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COMMENTARY ON SPACE

PROPULSION ACTIVITIES

BY

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SUMMARY

First, our capability to loft large payloads into space is virtually here. Our ability to exploit this capability with equipment that can transport itself in the space environment is presently limited to Surveyor, Gemini and Apollo; to exploit it fully we need to lay the technological base for other missions.

Present space systems lag the launch vehicles in both development status and sophistication. We can expect considerable performance improvement by the use of more sophisticated space propulsion systems.

The pace of the space program elements has gotten awry because of the underestimation of what it takes to do these jobs. There are several contributing factors for this. While it is time to get the sag out of the space propulsion business, it appears mandatory that we do so on the base of sound planning and experience to prevent re-creating a situation such as we have now.

PRELUDE

The first thing that should be said is that this presentation is one man's view of the spacecraft propulsion business. My colleagues will not always agree with these views; in fact, there may be some that would feel that this talk is critical, particularly of them. In their behalf I feel compelled to recount a story[1)] about an old man, a little boy and a burro, who set off on a long trip with the man and boy walking together and leading the little donkey. After a time they encountered another man who asked why the old man didn't put the little boy on top the donkey which after all was a beast of burden. This was done. Several miles later a second man approached the old man with the idea that he who was old should ride and the young boy should walk. And so places were traded. After a long time a third man was met and he observed that adding the small boy to the donkey's burden was negligible. And so thereafter they proceeded with both the man and the boy on the burro's back. In crossing a small stream, the normally sure-footed beast, now very tired, slipped and fell and, unable to rise with the heavy burden on its back, drowned.

1) Told by Irving Pinkel of LeRC. His source unknown.

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The lesson to be learned from this story is that if you listen to everybody's advice you'll lose your ass.

Of course there are those who listen for flute music regardless of the melody, and this is particularly true in Washington. I must say to them that the theme, rather than the tone of the presentation, carries the message. The talk is illustrated by a few slides that have little to do with the discussion but are shown to entertain those who attend these meetings primarily for the cocktail parties.

INTRODUCTION

At this time the United States stands on the threshold of transport in the space environment. Until now, with the exception of a relatively few payloads such as Syncom, payloads launched into space were put on their trajectory by the launch vehicle. Only minor path corrections were applied by the on-board propulsion systems. Even the Mercury capsule returns were made by a relatively minor slowing of the orbiting capsule, with aerodynamic braking providing the rest of the kinetic energy change. However in Gemini which may fly with men this year, and which will later effect rendezvous of separate payloads in space, and in

Apollo, which will perform an intricate series of space maneuvers, we recognize systems that carry significant propulsion capability into space for use entirely in that environment. The time is rapidly coming when space is no longer something we throw darts into but is an environment in which working propulsion systems will maneuver and transport spacecraft payloads, and eventually convey these payloads back to the earth's atmosphere for descent to the surface to be used again.

On the launch vehicle end of the business, Saturn I has demonstrated the capability to launch payloads heavy enough to contain the spacecraft systems I'm talking about. Furthermore, Saturn V, with ten-fold the payload lofting capability of Saturn I follows close behind.

One of the issues I want to examine is our preparation to exploit this now rapidly developing capability to move in, not just into, space. The other issue is to survey some of the problems being encountered presently in the spacecraft propulsion system developments and to suggest factors which may be contributing to their origin.

BACKGROUND

Let's see how we got where we are. History is a mute teacher; its patterns, however, can provide the molds for casting new answers.

In October 1957, which is presently less than seven years ago, the United States was injected into space by the Russians. The revelation that the atmospheric boundary could be pierced found the United States with several missile systems under development; some of these could be lashed up to permit the USA to enter the orbiting contest. And this was done. As a consequence, almost all our early space systems were adaptations of technology developments for missile systems.

Most early space missions could be characterized as impulsive propulsion missions; that is, whether the purpose was to orbit a payload around the earth, or pursue a planet, the propulsion requirements were met in a successive series of stage burns, with only very minor propulsion requirements after the first several minutes of flight. The minor requirements to maintain attitude, or to make trajectory corrections, or in the case of re-entry bodies, to de-orbit, could be met with relatively low performance systems without serious weight penalty. Cold gas propulsion systems, peroxide systems, and solid propellant de-orbit systems were built to meet the relatively small acceleration requirements of the orbiting maneuvers, or more accurately, adjustments.

As a consequence, the attention of propulsion personnel, which commercially tends to be attracted to the expensive projects, continued to focus on launch vehicle stages. Atlas, Saturn I, Titan II, and then in quick succession, Saturn II, III, IV and V dominated the scene. And there are those that contend that Saturn V spawned into reality before its gestation was complete; Saturn V would have been the original Nova; this however is not the principal subject here. The point to be observed is that for a time the need for developing sophisticated spacecraft propulsion equipment was deferred.

But not for ever. In 1961, President Kennedy's announcement of the decision to land a man on the surface of the moon established the requirement for dependable space-maneuvering propulsion systems. The requirement to land gently demanded variable thrust, a feature unnecessary for launch vehicle propulsion. We were caught in the dilema of either adapting launch vehicle engines, which through 25 years of effort had evolved into efficient turbopumped and regeneratively-cooled systems of considerable complexity, or deciding in favor of new technological approaches that emphasized system simplicity for the sake of early system reliability. By that time, flight experience had demonstrated that minor components that seemed infallible in ground tests failed under high accelerations and loading, or after exposure to space conditions. Therefore on the logic that the component which is not used cannot cause mission failure, the new spacecraft propulsion systems were designed with maximum emphasis on simplicity and rugged utility. Reliability experts showed how this approach could be justified with mathematics. This philosophical approach is sound but it needs periodic re-examination in terms of the developing state-of-the-art. I wonder what answers for inherent reliability would result from an analysis of an automobile, for example.

PROPELLANT-PERFORMANCE-PAYOFF

The space propulsion systems that are being developed for Gemini and Apollo use nitrogen tetroxide as oxidizer and as fuels, various amine mixtures, generally approximating monomethyl hydrazine in chemical constitution. The choice to use these storable propellants was dictated by the uncertainties of storing the cryogenic propellants in space, the lack of a sufficient technological base for some of the more exotic propellant combinations, and the general conservatism that is engendered by application in a manned flight vehicle to be developed on a short time table. The decision to use the low performance propellants was a prudent one, sacrificing mission capability in order to realize a manned lunar landing within a decade.

If we evaluate the extent of this sacrifice in performance we find it fairly costly. While high performance propellants pay off in any stage, in appraising the value of performance in succeeding stages, it isn't long before one recognizes that the effective cost of each stage, in flight, involves the cost invested in all preceding stages. Thus where the first stage is being considered, with no prior stage cost, what matters is simply the greatest impulse delivered per dollar of system cost including launch operations costs appropriate to the first stage. Thus, a cheap low performance system can compete with a more expensive high performance system. Solid propellant boosters can compete with hydrogen-oxygen systems and it's not clear which should win; much of the answer lies in the extra launch facility cost involved in accommodating the additional weight and thrust of the solid propellant system.

In the second stage, however, each extra pound generally involves from 4 to 10 additional pounds in the first stage. If one assumes that the system cost per pound of hardware is the same - which is not really true but which is not so wrong as to change the result of this argument - one can see by inspection that performance is many times more valuable in the second stage than in the first. The multiplication continues through each succeeding stage. By the time we get to a possible lunar landing stage, a pound is worth several hundred pounds in lower stage equipment, which can amount to enough value to make the intrinsic cost of the landing stage (the propulsion part of it) a pretty small part of the total investment. Thus we can see that performance gains, which translate into additional payload capability, have great value in spacecraft stages.

For example, if hydrogen-oxygen propellants were used in the Apollo spacecraft, then the "payload" - in this case the mass of the Lunar Excursion Module returned to the orbiting Service Module - could be increased by at least 50%. What is that worth? For a while it appeared that might be worth the entire cost of the manned lunar project. It now seems certain that the mission can be accomplished with storable propellants, albeit without generous margins. If we use the criterion that value is proportional to payload, then the 50% added payload would be worth half again the cost of the vehicle development part of the program. At some limit, any linearized projection becomes absurd, but the message of payload-performance-payoff should be coming through.

RELATIVE LAUNCH VEHICLE - SPACECRAFT PROPULSION STATUS

In three years, the United States will be able to lift nearly a quarter of a million pounds into orbit. All stages, test equipment and launch facilities for the Saturn V vehicle, designed to propel the Apollo spacecraft into an earth escape trajectory toward the moon, are under development toward that schedule. A full year earlier the Saturn IB, with a capability of 32,000 pounds in earth orbit will be available. The Saturn I, a bird which has been overtaken by the advancements of technology, exists right now. In spite of its obsolescent status, its flight records have seriously distorted the random statistically distribution of success. Saturn I can put 20,000 pounds of true payload in orbit. The Air Force has under development the Titan III vehicle which also has lofting capability in the 20,000 pound class. Gemini will be launched on Titan II, which can be classed with the lash-ups of military missile systems, as can the Surveyor. Surveyor will use the Atlas-Centaur launch vehicle.

While Atlas-Centaur pairs with Surveyor, Titan II mates with Gemini, Saturn IB with the earth-orbiting Apollo system, and Saturn V with the Apollo lunar journey, it is apparent that other payloads are not being built to expand and exploit the payload lofting capability. Considering the fact that the attention of propulsion people continues to be drawn to boosters and uprating of existing vehicles, this appears to me to be a case of looking into the wrong end of the telescope. The time is at hand, it seems to me, for propulsion people to focus on the possibilities for expanded Gemini and Apollo missions, and for additional missions to be launched on these soon-to-be-available boosters.

I again observe that the Gemini and Apollo spacecraft propulsion systems don't match the sophistication of the booster vehicles. While the Saturn I second stage, already flown, has second stage engines producing a specific impulse near four and a third hundred pound-seconds per pound, the present spacecraft propulsion systems cannot better 75% of that figure.

It is also observable that in general the booster engines have passed or, in the case of the Saturn V engines, are approaching their preliminary flight rating tests, while the more conservative spacecraft propulsion systems have not yet arrived at that milepost. While these spacecraft engines may be expected to come along at a faster pace than the big booster engine developments the fact is that they are presently in a tail chase situation. I think we must observe that at this moment the status of spacecraft propulsion systems under development lags the development status of launch vehicle engines and is additionally behind in performance sophistication. That is the area that warrants propulsion attention.

I don't wish to imply that NASA has been completely negligent in planning for this expansion of spacecraft propulsion capabilities. This country has a high-performance engine of suitable thrust level which has demonstrated throttled operation over a 10:1 range, and which has operated at "idle" to produce about 3 per cent of full thrust. NASA also has technology programs to examine other high-performance propellants, with a view particularly to propellants more amenable to long-term storage in the space environment than is hydrogen. These programs, however, are in a relatively immature status and at present funding levels will not be ready for development until the late sixties. Clearly some foresight has been exercized. But there is presently a reluctance among NASA officials to expand the tightly funded space program. Also, the NASA manpower to manage and control effectively this vast undertaking is already up to its eyeballs in work. These restraints have held some of the plans to advance the spacecraft capabilities in abeyance.

PACE

It would be the height of impropriety to imply that government planning is poor, because I believe industry is an accessory to the fact that something's out of kilter. And that, I think, is the pace of the elements of the program relative to each other. Let's examine why.

With a late start on spacecraft propulsion development the United States chose the conservative systems for development in order to overtake the booster capability. Industry representatives represented that this path assured early success. And yet the development schedules of these conservative systems have fallen back and the projects are consuming more money than was originally estimated. The space program provides no contingencies. Accordingly, since money can flow only at some limited rate, demands for greater expenditures inevitably cause the pace of the entire program to sag and this, I think, has augmented the imbalance between launch and spacecraft capability. As on the race track, when the caution flag is out there's no way to gain laps on the leader.

THE PROBLEMS

Let's look at the record. The record says that the Surveyor project has recently cancelled the first contract to adapt an existing on-the-shelf vernier propulsion system because of technical difficulties. These engines, used for landing the spacecraft, must have controlled variable thrust. The contractor had discovered that when the propulsion system was operated under certain down-throttling conditions that cannot be considered a remote possibility, the fuel in the regeneratively cooled jacket decomposes giving erratic thrust performance at the most critical time of the flight. The engine performance is good; its life is far beyond mission requirements. But, to use a homely analogy, you've got to be able to putt.

Gemini is having trouble in another direction. Its reaction control thrusters, used for re-entry as well as for the orbit and attitude maneuver system, have ablative chambers. Although results are often surprisingly good, the useful life of these ablative chambers is somewhat erratic. This is a materials and fabrication control problem. In order to protect the chamber walls and throat, performance has been lowered. Deliveries have fallen back in schedule.

Apollo's programs are not quite so current. Apollo has small thrusters of both the ablative type and the radiation cooled type. Among the small ablative type chambers some of the problems being encountered are common to those of the Gemini thrusters. The radiation cooled reaction control thrusters used in both the Service Module and the Lunar Excursion Module occasionally experience explosions on starting. This phenomenum appears to be caused by the extremely quick response valves of these systems under certain conditions; the system is designed to be operated in a repeated pulse mode. The fact that damage is rare doesn't console those of us involved, even though a redundant system will be aboard.

Among the larger spacecraft propulsion systems in Apollo the problem is that of obtaining and maintaining high performance. The original proposals were bought on the basis of performance numbers that do not appear to be in the deck. Performance actually being measured cuts into margins that were intended to be available to the Apollo system.

THE PROBLEMS' ORIGIN

Let's face certain facts. The spacecraft propulsion system requirements for reliability and (nominal) performance are far more critical than for military weapons where a moderately high success ratio is adequate. Contractors have, in my opinion, failed to appreciate the difference in requirements for space systems and military systems. In the absence of any standardized program profile - which incidentally I believe to be a necessity for future development program bidding - the industry has used its prior experience in developing military systems to project schedules and costs for spacecraft propulsion, and in its anxiety to participate in the program and its' proceeds, it has squeezed the result. Admittedly we're all new in this space business and the government has displayed its naivete in accepting such proposals from industry. The result has been overruns in cost estimates of two and three-fold, with concomitant program schedule slips which result indirectly in sacrifices and deferment of the new programs which should logically begin now if we are to make the most of our capability. It is interesting to note that the ratio of final to originally estimated cost in these projects seems to converge on e, the natural base of logarithms. Since e falls out of infinite series in several suprisingly different forms there may be some mathematical logic for approaching this ratio in a series of contract renegotiations; however, I contend that a sound contract expressing and covering the entire development task to be accomplished should be possible to write, in which case a long series of renegotiations will be unnecessary.

SUGGESTED IMPROVEMENTS

To do so will require on the part of the government the development and full utilization of technically expert people to determine the program requirement, consider the alternatives, judge the realism of bids in terms of effort and equipment requirements, and survey, gauge, and adjust program progress. On the part of industry it will require an honest technical study of the procedures necessary to accomplish the job, and formal disciplining of manpower effort to follow those procedures without waste motion. Let's stop kidding ourselves - the cheapest way to run a program is to do it right, rather than to do it cheap and then do it over. Ignorance may have its excuse but there's none for repeating errors in procedure.

Full utilization of capable talent will require that we avoid a sociological problem that exists in various degrees, both in industry and in the government, an in fact, internationally. It's unfortunate that organization charts are set up with people identified in boxes. There is a tendency for people to go to work and come back home through the top of the box. This keeps management channels direct and simple. But it also fosters a modern-day feudalism that not only frustrates maximum talent utilization but often limits the work that can be handled properly. The problem is more apparent in propulsion, perhaps, than in other disciplines because first, propulsion is [illegible]

vehicles and spacecraft, and to unmanned and manned flight,

and therefore is contained somewhere in everyone's box;

that spreads out the propulsion team. Second, since propulsion systems are not primary systems, propulsion development projects are often in the second or third tier of the system management chain and are therefore not readily visible when the box walls are high and thick. I contend that this combination of factors thwarts full utilization of the technical expertness that exposure to many propulsion jobs can develop; it inhibits simplification and standardization of procedures for program planning, testing, and reporting; it stultifies objective evaluation of new or alternative ideas and concepts; it discourages possible reuse or modification of existing systems or systems under development in other programs; it neglects support by research technology investigations. Correcting these points is not just for "goodness" sake. I can cite specific developments where one or more of these specific problems has had a detrimental effect on work progress. I am personally convinced that the national capability in propulsion is tremendous. We have literally solved problems when industry leaders had argued "that can't be done." We must find means of applying this ingenuity, resourcefulness, and experience.

The government owes itself and the industry an education. Education will save effort, which is money.

Dealing with the industry from the government's side for six years convinces me that there is a serious technological gap between what is being explored by research workers and what can be reduced to a sound set of criteria or specifications. The exigencies of the present programs have usurped much of the funding required to fill that gap. But if we are to get up and go into space with logical follow-ons to Surveyor, Gemini, and Apollo, we need more than program office studies. From my point of view these studies are often carried out simply to elevate a preconceived notion to a foregone conclusion, and while they have some merit in surveying possible mission alternatives, what it really takes to develop new equipment can only be judged from a sound technological base. Not only do we need proof of the validity of new concepts but developers need good experimental data information. Before asking for proposals to develop major pieces of expensive equipment we need engineering experience to judge the technical difficulties underlying the specifications, and a sound layout of program sequences that will result in a successful development. Because of its nature the space program must operate in the fringe of new technologies but let's not try to work on the unexamined part of the fringe. There is no question that a sound technical base and sufficient advanced experimental development work to measure the practical difficulties of a new endeavor will pay for itself in time and funds saved during the course of the development of the new equipment. Even Arnold Palmer plays the course before the tournament.

CONCLUDING REMARKS

Lastly, I would like to inject an optimistic note. My comments are intended to examine what caused trouble with the hope that these problems are behind us if we learn from them. In spite of some trouble, great progress has been made in assembling a machine - a team of government leaders, university, government and industry researchers, and industry fabricators (hardware, that is) with appropriate facilities and equipment. It has taken a while to become accustomed to the response, the feel of this tremendous machine we've cranked up. With a little adjustment of the controls, I think we can get the components to work at equivalent stress; then we will see that machine work efficiently.

Mr. Buckley,[2] watch our tracks!

[2] Mr. Buckley is Director of the Office of Tracking and Data Acquisition for NASA.