Space Shuttle Main Engine: fuel and tank analysis

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Acronyms

LCH_4 liquid methane. 3

LH_2 liquid hydrogen. 3

LO_2 liquid oxygen. 3

ET external tank. 3

HPTP high pressure turbopump. 3

ISS International Space Station. 3

LPTP low pressure turbopump. 3

NASA National Aeronautics and Space Administration. 3

SRB Solid Rocket Boosters. 3

SSME Space Shuttle Main Engine. 3

STS Space Transportation System. 3

1 Introduction

Space exploration represents one of the most fascinating and complex frontiers of contemporary science and technology. At the heart of this field is the Space Transportation System (STS), commonly known as the Space Shuttle launch system, which played a fundamental role in the development of human capabilities to explore and utilize space. Operated by NASA from 1981 to 2011, the Space Shuttle was the first reusable space transportation system, an innovative orbital vehicle that combined the characteristics of a rocket and an airplane. The Space Shuttle program enabled numerous scientific and technical missions, including the launch of satellites, the construction, maintenance of the International Space Station (ISS) and a variety of scientific experiments in orbit. This vehicle allowed astronauts and payloads to be transported into space and returned to Earth, marking a turning point in the history of astronautics.

The launch system consists of three RS-25 (SSME) and two additional Solid Rocket Boosters (SRB). The Space Shuttle Main Engine (SSME) was one of the most advanced and crucial technological elements of the STS. The SSMEs were the primary rocket engines, propelled by liquid hydrogen (LH_2) and liquid oxygen (LO_2), providing the necessary thrust for the Shuttle's liftoff and initial ascent to low Earth orbit. These engines were known for their efficiency and reliability, being able to operate under extreme conditions and be reused for multiple launches.

The purpose of this report is to initially size the real Space Shuttle Main Engine (SSME) and then, based on the total impulse and burning time of this engine, to resize the engine while changing the fuel from liquid hydrogen to liquid methane (LCH_4). This analysis anticipates a simplification of the system components and a reduction in the mass of the external tank (ET) given that methane has a much higher density than hydrogen. Additionally, the storage temperature of methane is very similar to that of oxygen, which could help avoid issues related to thermal exchange between the fuel and oxidizer tanks. The path followed in this report involved taking upstream and downstream pressures of each component, the inlet temperatures to the various components, and the mass flow rates of the fuel and oxidizer. Using these parameters, the turbopumps, injectors, combustion chamber, nozzle, and external tank were appropriately sized through MATLAB. For the engine's performance analysis, NASA's CEA software was utilized. Subsequently, by observing these performances and using the burning time, O/F ratio, total engine impulse, and combustion chamber pressure as starting points, the engine was resized for the new fuel LCH_4 by working backward from these parameters.

2 SSME original fuel analysis

As stated in section 1 the original SSME cycle uses liquid hydrogen and liquid oxygen. After being withdrawn from the external tank (ET) both the fuel and the oxidizer go through a low pressure turbopump (LPTP), a high pressure turbopump (HPTP) and a preburner before meeting in the combustion chamber. What follows is an analysis of every turbomachine of the cycle. Figure 1 is missing some components, such as the pogo oscillation suppression system accumulator, mounted before the oxidizer HPTP. However this goes beyond the

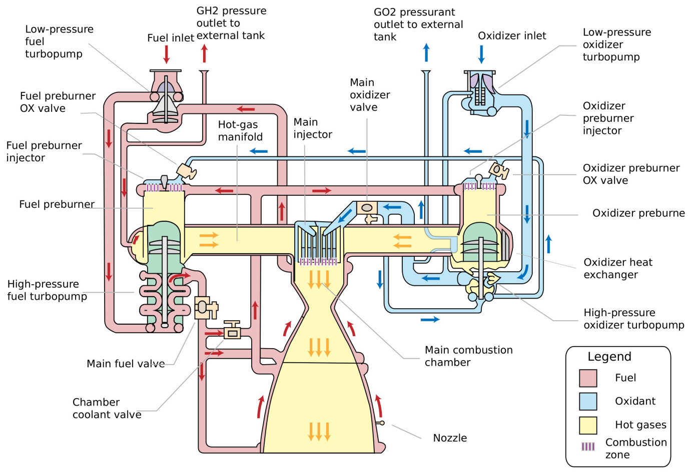

Figure 1: A functional diagram showing the flow of propellant through an RS-25 engine.

scope of our analysis and will be disregarded.