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EVALUATING THE PERFORMANCE OF SENSOR SYSTEMS BY SIMULATION

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ABSTRACT

The U.S. Air Force, in order to try and improve the image quality of Reconnaissance Sensors, has established a Sensor Evaluation Center at the Avionics Laboratory located at Wright-Patterson Air Force Base in Ohio. This organization has been involved with environmental testing to determine and improve sensor system performance for many years. Its unique test evaluation methodology, equipments, and personnel have evolved a new analytical test philosophy that stresses physical and mathematical simulation or modeling together with pre and post flight tests to verify, validate, modify and estimate performance results. This overall scheme is called "the closed loop approach."

The concept's primary elements are physical and mathematical model simulations performed at the Dynamic Analyzer Complex. This facility simulates the environmental phenomena experienced by reconnaissance sensors in-flight. This simulation embraces a testing philosophy which rejects the piecemeal of fragmented approach apparent in "classical" environmental specifications, and instead directs its attention to the actual sensor vehicle environment. Sensor systems undergoing tests in the capsule can be tested under any or all environment variables including pressure, temperature, roll, pitch, yaw, humidity, and vibration. In addition, math models addressing image motion, geometry, target contrast and energy are used to validate/predict sensor performance throughout the test and evaluation cycle. It has been shown that simulation and modeling techniques are an extremely important part of the analytical cycle.

INTRODUCTION: The rapid pace of technological development in reconnaissance related engineering and scientific areas has presented some rather difficult problems to engineering management. In the past, emphasis generally has been given to the developmental rather than the analytical aspects of advanced sensor system development; those engaged in system performance analysis often have not received adequate support to accomplish their work properly.

The relegation of performance analysis to a secondary or "afterthought" position has been detrimental to the development of many sensor systems because some serious problems were not identified and corrected during system tests. As a result, some expensive, time consuming modification programs have had to be implemented after systems have been released to the operational users. It is essential that today's analytical engineers, with support and encouragement from management, develop their individual skills and expertise as well as their laboratory facilities so that they can provide the analytical support needed for the development of future reconnaissance systems.

This disregard for sensor performance analysis has led to unrealistic testing procedures where system design engineers were concerned primarily with designing equipment that would pass the environmental tests; system performance was a secondary consideration. Not only did the pragmatic approach taken by the designers eliminate many promising sensor system designs, but it also forced the costs of development, production, and operation to be much higher than necessary. Over design has not necessarily contributed to system performance but it has increased costs significantly.

As long ago as the late 1950's, it became apparent that new methods and approaches were required to adequately test and evaluate advanced reconnaissance sensors that were then in the conceptual phase of development. A new testing philosophy slowly evolved that has recognized and dealt with many of the major problems that have faced analytical engineers since that time. For example, the ability to perform static bench tests was recognized as an important first step. Following static tests, there was a need to subject the sensor system to the same dynamic environment that was to be found in-flight. To accomplish the latter task, two important things were needed: a facility that is capable of physical and mathematical simulation of the dynamic environment of flight, and a suitable method of determining just what the in-flight environment was like.

The word "simulation" is defined by Webster as, "having the appearance of, to be more like, an imitation of." This definition infers that simulation provides a basis for comparison which, incidentally, is the way simulation is used at the AF Sensor Evaluation Center (AFSEC).

Very simply stated, the simulation techniques employed at the AFSEC permit the analytical engineer to integrate all facets of test and analysis into a cohesive solution describing total system performance.

The simulation consists of both physical (Dynamic Analyzer) and mathematical (Modeling). Each is described in the following.

DYNAMIC ANALYZER. The basic concept of dynamic analysis has slowly evolved since the late 1950's. Prior to that time, it was assumed that flight tests provided the only true measure of a reconnaissance system's performance. As a result, essentially all system performance tests were conducted in-flight. Although that assumption was basically correct, flight tests were not then, and are not now, cost effective during early phases of system performance evaluation. It would be virtually impossible to install a new reconnaissance sensor in a selected test aircraft and have it operate properly unless sufficient preliminary testing was performed prior to beginning flight test phase.

Dynamic analysis is defined as that phase of testing that follows the static laboratory bench tests but precedes flight tests. It involves subjecting the candidate sensor system to essentially the same dynamic operational environment that would be experienced in-flight. The key to the dynamic analysis process is the realistic environmental simulation and modeling in a controlled laboratory setting. In general, dynamic analysis has proven to be very cost effective because it allows the entire system to undergo extensive operational and performance tests prior to flight. Although the dynamic analysis concept is neither fully understood nor accepted at all levels, its validity has been demonstrated continually since the Dynamic Analyzer began operation in 1963.

The Dynamic Analyzer was completed and placed in operation in 1963 following several years of experimental and developmental work. The primary purpose of the new facility was to provide the expertise needed for laboratory testing and evaluation of reconnaissance systems and subsystems undergoing development. Secondary purposes included measuring baseline and operational performance levels, determining design and operational deficiencies, and proposing and testing alternative solutions to system performance problems. Since its inception, the Dynamic Analyzer has been very effectively utilized on a large number of significant projects and programs.

The heart of the Dynamic Analyzer is a 27-ton stainless steel capsule that is capable of subjecting payloads weighing over 2300 pounds to selected dynamic environments (See Figure 1). Because of the very generous internal dimensions of the capsule (i.e., a cylinder with a diameter of six feet and a length of ten feet), rather large payloads can be accommodated (See Figure 2). Indeed, most airborne sensors, sensor mounts, and in some cases, even actual aircraft equipment bay sections can be placed inside the capsule for tests. Specifications for the capsule are shown in Table I.

In addition to the capsule described above, an extensive array of other types of sophisticated equipment and facilities are available within the AFSEC to support analytical programs.

For example, the AFSEC has its own film processing laboratory and data processing center. It also has shop facilities for designing, building, checking and installing environmental instrumentation packages for both in-house and flight test programs. Other features, somewhat unique in the optical field, include a scene simulator, an FMC simulator and a low light simulator. In summary, the AFSEC has an in-house capability for measuring a sensor's performance while subjecting the entire reconnaissance sensor system to very carefully defined and controlled environmental conditions.

THE DYNAMIC ANALYZER SIMULATION CYCLE. The total analytical process employed at the AFSEC involves other steps or phases in addition to dynamic analysis.

Prior to the arrival of a sensor at the AFSEC for evaluation, the requestor, in consultation with an in-house engineer, has generally established most of the major test objectives and parameters. For example, the test requestor usually designates what type of aircraft and mission profiles are to be used, where and how the sensor and its components are to be installed in the aircraft, and under what conditions the sensor system is to be operated. If environmental data are available for the specific conditions described by the requestor, they are prepared so that they can be used to control the capsule's environment during the dynamic tests. In the event such data are not available, arrangements are made to fabricate and install a standardized instrumentation package in an operational aircraft for the acquisition of the desired data. While vehicle environmental data are being collected and processed, the sensor system and its components are subjected to a series of laboratory static tests designed to determine their operational condition as well as their baseline performance levels. After the preliminary testing phase has been completed, the sensor system, including its mounts and when possible the entire aircraft equipment bay, are instrumented and placed in the capsule for the dynamic testing phase which follows.

Tests conducted during the dynamic analysis phase range from extremely simple to very complex. For example, sensor systems undergoing tests in the capsule can be subjected to a single variable such as temperature or pressure, or several different variables such as the motions of roll, pitch, yaw and vibration, each tested serially. In the most complex tests, all environmental parameters are varied concurrently according to predetermined environmental data. During the entire dynamic analysis phase, system performance is carefully monitored and correlated to the various programmed events tested. As a result, many important operational problems are discovered and corrected during this phase. Unforeseen problems of this type are often very difficult to resolve if they occur during flight tests because a test aircraft simply cannot be placed on "hold" while a group of engineers and technicians attempt to locate and correct a particular problem. Fortunately, the capsule does have a "hold" operational mode and it is frequently used. Following the dynamic environmental tests, the performance data are reviewed and recommendations are made regarding the system's performance, deficiencies and limitations. If needed, recommended corrective actions are also included. Finally, the resultant test data are used to forecast the probable level of system performance when the system is installed on an aircraft for flight tests.

The final test phase of the analytical cycle is primarily concerned with flight testing the candidate system. If the work done during the previous phase was accurate and complete, the flight tests simply verify those results. Over the years, flight test performance levels have been predicted during the dynamic analysis phase. These predictions have generally been very accurate when compared with the actual flight test results. Verification and/or other feedback is provided to the requestor, as well as to design and performance engineers, thus closing the analytical cycle "loop."

MATHEMATICAL SIMULATION. System performance is also investigated using suitable modeling and simulation techniques in lieu of flight or Dynamic Analyzer tests. This mathematical simulation is performed in conjunction with the Dynamic Analyzer or flight tests. As tests are performed that provide environmental data on the sensor such as natural frequencies, etc., these data are applied to the models to predict and verify test results.

The mathematical models available at the AFSEC are used in routine analysis like any other instrument or tool. During their use various models have been refined as new data has become available--refined in the sense of greater utility and improved validation. However, even though the models are highly sophisticated, they are still a simulation of the real world and not an actual representation. Indeed, they are like road maps because they can show the route to take in order to arrive at a specific destination and they also indicate many problem areas along the way. Like road maps, however, they require human judgements for effective use.

A system analyst can use the more sophisticated models to create a new system's design. During this type of analytical exercise, numerous system parameters are submitted to an iteration process in order to determine the performance tolerances for critical components. This results in a theoretically optimized system for the given flight conditions. In addition to the usual design data compiled during the exercise, other related data are available for inclusion in such items as operational handbooks.

During the data analysis phase of both laboratory and flight tests, models are used to evaluate many aspects of system performance. The principle use of models during this phase of evaluation is to permit the reconnaissance problem to be divided into subelements. These elements are first analyzed separately; then their results are combined, thereby forming an integral part of the closed loop cycle described above. Models are used to address four major areas of data analysis: image motion, mission geometry, target contrast, and target energy. Each area is discussed briefly below.

System motion data (pitch, roll, yaw, vibration and V/H) are measured, recorded, and processed to determine discrete values. The unique data thus acquired are then evaluated using a model to postulate system resolution. This task is accomplished by first examining each motion variable as a single parameter and defining the resultant performance limit. After the limits are determined for each of the motion parameters, they are combined to determine their integrated effect upon system performance. Then computed values can be presented as a single value related to specific sensor images, or combined statistically to summarize the entire mission data set.

Mission geometry is modeled to include the following parameters: altitude, sensor look angle, angular coverage, and the sun/target relationship. During this process, energy and contrast values are compiled for the specific test conditions encountered. Contrast variations and system resolution are evaluated to identify the threshold limits. The energy data are then used to evaluate photographic exposure variations and performance limits.

The final step in the data analysis procedure is to correlate the limitations imposed by the various parameters to system performance. At this point in the program, data generated by the baseline tests, the modeling programs and the various simulation tools are utilized through closed loop analysis to assess the reconnaissance system's performance capability.

COST SAVINGS THROUGH SIMULATION AND MODELING. At the present time, the entire research and development community is facing three major problems. Costs are escalating because of inflation, budgets are being reduced, and the users are pleading for better equipment in terms of performance and reliability. There seems to be just one acceptable answer; somehow we must do more with less.

The costs involved in research and development testing are certainly not incidental. An old saw has it that "Adequate testing costs too much, but too insufficient testing costs even more." The obvious answer, of course, is simple--to find the optimum cost/test ratio and then apply it as needed. The ideas just expressed are not to ridicule our concern with the costs of testing; rather, they are intended to draw attention to cost as a real constraint imposed upon the research and development community. In a sense, budgetary constraints are good because they force most groups to focus more precisely upon real problems and to avoid the incidental. They also encourage innovation, i.e., more efficient and effective ways of accomplishing necessary tasks.

The AFSEC has made some rather significant contributions to operational systems that have resulted in substantial cost savings. For example, evaluating the performance of sensor systems used in high-risk or one-way vehicles, such as drone aircraft or missiles, can be rather difficult because neither the vehicle nor the sensor system are always recovered. This type of problem was readily solved by subjecting the sensor systems to simulated dynamic environments similar to those experienced in-flight. As a result, cost savings equal to the entire cost of the Dynamic Analyzer

Facility were realized during its first year of operation.

More recently, an optical reconnaissance sensor system was developed, flight tested, and placed in the operational fleet. The users, however, were unable to make the system perform at its designed level. Some rather expensive proposals for system modification were prepared, but it was decided that the problem should be studied at the AFSEC before any modification plan would be approved. An operational sensor, including the entire aircraft equipment bay, was subjected to a series of dynamic environmental tests. The cause of the problem was isolated, identified, and corrected. It was found that a small shim was needed to correct the lens focus problem. On other occasions the mathematical simulation of a sensor system has even eliminated the need for tests or specified early design changes.

In terms of both cost and time, simulation of the dynamic environment makes a great deal of sense. From the cost point of view, tests that involve simulators rather than aircraft are much less expensive. For example, on large programs there seems to be a cost difference of about one order of magnitude. Likewise, if time is important, tests involving simulation can usually be completed in about ten percent of the time needed for flight tests. From the above, it is apparent that adequate testing is necessary if system costs are to be held at a reasonable level.

CONCLUSION. For the past decade the Air Force Sensor Evaluation Center has been actively engaged in work involving the three test phases of the Research and Development Cycle: static and bench tests, dynamic and environmental tests, and flight tests. Experience has shown that dynamic analysis, through the use of modeling and simulation techniques, can provide a basis for identifying and correcting most operational performance deficiencies prior to flight testing. As a result, substantial savings in both resources and time have been repeatedly demonstrated. The adoption of a more realistic test concept such as advocated above will provide results that are cost effective and conclusive. The time has now come to replace the old adage quoted earlier. It should now state, "Insufficient testing is expensive, whereas adequate testing pays dividends." Furthermore, it has been shown that simulation and modeling techniques are an extremely important part of the analytical cycle. Through simulation and modeling it is possible to relate system baseline performance to probable operational mission performance. With this improved knowledge of the system's performance capability, operational users can more effectively optimize reconnaissance missions.

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TABLE I

Chamber

Internal Dimensions

Length - 3.96 meters (13 ft)
Diameter - 2.13 meters (7 ft)
Weight - 24,494 kg (54,000 lbs)
Material - 304 Stainless Steel
Chamber Support - 6 Hydraulic Rams; (3 vertical and 3 horizontal)

Capsule Motion Parameters

Roll - $\pm 15^{\circ}$, .1 Hz to 30 min/cycle, to 5 Hz at less angular displacement.

Pitch - $\pm 15^{\circ}$, .1 Hz to 30 min/cycle, to 5 Hz at less angular displacement.

Yaw - $\pm 2^{\circ}$, .1 Hz to 15 min/cycle, to 5 Hz at less angular displacement.

(The yaw point of rotation is variable from the center of gravity out to 9.14 meters (30 ft) at 1.52 meters (5 ft) increments).

Chamber Internal Environments

Vacuum - 3.8×10^{-7} torr, 241.4 km (150 miles) alt.
Temperature - -73° to 177°C.
Vehicle Section Heating - Up to 300,000 watts quartz lamps. Programmed temperatures up to 427°C.
Subsystem Modular Cooling - Separate conditioning air (hot or cold) for equipment or compartments.

Payload Vibration

Vibration - 2 to 800 Hz at 0 to 5 g's (3-dimensional).
Actuators - 12 (2 opposing pairs on each of three mutually perpendicular axes).

TABLE I (continued)

Target Cart (Visual)

Optical Collimator

Focal Length - 4.27 meters (14 ft)
Clear Aperture - 457 mm (18 inches)
Resolution - 100 lines/mm
Image Motion - .254 mm to 2.54 meters/sec (.01 to 100 in/sec)
Light Intensity and Spectral Characteristics - Controlled.

Target Cart (Infrared)

Viewing Altitude - 60.96 mm (200 ft) to infinity.
Spectral Range of Targets - 1 to 20 microns.

Target Motion - Simulates target motion from .005 to 7.0 radians/second.

Infrared Targets/Moving Targets - Simulates targets to perform resolution and sensitivity tests, both along and across the simulated line of flight with a temperature range from -20° to $500^{\circ}C$.

Calibration Reference - Target temperature adjustable from -20° to $100^{\circ}C$; eight operator selected filters and nine operator selected apertures in any combination; drive permits target positioning at any point in target field.

Thermal Gradient Target - Adjacent extended sources with temperature differential adjustable from 0 to $15^{\circ}C$ and average temperature adjustable between -20° to $300^{\circ}C$.

Modulation Transfer Function (MTF) - Modulation-Transfer-Function image analysis with temperature range from -20° to $500^{\circ}C$ and background simulation from -25° to $50^{\circ}C$.

Background Temperature - Simulates a constant background temperature adjustable -25° to $50^{\circ}C$.

Light Intensity - Controlled.

Spectral Characteristics - Controlled.

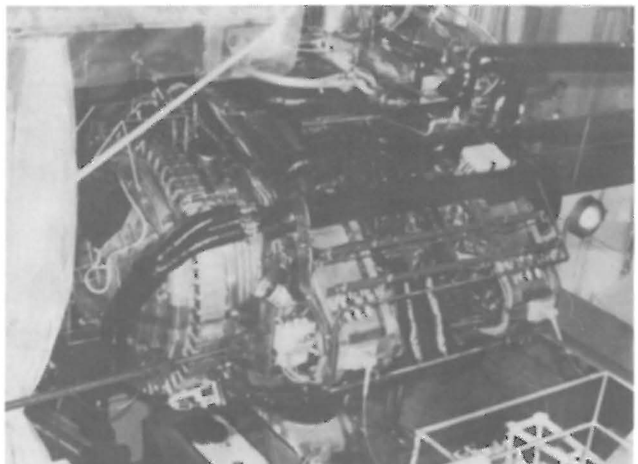

FIGURE 1. DYNAMIC ANALYZER

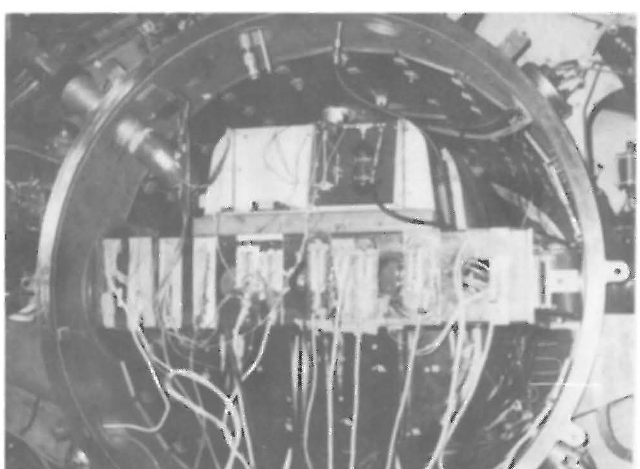

FIGURE 2. INSTRUMENTED PAYLOAD