Memo on general design topics for propulsion sub-systems (from general bibliography)

Functions

a. The propulsion system shall provide the total impulse, minimum impulse bit, thrust levels and torques required by the AOCS.

b. The following aspects shall be defined:

1. Thruster firing modes

   NOTE For example: steady state, off-modulation, pulse mode.

2. Thrust level and orientation
3. Thrust-vector control
4. Thrust centroid time
5. Minimum impulse bit
6. Impulse reproducibility
7. Total impulse
8. Cycle life
9. Mission life
10. Reliability level
11. Thrust noise
12. Propellant gauging.

c. The propulsion system shall fulfil its functions while subjected to the specified external loads during its mission, including:

1. mechanical loads;

   NOTE For example: quasi-static loads, vibrations, transportation.

2. thermal loads;
3. electrical loads.

Constraints

Accelerations

a. Limits on acceleration levels, induced or experienced by the propulsion system, shall be specified at spacecraft level.

NOTE This is in order to:

- avoid perturbations, e.g. during possible observations or experiments;
- protect sensitive equipments;
- design adequate tank PMD.

Pressure vessels and pressurized components

a. Support structures of pressure vessels and pressurized components shall allow deformations of the vessels due to pressure or temperature changes and cycles to occur without causing stresses that exceed acceptable limits.

Induced and environmental temperatures

a. The non-operating and operating temperature limitations of the propulsion system shall be specified.

Thermal fluxes

a. Thruster surroundings shall conform to the radiative and conductive heat fluxes rejected by the thrusters.

Thruster plume effects

a. Elements of the spacecraft sensitive to plume effects shall be identified.

b. The allowed plume effects on elements identified shall be specified at spacecraft level.

c. The generation of perturbing torques, forces, thermal gradients, contamination and erosion of surfaces, due to plume effects, shall be defined and documented accordingly.

d. The plume analysis specified shall be reported in conformance with the Plume analysis report.

Interfaces

a. The liquid propulsion system shall conform to its specified spacecraft interfaces, including:

1. Structure

   NOTE For example: inserts, tank support structure and vibration levels.

2. Thermal

   NOTE For example: conduction, radiation levels, tank, thruster and line thermal control.

3. Power

   NOTE For example: valve drivers, pressure transducers, thermistors, heaters and thermocouples.

4. Electromagnetic compatibility

5. Pyrotechnics

   NOTE For example: pyrotechnic valves.

6. Mechanisms

   NOTE For example: valves, regulators, actuators and actuation system.

7. AOCS, OBDH and TM/TC.

   NOTE For example: commanding, handling of data for status and health monitoring and failure detection.

b. Interfaces shall be defined:

1. For ground tests and loading activities, with the propulsion GSE.

2. For safety and prelaunch operation with the launcher authorities.

Design

General

Architecture

a. The propulsion system architecture shall apply the requirements of dependability.

b. The propulsion system architecture shall provide evidence that fail safe, redundancy, reliability and safety requirements are met.

Replacement of parts

a. For replacement of parts during development, testing and mission life pre-launch activities

The propulsion system lay-out shall allow the replacement of subsystems

The propulsion system lay-out should allow the replacement of components.

Parts identified as critical shall be made replaceable.

Water-hammer effect

a. A water-hammer effects analysis shall be performed to support the propulsion system design and ensure proper functioning:

- transient operations of a propulsion system or subsystem e.g. ignition, chill-down, shut-down, effects of valve opening and closing
- water-hammer effect,
- adiabatic compression,
- cross-talk between thrusters,
- system priming

b. The analysis specified clause here above shall be reported in conformance with the Propulsion transient analysis report requirements.

Piping

a. A pipework design analysis shall be performed including non-consumables, cross-coupling, leakage, pressure, eigenfrequencies, water-hammer.

b. The consequences in terms of operational restrictions shall be identified.

Closed volumes

a. The design of the propulsion system shall prevent hazardous pressure increase in closed volumes.

b. The need for any pressure relief capability shall be identified and analysed.

Pressure vessels and pressurized components

a. The design of pressure vessels and pressurized components shall:

1. Apply margins and factors of safety (FOS) for proof, burst and component life cycle.

   NOTE See Structural design and verification of pressurized hardware.

2. Conform to the environmental aspects, including but not limited to:

   (a) Temperature

   (b) Vibration

   (c) Humidity

   (d) Corrosive environment

   (e) Vacuum

   (f) Outgassing

   (g) Radiation.

Multi-tanks

a. If a multi-tank layout is used, inadvertent propellant transfer between tanks shall be prevented by design.

b. If PMD tanks are being used, the consequences of selecting parallel or series connections shall be analysed.

Cycles

a. The system and its components shall be designed for the expected number of cycles during the whole mission life, for both on-ground and in-service operation.

Selection

Reporting

a. The reporting shall be done in the DJF in conformance with system engineering implementation requirements for space systems.

General

a. The selection shall be based on trade-off analyses of:

1. The propulsion system.

   NOTE For example: monopropellant, bipropellant, or cold gas.

2. The operating mode.

   NOTE For example: pressure regulated and blow-down.

b. Selected materials, propellants and test fluids shall be compatible for all components.

NOTE Compatibility includes:

- dissolution;
- chemical reaction;
- erosion;
- corrosion.

Propellant selection

General

a. The criteria to be used for propellant selection shall include:

1. Mission requirements
2. Resulting layout of the propulsion system
3. Availability of off-the-shelf components
4. Experience
5. Compatibility and contamination
6. Performance.

b. The propellant shall be defined and specified including:

1. Chemical composition
2. Purity
3. Cleanliness.

Propellant for Thruster qualification

a. Thruster qualification firing tests shall use the same propellant grade as the one selected for flight.

Sizing

a. The sizing process shall begin with a definition of the life phases of each subsystem or component, including at least:

1. Pressure cycles combined with temperature cycles
2. Propellant, pressurant and leakage budgets
3. Establishment of the operational envelope

4. Minimum and maximum electrical supply voltages
5. Interfaces with GSE functions
6. Evolution of the operational conditions.

b. The sizing process shall demonstrate margins based on:

1. Safety
2. Reliability requirements established by the customer
3. Industry and launch authorities, or agencies operational constraints
4. Thruster performance efficiency
5. Plume effects
6. Modelling errors and uncertainties.

c. Pressurant, propellant and contaminants budgets shall include:

1. Their impact on lifetime
2. Variation of performance during lifetime
3. Quantity for deorbiting
4. Residuals.

d. During sizing process FMECA shall be performed.

NOTE 1 The sizing is an iterative process between the propulsion system definition, the FMECA results, the performances, the reliability, the safety, the schedule, and the project risk and cost requirements.

Design development

General

a. The development shall allow for an incremental verification at component or block level, if a fully representative functional test (i.e. hot firing and gravity-dependent functions) cannot be performed after the integration of the system components on the spacecraft.

b. If the flight version of the system is divided into independent blocks, they should be separated by safety barriers such as pyrovalves, latch valves or burst membranes.

Development tests

a. Development tests of each block should be defined to represent the conditions foreseen during the operation of the complete system.

b. At least the following characteristics of the propellant feed system shall be determined by hydraulic tests:

1. mass flow rate;
2. dynamic and static pressure;
3. temperature;
4. response time.

c. The testability at integrated spacecraft level and the ability to return after test to safe and clean conditions shall be demonstrated for each of the system blocks.

d. Design and procedures shall be defined according to clause here above c.

Contamination

External contamination

a. The thruster design, layout and orientation should prevent contaminant deposition on elements sensitive to contamination identified in clause constrains above.

NOTE Contaminants deposition on sensitive elements, such as solar panels, star trackers, and optics, depends on the propellants used, the thruster characteristics, the layout of the propulsion system, the thruster orientation and the thruster duty cycle.

b. The potential hazard of contamination and the expected level of contamination due to thruster exhaust shall be included in the plume analysis.

NOTE See clause constrains above.

Internal contamination

a. The propulsion system shall be designed to avoid the effects of internal contaminants, including propellant vapours, by:

1. Preventing intrusion, internal generation and circulation of contaminants.
2. Preventing or controlling accumulation of contaminants throughout the various parts of the system.
3. Preventing accumulation of contaminants during the various steps of production, verification and operation of the system.

NOTE 1 The presence of contaminants inside the propulsion system can lead to the loss of performance of some components or even to catastrophic failures.

NOTE 2 For example, propellant vapours can be considered as contaminants in a pressurisation system.

b. The expected maximum level of contaminants inside the propulsion system shall be specified.

c. The propulsion system design shall conform to the expected maximum level of contaminants.

Draining

a. The system design shall allow for on-ground draining.

b. The location of fill-and-drain valves and piping layout shall:

1. Prevent trapping of liquid in the system by on-ground draining.
2. Prevent contact between dissimilar fluids.
3. Allow purging of the system after draining.

Risk of explosion

a. For hydrazine and other monopropellants, adiabatic compression of vapours, hot spots or undesired contact with a catalyst material shall be avoided.

b. Propellant explosions, leakage of propellant and propellant vapours shall be prevented.

c. Item clause above b shall be supported by analysis, simulation, or testing or all of them.

d. The propulsion system design shall ensure elimination of undesired mixtures, migration or leakage of propellant and propellant vapours, and condensation of fuel.

e. The propulsion system requirements shall specify operation under conditions different from operational conditions, such as ground tests.