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REAL-TIME DATA TRANSMISSION FROM AIRCRAFT

ABSTRACT

While performing a flight inspection mission, the results of the facility performance are presented to the operator in various types of displays, such as a colour monitor, and printer/plotter. The data may also be digitally recorded for subsequent analysis on the ground. However, no facility performance information, other than a pass/fail decision, is available until the aircraft completes its mission and returns to its home base.

In certain types of inspections, such as periodic with monitors and commissioning for ILS and MLS, it is useful for the personnel on the ground to receive real-time data that is observed in the aircraft. This paper will discuss the types of data displays presented on the ground that contain facility performance information in real-time as it is monitored in the aircraft. Furthermore, the architecture of the airborne equipment to support this capability will be addressed.

In the future, the Parker Automatic Flight Inspection System (AFIS) architecture will be able to support remote control of the flight inspection equipment, using a high-speed data link interface when it becomes cost effective. This capability already exists today having successfully controlled and monitored the flight inspection equipment remotely via an Internet connection. Using this approach, the operators could be placed in a centralized location on the ground, instead of the aircraft, thus reducing the cost of flight inspection operation.

INTRODUCTION

Over many years the flight inspection equipment has been upgraded to provide enhanced system performance by gradually phasing in new capabilities. This was necessary to satisfy the changing requirements for flight inspection imposed by new navaids and procedures, as well as to use new technology for improving the way the flight inspection mission is accomplished. One of the areas where much emphasis has been recently placed is reducing the overall cost of carrying out the flight inspection mission.

The approach that has been successfully used by Parker is one of technology insertion. Instead of replacing the entire flight inspection equipment, it has been upgraded in a phased implementation using state-of-the-art technology to provide enhanced system capabilities. One of the latest technology upgrade is the introduction of the Ethernet data link, interfacing the major flight inspection subsystems in the aircraft. This architecture allows a radical change in the way flight inspection is implemented. Eventually, one can visualize an environment where the flight inspector will no longer be monitoring and controlling the equipment from within the aircraft. Instead, this function could be performed from a centralized location on the ground interfacing to all flight inspection aircraft over a high-speed satellite wide area data network.

This paper presents how this technology evolution is being applied to achieve this ultimate goal.

ORIGINAL SYSTEM ARCHITECTURE

The Parker AFIS architecture has been evolving for over 15 years. Therefore, design decisions were made based on the best available technology at that time. In those days display technology was limited to only dumb terminals, and consequently, the screen data formatting function has been allocated to the Navigation Computer Unit (NCU). Figure 1 illustrates the top-level interfaces between the major system components in the original design.

The RS-232 interface between the NCU and In-Flight Workstation (IFWS) was adequate to transmit the screen display information from the NCU, and to send the control commands from the IFWS. Subsequently, a digital data logger was added through a SCSI interface connected to the NCU. SCSI supported data logging adequately, however, being a bus interface primarily limited to peripheral devices, it could not have been easily expanded to communicate with additional devices. Even though this architecture fulfilled the flight inspection needs, it had limitations for future growth and expansion.

ENHANCED SYSTEM ARCHITECTURE

The introduction of Ethernet is part of an on-going strategic enhancement that Parker has undertaken in the last few years. The results of this activity has significantly impacted the architecture by changing the functional partitioning of the major sub-systems within the aircraft environment, and by opening new opportunities in the ability to transmit processed facility parameters to the ground personnel in real-time. Specifically, Ethernet established a high bandwidth communications link from the NCU to the IFWS, which has re-allocated a part of the real-time processing to the IFWS. The IFWS, now being a smart terminal, is capable of data processing and interfacing to other peripheral devices. Figure 2 depicts the changes to the interfaces made in the enhanced system architecture.

The first implementation of Ethernet has been interfacing the Television Positioning System (TVPS) controller to the IFWS. All of the controls and processing of the threshold image cursor positioning are now handled within the IFWS, and after making

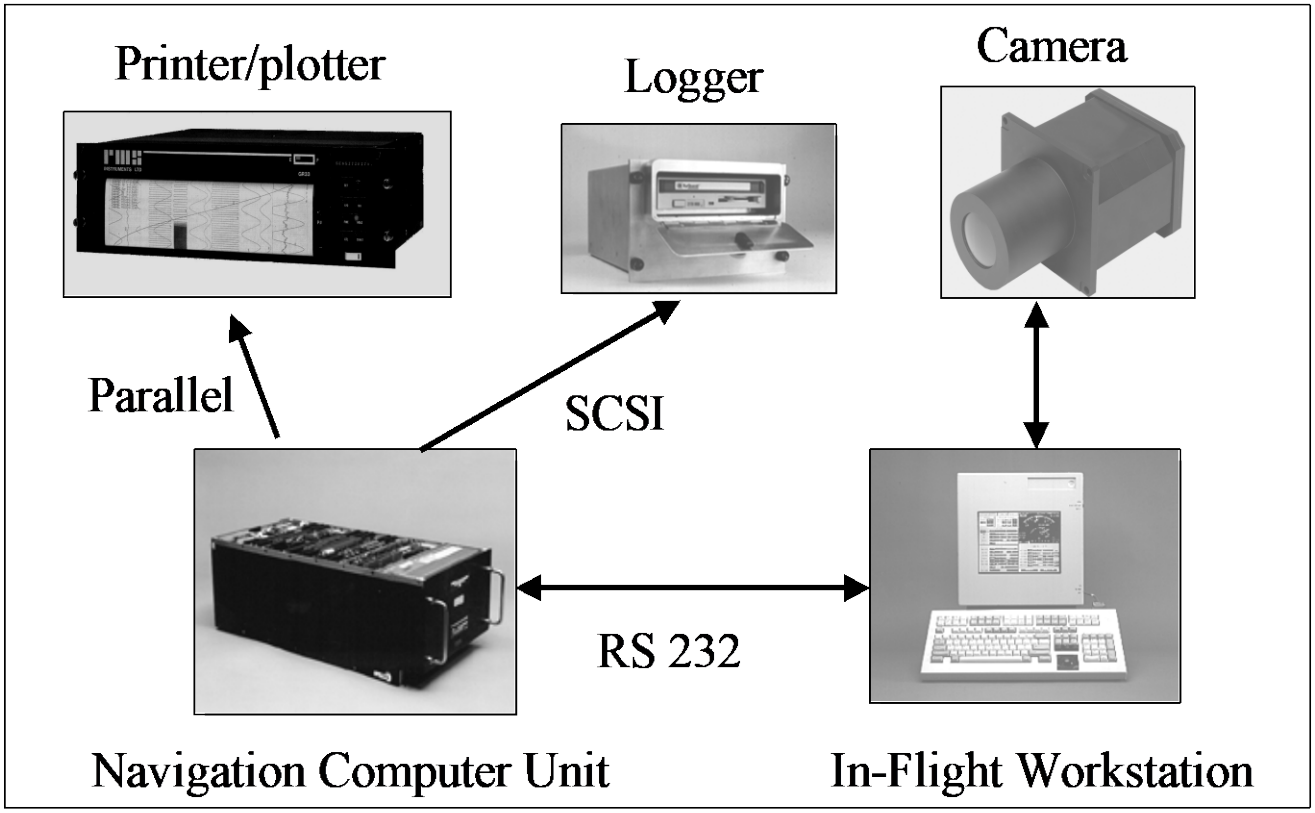


Figure 1. Original System Architecture.

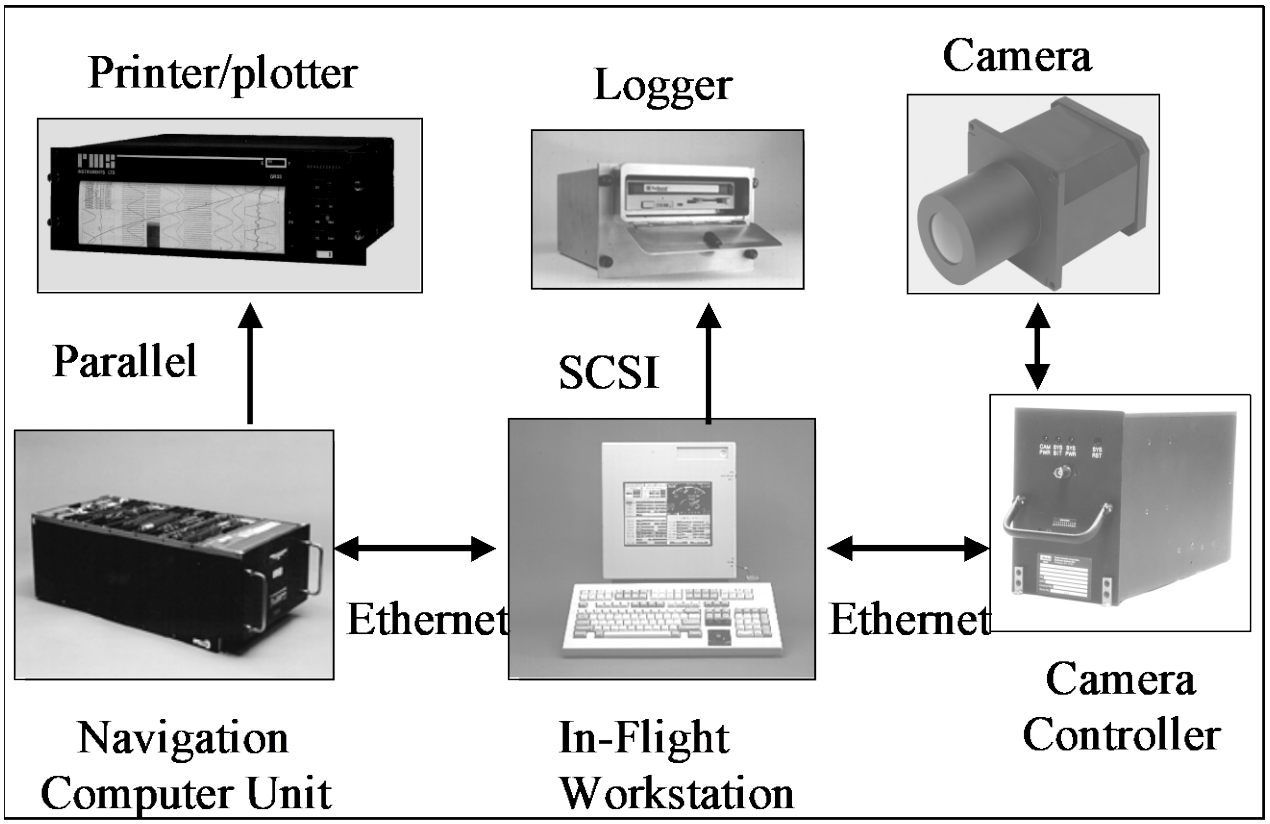


Figure 2. Enhanced System Architecture.

the computation for the final fix correction, it is transmitted to the NCU.

The benefits resulting from this modification are quite extensive. The IFWS has access to the entire set of the real-time data generated by the NCU. The IFWS can process this data, and generate real-time graphical displays using off-the-shelf Windows application programs. Virtual plotting of pop-up displays is easily implemented as well.

The next enhancement utilizing Ethernet connectivity between the NCU and the IFWS is the Remote File System (RFS) which was developed on the IFWS to save disk logger files. Basically the RFS and supporting NCU software is similar in concept to a network file server. The RFS responds to NCU file operations such as open a file, read and write data, and close the file. This architecture allows log data to be shared and accessed by various IFWS based applications. In the previous NCU architecture, data logger files were written to a SCSI disk drive controlled by the NCU. In order to share data, the operator had to eject the hard disk media and remount it into another disk drive on the IFWS. In the new design, the flight inspector can readily access logged data throughout the flight inspection mission, and has the capability of preparing reports on completed facilities while flying to the next inspection site.

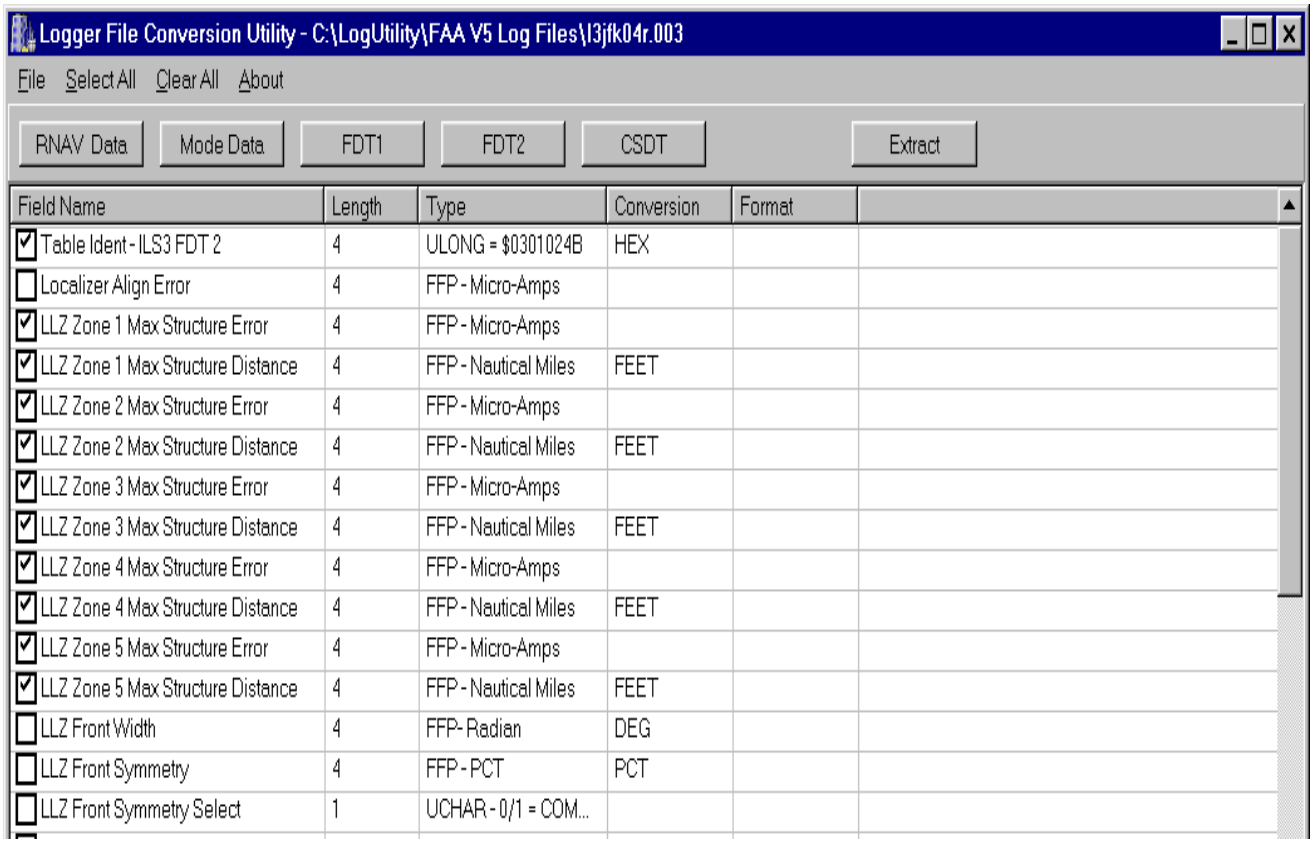
The incorporation of an Ethernet backbone into the AFIS provides a simpler approach of integrating other peripheral devices to accommodate future growth.

DATA CONVERSION AND TRANSMISSION TO GROUND

The next enhancement to the Parker system was the development of the Logger File Conversion Utility (LFCU). This Windows based program provides the user with the ability to selectively extract inspection logger file data fields. The LFCU works in both an interactive and automated mode.

In the interactive mode, the user selects data fields from a selection screen shown in Figure 3. The data selection criteria can

be saved and later recalled. Each AFIS log file format is defined in external definition tables. These tables specify data field names, data types, location in the record, and the default conversion units. The external tables provide flexibility for modification and version control. Various data conversions are also performed on the data fields. For example, distances can be converted to nautical miles, feet or meters.



Field Name	Length	Type	Conversion	Format
☑ Table Ident - ILS3 FDT 2	4	ULONG = $0301024B	HEX	
☐ Localizer Align Error	4	FFP - Micro-Amps		
☑ LLZ Zone 1 Max Structure Error	4	FFP - Micro-Amps		
☑ LLZ Zone 1 Max Structure Distance	4	FFP - Nautical Miles	FEET	
☑ LLZ Zone 2 Max Structure Error	4	FFP - Micro-Amps		
☑ LLZ Zone 2 Max Structure Distance	4	FFP - Nautical Miles	FEET	
☑ LLZ Zone 3 Max Structure Error	4	FFP - Micro-Amps		
☑ LLZ Zone 3 Max Structure Distance	4	FFP - Nautical Miles	FEET	
☑ LLZ Zone 4 Max Structure Error	4	FFP - Micro-Amps		
☑ LLZ Zone 4 Max Structure Distance	4	FFP - Nautical Miles	FEET	
☑ LLZ Zone 5 Max Structure Error	4	FFP - Micro-Amps		
☑ LLZ Zone 5 Max Structure Distance	4	FFP - Nautical Miles	FEET	
☐ LLZ Front Width	4	FFP- Radian	DEG	
☐ LLZ Front Symmetry	4	FFP - PCT	PCT	
☐ LLZ Front Symmetry Select	1	UCHAR - 0/1 = COM...		

Figure 3. Data Field Selection.

A third enhancement dynamically links the RFS and the LFCU. This feature provides a direct link into the LFCU data extraction process as the data is being written to the

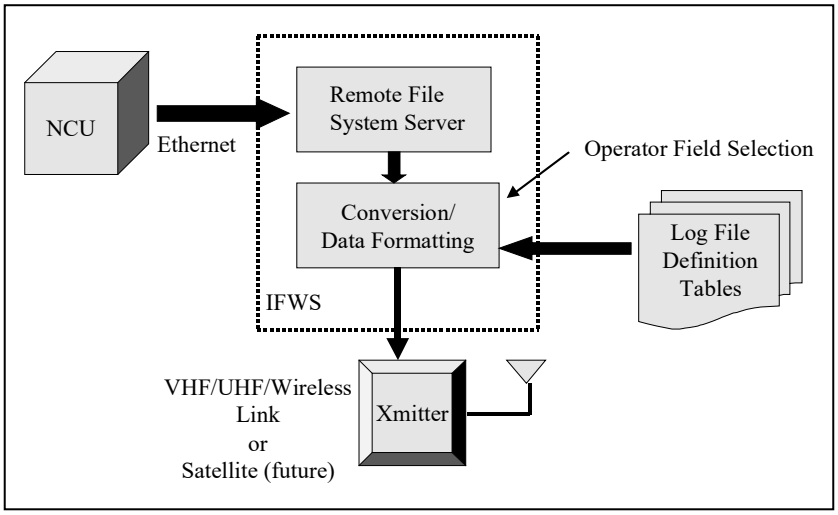


Figure 4. Data Extraction Block Diagram.

In the automated mode, previously defined selection criteria is automatically applied to a log file. When the user starts the extraction process, the requested data fields are extracted from the log file and written to a new output file. The output file is created in a format so it can be used as input to other user applications such as Microsoft Excel.

RFS by the NCU in real-time, as shown in the block diagram in Figure 4. A special output format compresses the data so it can be transmitted to the ground using a 2400 baud rate VHF radio data link. Even though this is a limitation in the amount of data that can be transmitted, useful information can be collected by ground personnel performing site evaluation analysis.

As an example, for an ILS inspection data is collected and processed in the airborne flight inspection equipment eight times a second. The instantaneous data consists of RNAV parameters (A/C position, velocity, heading, altitude) and facility data (modulation, signal strength, deviation, etc.). The final processed data computed after the completion of each run provides facility performance parameters, such as alignment, symmetry, and structure. Even though all instantaneous data cannot be transmitted in real-time at the 2400 baud rate, selected parameters can be sent using a data compression algorithm. The filtering of the transmitted parameters is accomplished using the data selection screen shown in Figure 3. On the ground, this data is expanded and used as input to a graphical display program.

The architecture shown in Figure 4 is not limited to local data transmission using low data rates. This design can easily accommodate other types of transmitters or wireless links. In the future, when the cost of high speed satellite data links becomes affordable, the aircraft flight inspection system can be connected to a wireless Ethernet wide area network, as portrayed in Figure 5.

In this environment, real-time flight inspection data could be transmitted to a ground based central data base where all facility records are maintained, and the required processing is performed to determine the operational status of each navaid. Reported failures or discrepancies would be disseminated in a timely fashion to the designated authorities.

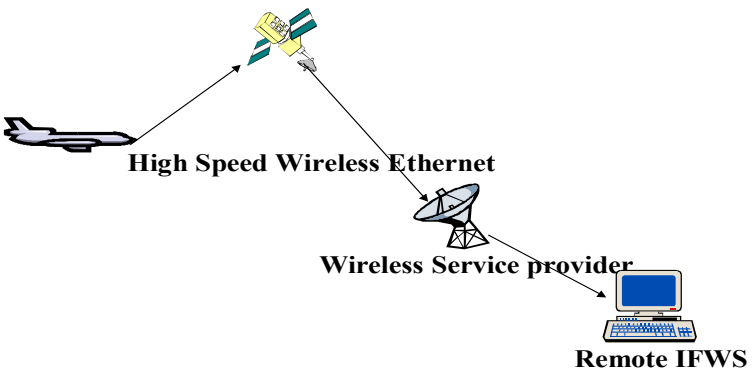


Figure 5. High Speed Wireless Link.

DATA PROCESSING AT FACILITY

So far what was discussed in this paper is the airborne flight inspection equipment architecture enhancements, supporting the extraction and processing of facility parameters for transmission to the ground. What are the benefits and advantages to receive real-time data at a facility from the aircraft that is performing its inspection mission? First, we will address the application of such data at an ILS facility undergoing site evaluation or commissioning. And finally, a future methodology to control the airborne Flight Inspection system from a remote ground location will be presented.

As part of the site evaluation for a new navaid installation, the downlinking of data from a flight inspection aircraft is necessary to make the decision process more timely. The information is used to:

1. Make adjustments to bring facilities to an in-tolerance condition, or to optimize performance.
2. Determine if a site being tested is suitable for a permanent installation.
3. Decide on the type of antenna system to install after a site test.
4. Evaluate problems to decide the course of action, i.e. remove a hangar or modify/relocate an antenna system.
5. Decide on whether to modify antenna systems if the facility performance is less than desirable.

Evaluation of real-time data may reduce the time spent flying a facility if it points to multipath as the source of a problem, instead of other easily fixable conditions, such as transmitter adjustments. Also, real-time data can be used to best utilize the runs, so that the altitudes (or other flight maneuver choices) that are used demonstrate the problem most clearly.

Multipath interference is a concern for many types of ground-based navaids: localizer (LOC), glide slope (GS), and very high-frequency omni-range (VOR) facilities are especially vulnerable to it. This is due to these systems radiating multiple signals, including some that do not contain carrier energy. One "classic" example of LOC multipath is shown in Figure 6. In this example, the energy that travels directly from the LOC to the receiver is called the direct energy. Energy will also arrive at the receiver by way of the hanger and this is called the reflected energy ("multipath"). The "angle of incidence" (δ on the right side of the hanger) will be equal to the "angle of reflection" (δ on the left side of the hanger) of the multipath signal. Due to fact that these two angles must be the same, there is a specific area in which multipath is expected to have an effect. This area of potential interference is shown in Figure 7.

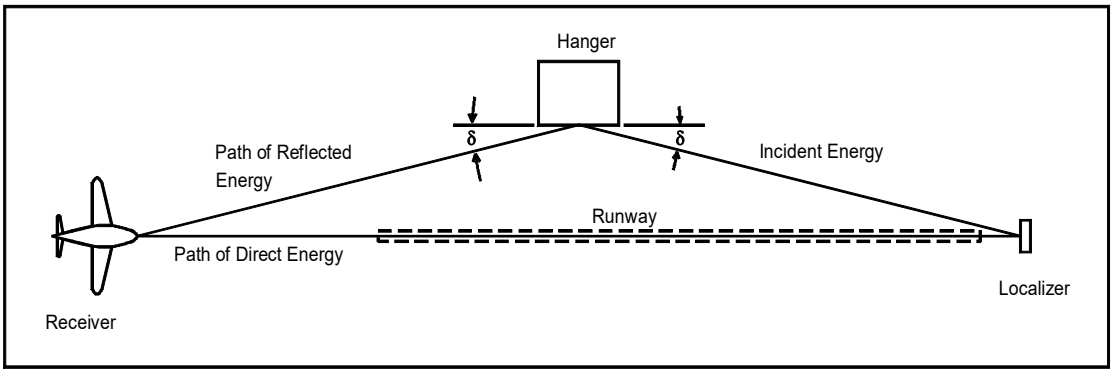


Figure 6. "Classic" Example of Localizer Multipath

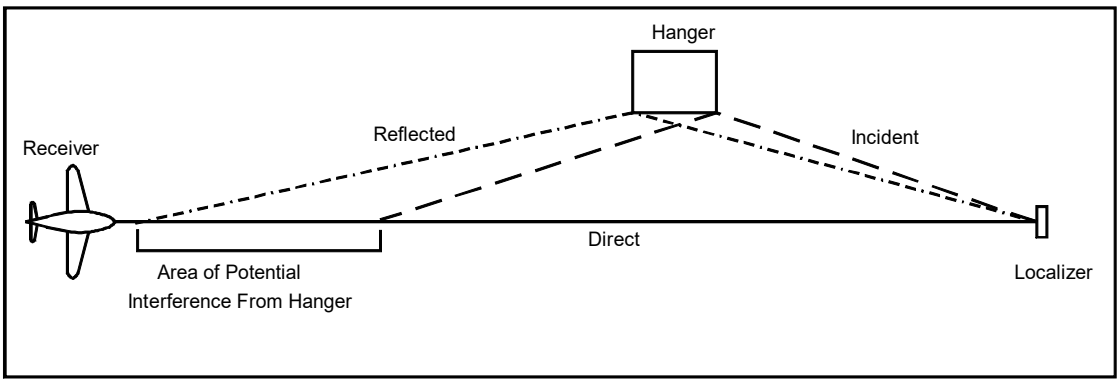


Figure 7. Area of Potential Interference Due to Hanger

For the "classic" multipath case shown in Figure 6, the aircraft receiver output (the crosspointer trace on flight inspection records) will oscillate or produce scallops as a result of the algebraic summation of the signals. The length of the scallops is a result of the geometry, and the amplitude of the scallops is a result of the reflection coefficient of the reflector.

The navaid receiver output will be a complete sinusoidal scallop (360 electrical degrees) every time the difference in the path lengths changes by 1 wavelength (at the operating frequency of the system). For the LOC shown in Figure 6, this means that when the difference between the incident plus reflected path length and the direct path length changes by about 8.9 feet (a localizer wavelength) a complete scallop is produced. The actual value of [(incident + reflected) – direct] is not important, it can be several hundred feet; what is important is that the receiver output will be a complete scallop each time the difference in the expression [(incident + reflected) – direct] changes by 1 wavelength. The distance an aircraft flies for each complete scallop at the receiver output is determined by the relative geometry of the navaid, the reflector and the receiver.

As far as the real-time data being used to evaluate multipath, the crosspointer, the modulation traces, and the AGC are primarily looked at.

One of the uses of real-time data is to optimize facilities in which the multipath aspects may be noticed, but not evaluated in detail. An example is to adjust the antenna phasing of a glide slope and be able to readily see its effect on the signals measured by the aircraft. By having the ability to view real-time data, many of the nuances of improper phasing adjustments may be easily seen on the received signals, and the proper adjustments can be made. This information is not completely described by the data announced by the AFIS computer. However, such numbers can be easily communicated to the ground using a radio data link, and this has been the only method of sharing data with the ground other than landing.

As far as displaying the information, it is desirable to view a graphical display of the traces, something like the graphical traces of a flight inspection record. The scalloping levels provide very valuable inputs in determining the facility operational performance. As far as the computer announcements, such as path width, alignment, etc. they are useful as well.
The system used on the ground for this type of work has an alpha-numeric screen for controlling the saving of data and starting/stopping a run. After the completion of a run, a Windows-based graphical screen provides the ability to look at a portion of the data that is of interest. An additional feature is available that can display the alpha-numeric information for a given frame of data so that digital precision is available, if desired.

Figure 8 is representative of a graphical display of a Localizer ILS-3 run that was generated from actual data received from the aircraft. The top (black) line is the raw crosspointer data, the second line from the top (blue) is the theodolite, the third line from the top (red) is the corrected trace, and the bottom line (red-brown) represents the marker beacon traces. The 250 line represents ideal alignment for the red corrected trace. The outer marker is

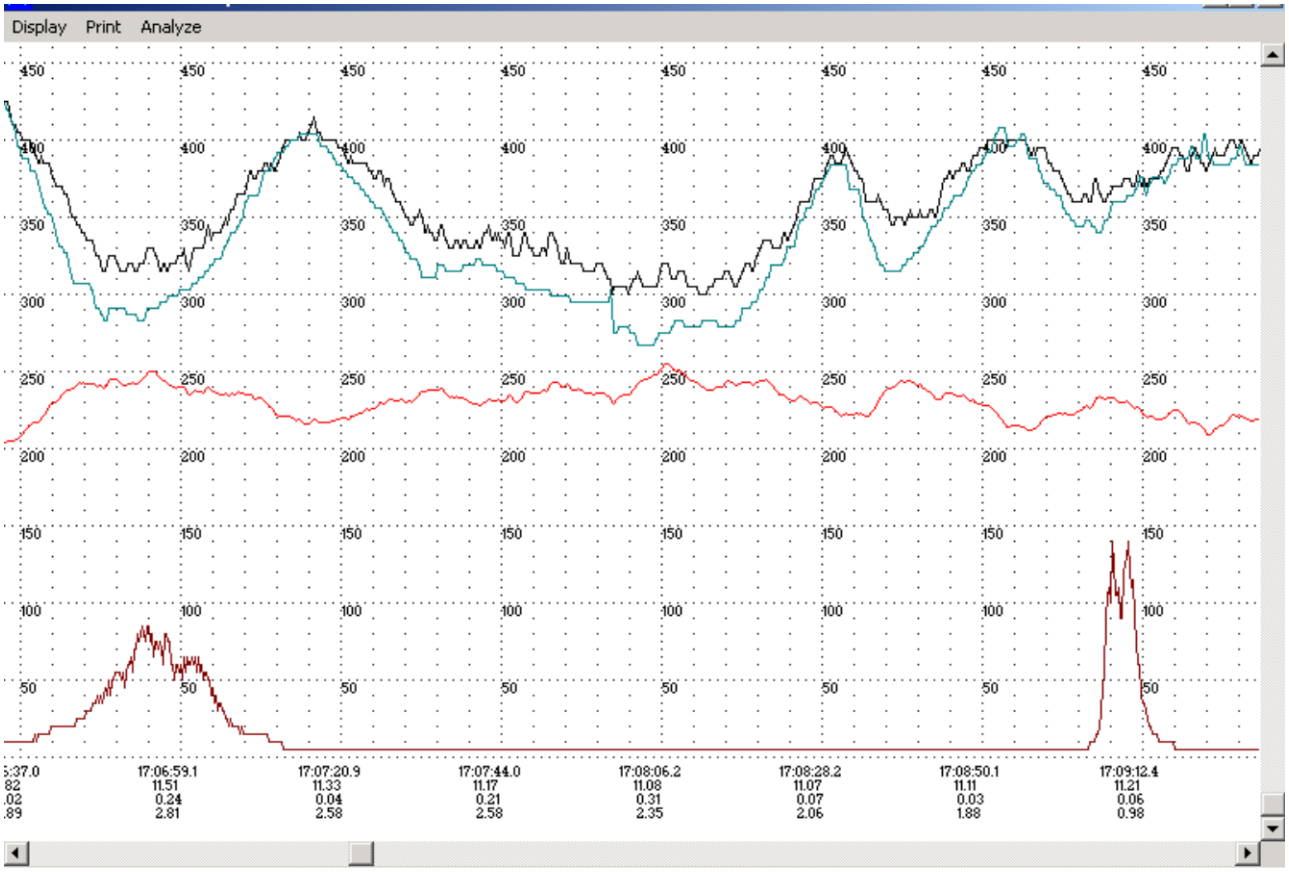


Figure 8. Representative Data Plot on Ground.

shown on the left side of the screen, and the middle marker is shown on the right. The scale at the bottom is (from top to bottom): time stamp, distance from localizer in NM, azimuth from runway centerline and vertical angle from localizer.

REMOTE CONTROL FROM GROUND

One application that has not yet been discussed is the future possibility of controlling the airborne flight inspection equipment for the entire aircraft fleet from a centralized location on the ground. This new approach could offer substantial financial benefits to an organization like the FAA, operating a large fleet of aircraft.

In this environment, the flight inspector would no longer be located in the aircraft, but instead would be operating from a central ground location, having access to the flight inspection system in all the aircraft. In effect, the display and control capabilities would be identical as if he was flying in the aircraft. Furthermore, since all facility parameters would be immediately available on the ground, experts, possibly from a remote location, could address performance issues in near real-time prior to the aircraft leaving the area. Facility malfunctions would be resolved in a much more expeditious and economical manner. This technique is realistic based on records indicating that approximately 85% of inspections are routine in nature, requiring little operator intervention. However, to maintain local control capability, the IFWS will remain in the aircraft.

Another benefit to this approach is the essential elimination of all travel requirements for flight inspectors. The ground-based location selected for the operation and control could be centralized, or distributed among several offices throughout the country.

And finally, another potential advantage is the efficiency of implementing the entire flight inspection mission. In today's environment much of the time is spent flying from one facility to the next, where no flight inspection activity is taking place. Therefore, by having a staff of inspectors in a central location, one individual could control and monitor more than one aircraft at a time. But even if this efficiency cannot be achieved, the inspector would be more productive in a comfortable environment on the ground, and could work on the preparation of inspection reports while the aircraft is re-positioning from one facility to the next.

In summary, a productivity improvement can be realized with a ground-based centralized operation and control of the airborne flight inspection equipment. Even though this feature can be implemented using technology that is available today, the decision is based on the cost trade-off of accessing a high-speed data link system. It is recognized that even though at this time this is not a cost-effective solution, data transmission costs have been going down, and this alternative may be practical in the not too distant future.

REMOTE CONNECTIVITY USING INTERNET

To validate the concept of remote connectivity of a flight inspection system, Parker and the FAA conducted a test in late 2001. The purpose of the test was to determine if a flight inspection system could be reliably operated from a remote location.

The test consisted of controlling and monitoring the flight inspection equipment, located in the Parker laboratory in Smithtown, New York, from the FAA site at the Mike Monroney Aeronautical Center in Oklahoma City. The IFWS at the FAA was connected to the NCU at Parker through the Internet using the Ethernet TCP/IP protocol. Figure 9 is a diagram of the equipment and its interfaces used to perform this test.

It was important to run the system under realistic operational conditions to identify effects from potential message propagation delays. The NCU was operating with a dynamic Simulator that simulated all aircraft RNAV and inspection receiver signals. The ILS-3 Mode was selected on the Simulator and the control to initiate the

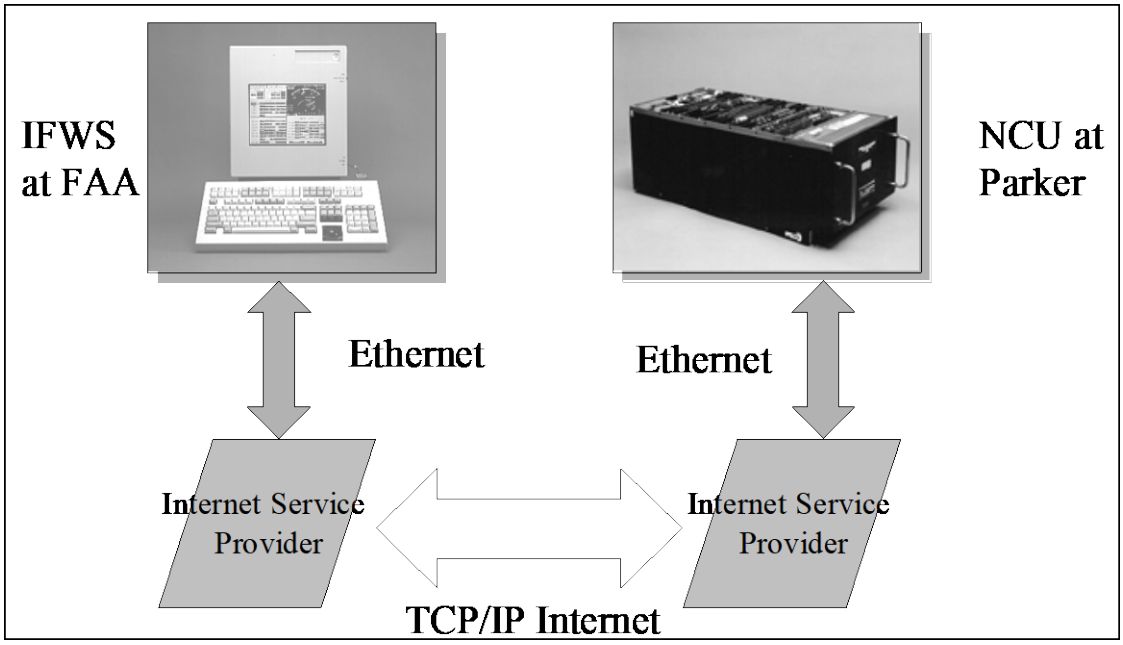


Figure 9. Remote connectivity test environment.

run was executed on the IFWS at the FAA. Coordination of activities was accomplished by telephone.

From the beginning of the run which was initiated at the FAA, the operators commented that the "touch and feel" of the system was identical to a normal local operation. Both execution of commands and display of the flight inspection data on the monitor did not show any noticeable delays. In summary, the FAA personnel felt that the operation of the system from a remote location was a success, and this technique opened the door to a possibly different implementation policy for the flight inspection mission.

CONCLUSION

The Parker flight inspection system has been in operation for over 15 years. During this period many enhancements have been implemented to satisfy the continuously changing requirements for inspecting new types of facilities, and the use of GPS in the approach procedures. Recently, advances made in the field of communication technology have allowed the development of new capabilities that may have a financial benefit in the operation of the flight inspection mission.

In particular, real-time data transmission from the aircraft provides an opportunity to modify some of the methodology in the performance of flight inspection. One such aspect is to provide personnel, located at a facility, parameter information as observed in the aircraft. This has been demonstrated to reduce the time it takes to make adjustments to the various facility components.

And recently, a significant breakthrough was achieved by operating the flight inspection system from a remote location over the Internet. As the cost of high-speed communication decreases, remote control from the ground may be a cost-effective solution in the not too distant future.

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