**SEE REFERENCE LITERATURE**

# Functional Analysis

Introduction of functions that sys must perform

* ADS functions
* ACS functions
* GNC functions

Difference between probe and orbiter

* Probe is limited to EDL only
* Orbiter primarily for on-station life

# Requirements

* Summary of requirements from baseline
* Update TBDs here
* Indicate if new requirements are added/ discovered
  + Maneuver rates
  + Slew maneuvers

# Calculations and model

**Functional results**:

* Note: Actions based on heritage (MSL/ phoenix for entry, MRO for orbiter)
* GNC process [Elements…]
  + sense data with IMU,
  + create estimation
  + transmit to earth
  + receive ephemeris data
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  + Use stored momentum to passively counter torques
  + Use additional momentum for maneuvers
  + Periodic momentum desaturation
  + Thrusters for high-rate maneuvers/ desaturation

**Design process/results**:

* Process
  + Name key steps of this design phase (discussed later)
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      * Control modes result
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    - Disturbance Torques
      * Parametric python model
    - Hardware Selection
      * Parametric python model
    - Budgets
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  + Steps for later design phases
    - Control logic
    - Refined inputs
* ACS Type (3-axis stable, RWs)
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  + Cyclic vs Secular
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* Budget summary
  + Final results
* Model Limitations:
  + LOD that of SMAD/ Elements (first order sizing)
  + Limited knowledge of required maneuvers and s/c geometry
  + Based on worst-case scenarios

# Risk

Consequences:

* Power loss
* Communication failure
* Mission failure

Mitigation:

* Based on heritage standard practices
* Critical components at least once redundant
* All critical maneuvers can be performed with both reaction wheels and thrusters
* Reaction wheels greater than minimum to use off-the-shelf components
* Flight proven hardware:
  + MIMU
  + RW
  + Star Trackers
* Sizing based on worst-case conditions

# V&V

* All functions verified independently
* Validated with FireSat mission design described in SMAD
  + Different input parameters
  + Output identical

# Compliance matrix

Table of requirements that are met

# Recommendations

Refinement of model:

* Better geometry data when available
* Larger hardware selection
* More specific requirements
  + Sensor accuracy -- > better sensor selection
  + Jitter + Settling Time -> exact thruster design
* Control Law definition

BODY TEXT

The Attitude and Orbit Control System (AOCS) consists of two primary sub-systems. The Attitude Control System (ACS) ensures that the spacecraft remains oriented in the proper direction, as defined by mission and sub-system requirements. The Orbital Control System (OCS) is responsible for determining the spacecraft's position and controlling manoeuvres to change its orbit. These changes may originate from station-keeping requirements or mission objectives. \cite{techreport:midterm2020} The following design is a first-order sizing of the most critical AOCS components. The mass, power and volume estimates driven by the specific hardware selection contribute to the overall design of the spacecraft.

# Functional Analysis

Introduction of functions that sys must perform

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* GNC functions

Difference between probe and orbiter

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* Orbiter primarily for on-station life

The MarsReveal mission has two applications of the AOCS: aboard the orbiter and on each of the probes. For each probes it is responsible for pointing during the de-orbit burn, and to maintain proper attitude during the entry, descent and landing phases. The control method here of is determined using heritage and trajectory requirements. Concerning the orbiter, the AOCS is responsible for keeping a specified pointing direction throughout all phases of the mission. During the nominal operation of the orbiter, when in a circular orbit around mars, one face containing the UHF antenna must always be nadir pointing. Any disturbing torques on the orbiter must therefore be accounted for to prevent pointing deviations.

The AOCS is a closely integrated system that must autonomously monitor the spacecraft and perform corrective manoeuvres where necessary. The attitude determination system consists primarily of sensors that generate an estimate of the spacecraft’s attitude and position. The attitude control system (ACS) is designed to handle the torques and momentum acting on the spacecraft throughout its operational phase. For the orbiter this is calculated per orbit, while for the probe it mainly concerns the torques caused by the aerodynamics during re-entry. Each of these sensors has imperfections resulting in overall inaccuracies. To account for this, as well as

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# Calculations and model

The AOCS sizing process for the orbiter is based primarily on its nominal mission phase, where it would function as a communications relay in a circular Martian orbit. The orbiter would not be subjected to large slewing requirements, but would need to maintain a reliable nadir pointing throughout the orbit. Due to pointing accuracy requirements along each of its axes, a 3-axis stabilised system is selected for the orbiter. This design choice is reinforced by performance tables found in SMAD, as well as previous similar missions such as the Mars Reconnaissance Orbiter (MRO). The lack of slewing requirements allows the system to utilize momentum wheels for primary attitude control. Attitude control thrusters are also included for possible exceptional high-rate slewing manoeuvres, and for periodic momentum wheel desaturation.

For the probe, the AOCS is only active during the EDL phase. It must perform accurate pointing for the de-orbit burn, and attitude control during the atmospheric entry. Needing less pointing accuracy than the orbiter, and experiencing greater disturbance torques, the probe will rely on cold-gas thrusters for attitude control. For the de-orbit burn, it will utilize spin-stabilisation to rotate the entire probe about its roll axis, effectively fixing the angular momentum vector in inertial space \cite{SMAD}. This removes the need for vectored thrust control and minimizes the overall mass of the probe. The overall disk shape of the probe further ensures that the roll axis will have the greatest moment of inertia, guaranteeing stability. Prior to atmospheric entry, the probe is de-spun, changing the control type to 3-axis stabilized. The aeroshell is designed such that it will be inherently stable throughout the hypersonic phase, and will need few corrective inputs from the attitude control thrusters. This is supported by the design of the Mars Science Lander, which required limited active control to remain within the specified deadbands \cite{2007\_Brugarolas}. Upon reaching the transonic phase, the ACS will become more active due the instability around Mach 1. This is necessary for the propelled descent as described in \chapter{EDL}

\subsection\*{AOCS Design}

The AOCS design process consisted of six distinct steps: requirements determination, ACS type, quantification of disturbance torques, hardware selection, budget updates, and finally control logic selection. A parametric tool was created in python to size the AOCS and select specific actuator hardware to meet the functional requirements. The sizing is based on worst-case conditions, to ensure that the requirements will always be met. This tool is based on inputs as described in tableXXX (summarize design\_params.xlsx) which are estimates of mission requirements based on heritage data as well as the driving requirements as described previously.

Having selected the attitude control methods, the magnitude of the disturbance torques are needed to determine the sizing of the hardware. For the probe, the primary disturbance torque would be the aerodynamic loads, but due to the shape of the aeroshell, there would be little need for active control. The thruster propellant estimation is therefore based primarily on heritage data, referencing the MSL and Phoenix lander which utilized similar EDL profiles \cite{2007, 2008\_G, 2008\_P, 2013\_S, THE\_R}.

For the orbiter, both internal and external disturbance torques are analysed. These can be divided into cyclic and secular torques, where “the cyclic torques will cause cyclic rates, while secular torques cause gradual divergence” \cite{SMAD p369}. These secular torques will accumulate momentum throughout the orbit necessitating periodic momentum desaturation of the reaction wheels.

A rough parametric model of the orbiter is generated based on the locations and masses of major components. The model calculates the center of gravity of the orbiter, and the resulting moments of inertia about each axis. Additionally, the center of pressure for a worst-case configuration is estimated, which is used for external disturbance torque calculations. These physical properties are updated and recalculated with each iteration of the overall design.

For external torques, gravity gradient, aerodynamic, solar radiation, and magnetic torques are modelled. Major internal torques generated by actuation of solar array or antenna gimbals are also calculated. The tool identifies the maximum torque that the orbiter may be subjected to, and calculates the momentum of the reaction wheels necessary to overcome this. By utilizing momentum wheels, the orbiter will be stable throughout the orbit without the need for active manoeuvers to counteract individual disturbances.

The sizing of the momentum wheels is based on three criteria. First, disturbance rejection, where the torque of the reaction wheels must at a minimum be able to counteract the worst-case disturbance torque. Second, slew torque where the reaction wheels on the orbiter will be required to slew the spacecraft during maneuvers. The largest will be after the aerobraking, when the orbiter needs to rotate from a maximum-drag attitude to a minimum-drag attitude, fully loaded with all probes on board. This is a 90deg rotation in 50min window. Third, momentum storage, which is calculated by integrating each cyclic torque over half its period, and summing with the maximum secular momentum that can be accumulated. Based on heritage data, the momentum wheels will be desaturated once every 48 hours. \cite{SMAD}.

The sizing of the thrusters is dependent on the thruster placement and maneuver requirements. As further detailed in \ref{sec:AOCS risk}, the thrusters are sized to be able to counter any disturbance torque or execute a worst-case slew maneuver. Using the calculated center of gravity from the geometric model, the effective moment arm of each thruster is calculated and the least-effective thruster pair is used for sizing. Assuming an acceleration of 5\% of the total maneuver time \cite{SMAD} (equation here), the minimum force of each thruster is calculated. The thruster force for momentum desaturation is calculated using eqXXX. Combining the thruster pulse life with the specific impulse creates an estimation of minimum propellant mass required. This is verified to be less than what is budgeted by the propulsion subsystem design \ref{ch7}.

The third type of hardware to be selected is the sensor suite. The detailed selection has been reserved for a later detailed design phase

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