F-15 Computational Subsystem

T. V. McTigue*
McDonnell Aircraft Company, St. Louis, Mo.

A description of the computational subsystem used in the F-15 air superiority fighter is presented. The consolidated design approach is discussed in which the computational tasks are divided between the central computer and sensor computers. The salient features of the central computer hardware and software design are described. Finally, the multiplex communications system between the central computer and the interfacing peripheral avionics equipment is discussed.

Introduction

THE purpose of the F-15 weapon system is to deliver air-to-air and air-to-ground weapons on targets that must be detected, identified, acquired, tracked, and destroyed by the pilot using sophisticated sensors and weapons. In the course of an F-15 mission, millions of split-second computations and decisions must be made within the aircraft. The pilot, in addition to flying the aircraft, must monitor the instruments constantly and interpret the readings to insure that the weapon system can accomplish its purpose. The minimization of pilot workload was a prime goal in the design of the F-15. Every decision that could be removed safely from the pilot's tasks was incorporated in a highly integrated computational subsystem. The operations within the subsystem are still at the pilot's command, but he is able to perform his primary tasks with confidence based on reliable, real-time operation of his computational subsystem.

The computational subsystem consists of a single central computer and several smaller computers in various sensor and display equipment, as shown in Fig. 1. The central computer, which employs the IBM Advanced Processor-1 (AP-1) computer, integrates the overall operation of the avionics. The operational flight program (OFP) for the central computer was developed by McDonnell Aircraft Company and was flight-tested and qualified by both McDonnell and Air Force pilots at Edwards Air Force Base in California.

Division of Computational Tasks

To satisfy the primary requirement of the F-15 to provide accurate air-to-air and air-to-ground weapon delivery during all weather conditions under one-man operation, numerous and varied computational tasks are required. Once these tasks are specified, a major design decision is required to determine the partitioning of the functions within the computational subsystem.[1]

The F-15 computational tasks fall into two general categories: 1) sensor-oriented computations, and 2) mission-oriented computations. Sensor-oriented computations are those independent computations, such as sensor coordinate transformations, platform management, and signal processing, which are peculiar to a particular sensor or display and are not dependent on information from other sensors. Mission-oriented computations, such as weapons launch calculations, are related directly to performing the mission and are dependent on the integration of information from several avionics subsystems. Table 1 shows typical examples of the two categories of computations.

Presented as Paper 75-590 at the AIAA Digital Avionics System Conference, Boston, Mass., April 2-4, 1975; submitted May 14, 1975; revision received Dec. 15, 1975.

Index category: Aircraft Subsystem Design.

*Subsystem Manager.

Table 1 Computational categories

Sensor-oriented
Air data calculations
Radar signal processing
Inertial platform management
CRT display symbol generation
Mission-oriented
Air-to-air steering and launch for guns and missiles
Air-to-ground steering and release for bombs, rockets, guns, and missiles
Selection of "best available" among various sensors
Integrated display management

The F-15 computational subsystem is partitioned accordingly as a "consolidated" computer configuration, in which the "mission-oriented" computations are performed in a central computer and the "sensor-oriented" computations are performed in special processors in the various sensor and display equipment.[2] This approach offers functional modularity of the sensors, whereas system integration is provided by the central computer. Hence, improved sensors and displays can be added to the avionics system, and present ones can be changed with minimum impact on other equipment. Likewise, if the armament is altered for new or different weapons as the mission of the aircraft is enlarged, changes in delivery computations need be made only to the central computer software.

Central Computer Hardware

The F-15 central computer (CC), designated the CP-1075/AYK, uses the IBM AP-1 computer. It is a high-speed, general-purpose digital computer specifically designed to meet the real-time requirements of the F-15 aircraft. The CC has completed formal qualification testing to Mil Standard 810B and reliability testing to Mil Standard 781B. It has proven itself flightworthy in over 16,000 flight hours at Edwards, Luke, and Langley Air Force Bases.

The computer consists of three major functional sections: 1) central processing unit (CPU), 2) memory, and 3) input/output (I/O). These functional sections are implemented by means of 12 plug-in modules and a single plug-in modular power supply contained in one line replaceable unit (LRU) weighing about 40 lb and occupying less than 0.9 ft^3. Table 2 summarizes the salient features of the computer.

Central Computer Software

The operational flight program is partitioned by functional tasks into eight software modules: executive, air-to-air, air-to-ground, navigation, flight director, controls and displays, computer self-test, and math subroutines. Figure 2 is a block diagram of the OFP showing its modular organization.

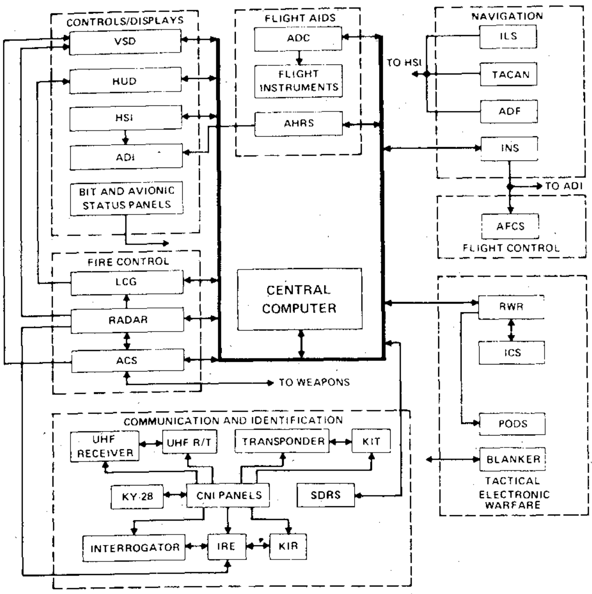

Fig. 1 F-15 avionics simplified block diagram.

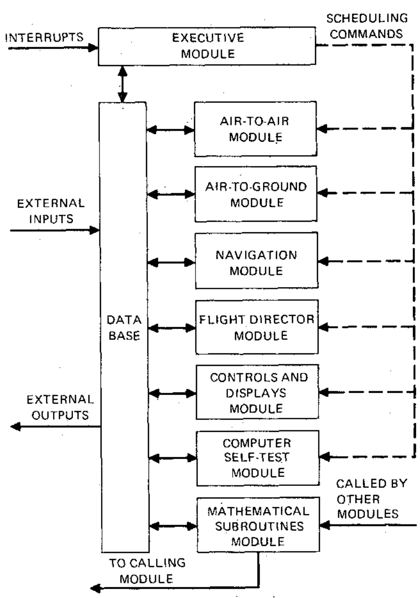

Fig. 2 Central computer software internal modular design.

Executive Module

The executive program module imposes order and structure on the entire F-15 operational flight program. All functional program modules are processed under executive control, which sequences them in an appropriate flow and calls them at a rate consistent with their requirements. Since the executive is the most frequently executed program and yet does not perform any mission function directly, it was designed to meet four basic criteria. First, it must be as straightforward and uncomplicated as possible and yet adequately perform its assigned tasks. Second, it must execute in a minimum amount of time. Third, it must occupy as little memory space as possible. Fourth, it must remain flexible to permit growth in the tasks it performs, growth in the number of functional modules it schedules, and changes in the rates at which it schedules the modules.

Four major tasks are performed by the executive module. First, it initializes the CC after start-up or after restart from a power interruption. Second, it schedules the order and rate of execution of each functional module. Third, it schedules the order and rate of input/output operations for each module.

Table 2 Central computer characteristics

Type and organization	General-purpose, stored program, parallel, binary, fixed-point, fractional, two's complement		
Storage	16,384 words, 32 bits/word + 2 bits parity, nonvolatile, random access, 2½ D magnetic core, 1-μsecs cycle time, 16-bit addressable; internal expansion capability of an additional 8192 32-bit words		
Instruction execution rate	300,000 to 400,000 operations/sec, depending on instruction mix		
Input/output	4 independent multiplex channels (serial, 16 data bits plus 1 bit parity, transformer-coupled, 1 MHz, 45,000 words/sec/channel)		
Interrupts/clocks	4 external, 12 internal; 3 programmable clocks		
Execution times (typical, μsec)		Memory	Register
	Load	2.2	1.5
	Store	2.2	...
	Add	2.2	1.5
	Multiply	7.0	6.2
	Divide	11.0	10.2
	Shift (3 bits)	...	2.2
	Branch	1.5	1.2

Fourth, it controls the servicing of all interrupts, external and internal.

Air-to-Air Module

The air-to-air module performs the following functions: 1) in the automatic mode, initializes the radar air-to-air search pattern based on the weapon selected: 20-mm gun, AIM-9E and AIM-9L Sidewinder short-range missiles, or AIM-7F Sparrow medium-range missile; 2) computes minimum and maximum launch ranges, and steering cues for each missile; 3) for the gun, calculates a disturbed reticle for the target tracking to insure accurate delivery; 4) provides a special steering mode to achieve a specific geometric relation to the target/tanker aircraft to aid the pilot in visually identifying it; and 5) controls head-up display (HUD) and vertical situation display (VSD) symbology as a function of sensor tracking status and weapon selected.

Air to Ground Module

The air-to-ground module performs the following functions: 1) provides logic to assist the pilot in designating ground targets using both radar and visual means; 2) automatically positions the radar antenna to maintain track of preplanned or pilot-designated ground targets; 3) calculates ballistic release times to maximize weapon effectiveness based on the selected weapon; 4) calculates steering cues to aid the pilot in flying the correct release path and in reattacking the target; 5) manages the displays for target designation, attack steering, and weapon release cues; and 6) manages a special clock-driven interrupt to issue weapon release pulses at the correct delivery times and intervals.

Navigation Module

The navigation module performs the following functions: 1) selects/calculates the best available attitude, heading, velocities, and position, based on sensor availability and pilot selection, for use by other program modules and for transmission to other avionics subsystems; 2) stores and recalls the coordinates of targets, destinations, identification points, and TACAN stations; 3) calculates relative position for steering to prestored destinations or targets; 4) provides logic and calculations to update velocities based on Doppler radar measurements, and to update position based on visual, radar, and TACAN information; 5) records, on pilot request, current aircraft or target position for later reference; and 6) services the navigation control panel displays and pilot data entries.

Flight Director Module

The flight director module performs the following functions: 1) calculates the range, bearing, command heading, and steering error for the selected destination, target, and TACAN station for display on the horizontal situation indicator; and 2) calculates bank steering commands to fly to the selected destination, target, and TACAN station, and pitch and bank steering commands to fly instrument landing approaches, for display on the HUD and attitude director indicator.

Controls and Displays Module

The controls and displays module performs the following functions: 1) unpacks and reformats control inputs to the CC, for use by other program modules (where inputs are not currently available, they are set to predetermined states); 2) monitors, stores, and recalls the selection of weapon release parameters for preplanned air-to-ground missions; 3) automatically controls the HUD camera to record gun and missile firings; 4) calculates symbol positioning based on data from other modules and equipment, and packs and reformats the on/off status of HUD and VSD symbology; and 5) packs documentary data for an onboard recording subsystem.

Computer Self-Test Module

The computer self-test module performs the following functions: 1) immediately after computer turn-on, tests those functions of the CC CPU, memory, and I/O which, when tested, interfere with normal computer operation, including tests of hardware clocks, interrupts, and parity checking circuitry; 2) periodically tests those functions of the CC CPU, memory, and I/O which, when tested, do not interfere with normal computer operation, including instruction execution, register and memory addressing, storage, recall, memory checksum, and I/O control and timing, as well as performing an end-to-end check of the capability of the CC to communicate with each peripheral; 3) maintains error information for later maintenance action; and 4) latches LRU fault indicator, and sets CC go/no-go status signal as required.

Mathematical Subroutines Module

The mathematical subroutines module supports the other program modules by providing common mathematical routines such as trigonometric, logarithmic, and matrix operations.

Central Computer Multiplex System

Digital data between the central computer and the peripheral avionic components is transmitted over the CC-controlled multiplex buses. Each bus is operated as a half duplex channel (two-way transmission, but not simultaneously) using word-serial, bit-serial, time-division format. All transmissions are formatted into standard messages. The CC initiates each message transmission by sending a select word that identifies the message, the number of data words, and the peripheral involved. Each select and data word contains 16 data bits plus one parity bit. A continuous system clock signal, originating in the CC, provides the timing reference.

A multiplex bus is composed of two transmission lines. One line carries the 1-MHz system clock reference signal from the CC to all terminals on the bus, and the other line carries digital data signals at a 1-Mbit rate between the CC and the peripheral units. All peripheral units on a single bus are connected to the transmission lines comprising that bus in parallel, party-line fashion, such that the physical removal of a unit from the lines does not interrupt the continuity of the lines. The four independent multiplex buses are operated by the CC executive software module as two redundant pairs, with only one of the buses of each redundant pair being active at any one time. Each peripheral is connected to one or the other pair of buses so that all units on the same bus-pair see all of the data on that pair of buses. However, on a given bus-pair, data are transferred only between the CC and a single peripheral at a time. The CC selects which of the data buses is to be used for data transmission and initiates each data exchange over the selected bus. No peripheral is required to receive or transmit over more than one bus at a time. Data words transmitted by the CC or the peripheral always are transmitted over the same bus that carried the select word.

A multiplex terminal is incorporated as an integral part of each equipment interfaced with the CC. Each terminal performs the necessary functions to receive and validate data from the CC and transmit data to the CC, using the incoming system clock signal as a reference. In addition, it provides the necessary conversion/reformatting of data to interface with the equipment component logic and accepts/generates the control signals that coordinate the transfers with the equipment.

If the CC detects an I/O error, i.e., no response from a peripheral, a parity error, or a data dropout, it will shut down the active bus. When a bus is shut down, both the data line and clock line are disabled by the CC. All terminals operating on a bus that is shut down during operation resynchronize their terminal data-processing functions regardless of their operating mode, either transmitting or receiving. After the bus is shut down, the CC reinterrogates the same peripheral by retransmitting the same select word on the redundant bus. If the error reoccurs on the redundant bus, the CC internally flags an invalid response condition and proceeds to the next transmission scheduled for the peripherals on that bus.

Summary

In summary, the F-15 computational subsystem is a consolidated configuration of computers, in which the mission-oriented computations are performed in a single central computer, and the sensor-oriented computations are performed in special processors in various sensor and display equipment. The central computer provides adequate memory and execution time for future growth. This reserve memory and speed along with the flexibility of the CC multiplex input/output system and the functional modularity of the computations makes the F-15 computational subsystem easily adaptable to changes and expansions in F-15 mission requirements.

References

[1]Griffith, V. V., Keifer, L. F., Paxhia, E. C., et al., "Aircraft Avionics Trade-Off Study (AATOS)," McDonnell Aircraft Co., St. Louis, Mo., ASD/XR 73-20 Final Rept., Nov. 1973.

[2]Finke, H. G. and Rosenkoetter, E., "Aircraft Avionics from the Aircraft Manufacturer's Point of View," McDonnell Aircraft Co., St. Louis, Mo., MCAIR 73-023, Sept. 1973.