Optimum Size Selection For Spring Loaded Detachable Canister Launch Vehicle Interface For Multistage Long Range System

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***Abstract*-Canister-launch vehicle(LV) interface size is optimised using selective assembly method. Any over or under size of the interface is a mission critical. LV and canister are made of nos of sections and their respective positions are fixed in a assembly. Due to tolerance stack up in the assembly shape of the canister and LV varies from a perfect cylinder. Optimum size of the interface is found out for the assemblies where it satisfies the functionality without any interference or extra clearance for canister-LV assembly. Various sets of sections are available for LV and canister in production line and they are assembled selectively based on their effect on final assembly deviation. Assembly deviations are accepted such that the range of deviation for LV or for canister is minimum. One particular size of the interface suits to all the canister-LV combination without affecting the mission requirement. This paper explain how optimum inter face size is decided for sets of canister-LV assemblies based on tolerance stack up model. Selective assembly method and genetic algorithm are used to find out suitable canister-LV combinations. The method of finding out optimum interface size helps to avoid nos of assembly-disassembly trials and related testing to find out suitable canister-LV pair and leaves remote chances of getting some assemblies which does not meet the functional requirement.**

Keywords- Canister-LV interface, selective assembly, tolerance stack-up, genetic algorithm.

I. INTRODUCTION

Multistage long range LV is canisterised for quick reaction, camouflaging and better mobility. It will be ejected out of it's launch canister by pressurized hot gases from the hot gas generator. The a canister launch is characterised by high mobility on the part of the launcher. Once out of canister, the main booster ignites and takes the launch vehicle to it's course. The LV is loaded inside canister in horizontal condition. Three interfaces are assembled at three different cross section along the length of the launch vehicle[1]. Launch vehicle is rested inside the canister at these three locations. Obturator seal is mounted at the bottom of the LV[Fig-1]. Obturator seal seals the leak path of the hot gases produced by the gas generator. Clearance between interface outer diameter (OD) and canister inner diameter(ID) is an important design decision. Since the LV OD and canister ID are fixed, the height of interface decides the clearance between interface OD and canister ID. Optimum value of the clearance needs to be arrived at, as any under or over clearance leads to serious consequences like jamming of LV inside canister while dragging or creating a leak path through obturator seal. There are number of factors that need to be considered in arriving at the optimum clearance value. Listing out the consequences, the major consequence of under clearance is jamming of LV inside canister. In this case clearance will not be able to cater for tolerance stack of LV as well as canister. Because of this case of tolerance stack up effective diameter of LV is more than effective ID of canister, that means interference exists between LV and canister which will lead to LV getting stuck inside canister. Because of under clearance interfaces will not be able to cater for the above interference. LV is loaded inside canister in horizontal condition; radial clearance of 10 mm may lead to 20 mm gap between support OD and canister ID at top at any section. Since the interfaces projection is free to come out of LV pockets, spring steel strip will give the required force for the interfaces to come out of pocket if clearance more than projection of interface inside canister is available[1]. At the same time it's projection inside pocket also cannot be increased to greater depths. Since the LV is loaded in horizontal condition, LV will be seated at bottom

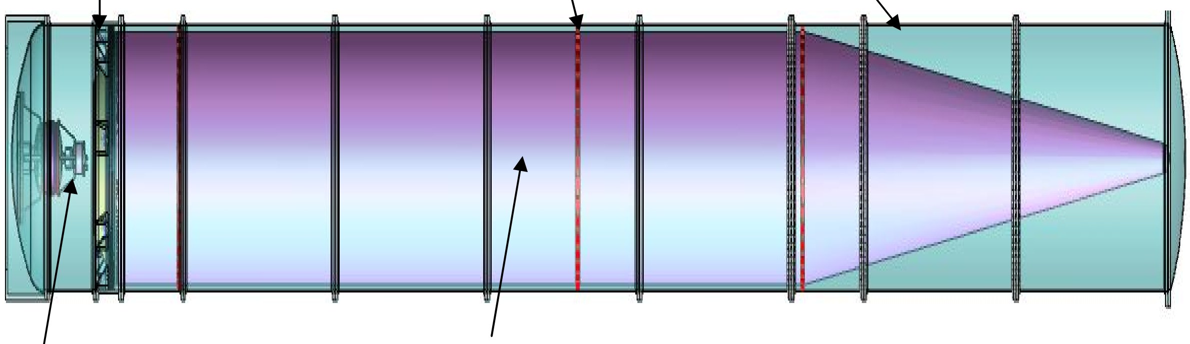


Fig 1 A Typical Schematic of Launch Vehicle inside Canister

on canister and clearance will exist at top between LV and canister. Eccentricity exists between LV and canister. But the LV will be integrated to canister at the aft end using fasteners through the holes of LV and intermediate BH of canister. Due to above mentioned eccentricity, mismatch will exist in the corresponding holes of LV and canister. This clearance more than specified limits also creates a leak path for GG hot gas at the bottom of the launch vehicle and cause failure to the mission. The effect of tolerance parameter of each sections of LV or canister on the assemblies are studied based on adjusted root sum square method(ARSS)[2]. Based on the assembly deviation calculated by ARSS method, sections are chosen for selective assemblies of canister/LV using genetic algorithm tool [4], [5]. Optimum interface size is selected based on the deviations on optimum assemblies.

II. PROBLEM BACK GROUND

Launch vehicle and canisters are made of nos of sections as depicted in fig-2a and fig-2b. Due to dimensional deviations tolerances will be accumulated in the assembly. The assembly variations to a certain levels are only acceptable. As the requirement is here that there will be assemblies meeting the functional requirements and all the available stores will be used. Using selective assembly, optimum sets of LV-Canister will be made and based on the deviation requirement optimum size of the interface assembly to be chosen suiting to all the assemblies. The interface face size will be such that it will avoid the chance of leaking of hot gases at the bottom of the canister and also avoid any chance of jamming of LV during loading. Based on the centre shift of the each section due to assembly tolerance values geometrical perfect cylinder available is calculated. Based on the tolerance values optimum LV and canister assemblies are selected using genetic algorithm. Optimum assemblies are chosen such that the range of final deviations will be minimum considering for LV assemblies and canister assemblies separately.

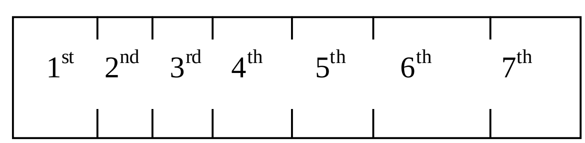


Fig 2.a Schematic of Canister Assembly

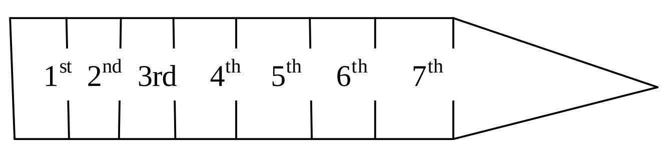


Fig 2.b Schematic of LV Assembly

III. TOLERANCE STACK UP METHODOLOGY

Clearance requirement is calculated based on tolerance stack up analysis of all the sections of canister and LV sections enclosing the interfaces stations , as the LV is supported at all the interfaces stations before being dragged into canister, deflection will be zero at these stations. So deflection pattern of LV is not considered. For the case of canister as modulus of rigidity is higher in comparison to its weight, deflection is taken negligible and hence its deflection pattern is also not considered for clearance calculation. Gradual centre shift of the sections of LV/canister which are being assembled, are considered for calculation of effective perfect cylinder inside canister and outside launch vehicle. Section wise centre shift due to concentricity, parallelism and spigot clearance for 08 sets of launch vehicle sections are tabulated in Table-1 and for canister in table -2. Cumulative deviations for 07 nos of LV sections/ 07 nos of canisters sections are calculated based on Root Sum Squares (RSS) method. A factor of 1.5 is multiplied with the RSS value to get more realistic value and that is called adjusted RSS. For different combination of canister and launch vehicle sections the ARSS value is calculated and optimum eight sets of LV and canister combinations are found out based on selective assembly method using Genetic algorithm tool. Optimum eight sets are found out such that the range of deviation for eight LVs as well as range of deviations for eight sets of canister are minimum. Four assemblies of LV are prepared and centre shifts of the assemblies are measured using portable Coordinate measuring machine (Leica Laser Tracker LTD 500) and in all four cases the deviations between the calculated based on ARSS and measured assembly variations are less than 5%.

IV. TOLERANCE STACKUP FOR CANISTER AND LV

Since sections of LV enclosing the three interfaces stations only are considered for our analysis. Center shift of one interfaces station with respect to other two interfaces station sections decides the effective diameter of LV. In this case successive sections centers matching will be ensured by spigots of corresponding sections. Co-axiality of successive sections will be ensured by end bulk heads parallelism. Therefore tolerances on parallelism of end bulk heads, spigot concentricity of a section and spigot clearance will decide the center shift of the assembly. Since the interfaces are integrated over end bulk heads of section, center shift of one interfaces station with respect to other two interfaces stations is decided by same mating features viz. spigot concentricity and end bulk parallelism for all successive sections in our assembly chain.Centre shift for the canister sections are also calculated using same method. Based on the centre shift of the canister assemblies effective canister inner diameter is calculated as the maximum diameter of the perfect cylinder available inside canister.Center shift (CSp) due to parallelism between end faces of a section is calculated as per equation-(01), Center shift(CSc) due to concentricity of spigots of end faces of a section is calculated as per equation-(02) and center shift(CSs) due to clearance between spigot and it's corresponding groove is calculated as per equation-(03).

$$\text{CSp} = \pm \sin\left(\tan^{-1}\left(\frac{\textit{parallelism tolerance}}{\textit{diameter of section}}\right)\right)\times \textit{section length} \quad \text{... (01)}$$

$$\text{CSc} = \pm \frac{\textit{spigot concentricity}}{2} \quad \text{... (02)}$$

$$\text{CSs} = \pm \frac{\textit{Upper limit for spigot groove dia} - \textit{Lower limit for spigot projection dia}}{2} \quad \text{... (03)}$$

TABLE-1

INPUT PARAMETER FOR LV ASSEMBLIES

Sl. No.	Centre shift due to concentricity							Centre shift due to parallelism							Centre shift due to spigot and groove clearance						
	s-1	s-2	s-3	s-4	s-5	s-6	s-7	s-1	s-2	s-3	s-4	s-5	s-6	s-7	s-1	s-2	s-3	s-4	s-5	s-6	s-7
1	1.0	1.5	1.2	1.5	0.9	0.8	1.1	0.2	0.80	0.19	0.10	0.30	0.23	0.29	1.2	0.23	0.18	0.24	0.16	0.25	0.26
2	2.0	2.2	1.8	0.6	0.6	1.3	1.5	0.25	0.30	0.29	0.25	0.23	0.18	0.60	2.0	0.12	0.2	0.26	0.13	0.29	0.3
3	1.8	1.2	2.0	1.6	0.8	2.1	1.5	0.10	0.09	0.07	0.40	0.30	0.32	0.40	1.8	0.15	0.26	0.18	0.4	0.26	0.25
4	1.6	0.6	0.8	1.9	2.0	1.5	0.9	0.50	0.30	0.23	0.50	0.10	0.19	0.32	0.8	0.21	0.14	0.16	0.4	0.26	0.25
5	0.8	1.4	0.9	1.6	2.1	0.9	1.6	0.20	0.15	0.20	0.25	0.30	0.25	0.30	1.5	0.35	0.25	0.28	0.29	0.26	0.25
6	0.6	1.3	1.9	2.1	1.5	1.6	1.1	0.21	0.27	0.19	0.15	0.28	0.12	0.15	1.4	0.9	0.8	0.24	0.6	0.4	0.2
7	1.2	1.6	1.9	2.1	1.5	1.6	1.1	0.30	0.30	0.10	0.18	0.60	0.22	0.25	0.21	0.19	0.16	0.18	0.19	0.23	0.22
8	1.6	1.3	1.4	1.6	1.1	1.5	1.3	0.25	0.21	0.25	0.32	0.40	0.30	0.24	0.23	0.2	0.4	0.26	0.1	0.28	0.26

TABLE-2

Input parameter for canister Assemblies

Sl. No.	Centre shift due to concentricity							Centre shift due to parallelism							Centre shift due to spigot and groove clearance						
	s-1	s-2	s-3	s-4	s-5	s-6	s-7	s-1	s-2	s-3	s-4	s-5	s-6	s-7	s-1	s-2	s-3	s-4	s-5	s-6	s-7
1	1.2	1.4	0.9	0.8	1.1	1.4	0.8	0.3	0.2	0.09	0.23	0.29	0.2	0.19	0.2	0.4	0.3	0.25	0.26	0.3	0.11
2	0.8	0.9	1.2	1.3	1.5	1.1	0.9	0.25	0.3	0.1	0.18	0.6	0.12	0.21	0.19	0.23	0.3	0.29	0.3	0.5	0.4
3	1.2	1.6	1.9	2.1	1.5	0.9	0.98	0.08	0.21	0.25	0.32	0.4	0.31	0.14	0.3	0.28	0.27	0.26	0.1	0.5	0.24
4	0.8	1.6	1.9	2.1	1.5	0.8	0.85	0.3	0.23	0.22	0.19	0.31	0.23	0.08	0.23	0.2	0.4	0.26	0.2	0.42	0.5
5	1.6	1.3	1.4	1.6	1.1	0.75	0.78	0.4	0.25	0.35	0.25	0.30	0.21	0.09	0.21	0.19	0.16	0.18	0.19	0.32	0.48
6	1.4	2.1	1.5	0.9	1.6	0.64	0.89	0.3	0.29	0.33	0.12	0.15	0.14	0.11	0.23	0.23	0.26	0.25	0.22	0.5	0.36
7	1.1	0.81	0.5	0.55	0.8	0.98	1.2	0.2	0.16	0.14	0.3	0.24	0.16	0.16	0.21	0.23	0.19	0.22	0.28	0.16	0.6
8	0.8	0.53	0.6	0.5	0.34	0.15	1.5	0.1	0.15	0.2	0.16	0.04	0.12	0.17	0.19	0.17	0.2	0.21	0.21	0.18	0.22

V. BEST SELECTIVE GROUP COMBINATION USING GENETIC ALGORITHM (GA)

GA is used to find the best combination of selective groups of mating sections for selective assembly to obtain the minimum assembly variation. The length of the chromosome for this problem depends on the number of mating sections in an assembly. The basic search process of proposed GA is shown in Figure 3. It consists of six modules namely, input module, initialization module, evaluation module, new population generation module, termination module and output module. MATLAB GA tool is used to find the best combination of different group size. Optimisations function is defined for calculation of ARSS assembly variation. A population function is defined to create initial population. A mutation and a cross over functions are also defined to get next generation chromosome of GA. Using these custom made functions of fitness, population generation, cross over and mutation GA toll is run and optimum assemblies are noted as a output of the GA tool.

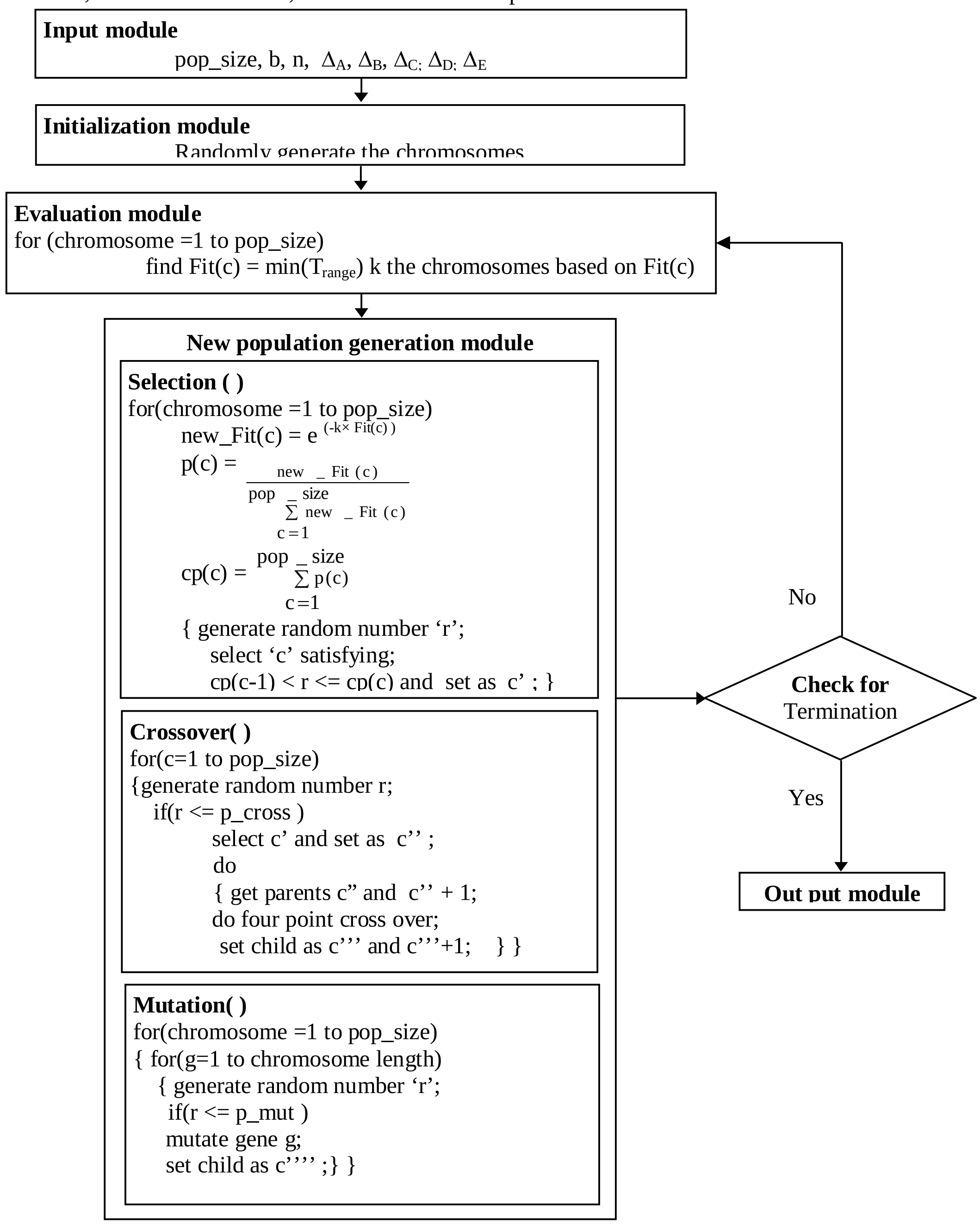


Fig 3 GA search for best combination of minimum assembly variation

VI. Results and discussion

Canister and LV each are made of seven sections each as shown Fig 2a and Fig 2b. Eight sets of each section are available for making eight no. of canister and eight no of LV assemblies. All eight sets of sections are interchangeable without changing the relative position in the assembly. Canister- LV assembly combination is worked out such that a certain size of the interface assembly is suitable for all eight sets of canisterised LV without deviating from it's functional requirement.So that LV is smoothly canisterised and there is no leak path at the obturator seal. In conventional assembly all 1st set of LV sections are assembled to get 1st LV and same way for other sets of LV/Canister. Assembly deviations of the conventional LV assemblies are tabulated in table-3 and assembly variations are plotted in plot- 1 and for conventional canister in table-4 and plot -2. Optimum assemblies for LV and canister are tabulated in table-6 and plotted in plot-3 and table-7 and plot-4 respectively.

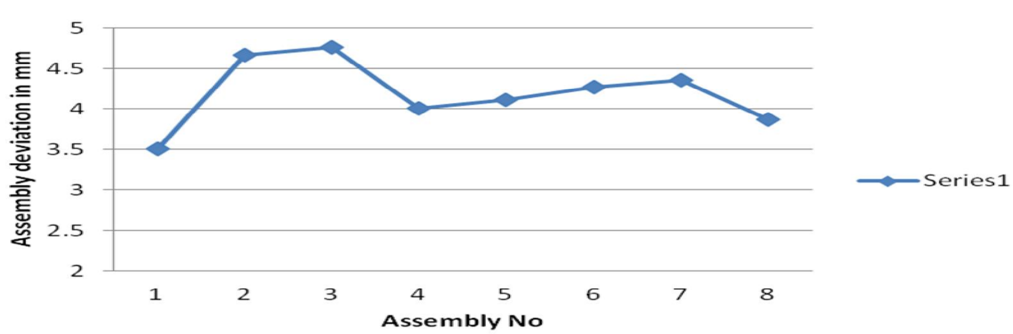
TABLE 3

CONVENTIONAL ASSEMBLY FOR LV

Assembly No	Serial No of the Section being used in the assembly							Assembly deviation
1	1st	1st	1st	1st	1st	1st	1st	3.506 (Min)
2	2nd	2 nd	2 nd	2 nd	2 nd	2 nd	2 nd	4.6688
3	3 rd	3 rd	3 rd	3 rd	3 rd	3 rd	3 rd	4.7619 (Max)
4	4th	4 th	4 th	4 th	4 th	4 th	4 th	4.0051
5	5 th	5 th	5 th	5 th	5 th	5 th	5 th	4.1091
6	6 th	6 th	6 th	6 th	6 th	6 th	6 th	4.2707
7	7 th	7 th	7 th	7 th	7 th	7 th	7 th	4.3599
8	8 th	8 th	8 th	8 th	8 th	8 th	8 th	3.8698
Range of the Deviation(Max-Min): 1.2559mm								

PLOT-1

ASSEMBLY VARIATION OF LV FOR CONVENTIONAL ASSEMBLY



TAVLE 4

CONVENTIONAL ASSEMBLY FOR CANISTER

Assembly No	Serial No of the Section being used in the assembly							Assembly Deviation
1	1st	1st	1st	1st	1st	1st	1st	3.0876
2	2nd	2 nd	2 nd	2 nd	2 nd	2 nd	2 nd	3.1979
3	3 rd	3 rd	3 rd	3 rd	3 rd	3 rd	3 rd	4.1422
4	4th	4 th	4 th	4 th	4 th	4 th	4 th	3.2800
5	5 th	5 th	5 th	5 th	5 th	5 th	5 th	3.4940
6	6 th	6 th	6 th	6 th	6 th	6 th	6 th	3.7692
7	7 th	7 th	7 th	7 th	7 th	7 th	7 th	2.5275
8	8 th	8 th	8 th	8 th	8 th	8 th	8 th	2.0823)
Range of the Deviation(Max-min): 2.05mm								

PLOT-2

: ASSEMBLY VARIATION OF CANISTER FOR CONVENTIONAL ASSEMBLY

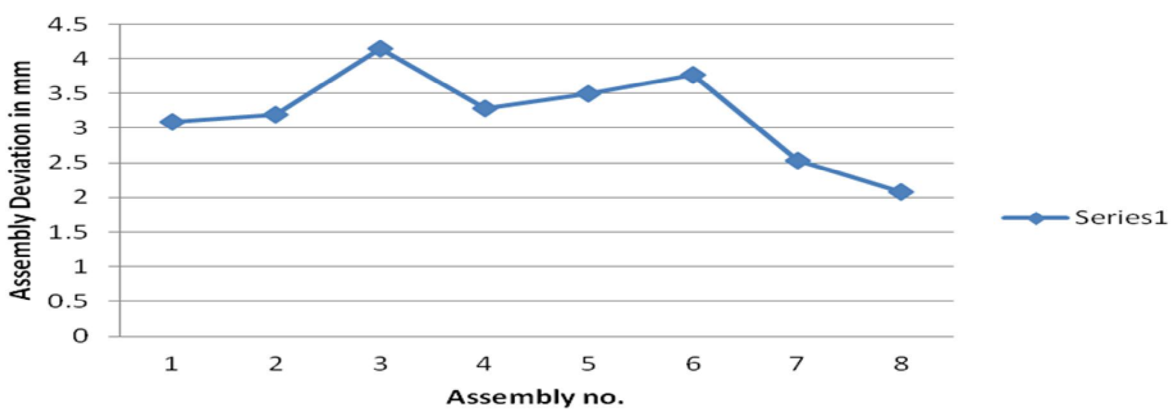


TABLE 3

OPTIMUM GROUPING FOR LV

Assembly No.	SEC-1	SEC-2	SEC-3	SEC-4	SEC-5	SEC-6	SEC-7	Assembly Deviation
1	5th	1st	8	1st	5 th	1st	3rd	3.2532
2	7 th	6 th	7	8 th	3rd	4 th	5 th	3.2562
3	6 th	7 th	6	7 th	2 nd	3rd	2 nd	3.2519
4	8 th	8 th	2 nd	3 dr	8 th	2 nd	7 th	3.2557

5	4 th	3 rd	4	6 th	7 th	7 th	8 th	3.2612
6	2 nd	4 th	5	4 th	1st	6 th	1st	3.2531
7	3rd	2 nd	3	2 nd	4 th	5 th	6 th	3.2613
8	1st	5 th	1st	5 th	6 th	8 th	4 th	3.2559
	Range of the Deviation: 0.03009mm							

PLOT-3

ASSEMBLY VARIATION OF LV FOR SELECTIVE ASSEMBLY

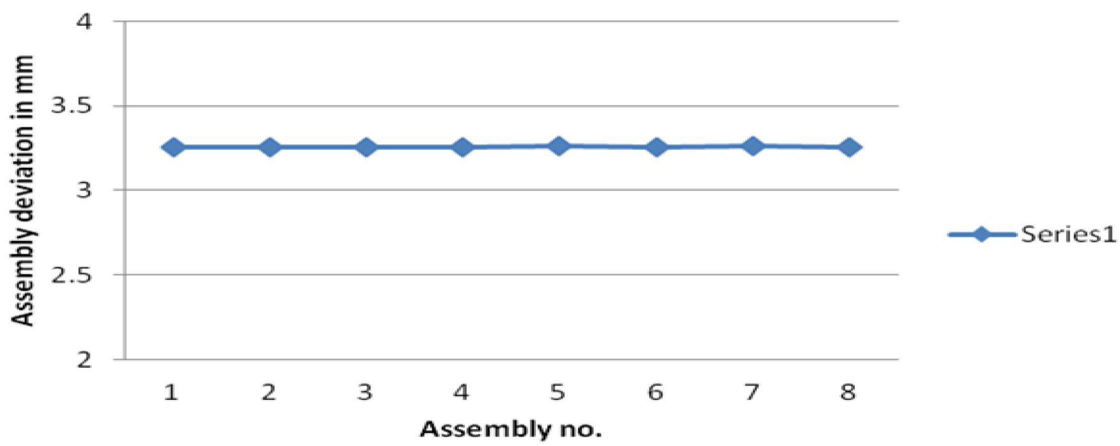


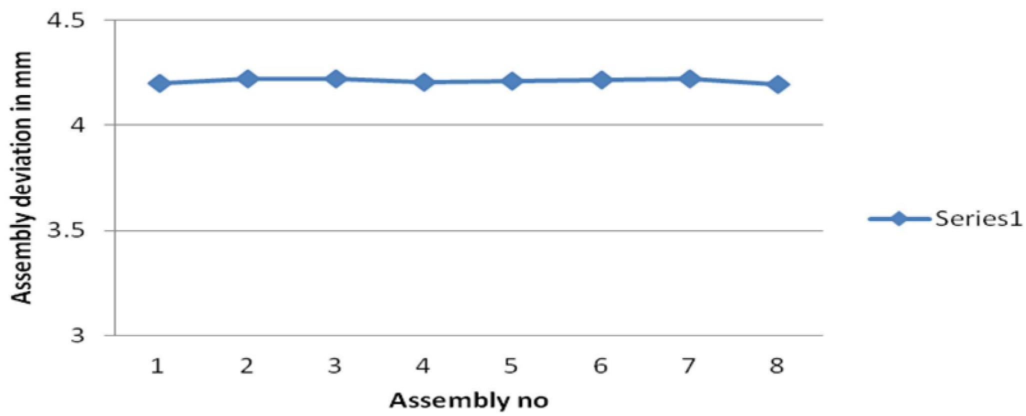
TABLE 6

OPTIMUM GROUPING FOR CANISTER

Assembly No.	SEC-1	SEC-2	SEC-3	SEC-4	SEC-5	SEC-6	SEC-7	Assembly Deviation
1	1st	2nd	1st	7 th	3rd	5 th	3rd	4.2021
2	2nd	3rd	5 th	8 th	1st	4 th	1st	4.2210
3	6th	4 th	2nd	4 th	5 th	6 th	4 th	4.2192
4	8 th	6 th	7 th	5 th	7 th	1st	2nd	4.2067
5	3rd	8 th	8 th	2nd	6 th	2nd	7 th	4.2122
6	5 th	5 th	3rd	1st	8 th	7 th	6 th	4.2165
7	7 th	7 th	6 th	6 th	4 th	8 th	8 th	4.2237
8	4 th	1st	4 th	3rd	2nd	3rd	5 th	4.1929
	Range of the Deviation: 0.0094 mm							

PLOT-4:

ASSEMBLY VARIATION OF CANISTER FOR SELECTIVE ASSEMBLY



Addition of range of deviation for LV and canister for conventional assembly (1.2559+2.05) = 3.3059 mm where as addition of range deviation for LV and canister for Selective assembly:(0.03009+0.0094)= 0.0403 mm only. Max clearance requirement between canister ID and interface OD for conventional assembly =(4.7619+4.1422) =8.9041 mm. Seal at the bottom of the canister can tolerate a maximum gap of 8mm between interface OD and canister ID. So, in conventional assembly some of the LV- canister assembly will not meet the mission requirement. Max clearance requirement between canister ID and interface OD for conventional assembly (3.2613+4.2237) =7.4849 mm.

VII. CONCLUSION

All the selective assemblies of canister-LV pairs meet the mission requirements. For these selective assemblies one particular size of interface is suited without creating any chances of jamming of LV or a leak path for hot gasses at the bottom. Clearance requirement for all the canister-LV pair is same. Once LV and canister are assembled as per the out put of the selective assembly model, all canister-LV pair will meet the mission requirement with only one optimum size of interface. This method of selecting assemblies for optimum interface size reduces lot of efforts for assembly trials, testing and repeated assembly variation measurements for finding proper canister-LV combinations meeting the mission requirement. This methodology also reduces the chances of rejections of flight hardware which are having deviations more than its specified limits.

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