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WEIGHTLESSNESS AND MANAGEMENT OF LIQUID ROCKET PROPELLANT

by

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WEIGHTLESSNESS AND MANAGEMENT OF LIQUID ROCKET PROPELLANT

Not an Imagination

We all know that a person will float under the condition of weightlessness. Then after a rocket is launched, the liquid propellant will also float around in the container with the possibility of causing various kinds of accidents. This is not imagined words to attract attention. Under weightlessness, the liquid propellant will mix with the gas used to increase pressure because now the molecular forces in matter dominate and the adhesive force between the propellant and the container wall is greater than its own cohesive force. Hence, it will crawl along the wall and finally cut up the gas and surround it (Figure 1). Now the rocket fuel pump may also pump the gas and the flight will fail because of engine fuel "shortage". At the same time, the drifting of the propellant will make the center of mass of the rocket vary randomly, causing a problem in attitude control. In addition, the amplitude of propellant oscillation will increase as the main engine thrust changes from large to small. Similar to the case of a fast moving vehicle stopping suddenly when a person inside will rush forward, the propellant will gush toward the bottom. The vibrational amplitude increases proportionally with the square root of the decrease in thrust. For instance, when the thrust of the main engine is 1000 kilogram, the vibrational amplitude of the propellant before engine shut-off is 10 cm. Let the engine thrust be 10 kilogram as the propellant sinks to the bottom. Then the vibrational amplitude will increase 10 times as thrust decreases from 1000 to 10 kilograms, and the vibrational amplitude will increase to 1 meter. If the bottom engine thrust is 2.5 kilograms, then when the thrust changes from 1000 to 2.5 kilograms, the vibrational amplitude will increase by 20 times with the amplitude increased to 2 meters. Vibrations with amplitude as big as this are not allowed because the fuel might drift over to the inlet of the exhaust valve. If the exhaust valve happens to be open, then the fuel will be expelled with the gas. When liquid is expelled, on one hand there will be a waste of fuel and on the other, it will exert a large thrust as it is

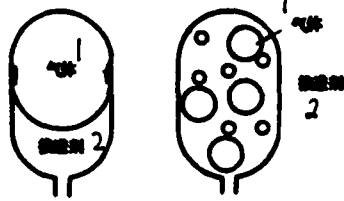


Figure 1. Propellant drift due to weightlessness
1--gas; 2--propellant

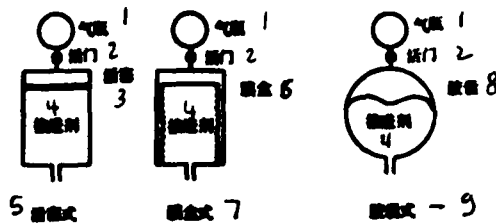


Figure 2. Active system
1--gas bottle; 2--valve; 3--piston;
4--propellant; 5--piston type;
6--membrane box; 7--membrane box type;
8--plastic bag; 9--plastic bag type

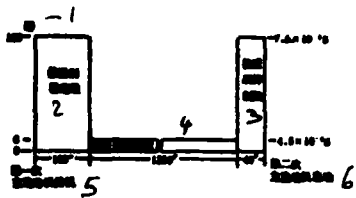


Figure 3. Centurion AC-8 gliding stage
1--pound; 2--propellant stabilizing stage; 3--propellant control stage; 4--propellant maintenance stage; 5--main engine shut down for the first time; 6--main engine start up for the second time

expelled because the liquid will rapidly vaporize in the near vacuum surrounding the rocket. If the exhaust is not symmetric, this thrust will upset the rocket. The Centurion AC-4 launched by the U. S. on December 11, 1964, failed precisely due to this reason.

Human effort makes the difference

Suitable management procedures for liquid propellant need to be taken in the above mentioned situation to guarantee the normal operation of the main engine. For different situations, various methods have to be used. Currently, the more practical ones are as follows:

(1) The active method. The propellant is stored in plastic bags or metal waveline containers to be squeezed into the engine with an external force during firing (see Figure 2). This is suitable for situations where the thrust is not large and where stored propellants may be used, such as the attitude control during the rocket gliding motion and the small thrust engine used in managing the propellant.

(2) Semi-active method. The liquid propellant is kept at a designated position in the container by artificial gravitation field or electromagnetic field.

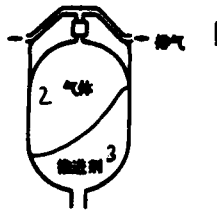


Figure 4. Balance symmetrical gas exhaust
1--gas exhaust; 2--gas;
3--propellant

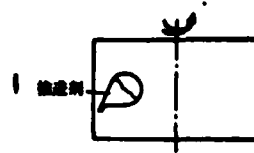


Figure 5. Design that uses centrifugal force
1--propellant

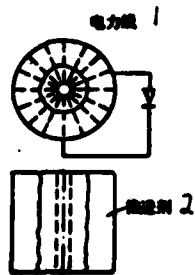


Figure 6. Electric migration system
1--electric field;
2--propellant

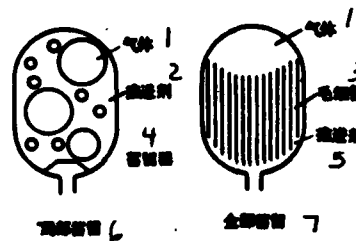


Figure 7. Capillary retention device
1--gas; 2--propellant; 3--
capillaries; 4--retainer; 5--
propellant; 6--partial retention;
7--total retention

The artificial gravitational field is an inertial force much greater than the molecular force, produced during the thrustless gliding period after the main engine shuts down with small thrust engines so that the rocket is not in a weightlessness state and the propellant sinks to the bottom. Generally, the ratio of inertial force to the molecular force is called constant N_B . The number of present day rockets is between 70-450.

To avoid increasing the vibrations when the main engine shuts down, the thrust cannot be reduced all at once. There must be a suitable gradient. The first stage in the thrust program is called the stabilization stage. Its effect is to lower and damp out the vibrational amplitude. The second stage is the small thrust bottom

maintenance stage. The third stage is the control stage to prevent any accidental interference and to guarantee the bottoming of the propellant so that the engine will operate normally. Centurion AC-8 adopted this program (see Figure 3) and after some measures are taken in regard to the structure, was successfully launched.

Thrust program

The common structural measure is to install vibration prevention plates in the container and to install at the pressure inlet energy reduction devices to greatly reduce the flow speed of the pressurizing gas so that the liquid will not splatter. There is also the method of balancing the symmetrical release of gas, etc. (see Figure 4).

When applied to the satellite, the centrifugal force of the gyration of the satellite is commonly used to make the propellant stay at the outlet (see Figure 5).

Figure 6 is an electrical migration system which separates the gas from the liquid with an electrical migrational force. A corpuscular material is added to the propellant which become polarized in the electric field. The non-uniform electric field has a stronger attraction toward the stronger electrode. This causes the polarized material to move towards it. This system is only good for situations where the dimensions are not large and the propellant volume is small.

(3) The passive type. The capillary effect of separation plates and grids is used to keep the propellant in the designated location of the container. This is again divided into local retention and total retention situations (see Figure 7).

In local retention, only a small portion of the propellant is retained, enough to enable the main engine start. The rest of the propellant is made to sink to the bottom for continuous supply. This kind of local retention device was used in the U. S. rocket Achilles D.

In total retention, the whole container or one layer of the interior wall of the container is filled with capillaries so that all the liquid is now connected to the drain tube and as the fuel pump operates, propellant will be sucked in.

Examples of weightlessness

After all, when does weightlessness occur for a rocket?

As an example, we know that the easiest way to launch a satellite is to first launch the satellite with the upper stage rocket into an orbit several hundred kilometers above ground. This is called the parking orbit. After the rocket glides freely in this parking orbit over a certain distance, its main engine is started again at a certain point to continue accelerating the rocket forward. This free inertial flight stage is under weightlessness. The engine shut off that increases the vibration of the liquid propellant is even more commonly seen. Thus, propellant management when the rocket is under weightlessness or reduced gravitational force is an important technological item which is paid much attention in other countries. Large amounts of research is carried out on this topic but using such devices as direct launching of experimental rocket, using the airplane for small overload flight and drop tower. Centurion AC-4 and AC-8 were launched just for this purpose.

As space activities become increasingly more frequent, the vehicle rocket is faced with more and more difficult responsibilities and the need for multiple operation of the engine is more urgent. Weightlessness brings new problems for the vehicle rocket that urgently need solutions.

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