Solid Rocket Motor

- Part 5 Design of Combustion Chamber

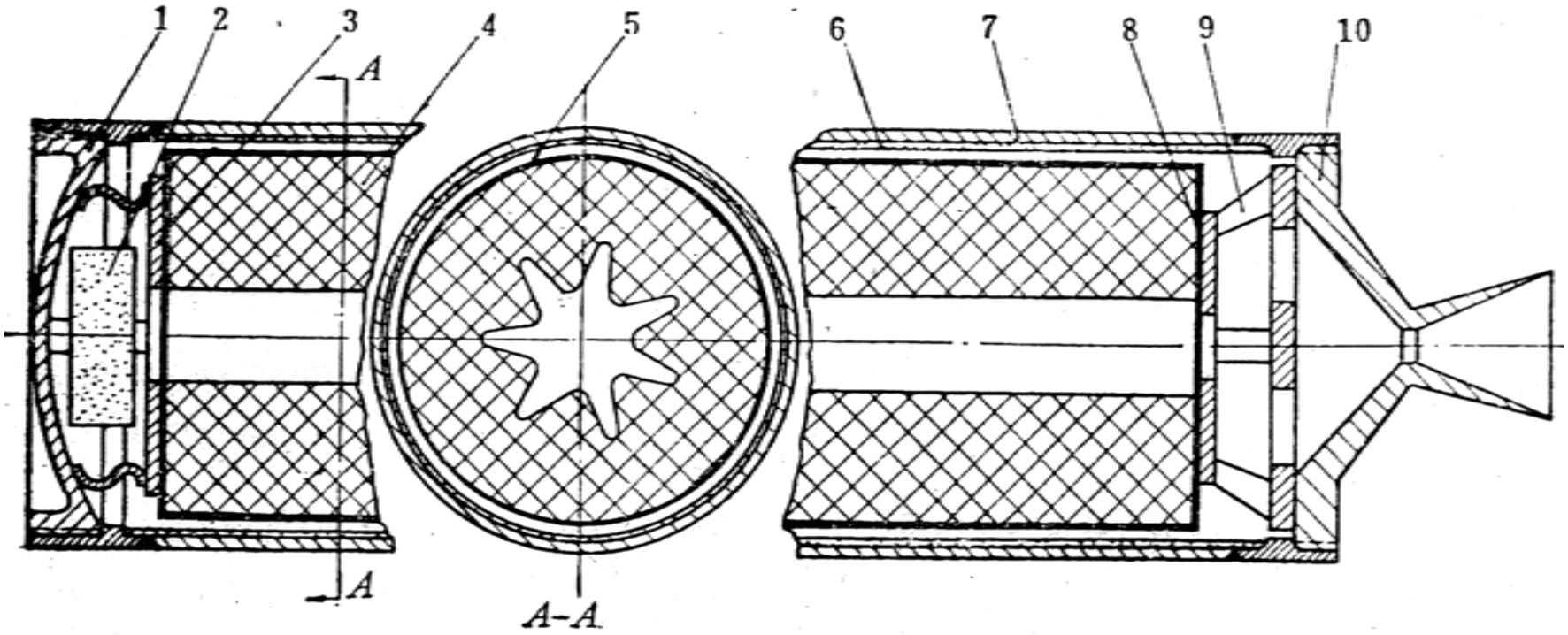
■Basic conception of combustion chamber

- Combustion chamber is the device that used to storage the solid propellant for combustion;

- The internal of the combustion chamber need to bear high temperature and high pressure;

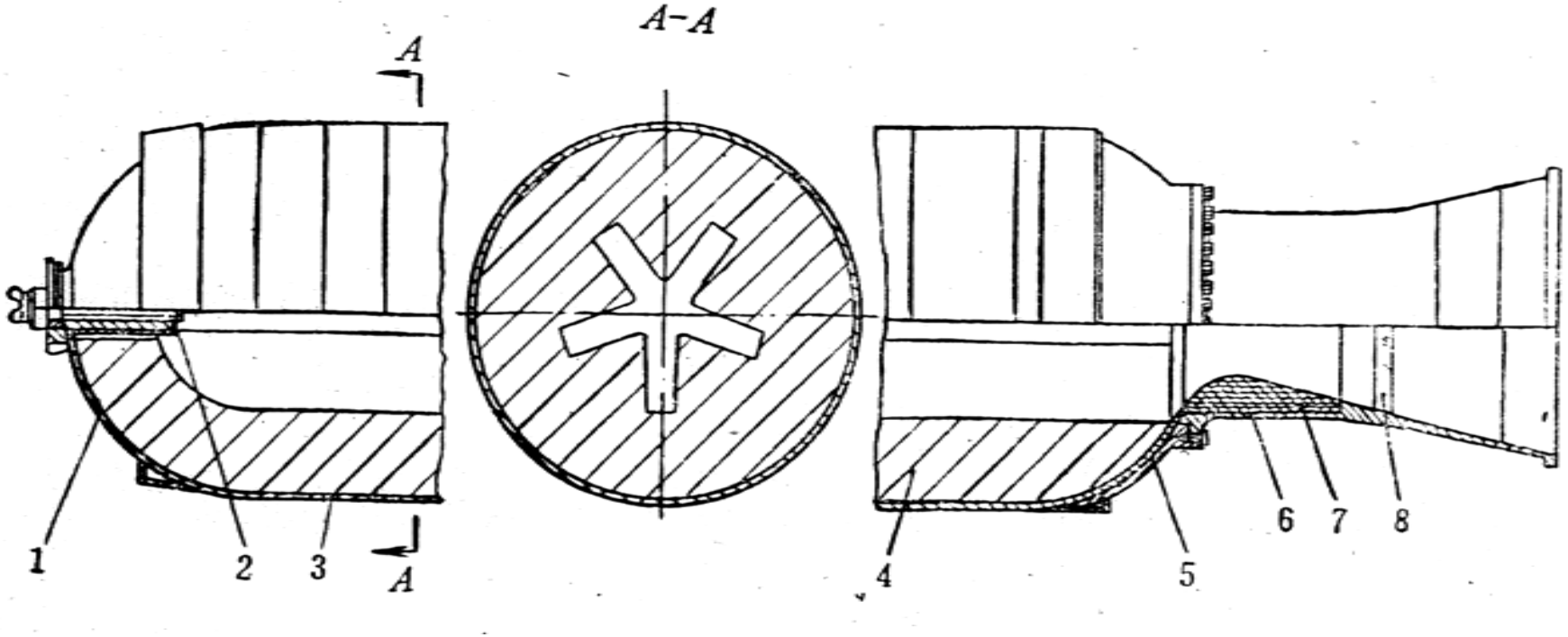
- The combustion chamber is a part of the missile, many parts are connected with it, and it also bear some other loads.

■Typical structure of freestanding combustion chamber



1—Forward dome；2—ignition systems；3—Elastic support；4—Grain；
5—Coated column；6—Insulating layer；
7—cylinder section；8—Coated column；9—Propellant Baffle；10—Nozzle.

■ **Typical structure of case-bonded combustion chamber**



1—Forward dome；2—Ignition systems；3—Case of Combustion chamber+ Insulating layer +Liner；4—Grain；5—Aft dome；6—Nozzle；7—Graphite bushing；8—Nozzle cap.

■Main components of combustion chamber

- Case:

  Mainly under the pressure of the internal pressure, as the shell is a part of the shell, it also need to bear the role of external load.

- Inner insulating layer :

  Used for thermal protection of the case.

- Liner:

  Bonding the grain and inner thermal insulation to prevent the migration of molecules. Making the Coated column and the inner insulation layer more firmly bonded, and ease the stress transfer between the column and the inner insulation layer.

- Supporting structure of medicine column and baffle plate :

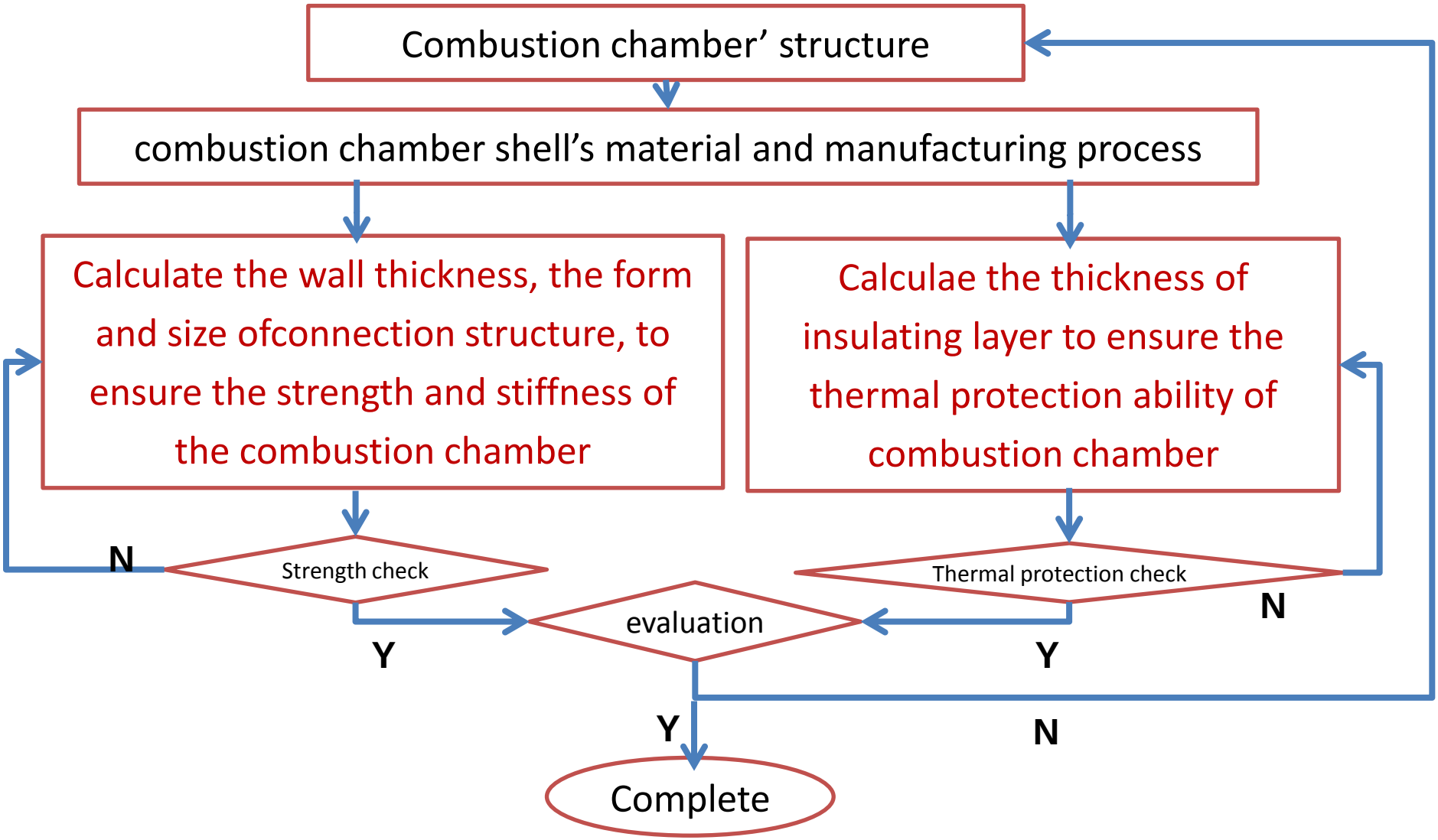
  To avoid the free movement of the grain and prevent the blockage of the nozzle.

Design of Combustion Chamber

■Design requirements of combustion chamber

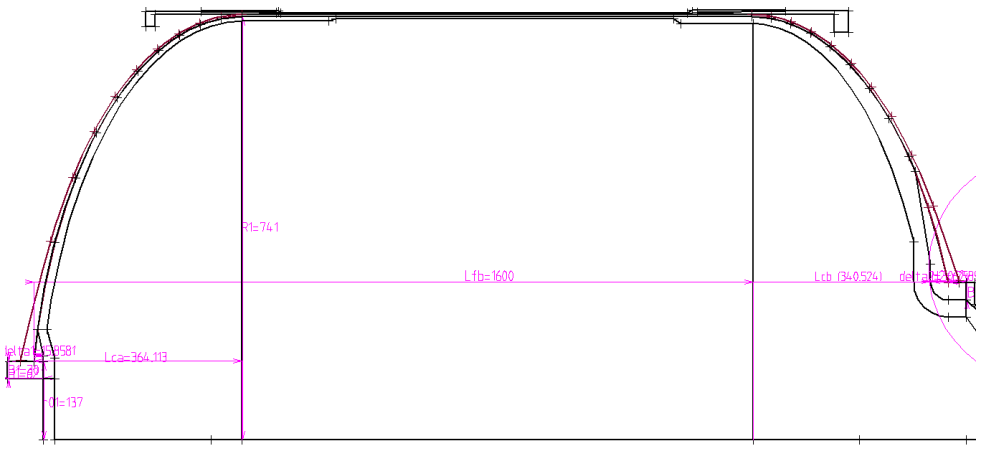
- The shell shall have sufficient stiffness and strength to withstand the effects of internal and external loads ;
- Thermal insulation layer should have a good ability to protect the engine during the work can not be too high temperature, or even burn through the phenomenon;
- The structure of quality should be light (PW/Vc), grain filling fraction should be higher, to improve the engine quality than that of domestic large engine quality ratio of 0.92~0.93 (carbon fiber shell), small engine mass ratio can reach more than 0.8;
- Resource rich, good technology, short production cycle, low manufacturing costs.

■ Design flow of combustion chamber



■Design contents of combustion chamber

- 1. Determine the structural shape of the shell and sketch
  - Mainly according to the use and requirements of the product to determine the structure of the shell, including the form of the dome, the connection between the components of the form, the sealing structure and internal wall thermal protection technology.
  - The structure of the combustion chamber is related to the selected material and forming method, and the shape of the shell must be coordinated with the structure of the column.



■ Design contents of combustion chamber

- 2.selection of material and manufacturing process

  - The material of the shell is mainly divided into two categories: metal and nonmetal ;
  - The mainly metal material is steel; the mainly non-metallic materials are fiber reinforced composite materials (glass steel, Kevlar, carbon fiber); also used metal and fiber reinforced plastic composite structure;
  - The principle of material selection: In the limit specified range of case's quality,can bear the full load, and has a certain design margin;
  - Material sources and low manufacturing costs
  - Material decide the process.

Design contents of combustion chamber

- 3. strength design and check of combustion chamber

- Select reasonable safety factor to determine the shell geometry, such as wall thickness, the form and size of the connection structure;

- According to the detailed design parameters of the design sketch and calculation, a detailed three-dimensional model of the combustion chamber shell is built and the stress and strain of the shell are checked within the allowable range by means of finite element analysis.

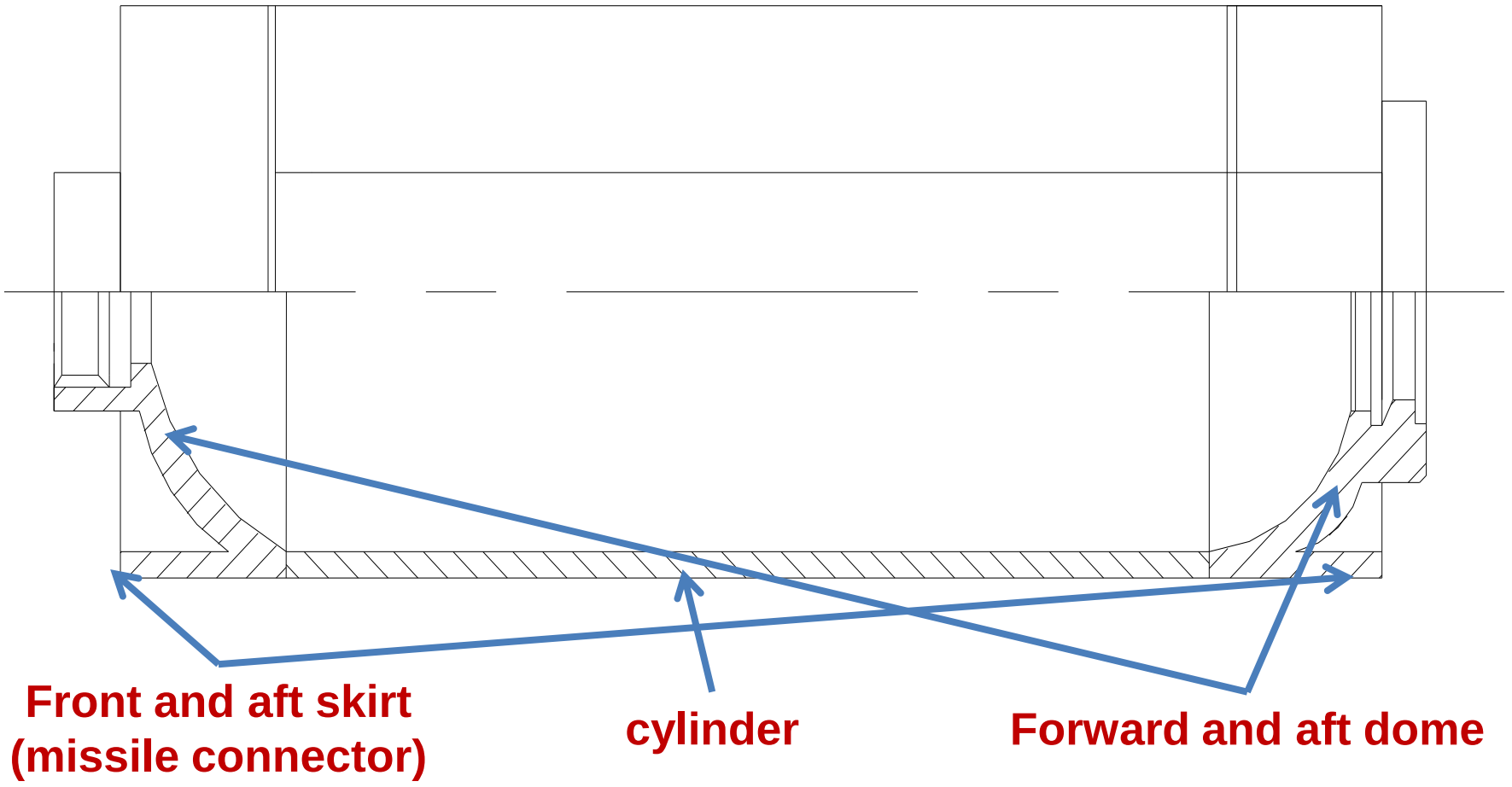
- If necessary, hydraulic testing can also be used to determine the strength of the combustion chamber

Design contents of combustion chamber

- 4.thermal protection design and check of combustion chamber
- According to the calculation of the heat transfer of 0- dimension or 1-dimension, the thickness of the insulation layer of the combustion chamber is determined;
- If necessary, the 3- dimension model can be used to simulate the actual performance of the insulation layer;
- In addition, it can also be used to determine the thermal protective performance of the insulating layer by the ablation test of the thermal insulation material.

Structure of combustion chamber case

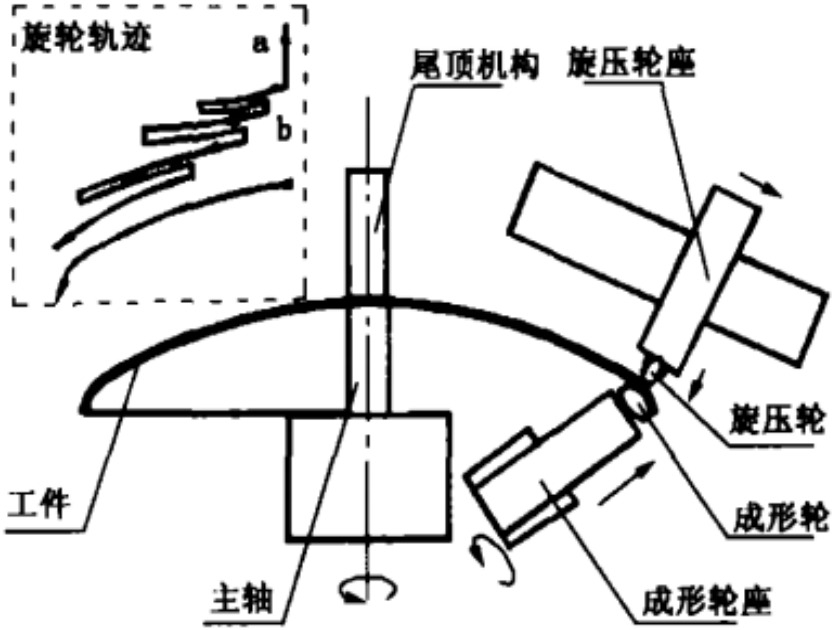
■ Structure of combustion chamber case

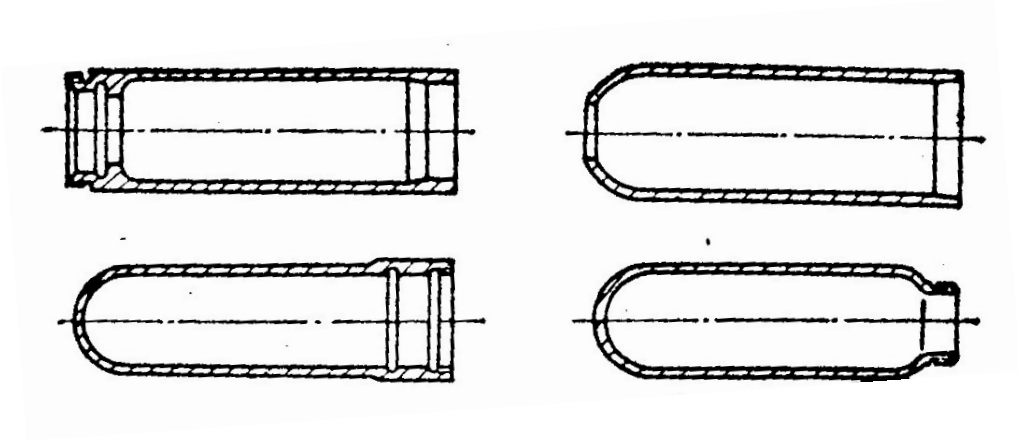


Structure Design

■ Structure of cylinder

- Metal cylinder
  - Spinning forming





- The spinning process can make the cylinder and the capped end into a whole, but the other end must be open;

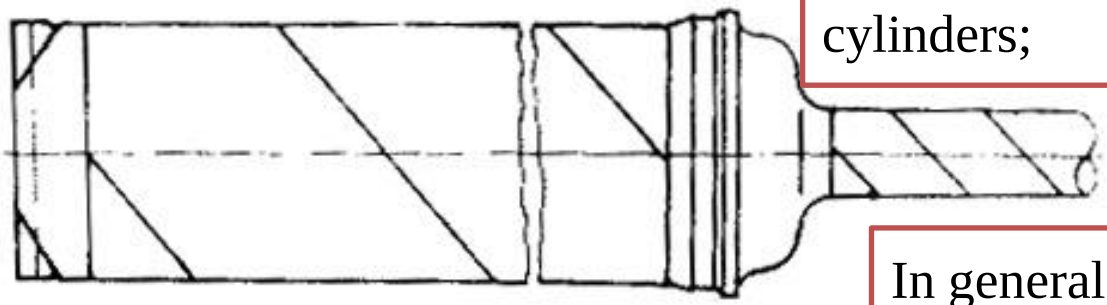
- Spinning forming is a kind of non chip processing technology, the thickness of the case's wall can be processed into equal thickness or variable thickness.

Structure Design

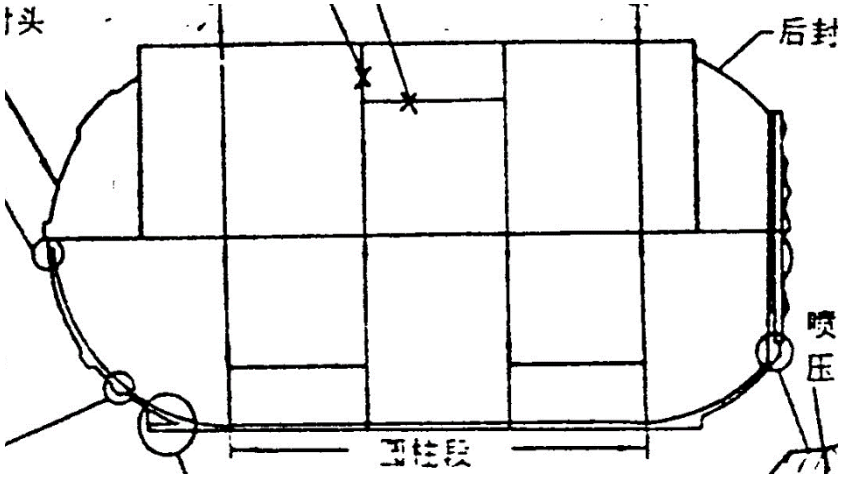
■ Structure of cylinder

- ➢ Metal cylinder
- ◆ Weld forming

The cylinder of the welded structure is welded by one or a plurality of steel sheets, and when the cylinder is longer, the welded cylinders can be welded together by a plurality of welded cylinders;



In general, the butt welding seam is staggered by 180 degrees, so as to avoid the excessive deformation and strength. The welded cylinder is welded with the front end and the back end.

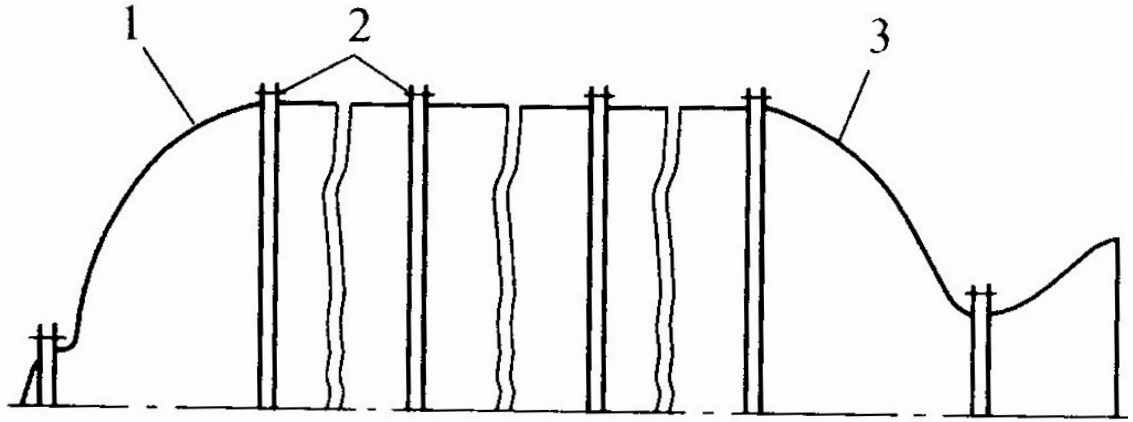


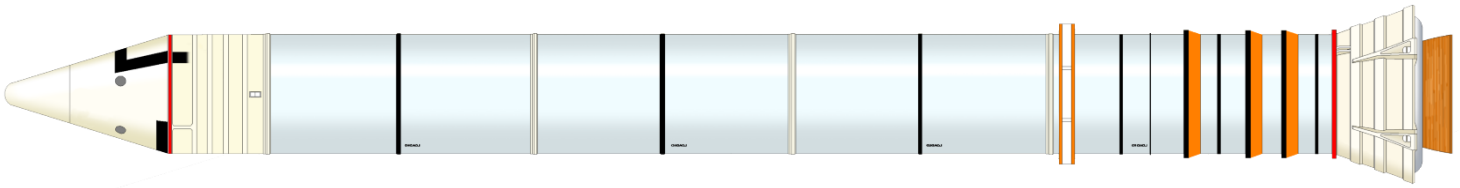
Structure Design

■ Structure of cylinder

- Metal cylinder
  - Segmented Manufacturing

For large solid rocket motors, such as space shuttle booster, can only use subsection pouring, and then the product each paragraph docking mode 。

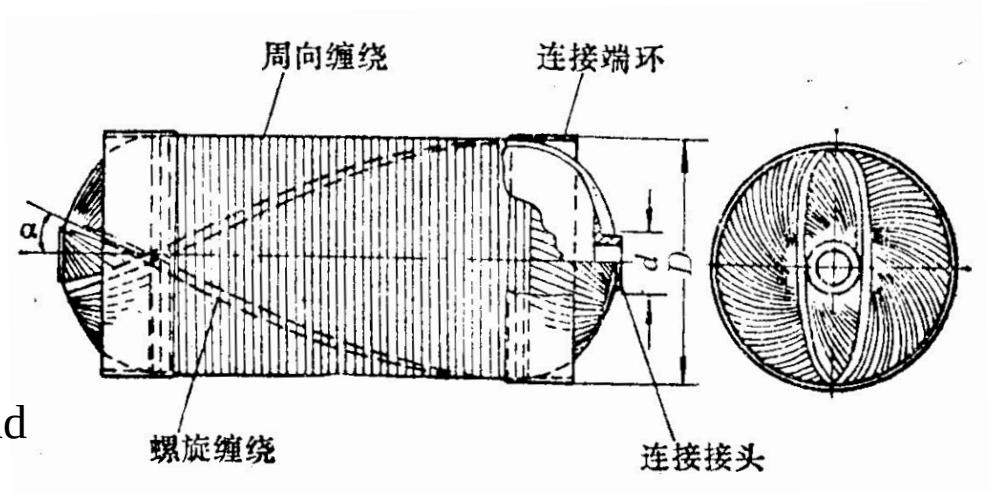




Structure Design

■ Structure of cylinder

- The filament winding case is usually made of the capped end and the cylinder body, and the resin fiber bundle is wound on the core of the winding machine;
- There are three basic winding methods: plane winding, circumferential winding and spiral winding. The plane winding and the circumferential winding can not be used singly, and the spiral winding is seldom used separately, and the plane winding and the winding of the coil are used more frequently;
- The connection of the fiber winding case is usually made of a metal joint, a metal skirt or a composite skirt with a metal end frame;
- The outer layer is a thin metal case, and the inner layer is a fiber reinforced structure.



■ Structure of cylinder

- Composite cylinder

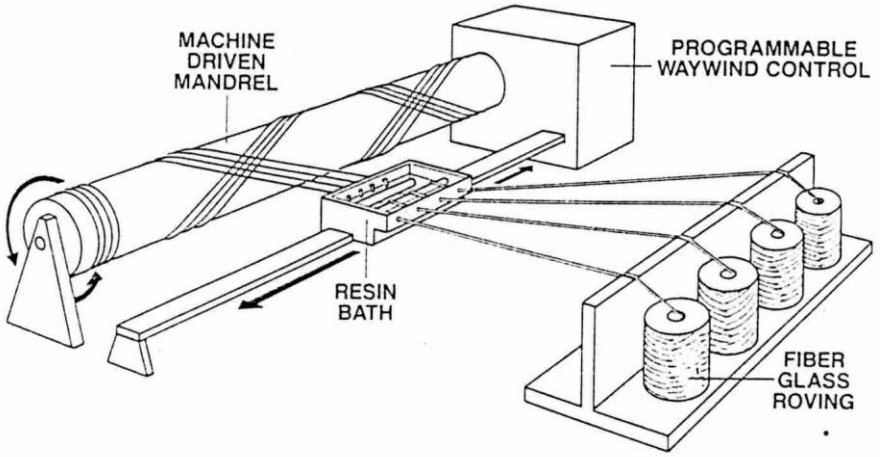
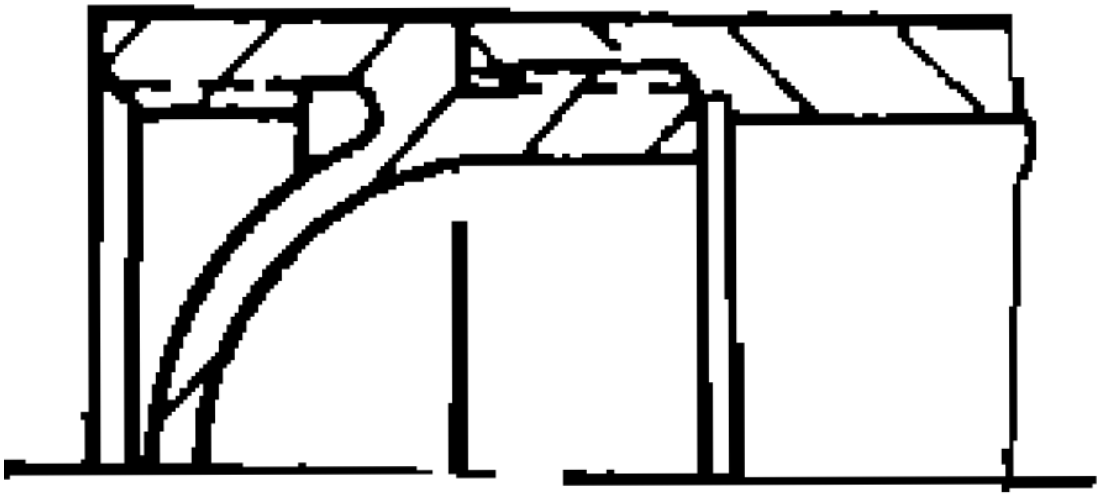


Figure 2.10. Filament winding operation. (Courtesy of CertainTeed Corp.)

Structure of cylinder

- Hemispherical dome

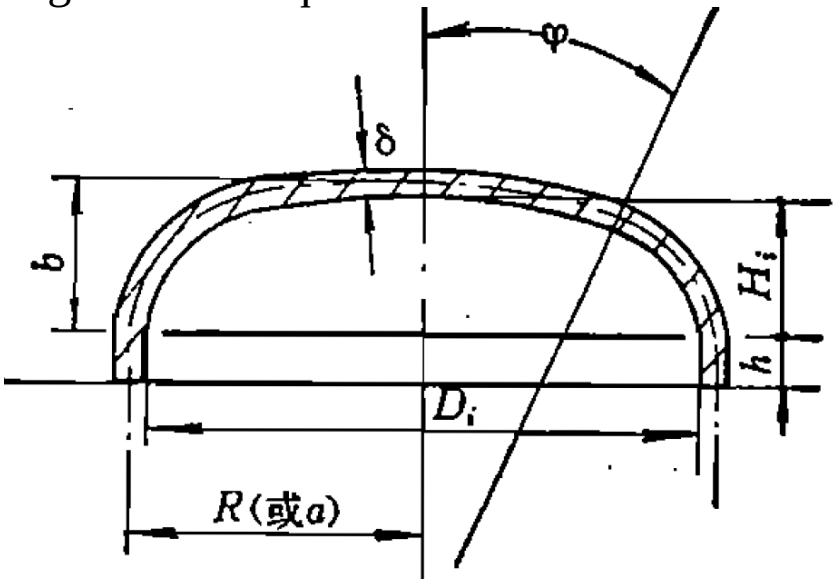
  - The mechanical characteristic of the hemispherical dome, So the wall is thin, and weight is light.
  - However, the depth of the dome is large, and the plasticity of the material need to be high.
  - When the shell length is fixed, the case with the same diameter is smaller than the ellipsoidal dome.



■ Dome structure

- Ellipsoidal dome

  - The ellipsoidal dome is formed by the rotation of an elliptic curve over its short axis. Due to the continuous change of the meridional curvature of the ellipsoid, the stress on the dome is changed continuously, and the stress concentration is not concentrated.
  - Generally take the ratio of the length and radius of the ellipsoid m=2, the maximum stress on the dome (vertex) and the maximum stress on the cylinder is equal, at this time the dome can be designed with equal wall thickness without waste of strength.
  - Usually used for large engines.



■ Dome structure

- Dished dome

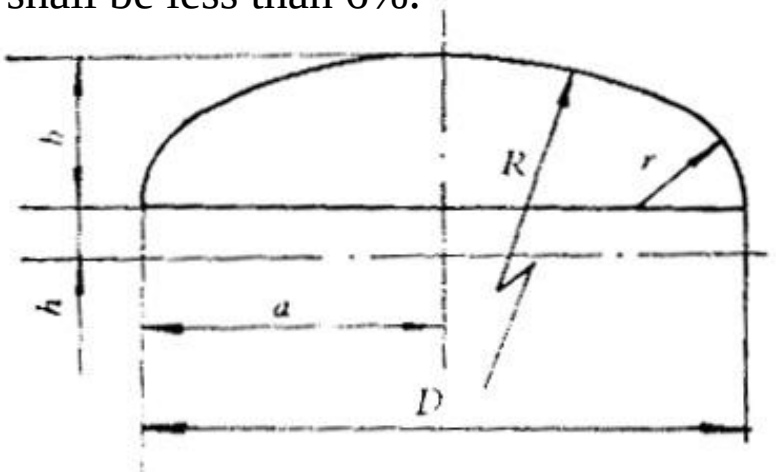
◆ The top is a part of the spherical shell with a radius of R, and the edge is rotated by an arc with a radius of R.

◆ Because of the discontinuity of the geometric curvature of the dished dome, the discontinuous stress will be produced at the junction of the different geometry, thus reducing the bearing capacity of the dome.

◆ The smaller the ratio of r to R, the greater the bending stress at the junction, the r shall not be less than 3 times of the thickness of the dome, and shall not be less than the inner diameter, the wall, the thickness of the dome shall be less than 6%.

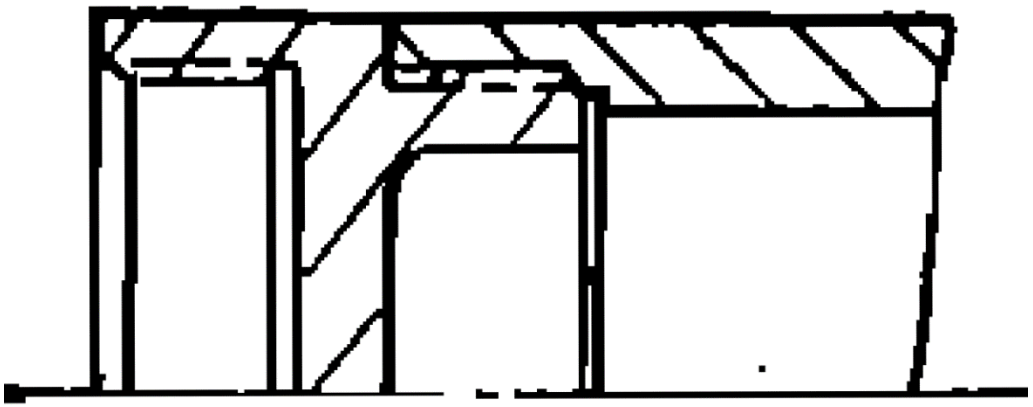
◆ Mold manufacturing is easier 。

◆ Usually used for small engine



dome structure

- Flat dome
  - The structure is simple and easy to process;
  - But the mechanical characteristic is also the worst, must be done very thick, increase the quality of the structure;
  - The production can be made by section or spinning;
  - Usually be used in small engine ground test.



Structure Design

■ dome structure

- Selection of structural form of dome

Mechanical properties of dome:

Hemispherical > Ellipsoidal > Dished > Flat

According to the mechanical properties and the engine type to select the dome structure.

■ Connection structure

Connection →

- Between case cylinder and dome or nozzle
- Between aft dome and nozzle
- Between front dome and ignition device
- Between the combustion chamber and the other cabin (such as missile inter-stage, warhead)

The main requirements of connection structure：

- Reliable connection
- Good sealing and co-axiality ；
- Convenient for filling or pouring ；
- Easy machining and assembly;
- Light quality .

■ Connection structure

Detachable connection → screw thread, bolt, clasp and dowel pin, etc.

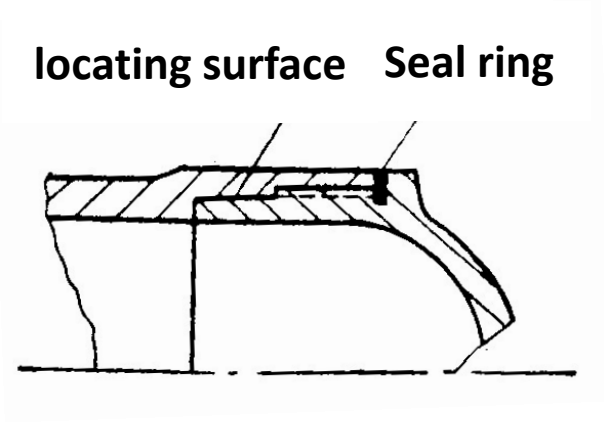
Non-Detachable connection → rivet, bonding, welding, shrink fit

Welding has the advantages of high reliability, simple structure and light weight. It is one of the most widely used in non-detachable connection.

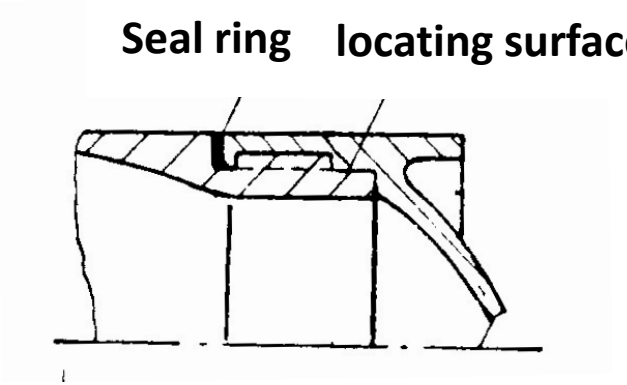
In order to load or casting the propellant grain, at least one end of the case should use connection structure.

■ Connection structure

➢ screw thread



Internal thread



External thread

- Simple, reliable, easy manufacture and easy assembly, but processing and assembly of large size thread is more difficult.
- Widely used in small and medium-sized engines.
- Seal with gasket or seal 。

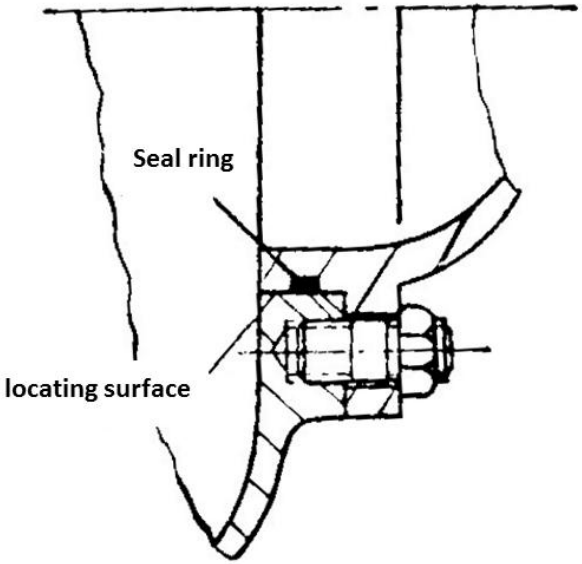
To the cylinder as a benchmark, can be classified into internal and external thread.

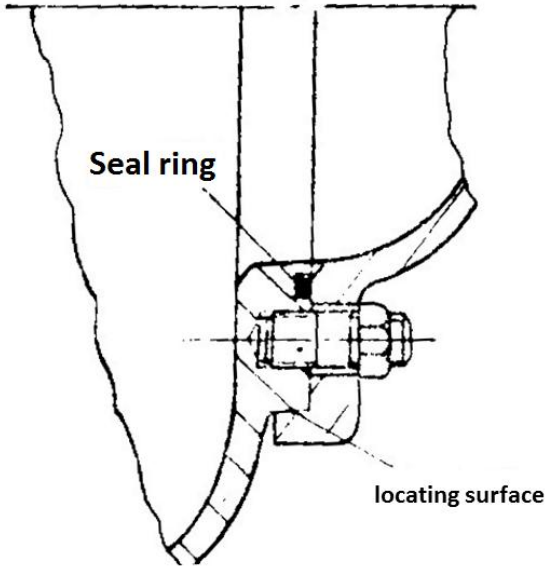
- The reliability and air tightness of external thread is batter than internal thread
- The outer diameter of the external thread connection is relatively large, and the internal thread is used when the outer diameter is limited.

■ Connection structure

➢ 2 Flange + stud

- ◆ Reliable, good coaxial and air tightness, large size connection structure of the manufacturing and assembly easy.
- ◆ Used for large engines.
- ◆ larger weight.

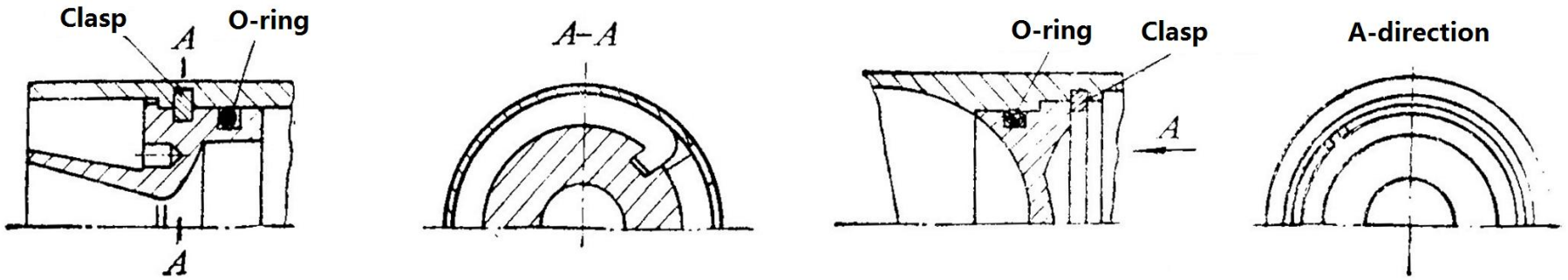




■ Connection structure

➢ 3 clasp

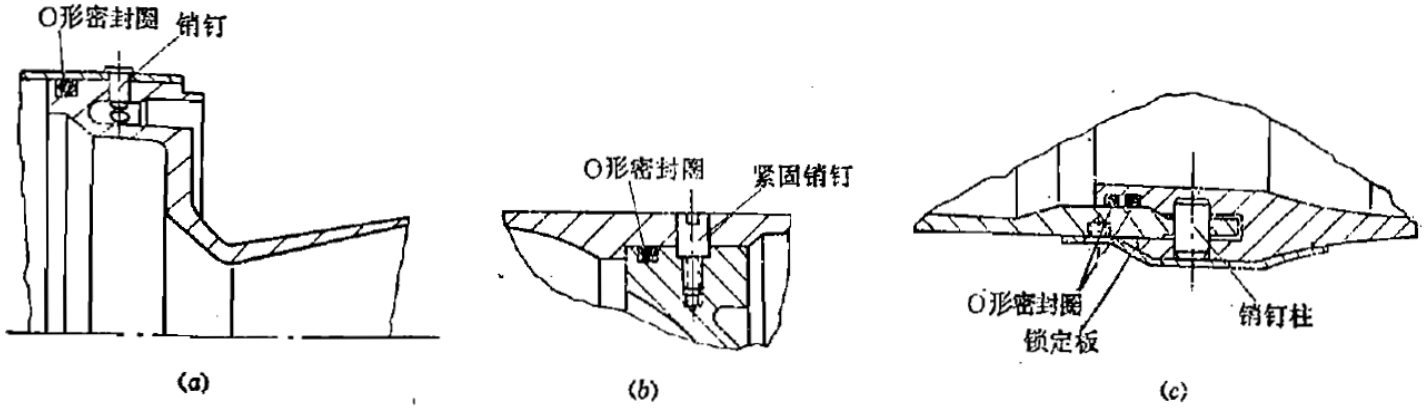
- ◆ Simple structure, light weight and good process.
- ◆ The disadvantage is to open a certain depth of the ring groove, the need to increase the local wall thickness.
- ◆ Suitable for small and medium-sized engines.



■ Connection structure

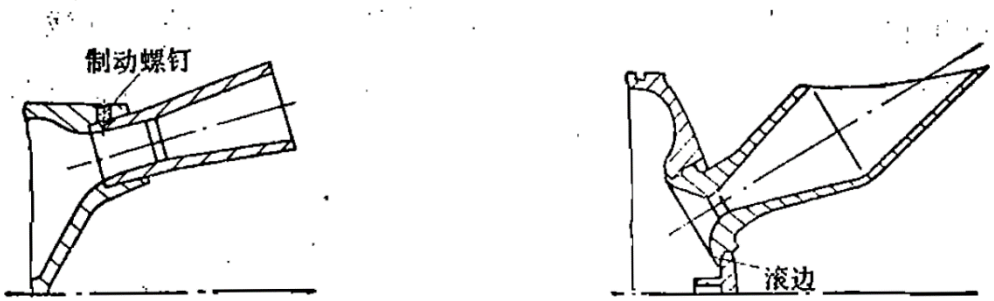
➢ 4 dowel pin

- ◆ Simple structure, light weight
- ◆ Require precision manufacturing



➢ 5 shrink fit

- ◆ Use of thermal expansion and contraction principle



■ Sealing

In order to prevent gas leakage during the work of the combustion chamber, and to ensure that the engine in the storage and transportation of internal moisture and corrosion, must require the connection parts have good sealing performance.

- Gas exhaust will not only destroy the ballistic trajectory, but also burn down the case at the connection face, or even lead to explosion.
- At low temperatures, the invasion of the outside world will produce a layer of frost on the surface of the grain and will lead to ignition failure.
- At high altitude, if the pressure inside combustion is as low as the outside, also can cause ignition failure.
- In storage and transportation, it is easy to make moisture deterioration.

Case sealing design is very important ！

■ Sealing

➢ sealing element

1）Flat washer：

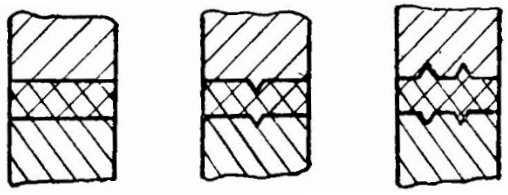
2）O-ring：

3） Sealant： Silicone Rubber

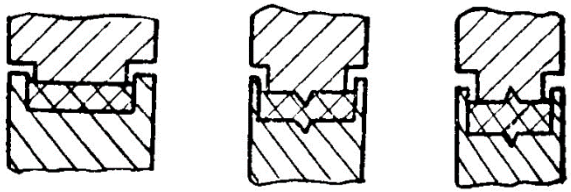
■ Sealing

➢ Flat washer

- Mainly used for end seal, the sealing and gasket material elasticity, the shape of the contact surface and the size of the preload.
- Annealing copper, rubber asbestos, polytetrafluoroethylene and so on.
- The shape of the contact surface has a great influence on the sealing property. If the opening surface is opened with 1 to 2 triangular grooves or flanges, the sealing property can be greatly improved. The trough contact surface is better than the face contact and is not easy to crush.
- Preload is too large, crush the gasket, sealing unreliable; preload is too small, the lack of adequate sealing pressure, sealing unreliable.



face structure

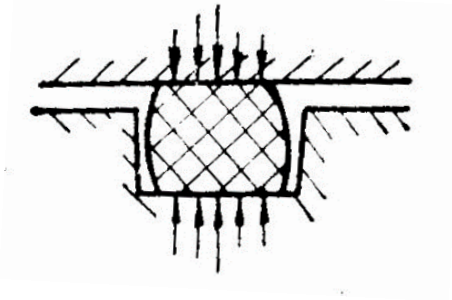


Groove structure

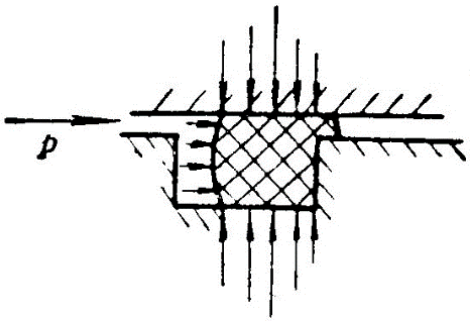
■ Sealing

➢ O-ring

- ◆ O-ring is widely used in combustion chamber case can be connected parts, simple structure, assembly and disassembly program, sealed and reliable.
- ◆ Select the sealing ring material, determine its shape and size, and so on.
- ◆ Silicone rubber, fluorine rubber, nitrile rubber and polytetrafluoroethylene plastic.
- ◆ The seal groove size can be designed according mechanical manual.



Fixing pattern

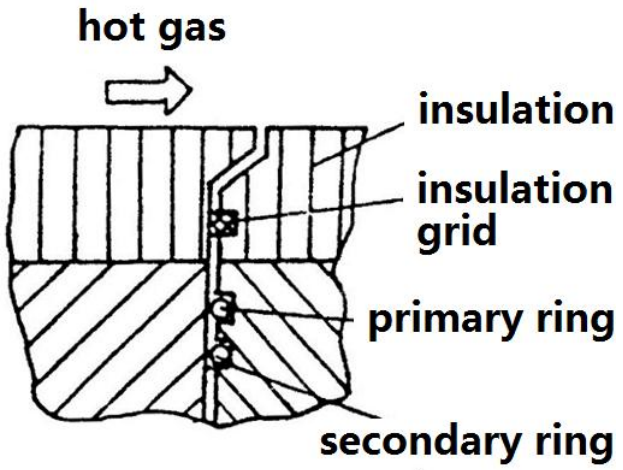


Loading pattern

■ Sealing

➢ O-ring

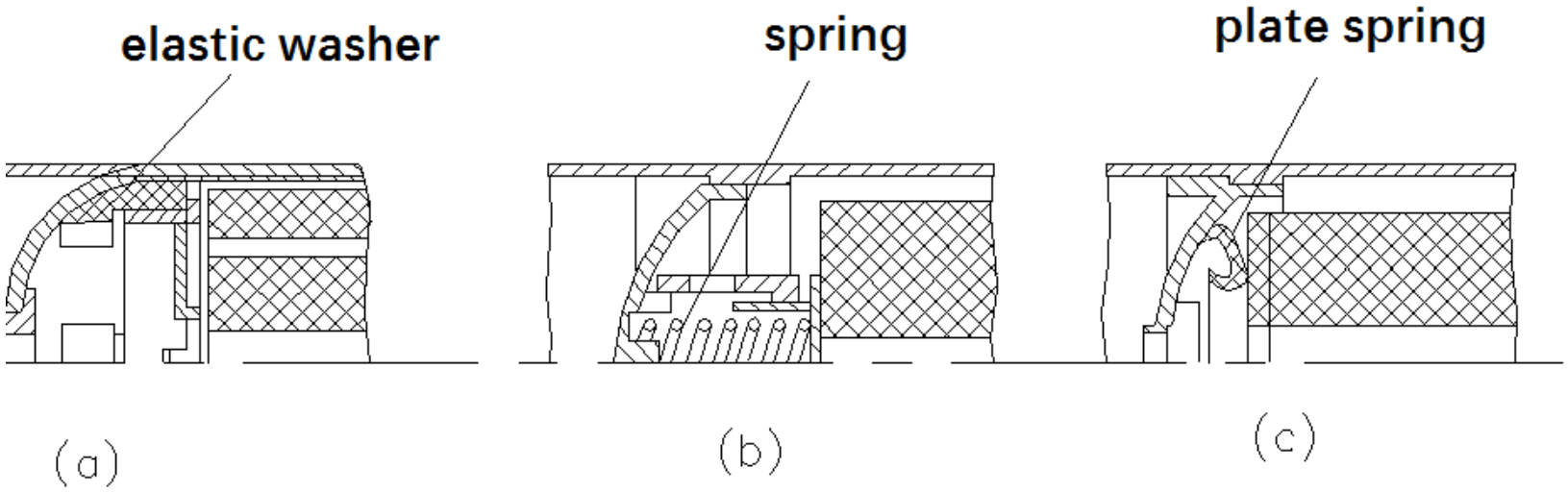
- According to the suffer of Challenger spaceshuttle, the ring of resilience must keep up with the sealing surface gap due to pressure caused by increased deformation;
- In order to prevent the sealing ring in the low temperature loss of resilience, can be filled with heat-resistant putty, add a heater, or use new materials, and appropriate bold O-ring cross-sectional size;
- To prevent the gas from burning the ring, fill the inside of the gas with zinc acetate putty, or increase the insulation grid.



■ back stand for propellant

➢ Front back stand

- Function: axial and radial positioning, allowing the thermal expansion and contraction.
- Features: not bear inertial force, low gas flow speed, light ablation
- Structure: elastic deformation in the axial direction (elastic pad, spring, leaf spring)
- Material: spring, felt, rubber and so on.



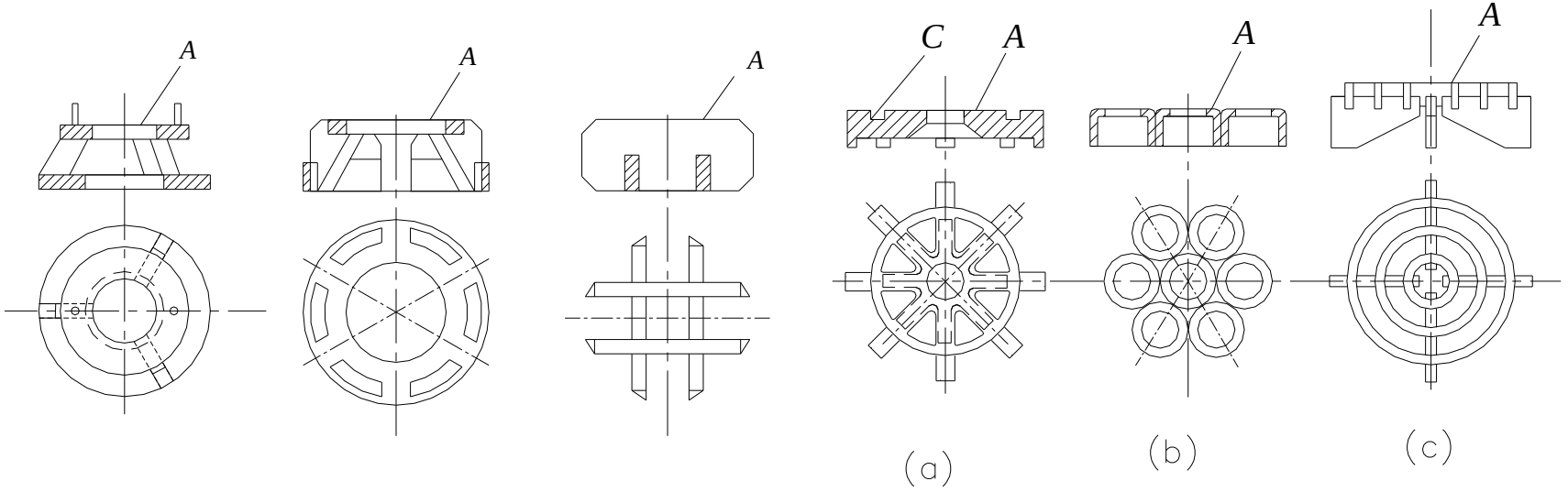
■ back stand for propellant

➢ **aft back stand - Propellant Baffle**

- Functions: axial, radial positioning; blocking grain fragment, to prevent nozzle blocking
- Features: by the inertia of the role of the pill, by the gas scouring, generally rigid

① single charge : simple structure

② multiple charge: complex structure

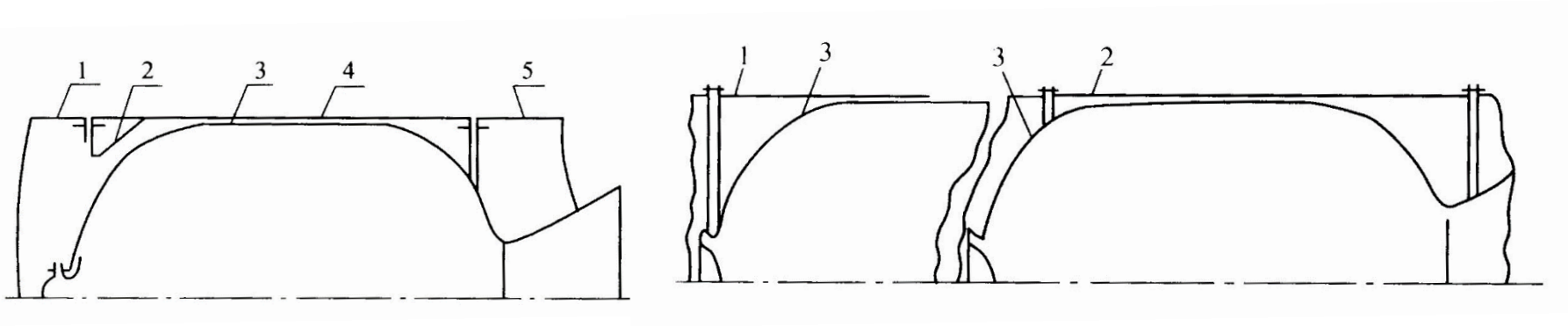


single charge **multiple charge**

■ connection between motor and other components

➢ Multi-segments design

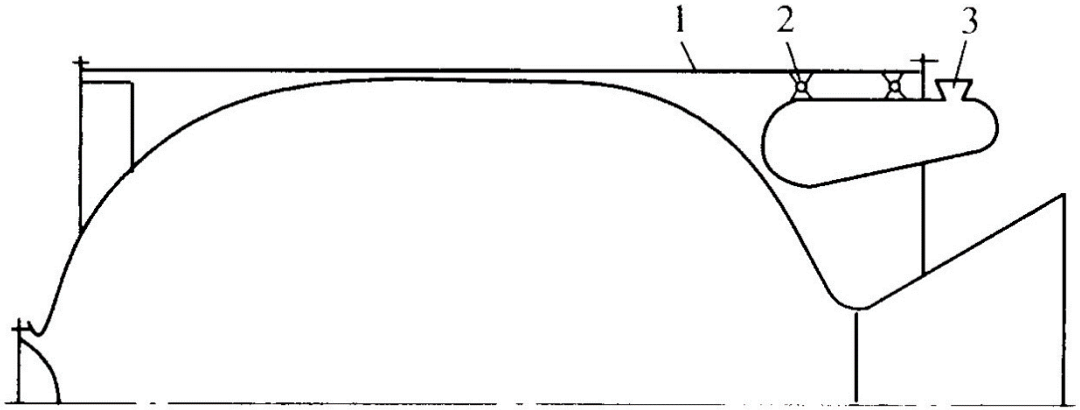
- two or more butt joints, located at the front and rear ends of the housing.
- The length of the butt is dependent on the structure of the rocket. If there is no rocket compartment, the adjacent engine can be docked directly.
- The connector is mounted on the connecting skirt of the shell.



1-upper stage，2-forword skirt, 3-force bearing inner case，
4-out case, 5-lower stage

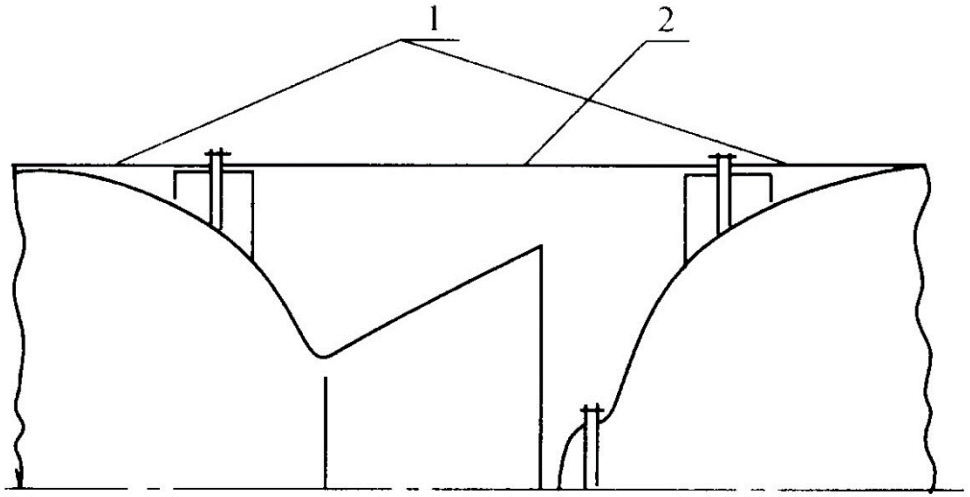
■ connection between motor and other components

- **Multi-segments design**



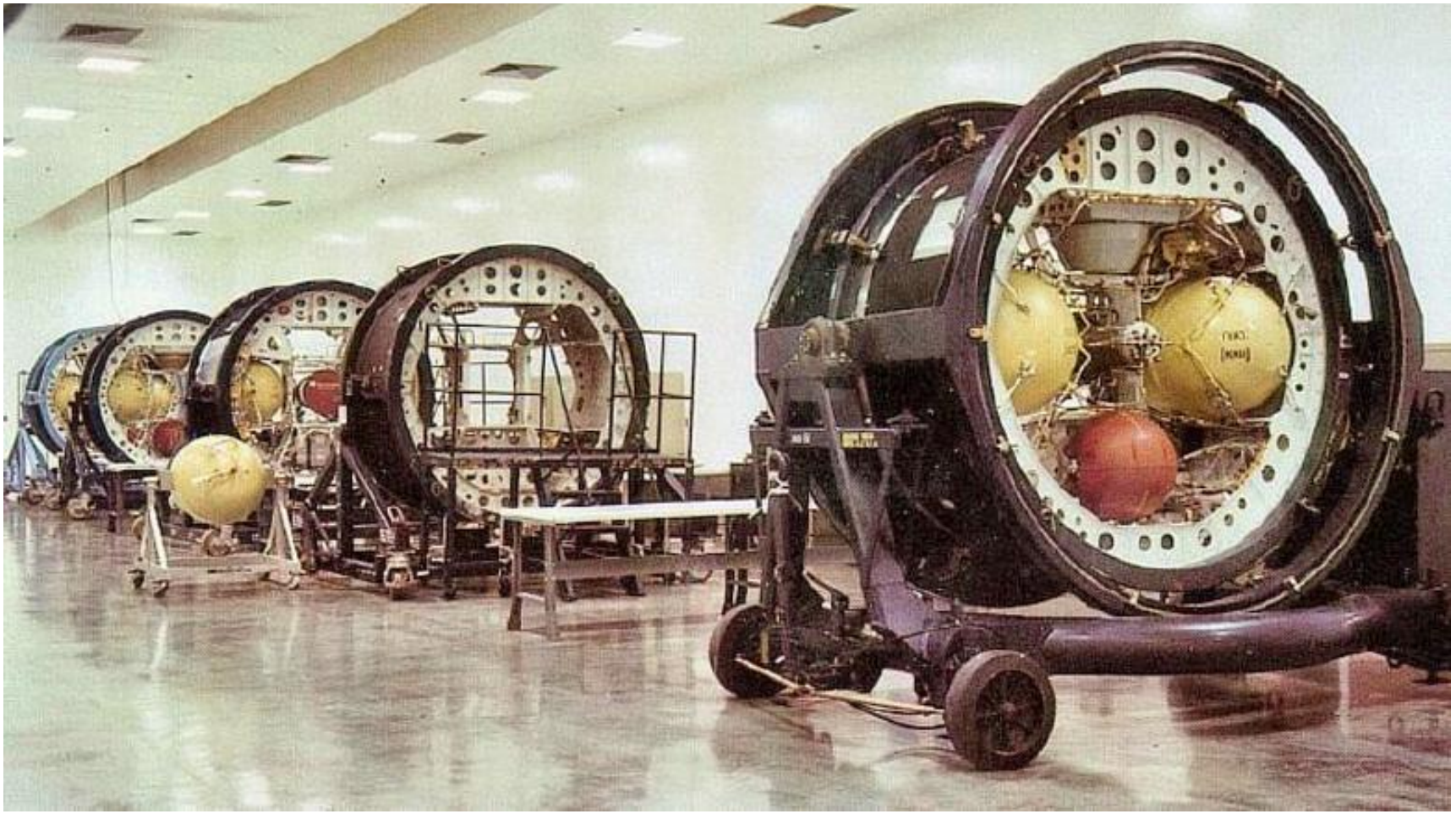
Up and down the engine directly using the shell connection, shorten the length

The housing extends downwardly to connect the auxiliary engine structure



■ connection between motor and other components

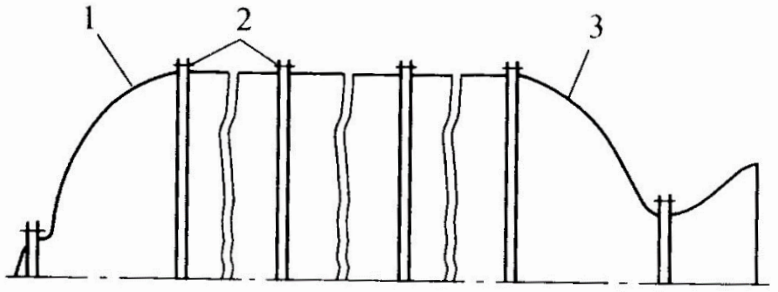
- **Multi-segments design**



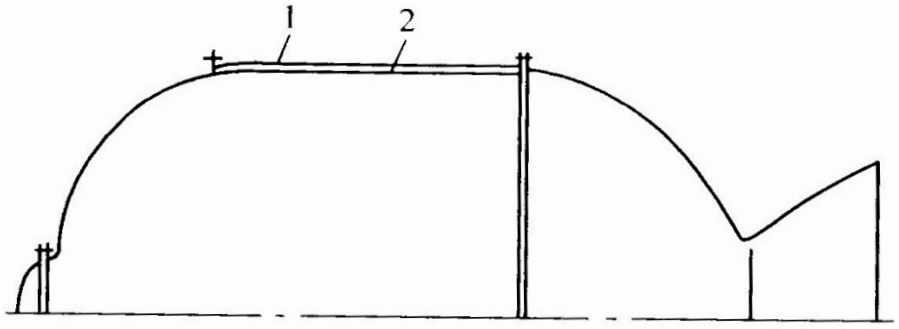
■ connection between motor and other components

- The segmented case has several abutting faces in the cylindrical section or the cone section. The abutment surface of the shell section is determined by the outer dimension, the mass limit and the pillar transport overload. The large segmented engine is transported to the launch field , And then assembled to launch.
- The outer case is a thin metal shell, and the inner layer is a composite material, which solves the problem of connecting the composite material and solves the problem of heating the metal structure.

Segmented case



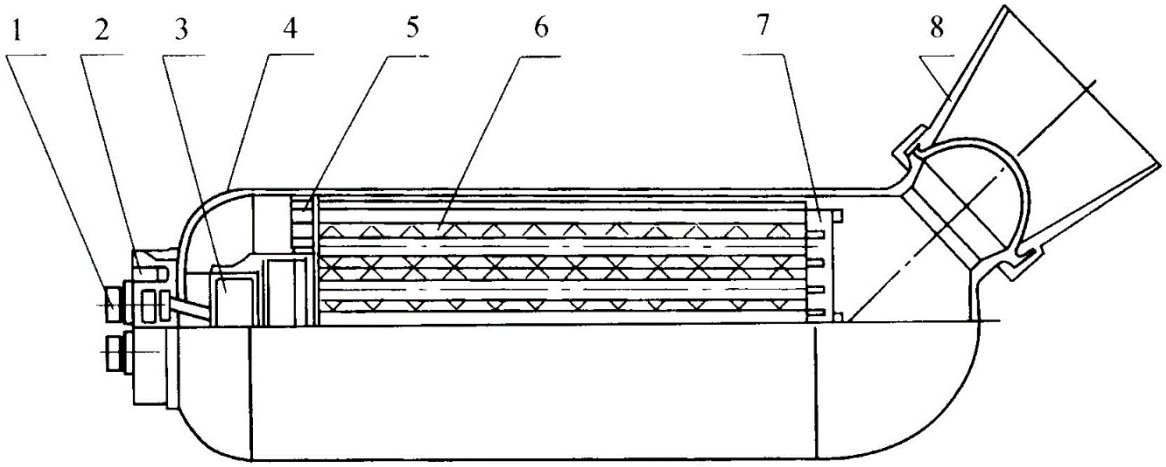
Combination case



■ special combustion chamber

➢ Rocket motor for ejection seat

- Metal case, welded structure
- Dish front dome, welded with case
- Hemispherical aft dome, 45 degree angle with axis
- welded nozzle thread with the aft dome
- case and back stands are coating or without thermal protection

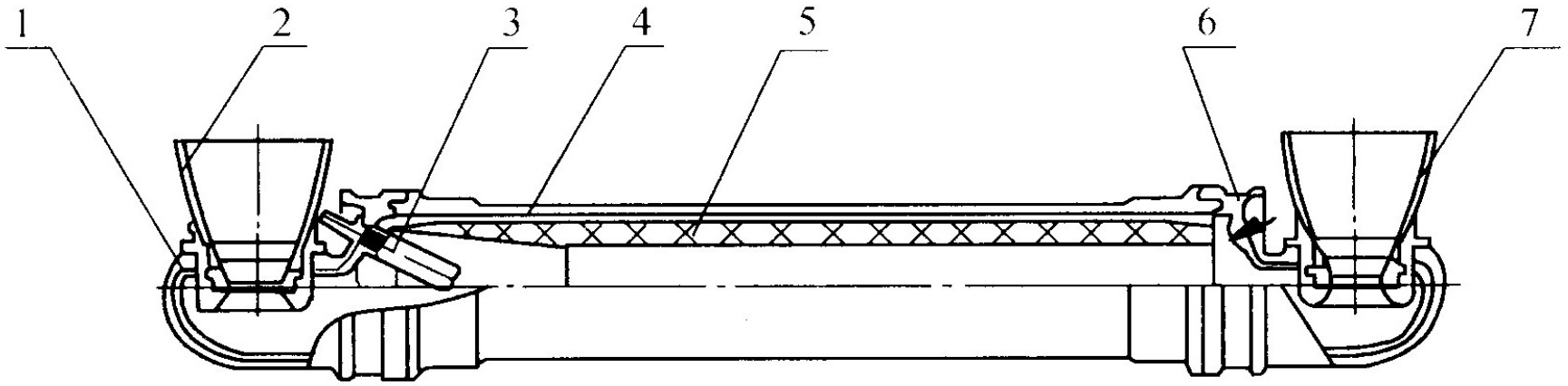


1-3 blast tube，igniter, 4-matal case, 5，7- back stand, 6-double based grain, 8-nozzle

■ special combustion chamber

- **double nozzle rocket for components separation or deflection**

- Hemispherical forward and aft domes (to hold nozzles)
- Aft dome and nozzle are connected to the case using pins
- Case banding grain to ensure interior ballistic characteristics



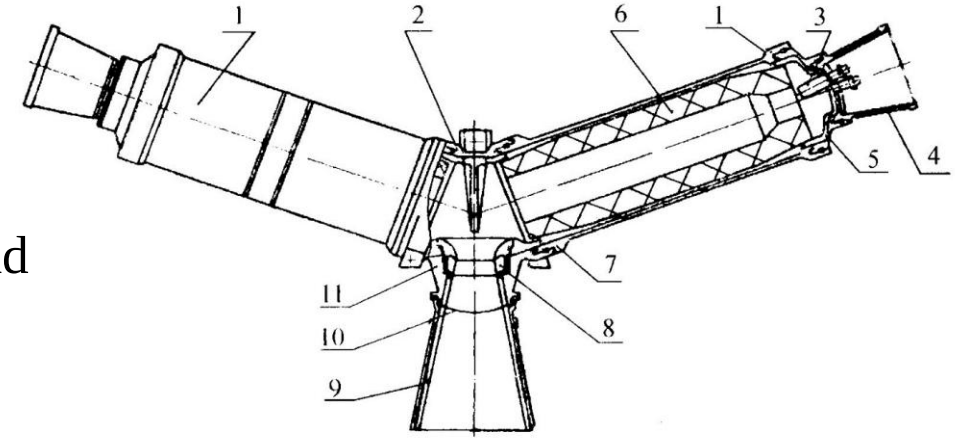
1-front dome，2，7-nozzle, 3-igniter, 4-case, 5-grain, 6-aft dome

■ special combustion chamber

➢ **landing rocket**

- Metal welded case with insulation
- Metal welded connector with insulation
- case bonded casting grain with stepped bore
- aluminum alloy nozzle block
- pin connection between case and connector
- metal welded nozzle shell

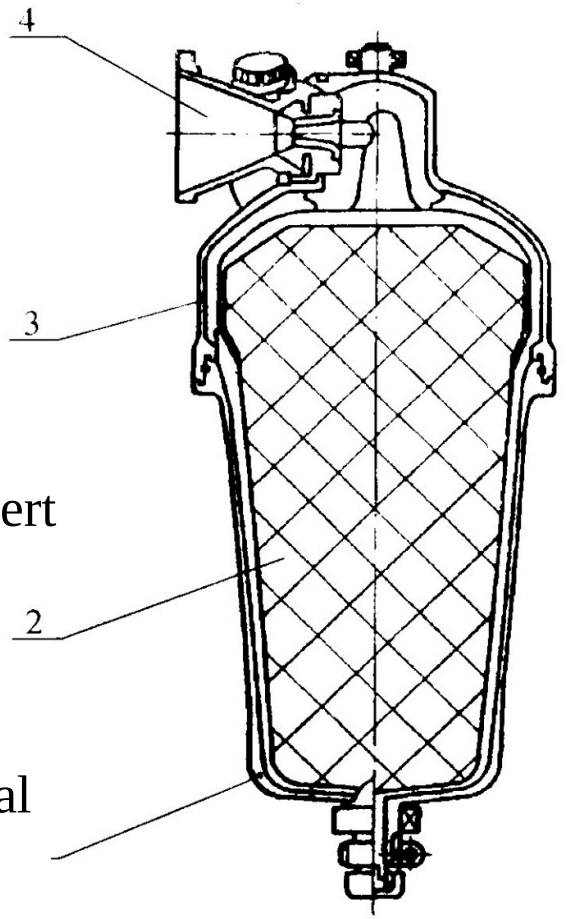
1，7-case，2- Connector, 3-igniter, 4-thrust termination 5-closure, 6-grain, 8-nozzle, 9-nozzle exit cone, 10-nozzle block, 11-nozzle shell



■ special combustion chamber

➢ **Special motor for rolling control**

- flat forward closure
- metal welded case
- titanium alloy nozzle with molybdenum insert
- Threaded connection between nozzle and aft dome
- pin connected between aft hemispherical dome and case
- end-burning case bonded grain with reduced cross section to meet the ballistic requirements



1-Case，2-Grain, 3-Aft dome

4-Nozzle

THE END