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IN THE MANUFACTURE, assembly and maintenance of spacecraft, accessibility to subsystems for replacement, repair, and maintenance has presented one of the more costly situations of preflight preparation.

Never before in the history of the world and man's adventures along the road of technological growth has accessibility had such an impact as it has on America's space program. And I mention one of the most prevalent -- the Saturn V program. Its impact starts in manufacturing and continues on through test, modifications after test, checkout, and finally, during countdown.

EFFECTS OF LACK OF ACCESSIBILITY

During the development of a spacecraft where we are pushing the state-of-the-art, compelled by the space programs, we find ourselves living in a world of modifications, such as:

1. Development changes.
2. Design fixes due to qualification failures.
3. Design changes to incorporate new requirements.
4. Design changes to make fit.
5. Design changes to simplify manufacturing.
6. Design changes to correct omissions.

Some modifications require removal and reinstallation of components and systems.

On the other hand, problems develop during manufacturing; test and checkout that again require removal and reinstallation of components plus assemblies, such as:

1. Damaged hardware.
2. Contamination of systems.
3. Failed components or systems.
4. Poor workmanship.
5. Questionable components or systems.

Now, I have named several possible reasons for removal and reinstallation of components and systems, and when we consider that other systems may have to be removed to gain accessibility, it is easy to see how the problems can be compounded completely out of proportion. An example of a typical happening would be a component failure on a major subassembly. This, in turn, caused the disassembly of a major subassembly, transporting the malfunctioning major subassembly back to the repair shops, disassembly of the subassembly to replace the failed component, reassembly, recheckout, transport back to the spacecraft, reinstall, and integration of the next major assembly and checkout. This type of failure could occur at any time prior to launch.

Under these circumstances, schedules and cost could run into the millions of dollars for a single day's delay if encountered during the launch countdown. During this phase, thousands of technical people are involved, requiring expenditures of money for travel funds, deployment of tracking ships, and, in addition, the expenditure of funds to con-

ABSTRACT

The purpose of this paper is to emphasize the need for accessibility in the assembly and maintenance of spacecraft. This is especially pertinent because accessibility to subsystems for replacement, repair, and maintenance has proven to be one of the more costly phases of preflight preparation.

The most successful programs in this day and age have been when the design and manufacturing engineers work side by side around a mockup where solutions to the problems can be visually seen and solved, keeping in mind the assembly as related to accessibility.

Therefore, it will be shown that in order to overcome the difficulties, designers should adapt a hard, fast ground rule that each unit must be accessible and individually removable without disturbing the other units.

tinue the program beyond its completion date. At the outset, anyone can see the tremendous task to attempt a valid cost estimate under these circumstances. We may, at this point, look briefly at the problem of cost estimation from the big picture associated with allocation of a budget. As we know, agencies or departments must present to the Bureau of Budget and the President preliminary calculations on broad program estimates covering the desired objectives and goals. This is begun some 16 months prior to the fiscal year for which the appropriation is being asked. I am sure you will agree that this procedure of government budgeting was certainly not designed for modern day technical programs. True, there does remain a continuous back-and-forth communication between the Budget Bureau and the agency as the President's Budget Brief is drafted. Even when an approved budget message is prepared and submitted to Congress, this is done 6 months prior to the fiscal year, and the agency must defend its budget request before Congress with the full awareness of rising unpredictable costs to the program. Complicated with schedule changes one can readily see the tremendous problem facing our management today. However, time will not permit me to explore this problem now, and it is not the main issue that I desire to leave with you.

Cost and time play a more important role in our society today than a few years ago. Prior to World War II, the entire public expenditure would not exceed five billion dollars. Today our space effort alone will approach this figure with a single program effort taking the greater portion, as we may well expect in the Saturn V program. What may have been a relatively small problem some years ago now cannot be considered as such in any sense of the imagination.

As we further think of cost, we may conjecture a thought of the future -- what demands will be placed upon technology when man will find himself in extended duration in space, limited in movement and materials? If we are experiencing unprecedented problems today, what of tomorrow? Let us now realize that if our aims and goals are to be reached we must move in a more united direction. Should the repairs to a car be more expensive than the car itself? Certainly not. We may ask ourselves if we can continue to live with such uncertainties that absorb vast sums of our expenditure as well as time.

Here, I have attempted in a few words to reflect the magnitude of the problem facing us from an economic viewpoint.

On the other hand, costs may not always be beyond estimate as accessible item replacement can usually be accomplished in the matter of minutes or hours with minimum impact to schedule and cost.

CHANGE ASSESSMENT
IMPACT

When a change analyst receives a change for cost and schedule impact, he finds the job relatively easy to make reliable estimates, particularly when a change involves an accessible item. The timing of the change being incorporated into the spacecraft usually makes little difference, except in the areas where a retest is involved, and this usually requires a retest only on the system involved.

On the other hand, a change involving an inaccessible item, as pointed out earlier, becomes highly involved and, in many cases, unpredictable. This is due to Murphy's Law which states "if anything can go wrong, it will." Inaccessibility raises the number of "go wrong" possibilities directly proportional to the degree of inaccessibility.

PLANNING IMPACT - Planning for the removal and reinstallation of an accessible item is relatively easy as the involvement is restricted to only that item. This allows the same paper to be used over and over again, more like a standard repair. Whereas, the planning papers on an inaccessible item must take into consideration the involvement at a given point in time for each installation involved, and this cannot include the unforeseen events that can take place requiring more planning to properly document the events that actually took place. We may conjecture theories on program change designed around elimination of this problem, and from the hardware design viewpoint strive to prepare for such eventualities. This I assure you is being done in many areas.

IMPACT ON RELIABILITY - Inaccessibility fosters poor workmanship. Wire bundles, tubing, and connectors that must be removed to allow removal and replacement of an inaccessible part or unit are subject to damage and contamination requiring repair or replacement recleaning, and retesting.

Human errors also tend to rise sharply as most repairs are done, under schedule pressures, by workmen less familiar with that particular installation and usually under less favorable conditions.

Flaws in workmanship may go undetected only to manifest themselves at a later and more critical time in the program.

When workmen see a beautiful installation torn out because of inaccessibility, their moral is adversely affected and they begin to feel as though they are working in circles and accomplishing nothing. This often leads to an "I don't care" attitude which, in turn, affects the hardware quality.

Desirable improvements are often turned down because of schedule impacts due to inaccessibility.

During the countdown, a decision to fly with a faulty component may be made because of inaccessibility where it can be firmly established that safety is not involved.

This list of items is not complete, but I am sure that the message is quite clear.

From a management point of view, we look at mission demands as related to goals, engineering as to effects on performance, manufacturing as to production and cost problems, and quality control as to inspection problems and quality trends. From the earliest phases of design through hardware completion, all areas must stay within their respective variable allocations of time and cost.

The obvious answer, is, if the general level of quality and consistency are a concern, and they are, it only goes

to assume that accessibility for changeout should be built into the hardware.

MANUFACTURING ROLE IN DESIGN DEVELOPMENT

So far, I have been discussing the impact of inaccessibility on manufacturing which I thought necessary in order to emphasize the importance of the subject. Far too often manufacturing is pushed into a role or accepts the role of "you design it and we'll build it." This attitude, gentlemen, needs to be corrected. The most successful programs in this day and age have been when the design and manufacturing engineers work side by side around a mockup where solutions to the problem can be visually seen and worked out. Thus, they keep constantly and foremost in their minds producibility and maintainability, not only of the individual components, but, most important, the assembly as related to accessibility.

Can we then say that system and component installation is contingent on certain factors and design for eventual change? We can now say with some degree of accuracy that we are going to eliminate or reduce error and change-out difficulties. We now may look for a medium or degree of accessibility based upon variables of allowable cost and time. We are moving from unit thinking to sensitivity analysis or over-all performance design. What is our direction then?

The concept of phasing design and development of manufacturing plans sequentially must be replaced by a concept of design engineers and manufacturing engineers working in parallel as a team from the beginning of layout of design concepts. This cannot be stressed too much. These engineers must know each other from the beginning of a project so that the sequence of operation, manufacturing techniques, and tooling concepts can be developed while the design is progressing. The thinking of the design engineers is, and must be, first oriented to systems and subsystems engineering while the manufacturing engineers think in units of subassemblies.

INDIVIDUAL ACCESSIBILITY - To overcome the difficulties of inaccessibility, designers must adapt a hard and fast ground rule that each unit must be accessible and individually removable without disturbing the other units. This ground rule should also apply to tubing and wire bundles to avoid threading these through the structure, or distorting them during installation.

The use of mockups is indispensable for the development of the needed engineering and manufacturing information. Too often the push to see structural hardware on the floor overshadowed the real need to first analyze the structure along with the systems that must be installed on or inside it. In vehicles such as our spacecraft, where weight and reliability are of the utmost importance, it would be cheap at double the price to develop several mockups of different configurations to be able to choose the most desirable.

MODULAR CONSTRUCTION - The vehicle should consist of discrete modules which generally accomplish a single function with interfaces between modules as simple as possible, thus allowing each module to be built and tested independently. This allows manufacturing and testing to be done parallel, and facilitates later modifications and late replacement of malfunctioning or damaged modules.

ADVANTAGES OF MANUFACTURING ENGINEERING WORKING WITH DESIGN ENGINEERING -

1. Difficult problems are flushed early in the program allowing time for solutions to be worked out. (Oftentimes simple solutions.)
2. The intent of the design is better understood by the manufacturing engineer, which prepares him to make worthwhile contributions.
3. In space, change-out and repairs will be anticipated and solutions known.
4. Reduction of component failure while in space -- overall hardware more reliable.

DESIGN QUALITY - The quality of the design is reflected in the quality of the hardware. This can best be achieved by close-knit teamwork between design and manufacturing, with both parties spending a lot of time on the shop floor "feeling the hardware."

I think it extremely important that we, as design and manufacturing engineers, not let ourselves be pushed during the early phases of a program to the extent that we end up with a design that forces us into a situation that will cause delays and cost escalations far above that which would have been used early in the developmental phase had we taken the time to do it right in the first place.

How much more successful and reliable will our efforts be if we move in the direction I have suggested here? Untold problems and possibly disaster will be eliminated in future efforts, giving us greater capacity for productivity that counts -- a safer and more reliable spacecraft.

CONCLUSIONS

Accessibility engineering, better known as maintainability engineering, has a very significant role in the space programs. It must be actively promoted and pursued throughout the staff and line structures of an organization to enable effective fulfillment of its mission in an ever increasingly costly and complex design and manufacturing era.

It must have full support from top management down through all supporting elements of an organization to be able to achieve the goals so badly needed in keeping systems reliable, programs on schedule and costs down.

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