} + V_V\, CSII_{33}$

(h) $V = [V_N^2 + V_E^2 + V_V^2]^{1/2}$

Otherwise:

exit from module

OUTPUTS (@40 Hz):

	Parameter	Destination
Sightline velocity	V	7.5
I sightline velocity component	V_I	7.5
J sightline velocity component	V_J	10.1
K sightline velocity component	V_K	7.5, 10.1

COMMENTS:

(a) CSII is inertial-to-sightline co-ordinate transformation matrix, defining the current direction of the PT Pod sightline in track mode.

IX.6 MODULE 7.5: PT POD SIGHTLINE VECTOR IN TRACK MODE (WITHOUT LASER FIRE)

PURPOSE:

To determine PT pod sightline vector in track mode prior to firing the laser.

INPUTS (@40 Hz):

	Parameter	Source	Update
Pave tack prime (Binary)	PT PRM	1.5	cs
Dead-man switch depressed to 1/2 ACTION (Binary)	1/2 ACTION	1.5	cs
Pod in track (Binary)	PIT	1.5	cs
PT sightline transformation matrix	CSI	1.6	cs
Untrimmed east range	R_{EA}	7.1	@40 Hz
Untrimmed north range	R_{NA}	7.1	@40 Hz
Untrimmed vertical range	R_{VA}	7.1	@40 Hz
Z aimpoint range	R_Z	7.1	@40 Hz
Trimmed north range	$R_N(i-1)$	7.3, 7.5, 7.6	@40 Hz
Trimmed east range	$R_E(i-1)$	7.3, 7.5, 7.6	@40 Hz
Trimmed vertical range	$R_V(i-1)$	7.3, 7.5, 7.6	@40 Hz
North range trim	$\delta R_N(i-1)$	7.3, 7.5, 7.6	@40 Hz
East range trim	$\delta R_E(i-1)$	7.3, 7.5, 7.6	@40 Hz
Vertical range trim	$\delta R_V(i-1)$	7.3, 7.5, 7.6	@40 Hz
I sightline velocity component	$V_I(t_{20})$	7.4	@40 Hz
K sightline velocity component	$V_K(t_{20})$	7.4	@40 Hz
PT Pod sightline velocity	$V(t_{20})$	7.4	@40 Hz
Laser firing (Binary)	LSR FIRE	1.5	cs
Vertical correction	ALTRIM(i-1)	1.6, 7.5	@40 Hz
Sightline pitch (elevation) rate	ω_{RJ}	10.1	@40 Hz
Elevation operator adjustment	$\delta_{Elevation}$	10.4, 11.17	@40 Hz
Weapon delivery in progress (Binary)	WDIP	7.1	@40 Hz

PROCESSING:

Timing reference t_{20}:

If PT PRM = 1 and 1/2 ACTION = 0 and PIT = 1 and LSR FIRE = 0 then set:

(a) LRA = 0

(b) $CSII_{11} = CSI_{11}$

(c) $CSII_{12} = CSI_{12}$

(d) $CSII_{13} = CSI_{13}$

(e) If $|\omega_{RJ}| < 0.0033$ then set:

$$ALTRIM(i) := ALTRIM(i-1) + (CSII_{13}\ R_{SPTSP}\ \delta_{Elevation})/(0.0033 \times 40)$$

Otherwise:

$$ALTRIM(i) := ALTRIM(i-1) + (CSII_{13}\ R_{SPTSP}\ \delta_{Elevation})/(|\omega_{RJ}| \times 40)$$

(f) If ALTRIM(i) > 512 then set:

$$ALTRIM(i) := 512$$

(f) If ALTRIM(i) < -512 then set:

$$ALTRIM(i) := -512$$

(g) $\hat{R}_V(i) = R_Z + ALTRIM(i)$

(h) $\hat{R} = \hat{R}_V(i)/CSII_{13}$

(i) $K_{RGAIN} = \dfrac{[(2.0\ V_K/V)^2 + (2.0\ V_J)^2 + (0.003\ V_J)^2]^{1/2}}{[(0.05\ V_K/V)^2 + (2.0\ V_K/V)^2 + (2.0\ V_J)^2 + (0.003\ V_J)^2]^{1/2}}$

(j) $R_W = \hat{R} + K_{RGAIN}\ [\ R_Z/CSII_{13} - \hat{R}]$

(k) $\hat{R}_N(i) = R_W\ CSII_{11}$

(l) $\hat{R}_E(i) = R_W\ CSII_{12}$

(m) $\hat{R}_V(i) = R_W\ CSII_{13}$

(n) $\delta R_N(i) = \delta R_N(i-1) + 0.0333\ [\hat{R}_N(i) - R_N(i-1)]$

(o) $\delta R_E(i) = \delta R_E(i-1) + 0.0333\ [\hat{R}_E(i) - R_E(i-1)]$

(p) $\delta R_V(i) = \delta R_V(i-1) + 0.0333\ [\hat{R}_V(i) - R_V(i-1)]$

(q) $R_{VA} = R_{ZP}$

(r) $R_N(i) = R_{NA} + \delta R_N(i)$

(s) $R_E(j) = R_{EA} + \delta R_E(i)$

(t) $R_V(i) = R_{VA} + \delta R_V(i)$

(u) LASER OFF = 1

(v) $R_{SPTSP} = R_W$

(w) If sightline deviation from velocity vector is greater than 15 °, and WDIP = 0, then

Set RTA = 1

Otherwise:

Set RTA = 0

(x) LRA = 0

Otherwise:

exit from module

OUTPUTS (@40 Hz):

	Parameter	Destination
North range trim	$\delta R_N(i)$	7.5, 7.6, 7.7
East range trim	$\delta R_E(i)$	7.5, 7.6, 7.7
Vertical range trim	$\delta R_V(i)$	7.5, 7.6, 7.7
North direction cosine	$CSII_{11}$	7.7
East direction cosine	$CSII_{12}$	7.7
Vertical direction cosine	$CSII_{13}$	7.7
Vertical correction	ALTRIM(i)	7.5
Trimmed north range	$R_N(i)$	7.5, 7.6
Trimmed east range	$R_E(i)$	7.5, 7.6
Trimmed vertical range	$R_V(i)$	7.5, 7.6
Laser off (Binary)	LASER OFF	7.6
Slant range to sighting point	R_{SPTSP}	10.1, 7.3, External
Range trim available (Binary)	RTA	7.7
Laser range available (Binary)	LRA	7.7

COMMENTS:

(a) The PT pod best estimate of target position is defined by value of R_W, and $CSII_{11}$, $CSII_{12}$, and $CSII_{13}$ where the intersection point of the PT cursors is positioned directly over the visual image of the target on the PT VID display.

(b) Position error is difference between aircraft sighting point defined by (R_{XP}, R_{YP}, R_{ZP}) and PT Pod sighting point defined by (R_W, $CSII_{11}$, $CSII_{12}$, $CSII_{13}$), This assumes no error contribution due to difference between PT pod actual sighting point and absolute target position.

(c) If target absolute position with respect to the aircraft is given by (R_{STGT}, CSI_{11}, CSI_{12}, CSI_{13}), then the error contribution due to the difference between actual PT pod sighting point with respect to absolute target position is the difference between R_{STGT} and R_W .

(d) If the PT pod sightline is not directly positioned over the visual image of the target on the PT VID display, then these may be corrected by operator thumb tracker inputs, resulting in perturbations in $CSII_{11}$, $CSII_{12}$, and $CSII_{13}$, and hence perturbations in $\delta R_N(i)$, $\delta R_E(i)$, and $\delta R_V(i)$.

(e) If track mode (non-laser) has just been entered from coarse cue mode, then initial values of trimmed ranges are those last computed in coarse cue mode.

(f) If laser fire was just commanded from on to off, then $R_{N,E,V}(i-1)$ are the values last computed while the laser was firing.

(g) Altrim is the PT pod computed vertical correction, derived from thumb-tracker inputs by the operator to adjust the PT pod sightline whilst in track mode.

IX.7 MODULE 7.6: PT SIGHTLINE VECTOR IN TRACK MODE (WITH LASER FIRE)

PURPOSE:

To determine PT sightline vector in track mode, with laser firing.

INPUTS (@40 Hz):

	Parameter	Source	Update
Pave tack prime (Binary)	PT PRM	1.5	cs
Dead-man switch depressed to 1/2 ACTION (Binary)	1/2 ACTION	1.5	cs
Pod in track (Binary)	PIT	1.5	cs
Pave tack sighting point laser slant range	R_{SL}	1.6	cs
PT pod sightline matrix	CSI	1.6	cs
Untrimmed east range	R_{EA}	7.1	@40 Hz
Untrimmed north range	R_{NA}	7.1	@40 Hz
Untrimmed vertical range	R_{VA}	7.1	@40 Hz
Laser firing (Binary)	LSR FIRE	1.5	cs
Laser off (Binary)	LASER OFF	7.5	@40 Hz
Time Laser Fired	LSR TIME	1.5	cs
Trimmed north range	$R_N(i-1)$	7.5, 7.6	@40 Hz
Trimmed east range	$R_E(i-1)$	7.5, 7.6	@40 Hz
Trimmed vertical range	$\underline{R}_V(i-1)$	7.5, 7.6	@40 Hz
Smoothed filtered north range	$\underline{R}_N(i-1)$	7.6	@40 Hz
Smoothed filtered east range	$\underline{R}_E(i-1)$	7.6	@40 Hz
Smoothed filtered vertical range	$R_V(i-1)$	7.6	@40 Hz
North range trim	$\delta R_N(i-1)$	7.5, 7.6	@40 Hz
East range trim	$\delta R_E(i-1)$	7.5, 7.6	@40 Hz
Vertical range trim	$\delta R_V(i-1)$	7.5, 7.6	@40 Hz
Untrimmed aircraft north velocity	V_{NA}	7.1	@40 Hz
Untrimmed aircraft east velocity	V_{EA}	7.1	@40 Hz
Untrimmed aircraft vertical velocity	V_{VA}	7.1	@40 Hz

PROCESSING

Timing reference t_{20}:

If PT PRM = 1 and 1/2 ACTION = 0 and PIT = 1 and LSR FIRE = 1 then:

(a) $CSII_{11} = CSI_{11}$

(b) $CSII_{12} = CSI_{12}$

(c) $CSII_{13} = CSI_{13}$

(d) If LASER OFF = 1 then set:

  (i) LASER OFF = 0

  (ii) $\bar{R}_N(i-1) = R_{SL}\ CSII_{11}$

  (iii) $\bar{R}_E(i-1) = R_{SL}\ CSII_{12}$

  (iv) $\bar{R}_V(i-1) = R_{SL}\ CSII_{13}$

Otherwise set:

  (i) $R_{EN}(i) = \bar{R}_N(i-1) - [0.025\ V_{NA}]$

  (ii) $R_{EE}(i) = \bar{R}_E(i-1) - [0.025\ V_{EA}]$

  (iii) $R_{EV}(j) = \bar{R}_V(i-1) - [0.025\ V_{VA}]$

  (iv) $\bar{R}_N(i) = R_{EN}(i) + 0.1126\ [R_{SL}\ CSII_{11} - R_{EN}(i)]$

  (v) $\bar{R}_E(i) = R_{EE}(i) + 0.1126\ [R_{SL}\ CSII_{12} - R_{EE}(i)]$

  (vi) $\bar{R}_V(i) = R_{EV}(i) + 0.1126\ [R_{SL}\ CSII_{13} - \quad R_{EV}(i)]$

(e) $R_{SSL}(i) = [R_N(i)^2 + R_E(i)^2 + R_V(i)^2]^{1/2}$

(f) $\hat{R}_N(i) = R_{SSL}(i)\ CSI_{11}$

(g) $\hat{R}_E(i) = R_{SSL}(i)\ CSI_{12}$

(h) $\hat{R}_V(i) = R_{SSL}(i)\ CSI_{13}$

(i) $\delta R_N(i) = \delta R_N(i-1) + 0.025\ [\hat{R}_N(i) - R_N(i-1)]$

(j) $\delta R_E(i) = \delta R_E(i-1) + 0.025\ [\hat{R}_E(i) - R_E(i-1)]$

(k) $\delta R_V(i) = \delta R_V(i-1) + 0.025\ [\hat{R}_V(i) - R_V(i-1)]$

(l) $R_N(i) = R_{NA} + \delta R_N(i)$

(m) $R_E(i) = R_{EA} + \delta R_E(i)$

(n) $R_V(i) = R_{VA} + \delta R_V(i)$

(o) $R_{SPTSP} = [R_N(i)^2 + R_E(i)^2 + R_V(i)^2]^{1/2}$

(p) (i) If LSR FIRE = 1 for more than 1 s, that is time - LSR TIME > 1, then set:

    LRA = 1

    RTA = 1

(ii) Otherwise:

LRA = 0

RTA = 0

Otherwise:

exit from module

OUTPUTS (@40 Hz):

	Parameter	Destination
Smoothed and filtered north range	$\underline{R}_N(i)$	7.6
Smoothed and filtered east range	$\underline{R}_E(i)$	7.6
Smoothed and filtered vertical range	$R_V(i)$	7.6
Trimmed north range	$R_N(i)$	7.5, 7.6
Trimmed east range	$R_E(i)$	7.5, 7.6
Trimmed vertical range	$R_V(i)$	7.5, 7.6
North range trim	$\delta R_N(i)$	7.5, 7.6, 7.7
East range trim	$\delta R_E(i)$	7.5, 7.6, 7.7
Vertical range trim	$\delta R_V(i)$	7.5, 7.6, 7.7
North direction cosine	$CSII_{11}$	7.7
East direction cosine	$CSII_{12}$	7.7
Vertical direction cosine	$CSII_{13}$	7.7
Range trim available (Binary)	RTA	7.7
Laser trim available (Binary)	LRA	7.7
Slant range to sighting point	R_{SPTSP}	10.1, 7.3, External

COMMENTS:

(a) Target absolute position with respect to aircraft is defined by value of R_{STGT} and CSI_{11}, CSI_{12}, and CSI_{13}.

(b) PT pod best estimate of target position is defined by value of R_{SL}, and $CSII_{11}$, $CSII_{12}$, and $CSII_{13}$.

(c) Position error is difference between aircraft sighting point defined by (R_{XP}, R_{YP}, R_{ZP}) and PT Pod sighting point defined by (R_{SL}, $CSII_{11}$, $CSII_{12}$, $CSII_{13}$). This assumes no error contribution due to difference between PT pod lasing point and absolute target position.

IX.8 MODULE 7.7: PT POD OUTPUT PROCESSING (@3125/13 Hz)

PURPOSE:

To output PT pod sighting point direction cosines and computed position corrections to the aircraft.

INPUTS (@3125/13 Hz):

	Parameter	Source	Update
North direction cosine	$CSII_{11}$	7.2,7.3,7.5,7.6	@40 Hz
East direction cosine	$CSII_{12}$	7.2,7.3,7.5,7.6	@40 Hz
Vertical direction cosine	$CSII_{13}$	7.2,7.3,7.5,7.6	@40 Hz
North range trim	$\delta R_N(i)$	7.2,7.3,7.5,7.6	@40 Hz
East range trim	$\delta R_E(i)$	7.2,7.3,7.5,7.6	@40 Hz
Vertical range trim	$\delta R_V(i)$	7.2,7.3,7.5,7.6	@40 Hz
Laser range available (Binary)	LRA	7.2,7.3,7.5,7.6	@40 Hz
Range trim available (Binary)	RTA	7.2,7.3,7.5,7.6	@40 Hz

PROCESSING:

Timing reference t_{21}:

(a) $CSIIX = CSII_{12}$

(b) $CSIIY = CSII_{11}$

(c) $CSIIZ = \cos(\pi - \cos^{-1} CSII_{13})$

(d) $DELRX = \delta R_E(i)$

(e) $DELRY = \delta R_N(i)$

(f) $DELRZ = \delta R_V(i)$

(g) Set bit 13 of PT STAT = RTA

(h) Set bit 11 of PT STAT = LRA

OUTPUTS (@3125/13 Hz):

	Parameter	Destination
X direction cosine	CSIIX	8.1
Y direction cosine	CSIIY	8.1
Z direction cosine	CSIIZ	8.1
X correction	DELRX	8.1
Y correction	DELRY	8.1
Z correction	DELRZ	9.2
PT status	PT STAT	8.1

```
                    ENTRY
                      |
                      V
                     7.1
   INPUT PROCESSING FOR PT POD SIGHTLINE CONTROL (@40 Hz)
                      |
                      V
                     7.2
   DETERMINE PT POD SIGHTLINE VECTOR (CUE MODE) (@40 Hz)
                      |
                      V
                     7.3
DETERMINE PT POD SIGHTLINE VECTOR (COARSE CUE MODE) (@40 Hz)
                      |
                      V
                     7.4
  DETERMINE PT POD VELOCITY VECTOR (TRACK MODE) (@40 Hz)
                      |
                      V
                     7.5
DETERMINE PT POD SIGHTLINE VECTOR (TRACK MODE WITHOUT LASER) (@40 Hz)
                      |
                      V
                     7.6
DETERMINE PT POD SIGHTLINE VECTOR (TRACK MODE WITH LASER) (@40 Hz)
                      |
                      V
                     7.7
         OUTPUT PROCESSING (@3125/13 Hz)
                      |
                      V
                     EXIT
```

Figure IX.1: Sequence of events for PT pod sightline vector positioning (module 7)

APPENDIX X

FPTS: PAVE TACK POSITION UPDATING (MODULE 8)

THIS IS A BLANK PAGE

CONTENTS

X.1 INTRODUCTION 171

X.2 MODULE 8.1: INPUT PROCESSING FOR PT POSITION UPDATING (@16 Hz) . . . 171

X.3 MODULE 8.2: INPUT PROCESSING FOR PT POSITION UPDATING (@1 Hz) 172

X.4 MODULE 8.3: PT POSITION UPDATING MODE 172

X.5 MODULE 8.4: PT POD POSITION CORRECTIONS 177

X.6 MODULE 8.5: AZIMUTH ONLY POSITION CORRECTIONS 178

X.7 MODULE 8.6: POSITION CORRECTION SLEWING SIGNALS 180

X.8 MODULE 8.7: POD FIX IN PROGRESS STATUS 183

X.9 MODULE 8.8: OUTPUT PROCESSING FOR PT POSITION UPDATING (@16 Hz) 184

FIGURES

X.1: Sequence of events for Pave Tack position updating (module 8) 186

THIS IS A BLANK PAGE

X.1 INTRODUCTION

The events associated with module 8 are illustrated in Figure X.1. Each of the submodules of this event sequence is detailed below.

X.2 MODULE 8.1: INPUT PROCESSING FOR PT POSITION UPDATING (@16 Hz)

PURPOSE:

To sample input parameters required for Pave Tack position updating.

INPUTS (@16 Hz):

	Parameter	Source	Update
X direction cosine	CSIIX	7.7	@3125/13 Hz
Y direction cosine	CSIIY	7.7	@3125/13 Hz
Z direction cosine	CSIIZ	7.7	@3125/13 Hz
X correction	DELRX	7.7	@3125/13 Hz
Y correction	DELRY	7.7	@3125/13 Hz
PT status	PT STAT	7.7	@3125/13 Hz

PROCESSING:

Timing reference t_2:

(a) Input CSIIX

(b) Input CSIIY

(c) Input CSIIZ

(d) Input DELRX

(e) Input DELRY

(f) $\cos\theta_X$ = CSIIX

(g) $\cos\theta_Y$ = CSIIY

(h) $\cos\theta_Z$ = CSIIZ

(i) ΔR_X = DELRX

(j) ΔR_Y = DELRY

(k) Input RTA (Bit 13 of word PT STAT)

(l) Input LRA (Bit 11 of word PT STAT)

OUTPUTS (@16 Hz):

	Parameter	Destination
X direction cosine	$\cos\theta_X$	8.5
Y direction cosine	$\cos\theta_Y$	8.5
Z direction cosine	$\cos\theta_Z$	8.3
X correction	ΔR_X	8.4
Y correction	ΔR_Y	8.4
Range trim available (Binary)	RTA	8.3
Laser range available (Binary)	LRA	8.3

X.3 MODULE 8.2: INPUT PROCESSING FOR PT POSITION UPDATING (@1 Hz)

PURPOSE:

To sample input parameters required for pave tack position updating.

INPUTS (@1 Hz):

	Parameter	Source	Update
Present position latitude	λ_P	2.4	cs

PROCESSING:

Timing reference t_{13}:

(a) Input λ_P

(b) $\lambda_{PP} = \lambda_P$

OUTPUTS (@1 Hz):

	Parameter	Destination
Sampled present position latitude	λ_{PP}	8.6

X.4 MODULE 8.3: PT POSITION UPDATING MODE

PURPOSE:

To determine PT pod position updating mode.

INPUTS (@16 Hz):

	Parameter	Source	Update
Fixpoint bearing	$\theta_F(n_{16})$	4.4	@16 Hz
Fixpoint bearing	$\theta_{FS}(n_{16}-1)$	8.3	@16 Hz
Slant range	$R_{S1}(t_3)$	3.6	@32 Hz
Ground range to target	$R_G(t_4)$	4.4	@16 Hz
Height above target	$H_G(t_3)$	4.1	@32 Hz
Ground speed	$V_G(t_3)$	4.1	@32 Hz

Z direction cosine	$\cos\theta_Z(t_2)$	8.1	@16 Hz
Pod in track (Binary)	PIT	1.5	cs
Laser range available (Binary)	$LRA(t_2)$	8.1	@16 Hz
Angle count flag	$ANGCOUNT(n_{16}\text{-}1)$	8.3	@16 Hz
Position update cycle counter	$PUIP(n_{16}\text{-}1)$	8.7	@16 Hz
LRA detection counter	$LRACOUNT(n_{16}\text{-}1)$	8.3	@16 Hz
PT pod fix mode	$COND(n_{16}\text{-}1)$	8.3	@16 Hz
Range trim available (Binary)	$RTA(t_2)$	8.1	@16 Hz
PT pod along track correction	$C_{TP}(n_{16}\ \text{-}1)$	8.3, 8.6	@16 Hz
PT pod cross track correction	$C_{CTP}(n_{16}\text{-}1)$	8.3, 8.6	@16 Hz
Update cycle counter	CONCNT	8.3, 10.14	See note a
Improved pressure altitude rate	$\dot{H}_1$	4.1	@32 Hz
AIC dead-man switch at 1/2 action (Binary)	1/2 ACTION	1.5	cs
Ground track	θ_T	4.1	@32 Hz

PROCESSING:

Timing reference t_4:

(a) If PIT = 0 then set:

(i) RTV = 0

(ii) COND = 0

(iii) $\Delta R_{X1}(n_{16}) = 0$

(iv) $\Delta R_{Y1}(n_{16}) = 0$

(v) $\Delta\overline{R}_{X3}(n_{16}) = 0$

(vi) $\Delta\overline{R}_{Y3}(n_{16}) = 0$

(vii) PUIP = 0

(viii) VALVLT = 0

(ix) CONCHG = 0

(x) NOUPDT = 0

(xi) CP = 0

(xii) $C_{TP} = 0$

(xiii) $C_{CTP} = 0$

(xiv) LRADET = 0

(xv) LRACOUNT = 2

(xvi) ANGCOUNT = 32

```
    (xv) FCFG = 0
    (xvi) TCNT = 0
    exit from module
Otherwise:
(b) If PIT = 1 then set:
    RTV = 1
(c) If LRA = 1 then:
    (i) If LRACOUNT = 0 then set:
        LRADET = 1
    (ii) Otherwise set:
        LRACOUNT = LRACOUNT - 1
        LRADET = 0
  Otherwise set:
    (i) LRACOUNT = 2
    (ii) LRADET = 0
(d) $\dot{\beta}_A = [R_G \dot{H}_1 + H_G V_G \cos(\theta_T - \theta_F)] / R_{S1}^2$
(e) $\dot{\theta}_F = [\theta_F(n_{16}) - 16\ \theta_{FS}(n_{16} - 1)]$
(f) $\theta_{FS}(n_{16}) = \theta_F(n_{16})$
(g) VALVLT = 0
(h) CONCHG = 0
(i) If PUIP ≠ 0 then set:
    (i) $C_{TP}(n_{16}) = C_{TP}(n_{16}-1)$
    (ii) $C_{CTP}(n_{16}) = C_{CTP}(n_{16}-1)$
    exit from module
Otherwise:
(j) If $|\dot{\theta}_F| > 24$ degrees/s or $|\dot{\beta}_A| > 24$ degrees/s then set:
    (i) NOUPDT = 1
```

(ii) ANGCOUNT = 0

(iii) CP = 0

(iv) $C_{TP} = 0$

(v) $C_{CTP} = 0$

(k) If $|\dot{\theta}_F| \le 24$ degrees/s and $|\beta_A| \le 24$ degrees/s then:

(i) If ANGCOUNT(n_{16}-1) = 32 then set:

NOUPDT = 0

(ii) Otherwise set:

(i) ANGCOUNT(n_{16}) = ANGCOUNT(n_{16} -1) + 1

(ii) NOUPDT = 1

(iii) CP = 0

(iv) $C_{TP} = 0$

(v) $C_{CTP} = 0$

(l) If LRADET = 1 and COND(n_{16}-1) ≠ then set:

(i) COND = 1

(ii) CONCHG = 1

(iii) $\Delta\overline{R}_{X3}(n_{16}) = 0$

(iv) $\Delta\overline{R}_{Y3}(n_{16}) = 0$

(m) $\theta_Z = \cos^{-1}(\cos\theta_Z)$

(n) $\beta_P = \theta_Z - 90$

(o) If LRADET = 0 and RTA = 1 and $\beta_P \ge 15$ degrees and COND(n_{16}-1) ≠ 2 then set:

(i) COND = 2

(ii) CONCHG = 1

(iii) $\Delta\overline{R}_{X3}(n_{16}) = 0$

(iv) $\Delta\overline{R}_{Y3}(n_{16}) = 0$

(p) If LRADET = O and COND(n_{16}-1) ≠ 3, and
either (i) RTA = 0 or
(ii) $\beta_P < 15$ degrees, then:

(i) COND = 3

(ii) CONCHG = 1

(iii) $\Delta R_{X1}(n_{16}) = 0$

(iv) $\Delta R_{Y1}(n_{16}) = 0$

(q) If CONCHG = 1 then:

(i) CONCNT = 0

(ii) Set CFTFG = 0

(r) If CONCHG = 0 and CONCNT $\neq$ 24 then set:

CONCNT = CONCNT + 1

Otherwise:

exit from module

OUTPUTS (@16 Hz):

	Parameter	Destination
Range trim valid (Binary)	RTV	8.4, 8.5, 8.6, 8.7
PT pod fix mode	COND	8.3, 8.4, 8.5, 8.6, 8.7
Correction first time flag	CFTFG	8.5
Filter constant flag	FCFG	8.4, 8.5
Update cycle count	CONCNT	8.3, 8.4, 8.5, 8.6, 8.7
LRA detection counter	LRACOUNT(n_{16})	8.3
LRA detected (Binary)	LRADET(n_{16})	9.3, 9.4
Angle count flag	ANGCOUNT(n_{16})	8.3
Valid voltage flag	VALVLT	8.7
Update inhibit flag	NOUPDT	8.4, 8.5, 8.6
Stored fixpoint true bearing	$\theta_{FS}(n_{16})$	8.3
PT X correction term	$\Delta R_{X1}(n_{16})$	8.4
PT Y correction term	$\Delta R_{Y1}(n_{16})$	8.4
Azimuth Only X correction term	$\Delta R_{X3}(n_{16})$	8.5
Azimuth Only Y correction term	$\Delta R_{Y3}(n_{16})$	8.5
Along track correction	C_{TP}	8.3, 8.8
Cross track correction	C_{CTP}	8.3, 8.8
Dead-man switch flag	CP	8.8

COMMENTS:

(a) Input parameters from module 8.3 are updated at 16 Hz; parameters from module 7.3 are updated at 40 Hz.

(b) If COND = 0, then position updating is inhibited.
If COND = 1, then position updating is accomplished using laser derived range trims.

If COND = 2, then position updating is accomplished using kinematic derived range trims.
If COND = 3, then position updating is accomplished using azimuth only derived range trims.

(c) LRA detection is delayed by 0.125 s (time taken for LRACOUNT to be decremented to zero) after laser range becomes available to accommodate delay in PT pod filters when using PT pod computed laser derived position corrections for position updating.

(d) Position correction data is not considered valid if LOS depression angle rate, or fixpoint bearing rate exceeds limits of 24 degrees/sec within the last 2 s, ie until ANGLECOUNT has been incremented to a value of 32. Flag NOUPDT is set true, and position updating is inhibited until position data is valid again.

(e) If a PT position update is already in progress, (ie PUIP $\neq$ 24) then mode calculations are bypassed.

(f) If the PT Pod is not in track then no position corrections are available, and position updating is inhibited.

(g) For a constant value of position update mode COND, CONCNT is incremented by one each cycle. This results in a delay of 1.5 s between the last position update and the first cycle of the next position update that results from a new value of COND.

(h) PT position updating mode is operator selectable during flight.

X.5 MODULE 8.4: PT POD POSITION CORRECTIONS

PURPOSE:

To determine PT pod fix magnitude during PT position updating using laser or kinematic range. trims.

INPUTS (@16 Hz):

	Parameter	Source	Update
Range trim valid (Binary)	RTV	8.3	@16 Hz
Position update cycle counter	PUIP(n_{16}-1)	8.7	@16 Hz
PT pod fix mode	COND	8.3	@16 Hz
Update inhibit flag	NOUPDT	8.3	@16 Hz
Update cycle counter	CONCNT	8.3	@16 Hz
X correction	$\Delta R_X(t_2)$	8.1	@16 Hz
Y correction	$\Delta R_Y(t_2)$	8.1	@16 Hz
PT pod X correction	$\Delta R_{X1}(n_{16}-1)$	8.3, 8.4	@16 Hz
PT pod Y correction	$\Delta R_{Y1}(n_{16}-1)$	8.3, 8.4	@16 Hz
Filter constant flag	FCFG(n_{16}-1)	8.3, 8.6	@16 Hz

PROCESSING:

Timing reference t_4:

(a) If RTV = 0 or NOUPDT = 1 or COND = 3 or PUIP(n_{16}-1) $\neq$ 0 then:

exit from module

(b) If NOUPDT = 0 and COND ≠ 1 and CONCNT ≠ 24 then:

exit from module

Otherwise:

(c) $\Delta R_{X1}(n_{16}) = \Delta R_X$

(d) $\Delta R_{Y1}(n_{16}) = \Delta R_Y$

(e) (i) If FCFG = 1 then set:

$$\Delta R_{X2} = \Delta R_{X1} - 0.2555\ \Delta R_{X1}(n_{16}-1)$$

$$\Delta R_{Y2} = \Delta R_{Y1} - 0.2555\ \Delta R_{Y1}(n_{16}-1)$$

(ii) Otherwise set:

$$\Delta R_{X2} = \Delta R_{X1} - 0.9394\ \Delta R_{X1}(n_{16}-1)$$

$$\Delta R_{Y2} = \Delta R_{Y1} - 0.9394\ \Delta R_{Y1}(n_{16}-1)$$

(f) $\Delta R_{XP} = \Delta R_{X2}$

(g) $\Delta R_{YP} = \Delta R_{Y2}$

(h) $K_{TH} = 17.5\text{x}10^{-4}$

OUTPUTS (@16 Hz):

	Parameter	Destination
X correction	ΔR_{XP}	8.6
Y correction	ΔR_{YP}	8.6
Threshold	K_{TH}	8.6
PT Pod X correction	$\Delta R_{X1}(n_{16})$	8.4
PT Pod Y correction	$\Delta R_{Y1}(n_{16})$	8.4

X.6 MODULE 8.5: AZIMUTH ONLY POSITION CORRECTIONS

PURPOSE:

To determine PT fix magnitude during azimuth only updating.

INPUTS (@16 Hz):

	Parameter	Source	Update
Range trim valid (Binary)	RTV	8.3	@16 Hz
Position update cycle counter	$\text{PUIP}(n_{16}-1)$	8.7	@16 Hz
PT pod fix mode	COND	8.3	@16 Hz
Update inhibit flag	NOUPDT	8.3	@16 Hz

Update cycle counter	CONCNT	8.3	@16 Hz
Azimuth only X correction	$\Delta \bar{R}_{X3}(n_{16}-1)$	8.3, 8.5	@16 Hz
Azimuth only Y correction	$\Delta R_{Y3}(n_{16}-1)$	8.3, 8.5	@16 Hz
Filter constant flag	FCFG(n_{16}-1)	8.3, 8.6	@16 Hz
Correction first time flag	CFTFG	8.3, 8.5	@16 Hz
X aimpoint range	R_{XP}	4.4	@16 Hz
Y aimpoint range	R_{YP}	4.4	@16 Hz
Z aimpoint range	R_{ZP}	4.4	@16 Hz
X direction cosine	$\cos\theta_X$	8.1	@16 Hz
Y direction cosine	$\cos\theta_Y$	8.1	@16 Hz

PROCESSING:

Timing reference t_4:

(a) If RTV = 0 or NOUPDT = 1 or CONCNT ≠ 24 then:

exit from module

(b) If NOUPDT = 0 and COND ≠ 3 then:

exit from module

Otherwise:

(c) $R_{GP1} = [R_{XP}^2 + R_{YP}^2]^{\frac{1}{2}}$

(d) $R_{SP} = [R_{XP}^2 + R_{YP}^2 + R_{ZP}^2]^{\frac{1}{2}}$

(e) $R_{XP2} = R_{SP} \cos\theta_X$

(f) $R_{YP2} = R_{SP} \cos\theta_Y$

(g) $R_{GP2} = [R_{XP2}^2 + R_{YP2}^2]^{\frac{1}{2}}$

(h) $R_{XP3} = (R_{GP1}/R_{GP2})\, R_{XP2}$

(i) $R_{YP3} = (R_{GP1}/R_{GP2})\, R_{YP2}$

(j) $\Delta R_{X3} = R_{XP3} - R_{XP}$

(k) $\Delta R_{Y3} = R_{YP3} - R_{YP}$

(l) If CFTFG = 0 then set:

(i) $\Delta \bar{R}_{X3}(n_{16}) = \Delta R_{X3}(n_{16})$

(ii) $\Delta \bar{R}_{Y3}(n_{16}) = \Delta R_{Y3}(n_{16})$

(iii) CFTFG = 1

(m) $\Delta \bar{R}_{X3}(n_{16}) = \Delta \bar{R}_{X3}(n_{16}-1) + 1/16[\Delta R_{X3}(n_{16}) - \Delta \bar{R}_{X3}(n_{16}-1)]$

(n) $\Delta R_{Y3}(n_{16}) = \Delta \bar{R}_{Y3}(n_{16}-1) + 1/16[\Delta R_{Y3}(n_{16}) - \Delta \bar{R}_{Y3}(n_{16}-1)]$

(o) If PUIP = 0, then:

exit from module

(p) If PUIP = 0 and FCFG = 1 then set:

(i) $\Delta R_{X4} = \Delta \bar{R}_{X3} - 0.2555\ \Delta \bar{R}_{X3}(n_{16}-1)$

(ii) $\Delta R_{Y4} = \Delta \bar{R}_{Y3} - 0.2555\ \Delta \bar{R}_{Y3}(n_{16}-1)$

(q) If PUIP = 0 and FCFG = 0 then set:

(i) $\Delta R_{X4} = \Delta \bar{R}_{X3} - 0.9394\ \Delta \bar{R}_{X3}(n_{16}-1)$

(ii) $\Delta R_{Y4} = \Delta \bar{R}_{Y3} - 0.9394\ \Delta \bar{R}_{Y3}(n_{16}-1)$

(r) $\Delta R_{XP} = \Delta R_{X4}$

(q) $\Delta R_{YP} = \Delta R_{Y4}$

(r) $K_{TH} = (17.5 + 0.001\ R_{SP})\ 10^{-4}$

OUTPUTS (@16 Hz):

	Parameter	Destination
X correction	ΔR_{XP}	8.6
Y correction	ΔR_{YP}	8.6
Threshold	K_{TH}	8.6
Filter first time flag	$CETFG(n_{16})$	8.5
Azimuth only X correction	ΔR_{X3}	8.5
Azimuth only Y correction	ΔRY3	8.5

COMMENTS:

(a) Azimuth only corrections are utilised for position updating if the PT pod sightline depression angle is less than 15°.

(b) Corrections are computed based on the change in pod sightline as detected by a corresponding change in PT pod direction cosines. Corrections do not affect the magnitude of slant range to the PT sighting point.

X.7 MODULE 8.6: POSITION CORRECTION SLEWING SIGNALS

PURPOSE:

To determine magnitude and duration of slewing signals to be applied to effect PT position updating.

INPUTS (@16 Hz):

	Parameter	Source	Update
Range trim valid (Binary)	RTV	8.3	@16 Hz
Position update cycle counter	$PUIP(n_{16}-1)$	8.7	@16 Hz
PT pod fix mode	COND	8.3	@16 Hz
Update inhibit flag	NOUPDT	8.3	@16 Hz
Update cycle counter	CONCNT	8.3	@16 Hz
X correction	ΔR_{XP}	8.4, 8.5	@16 Hz
Y correction	ΔR_{YP}	8.4, 8.5	@16 Hz
Ground track	$\theta_T(t_1)$	4.1	@32 Hz
Present position latitude	$\lambda_{PP}(t_{13})$	8.2	@1 Hz
Threshold	K_{TH}	8.4, 8.5	@16 Hz

PROCESSING:

Timing reference t_4:

(a) If RTV = 0 or NOUPDT = 1 or PUIP $(n_{16}-1) \neq 0$ then:

exit from module

(b) If NOUPDT = 0 and COND $\neq$ 1 and CONCNT $\neq$ 24 then:

exit from module

Otherwise:

(c) $\Delta R_{CTP} = \Delta R_{XP} \cos\theta_T - \Delta R_{YP} \sin\theta_T$

(d) $\Delta R_{TP} = \Delta R_{XP} \sin\theta_T + \Delta R_{YP} \cos\theta_T$

(e) (i) $K_T = \Delta R_{TP}/(10126.25 \cos\lambda_{PP})$ for $0.1 \leq |\cos\lambda_{PP}| \leq 1.0$

(ii) $K_T = \Delta R_{TP}/(10126.25 \times 0.7)$ for $|\cos\lambda_{PP}| < 0.1$

(f) (i) $K_{CT} = \Delta R_{CTP}/(10126.25 \cos\lambda_{PP})$ for $0.1 \leq |\cos\lambda_{PP}| \leq 1.0$

(ii) $K_{CT} = \Delta R_{CTP}/(10126.25 \times 0.7)$ for $|\cos\lambda_{PP}| < 0.1$

(g) (i) If $[K_T]_{ABS} > [K_{CT}]_{ABS}$ then $K_{MAX} = [K_T]_{ABS}$

(ii) Otherwise: $K_{MAX} = [K_{CT}]_{ABS}$

(h) $K_{MAX} < K_{TH}$ then set:

FCFG = 0

exit from module

Otherwise set:

FCFG = 1

(i) $LTCOR = 2\ \mathrm{int}[1.6\ K_{MAX} + 1]$

(j) If $LTCOR > 8$ then set:

$LTCOR = 8$

(k) $TCOR = LTCOR / 16$

(l) $VK_{TP} = 1.2\ K_{T} / TCOR$

(m) $VK_{CTP} = 1.2\ K_{CT} / TCOR$

(n) $t_{COR} = TCOR$

(o) If $VK_{TP} > +5$ VAC then set:

$VK_{TP} = +5$ VAC

(p) If $VK_{TP} < -5$ VAC then set:

$VK_{TP} = -5$ VAC

(q) If $VK_{CTP} > +5$ VAC then set:

$VK_{CTP} = +5$ VAC

(r) If $VK_{CTP} < -5$ VAC then set:

$VK_{CTP} = -5$ VAC

(s) $C_{CTP} = VK_{CTP}\ 10126.25 \cos\lambda_{PP}$

(t) $C_{TP} = VK_{TP}\ 10126.25 \cos\lambda_{PP}$

(u) Set $VALVLT = 1$

OUTPUTS (@16 Hz):

	Parameter	Destination
Pave tack along track correction	C_{TP}	8.3, 8.8
Pave tack cross track correction	C_{CTP}	8.3, 8.8
Computed correction time	LTCOR	8.7
Dead-man switch duration	t_{COR}	8.8
Valid voltage flag	VALVLT	8.7
Filter constant flag	$FCFG(n_{16})$	8.4, 8.5

COMMENTS:

(a) Flag VALVLT is set true if computed correction voltages are valid.

(b) Filter constant flag is set true if time lapsed from last computation is only 1/16 s (ie one cycle time).

(c) LTCOR is the number of 1/16 s that gives the time that CP is to be set to 1.

(d) Time of correction (t_{COR}) is the number of 1/8 s such that it is the next larger integer greater than 1.6 K_{MAX}. This must be multiplied by two to obtain the number of 1/16 s for time of correction.

(e) If K_{MAX} is less than the threshold, then no position updating is initiated.

X.8 MODULE 8.7: POD FIX IN PROGRESS STATUS

PURPOSE:

To determine if pod fix is in progress.

INPUTS (@16 Hz):

	Parameter	Source	Update
Range trim valid (Binary)	RTV	8.3	@16 Hz
Position update cycle counter	$PUIP(n_{16}-1)$	8.7	@16 Hz
PT pod fix mode	COND	8.3	@16 Hz
Update cycle counter	CONCNT	8.3	@16 Hz
Valid voltage flag	VALVLT	8.3, 8.6	@16 Hz
Computed correction time	LTCOR	8.6	@16 Hz
Dead-man switch flag	$CP(n_{16}-1)$	8.7	@16 Hz
Dead-man switch duration counter	$TCNT(n_{16}-1)$	8.7	@16 Hz

PROCESSING:

Timing reference t_4:

```
(a) If RTV = 0 then:
        exit from module
(b) If VALVLT = 1 then set:
        (i) TCNT = LTCOR
        (ii) $PUIP(n_{16}) = 24$
        (iii) CP = 1 (for time $t_{COR}$)
        exit from module
(c) If VALVLT = 0 then:
        (i) If TCNT = 0 then set:
                CP = 0
        (ii) If TCNT $\neq$ 0 then set:
```

$TCNT = TCNT-1$

$CP(n_{16}) = CP(n_{16}-1)$

(c) (i) If $PUIP(n_{16}-1) = 0$ then set:

$PUIP(n_{16}) = PUIP(n_{16}-1)$

(ii) If $PUIP(n_{16}) \neq 0$ then set:

$PUIP(n_{16}) = PUIP(n_{16}) - 1$

OUTPUTS (@16 Hz):

	Parameter	Destination
Pod update cycle counter	$PUIP(n_{16})$	8.3, 8.4, 8.5, 8.6, 8.7
Dead-man switch flag (Binary)	$CP(n_{16})$	8.7, 8.8
Dead-man switch duration counter	$TCNT(n_{16})$	8.7

COMMENTS:

(a) TCNT is the number of 16 Hz rate group cycles during which CP is 1 (ie for time period t_{COR}).

(b) PUIP is the 1.5 s cycle timer.

X.9 MODULE 8.8: OUTPUT PROCESSING FOR PT POSITION UPDATING (@16 Hz)

PURPOSE:

To output computed along track and cross track correction signals.

INPUTS (@16 Hz):

	Parameter	Source	Update
PT along track correction	C_{TP}	8.3, 8.6	@16 Hz
PT cross track correction	C_{CTP}	8.3, 8.6	@16 Hz
Dead-man switch depressed (Binary)	C_P	8.3, 8.7	@16 Hz
Dead-man switch duration	t_{COR}	8.6	@16 Hz

PROCESSING:

Timing reference t_6:

(a) Convert C_{CTP} from digital to analog form

(b) Convert C_{TP} from digital to analog form

(c) Convert CP from digital to analog form

(d) $C_{CT} = C_{CTP}$

(e) $C_T = C_{TP}$

(f) $C_P = CP$

(g) $t_{AIC} = t_{COR}$

(h) Output C_{CT}

(i) Output C_T

(j) Output C_P (for time t_{AIC})

OUTPUTS (@16 Hz):

	Parameter	Destination
Along track correction signal	C_T	6.3
Cross track slewing signal	C_{CT}	6.3
Dead-man switch depressed (Binary)	C_P	2.4, 2.5, 6.3
Dead-man switch duration	t_{AIC}	2.4, 2.5

ENTRY
|
V
8.1
PERFORM INPUT PROCESSING FOR PT POSITION UPDATING (@16 Hz)
|
V
8.2
PERFORM INPUT PROCESSING FOR PT POSITION UPDATING (@1 Hz)
|
V
8.3
DETERMINE PAVE TACK POSITION UPDATING MODE (@16 Hz)
|
V
8.4
DETERMINE PAVE TACK POSITION CORRECTIONS (@16 Hz)
|
V
8.5
DETERMINE AZIMUTH ONLY POSITION CORRECTIONS (@16 Hz)
|
V
8.6
DETERMINE BOMB AND NAVIGATION SYSTEM CORRECTION SLEWING SIGNALS
(@16 Hz)
|
V
8.7
DETERMINE IF POD FIX IS IN PROGRESS (@16 Hz)
|
V
8.8
PERFORM OUTPUT PROCESSING FOR PT POSITION UPDATING (@16 Hz)
|
V
EXIT

Figure X.1: Sequence of events for Pave Tack position updating (module 8)

APPENDIX XI

FPTS: PAVE TACK ALTITUDE CALIBRATION (MODULE 9)

THIS IS A BLANK PAGE

CONTENTS

XI.1 INTRODUCTION 191

XI.2 MODULE 9.1: INPUT PROCESSING FOR PT ALTITUDE CALIBRATION (@32 Hz) 191

XI.3 MODULE 9.2: INPUT PROCESSING FOR PT ALTITUDE CALIBRATION (@16 Hz) 191

XI.4 MODULE 9.3: PAVE TACK ALTITUDE CALIBRATION TERM 192

XI.5 MODULE 9.4: HAT ALTITUDE CALIBRATION TERM 193

XI.6 MODULE 9.5: OUTPUT PROCESSING FOR PT ALTITUDE CALIBRATION (@16 Hz) 195

FIGURES

XI.1: Sequence of events for PT altitude calibration (module 9) 197

THIS IS A BLANK PAGE

XI.1 INTRODUCTION

The events associated with module 9 are illustrated in Figure XI.1. Each of the submodules of this event sequence is detailed below.

XI.2 MODULE 9.1: INPUT PROCESSING FOR PT ALTITUDE CALIBRATION (@32 Hz)

PURPOSE:

To determine values of parameters required for PT altitude calibration.

INPUTS (@32 Hz):

	Parameter	Source	Update
LARA altitude calibrate (Binary)	AC	1.5	cs
PT altitude calibrate (Binary)	PT ALT CAL	1.5	cs

PROCESSING:

Timing reference t_1:

(a) Input PT ALT CAL

(b) Input AC

OUTPUTS (@32 Hz):

	Parameter	Destination
LARA altitude calibrate	AC	9.3,9.4
PT altitude calibrate	PT ALT CAL	9.3, 9.4

XI.3 MODULE 9.2: INPUT PROCESSING FOR PT ALTITUDE CALIBRATION (@16 Hz)

PURPOSE:

To determine values of parameters required for PT altitude calibration.

INPUTS (@16 Hz):

	Parameter	Source	Update
Z range trim	DELRZ	7.7	@3125/13 Hz

PROCESSING:

Timing reference t_2:

(a) Input DELRZ

(b) ΔR_Z = DELRZ

OUTPUTS (@16 Hz):

	Parameter	Destination
Z correction	ΔR_Z	9.3, 9.4

XI.4 MODULE 9.3: PAVE TACK ALTITUDE CALIBRATION TERM

PURPOSE:

To determine magnitude of vertical correction term obtained when firing the laser to accomplish pave tack altitude calibration.

INPUTS (@16 Hz):

	Parameter	Source	Update
PT calibration mode (Binary)	PT ALT CAL(t_1)	9.1	@32 Hz
LARA altitude calibrate mode (Binary)	AC(t_1)	9.1	@32 Hz
Z correction	$\Delta R_Z(t_2)$	9.2	@16 Hz
PT altitude calibration term	$\Delta R_{ZCAL}(n_{16}\text{-}1)$	9.3	@16 Hz
HAT calibration term	$\Delta R_{ZHAT}(n_{16}\text{-}1)$	9.3, 9.4	@16 Hz
Stored Z calibration term	$\Delta R_{ZST}(n_{16}\text{-}1)$	9.3, 9.4	@16 Hz
Update counter	UDCNT(n_{16}-1)	9.3, 9.4	@16 Hz
LRA detected (Binary)	LRADET(n_{16})	8.3	@16 Hz

PROCESSING:

Timing reference t_4:

(a) If AC = 1 then set:

(i) UDCNT(n_{16}) = 0

(ii) $\Delta R_{ZCAL} = 0$

(iii) $\Delta R_{ZHAT} = 0$

(iv) $\Delta R_{ZST} = 0$

(v) $\Delta H_p = 0$

exit from module

(b) If PT ALT CAL = 0 then:

exit from module

Otherwise:

(c) $\Delta R_{ZCAL} = \Delta R_{ZCAL}(n_{16}-1) + \Delta R_{ZHAT}(n_{16}-1)$

(d) $\Delta R_{ZHAT} = 0$

(e) If LRADET = 1 and UDCNT(n_{16}-1) = 0 then set:

(i) UDCNT(n_{16}) = 15

(ii) $\Delta R_{ZLD} = \Delta R_Z - 0.403\ \Delta R_{ZST}(n_{16}-1)$

(iii) $\Delta R_{ZCAL} = \Delta R_{ZCAL} + \Delta R_{ZLD}$

(iv) $\Delta R_{ZST} = \Delta R_Z$

(f) If LRADET = 1 and UDCNT(n_{16}-1) ≠ 0 then set:

UDCNT(n_{16}) = UDCNT(n_{16}) - 1

(g) If LRADET = 0 then set:

(i) $\Delta R_{ZST} = 0$

(ii) UDCNT(n_{16}) = 0

(h) $\Delta H_p = \Delta R_{ZCAL} + \Delta R_{ZHAT}$

OUTPUTS (@16 Hz):

	Parameter	Destination
Pressure altitude correction	ΔH_p	9.5
PT altitude calibration term	$\Delta R_{ZCAL}(n_{16})$	9.3, 9.4
HAT calibration term	$\Delta R_{ZHAT}(n_{16})$	9.3, 9.4
Stored Z calibration term	$\Delta R_{ZST}(n_{16})$	9.3, 9.4
Update count	UDCNT(n_{16})	9.3, 9.4

COMMENTS:

(a) PT pod z range trims are only utilised to update pressure altitude if laser is firing.

(b) If the laser is not firing then the ΔR_{ZCAL} correction term is retained at the last computed value.

(c) If a LARA altitude calibration mode is selected then the pressure altitude correction term is reset to zero.

(d) If PT altitude calibration mode is selected then only the ΔR_{ZCAL} component of pressure altitude correction term is updated.

(e) PT altitude calibration mode is operator selectable during flight.

XI.5 MODULE 9.4: HAT ALTITUDE CALIBRATION TERM

PURPOSE:

To determine magnitude of vertical correction term obtained when firing the laser to accomplish a pave tack HAT calibration.

INPUTS (@16 Hz):

	Parameter	Source	Update
Bomb mode (Binary)	BM(t_1)	4.1	@32 Hz
Auto bomb (Binary)	AB(t_1)	4.1	@32 Hz
PT calibration mode (Binary)	PT ALT CAL(t_1)	9.1	@32 Hz
LARA altitude calibrate mode (Binary)	AC(t_1)	9.1	@32 Hz
Z correction	$\Delta R_Z(t_2)$	9.2	@16 Hz
PT altitude calibration term	$\Delta R_{ZCAL}(n_{16})$	9.3	@16 Hz
HAT calibration term	$\Delta R_{ZHAT}(n_{16}-1)$	9.3, 9.4	@16 Hz
Stored Z calibration term	$\Delta R_{ZST}(n_{16}-1)$	9.3, 9.4	@16 Hz
Update count	UDCNT(n_{16}-1)	9.3, 9.4	@16 Hz
LRA detected (Binary)	LRADET	8.3	@16 Hz

PROCESSING:

Timing reference t_4:

(a) If AC = 1 or PT ALT CAL = 1 then:

exit from module

(b) If BM = 0 and AB = 0 then set:

(i) $\Delta R_{ZHAT} = 0$

(ii) $\Delta R_{ZST} = 0$

(iii) UDCNT(n_{16}) = 0

(iv) $\Delta H_P = \Delta R_{ZCAL} + \Delta R_{ZHAT}$

exit from module

Otherwise:

(c) If LRADET = 1 and UDCNT(n_{16}-1) = 0 then set:

(i) UDCNT(n_{16}) = 15

(ii) $\Delta R_{ZHUD} = \Delta R_Z - 0.403\ \Delta R_{ZST}(n_{16}-1)$

(iii) $\Delta R_{ZHAT} = \Delta R_{ZHAT} + \Delta R_{ZHUD}$

(iv) $\Delta R_{ZST} = \Delta R_Z$

(f) If LRADET = 1 and UDCNT(n_{16}) ≠ 0 then set:

UDCNT(n_{16}) = UDCNT(n_{16}-1) - 1

(g) If LRADET = 0 then set:

(i) $\Delta R_{ZST} = 0$

(ii) $UDCNT(n_{16}) = 0$

(h) $\Delta H_P = \Delta R_{ZCAL} + \Delta R_{ZHAT}$

OUTPUTS (@16 Hz):

	Parameter	Destination
Pressure altitude correction	ΔH_P	9.5
HAT calibration term	$\Delta R_{ZHAT}(n_{16})$	9.3, 9.4
Stored Z calibration term	$\Delta R_{ZST}(n_{16})$	9.3, 9.4
Update count	$UDCNT(n_{16})$	9.3, 9.4

COMMENTS:

(a) If the laser is not firing then the ΔR_{ZHAT} correction term is retained at the last computed value.

(b) If PT HAT calibration mode is selected then only the ΔR_{ZHAT} component of pressure altitude correction term is updated.

(c) If PT altitude calibration mode is selected then the ΔR_{ZHAT} component of pressure altitude correction term is reset to zero.

(d) The ΔR_{ZHAT} term is only computed if AUTO BOMB mode is selected. If AUTO BOMB mode is not selected then the ΔR_{ZHAT} term is reset to zero.

XI.6 MODULE 9.5: OUTPUT PROCESSING FOR PT ALTITUDE CALIBRATION (@16 Hz)

PURPOSE:

To convert computed value of altitude correction terms from digital to analog form for pressure altitude determination.

INPUTS (@16 Hz):

	Parameter	Source	Update
Pressure altitude correction	ΔH_P	9.3, 9.4	@16 Hz

PROCESSING:

Timing reference t_6:

(a) Convert ΔH_P from digital to analog form

OUTPUTS (@16 Hz):

	Parameter	Destination
Pressure altitude correction	ΔH_P	2.6

COMMENTS:

(a) Parameter value is dependent on prior history of flight. A discrete change in value indicates the start of a new event.

ENTRY
|
V
9.1
INPUT PROCESSING FOR PT ALTITUDE CALIBRATION (@32 Hz)
|
V
9.2
INPUT PROCESSING FOR PT ALTITUDE CALIBRATION (@16 Hz)
|
V
9.3
DETERMINE PT ALTITUDE CORRECTION TERM (@16 Hz)
|
V
9.4
DETERMINE HAT CORRECTION TERM (@16 Hz)
|
V
9.5
OUTPUT PROCESSING FOR PT ALTITUDE CALIBRATION (@16 Hz)
|
V
EXIT

Figure XI.1: Sequence of events for PT altitude calibration (module 9)

THIS IS A BLANK PAGE

APPENDIX XII

FPTS: POSITION OF TARGET RELATIVE TO AIRCRAFT (MODULE 10)

THIS IS A BLANK PAGE

CONTENTS

XII.1 INTRODUCTION 203

XII.2 MODULE 10.1: PT POD SIGHTLINE RATE AIDING SIGNALS (@40 Hz) 203

XII.3 MODULE 10.2: CALCULATION OF AIRCRAFT TO INERTIAL MATRIX (@40 Hz) 204

XII.4 MODULE 10.3: PT POD SIGHTLINE DIRECTIONAL COSINES, WITH MANUAL OPERATOR (@40 Hz) 206

XII.5 MODULE 10.4: PT POD SIGHTLINE DIRECTIONAL COSINE WITH PERFECT OPERATOR (@40 Hz) 208

XII.6 MODULE 10.5: PRECISE AIRCRAFT POSITION AND AIRCRAFT-TO-TARGET RANGES 210

XII.7 MODULE 10.6: LASER RANGE CALCULATION (@10 Hz) 212

FIGURES

XII.1: Sequence of events for position of target relative to aircraft (module 10) 214

THIS IS A BLANK PAGE

XII.1 INTRODUCTION

The events associated with module 10 are illustrated in Figure XII.1. Each of the submodules of this event sequence are detailed below.

XII.2 MODULE 10.1: PT POD SIGHTLINE RATE AIDING SIGNALS (@40 Hz)

PURPOSE:

To determine PT Pod sightline rate aiding signals.

INPUTS (@40 Hz):

	Parameter	Source	Update
Pave tack prime (Binary)	PT PRM	1.5	cs
Dead-man switch depressed to 1/2 action (Binary)	1/2 ACTION	1.5	cs
Pod in track (Binary)	PIT	1.5	cs
J sightline velocity component	V_J	7.4	@40 Hz
K sightline velocity component	V_K	7.4	@40 Hz
Slant range to sighting point	R_{SPTSP}	7.5, 7.6	@40 Hz
Pitch integration correction for (elevation) hand control	HJINT	11.15, 10.1	@40 Hz
Yaw integration correction for (azimuth) hand control	HKINT	11.15, 10.1	@40 Hz
Elevational operator adjustment	DelElevation	11.17	cs
Azimuthal operator adjustment	DelAzimuth	11.17	cs

PROCESSING:

Timing reference t_{20}:

If PT PRM = 1 and 1/2 ACTION = 0 and PIT = 1, then:

(a) HJINT = HJINT + DelElevation / 40

(b) $\omega_{RJ} = V_K/R_{SPTSP}$ + HJINT

(c) HKINT = HKINT + DelAzimuth / 40

(d) $\omega_{RK} = - V_J / R_{SPTSP}$ + HKINT

(c) If $|\omega_{RJ}| < 61.0 \times 10^{-6}$ rad s^{-1} then:

Set $\omega_{RJ} = 0.0$ rad s^{-1}

(d) If $|\omega_{RJ}| > 2.0$ rad s^{-1} then:

Set $\omega_{RJ} = \pm 2.0$ rad s^{-1}

Otherwise:

exit from module

OUTPUTS (@40 Hz):

	Parameter	Destination
Sightline pitch (elevation) rate	ω_{RJ}	10.3, 10.4, 7.5
Sightline yaw (azimuth) rate	ω_{RK}	10.3
Pitch integration correction for (elevation) hand control	HJINT	10.1
Yaw integration correction for (azimuth) hand control	HKINT	10.1

COMMENTS:

(a) V_J and V_K are components of aircraft velocity along the sightline axes J and K (see Appendix I for details of the coordinate systems used) and are used to generate rate-aiding signals. These signals attempt to compensate for sightline drift caused by aircraft motion and assist the operator in maintaining target designation in track mode.

(b) Sightline pitch rate signals are limited to the range $61.0\times10^{-6} < |\omega_{RJ}| < 2.0$ rad s^{-1}.

XII.3 MODULE 10.2: CALCULATION OF AIRCRAFT TO INERTIAL MATRIX (@40 Hz)

PURPOSE:

To calculate the matrix that transforms the inertial coordinate system to the aircraft reference frame and calculates the aircraft coordinate ranges to the target.

INPUTS (@40 Hz):

	Parameter	Source	Update
Aircraft yaw angle	Yaw_A	External	cs
Aircraft pitch angle	$Pitch_A$	External	cs
Aircraft roll angle	$Roll_A$	External	cs
Pod in track (Binary)	PIT	1.5	cs
Cue mode status indicator (Binary)	CueButton	1.5	cs
Pave tack prime (Binary)	PT PRM	1.5	cs
Perfect operator selected (Binary)	PerfectOp	11.2	cs
True north range	NR	10.5	cs
True east range	ER	10.5	cs
True vertical range	VR	10.5	cs
Arbitary point on sight line	LoS	7.2	@40 Hz

PROCESSING:

Timing reference t_{20}:

If PT PRM = 1, then

(a) Construct yaw transformation matrix Ψ for yaw angle Yaw_A

(b) Construct pitch transformation matrix Θ from pitch angle Pitch_A

(c) Construct roll transformation matrix Φ from roll angle Roll_A

(d) CAI = $\Phi \; \Theta \; \Psi$

(e) Activate module 10.5

(f) If PerfectOp = 0, or PT PRM = 1 and CueButton = 1 and PIT = 0 then set:

    (i) Ranges_1 = NR

    (ii) Ranges_2 = ER

    (iii) Ranges_3 = VR

Otherwise:

    (i) $\text{Ranges}_1 = \text{LoS}_1$

    (ii) $\text{Ranges}_2 = \text{LoS}_2$

    (iii) $\text{Ranges}_3 = \text{LoS}_3$

(g) T = CAI Ranges

(h) If $T_3 \leq 0$ then :

    (i) Inhibit = True

    (ii) PIT = 0

    (iii) 1/2 ACTION = 0

    (iv) CueButton = 1

    (v) LSR ARM = 0

    (vi) LSR FIRE = 0

Otherwise:

    Inhibit = False

OUTPUTS (@40 Hz):

	Parameter	Destination
Inertial to aircraft transformation matrix	CAI	10.3, 10.4, 7.3
Aircraft coordinate ranges to the target	T	10.4
Laser armed (Binary)	LSR ARM	1.5
Laser firing (Binary)	LSR FIRE	1.5
Pod in track (Binary)	PIT	1.5
Dead-man switch at half action (Binary)	1/2 ACTION	1.5

Cue mode status indicator (Binary)	CueButton	1.5
Inhibited region indicator (Binary)	Inhibit	11.14, 11.15, External

COMMENTS:

(a) The reader is referred to Appendix I for full details of the coordinate systems and associated transformations adopted in the simulation.

(b) In this instance, external input refers to data relating to the pre-generated flight profile of the aircraft.

(c) A very simple inhibited region, represented by the upper hemisphere of the aircraft, is used in this simulation. It should be noted that this is not in any way a true representation of the true inhibited region of the aircraft. The effect of entering this region is illerstrated in process (h).

XII.4 MODULE 10.3: PT POD SIGHTLINE DIRECTIONAL COSINES, WITH MANUAL OPERATOR (@40 Hz)

PURPOSE:

To determine PT Pod directional cosines from rate aiding signals (where appropriate) and operator adjustments.

Inputs:

	Parameter	Source	Update
Pave tack prime (Binary)	PT PRM	1.5	cs
Dead-man switch depressed to 1/2 ACTION (Binary)	1/2 ACTION	1.5	cs
Pod in track (Binary)	PIT	1.5	cs
Sightline pitch (elevation) rate	ω_{RJ}	10.1	@40 Hz
Sightline yaw (azimuth) rate	ω_{RK}	10.1	@40 Hz
Elevational operator adjustment	$\delta_{Elevation}$	11.17	cs
Azimuthal operator adjustment	$\delta_{Azimuth}$	11.17	cs
Inertial to aircraft transformation matrix	CAI	10.2	@40 Hz
Perfect operator selected (Binary)	PerfectOp	11.2	cs
Horizon natural selected (Binary)	HorNat	1.5	cs
Pave tack pod view selected (Binary)	PV	1.5	cs

PROCESSING:

Timing reference t_{20}:

If PT PRM = 1, and PerfectOp = 0 then:

(a) Outer Roll(n-1) = $\tan^{-1}(-T_2/T_3)$

(b) Outer Pitch(n-1) = $\tan^{-1}[-(T_2^2+T_3^2)^{\frac{1}{2}}/T_1]$

(c) Inner Yaw(n-1) = 0

```
(d) If 1/2 ACTION = 0 and PIT = 1, then:
    $\text{Inner Yaw}(n) = \text{Inner Yaw}(n-1) + \omega_{RK}/40 + \delta_{Azimuth}$
    $\text{Outer Pitch}(n) = \text{Outer Pitch}(n-1) + \omega_{RJ}/40 + \delta_{Elevation}$
Otherwise:
If 1/2 ACTION = 1 and PIT = 0, then:
    $\text{Inner Yaw}(n) = \text{Inner Yaw}(n-1) + \delta_{Azimuth}$
    $\text{Outer Pitch}(n) = \text{Outer Pitch}(n-1) + \delta_{Elevation}$
(e) If $\text{Inner Yaw}(n) > \pi$ then:
    $\text{Inner Yaw}(n) = -2\pi + \text{Inner Yaw}(n)$
Otherwise If $\text{Inner Yaw}(n) < -\pi$ then:
    $\text{Inner Yaw}(n) = 2\pi + \text{Inner Yaw}(n)$
(f) Construct yaw transformation matrix $\Psi$ from yaw angle Inner Yaw(n)
(g) Construct pitch transformation matrix $\Theta$ from pitch angle Outer Pitch(n)
(h) Construct roll transformation matrix $\Phi$ from roll angle Outer Roll(n)
(i) $CSA = \Psi\ \Theta\ \Phi$
(j) $CSI = CSA\ CAI$
(k) $ZTheta_1 = \cos^{-1}(CSI_{1,3})$
(l) If $ZTheta_1 > \pi/2$ then $ZTheta_1 = ZTheta_1 - \pi$
(m) If PIT = 1 then set:
    (i) $ThetaLoS = |\sin^{-1} CSA_{13}|$
    (ii) $PsiLoS = \tan^{-1}(CSA_{12}/CSA_{11})$
    (iii) If PV = 1 then set:
        $\tau = 0$
    Otherwise:
    If HorNat = 1 then set:
        $\tau = \tan^{-1}[\sin(\text{Outer Roll})/(\cos(\text{Outer Pitch})\cos(\text{Outer Roll}))] - \sin(\text{Inner Yaw})/2$
```

Otherwise:

$$\tau = \tan^{-1}[\sin(\text{Outer Roll})/(\cos(\text{Outer Pitch})\cos(\text{Outer Roll}))] - \sin(\text{Inner Yaw})/2 - \text{PsiLoS}$$

Otherwise:

exit from module

OUTPUTS (@40 Hz):

	Parameter	Destination
Inertial to sightline transformation matrix	CSI	1.6, 10.6
Pod pitch angle	Outer Pitch(n)	10.4
Depression angle	ZTheta_1	External
Depression angle line-of-sight marker	Theta LoS	External
Azimuth angle line-of-sight marker	Psi Los	External
Derotation angle	τ	11.17, External

COMMENTS:

(a) CSA is the aircraft-to-sightline coordinate transformation matrix (see Appendix I for full details). Subscripts of CSA refer to elements of this matrix.

(b) Outer and inner angles refer to outer gimbal and inner gimbal rotations of the PT pod. Manual adjustments made by the operator to the positioning of the pod sightline are achieved by changes in the inner gimbal angles; inner yaw and inner pitch. Since the inner gimbals have limited travel, the pod continually attempts to nullify them by making adjustments to the outer gimbal angles. This is emulated in the simulation by equations (a) to (d).

(c) In horizon natural mode the horizon of the PT image display is always shown horizontally. The derotation function serves to translate the correction signals of the operator (who views such a display) into appropriate azimuth and elevational rotations of the pod sightline. The derotation function also, in horizon natural mode, rotates the PT image appropriately so that the image remains upright when the aircraft flies directly or nearly directly over the target.

XII.5 MODULE 10.4: PT POD SIGHTLINE DIRECTIONAL COSINE WITH PERFECT OPERATOR (@40 Hz)

PURPOSE:

To determine PT Pod directional cosines from the precise ranges to target for use while in perfect operator mode.

INPUTS (@40 Hz):

	Parameter	Source	Update
Pave tack prime (Binary)	PT PRM	1.5	cs
Dead-man switch depressed to 1/2 action (Binary)	1/2 ACTION	1.5	cs
Pod in track (Binary)	PIT	1.5	cs
Inertial to aircraft transformation matrix	CAI	10.2	@40 Hz
Aircraft coordinate ranges to the target	T	10.2	@40 Hz

Perfect operator selected (Binary)	PerfectOp	11.2	cs
Sightline pitch (elevation) angle	Outer Pitch(n-1)	10.4,10.3,7.2,7.3	@40 Hz
Sightline pitch (elevation) rate	ω_{RJ}	10.1	@40 Hz
Horizon natural selected (Binary)	HorNat	1.5	cs
Pave tack pod view selected (Binary)	PV	1.5	cs

PROCESSING:

Timing reference t_{20}:

If PT PRM = 1 and PerfectOp = 1 and
if PIT = 1 or 1/2 ACTION = 1 but not both simultaneously then:

(a) (i) PPitch = Outer Pitch(n-1) + $\omega_{RJ}/40$

(ii) Outer Roll(n) = $\tan^{-1}(-T_2/T_3)$

(iii) Outer Pitch(n) = $\tan^{-1}[-(T_2^2 + T_3^2)^{1/2}/T_1]$

(iv) Inner Yaw(n) = 0

(v) DelElevation = Outer Pitch(n) - PPitch

(b) Construct yaw transformation matrix Ψ from yaw angle Inner Yaw(n)

(c) Construct pitch transformation matrix Θ from pitch angle Outer Pitch(n)

(d) Construct roll transformation matrix Φ from roll angle Outer Roll(n)

(e) CSA = $\Psi \Theta \Phi$

(f) CSI = CSA CAI

(g) $\text{ZTheta}_1 = \cos^{-1}(\text{CSI}_{1,3})$

(h) If $\text{ZTheta}_1 > \pi/2$ then $\text{ZTheta}_1 = \text{ZTheta}_1 - \pi$

(m) If PIT = 1 then set:

(i) ThetaLoS = $|\sin^{-1}\text{CSA}_{13}|$

(ii) PsiLoS = $\tan^{-1}(\text{CSA}_{12}/\text{CSA}_{11})$

(iii) If PV = 1 then set:

$\tau = 0$

Otherwise:

If HorNat = 1 then set:

$\tau = \tan^{-1}[\sin(\text{Outer Roll})/(\cos(\text{Outer Pitch}) \cos(\text{Outer Roll}))] - \sin(\text{Inner Yaw})/2$

Otherwise:

$$\tau = \tan^{-1}[\sin(\text{Outer Roll})/(\cos(\text{Outer Pitch})\cos(\text{Outer Roll}))] - \sin(\text{Inner Yaw})/2 - \text{PsiLoS}$$

Otherwise:

exit from module

OUTPUTS (@40 Hz):

	Parameter	Destination
Inertial-to-sightline transformation matrix	CSI	1.6, 10.6
Sightline pitch (elevation) angle	Outer Pitch(n)	10.3, 10.4
Elevatin operator adjustment	DelElevation	7.5
Depression angle	$ZTheta_1$	External
Depression angle line-of-sight marker	Theta LoS	External
Azimuth angle line-of-sight marker	Psi Los	External
Derotation angle	τ	11.17, External

XII.6 MODULE 10.5: PRECISE AIRCRAFT POSITION AND AIRCRAFT-TO-TARGET RANGES

PURPOSE:

To determine the precise position of the aircraft for calculation of precise laser range.

INPUTS (cs):

	Parameter	Source	Update
Inertial velocity north	V_{IN}	1.4	cs
Inertial velocity east	V_{IE}	1.4	cs
Pressure altitude rate	$\dot{H}_1$	1.4	cs
Pressure altitude rate at last calculation	$\dot{H}_1'$	10.5	cs
Initial latitude	λ_{PO}	1.1	cs
Initial longitude	L_{PO}	1.1	cs
Pressure altitude	H_P	1.4	cs
Destination latitude	λ_{DO}	1.2	cs
Destination longitude	L_{DO}	1.2	cs
Fixpoint elevation	H_F	1.2	cs
Stored offset north	K_{NO}	2.1	cs
Stored offset east	K_{EO}	2.1	cs
Stored offset vertical	K_{VO}	2.1	cs
Radar prime (Binary)	RDR PRM	1.5	cs
Offset mode selected (Binary)	OS	1.5	cs
PT pod differential sighting selected (Binary)	R/T LOS SEL	1.5	cs
Current time	Time	External	cs
Time of last calculation	TimeLast	10.5	cs
Position at last calculation	Pointl(n-1)	10.5	cs

```
PROCESSING:

Timing reference $t_0$:

(a)  If Time = 0 then:

          $Point1_1(n) = \lambda_{PO}$

          $Point1_2(n) = L_{PO}$

          $Point1_3(n) = H_P$

     ELSE:

(b)  $Point1_1(n) = V_{IN}(Time\text{-}TimeLast)/rn + Point1_1(n\text{-}1)$

     $Point1_2(n) = V_{IE}(Time\text{-}TimeLast)/(re\ \cos(Point1_1(n))) + Point1_2(n\text{-}1)$

     $Point1_3(n) = \dot{H}_1(Time\text{-}TimeLast) + Point1_3(n\text{-}1) + (\dot{H}_1 - \dot{H}_1')$

     TimeLast  = Time

     $\dot{H}_1' = \dot{H}_1$

(c)  $Point2_1(n) = \lambda_{DO}$

     $Point2_2(n) = L_{DO}$

     $Point2_3(n) = H_F$

(d)  $Point3_1(n) = Point2_1(n)$

     $Point3_2(n) = Point2_2(n)$

     $Point3_3(n) = Point2_3(n)$

(e)  $\Delta Pt_1 = Point3_1(n) - Point1_1(n)$

     $\Delta Pt_2 = Point3_2(n) - Point1_2(n)$

     $h_{\varphi 2} = (\Delta Pt_2/2) \sin(\Delta Pt_2) \cos(Point1_1(n)) \sin(Point3_1(n))$

(f)  If OS = 1 and R/T LOS Sel = 0 or RDR PRM = 1, then:

          $NR = 6076.98(3437.747\Delta Pt_1 + h_{\varphi 2}) + K_{NO}$

          $ER = 6076.98(3437.747\Delta Pt_2 \cos(Point3_1(n)) + K_{EO}$

          $VR = Point1_3(n) - Point3_3(n) + 2.39 \times 10^{-8} (NR^2 + ER^2) + K_{VO}$

     Otherwise:

          $NR = 6076.98(3437.747\Delta Pt_1 + h_{\varphi 2})$
```

$$ER = 6076.98(3437.747\Delta Pt_2 \cos(Point3_1(n))$$

$$VR = Point1_3(n) - Point3_3(n) + 2.39 \times 10^{-8} (NR^2 + ER^2)$$

OUTPUTS (cs):

	Parameter	Destination
Aircraft's actual position	Point1	10.5
Precise north range	NR	10.2, External
Precise east range	ER	10.2, External
Precise vertical range	VR	10.2,10.6, External
Time of last calculation	TimeLast	10.5
Pressure altitude rate	$\dot{H}'_1$	10.5

COMMENTS:

(a) Point2 represents the coordinates of the centre of the crosshairs on the screen, when the weapons officer is looking at the aimpoint.

(b) Point3 represents the coordinates where the centre of the line of sight first intersects with the ground.

(c) The term 2.39×10^{-8} is a numerical quantity used in the compensation of earth curvature between the aircraft and aimpoint.

(d) Precise quantities are those parameter values known to the analyst but not to the system (see Section 5 of the main text for further details).

(e) The variables rn and re in equation (b) represent the earth's radius (in feet) in the latitude and longitude directions.

XII.7 MODULE 10.6: LASER RANGE CALCULATION (@10 Hz)

PURPOSE:

To determine the laser range to the aimpoint being viewed.

INPUTS (@10 Hz):

	Parameter	Source	Update
Precise vertical range	VR	10.5	cs
Vertical direction cosine	$CSI_{1,3}$	10.3, 10.4	@40 Hz

PROCESSING:

Timing reference t_{22}:

(a) If $CSI_{13} \neq 0$, then

$$R_{SL} = VR/CSI_{13}$$

Otherwise:

$$R_{SL} = 1.7 * 10^{300}$$

OUTPUTS (@10 Hz):

	Parameter	Destination
PT Pod laser slant range	R_{SL}	1.6

COMMENTS:

(a) In the OFP the laser range is an external input and is both a sight line position and terrain dependent quantity. The above steps are conducted to simulate this range by using the known positions of the target (or offset) and aircraft and by assuming a flat terrain in the vicinity of the aimpoint.

ENTRY
|
V
10.1
CALCULATION OF RATE AIDING TERMS (@40 Hz)
|
V
10.2
DETERMINATION OF AIRCRAFT TO INERTIAL COSINES (@40 Hz)
|
V
10.3
DETERMINATION OF SIGHTLINE TO INERTIAL COSINES
WITH MANUAL TRACKER (@40 Hz)
|
V
10.4
DETERMINATION OF SIGHTLINE TO INERTIAL COSINES
WITH PERFECT TRACKER (@40 Hz)
|
V
10.5
DETERMINATION OF PRECISE AIRCRAFT POSITION (cs)
|
V
10.6
LASER RANGE CALCULATION (@10 Hz)
|
V
EXIT

Figure XII.1: Sequence of events for position of target relative to aircraft (module 10)

APPENDIX XIII

FPTS: OPERATOR INTERACTION (MODULE 11)

THIS IS A BLANK PAGE

CONTENTS

XIII.1 INTRODUCTION 219
XIII.2 MODULE 11.1: SET THE PT MODE OF OPERATION 219
XIII.3 MODULE 11.2: PERFECT OPERATOR SWITCH 220
XIII.4 MODULE 11.3: LASER ARM AND FIRE FUNCTION 221
XIII.5 MODULE 11.4: POD ALTITUDE MODE SELECTION 222
XIII.6 MODULE 11.5: POD VIEW MODE SELECTION 222
XIII.7 MODULE 11.6: RADAR ALTITUDE MODE SELECTION 223
XIII.8 MODULE 11.7: UPDATE SELECTION MODE 224
XIII.9 MODULE 11.8: DIFFERENTIAL SIGHTING SELECTION 224
XIII.10 MODULE 11.9: BOMB OR NAVIGATION MODE SELECTION 225
XIII.11 MODULE 11.10: OFFSET SELECTION MODE 227
XIII.12 MODULE 11.11: RADAR MAGNIFICATION SELECTION 229
XIII.13 MODULE 11.12: WEAPON RELEASE SELECTION 230
XIII.14 MODULE 11.13: HORIZON NATURAL SWITCH 231
XIII.15 MODULE 11.14: DEAD-MAN SWITCH 1/2 ACTION CONTROL 232
XIII.16 MODULE 11.15: DEAD-MAN SWITCH AT FULL ACTION 233
XIII.17 MODULE 11.16: CUE BUTTON DEPRESSED 234
XIII.18 MODULE 11.17 PT SIGHTLINE ADJUSTMENT (@40 Hz) 235
XIII.19 MODULE 11.18: RADAR MODE ADJUSTMENTS (@40 Hz) 236

FIGURES

XIII.1: Baseline sequence of events for operator interaction (module 11) 238

THIS IS A BLANK PAGE

XIII.1 INTRODUCTION

The events associated with module 11 are illustrated in Figure XIII.1. Each of the submodules of this event sequence are detailed below.

XIII.2 MODULE 11.1: SET THE PT MODE OF OPERATION

PURPOSE:

To set either the radar or PT screen to be prime and to set the PT mode of operation.

INPUTS (cs):

	Parameter	Source	Update
Primary screen selection key	"p"	Keyboard	cs
PT mode selection key	"l"	Keyboard	cs
PT mode selection variable	PT MODE SEL	11.1	cs
PT prime (Binary)	PT PRM	1.5, 11.1	cs
Radar prime (Binary)	RDR PRM	1.5, 11.1	cs

PROCESSING:

Timing reference t_{21}:

If the "p" key was pressed or the "l" key was pressed then:

(a) If the "p" key was pressed then

(i) PT Prm = 1 - PT Prm

(ii) Rdr Prm = 1 - Rdr Prm

(iii) 1/2 ACTION = 0

(iv) PIT = 0

(v) LSR ARM = 0

(vi) LSR FIRE = 0

(b) If PT PRM = 1 and the "l" key has been pressed, then:

PT MODE SEL = 1 - PT MODE SEL

Otherwise:

exit from module

OUTPUTS (cs):

	Parameter	Destination
PT prime (Binary)	PT PRM	1.5, 11.1

Radar prime (Binary)	RDR PRM	1.5, 11.1
Dead-man switch at 1/2 action (Binary)	1/2 ACTION	1.5
Pod in track (Binary)	PIT	1.5
Laser armed (Binary)	LSR ARM	1.5, 11.3
Laser firing (Binary)	LSR FIRE	1.5
PT mode selection variable	PT MODE SEL	11.1, External

COMMENTS:

(a) When the variable PT MODE SEL takes the value of 1 the pod is placed into normal mode, when it takes the value of zero the pod is in navigation mode.

(b) When the operator changes the display on the primary screen the values of 1/2 ACTION and PIT are reset to zero, ie the trigger on the AIC is considered to be released.

XIII.3 MODULE 11.2: PERFECT OPERATOR SWITCH

PURPOSE:

To allow the program to be switched from manual operator to perfect operator, and vice versa.

INPUTS (cs):

	Parameter	Source	Update
Operator switch key	Spacebar	Keyboard	cs
Perfect operator selected (Binary)	PerfectOp	11.2	cs

PROCESSING:

Timing reference t_{21}:

```
If the space bar has been pressed, then:
    (a) If PerfectOp = 1 then:
            PerfectOp = 0
    else:
            PerfectOp = 1
Otherwise:
exit from module
```

OUTPUTS (cs):

	Parameter	Destination
Perfect operator selected (Binary)	PerfectOp	10.2, 10.3, 10.4,11.2, 11.17, 11.18

XIII.4 MODULE 11.3: LASER ARM AND FIRE FUNCTION

PURPOSE:

To allow the operator to arm and then fire the laser.

INPUTS (cs):

	Parameter	Source	Update
Arm/disarm laser key	"r"	Keyboard	cs
Laser fire/stop fire key	"f"	Keyboard	cs
Laser armed (Binary)	LSR ARM	1.5, 11.3	cs
PT prime (Binary)	PT PRM	1.5	cs
Pod in track (Binary)	PIT	1.5	cs
Laser firing (Binary)	LSR FIRE	1.5, 11.3	cs
Current time	Time	External	cs

PROCESSING:

Timing reference t_{21}:

If PTPrm = 1 and if the "r" or "f" keys have been pressed, then:

(a) If "r" was pressed and PIT = 1, then:

LSR ARM = 1 - LSR ARM

(b) If "f" was pressed and LSR ARM = 1, then:

LSR FIRE = 1 - LSR FIRE

(c) If LSR ARM = 0, then:

LSR FIRE = 0

(d) If LSR FIRE = 1, then:

LSR TIME = TIME

Activate 10.5

Otherwise:

exit from module

OUTPUTS (cs):

	Parameter	Destination
Laser Armed (Binary)	LSR ARM	1.5, 11.3
Laser Firing (Binary)	LSR FIRE	1.5, 11.3
Time Laser Fired	LSR TIME	7.6

XIII.5 MODULE 11.4: POD ALTITUDE MODE SELECTION

PURPOSE:

To allow the operator to change the pod altitude mode while in flight.

INPUTS (cs):

	Parameter	Source	Update
PT altitude switch key	"v"	Keyboard	cs
PT altitude calibration selected (Binary)	PT ALT CAL	11.4	cs
PT prime (Binary)	PT PRM	1.5	cs

Processing:

Timing reference t_{21}:

If PT PRM = 1 and the "v" key has been pressed, then

(a) PT ALT CAL = 1 - PT ALT CAL

Otherwise:

exit from module

OUTPUTS (cs):

	Parameter	Destination
PT altitude calibration selected (Binary)	PT ALT CAL	1.5, 11.4

XIII.6 MODULE 11.5: POD VIEW MODE SELECTION

PURPOSE:

To allow the operator to change the field-of-view of the pod between the wide and narrow status.

INPUTS (cs):

	Parameter	Source	Update
PT view switch key	"v"	Keyboard	cs
PT narrow FOV selected (Binary)	VIEW SEL VAR	11.5	cs

PROCESSING:

Timing reference t_{21}:

If PT PRM = 1 and the "v" key has been pressed, then:

(a) VIEW SEL VAR = 1 - VIEW SEL VAR

(b) If VIEW SEL VAR = 0 then

VIEW ANGLE V = 7.5°

VIEW ANGLE H = 10°

Otherwise:

VIEW ANGLE V = 2°

VIEW ANGLE H = 2.5°

Otherwise:

exit from module

OUTPUTS:

	Parameter	Destination
PT narrow FOV selected (Binary)	VIEW SEL VAR	11.5
Pod vertical field of view	VIEW ANGLE V	11.17, External
Pod horizontal field of view	VIEW ANGLE H	11.17, External

XIII.7 MODULE 11.6: RADAR ALTITUDE MODE SELECTION

PURPOSE:

To allow the operator to change the radar altitude mode.

INPUTS (cs):

	Parameter	Source	Update
Radar altitude switch key	"g"	Keyboard	cs
LARA calibration selected (Binary)	AC	11.6	cs

PROCESSING:

Timing reference t_{21}:

If the "g" key has been pressed, then

(a) AC = 1 - AC

Otherwise:

exit from module

OUTPUTS (cs):

	Parameter	Destination
LARA calibration selected (Binary)	AC	1.5, 11.6

COMMENTS:

(a) This module is not currently activated in the program, as one of the assumptions of the current program is that LARA altitude calibration is never selected.

XIII.8 MODULE 11.7: UPDATE SELECTION MODE

PURPOSE:

To allow the operator to swap between present and destination position updating.

INPUTS (cs):

	Parameter	Source	Update
Update switch key	"u"	Keyboard	cs
Destination (or present position) selected (Binary)	PP/DEST	11.7	cs

PROCESSING:

Timing reference t_{21}:

If the "u" key has been pressed, then

(a) PP/DEST = 1 - PP/DEST

Otherwise:

exit from module

OUTPUTS (cs):

	Parameter	Destination
Destination (or present position) selected (Binary)	PP/DEST	1.5, 11.7

XIII.9 MODULE 11.8: DIFFERENTIAL SIGHTING SELECTION

PURPOSE:

Allows the operator to place the pod into differential sighting mode during flight.

INPUTS (cs):

	Parameter	Source	Update
Differential sighting key	"d"	Keyboard	cs
PT pod differential sighting selected (Binary)	R/T LOS SEL	11.8	cs

PROCESSING:

Timing reference t_{21}:

If the "d" key has been pressed, then:

(a) R/T LOS SEL = 1 - R/T LOS SEL

(b) 1/2 ACTION = 0

(c) PIT = 0

(d) LSR ARM = 0

(e) LSR FIRE = 0

(f) CueButton = 1

Otherwise:

exit from module

OUTPUTS (cs):

	Parameter	Destination
PT pod differential sighting selected (Binary)	R/T LOS SEL	1.5, 11.8
Dead-man switch depressed to 1/2 action (Binary)	1/2 ACTION	1.5
Pod in track (Binary)	PIT	1.5
Laser arm (Binary)	LSR ARM	1.5
Laser fire (Binary)	LSR FIRE	1.5
Cue mode status indicator (Binary)	CueButton	1.5

XIII.10 MODULE 11.9: BOMB OR NAVIGATION MODE SELECTION

PURPOSE:

Allows the operator to change the bomb or navigation mode.

INPUTS (cs):

	Parameter	Source	Update
Short range navigation selection key	"m"	Keyboard	cs
Auto bomb mode key	","	Keyboard	cs
Trail bomb mode key	"."	Keyboard	cs
Range bomb mode key	"/"	Keyboard	cs

PROCESSING:

Timing reference t_{21}:

If any of the "m", ",", "." or "/" keys have been pressed, then:

(a) If the "m" key has pressed, then:

(i) SR = 1

(ii) BM = 0

(iii) RB = 0

(iv) AB = 0

(b) If the "," key has been pressed, then:

(i) SR = 1

(ii) BM = 1

(iii) RB = 0

(iv) AB = 1

(c) If the "." key has been pressed, then

(i) SR = 1

(ii) BM = 1

(iii) RB = 0

(iv) AB = 0

(b) If the "/" key has been pressed, then:

(i) SR = 1

(ii) BM = 1

(iii) RB = 1

(iv) AB = 0

Otherwise:

exit from module

OUTPUTS (Binary) (cs):

	Parameter	Destination
Short range navigation selected	SR	1.5
Bomb mode selected	BM	1.5
Auto bomb selected	AB	1.5
Range bomb selected	RB	1.5

XIII.11 MODULE 11.10: OFFSET SELECTION MODE

PURPOSE:

This module allows the operator to select an offset aimpoint in flight.

INPUTS (cs):

	Parameter	Source	Update
Target selection switch key	0	Keyboard	cs
First selection switch key	1	Keyboard	cs
Second selection switch key	2	Keyboard	cs
Third selection switch key	3	Keyboard	cs
Fourth selection switch key	4	Keyboard	cs
Fifth selection switch key	5	Keyboard	cs
Sixth selection switch key	6	Keyboard	cs
PT pod differential sighting selected (Binary)	R/T LOS SEL	1.5	cs
PT prime (Binary)	PT PRM	1.5	cs

PROCESSING:

Timing reference t_{21}:

If one of the number keys between 0 and 6 were pressed, then:

(a) OS = 1

(b) If the "0" key was pressed, then:

OS = 0

(c) If the "1" key was pressed, then:

(i) OFFSET#1 = 1

(ii) OFFSET#2 = 0

(iii) OFFSET#3 = 0

(iv) OFFSET#4 = 0

(v) OFFSET#5 = 0

(vi) OFFSET#6 = 0

(d) If the "2" key was pressed, then:

(i) OFFSET#1 = 0

(ii) OFFSET#2 = 1

(iii) OFFSET#3 = 0

  - (iv) OFFSET#4 = 0
  - (v) OFFSET#5 = 0
  - (vi) OFFSET#6 = 0

(e) If the "3" key was pressed, then:

  - (i) OFFSET#1 = 0
  - (ii) OFFSET#2 = 0
  - (iii) OFFSET#3 = 1
  - (iv) OFFSET#4 = 0
  - (v) OFFSET#5 = 0
  - (vi) OFFSET#6 = 0

(f) If the "4" key was pressed, then:

  - (i) OFFSET#1 = 0
  - (ii) OFFSET#2 = 0
  - (iii) OFFSET#3 = 0
  - (iv) OFFSET#4 = 1
  - (v) OFFSET#5 = 0
  - (vi) OFFSET#6 = 0

(g) If the "5" key was pressed, then:

  - (i) OFFSET#1 = 0
  - (ii) OFFSET#2 = 0
  - (iii) OFFSET#3 = 0
  - (iv) OFFSET#4 = 0
  - (v) OFFSET#5 = 1
  - (vi) OFFSET#6 = 0

(h) If the "6" key was pressed, then:

  - (i) OFFSET#1 = 0
  - (ii) OFFSET#2 = 0

(iii) OFFSET#3 = 0

(iv) OFFSET#4 = 0

(v) OFFSET#5 = 0

(vi) OFFSET#6 = 1

(i) IF R/T LOS = 0 and PT PRM = 1, then:

(i) 1/2 ACTION = 0

(ii) PIT = 0

(iii) LSR ARM = 0

(iv) LSR FIRE = 0

(v) CueButton = 1

Otherwise:

exit from module

OUTPUTS (Binary) (cs):

	Parameter	Destination
First stored offset selected	OFFSET#1	1.5
Second stored offset selected	OFFSET#2	1.5
Third stored offset selected	OFFSET#3	1.5
Fourth stored offset selected	OFFSET#4	1.5
Fifth stored offset selected	OFFSET#5	1.5
Sixth stored offset selected	OFFSET#6	1.5
Offset mode selected	OS	1.5
Dead-man switch depressed to 1/2 action	1/2 ACTION	1.5
Pod in track	PIT	1.5
Laser arm (Binary)	LSR ARM	1.5
Laser fire (Binary)	LSR FIRE	1.5
Cue mode status indicator (Binary)	CueButton	1.5

XIII.12 MODULE 11.11: RADAR MAGNIFICATION SELECTION

PURPOSE :

This module allows the operator to change the magnification of the radar display.

INPUTS (cs):

	Parameter	Source	Update
Increase radar magnification key	">"	Keyboard	cs
Decrease radar magnification key	"<"	Keyboard	cs
Radar prime (Binary)	RDR PRM	1.5	cs

Radar magnification value	RDR MAG	11.11	cs

PROCESSING:

Timing reference t_{21}

If RDR PRM = 1 and if the ">" or "<" keys have been pressed, then:

(a) If the ">" key has been pressed, then:

RDR MAG = RDR MAG + 1

Otherwise:

RDR MAG = RDR MAG - 1

(b) If RDR MAG < 1 then:

RDR MAG = 1

(c) If RDR MAG > 7 then

RDR MAG = 7

Otherwise:

exit from module

OUTPUTS (cs):

	Parameter	Destination
Radar magnification value	RDR MAG	11.11, 11.18, External

COMMENTS:

(a) There are 8 different magnifications for the radar screen.

XIII.13 MODULE 11.12: WEAPON RELEASE SELECTION

PURPOSE :

To allow the operator to release a bomb manually or to manually disengage the weapon release switch.

INPUTS (cs):

	Parameter	Source	Update
Release switch key	"b"	Keyboard	cs
Release switch selected (Binary)	REL SWT	11.12,5.5	cs
Number of weapons left	n_{WL}	11.12,5.5	cs

PROCESSING:

Timing reference t_{21}:

If the "b" key has been pressed, then:

(a) REL SWT = 1 - REL SWT

(b) If REL SWT = 1, then:

$n_{WL} = n_{WL} - 1$

(c) If REL SWT = 1 and n_{WL} >= 0, then:

Set $W_R = 1$ for time t_{WR} before returning to 0

(d) If $n_{WL} < 0$, then:

REL SWT = 0

OUTPUTS (cs):

	Parameter	Destination
Release switch selected (Binary)	REL SWT	11.12, 1.2, External
Number of weapons left	n_{WL}	1.2, 11.12
Weapon released (Binary)	W_R	1.5, External

COMMENTS:

(a) The value of W_R is reset to zero whenever the time to impact is less than zero or after t_{WR} seconds.

XIII.14 MODULE 11.13: HORIZON NATURAL SWITCH

PURPOSE:

To allow the operator to select and deselect Horizon Natural mode.

INPUTS (cs):

	Parameter	Source	Update
Operator switch key	"z"	Keyboard	cs
Operator switch key	"h"	Keyboard	cs
Pave tack pod view selected (Binary)	PV	11.13	cs
Horizon natural selected (Binary)	HorNat	11.13	cs

PROCESSING:

Timing reference t_{21}:

(a) If the "z" key has been pressed, then:

```
        PV = PV - 1

    (b) If the "h" key has been pressed, then:

        If HorNat = 1, then:

            HorNat = 0

        else:

            HorNat = 1

Otherwise:

exit from module
```

OUTPUTS (cs):

	Parameter	Destination
Pave tack pod view selected (Binary)	PV	1.5, 11.13
Horizon natural selected (Binary)	HorNat	1.5, 11.13

XIII.15 MODULE 11.14: DEAD-MAN SWITCH 1/2 ACTION CONTROL

PURPOSE:

To allow the operator to place the AIC trigger into 1/2 Action while in flight.

INPUTS (cs):

	Parameter	Source	Update
Operator switch key	"t"	Keyboard	cs
Radar prime (Binary)	RDR PRM	1.5	cs
Dead-man switch at 1/2 action (Binary)	1/2 ACTION	1.5, 11.14	cs
Current time	Time	External	cs
PT pod in track (Binary)	PIT	1.5, 11.15	cs
Inhibited region indicator (Binary)	Inhibit	10.2	@40Hz

PROCESSING:

Timing reference t_n :

```
If RDR PRM = 1 or Inhibit = 0,

and the "t" key was pressed, then:

    (a)  If 1/2 ACTION = 0, then:

            (i)   1/2 ACTION = 1

            (ii)  If RDR PRM = 1, then
```

TIME LAST MOVE = Time

(iii) If PIT = 0, then

CueButton = 0

Otherwise:

(i) 1/2 ACTION = 0

(ii) CONCNT = 0

Otherwise:

exit from module

OUTPUTS (cs):

	Parameter	Destination
Last time checked for adjustment	TIME LAST MOVE	11.18
Dead-man switch at 1/2 action (Binary)	1/2 ACTION	1.5, 11.14
Update cycle count	CONCNT	8.3
Cue mode status indicator (Binary)	CueButton	1.5

XIII.16 MODULE 11.15: DEAD-MAN SWITCH AT FULL ACTION

PURPOSE:

To allow the operator to place the pod into track mode from search mode and vice versa.

INPUTS (cs):

	Parameter	Source	Update
Operator switch key	"y"	Keyboard	cs
PT prime (Binary)	PT PRM	1.5	cs
PT pod in track (Binary)	PIT	1.5, 11.15	cs
Inhibited region indicator (Binary)	Inhibit	10.2	@40 Hz

PROCESSING:

Timing reference t_{21}:

If PT PRM = 1, and Inhibit = 1, and "y" key was pressed, then:

(a) If PIT = 0, then

(i) PIT = 1

(ii) 1/2 ACTION = 0

(iii) CueButton = 1

Otherwise:

(b) (i) PIT = 0

(ii) 1/2 ACTION = 0

(ii) LSR ARM = 0

(iii) LSR FIRE = 0

(iv) HKINT = 0

(v) HJINT = 0

Otherwise:

exit from module

OUTPUTS (cs):

	Parameter	Destination
PT in track (Binary)	PIT	1.5, 11.15, 11.14
Dead-man switch at 1/2 action (Binary)	1/2 ACTION	1.5
Cue mode status indicator (Binary)	CueButton	1.5
Laser firing (Binary)	LSR FIRE	1.5
Laser armed (Binary)	LSR ARM	1.5
Operator sightline adjustment in the J direction	HJINT	10.1
Operator sightline adjustment in the K direction	HKINT	10.1

COMMENTS:

(a) The laser is automatically turned off and disarmed whenever then pod goes from track to a search mode.

XIII.17 MODULE 11.16: CUE BUTTON DEPRESSED

PURPOSE:

Allows the operator to renter cue mode after being in course cue mode.

INPUTS (cs):

	Parameter	Source	Update
Operator switch key	"c"	Keyboard	cs
Cue mode status (Binary)	CueButton	11.16	cs

PROCESSING:

Timing reference t_{21}:

If PT PRM = 1 and "c" key was pressed, then:

CueButton = 1

Otherwise:

exit from module

OUTPUTS (cs):

	Parameter	Destination
Cue mode status indicator (Binary)	CueButton	1.5

COMMENTS:

(a) When the operator enters course cue mode from cue mode by depressing the AIC trigger to the half action position the sight line of the pod may be changed. The sight line is then slaved to this new point, even after the trigger is released. To return to the origanal sight line the operator must press the cue button.

XIII.18 MODULE 11.17 PT SIGHTLINE ADJUSTMENT (@40 Hz)

PURPOSE :

To allow the operator to adjust the pod sightline while in track or course cue mode.

INPUTS (@40 Hz):

	Parameter	Source	Update
Pod in track (Binary)	PIT	1.5	cs
Dead-man switch at 1/2 action (Binary)	1/2 ACTION	1.5	cs
PT prime (Binary)	PT PRM	1.5	cs
Pod vertical field of view	VIEW ANGLE V	11.5	cs
Pod horizontal field of view	VIEW ANGLE H	11.5	cs
Derotation angle	τ	7.2,7.3,10.3,10.4	@40 Hz
Perfect operator selected (Binary)	PerfectOp	11.2	cs

PROCESSING:

Timing reference t_{20}

If PT PRM = 1, and PerfectOp = 1 then:

(a) If PIT = 1 or 1/2 ACTION = 1 then:

(i) Read left-to-right and fore-to-aft signals from operator joystick. Set to DIFF X and DIFF Y respectively.

(b) $H_X = -3$ (DIFF Y) (VIEW ANGLE V/(Height of screen))

(c) $H_Y = -$ DIFF X * 3 * VIEW ANGLE H/(Width of screen)

(d) $\delta_{Elevation} = -H_Y \sin(\tau) + H_X \cos(\tau)$

(e) $\delta_{Azimuth} = H_Y \cos(\tau) + H_X \sin(\tau)$

Otherwise:

exit from module

OUTPUTS (@40 Hz):

	Parameter	Destination
Elevational operator adjustment	$\delta_{Elevator}$	7.5, 10.1, 10.3
Azimuthal operator adjustment	$\delta_{Azimuth}$	10.1, 10.3

COMMENTS:

(a) H_X and H_Y are manual acceleration signals from the thumb joystick and are used to adjust pod sightline rate when in track mode.

XIII.19 MODULE 11.18: RADAR MODE ADJUSTMENTS (@40 Hz)

PURPOSE :

To allow the operator to move the radar cursors during the flight.

INPUTS (@40 Hz):

	Parameter	Source	Update
Radar fixpoint relative bearing	θ_B	3.7	@16 Hz
Radar slant range	R_{SR}	3.6	@32 Hz
Ground track	θ_T	2.2	cs
Last time checked for adjustment	TIME LAST MOVE	11.14, 11.18	@40 Hz
Dead-man switch at 1/2 action (Binary)	1/2 ACTION	1.5	cs
Radar prime (Binary)	RDR PRM	1.5	cs
Perfect operator selected (Binary)	PerfectOp	11.2	cs
Radar magnification value	RDR MAG	11.11	cs
Destination latitude	λ_D	2.5	cs
Destination longitude	L_D	2.5	cs
Stored offset north	K_{N0}	2.1	cs
Stored offset east	K_{E0}	2.1	cs
Current time	Time	External	cs

PROCESSING:

Timing reference t_{20}:

If RDR PRM = 1 and PerfectOp = 1 then:

(a) (i) $\delta_{North1} = 0$

(ii) $\delta_{East1} = 0$

(iii) $\delta_{North2} = 0$

(iv) $\delta_{East2} = 0$

(b) tAIC = TIME - TIME LAST MOVED

(c) TIME LAST MOVED = Time

(d) Read left-to-right and fore-to-aft signals from AIC handle. Set to DIFF X and DIFF Y respectively.

(e) MagScale = $2^{RDR\ MAG\ -\ 1}$

(f) If DIFF Y $\neq$ 0, then:

(i) $\delta_{East1} = 3$ -DIFF Y R_{SR} MagScale / (K_1 $|\mathrm{Sin}(\theta_t + \theta_B)|$)

(ii) $\delta_{North1} = 3$ -DIFF Y RSR MagScale / (K_1 $|\mathrm{Cos}(\theta_t + \theta_B)|$)

(g) If DIFF X $\neq$ 0, then:

(i) $\delta_{East2} = 3$ DIFF X R_{SR} MagScale / (K_2 $|\mathrm{Cos}(\theta_t + \theta_B)|$)

(ii) $\delta_{North2} = 3$ DIFF X RSR MagScale / (K_2 $|\mathrm{Sin}(\theta_t + \theta_B)|$)

(h) $\delta_{NorthT} = \delta_{North1} + \delta_{North2}$

(i) δEastT = $\delta_{East1} + \delta_{East2}$

(j) λRDRRET = $\lambda_D + (K_{N0} + \delta_{NorthT})$ / RN

(k) LRDRRET = $L_D + (K_{E0} + \delta_{EastT})$ / (RE cos(λ_{RDRRET}))

(l) $\lambda_{PPABS} = \lambda_{RDRRET}$

(m) $L_{PPABS} = L_{RDRRET}$

OUTPUTS (@40 Hz):

	Parameter	Destination
AIC dead-man switch depressed duration	t_{AIC}	1.5
Time last time check for adjustment	TIME LAST MOVE	11.18
Radar return absolute latitude	λ_{PPABS}	1.4
Radar return absolute longitude	L_{PPABS}	1.4
Radar return latitude	λ_{RDRRET}	1.4
Radar return longitude	L_{RDRRET}	1.4

COMMENTS:

(a) The symbols K_1 and K_2 represent scaling constants that adjust the sensitivity of the AIC handle.

(c) The symbols RN and RE represent approximations to the radius of the earth along lines of longitude and latitude and take the values 20.8961×10^6 and 20.9667×10^6 ft respectively.

```
                              ENTRY
                                |
                                V
                               11.1
        PRIMARY SCREEN AND PT MODE SELECTION (cs)
                                |
                                V
                               11.2
              PERFECT OPERATOR SELECTION (cs)
                                |
                                V
                               11.3
                LASER CONTROL SELECTION (cs)
                                |
                                V
                               11.4
              PT ALTITUDE MODE SELECTION (cs)
                                |
                                V
                               11.5
                   PT VIEW SELECTION (cs)
                                |
                                V
                               11.6
           RADAR ALTITUDE MODE SELECTION (cs)
                                |
                                V
                               11.7
           PRESENT/DEST UPDATE SELECTION (cs)
                                |
                                V
                               11.8
          DIFFERENTIAL SIGHTING SELECTION (cs)
                                |
                                V
                               11.9
               NAV/BOMB MODE SELECTION (cs)
                                |
                                V
                              11.10
                 OFFSET MODE SELECTION (cs)
                                |
                                V
                              11.11
          RADAR MAGNIFICATION SELECTION (cs)
                                |
                                V
                              11.12
              WEAPON RELEASE SELECTION (cs)
                                |
                                V
                              11.13
             HORIZON NATURAL SELECTION (cs)
                                |
                                V
                              11.14
              1/2 ACTION SWITCH MODULE (cs)
                                |
                                V
                              11.15
              FULL ACTION SWITCH MODULE (cs)
                                |
                                V
                              11.16
             CUE MODE SELECTION MODULE (cs)
                                |
                                V
                              11.17
           PT SIGHTLINE ADJUSTMENTS (@40 Hz)
                                |
                                V
                              11 18
          RADAR CURSOR ADJUSTMENTS (@40 Hz)
                                |
                                V
                               EXIT
```

Figure XIII.1: Baseline sequence of events for operator interaction (module 11)

DISTRIBUTION

Australian Defence Force

	No. of Copies
Headquarters Australian Defence Force	
Director Combat Force Development (Air)	
Attention: SQNLDR J. Bennett OFFOPS2	1 copy
Navy	
Navy Scientific Adviser	1 copy
Army	
Scientific Adviser, Army	1 copy
Air	
Air Force Scientific Adviser	1 copy
501 Wing RAAF Base Amberley	
Attention: OIC Sim	1 copy

Defence Intelligence Organisation

Assistant Secretary Scientific Analysis	1 copy

Defence Science and Technology Organisation

Chief Defence Scientist Central Office Executive	1 shared copy
Counsellor, Defence Science, London	Cnt Sht
Counsellor, Defence Science, Washington	Cnt Sht
Senior Defence Scientific Adviser	1 copy
Scientific Adviser POLCOM	1 copy

Electronics and Surveillance Research Laboratory

Director	1 copy
Chief, Information Technology Division	1 copy
Chief, Communications Division	Cnt Sht
Chief, Electronic Warfare Division	Cnt Sht
Chief, Guided Weapons Division	Cnt Sht
Research Leader, Command and Control and Intelligence Systems	1 copy
Head, Systems Simulation and Assessment	1 copy
Attention: Mr D.A.B. Fogg	1 copy
Attention: Dr M. Davies	1 copy
Attention: Mr F.D.B. Bowden	1 copy
Attention: Dr R.T. Janus	1 copy
Publications & Publicity Officer, Information Technology Division	1 copy

Aeronautical and Maritime Research Laboratory

Director	1 copy
Chief, Flight Mechanics and Propulsion	1 copy
Attention: Mr C. Martin	
Attention: Mr R. Rossa	
Chief, Air Operations Division	1 copy
Attention: Mr R. Dancer	

Libraries and Information Services

Australian Government Publishing Service	1 copy
Defence Central Library, Technical Reports Centre	1 copy
Manager, Document Exchange Centre, (for retention)	1 copy
Defence Research Information Centre, United Kingdom	2 copies
National Technical Information Service, United States	2 copies
Director Scientific Information Services, Canada	1 copy
New Zealand, Ministry of Defence	1 copy
Defence Science and Technology Organisation Salisbury, Research Library	2 copies
Librarian Defence Signals Directorate	1 copy
British Library Document Supply Centre	1 copy
Parliamentary Library of South Australia	1 copy
The State Library of South Australia	1 copy

Spares

Defence Science and Technology Organisation Salisbury, Main Library	6 copies

Department of Defence

DOCUMENT CONTROL DATA SHEET

1. Page Classification
Unclassified

2. Privacy Marking/Caveat (of document)

3a. AR Number
AR-007-005

3b. Laboratory Number
ERL-0656-RR

3c. Type of Report
Research Report

4. Task Number
90/096

5. Document Date
MARCH 94

6. Cost Code
803857

7. Security Classification

* U	U	U
Document	Title	Abstract

S (Secret) C (Confi) R (Rest) U (Unclass)

* For UNCLASSIFIED docs with a secondary distribution LIMITATION, use (L) in document box.

8. No. of Pages 248

9. No. of Refs. 38

10. Title

A PC-BASED INTERACTIVE SIMULATION OF THE F-111C PAVE TACK SYSTEM AND RELATED SENSOR, AVIONICS AND AIRCRAFT ASPECTS

11. Author(s)

David A.B. Fogg, Mike Davies,
Fred D.J. Bowden and Ray Janus

12. Downgrading/Delimiting Instructions

N/A

13a. Corporate Author and Address

Electronics & Surveillance Research Laboratory
PO Box 1500, Salisbury SA 5108

13b. Task Sponsor

ADA

14. Officer/Position responsible for

Security:..

Downgrading:..

Approval forRelease:...DERL..

15. Secondary Release Statement of this Document

APPROVED FOR PUBLIC RELEASE

16a. Deliberate Announcement

No Limitation

16b. Casual Announcement (for citation in other documents)

☒ No Limitation ☐ Ref. by Author , Doc No. and date only.

17. DEFTEST Descriptors

Pave Tack
Computerised simulation
Performance evaluation
Navigational aids

18. DISCAT Subject Codes

12

19. Abstract

Pave Tack is an all weather, day and night, navigation and weapon delivery system fitted to the F-111C aircraft. A PC-based, interactive digital computer simulation has been written which can be used to assess the performance of the Pave Tack system and also as a computer-aided training device. In forming the simulation, it was necessary to model a number of avionics and sensor aspects and an F-111C flight path generator was used to produce accurate data off-line. This report details the history, structure and general capabilities of the F-111C Pave Tack Simulation (FPTS).