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Carnegie-Mellon University
Software Engineering Institute

**Generic Avionics
Software Specification**

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Real-Time Scheduling in Ada Project**

December 1990

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Technical Report

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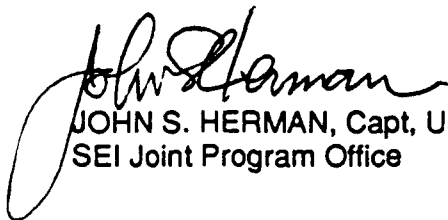
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Generic Avionics Software Specification

Abstract: This report informally specifies the general functions, data interactions, and timing constraints for a hypothetical avionics mission control computer (MCC) system. Avionics functions and equipment are described only to the extent needed to specify generic MCC behavior. The specification was developed primarily to exemplify timing requirements and functional interactions in a heavily loaded real-time system. The devices, functions, and architecture presented here were prepared for illustrative purposes and are not those of any specific military aircraft. In particular, the quantitative timing information and discussion of functional interactions is hypothetical.

The specification consists of an introductory description of the environment in which the mission computer operates followed by a functional description of the requirements imposed on the mission computer. The functional description is minimal and serves mainly to characterize computer workload and data interactions. An appendix contains a summary of the timing requirements together with an analysis of the expected CPU load for a possible attack scenario.

1. Introduction

This document presents an informal and partial specification for a hypothetical avionics mission control computer (MCC) system. Although the specification is reasonably representative of the complexity, functional load, and data handling constraints typical of a wide variety of aircraft platforms, the avionics functions and equipment are described only to the extent needed to illustrate the general nature of MCC functions. Moreover, the quantitative and qualitative information given in this report is not identical to the specifications for any actual aircraft. This information has been created to illustrate certain real-time issues that must be addressed in developing software for certain kinds of real-time systems.

This document has been produced for a project whose goal is to implement and compare several competing Ada real-time architectures, thus providing a basis for evaluating them with respect to attributes such as:

- Meeting all application time constraints.
- Encouraging correct software design and implementation.
- Facilitating a robust design in the event of new hardware or new functional requirements.
- Meeting time constraints with and without Ada run-time scheduling modifications.

The functional specification has been structured to restrict a software design as little as possible. The intent is to allow a wide variety of possible implementation approaches.

All aircraft with the equipment described in this specification could have several possible missions, such as strike, escort, interdiction, etc. The functions described here, however, are confined to those needed for a single mission, an air-to-surface attack. Furthermore, we assume that the aircraft is configured only with the specified weapons and sensors, that it has arrived at the location at which this mission is to be performed, and that it is (so far) undamaged. Thus, we do not currently plan to use this specification to investigate the effects of major mode changes due to damage or mission phase.

Although we identify a set of devices available for our hypothetical aircraft, we do not attempt to specify each completely; in particular, we omit details that are not germane to the mission defined above. For example, built-in test functionality is described only with respect to the timing requirements for determining and reporting device failures.

This specification does not identify the processor to be used, although we do assume it is a general purpose processor having a nominal performance in the vicinity of 1 million instructions per second and sufficient memory to perform the required functions. Thus problems associated with, for example, memory addressing and I/O limitations of existing avionics processors such as the AN/AYK-14 or MIL-STD-1750A, are not considered.

The remainder of this specification consists of two sections: an introductory description of the environment in which the mission computer operates followed by a description of the functions to be performed by the mission computer in that environment. Included in the functional description is the response time or periodicity requirement for each device and function together with a broad description of the information that must be handled for each function. Appendix A contains a glossary of acronyms. Appendix B contains a summary of the timing requirements together with an analysis of the expected CPU load for a particular attack scenario.

2. Typical Avionics Systems

This chapter provides an introductory discussion of MCC functions found in typical Navy/Marine Corps aircraft. Typical MCC functions include navigation, sensor control, weapons targeting and release, controls and displays management, and fault isolation test. Other specialized avionics computers (e.g., those that handle radar signal processing, dynamic air data, inertial navigation, threat warning, weapons and stores management, flight control, and display processing) are mentioned only to provide a context for the mission control computer functions.

2.1. Avionics System Structure

Combat aircraft employ a federated, distributed computer network with many specialized processors to perform avionics functions. These processors are controlled by the MCC and are interconnected by one or more serial data buses. Although the MCC is typically a single processor in existing systems, the specification in Section 3 is not intended to imply that this is a requirement. The data bus used is designed to have a unique bus controller which determines tenancy on the bus; the MCC typically is the bus controller.

Figure 2-1 is a high level block diagram for the avionics system of our attack aircraft. See Appendix A for explanations of the acronyms used. Only the most important avionics components (from the point of view of mission computer processing) are shown.

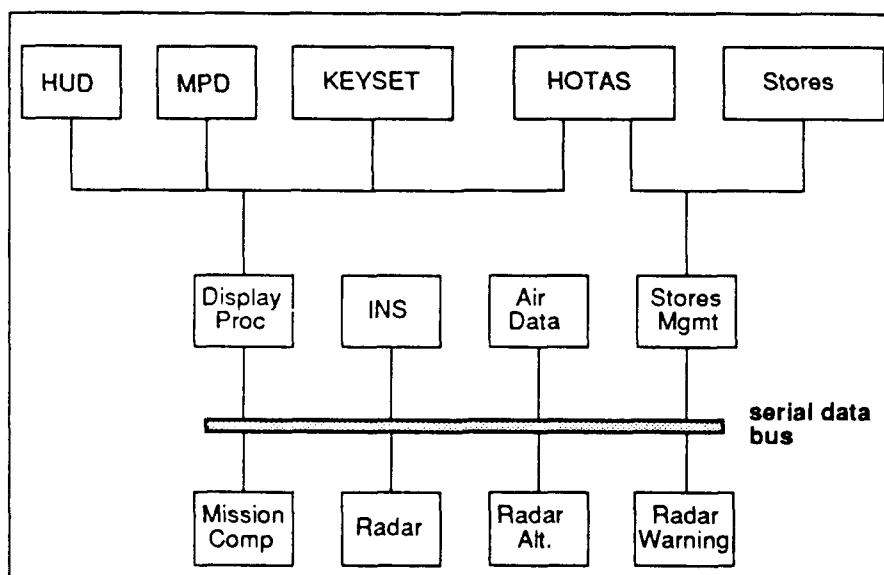


Figure 2-1: Avionics Block Diagram

The actual functions performed by the various boxes are described in the following sections. The boxes represent the following equipment:

- Display Processor (DP), which controls the following:
 - Head Up Display (HUD)
 - Multi-Purpose Display (MPD)
 - Keypad
- Inertial Navigation System (INS)
- Air Data Computer (ADC)
- Stores Management System (SMS)
- Radar
- Radar Altimeter (RALT)
- Radar Warning Receiver (RWR)
- Hands-On Throttle And Stick (HOTAS)

2.2. Controls and Displays

Controls and displays include the head-up display (HUD), the multi-purpose display (MPD), the aircrew's keypad, and the hands-on throttle and stick (HOTAS) switches. These define the man-machine interface between the aircrew and the avionics computers.

A modern combat aircraft places an enormous workload on an aircrew, particularly during the most stressful phases of a mission such as air-to-air combat or attack on a highly defended ground or surface target. Cockpit controls and displays are designed to be multipurpose, configurable, and easy-to-use. This means that most controls are software-programmable switches and most displays are computer-generated. Primary exceptions are HOTAS controls (that must be easy to reach during high-G maneuvers) and backup controls and displays for use in the event of computer failure (which we will ignore in this document).

At least two simultaneous displays are normally available. The HUD display, which is a transparent display with computer-generated images superimposed on the out-the-window view, shows aircraft flight data (airspeed, pitch ladder, heading, etc.) plus weapon aim point and/or seeker position. The MPD display usually shows the tactical situation, including threat data, superimposed on a digital moving map. The MPD can also, by aircrew selection, show a display of stores (expendables) remaining, sensor (radar) visual display information, status and warning information, or a duplicate of the HUD display.

In some current aircraft (e.g., the F/A-18) display management is done in a mission computer, but the trend is toward use of special-purpose display processors that control the HUD, MPD, and aircrew's keypad.

As shown in Figure 2-1, the HOTAS is connected both to the Display Processor and to the Stores Management System.

2.3. Sensors

Attack aircraft typically carry three types of sensors: navigation sensors, threat warning sensors, and targeting sensors.

Navigation sensors include:

- Air Data Computer (ADC): provides barometric altimeter plus dynamic and static pressure data.
- Inertial Navigation System (INS): provides aircraft position and velocity plus attitude and heading reference data.
- Radar Altimeter (RALT): provides measured height above the ground.

The Radar Warning Receiver (RWR) is a threat warning sensor that warns the aircrew of hostile radar energy being beamed at the aircraft, such as from a fire control radar or a radar-homing missile.

Targeting sensors, such as radar, provide range and angle data (including rates) of sufficient accuracy to track moving targets. Targeting sensors may be active (emitting energy, such as the radar) or passive (sensing the energy emitted from the target, such as a targeting TV video tracker). In the future, increased reliance on passive targeting is likely because of the reduced chances for enemy detection and counter-measures.

2.4. Stores

Fighter/attack aircraft can carry a number of items fastened to racks underneath the aircraft. These items are called "stores" and include weapons (bombs, rockets, missiles), extra fuel tanks, extra sensor pods, or decoys (e.g., chaff to fool radar-guided missiles and flares to fool infra-red guided missiles). The Stores Management System (SMS) manages the mechanical and electrical connections to weapons and senses their status under control of the MCC; thus all weapons are readied via the SMS.

Weapons carried may include rockets, bombs (both ballistic and radar, infra-red, or TV guided), and missiles (which are typically "fire and forget" self-guided using TV video, laser, imaging infra-red, or radar seekers). Most aircraft also have internal fuselage-mounted guns.

Weapon release modes include automatic (AUTO) and continuously computed impact point (CCIP) plus special modes for guided weapons. In AUTO mode, the MCC controls weapon release based on computed impact point, current target position, and predicted aircraft position at release. In CCIP mode, the MCC computes a predicted impact point which is displayed on the HUD, and the aircrew controls weapon release with the bomb button on the HOTAS.

Air-to-air weapons are carried only for self-defense and typically consist of guns and short range air-to-air heat seeking missiles. For the purpose of this specification (which describes only an air-to-ground attack), we restrict our weapons to six bombs.

2.5. Device Interface and Timing to the MCC

Communication to all of these devices is handled by a standard military data bus. This bus is a one megabyte per second serial network that contains a single bus controller (usually the MCC) that periodically polls each device (called remote terminals) at a rate sufficient to limit the latency of information communicated to and from the device. In no case does a device have the ability to initiate an interrupt to the MCC; all communication takes place in immediate response to bus controller (MCC) polling.

2.6. Interrupts

In many existing avionics systems, designers take great pains to avoid external interrupts to the MCC (the use of a communications bus as described in the previous section eliminates the need for most, if not all, interrupts). For other avionics systems, interrupts provide a primary mechanism to allow for asynchronous events to be provided to the MCC; devices with a need to ensure an immediate MCC response can generate an interrupt independently of the data bus. In such systems, however, care must be taken by the designer to ensure that the MCC is not given unnecessary interrupts that would interfere with the system's ability to respond to externally defined timing requirements.

Although external interrupts to the MCC are frequently not used, several types of internally generated interrupts may disrupt MCC processing. Many internal interrupts represent error conditions, such as MCC power loss or avionics serial data bus failure. Two types of internally generated interrupts are part of normal MCC processing:

1. Expiration of timing delays for scheduling both periodic and aperiodic processing.
2. Input/output completion (IOC) interrupts from the bus controller hardware.

Figure 2-2 shows clock and bus controller interrupts to the MCC central processor.

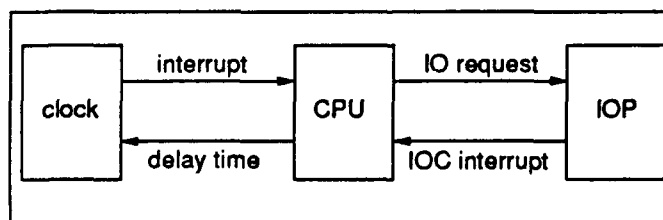


Figure 2-2: Clock and Bus Controller Interrupts

The MCC contains one or more hardware clocks to handle scheduling of periodic and aperiodic computations. Typically, these are count-down clocks. The MCC loads a time delay into the clock; the clock then counts down to zero and generates a clock expiration interrupt to the MCC main processor.

The MCC frequently contains a separate input/output processor (IOP) to handle the communications protocol on the avionics serial data bus. Messages (either outgoing data or requests for incoming data) to other avionics boxes are scheduled by the MCC software for processing on the IOP. When IOP processing is completed, the IOP generates an input/output completion interrupt to the MCC main processor.

2.7. Timing and Deadlines

The majority of avionics processing time is spent performing periodic processing; even aperiodic tasks often are done by servicing them periodically. Thus, the definition of period requirements for each function is critical to successful implementation. Processing a function at too high a rate will result in unnecessary processor utilization and can lead to processor overload. However, processing a function at too low a rate will result in not meeting significant mission requirements (e.g., navigation accuracy, human perception limits, weapon delivery accuracy, etc.).

Requirements for how frequently MCC functions need to be performed come from three sources:

1. **Hardware requirements:** for example, sensor control computations usually must be done at a rate of 20–1000 Hz to keep up with the hardware. Generally, sensor computations are done in separate sensor processors rather than in the MCC described here.
2. **Algorithmic requirements:** for example, weapon delivery computations typically need to be done at a rate of 20–40 Hz in order to maintain numerical stability. This translates directly to the accuracy with which the target may be attacked.
3. **Human factors requirements:** for example, moving symbols on displays need to be updated at a rate of 10–25 Hz to avoid the appearance of jerky screen movements. This range of update rate reflects differences in the screen and lighting characteristics of different hardware; for example, the HUD typically requires a higher update rate than the MPD. Response to aircrew keyset inputs should occur within 200 to 500 ms. to convince the aircrew that the system is still responding.

2.8. Modes of Processing

MCC processing is often organized into modes, such as navigation, air-to-ground, and air-to-air. The information content of displays differs depending on the current processing mode. Some functions may not be available in some modes. For example, release of bombs usually can be done only in air-to-ground mode. Change of mode typically changes

the period requirements of some of the computations. This specification does not, however, address mode change requirements.

3. MCC Functional Specifications

MCC primary functions can be summarized as follows:

- *Navigation*: compute current aircraft flight data based on inputs from the ADC, INS, and RALT. Provide steering cues to aircrew. Allow aircrew to update aircraft position.
- *Radar Control*: control radar mode of operation including contact management.
- *RWR Control*: "set up" sectors and frequencies for RWR operation.
- *Threat Response*: warn aircrew of threats using the MPD tactical display. Trigger automatic chaff dispensation, if selected.
- *Targeting*: designate and track the target of attack.
- *Weapons Control*: select, aim, and release weapons.
- *Controls and Displays*: handle aircrew inputs and prepare various data for display on the HUD and MPD.
- *Built-in Test*: monitor the status of the avionic system and warn aircrew of any problems or failures.

This section specifies the functions to be performed by the MCC in concert with other aircraft devices. For each function, we provide a brief description, a list of inputs and outputs, and timing and sequencing information.

3.1. Aircraft Flight Data

Inputs are processed from the ADC, INS, and RALT to determine the best available estimates of aircraft position, velocity, attitude, motion through airmass, etc. Outputs from this function are used for steering, target designation and tracking, weapon aiming, and display to the aircrew.

Timing

Aircraft flight data must be processed every 55 ms. in order to maintain aircraft parameters within tolerances. The processing takes 8 ms. to complete.

Inputs

- ADC.Angle_of_Attack
- ADC.Mach_Number
- ADC.Barometric_Altitude
- ADC.Magnetic_Heading
- ADC.True_Airspeed
- INS.Body_Rates (roll, pitch, yaw)
- INS.Acceleration (lateral, longitudinal, normal)
- INS.Present_Position (latitude, longitude)
- INS.True_Heading
- INS.Velocity (north, east, vertical)
- RALT.Radar_Altitude

Outputs

- INS.Reference_Velocity (north, east, vertical)
- NAV.Airspeed
- NAV.Rate_of_Change_Airspeed
- NAV.Position (latitude, longitude, altitude)
- NAV.Angle_of_Attack
- NAV.Attitude (roll, pitch, yaw)
- NAV.Body_Rates (roll, pitch, yaw)
- NAV.Flight_Path_Angle
- NAV.Ground_Speed
- NAV.Ground_Track_Angle
- NAV.Magnetic_Variation
- NAV.Altitude
- NAV.Velocity (north, east, vertical)
- NAV.Acceleration (lateral, longitudinal, normal)
- NAV.Wind (direction, magnitude)
- NAV.Body_to_Earth_Transform
- NAV.Body_to_Horizon_Transform
- NAV.Radar_to_Body_Transform
- NAV.Radar_to_Earth_Transform

3.2. Steering

Compute the steering cues for display on the HUD and MPD based either on waypoint steering or target attack steering. The MCC can hold up to 15 aircrew-entered waypoints (latitude, longitude, altitude) which may be used as steer-to points and as target designation points. The aircrew may also associate an offset (range, bearing) from the currently selected waypoint which is taken into account. Prior to target designation, steering cues are provided based on the currently selected waypoint (if any). After target designation, steering cues are provided based on target location relative to aircraft position.

Timing

Steering cues must be updated every 80 ms. This rate is dictated by human factors considerations for operator cueing and for aircrew response time in steering the aircraft on the correct flight path. This update takes 6 ms. to complete.

Inputs

- NAV.Position (latitude, longitude, altitude)
- NAV.Velocity (north, east, vertical)
- MPD.Waypoint_Counter
- Keyset.Waypoint_Table (latitude, longitude, altitude)
- Keyset.Offset (range, bearing)
- Keyset.Waypoint_Steering_Selected
- AG.Target_Location (range, azimuth, elevation)

Outputs

NAV.Steer_to_Point (range, bearing, time_to_go)

3.3. Radar Control

The radar operates in one of three modes: ground map, ground search, or single-target track. Ground map mode is used to display a radar view of terrain on the MPD radar display. Typically, however, this mode would be used only for terrain avoidance enroute to the target rather than during an attack phase. Ground search mode is used to detect and identify possible ground targets and/or threats (e.g., surface-to-air missile sites). In ground search mode, the radar reports contact range and bearing for up to 10 contacts. The aircrew (via the MPD) may select any one of these contacts for the radar to track. The MCC commands the radar into single-target track mode and the radar provides range, range rate, line-of-sight (LOS) angles (azimuth and elevation), and LOS angle rates to the target.

Timing

Contact range and bearing must be updated every 80 ms.; target tracking data must be updated every 40 ms. This will allow position calculations accurate enough for the weapon release algorithms. Both of these updates take 2 ms. each to complete. Response to the aircrew input to begin tracking must occur within 200 ms. of initiation and requires 2 ms. to complete.

Inputs

Radar.Mode
Radar.Contact_Table (range, bearing)
Radar.Target_Position (range, azimuth, elevation)
MPD.Contact_Number_to_Track

Outputs

Radar.Mode
Radar.Contact_Number_to_Track
Radar.Status

3.4. Target Designation

The aircrew may designate a target for air-to-ground attack in one of two ways: by radar or by HUD designate. Only one target may be designated at a time. To designate a target by radar, the radar must already be tracking a target. The radar target is identified as the ground attack target by a member of the aircrew pushing the designate switch on the HOTAS. To perform a HUD designation, the aircrew must first position the HUD reticle (on the HUD) using the target designator controller (TDC) switch on the HOTAS (the TDC switch is similar to a joystick). Once the HUD reticle is properly positioned, the aircrew pushes down on the TDC switch to designate a target. The MCC must transform the HUD

reticle position from HUD coordinates to obtain range, azimuth, and elevation to target. No matter how the target was designated, the HUD reticle changes shape to indicate that a target is designated. A designated target may be undesignated by pushing the undesignate switch on the HOTAS.

Timing

Capture of target position relative to the aircraft must occur within 40 ms. of target designation in order to provide target position accuracy sufficient for weapon employment and delivery processing. The capture of the target position takes 1 ms. to complete. Confirmation of target designation must occur within 200 ms. of initiation and requires 1 ms. to complete.

Inputs

- NAV.Aircraft_Position (latitude, longitude, altitude)
- HOTAS.HUD_Designation_Selected
- HUD.Reticle_Position (azimuth, elevation)
- HOTAS.Radar_Target_Designation_Selected
- Radar.Target_Position (range, azimuth, elevation)
- HOTAS.Undesignate_Selected

Outputs

- AG.Target_Location (range, azimuth, elevation)
- AG.Target_Location (north, east, down)
- HUD.Target_Reticle (shape)
- HUD.Reticle_Position (azimuth, elevation)
- AG.Radar_Target_Designation_Selected
- AG.HUD_Target_Designation_Selected

3.5. Target Tracking

Target tracking computations depend on how the target was designated. For a radar-designated target, the radar continues to track the target and report target location and motion with respect to the aircraft (targets not tracked by radar are assumed to be fixed on the earth's surface.) In any case, the current location of the target with respect to the aircraft is displayed on the HUD using the modified HUD reticle. For HUD designations, the aircrew may "sweeten" (i.e., improve) the target by using the TDC switch to move the HUD reticle. This causes the MCC to recompute the target's location with respect to the aircraft while continuing to track it.

Timing

Target position must be computed and/or obtained from the radar and displayed on the HUD and MPD tactical display every 40 ms. to maintain a real-time appearance to the aircrew and to avoid aircrew oversteering. The computation takes 4 ms. to complete. Sweetening of target tracking must occur within 40 ms. of initiation and requires 2 ms. to complete.

Inputs

- NAV.Aircraft_Position (latitude, longitude, altitude)
- AG.Target_Location (north, east, down)
- AG.HUD_Target_Designation_Selected
- HOTAS.TDC_HUD_Reticle_Delta (azimuth, elevation)
- AG.Radar_Target_Designation_Selected
- Radar.Target_Position (range, azimuth, elevation)

Outputs

- AG.Target_Location (range, azimuth, elevation)
- AG.Target_Location (north, east, down)
- HUD.Target_Reticle (shape)
- HUD.Reticle_Position (azimuth, elevation)

3.6. Weapon Selection

Weapon selection includes selecting the type of weapon, the number to drop, and the desired spacing on the ground. This is done by the aircrew using the MPD stores display and Keypad switches. Depending on the type of weapon selected, a default delivery mode is defined and displayed. At any time prior to weapon release, the aircrew may push the AUTO/CCIP toggle switch on the Keypad, causing the delivery mode to change from AUTO to CCIP or from CCIP to AUTO. Weapon-ready determination is also assumed to be part of this function.

Timing

Response to aircrew inputs must occur within 200 ms. Response to the AUTO/CCIP toggle must occur within 200 ms. of initiation and requires 1 ms. to complete. These response times are necessary to provide the aircrew with an appearance of instantaneous response. Weapon selection involves approximately 20 button depression invocations; each invocation takes 1 ms. to process. An additional 2 ms. is required for formatting the weapon selection response after all necessary information has been entered by the aircrew and must be completed within 400 ms.

Inputs

MPD.Weapon_Select_Request
Keyset.Quantity_Select_Request
Keyset.Interval_Select_Request
AG.Delivery_Mode_Selected
Keyset.AUTO_CCIP_Toggle

Outputs

MPD.Weapon_Selected
MPD.Quantity_Selected
MPD.Interval_Selected
MPD.Delivery_Mode_Selected
HUD.Delivery_Mode_Selected
SMS.Weapon_Selected
SMS.Quantity_Selected
SMS.Interval_Selected
AG.Delivery_Mode_Selected

3.7. Weapon Trajectory (Ballistics)

For ballistic (unguided) weapons, the MCC solves the ballistic trajectory equations of motion. This is done initially to determine weapon time of fall when the estimated time-to-go to release (based on aircraft ground speed and target ground range) is less than one minute. Initialization must be repeated if a new target is designated. Once initialized, the weapon trajectory must be computed at least every 100 ms. Outputs include time-to-go to release, weapon time of fall, down range error, and cross range error. When time-to-go to release falls below 800 ms. and AUTO delivery mode is selected, weapon release is scheduled. Thereafter, whenever time-to-go to release is recomputed, weapon release is rescheduled.

Timing

Beginning one minute before estimated time-to-go to release, the weapon trajectory must be computed every 100 ms. and takes 7 ms. to complete. Reinitialization of the ballistic trajectory must occur within 400 ms. of initiation and requires 6 ms. to complete. AUTO weapon release must be scheduled when time-to-go to release is less than 800 ms. These timing requirements are necessary to achieve accurate weapon aiming.

Inputs

- NAV.Aircraft_Position (latitude, longitude, altitude)
- NAV.Barometric_Altitude
- NAV.Aircraft_Velocity (lateral, longitudinal, normal)
- NAV.Mach_Number
- NAV.Wind (direction, magnitude)
- NAV.Angle_of_Attack
- NAV.Attitude (roll, pitch, yaw)
- NAV.Body_Rates (roll, pitch, yaw)
- AG.Target_Location (north, east, down)
- MPD.Weapon_Selected
- AG.Delivery_Mode_Selected
- SMS.Ballistic_Coefficients

Outputs

- AG.Time_to_Go_to_Release
- AG.Weapon_Time_of_Fall
- AG.Weapon_Down_Range_Travel
- AG.Weapon_Cross_Range_Travel
- AG.Weapon_Down_Range_Error
- AG.Weapon_Cross_Range_Error

3.8. Weapon Release

The behavior of this function depends on the delivery mode. In CCIP mode, a weapon release signal must be sent from the MCC to the SMS as soon as the aircrew pushes the "bomb button" on the HOTAS. In AUTO mode, a weapon release signal must be sent to the SMS as soon as the scheduled weapon release time is reached, but only if a member of the aircrew is pushing the "bomb button." For multiple weapon releases, the MCC computes the time interval between releases and sends a release signal to the SMS for each release. This occurs for both AUTO and CCIP delivery mode.

Timing

A weapon release signal must be sent to the SMS within 5 ms. of the desired release time in order to ensure the impact point on the designated target and to maintain consistency with the weapon trajectory calculation and the weapon release point calculation. Intervals between releases for multiple weapon drops will vary from 10 to 200 ms. and take 1 ms. to complete per invocation, with a maximum of up to 6 invocations (maximum of 6 bombs aboard the aircraft).

Inputs

- AG.Time_to_Go_to_Release
- AG.Weapon_Release_Interval
- AG.Delivery_Mode_Selected
- SMS.Bomb_Button_Depressed

Outputs

- SMS.Release_Signal

3.9. HUD Display

The display functions send all legends, labels, symbology, and numeric values for display on the HUD. (Normally, the aircrew can declutter the HUD by removing pre-specified parts of the display, but we ignore this here). This function also updates the HUD reticle position when an air-to-ground target is designated, and updates the CCIP symbology on the HUD when selected.

Timing

Moving symbols and numeric values must be updated at least every 52 ms. to avoid jerkiness in the display. Display update will take 6 ms. to complete.

Inputs

- NAV.Airspeed
- NAV.Position (latitude, longitude, altitude)
- NAV.Angle_of_Attack
- NAV.Attitude (roll, pitch, yaw)
- NAV.Body_Rates (roll, pitch, yaw)
- NAV.Barometric_Altitude
- NAV.Velocity (north, east, vertical)
- NAV.Steer_to_Point (range, bearing, time_to_go)
- HUD.Target_Reticle (shape)
- HUD.Reticle_Position (azimuth, elevation)
- AG.Time_to_Go_to_Release
- AG.Delivery_Mode_Selected
- AG.Weapon_Down_Range_Travel
- AG.Weapon_Cross_Range_Travel

Outputs

- DP.HUD_NAV_Data_Message
- DP.HUD_Pitch_Ladder_Message
- DP.HUD_Velocity_Vector_Message
- DP.HUD_Steering_Cue_Message (if waypoint or target)
- DP.HUD_Reticle_Message
- DP.HUD_Weapon_Release_Message (if weapon selected and target designated)
- DP.HUD_CCIP_Display_Message (if CCIP selected)

3.10. MPD HUD Display

This duplicate of the HUD display is used as a backup in case of HUD hardware failure. The HUD reticle on the MPD cannot be used for HUD designation of a target, but does represent the out-the-window position of the target if a target is designated via radar. Timing, inputs, and outputs are the same as for the HUD.

3.11. MPD Tactical Display

The MPD tactical display shows a "bird's eye" view of the tactical situation. The aircraft is fixed at the center. Radar contacts and the target are plotted by range and bearing. RWR threats are shown by bearing only. The scale of the display is variable from 1 to 100 nautical miles.

Around the edge of the MPD display are 25 buttons that are software programmable. These are used to select display options, to select waypoints, to select radar contacts, to designate the selected waypoint or radar contact, to select weapons, and to select another MPD display mode.

Timing

Moving symbology and numeric values must be updated at least every 52 ms. to avoid jitter in the display appearance. This update takes 8 ms. to complete. Response to aircrew switch selections (except to change MPD display mode) take 1 ms. to process and must occur within 200 ms. Change of MPD display mode, when selected, must occur within 200 ms. and requires 1 ms. to complete. These response times are to meet human response requirements.

Inputs

- MPD.Tactical_Display_Scale_Selected
- Radar.Contact_Table (range, bearing)
- RWR.Threat_Table (bearing, frequency)
- NAV.Position (latitude, longitude, altitude)
- NAV.Magnetic_Variation
- NAV.Steer_to_Point (range, bearing, time_to_go)
- Radar.Target_Position (range, azimuth, elevation)
- AG.Target_Location (range, azimuth, elevation)

Outputs

- DP.MPD_Tactical_Radar_Contacts_Message
- DP.MPD_Tactical_Radar_Target_Message
- DP.MPD_Tactical_Threats_Display_Message
- DP.MPD_Tactical_Compass_Rose_Message
- DP.MPD_AG_Target_Message

3.12. MPD Stores Display

The MPD stores display shows a wing platform and all the stores hung on the aircraft, as well as rounds remaining for fuselage guns. MPD buttons are used to select a type of weapon. The SMS selects the particular wing station(s) from which to release stores in order to keep the aircraft balanced. The release sequence is also shown on the MPD stores display. While the MPD stores display is selected, the aircrew may enter weapon quantity and release interval via the Keyset.

Timing

Timing regarding the stores display is specified in Section 3.6. Timing regarding selection of the display mode is specified in Section 3.11.

Responses to aircrew inputs (including selection of the MPD stores display) must occur within 200 ms. to meet human factors requirements.

Inputs

Numerous

Outputs

DP.MPD_Stores_Remaining_Message

3.13. MPD Status Display

The MPD status display shows the status of all aircraft avionics devices. Results from built-in test (BIT), covered in Section 3.17, are part of the MPD status display. As described in Section 3.17, if BIT detects equipment failure while the MPD status display is not selected, a warning legend is flashed on both the HUD and the MPD for 2 seconds. If BIT failure is detected while the MPD status display is selected, a warning legend is still flashed on the HUD, but not on the MPD; the status line for the failed equipment flashes in reverse video.

Timing

BIT status display updates take 2 ms. to process. (This is in addition to the 5 ms. to perform the BIT calculations as specified in Section 3.17.) For normal BIT, the status display must be updated at least every second. For BIT failure warnings, the reversed video status must be displayed within 200 ms.; selection of reversed video display mode is assumed to take no additional processing time.

Inputs

MCC.Status
ADC.Status
INS.Status
SMS.Status
Radar.Status
RWR.Status
RALT.Status

Outputs

DP.MPD_Periodic_BIT_Message

3.14. Keypad and HOTAS

Aircrew inputs are provided by both the Keypad and the HOTAS. Of the various buttons and switches on the HOTAS, three are considered in this specification:

- Bomb button: the aircrew pushes this button to release the selected weapon (see Section 3.8).
- Target Designator Controller (TDC): the TDC or slew control is used to move the target designator (TD) symbol around on the HUD and to designate a target as described in Section 3.5.
- Undesignate button: the aircrew pushes this button to cancel a target designation.

The Keypad consists of two components: the keypad for entering position updates, weapon quantity and interval, and other numeric data, and the options-display, which consists of buttons with software-programmed labels. The Keypad is used as an aircrew input device for many functions, including:

- Waypoint/offset entry (not a part of this specification)
- Weapon programming
- Delivery-mode toggle
- Radar Warning Receiver programming

Timing

To meet human factors requirements, response to aircrew keypad input must occur within 200 ms. for most inputs. Each response takes 1 ms. to complete with a maximum of 10 keypad inputs per second.

For the HOTAS, the target designation response must occur within 40 ms. and requires 1 ms. to complete. The response to pushing the bomb button must occur within 40 ms. of initiation and requires 1 ms. to complete. This is in addition to the weapon release processing described in Section 3.8.

Inputs

- DP.Keyset_RWR_Program_Message
- DP.Keyset_Weapon_Program_Message
- DP.Keyset_Target_Designation_Message
- DP.Keyset_Delivery_Mode_Toggle_Message

Outputs

- Keyset.Waypoint_Table (latitude, longitude, altitude)
- Keyset.Waypoint_Offset (range, bearing)
- Keyset.Waypoint_Steering_Selected
- Keyset.Quantity_Select_Request
- Keyset.Interval_Select_Request
- Keyset.AUTO_CCIP_Toggle
- Keyset.RWR_Frequency_Table
- Keyset.RWR_Search_Sector_Table

3.15. RWR Control

The Radar Warning Receiver (RWR) consists of numerous radar receptors scattered about the aircraft connected to a special-purpose computer which analyzes any radar receptions to determine the frequency and the estimated bearing. The RWR reports contacts only for those frequencies and in those sectors requested by the aircrew via the MCC. This function accepts aircrew inputs and "programs" the RWR.

Timing

Programming of the RWR must be completed within 400 ms. of completion of aircrew inputs. During RWR programming, response to aircrew key pushes must occur within 200 ms. to meet human factors requirements. Each response to a button depression requires 1 ms. to complete with 20 button depressions required to program the RWR. Two additional milliseconds are required to format the messages to be sent to the RWR.

Inputs

- Keyset.RWR_Frequency_Table
- Keyset.RWR_Search_Sector_Table

Outputs

- RWR.Threat_Radar_Frequency_Message
- RWR.Threat_Search_Sector_Message

3.16. RWR Threat Response

When the RWR detects radar energy in one of the frequency ranges and within one of the sectors selected by the aircrew, it notifies the MCC, which must generate a warning to the aircrew and also update the MPD tactical display.

Timing

The MCC must poll the RWR every 200 ms. to determine if any threats have been detected at the specified radar frequency bands and within the designated search sectors. Two ms. are required to poll the RWR. If any threats have been detected, the selected threat response must occur within 100 ms. of initiation and requires 3 ms. to complete. These timing requirements are necessary to allow for human response to the possible threat, to ensure threats are not lost, and to account for processing time for an appropriate response consistent with the threat.

Inputs

RWR.Threat_Table (bearing, frequency)

Outputs

SMS.Stores_Select
SMS.Stores_Release
MPD.Threat_Warning
HUD.Threat_Warning

3.17. Built-In Test

The built-in test (BIT) function periodically queries each aircraft device and analyzes responses to determine if a failure has occurred. Results are displayed as part of the MPD status display. If BIT detects equipment failure while the MPD status display is not selected, a warning legend is flashed on both the HUD and the MPD for 2 seconds.

When the MPD status display is selected, the aircrew may request additional tests for a particular device. Results from this additional testing, called initiated BIT, are displayed on the MPD status display.

Timing

BIT is performed every second and takes 5 ms. to complete. BIT results must be displayed within 400 ms. of initiation. The flashing display warning of device failures or degradations must occur within 200 ms. of detection and is assumed to take no additional processing time. These timing requirements are necessary to meet human response requirements.

Initiated BIT normally takes less than 10 ms. per request, including display processing. The results must be displayed within 800 ms. of initiation.

Inputs

Equipment status message

Outputs

MCC.Status

ADC.Status

INS.Status

SMS.Status

Radar.Status

RWR.Status

RALT.Status

DP.MPD_Error_Advisory_Message

DP.HUD_Error_Advisory_Message

Appendix A: Acronyms

ADC	air data computer
AG	air-to-ground
AUTO	automatic delivery mode
BIT	built-in-test
CCIP	continuously-computed impact point
CPU	central processor unit
DP	display processor(s)
HOTAS	hands-on throttle and stick
HUD	head-up display
INS	inertial navigation system
IOC	input/output completion interrupt
IOP	input/output processor
Keyset	aircrew's MCC control switches
LOS	line-of-sight
MCC	mission control computer(s)
MPD	multi-purpose display
RALT	radar altimeter
RWR	radar warning receiver
SMS	stores management system
TDC	target designator controller

Appendix B: Functional and Timing Summary

The following table summarizes the functions and timing information provided in the specification. Utilizations in this table are rounded up to the nearest thousandths to guard against underestimation of the utilization implied for a 1 MIPS processor. The total workload for all functions exceeds 100% for several reasons:

1. It is possible for the aircrew to overload the MCC by requesting too much processing; when that occurs, less important workload must be shed to guarantee deadlines for more important workload. Table B-1 indicates the relative importance of different functions.
2. Normally only a few of the many possible aperiodic tasks are performed at any one time. For example, of the MPD display functions (HUD, tactical, status, and stores), at most one can be selected at any given time. Moreover, depending on mission phase, some functions are more likely to be performed than others. Table B-1 indicates the likelihood that each function will be performed during the weapon delivery phase of the mission. In calculating the total worst-case workload, we have included only those functions characterized as "certain", "likely", or "possible".

The following scenario specifies indirectly which functions need to be performed during the weapon delivery phase of a mission.

A fighter/attack aircraft is making an air-to-ground attack on a heavily defended ground target with ballistic weapons, using a video TV sensor for targeting. All keyset entries needed to select the weapon, the weapon delivery mode, the target, and the targeting sensor have been made. No more keyset entries are expected. The only aircrew input is via the HOTAS bomb button and the HOTAS target designator control (TDC).

The TV sensor is locked on and tracking the target. As the aircraft nears the target, the aircrew will "sweeten" the target by adjusting the TDC symbol on the HUD. This will probably happen three times to get the TDC symbol exactly on target. ("Sweetening" will precede weapon release.)

Since the target is heavily defended, the aircrew initiates the radar warning system and selects AUTO delivery mode. The aircrew will follow the steering cues on the HUD to the weapon release point computed by the MCC. Weapon release is triggered by the MCC, but only if the HOTAS bomb button is depressed. The "bomb button" task then runs, followed by a train of six "weapon release" actions (one for each of six bombs). The minimum release interval is assumed to be 10 ms. However, the weapon release calculation must complete within 5 ms. after each initiation to ensure accurate delivery (a "jitter" requirement).

Immediately after weapon release, the target defenses fire surface-to-air missiles at the aircraft, triggering the threat display and response.

Given this scenario, we can reasonably assume that the following functions have already been performed before the weapon delivery phase: target designation and confirmation, weapon selection, initialization of trajectory computation, MPD status display, requests for

additional built-in test for questionable components, all necessary keyset processing, and RWR programming. The only aperiodics expected to occur during weapon delivery are: target sweetening, weapon release (six times), and bomb button. Others are possible, but not expected: AUTO/CCIP toggle, trajectory reinitiation, and BIT failure warning.

The total worst-case workload during the weapon delivery phase is summarized below, based on the information in Table B-1.

	Periodic	Aperiodic	Total
critical	0.541	0.110	0.651
essential	0.280	0.015	0.295
background	0.005		0.005
Total	0.826	0.125	0.951

Sec. Function	CPU	Period	Deadline	Importance	Likelihood	Util.	Class ¹
Navigation							
3.1 Aircraft flight data	8 ms.	55 ms.		critical	certain	.146 ²	CP
3.2 Steering	6	80		critical	certain	.075	CP
Radar Control							
3.3 Radar search or	2	80		critical	unlikely		
Radar tracking	2	40		critical	likely	.050	CP
Initiate tracking	2		200	essential	unlikely		
Targeting							
3.4 Designate target	1		40	critical	unlikely		
Confirm designation	1		200	critical	unlikely		
3.5 Target tracking	4	40		critical	certain	.100	CP
Target sweetening	2		40	critical	likely	.050 ³	CA
Weapon control							
3.6 Input for weapon selection	1		200	essential	unlikely		
Weapon selection processing	2		400	essential	unlikely		
AUTO/CCIP toggle	1		200	critical	possible	.005 ³	CA
3.7 Weapon trajectory	7	100		critical	certain	.070	CP
Reinitiate trajectory	6		400	essential	possible	.015 ²	EA
3.8 Weapon release	1	10	5 ⁴	critical	certain	.100 ⁵	CP
Controls and Displays							
3.9 HUD display	6	52		essential	certain	.116	EP
(assuming AUTO-delivery)							
3.10 MPD HUD display	6	52		essential	unlikely		
3.11 MPD tactical display	8	52		essential	likely	.154	EP
MPD button response	1		200	background	unlikely		
Change display mode	1		200	background	unlikely		
3.12 MPD stores display	(see 3.6, above)						
3.13 MPD status display	2	1000		background	unlikely		
BIT failure warning	(see 3.17, below)						
3.14 Keypad response	1	100	200	background	unlikely		
HOTAS designation	1		40	critical	unlikely		
HOTAS bomb button	1		40	critical	certain	.025 ³	CA
3.16 Threat response display	(see 3.16, below)						
RWR Control							
3.15 RWR program input	1	100	200	background	unlikely		
RWR programming	2		400	background	unlikely		
Threat response							
3.16 Poll RWR	2	200		essential	likely	.010	EP
Threat response display	3		100	critical	likely	.030 ³	CA
Built-in Test							
3.17 Periodic BIT	5	1000	400	background	certain	.005 ⁵	
BIT failure warning			200	essential	possible		
Initiated BIT	10		800	background	unlikely		

¹Note: CP indicates a critical periodic task; CA, critical aperiodic; EP, essential periodic; and EA, essential aperiodic.

²Note: rounding is always to the next higher number since we must not underestimate utilization.

³Note: Aperiodic workload during the weapon delivery phase.

⁴Note: Weapon release executes, when active, at a 10 ms. maximum rate with a jitter requirement to complete within 5 ms. of initiation of each period.

⁵Note: Utilization is based on the period, not on the deadline.

Table B-1: Summary of Timing Data

8a. NAME OF FUNDING/SPONSORING ORGANIZATION SEI JOINT PROGRAM OFFICE		8b. OFFICE SYMBOL (If applicable) ESD/ AVS	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F1962890C0003	
8c. ADDRESS (City, State and ZIP Code) CARNEGIE MELLON UNIVERSITY PITTSBURGH, PA 15213		10. SOURCE OF FUNDING NOS.		
11. TITLE (Include Security Classification) GENERIC AVIONICS SOFTWARE SPECIFICATION		PROGRAM ELEMENT NO. 63752F	PROJECT NO. N/A	TASK NO. N/A
12. PERSONAL AUTHOR(S) C. Douglass Locke, David R. Vogel, Lee Lucas, and John B. Goodenough				
13a. TYPE OF REPORT FINAL	13b. TIME COVERED FROM _____ TO _____	14. DATE OF REPORT (Yr., Mo., Day) December 1990	15. PAGE COUNT 35	

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) avionics real-time software specification
FIELD	GROUP	SUB. GR.	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report informally specifies the general functions, data interactions, and timing constraints for an avionics mission control computer system typical of those found in some existing U.S. Navy/Marine Corps aircraft. Avionics functions and equipment are described only to the extent needed to specify MCC behavior, with primary emphasis being given to timing constraints and data interactions. The specification is intended to allow a wide variety of possible implementation approaches and was developed primarily to exemplify timing requirements and functional interactions in a typical real-time system.

The specification consists of an introductory description of the environment in which the mission computer operates followed by a functional description of the requirements imposed on the mission computer. The functional description is minimal and serves mainly to characterize computer workload and data interactions. An appendix contains a summary of the timing requirements together with an analysis of the expected CPU load for a particular attack scenario.

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