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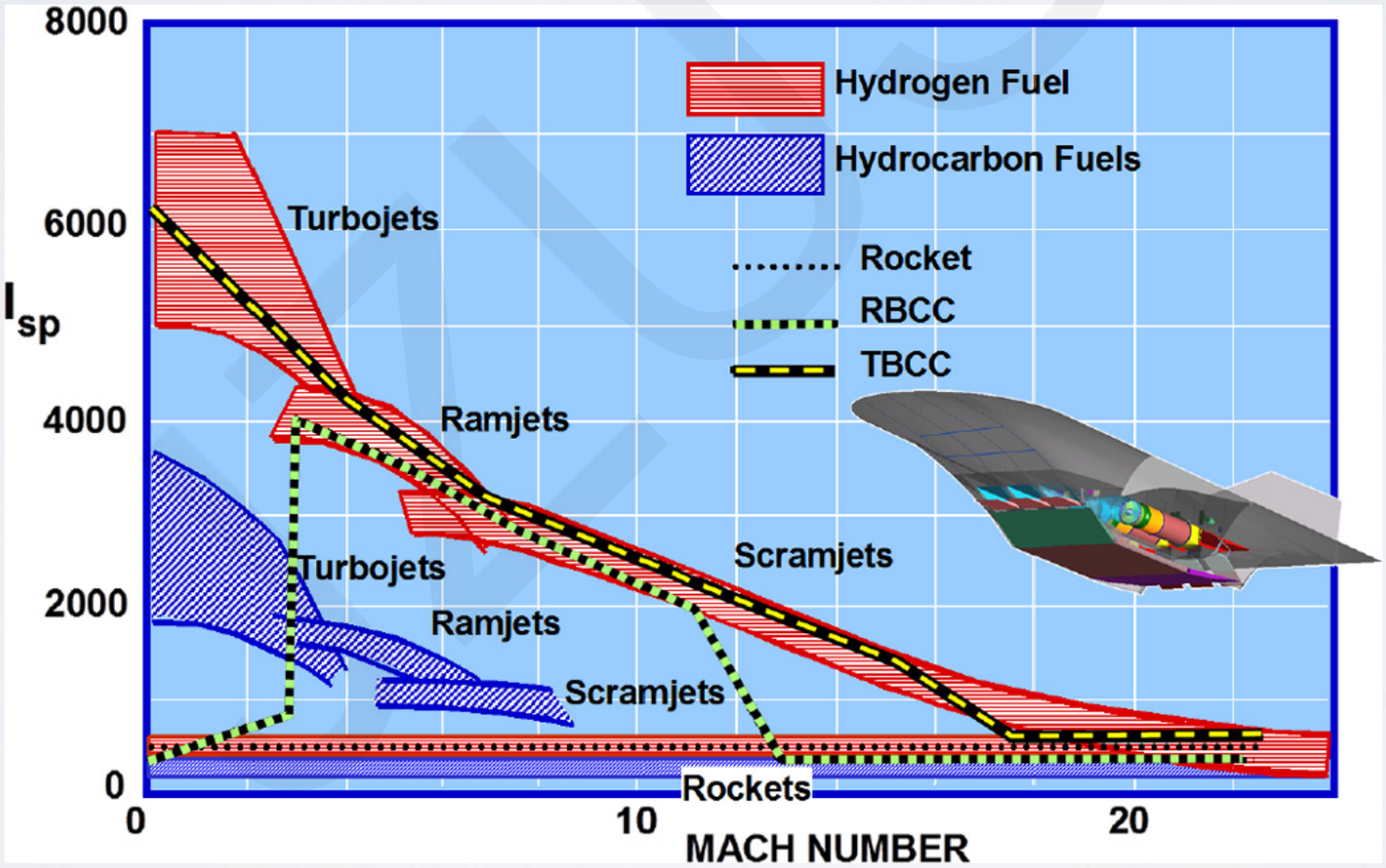
The overall layout of rocket-based combined-cycle engines: a review

Key words:
Rocket-based combined cycle (RBCC) engine;
Single stage to orbit;
Space round trip;
Engine-airframe integration

Introduction

Rocket-based combined-cycle (RBCC) engines are known as the most promising type of engine with the potential to realize ‘single stage to orbit’ (SSTO). The mode transition cycles make it possible to work effectively in different speed and altitude.

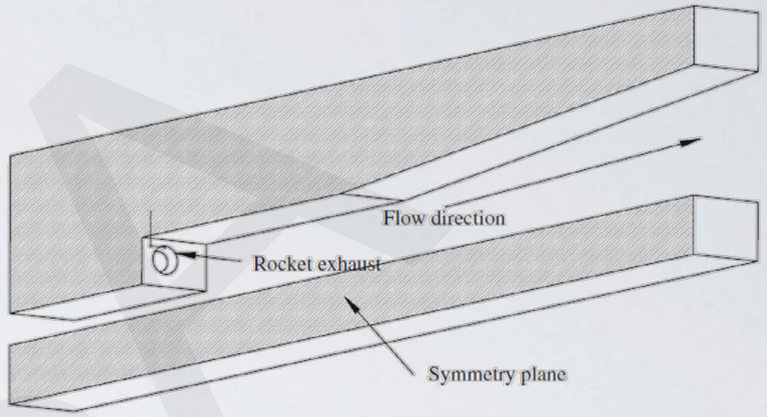


Comparison of Specific impulse versus Mach number among different engine systems

Configuration classification of RBCC engines

- RBCC
  - rectangular section
    - Backward step
    - Strut
  - axisymmetric
    - Conical rocket
    - Annular rocket

[1]



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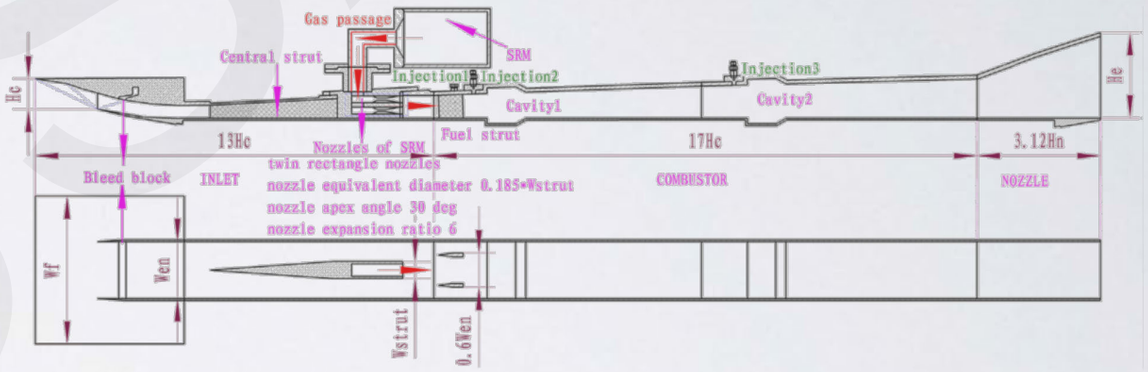
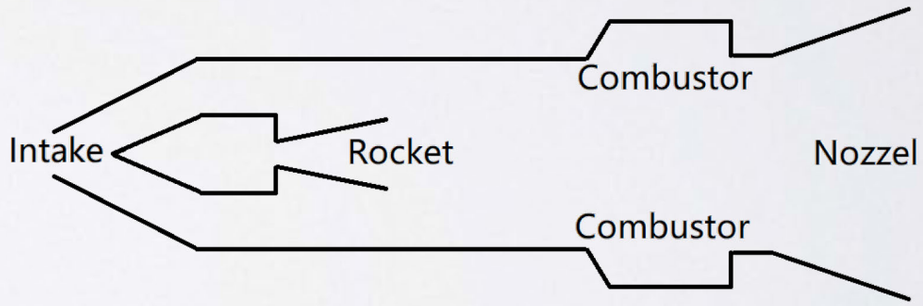
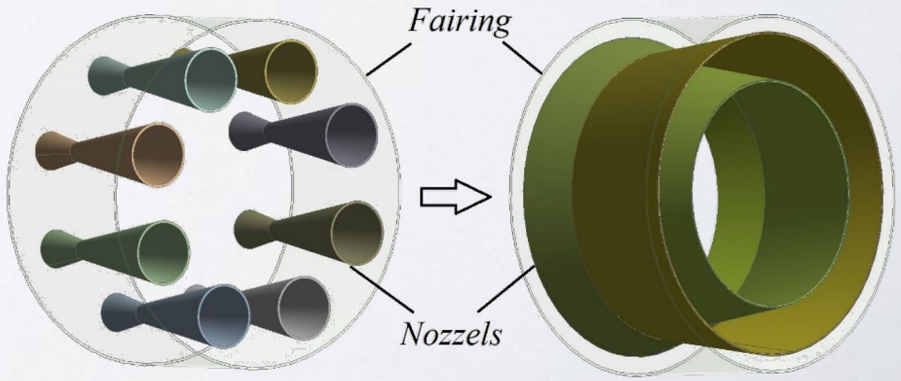




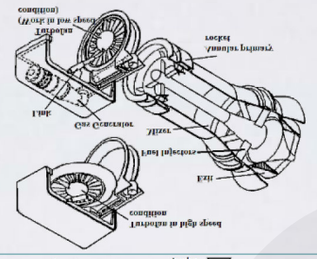
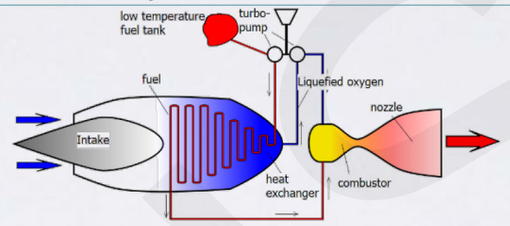
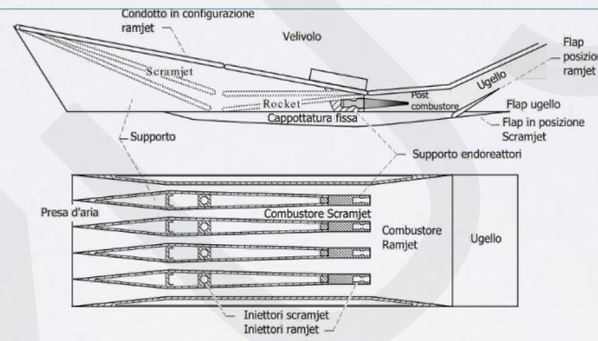
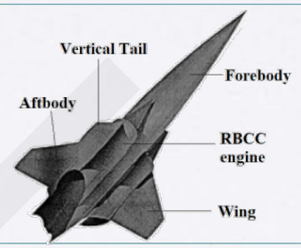
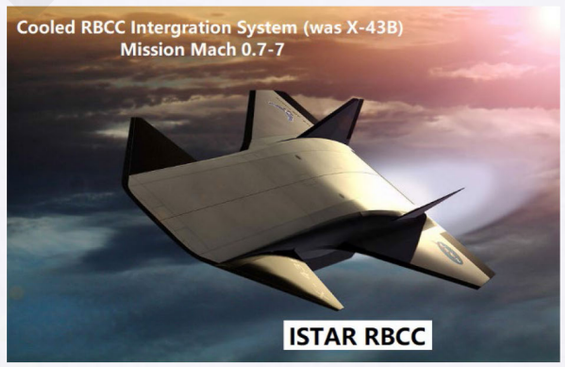


Multiple bell nozzels **Annular nozzel**

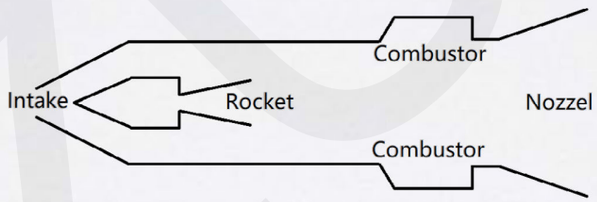
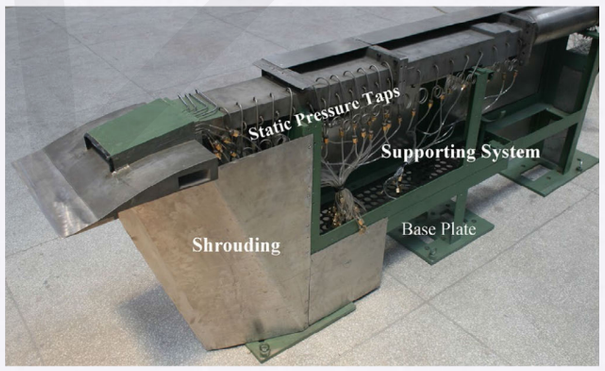
[1]Etele, J et al. (2014) *Journal of Propulsion & Power*. **30**(4):944-951.

[2]Shi, L et al. (2016). *Acta Astronautica*. **128**:350-362.

Rectangular section RBCC engines

Nation	Research unit	Project	Schematic	Fuel	Development
USA	Marquardt Co., Rocketdyne Co., Lockheed-California Co.	SERJ[3]		LH2/O2, JP/H_2O_2	Subscale engine ground test; Terminated during late 1960s
		Scram-LACE		LH2/O2	Conceptual design; Testbed system available; Terminated during late 1960s
	Aerojet Co., Lewis Co., US Air Force, GASL, Lockheed-Martin Co.	Strutjet		LH2/O2	Ground test; Modular test; Feasibility of Strutjet is proved.
	Green Research Centre	GTX[4]		LH2/O2	Quasi-1D analysis; Numerical analysis,
	NASA, American Air Force	ISTAR		JP27/ H2O2	Mission planed, Direct-Connect Combustor Experiment (full scale thruster injector test, fuel characterization, subscale inlet test); Mission terminated around 2003; X-43B developed based on ISTAR

Rectangular section RBCC engines

Nation	Research unit	Project	Schematic	Fuel	Development
Japan	JAXA	E3[5]		LH2/O2	Numerical simulation, Modular design, Ground test (ejector configuration, combustor), MDO of RBCC powered TSTO vehicle
Canada	Carlton University	Exchange inlet		–	Parametric design; Performance analysis coding, configuration optimization analysis; Eject performance validation
Italy	Politecnico di Torino	Ejector-ram-rocket (ERR)		LH2/O2	Quasi-1D analysis; Multi-objective optimization
China	Northwestern Polytechnical University	NWPU RBCC[6]		JP-10	Quasi-1D analysis; Numerical investigation; Ejector, ramjet/scramjet ground test (direct connect combustor experiment, free-jet tests) MDO of RBCC powered TSTO vehicle

[3]Olds, J.R. and Bradford, J.E., (2001) *Journal of Propulsion & Power*. **17**(2):333-339.

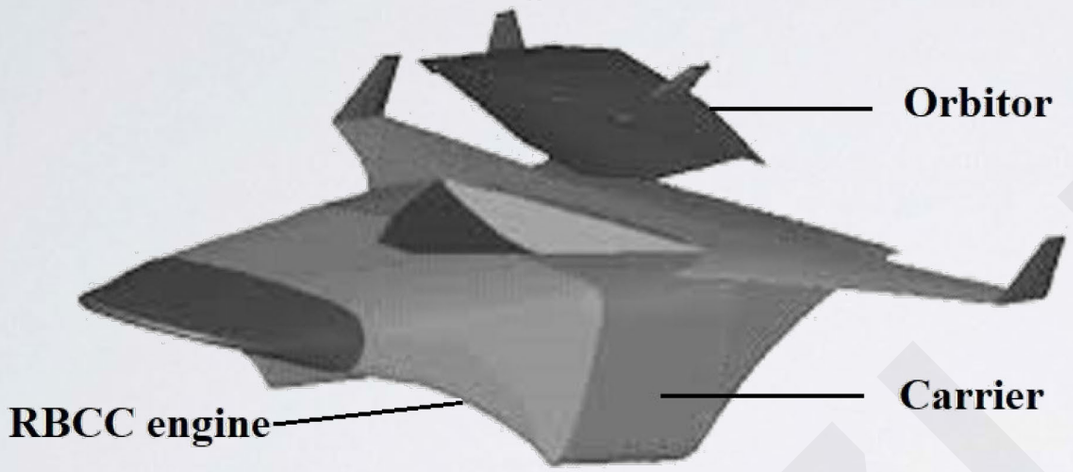
[4]Yungster S and Trefny CJ, (1999) *Proceedings of the 35th Joint Propulsion Conference and Exhibit*, Article No. 2393.

[5]Kanda T, et al., (2005) *JAXA Re-search & Development Report*, 6:1-15.

[6]Shi, L et al. (2016). *Acta Astronautica*. 128:350-362.

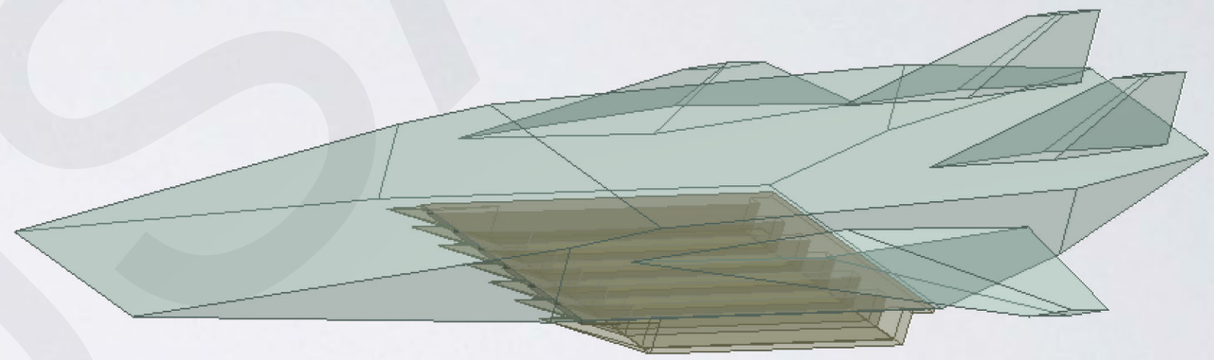
RBCC powered aircraft system

Two-stage-to-orbit (TSTO)



The TSTO configuration has two parts: a carrier for the RBCC engine and an orbiter powered by rockets[7].

Single-stage-to-orbit (SSTO)



The SSTO configuration has a highly integrated airframe-engine system. The RBCC engine can work in eject mode, ramjet mode, scramjet mode and the pure rocket mode[8].

[7]Kanda T, et al., (2007) *Journal of Propulsion and Power*, 23(2):301-309.

[8]Olds JR and Lee H, (1996). *Proceedings of the 6th Symposium on Multidisciplinary Analysis and Optimization.*

The obstacles and benefits of RBCC research

The project of making RBCC engines a practical reality faces several difficult obstacles. For example:

- increasing thrust gain in eject mode
- realizing smooth transition among working modes
- propulsion/airframe integration design, and thermal protection design.

Therefore, it is not easy to generate a practical RBCC engine powered aircraft. However, research on RBCC engine techniques will greatly benefit the related disciplines and the payoff for future space round trips makes work on RBCC engines worth-while.