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Minuteman III Liquid Propulsion System Storage Surveillance Program

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Introduction

SINCE 1966, Textron's Bell Aerospace Company has been conducting a program of storage surveillance on the Minuteman III, Stage IIIa liquid bipropellant system. The objective of the surveillance program is to predict the life of deployed systems with sufficient warning of ageout to allow replacement or refurbishment to be planned. Hardware tests, ranging from full-scale systems to laboratory specimens after predetermined periods of storage, have been made. Test parameters which are judged to be sensitive to aging and critical to the successful performance of the mission are monitored for age regressions to detect significant trends toward a particular mode of failure. This Note reports the progress which has been made in identifying potential weak link components and estimating the likelihood of reliability degradation with continued storage of the system.

System Description

Before discussing the service life investigation, it will be useful to identify the system and its function. The system is characterized by a 52-in.-diam, cork-insulated, magnesium shell within which various assemblies are enclosed (Fig. 1). The system attaches to the aft end of the missile guidance set (MGS) and re-entry vehicle and to the forward end of the third stage solid propellant booster. Electrical signals are transmitted from the MGS to each of five isolation valves, to each of ten low-thrust bipropellant valves, to a high-thrust bipropellant valve, and to an interstage connector.

The function of the system is to provide the necessary maneuvering capability to deploy the re-entry vehicles at altitudes above 300,000 ft. When not functioning—that is, during storage—the system has a storage requirement of 3 yr fully loaded with pressurant and propellants. Part of this storage time is logistic storage, which covers the interval from the time the system is pressurized and loaded with propellant to the time the system is declared operational in the silo, and requires that the system withstand a range of temperatures from 20–125°F at 60% maximum relative humidity. In the silo environment, the conditions are 60–80°F at 60% maximum relative humidity.

Reliability During Operational Storage and Flight

There are two mission phases to be considered in evaluating the service life of Minuteman Stage IIIa: a storage phase and a flight phase. The probability of no failure (ageout) during the storage phase of the mission, can be readily evaluated by considering the number of aged systems (11 months or older) which have been stored successfully to date.

It can be shown that the probability curve has the time dependency shown in Fig. 2, from which the probability of no ageout within the 3 yr storage period at 90% confidence, is interpolated to be over 98%. In a similar manner, the probability of no ageout during the flight mission phase, within a 3-yr storage period, can be derived.

The probability curve (Fig. 3) shows a demonstrated probability of over 90% at 90% confidence. From the foregoing, it is clear that there is considerable margin for aging. The problem is to determine what the margins are for critical parameters of the

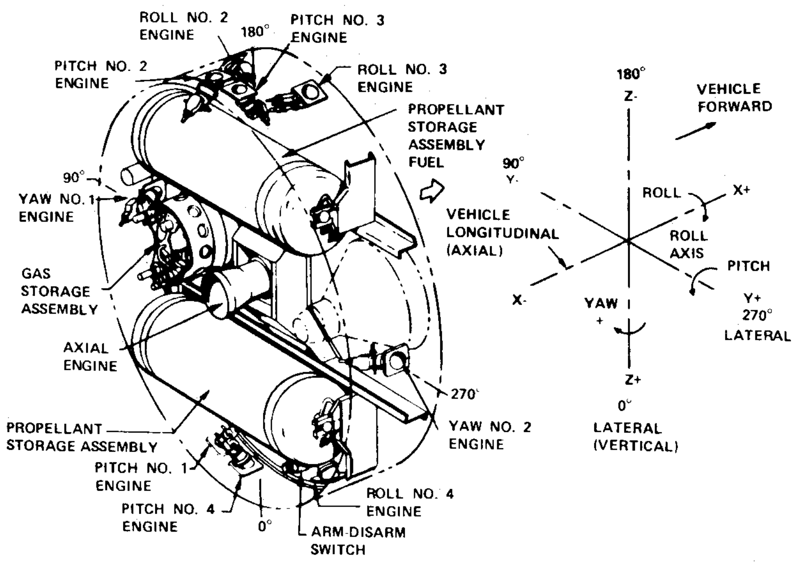

Fig. 1 Propulsion system rocket engine.

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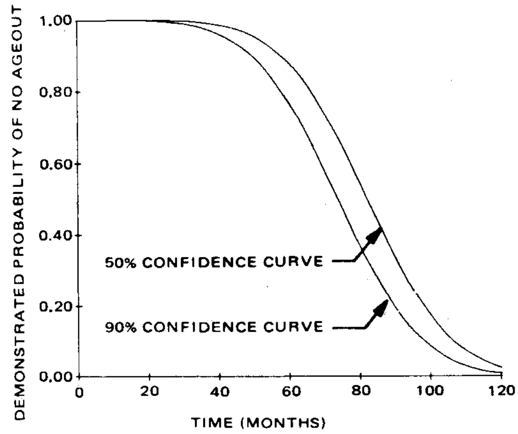

Fig. 2 Probability of no ageout-stored systems.

system and to develop methods for investigating the age regressions which reduce these margins.

Selection of Critical Parameters

The system design created specifications of the performance required from each component and acceptance tests were designed to check that the specified performance was actually obtained from production items. The acceptance tests, therefore, cover all the parameters which are necessary for detecting age effects. It would satisfy the aims of the surveillance program if all acceptance test parameters from all components were tracked for age regression but, in practice, the very large number of parameters makes this approach impracticable. It has been necessary to make a selection of those parameters which are affected by materials suspected to be age sensitive and critical to mission performance and which at the same time have little safety margin. By weighing the degree of age sensitivity, mission impact, and the safety margin, a measure of criticality was obtained and the most sensitive of these parameters were defined as critical parameters.

Investigation of Age Regression Trends

Figure 4 illustrates the basic elements of the investigation of age regression for a typical critical parameter. The 3-sigma limit of the unaged population is established from prestorage tests of the component incorporating the critical parameter. The ageout alert limit is the specification limit or acceptance test limit for the parameter, while the failure limit is the calculated threshold beyond which there is high probability that the system will fail. The margin of safety reflects the difference between the 3-sigma limit, within which approximately 99.7% of the population of values is contained, and the failure limit. If, as a result of age

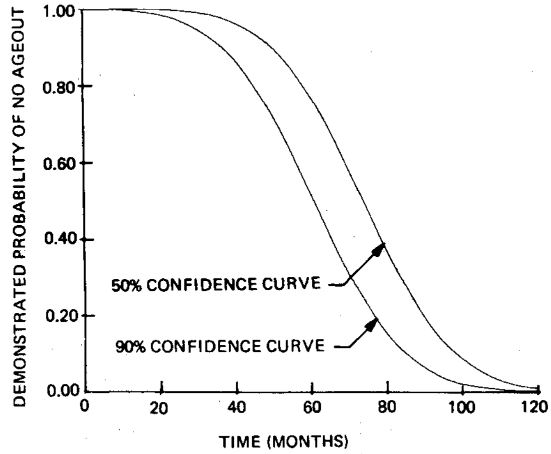

Fig. 3 Probability of no ageout-stored and fired systems.

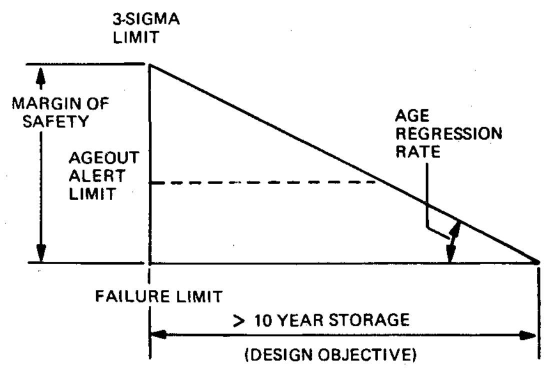

Fig. 4 Essential elements of service life investigation.

regression, the 3-sigma limit exceeds the ageout alert limit short of the 10-yr design objective, the component typified by that parameter is investigated as a potential life-limiting component.

Of prime importance in the investigation has been the treatment of data bias arising from 1) Pre- and post-storage testing of hardware at different facilities. 2) Differing configuration levels, and 3) Differing levels of test; such as system, component, and laboratory levels.

Another important part of the age regression analysis is the computation of a failure limit. It was originally intended to evaluate critical failure limits for all critical parameters, but it was found that an extensive effort was needed to arrive at a truly critical limit in many cases. It was then clearly cost-effective to calculate critical limits only when absolutely necessary for evaluating service life. Accordingly, critical limits have been derived for only a few parameters. It follows from this policy that some other limit, inside the critical failure one, is needed to direct attention to the parameter when the regression trend is significant and has progressed appreciably in the critical direction. These limits have been set for all critical parameters and are called "ageout alert limits," In general, it has been possible to take these limits to be the same as the model specification or acceptance test limits because there is some margin between these limits and the zero time performance of hardware.

Results of Age Regression Analysis

Storage Phase

The current investigation of the selected critical parameters shows that only one parameter appears remotely capable of

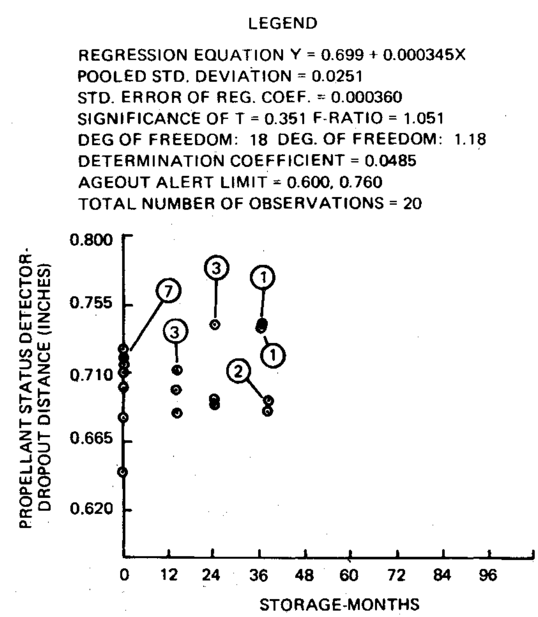

Fig. 5 Age regression of PSD dropout distance.

impacting the 10-yr design objective in the storage phase: the propellant status detector dropout distance (Fig. 5). The concern lies in the fact that the population of values appears to be concentrated at the upper ageout alert limit.

The trend of PSD dropout distance as a function of age is not significant, and the low determination coefficient suggests little or no time dependency. Moreover, no significant aging mechanisms have been identified to postulate an aging trend. Assuming, however, that an aging trend does materialize, and does result in intersection of the 3-sigma prediction limit and upper ageout alert limit within 10 yr, the predicted impact on the mission could be failure to signal low propellant volume. The actual probability of starting a mission with less than the required propellant volume is presently 10^{-15}, based on actual leakage rate measurements. Moreover, the probability of corrosion creating a sudden gross leakage problem is equally unlikely, given the absence of a significant decreasing trend in corrosion inhibitor (nitric oxide) and the absence of visible evidence of corrosion to date. In view of these facts, the data in Fig. 5 is considered of little significance at the present time.

Flight Phase

Two distinct failure types are postulated in the flight phase: the sudden catastrophic failure, the probability of which is greatest during the boost, stage separation, and immediate post-boost phases of the mission; and the flight performance failure, which is characterized by an inability to perform the required flight maneuvers with sufficient accuracy.

Evidence to date shows that only the RF current attenuation for the pyrotechnic control cable at 10 MHz frequency (Fig. 6), could possibly be interpreted as a parameter of concern and for the same reason previously cited: the population of values is concentrated at the ageout alert limit. The significant trend and fairly high determination coefficient may be ignored in this case, because it is suspected that the post storage data, having been measured on cables which were stressed, show lower attenuation values than the zero time data, which reflect the unstressed cables. Moreover, no aging mechanisms have been identified to account for the significant decrease in attenuation. This, of course, does not alter the concern that a true aging trend would produce

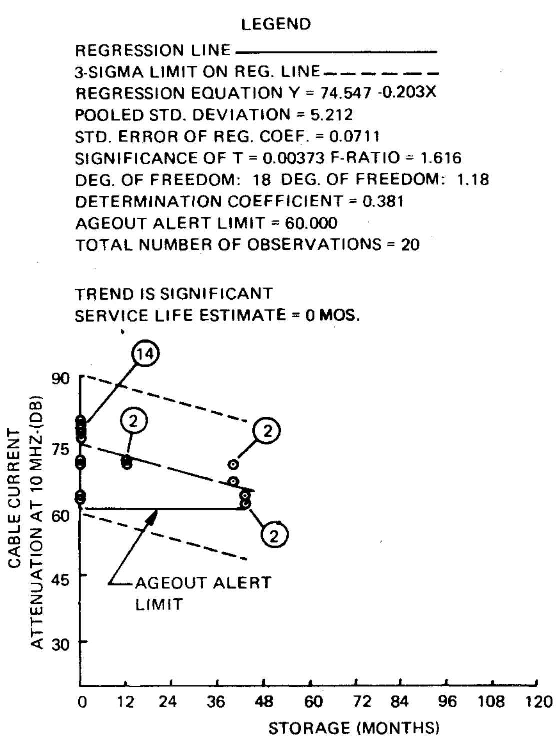

Fig. 6 Age regression of pyrotechnic control cable current attenuation at 10 MHz frequency.

intersection of the 3-sigma prediction limit and ageout alert limit, but documentation is available to show that a wide safety margin exists. The present data therefore, is not considered to be indicative of a potential life-limiting problem.

Summary and Conclusions

The present evidence offers very high confidence that the Minuteman Stage IIIa will meet its 3-yr storage requirement easily without maintenance. There is considerable margin for aging, and in all but two cases, it does not appear likely that this margin will be dissipated within the 10-year design objective. In the two cases in which this statement cannot be made categorically, further operating margins are evident upon closer examination.

Accuracy of Orbit Determination from Ionospherically Corrupted Tracking Data

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Nomenclature

De	= ionospheric maximum electron density, el/m^3
f_m, f_R, f_{RR}	= radio frequency of the interferometer, range, and range-rate signals, respectively, Hz
He	= height at which De occurs, km
L	= logarithm to the base ten of De
l, m	= interferometer direction cosines
$\Delta l, \Delta m$	= ionospheric effects on l and m
RG	= geocentric radius of the ground station, km
ρ	= range of the satellite relative to the ground station, km
$\Delta\rho, \Delta\dot{\rho}$	= ionospheric effects on range and range rate, respectively, m, m/s
$\theta, \dot{\theta}$	= elevation angle of the satellite from the ground station, and its rate of change, rad, rad/sec

I. Introduction

TRACKING data at frequencies in the region of 150 MHz (vhf) are commonly used for tracking satellites. These data are significantly affected by passage through the ionosphere. Predicting the accuracy with which the satellite orbit can be determined using the vhf data has been a problem in the past because of the lack of an ionospheric model whose statistical behavior can be introduced into the usual orbit determination accuracy software. Previous studies have: a) assumed a constant large error,[1] b) treated worst-case situations only,[2] or c) assumed a percentage error on the ionospheric effect.[3]

This study introduces a procedure whereby the ionosphere is modeled by a single parameter whose statistical distribution is approximately normal. This parameter is then included in the solution vector along with the satellite position and velocity (state vector). Unlike methods a), b), or c) this procedure

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