LINKÖPING UNIVERSITY

SABRE Rocket

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1 Introduction to SABRE

SABRE (Synergistic Air-Breathing Rocket Engine) is a hypersonic pre-cooled hybrid air-breathing rocket engine. It is a concept of a single stage rocket engine, curently in development by *Reactions Engines Limited*. The engine is to be mounted on the *Skylon spaceplane*, which would be able to fly as high as entering Earth's low orbit.

2 Subsystems

The SABRE rocket basically contains of 5 main subsystems.[1] These subsystems, as well as some other components can be found in Fig.1. Let's start from the nose and go back to the thrust chambers (from right to left).

- Air intake: The air intake is used to feed the engine with air. Its task is also to slow the speed of the air down to subsonic speeds. Its set to operated between Mach 0 and 5. If the speed is higher that that it will enter rocket mode.

- Pre-cooler: Air that travel in supersonic speeds, or even faster, becomes hot due to the compressibility effects. The pre-cooler is capable of transferring 400 MW of heat with less than 1 tonne of hardware.

- Compressor: It has a 2-stage axial compressor which is driven by a helium turbine. The pre-cooled air enter the compressor and get compressed to about 140 atmospheres before going to the rocket combustion chamber.

- Rocket engines: It uses a high performance LH2/LOX engine combined with other SABRE subsystems.

- Ramjet: The ramjet is the part at the back of the rocket around the nozzles. It is used to generate thrust during the acceleration with the use of air and evaporated hydrogen.

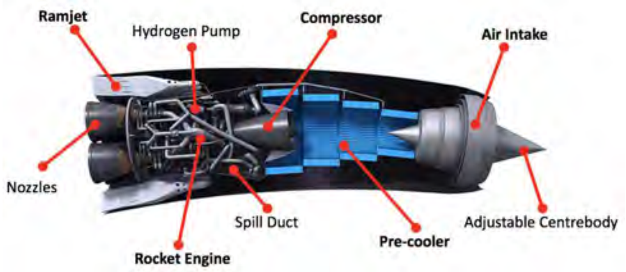

Fig. 1 . Showing a split view of the SABRE rocket and its subsystems/components (adapted from [2]).

3 Operation principle

The SABRE is a combined power cycles of rocket engine and jet engine. Initially it works as a regular jet engine by breathing air from the atmosphere and ignites the hydrogen fuel. As the altitude increases, the air gets too thin the engine switches its oxygen supply from on-board LOX tank then its works as a regular rocket engine with higher Mach number. When atmospheric air enters the SABRE the inlet of shock cone reduces the flow to subsonic speed due to this air temperature raises to very high because of compressibility effects. Then some of the air passes through pre-cooler and the remaining air goes to bypass of the engine. In the pre-cooler the air temperature reduces from 1000 °C to −150 °C in a 1/100th second without ice formation. This process is done by powerful heat ex-changer using helium as a coolant. The hot helium is cooled by a liquid hydrogen fuel in a heat exchanger and its heat energy is used to vaporize the hydrogen fuel. After passing through the pre-cooler the atmospheric air enters the high-pressure ratio turbo compressor there its pressure increases to 140atm and then it feeds into the combustion chamber of the engine. Unlike conventional jet engine the compressor runs by a turbine which is powered by a helium loop. The helium loop recycles the heat energy to power the turbine and liquid hydrogen pump thus increases the efficiency of the engine. After reaching higher altitude the engine switches to rocket mode by burning the hydrogen as a fuel and liquid oxygen as a oxidizer from the on-board tank. [3] [4] A schematic of the working process can be seen in Fig.2.

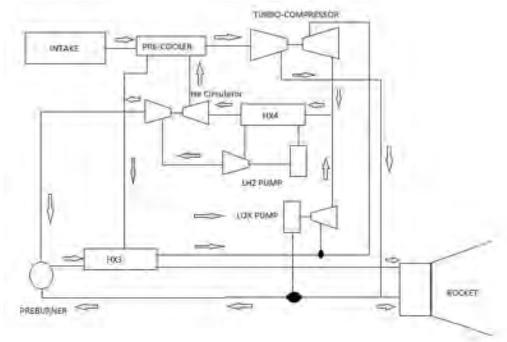

Fig. 2 . Box schematic of SABRE's working principle. (adapted from [3])

4 Comparison

With the intent of putting SABRE into context, the following aims to provide a comparison with current state of the art single-stage-to-orbit (SSTO) engines.

Nevertheless, this comparison is not without its flaws as, to date, no SSTO launches have been performed. The driver of this scarcity is intrinsic to the SSTO concept as the whole mass of the vehicle is put into orbit. This leads to vehicle dry mass minimization and engine efficiency being critical in SSTO design which in turn requires the highest level of technology available [5]. Therefore, the present analysis will be relegated to a mere theoretical standpoint.

Being the main proponent of the SSTO rocket engine family, liquid H_2/O_2 rockets attain high thrust/weight ratios compared to SABRE but lower specific impulse (i.e. efficiency). These characteristics encourage vertical take off and thus do not require lifting surfaces. Their single-stage nature does reduce the payload fraction significantly (near 1%), therefore multi-stage rockets are widely used [6]. However, the technology has been thoroughly researched and tested providing high levels of reliability as compared to SABRE.

Turborockets are part of the air-breathing family and are based on a multi-mode concept for different Mach conditions. Beginning from sea levels conditions, turbojets are used as in conventional aircraft. As thrust output is impaired above Mach = 3, the ramjet engine is operated which uses a compressor-less geometry to compress the incoming flow. Nevertheless, as flow is slowed at the combustion chamber to perform subsonic combustion, at about Mach = 6 efficiency drops and so the scramjet is employed. In this transition a new engine per se is not used but rather the geometry of the ramjet is reconfigured to allow for supersonic combustion. Finally, although the scramjet could reach scape velocity, above Mach = 15 efficiency is hindered and thus it has been proposed to use rocket power to finalize the climb [7]. The obvious flaw in this design is that off regime engines generate an overall low thrust/weight ratio as compared to SABRE.

Finally, compared to current launcher vehicles, SABRE offers to reduce maintenance and other reoccurring costs yet the high technological requirements are currently driving development costs up excessively. It will remain to be seen whether or not the benefits of SABRE and other SSTO vehicles can outweigh the comparatively low costs that economies of scale produce for expendable multi-phase launchers.

5 Conclusion

The technology behind this type of engine cooling is a breakthrough in the aviation industry. The engine itself is capable of drastically lowering the price of space travel and thus changing the aerospace industry completely. But for now the future stands in the hands of the engineers from *Reactions Engines Limited*.

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REFERENCES

[1] Reactionengines. *Synergetic Air-Breathing Rocket Engine*. Reactionengines [Internet], 2017.

[2] SAE International. *BAE Systems reacts to Reaction Engines' SABRE with collaboration*. SAE International [Internet], 2015.

[3] Aggarwal Rupesh S P and Co. *SABRE ENGINE: Single Stage to Orbit Rocket Engine*. International Journal of Innovative Research in Science, Engineering and Technology [Internet], 2015.

[4] Jesse E. *REL's Skylon spaceplane aims to take on SpaceX with a reusable rocket design*. The Verve [Internet], 2016.

[5] Bentley, Matthew A. *Spaceplanes: From Airport to Spaceport*. Springer [Internet], 2009.

[6] Dick S and Lannius R. *Critical Issues in the History of Spaceflight*. NASA Publication [Internet], 2006.

[7] R V and A B. *A Comparison of Propulsion Concepts for SSTO Reusable Launchers*. 2003.