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Challenges in Aerospace Propulsion

Dear Friends:

As we all aware, the aerospace propulsion is broadly classified into airbreathing propulsion and rocket propulsion. What are the challenges or the so called “market forces” to the propulsion community in these two broad areas of propulsion?

Airbreathing Propulsion

In the areas of airbreathing propulsion, the challenges for the propulsion fraternity in the Country are two: first and foremost, the development of high performance gas turbine jet engine and second the development of ramjet engines for high supersonic and hypersonic propulsion. To meet with these challenges we have to master two problem areas: one, supersonic and hypersonic flows in adverse pressure gradients and two, thermal energy addition by fuel combustion in supersonic flows.

The basic problem with supersonic and hypersonic flows is that upstream “fellow” does not know what the downstream “fellow” is facing or doing. Consequently higher the speeds, narrower are the acceptable operating ranges. The situation further worsens with the supersonic and hypersonic flows in adverse pressure gradients as in intakes and compressors. Consequently, introducing variable configuration becomes mandatory.

Most compressors in high performance gas turbine jet engines are of transonic type, wherein acceleration to supersonic Mach numbers with mechanical energy addition and deceleration to high subsonic values take place in every stage. The problem further gets complicated because these machineries rotate at a few tens of thousands rpm.

Supersonic combustion ramjets, namely SCRAMJETS have intakes that decelerate hypersonic flows to supersonic conditions, and combustion chambers wherein thermal energy addition has to take place without “shock down”. While hydrocarbon fuels are being tried in our Country for low hypersonic SCRAM jets, adopting the low molecular weight fuel hydrogen looks mandatory for high hypersonic airbreathing propulsion.

Therefore, to meet with the challenges in airbreathing propulsion the problem areas appear to be (1) hypersonic and supersonic flows in adverse pressure gradients and (2) thermal energy addition in supersonic flows.

Rocket Propulsion

Now let us now turn to rocket propulsion. The near term challenges are two: first, the reduction of satellite launch cost and the second realizing deep space missions within our solar system.

The current rates of satellite launch cost are estimated to be varying from 10000$ to 18000$ per kg for a low Earth-orbit, and 18000$ to 33000$ per kg for a geo-transfer orbit. Chairman of ISRO Mr. Radhakrishnan said two years back that the launch cost for a geo-transfer orbit (GTO) was about 20000$ per kg. If we compare a GTO mission with an equivalent flight by an aircraft, the cost per kg works out to a maximum of about 30$/kg. Therefore, the reason for about three orders of magnitude higher cost to reach GTO is the "use and throw away" concept applied to space launch vehicles, namely expendable launch vehicles.

A critical study in 1999 by an American company has revealed that there were totally 4377 space launches worldwide from 1957 to 1999. Out of these there were 389 failures, resulting in 91% success rate. Looking at the trend for the last two decades of the above period (1979-'88 and 1989-'98), it appears that the success rate for the improved concept of launch-vehicle technology has reached a steady value of around 95%. The review for the causes for these failures revealed that the propulsion subsystem is the Achilles' heel of the space programme - out of the 85 failures, 53 were identified to be due to the propulsion subsystem alone, whereas the next highest number of failures was just 10 and it was due to the avionics.

The propulsion subsystem operates under high pressures and extreme temperatures. As per the current design concept, it is always made to operate at its maximum power *all the time* resulting in very low margins on performance and safety.

The high launch cost (because of the "use and throw away" concept) and the frequent launch failures (due to the low margins on performance and safety) are the two principal impediments for faster long-term growth in space technology. These two obstacles point to, as solutions, the component reusability and enhanced margins on performance and safety.

Let us now turn to the second challenge under rocket propulsion, namely realizing space missions within our solar system. ISRO is reported to be working on Mars mission. The journey to Mars is planned to take 250 days.

For a satellite to function in space, different power-supply units are needed to deliver thermal-, electrical-, and mechanical-powers. For the satellites in the Earth orbits, these thermal- and electrical-power are derived generally from solar power with chemical-batteries backup. And, for the mechanical power, the chemical rocket engines are adopted. In all, we see that, for the different power-supply needs, spacecraft in the Earth orbits generally depend on solar power and the chemicals stored on-board.

In the deep-space missions away from Sun, spacecraft travel to environments where the solar power is too feeble. Chemical systems being energy limited cannot serve deep space missions. Therefore we have to look for a different power source. Nuclear power, being energy unlimited, is the source that one has to depend for deep space missions.

As mentioned previously, heat is required to keep certain compartments of spacecraft at desirable temperatures. For this, the heat from a radioactive-decay unit can be used directly and the unit is known as radioisotope heater-unit (RHU). The heat energy obtained from the radioactive decay can be directly converted into electricity by the use of either thermoelectric- or thermionic-materials. The system that directly converts the heat from radioactive decay into electricity using a thermoelectric material is known as radioisotope thermoelectric generator (RTG). Radioisotope units are constructed to supply heat as well as electricity and such units are known as general purpose heat source radioisotope thermoelectric generators (GPHS-RTGs). In deep space missions, the required mechanical power is obtained by the use of electric rocket engines, which derive the required electric power from the radio isotope thermoelectric generators. The electric rocket engines accelerate and eject electrically charged particles at very high speeds in the form of a jet to produce a thrust force.

Conclusions

As conclusions, the following appear to be the areas for intensive developments to meet the challenges in aerospace propulsion in our Country. In the area of air breathing propulsion let us master the following problem areas.

(1) Hypersonic flows in adverse pressure gradients.
(2) Supersonic flows in adverse pressure gradients with mechanical energy addition.
(3) Thermal energy addition in supersonic flows.

In the areas of rocket propulsion, let us master the following.

(1) Development of reusable components with enhanced margins on performance and safety which will culminate in realizing reusable satellite launch vehicles.
(2) Develop radioisotope heater units and radio isotope thermoelectric generators to supply thermal- and electrical-powers needed in spacecraft for deep space missions.
(3) Develop suitable electric rocket engines that operate on the electric power supplied by the radio isotope thermoelectric generators.

Thank you for your attention.

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