1st APSCO & ISSI-BJ Space Science School

Satellite System Engineering

-- Timeline and System Modes

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Issue

How intelligent should the spacecraft be ?

How much is done from Ground and how much is left to the spacecraft to do ?

The answer to this questions is a fundamental driver for:

- Mission Operations concept and cost
- Spacecraft avionics architecture
- Onboard Software
- Reliability analyses

Tendency to define this too late in the project (late Phase B) for historical reasons causing "software crisis" halfway into the project

Solution is mission-specific as it depends on mission requirements (examples: Planetary landing must be autonomous, mission with complex AOCS or high availability requirements must have high autonomy, etc.)

Spacecraft intelligence - The Past (and often still the present)

- Very little automation and autonomy onboard: most operations require ground planning, commanding and intervention
- Little onboard capability for fault detection, isolation and resolution
- Most of satellite tasks are time driven
- Satellite resource scheduling is manually performed on ground
- Payload data processing is made on-ground
- Autonomy perceived as risky and not cost-effective due to the cost of the associated software (which may offset the operations cost)

Process to define the approach

1. Definition of mission timeline (phases, main events)
2. Identification of required system functions and modes
3. Based on function and mode analysis, apportionment of functions to system elements
4. Spacecraft autonomy requirements
5. Mission operations concept
6. Software requirements

Mission timeline - Example

Mission Timeline

Mission Phase	Event	Start date	Day counter
Launch & early orbit	Launch to HEO	15/12/2016	0.00
	HEO to Jupiter transfer orbit	14/01/2017	30.00
Cruise to Venus	Transfer to Venus swingby		
Venus swingby	Venus swingby	20/06/2017	157.00
Cruise to Earth	Transfer to Earth swingby		
Earth swingby	Earth swingby 1	06/03/2018	446.00
	Earth swingby 2	19/03/2020	1190.00
Cruise to Jupiter	Navigation correction manoeuvre		
	Orbiter commands probe 1 separation		
	Probe 1 release	20/06/2022	2023.00
	ODM 1	30/06/2022	2033.00
	Orbiter commands probe 2 separation		
	Probe 2 release	10/07/2022	2043.00
	ODM 2	20/07/2022	2053.00
	Ganymede Swingby		
Capture into Jupiter orbit	JOI	17/11/2022	2163.00
	Transmit probe data to Earth when possible		
Probe entry and relay phase	Probe 1 relay	17/11/2022	2163.00
	Reorient orbiter HGA for second probe		
	Probe 2 relay	17/11/2022	2163.00
	Transmit in real time to Earth, store data for later transmission		
Transfer to operational orbit	PRM (Perijove raise manoeuvre)		
	Line of apses reorientation		
	ALM (Apojove lowering manoeuvre)		
Operational	Magnetosph P/L science		

System modes

System modes are used to describe the different "statuses"/operational configurations of a system in different phases of the mission.

They include a description of the configuration, the functions of all the subsystems in each given "status", the environment and the link to the mission phase.

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System modes - Example

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#	Mode Name	Start event	End event	Description: Actions	Instruments	AOCS / Propulsion	Power	DHS	Comms	Acronym	Duration (min)
				Liftoff to Separation from LV							
1	Launch Mode	Take off	Insertion into L2 Transfer orbit	All subsystems are off except for essential equipment	Offline	Offline	Batteries discharging	On	None	LM_MSC	47
				Activation and trajectory insertion							
2	Initialisation Mode	Insertion into L2 Transfer orbit	Solar Array sun pointing	Equipment activated upon separation Coarse sun pointing provided by upper stage at separation	Offline	Dispersion correction / attitude acquisition by sun pointing	SA (used for sun pointing)	On	LGA	IM_MSC	90
				SVM commissioning and calibration							
3	Cruise Mode	Solar Array sun pointing	L2 orbit insertion	Subsystem calibration and checkout prior to arrival into operational orbit	Calibration	Trajectory determinations and corrections	SA	On	LGA (with HGA if possible)	CM_MSC	43200
				Perform observations							
4	Observation Mode	Initiation of field imaging	End of field imaging	All Instruments generate science data	Data acquisition for all instruments	No propulsive manoeuvres	SA	On	HGA	OBS_MSC	32
				Perform manoeuvres to correct orbit and change attitude							
5	Manoeuvring Mode	End of field imaging	Initiation of next field imaging	Actuation, stabilisation and recalibration prior to restart of science observations	Online but not acquiring data	Actuation to perform manoeuvres and stabilisation	SA	On	None	MAN_MSC	5
				Hibernation and Failure Recovery mode							
6	Safe Mode			Non-essential functions are halted, failure detection and recovery are executed by the ground	Standby	Maintain S/C orientation so that SA are sun pointing	SA	On	LGA	SM_MSC	10080

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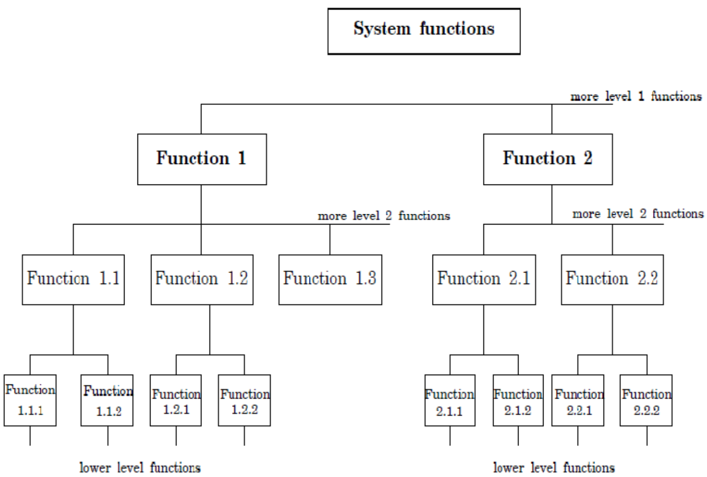
System Functions Apportionment (Functional Analysis)



- Derived from modes
- Hierarchical structure: functions are decomposed into lower level functions

Further use of System modes

Reference for:

- Definition of AOCS modes for subsystem sizing
- Evaluation of Power budget and sizing cases for power generation and storage
- Definition of worst design cases for thermal
- Definition of “mechanical states” (e.g. stowed configuration)

Safe Mode

System Mode used in case of contingency/failure

It allows the spacecraft to be put in a state where no further damage may happen and the satellite can wait to be recovered from Ground

Typical:

- Pointing array to the Sun
- Switching off/stand-by of all non-critical loads (including payload)
- Attitude that allows reception of Earth telecommands
- Often specific AOCS sensors for this mode

It shall be thought of since the earliest stages of mission design.

During mission operations safe mode is not a rare occurrence but, transition to safe mode shall be minimised by design to avoid wasting a lot of mission time

For time critical events (e.g. planetary orbit insertion) safe mode needs to be de-activated

Onboard Autonomy

Several flavours:

- Autonomy in nominal operations
- Autonomy in case of contingency
- Autonomy in data collection and processing

Most important (and difficult): Capability of a spacecraft to initiate operations by itself after an unplanned event

FDIR

Typical expression of autonomy

Set of functions to:

1. Detect off-nominal conditions
2. Isolate the problem to a specific component/subsystem
3. Send the spacecraft in safe mode or reconfigure and recover the spacecraft autonomously

A degree of re-configurability and redundancy is needed within the design

May require a complex software to handle many failure cases