Skylab Checkout Operations

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The Skylab Program at Kennedy Space Center presented many opportunities for interesting and profound test and checkout experience. It also offered a compilation of challenges and promises for the Center and for the contractors responsible for the various modules making up Skylab. It is very probable that the various contractors had common experiences during the module and combined systems tests, but this paper will discuss those experiences from the viewpoint of the Multiple Docking Adapter contractor. The experience will consider personnel, procedures, and hardware.

PERSONNEL

Earlier programs of multiple launches (Gemini, for example) demonstrated two areas of concern with personnel. First were start-up concerns associated with the formation of the test team. New relationships had to be formed as the team members learned to work together, the process of certification and training had to be carried out, and the new customer and his methods of conducting the Center's operation had to be learned. These items usually have wrinkles, but these wrinkles can be straightened out by the time the second vehicle is in test and the teamwork continues to smooth out on subsequent vehicles. Then later comes the inevitable last vehicle and with it a new set of concerns for the test team - will the men and women work full-bore, dedicated, and above all carefully on the last article in the face of their individual concerns over their individual futures? On past programs these last-article worries were diminished through the application of various motivators and panaceas - bonuses, promises of transfers, recognition from the home office or plant, and assistance in job hunting; these steps, plus the professional pride of the individuals, have prevailed and the multiple flight programs have gone to the wire with the last flight as good as any - a tribute to those individuals who were concerned for their future but were competent professionals above all.

The Skylab Program at KSC didn't have either first-flight start-up concerns or last flight let-down concerns; Skylab had both at one time.

The Skylab test teams were assembled through personnel relocations from many areas; the Workshop from Huntington Beach, the Airlock from St. Louis, the MDA from Denver, and the Telescope Mount from Huntsville (the Apollo CSM crew was incumbent). For the MDA, as for other modules, the start-up was assisted greatly by a diffusion of personnel representing two primary experience resources. The cadre of the team was dominated by personnel representing experience in working with KSC on prior programs such as Gemini and the Lunar Module. This cadre was later augmented by personnel with actual module design, build, and test experience - the relocations mentioned above. This dual reservoir of talent and its diffusion formed a team optimized for testing one-time modules, and the team's performance verified this approach by responding quickly into cohesive units.

PROCEDURES

Spacecraft testing at KSC is a disciplined effort pragmatically developed. No screw is torqued and no switch is thrown unless the specific action is called out for in writing. Whether by Test Preparation Sheet (TPS), Discrepancy Report (DR), or by Test and Checkout Procedure (TCP), all actions are specified in advance, reviewed by the NASA-Contractor counterpart check and balance system, and released for action by the Operations area of KSC. The function then is performed as written and is verified by contractor and NASA Quality personnel. Any departure from the written procedure must be done under the control of a deviation in writing which in turn is also subject to the counterpart check and balance controls and the functional Quality surveillance enforced on the original paper authorization. This discipline and control may appear slow to some, bureaucratic to others but necessary to the experienced. It was conceived, enforced, and reinforced for the Apollo Program; who can rise and criticize the results?
An interesting note with reference to the development and performance of procedures should be added at this point. Crew interface training is augmented at KSC during spacecraft checkout. Therefore, the procedures are developed in accordance with the crew "checklist" which is the procedure they will use while operating in space. This accomplishes two things: it verifies the checklist and the capability of the astronaut to accomplish the task.

For a program consisting of "N" launches, these controls have resulted in a learning curve in which the first article as-run procedures, with their deviations, were recompiled into clearer, more efficient procedures for the second, improved again for the third, and the benefit of experienced crews and clear procedures enhanced precise scheduling, successful testing, and reduced effort for subsequent articles. For Skylab, with "N" equal to one, none of the learning curve benefits occurred. The as-run procedure, often a six-inch stack of paper, was more pink (deviation) than white (original TCP).

The schedule for the Skylab flow through KSC was established and announced as a success-oriented schedule. It was based upon a two-shift, five-day week with the expectation and realization that the work would expand to fill the allotted time. Experience had shown that a factor of 1.6 was a realistic estimate of the growth in consumed time between the success-oriented (green light) schedule and first-article realism. This factor has proved to be an optimistic approximation for Skylab. The original posted flow schedule has been held quite well, but only by growing the available time by increasing to full 24-hour shifts and at least six and more normally seven-day weeks. Procedure difficulties significantly forced this growth, but not from any single cause. There were many: New teams were producing the procedures; the hardware was being modified; the test requirements were immature; few as-run procedures were available; the procedure release fell behind test-start desired lead time; and, above all, no program had ever before encompassed the complex inter-module and inter-contractor interfaces. The MDA, for example, looks aft at the Airlock and McDonnell Douglas, to the side (deployed) at the ATM and Marshall Space Flight Center, and forward at the Apollo CSM and Rockwell International. Procedures had to accomplish integrated tests required over 10,000 pages of basic procedures, and deviations typically replaced half of these pages during the conduct of the test.

Repeating, the interfaces were more complex than any previous spacecraft, the teams were new, the time was short, the requirements were immature, the hardware was newly developed, and the test procedures were being released only days before the start of testing. Even with these hurdles to overcome, the O&C testing was completed within two weeks of a target date established five months earlier!

HARDWARE

The interfacing complexity of the Skylab modules has previously been mentioned (1,900 interface functions), but it is difficult to portray the complexities of the module systems, subsystems, and experiments. (An example can be derived from the data flow from one experiment, the S192 Multiband Scanner. It fills 24 tracks of tape of 20,000 bits per inch resolution at 60 inches per second.) Some of the module systems were inherited from Apollo and had development and test maturity, but they now had to support an eight-month mission. Most systems were newly developed for Skylab, and all experiments were new developments of sophisticated equipment. Their degree of development could best be indicated by counting the remove-and-repair cycles, but it can be simply stated that all of the experiments on the MDA were either removed and repaired or replaced or repaired in place, plus a high percentage of experiment support equipment. And some more than once!

On previous programs, several techniques were employed to verify that the facility and GSE would be compatible with the flight hardware. Facility verification vehicles and separate GSE for each location were allocated to insure trouble-free checkout.
For most of Skylab, only one set of GSE was allocated and it moved with the vehicle.

As is always the case when complicated electronic equipment is moved, the probability of creating problems is increased; therefore, scheduled time is increased. The converse is also true in cases when existing facilities and hardware could be pressed into use at KSC to help analyze the complex experiment data. Through simple changes and utilization of existing computer facilities, tests were monitored real time for the first time in the program. Computer programs were developed to analyze the data and permit problems to be promptly defined and corrected, and this helped to offset problems associated with the relocated GSE.

One module stood out from the rest early in the test cycle at KSC — the Apollo Telescope Mount. It had fewer schedule delays, less growth in shifts worked over planned shifts, fewer items of open paperwork (Discrepancy Reports, Deviations, and Test Preparation Sheets), and less equipment changeout. From this module’s performance, one should and can extract some do-better-on-future-program ideas. For example, Post Manufacturing Tests at Huntsville and Thermal System Tests at Houston were run with KSC procedures and other KSC paperwork. By the time final testing was done at KSC, the procedures had been used, modified, and verified.

In addition, the thermal vacuum testing at Houston (JSC) was unique for the Saturn Workshop and represented additional test time and test experience for the ATM and its team. The ATM, therefore, benefited from the use of as-run procedures, from the experience of a crew which had progressed through three major ATM tests plus thermal simulation tests, and from the maturity of the hardware as a result of the extra tests. This programmed flow of the test team and the early use of KSC procedures and paperwork should be considered by anyone in planning a future program which flows through KSC.

An unrelated oddity stands out from the above discussion. Only the unmanned module of the Saturn Workshop had its orbital performance verified in a thermal vacuum chamber. The manned modules, the Airlock, the MDA and the OWS, have never had their internal environment verified by thermal vacuum test — only by analysis. This is a "first" for manned space flight, and it represents not recklessness but the recent advancements made in thermal analysis, the profound developments in thermal computer programs, and the degree of faith placed in computer models of the cluster. It is a balance between the similitude errors of thermal testing and the correlated accuracy of analysis, plus the programmatic aspects of cost and facilities required for thermal testing of such magnitude as would be required for the OWS.

Some examples of uncertainties in computing influencing parameters on the module thermal systems are solar constants, albedo constants, earth emission, internal power, boundary temperatures, surface absorptivity and emissivity, linear conductance, and view factors. Among these, many carry over into thermal vacuum testing as uncertainties (the first four, for example) and others such as the boundary temperatures are unrealistic in a gravity-dominated environment if air is used and also if a vacuum is substituted. In the two-gas (Skylab air) environment, attempts to inhibit convection cause sacrifices in radiation similitude, and convection within the liquid system introduces an error into the test which has to be analyzed out as in the two-gas inhibited convection, impeded-radiation case.

The best justification for the rationale for using analysis in place of complete module thermal tests can be found in the correlation of predicted versus measured temperatures associated with the ATM analysis and test. This complex spacecraft yielded excellent correlation between the analytical model and test results.

For ATM rack-mounted components, the more difficult analysis zone of the component locations showed over 93% of the test measurements agreed within 10° F of the predicted temperatures. In a thermally well-designed zone, the correlation was even better with only a 5° F variation measured in the same 93% band. These measurements were taken over various cold, nominal, and hot case runs, and represented a variety of measurement locations within the test zones.

Another measure of the prediction accuracy of the ATM can be found in the design changes resulting from the test results. Only nine components were indicated by test results to be operating outside of their design limits. Five of these were corrected by additional insulation and isolation, three had their lower qualification temperatures reduced, and one had a ten-watt heater mounted to adjacent structure. None of these changes involved a component design change. This was a significant vote of confidence for the accuracy of thermal analysis.

In summary, the programmatic aspects of cost did not dominate alone — the lack of zero-g similitude in the testing compared
to the accuracy of the developed math models enabled a well justified decision to use analysis to verify that the internal environment of the modules will be comfortable and safe for the crews and that the equipment will be operated within its design temperature band.

SUMMARY

If this paper appears to be only a compendium of difficulties and complexities impeding efficient and successful testing at KSC, then the results of these tests to date indicate that more was done to assist than to impede. Naturally, this is the case, as the Skylab Program represents a major accomplishment by NASA in program integration. Through the use of formal reviews, interface functional simulators, interface control documents, matched tooling, and a broad application of good systems engineering, this complex space station came together for the first time at KSC with no mechanical interface mismatches, no electrical interface mismatches, no major systems problems, and no serious delays. The integration "homework" produced good hardware, the test philosophy will assure program success, the procedural rigor at KSC assures the fulfillment of test requirements, and the professional pride of the participants will assure a safe and successful mission.