SAVOIR FDIR handbook: update for CPO like missions

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The authors extend their profound gratitude to the members of the working group, the SAG (Savoir Advisory Group), and the reviewers for their essential contributions to the handbook's update. Their expertise, insights, and unwavering commitment have been pivotal in formulating the guidelines, ensuring they remain pertinent and practical.

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DOCUMENT

SAVOIR FDIR Handbook

SAVOIR
space avionics open interface architecture

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Scope of update: Second version of the HB

The main goals of the updated HB are:

- Identify missions or technologies for which common FDIR design and processes recommended in the first issue of the handbook are **not applicable or require tailoring**
- Identify minor aspects within the handbook that are needed for update to be **aligned with other existing handbooks or technical notes**
- **Revise** overall handbook and **alignment with ECSS**
- Gather **lessons learned** from satellite manufacturers and mission operators on FDIR, either internally and from the industry, and integrate those lessons learned in the handbook
- Ensure the handbook can be used for a large range of types of missions, including with regards to new niches such as **Close Proximity Operations**, **CubeSats** and **Constellations.**

FDIR Pillars in ESA

FDIR Project support and synergies
(from SRR to QAR)

FDIR in support to Zero Debris policy and Close Proximity Operations WG

FDIR Research and Development (CD3 and CD9)

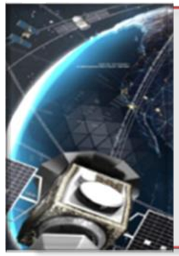
FDIR Handbook maintenance (SAG)

Standardization of FDIR
ECSS

FDIR for unconventional early design missions
CDF

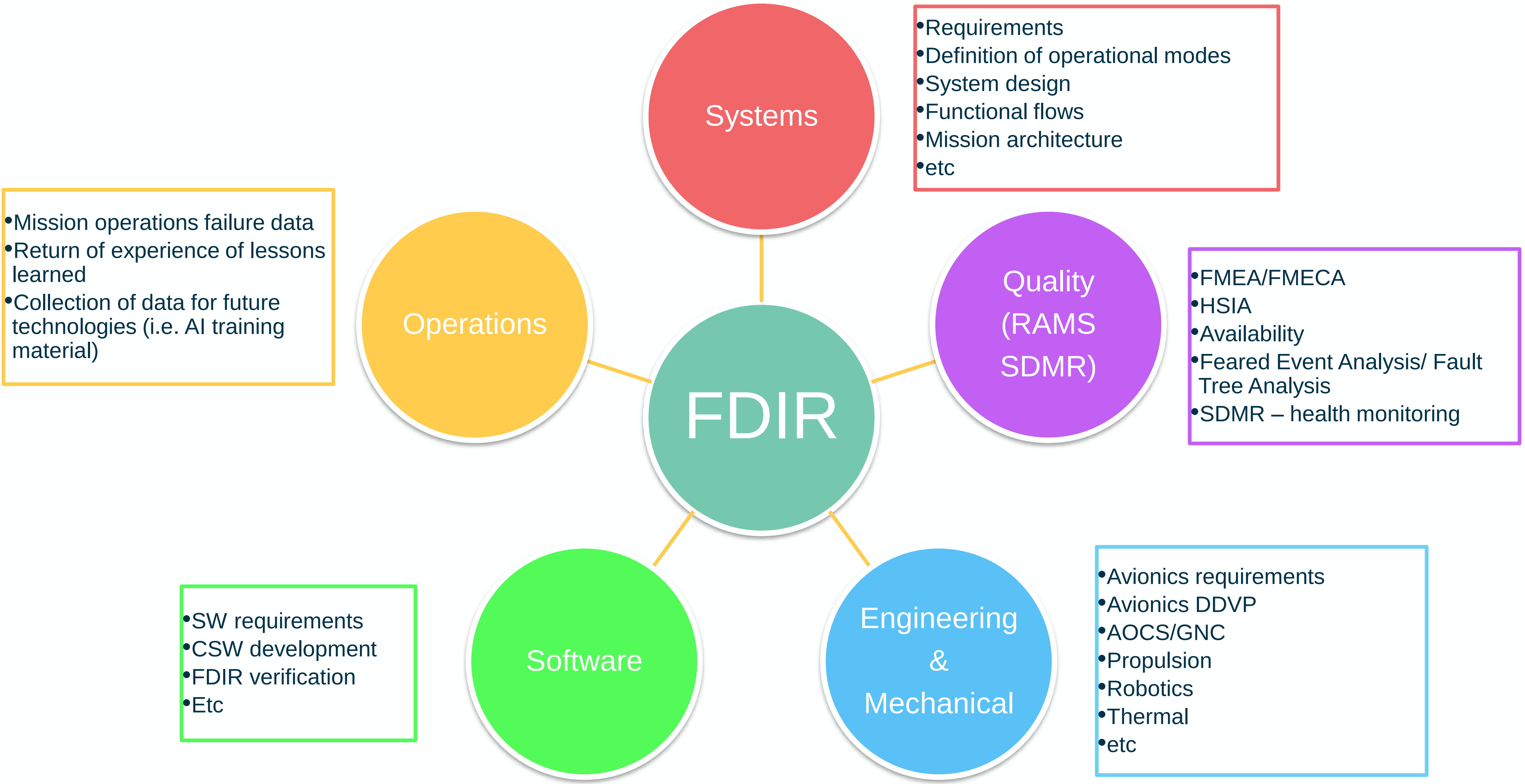
FDIR training
(Knowledge management)

FDIR dissemination, bilateral and workshops

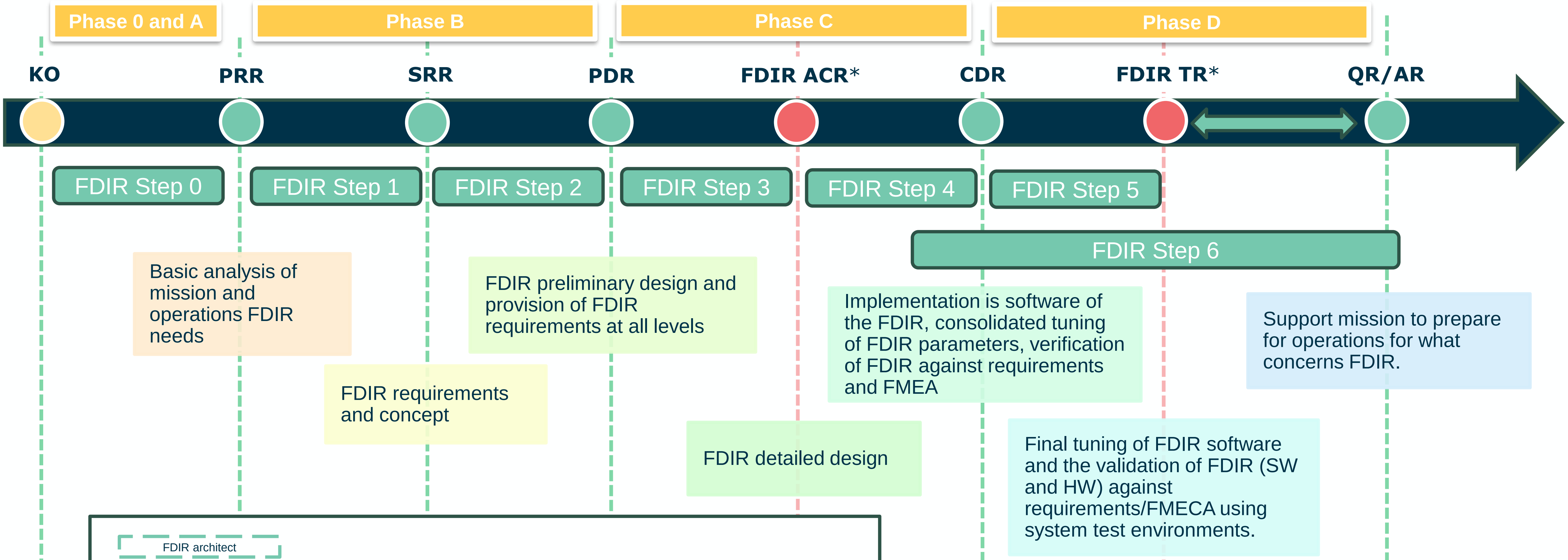


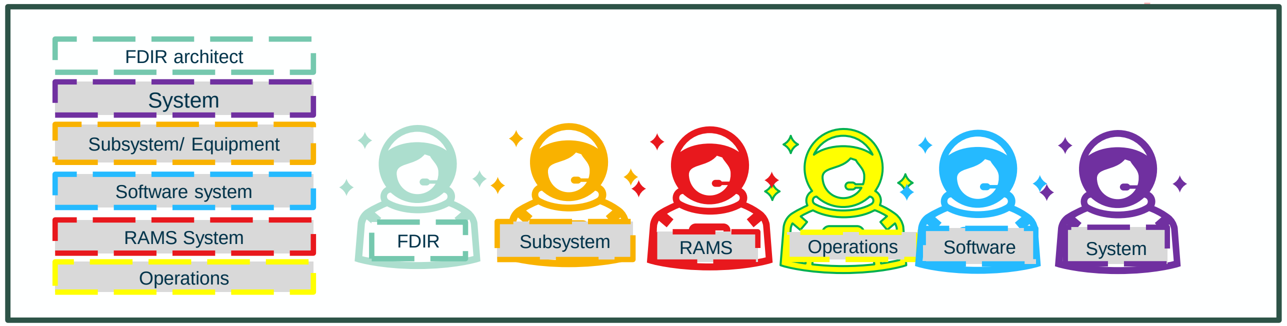
FDIR during operations (collection of data for future prognostics based algorithms)

Relationship (synergies) technical diagrams



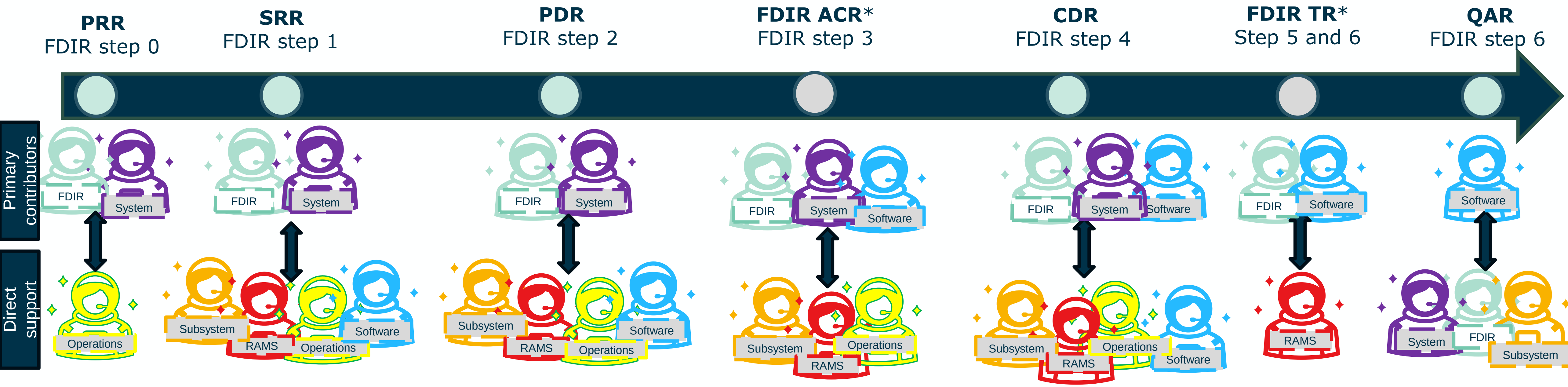
Scope of FDIR architect in project





***ACR – Architecture Checkpoint Review**
***TR – Tuning Review**

FDIR architect role in mission phases



- ✓ Software Engineer becomes primary contributor from FDIR ACR to QAR.
- ✓ FDIR architect supports FDIR design and architecture as primary contributor in parallel to system from PRR to CDR.

FDIR architect role in mission phases

Key Considerations

- **Collaboration:** Pivotal role of a dedicated FDIR engineer working closely with the system engineer.
- **Pitfalls:** Navigate challenges such as late integration and flexibility issues to ensure seamless alignment with system goals.

Challenges

- **Infinite Possibilities**: Complexity arises from the vast array of potential unintended behaviors.
- **Balancing Act**: Delicate equilibrium between rigor and information management in FDIR engineering.

FDIR Architect main tasks

- to ensure that FDIR is addressed in all life cycle phases, by all system constituents.
- to design the FDIR concept in alignment with the system design.
- ensure that a rigorous process is followed, that convincingly demonstrates fit for use.
- to collect, organise, verify and to timely disseminate consolidated FDIR information and to enforce that this information is correctly used across all design artefacts.
- manage the level of flexibility realised in the system design to cater for FDIR needs.
- demonstrate the appropriateness of the identified mitigations in terms of acceptable added system complexity and acceptable impact on verification and validation.
- ensure stakeholder convergence on acceptability of residual risks.

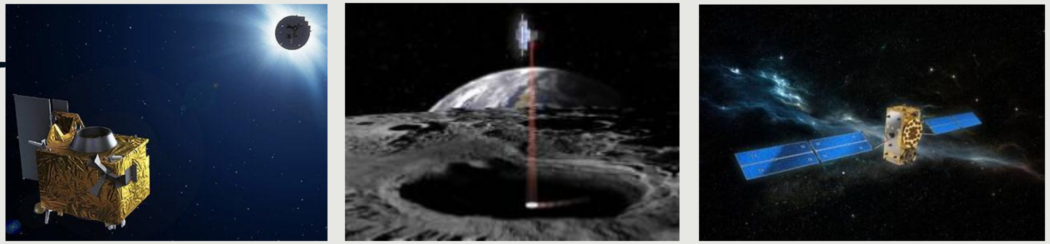
FDIR use cases

Appendix F

In the Handbook, Appendix F provides a series of FDIR use cases. The goal was to offer examples for missions that are more specific and less conventional, where different or slightly modified designs and processes may be more suitable.

The use cases provided are:

- CubeSats
  - Mission examples: M-ARGO, LUMIO, VMMO, e.inspector



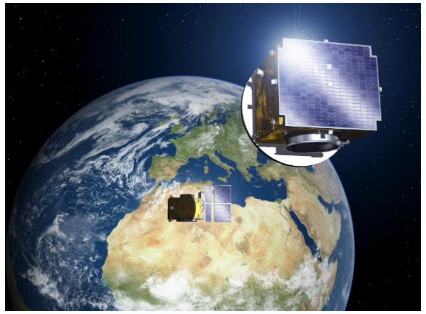
- CPOs
  - Mission examples: ADR: ELSA-M, CS-1; IOS: Rise

FDIR in CPO cooperative w/o Capture And Formation Flying

In cooperative rendezvous and formation flying missions, two S/Cs collaborate to achieve a common goal.

Typically, one S/C, the chaser, performs thrusting manoeuvres while the other, the target, maintains a favourable attitude.

The target S/C may also have active or passive elements to aid relative state measurement.



Drivers for FDIR:

- Need to detect and avoid collisions
- Need to manage small inter-satellite distances,
- Need to handle FDIR separately for chaser and target S/C.

Tailoring Needs:

- Incorporating specific drivers into requirements analysis, considering interactions between chaser and target S/C
- Ensuring FDIR capabilities without requiring direct communication links.
- The Feared Event Analysis shall explicitly consider any potential interaction between the two S/C
- The Safe Mode concept shall take into account that it may be preceded by a Collision Avoidance Manoeuvre (CAM)

Example Missions:

- Proba-3, an ESA Formation Flying technology demonstration mission involving two small satellites to test and validate FF mission architectures and techniques.

Lessons Learned:

- A master/slave approach for CAM execution allows for one S/C to initiate CAM, with the other acting as a backup if needed. This ensures efficient management of collision risks.

FDIR in CPO Non-cooperative w/o Capture (RDV)

Appendix F

Non-cooperative rendezvous without capture missions involve a chaser spacecraft performing manoeuvres to maintain a desired relative pose with respect to a non-cooperative target.

In this use case, non-cooperative is understood as the target S/C i) not being actuated (i.e., a stable attitude cannot be assumed) and ii) not being equipped with any relative navigation-aid device or marker. Otherwise, the target S/C is cooperative.

Drivers for FDIR:

- Need to detect and prevent collisions between the chaser and target spacecraft, especially during close manoeuvres.
- Inter-satellite distances can be small without indicating a failure, necessitating collision avoidance measures.

Tailoring Needs:

- Incorporating specific drivers into the FDIR requirements analysis
- Considering collision events as feared events
- Use the FDIR design of the target S/C as an input for the chaser S/C FDIR design, accounting for the functional chains that can be disabled.
- Ensure it accounts for the possibility of being preceded by a collision avoidance manoeuvre or other manoeuvres to prevent collisions within a set number of days.
- Should be executable without the need for ground intervention.

Example Missions:

- PRISMA, led by the Swedish Space Corporation, demonstrated formation flying and rendezvous. e.Inspector, led by ESA, aims to image ENVISAT in its status

Lessons Learned:

- CAM execution, as observed in missions like MSR-ERO, may involve a second onboard computer for faster reaction times in critical scenarios.

FDIR in CPO Non-cooperative with Capture

esa

Appendix F

Non-cooperative rendezvous with capture missions involve a spacecraft, called chaser or servicer, manoeuvring to capture a non-cooperative target in space, such as debris or satellites. Typical examples of such missions include Active Debris Removal (ADR) missions, in which the main objective is to capture and remove debris

Drivers for FDIR:

- Hinders relative navigation and limits manoeuvre types due to the target's non-cooperative nature.
- Increased risk of uncontrolled collision during the final approach and capture phase.
- Uncertain target state - especially for debris or long-standing objects in space, which may not be intact.

Tailoring Needs:

- Incorporating specific drivers into the FDIR requirements analysis
- Close inter-satellite distances are normal and should not trigger false alarms within the FDIR system.
- Unlike cooperative RdV missions, the target S/C cannot perform collision avoidance manoeuvres, increasing the responsibility of the chaser S/C's FDIR system.
- Consider interactions between chaser and target S/C and Consider collision events as feared events
- Ensuring the FDIR is capable of operating considering changes after capture.
- Ensure it accounts for the possibility of being preceded by a collision avoidance manoeuvre or other manoeuvres to prevent collisions within a set number of days.

Example Missions:

- ClearSpace-1 from ESA's ADRIOS program, which aims to remove debris from space. Another example is IOS missions to service uncooperative satellites.

Lessons Learned:

- Potential use of a second onboard computer (OBC2) for executing CAMs to improve reaction times in critical scenarios, as observed in missions like MSR-ERO.

FDIR in CPO cooperative with Capture

Cooperative rendezvous with capture missions involve reducing the distance between two S/Cs to zero in a controlled manner, commonly seen in In-Orbit Servicing (IOS) missions.

Drivers for FDIR:

- The FDIR is effectively split between target and chaser with potentially no direct communication link between the two (in case of inter-satellite link failure).
- Requirements for target capture impose the need for the chaser S/C to take over attitude control of the composite.
- The target S/C should allow for the chaser S/C to take over attitude control of the composite.

Tailoring Needs:

- Incorporating specific drivers into the FDIR requirements analysis
- Consider interactions between chaser and target S/C and Consider collision events as feared events
- Ensuring the FDIR is capable of operating considering changes after capture.
- Ensure it accounts for the possibility of being preceded by a collision avoidance manoeuvre or other manoeuvres to prevent collisions within a set number of days.
- Should be executable without the need for ground intervention.

Example Missions:

- Mars Sample Return – Earth Return Orbiter (MSR-ERO), tasked with capturing the Orbiting Sample in Mars orbit, where an uncontrolled collision could jeopardize the mission. IOS missions, such as satellite refuelling or repair, also fall under this category.

Lessons Learned:

- In MSR-ERO, failure detection relies on mechanisms within OBC1, but CAM execution is preferably handled by OBC2 for faster reaction times in certain scenarios, demonstrating the importance of efficient FDIR mechanisms.

FDIR lessons learned

Appendix D

- ✓ The lessons learned derived from practical experiences in the field of FDIR are presented in **Appendix D in the HB**, and some of them are also inserted in Chapter 4, related to the different steps of the process.
- ✓ This compendium is structured to provide a **summary**, organized according to the distinct phases inherent to the FDIR process.

The **different categories** identified are:

- FDIR System Considerations
- FDIR Analyses
- FDIR Design
- Validation and Verification
- Time Schedule and Cost Control
- FDIR Standards and Definition
- Constellations

- ✓ Source: **RIDs** identified during system PDR and CDR, as well as FDIR-related documents from various projects coming from ESA or industry.
- ✓ Each lesson learned category has a related table highlighting in black the **mission phase**(s) (A, B, C, D or E) for which it is applicable.

ESA Mission Classification

ESA mission classification table can be found in appendix G

Appendix G

The **ESA mission classification** table is as it follows:

Class type	I	II	III	IV	V
Mission Criteria and Marking					
Criticality to Agency strategy (Flagship mission, Internationnal cooperation, Impact on ESA strategic goals, and image)	Extremely high Criticality	High Criticality	Medium Criticality	Low Criticality	Educational purposes
Marking					
Mission Objectives (Directorate priority and purpose, e.g in orbit demonstration, educational)	Extremely high Priority	High Priority	Medium Priority	Low Priority	Educational purposes
Marking					
Cost (Cost at Completion, Including Phase E1)	>700 M€	200 - 700M€	50 - 200M€	1 - 50M€	< 1M€
Marking					
Mission Lifetime (Nominal mission life duration)	> 10 years	5-10 years	2-5 years	1-2 years	1 year
Marking					
Mission Complexity (Design interfaces unique payloads, New technology development)	High	High to Medium	Medium	Medium to Low	Low
Marking					

Classes I, II, and III, thorough adherence to the FDIR design and processes is expected and recommended, following all steps outlined in the HB from Step 0 to Step 6, including proposed reviews.

Classes IV and V, where missions might be educational or have limited budgets, it's acceptable to skip some steps due to insufficient resources.

Class IV, Steps 0 and 1 are optional, and Steps 3 and 4 can be merged and revised at CDR.

Class V, typically educational missions, it's beneficial to go through all steps, but it's acceptable to skip Steps 0 and 1 and start FDIR concept at Step 2 due to simplicity.

Similarly, merging Steps 3 with 4 and Step 6 are optional for **Class V**.

Also, the **recommended applicability of the FDIR steps per mission class** can be found here.

Mission class	Step 0	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
I.	A	A	A	A	A	A	A
II.	A	A	A	A	A	A	A
III.	A	A	A	A	A	A	A
IV.	O	O	A	A		A	A
V.	NA	O	A	A		A	O

A – applicable
NA – not applicable
O - Optional

Conclusions and Future initiatives

- **The SAVOIR FDIR HB represents a step forward towards the standardization of FDIR in Europe**
  - While not normative, it provides guidelines for cross-disciplinary aspects of the FDIR process, interfacing with other engineering disciplines
  - It is aligned with ECSS and other existing handbooks and technical notes
  - It contributes to a uniform understanding of FDIR drivers, requirements, processes, and interfaces, in Europe
- **New release (issue 3.0) of the SAVOIR FDIR HB on 25th June**

Stay tuned!

- **The SAVOIR FDIR HB provides a clear indication of the relevance of the standardization of FDIR in Europe**
  - The SAVOIR FDIR HB is the first step towards the elaboration of an ESA FDIR standard
  - This is a need identified by the different stakeholders of the space sector (ESA, the industry, research institutes, academia, etc.)

- **We'll continue promoting the use of the SAVOIR FDIR HB!**
  - ESA provides dedicated training, upon project requests

Thank you, Questions?

Space Team Europe