ISFab '80-ISRO Symposium On Fabrication Technology

A Report By S. V. NADKARNI

Nearly 200 delegates representing the steel and non-ferrous metal industry, fabrication industry and R & D institutions participated in ISFab '80, organised by Indian Space Research Organisation (ISRO) at Vikram Sarabhai Space Centre, Trivandrum, on October 21-22 to know ISRO's space programme for the decade of the eighties, fabrication challenges demanded for its implementation, and the contribution expected from them. Inspired by the success of the project SLV-3, ISRO projected an ambitious programme for the next 10 years which is expected to strain the technical capabilities of the Indian fabrication industry including the welding industry to their utmost limit.

This programme involves development of large satellite launch vehicles and spacecraft structures, designing and fabrication of large antennas, hardware for ground segments and launch facilities like launchers, transporters, test stands etc.

Launch vehicles weighing around 300 tonnes at lift-off and satellite structures for satellites weighing nearly 1000 kg, test stands to handle a main thrust level of around 500 tonnes, antennas of around 50 metres dia and the launch towers around 80 metres tall and weighing 1000 tonnes, special low bed transporters which will have capability of 500 tonnes and high precision components for inertial measurement and control systems are representing the future systems requirement in this area.

Vehicles

To put a satellite or payload in to orbit and altitude a unit with propulsive force and control on its flight path is used as the "Carrier". This will have aerodynamic design and will have stages (e.g. SLV-3 has 4 stages) to improve the payload capability and accuracy on control parameters. This carrier with propulsion units, seperation system, control units, command system etc. integrated together as a single unit is generally referred as the "vehicle" in aerospace terminology.

Among the future vehicles envisaged are SPSLV (SHAR launched polar satellite launch vehicle) and ASLV (Augmented satellite launch vehicle).

Fig. 1—compares the dimensions of SLV-3 and SPSLV. SPSLV is a 4-stage vehicle with two "Strap ons" (Refer to SPSLV diagram, the central portion of the vehicle is called "Core" and the stages coming on the sides are called strap ons or zero stage). SPSLV will take a satellite of 600 kg to polar orbit 1000 km near circular.

Second stage of SPSLV is with a liquid engine. All other stages including strap ons are with solid propellant. First stage is 2.8 M dia and total length of vehicle is 34.9 M.

ASLV, shown in Fig. 2, is also a 4-stage rocket with same configuration and length as SLV-3 except for two

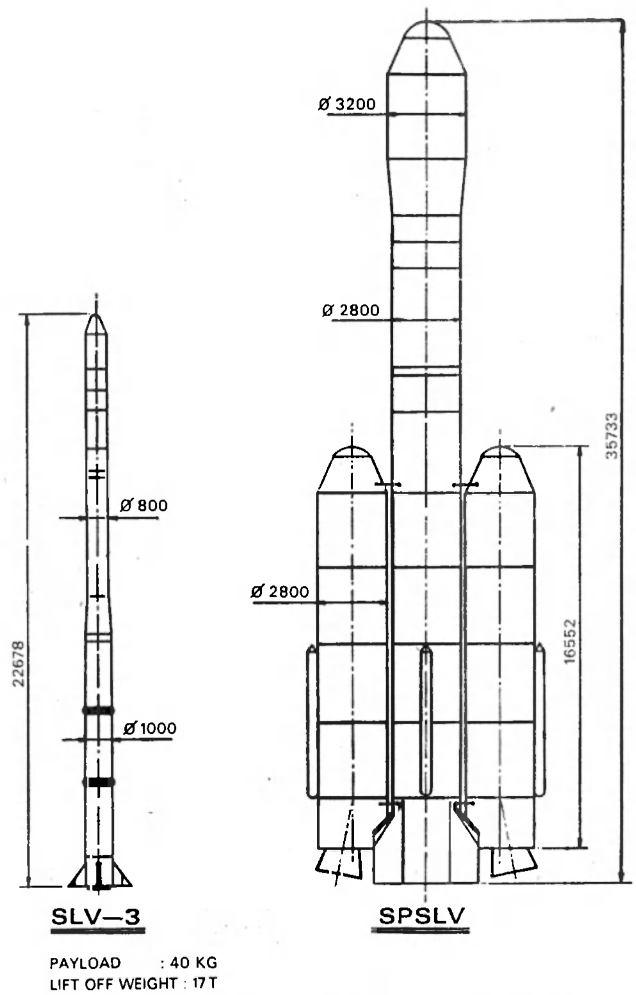


Fig. 1. Comparison of SLV 3 and SPSLV

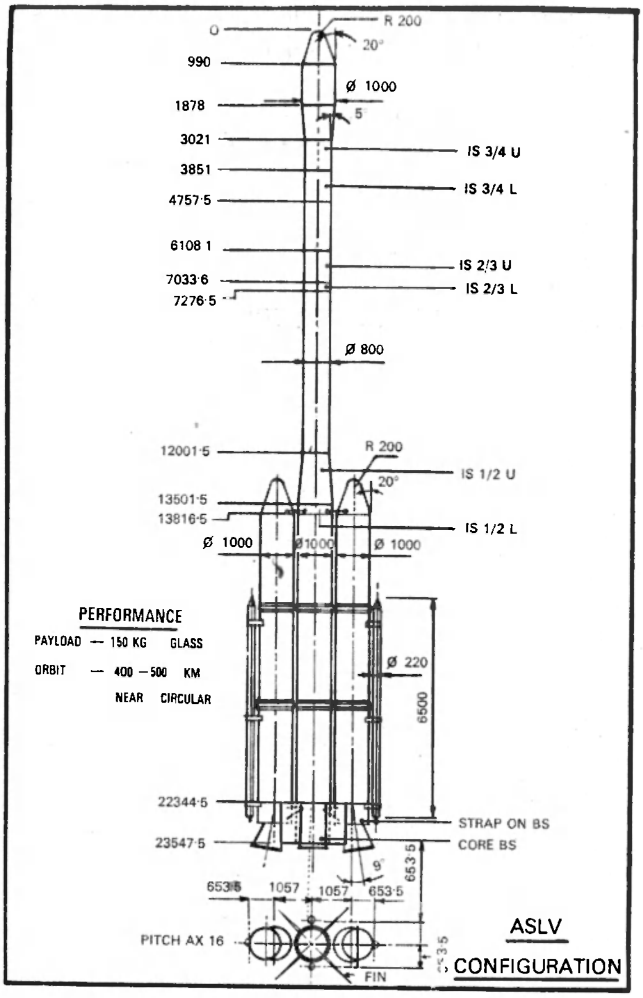


Fig. 2. ASLV Configuration

strap ons at diametrically opposite sides of the first stage. The core vehicle is exactly SLV-3. The two strap ons are two additional first stages diametrically opposite clamped on to the first stage. All stages including strap on work with solid propellant. This takes a satellite of 150 kg to 400 km orbit.

Following table gives important details of the three vehicles at a glance :

	Pay load kg	lift off Wt (Tonnes)	Launcher Wt (Tonnes)	Remarks
SLV-3	40	17	16	4 stages. All stages solid propellant.
ASLV	150	39	45	4 stages +2 strap ons. All stages solid.
PSLV	600	650	450	4 stages +2 strap ons. second stage liquid engine.

Note :

1. Lift off wt = Weight of the vehicle at the instant of leaving the launcher

2. Launcher wt = Weight of the structure alone on ground-supports the vehicle

Fig.3 shows the SLV-3 Transporter, a welded structural fabrication, whose specifications are :

Total weight with vehicle (Tonnes)	...	28.0
Over all length (M)	...	22.0
Wheel base (M)	...	19.75
Width of the structure (M)	...	2.172
Ground clearance (MM)	...	310
Longitudinal traverse of the cradle (MM)	...	400

Cross traverse of the cradle (MM)	...	± 50
Vertical lift of the cradle (MM)	...	200
Angular rotation of the cradle	...	$\pm 15°$
Pneumatic tyre size	...	$69.00 \times 20 \times 12^{6}$ PLY
Tyre pressure (PSI)	...	100
Maximum towng speed (KMPH)	...	5
Tractor HP	...	75

Another critical welded fabrication is SLV-3 Launcher with vehicle detailed in Fig. 4 which played an important role in the success of SLV-3. The Launcher for PSLV, as the above table shows, will be nearly 30 times bigger and will constitute another challenging welded fabrication for the future.

Base Metals

The programme calls for the fabrication of the following metals and alloys by welding.

(i) *Q & T Steel* :

The main material required for rocket motors is low-alloy, high strength, quenched and tempered steel as per AFNOR 15CDV6 (equivalent to HY-130) having the following properties :

Chemical composition :

Carbon	—	0.12 to 0.18
Manganese	—	0.8 to 1.10
Silicon	—	0.2 max.
Chromium	—	1.25 to 1.50
Molybdenum	—	0.8 to 1.0
Vanadium	—	0.2 to 0.3
Phosphorus	—	0.02 max.
Sulphur	—	0.015 max.

Mechanical properties :

Air-quenched, tempered at 650°C and air-cooled is shown in (A).

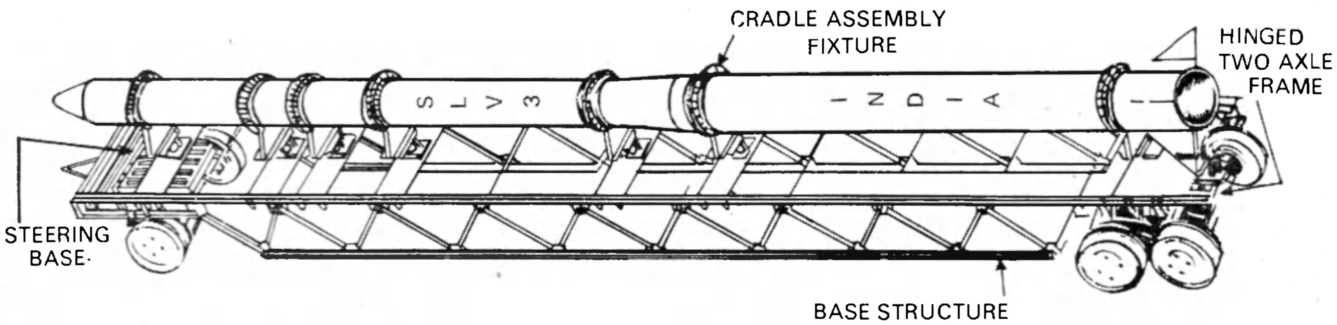
Oil-quenched, tempered at 625°C and oil-cooled is shown in (B).

	(A)	(B)
Tensile Strength	105 kg/mm^2	155 kg/mm^2
Yield Point	85 kg/mm^2	115 kg/mm^2
Elongation (5d)	16%	16%
Impact Strength U.F.	9 kgm/cm^2	13 kgm/cm^2

The rocket motor casings will also require a number of profilemachined forged rings having 2.8 m dia. with a rectangular section of 300×100 mm after forming and welding, 300 mm being the length in the axial direction. It has been suggested that these rings be formed by rolling and welding.[1]

SLV-3 TRANSPORTER

(ASSEMBLY-CUM-TRANSPORT TRAILOR)



SPECIFICATIONS

TOTAL WEIGHT WITH VEHICLE (TONNES)	--	28·0
OVER ALL LENGTH (M)	--	22·0
WHEEL BASE (M)	--	19·75
WIDTH OF THE STRUCTURE (M)	--	2·172
GROUND CLEARANCE (MM)	--	310
LONGITUDINAL TRAVERSE OF THE CRADLE (MM)		400
CROSS TRAVERSE OF THE CRADLE (MM)	--	$\pm$ 50
VERTICAL LIFT OF THE CRADLE (MM)	--	200
ANGULAR ROTATION OF THE CRADLE	--	$\pm$ 15°
PNEUMATIC TYRE SIZE		9·00 x 20 x 12 PLY
TYRE PRESSURE (PSI)	--	100
MAXIMUM TOWING SPEED (KMPH)	--	5
TRACTOR HP	--	75

Fig. 3.

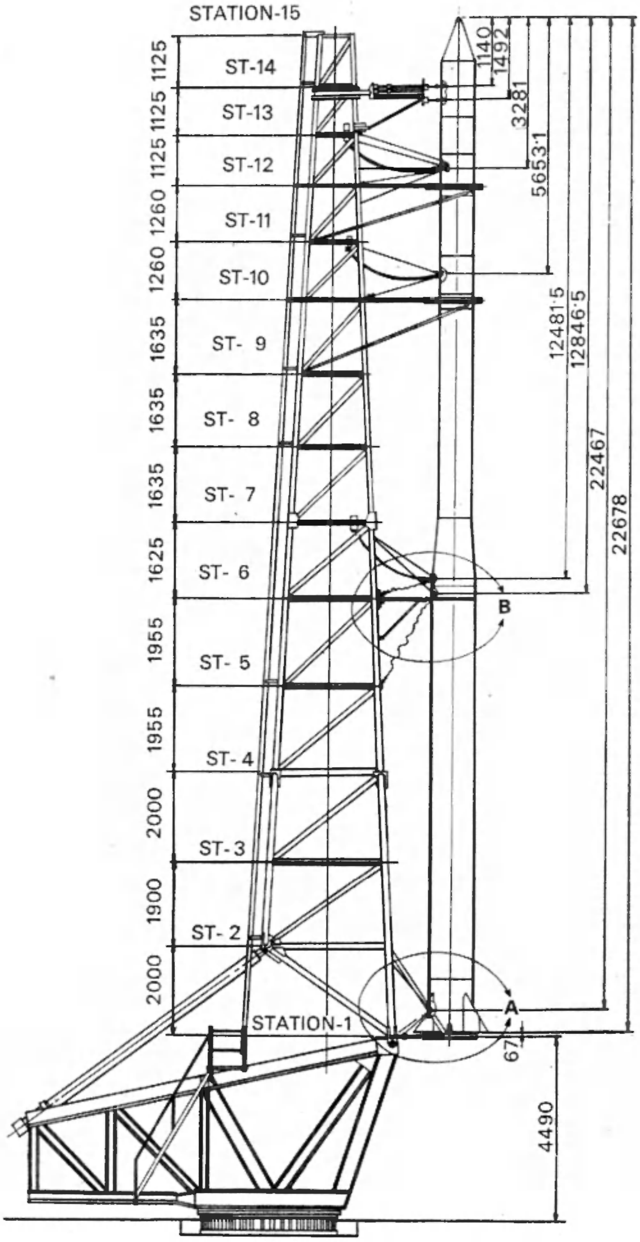


Fig. 4. SLV 3 Launcher with Vehicle

(ii) *Light non-ferrous alloys* :

Ring forgings of 3 m dia. and 80 mm section thickness formed by ring rolling will be required. In case of interstage structures required for the launch vehicle, high-strength aluminium alloy rings of quality in AA2024 of dimension 2.8 metre diameter and section of 200/100 mm will be required which is to be ring rolled/mandrel forged. It also will use aluminium alloy extrusions of various cross-sections out of this high strength alloy. In case of spacecraft structures aluminium alloy rings, sections and sheets will be extensively used. Magnesium alloy sheets and sections also could be used in this application extensively.

(iii) *Structural steels* :

In case of ground equipments like launcher, antennas, test stands, transporter, high strength structural quality material in various sections will be called for. Since these structures have to be erected in coastal environments, they have to be made out of material which can withstand highly corrosive saline atomosphere.

(iv) Stainless steels of type 304L, 321, 347 and precipitation-hardening types.

(v) Ultra-high strength steel described in the table below :

Some HSLA steels used in space engineering (containing Ni, Cr, V, Mo and Co)

Mechanical properties	Steel (Republic Steel Corpn.)			
	HP 9.4.20	HP 9.4.30	300M	HP 310
Tensile strength (kgf/mm²)	138	159	196	216
Yield strength (kgf/mm²)	131	134	165	187
Reduction Area %	60	45	30	50
Elongation %	18	13	9	-9

(vi) *Sophisticated alloys* :

Use of maraging steels and titanium alloys is also being considered.

Steel for motor casing

Rocket motor casings for SLV-3 were fabricated from steel as per AFNOR 15CDV6 in 3 mm thickness supplied by Rourkela Steel Plant.

The alloy steel was cast at Alloy Steel Plant, Durgapur and was subsequently rolled into sheets at RSP's Semi-continuous hot strip mills with a close control of finishing and coiling temperatures. This was a challenge to RSP since an important processing characteristic of this steel is that it develops quite a high strength and hardness during the rolling process itself. The high hardness of the hot rolled coils necessitates an annealing process for softening to enable further metal working of the sheets which was successfully carried out at RSP.

Welding of motor casings

Three fabricators from the Western region have been associated with the welding of motor casings for ISRO, including those for SLV-3 project. The material as mentioned earlier, is AFNOR 15CDV6 steel in 3 mm thickness. The casings have been welded by manual TIG process using imported filler wires of 3 mm size having the following chemistry :

C	Mn	Si	Mo	Cr
0.10%	0.6 to 1.4%	1.00%	0.6 to 1.2%	2.5 to 3.5%

S	P	V
0.010%	0.015%	absent

One of the fabricators, whose welding quality was appreciated by ISRO, used the following welding data:[2]

Joint groove	:	Vee of 60—70°
Root face	:	1 mm
Root gap	:	0.25—0.5mm
Current	:	DC, 100±5 amps
Voltage	:	12 V
Electrode	:	Thoriated tungsten, 3.17 mm
Argon feed	:	5 l/min.

The joints were assembled in a locating fixture provided with copper backing bar and argon purging. Argon purging was done at 3.9 l/min.

Special consideration was given to the purity of argon gas and the following specification was prescribed for it :

	Component	*Max (ppm)*
1.	Oxygen	4
2.	Moisture	5
3.	Carbon Dioxide	0.5
4.	Carbon Monoxide	0.5
5.	Oxides of Nitrogen	0.5
6.	Hydrogen	2
7.	Argon	99.998
8.	Hydrocarbons	0.5
9.	Sulphur	Nil

An important requirement was to maintain the ovality of the 10 m long, 1 m dia., 3-3.5 mm thick shell within 0.2 mm. This demanded accurate control of diameter and circularity after overcoming welding distortion through judicious use of tooling and fixtures. Based on past experience, one fabricating firm described[3] a novel concept of a single fixture for set-up, welding and final machining of the casing. Another paper[4] by the same firm commented on this tooling concept as follows :

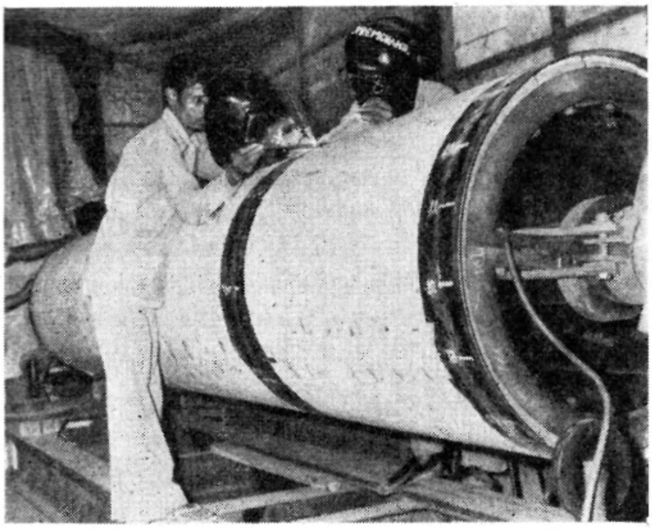


Fig. 5. Circumferential Seam Welding of motor casing segment by TIG Process.

"This concept should be welcomed as it is the only way of eliminating the drawbacks of the present method and speeding up the manufacturing schedules, though at a higher tooling cost. The presently used purely mechanical fixtures, even though they have been delivering the goods, need to be replaced with more sophisticated and satisfactory hydraulic fixtures. This change is essentially required for better quality of the job and for other reasons also. Hydraulic systems will be simple to operate and will exert a uniform force throughout the length of weld edge which will help in minimizing distortion. However, in this case, a pneumatic system may be preferred so that leakages do not contaminate the weld locations and can avoid the resultant defects. These collapsible type of fixtures will be easy to install or dismantle and will be clean to operate with, consuming very little time."

For future motor casings involving higher plate thicknesses, the combined use of the automatic TIG equipment, longitudianal weld seamer and welding column and boom was suggested.[5]

Quality rating technique (QUART)

ISRO followed a novel system called QUART for defining the performance rating of rocket casing fabricators.[6] In this system, defects were classified into four categories as follows :

1. Critical (C) Defects which will reduce the margin of safety of products almost to zero. These defects may

call for modifications on other systems.

2. Major (M) Defects that could result in modification on the system or which calls for major compromises in functional requirements.

3. Minor (N) Defects that will make the procuct difficult to use directly which require rework.

4. Incidental (I) Defects which do not have any bearing on the effective use of the products.

Next, a scoring system was adopted to calculate the demerit score of a fabrication. The following demerit score allotted to each class of defect was the basis :

Class of defect	*Demerit score*
Critical (C)	20
Major (M)	15
Minor (N)	5
Incidental (I)	1

The total marks scored by a fabrication were calculated from the formula :

$$C_n \times 20 + M_n \times 15 + N_n \times 5 + I_n \times 1$$

The actual scores obtained are tabulated below :

Comparative Rating of First Stage Motor from various contractors.

Contractor	A				B		
Sl. No of Motor Case	1	2	3	4	5	6	7
Demerit Score	534	480	176	324	283	155	117
No of defects							
Critical	13	8	—	8	3	—	—
Major	8	15	3	8	8	3	2
Minor	30	18	25	10	20	19	17
Incidental	4	5	6	4	3	15	2

Comparative Rating of Second Stage Motor from various contractors.

Contractor	A		B			C			
Sl. No of Motor Case	1	2	3	4	5	6	7	8	9
Demerit Score	429	261	234	233	250	207	174	136	132
No of defects									
Critical	10	4	3	—	3	1	2	—	—
Major	12	11	8	11	8	8	4	4	4
Minor	9	1	10	13	14	13	14	13	13
Incidental	4	1	4	4	—	2	4	11	7

It is obvious from the above, that the fabricators showed marked improvement with each subsequent casing, thus proving the fact that the exceptional quality aimed at can be achieved with persistent effort and constructive analysis of previous performance.

Divergent nozzle

An important welded component is the divergent nozzle for SLV which plays an important role in successful launching. BHPV, who fabricated it from 15CDV6 steel sheet by forming two halves of a cone on press brake, had to devise special internal and external fixtures and techniques to maintain uniformity of thickness, concentricities and parallelities in spite of welding and heat treatment and the possibility of distortion. The fabrication also involved the accurate placement and welding of end flanges and valve seats for which the TIG and MMA processes were used.

Electron beam welding

Electron beam welding group of Gas Turbine Research Establishment (GTRE), Bangalore, have gathered considerable experience in welding a variety of components of the aerospace equipment made from materials like titanium, aluminium, nickel, chromium and zirconium and their alloys. Encouraged by this experience, ISRO are keen to use this process as widely as possible in their future programme.

In a paper[8] presented at the Symposium, GTRE highlighted the unique features of the EB process and went on to describe the following jobs produced at their fabrication facility :

(1) H.P. Compressor drum of the GTX engine

This was fabricated from a titanium alloy Ti-685 (6A1-57R-0.5 si). It consisted of 8 welded joints of thicknesses varying from 4.0 to 5.35 mm. The concentricity between the first and the last disc was to be held to within 0.05 mm. The length of the welded sub-assembly was 294 mm and the maximum dia 409 mm.

(2) L.S. Compressor drum of the GTP engine

This consisted of 4 welded joints of 7.5 mm thickness in Ti-318 (6AL-4 V alloy). The concentricity required was of the same order as that of the H.P. drum. The length and dia. of the drum were 362 mm and 478 mm respectively.

(3) Combustion chamber swirler for the GTX engine

The swirler blades were made of Nimonic 75, 1.4 mm t.

(4) Ti-318 gas bottles

The welded joint here is 5 mm thick and the diameter of the gas bottle is 210 mm. The main problem found here is poor access for cleaning after completion of welding.

(5) Pressure transducers

These were of stainless steel, 2.0-3.0 mm t.

Future challenges

An example of the future challenges to be met is the turbo pump fed high thrust liquid engine envisaged for ISRO's future applications. The main materials used are stainless steels ZO8CNDT 17-12, 230C13, alloy steels 25CD4S, all conforming to AFNOR. The major sub systems of a turbo pump fed liquid engine are the principal valves for the fuel, oxidiser and water lines, the turbo pump to pump fuel, oxidiser and water, gas generator to produce the hot gas required for running the turbine wheels, the injector where the fuel and oxidiser mix, convergent divergent assembly where the combustion and expansion takes place, and the articulation interface for single plane and double plane gimballing. A variety of fasteners, O rings, dynamic seals, bearings and filters are used in the engine assembly.

To successfully manufacture the above sub systems numerous fabrication processes are employed. To name a few : copy milling, copy turning, EDM, ECM, 5 axis machining, investment casting, spline hobbing, precision grinding, spinning, fluid forming, expanding mandrels and TIG/EB welding. 4H5H thread tolerances are quite common; surface finish requirements also go as far as 0.2 microns.

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4. 'Concepts and criteria for design of tools for 2800 mm dia. flight motors based on our experiences of SLV-3 flight motor casings' by K. C. Girotra and J. G. Joshi

5. 'Welding of rocket motor case' by S. V. Nadkarni.

6. 'Quality rating technique (QUART) for aerospace product' by Koshy Mammen

7. 'Fabrication of divergent nozzle for satellite lunch vehicle' by A. V. R. Pantulu and G. K. Rao

8. 'Applications of electron beam welding—an aerospace experience at GTRE' by Philip de Costa.