DESIGN OF SOME AERODYNAMIC FLEXIBLE STRUCTURES FOR RELIABLE PERFORMANCE

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by

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CHAPTER 10

CONCLUSIONS AND SCOPE FOR FURTHER WORK

Abbreviations

AAD	Auto Activation Device
CM	Crew Module
FMEA	Failure Mode and Effects Analysis
FTA	Fault Tree Analysis
TCS	Top Cover Separation
*w*RPN	Weightage Risk Priority Number

10.1 Introduction

Parachute deceleration system for CM, especially those with a parachute cluster, required testing to identify and reduce the probability of failures. This is especially important when the spacecraft in question is human-rated. Detailed literatures investigated in this field and discussed in Chapter 2.

The prime purpose of this study is to design such an aerodynamic decelerator system for re-entry crew module which gives maximum drag force, minimum flow disturbance and provide steady descent to the crew module with no error in the system. The parachute sizing, parachute selection criteria and design of parachute deceleration system and establish the reliability of each component are the key investigation of this study and presented in previous chapters. The parachute system is the most critical and important part of the space module recovery system. Parachute size is restricted by the required landing speed, materials, and weight of payload. Parachute materials are selected based on the various forces experienced by the parachute. An investigation has been carried out to design a parachute system which gives less impact velocity, less angle of oscillation and less impact load for the landing of a crew module. The mathematical analyses and experimental determination show that the circular slotted parachute for main parachute has less opening shock in reefed condition and minimum size for the same payload amongst the other parachute types. The one of the outcomes of the experimental investigation is parachute coefficient of drag, which is measured and compared with the value found in literature, wind tunnel test. The result of the above analysis and experimental testing in dynamic and simulated flights indicate that this configuration of parachute gives stable and steady descent to the crew module.

In human rate parachute risk is involved at every stage of launching and recovery. Therefore, risk-based design analysis covers the maximum possible hazard and risks in design as well as in operation have been presented in Chapter 6. Packing risk is most important factor for failure cause and hence suggested to minimum human involvement.

The failure modes of deceleration system right from the sensing of deployment altitude to splash down of CM on sea are identified in which single point failures are highlighted. The failures are categorized in accordance with the severity of failure and probability of occurrence. Majority of the failure modes identified were catastrophic in nature but that is due to failure of both primary and redundant system. The other failures can be overcome by applying corrective action proposed. A combined approach FTA-FMEA has been discussed in Chapter 7 to figure out the catastrophic failures during design process. Based on these two failure mitigation methods, risk has been priority and ranked them according to their RPN. Subsequently, severity, occurrence and detection pie chart has been prepared and presented for decision analysis.

Parachute structural arrangement has been presented in the form of RBD for reliability estimation and design-based reliability analysis has been carried out and compared with target reliability, discussed in Chapter 8. It is found that component reliability is very high but packing reliability is less which reduces the overall system reliability. It means that parachute packing required a greater number of tests and more data to be collected for accurate estimation of system reliability.

10.2 Summary of Finding and Suggestions

Following are the brief summary and suggestions of the research work:

(i) One active redundancy proposed in each parachute configuration.

(ii) Standardized the size of TCS and Pilot chutes to reduce the variety of materials, qualification testing and additional inventories.

(iii) A new gore layout for Main parachute proposed to get better stability and high drag coefficient.

(iv) One stage reefing is proposed in Main parachute to reduce the parachute size, huge drag force and strength of the materials. Hence, light structure of PRU and bulk head of CM.

(v) Parachute risk analysis carried out to reduce the severity and hazard of parachute system. Proposed an additional device for parachute initiation, like Over-ride Switch to the crews or AAD.

(vi) Different possible accident scenario and remedial suggestions have been presented

in this report.

(vii) CM and Forward heat shield re-contact trajectory analysis carried out and found that minimum differential velocity should be 30 m/s between Forward heat shield and CM.

(viii) A new FTA-FMEA combined model proposed to find the multi failure in parachute system. This model shows that traditional FMEA ranked RPN can change according to weightage of contribution of parts and hence a new wRPN is estimated for identifying, evaluating and prioritizing the risks associated with different components in a complex system.

(ix) Reliability of each critical components of parachute established. It is found that system reliability is 0.99596 which is less than Apollo (0.999) but higher than Soyuz (0.96) and target reliability (0.98589). This value can be improved by increasing the parachute packing operational reliability with a greater number of tests.

(x) From the analysis on optimized designed of hybrid tether, it is found that the design factor is in the range of 2.6 to 3.5 to obtain corresponding reliability in the range of 0.9898 to 0.9964, respectively. The reliability beyond 0.9964 will increase the size of tether, weight and cost.

10.3 Limitations of the Present Work

The results of this investigation are carried out perform the mission at no wind conditions but in actual operation wind may drift the system away from the target, therefore, landing site may change. It is suggested to perform re-entry during calm wind and well predicted environment. This study does not cover the parachute triggering mechanism, parachute housing configurations, and certain secret data because these are part of the mission of another agency.

10.4 Scope for Further Work

It is recommended that an active redundant parachute must be used in all stages of parachutes or alternatively, one complete set of parachute system should be considered to remain as back-up to provide a two-fault tolerant system as used by Soyuz (Russia) and Shenzhou (China). **S**ince design has not considered the wind effects on parachute performance, it would be suggested to consider the large atmospheric uncertainties in design. Furthermore, a wind dispersion study still has to be performed and to be incorporated in reliability analysis. For implementation point of view, it's disappointing a thorough wind analysis could not have been incorporated and it is a critical parameter for parachute deployment.

The performance and reliability are assessed by simple methods based on simulated data. An accurate structural parachute models, environmental models and trajectories are to be modeled for more accurate prediction of reliability.

It is recommended for those parachute systems of similar complexity to the Apollo that will be used for human flight to perform enough system level tests to drive the failure rate down during development testing so that design updates can be incorporated to achieve the most reliable parachute system possible. To aid in eliminating failure modes seen during testing, as much data as possible should be collected, including as many different video images and views of the parachutes as possible, including views of the deploying parachutes. In addition, all anomalous events during testing, as well as any damage to the parachutes, should be tracked and root causes found so that the parachute system design can be changed to prevent those failure modes. Also, it is recommended to carry out the Event Tree Analysis (ETA), Root Cause Analysis of possible failures during flights which are not covered in this dissertation.