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PLASTICS IN SPACE FLIGHT PROGRAMS

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Among the several industries involved in the material science and engineering technology, there can be little question that the most aggressive is that industry which is described by the broad, generic term of plastics. I begin this way to attempt to relieve the excessive criticism which is all too often directed toward this industry. Any fast growing, aggressive institute is always the subject of much controversy, and I believe this to be healthy. Therefore, if the remarks I make in this paper appear critical, please accept them as my attempt to improve the health and welfare of the industry.

To completely cover the topic of plastics and NASA would have taken literally months on my part of touring the several NASA Centers, and hours on your part to listen to the material I had collected. Therefore, my coverage of plastics and NASA is limited to the NASA Manned Space Flight Program. with which I am directly associated. This coverage is designed to show you how and why the manned space flight program depends on plastics for its life's blood. Without plastics the Apollo Saturn Program could not succeed. With better plastics it could be more effective. To more clearly depict to you why I say this, the first slide is a cut-a-way view of the Apollo Saturn V which is color coded to show where plastics are used. As shown here, each element of the vehicle has a significant dependency on plastics. Although on a weight basis, the application of plastics is a small percent of the total, the criticality of the plastic components equals and in some cases exceeds that of other materials.

Without a detailed discussion of justification, the next slide categorizes the application of plastics in the current manned space flight program. Each of these requires careful attention since each must fulfill a very critical need. For example, foams are used quite liberally in all stages of the Apollo Saturn V for significantly different reasons and in significantly different environments. In the first or S-IC stage, one application of foam is to fill the cavity in the bottom fuel tank bulkhead. Since five engines are fed by this tank, the outlets are well above the bottom apex. However, for structural integrity this bulkhead shape must be maintained. Thus by filling this spherical cavity with a low density foam and adhesively bonding it into place, the total weight of the fueled stage is reduced by over 3,000 pounds. For this environment, the foam is isolated from the fuel (RP-1) by sealing it with a polyurethane resin. In this application, the foam is machined into blocks which are then installed individually in mosaic style. To be successful, the foam must be over 30 inches high in the center and be capable of standing the weight of a full fuel tank under a 4 g environment. This has been used successfully on all Saturn V flights.

In the second or S-II stage, polyurethane foam is used as an insulation for the liquid hydrogen fuel tank. The function of the foam in this application is to insulate the tank sufficiently to prevent liquid hydrogen boiling which occurs at -423°F at one atmosphere pressure. In this application, the foam is applied external to the tank and as a part of the structural design of the metal tankage, the insulation must also assure that the metal tank is also at -423°F since the mechanical properties of the metal at -423°F were used in the tank design. Since the foam insulation is external, it is exposed to aerodynamic heating during ascent of the vehicle and the exterior surface can reach a temperature of +450°F. In our early flight models, the foam was applied into a plastic honeycomb core. Later versions will utilize a spray foam of urethane without the honeycomb, thus effecting a weight savings of approximately 1400 pounds. To assure that no air or moisture permeates the foam, it is sealed with a polyurethane resin. Formation of liquid air or liquid oxygen in this system must be avoided since the organic foam is chemically incompatible with these fluids. It is noteworthy that the insulation is applied in a thickness of greater than 1 inch and in the early flight models was adhered to the metal skin by a polyurethane adhesive which reaches its peak efficiency at the cryogenic temperatures. Since changing to spray foam, a primer is used to assure adhesion rather than an adhesive per se.

In the third stage of Saturn V, the S-IVB stage, again freon blown polyurethane foam is used to insulate the liquid hydrogen fuel, but in this case the foam is applied to the tank interior. This causes an even different environment because the foam is immersed in liquid hydrogen. To add to the structural integrity of the foam, glass fibers are built into the foam in three dimensions. The foam is prepared in tiles with an overlap joint and is installed again as a mosaic. To assure that no foam chipping occurs, the foam, after installation, is sealed with a polyurethane impregnated glass fabric. In this instance as in the early S-II flight models, the insulation is adhesively bonded to the aluminum tank wall. To add a special flavor, the skin contains integral stiffeners internally in this stage so the insulation foam must be specially precut and shaped to accommodate the structural system. Here then are three applications of foam, each significantly different from the other, in the three Saturn V stages. A lighter foam would be beneficial to each stage, a high and low temperature resistant foam or more reliable quality characteristics would beneficiate the second stage and a more hydrogen impermeable foam would be most helpful in the third stage. The materials available now do the job, but improvements could be made in each.

A second major requirement of plastics in the Apollo/Saturn space vehicle is that of heat rejection. In the base region of each of the three booster stages, the structure which connects the rocket engines to the primary structure, without protection, would be exposed to temperatures approximating 2,000°F during the engine burn time. Heat shields are employed to keep the structural temperature below 300°F. The problem in the first stage was so gross that plastics could not be used. Before you express disbelief, let me explain that the heat is almost exclusively from radiation; therefore, the principle of ablation is most inefficient. An unfired ceramic is used on this stage. However, on the other stages, where the heating is convective, plastics are used. A major problem, however, is weight. More material than is needed for insulation purposes must be used to assure structural integrity since no structural reinforcement of the heat shield has been used. I suppose that some of the newer plastics in late development today may be more efficient than those now used but these are insufficiently characterized to permit immediate application to Saturn.

Of course, probably the singularly most advertised application of plastics in Apollo is the Command Module heat shield which protects the astronauts during earth re-entry. As you know, this most demanding task has been satisfied by a plastic material. The situation surrounding the particular material selected has been the source of some controversy; however, one thing on which all can agree is that although the Apollo heat shield has been demonstrated to be capable of accomplishing its designed task, this task could be done better with more efficient ablators. Over 14 years ago this month, I participated in what I believe were the first experiments designed specifically to evaluate the process of heat rejection by ablation. The results of those experiments were sufficiently encouraging to prompt by collegues and me to pursue this concept for re-entry body protection. Our program resulted in the application of ablation materials to the nose cone of the Jupiter missile. The perplexing truth, however, is that little progress of significance in understanding the mechanism of ablation or in materials for ablation application has been made since the first production application of the ablation concept was made even though literally millions of dollars have been spent in pursuing the ablation concept. So, in effect, our most sophisticated space program employs materials of some considerable vintage to protect the astronauts during re-entry.

I could make similar comparisons for each of the items listed in category A of this slide. However, let me use just one more of these for emphasis. Conformal coatings are widely used in the commercial industry. Where a failure rate of 1 in 1000 is acceptable, and the environment to which printed circuit boards is exposed is no more serious than the inside of a television set, conformal coatings on the market today are acceptable. But transform that environment to that of a Saturn V and include over 10,000 PC boards. This, by commercial practices means 10 PC boards in every vehicle are suspect. We require component reliabilities of 1 failure in a million units because we have thousands on board. Our environment includes not only temperature extremes considerably in excess of commercial requirements, but also mechanical vibrations must be accepted. Additionally, we are required to operate with PC boards in a pure oxygen environment. Although all of these do not necessarily occur simultaneously, two of the three environments quite often do. We have found that thermal stresses from the conformal coating material are sufficient to break soldered connections. Similarly, mechanical spalling of conformal coatings have been experienced: and finally, the potential of fire from a broken connector igniting a conformal coating necessitates extreme precautions in an oxygen environment. Although we are seeking solutions to these situations, to the best of my knowledge each of these is government sponsored. I am convinced from my previous experience that a conformal coating insensitive to these environments can be produced as economically as conformal coatings which do not satisfy them. The component of this development lacking is not money, it is initiative. In this area and many others, the plastics industry of this country does not lack in talent for I have seen what it can do.

A second broad category of plastics the plastics industry must consider is future needs. Let us accept that the plastics available today, although not necessarily the best, can be made, with ingenuity, to accommodate today's needs. Where are the markets of tomorrow? I believe that it is self evident that plastics have made sizeable inroads into the metal industry. But look carefully, plastics, to a large extent, are augmenting metals, not replacing them. I suppose I can feel comfortable in this environment to say that the metals' industry has become quite complacent because plastics have been unsuccessful in breaking into the really big area of primary structural materials. And yet the reasons why the plastics have not perturbed the primary structure industry are really quite vague. We all know that plastic materials equal to or greater in strength than metals are available to us, and for airframe construction these materials are lighter. Many other facets of plastics are more desirable than metals. We have spent years proclaiming the potential of certain plastics, and yet, the plastics industry in general and SPI in particular can be correctly criticized for not having published a document similar to MIL-HDBK-5 on metals. One of the main reasons for this, and for the failure of so many plastics handbooks, is directly attributable to the multitude of proprietary claims on everything imaginable that goes into a plastic material. Because it is my job to know what materials are used in the NASA manned space flight program that involves any of the Saturn launch vehicles, I have first hand knowledge of the problem of proprietary rights on plastics. We have found everything from major processing procedures to vegetable coloring techniques called proprietary. How, then, can one prepare a document that specifies absolute mechanical and physical properties of so broad a spectrum of so-called "proprietary" materials. The aluminum industry has its own association and handles this kind of problem without hurting itself. The plastics industry must do the same if it is going to assume its rightful place in the world of materials technology.

Because of the great promise of plastics for future structures, it is imperative that the industry in general draw the line on certain products and thoroughly characterize these landmark materials. Otherwise, plastics will continue to be promising--- and promising---and promising. To attempt to alleviate this situation, NASA sponsored a program with industry to establish certain basic test procedures which could be used industry-wide in developing uniform data on like products. The results of that effort are published in a Goodyear Aerospace Corporation Report, GER 12792 It is difficult to say whether the technology needs of tomorrow will be met by the current plastic materials since there is no clear understanding of the limitations on today's materials. However, in the world of NASA, I can tell you what some of the needs, to which we have no apparent answer, will be. First, in the field of space, the need for materials which can be inserted into orbit and then expanded into useful structures is becoming increasingly more evident. I do not mean ECHO I and II type structures, I mean structures which can be inhabited by man. I can envision a compact package which could be expanded, stabilized and occupied which could be capable of supporting man for long periods of time. I believe this is a logical next step beyond current plans for the immediate future. However, before this can be realized, better systems for stabilization than pressurization will be required. Furthermore, one must take advantage of all disciplines of chemistry and physics to assure that such a structure will not be vulnerable to the space environment. Second, no material shows such great application potential for supporting cryogenic tankage as do plastics. It is not difficult to envision the tremendous heat leak associated with metal tank supports when the tank contains a cryogenic fluid such as liquid hydrogen. If reinforced plastics could be sealed so as to prevent permeating of hydrogen during storage, this would provide probably the ultimate in our current knowledge of materials for cryogenic storage in space. This requirement signifies the need for better and denser coating materials, or impregnants for plastic materials.

A second area of primary need in plastics is for better adhesives. Adhesive bonding could provide the solution to many problematic designs. I am fully aware of the abundance of adhesives on the commercial market but I am also aware of the deficiencies of these adhesives. I also recognize the limited amount of adhesives used currently by the aerospace industry but the fundamental reason for the limited use of adhesives is directly attributable to two simple causes. Current widely used adhesives are limited in application potential. More universal adhesives require extreme care in handling, in fact more care than can be expected from craftsmen. With appropriate attention there is no apparent reason why the adhesive technology of today cannot be expanded significantly. With more effective and more easily handled adhesives, there is no reason why these materials would not find widespread use in a variety of commercial applications. I am sure you are aware of the experimental house which has been built using adhesive bonding of reinforced plastics exclusively. One of the major problems in construction of this house was that of adhesive bonding. The adhesives had too short a working life to be compatible with the construction workers requirements. Such situations are continued occurrences in all industries and must be improved before the science of adhesive technology can assume its rightful place in the field of materials.

Looking at problems which can be separated from space travel, one of the major hurdles still confronting the development of the supersonic aircraft is that of sealing the fuel tanks. The seal material must be chemically compatible with the fuel, a kerosine base liquid, at a temperature of approximately 500°F, and must be capable of an expected life of 50,000 hours. An exhaustive search of commercial products currently available reveals the fact that there is no sealant type material which can meet these criteria. I am sure that any of you who have spent time on propeller driven aircraft have seen at least the streaks on the aircraft wings where the fuel has leaked from the tankage. Although we have lived with this problem for many years, we are now at a point where improvement must be made. There is no reason at present to believe that such improvement would not find wide application in other products. We cannot continue to meet tomorrow's needs with yesterday's materials, and this is not just an interesting phrase, it is true.

Another example of our needs is best described by explaining how we expel propellant from a tank in a zero "g" environment. As you know, most of our zero "g" systems are pressure fed, that is propellants are expelled by pressurizing a full tank. Since under zero "g", the pressurizing gas could infiltrate the propellant, a situation which is intolerable, one method of precluding this is to place the propellant in a bladder and applying the pressure external to the bladder. Ideally, this would be done by taking an elastomeric material and expanding it with the propellant. However, our inability to provide an elastomeric bladder which is compatible with the propellants of interest results in a most cumbersome solution. The bladder is filled with propellant and then the bladder is collapsed by pressure as the propellant is required. This can be likened to collapsing a paper bag with your hand. The strains and stresses introduced into this inelastic bladder cause early failures of the bladder and, as a result, of the propellant feed system. To circumvent this problem in today's world, extreme care must be taken in bladder design to assure only "acceptable" type wrinkling occurs. The real solution here is a compatible elastomer. I have heard it said that such a requirement is impossible to meet. I am sure that statement is true for the individual who said it because his mind is made up. However, if we look back through the annals of materials technology it is interesting to see how many "impossible" things have been done. I believe that when you or I reach the stage of decreeing the impossible, we should step down and let others with more vision take our place.

A final area of need which I would be remiss in omitting from a discussion such as this is the development of plastic materials which are resistant to fire in oxygen rich environments. Until we can more thoroughly assess the metabolic reaction of man to space, it appears that our medical associates will insist on oxygen enriched environments for all manned spacecraft. It is not hard to comprehend the need to assure that fire does not occur in orbiting spacecraft since the point of return for the crew is untenable. Therefore, to guarantee that fire will not be a hazard, one must assess the elements necessary for fire to occur and then preclude such elements categorically. Of course, for fire to occur, the presence of oxygen, fuel, and an igniter is required. In any spacecraft, both oxygen (in the breathing gas) and an igniter (in the form of electricity) are ever present. Thus, to preclude fire, the fuel must be eliminated. This means that only materials which are nonflammable in oxygen enriched environments can be exposed in the crew bay area. I am not at all convinced that this requirement presents an unsurmountable hurdle. I am convinced that it challenges man's ingenuity. A limited amount of work on selected polymer systems has shown that with certain fluorination processes, some polymers can be made fire resistant in an enriched oxygen environment and based on these promising results, my collegues at the Manned Spacecraft Center in Houston, Texas, are planning to pursue the development of an adhesive system which is nonflammable in an enriched oxygen environment. Additionally, by imagination, encapsulating techniques have been developed which isolate flammable materials from the crew bay environment, thus precluding the possibility of fire. It remains to be seen how the ingenuity and inventiveness of mankind handles the development of concepts to provide nonflammable materials for manned space flight.

In the past several minutes I have tried to show how plastics are used in some typical applications in the National Space Program. Additionally, it was my intent to indicate to you the variety of environments where plastics are used and how improved plastics could help this or other programs. Finally, I have tried to stimulate your imagination by describing some of the more pressing needs for plastic materials in the overall aerospace industry in hopes that you might carry these thoughts to your respective organizations. I appreciate the opportunity you have afforded me in listening to my dissertation.