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IMPLEMENTATION OF AN OPTIMUM PROFILE GUIDANCE SYSTEM ON STOLAND

By

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for

AMES RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Moffett Field, California

ABSTRACT/SUMMARY

The report describes briefly the implementation on the STOLAND airborne digital computer of an Optimum Profile guidance system for the Augmentor Wing Jet STOL Research Aircraft. Major tasks under this contract were to implement the guidance and control logic, developed by NASA, to airborne computer software and to integrate the module with the existing STOLAND navigation, display, and autopilot routines. The optimum profile guidance system comprises an algorithm for synthesizing minimum fuel trajectories for a wide range of starting positions in the terminal area and a control law for flying the aircraft automatically along the trajectory. The report also touches on operational aspects of the system. In addition to describing the avionics software developed, a FORTRAN program is described that has been constructed to reflect the modular nature and algorithms implemented in the avionics software. The technical monitors as well as the principal contributors to the analytical development of the system are John D. McLean and Heinz Erzberger of NASA/ARC.

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I PROJECT SYSTEM DESCRIPTION

Background

The NASA Ames STOLAND system is an integrated digital avionics package designed for testing guidance, navigation and control concepts and for investigating operational procedures for short takeoff and landing aircraft. The STOLAND system includes navaid receivers, onboard sensors and pilot control and command inputs that are interfaced with a Sperry 1819A computer. The computer is used to provide both pilot assist modes and automatic modes for control of the aircraft. The Stoland system provides various displays (EADI, MFD, HSI), control actuators, mode select and data entry devices, vehicle sensors and a data acquisition system. The Sperry 1819A computer with auxiliary memory used in the STOLAND system provides 32K of words of 18-bit memory.

The standard Sperry developed software for the Augmentor Wind aircraft (Reference 1) provides interface with all required systems to support flight operations. In the implementation of the Optimum profile guidance and control program significant revision of the standard software system was required to provide required memory and CPU time. The following revisions to the standard system were performed.

a) removal of the existing reference flight path package to create memory space

b) implement a revised executive package to provide sufficient real-time for execution of the Optimum profile guidance and control package

c) develop a revised utility package with overlay capability to create memory space and provide a more comprehensive diagnosis tool for laboratory checkout (Reference 2)

d) Revise the strip chart routine to provide multiplexed strip charts in the laboratory to provide an improved diagnosis tool

e) moving all code from bank 5 to provide an effective data area for the Optimum profile guidance and control package

f) revision of the keyboard entry and display MFD, EADI, and HSI routines to provide the required interface

Design Method for the Guidance System

The purpose of the system is to assess the performance of a fuel efficient onboard guidance system for powered lift of STOL aircraft. The system generates a minimum fuel/noise trajectory for the Augmentor Wing aircraft and controls the aircraft along that trajectory.

Upon entering the terminal area the system, operating in fast-time, synthesizes a minimum-fuel reference trajectory from the current aircraft position to touchdown. The calculation makes use of energy-rate schedules, generated off line and stored in the STOLAND computer. The schedules give the controls (flaps, throttle, nozzle, and angle of attack) yielding the least fuel flow for a given normalized energy rate, $\dot{E}_n$, aircraft weight, altitude and equivalent airspeed. The normalized energy rate, $\dot{E}_n$, is defined by

$$\dot{E}_n = \sin\gamma_a + \dot{V}_a/g$$

where γ_a is the aerodynamic flight-path angle and V_a is the true airspeed. One such schedule is illustrated in Figure 1, where circled points indicate data storage points. The reference controls obtained from these tables were derived subject to the maneuver margin requirements and engine RPM limits specified for STOLAND. The values of engine RPM are also corrected to compensate for deviations of the ambient temperature from standard values.

Upon engagement of the 'Capture' mode (entered by pushing the Reference Flight Path button) the system synthesizes a minimum-fuel reference trajectory

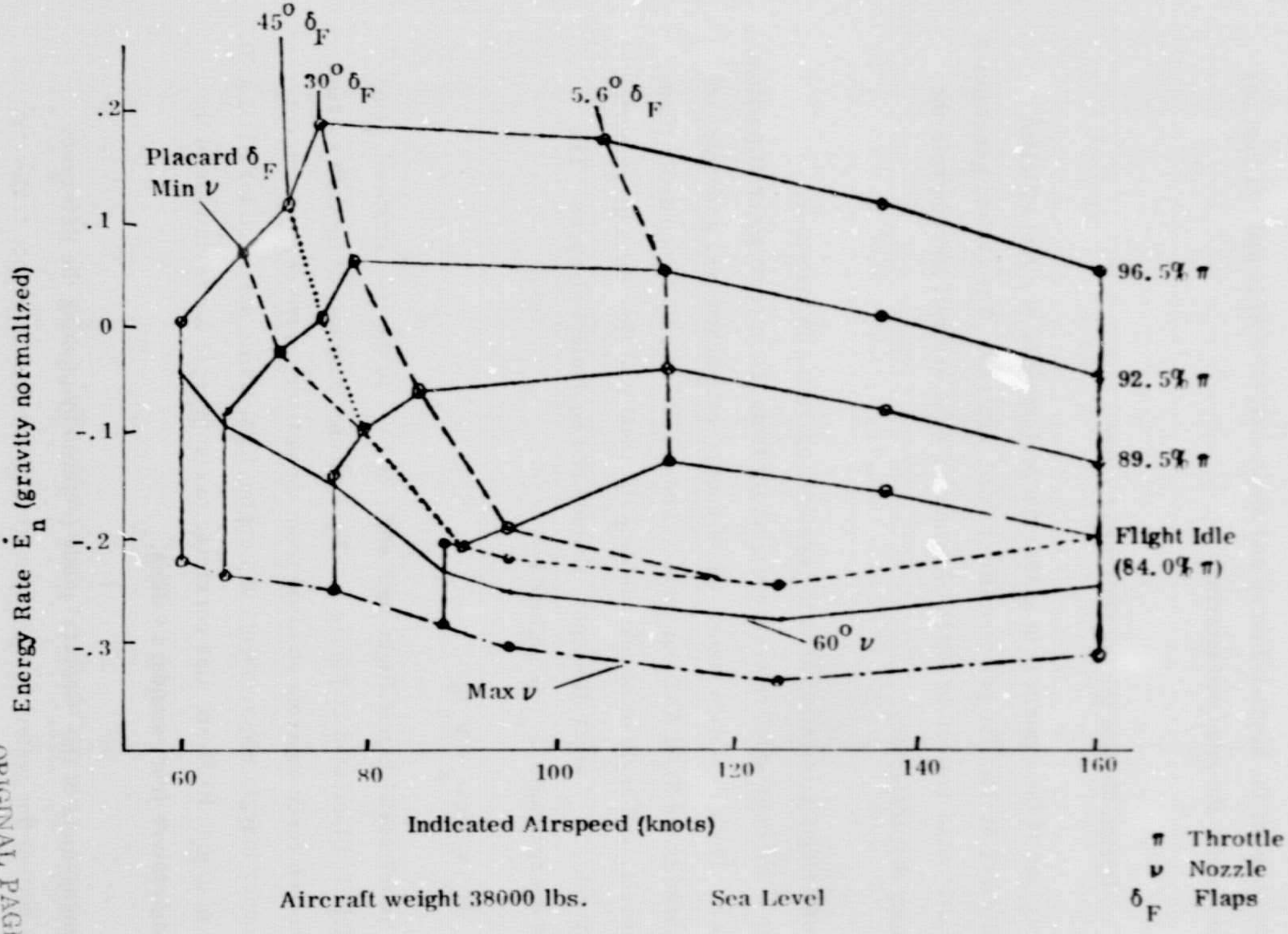


Figure 1. Typical Energy-rate Schedule

from the current aircraft position to touchdown. The reference flight path consists of two parts as shown in the example in Figure 2. The fixed route is specified by input waypoints and the final segment is always a straight, constant-speed glide slope. Note that although the trajectory is computed to touchdown as shown in the figure, the minimum-fuel guidance system will be disengaged during the final segment at the preset altitude sufficient to allow manual landing or go-around.

The initial portion of the trajectory, shown in dashed lines, is the 'Capture' trajectory which transfers the aircraft from its current position to the capture waypoint specified by the pilot. The capture trajectory is resynthesized continously as the aircraft moves until 'Track' mode is engaged (entered by pushing FULLAUTO or HORNAV button). At that time the reference trajectory is fixed and the aircraft is automatically controlled to the reference. There is no flight-director guided manual mode.

The optimum guidance system can be initiated from any initial aircraft position heading or airspeed in the terminal area where a capture waypoint on a stored reference trajectory and a loiter speed is specified by the pilot. The system will attempt to synthesize a trajectory to the runway and provides information on the MFD display related to no-capture conditions. When capture is feasible, the predicted time of arrival at the runway is displayed.

In the 'Capture' mode, the pilot can use speed control or path streching to control the approximate time of arrival. The trajectory is compensated for predicted wind conditions entered by the pilot via the keyboard as a function of altitude. The display techniques and two dimensional capture trajectory generation method was taken from previous work (Reference 3).

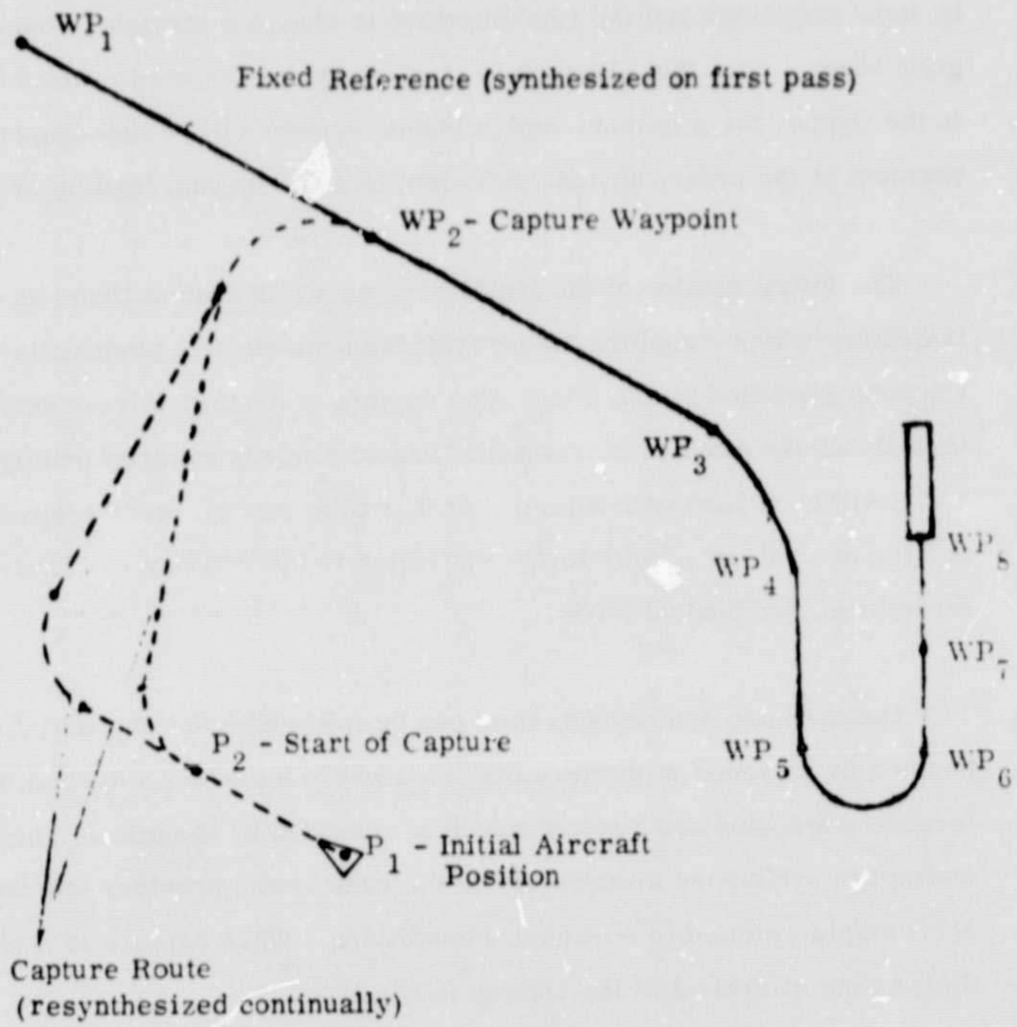


Figure 2. Reference Flight Path

The wind profile and runway temperature are entered through the keyboard as follows:

RWT = xx	xx = runway temperature, ^{o}C
EW_ = yy.xx	xx = Wind magnitude, knots yy = Wind heading, degrees /10

The third letter in EW_ denotes altitude as follows:

MNEMONIC	ALTITUDE, FT
EWA	0
EWB	250
EWC	500
EWD	1000
EWE	2000
EWF	4000
EWG	8000

These inputs will normally be made prior to the flight but can be changed during flight.

When the aircraft reaches cruise altitude:

AUTO FLAPS: ON
AUTO ON
AUTO THROTTLE ON
KEYBOARD : WGT = A/C WEIGHT, LBS.
LAS = LANDING AIRSPEED, KNOTS
(DEFAULT = STOLAND MINIMUM LAS)

AIRSPEED HOLD
ALTITUDE HOLD
HEADING HOLD
} Optional variations in these parameters will cause initial errors on track

KEYBOARD LTS = LOITER SPEED, KNOTS
(default value 140)

PUSH TACAN	Enable navigation system
PUSH FP1	There is only one reference flight path
PUSH REFP	

When REFP is pushed the system is in the 'Capture' mode, and the fixed portion of the reference flight path appears on the MFD with the triangle which indicates current aircraft position and heading. At this time the capture waypoint, WPT, must be entered by keyboard. The default value of WPT is zero and the guidance system will indicate no capture until a waypoint is chosen. WPT is set to zero whenever the REFP is turned on and must be keyboard entered.

When a waypoint is selected the system predicts the aircraft position 15 seconds in the future, assuming straight constant-speed flight, and attempts to construct a horizontal flight path from that point to the capture waypoint. Failuse to find a flight path results in a "NO CAP HOR" message on the MFD. This can be corrected by changing aircraft position and heading or the capture waypoint. Any waypoint except the last one (touchdown) may be captured. A 15 second prediction is made using the current aircraft speed, heading and flight path angle at the beginning of each capture trajectory to allow time for synthesis computation, and variations in those parameters during the cycle will cause initial errors when the track mode is engaged.

When the horizontal capture path has been found, see Figure 3, a minimum-fuel speed-altitude profile is generated along the combined capture and fixed routines from aircraft to touchdown by integrating the point-mass equations of motion. Beginning at point P_2 the aircraft immediately accelerates or decelerates, at constant altitude to the "loiter" speed, LTS, input by keyboard; airspeed is then held constant until the change to the capture waypoint speed must be initiated. Figure 3 provides a graphical representation of the speed-altitude profile to the capture waypoint.

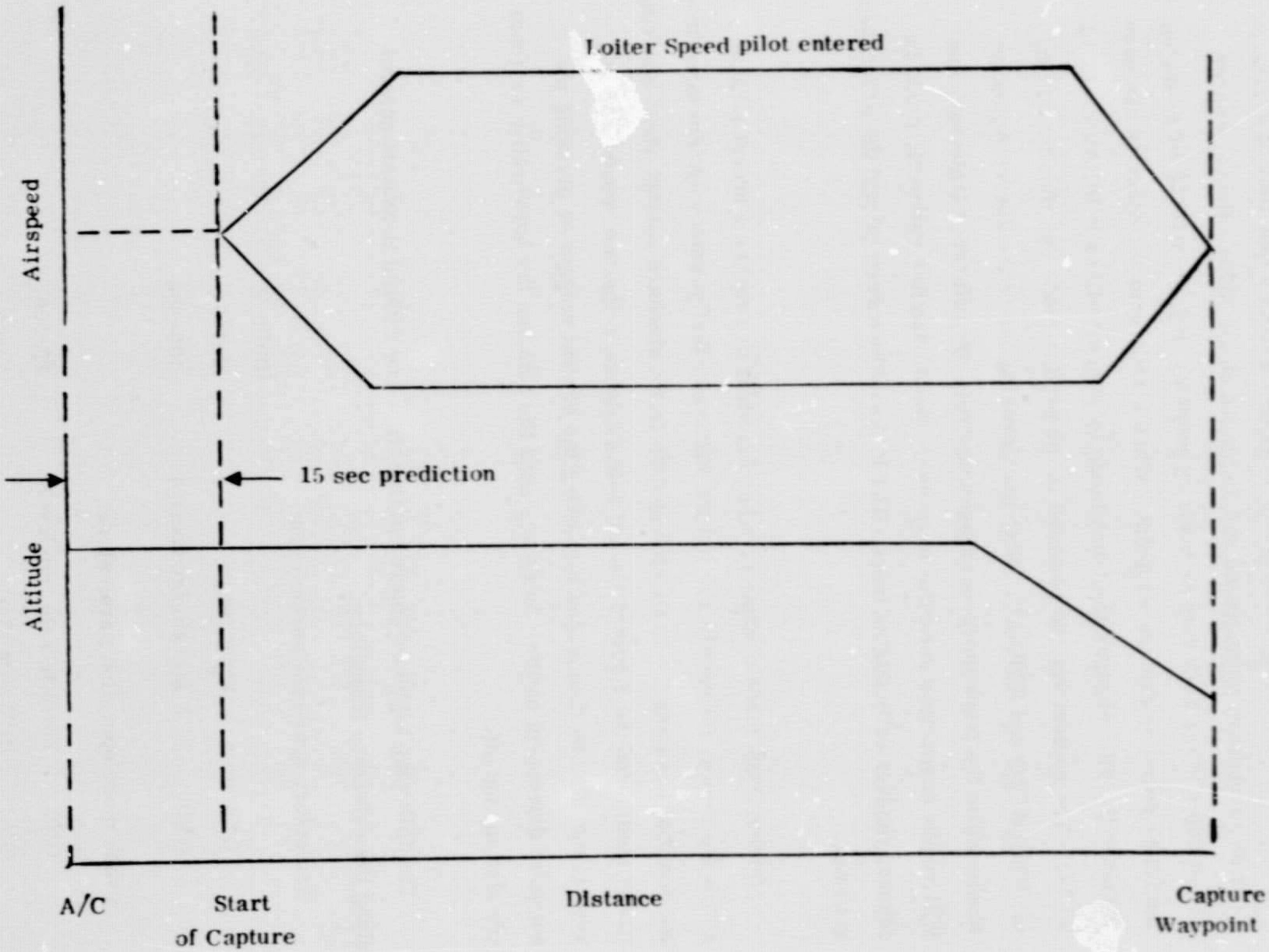


Figure 3. Typical Speed - Altitude Profile in Capture

Each time the capture trajectory is resynthesized a new time of arrival, TOA,(at touchdown) is computed and displayed on the MFD. Hence, coarse adjustments to the TOA may be made by maneuvering the aircraft or changing the loiter speed or capture waypoint. When a satisfactory trajectory has been achieved the pilot engages the track mode by pushing either HORNAV or FULL-AUTO. The system may be returned to the predict mode any time by turning off FULLAUTO and HORNAV. Note that invoking one of the Sperry Autopilot modes while the track mode is engaged destroys the reference trajectory and will result in spurious autopilot response. Should another automatic mode be invoked inadvertently during track, REFP should be turned off and the procedure repeated.

During track mode operation, when the aircraft reaches a preset altitude above the runway (presently 300 ft.) the minimum-fuel guidance system disconnects automatically leaving the STOLAND system in the standard control wheel steering (CWS) mode, and the autothrottle and auto switches in the "on" position. The system can also be disengaged by moving the control column or pressing the autopilot disconnect button. In these cases the auto and the autothrottle switches are also turned off.

The following keyboard entered parameters are related to system control along the reference trajectory.

Trajectory synthesis parameters:

		limits %
GNA	γ - V_a/g ratio	0-100
GNB	% E margin for control	100-500

Track mode operation parameters:

GNC	Throttle rate trip level	25-500
GND	RPM min bias	0-500

		limits %
GNE	Max deceleration in RFP	0-200
GNF	Nozzle monitor trip level	25-500
GNG	Δ alt feedback on pitch *100fps/V_g	0-200
GNH	$\int\Delta$ alt feedback on pitch *100 fps/V_g	0-200
GNI	θ pitch rate gain	25-500
GNJ	Nozzle feedback control factor	0-200

Control Logic

Reference flaps are determined by the optimization procedure at each point along the reference flight path. The flap command is the reference value limited to the placard value as determined from the current actual airspeed and also constrained to prevent retraction. Some combinations of capture waypoint and loiter speed may call for extension of the reference flaps followed by retraction after reaching the capture waypoint. This will result in the actual flap setting larger than the reference value and cause slowly decaying transient errors in speed and altitude. The transient is repeated at each change in command until the reference flaps increase again.

Figure 4 shows the flight envelope divided according to the use of nozzle and throttle for control. Over most of the flight envelope nozzle is used only when the throttle is at its lower limit and further reduction in $\dot{E}_n$ is called for. (For this purpose settings of 45^o or more it is actually the reference value.) However, for large reference flap settings $\dot{E}_n$ is increased by simulataneously increasing the throttle and retracting the nozzle.

The standard system stall prevention and RPM limiting routines are operative. However, the engine RPM's commanded by the minimum-fuel system are generally within the Sperry limits and no noticable effects are seen from either RPM limiting or stall prevention during normal operation. The maximum RPM algorithm has been modified as required for revised engine data.

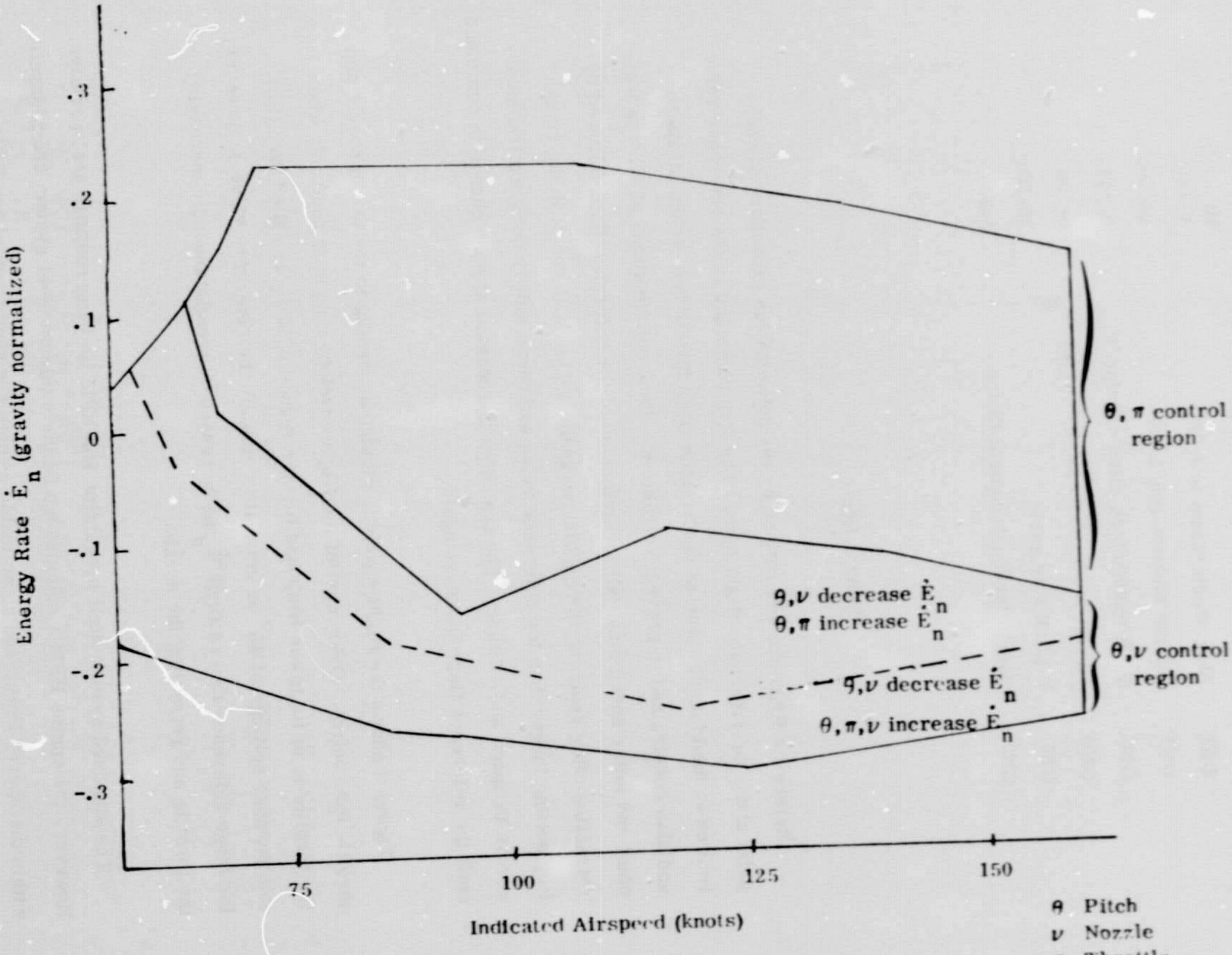


Figure 4. Use of Nozzle and Throttle for Control

The standard airspeed limit no longer has a direct connection to the throttle servo. The "Minimum Speed" and "Raise Flaps" messages are still displayed when the standard limits are encountered. The "minimum speed" message is usually on in cases where flaps are extended and there is a large negative flight-path angle. In this case the standard minimum, including bank angle protection is 3 or 4 knots higher than the reference airspeed; however, the reference conditions always meet the maneuver margin requirements.

Executive for the Airborne System

The program has been modularized to separate the capture trajectory synthesis segment of the system from the time constrained guidance and control segment. The revised avionics software utilizes existing navigation, inner loop autopilot and many automatic modes with only minor modifications. The basic capabilities removed for this application are the preflight test module and the reference flight path automatic guidance and control mode.

To provide the required real time for the Optimum profile guidance and control algorithms a new executive was incorporated in the basic program. The executive used has been tested previously in a flight environment in the Twin Otter Kalman Filter Airborne Program (Reference 4). The executive was designed to execute foreground and 4 levels of background. Foreground, a 10 Hz control module background and a far background synthesis module have been used for this application. To accommodate the levels of background, the executive is designed to save the restore interrupt locations, register values and library function parameters for each level of background. The library function parameters allow the SINCOS, ARCTAN and SQROOT to be re-entrant at any level. A macro-flow chart of the executive is presented (Figure 5). At program start initialization logic is executed. The interrupts are then enabled and the far background logic is entered.

The far background logic generates a continually updated capture trajectory to the specified capture waypoint and synthesizes this trajectory. During 'Track' mode, the far background module performs derivative calculations for the forward integration. The system performs these operations recursively using time not required to service foreground or other levels of background. The program performs far background calculations until an interrupt occurs. The

MACRO FLOW CHART

ADVANCED GUIDANCE AND CONTROL EXECUTIVE

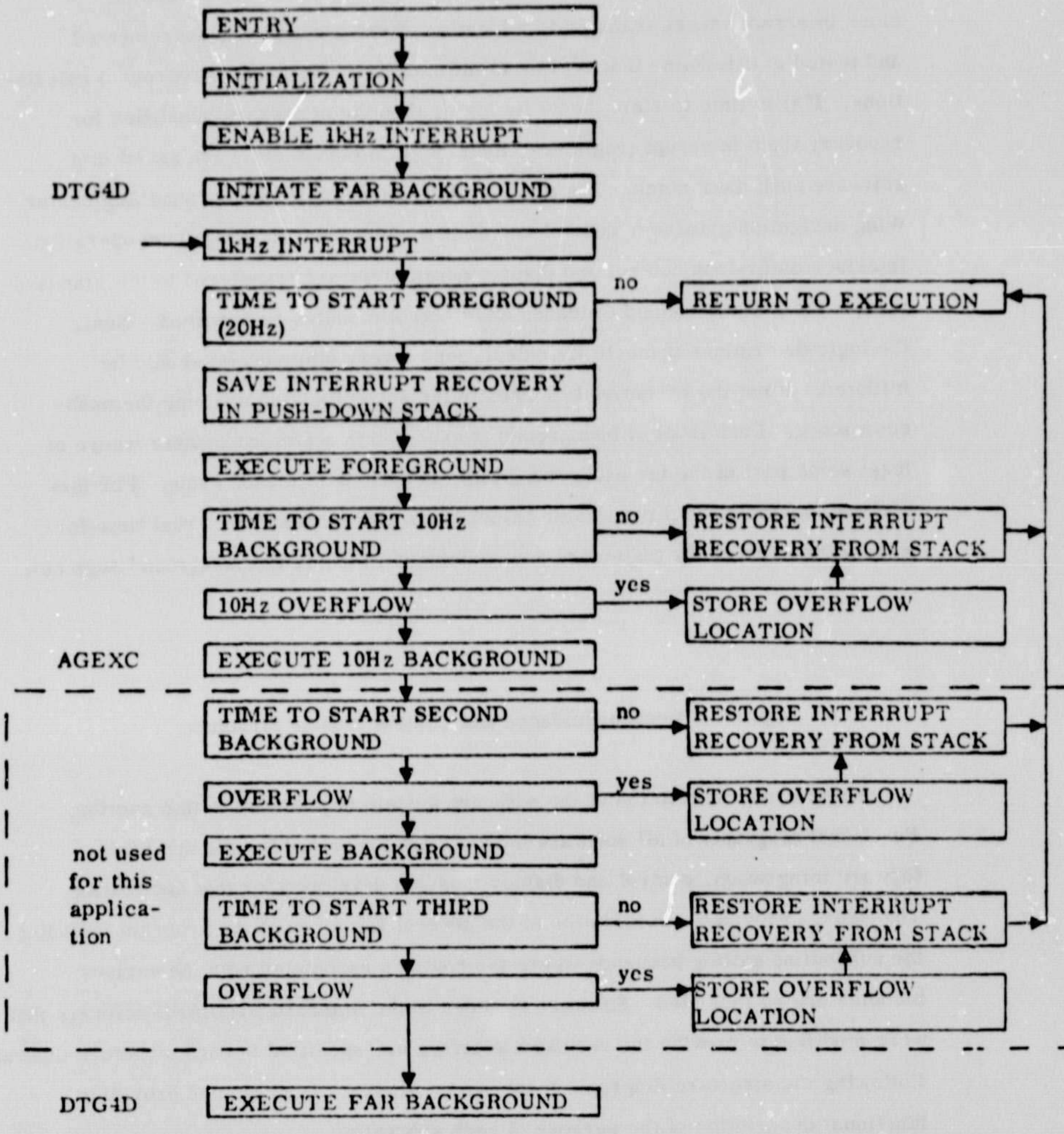


Figure 5. Advanced Guidance and Control Executive

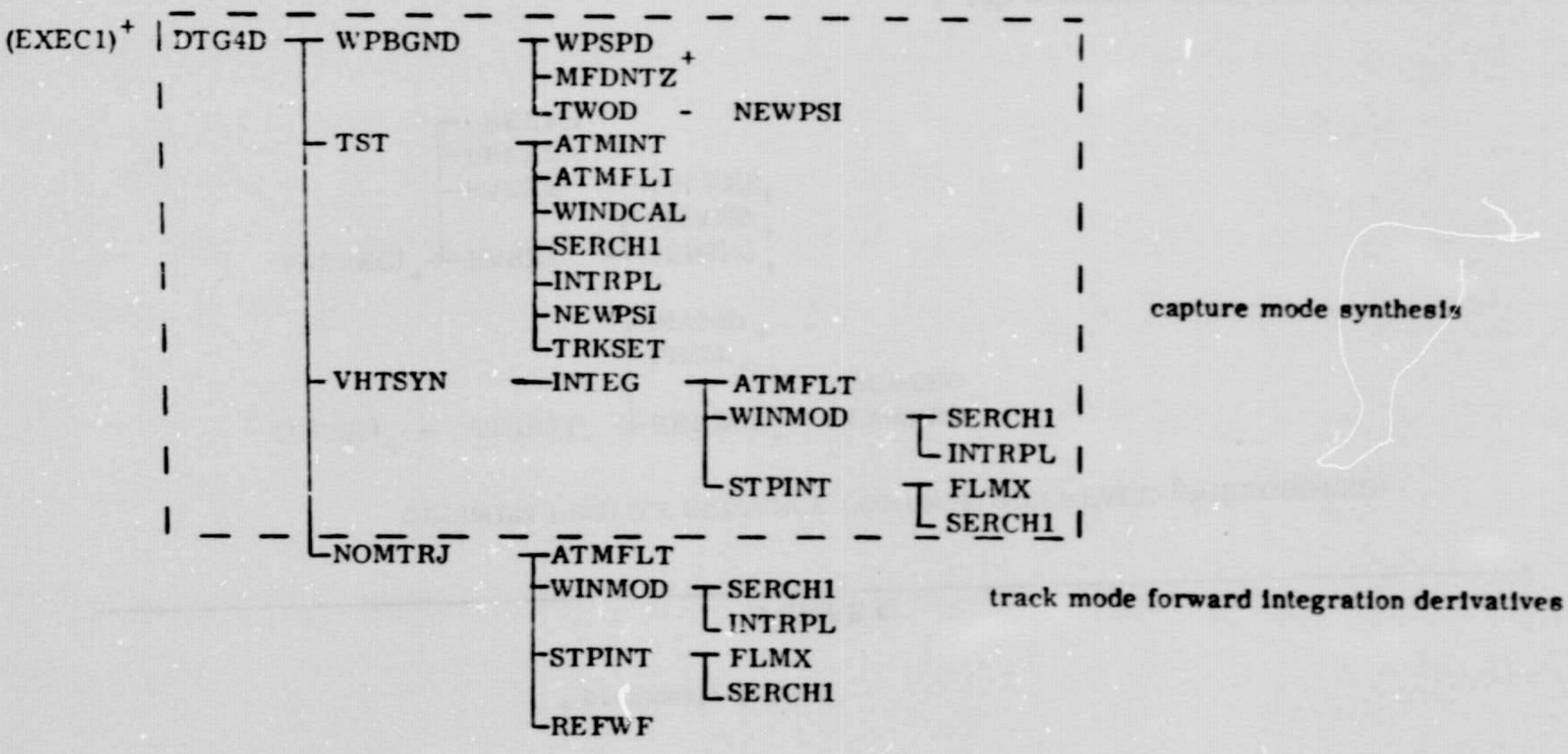
system requires several sources of interrupt, however, only the interrupts triggered by the 1kHz internal clock of the 1819A computer are presented. A clock interrupt causes transfer to a location where a counter is decremented and tested to determine if it is time to initiate the 20 Hz logic (foreground) calculations. If it is time to start the 20 Hz logic, then the necessary quantities for recovery from interrupt (registers, location at interrupt etc.) are saved in a software push down stack. The program then executes the foreground Augmentor Wing navigation guidance, control and display software. In foreground operation, interface outer-loop control and display parameters are transfered to the standard system from the Advanced Guidance and Control modules as required. Next, the logic determines if the 10 Hz calculations (every other cycle) should be initiated. If not the executive branches to the saved location utilizing the push-down stack. Each level of background is executed in a similar manner where at least some part of the far background logic is executed on each cycle. For this application, the control parameter calculations and the associated real time forward integration of the trajectory are performed in the 10 Hz background segment.

Optimum Profile Guidance and Control Module Structure

A functional description of the software system is provided in this section. Functional diagrams of all software modules are presented for the synthesis, forward integration, control and display modules developed for this application. The figures provided a description of the general structure of the program including the subroutine calling sequence where the routines associated with the various modules are so indicated. Software modules in the standard STOLAND software that were modified to provide the required interface are specified in each structure diagram. Following the structure diagrams a subroutine glossary is presented providing a functional description of the purpose of each subroutine.

OPTIMUM PROFILE GUIDANCE CAPTURE/DERIVATIVE MODULE

(EXECUTED IN FAR BACKGROUND)



trig, square root and mod function calls excluded
\+ sub-programs provided in origional avionics software
( ) interfacing sub-program

Figure 6. Capture/Derivative Module

OPTIMUM PROFILE GUIDANCE CONTROL BACKGROUND (100MS)

```
(EXEC1)+   AGEXC  ┬─CNTRLI   ┬─ARCRFT
                  │          ├─CNTRL    ┬─ARCRFT
                  │          │          ├─FLMXC
                  │          │          ├─BLIM
                  │          │          └─DSCADV
                  ├─CNTRL *  └─NOMR2     ─FLNN  — SCRCH1
                  └─NOMTR2 *
```

* previously defined

FIGURE C

OPTIMUM PROFILE GUIDANCE CONTROL INTERFACE (FOREGROUND)

```
(TASH1)+  –  JTHRTL  ┬─REFPOF+  ┬─CWSENG+
                     │          └─PCWSEG+
                     ├─LIMIT+
                     └─DIV10D+

(APEXEC)+ ┬─PAREF    ┬─GENSNC+
          │          └─PITAMS+
          ├─RAREF     ─ROLAMS+
          ├─PREFFP
          └─PREFFP
```

\+ sub-programs provided in basic avionics software

( ) interfacing sub-programs

Figure 7. Control Modules

OPTIMUM PROFILE GUIDANCE MFD DISPLAY MODULE

```
(MFDMAP)+  MSG4D  ┬ BUFSTR+
                  ├ WYPTDS ┬ TDAYET
                  │        ├ BUFSTR
                  │        ├ FRMTTM+
                  │        └ STRTER ┬ BUFSTR
                  │                 └ MINSEC  — BUFSTR
                  ├ STRWYD ┬ BUFSTR
                  │        ├ MINSEC  — BUFSTR
                  │        └ OCTBCD
                  ├ LEVELR
                  └ CAPTRJ ┬ RNYMAP+
                           ├ CTURN
                           └ LEVELR
```

FIGURE E

OPTIMUM PROFILE GUIDANCE KEYBOARD INTERFACE MODULE

```
(KEYBRD)+ ┬ FODLOD    — INKBRD+
          ├ FODDIS
          ├ LTSLOD    — INKBRD+
          ├ LTSDIS
          ├ RWTLOD    — INKBRD+
          ├ RWTDIS    — KB3SPS
          ├ EWDLOD    ┬ NUKBRD
          │           └ KERROR+
          └ (WPTLOD)  — WPENTR
```

\+ sub-programs provided in basic avionics software

( ) interfacing sub-programs

Figure 8. Display and Entry Modules

AGEXC	Optimum profile guidance 100 MS background executive. Driver for the forward integration and control sub-programs
ARCRFT	Loads and converts aircraft parameters for the autopilot control sub-program.
ARCSIN	Approximate arc sine routine. Input sine at B0, output angle in radians.
ATANA	Approximate arc tangent. Input tangent at B0, output angle in radians.
ATMFLT	Computes atmospheric parameters as a function of altitude and temperature for reference trajectory calculations.
ATMINT	Computes initialization parameters used in atmospheric calculations including temperature correction coefficient for landing airspeed calculation.
BLIM	Function to limit between input maximum and minimum values.
CAPTRJ	Generates the capture trajectory for the MFD display.
CNTRL	Calculates control parameters for the outerloop autopilot using the advanced guidance synthesis and current aircraft configuration.
CNTRLI	Provides first entry to CNTRL at Track mode initialization.
CTURN	Computes turn points for capture trajectory MFD display.
DSCADV	Descale angle for display function.
DTG4D	Advanced guidance far background executive. Driver for the trajectory synthesis during capture mode and derivative calculations for forward integration in Track mode.
EWDDIS	Provides the capability to display the values of EWA - EWG.

EWDLOD	Provides the capability to load an estimated wind profile as a function of altitude via keyboard entry (EWA - EWG)
FLMX	Function used to calculate reference value of flaps as a function of air speed.
FLMXC	Performs same function as FLMX for the 100 MS module.
FLNN	Computes a throttle fuel rate factor as a function of throttle and temperature.
FODDIS	Displays keyboard FOD mode option. FOD not currently activated.
FODLOD	Provides the capability to load the FOD mode option via keyboard. FOD not currently activated.
INTEG	Performs the altitude - speed profile integration used in the trajectory synthesis.
INTRPL	Performs a linear interpolation for a function of a single variable.
JTHRTL	Provides the interface between the advanced guidance control module and the inner loop autopilot for throttle and nozzle.
KUBICX	Performs $X^3/3$ trigonometric expansion coefficient calculation.
LTSDIS	Displays capture loiter speed via keyboard.
LTSLOP	Loads capture loiter speed (LTS).
MINSEC	Formats time parameters for MFD display (TWPT, TER).
MSC4D	Optimum profile guidance MFD display executive.
NEWPSI	Computes the turn parameters for the 2D capture trajectory. Used in initialization to compute turn parameters for the fixed trajectory.
NOMTRJ	Performs derivative calculations for the forward integration in Track mode.

NOMTR2	Performs the real time forward integration of the reference trajectory in track mode.
NTMOD	Performs angle modulation for NOMTR2.
NUKBRD	Provides keyboard entry of two parameters for wind profile entry (heading and speed).
PAREF	Pitch arming routine.
PIMOD	Performs angle modulation for far background module.
PREFFP	Performs pitch engage for the advanced guidance reference flight path mode.
RWTDIS	Displays runway temperature via keyboard.
RWTLOD	Loads runway temperature via keyboard.
SCRCH1	Performs same operation as SERCH1 for the 100 MS module.
SERCH1	Computes algebraic function used in linear interpolation.
SINCSI	Interface to re-entrant SINCOS routine with index register protection.
SINX	Approximate sine routine. Input angle in radians at B0, output at B0.
SQRTA	Interface to re-e trant SQRT routine with index register protection.
STPINT	Computes derivatives and integrates the reference trajectory a single step.
STRTER	Computes time error MFD display.
STRWYD	Displays capture waypoint parameters on MFD.
TANX	Approximate tangent routine.
TDAYET	Computes time of day for predicted arrival at runway. Used for MFD display.

TRANTM	Performs TACAN to MODILS transition.
TRKSET	Stores capture waypoint parameters into MFD waypoint array.
TST	Computes the 2D capture trajectory.
TWOD	Computes the 2D fixed trajectory.
VHTSYN	Controls the computation of the altitude - speed profile for the complete reference trajectory and loads the command table.
WINMOD	Extracts wind parameters from estimated wind table for reference trajectory.
WNDCAL	Generates estimated wind table from keyboard entered data.
WPBGND	Transfers reference flight path parameters to advanced guidance internal tables and performs initial calculations for MFD display.
WPENTR	Transfers waypoint coordinates.
WPSPD	Converts waypoint speeds to internal units and applies landing airspeed constraints where required.
WYPTDS	Displays time of arrival and time error on MFD.

Core Summary of the Airborne System

The table provided below presents a core summary of the complete system including the revised standard software and the Optimum profile guidance and control modules. The total memory storage used for the flight software is 28082 words. Total system capability is 32K words of which 2000 words are reserved for utility purposes.

The first seven sections represent the revised standard system and the final sections represent the new capability implemented.

Revised Standard System

Section	Locations	Size	Description
1	30000 - 33776	2047	Function library - Data Area
2	34000 - 37750	2025	Protected Data
3	200 - 1241	546	Executive
4	10000 - 16361	3314	Autopilot
5	20000 - 27300	3777	Data Interface
6	40000 - 47743	4068	Navigation - Displays
7	60000 - 67102	3651	MFD Display

Advanced Guidance and Control Modules

Section	Locations	Size	Description
8	1246 - 2747	834	Capture Modules
9	16400 - 17630	665	Autopilot - Control
10	27350 - 27714	229	Keyboard Entry
11	50000 - 57552	3947	Data - MFD Interface - Synthesis
12	72000 - 77642	2979	Derivative Integration

III FORTRAN SIMULATION PROGRAM (AUG4D)

Structure and Design

The final section of this report represents a current update and extension to AMA Report No. 76-19 performed under contract NAS2-9216 (Reference 5).

Modular Structure The purpose of this Fortran simulation program is to assess the performance of a fuel efficient onboard guidance system for powered lift STOL aircraft. The simulation program, resident on the Ames TSS360/67 facility, provides a test-bed for the Optimum Profile Guidance and Control Airborne System. The Optimum Profile Guidance Simulation Program, AUG4D, is a combination of a fast-time 3D guidance simulation and a 4D trajectory synthesis program developed by NASA/ARC. The program has been modularized to separate the onboard portion of the simulation as presented in Figure 9. The subroutine calling sequence is presented in Figure 10. This figure describes the general structure of the program where the routines associated with the various modules are so indicated. The display and real time data entry software provided in the avionics software has not been simulated in the FORTRAN Program.

Following this discussion a subroutine glossary is presented giving a brief description of the purpose of each subroutine. Finally, sub-program and common cross-reference tables for the complete program are presented in this section In this implementation, the common arrays have been grouped so that each labelled common is associated with a particular module. The labelled common arrays required by the flight module are indicated in the Common Array Size Requirement Table.

AUG4D MODULAR STRUCTURE

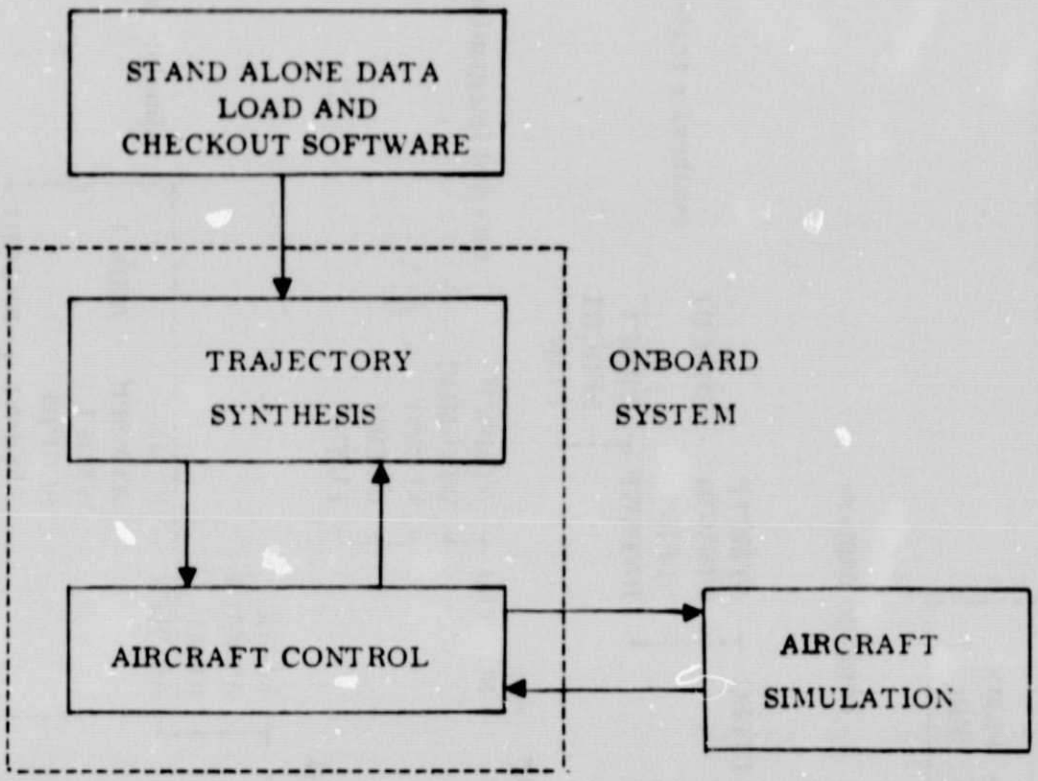


Figure 9. AUG4D Modular Structure

AUG4D FORTRAN SUBROUTINE CALLING SEQUENCE

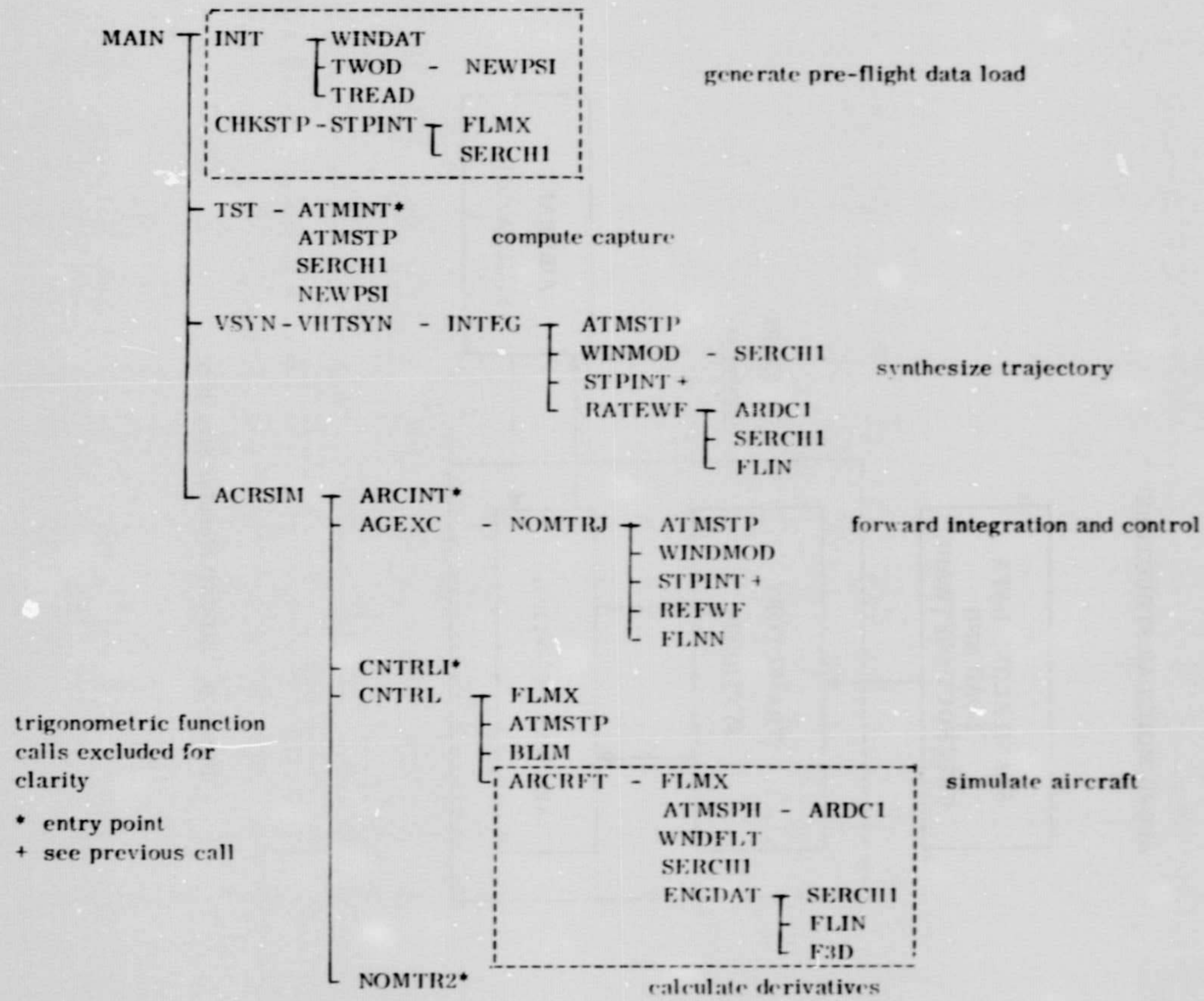


Figure 10. AUG4D Macro-Flowchart

SUBROUTINE CROSS REFERENCE TABLE

NAME	SUBPROGRAMS REFERENCING MEMBER
ACRSIM	MAIN
AGEXC	ACRSIM
ARCINT	ACRSIM
ARCRFT	CNTRL
ARDC1	ATMFLT ATMSPH RATEWF
ATMINT	TST
ATMSPH	ARCRFT
ATMSTP	CNTRL INTEG NOMTRJ TST
BLIM	CNTRL
CHKSTP	MAIN
CNTRL	AGEXC
CNTRLI	AGEXC
ENGDAT	ARCRFT
FLIN	ENGDAT RATEWF
FLMX	ARCRFT CNTRL STPINT
FLNN	NOMTRJ
F3D	ARCRFT ENGDAT
INIT	MAIN
INTEG	VHTSYN
NEWPSI	TST TWOD
NOMTRJ	AGEXC
NOMTR2	AGEXC
PIMOD	ACRSIM ARCRFT CNTRL NEWPSI TST TWOD
RATEWF	INTEG
REFWF	NOMTRJ
SERCH1	ARCRFT ENGDAT FLNN RATEWF STPINT TST WINMOD UNDFLT
SGN	NEWPSI
STPINT	ARCRFT CHKSTP INTEG NOMTRJ
TREAD	INIT
TST	MAIN
TWOD	INIT
VHTSYN	VSYN
VSYN	MAIN
WINDAT	INIT
WINMOD	INTEG NOMTRJ
WNDFLT	ARCRFT

ENTRY POINT SUMMARY

ENTRY	SUB-PROGRAM
ARCINT	ARCRFT
ATMINT	ATMSTP
CNTRLI	CNTRL
NOMTR2	NOMTRJ

Figure 11. Subroutine Cross Reference Table

```
COMMON     CROSS REFERENCE TABLE

 NAME     SUBPROGRAMS REFERENCING MEMBER
 ACDATA    ARCRFT BLK DT ENGDAT INIT
 ACFLT     ACRSIM ARCRFT CNTRL  INIT   NOMTRJ WNDFLT
 ACREF     ACRSIM AGEXC  ARCRFT CNTRL  INIT   NOMTRJ
 B1        INIT   INTEG  NOMTRJ TST    TWOD   VSYN   WINMOD
 B1A       ARCRFT INIT   VSYN   WNDFLT
 B2        ARCRFT BLK DT CHKSTP CNTRL  INIT   INTEG  MAIN
           NOMTRJ STPINT
 B3        ARCRFT INIT   INTEG  MAIN   NOMTRJ VHTSYN
 B4        ARCRFT CHKSTP INIT   INTEG  NOMTRJ STPINT
 CMFLT     ATMFLT BLK DT CHKSTP FLWN   INTEG  NOMTRJ RATEWF
           STPINT TST    TWOD
 CMFLTA    ATMSTP CNTRL  REFWF
 CONTRL    ACRSIM ARCRFT BLK DT CNTRL  MAIN
 D1        INIT   MAIN   TST    TWOD   VHTSYN VSYN
 ENDATA    ARCRFT ATMSPH BLK DT CNTRL  ENGDAT
 INOUT     ACRSIM AGEXC  ARCRFT ATMFLT ATMSPH ATMSTP BLK DT
           CHKSTP CNTRL  ENGDAT INIT   INTEG  MAIN   NOMTRJ
           STPINT TST    TWOD   VHTSYN
 INTCL     ACRSIM CNTRL  NOMTRJ
 INTG1     INTEG  VHTSYN
 STOL      CHKSTP INIT   MAIN   STPINT
 STP1      ACRSIM ARCRFT CHKSTP INTEG  NOMTRJ STPINT
 SYN       ARCRFT INIT   MAIN   NOMTRJ TST    TWOD   VHTSYN
           VSYN
```

Figure 12. Common Cross Reference Table

Subroutine Glossary

MAIN	Provides the overall control for the execution of a case
ACRSIM	Executive for the aircraft simulation
AGEXC	Executive for the forward integration and control sub-programs
ARCRFT	Aircraft simulator
ATMFLT	Evaluates the atmospheric model for the flight module
ATMSPH	Evaluates the atmospheric model for the simulation module
ATMSTP	Evaluates the atmospheric model for the onboard module
BLIM	Function to limit between input minimum and maximum values
CHKSTP	Software verification module to evaluate derivative calculations
CNTRL	Control law routine, generates commands to fly the aircraft along the reference
ENGDAT	Engine model routine used by the aircraft simulation module
FLIN	Algebraic function used for linear interpolation
FLNN	Computes fuel rate as a function of throttle and temperature
FLMX	Function used to calculate flaps as a function of speed
F3D	Algebraic function used for linear interpolation of a function of two or three variables
INIT	Controls the input of data for the preflight data load
INTEG	Determines the altitude-speed profile used in the flight module trajectory synthesis
NEWPSI	Computes the turn parameters for the 2D horizontal trajectory
NOMTRJ	Reproduces the synthesised reference trajectory in short segments using the command table
PIMOD	Function to reduce an angle to its principal value $\pm \pi$ radians

RATEWF	Computes fuel rate for the aircraft module
REFWF	Computes fuel rate for this onboard module
SERCH1	Computes an algebraic function used in linear interpolation
SGN	Function to return the sign of a real variable
STPINT	Computes the derivatives and integrates the aircraft trajectory a single step
TREAD	Controls program input of the list, drag and elevator used in the aircraft simulation module
TST	Computes the 2D capture trajectory
TWOD	Computes the 2D fixed trajectory for the pre-flight data load module
VHTSYN	Controls the computation of the altitude-speed profile for the complete trajectory and loads the command table
VSYN	Controls the computation of the minimum, maximum and nominal time trajectorys and loads the 4D tables
WINDAT	Controls the input of the wind tables
WNDFLT	Performs wind calculations for the aircraft simulation module
WINMOD	Performs wind calculations for the flight module

Program Input

In this section, the inputs and program options available through appropriate input selection are described. The inputs are conveniently divided into two groups or blocks, the pre-flight data load block read on logical units 8 and the standard input block read on unit 5. The pre-flight input block is composed principally of tabular data input via fixed formats. The pre-flight data block is not varied from case to case. The standard input block is read using the namelist feature of the Fortran language. The namelist is AUG4.

Pre-Flight Data Load Input

Data Description

HEADER (20)	Any alpha-numeric information	
	FORMAT (20I4)	
Wind Tables		
ALTW (12)	Values of altitude for the INWIND table	
	FORMAT 2(6F10.2)	
INWIND (48)	1-12 Estimated wind speeds	knots
	13-24 Estimated wind headings	deg
	25-36 Actual wind speeds	knots
	37-48 Actual wind headings	deg
	FORMAT 4(12I5)	
	The "actual" wind parameters are used in the simulation module.	
Waypoint Table		
NWPI	Number of input waypoints	
	FORMAT(I4)	

XWP	Waypoint x coordinate	ft
YWP	Waypoint y coordinate	ft
ZWP	Waypoint z coordinate	ft
R	Waypoint turning radius	ft
VNOM	Nominal waypoint speed	knots
VMAX	Maximum waypoint speed	knots
VMIN	Minimum waypoint speed	knots

FORMAT NWP1(10X,3F10.1,4F10.4)

Energy-rate Schedule Table

MINMAX	Throttle variation index limit	≤ 6
LVMAX	Speed variation index limit	≤ 6
LHMAX	Altitude variation index limit	≤ 2
LWMAX	Weight variation index limit	≤ 2
MAXCOF	Coefficient matrix index	≤ 6

The matrix index is specified from the following table:

1. Speed
2. Nozzle
3. Normalized energy rate, $\dot{E}_n$
4. Interpolation coefficients
5. Angle of attack
6. Interploation coeffients

FORMAT (5I4)

HSET(LHMAX)	Altitude table for energy-rate schedule table	ft

FORMAT (2E14.7)

WTSET(LWMAX)	Weight table for force schedule table	lbs
	FORMAT (2E14.7)	

VWHA (MINMAX, LVMAX, LHMAX, LWMAX, MAXCOF)

Force schedule matrices used to obtain nozzle, $\dot{E}_n$ and angle of attack.

FORMAT (3E14.7)

Lift and Drag Tables

NF	Flaps variation index limit	
NCJ	Cold thrust index limit	
NALFW	Angle of attack index limit	
	FORMAT (3I5)	

CLP (NF, NCJ, NALFW)

Lift coefficient table

CDP (NF, NCH, NALFW)

Drag coefficient table

DEP (NF, NCJ, NALFW)

	Elevator table	deg

Namelist AUG4

DACTS	Time step size used in the integration of the aircraft simulation equations	sec	.1
DEDS	Distance step size for the integration of the synthesized trajectory	ft	100.

DEDTK	Gain on $\Delta\gamma$ used in throttle control equation		.17
DEINTK	Gain on integral of error in speed used in the throttle control equation		.13E-2
DKX	Gain on error in altitude in control law for throttle control equation		.035
DLT	Time offset for capture initialization	sec	10.
ELMAX	Maximum limit on elevator	deg	+15.
ELMIN	Minimum limit on elevator	deg	-25.
ENAK	Gain on altitude error in nozzle control		.5
ENGK	Gain on flight path error in nozzle control		3.
ENSK	Gain in integral speed error in nozzle control		.5
ENUK	Gain on nozzle in aircraft simulation model - servo gain		1.
ENULK	Nozzle deployment lead time ratio		.5
ENUMAX	Maximum limit on nozzle	deg	104.
ENUMIN	Minimum limit on nozzle	deg	6.
ENURL	Rate limit on nozzle	deg/sec	5.
ENVK	Gain on speed error in nozzle control		5.
EPSLN	Control factor for E		1.
ETMAX	Maximum limit on E_n		1.
ETMIN	Minimum limit on E_n		-1.
FAK	Gain on flaps in aircraft simulation model - servo gain	deg	.5

FDMAX	Rate limit on flaps	deg/sec	3.5
FLK	Flap deployment lead time ratio		.5
FLMX2	Flap limit when throttle us less than 89.5%	deg	43.5
GAMK	Gain on altitude in flight path angle control		.1
GLK	Lead time ratio for flight path angle changes		.5
HAC	Initial aircraft heading	rad	*
I4D	4D control flag. Set to zero only 3D synthesis is performed		0
IOPT	Simulation control flag. Set to one generates reference and simulated actual using ACRSIM. If set to two only the reference trajectory is synthesized		1
ISCALE	Provides option to generate energy-rate schedule table file for use in onboard program		0
IPRNT	Provides detailed print of derivative parameters		2
ISTND	Provides stand alone derivative calculation capability		0
KKOUNT	Print step bypass counter in ACRSIM		20
KMODE	Aircraft simulation flag. Set to one the aircraft is simulated using ARCRFT. Set to two the simulation is bypassed		1
KPRINT	Trajectory synthesis print control. Set to zero generates most complete output		0
KSTEP	Number of integration setps using constant derivatives in generating the reference trajectory		10
NCAP	Capture waypoint index		1

PLIM	Roll rate limit	deg/sec	10.
PLK	Lead time ratio for bank angle changes		.7
PHPSK	Gain on cross track velocity error in roll equation		1.
PHYK	Gain on cross track position error in roll equation		.002
PK	Gain on roll in aircraft simulation model		1.
QLIM	Rate limit for pitch	deg/sec	5.
RQ	Fraction of energy rate allowed for control purposes		.1
RWT	Runway temperature		15.
SGMNN	Minimum limit on sine of flight path angle		-.13081
SGMXX	Maximum limit on sine of flight path angle		.13081
TANFI	Tangent of maximum bank angle		.46631
TBLSR	Energy rate schedule table temperature lapse rate	deg/ft	-.0019812
THACK	Gain on throttle in aircraft simulation servo model		1.
THARL	Throttle rate limit (not activated)	%/sec	2.
THDK	Gain on altitude error feedback in pitch control		10.
THEK	Gain in energy error in throttle equation in control law		.025
THQGK	Not activated		0.

THQK	Rate limit time constant for pitch in aircraft simulation model		10.
TIMEDA	Delay time for trajectory synthesis (not activated)		0.
TTBSL	Standard sea level temperature	^{o}K	288.5
TMPCR	Cruise temperature	^{o}C	15
VARC	Initial aircraft speed	knots	*
VGMIN	Minimum limit on true airspeed rate Gravity normalized	sec	-.05
VGMX	Maximum limit on true airspeed rate. Gravity normalized	sec	.05
VLN	Nominal aircraft loitering speed	knots	155.
VMAXN	Maximum aircraft loitering speed	knots	160.
VMINN	Minimum aircraft loitering speed	knots	150.
WGT	Aircraft weight	lbs	39000.
XAC	Initial aircraft x coordinate	ft	*
YAC	Initial aircraft y coordinate	ft	*
ZAC	Initial aircraft z coordinate	ft	*
PHLIM	Maximum bank angle allowed in control	deg	30.
DHINTK	Gain in integral altitude feedback in throttle control		.0015
THIK	Gain in integral altitude feedback in pitch control		.0035
ENHIK	Gain in integral altitude feedback in nozzle control		.04
GNUK	Nozzle control feedback factor		1.

---

* no default is provided for these parameters. They must be present in the NAMELIST input.

Namelist STPNL

Required input parameters are indicated by an *.

ALT	Aircraft altitude	ft	*
CEPS	Altitude/speed change ratio		*
COSPHI	Cosine of bank angle		
EDTMAX	Maximum change in energy rate. Gravity normalized		*
EDTMIN	Minimum change in energy rate. Gravity normalized		*
EPS	Control factor for energy rate		*
RTCFE	Temperature correction factor		*
RR	Fraction of energy rate reserved for control purposes		*
SGMX	Sine of maximum aerodynamic flight path angle		*
SGMIN	Sine of minimum aerodynamic flight path angle		*
VIAS	Indicated airspeed	ft/sec	*
VDGMX	Maximum deceleration. Gravity normalized		*
VDGMN	Minimum deceleration. Gravity normalized		*
VT	True airspeed	ft/sec	*
WT	Load factor	lbs.	*
AKW	Partial of wind speed with respect to altitude		*
KNTRJ	STPINT angle of attack computation flag		*
KSTOL	STOL mode indication		*
ALPHA	Angle of attack	deg	

ENUAC	Nozzle setting	deg	
FAC	Flap setting	deg	
SINGAM	Sine of flight path angle		
THAC	Throttle setting	%	
THMIN	Minimum throttle setting	%	
VADTG	Nominal deceleration. Gravity normalized		
VIAST	Speed criteria for flap deployment		
DEE	Total energy change on current waypoint		*
FLMX2	Flap limit when throttle is less than 89.5%	deg	*
ETMAX	Maximum limit on energy rate. Gravity normalized		*
ETMIN	Minimum limit on energy rate. Gravity normalized		*
IPRNT	Print flag for additional output in STPINT		*

Deck Setup and Machine Requirements

The AUG4D trajectory program and associated input data sets are stored at the NASA Ames Research Center TSS computing facility. The Fortran source decks are stored using standard line format. The object modules are stored as a single job library presently named TEX. Following is a typical deck setup for executing the AUG4D using the loader facility of the TSS operating system.

Program Execution

AMES USYSLIB

obtain standard atmosphere using system module ARDC1.

JBLB TEX — define job library for the AUG4D object modules

DDEF FT08F001,,AUGYDAT

define input unit for extremized force schedule table

DDEF FT05F001,,AUGFIX

define input unit for namelist AUG4 input

DDEF FT09F001,,FP4MDAT

define input unit for pre-flight data load input

DDEF FT10F001,,STPNL

define input unit for namelist STPNL

DDEF FT11F001,,DTA4D

define output unit for scaled force-schedule table used in onboard data load

All program printed output is performed on unit 6 and is printed on the installation defined standard output device.

LOAD BLCKAW$$	construct executable module
LOAD MAINAW$$	
CALL MAINAW$$	execute AUG4D

The following tables present the total machine requirements of the AUG4D program with the current TSS implementation. Since the flight module is incorporated in the Augmentor Wing STOLAND system, those associated subprograms and commons are so indicated.

Subroutine Size Requirements

	BYTES	FLT
MAINAWX$	3616	
BLCKAWX$	0	
ACRSIMX$	23936	
AGEXCX$	480	*
ARCRFTX$	5888	
ATMFLTR$	392	
ATMSPHR$	528	
ATMSTPX$	560	*
BLIMX$	280	*
CHKSTPX$	916	
CNTRLX$	2772	*
ENGDATR$	1280	
FLINR$	240	*
FLMXR$	448	*
FLNNX$	352	*
F3DR$	864	
INITX$	11784	
INTEGX$	9520	*
NEWPSIR$	1988	*
NOMTRJX$	8708	*
PIMODR$	392	*
RATEWFR$	588	*

REFWXS	512	*
SERCH1RS	516	*
SGNRS	284	*
STPINTXS	7476	*
TREAD3RS	2016	
TSTXS	3692	*
TWODXS	1316	
VHTSYNXS	4768	*
VSYNXS	2492	*
WINDATRS	2376	
WINMODRS	1284	*
WINFLTRS	1180	

*Sub-programs required in the flight module. (= 11215 words)

Common Array Size Requirements

COMMON	FLT MODULE	LENGTH (WORDS)
ACDATA		4233
ACFLT		25
ACREF	*	25
B1	*	61

B1A		61
B2	*	13
B3	*	984
B4	*	500
CMFLT	*	41
CMFLTA	*	3
CONTRL	*	19
D1	*	192
ENDATA		434
INOUT	*	120
INTCL	*	2
INTG1	*	18
STOL	*	4
STP1	*	27
SYN	*	178

* Total data arrays required in the flight module. (=2187 words)