DESIGN OF SOME AERODYNAMIC FLEXIBLE STRUCTURES FOR RELIABLE PERFORMANCE

Thesis submitted towards the partial fulfillment of the requirements towards the Award of Degree of

Doctor of Philosophy

by

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It is certified that the work contained in the thesis titled ***"*****Design of Some Aerodynamic Flexible Structures for Reliable Performance*****"*** by **"Mr. Mahendr Pratap** (Roll No. 14101002)" has been carried out under our supervision and that this work has not been submitted elsewhere for the award of any degree or diploma. It is further certified that the student has fulfilled all the requirements of Comprehensive Examination, Candidacy, State of Art seminar and Open seminar for the award of Ph.D. Degree.

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DECLARATION BY THE CANDIDATE

I, **Mahendr Pratap,** certify that the work embodied in this thesis is a bonafide research work carried out by me, under the supervision of **Professor Anil Kumar Agrawal** and **Dr Subhash Chandra Sati** from July 2014 to January 2021, at the Department of Mechanical Engineering, Indian Institute of Technology (BHU), Varanasi. The matter embodied in this thesis has not been submitted elsewhere for the award of any other degree or diploma. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not wilfully copied other's work, paragraphs, text, data, results, etc., reported in journals, books, magazines, reports dissertations, theses, etc., or available at websites, and have not included them in this thesis and have not cited as my own work.

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ॐ तत्पुरुषाय विद्महे महादेवाय धीमहि तन्नो रुद्रः प्रचोदयात ।

Om, let me meditate on the great God of God Lord Shiva, Oh, greatest God, give me higher intellect, and let God Shiva illuminate my mind

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Mahendr Pratap

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PREFACE

India's plan for human space program calls for a first time to send two to three crew members in LEO for 7 days and safe landing on earth. These goals require the development of a spacecraft, launch & recovery systems and survival accessories which is based on the many studies carried out by India in past. This research is one of the pre-project activities of recovery system (i.e., parachute deceleration system) and can be reference for the future proposed mission.

The Crew Module provides a safe habitable volume for the crews during launch, spaceflight, and return through the atmosphere with help of decelerators called flexible Parachute Deceleration System (PDS). Function of PDS is to retard the module from high altitude to the sea level at reduced required velocities in stages. In the deceleration system, module speed is reduced in two stages by using two stage deceleration systems. These deceleration systems are deployed in air by pilot chutes and drogue parachute. At low atmospheric altitude, Top Cover Separation (TCS) chute take away the Forward heat shield of module and open the way to deploy other parachutes. Drogue parachutes diminish the damping of module oscillations and drag to slow down the speed for successful deployment of main parachutes. The proposed recovery parachute sequence is presented in Figure 5.1 and Figure 5.2, Chapter 5. The CM falls under the recovery parachute system in both conditions, during nominal re-entry and descent after an abort from a failed launch. First, mortars are fired and deploy two forward chutes which remove the forward heat shield from CM. Then, a mortar deploys two pilot chutes pulls out the two drogue parachutes. The drogue parachutes are retard the CM as a first stage deceleration and then jettisoned from the CM at pre-define altitude and in turn pull out two large main parachutes. The main parachutes passed through one reefing stage before they are fully opened and slow the CM for a water landing. The investigation on parachute design analysis, failure modes, risk and hazard analysis, reliability analysis are the part of the focus of this research.

Parachute system and tether reliability analyses are carried out and their related terms are the important factors in the parachute packing, development, production, operation, and maintenance of such complex system. An analysis of a design for reliability can identify critical failure modes and cause of unreliability and provide an effective tool. Application of design evaluation techniques can provide a sound basis for determining spare parts requirements, required part improvement programs, and needed redesign efforts, re-allocation of resources and other measures to assure specified reliability requirements will be met.

The primary objective of this research is to identify the weakness of the design, risk analysis, failure and reliability analyses to improve the parachute performance and optimized design of tether, so that, final product would be more reliable and requires maintenance free for human rated applications. Each Chapter contains its own specific introduction, analysis, methodologies and at the end thesis conclusions and further scope of work are proposed. Since this system has lot of sub systems, parts, components, sub components, therefore, only reliability of critical components have been considered for analysis. Potential failure parts have been identified before manufacture and accordingly corrective action suggested.

In the end of the research work (Chapter 10) covers the research conclusions from the work carried out related to parachute deceleration system and a hybrid aerostat tether. This chapter complies and summarizes the present research work and its limitations. This chapter also provides the recommendations for future research work in this field.