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INSULATED WIRE SELECTIONS ON THE APOLLO SPACECRAFT AND THE LUNAR EXCURSION MODULE

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BY

JAMES M. DAVIS
PROJECT LEADER

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APOLLO SUPPORT DEPARTMENT
GENERAL ELECTRIC COMPANY
DAYTONA BEACH, FLORIDA

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Summary

The Apollo spacecraft and the LEM are both designed for similar applications, and will experience similar environments. Yet the insulated wire selections made by each contractor for these two vehicles differ.

A thorough study has recently been completed on insulated wire constructions for space applications. This study, along with other information, indicates that the insulated wire selected for the LEM has greater reliability than that selected for the Apollo spacecraft. In addition, there is a potential weight savings of 160 pounds per mission by using the LEM insulated wire.

It is strongly recommended that a changeover to the LEM (H film) wire on the Apollo spacecraft be given consideration. If the impact upon schedules and costs is not too severe, the benefits of greater reliability and weight saving suggest a changeover without delay.

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I. Background

The environmental extremes of space have resulted in considerable research for more exotic materials for insulated wires. Generic names such as polyimides, polyolefins, polyvinylidene fluoride, fluorocarbons, etc., have become quite prevalent recently. In addition to improved physical and chemical properties, lighter weights have been sought.

To provide reliable data on the characteristics of several of the newer insulations, the Manned Spacecraft Center contracted with the General Electric Research and Development Center (Contract NAS9-4549) to undertake an evaluation program based on space conditions. The results of the study have just been published: "Evaluation of Thin Wall Spacecraft Wiring." This is the most reliable, comprehensive and independent study published to date that was primarily aimed at the space environment.

The study is of unique interest because of the controversy over the different insulated wire selections made by North American Aviation (NAA) and Grumman Aircraft Engineering Corporation (GAEC). For the Apollo Command Module, NAA has selected Teflon with a polyimide coating (specifically TFE-ML); and for the LEM, Grumman has selected H film, a polyimide tape construction. Both of these insulations are a product of E. I. DuPont de Nemours & Company.

The purpose of this paper is to present an evaluation of the two insulations, related to the probability of mission success.

II. Constructions

1. TFE-ML

TFE Teflon is not a new substance, having been developed by DuPont previous to World War II. It is the frictionless material commonly used in bearings, slide applications and most recently in frying pans. It has outstanding electrical properties. To overcome one of its physical limitations, the inability to withstand excessive abrasion and cut through conditions, a thin coating of a polyimide is added. This coating, called ML, is a DuPont product also. Since the ML coating has excellent properties, a reduction in the wall thickness of the TFE to save weight and space has been allowed. Whereas a wall thickness of .010" was previously used, a newer construction would be to use a .006" wall of TFE with a .001" ML coating. This is the construction NAA plans for Apollo.

There is no one insulation that is perfect for all applications, and the choice of insulation, coating, etc., is a series of trade-offs. While the ML coating on TFE improves its resistance to abrasion, the coating is not as resistant to some other factors, such as flexing at sub zero temperatures or to certain rocket fuels, as is TFE itself.

2. <u>H Film</u>

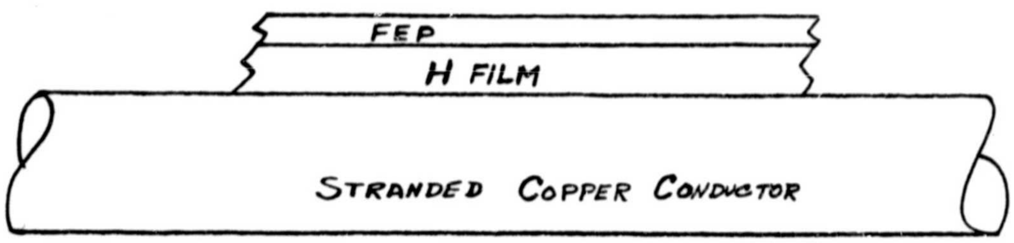
H film, or Kapton, as it is now known commercially, is a polyimide film. It is light amber in color, transparent, tough and flexible. It has very high heat resistance, does not melt, is flame resistant and does not char below 1500°F.

The H film manufacturing process is proprietary but the chemical reaction is common knowledge. Basically, polyimide film (technically known as polypyromellitimide) results from the polycondensation reaction between pyromellitic dianhydride and an aromatic deamine.

H film is available as a tape in thicknesses of 1/2, 1, 2, 3, and 5 mils and in width up to 16 inches. Since the H film is in tape form, it is wrapped around a wire and heat sealed to secure the insulation.

As previously stated, H film does not melt. To make it bond to itself is difficult. For most applications the H film is supplied bonded to 1/2 or 1 mil FEP Teflon, as shown below:

Cross Section of H-Film Construction
(1 Mil H, 1/2 Mil FEP Teflon)



After the conductor has been wrapped,heat is applied, the FEP fuses and bonds to itself. It should be noted that this construction is now limited to applications where temperatures are not expected to rise above 200°C, which is the upper temperature limit for FEP Teflon.

Other variations can be made using H film to meet specific requirements. Sometimes the FEP is bonded to both sides of the H film, copper foil can be added, and sometimes the whole construction receives an outer coating. The LEM insulated wire construction is a double H film wrap: the first wrap is 1 mil H, 1/2 mil FEP; the second wrap is 1/2 mil FEP, 1 mil H, 1/2 mil FEP, and the whole construction then receives a dispersion overcoat of 1/2 mil FEP Teflon. With the overlap of tape the net result is a wall thickness of approximately 7 mils.

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III. Results of Study

A total of 29 individual tests were made on 16 different samples of wires. Many tests were made in combinations of room, elevated, and cryogenic temperatures, normal atmospheric and vacuum pressures, 50 percent and 95 percent relative humidities, in oxygen atmospheres, and in loaded and unloaded conditions. The discussions here will be restricted to the NAA and LEM insulated wires and those tests that show significant differences. In all other cases the two insulations are equal, or the differences are slight and of no consequences for Apollo applications.

1. Insulation Resistance

Samples were immersed in water for three days previous to measurement. TFE-ML failed, H film-FEP passed. This test is a reflection of the homogeneity of the construction. The TFE-ML actually failed at the end of one hour.

2. Voltage Withstand

This is also known as the "hipot" test. The voltage used was 1600 volts for one minute. TFE-ML failed, H film-FEP passed.

3. Flashover

Flashover is not apt to be a problem with normal spacecraft voltages and danger would exist only in case of quite high overvoltages. Flashover may not cause permanent damage unless tracking or fire results. It should be noted that flashover will not occur in a properly designed electrical system (where creepage paths are long) if properly protected and free from contamination and defects.

In this test, performed at 5 psia, wet O_2, 23°C, H film-FEP tracked, and hence failed the test. TFE-ML, since it did not track, passed the test successfully.

4. Weight

Though not a factor in the reliability of the spacecraft electrical system, the weight of H film-FEP is nearly 10 percent less than TFE-ML. MSC determined that this potential weight savings would amount to 160 pounds per spacecraft.

5. Pull-Out Strength in Potting Compounds

Both insulations are held most securely with an epoxy potting compound. Minimum pull-out strength was 10.1 pounds for TFE-ML and 26.5 pounds for H film-FEP.

6. Flexibility

The importance of flexibility depends upon the application. At room temperature both insulations are satisfactory, though H film-FEP will withstand more cycles before failure. At cryogenic temperatures H film-FEP is again superior. Interestingly enough, at these lower temperatures TFE-ML does not perform as well as TFE alone.

7. Scrape Abrasion

This test consisting of scraping a needle back and forth across the surface of the insulation, to simulate the sawing action of insulation against a fairly sharp metal edge. The nature of the insulation, as well as the wall thickness, are significant factors in this test. Both insulations were the same thickness and TFE-ML proved superior by a ratio of 2:1.

8. Cut-Through

H film-FEP is superior.

9. Thermal Creep

H film-FEP is superior.

10. Flammability

Flammability becomes a problem only with the failure of protecting devices. Events that could cause flammability of insulation are:

a. Proximity to hot elements, by design or accident
b. Short circuit currents
c. Overload currents that tend to "bake" the insulation at high temperatures.

H film does not burn, and TFE only burns under extreme conditions in the 5 psia, wet O_2 atmosphere. For all practical purposes, smoke is nil.

11. Chemical Compatibility

TFE with no coating is essentially inert to degradation by rocket fuels and oxidizers. The ML coating is attached by oxidizers, as is H film. The FEP outer coating on the LEM construction offers only a little protection against fuels and oxidizers.

12. Other tests, where the two insulations were either similar, or at least satisfactory for spacecraft conditions, were:

a. Insulation resistance, wet O_2
b. Voltage breakdown

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c. Voltage breakdown, potted
d. Wicking
e. Thermal aging
f. Ultraviolet radiation
g. Off-gassing
h. Volatility in a vacuum
i. Corona

IV. Summary

The NAA insulated wire selection for the Command Module on Apollo is Teflon TFE, with a polyimide coating called ML. The GAEC selection for the LEM is a double wrap H film construction with an FEP dispersion overcoat. While either insulation would be satisfactory for some environmental conditions, the H film-FEP shows a superiority over TFE-ML for space conditions as indicated in these tests:

H Film-FEP Excels For	TFE-ML Excels For
Insulation resistance	Flashover
Voltage withstand	Scrape abrasion
Weight	
Pull-out strength	
Flexibility	
Cut-through resistance	
Thermal creep	
Flammability	

V. Conclusions

1. The H film-FEP insulation has definite superiority over TFE-ML for the Apollo mission. Flashover and scrape abrasion can be compensated for by proper engineering design.

2. It is strongly recommended that NAA change to H film insulation, similar to the LEM construction. The principal advantage is improved reliability with a bonus of lighter weight. Costs and schedules permitting, the change should be made as soon as possible.

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