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Reliability Assessment of L40 Stage GSLV Mk II

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Abstract - *Reliability of a component or system is the probability that a component or system will perform a required function for a given period of time when used under stated operating conditions. This paper discusses the reliability analysis of L 40 stage of Geosynchronous Satellite Launch Vehicle (GSLV Mk II). A variable mean time to failure rate model is also developed for analyzing observed failure data to ascertain probable cause.*

Key Words: **System reliability, System Unreliability, Liquid Strap-on, Geosynchronous Satellite Launch Vehicle, Mean time to failure.**

1. INTRODUCTION

System reliability is a measurement science of a system or component to perform its intended function for a specific period of time under a given set of time. GSLV Mk II (Figure1) The first stage (GS1) comprises a solid propellant motor (S139) and four liquid strap-ons (L40). The designations of the different version indicate the type of fuel used and the mass of propellant booster strapped on to the rocket. "S" denotes "Solid" and the "L" denotes liquid and the second number represent mass (in ton) of propellant. The liquid strap-ons (L40) comprises 40 ton of liquid propellant powered by vikas engine with four identical separate steel tank, analysing the reliability of these subsystem and their relative contribution to spacecraft failures is important for reliability growth of spacecraft and targeted system improvements. This paper deals with reliability assessment of L40 stage.

1.1 Configuration Description

GSLV Mk II (Figure1) is three stage vehicles with overall length of 49.13 m and lift off mass is about 414.75 tonnes. The second stage (GS2) is powered by vikas engine. The third stage (GS3) uses indigenous cryogenic engine (CE-7.5) Geosynchronous Satellite Launch Vehicle (GSLV Mk II) is the largest launch vehicle developed by Indian Space Research Organization (ISRO) This is the fourth generation launch vehicle with four liquid strap-ons. The Strap-ons are powered by vikas engine each and along with the solid rocket motor core of the first stage, provide an enormous thrust to the launcher.

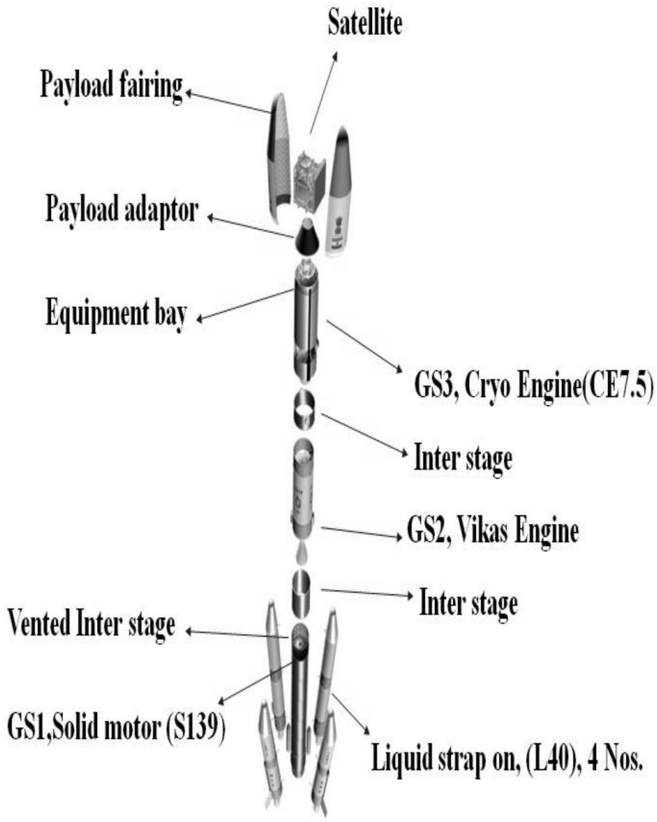

Fig -1: Configuration Description

Stage 1

Sample The first stage comprises of a solid propellant motor (S139) and four liquid propellant strapped on boosters (L40). S139 stage is 20m long and 2.8 m in diameter and it carries 138 tonnes of Hydroxyl Terminated Poly Butadiene (HTPB) based solid propellant. The stage develops about 4700 kN thrust and burns for 100 seconds. The four strapped on (L40) stages are 19.70 m long and 2.1 m in diameter. Each of them is filled with 42 tonnes of hypergolic propellants, namely, Unsymmetrical dimethylhydrazine (UDMH) and Nitrogen Tetroxide (N_2O_4) and produces 680 kN thrust and burns for 160 seconds.

Stage 2

The second stage is 11.6 m long and 2.8 m diameter. It is filled with 39.5 tonnes of hypergolic propellants (UDMH and N_2O_4). It produces a thrust of 800 kN and burns for a period of about 139seconds.

Stage 3

The third stage of GSLV is a Cryogenic Upper Stage Project (CUSP). The stage is 8.7 m long and 2.8 m in diameter and carries 12.8 tonne of liquid hydrogen and liquid oxygen and burns for a duration of about 720 seconds producing a nominal thrust of 75 kN.

Payload adapter and Separation system

It is a structure that works as an interface between spacecraft and launcher. Payload adapter includes payload separation system. The payload separation is executed by pyrotechnical bolt cutter system. The inboard computer initiates separation through the command. When target orbital conditions achieved cut the junction between the launch vehicle and the payload .The payload is then push away with the necessary energy through spring system. Flexible linear-shaped charge is used for first stage, Pyro-actuated collect release mechanism for second stage and merman band bolt cutter separation is used for third stage.

Payload Fairing

The Payload Fairing (Heat Shield) protects the payload during the phase of flight as well as during the ground operation. It is 7.8 m long and 3.4 m in diameter and designed to limit the aerodynamic thermal load transmitted to satellite and attenuate the acoustic loads from the main engine during launch. It is commanded when aero thermal flux decreases to value compatible to the payload (as typical value around 1140 W/m^2). The payload fairing is composed by two half shell, with a total height close to 8m with an external maximum diameter of 2.6m. It is jettisoned by a combine action of horizontal and vertical separation system commanded by pyrotechnic element. The fairing provides aerodynamic efficiency and shields protect the vehicle electronics and the spacecraft during its ascent through the atmosphere. It is discarded when the vehicle reached an altitude of about 115 km.

Table -1: Stage 1 details at a glance

S.No	GS1(First Stage)		
	Parameter	**S(139)**	**L(40)**
1	Fuel	HTPB	UDMH+ N_2O_4
2	Max.Thrust	4700kN	680kN
3	Burn time	100 Sec	160 Sec

2. RELIABILITY ASSESSMENT OF L40 STRAP ON BOOSTER

Reliability is the probability of component or system will performed its satisfied mission satisfactorily for the stated time. When used according to specified condition. In GSLV Mk II 4 Nos of liquid strap ons (L40) connected in parallel configuration such that, as long as not all of the system component fail, The entire system works conceptually, In parallel configuration the total system reliability is higher than the reliability of any single system component. A graphical description of parallel system of 4 liquid strap ons is shown in Fig. 2.

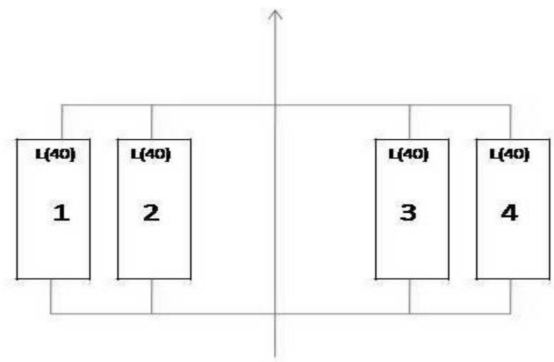

Fig -2: Parallel system of L40

Reliability Analysis with parallel systems using block concepts:

$R_s = 1 - \pi\,(1 - R_i) = 1-(1 - R_1) \times (1 - R_2) \times \ldots (1 - R_n)$; if the component reliabilities differ, or

$R_s = 1 - \pi\,(1 - R_i) = 1-[1-R]^n$ if all "n" components are identical: $[R_i = R;\ i = 1, \ldots, n]$

Here, n = 4 identical liquid strap ons

$R_s = 1 - \pi\,(1 - R_i) = 1-[1- R]^4$ if all "4" components are identical: $[R_i = R;\ i = 1, 2,3,4]$

$R_s = 1 - \pi\,(1 - R_i) = 1-[1- R]^4 = 4R- 6R^2 +4R^3 - R^4$

Using instead, the statistical formulation of survival function R(T), We can obtain MTTF(μ) for any arbitrary mission time T.

$R(T) = 1-[1- R_1(T)]\,[1- R_2(T)]\,[1- R_3(T)]\,[1- R_4(T)]$

$$= e^{-\lambda_1 T} + e^{-\lambda_2 T} + e^{-\lambda_3 T} + e^{-\lambda_4 T} - e^{-(\lambda_1+\lambda_2)T} - e^{-(\lambda_1+\lambda_3)T} - e^{-(\lambda_1+\lambda_4)T} - e^{-(\lambda_2+\lambda_3)T} - e^{-(\lambda_2+\lambda_4)T} - e^{-(\lambda_3+\lambda_4)T} + e^{-(\lambda_1+\lambda_2+\lambda_3)T} + e^{-(\lambda_1+\lambda_2+\lambda_4)T} + e^{-(\lambda_1+\lambda_3+\lambda_4)T} + e^{-(\lambda_2+\lambda_3+\lambda_4)T} - e^{-(\lambda_1+\lambda_2+\lambda_3+\lambda_4)T}$$

λ denotes failure rate in failure/hrs or cycle.

⇒ MTTF(Mean time to failure)

$$\int_0^{\infty} R(T)dT$$
$$= \frac{1}{\lambda_1} + \frac{1}{\lambda_2} + \frac{1}{\lambda_3} + \frac{1}{\lambda_4} - \frac{1}{\lambda_1+\lambda_2} - \frac{1}{\lambda_1+\lambda_3} - \frac{1}{\lambda_1+\lambda_4} -$$
$$\frac{1}{\lambda_2+\lambda_3} - \frac{1}{\lambda_2+\lambda_4} - \frac{1}{\lambda_3+\lambda_4} + \frac{1}{\lambda_1+\lambda_2+\lambda_3} -$$
$$\frac{1}{\lambda_1+\lambda_2+\lambda_4} + \frac{1}{\lambda_1+\lambda_3+\lambda_4} + \frac{1}{\lambda_2+\lambda_3+\lambda_4} - \frac{1}{\lambda_1+\lambda_2+\lambda_3+\lambda_4}$$

System Unreliability U(T)= 1-R(T) = 1- Reliability

3. Result and Discussion

The reliability of L40 (liquid strap on booster) is analyse through the reliability function R(T). Reliability of each individual L(40) is calculated through reliability function. Since the system is in parallel then total reliability of the system is calculated by reliability function R(T). Also, Critical components at first stage were identified and reliability of this component is calculated through the reliability function. By analysing MTTF, We evaluate the reliability of pieces of hardware or other technology.

4. Conclusion

This paper develops reliability analyses of L40 booster or components. System failure increases the probability of catastrophic related accident. There is a greater need of reliability in the performance of system as the demands of global economy require manufacturer to produce high reliable and easily maintainable system. Reliability analysis achieves high productivity high quality with utmost safety.

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