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DELTA LEGACIES
IN
LAUNCH COST REDUCTION

By
Philip W. Payne

ABSTRACT

Delta launches have had a high success ratio. One factor has been successful field processing. Review of hard experience and study of critical costs, produced a test philosophy which led to development of improved methods and equipment. This test philosophy saw several virtues in the minimization of human access to flight hardware, both in and out of test.

Planning and precision were the adopted characteristics of "people performance." Automation and mechanization of test exercises and of data-taking were implemented by launch site concepting, designing, and fabricating special test equipments. These are illustrated and discussed.

The success of these methods and equipments has had time to mature in routine use. Evaluation indicates they made a major contribution to the outstanding cost effectiveness and reliability of the DELTA LAUNCH VEHICLE.

INTRODUCTION

The Delta Program began in 1959. It has run twenty-five fruitful years and launched more than 200 satellites with perhaps the most efficient space rocket serving the scientific and civilian community. Now the end of the Delta Program may be in sight. Only five American launches remain scheduled, three this year. This paper, in reporting the origin and ontogeny of Delta's field processing methods, may serve the operational refinement of other present or future programs.

BRIEF HISTORY

First launch of a Delta was May 13, 1960. It carried an Echo passive balloon satellite and was unsuccessful due to a second stage attitude control system malfunction. Following a path thereafter of relative success, as compared with other launch vehicles, Delta continued through generations of technical growth. Under a very small management team which allowed it to be efficient, the Delta found new uses and customers beyond the first buy of 12 vehicles. Goddard Space Flight Center's Delta Project Management established a Delta strategy of **simplicity**, economy and progressive, but very careful, growth. Largely ignored by greater movements in the federal machinery, the Delta persisted and performed. It endured, grew and provided service to a wide range of customers over many years. The last US Delta launched at this writing (March 1984) was number 174, the 40th consecutive success of the complete vehicle. Japan bought a transfer of Delta technology from McDonnell Douglas. All 13 of the Japanese launch vehicles performed through injection properly. No satellite-launching rocket has equalled that record.

Out of the 174 multi-stage American Delta vehicles launched, all stages performed as required on 163. Eleven failed to carry out their mission. This record of reliability is high among its peers. The preponderance of the 11 failures occurred in the first half of the program, seven in the first 86 launches.

The four failures in the last 88 launches have all been caused by latent flaws (structural or component failure) not detectable in field processing.

This success has been due to a few elemental factors: (1) The basic Delta hardware has been a sound product, well screened and tested in manufacture, of design as simple as possible consistent with its mission, and, in ruggedness, somewhat forgiving -- even without much redundancy. (2) The people of the Delta Program have been talented and dedicated, enduring and motivated -- because all stages of the Delta, as well as software and flight predictions, have been the product of one company, because the program organization is simple, and because communications therefore have always tended to be personal and easy. (3) Field operations have developed refined disciplines in that final arena of flight preparations and high-cost consequences.

Cost of the Delta has been modest, owing to tacit program policies: (1) To shun unnecessary complexity and (2) to avoid new developments where the extemporization of elements already perfected for other programs could be availed. Delta was an outgrowth of Thor and Vanguard. They paid its primary development cost. The use of available systems has been a Delta hallmark. For years the second stage engines were excess lunar-lander engines. The first stage main engines for the last 78 Deltas manufactured have been repackaged surplus engines from the Saturn I-B program. The first stage hydraulic system was modified to use "surplus" Saturn IV-B integrated "power pacs". The Delta flight computer and strapped-down guidance system is an adaption of the lunar lander backup navigation system, recently further developed for Delta by McDonnell Douglas to add redundancy. It has flown successfully in all 91 (including Japanese) of its flights.

In terms of payload-value delivered per dollar actual cost, the Delta exceeds other satellite-injecting rockets. Until now STS users have been charged token costs to induce their participation. Actual cost comparison with the Delta would be unfair until after greater STS maturing.

In terms of Government dollars outlaid for development, the availability of Delta as an American tool has been achieved for the users of the world at very low cost. This is because, first constructed out of other-developed elements, the Delta improvements were fully amortized on programs such as Thor, Vanguard, and Saturn.

Commercial and foreign users have been charged full costs of growth and improvement, as well as stage manufacture and field operations. These charges, undertaken and paid profitably (because they were economical), have included pro-rata shares of all Delta's many stair-step growth developments. They have also included cost of all problem pursuits and failure investigations through all remedies and improvements. For many years, the American taxpayer has had no development or underwriting burden from the Delta. He has paid for it only when used as the vehicle for a Government launch. It should be noted that the Castor IV (3900) and PAM-D upgrades of the Delta's launch capability were the first commercial space launch vehicle programs. These programs were commercially funded by McDonnell Douglas with development cost recovery through commercial foreign sales.

A share of the cost control and reliability has been in the field. While the Delta is largely manfactured in Huntington Beach, California, the stacking and completion of the vehicle on its launch pad entails field assembly of over ten thousand components. In complexity of assembly, with the nine strap-on solid motors, their quick separation systems and all the thermal protection provisions that must go with them, the field preparation of Delta is equal to or greater than the effort required to stack and prepare any other expendable, multi-stage vehicle, yet the manpower to accomplish these tasks has been characteristically less than for other vehicles, as shown in Table -I-.

TABLE -I-

TYPICAL (1981-1982) LAUNCH TEAM PERFORMANCE COMPARISON

	Head Count (H/C)	Launches/Year (Total)	Task Complexity Factor (C.F.)	Figure Of Merit (LR X 1000 CF/HC)
Delta	227	9	1	39.6
Titan	708	7	0.90	8.9
Atlas & Centaur	485	6	0.8	9.9

One of the reasons for Delta reliability at modest cost has been improvements in field preparation. These improvements were not random but were consciously introduced based on a study of hard experiences in our industry. They were designed and introduced in the early '70s as a group of coherent facets intended to provide a unified solution to many problems of launch operations in the field, from preventing flight failure, damage and injury, to avoiding excessive expenditures of cost and time. They were aimed at mission success at moderate price.

A Change From Early Beginnings

First launches of long distance vehicles were tests of weapons. While success was urgently desired, correct performance by 65% of the missions was acceptable. The field effort was developmental. The value at risk was little more than that of the launch vehicle. However, in the launching of satellites to orbit, the values of spacecraft exceeded values of the launch vehicles, sometimes by an order of magnitude. Failure was dear and painful. It was the anguish of early hard experiences that led to formulation of a field philosophy within the McDonnell Douglas launch crews. This formulation was particularly catalyzed by the Vandenberg AFB loss of the NASA Thor Agena for Nimbus-B, where the payload estimated cost was about $200 million in 1968 dollars and that of the first stage vehicle which caused the failure less than a million. Other experiences were studied. These experiences were not limited to Delta but included those known from Thor, Atlas, Centaur, Titan, Vanguard, Navajo, Agena, and other rockets.

A field improvement study was set in motion by McDonnell Douglas Field Site Management, the objective was to determine common causes for problems and from them, opportunities for improving field operations. For the study, done by field operations supervisors, field-preventable or field-caused flight or static test failures were the most dramatic lessons.

In 1957, the first launch of a Thor detonated on liftoff due to contamination. In 1958, at Sacramento Field Test Station in California, a test of a Thor liquid oxygen transfer sled killed three workers and severely injured others, owing to nylon in LOX and aggravated by poor test and personnel control. A Delta solid motor accident at Cape Canaveral in 1964 killed three workers, a result of static discharge. In May of 1968, the Nimbus-B mission from Vandenberg was lost because of field misinstallation of a rate gyro. That gyro was installed misclocked, and an inconclusive test, intended to find such a problem, did not. Validity of the test itself had not been tested but was assumed. In October 1971 Delta 86 was lost because of a vent valve leak on the second stage that could have been detected on the launch pad. Other problems on other programs studied included the inter-agency communications lack which led to the Gemini/Agena mission failure known as "The Angry Alligator," and the explosion of the "T-Bird" (first test vehicle of the Saturn S-II) which was destroyed on the Mississippi test stand through communication error and assumption (pressurizing main tanks with a disconnected pressure transducer).

Other less dramatic problem aspects of the then Douglas Company field work were studied for factors of delay, hazards and expense.

It was learned that on Thor and Delta launch complexes, as exist in all organizations, there were opportunities for improvement. Errors had been introduced through the replacement of components for preventive maintenance. A trial policy change was made to halt much of this prescheduled replacement. It was seen that more manhours had been consumed in correction of misinstallations than was saved by this maintenance, that components left in place continued working well long after expiry of their arbitrary maintenance schedules. Not removing them not only saved the replacement and retest efforts, but avoided system disruptions, possibilities of contamination and many scheduling headaches. Risks of failure were evaluated component by component.

From study results most scheduled maintenance was stopped; systems were in constant use and therefore of known condition. "Fix it when it breaks" was adopted as a final policy with eminent success.

The study also revealed that departments, though trying to work together, used paper forms unshared by other departments. Team personnel of other departments who needed to be involved had no access to one another's paper and were therefore uninformed. From this observation came the policy of using a single, all-department documentation system, accountable for all launch processing actions and used by, and contributed to, by all departments. This became known as the LPD (Launch Processing Document). Its use was developed into a highly refined but straightforward operating system, computer maintained, and tracked for completion of each test requirement and each installation. See Figure -1-.

A study of main causes of manhours consumed at the launch sites revealed three primary areas where expenditure of manhours was high but avoidable: largest was the domain of retest and re-exercise owing to test data indicating anomalies or system performance errors. Unfortunately these were found to be so frequent and were so habitually resolved to be "no problem" by repetitive further testing, that they were interpreted not as failures but as system "uncertainties." Tabulations of tests and efforts over a number of Thor and Delta launches at Vandenberg AFB showed a high incidence of "uncertainty" developing in tested systems owing to questionable data taken during original or subsequent testing. Many test repeats studied did not indicate a high rate of actual system or component failure. It had been the practice to retest many times on the understanding that actual mechanism problems do not come and go, but -- once there -- can be repeated and understood. This was a "crude confidence" approach. It was observed that multiple tests tend to be done with increasingly systematic care. When a data-taking problem occurred, multiple test was the method used to distinguish this from a real system problem and to gain system confidence. This method, once reviewed in perspective, was considered poor in contrast to avoidance of bad data-taking in the first place.

The study showed a very large proportion of all test uncertainties were due to improper data, resulting from careless performance, poor human observation, or reliance on verbal reporting without written follow-up.

Causes were often:

- Lack of complete readiness for the tests, leading to carelessness.
- Lack of thorough team understanding.
- Poor initial plan or a late change to the plan leading to confusion, performance errors, or data-taking methods that were unsystematic.

From this observation arose policies to:

- Design and build test equipment which will take data in recorded fashion, with greater mechanization, and with less chance for operator error. These equipments came into being and formed a major part of the Delta Launch Sites culture. Examples are discussed in this paper.
- Develop rigorously studied and prepared procedures, refined by test and use.
- Adhere to these tightly on launch after launch, changing only with strong reason and great care.
- Increase attention to test and operation management such that a test conductor and countdown format is used on essentially all vehicle operations.

Second largest area of reducible manhour consumption was the domain of retesting done to give a currency to system confidence. Since launch delays for reasons other than the readiness of the rocket often occurred, they were considered "normal." The "health" or launch-readiness of systems was known to decay (as testified by problems found in these retests). Testing was therefore planned on a repeating and periodic basis. The study perused past records for causes of readiness decay where it actually had been found. Some decay of tested condition was noted due to moisture intrusion in circuits. None was found due to aging of soft goods. None was found due to corrosion or other chemical change (in the short times involved). Only one substantial factor was found to justify the erosion of confidence in tested readiness: Human access.

Access to tested flight hardware had not customarily been prevented. Intrusions were numerous and, taken one by one, each generally carried good reason. Access was informal in opening flight boxes, entering ground terminal boards, breaking into gas supplies, propellant lines, etc. Individually, each action generally was driven by a well-meaning sponsor interested in rechecking a set of terminators or in incorporating a later and "better" modification. But as a whole, such access was destructive.

Also there was casual access -- human presence which focused on one objective in one system while accidentaly disturbing another; wrong placing of a foot or hand, a dropped wire strand or a pocket pencil.

The study concluded that access invalidation of tests could be avoided by:

- Exclusion of access where possible.
- Rigorously controlling access to tested systems, and inserting special care where sucn access was imperative.
- Implementing policies to mandate system closure after test.

These actions were taken. Periodic and repeating test were largely dropped.

The third area of manhour expenditure found to be reducible was: "Habitual Testing." This is testing for which the reason -- once clear to someone -- is no longer known. Or if it is known, represents a refragmentation of an integrated system into components. This is a natural trend where a test engineering department is divided into disciplines. In the testing studied, a notable example was seen: the internal disconnect of the guidance system from the hydraulic system. The hydraulic engineers had always required the VATS (Valve Actuator Test Set) to be employed to drive the hydraulic system to full stops. The reason, when asked, was to assure the main engine did not strike the legs of the launch mount. However the electrical disconnecting had accounted for numerous severe damages to the flight control electronics, due to uncoordinated turn-on in the unloaded (disconnected) condition.

This example of "Habitual Testing" was averted by cutting away launch mount legs for clearance to remove all probability of engine contact. The break-in to this tested system was no longer done routinely. Flight vehicle hydraulic testing was accomplished only through flight electronics. Damage to the flight controller ceased.

From this study of manhour consumption came a realization that testing by somewhat blind, habitual repetition of what had been done earlier led to inappropriate testing. Such testing, as conditions changed in the development of a program and its flight hardware, may no longer be warranted without some vehicle of better analytical perspective.

The idea of an abstract of "testing requirements" came. For convenience, this was divided into two general listings:

- Those tests of specific systems (and specific components, where necessary) needed late (at the launch site) by virtue of their component physical nature. These features require test after vehicle emplacement on the launch pad to assure specific performance characteristics have remained.
- Those tests and operations which our experience has taught are prudent and necessary for contingency reasons or which are required on a Government range. These are as much a listing of what to avoid as what to do.

On the Delta Program, two documents resulted, the former a TRD (Test Requirements Document) and the latter an ORD (Operating Requirements Document).

Finally the study brought forth the realization that much time and labor was expended due to error-driven flight equipment damage and its subsequent repair, replacement, and retest. This was particularly caused by test set-up damage. It occurred on electrical connectors (bent pins) and in clean systems (contamination). Testing had traditionally been done with set up and tear down preceding and following each test. This meant much set up traffic and much damage. From this realization sprang a feature of the field philosophy which thereafter shaped the development of new test equipment and a simpler test flow. It had the objective of making a single hookup of ground test systems to a launch venicle and having just a single removal.

The study showed need for all operations to be under direction of a senior real time, system-wise, multi-disciplined test authority. The real time Test Conductor over all agencies was needed to keep operations technically and operationally compatible. His necessary functions included the promulgation of understanding between all active parties on a single launch pad. This is a function of communications management. To do it properly, operations must be conducted on a communications net. By acting as the "Blind Man" on the net the "TC" can induce team members to verbalize events, thus promoting a wide distribution of team understanding.

Other vital outcomes were also arrived at for sound reasons, as outlined in the field philosophy to which these inquiries gave rise:

- Plan testing and operations in detail, in advance.
- Control test operations hierarchically.

- Maintain ground equipment through necessary repairs discovered in frequent use rather than through extensive replacements in a maintenance program.

- Include all departments in a single plan. Let them operate as a team, not as factions.

- Mechanize tests and test equipments to:
  - Reduce operator variability
  - Reduce data judgement error
  - Increase data validity.

- Restrict and control access to tested hardware, both ground and flight.

- Divide launch site processing into domains:
  - Assembly of rocket
  - Test preparation
  - Systems testing
  - Test systems removal
  - Flight preparation
  - Launch countdown.

- Organize work paper to be:
  - A coherent plan.
  - Used and understood by all departments.
  - Best thought inputs of all departments.
  - Sequenced, detailed, step by step instruction, organized in timeliness so that details are given when to be used, rather than as "boilerplate' to be unheeded.
  - Devoid of vague generalities that can be someone's excuse that forethought and instructions are contained while they may not be effectively contained.
  - Graphically illustrated.
  - Validated point by point, progressively.
  - Augmented with interpretive notes.
  - A record of all that has happened.
  - Evaluated by engineers and managers in later making the case for readiness to launch.

- Do all operations according to coordinated, deliberated plan. Where plan needs change (due to inadequacy, changing conditions, malfunction or troubleshooting), re plan.

- Do not shortcut plan for haste or hurry; remember the high value of the hardware you handle. Shortest course is a studied course.

- Develop and maintain highest disciplines of crew performance in terms of:
  - Precision
  - Observation and report
  - Communication.

- Germinate and cultivate a special anomaly handling culture: any single player can report an anomaly. No single player can adjudicate an anomaly. Unexpected observations are (1) registered, (2) developed for full factual substance, (3) widely communicated, (4) variously judged by all concerned agents and groups, and (5) accepted only in concensus.

Implementation of these study results into the Delta field processing involved transition into new people disciplines, new paper systems and the creation of new precision equipments.

New families of equipment were necessary to carry out the philosophical objectives of reducing:

- Manpower costs
- Motion and time to/of test
- Misperformances
- Mis-taking of data
- Unintended abuse to flight hardware.

These equipments had to be designed. They were conceived by field personnel and largely designed in the field (to use to best advantage the knowledge of systems and of test problems held by the field engineers). This task also provided mind and talent honing challenges to the field engineers while at the same time avoiding costs by more productive utilization of time between tests. Similarly, these equipments were largely built in the field to utilize the talents of the field technicians and minimize cost.

The design factors to be achieved within the limits of time and with little additional money were:

- Capability to be connected once in the launch campaign.

- Capability to operate in a programmed, hands-off mode.

- Capability to take recorded data.

- Capability to take data remotely on high-hazard systems, therefore make possible the thorough testing of these systems without undue exposure of personnel.

- When hazardous systems require human presence, to provide full and best protection.

- Additional to the more proficient taking of data was the design objective of better assimilation of data taken.

Resulting were the following Launch Site testing and operating systems:

DOTS: The Delta Ordnance Test System was appropriately the first of the ground equipment improvements because the Delta is a heavy user of ordnance-activated devices and much data difficulty had been encountered in assuring all ordnance firing commands were emanating on time and in correct magnitude from the vehicle to the several electro-explosive devices (EED's). The DOTS replaced a collage of test devices which used flashbulbs and circuit breakers without timing or recorders; they were for perceiving electrical firing commands at ordnance device connectors. The old systems used short cables to connect to the three stages separately. They were coupled before each test and removed promptly afterward. This had been necessary because Delta gantries were open. Equipments could not reasonably be left exposed to weather for extended periods.

An indoor central console, Figure -2-, was used with "octopus cables" reaching to every ordnance connector on the 3-stage vehicle. Signal occurrences was thereafter recorded with respect to range timing. Further, the intensity and duration of the bridge wire currents were monitored for adequacy by special modules mounted in the load contact boxes (Figure -3-) and were limited such that errant values could not injure launch vehicle wiring. This monitoring and limiting was accomplished by ordnance simulator modules adapted from surplus gear of the Saturn Program and built into DOTS.

In pre-DOTS times, another variety of data had been perceived and reported by a most imprecise means. The second stage attitude control cold gas jets were noted to "fire" by men listening nearby. Timing was absent or inaccurate. The certainty of which jets fired when, often dissolved in confusion and differences of opinion.

Small protective assemblies being otherwise needed to protect the fragile jet nozzles, the RACS monitors, Figure -5-, were devised to convert gas puffs into electrical signals. In addition they protected nozzles. Receptor venturis were connected to inexpensive bellows switches with tygon tubing. Their switch closures were then registered along with ordnance signals on the DOTS chart recorders.

The DOTS was able to bring test equipments indoors by virtue of a specially-built gantry room. That this system could then remain connected to the launch vehicle during the entire launch testing period of each rocket's launch campaign eliminated most connect/disconnect damage. Reduction of ordnance-firing and jet-firing data to timed record eliminated much need for retesting.

FLOPI: The number of Delta retests required by misoperation during the largest of all tests, the multi-stage flight simulation, was exorbitant. Manhours and schedule days were wasted. Most often miscued was the pulling of the "liftoff pins." These pins are part of the launch mount and actuate vehicle switches as they leave their vehicle nacelles at liftoff. They signal the vehicle systems to perform the flight program. There are two, on opposite sides of the rocket base plane and are pulled, hopefully, on the right second by two independent technicians listening to a count. One or both were often mis-timed. FLOPI (Flight Lifoff Pin Initiator) implemented a blockhouse-originated signal to pull the pins using pneumatic actuators. The resultant precision virtually suspended this frequent cause for retest.

OCAT: The possession of the DOTS gave rise to a new opportunity to eliminate another source of time-consuming labor, the detailed pin-to-pin measurement of stray voltage on the ordnance circuits of the vehicle at the time of final ordnance connection. One of the development efforts of the Delta Launch Team had been the shortening of the long countdown on launch day. A task of that day has always been the arming of the strap-on solid motors.

To accomplish this quickly required arming through one large connector rather than at the many individual detonator points, as traditional. However, it was our safety policy - in pre-connection measuring to assure no stray voltage present on ordnance circuits - to measure not only the absence of spurious voltage across the wires leading to each bridge wire, but also to measure from every pin in each connector to every other pin and to the shell of each connector. In small, two or four-wire connectors, this is a manageable task for manual measurements. In connectors of large size, the permutations of measurement cause the task to grow enormously. A computer or other automation medium was needed. Thus a major stimulus for developing OCAT was this need to arm solid motors out of a single, large connector.

The computer driven measurement system which became known as OCAT was, in 1972, merely an adaptation of the HP2100 ground resident computer newly supplied to the launch locations to interface with the on-board flight computer. This computer was first flown on Delta in July 1972. OCAT extended the use of the HP2100 computer in the blockhouse to work through the DOTS (which was already normally connected most of the time to every ordnance circuit on the rocket). The ground computer's time free from its occasional use in commanding the on-board computer, was not greatly impacted by new employment. OCAT was implemented by adding late technology wire wrap circuitry, arrays of reed relays, and digital voltmeters to the DOTS. This accommodated computer access and provided switching capability to each of the DOTS rocket ordnance circuits. By this means the blockhouse computer became able to address all vehicle ordnance circuits and to switch any two to a digital voltmeter system located near the rocket-side within the DOTS connection boxes. With programming, OCAT was then able to profile in rapid sequence all ordnance circuits on the rocket for resistance, isolation, and stray voltage. The judging of the measurements was also programmed so that, while all results were printed out for human perusal, all unsatisfactory readings were flagged. OCAT also provided such capability to the main solid motor initiation and separation connector. By means of OCAT it became possible thereafter to accomplish all pretest, post-test and pre-arming surveys of the condition and health of all ordnance firing circuits promptly, with high confidence, few delays, and with a minimum of manpower. By the incorporation of continuous monitor and alarm circuits, it also became possible to watch for the presence of any significant stray voltage continuously and to record any such voltage for later time correlation with passing electrical storms, work access, or other events.

OCAT reduced the the amount of time required to arm the launch vehicle from expenditure of many hours, by many technicians, to the spending of minutes by a few. It made many fewer errors and produced more accurate data, all with a net reduction of hazard exposure.

EEDAT: Although redundancy has been used in the Delta ordnance system design, failure of electro-explosive devices could cause mission failure. Therefore, confirmation of EED integrity as late as possible before installation is an important action for mission success. The traditional method of handling and testing EED's such as explosive bolts, pyrotechnic cable cutters and small actuation rockets involved days of hands-on testing. Men travelled to ordnance bunkers and employed Alinco meters, test leads, and pin sleeves to measure painstakingly -- and at some hazard -- the continuity and resistance of all the bridge wires in all the EED's, both primaries and spares. For multi-stage Delta, ordnance checkout could take as long as five days. Many man days were consumed per mission in his activity. Even then, the testing was necessarily completed long before installation. Retesting in cases of abort were equally time consuming. Despite care and proficiency, there were errors and uncertainties.

The EEDAT (Electro-explosive Device Automatic Tester) converted this chore to systematic good results. EEDAT was conceived as the marriage of an ordnance safety system to the computer driven measurement and readout system of OCAT. Actually they were a symbiotic development, as the germ ideas of each affected the final outcome of both. The ordnance safety was provided by designing new ordnance carrying cases (Figure -6-). These were "Haliburton cases" fitted with stout aluminum/steel manifolds to hold sets of ordnance safely. Even if the case is hand held, and all ordnance devices detonate simultaneously, the manifold contains and safely bleeds down resultant pressures. The design was proven by test. A cable harness inside the case is made to connect to each of the EED's and to an external connector on the surface of the case. During all handling except actual device testing, this external connector is "shorted" with a faraday cap. In routine use, manifolded cases are provided for a complete ship-set of EED's plus spares. EED's are only inspected physically, then loaded into the manifolds by screwing into the ports. This occurs at the ordnance storage bunker. Thereafter the ordnance can be safely carried and even stored at the rocket-side until ready for testing.

The coupling of the EEDAT box to the computer-driven readout system (Figure -7-) involved only the addition of a current-limited signal injection feature and simple cable connection to the OCAT system. A software program was provided to the blockhouse computer for driving this system. By this means, small currents are sent in succession through each of the EED bridge wires. The resulting infinitesimal voltage drops across the bridge wires are measured to ascertain bridge wire resistance. The automatic measurement, performed in an instant, immediately precedes installation of explosive devices in the rocket. By means of EEDAT the earlier logistics problems surrounding the handling of ordnance were eliminated with added safety and with greater validity of checkout of each EED at the time of installation. After a decade of use, EEDAT has made thousands of measurements through the bridge wires of live ordnance without an instance of dudding or detonation.

RLE: Leak detection in lightweight flight systems has long been the predicate of field problems. Design margins in such systems are often low for purposes of weight conservation, 1.2 to 1.4 burst-over-operating pressures being common. Such systems cannot be safely approached when fully pressurized. Leak detection by traditional methods of bubble solution and observation must be done at much lower pressures. For systems which must remain in space without body moments or losses from gas leaks, a complete and accurate leak check is mandatory. Leak check by the decay method was long the only available means to assure leak tightness of such systems. This was time consuming and often produced inexact results during the hours of diurnal temperature variation. Also, the method was only valid if there were no leaks. If leaks were present, it was impossible to locate them at full pressure. If they were the type leaks which only appear at high pressure, then the location and repair became an entire impossiblity. These facts, plus the loss of Delta 86 because of a small leak on the second stage, were the stimuli for the invention and development of the RLE (Remote Leak Evaluator) sytem.

Conceived and designed by launch site engineers, perfected in 1973 through a series of prototyping and proving test, and used proficiently on all Delta launch pads through the decade since that time, RLE has brought to launch processing of liquid rocket stages a new dimension of leak-free certainty. (Figures -8- and -9-)

The principle of operation is simple (refer to Figure -10-). A tracer gas is injected into vehicle systems. Helium is used because of its safety and mobility. The exterior of each rocket system to be tested is laced with a harness of 1/8" nylon tubules, one for each possible leak address, and a few for general area detection. These are numbered and brought in harness form off the launch vehicle into an array at the top of a low pressure box. A vacuum pump maintains the internal pressure of this "scavenge box" substantially below atmospheric pressure.

As a result, a steady flow of ambient air proceeds into the open end of the tubules and toward the scavenge box. Over the open end of each tubule a loose envelope of foil, usually aluminum, is formed around the joint to be leak tested. The launch pad area is cleared of personnel, and the rocket systems are brought to full flight pressure with pure helium or a helium-nitrogen mixture. Helium molecules that escape the joints are swept up by incoming air and carried off toward the scavenge box through the tubules. Inside the box is an addressing mechanism which positions the probe of a high vacuum helium detection device -- sequentially or on command -- at the injecting point of each tubule. Output is in the form of a mass spectrometer quantitative indication of parts per million of helium. Control of the addressing, dwell time, recording and evaluation of detected leakage is concentrated at a console in the blockhouse. System accuracy is greater than needed and periodic self-calibration is provided by known internal calibrated leaks (0.06, 0.6, 1.0, 8.0 SCCM). The system is able to detect leaks far below the level of significance for Delta systems and far below the level detectable by bubble soap and the human eye.

In the ten years of use, while there have been some infrequent machine startup and calibration problems, RLE has not been known to fail in detection of a launch vehicle leak to which it was exposed.

BAS: Loading propellants in the Delta second stage is <u>not</u> done entirely remotely. It is accomplished in the final days before flight. The propellants, nitrogen tetroxide and Aerozine 50, are highly toxic. To be quite certain the load is locked aboard without leakage and to minimize vehicle weight, fly-away quick disconnects are not used. All hose connections and disconnections, as well as final load adjustments are made by men at the rocket side. The propellants are driven aloft to the second stage by pressurization of trailer-mounted storage tanks. While this operation is controlled by switches from the blockhouse, certain valve settings as well as confirmations of flow, sightglass levels and scale poise conditions, require men at the storage units. Means to protect these men completely in an envelope of clean, fresh air is necessary when handling the highly toxic Delta second stage propellants.

First use of the standard, liquid air pack, "SCAPE" suits at the Delta complex at Vandenberg AFB produced chilled and fatigued workers. Medical qualifications to use these suits involved stress testing which only a portion of the rather "senior" corps of McDonnell Douglas technicians on the Delta Program could pass. Crew-suited time was limited, requiring a full complement relief crew to be utilized for each propellant loading operation. In the small contingent Delta launch team these requirements posed economic as well as hazard and discomfort factors. In addition, Delta launches from the California location required the transport of a SCAPE suit support group, plus equipment, across the continent for each mission. For the cost of one such mission, the BAS (Breathing Air System) was designed by McDonnell Douglas and built by launch site technicians out of surplus SCAPE suits.

The original BAS utilized a trailer of Del Monox diving air filters to purify the output of an ordinary construction site, diesel air compressor (Figure -12-). This trailer was equipped with a carbon monoxide sensor and alarm system. Its output fed a system of manifolds and hoses about the launch complex from which, at distribution points, suited workers took their air supply via hoses. Into the surplus SCAPE suits McDonnell Douglas engineers designed changes; liquid air packs were removed; hose attachments were mounted at waist level and tied into the internal distribution system; vortex tubes of small dimensions and no moving parts were incorporated to sort hot from cold incoming air molecules for the user to adjust his own temperature; an emergency egress air-bottle attachment was incorporated; and finally communications were installed in the helmets to make them compatible with the launch pad nets. The rework was accomplished in contract scope by McDonnell Douglas technicians. These suits were tried and found to offer a much lower fatigue and stress level to the user and to offer an economic bonus over the original SCAPE suits, now referred to as Category I SCAPE. On the California Delta launch complex these suits have remained in use for twelve years. In the first drop testing of the Shuttle at NASA's Dryden Center, these suits were borrowed, together with their supporting air filtration system, and found to be satisfactory in servicing Shuttle hypergolic propellants. This type of suit protection was recognized with a new NASA name: Category IV SCAPE and is now in wide service on STS. Delta operations at KSC were converted to this system in 1981, and maintenance of the suits is now accomplished by McDonnell Douglas at low cost.

QUIPU: This system, named for the earliest of computation systems (the Inca Indian set of knotted strings pronounced: "kee-poo") was a combination of HP1000 computer and Gould high speed jet printer with a set of CRT monitors and telemetry/landline instrumentation coming, primarily from launch vehicle systems (Figure -14-). It was designed and built in 1974, again to produce an efficiency and an effectiveness in launch preparation testing and a care in data handling. It is, in effect, an automated data engineer. QUIPU coverts all data instantly to engineering units, a great saving of engineering time. Superimposed on the unsophisticated Delta "finger-and-switch" ground test control system, it operates to monitor redlines during tests and to read and summarize test results rapidly. Redlines and operating limits are changed progressively in synchronism with system condition. QUIPU's benefit has been to confirm the acceptability quickly after a day of testing, somewhat relieving, but not entirely replacing, the long hours of reading strip charts and data analysis, which earlier held launch engineers into the night. QUPIU monitors differences on selected parameters through the succession of tests and helps detect degradation trends of transducers, should they occur.

SUMMARY

Material presented in this paper outlines the holistic approach to field operations which grew out of lessons in disaster and which has been used with good results on the Delta Program for more than a decade. Change was effected not alone in methods and instruments of planning, performing and documenting field operations, not alone in the structure and fit of paper systems to make them most effective, and not alone in the disciplines of test and assembly operations, nor in the equipments and instruments of taking and preserving data. Changes were made in all of these. They were harmonious changes, striving toward a common goal of focussed, effective processing with least confusion, least repeat, least damage, and least oversight.

The holistic approach, tried and tested a decade with Delta, is recommended for other large launch programs or large field undertakings.

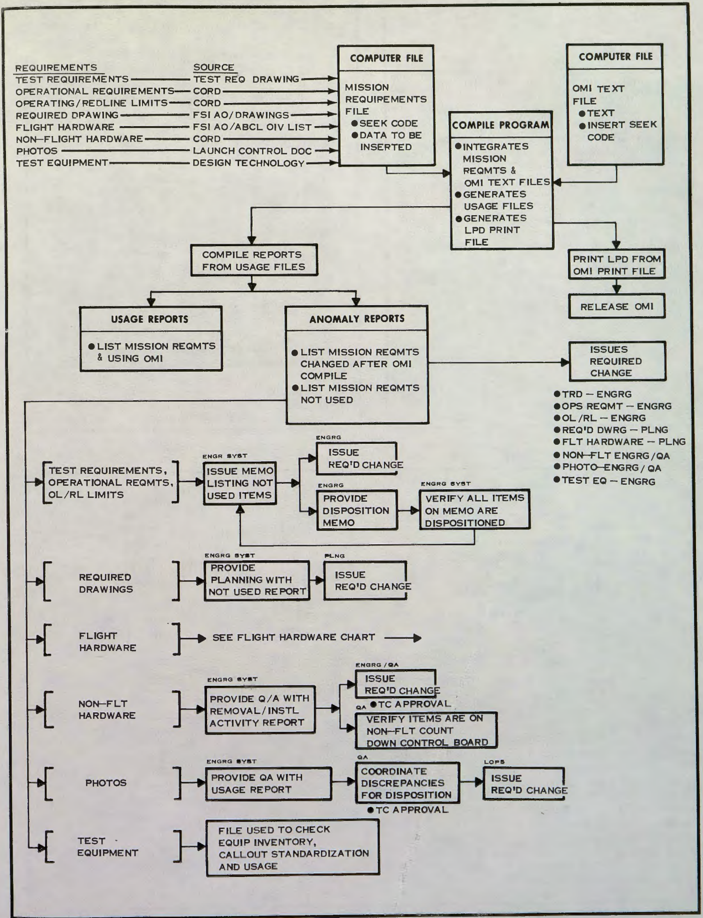

FIGURE -1- LPD DIAGRAM

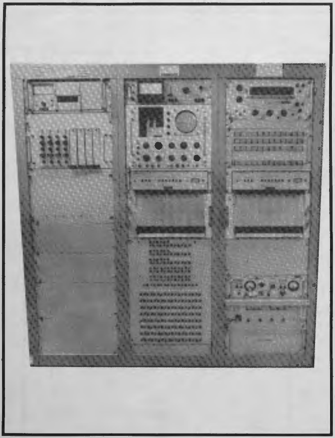

FIGURE -2- DOTS CENTRAL CONSOLE

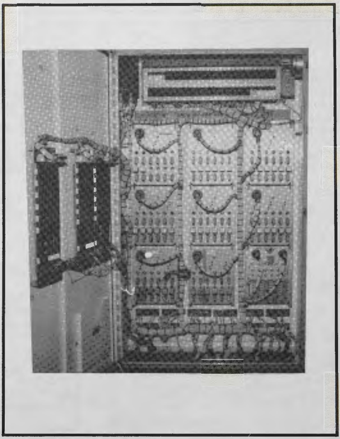

FIGURE -3- LOAD CONNECT BOX

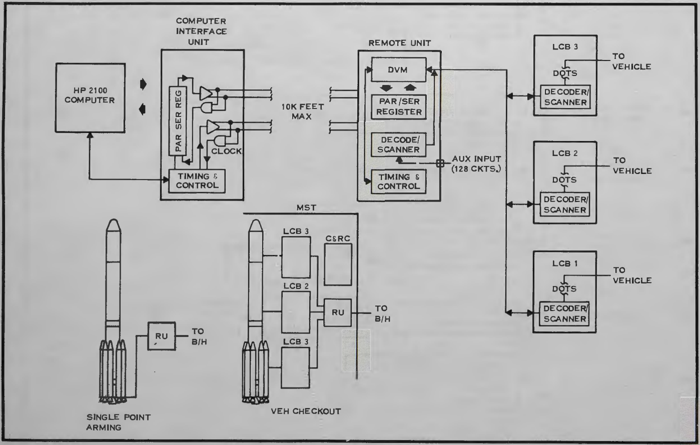

FIGURE -4- DOTS/OCAT BLOCK DIAGRAM

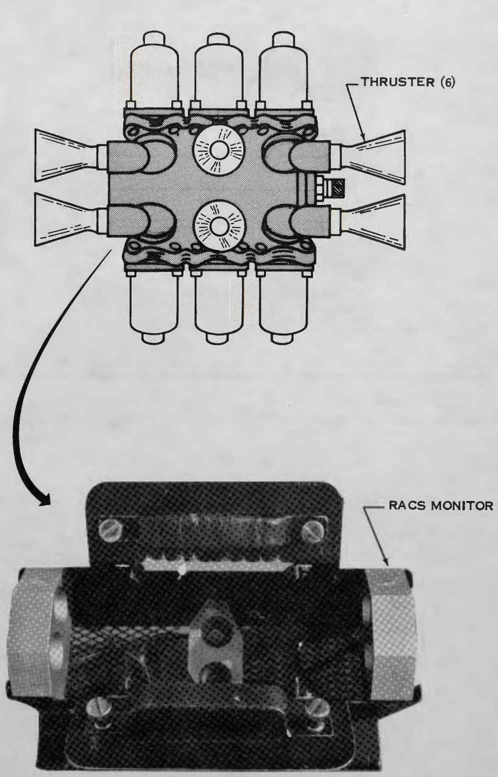

FIGURE -5- REDUNDANT ATTITUDE CONTROL SYSTEM

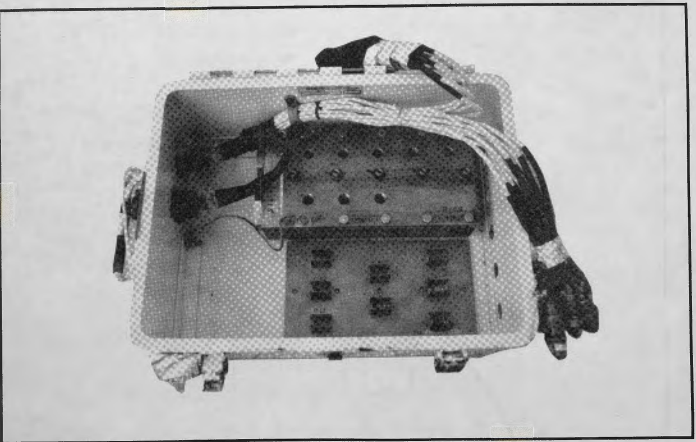

FIGURE -6- PHOTO EEDAT

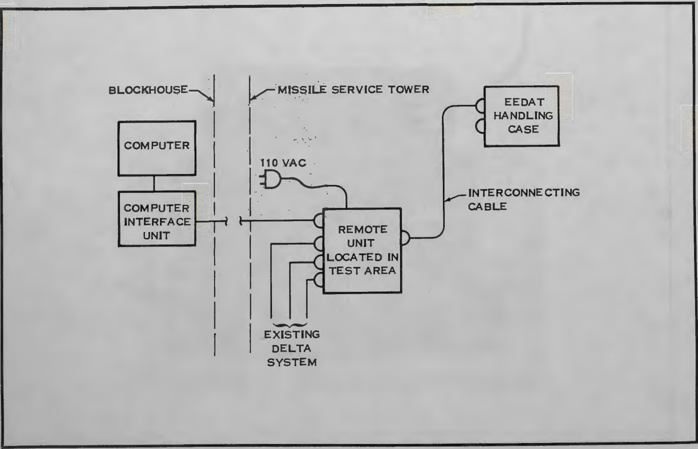

FIGURE -7- EEDAT BLOCK DIAGRAM

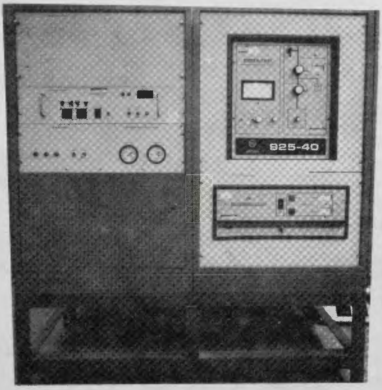

FIGURE -8- RLE ROCKET INTERFACE UNIT

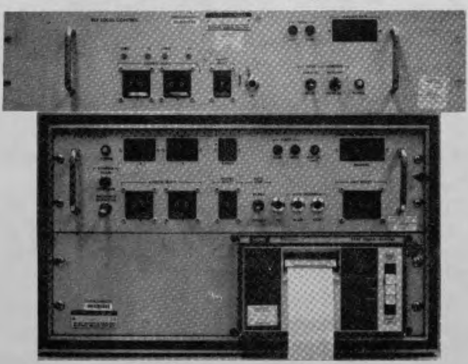

FIGURE -9- RLE BLOCKHOUSE CONTROLLER

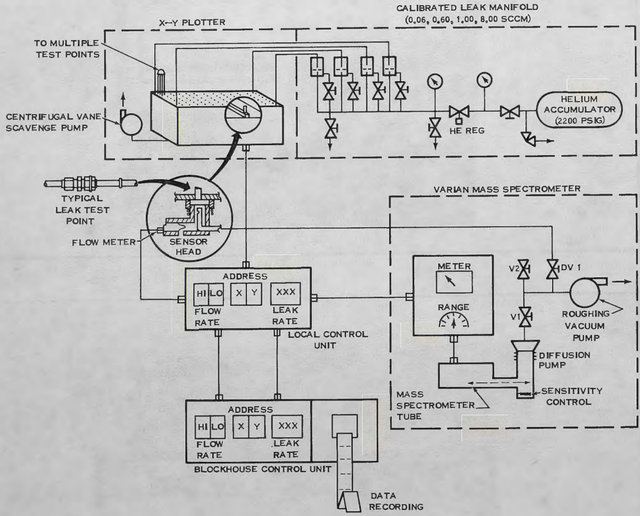

FIGURE -10- OPERATING DIAGRAM RLE

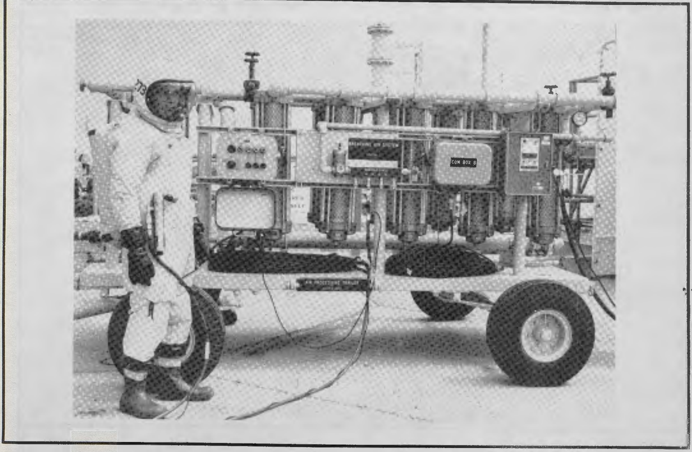

FIGURE -11- BAS PHOTO

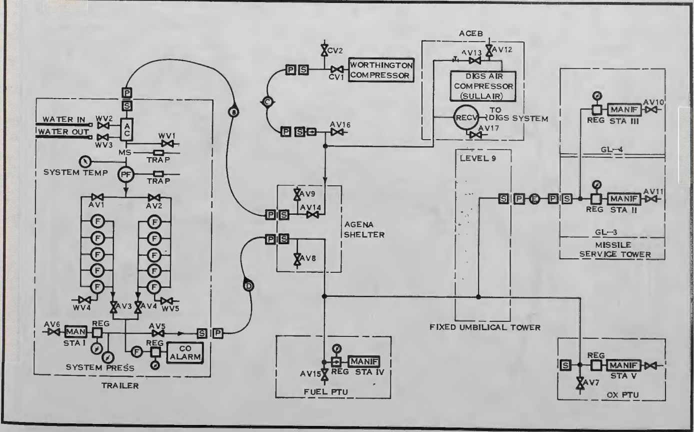

FIGURE -12- BAS SCHEMATIC

FIGURE -13- QUIPU

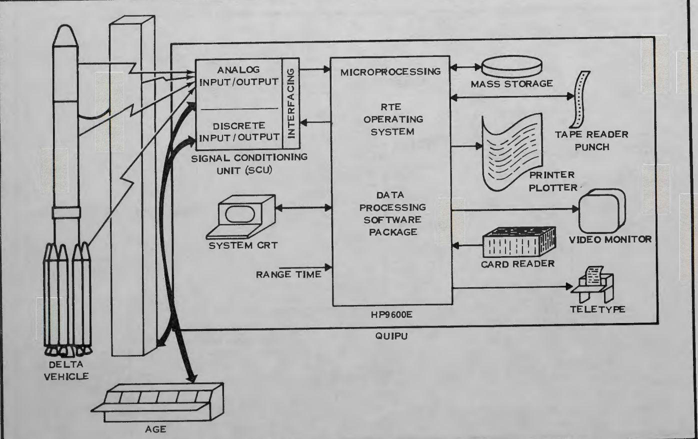

FIGURE -14- QUIPU BLOCK DIAGRAM