N95- 70877

Orbital Maneuvering and Reaction Control Systems

Eric Hurlbert
Propulsion and Power Division
NASA - Johnson Space Center

Orbital maneuvering systems (OMS) and reaction control systems (RCS) provide capabilities to spacecraft that include orbit circularization, rendezvous maneuvers, attitude control, and re-entry delta velocity. The mission and vehicle requirements can place severe demands on the orbital maneuvering and reaction control systems. In order to perform proper trade studies and to design these systems, the mission and vehicle configuration must be well defined. In the absence of a clearly defined mission and vehicle configuration, the research and development of basic technologies must support future design efforts by providing a range of options and data from which to select. This paper describes the key OMS and RCS requirements and technology.

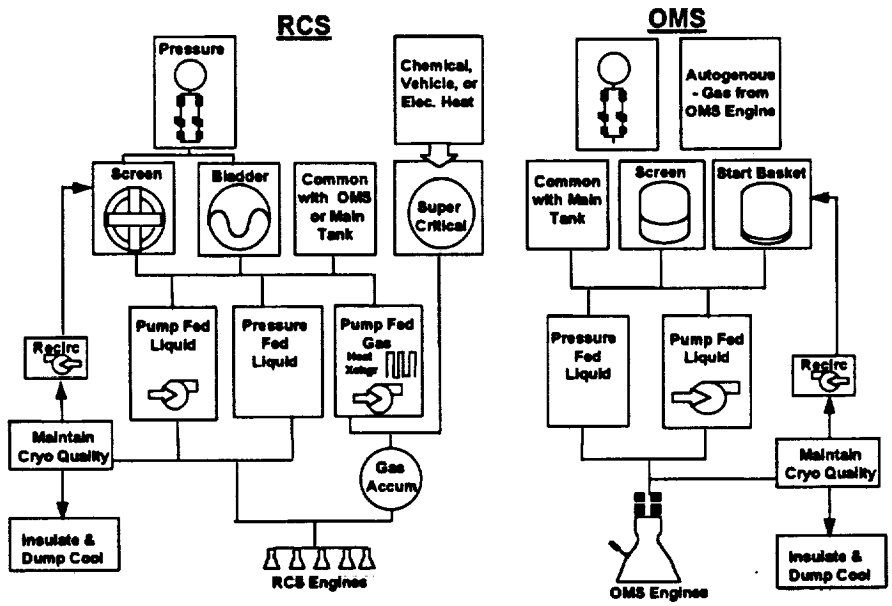

Figure 1 Design Options for OMS and RCS

In general, the mission of a spacecraft may include delivering payloads to orbit, transporting humans to orbit, providing a platform for research, landing material on the moon, or exploring the solar system. Each of these missions places unique requirements on OMS and RCS that must be fully understood.

In the case of the space shuttle, its mission is to deliver payloads and humans to orbit, to provide an orbiting platform for research and observation, and to assemble a space station. The space shuttle consists of a reusable winged orbiter, expendable tanks, and reusable boosters. Given this mission and vehicle, storable propellants were found to be optimum. Both Apollo and the space shuttle use storable propellants, which have provided 100% mission reliability. Key technology developments were engine life, combustion stability, and material compatibility.

Key Requirements

The requirements for the OMS and RCS are essentially derived from the shuttle mission and the vehicle configuration. The following is a list of key design drivers for OMS and RCS systems.

Ascent to Orbit Duty Cycle - The ascent duty cycle includes critical spacecraft maneuvers during ascent or aborts. For example, the shuttle requires the RCS to provide roll control in the event 2 SSME's are out. The shuttle also requires the RCS to quickly maneuver the shuttle away from the external tank duration separation to prevent recontact. This requires a system with 870 lbf thrusters. Key future technology developments are dual mode or thrust engines which perform high thrust maneuvers as well as low thrust docking maneuvers.

Duty Cycle On Orbit - This includes total burn duration, total number of pulses, and the duration on orbit. The Shuttle RCS has a total life of 20,000 seconds and a cycle life of 20,000 pulses. The duration on orbit can range from hours to years. The space shuttle duration is about 15 days. During this period the RCS is continuously active for attitude control, thermal control, rendezvous, and debris avoidance. For simplicity, this drives the RCS and OMS design to either have a gas or an ambient liquid in the feedlines. If the propellant is allowed to become two-phase, either a recirculation pump or a propellant dump is probably required prior to engine start. The shuttle uses storable liquids and avoids any complications. Key technologies for future vehicles, with on orbit duration greater than hours, include supercritical storage and delivery of gaseous oxygen, subcritical liquid-to-gas propellant (i.e. LH_2) feed systems, and testing of ambient hydrocarbon or alcohol fuels for RCS applications.

Entry Duty Cycle Requirements - A reusable vehicle requires RCS until aerosurfaces become effective. This can require a large amount of propellant in a short period of time. The shuttle uses 1100 lbm or more of propellant in 30 minutes. This can be significant in designing systems that utilize gaseous propellant in terms of accumulator sizing, supercritical tank heat addition, and liquid-to-gas conversion heat exchangers and pumps.

Redundancy Requirements - This defines the number of thrusters required and can significantly complicate systems. In the case of the shuttle, the RCS is used to back up the OMS engines, which requires an 800 second burn duration for the aft facing RCS engines. In total there are 38 primary and 6 vernier RCS thrusters. Future vehicles programs may select to avoid this complication of RCS back-up, however some redundancy is required due to the value of human life and payload. Key technologies to reduce the number of thrusters may be dual mode or thrust engines, which allow combination of duties.

Total Impulse and Mass Requirements - As the total impulse requirement increases, the necessity for a higher total system performance increases. The shuttle OMS engine at a specific impulse of 315 seconds at 55:1 expansion is reneratively cooled. Future vehicles may require higher performance to meet total impulse and vehicle mass requirements. Key technologies are higher system performance propellants, high temperature chamber materials, advanced cooling techniques, and efficient combustor designs.

Packaging or Volume Constraints - The size of the system can be critical as payload space or aerodynamic drag considerations compete with the OMS and RCS design. The propellants, N2O4 and MMH, reduce system volume in the externally mounted pods on the space shuttle. Key future technologies areas include high density propellants oxidizers such as liquid oxygen and hydrogen peroxide, and the fuels such as RP1, alcohol, and other hydrocarbons.

Ground Operations - While not as significant in ground operation requirements as main propulsion, an OMS and RCS design is driven to the use of non-toxic, non-flammable, non-explosive, low leakage, ambient propellants in a long life, simple, low maintenance system. The shuttle system, while simple, uses the toxic propellants MMH and N2O4. Key future technology areas are low toxicity propellants such as liquid oxygen, hydrogen peroxide, RP1, and alcohol.

Zero-G Acquisition - The RCS tanks are required to provide acquisition of propellants and venting of gases under zero-G conditions. The shuttle RCS tank uses screens positioned 360 degrees around the tank, that remain wetted by surface tension forces. Storable propellants do not require venting. Key future technologies are supercritical storage tanks and zero-g vent systems.

Reliability - Reliability is a function of the number of components and the complexity of those components. The shuttle uses a pressure fed system with hypergolic ignition. Key future technology areas are supercritical propellant storage for a pressure fed system, reliable non-hypergolic ignition, and testing of ambient hydrocarbon fuels for OMS/RCS.

Cost and Schedule - Cost and schedule includes both DDTE and Operations. The three most important questions are does it meet the mission, how much does it cost, and what is the schedule. These issues are directly tied to complexity and technology readiness. Key future technologies, that will end up being used, are those that can answer these three questions.

Trade Study Selection Criteria For Future OMS and RCS System

The selection criteria must include all program considerations and be as quantitative as possible. Figure 2 lists a hierarchy of attributes that can weighted against each other to allow comparison of various design options. Details on each design option such as mass, volume, number of components, number of measurement instruments, toxicity, technology readiness, etc. need to be accumulated from schematics and design analysis. One possible method for comparing the options, once all the design details have been determined, is the Analytic Hierarchy Process (AHP). Relative weights between the high level attributes should be chosen by the program managers.

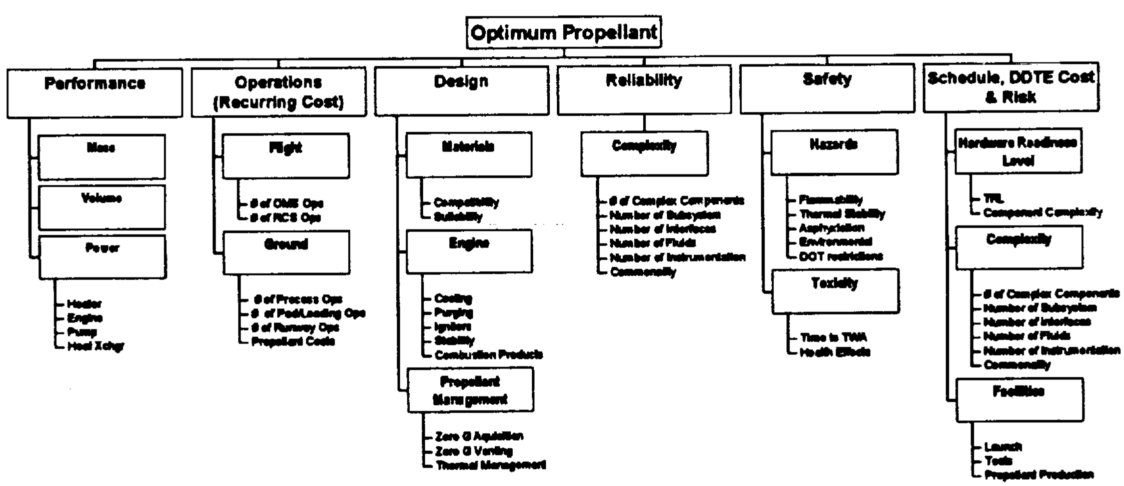

Figure 2. Hierarchy For Selection Propellant for OMS and RCS

Summary of Key Technologies

A chart showing the key future OMS and RCS system technologies is shown in figure 3. The chart decomposes the components of an OMS and RCS System into technology development areas. The chart also indicates where the developments would be applicable.

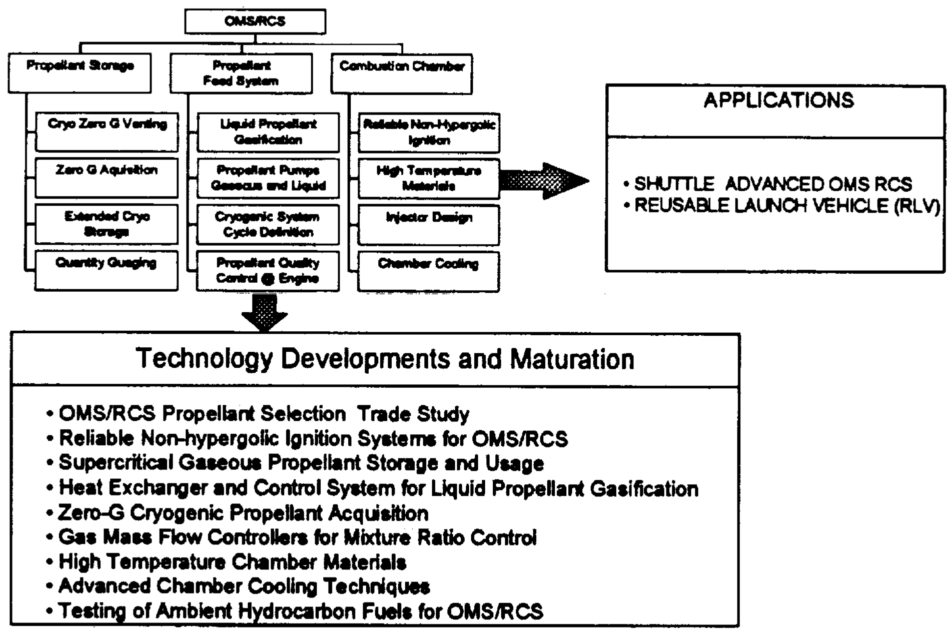

Figure 3. Technology Development Areas

Conclusion

Storable propellants have provided reliable propulsion for Apollo and Space Shuttle programs, with the major technology developments being engine chamber life, combustion stability, and material compatibility. For future OMS and RCS systems, the goal is to reduce toxicity and ground operations, but not at the expense of simplicity, reliability, and cost. To meet the future needs, new technologies are required. Detailed trade studies using well defined vehicle requirements are needed to provide a basis for sound decisions.