FALCON EYE

FalconEye system : Debris mitigation

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Summary

This document aims at explaining how the Falcon Eye satellites are designed and operated in order to mitigate debris generation risks.

It recalls what is the legislative frame related to this risk mitigation, and how this is controlled. Then it develops the result of analyses made during design phase and the operational plan to achieve extremely low risk of debris generation, and collision avoidance.

It is issued to support the application for use of the North Pole station in Alaska to contribute to command/control of the Falcon Eye Satellites.

Document change log

ISSUE/ REVISION	DATE	MODIFICATION NB	MODIFIED PAGES	OBSERVATIONS
01/00	20/05/2019		All	First issue of the document
01/01	20/10/2020		7	Update of launch date

Table of contents

1. SCOPE OF DOCUMENT

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2. REFERENCES

2.1 Applicable documents

N/A

2.2 Reference documents

RD NO.	DOCUMENT TITLE
[RD 01]	Loi relative aux operations spatiales du 3 juin 2008 (Space Operations Law) https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000018931380#LEGISCTA000018939304

3. OVERVIEW OF FALCON EYE SYSTEM

3.1 SYSTEM DESCRIPTION

Falcon Eye is an Earth Observation satellite system composed of two low earth orbiting satellites taking images of the Earth in the visible spectrum for Mapping, Environment and Security purpose, and a Ground Segment ensuring satellite control and command, and image reception and processing.
The Falcon Eye system is also making use of

- A CSPOC service in order to contribute to overall collision avoidance in low Earth Orbits
- A cooperation with Swedish Space Corporation's Kiruna services to increase communication opportunities between satellites and ground, for command/control purpose and for image downloading
- A cooperation with Swedish Space Corporation's North Pole services to complement the command/control communication opportunities for orbits not covered by the Kiruna visibility circle. North Pole station is only used in S-Band, for command/control purpose.

The FM2 satellite will be launched by Arianespace in November 2020, from French Guiana spaceport.

3.2 SYSTEM OWNERSHIP AND OPERATIONS

The system is built by a French consortium associating Airbus Defence & Space and Thales Alenia Space. It is ordered, and it will be owned by The United Arab Emirates government, who has mandated Yahsat to technically advise and support him in the monitoring of the development of this system.
After launch and in orbit testing of the satellites, the system will be operated by the United Arab Emirates government. Prior to taking ownership of the system, the customer will have received proper training and operational qualification related to:

- Safe operation of the system during nominal and possible extended lifetime
- Management of failures and their recovery
- Activities at end of life for de-orbiting and satellite passivation

4. MANUFACTURER OBLIGATIONS

4.1 APPLICABLE LAW

As a French company consortium, Airbus Defence & Space and Thales Alenia Space are subject to French law.

Especially, the Space Operations law (3 June 2008) is applicable. It sets obligations to the manufacturer to limit the risks of space debris. The web link to that law (in French) is given in the reference documents section

4.2 ENFORCEMENT AND CONTROL

As stated in RD1, the manufacturer has to obtain a formal authorization from the French authorities prior to the launch of the satellites. Such authorization is generally applied for 3 months before the launch. The French Space Agency instructs the technical file.

The law also states that the holder of an authorization may transfer it only with the approval of the French authorities; such approval results from a check that the new operator is able to respect the same obligations.

5. MANUFACTURER DESIGN ELEMENTS FOR DE-ORBITING

5.1 MISSION

The orbit is sun-synchronous. When both satellites are in orbit, they will be 180 degrees out of phase.

- Cycle length 25 days
- Number of revolutions in cycle 371
- Number of revolutions per day 14 + 21/25
- Eccentricity e0 = 0.00123272 (frozen orbit)
- Altitude 610,9 km at the equator
- 97.9256 degrees tilt (sun synchronous orbit)
- Average local time of the descending node: 22:30

The nominal injection strategy of the two satellites is to aim for a circular orbit 30 km below the operational orbit, and to retrieve the nominal altitude while correcting for possible dispersions in launcher ingestion and phasing the satellites into the final orbit.

Maintaining the reference orbit requires two types of maneuvers:

- maneuvers in the plane in order to maintain the phase shift at the equator and to raise back the orbit which tends to descend under the effect of atmospheric drag. On average, over the lifetime of the FM1, approximately 13.9 m / s will be required. These corrections will be divided into about 80 maneuvers, performed every 40 days. FM2, being launched on a very close date, will follow the same strategy.
- out-of-plane maneuvers to control the ground track against a reference grid and maintain local time. They require a total correction of 40.5 m / s. These corrections are made every 2 years.

The total ΔV budget is summarized below, also considering a provision for collision avoidance maneuvers of 1 m / s corresponding to a collision avoidance maneuver per year over the 10 years of service life.

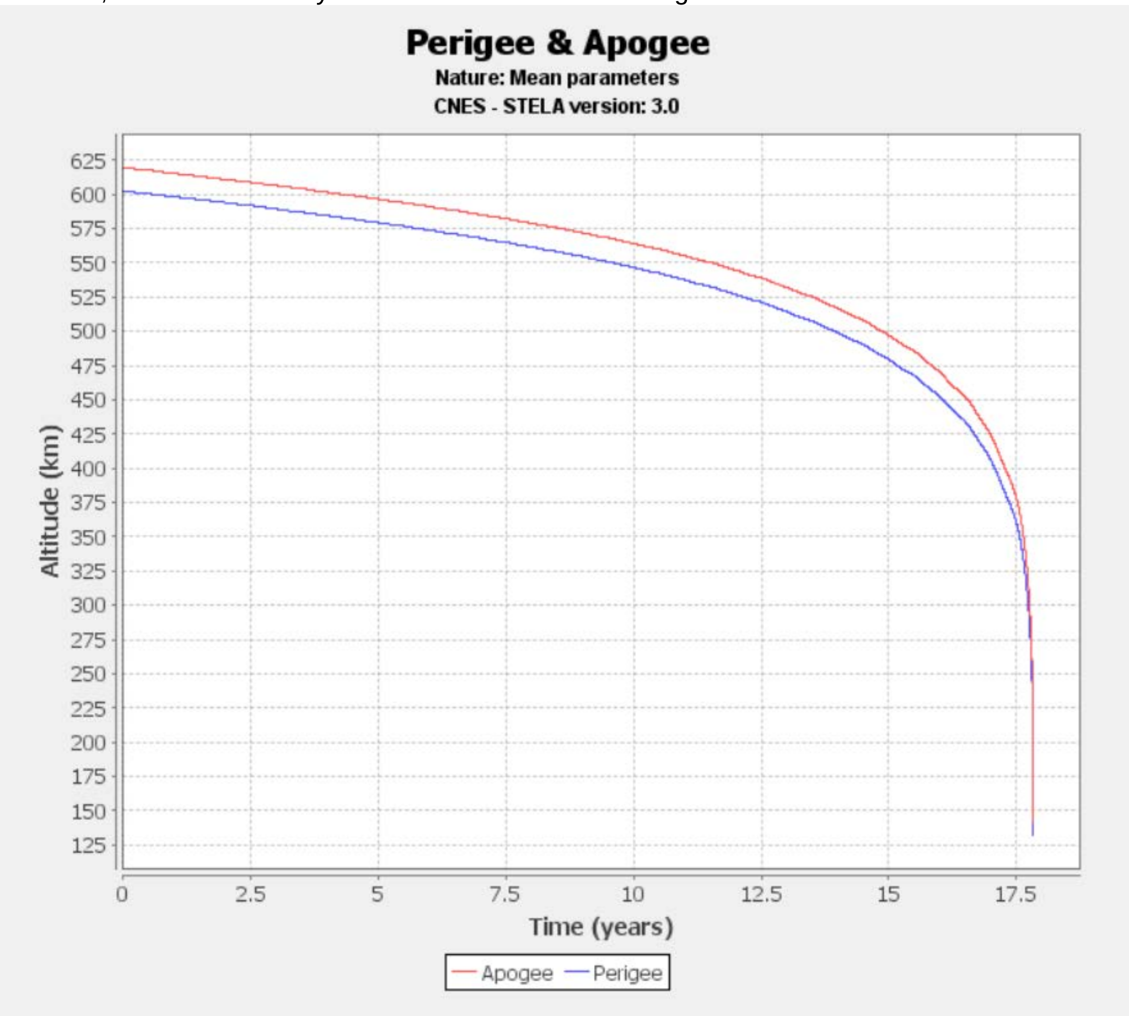
LEOP	16.3 m/s
Out of plane station keeping	40.5 m/s
In plane station keeping	13.9 m/s
collision avoidance maneuver	1 m/s
EOL/Deorbiting (see below)	0 m/s
Total	***71.7 m/s***

Total ΔV Budget – satellites 1 & 2

5.2 STRATEGY FOR DE-ORBITING

French Space Law imposes that, at end of life of the satellite, it returns to Earth in less than 25 years, under the effect of the atmospheric drag or through active deorbiting.
To evaluate the respect of the return in less than 25 years, Airbus used the reference tool of CNES: STELA.

For the FM1, placed on an orbit at 610.9 km, with a sun-synchronous inclination, for any value of ascending node, and a date of end of mission in 2029, assuming the end of station keeping maneuvers and natural atmospheric drag effect, one finds an orbit which returns in less than 18 years.
In conclusion, it is not necessary to do maneuvers of deorbiting**.**



Evolution of the perigee and apogee of the orbit during the end of life (FM1)

For the second satellite, which is launched only a few months later, the time required to return from the nominal orbit will also be less than 18 years.
The propellant tank will be full at launch time, even if its capacity is greater than the need in ΔV.

Service termination operations will end with satellite passivation.

5.3 SPACE DEBRIS LIMITATION PLAN

The Falcon Eye system and the FM1 and FM2 satellites are designed, produced and implemented to not intentionally generate debris during nominal operations.

The FM1 and FM2 satellites have not been designed to avoid generating space debris in case of collision with space objects (debris, micrometeorites). The pressurized structures in particular are not demonstrated "leak before burst".

Probability of occurrence of accidental disintegration

The table below lists the sources of danger and the dangerous entities that may lead to partial or complete accidental disintegration of the satellite.

Danger source	Dangerous Entities
Propellants	**Hydrazine (N2H4): explosion due to unintentional heating (1)**
Parts under pressure	**Propellant tank (2)** **Battery** (3)
Mechanical energy	**Gyro actuators (4)**
Environment	**External elements: disintegration (5)**
Mechanical design	**Internal structural elements of the satellite (6)**

1- The probability of occurrence of a permanent undesired heating of hydrazine or a lack of reheating (which can lead to ergol gel) can be estimated much lower than 10^{-4} over the whole duration of the mission of 10.25 years (failure of either the control of a heater and its monitoring or the passivation means).

2- The leak (or explosion) of the tank or piping over the mission was estimated to be less than 1.1 10^{-7}. The propulsion system is sized for a test pressure of 1.5 MEOP and a failure pressure of 2 MEOP (Maximum Expected Operating Pressure).

3- The battery is made of SONY US18650 Li-Ion cells equipped with safety mechanism:

- Circuit breaker in case of overload, which isolates the cell from the rest of the battery,
- Protection against short circuit,
- Over-temperature protection: Each Li-Ion cell is equipped with a pressure relief vent to reduce the pressure in a controlled manner and without explosion risk.

4- The gyroscopic actuators are equipped with overspeed protection. The corresponding risk was estimated in the justification file of the gyroscopic much lower than 10^{-4} over the whole mission

5- Materials and processes are qualified vis-à-vis the orbital environment and launch. State-of-the-art techniques for minimizing debris generation, such as MLI and NIDA boarding, are applied to both satellites

6- State of the art structural design of the satellites : loads considered at 3σ and material characteristics including margins. Successful structural elements qualification tests, including these safety factors, confirm that the probability of rupture is guaranteed well below 10^{-3}.

Hence, the probability of occurrence of accidental disintegration can be estimated well below 10^{-3} over the entire 10.25 years mission. Beyond this duration, the satellite is in an orbit allowing a return in less than 25 years, and is passivated. This passivation ensures that the systems subjected to wear (mechanisms) are neutralized while those subject to aging are limited to external elements without debris danger (thermal coatings, solar cells).

Passivation of the satellite after the withdrawal of service

Fluid passivation

There is no fluid passivation mechanism in the satellite design: fluid passivation is therefore achieved by emptying the tank to the maximum using nozzles.

Electrical passivation

Electrical passivation consists in placing the satellite in a spinned attitude, oriented so as to minimize the solar flux on the Solar panels. The consumption of the satellite will be forced. The objective is to reach a battery voltage lower than 20 Volts which leads to an irreversible degradation of the Li-Ion battery. In such case, the copper of the anode dissolves, the resistance increases, so does the temperature and eventually, the cell circuit opens.

5.4 COLLISION AVOIDANCE PLAN

UAEAF have subscribed to the Combined Space Operations Center (CSpOC) alerting services that will provide collision probability estimates.

As the satellites have maneuvering capabilities, they will carry out these avoidances during their orbital life. This avoidance strategy uses the alerts from CSpOC. Each alert is analyzed by the Flight Dynamic System (FDS) of the ground segment. If necessary, an updated orbit can be calculated by the FDS and transmitted to CSpOC to verify that this new avoidance orbit does not present a new risk of collision.

Avoidance maneuvers will be carried out by the United Arab Emirates operator, who have been trained and qualified for this.

This approach does not address small unidentified debris (small debris, micrometeorites).

5.5 RE-ENTRY ANALYSIS

The risk assessment for uncontrolled re-entry is presented in the analysis below, based on the DEBRISK analysis tool. It provides the "bruised surface" and energy associated with each object falling on Earth, as well as the disintegration altitude for other objects. These results make it possible to estimate the risk of human damage caused by an object falling on Earth.

Results are split between the satellite bus and the payload:

On Bus side

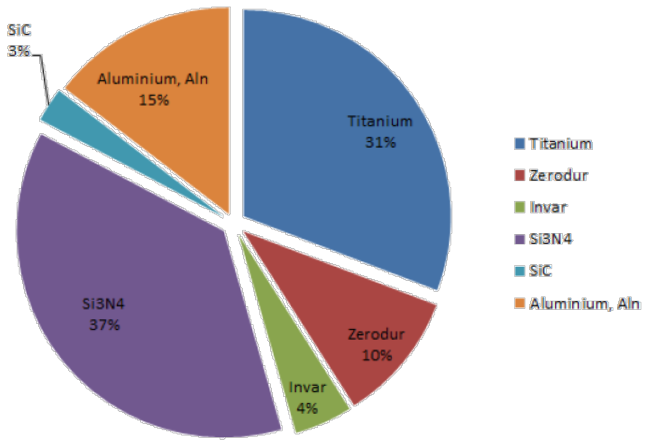
Name	Q	Demise altitude	Impact energy	ΣCasualty area	Max. surface	End mass_a	Ini mass_a	%Mass_a left	Max T	End T
PM25 tank	1	99.44	3238.616	1.261	0.273	6.9	6.9	100.0	1642	436
CMG_cardan complet	4	94.43	1450.587	2.534	0.038	2.253	10.0	22.53	1877	609
struct STROH Invar	3	91.72	56.077	1.464	0.01	0.242	0.5	48.45	1700	335
Root Object	1	78000.0	0.0	0.0	8.82	0.0	1103.9	0.0	300	300

The total bus “Debris Casualty Area” (DCA) is 5.3 m²

On Payload side

Zone	Modeled Mass (kg)	DCA (m^2)
M2 area	23.6	5.1
Front Cavity	36.2	11.4
M1 area	12.9	2.8
Mirrors	71.8	6.5
Back Cavity	114.4	10.4
Bipode Supporting	10.3	3.4
Detector Unit	42.9	4.7
Detector Unit - Radiator	2.8	0.0
TOTAL	**315.**	**44.**

The total payload DCA is 44 m², and total mass reaching the ground is 179 kg (58 objects):



Synthesis: full satellite:
DEBRISK tool gives a total Debris Casualty Area just below 50 m² for the satellite, and a total mass of debris reaching the ground of 186 kg.
The corresponding probability of casualty on ground is 7.6 10^{-4}

6. CONCLUSION

This document establishes that the Falcon Eye System will respect the orbital debris mitigation standards expressed by French Space Agency and turned into a French law. It gives details of analyses performed for mission, de-orbiting strategy, space debris mitigation plan, collision avoidance and re-entry.