Development of the F-15 Integrated Data System

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The F-15 Integrated Data System is designed to provide final flight test data within 24 hr after flight. Major elements of this system, including the airborne instrumentation, preflight checkout system, and the data processing system, are integrated by a ready-access computerized data file. The airborne equipment includes a central unit memory that is loaded from a preflight console. Both preflight setup of the airborne instrumentation and processing of the flight tape are accomplished through a common set of punched cards. System development has involved both ground and flight tests to assure a fully developed system prior to first flight of the F-15.

Introduction

THE F-15 Integrated Data System (IDS) emphasizes both instrumentation and data processing time-saving objectives which are essential to ensure timely achievement of the flight test program. Objectives for the airborne instrumentation aim at time reductions during all operational phases, beginning with the installation of equipment and wiring in the aircraft and extending to flight readiness. Similarly, data objectives require significant treatment of each phase of data processing operations. This paper describes in broad terms some features of the F-15 IDS and summarizes the development program being used to assure a fully functional system prior to first flight.

The F-15 IDS, which is being developed by McDonnell Aircraft Company (MCAIR) under contract to the U.S. Air Force, incorporates many innovations in both instrumentation and data processing applications. MCAIR's experience with recent programs such as the F-4 aircraft and Gemini spacecraft has provided the technical basis and management recognition for company-sponsored studies and laboratory developments that necessarily preceded the F-15 program. Incorporation of advanced concepts from the laboratory stage into this fully integrated system has now become a reality for the F-15 program.

Present-day techniques and concepts, although considerate of established trends which place greater demand for improved accuracy or measurement capacity, are being shaped more by time-saving considerations to enable the protection of program schedules and operating budgets. These cost/schedule considerations have led many test organizations to adopt a "systems" approach that integrates the data processing and instrumentation functions.

Each aircraft development program has specific objectives which, in turn, determine where emphasis must be placed for its peculiar data system. Some programs, for example the DC-10, strive to obtain final processed data while the test is in process. The DC-10 concept, which employs an on-line computer and some rather versatile CRT displays, would not necessarily be cost-effective for aircraft that average less test time during a flight. On the other hand, since the installation, checkout, and maintenance of airborne instrumentation have long been major contributors to flight test program delays, our program objectives stress minimizing test instrumentation preparation time, thereby increasing test aircraft utilization which results in benefits to the F-15 program.

F-15 Data System Concepts and Performance Objectives

Equipment developments in MCAIR's Flight Test Instrumentation Laboratory and Data Methods Laboratory have been paralleled by engineeering studies of test data system concepts. From past attempts to achieve similar time savings, we found that many of the normal delays were of common origin for both data and instrumentation functions. For instance, satisfactory performance of either function depends upon precise knowledge of measured sample rates, sample sequencing, and instrumentation calibration factors. Determining this vital information from instrumentation records can be expected to take some time and, hence, delay the start of data processing. To understand this process, we must recognize that a data engineer needs valid calibration information and a full knowledge of instrumentation changes since the previous flight. Communications from flight test engineering personnel regarding instrumentation requirements, such as the need to recalibrate a measurand, correct known deficiencies, or add new instrumentation transducer/pickups, have usually been conveyed to instrumentation personnel in a routine and sometimes untimely manner. The opportunity for delay, error, and miscalculation even under a closely managed environment is high (to say nothing of the wasted effort for data processing computer reruns) and can be estimated as roughly proportional to the number of active measurands per test aircraft. We can see that communication delays or omissions would, and ordinarily do, increase as the data group is required to serve more test aircraft.

The foregoing considerations point out the need for a rapid, single, error-free source of measurand information. With recent advancements in computer storage and retrieval capabilities, a computer-indexed information file with sufficient capacity to serve both instrumentation and data functions has become a practical reality. A common data bank naturally integrates the instrumentation and data processing subsystems without compromising either subsystem. This is the keystone to the F-15 IDS concept. The F-15 design features a deck of universal instrumentation/data cards for each test aircraft. Figure 1 shows the principal elements, although some system elements, such as a ground monitor station and postflight, quick-look stations, are omitted from this sketch for clarity.

Before examining the mechanization of the system, it seems appropriate to identify the principal performance objectives

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Presented as paper 71-774 at the AIAA 3rd Aircraft Design and Operations Meeting, Seattle, Wash., July 12–14, 1971; submitted July 12, 1971; revision received May 4, 1972. Although the authors have attempted to relate some of the pertinent contributions to the formulation and development of the F-15 Integrated Data System, the technical innovations and system logic have been the product of a dedicated group of MCAIR flight test specialists. These efforts, guided by the foresight of this test organization's management, have placed us on the threshold of achieving these long-sought test efficiency objectives. The authors sincerely express their thanks to the many contributions and dedicated efforts which have been put into this program, and we consider it indeed a privilege and an honor to represent the MCAIR team in this endeavor.

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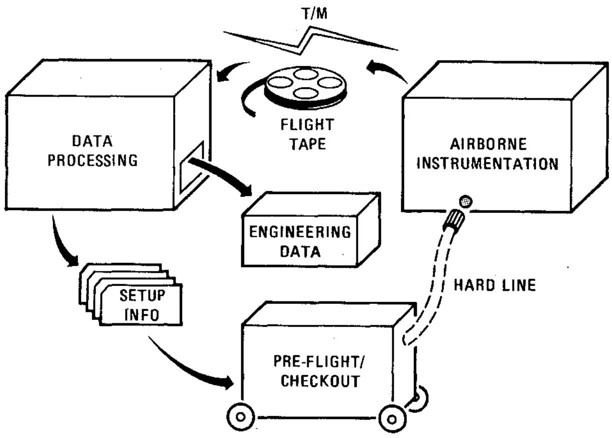


Fig. 1 F-15 Integrated data system.

that have long been MCAIR flight test goals and have been adopted for the F-15 program. 1) Data processing—to provide program decision (final) data within 24 hr. 2) Instrumentation—to provide airborne instrumentation that will enable the most efficient use of test aircraft.

The F-15 IDS does not fit a classic "system concept" in which subsystem performance objectives are systematically tailored to accomplish only the stated system objectives. It would be a false claim to suggest that a pure systems approach had been used to arrive at the configurations of all components of this data system. For example, a more in-depth assessment of instrumentation subsystem performance objectives will reveal instrumentation accuracy refinements that are not readily traceable to the above system objectives.

In addition to over-all performance objectives 1 and 2, mentioned previously, another very significant goal was essential to this program: system development—to provide a proven, fully developed and operationally ready data system prior to the first F-15 flight. Achievement of this final objective obviously requires prior testing, including ample time to debug the system.

Airborne Instrumentation Subsystem

The F-15 program environment requires certain flexibility and data system objectives that are not achievable with earlier instrumentation installations. For example, the F-15 instrumentation system features remote multiplexing to reduce EMI susceptibility and save wiring time; pulse code modulation (PCM) to achieve higher noise tolerance and to afford a ready interface with F-15 digital avionics; stored program memory to enable fast, flexible instrumentation setup; and a preflight console to provide card deck loading of the central unit memory and to assess each measurand automatically with respect to a predetermined tolerance. The F-15 instrumentation design, thus, is principally a blend of new and existing equipment with concepts and approaches that can be refined and proved within the time frame allotted for development.

Instrumentation Accuracy and Capacity Improvements

Because of established trends for more and better data, F-15 instrumentation features include objectives for increased accuracy and recording capacity to cope with a more stringent aircraft development criteria. Primary encoding modes include both PCM and frequency modulation (FM) to accommodate both low- and high-frequency measurand requirements, respectively. It is significant to mention that, aside from other benefits, PCM encoding was a cost-effective necessity for the F-15 in order to interface instrumentation with the digital avionics.

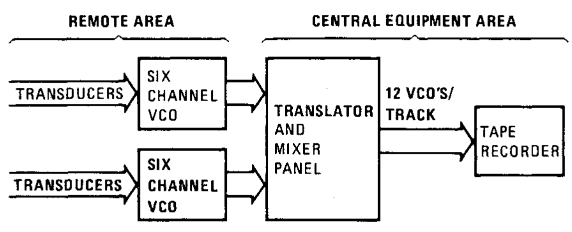
Past capacity demands usually have been satisfied by adding multiplexers and using more of the available tape recorder tracks. For example, the F-4 aircraft PDM multiplexer allows 45 or 90 measurands per tape track at sample rates of 20 or 10 samples/sec, respectively. In addition to the necessity for large wire bundles in the central recording area, fewer of the available tape tracks are then available for high-frequency measurand recording. PCM sample rate for the F-15 was chosen to accommodate all predicted low-frequency (5 Hz and below) measurand requirements on a single tape track to simplify and speed data processing. No practical sample rate would facilitate F-15 high-frequency data; therefore, no advantage was to be gained by choosing PCM sample rates beyond those needed for the low-frequency data. A 28.8 kilobit/sec system was devised that would provide 360 eight-bit words 10 times/sec. Design provisions include the capability to use double words for high-accuracy measurands; and when required, individual measurand sample rates up to 60 samples per sec can be achieved by supercommutation.

Dynamic data for such tests as flutter, inlet distortion, vibration surveys, etc., depend upon FM data techniques to achieve adequate frequency response. Past FM systems have employed proportional bandwidth (PBW) equipment with voltage control oscillators (VCO's) tailored to the frequency range of interest. Multiplexing techniques enable recording of a number of FM data channels per tape track. Use of a constant bandwidth (CBW) VCO system permits more efficient tape track utilization than an equivalent PBW system for the F-15 data frequency ranges. The F-15 CBW system utilizes six basic VCO center frequencies. When added capacity is needed, frequency translation is used to obtain a 12-channel-per-tape-track maximum capability. This is illustrated in Fig. 2. In addition to being cost-effective, frequency translation provides greater immunity to tape recording anomalies, resulting in improved data accuracy.

Wiring Improvements and Remote Multiplexing

No other single feature of the airborne instrumentation installation is more responsible for test aircraft delays than instrumentation wiring. During instrumentation installation, the impact is felt as the wires are strung through the aircraft and emerge as massive bundles which are then painstakingly connected to the signal conditioning/recording equipment. At this point exists the potential for EMI and noise problems. In addition, this preponderance of wiring takes time to install and increases instrumentation cost, to say nothing of causing maintenance troubles during the test program.

One of the foremost advantages of the F-15 installation is the circumventing of much of the wiring problems. This



CONFIGURATION	VCO QUAN	VCO f_c (KHz)	MAX. DATA FREQ. (KHz)	REF. FREQ. KHz (IF USED)	TAPE SPEED (IPS)
1 CHASSIS	6	16,24,32, 40,48,56	2	60	15
2 CHASSIS	12	16,24,32, 40,48,56, 64,72,80, 88,96,104	2	120	30

Fig. 2 F-15 flight test instrumentation frequency division multiplexing system (FDMS).

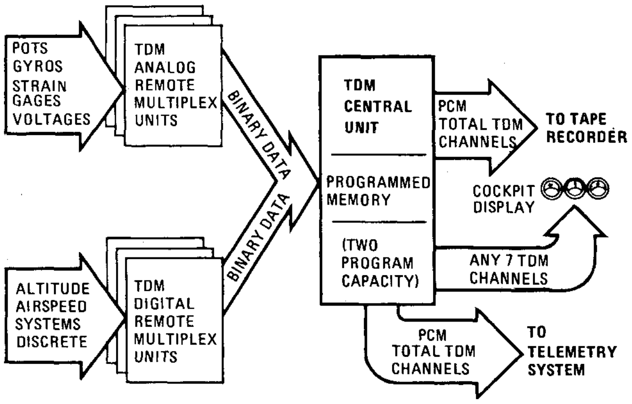


Fig. 3 Time Division multiplex characteristics.

has been achieved by placing the necessary signal conditioning and multiplexing equipment in locations that are closer to the measurand pickups. These remote units are then connected to the central area by party lines. These remote units have been designed to satisfy a wide variety of measurand requirements, both analog and digital. All signals to them are converted to the proper digital format and inserted into the data stream upon command from the central unit, as shown in Fig. 3. A variety of plug-in modules have also been designed to handle the full spectrum of F-15 low-frequency data requirements.

Stored Program Memory

The stored program memory is the largest single innovation of the F-15 instrumentation subsystem. It eliminates the requirement for patch panels that are normally used for selecting the instrumentation for a particular flight. In past F-101 and F-4 aircraft instrumentation systems, one or more patch panels have been required in the vicinity of the central multiplexing unit and recorder. Manual patching results in additional problems. Connector failures (caused by wear and tear), human error, and time delays all combine to make patch panels less than satisfactory. A stored program concept enables rapid instrumentation setup and affords an opportunity for automatic assessment of each measurand. Based on past experience, checks of ambient readings and noise levels are generally considered adequate for this assessment. Automatic assessment is accomplished with an instrumentation preflight console that has been specifically developed for this purpose.

Other salient features of the stored program include: control of measurand sample rate, capability to display any TDMS channel in the cockpit, and the capability to set the remote unit for the desired measurand gain and offset, for each measurand. This latter feature substantially replaces special signal conditioners. The F-15 stored program memory has a sufficient capacity for two separate 360-channel programs (A and B), which are both inserted during preflight operations. The pilot has the option of selecting Program A or B at any time during the test. This capability will not be fully appreciated until it has been in use for some time; however, the potential for making maximum use of aircraft test time is easily seen.

TDMS Party Line

The TDMS party line offers unique benefits. Primary wiring to the central unit memory involves three party-line loops of shielded, twisted pairs of wire. As shown in Fig. 4, one each of these loops extends to the nose and one each extends aft to the left and right sides of the fuselage from the central instrumentation location. Each loop can accept up to 15 remote units. The loop provides redundancy, and it has been demonstrated that the remote units on a given loop will operate unimpaired with the loop either open or shorted.

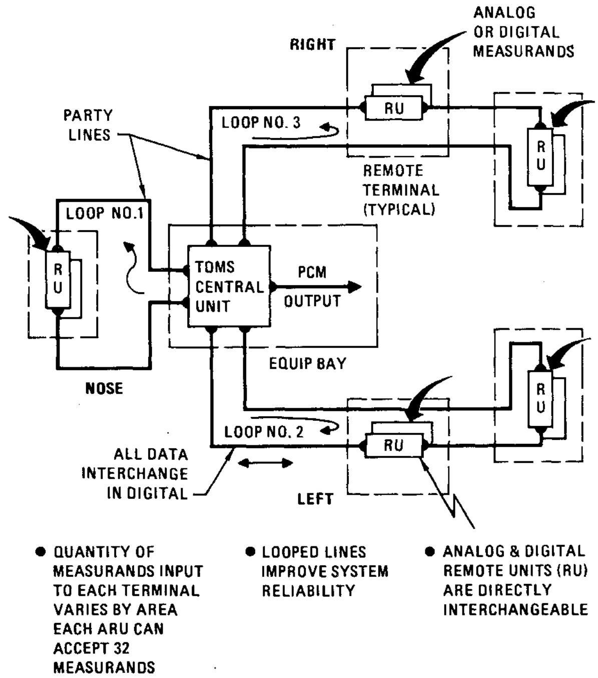


Fig. 4 TDMS common line wiring.

Data Processing

The term "final data" implies that all corrections, instrumentation calibration factors, computations, and/or other qualifications have been incorporated and the results yield expected accuracies. The primary F-15 IDS objective of providing 24-hr final data suitable for making decisions that affect the conduct of the program is actually the foremost of the following three data timing objectives. 1) Program direction/decision data will be provided within 24 hr after flight. 2) Flight direction/decision data will be displayed in real time via telemetry. 3) Summary/documentation data will be available within 7 days after flight.

Figure 5 is a compilation of F-4 data processing history that graphically portrays timing differences between the two systems. These curves imply "average" data processing times and are forecast for multi-aircraft test operations at the Air Force Flight Test Center (AFFTC). These processing times can vary and are dependent upon the number of test aircraft on flight status. The summary/documentation data objective, Item 3, will not be further highlighted except to acknowledge the importance of data analysis software preparations and, in some cases, special equipment that may be required.

Flight Direction (Real Time) Telemetry Data

This segment of the final data product, although a small percentage of the total, plays a vital role during test conduct. Except for flutter test data, most telemetry-monitored results are considered backup to the onboard tape records, and extreme measures are not taken to achieve high accuracy.

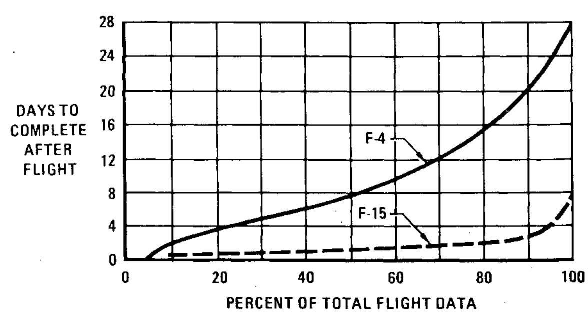


Fig. 5 F-15 Integrated data system design criteria.

Strip-chart and CRT bargraph presentations are used to permit a test engineer to assess quickly each maneuver and decide upon subsequent flight conditions. The benefits of this flight monitoring capability are usually proportional to the time invested preparing for test, including pilot briefings. The pilots and engineers, working as a team, can more appropriately evaluate and properly judge each test with the help of telemetered data.

Separate ground stations are used for telemetry monitoring and post-flight (quick look) processing of the flight tapes. Such ground stations are both essential to the instrumentation/data integration process and, like the data processing and instrumentation subsystems, must be set up for each flight. A comprehensive description of ground station features is beyond the scope of this paper, but it is worth mentioning that to assure a compatible setup for each aircraft flight, the stations are mechanized with programmable decommutation capabilities that are input from the preflight card deck. This enables rapid turnaround of the ground stations to support different aircraft. This feature will be most appreciated during periods of peak flight activity.

The F-15 requirements for real-time final data have so far been limited to flutter tests. The nature of these tests requires processed data of high quality for safe flight conduct. From past F-4 experience, real-time final flutter data have been shown to be extremely cost-effective. Flutter testing for the F-15 will employ special equipment to excite the structure throughout a broad frequency range for an adequate assessment of aeroelastic stability trends. To supplement this onboard equipment, the ground station incorporates special computation and display provisions that give the test engineer precise knowledge of the transfer function, structural damping and a parameter that indicates flutter margin based upon structural response. Special ground equipment presently being provided for this purpose includes a transmissibility plotter and an on-line computer which outputs to a CRT display.

Key Data Subsystem Design Factors

Before we examine the intricacies of F-15 data flow, it is first appropriate to explain certain of the F-15 data subsystem design features. Most modern data processing activities can, on a particular occasion, demonstrate extremely rapid data service provided that certain preparations have been made. Where then is the stumbling block that prevents consistently achieving this performance? A solution is not simple because of the many variables in the equation. We have mentioned compatibility and the need to minimize human error; however, three additional factors are considered relevant to a consistent, rapid turnaround, data handling capability: 1) dedicated computer facility, 2) data transmission provisions, and 3) data processing preparations.

Dedicated Computer Facility

Operations at a customer flight test central computer facility involve dependence on a system of priorities. Preferential treatment is logically given to programs of the highest importance. No matter how fairly and reasonably these priorities are administered, the fact remains that even with highest priorities there will be uncontrollable delays at times in a multiprogram environment (even the lowest priority program must be permitted some use of the facility). Computer time-sharing has not advanced to the stage where several flight test programs can enjoy simultaneous use of central computer facilities. Therefore, F-15 Category I flight test program objectives have dictated that some computations be accomplished on dedicated flight test equipment at St. Louis, with the Air Force facility used when available. This decision obviously poses problems in transmitting flight records and final data from the MCAIR/Edwards AFB facility to St. Louis; however, studies have shown that cost-effective and reliable means of transmitting digital data are currently available. Even considering the high speed (7200 bits/sec) of these data transmission methods, a problem became apparent. The preponderance of data points normally taken per flight would probably absorb the majority of available transmission time without the use of some selective considerations for minimizing the amount of data to be transmitted. However, much of the data ordinarily processed is redundant and can be removed without impairing final data assessment.

Precomputer test record editing in order to limit computer costs has been a MCAIR practice for years. Some test organizations advocate an opposite approach wherein the complete flight record is first processed to reduce or avoid the precomputation tape handling and editing requirements. Without entering into the pros and cons of either approach, suffice to say that the F-15 data processing concept places a premium on preprocessing editing. We have long used the start/stop time to control the processing for each data run, but until recently we have given little consideration to selecting only the needed points and removing redundant data within a particular run. Actually, redundancy removal depends somewhat upon the test in question. For example, steady-state cruise test conditions naturally offer higher data compression ratios than say a dynamic maneuver for stability or structural test purposes. It is safe to conclude then that possibilities for data compression will be a function of an individual test and, if used, must be preselected for each data run. A potential compression ratio of 15:1 appears likely based on assessment of a cross-section of F-4 program data. Evaluation of F-15 requirements has shown that the following algorithms will adequately fulfill data compression requirements: ZFN—zero order, fixed aperture, nonredundant point transmitted (established tolerance band within which successive data points are discarded); ZVA—zero order, variable aperture, adjusted point (diminishing tolerance band where the last contained midpoint is saved; TAV—time average—data are averaged over a selectable number of frames); DEL—deletion (inoperative data channels discarded); and THR—thruput (all data saved).

Data Processing Preparation

Adequate preparation for all data operations underlies the basic philosophy behind the F-15 data processing concept. All significant reference material regarding the data to be processed, instrumentation measurand factors (including current calibrations), special analyses, and maintenance of test data summaries must be planned well in advance of the test phase. The data bank, besides being the foundation for instrumentation/data integration, also serves as the nerve center for all data operations. As shown by Fig. 6 this rapid access file, which requires 80 million bytes of storage, accepts the documented program inputs into separate file segments. The most important outputs of this access file include the data processing/presentation setup and the ground station display/instrumentation preflight setups. The punched card deck is provided from this file for each aircraft, with individual flight changes as necessary.

The absolute dependence of an orderly preparation phase to the successful operation of the F-15 data processing subsystem cannot be overstressed. All test requirements stemming from F-15 test specifications are contained in Test Information Sheets (TIS's) which also identify specific instrumentation and data requirements. Detailed analysis programs and summary data analysis programs are naturally developed from TIS requirements, but they must be substantially complete to enable preparation checkout of software before start of tests. Changes subsequent to the flight program are possible and to be expected, but such changes will not produce the same timely data service.

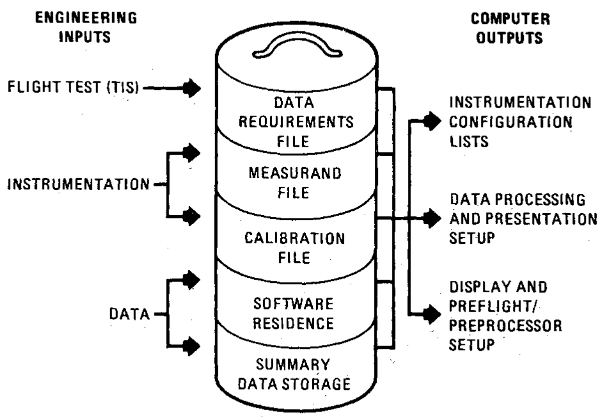


Fig. 6 Rapid access data bank.

Data Flow Diagram

Figure 7 shows the significant F-15 data subsystem components tied together and reflects the location of key elements at St. Louis and the MCAIR/Edwards AFB facility. Several additional points not previously mentioned are significant. The data transmission is a two-way secure system; data are transmitted directly to the computer for final operations, or the final computed data are transmitted to a recorder or an on-line plotter at the opposite location. This two-way service enables data to be processed and available at either location. Since data file update and preflight card decks must also be transmitted without delay, a low-speed teleprocessing line is also available when the normal high-speed link is in use for flight test data transmissions. This arrangement of facilities at either location provides a redundant computer capability with a minimum of duplication. Computer file update can be accomplished by either link so that current operations are not impaired by a single breakdown.

Instrumentation Preflight Checkout

We have repeatedly stated that F-15 data system integration is founded upon a common reference file for data and instrumentation functions. From individual test requirements identified in each TIS, setup information for the ground stations, data processor, and airborne instrumentation is outputted from this file in the form of a universal card deck for each test flight. Card deck information is inserted in the aircraft instrumentation central unit memory by the use of a preflight console (PFC), a specially designed mobile ground equipment console.

The computer-controlled PFC loads the TDMS airborne memory, verifies that the memory is loaded correctly, and assesses the quality of each TDMS measurand using previously established norms. In addition, the PFC also analyzes each FDMS measurand and prints out its status relative to an expected value. This is briefly illustrated in Fig. 8. The PFC basically consists of a punched card reader, a minicomputer, programable constant bandwidth FM discriminator, and a printer. An integral air-conditioning unit is also provided.

The preflight cards are identified by aircraft and card punch day and hour. The card reader reads and transfers the information into the PFC mini-computer. The information is in alphanumeric format and is measurand-sequence-number-oriented, consisting of PCM word address, remote unit program, ambient limits, and noise tolerance. The control panel is relatively simple and designed to minimize the probability of operator error. The operator can verify, if desired, that the PFC computer has been loaded correctly by re-reading the deck. The programing logic is such that the PFC will

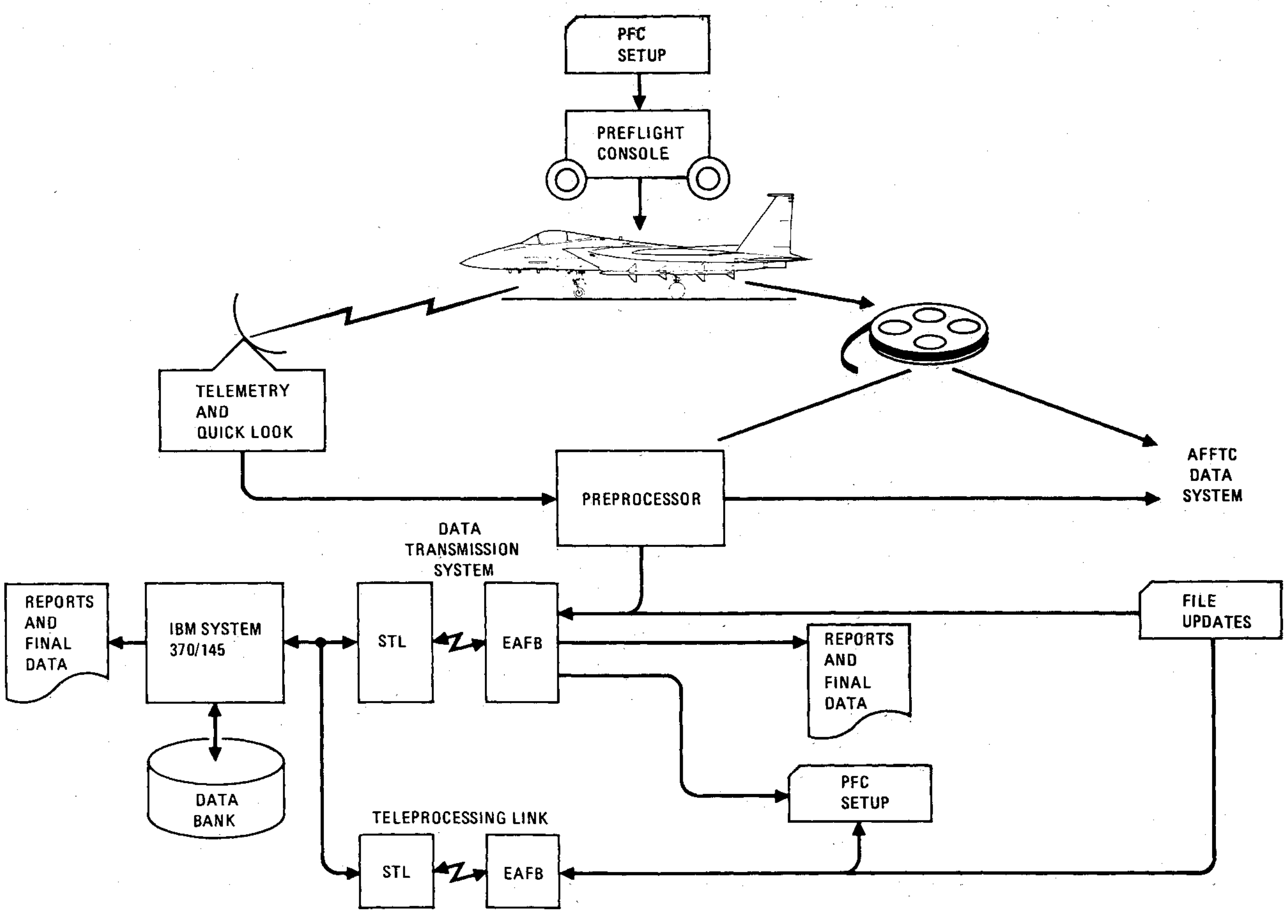


Fig. 7 F-15 data processing system.

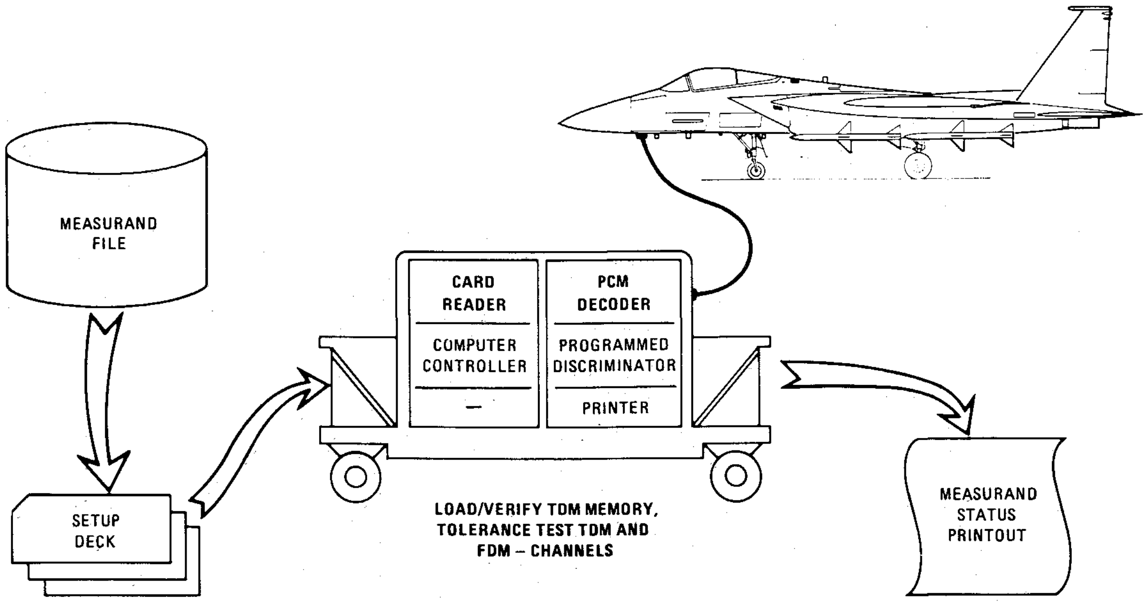


Fig. 8 Instrumentation preflight operations.

print out any discrepancies between first and second read-ins. The computer control logic is provided by an executive program that resides in permanent core storage.

At this point, the PFC is ready to load and verify the airplane TDMS memory. The time to load and verify the console memory, load and verify the airborne memory, and evaluate the TDMS is 10 min. The time to verify the FDMS, dependent on the number of channels, is a fraction of this, taking roughly 3 sec per channel.

Measurand evaluation is performed by collecting 50 consecutive samples of each channel, averaging, and comparing each measurand against the predetermined limits. The arithmetic mean of these samples is computed as the "ambient reading." The standard deviation from this mean is then computed and identified as the existing "noise level" for that channel. Comparison of these ambient readings and noise level values to the predetermined allowable values is performed, and a printout (Fig. 9) is made of channels; error flags (*) denote the deviations from acceptable levels. To aid the technician in measurand assessment, special three-digit words, 252, 253, 254, and 255, are used to denote conditions of underscale, unused word slot, overscale, and no response, respectively. The operator has the choice of complete memory printout or a printout of only those measurands that are out of tolerance.

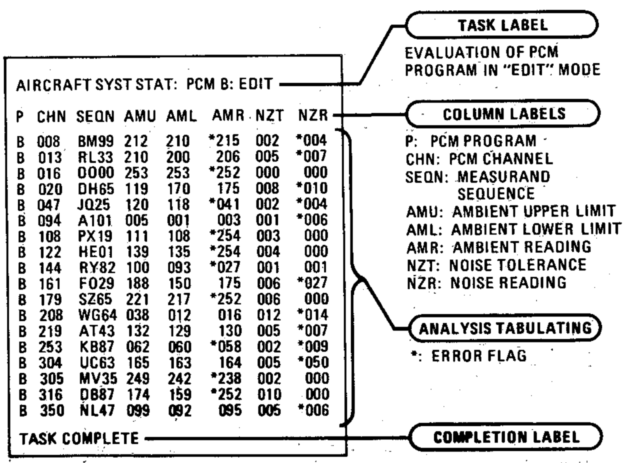


Fig. 9 F-15 preflight console printer listing (typical).

The PFC contains provisions for real-time binary and digital readout of any selected four PCM word locations or FM channels. This PFC feature is of particular use to troubleshoot identified problems and, with the maintenance console, to make repairs on the aircraft instrumentation systems. One advantage of a quick status check is to enable a test engineer to choose whether to accept the airborne instrumentation as is, modify the test flight plan, or request that the instrumentation be repaired.

Development Testing

The third key F-15 IDS objective requires early development and qualification of key units from the individual component level up to and including operational testing of the complete system. Component tests have been accomplished both at vendor plants and in the MCAIR development laboratories. Subsystem integration tests include both ground and flight tests with a compatibility integration mock-up (CIMU) and an F-4 test bed aircraft, respectively. Initial development has been done with a limited quantity of prototype units, and changes have been made as necessary to achieve the desired performance. The intent has been to assure that follow-on production of the components reflects a configuration well-suited to system performance objectives. Numerous component and interface problems have been uncovered using the CIMU and were corrected before the equipment was installed in the test aircraft. The CIMU environment also enabled full exposure of all special instrumentation ground support equipment. This equipment includes installation consoles used during final aircraft assembly, maintenance consoles for extensive problem solving during test operations, and, of course, the preflight console.

The instrumentation development phase has proceeded through the CIMU and the flight test program stages from which configurations have been finalized to enable initiation of final procurement options. The data processing subsystem and the ground station monitoring capabilities are in the final stages of equipment/software integration, and operational tests with the data compression/transmission equipment and data processing functions have been accomplished. Naturally, the existing flight tapes from the instrumentation test bed have been used for final development and checkout of the complete system. All ground station equipment has been installed at the AFFTC remote test site, and final checkout is in process for first flight.