Ref. Ares(2021)210240 - 11/01/2021

D3.4 Test Plan Document

Due date of deliverable: 01/01/2021

Actual submission date: 11/01/2021

Leader/Responsible of this Deliverable: Andrea Coluccia (RDL)

Reviewed (Y/N): Y

Document status		
Revision	**Date**	**Description**
01	22/12/2020	1st Official Release

Dissemination Level		
PU	Public	X
CO	Confidential, restricted under conditions set out in Model Grant Agreement	
CI	Classified, information as referred to in Commission Decision 2001/844/EC	

Start date of project: 02/01/2020 Duration: 24 months

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under GA No 870257

CONTRIBUTING PARTNER

Name	Company	Roles/Title
Omar Garcia Crespillo	DLR	WP3 Leader & Contributor
Matthias Fehr	DLR	Contributor
Chen Zhu	DLR	Contributor
Aleš Filip	UPA	Contributor
Filip Holík	UPA	Contributor
Alessandro Neri	RDL	Contributor
Andrea Coluccia	RDL	Contributor
Arianna Persia	RDL	Contributor
Cesare Dionisio	RDL	Contributor
Panagiotis Xefteris	RDL	Contributor
Pietro Salvatori	RDL	Contributor
Roberto Capua	SGI	Contributor
Luca Gattuso	SGI	Contributor
Manuele Innocenti	SGI	Contributor
Marco Giangolini	SGI	Contributor
Ondrej Kutik	RBA	Contributor
Miroslav Krajíček	RBA	Contributor
Michael Loupis	ITC	Contributor
John Spanoudakis	ITC	Contributor

DISTRIBUTION LIST

Name	Company	Roles/Title
Alessandro Neri	RDL	Project Coordinator
Daniel Lopour	GSA	GSA Programme Officer
Eutimio Tiliacos	GSA	Reviewer
Jose Eugenio Naranjo	GSA	Reviewer
Maurizio Salvitti	RDL	Project Manager
Aleš Filip	UPA	WP2 Leader
Omar Garcia Crespillo	DLR	WP3 Leader
Ondrej Kutik	RBA	WP4 Leader
Pietro Salvatori	RDL	WP5 Leader
Roberto Capua	SGI	WP6 Leader

APPROVAL STATUS

Document Code	Rev.	Role	Approved	Authorised	Date
HELMET_D3.4	01	WP3 Leader	O. Garcia Crespillo (DLR)	-	22/12/2020
		Coordinator	A.Neri (RDL)	A.Neri (RDL)	22/12/2020

EXECUTIVE SUMMARY

This document is the deliverable ***D3.4 Test Plan Document*** which describes the test plan of the HELMET architecture with focus on the architecture solutions for the augmentation network subsystem as well as the general architecture solution for the onboard subsystem for each transportation segments (Railway, automotive and UAV segments).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

DEFINITION AND ABBREVIATIONS

Acronym	Description
A	Availability
AIMN	Augmentation and Integrity Monitoring Network
ARAIM	Advanced Receiver Autonomous Integrity Monitor
ATP	Along Track Position / Positioning
ATPL	Along Track Protection Level
BTM	Balise Transmission Module
CCF	Common Cause Failure
CENELEC	Comité Européen de Normalisation Électrotechnique
CCS	Control Command and Signalling
CCS TSI	Control Command and Signalling Technical Specifications for Interoperability
CMD	Cold Movement Detector / Detection
CONOPS	Concept of Operations
DHD	Double Heading Differences
E/E/PE	*Electric/Electronic/Programable Electronic*
EGNOS	European Geostationary Navigation Overlay Service, i.e. European SBAS
EGNSS	European GNSS
EMI	Electro-magnetic interference
ERA	The *European Union* Agency for Railways
ERTMS	European Rail Traffic Management System
ESA	European Space Agency
ETCS	European Train Control System
EU	European Union
EVC	*European Vital Computer*
FFR	Functional Failure Rate
FOG	Fibre Optic Gyroscope
FR	Failure Rate
FTA	Fault tree Analysis
Galileo	European GNSS
GBAS	Ground Based Augmentation System
GNSS	Global Navigation Satellite System
GNSS MI	GNSS Misleading Information
GNSS SIS	GNSS Signal-in-Space
GNSS SoL	GNSS Safety of Life (service)

1 INTRODUCTION

In the present deliverable D3.4 we develop a test plan for the multimodal positioning and localization system.

The multimodal positioning and localization system is designed to operate in three different application segments (Railway, automated car and UAV segments). Each vehicle localization system consists of different subsystems, i.e. the Augmentation Subsystem, Communication Subsystem and the On-board Subsystem. Figure 1 shows again the different hierarchies of our architecture. The Augmentation subsystem is identical for all three application segments while the communication subsystem and the On-board subsystem are tailored to each application. In the following sections we will therefore describe test plans for the Augmentation subsystem (section 2) and the On-board subsystems for all three applications (section 3, 4 and 5).

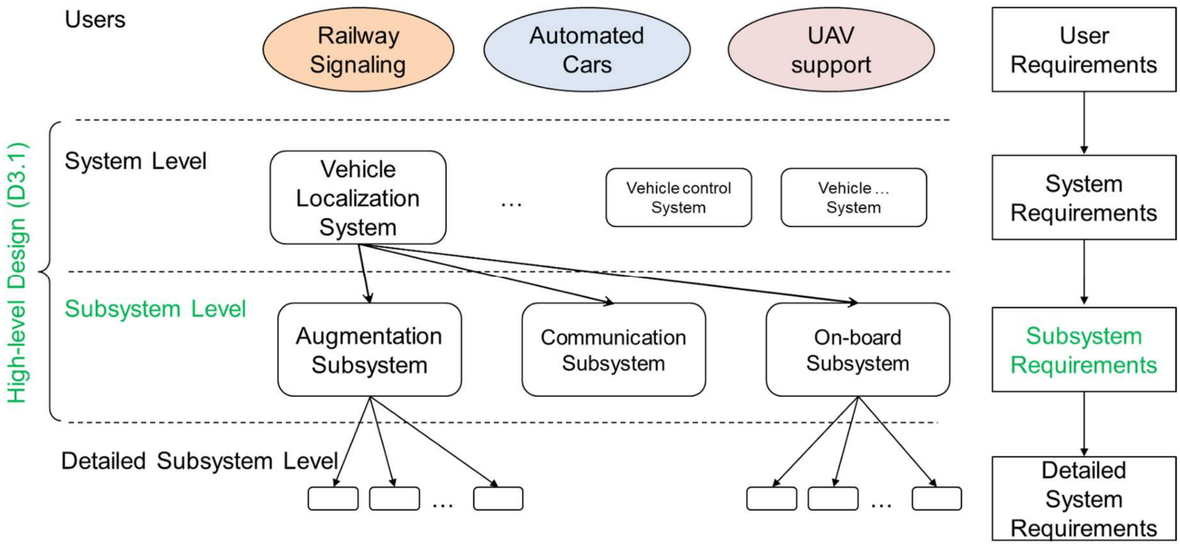


Figure 1: Overview of different design levels and their dependency

2 TEST PLAN FOR AUGMENTATION INTEGRITY MONITORING NETWORK

The aim of this section is to describe the test plan for the Augmentation Integrity Monitoring Network, in terms of single components to be tested (Unit Testing) and Augmentation subsystem integration testing.

2.1 UNIT TESTING

2.1.1 Features to be tested

The test has to check the correct functionalities of the AIMN subsystem. The components to be tested are:

- Augmentation System link to the Reference Stations messages generation
- Augmentation Messages generation
- NTRIPCaster Front-End
- Reference Framework Processing Centre
- Link to Satellite Ground Services
- Ancillary data generation

2.1.2 Test Case Identification

Test Cases ID are reported hereinafter:

- 01-UT-01: Augmentation Message Communication Gateway
- 01-UT-02: Reference Framework
- 01-UT-03: Augmentation Messages Calculation and Formatting – SIS and FDE
- 01-UT-04: Augmentation Messages Calculation and Formatting – DGNSS and RTK
- 01-UT-05: Ancillary Data Gateway and messages

The test case identification is showed in Table 4.

Table 1 - List of HELMET Augmentation System Test Cases

Test Case ID	Test Description	Pass/Fail Criteria
01-UT-01.01	Control Centre GNSS Reference Station Real-Time data gathering	Each Reference Station selected for the Pilot Projects is connected to the Augmentation Gateway and relevant real-time streams are sent to the Augmentation Messages Calculation and Formatting component
01-UT-01.02	User access to the Augmentation Gateway	The mountpoints for each of the Reference Stations and for the NEAREST access mode are available on the NTRIPCaster Sourcetable and a user is able to connect, retrieve and correctly decode and apply in real-time RTCM v3 streams

01-UT-02.01	Reference Stations Georeferentiation	Reference Stations RINEX data are processed and relevant Coordinates calculated in the IGS14 and ETRF2000 Reference Framework, following EUREF Guidelines
01-UT-03.01	Augmentation Messages Calculation and Formatting – Fault Detection and Exclusion for SIS	The Pmd is guaranteed by the GRDNet Monitoring System 2-Tiers Algorithm. An ephemeris or clock correction Fault is detected. The Satellite Integrity Mask into the Integrity Message is set and transmitted to the user through the Augmentation Gateway
01-UT-03.02	Augmentation Messages Calculation and Formatting – Fault Detection and Exclusion for Reference Stations	The Pmd is guaranteed by the GRDNet Monitoring System 2-Tiers Algorithm and Internal Reference Stations Monitoring features. A Reference Station Fault is detected and Reference Station Integrity Masks into the Integrity message is transmitted to the user through the Augmentation Gateway
01-UT-03.03	Augmentation Messages Calculation and Formatting – Fault Detection and Exclusion for Rail	Full 2-Tiers messages sent to the Rail user, decoded and applied. Tail THR is assured, as demonstrated in the ERSAT-EAV Project
01-UT-04.01	Augmentation Messages Calculation and Formatting – DGNSS	User access requests are accepted and RTCM V3 OSR messages provided to the Augmentation Gateway for the transmission to the user for DGNSS
01-UT-04.02	Augmentation Messages Calculation and Formatting – RTK	User access requests are accepted and RTCM V3 OSR messages provided to the Augmentation Gateway for the transmission to the user for RTK
01-UT-04.03	Augmentation System nominal Service Level – Accuracy performances	RTK and DGNSS performances are tested through the ROMA Reference Station and a rover and achievable accuracy tested
01-UT-05.01	Ancillary Tropospheric data gathering from Reference Stations	Test is passed if data streams are received from the selected Reference Stations and correctly decoded by the Augmentation Control Centre. Such test is performed subject to the availability of Reference Station in the Italian Pilot equipped with tropospheric sensor for which a data parser is available

01-UT-05.02	Ancillary Tropospheric data gathering from Meteo Stations	Test is passed if data streams are received from the selected Meteo Stations and correctly decoded by the Augmentation Control Centre. The parser for the available sources in the Italy Pilot area only is implemented.
01-UT-05.03	Ancillary Tropospheric data gathering from OBUs	Test is passed if data streams are received from OBUs and correctly decoded by the Augmentation Control Centre
01-UT-05.04	Ancillary Tropospheric data check	Test is passed if Tropospheric data are within the nominal ranges and not corrupted
01-UT-05.05	Ancillary Cadastral RP data availability	Test is passed if the Cadastral RP data (including ID and coordinates) for Italian Pilot area are available to the Augmentation Control Centre
01-UT-05.06	Ancillary data formatting	Test is passed if data are correctly formatted and sent
01-UT-05.07	Ancillary tropospheric data generation for the End Users	The receiver provides the approximate position and the tropospheric data are generated for the user in two possible modes: ▪ Nearest source of data ▪ Basic interpolation of the sources close to the user The generated P, H, T, ZTD data are logged and the contents of the message verified against the generated ones
01-UT-05.08	Precise ephemeris and clock data gathering from Satellite Ground Services for Reference Framework	sp3 files and clk file are downloaded from the IGS Centres ftp services and correctly loaded by the GNSS Reference Framework determination component
01-UT-05.09	Precise ephemeris and clock corrections are gathered in real-time from the IGS Caster and made available through the Augmentation Messages calculation and Formatting component	Precise Ephemeris and clock corrections are transmitted through relevant RTCM v3 messages. The messages are gathered from the NTRIPCaster and correctly decoded

2.1.3 Test Case Specification

In this paragraph the detailed Test Cases specifications are reported and relevant results for the Assembling, Integration and Tests Phase.
For each Test Case identified in the previous section, the following table has to be produced.
For each Test Case, the following specifications are provided:

- Test case identifier
- Test items
- Input specifications
- Output specifications
- Environmental needs and Test Procedure
- Intercase dependencies (test cases to be executed before the current one)

Relevant Pass/not Pass test results will be provided within the D4.3.

Table 2 - List of HELMET Augmentation System Test Case Specifications

Test Case ID	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-UT-01.01	Each selected Pilot Project Reference Stations is connected to the HELMET Augmentation Communication Gateway	Reference Stations RTCM v3 Real-Time streams coming to the Augmentation Gateway NTRIPCaster	Mountpoint available on the NTRIPCaster and RTCM OSR messages correctly decoded by the Augmentation Messages Calculation and Formatting Control Centre	- Communication Link available - NTRIPCaster and NTRIPServer configured and Reference Stations connected to the Augmentation Gateway	
	The user has to be able to connect to the Augmentation Gateway Reference Station mountpoint and to gather Augmentation messages	Reference Stations RTCM v3 Real-Time streams to the Augmentation Gateway NTRIPCaster Users select the Reference Station mountpoint	User receiver gathers the RTCM v3 stream and performs RTK positioning	- Communication Link available - Reference Station mountpoint available	01-UT-01.01
01-UT-01.02	The user has to be able to connect to the Augmentation	Reference Stations RTCM v3 Real-Time streams to the	Users receiver gathers the RTCM v3 stream from the closest	NEAREST mountpoint available	01-UT-01.01

	Gateway NEAREST mountpoint and to gather Augmentation messages	Augmentation Gateway NTRIPCaster Approximate position received from the user receiver	Reference Station and performs RTK positioning		
01-UT-02.01	Reference Stations Georeferentiation	Reference Station RINEX data at 30 s sampling rate for 1 week	IGS14 and ETRF2000 Coordinates	- Bernese Software - sp3, clk, DCB files and IGS CODE needed file	
01-UT-03.01	Augmentation Messages Calculation and Formatting – Fault Detection and Exclusion for SIS	-Real-Time Reference Station data stream - Simulated Real-Time Fault on GNSS satellite ephemeris and clock through a ramp error	Single or multiple satellite Fault is Detected and the relevant bits on the Satellite Integrity Mask set to ‘10’ = Don’t use. The message is sent through a dedicated mountpoint, logged for verification and correctly checked	- Communication Link available - SIS precise Ephemeris and clock error simulation	01-UT-01.01
01-UT-03.02	Augmentation Messages Calculation and Formatting – Fault Detection and Exclusion for Reference Station Fault	-Real-Time Reference Station data stream -Simulated Real-Time Fault on Reference Station	Single or multiple Reference Station Fault is Detected and Reference Station Integrity Flag set to ‘10’ = Don’t use.	- Communication Link available - Reference Station error simulation	01-UT-01.01

			The message is sent through a dedicated mountpoint, logged for verification and correctly checked		
01-UT-03.03	Full 2-Tiers test for Rail	Simulated SIS and Reference Station Fault	2-Tiers parameters are transmitted and correctly decoded by the Rail user receiver for PL calculation	Rail post-processing simulation platform (Viriglio)	01-UT-03.01 01-UT-03.02
01-UT-04.01	Augmentation Messages Calculation and Formatting – DGNSS	RTCM v3 Streams from Reference Station received from the NTRIPCaster	The Augmentation Messages Calculation and Formatting Receives the Reference Stations data streams, formats the required RTCM v3 data and send them to the Gateway for transmission to the user. An RTCM Message parser connected to the mountpoint decode the messages	- Communication Link available - RTKlib - RTCM parser	01-UT-01.01
01-UT-04.02	Augmentation Messages Calculation and Formatting –	RTCM v3 Streams from Reference Station	The Augmentation Messages Calculation and Formatting Receives the Reference Stations	- Communication Link available - RTKlib	01-UT-01.01

	Reference Station RTK	received from the NTRIPCaster	data streams, format the required RTCM v3 data and send them to the Gateway for transmission to the user. An RTCM Message parser connected to the mountpoint decode the messages	- RTCM parser	
01-UT-04.03	Augmentation System nominal Service Level- DGNSS	Reference Station RTCM v3 data streams	A rover receiver, simulated through a Reference Station close to the ROMA Reference Station, connects to the relevant mountpoint and meet the nominal SL1 service Level	The ROMA Reference Station is connected to RTKlib and performs DGNSS positioning	01-UT-01.01 01-UT-04.01
	Augmentation System nominal Service Level- RTK	Reference Station RTCM v3 data streams	A rover receiver, simulated through a Reference Station close to the ROMA Reference Station, connects to the relevant mountpoint and meet the nominal SL2 service Level	The ROMA Reference Station is connected to RTKlib and performs DGNSS positioning	01-UT-01.01 01-UT-04.02

01-UT-05.01	Ancillary Tropospheric data gathering from Reference Stations	Tropospherical data stream (Pressure, Humidity, Temperature) from the meteorological station co-located to an existing Reference Station	The Reference Station is connected and relevant data streams are gathered and decoded	- Communication Link available - Reference Station equipped with high end meteorological station - Reference station data parser	01-UT-01.01
01-UT-05.02	Ancillary Tropospheric data gathering from Meteo Stations	Tropospherical data stream (Pressure, Humidity, Temperature)	Each selected Pilot Project Meteo Stations is connected to the Ancillary Data Gateway and relevant data streams are decoded	- Communication Link available - Meteo Stations available in the Pilot Area - Meteo station data parser	
01-UT-05.03	Ancillary Tropospheric data gathering from OBU	Tropospherical data stream (Pressure and Temperature)	OBU is connected to the Ancillary Data Gateway. On-Board INS sensor data are downloaded and relevant data streams are logged and correctly decoded	Manufacturer INS interface and data decoding software	

01-UT-05.04	Ancillary Tropospherical data quality check performed by the Augmentation Control Centre	Tropospherical data stream (Pressure, Humidity, Temperature)	The logged Tropospheric data are within the declared nominal ranges and ready to be processed		01-UT-05.01 01-UT-05.02 01-UT-05.03
01-UT-05.05	Cadastral RP data availability to the Ancillary Data Gateway	Cadastral Reference Points data (Id, Coordinates)	Cadastral RP data are formatted for the Pilot area and broadcast	- Communication Link available - A Cadastral RP preloaded table for the Italian Pilot Area, based on the NMCA available data, is available	
01-UT-05.06	Tropospheric data Augmentation message calculation and formatting	Meteorological Station data	Pressure, Humidity and Temperature data messages from the meteorological stations are correctly formatted and ready to be broadcasted. A log of the generated data contains the correct fields	Meteorological station data parser	01-UT-05.04

	Cadastral RP Augmentation message calculation and formatting	User approximate position Cadastral RP data (Id, Coordinates, URL)	Based on the approximate position, the Coordinates and URLs for the Cadastral Reference Points around a circle of 5 km is contained into the message. The present test is applied to the Italian Pilot only. The decoded message contains the Cadastral Reference Point data as specified in the proposed message	Preloaded Cadastral RP table for the Italy Pilot Area	01-UT-05.05
01-UT-05.07	Tropospheric data access -NEAREST	User approximate position transmitted through NMEA GGA by the user Formatted Ancillary Tropospheric data from meteorological stations	End User is connected and relevant data streams are received. An NTRIP Client decoder logs the streams and data are correctly filled into proposed Tropospheric message	Communication Link available	01-UT-05.06
	Tropospheric data access - Interpolation	User approximate position transmitted	End User is connected and relevant data streams are received. An	- Communication Link available	01-UT-05.06

		through NMEA GGA by the user Formatted Ancillary Tropospheric data from meteorological stations, Reference Stations or OBU	NTRIP Client decoder logs the streams and data are correctly filled into proposed Tropospheric message	- Interpolation routine starting from the approximate position and meteorological station data	
01-UT-05.08	Precise ephemeris and clock data gathering from Satellite Ground Services for Reference Framework	Processing data sp3 and clk ultrarapid and final files available from the IGS Centre	sp3 and clk files are available into the correct folder	ftp server and credentials for product download from IGS sites	
01-UT-05.09	Precise Ephemeris and clock corrections real-time gathering	RTCM v3 SSR messages from the IGS site	RTCM SSR messages are received and correctly decoded from the IGS RTS site from the Augmentation Calculation and Formatting component	RTCM SSR messages decoder	

2.1 INTEGRATION TESTING

This section will describe the integration testing of the Augmentation sub-system. Once the unit testing have been performed a subsystem integration test case. At this stage we consider the interfaces as already assessed in the corresponding unit testing as described in section 3.1.

Table 3 - List of HELMET Augmentation Subsystem Integration Test Cases

Test Case ID	Test Description	Pass/Fail Criteria
01-OBU-AUG-01	Augmentation System nominal performances	The Augmentation System the requirements under nominal condition for a continuous 4 hours operation of a connected static receiver
01-OBU-AUG-02	SIS and Reference Station Integrity Messages transmission to the Car OBU	Simulated Real-Time SIS and Reference Stations Faults are transmitted to a decoder and correctly decoded
01-OBU-AUG-03	Tropospheric messages transmission	After connection to the Augmentation gateway, Tropospheric data for a testing point within the Pilot Area are logged in a file and the contents are equivalent to the transmitted one for a continuous 4h operation

3 TEST PLAN FOR RAILWAY MOBU NAVIGATION UNIT

3.1 UNIT TESTING

3.1.1 Features to be tested

The aim of this section is to identify the features objective of the test activities. Particularly, the components to be tested are:

1. GNSS correction
    a. The block shall be able to import the GNSS raw data from the COTS GNSS receiver;
    b. The block shall be able to import the integrity mask and the eventual augmentation data from the augmentation network;
    c. The block shall be able to apply the integrity mask and the eventual augmentation data received from the augmentation network;
    d. The block shall be able to provide the corrected/filtered GNSS raw data.
2. GNSS FDE
    a. The block shall be able to import the GNSS raw data from the GNSS correction block;
    b. The block shall be able to import the I/Q samples from the COTS receiver;
    c. The block shall be able to receive the feedback from the estimation computer (PVT estimation);
    d. The block shall be able to ensure the GNSS data consistency and to identify/exclude faulty measurements.
    e. The block shall be able to provide the filtered GNSS raw data.
3. Other sensors' consistency check
    a. These blocks shall be able to import the raw data from the sensors;
    b. These blocks shall be able to ensure the data consistency;
    c. These blocks shall be able to provide the filtered raw data.
4. Multi-sensor exclusion
    a. The block shall be able to import the GNSS raw data from the GNSS FDE block;
    b. The block shall be able to import the sensors' raw data from the Other sensors' consistency check blocks;
    c. The block shall be able to receive the feedback from the integrity monitoring;
    d. The block shall be able to ensure the data consistency;
    e. The block shall be able to provide the GNSS raw data and the sensors' raw data.
5. Estimation computer
    a. The block shall be able to import the GNSS raw data and the sensors' raw data; from the Multi-sensor exclusion;
    b. The block shall be able to receive the feedback from the integrity monitoring;
    c. The block shall be able to receive the GNSS raw data and/or the integrity information from the augmentation network;
    d. The block shall be able to perform the PVT estimation;
    e. The block shall be able to provide the PVT estimation and the related track identifier.
6. Integrity monitoring
    a. The block shall be able to import the PVT estimation and the related track identifier;
    b. The block shall be able to monitor the integrity and evaluate the associated PL;

c. The block shall be able to provide the PVT estimation, the associated PL and the related track identifier.

3.1.2 Test Case Identification

The test case identified are the following:

Table 4 - List of HELMET Rail OBU Test Cases

Test Case ID	Test Description	Pass/Fail Criteria
01-OBURail-01.a	The GNSS correction block shall be able to import the GNSS raw data from the COTS GNSS receiver	The data are properly read and stored in the internal structure of the function (i.e. variable)
01-OBURail-01.b	The GNSS correction block shall be able to import the integrity mask and the eventual augmentation data from the augmentation network	The data are properly read and stored in the internal structure of the function (i.e. variable)
01-OBURail-01.c	The GNSS correction block shall be able to apply the integrity mask and the eventual augmentation data received from the augmentation network	The test is passed if: 1. the eventual corrections are applied correctly and on the proper satellite 2. Only the satellites labelled as unhealthy are excluded by the usable list
01-OBURail-01.d	The GNSS correction block shall be able to provide the corrected/filtered GNSS raw data.	The data are properly present in the output internal structure (i.e. variables) and properly provided as output
01-OBURail-02.a	The GNSS FDE block shall be able to import the GNSS raw data from the GNSS correction block	The data are properly read and stored in the internal structure of the function (i.e. variable)
01-OBURail-02.b	The GNSS FDE block shall be able to import the I/Q samples from the COTS receiver	The data are properly read and stored in the internal structure of the function (i.e. variable)
01-OBURail-02.c	The GNSS FDE block shall be able to receive the feedback from the estimation computer (PVT estimation)	The data are properly read and stored in the internal structure of the function (i.e. variable)

01-OBURail-02.d	The GNSS FDE block shall be able to ensure the GNSS data consistency and to identify/exclude faulty measurements	The test Is passed if the block is able to: 1. Discriminate the presence (or the absence) of a fault 2. In case of a fault to indicate which is the involved satellite
01-OBURail-02.e	The GNSS FDE block shall be able to provide the filtered GNSS raw data	The data are properly present in the output internal structure (i.e. variables) and properly provided as output
01-OBURail-03.a	The Other sensors' consistency check blocks shall be able to import the raw data from the sensors	The data are properly read and stored in the internal structure of the function (i.e. variable)
01-OBURail-03.b	The Other sensors' consistency check blocks shall be able to ensure the data consistency	The test is passed if the block is able to discriminate the presence (or the absence) of an inconsistency among the expected temporal model and the data acquired from the sensors
01-OBURail-03.c	The Other sensors' consistency check blocks shall be able to provide the filtered raw data	The data are properly present in the output internal structure (i.e. variables) and properly provided as output
01-OBURail-04.a	The Multi-sensor exclusion block shall be able to import the GNSS raw data from the GNSS FDE block	The data are properly read and stored in the internal structure of the function (i.e. variable)
01-OBURail-04.b	The Multi-sensor exclusion block shall be able to import the sensors' raw data from the Other sensors' consistency check blocks	The data are properly read and stored in the internal structure of the function (i.e. variable)
01-OBURail-04.c	The Multi-sensor exclusion block shall be able to receive the feedback from the integrity monitoring	The data are properly read and stored in the internal structure of the function (i.e. variable)
01-OBURail-04.d	The Multi-sensor exclusion block shall be able to ensure the data consistency	The test is passed if the block is able to discriminate the presence (or the absence) of an inconsistency among the data acquired from the sensors
01-OBURail-04.e	The Multi-sensor exclusion block shall be able to provide the GNSS raw data and the sensors' raw data	The data are properly present in the output internal structure (i.e. variables) and properly provided as output

01-OBURail-05.a	The Estimation computer block shall be able to import the GNSS raw data and the sensors' raw data; from the Multi-sensor exclusion	The data are properly read and stored in the internal structure of the function (i.e. variable)
01-OBURail-05.b	The Estimation computer block shall be able to receive the feedback from the integrity monitoring	The data are properly read and stored in the internal structure of the function (i.e. variable)
01-OBURail-05.c	The Estimation computer block shall be able to receive the GNSS raw data and/or the integrity information from the augmentation network	The data are properly read and stored in the internal structure of the function (i.e. variable
01-OBURail-05.d	The Estimation computer block shall be able to perform the PVT estimation	The test is passed if the block provides a PVT estimation that differs (in absolute value) from the expected PVT within a certain threshold.
01-OBURail-05.e	The Estimation computer block shall be able to provide the PVT estimation and the related track identifier	The data are properly present in the output internal structure (i.e. variables) and properly provided as output
01-OBURail-06.a	The Integrity monitoring block shall be able to import the PVT estimation and the related track identifier	The data are properly read and stored in the internal structure of the function (i.e. variable)
01-OBURail-06.b	The Integrity monitoring block shall be able to monitor the integrity and evaluate the associated PL	The test Is passed if the block is able to: 1. Discriminate the presence (or the absence) of a fault 2. In case of a fault to indicate which is the involved satellite
01-OBURail-06.c	The Integrity monitoring block shall be able to provide the PVT estimation, the associated PL and the related track identifier	The data are properly present in the output internal structure (i.e. variables) and properly provided as output

3.1.3 Test Case Specification

For each Test Case identified in the previous section, the following table has to be produced. For each test case, the following specifications are provided:

- Test case identifier
- Test items
- Input specifications
- Output specifications
- Environmental needs and Test Procedure
- Intercase dependencies (test cases to be executed before the current one)

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-01.a	The GNSS correction block shall be able to import the GNSS raw data from the COTS GNSS receiver	RTCM stream	Internal variable	Personal Computer and GNSS receiver	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-01.b	The GNSS correction block shall be able to import the integrity mask and the eventual augmentation data from the augmentation network	RTCM stream	Internal variable	Personal Computer with a network connection	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-01.c	The GNSS correction block shall be able to apply the integrity mask and the eventual augmentation data received from the augmentation network	1. GNSS raw data; 2. Integrity mask; 3. Augmen. data	Filtered GNSS raw data	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-01.d	The GNSS correction block shall be able to provide the corrected/filtered GNSS raw data.	Internal variable	Internal stream	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-02.a	The GNSS FDE block shall be able to import the GNSS raw data from the GNSS correction block	Internal stream	Internal variable	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-02.b	The GNSS FDE block shall be able to import the I/Q samples from the COTS receiver	Receiver Proprietary stream	Internal variable	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-02.c	The GNSS FDE block shall be able to receive the feedback from the estimation computer (PVT estimation)	Internal stream	Internal variable	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-02.d	The GNSS FDE block shall be able to ensure the GNSS data consistency and to identify/exclude faulty measurements	1. GNSS raw data; 2. I/Q samples; 3. PVT estimation	Filtered GNSS raw data	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-02.e	The GNSS FDE block shall be able to provide the filtered GNSS raw data	Internal variable	Internal stream	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-03.a	The Other sensors' consistency check blocks shall be able to import the raw data from the sensors	Sensor specific proprietary binary stream	Internal variable	Personal Computer and sensors	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-03.b	The Other sensors' consistency check blocks shall be able to ensure the data consistency	Sensors raw data	Filtered sensors raw data	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-03.c	The Other sensors' consistency check blocks shall be able to provide the filtered raw data	Internal variable	Internal stream	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-04.a	The Multi-sensor exclusion block shall be able to import the GNSS raw data from the GNSS FDE block	Internal stream	Internal variable	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-04.b	The Multi-sensor exclusion block shall be able to import the sensors' raw data from the Other sensors' consistency check blocks	Internal stream	Internal variable	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-04.c	The Multi-sensor exclusion block shall be able to receive the feedback from the integrity monitoring	Internal stream	Internal variable	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-04.d	The Multi-sensor exclusion block shall be able to ensure the data consistency	1. GNSS raw data; 2. Sensors raw data	1. GNSS raw data; 2. Sensors raw data	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-04.e	The Multi-sensor exclusion block shall be able to provide the GNSS raw data and the sensors' raw data	Internal variable	Internal stream	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-05.a	The Estimation computer block shall be able to import the GNSS raw data and the sensors' raw data from the Multi-sensor exclusion	Internal stream	Internal variable	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-05.b	The Estimation computer block shall be able to receive the feedback from the integrity monitoring	Internal stream	Internal variable	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-05.c	The Estimation computer block shall be able to receive the GNSS raw data and/or the integrity information from the augmentation network	Internal stream	Internal variable	Personal Computer with a connection network	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-05.d	The Estimation computer block shall be able to perform the PVT estimation	1. GNSS raw data; 2. Sensors raw data; 3. Augmentation data	1. PVT estimation; 2. Track Id	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-05.e	The Estimation computer block shall be able to provide the PVT estimation and the related track identifier	Internal variable	Internal stream	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-06.a	The Integrity monitoring block shall be able to import the PVT estimation and the related track identifier	Internal stream	Internal variable	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-06.b	The Integrity monitoring block shall be able to monitor the integrity and evaluate the associated PL	1. PVT 2. Track Id 3. GNSS raw data	1. Checked PVT; 2. Checked Track Id; 3. PL	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBURail-06.c	The Integrity monitoring block shall be able to provide the PVT estimation, the associated PL and the related track identifier	Internal variable	Internal stream	Personal Computer	N/A

3.2 INTEGRATION TESTING

This section will describe the integration testing of the sub-systems that compose the MOBU Rail. Once the unit testing have been performed an integration test case for each of the identified block will be provided. At this stage we consider the interfaces as already assessed in the corresponding unit testing as described in section 3.1.

Table 5 - List of HELMET Rail OBU Integration Test Cases

Test Case ID	Test Description	Pass/Fail Criteria
02-OBURail-01	The GNSS correction block shall be able to apply the integrity mask and the eventual corrections provided by the Augmentation Network to the GNSS raw data acquired from the COTS receiver	The test is passed if: 1. the eventual corrections are applied correctly and on the proper satellite 2. Only the satellites labelled as unhealthy are excluded by the usable list)
02-OBURail-02	The FDE block shall be able to identify inconsistencies/faults in the GNSS SIS and exclude them	The test Is passed if the block is able to: 1. Discriminate the presence (or the absence) of a fault 2. In case of a fault to indicate which is the involved satellite
02-OBURail-03	The Other sensors' consistency check block shall be able to identify inconsistencies in the data acquired from the sensors	The test is passed if the block is able to discriminate the presence (or the absence) of an inconsistency among the expected temporal model and the data acquired from the sensors
02-OBURail-04	The multi-sensor exclusion block shall be able to identify inconsistencies among the different sensors	The test is passed if the block is able to discriminate the presence (or the absence) of an inconsistency among the data acquired from the sensors
02-OBURail-05	The estimation computer block shall be able to provide a PVT estimation	The test is passed if the block provides a PVT estimation that differs (in absolute value) from the expected PVT within a certain threshold.
02-OBURail-06	The Integrity monitoring block shall be able to monitor the integrity of the solution	The test Is passed if the block is able to:

		1. Discriminate the presence (or the absence) of a fault 2. In case of a fault to indicate which is the involved satellite

4 TEST PLAN FOR AUTOMOTIVE MOBU NAVIGATION UNIT

4.1 UNIT TESTING

4.1.1 Features to be tested

The aim of this section is to identify the features objective of the test activities to be carried out related to the automotive onboard unit. Particularly, the components to be tested are:

GNSS Processing

1. Local Threats protection
    a. The block shall be able to import the raw data from the COTS receiver;
    b. The block shall be able to ensure the GNSS data consistency and to discard faulty measurements.
    c. The block shall be able to discard measurements under certain elevation mask, under certain CN0 mask.
    d. The block shall be able to detect and discard measurements with excessive multipath error.
    e. The block shall be able to provide the GNSS raw data after applying the protection masks.
2. Augmentation Correction
    a. The block shall be able to import the GNSS raw data from the COTS GNSS receiver after mask from local threat protection have been applied;
    b. The block shall be able to import the integrity mask and the eventual augmentation data from the augmentation network;
    c. The block shall be able to apply the integrity mask and the eventual augmentation data received from the augmentation network;
    d. The block shall be able to provide the corrected/filtered GNSS raw data.
3. PVT / RTK
    a. The block shall be able to import corrected/filtered GNSS raw data
    b. The block shall be able to compute PVT solution
    c. The block shall be able to provide PVT solution information

INS & Sensor Fusion

4. Strapdown INS
    a. This block shall be able to import raw data from IMU sensor
    b. This block shall be able to compute position, velocity and attitude (PV-A) in a suitable reference frame
    c. This block shall be able to provide the compute INS solution
5. Extended Kalman Filter
    a. This block shall be able to import the INS PV-A and import the corrected GNSS raw measurements
    b. This block shall be able to estimate calibrated INS and GNSS PVT-A solution based on the available information over time

   c. This block shall be able to provide PVT-A solution as well as covariance matrices that overbound the underlying error of the estimated parameters.
6. KF Fault Detection and Exclusion
   a. This block shall be able to receive either KF innovations or KF SS residuals
   b. This block shall be able to determine whether a fault has occurred
   c. This block shall be able to determine SS case which satellites must be excluded depending on the detect fault hypothesis and provide this to the EKF block.
7. Integrity Monitoring
   a. This block shall be able to import the PVT-A estimation and covariances from the EKF from the different subfilters
   b. This block shall be able to compute relevant protection levels.
   c. This block shall be able to provide PVT-A estimation, the associated PL

8. **Camera processing**
   a. This block shall be able to import the images from the cameras installed on the vehicle
   b. This block shall be able to detect the lanes of the road and compute a relative position with respect to them
   c. This block shall be able to provide the computed relative positioning to the localization mode selector

9. **Localization Mode Selector**
   a. This block shall be able to import the positioning solution information and associated integrity measures from the stand-alone PVT/RTK block, the INS & Sensor fusion block and the Camera processing block
   b. This block shall be able to determine the best solution to provide to the user along with integrity information.

4.1.2 Test Case Identification

The test case identified are the following:

Table 6 - List of HELMET Automotive OBU Test Cases

Test Case ID	Test Description	Pass/Fail Criteria
01-OBUAuto-01.a	The Local Threats Protection Block shall be able to import the raw data from the COTS receiver	The data are properly read and stored in the internal structure of the function (i.e. variable)
01-OBUAuto-01.b	The Local Threats Protection Block shall be able to ensure the GNSS data consistency and to discard faulty measurements	The test is passed if the block is able to: 1. Discriminate the presence (or the absence) of a fault

		2. In case of a fault to indicate which is the involved satellite
01-OBUAuto-01.c	The Local Threats Protection block shall be able to discard measurements under certain elevation mask, under certain CN0 mask.	The test is passed if the measurements from satellites under the elevation or CN0 are correctly discarded.
01-OBUAuto-01.d	The Local Threats Protection block shall be able to detect and discard measurements with excessive multipath error.	The test is passed if the measurements from satellites under the elevation or CN0 are correctly discarded.
01-OBUAuto-01.e	The Local Threats Protection block shall be able to provide the GNSS raw data after applying the protection masks.	The data are properly present in the output internal structure (i.e. variables) and properly provided as output
01-OBUAuto-02.a	The Augmentation block shall be able to import the GNSS raw data from the COTS GNSS receiver after mask from local threat protection have been applied	The data are properly read and stored in the internal structure of the function (i.e. variable)
01-OBUAuto-02.b	The Augmentation block shall be able to import the integrity mask and the eventual augmentation data from the augmentation network	The data are properly read and stored in the internal structure of the function (i.e. variable)
01-OBUAuto-02.c	The Augmentation block shall be able to apply the integrity mask and the eventual augmentation data received from the augmentation network	The test is passed if: 1. the eventual corrections are applied correctly and on the proper satellite 2. Only the satellites labelled as unhealthy are excluded by the usable list
01-OBUAuto-02.d	The Augmentation block shall be able to provide the corrected/filtered GNSS raw data	The data are properly present in the output internal structure (i.e. variables) and properly provided as output
01-OBUAuto-03.a	The PVT block shall be able to import corrected/filtered GNSS raw data	The data are properly read and stored in the internal structure of the function (i.e. variable)

01-OBUAuto-03.b	The PVT block shall be able to compute PVT solution	The test is passed if the block provides a PVT estimation that differs (in absolute value) from the expected PVT within a certain threshold.
01-OBUAuto-03.c	The PVT block shall be able to provide PVT solution information	The data are properly present in the output internal structure (i.e. variables) and properly provided as output
01-OBUAuto-04.a	The INS block shall be able to import raw data from IMU sensor	The data are properly read and stored in the internal structure of the function (i.e. variable)
01-OBUAuto-04.b	The INS block shall be able to compute position, velocity and attitude (PV-A) in a suitable reference frame	The test is passed if the block is able to compute iteratively a PV-A solution that is consistent with the expected drift rate of the sensor.
01-OBUAuto-04.c	The INS block shall be able to provide the compute INS solution	The data are properly present in the output internal structure (i.e. variables) and properly provided as output
01-OBUAuto-05.a	The EKF block shall be able to import the INS PV-A and import the corrected GNSS raw measurements	The data are properly read and stored in the internal structure of the function (i.e. variable)
01-OBUAuto-05.b	The EKF block shall be able to estimate calibrated INS and GNSS PVT-A solution based on the available information over time	The test is passed if the PVT-A solution obtained contains an error that is contained by the EKF covariances.
01-OBUAuto-05.c	The EKF block shall be able to provide PVT-A solution as well as covariance matrices that overbound the underlying error of the estimated parameters	The data are properly present in the output internal structure (i.e. variables) and properly provided as output
01-OBUAuto-06.a	The FDE block shall be able to receive either KF innovations or KF SS residuals	The data are properly read and stored in the internal structure of the function (i.e. variable)
01-OBUAuto-06.b	The FDE block shall be able to determine whether a fault has occurred	The test is passed if when measurement or position errors exceed the expected level a fault is declared
01-OBUAuto-06.c	The FDE block shall be able to determine SS case which satellites	The test is passed if a certain fault mode can be isolated as the

	must be excluded depending on the detect fault hypothesis and provide this to the EKF block	responsible for the declaration of a fault
01-OBUAuto-07.a	The Integrity Monitoring block shall be able to import the PVT-A estimation and covariances from the EKF from the different subfilters	The data are properly read and stored in the internal structure of the function (i.e. variable)
01-OBUAuto-07.b	The Integrity Monitoring block shall be able to compute relevant protection levels	The test is passed if the IM block provides protection levels that are consistent with the estimation uncertainty and the fault detector performance.
01-OBUAuto-07.c	The Integrity Monitoring block shall be able to provide PVT-A estimation, the associated PL	The data are properly present in the output internal structure (i.e. variables) and properly provided as output
01-OBUAuto-08.a	The Camera block shall be able to import the images from the cameras installed on the vehicle	The data are properly read and stored in the internal structure of the function (i.e. variable)
01-OBUAuto-08.b	The Camera block shall be able to detect the lanes of the road and compute a relative position with respect to them	The test is passed if for nominal situations, the block is able to detect the position of the lanes with an error contained in a certain level.
01-OBUAuto-08.c	The Camera block shall be able to provide the computed relative positioning to the localization mode selector	The data are properly present in the output internal structure (i.e. variables) and properly provided as output
01-OBUAuto-09.a	The Selector block shall be able to import the positioning solution information and associated integrity measures from the stand-alone PVT/RTK block, the INS & Sensor fusion block and the Camera processing block	The data are properly read and stored in the internal structure of the function (i.e. variable)
01-OBUAuto-09.b	The Selector block shall be able to determine the best solution to provide to the user along with integrity information	The test is passed if the best PVT solution is selected according to the current scenario. The data are properly present in the output internal structure (i.e. variables) and properly provided as output

4.1.3 Test Case Specification

For each Test Case identified in the previous section, the following table has to be produced. For each test case, the following specifications are provided:

- Test case identifier
- Test items
- Input specifications
- Output specifications
- Environmental needs and Test Procedure
- Intercase dependencies (test cases to be executed before the current one)

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-01.a	The Local Threats Protection Block shall be able to import the raw data from the COTS receiver	Receiver Proprietary stream	Internal variable	Personal Computer, GNSS antenna	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-01.b	The Local Threats Protection Block shall be able to ensure the GNSS data consistency and to discard faulty measurements	GNSS raw data	Filtered GNSS raw data	Personal Computer and GNSS receiver	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-01.c	The Local Threats Protection block shall be able to discard measurements under certain elevation mask, under certain CN0 mask.	1. CN0 values 2. Satellite Elevations	Filtered GNSS raw data	Personal Computer and GNSS receiver	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-01.d	The Local Threats Protection block shall be able to detect and discard measurements with excessive multipath error.	GNSS raw data	Filtered GNSS raw data	Personal Computer and GNSS receiver	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-01.e	The Local Threats Protection block shall be able to provide the GNSS raw data after applying the protection masks.	Internal variable	Internal stream	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-02.a	The Augmentation block shall be able to import the GNSS raw data from the COTS GNSS receiver after mask from local threat protection have been applied	RTCM stream	Internal variable	Personal Computer and GNSS receiver	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-02.b	The Augmentation block shall be able to import the integrity mask and the eventual augmentation data from the augmentation network	RTCM stream	Internal variable	Personal Computer with a network connection	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-02.c	The Augmentation block shall be able to apply the integrity mask and the eventual augmentation data received from the augmentation network	1. GNSS raw data; 2. Integrity mask; 3. Augmen. data	Filtered GNSS raw data	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-02.d	The Augmentation block shall be able to provide the corrected/filtered GNSS raw data.	Internal variable	Internal stream	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-03.a	The PVT block shall be able to import corrected/filtered GNSS raw data	Filtered raw GNSS data	Internal variable	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-03.b	The PVT block shall be able to compute PVT solution	Internal variable	1. PVT estimation 2. Associated Uncertainty	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-03.c	The PVT block shall be able to provide PVT solution information	Internal variable	Internal stream	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-04.a	The INS block shall be able to import raw data from IMU sensor	1. 3D Specific forces 2. 3D angular rates	Internal variable	Personal Computer and IMU sensor connection	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-04.b	The INS block shall be able to compute position, velocity and attitude (PV-A) in a suitable reference frame	Internal variable	1. Position 2. Velocity 3. Attitude	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-04.c	The INS block shall be able to provide the compute INS solution	Internal variable	Internal stream	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-05.a	The EKF block shall be able to import the INS PV-A and import the corrected GNSS raw measurements	1. Raw/corrected GNSS data 2. Augmentation information 3. INS solution	Internal variable	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-05.b	The EKF block shall be able to estimate calibrated INS and GNSS PVT-A solution based on the available information over time	Internal variable	1. Corrected INS solution 2. EKF Covariances 3. EKF residuals	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-05.c	The EKF block shall be able to provide PVT-A solution as well as covariance matrices that overbound the underlying error of the estimated parameters	Internal variable	Internal stream	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-06.a	The FDE block shall be able to receive either KF innovations or KF SS residuals	1. EKF residuals	Internal variable	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-06.b	The FDE block shall be able to determine whether a fault has occurred	Internal variable	Test statistic and satellite /hypothesis flag	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-06.c	The FDE block shall be able to determine SS case which satellites must be excluded depending on the detect fault hypothesis and provide this to the EKF block	Internal variable	Internal stream	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-07.a	The Integrity Monitoring block shall be able to import the PVT-A estimation and covariances from the EKF from the different subfilters	INS corrected PVT-A	Internal variable	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-07.b	The Integrity Monitoring block shall be able to compute relevant protection levels	Internal variable	Protection levels	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-07.c	The Integrity Monitoring block shall be able to provide PVT-A estimation, the associated PL	Internal variable	Internal stream	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-08.a	The Camera block shall be able to import the images from the cameras installed on the vehicle	Camera images	Internal variable	Personal Computer and connection to camera datalink	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-08.b	The Camera block shall be able to detect the lanes of the road and compute a relative position with respect to them	Internal variable	Relative position	Personal Computer and information about the roadmap	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-08.c	The Camera block shall be able to provide the computed relative positioning to the localization mode selector	Internal variable	Internal stream	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-09.a	The Selector block shall be able to import the positioning solution information and associated integrity measures from the stand-alone PVT/RTK block, the INS & Sensor fusion block and the Camera procressing block	1. Standalone (PVT/RTK) position solution 2. INS-EKF solution with PL 3. Relative Camera position	Internal variable	Personal Computer	N/A

Test Case	Test Items	Input	Output	Environmental Needs	Intercase Dependencies
01-OBUAuto-09.b	The Selector block shall be able to determine the best solution to provide to the user along with integrity information	Internal variable	1. Vehicle position and dynamics 2. Integrity/reliability information	Personal Computer and map information and scenario information	N/A

4.2 INTEGRATION TESTING

This section will describe the integration testing of the sub-systems that compose the Automotive MOBU. Once the unit testing has been performed an integration test case for each of the identified block will be provided. At this stage we consider the interfaces as already assessed in the corresponding unit testing as described in section 3.1.

Table 7 - List of HELMET Automotive OBU Integration Test Cases

Test Case ID	Test Description	Pass/Fail Criteria
02-OBUAuto-01	The Local Threats Protection block shall be able to detect and discard measurements with excessive unbounded error.	The test is passed if the measurements from satellites experiencing unacceptable errors are discarded.
02-OBUAuto-02	The Augmentation block shall be able to apply the integrity mask and the eventual augmentation data received from the augmentation network	The test is passed if: 1. the eventual corrections are applied correctly and on the proper satellite 2. Only the satellites labelled as unhealthy are excluded by the usable list
02-OBUAuto-03	The PVT block shall be able to compute PVT solution	The test is passed if the block provides a PVT estimation that differs (in absolute value) from the expected PVT within a certain threshold.
02-OBUAuto-04	The INS block shall be able to compute position, velocity and attitude (PV-A) in a suitable reference frame	The test is passed if the block is able to compute iteratively a PV-A solution that is consistent with the expected drift rate of the sensor.
02-OBUAuto-05	The EKF block shall be able to estimate calibrated INS and GNSS PVT-A solution based on the available information over time	The test is passed if the PVT-A solution obtained contains an error that is contained by the EKF covariances.
02-OBUAuto-06	The FDE block shall be able to determine whether a fault has occurred	The test Is passed if the block is able to: 3. Discriminate the presence (or the absence) of a fault 4. In case of a fault to indicate which is the involved satellite

02-OBUAuto-07	The Integrity Monitoring block shall be able to compute relevant protection levels	The test is passed if the IM block provides protection levels that are consistent with the estimation uncertainty and the fault detector performance.
02-OBUAuto-08	The Camera block shall be able to detect the lanes of the road and compute a relative position with respect to them	The test is passed if for nominal situations, the block is able to detect the position of the lanes with an error contained in a certain level.
02-OBUAuto-09	The Selector block shall be able to determine the best solution to provide to the user along with integrity information	The test is passed if the best PVT solution is selected according tot he current scenario. The data are properly present in the output internal structure (i.e. variables) and properly provided as output

5 TEST PLAN FOR UAV MOBU NAVIGATION UNIT

5.1 INTRODUCTION

5.1.1 Purpose

The Purpose of this Section is to provide a Test Plan for the Verification and Validation of the UAS HELMET Segment and specifically of its Airborne and Ground-board Navigation, C3 Link and Dedicated to the Rail and Automotive Applications Inspection, Monitoring and Traffic Management (IMTM) Payload Subsystems in terms and in accordance with the Functional, Operational Performance, Safety and Security Requirements provided in the deliverable document D2.3 System Requirements Specification and D3.3 Detailed Architecture Design Document. In addition, the scope of this section is to provide a description and rationale of the Test Program requirements, the main test tasks and the related organization which will manage and conduct the tests, the UAS items to be tested, the test criteria, the test means, facilities and environment, the test deliverables and associated Schedule and the Test Program Approach. The Planned Tests will be carried out in terms of cases and scenarios in accordance with the UAV CONOPS section of the D2.2 HELMET CONOPS Document.

The Tests for Verification and Validation of the IMTM Services UAS for rail and road will be planned into two (2) Categories, namely: a) UAS System Ground Testing and b) UAS System In-flight Testing. In the prospected testing, the role of <u>Verification</u> is to provide confirmation that the UAS Segment will comply with its specified requirements while the role of <u>Validation</u> is to provide proof that the UAS segment operational capability (ie. capabilities of the combination of the mission system and the support system) satisfies the HELMET user's needs in IMTM. Verification and Validation Testing (V&VT) is also an effective risk management tool through which system deficiencies can be identified and rectified early in the system development process. Early identification and rectification ensures that the system being developed achieves key milestones and meets the user's needs, and results in significant cost savings. An important part of V&V planning is to prioritise the deficiencies associated with non-compliances where the prioritisation is based on:

a) identifying the magnitude of the risk presented by the defect, and
b) the difficulty of remedying the defect.

This prioritisation will guide the level of effort applied to remedying the deficiencies by improving the design processes or the design of the system. Through analysis of the set of defects, V&VT may also allow the identification and rectification of systemic defects in the developmental process.

5.1.2 IMTM UAS Segment Test Program Main Objectives and Typology

There will be six (6) main objectives for the HELMET UAS Segment Ground and Flight Test Program Process implementation:

1) To verify and validate that the rail and road IMTM services UAS Segment ground and flight test results are credible and support the overall HELMET system acquisition decision making.
2) To provide the Test Program Requirements, needed Means (Tools, Equipment and Facilities) and related manpower profile for the Ground and Flight Test Program Implementation.
3) To mainly Verify and Validate through ground and flight testing the Airborne and Ground-board GNSS-Galileo Navigation System, the C3 (Command, Control and Communication) Link and the Dedicated to the Rail and Automotive Applications IMTM Payload Subsystems overall Operational Performance and Safety Capabilities within the established CONOPS Mission Scenarios.
4) To provide early identification of the HELMET IMTM services UAS segment operational performance and supportability deficiencies for resolution.
5) To identify and measure all key performance (Functional and Operational) and Safety parameters that are critical to UAS Mission effectiveness and suitability within the HELMET Network and UTM environment.
6) To provide early identification and timely acquisition of test assets.

The Front Part of the HELMET UAS Segment Testing will be mainly Developmental. Such type of testing denotes a generic term encompassing Verification and Validation engineering type tests that are used to Evaluate that design risks are minimized, that safety of the system is certified, that achievement of system technical performance is substantiated, and that readiness for Operations is validated and certified. The Developmental Testing generally requires instrumentation and measurements and is normally accomplished by engineers and specialist technicians. It is repeatable, can be environmentally controlled, and covers the complete spectrum of the system capabilities. Specifically, the HELMET UAS Segment will be subjected to the following Developmental Testing (DT) which will include actual field (Ground and Flight) testing but also and in some cases simulations:

a) Technical Feasibility Tests: A technical feasibility test is a developmental test typically conducted during concept and technology development to provide data to assist in determining safety and health hazards and establishing system performance specifications and feasibility.

b) Developmental Design Verification and Validation or Engineering Developmental Tests: This type of developmental tests are typically conducted during system development and demonstration to provide data on performance, safety, survivability/vulnerability, the achievability of the system's critical technical parameters, refinement of hardware configurations, and determination of technical risks. The engineering development tests include the testing of compatibility and interoperability with existing or planned equipment and systems and the system effects caused by natural and induced environmental conditions.

c) Software Verification and Validation Developmental Tests: The Software Verification and Validation Developmental Tests consist of program or module and cycle or system levels of testing. The software developmental testing will be conducted under an independent quality control function. The software test team validates that the functional requirements are being met. The unit or module test is the initial testing level. Testing is generally executed on local test-bed hardware, and benchmark test files are used. This testing provides data to assess the effectiveness of the instruction code and economy of subroutines and object components for efficient processing. It also ensures that input and output formats, data handling procedures, and outputs are produced correctly. The cycle or system test involves testing the combination of linkage of programs or modules into major processes. It is a formal test conducted by the software developer and the proponent agency to ensure that the technical and functional objectives of the system are met. It requires a separate formal test plan, test analysis report, and certification that the objectives were met and were satisfactory to all participants.

d) Developmental First article Tests (FAT): The FAT may be required for quality assurance purposes to qualify acquired by outsourcing items whether of COTS or Developments which are critical system assemblies, components, or parts conforming to requirements of the technical data package.

e) RAMS Verification and Validation Tests: This type of tests are dedicated to the actual and/or simulated tests for the verification and validation of the Reliability, Availability, Maintainability and Safety characteristics of the system. In a certain sense such testing is also performed to support in terms of verification and validation of the Technical Risk and Hazards Analysis done during the system design by System Engineering.

f) Ground and Flight Operational Trial Tests: This type of tests encompass the entire operational testing effort during development. Such testing is performed using the actual system as would have been deployed in the field and concerns the verification and validation of all software, firmware and hardware mainly under new developments (such as the UAS NAV and C3 Link subsystems).

5.1.3 HELMET UAS Segment Test Program General Requirements

The following are general Test Program Requirements that will be applicable to the HELMET UAS Segment for Verification and Validation of all Developmental Items:

1) Test Program General Requirements
   a) An UAS Segment coherent test program shall be established, encompassing each stage and level to implement the verification and validation by testing.
   b) The test program shall be performed incrementally at different system decomposition levels.
   c) UAS Segment Test procedures shall be derived from test specifications.
   d) The Test program and its implementation shall be in conformance with safety requirements as established in the HELMET Documents D2.1 and D2.3.

2) Developmental Testing General Requirements
   a) The UAS Segment Developmental testing shall be completed prior to the start of its formal Qualification and Certification Testing. Developmental tests shall be conducted over a range of operating conditions that can exceed the design range.
   b) Documented Records of test planning, configuration, test results and other pertinent data shall be maintained.

3) Test Management General Requirements
   a) HELMET Management shall assign clear responsibility for the implementation and conduct of the UAS Segment Test Program.
   b) In Terms of Reviews, the test program shall be decomposed in blocks. The entire test program shall be reviewed at the CDR.
   c) Typical test blocks for the UAS segment elements shall be: Integration, Alignment, Mechanical, EMC, EMI, RF, Electrical, Safety, Reliability, Functional and Performance tests.
   d) Each test block shall include the following formal reviews: Test Readiness Review (TRR) which shall be held before the start of the test activity to verify that all conditions allow to proceed with the test.; Post Test Review(s) (PTR); which shall be held in order to formally declare the test completed and allow the release of the item under test and test facility for further activity. Test Review Board (TRB) which shall be held to review all results and conclude on the test completeness and achievement of objectives.

4) Test Documentation General Requirements
   a) UAS Segment Test Program Documentation (Test Plan, Test Specification, Test Procedure, and Test Report) shall be generated at all system levels.
   b) The Required Test Program Documentation shall be delivered as follows: 1) the Test Plan shall be delivered prior to CDR, 2) the Test Specification shall be delivered prior to TRR, 3) Test Procedure of Specific Test shall be delivered at TRR, 4) Test Report shall be delivered after single testing blocks have been successfully completed and prior to TRB. The test report describes test execution, results and conclusions in the light of the test requirements. It shall contain the test description and the test results including the as-run test procedures, the considerations and conclusions with particular emphasis on the close-out of the relevant verification requirements including any deviation.

5) General Requirements for Anomaly or Failure during Testing
   a) Any failure or anomaly during testing shall be recorded.

b) All non-conformances shall be managed as per Test Specification.
c) The Non-conformance Review Board (NRB) shall decide on the necessity and extent of any retest activity in order to demonstrate the correctness of the disposition made.

6) Test Data General Requirements
   a) Test measurements and the environmental conditions shall be recorded for subsequent evaluation.
   b) A database of parameters shall be established for trend analysis.
   c) Trend analysis shall be performed using test data acquired across test sequences.

7) Test Conditions General Requirements
   a) Test conditions shall be established using predicted environment plus margins.
   b) Ground Tests shall be performed simulating the mission envelope, including operational and non-operational conditions with margins.
   c) For items tested in an environment different from the one it is expected to operate, the possible differences in behaviour shall be accounted for in the test levels and duration.
   d) Test facilities, tools and instrumentation shall not prevent to fulfil the test objectives.
   e) The Ground Support Test Equipment (GSTE) or other support systems of the item under test shall: 1) not jeopardize the results of tests; 2) be immune to signals used for susceptibility tests; 3) be designed to comply with the applicable legislation, including safety such as EU and/or EASA Directives.
   f) The combination of test set-up, test levels durations, and operational modes shall not create conditions that can: 1) induce failures of the item under test, 2) lead to rejection of adequate item under test, or 3) create hazardous conditions.

8) Test Tolerances General Requirements
   a) Test tolerances bands shall be specified in test error budgets prior to start of test.
   b) For the purpose of (8.a) above, test tolerances shall be justified by reference to the uncertainty budget and confidence level of the measurement instrument(s) used.
   c) Quantitative requirements demonstrated by measured test values shall account for test inaccuracies and tolerances, and be compared with the specified requested values.

9) Test Accuracies General Requirements
   a) Test accuracies shall be specified in test error budgets prior to test performance.
   b) The accuracy of test instrumentation shall be verified in accordance with approved calibration procedures, with traceability to international measurement standards.
   c) All test instrumentation shall be within the normal calibration period at the time of the test.
   d) Any anomaly of test instrumentation, detected at the first calibration sequence after the test, shall be reported.

5.1.4 UAS IMTM Key Mission Test Elements (MTE) Overall Description

The Test Program for the Verification and Validation of the UAS Segment Navigation Unit, C3 Link Subsystem and Mission Tailored Payload Performance will be in accordance with the D2.2 HELMET CONOPS Section 3.3 and within the HELMET Infrastructure. For Test purposes, the UAS will perform missions under selected Mission Test Element (MTE) within the Inspection, Monitoring and Traffic Management (IMTM) tasks supporting Rail and Automotive Operations. Such MTEs may include:

1) Railway and Road Infrastructural Assets Construction Works Status Inspection and Monitoring
2) Inspection and Evaluation of damages, defects or deformations and cracks of bridges, tunnels, depot buildings, railway tracks, and road pavement conditions for accessibility;

3) Inspection for maintenance of high value rail and road assets;
4) Aerial imaging to support Geographic Information System (GIS) database for Rail and Road assets;
5) Rail and Road Assets/Property General Survey and Inventory Control for future Growth and Development Needs;
6) Surveying and Classifying plant species to be removed and/or relocated while constructing a future railway track and/or highway and/or Urban or Extra-Urban Road;
7) Monitoring for Improving safety of labour when working on railway, highways and roads;
8) Monitoring Highway, Road (Urban and Extra-Urban) Traffic Conditions, and Tracking Vehicle movements at important and/or statistically dangerous intersections;
9) Monitoring and/or Managing Emergency and/or Civil Protection Vehicle Guidance;
10) Tracking, Surveillance and Monitoring of Accidents and/or Post-Accident on railways and roads;
11) Traffic Data Collection and signage inventory;
12) Surveillance for acts of vandalism on rail and road assets/property, monitoring illegal acts (i.e. theft) and intrusions in segregated for safety and high value rail and road property.
13) Monitoring for obstacles on railway tracks and roads that will cause incidents and accidents.

The total of the IMTM missions in RLOS and/or BRLOS operational modes will have the flight envelop depicted in Figure 2 below which as a planning reference will apply to the Test Flight Campaign Cases.

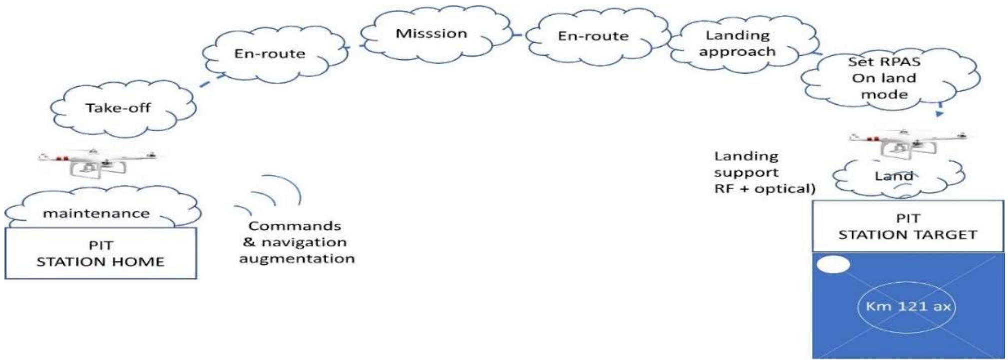


Figure 2. UAV Test Reference Mission Envelop and Operative Modes

5.1.5 UAS Key Segment Items Subjected to Test Campaign-Summary Description

The UAS Navigation Unit, C3 Link Subsystem, DAA and IMTM Payloads shall be the items to undergo specific testing for Functional, Operational, Safety and Security Testing. However, the actual testing won't take place under the present HELMET Project Contract but if approved it may be under a new dedicated project. The detailed description and design of the UAS Navigation Unit and C3 Link Subsystem is found in 3.3 Detailed Architecture Design Document. The overall UAS HELMET Application Segment overall Architecture is provided in Figure 3 While the UAS (Airborne and Ground-board systems) Command, Control and Communication (C3) link and selected mission payloads will be Commercially available Off-The-Self (COTS) items which will be subjected only to acceptance and integration testing, the Multi-Sensor On-Board Unit (MOBU) will be specifically be developed for the HELMET Program and thus as a novel item will be subjected to developmental testing for verification and validation.

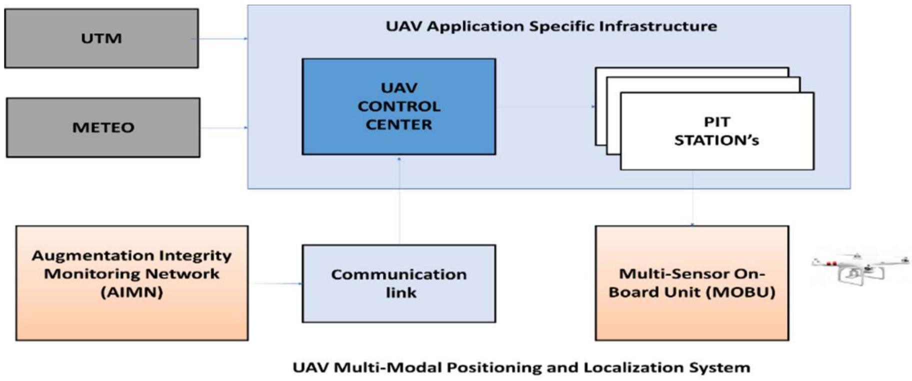


Figure 3. Overall UAS HELMET Application Segment Architecture

However, all items will be subjected to Field Performance Testing for Verification and Validation of being fully capable to satisfy the specified IMTM missions for the HELMET Infrastructure. The UAS MOBU and NAV Subsystem, therefore will be the item that is called herein to be more detailed in terms of testing needs since it will be subjected to a full Developmental Cycle in a future effort outside the present HELMET context. Figure 4 (Refer to Document D3.2) depicts the proposed architecture for the MOBU and associated Navigation Unit. Furthermore Figure 5 provides the Avionic Integrated Integrity Functional Block Diagram According to ABIA Principle and Legacy Standard ARAIM (Ref. Document D2.3).

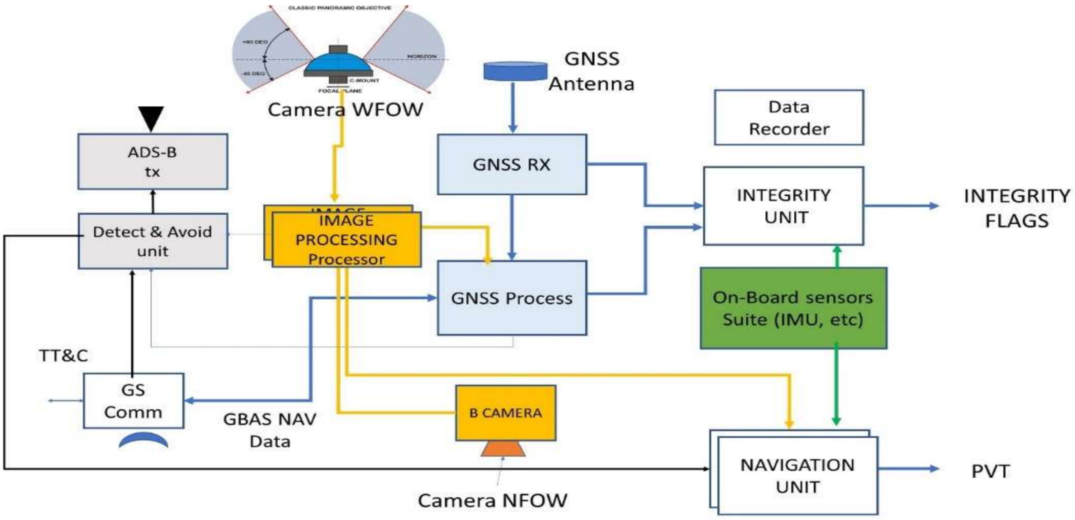


Figure 4. MOBU and Associated Navigation Function Block Diagram

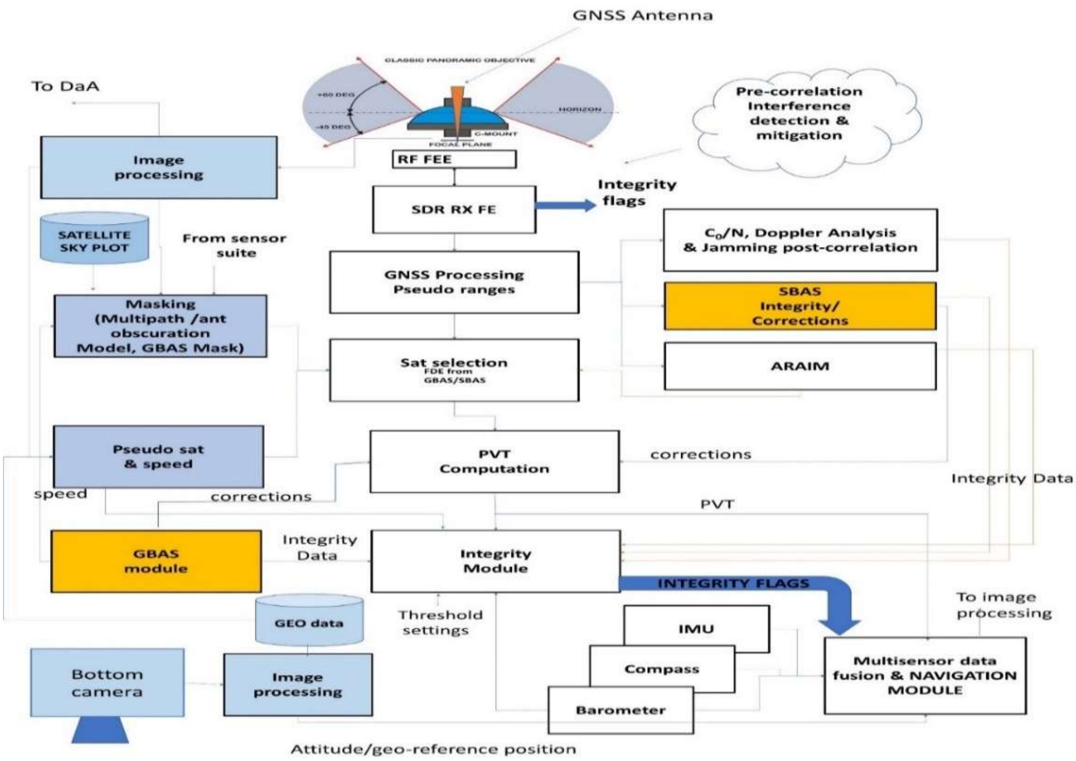


Figure 5. Avionic Integrated Integrity Functional Block Diagram According to ABIA Principle and Legacy Standard ARAIM

5.1.6 Overview of UAV Operative Modes Envelop Subjected to the Testing Program

The UAS Operational Framework (Refer to Figure 6) for all Railway and Road IMTM Applications will be established for defining the various scenarios for planning specific operational tests that will involve also a number of payloads is based on the following seven components in accordance with Document D2.1 User Requirements, Section 3.3.4:

1) Operational Framework
2) Flight Planning,
3) Flight Implementation,
4) Data Acquisition,
5) Data Processing & Analysis,
6) Data Interpretation and
7) Optimized Traffic Application.

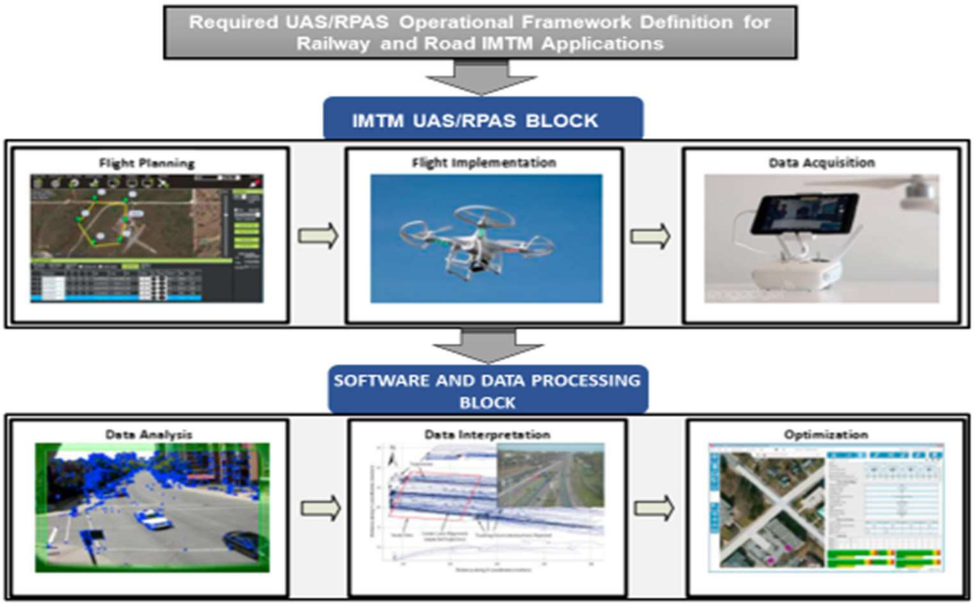


Figure 6. UAS/RPAS Operational Framework for Railway and Road IMTM Missions Block Diagram Subjected to Operational and Functional Performance Testing for Verification and Validation

The UAS Operational GNSS PVT and Augmentation services performance and Environment Framework applicable for IMTM missions for railway and road applications will be the basis for GNSS Galileo Verification and Validation Testing . All the aerial operations in RLOS, EVLOS and BRLOS mode at VLL conditions are considered modes for testing the GNSS-Galileo services performance within the railway and road area of normal operations. Therefore, for the test scenarios, the operational environment framework will be as follows:

1) Open Sky Regional and Sub-Urban IMTM UAS/RPAS Operational Test Environment: The Open Sky Environment for IMTM UAS/RPAS Operations is characterized by a good satellite visibility if the total number of GNSS satellites in view are appropriate for the PVT computation and are more than the minimum number for PVT computation. Moreover, an open sky environment is characterized by good satellite visibility if the overall geometry of the various GNSS satellites with respect to the user receiver results in a low DOP. Under the IMTM UAS/RPAS operational scenarios, these two conditions should be satisfied continuously with rare interruptions. In addition, an open sky environment also provides good EGNOS satellite visibility in terms of line of sight reception, with rare and limited reduction of such visibility. Under this environment will be verified and validated the UAS Navigation Unit Functional and Operational Characteristics, the HELMET Augmentation Services and the overall GNSS-Galileo Performance.

2) Restricted Regional and Sub-Urban IMTM UAS/RPAS Operational Test Environment: The Restricted Environment is characterized by frequent interruptions of satellite visibility, and a significant reduction of the number of available GNSS satellites for PVT computation and consequently a large value of the DOP. A restricted environment is also characterized by a continuously changing visibility of individual satellites and GNSS signal multiple reflections (multipath) or also with no direct reception of the satellite signal (NLOS Non-Line Of Sight reception). In a restricted environment, the EGNOS satellites might only be visible sporadically. Typical restricted environment areas are:
   a) Tunnels, under bridges
   b) Vicinity to other Infrastructures such as Industrial Areas, Airports etc.
   c) Woods/Forests
   d) Mountains and Canyons

Under this environment will be verified and validated the UAS Navigation Unit Functional and Operational Characteristics, the HELMET Augmentation Services and the overall GNSS-Galileo Performance.

3) Urban/Local Operational Environment: The Urban/Local Environment is characterized by frequent interruptions of satellite visibility, with the number of available GNSS satellites for PVT computation significantly reduced, and a continuous changing visibility of individual satellites and consequently a continuously changing DOP value greater than a minimum number. This is combined with high probability of multipath and NLOS phenomena affecting GNSS signals, largely due to reflections and obstructions created by surrounding buildings.
   Under this environment will be verified and validated the UAS Navigation Unit Functional and Operational Characteristics, the HELMET Augmentation Services and the overall GNSS-Galileo Performance.

It is important to stress that all of the above Operational Environments are subjected to variable intensity EMI phenomena caused naturally or are man-made together with the various other naturally occurring environmental conditions (temperature, rain, snow, wind, radiation etc.) which can influence the overall needed GNSS performance as two-way (up-link, downlink) interference.
The most common Flight Operative Modes Applicable to IMTM small UAS Test Campaign are described below:

1) MANUAL: (UAS attitude and height control only) In manual mode the pilot has full control of the aircraft; the FCU automatically controls the attitude of the UA/RPA on the horizontal plane to keep always a levelled flight and the height's control. No other control or software assistance is provided by the FCU in this flight mode. The pilot's commands are always mixed with the attitude and height control and are never overridden by on-board software in normal flight conditions.
2) ASSISTED: (Positioning, UAS/RPAS attitude and height control): In assisted mode the pilot has full control of the aircraft; the FCU automatically controls the attitude of the UA/RPA, the height and the horizontal position control. In this mode the UA/RPA is capable of hovering with outstanding precision in a fixed point in open sky. The wind's effect is autonomously corrected by using the on-board GNSS receiver. The pilot's commands are always mixed with on board software control the and never overridden by on-board navigation software in normal flight conditions.
3) IOC (Intelligent Orientation Control): The IOC operating mode is a simplified flight mode useful to ease the pilot in normal and emergency flight manoeuvres and it is valuable for some RLOS operations. IOC can be switched only from Assisted mode with sufficient GNSS satellite coverage, used for UAV position determination. In IOC flight mode the pilot's console control sticks are independent from aircraft's heading, but are referred to the aircraft HOME point position.
4) AUTO (Waypoint Navigation): In Auto (automatic) flight mode the pilot has no control of the aircraft during (autopilot) navigation, but he/she can always disengage autopilot system and take back full control of the aircraft in any moment. In this mode the aircraft is capable to implement an automatic flight plan with programmed waypoints.

Finally, there is an additional operational flight mode (*Failsafe*) which is handled internally by the FCU software. Failsafe is triggered by events or subsystems failures (*e.g. Loss of C2 link),* but it can also be switched by the pilot in emergency flight conditions forcing the aircraft to land or to return to home autonomously as it should be described in the emergency procedures of the UA/RPA manual. In the schematic of Figure 7. are shown Possible Transitions among Different Flight Modes that will be potentially tested. The red dotted arrows stands for autonomous transitions handled by on board software, the black ones stands for pilot's driven operational modes changes.

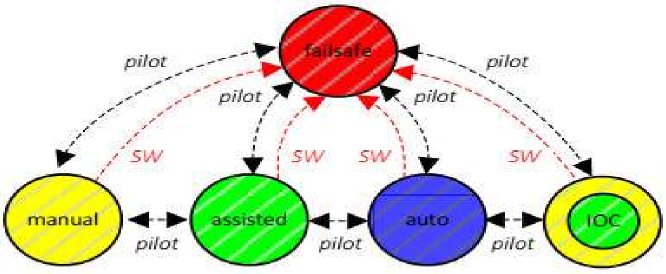


Figure 7. Possible Transitions Among Different Flight Modes

The Test effort will verify and validate the failsafe operating mode when is automatically driven through the on-board software that forces the aircraft to implement autonomously one of the following procedures:

a) Return-to-Home: Failsafe RTH is activated automatically if the remote C2 signal is lost for more than 3 seconds provided that the Home Point has been successfully recorded and the compass is working normally. The pilot can interrupt (override) the Return-To-Home procedure and regain full control of the aircraft if the remote controller signal is recovered.
b) Auto-Landing: Failsafe auto landing is activated automatically if the remote controller signal (including video relay signal) is lost for more than 3 seconds and there's no sufficient GNSS signal for RTH procedure.

In terms of IMTM UAS-PIT Station Flight Test Operations, the intended system architecture for all IMTM UAS Test scenarios is shown in Figure 8.

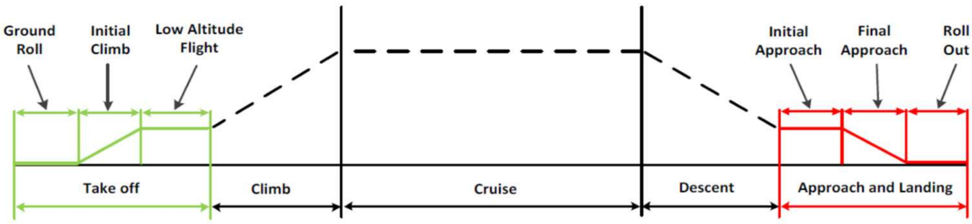


Figure 8. UAS Flight Test Operation Simplified PIT to PIT Schematic

During any IMTM Mission the UAV On-Board Unit (OBU) Operative Modes will be as per Figure 9. Such Modes will be part of the Operational Flight Test Campaign and they will be verified and validated for each mission scenario. Figure 10 provides the Ground Mission Initialization (GMI) Operational Sequence Envelop that will be adopted for the Field Test campaign.

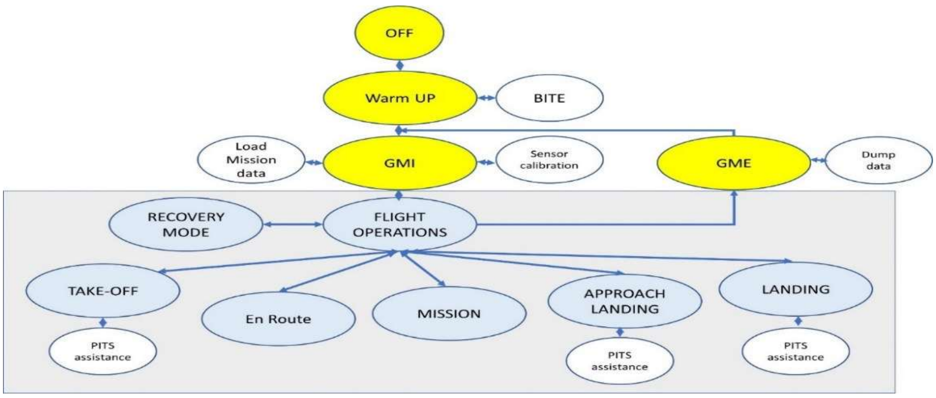


Figure 9. Overview of the OBU Operative Modes Subjected to Testing

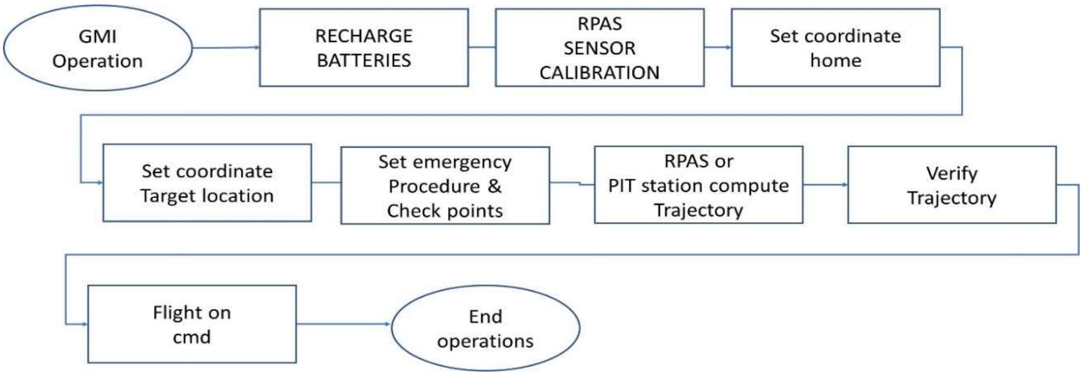


Figure 10. Ground Mission Initialization (GMI) Operational Sequence Envelop

5.2 HELMET UAS SEGMENT GROUND AND FLIGHT TESTING PROGRAM DESCRIPTION

5.2.1 HELMET UAS Segment Ground Test Campaign Operations Framework

In general, the UAS Ground Testing Framework encompasses tasks and procedures *(Ref. RTO AGARD 300, Flight Test Technique Series – Volume 27, AG-300-V27, 2010)* such as:

5.2.1.1 System Integration Tests

System Integration Testing (SIT) is an important test critical phase, which mostly is performed in a laboratory environment (when the UAS are small such as in the HELMET case then the actual aircraft will be tested in the lab environment) by testing individual components and subsystems. In most cases this is the first time that all of the components and subsystems are assembled and integrated in the intended operational configuration. This effort is typically the last phase prior to the commencement of the formal Developmental Testing (DT). System Integration Testing is intended to reveal problems not discovered in the traceability of functional requirements and Interface Control Documents used in the system design. These critical documents should be verified and corrected during the SIT. The SIT test set up should include the UAS Ground Control Station (GCS), the Unmanned UAV(UAV) itself, the CNPC Data Links, Launch and Recovery Systems (if any), and all other subsystems required for the system to execute the planned mission(s).

5.2.1.2 Data Link and Control Transfer

During System Integration Testing it is necessary to perform a thorough test of the UAS data link system. Depending on the system, it may not be safe to use the data link emitters in the laboratory environment due to hazards of electromagnetic radiation. In this case, the time and assets must be allocated to facilitate this critical test. By attenuating the output power of these systems and monitoring the received signal strength, it is possible to determine whether the data link will provide the range and margin determined by the design effort. This “range” check is a fundamental and critical step and should also be conducted in the intended flight test environment. It is also important to verify the procedures by which the secondary (or backup) data link assumes control in the event of a primary link failure. In many cases this operation is completely automatic and requires no operator intervention or action for the activation of the secondary link. The other more critical form of control transfer is when the control of the UAV is transferred from one GCS to another, compared to the control transfer from the primary data link to the backup data link. With less sophisticated (low cost) systems, this may be a simple matter of shutting down the data link from one station, while powering up the data link from a second station. However, even this simple process has critical operational procedural impact. In most cases, the fail-safe, or flight termination systems will be activated if the UAV receives no data link for a specified period of time. The same is usually true if the UAV is receiving two valid but conflicting data links simultaneously. Hence it becomes evident that operator participation, or operational training plan development be included in this phase of UAS ground testing. Failed control transfers have accounted for numerous UAS mishaps and loss of systems. A basic plan for the transfer of control between two GCSs where the transfer is accomplished simply by switching transmitters on or off is as follows:

1) Both stations confirm they are using the same form/frequency of communication link by positive voice communication prior to initiating the transfer process.
2) Both stations confirm that essential switches and critical flight control commands including throttle setting, attitude, kill switch position, and flight control commands are on the same settings prior to initiating the transfer.
3) The receiving station declares readiness to initiate the transfer.
4) The commanding station acknowledges and declares readiness to relinquish control.
5) The receiving station initiates the transfer by giving a “standby for transfer” notice, followed by un-keying the microphone to allow the commanding station to interrupt the transfer if conditions warrant.
6) The receiving station then calls for “transfer in” and commences a countdown from 3 followed by the word “transfer”.
7) On the word “transfer” the commanding station places its transmitter to OFF, and the receiving station places its transmitter to “ON”.
8) The receiving station immediately executes some manoeuvre (wing rock, heading change, etc.) to verify control, and then announces successful control transfer over the radio.

Current GCSs often incorporate an automated control transfer mechanism which may eliminate the need for voice communication among operators. Typically this will involve the UAV receiving a messaging code that indicates the “address” or identity of the GCS. When a control transfer is requested via the data link, the UAV avionics receive the request and relay it to any listening stations. If the commanding station acknowledges and approves of the transfer (again via the data link) the UAV will begin to take commands from the new station. The newest generation of UASs allow even more flexibility as the control of the payload or other subsystems may be transferred independently of the UAV control. In some cases the UAV may remain in fully autonomous flight while the control of such subsystems is transferred to the station where the data can best be exploited. In any event, the process by which control is transferred is critical and requires extensive trials during the ground test phase.

5.2.1.3 Built In Test and Automatic Test

Currently, UAVs of all sizes are making more and better use of Built in Testing (BIT) and Automatic Testing. The use of these test functions increase the probability that an UAV brought to the flight pad or area will be ready for a successful lift-off and provide the reduction the operator’s workload and thus also allowing for a reduction of operational level tasking. Again, SIT is an excellent place for these functions to be assessed, but if not done at that time, they need to be addressed in follow-on ground testing. Typically, these tests electronically check for UAV response to stimuli automatically initiated at the GCS, and for GCS response to stimuli injected at the UAV. In some cases the operator may be required to intervene or stimulate the system on either end. These tests are usually referred to as inter-active tests. In any event, the tests are only as good as the logic used to program them, and it should not be taken for granted that they will successfully diagnose all failure modes associated with the subsystems they are designed to test. In addition to the need to verify that the point to point flow of the stimulus to response is complete, it is highly desirable to inject numerous faults in order to determine which, if any are missed by the test. In some cases the BIT will simply yield a Go – No Go response. In more sophisticated systems a specific failure mode may be diagnosed and displayed to facilitate maintenance and trouble shooting. In general, the more sophisticated the BIT is, the more difficult it will be to test. A thorough understanding of the capability of the BIT or auto-test, the more likely that it will contribute to improved efficiency and ease of operation.

5.2.1.4 Electric Power Plant Tests

The electric motors used by some small UASs are in some ways easier to test as power produced can be established by current and voltage monitoring. It is important to establish during ground testing that the power storage devices (batteries) are sufficient to provide the motor(s) with sufficient power for the required flight duration since such parameter is fundamental to the mission endurance. The issues pertaining to the propellers used for these systems are similar to those discussed in the following paragraphs.
In the case of prototype or modified UAV by the incorporation of newly developed items, it is essential, as a minimum, to verify in ground testing that the engine/motor is developing its full rated power, and that the propeller is generating adequate static thrust to permit a safe take-off.
Given the inconsistent quality of many of the propellers manufactured for UAVs small in size, it is not unusual to have an engine fail to meet specified power output, and then by simply changing the propeller (same make and size), have it meet the specification. The operational impact of this is obvious, and should be considered when determining performance margins. Once it has been verified that the engine is producing its rated power, it is also important to take at least a rudimentary look at static thrust produced by the engine/propeller combination. Again, the inconsistent characteristics of the propeller will probably require several repetitions of the test to define the performance window even if only one size propeller by one manufacturer is to be used.

5.2.1.5 Attitude and Navigation Control Ground Testing

Some current UASs operate with direct rate controls. Attitude sensing and stabilizing systems are nearly always employed, as well as some form of inertial or GNSS navigation. While most of these systems will likely be tested during component and SIT, they must be exercised immediately prior to flight testing to ensure that they are operational and that their operating sense is correct. The attitude control system may be as elementary as a single rate gyro mounted on an incline to sense both roll and yaw, and to provide basic levelling. Such a system combined with a barometric sensor controlling altitude can provide basic autopilot and autonomous flight functions. Often, a vertical reference gyro with a yaw rate gyro and air data computer will be used to provide position control and autonomous operations. Larger and more sophisticated systems may employ redundant ring laser gyros and other attitude computing systems. Regardless of the component architecture, some basic safety of flight ground tests must be conducted. In cases where the design incorporates well-developed flight control laws, they can be assessed in terms of transfer functions to ensure that the correct control surface deflections result from measured attitude deviations. Ideally the vehicle is placed on a test stand to permit accurate attitude measurements. This test need not be extremely complicated however, and can usually be conducted with the vehicle on the ground. Very accurate, small, electronic angular measurement tools are available which allow alternate zero reference selection. Two such devices (calibrated) can be used to simultaneously measure UAV attitude in one axis and one control surface deflection. In addition, a device to stimulate the pitot-static system will be required. For a Hybrid (tilt rotor or wing) and fixed wing conventional UAV the attitude control system test would include some or all of the following:

1) Level the UAV (this may require slight nose up to account for angle of attack in normal flight and wing incidence angle).
2) Supply appropriate input to the pitot-static system to drive the elevator to neutral. This will vary according to the control laws for the specific air vehicle, but typically requires providing sufficient pitot pressure to match the airspeed report to the airspeed commanded in the ground control station (GCS).

3) Raise the nose 5 degrees and check for elevator deflection trailing edge down. The amount of travel can be verified if control laws are known. Verify GCS attitude display is in agreement. Repeat in 5-degree increments until maximum allowable elevator travel is reached.
4) Lower the nose 5 degrees and check for elevator deflection trailing edge up. The amount of travel can be verified if control laws are known. Verify GCS attitude display is in agreement. Repeat in 5-degree increments until maximum allowable elevator travel is reached.
5) Roll the UAV5 degrees right and check for left aileron deflection, trailing edge up (or rudder trailing edge left if rudder is used for roll axis control). The amount of travel can be verified if control laws are known. Verify GCS attitude display is in agreement. Repeat in 5-degree increments until maximum allowable aileron travel is reached.
6) Roll the UAV5 degrees left and check for left aileron deflection, trailing edge down (or rudder trailing edge right if rudder is used for roll axis control). The amount of travel can be verified if control laws are known. Verify GCS attitude display is in agreement. Repeat in 5-degree increments until maximum allowable aileron travel is reached.
7) While moving the UAV nose left, observe yaw rate display for correct direction, and rudder (if yaw or Dutch Roll damping is implemented) for deflection right.

The airspeed and altitude deviation response should also be tested. These will be dependent on control law implementation. In many cases, the altitude sensing system (usually static pressure, or radar) will drive the throttle actuator, and the airspeed system will drive elevator. Again, by inducing a difference between commanded and reported altitude and airspeed, the correct operating sense of the elevator and throttle can be verified (elevator trailing edge down for low reported airspeed, and throttle increase for low reported altitude). With fully defined control laws, the quantitative response can also be verified and validated. These systems will in many cases have some interaction such as long term integrators if the difference between commanded and reported data exists for an extended period. Even without any quantitative data on control laws, these simple steps can help to ensure that the first attempt at launch or take-off will lead to a productive and useful data collection flight. More complex UAV arrangements, such as V-Tails, and flying wing plan forms with elevon control can also be handled in similar fashion with a basic understanding of the control surface design.

Rotary wing UAVs can be assessed in this fashion by measuring cyclic pitch, collective pitch, tail rotor, and power responses. Similarly, the outer loop navigation functions need to be verified as safe for flight prior to developmental flight testing. In setting up for this ground test, a few critical steps must be taken. The GCS map display (if implemented), the UAV avionics, and any truth data (GNSS, etc.) must all be speaking the same language. This means ensuring that these systems are all operating in the same coordinate system (UTM Grid, Latitude/ Longitude, etc.), as well as using the same mapping datum (NAD 27, WGS 84, etc.). Failure to verify these parameters will result in poor quantitative accuracy data at best, and may result in completely incorrect response to navigation commands. Once these parameters are verified, it is possible to do some very simple ground tests to gain a significant degree of confidence in how the UAV will respond in flight to navigation inputs. The UAV can be placed on a given heading, and commanded to proceed to a waypoint to its right. The expected response for a conventional, Hybrid or Fixed Wing UAV is to see some right aileron deflection, trailing edge up. Knowledge of the control laws permits measurement of the surface deflection for various angles of the UAV relative to the commanded waypoint. This may be accomplished either by changing the waypoint, or rotating the UAV. Typically the controls will respond with increasing control surface deflection up to some maximum allowable angle as the heading difference is increased. Aileron deflection should be zero for waypoints on the UAV heading, providing the UAV is level, and way points to the left should result in similar left aileron deflection. Again, even without well-defined control laws to verify, this simple test can assess correct operating sense, and give the testers a qualitative feel for whether an appropriate amount of control surface deflection is induced. Any mixing of rudder deflection in this test should generally be in the same sense (coordinated turn) as the aileron deflection. One additional and highly advisable ground test for the navigation system is to verify that the system correctly identifies that the UAV has arrived at a designated waypoint and executes the next step in the navigation program. If the system cannot adequately simulate this step, it can usually be accomplished by towing the UAV or placing it on a ground vehicle depending on size. It is valuable, but not required, to know what the navigation software assigns as the "arrival circle" or distance from the waypoint at which it assumes it has reached the point. Convenient waypoints can then be programmed to allow the vehicle to be driven to within this radius and observed for response. The GCS displays should indicate that the waypoint has been reached, and what the new destination is. The UAV should respond with control surface deflection to initiate a turn toward the new point. It should also indicate altitude and airspeed response consistent with the programmed parameters. Response should be verified with new waypoints to the right and left of the UAV heading. Finally this test should be done while arriving at the last waypoint programmed. This step will verify the response of the UAV when the programmed mission is complete. It may be designed to return to base, continue on current heading, revert to some operator-controlled mode, or repeat the program. Control surface response should be verified, as well as some positive form of operator notification that the program has been completed. Like the attitude control system ground checks, these simple steps can also be conducted on more complex UAV arrangements as well as rotary wing UAVs, providing the basic control response is adequately understood. If it is not, then flight testing should probably not be attempted in any event. In general, it is possible to take a low cost system, about which little documentation is available and gain a reasonable level of confidence in the attitude and navigation control systems with some basic, inexpensive ground testing. More complex systems with well-defined control laws can benefit even more, as flight control algorithms can be verified during the process.

5.2.1.6 Electro-Magnetic Effects

Sometimes referred to as E-Cubed for Electro-Magnetic Interference (EMI), Electro-Magnetic Vulnerability (EMV), and Electro-Magnetic Compatibility (EMC), this discipline has become increasingly important in manned aircraft with the advent of digital flight control systems. With respect to UASs, electro-magnetic interference, vulnerability, and compatibility are the primary concerns due to the fact that UASs rely on Radio Frequency (RF) transmissions for all operator control inputs and all operator displays. There is no "steam gauge" or mechanical back up systems when the UAV may be many miles from the operator. UASs require attention to these issues in the design phase, and appropriate shielding/protection of components, actuators, wiring harnesses, and antenna cables must be built in. Furthermore, a system that is intended to go into operational use should be extensively tested in the intended operational environment. This is usually accomplished by defining that environment, and reproducing it in a controlled or "shielded facility". This facility must be capable of producing the desired frequencies of radiated energy, at the appropriate energy levels. For example, an UAS must be able to function in an environment that includes close range emissions from surface and air traffic radar systems, communications equipment, and electrical power generation and transfer systems. Failure to do so will require that variations to normal procedures be developed, such as emissions control during UAS operations. In other words, specific systems that cause problems for the UAS must not be operated during UAS operations. This situation is not desirable and can greatly reduce the effectiveness and benefit of the UAS. In addition to these outside sources or inter-system compatibility issues, UASs may also suffer from intra-system compatibility problems. In such cases, the problem is often related to a specific avionics or data link component, which injects RF noise into the wiring harness. The noise may then enter the data link receiver and effectively raise the noise floor, increasing the signal to noise ratio required to get a valid message received. This will reduce the effective range of the data link and may even render it unusable. It is possible for components as elementary as an updated component with a new clock oscillator to induce this failure mode. This is one of several reasons for the emphasis on configuration control and risk reduction efforts during UAS design, development and related test and evaluation phases. The range, or attenuated signal test is an effective mitigation technique, providing the configuration and environment are considered. A more thorough, but still basic EMC test should be considered mandatory before any first flight or following any configuration change. Such a procedure is called an EMC Safety Of Flight Test (SOFT) usually performed also under NATO standards which have been also adopted by civil UAS and manned aviation test procedures. It is essentially an intra-systems test, but if conducted in the environment of the intended flight (same test range) it also provides a level of comfort for system performance against any active emitters in the area. For UASs this test requires that all subsystems intended to be used during the flight be on and operating. This should include all data links, instrumentation, communications radios, and engine controls. It also requires that the UAV engine be running at several different RPM settings to account for ignition system noise. If the UAV is equipped with a generator or alternator, it must be on and operating, with any ground power or links disconnected. The test technique requires a test engineer (with appropriate training and safety equipment) to apply manual pressure to the control surfaces as standard control checks are conducted by the pilot/operator. This process is repeated for as many different data links, transmitter powers settings, antenna types, and engine speeds as listed in the EMC SOFT plan. The engineer is looking for any un-commanded control surface or engine control fluctuations. In addition, an electrical actuator or servo, which shows a marked decrease in centring or positioning force, is often an indication of electrical noise transmitted to the device via the signal wire. This is sometimes manifested visually by the control surface overshooting the commanded position and oscillating in a lightly damped, second order system motion before assuming the commanded position. These are positive indications of an EMC problem, and flight should not be attempted until the problem is identified and remedied. While the control surfaces are being checked, the ground control station displays are monitored for any abnormal indications, alerts, cautions, or warnings. Data link signal strength and loss of signal warnings are given extra attention. A radio frequency spectrum analyser may also be employed during this test to ensure that all intended emitters are operating and to aid in troubleshooting if problems are encountered. Installation of additional shielding, ferrite beads, toroid coils, or other filtering are typical corrective actions once a noise source has been identified. The EMC SOFT is planned by associating all of the flight critical systems in a source-victim matrix. This matrix is then used to execute the test and to help isolate both the source of the electro-magnetic interference, and the system being impacted (victim). A typical EMC SOFT matrix for a small UAS is presented in Table 8 below.

Table 8. EMC SOFT Source Victim Matrix
(Ref. RTO AGARD 300, Flight Test Technique Series – Volume 27, AG-300-V27, 2010)

SOURCE → VICTIM ↓	Airborne Video System	Autopilot and Servos	Downlink (All Modes)	Primary and Secondary Uplink	Test Payload	Ignition System
Primary and Secondary Uplink (All Modes)	X	X	X	X	X	
Downlink (All Modes)	X	X	X	X	X	
Autopilot and Servos	X	X	X	X	X	
Airborne Video System	X	X	X	X	X	

In line with the above general considerations, the IMTM UAV for the HELMET Project will be (as mentioned before) mostly a small Vertical Take-Off and Landing (VTOL) rotary wing aircraft (multi-rotor, rotorcraft, tilt rotor or hybrid wing type as per Table 9. IMTM UAS/RPAS Physical, Functional and Operational Performance Requirements, D2.1 User Requirements Document) which have an advantage in both their ground and flight testing. It is possible at an early stage to exercise the aircraft from component to full integrated aircraft level under equivalent full hover-flight conditions without it ever leaving the ground. Thus it does not incur risk in the later, in-flight testing to the same degree as does a Horizontal Take-Off and Landing (HTOL) aircraft. Inevitably, one of the more critical elements in a rotary wing UAV is the rotor system. UAS Flight Testing Test Campaign Framework. Whatever, the choice of the VTOL configuration, the system will be COTS but modified to accommodate new developmental items such as the MOBU and therefore will be subjected to Verification and Validation Tests on the ground. The ground testing will be mostly oriented to physical and functional integrity tests to the system component, subsystem, system and interface levels in terms of Software, Firmware and Hardware. Such tests will also verify, validate and qualify the ad hoc dedicated test means (special tools and equipment) and implemented procedures. All System Testing will follow a basic hierarchical procedure starting from the minimum test item which will be at the component level, followed by the equipment, subsystem, interfaces, system. Dedicated Hardware and Firmware Tests will be, where necessary and/or applicable, in terms of mechanical,

electrical (incl. EMC), environmental, EMI, reliability, assembly integrity and interface among items verification and validation. Software will be tested on the bench and later at the system level. Test efforts will also encompass ground subsystem and system level performance verification and validation together with all safety aspects by simulating functional and/or operational errors and faults in the various mission profiles and operational modes before the flight test campaign.
In parallel with the UAV testing, the Ground Control Station-PITT Station (GCS-PITT) will have been prepared. The several sub-system equipment, such as the communications, navigation, controls, displays, recording equipment, power-supplies etc. will have been separately checked out. Most of this equipment will have been out-sourced and come with certificates of conformity however a new developed software has to be considered since some of the related systems as it has been already mentioned will undergo modifications due to new developments.
The GCS-PITT infrastructure (Mobile, Transportable or fixed) will have been prepared with the necessary accommodation for the operator(s) and equipment and UAV(s) if relevant. Radio antennae will have been installed and elevating means, if relevant, will have been functioned. Air-conditioning for the operator(s) and equipment, as appropriate, will have been installed and operated. Now comes the time to assemble and test the GCS-PITT as a complete entity and then to integrate its operation with the UAV(s). The GCS-PITT must have the capability to command, control and communicate with at least three(3) UAVs simultaneously.
An on-board check-out of all sub-systems will be made to ensure their correct and continued functioning in their positions in the GCS-PITT. Checks will ensure that the ergonomic interfacing with the operator(s) is satisfactory, that there is satisfactory system integration and no adverse mutual electromagnetic or physical interference and that the air-conditioning system(s) maintain appropriate ventilation and temperatures for operator(s) and equipment. Radio communications will be functioned and checked for performance by transmitting data and control commands to a slave radio receiver, preferably positioned at some distance away. If all is satisfactory, the next step will have been the integration of the GCS-PITT with the UAV(s) on its ground functioning rig. The start-up procedure will be carried out and built-in-test-equipment (BITE) functioned. The BITE addresses the state of the UAV systems to ensure that it is ready for flight. i.e. that the on-board power supplies, sensors, control systems, payload, electrical gauging, etc. are all operating within the correct limits and that housekeeping data and health and usage monitoring system (HUMS) equipment (if fitted) are registering. During the ground testing of the UAV, the manipulation of controls and measurements made by the on-board instrumentation may have been transmitted by hard-wiring from and to a separate console for display and recording. This control must now be transferred to the GCS-PITT and communicated by the communication system. Similarly the results of the instrumentation should now be transmitted to the GCS-PITT for display and recording, either separately to or as part of the aircraft housekeeping data.
It is important that all these tests are accurately called up and the results recorded in the Test Reporting documents so that they can be produced for subsequent certification of the UAS Segment. Any shortcoming in performance, ease of operation or reliability will be reported for modification action and subsequent re-testing. The System Hierarchy document will also be contained in one of the control documents which will be held by the test engineers and subsequently by the operators. It will allow the testers and operators to identify faulty components for replacement and also to compile a record of failure rates for each sub-assembly or item. This information is used to determine which elements should be improved or replaced to give the most cost-effective increase in reliability. With the ground testing satisfactorily completed and the integration of the system proven, the system should now be readied for the in-flight testing phase.

5.2.2 HELMET UAS Flight Test Campaign Operations Framework

In general, the main objective of flight tests is to acquire empirical/experimental data that can be used to verify and validate the overall developmental design, mathematical models, performance figures, or capabilities that were initially estimated during the concept design phase. While testing a UAV system on the ground requires relatively little space, this is not true of in-flight testing. The entire Test Flight Program encompasses three (3) distinct in terms of tasking phases, such as:

a) Phase 1: Pre-Flight Operations
b) Phase 2: In-Flight Operations
c) Phase 3: Post-Flight Operations

In terms of Flight Test Campaign Sites for the HELMET IMTM Applications, the location of a suitable and available railway and road test site (e.g. Rail Test Site in Sardinia while for road can be used the Sardinian Aerospace District site) should be found early in the UAS Development program. Complete and extensive and rigorous testing, such that of the HELMET IMTM UAS Segment based on the D2.2 CONOPS, D2.3 System Requirements Specification and D3.3 Detailed Architecture Design Document, will require at least a segregated rail and road alike fields of at least 2.5 km long and 500m wide which will be related to a representative rail and road infrastructural configuration so as to simulate a realistic IMTM mission environment and fly in LOS and BLOS operational mode. The Field, the Airspace over the Test Field and certain classes of UAVs must have the appropriate Authorizations for Use and Permits to Fly (PTF) by the Local Aviation Authority. Initial flights will usually be performed with a UAV of minimum payload mass, but it will be carrying fully instrumented and integrated Non-Payload items such as the Command, Control, Communication, DAA and Navigation equipment. The UAV may therefore enter first flight at less than its design Maximum Gross Take-off Mass (MGTM), possibly at approximately 80% MGTM, and so may need less power for Take-off/Landing and for Hovering flight tasks than in life-cycle service operation. The UAV will then have to climb to a safe height of perhaps 100 m to a maximum 120m (400ft) [UTM Airspace]. A hybrid or a fixed wing UAV operating in the presence of wind from various directions may require a site of about 10km long × 500m wide while a VTOL UAV (which will be the majority of the HELMET Network UAVs) are the least demanding on site area and initial, low-speed flights could be made within an area of about 2.5km (minimum test spacing of a PIT-Station pair would be 1km). Tests at maximum performance of all types of the HELMET small UAVs will require the availability of a segregated test site having a length of between 2 and 4 km, depending upon maximum speed of the aircraft in order to allow measurement of performance at steady flight conditions. The Requirement of maximum 400ft Operational Mission Altitude remains together with the required Permits/Authorizations for the airspace usage provided by the Local Aviation Authority.

The Flight Test UAS pre-deployment formalities should be completed prior to the commencement of on-site UAS operations. In the process of completing this formal step, a range of UAS operating environment considerations must be assessed as follows:

a) Identification of site airspace designation (i.e. uncontrolled, controlled, restricted, prohibited, danger) and other aircraft operations (e.g. local aerodromes etc) and review any limitations on flight testing execution (e.g. a limit on maximum permitted aircraft flying height in a controlled airspace).
b) Obtain the site owner (if other than HELMET operator) permission for test operations.
c) Check the airspace restrictions (NOTAMs) schedule for all the required Flight Test Periods.
d) Consult Survey Maps to identify primary topographic / natural and manmade features (e.g. power lines, radio masts, radars etc) or areas (e.g. congested urban areas or habitation, recreational areas) significant to the UAS flight test operations.
e) Check thoroughly the GNSS Galileo Satellites area coverage for prospected UAS Flight Test Campaign operation timetable.
f) Verify that UAV is in operational condition and report any outstanding issues or limitations if necessary.
g) Check and/or Establish UAS Flight Testing Site area Communications and local services (UTM, ATM, etc).
h) Provide Pre-notification as required if a planned UAV test flight operation is to take place within 5km from any civil and/or military aerodrome and/or other test range facilities.
i) Upon arrival at the UAS Flight Test Campaign site location, the Test Program Management (TPM) team should carry out an on-site assessment survey to familiarise themselves with the local geography and arrangement of the site. This survey should be completed by undertaking a site walk-over to confirm the presence of any hazards marked on the pre-deployment report, and to identify any additional hazards. All findings should be recorded using an on-site assessment form.

j) The TPM should select a position from which to deploy, land and operate the UAS segment (including the PIT Stations designed for the tests), which should be kept clear of obstructions apart those which simulate the IMTM scenarios. This position should ensure full LOS and BLOS (BLOS may be simulated for the purposes of the project at least in the initial stages of the Development Program) over the Area of Interest (AOI) and preferably be positioned between the AOI and the sun to also avoid visual (VLOS) impairment during UAS Flight Test operations. The TPM team should select a take-off/landing zone (PIT and not PIT areas) and, where available, backup and/or emergency landing areas. In the case of VLOS operations (UAV visibility by a naked eye) this zone should be:
    - Be clear of physical obstacles (e.g., overhanging trees, rocks, buildings, power lines etc.)
    - Be on level terrain (avoiding steep slopes)
    - Consider effects such as wind shear (caused by vegetation, buildings, cliffs etc.)
    - All buildings and persons not under the control of the Remote Pilot (RP) must remain in a safe distance from the UAV when taking-off and landing.

Details of the specific UAS Test Campaign Operation should be issued to the Test Flight Team (TFT) at least 3 days prior to deployment. The RP will give a briefing to the TFT members before any test flight operations take place. The briefing will cover the criteria listed below.

- Advise of take-off, landing, operating areas.
- Confirm flight plan with the TFT members, including anticipated flight number and duration.
- Confirm emergency and risk mitigation procedures.
- Issue the required Flight Test portable gear and equipment specific to each member of the TFT.

The HELMET UAS Segment Flight Test Program will be oriented to the following four (4) Categories of Testing Tasks where applicable and/or required:

a) Pre-Flight Inspection/Tests: This is the "for Flight Preparation" phase of the entire Program. It encompasses the effort of Site Inspection, Acquisition of Environmental Data (including Weather), Test Apparatus start-up/Functional Checks/Alignments and establishment of Navigation and Communications Connections (Terrestrial and Satellite) and Integrity Checks, UAV System Preparation for Flight and Checks (Pre-Flight Checklist), UAV Safety Equipment/Elements Checks, GCS Pre-Flight and Emergency Checklist, PIT Station Equipment Tests and Pre-Flight Check List.

b) Verification and Validation Test Flights: This type of Flight Testing Tasks are directed to all first time flight developmental UAS items and/or modified COTS with new developments incorporated/integrated and developmental interface items ranging from entire subsystems, equipment and components. These test tasks will verify and validate all new Hardware (HW), Firmware (FW) and Software (SW) integrated in the UAS Segment that cannot be verified and validated by design and/or analysis.

c) Documentation Data Acquisition Test Flights: This type of Flight Testing Tasks are performed with the objective to obtain Functional, Operational Performance and Integration Data which will assist and consolidate further the UAS Segment development, critical and interface design effort.

d) CONOPS Instrumented (Payload) Mission Profile Flight Tests: This Flight Testing Tasks are oriented to the Verification and Validation of the UAS IMTM payload range (mostly COTS) to perform the Concept of Operations and Mission Scenarios as per document D2.2 HELMET CONOPS.

Most of the instrumentation used and proven in the ground testing will be retained in the UAV. Further instrumentation may be added, for example, vertical and lateral accelerometers to record in-flight manoeuvre conditions. Other equipment, which may or may not have been included before, such as gauges may now be added. Recommendations, voluntary or obligatory, may then be received from the Safety Engineer(s) to improve safety or to facilitate the tests.

5.2.2.1 HELMET UAS Flight Test Team Training Program

The task and capabilities of the system Flight Test Operators under developmental testing will be significantly different from that of the future user operators. Therefore a specific Training Program, directed to the Ground and Flight Test Team Members, must be devised and executed prior to the commencement of Developmental Testing effort. The Test Team responsible for the HELMET UAS initial flight testing will, at least in part, be drawn from the project engineers who will have carried out also the earlier ground testing. It is important that the team members are fully familiar with the detailed form, fit, function and operational capabilities of the complete HELMET UAS system and what tasks are required of them and of the system in the in-flight tests. The test team members must undergo formal Training in- class and on-the-job-training (OJT) on the prospected IMTM UAS models for the HELMET Network and qualify to expertly perform the ground and flight test program tasks.

Although some degree of automation of the control of the UAV in flight will be operative for the first flights, it is probable that most aspects of the flight will be controlled directly by the operator; 'piloting' the UAV within his sight and beyond. There should be an understood 'fall-back' to manual control to cover failure or inadequacy of those aspects which are automated. Should an irrecoverable emergency arise during flight, a forced recovery to land would be made and the person whose responsibility it is to initiate this must be agreed. It would be expected that the responsibility would be that of the appointed Test Engineering Manager in charge of the test program. For the in-flight tests, there must be a clear delegation of tasks. More operators are likely to be employed in testing than in user operations since data is being acquired for the development of the system. Hence the team may consist of an aircraft controller, a payload operator, an engineer monitoring the instrumentation aboard the aircraft and another monitoring the recording equipment for both aircraft and CS data. Generally, in user operations only two, or even merely one, operator may be required for each operating UAV. Prior to flight a detailed Test Requirement will have been prepared calling up the Build Standard of the system and scheduling the flights within the initial program. It will detail the required flight paths and profiles and the data required to be recorded from each flight. If possible, it could be of advantage for the expected aircraft flight control characteristics to be computer-simulated, so that the aircraft controller can have developed an understanding of what skill level may initially be expected of her/him. If possible, a full simulation of the flight profile would be made so that all of the operators can play their expected parts in the simulated operation.

5.2.2.2 UAV Flight Testing General Requirements and Conditions

Many different UAV flight test techniques are in existence depending on the air-vehicle typology. As technology evolves, UAV flight test techniques are developed to meet the challenge of assessing new developments in Unmanned Aircraft (UA) and its systems. Classical flight test techniques for the UAV itself can be placed in two general categories like in the manned aircraft: stability and control, and performance.

5.2.2.2.1 Stability and Control.

Stability and control encompasses air vehicle stability, air vehicle control, and air vehicle flying qualities.

a) Air Vehicle Stability. Air vehicle stability testing determines the air vehicle reaction to perturbations in the air vehicle flight condition.
b) Air Vehicle Control. Air vehicle control testing determines the air vehicle reaction to changes to the air vehicle flight control system and covers both pilot control inputs and automatic control inputs.
c) Air Vehicle Flying Qualities. Air vehicle flying qualities testing determines the level of difficulty for a pilot to execute a particular manoeuvre or establish a steady state flight condition. Air vehicle flying qualities result from the summation of stability and control characteristics and all pilot interfaces, flight controls, flight instruments, crew station design, and all other man-machine interfaces.

5.2.2.2.2 Air Vehicle Performance.

Air vehicle performance testing determines mission effectiveness, specification compliance, and provides handbook data for operators.

a) Mission Effectiveness. An air vehicle is designed to accomplish specific missions. Air vehicle performance testing determines whether the various air vehicle elements combine to permit acceptable mission accomplishment.
b) Specification Compliance. Specification compliance determines whether an air vehicle is constructed to the contractual standards established between the customer and the manufacturer.
c) Handbook Data. Handbook data are developed from performance testing to provide operators with information to conduct pre-mission performance planning, confirm in-mission performance, and provide advice to operators on how to maximize performance under various conditions.

5.2.2.2.3 Air Vehicle Systems Testing.

UAV systems testing determines the utility of air vehicle systems to assist the operator to accomplish the mission. Air vehicle systems include, but are not limited to, communication systems, navigation systems, detect and avoid systems, safety systems, and survivability systems.

5.2.2.2.4 Flight Test Procedural General Requirements and Conditions

5.2.2.2.4.1 Multi-Rotor and Rotary-Wing UAV Performance

The general flight test techniques and methods for multi-rotor and rotary-wing UAV performance testing are described in the following paragraphs:

1. Pitot/Static System Performance: The purpose of this flight test is to investigate thoroughly the flight characteristics of the aircraft pressure sensing systems to achieve the following objectives:
    a. Determine the airspeed and altimeter correction data required for performance data processing.
    b. Determine mission suitability.
    c. Assess compliance with pertinent Specifications and/or detailed model specification.
2. Engine Assessment: The purpose of these tests is to evaluate the engine (electrical and/or non-electrical) /rotor(s) compatibility and suitability for the mission of the host rotorcraft system. Specific tests that are conducted include an evaluation of the engine controls and displays; engine(s) operating procedures, both normal and emergency; engine(s) start and shutdown characteristics; engine(s) acceleration characteristics; engine(s) trim response; engine/rotor stability, both static droop and transient droop; engine torque matching; engine limiting characteristics; and engine power contribution during minimum power descents.
3. Engine Performance: The primary purpose of these tests is to determine power available and inlet performance and engine performance. An additional test technique, Running Lines, is frequently used to assess extreme engine performance and power available.
4. Hover Performance: The purpose of this test is to evaluate UAV rotorcraft hover performance characteristics. Airframe power required to hover will be determined and combined with engine power available to establish rotorcraft UAV hover performance.
5. Vertical Climb Performance: The purpose of this test is to investigate UAV vertical climb performance characteristics to achieve the following objectives:
    a. Determine the vertical climb correction factor for use in computing vertical climb performance.

   b. Determine mission suitability.
   c. Assess compliance with pertinent Specifications and/or detailed model specification.
6. <u>Level Flight Performance:</u> The purpose of this test is to investigate aircraft performance characteristics in level flight to achieve the following objectives:
   a. Determine significant performance parameters: maximum level flight airspeed (VH), maximum range airspeed (Vmax range), cruise airspeed (Vcruise), maximum endurance airspeed (Vmax end), combat radius, maximum endurance, and maximum range.
   b. Determine mission suitability.
   c. Assess compliance with pertinent Specifications and/or detailed model specification.
7. <u>Climb and Descent Performance:</u> The purpose of this test is to examine the forward flight climb and descent performance characteristics to achieve the following objectives:
   a. Determine the airspeed for maximum rate of climb, Vmax R/C.
   b. Determine the airspeed for best angle of climb, Vx.
   c. Determine mission suitability.
   d. Assess compliance with pertinent Specifications and/or detailed model specification.
8. <u>Autorotation Performance:</u> The purpose of this test is to examine the autorotation performance characteristics to achieve the following objectives:
   a. Determine the recommended autorotation airspeed.
      i. Determine the airspeed for minimum rate of descent, Vmin R/D.
      ii. Determine the airspeed for maximum autorotation glide range, Vmax glide.
   b. Determine the rotor(s) speed effects on descent rate.
   c. Determine mission suitability.
   d. Assess compliance with pertinent Specifications and/or detailed model specification.
9. <u>Rotorcraft Stability and Control:</u> The following flight test techniques and methods for rotorcraft stability and control testing:
   a. <u>Pilot Flying Qualities Evaluations.</u> The purpose of flying qualities testing is to evaluate the mission suitability of an aircraft's piloted flying qualities in a real or simulated mission environment.
   b. <u>Open Loop Testing.</u> The purpose of open loop testing is to quantify stability and control evaluations. Specific objectives of open loop testing are:
      i. Substantiate the pilot's qualitative opinion.
      ii. Document characteristics of the aircraft-control system combination.
      iii. Provide data for comparing the aircraft characteristics with others
      iv. Provide baseline data for expansion of flight and centre of gravity envelope.
      v. Provide data for predictive closed loop analysis.
      vi. Provide data for simulator applications.
      vii. Assess compliance with pertinent Specifications and/or detailed model specification.
   c. <u>Flight Control System Characteristics.</u> The purpose of the flight control system characteristics evaluation is to document the control system characteristics in support of stability, control, and flying qualities evaluations, as well as specification compliance.
   d. <u>Forward Flight Longitudinal Stability, Control, and Flying Qualities</u>. The purpose of these tests is to evaluate the forward flight longitudinal stability, control, and flying qualities of the rotorcraft. The engineering tests included in the evaluation are:
      i. Trimmed flight control positions.

ii. Static stability.
iii. Manoeuvring stability.
iv. Long-term dynamic stability.
v. Short-term dynamic stability.
vi. Control response.
vii. Gust response.

e. Forward Flight Lateral-Directional Stability, Control, and Flying Qualities. The purpose of these tests is to evaluate the rotorcraft forward flight lateral-directional stability, control, and flying qualities. The tests included in the evaluation are:
   i. Trimmed control positions.
   ii. Static stability.
   iii. Dynamic stability.
   iv. Spiral stability.
   v. Control response.
   vi. Gust response.

f. Hover and Low Airspeed Stability, Control, and Flying Qualities. The purpose of these tests is to evaluate the hover and low airspeed stability, control, and flying qualities of the rotorcraft. The tests included in the evaluation are:
   i. Trim control positions.
   ii. Critical azimuth.
   iii. Turn on a spot.
   iv. Static stability.
   v. Long-term dynamic stability.
   vi. Control response.
   vii. Mission manoeuvres.

g. Coupled Longitudinal and Lateral-Directional Stability, Control, and Flying Qualities. The purpose of these tests is to evaluate pilot requirements to compensate for coupling in trimmed steady flight and to suppress coupling in short- and long-term dynamic situations. As minimum, coupling evaluations include:
   i. Trim control positions for equilibrium in hover, low airspeed, and forward flight.
   ii. Trim control positions to maintain steady non-rectilinear flight such as forward flight turns.
   iii. Control positions required to perform long-term flight condition changes such as level accelerations, transition to climb, and diving accelerations for ordnance delivery.
   iv. Short term, off axis aircraft responses to rapid control inputs.

h. Sudden Engine Failures, Autorotation Flight, and Autorotation Landings. The purpose of these tests is to evaluate the handling qualities of the rotorcraft from engine(s) failure to completion of the landing. Tests are conducted to evaluate the following characteristics:
   i. Engine failure and autorotation entry.
   ii. Steady autorotation flight.
   iii. Autorotation landings.

5.2.2.3HELMET UAS Flight Test For Rail and Road IMTM Mission Scenarios

In accordance with Document D2.2 CONOPS, section 3.3.7 herein are presented, as the basis of the Initial Flight Test Program, a number of representative and but not exhaustive scenarios for

UAS/RPAS Railway and Road Assets IMTM Applications within the Open Sky, Restricted and Urban/Local environmental operational conditions. All Flight Test Scenario Missions are performed in LOS and BLOS Modes of Operations and the Test Pilot's main operational objectives are to: 1) Communicate, 2) Control, 3) Navigate, and 4) Avoid Hazards. These functions represent the primary operations that must take place for safe flight and they must be subjected to actions by the Test Team so as to verify and validate their integrity and overall performance through testing their related systems and equipment (SW, FW and HW).

The Communicate Function shall principally refer but not limited to voice and data exchanges among the UAS/RPAS operator, UTM and proximate traffic to communicate intent, instructions, and responses. It shall also include any exchange of information among UAS/RPAS operational personnel. The Communicate Function shall mainly include the following sub-functions:

- ✓ UAS/RPAS External Communications
  - Provision for External Communications between UAS/RPAS Operator(s) and UTM;
  - Provision for External Voice Communications between UAS/RPAS Operator and Operators of Proximate Traffic;
  - Provision for External Non-Voice Communications (i.e. Messaging) from UA/RPA to UTM.
  - Provision for External Non-Voice Communications between UA/RPA and Proximate traffic.
  - Provision for External Communications with HELMET OPS Centre and/or Ancillary Services.
- ✓ UAS/RPAS Internal Communications which shall provide the function of communications among the various interfacing UAS/RPAS crews and related personnel within the HELMET Network.

The Control Function shall refer to the capability/means of directing, regulating or restraining the aircraft's movement. The Non-flight functions shall refer to items such as transponder codes, radio frequencies, deploying the landing gear (if applicable) and making queries or initiating tests on UAS/RPAS sub-systems. The Control Function shall mainly include the following sub-functions:

- ✓ Provision for Command of UA/RPA Flight Controls
- ✓ Provision for Feedback from UA/RPA Flight Controls
- ✓ Provision for Command of UA/RPA non-Flight Controls
- ✓ Provision for Feedback from UA/RPA non-Flight Controls

The Navigate Function shall refer to the ability in obtaining and maintaining knowledge of the ownership current positional and geographic orientation information and of its destination(s) using reference cues (electronic or visual). It shall include the determination of path(s) to fly from its current position to its subsequent position or to its destination(s). The Navigate Function shall mainly include the following sub-functions:

- ✓ Provision for UA/RPA Altitude Information
- ✓ Provision for UA/RPA Heading and Course information
- ✓ Provision for UA/RPA Ground Position Information
- ✓ Provision for UA/RPA Temporal Data
- ✓ Provision for UA/RPA Trajectory Definition

The Avoid Hazards Function shall principally refer but not limited to the following sub-functions:

- ✓ Provide Ability to Detect and Avoid (DAA) Traffic
- ✓ Provide Clearance from Structures, Obstacles, and Terrain
- ✓ Provide Clearance from Atmospheric or Meteorological Hazards
- ✓ Provide Clearance from Unauthorized Airspace
- ✓ Provide Clearance from Below-Minimum Visibility Conditions
- ✓

1) Flight Test Scenario A: Rail and Road Assets Inspection Services Field Operations

1.1) Test Case 1A: UAS/RPAS Inspection of Railway and Road Assets In a Concurrent Operational Mission: Three (3) small UAS/RPAS of the HELMET Support Services Network (which includes the PIT stations installed along the Railway and Road Systems) are involved in concurrent Inspection operations of a real or dummy railway tunnel for maintenance, a railway metallic bridge structural condition and a road pavement condition in the UTM airspace under partially simulated open sky, restricted and urban/local environmental operational conditions. The first UAS/RPAS is a small rotary wing (quad-copter) involved in the tunnel inspection mission performing an Infrared Thermography in VLOS flight mode in restricted operational environment conditions (tunnel). The second UAS/RPAS is also a small rotary wing as the first with a Robotic Arm Extender Holding Ultrasonic Equipment and it is involved in inspecting a metallic railway bridge in a simulated urban/local area. The third UAS/RPAS is a fixed wing hybrid type equipped with a Light Detection and Ranging (LiDAR) sensor performing a road pavement condition inspection under open sky environmental conditions at BLOS mode. All of the UAS/RPAS involved can be fully supported by the PIT Stations distributed in strategic locations within the simulated HELMET Network service areas. All UAS/RPAS involved have a fail-safe flight mode capabilities and they have an approved flight plan by the local UTM and they aren't to exceed 100m altitude AGL during test flight operations within the established test site geo-fencing restrictions.

1.2) Test Case 2A Flight Phases, Mission Endurance and Range: This Test Case involves all Flight Phased Operations for all UAS/RPAS involved and these are Pre-Flight, Take-off, Arrival to the mission area, Performance of the Planned Aerial Work and Return to Base (Landing), Post-Flight Operations. However, there are some slight differences on the planned aerial work. For the first two, most of the aerial work is at hovering conditions at low altitude from 0.5m-20m (vertical) and lateral movements (25cm-10m) focusing at the inspection zone of the asset, while the third UAS/RPAS will have more complex flight trajectory going from straight flight up to 1km and back, to loitering and hovering periods around the target area at altitudes that can vary from 5m to 100m. All operational steps described in D2.2 CONOPS, section 3.3.4 document are applicable. Taking into account of the single UAS/RPAS involved in the above flight test mission profiles and performance capabilities the mean endurance will be 90min (without PIT Station Support) while the range will be variable from 500m to 2.5km (total minimum test site dimensions).

1.3) Test Flight UAS/RPAS Inspection Operational Performance Measurable Requirements for GNSS Galileo Services Verification and Validation (see Table 9 below) for all Cases in Scenario 1

Table 9. Requirements for GNSS from viewpoint of UAS/RPAS inspection operations

INSPECTION MISSION (RAIL/AUTOMOTIVE)	ACCURACY HORIZONTAL	ACCURACY VERTICAL	INTEGRITY	TIME-TO-ALERT	CONTINUITY	AVAILABILITY
Position/Navigation	1 m /10m	1 m /10m	1 – 2× 10–7	1s	1–1×10–4/h to 1–1×10–8/h	0.95-0.99
GEO-Awareness	1m	1m	1 – 2× 10–7	1s	1–1×10–4/h to 1–1×10–8/h	0.95-0.99

1.4) Flight Test Main Services Provisions Required for the Scenario 1:

1) UTM U1: Pre-tactical Geofencing;
2) UTM U2: Strategic Deconfliction; Flight Planning Management, Weather Information
3) GNSS Galileo Air Navigation Services
4) Terrestrial and Satellite Communication Services Provisions
5) HELMET Augmentation Services Provider

1.5) Organizations and Experts Involved during the Flight Tests :

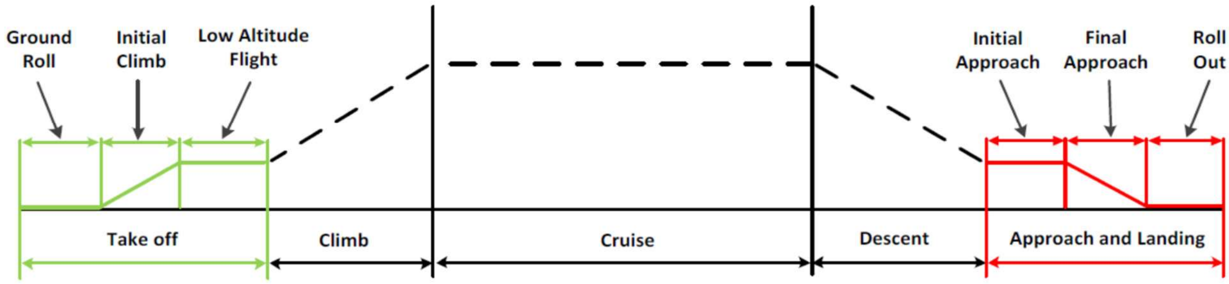
a) UTM Controller(s)

b) GNSS Galileo Representative Evaluator
c) UAS/RPAS Flight Test Manager, Flight Test Pilot, Flight Test Engineer, Flight Test Observer, Flight Test Technician(s)
d) Flight Test Quality Assurance Engineer and Flight Line Support Personnel
e) Test Site Railway Assets Management Personnel
f) Test Site Road Assets Management Personnel

1.6) Other Flight Test Operational Applications under the Scenario 1:(Railway and Road Infrastructural Inspections):

- Crack detection and inspection
- Rut and pothole detection
- Delamination detection
- Sight distance, slope, grade, and contours
- Ancillary and Support installations associated with railways and roads (water pipelines, electrical infrastructure, etc.

1.7) Scenario 1 Flight Phases Main Test Tasks List



1.7.1) Pre-Flight Phase Checks and Take-off from the PIT Station A:

All checks prior to flight and take-off will be executed by the standard checklist of each UAV/GCS type in accordance with the UAS Manufacturer's Instructions while the PIT Station will be controlled and set in accordance with the Design Engineering Instruction and individual COTS Equipment/Components standard instructions. All PIT Station Services will be turned on and aligned while the Test Pilot will turn-on and run the UAV pre-flight checks in the areas:

- ✓ Generate a Test Flight Plan for the specific mission;
- ✓ Check UAV Mechanical Structure, mechanical joints, moveable surfaces for Integrity and secure loose items;
- ✓ Check Rotors for correct connection and integrity;
- ✓ Turn-on/off UAV and GCS Electrical System and Check Indications (including the batteries);
- ✓ Check Functional Performance of all Dynamic Flight Systems (Min.and Max. indications);
- ✓ Check Rotor(s) RPM and Temperatures;
- ✓ Check all Computer/Computing systems for correct functioning and expected input-output indications;
- ✓ Check the overall CNPC Link correct and safe functioning by checking the command and control (including the autopilot) expected functions. Check back-up Link (if any) for correct function;
- ✓ Check all the Emergency Equipment, Modes, Harness, auxiliaries for correct functional indications and secure the system;
- ✓ Check and reconfirm the UAV identifier
- ✓ Set local coordinate and target PIT coordinate

- ✓ Set UAV heading and Select altitude and speed
- ✓ Connect to GNSS Galileo Navigation Services and Check the Avionics and Navigation Systems for correct functioning and alignment;
- ✓ Connect to Communication Services and Check Communications for correct functioning;
- ✓ Set the Flight Plan for the specific Flight, calculate and set the appropriate trajectory inputs;
- ✓ Set communication operative frequencies and encryption keys
- ✓ Select positioning accuracy AL and PL (for each phase)
- ✓ Set fence box vertical and horizontal limits
- ✓ Set emergency/ recovery actions
- ✓ Set alternative reference positioning and navigation objects. (i.e. geo localized sites that can be recognized by VBN)
- ✓ Set mission operative modes (i.e. observation, data gathering, etc.)
- ✓ Verify communication links operations
- ✓ Communicate the specific flight plan to UTM and request authorization
- ✓ Check PIT-Station Interfaces and surrounding area of flight;
- ✓ Get Approval and Permission from local UTM Controller to take-off;
- ✓ Take-off

All those activities can be done in autonomy but under the supervision and confirmation of the operator.

1.7.2) En-Route, Arrival to the Mission Area and Performance of the Planned Aerial Work Flight Testing

After the finalization of the Test Pre-Flight Phase, then the UAV will take-off and it will reach the pre-planned operative altitude for the tests. The Test Pilot will proceed to the following verifications:

- ✓ Check control performance of the autopilot on the trajectory and the correctness of the control flight systems attitude.
- ✓ Check any displacement from the trajectory that is timely compensated by the navigation system based on integrated avionics sensors including GNSS rx.
- ✓ Check the positioning error and verify it through the integrity mechanism.
- ✓ Check that during the en-route, the PIT station transmits to the UAV integrity data and augmentation data and observe for improving accuracy.
- ✓ Check by switching to the PIT-Station for controlling and commanding the UAV as alternative to other systems.
- ✓ Check that satellite communications are relayed from the PIT-Station to the UAV and Test Pilot.
- ✓ Check that the augmentation data comes from HELMET core service centre. In case there is a real time link between pilot and RPAS then it is possible to re-plan operation or take direct control of the RPAS.

1.7.3) Landing and Post-Flight Operational Phases Testing

Initialize the landing procedure automatic or assisted by pilot. In case of automatic the procedure foreseen speed reduction, attitude acquisition, reference signal acquisition form PIT station. (i.e. augmentation for attitude and heading or RTK data).

- ✓ Landing on the PIT Station B
- ✓ Hand over of communication links form PITA to PITB
- ✓ Acquire reference signal or data for landing (supported by optical or RF augmentation)
- ✓ Precision approach category I/II/III and/or visual assisted landing
- ✓ Augment Landing and attitude control (if requested)

- ✓ Landing
- ✓ Communicate flight plan to UTM
- ✓ Refuelling/Recharging
- ✓ Dump acquired data for tx to Pilot or users via ground or space networks
- ✓ Check-up health status
- ✓ Reprogram operation as for station A
- ✓ Goes next PIT stations

For the specific HELMET UAV Navigation Flight Test Operations (which the central aspect of the project) The Test team will consider a number of performance aspects to verify and validate the GNSS Galileo Navigation related equipment and services. The IMTM UAS Segment is designed for precision operation as shown in the Table 5. Fundamental tests in this category will include:

a) Time to First Fix: Time To First Fix (TTFF) is a measure of how quickly a receiver performs the signal search process. The Test team will want to verify how quickly after power-up the receiver can obtain its first valid navigational data point: both for the first time (Cold Start TTFF), and when earlier position information has been retained (Warm/Hot TTFF).

b) Acquisition Sensitivity: This test will verify and validate the minimum received power level at which a 'First Fix' can occur. The sub-sets of this are separate measurements for each of the cold, warm and hot start-up conditions.

c) Tracking Sensitivity: This Test will verify and validate the minimum power level at which a receiver can continue to maintain lock.

d) Reacquisition Time: This Test will verify and validate the time necessary for a receiver to regain its first valid navigational data point after total loss of all received signals (for example after a period in a GNSS Galileo-denied area).

e) Static Navigation Accuracy: This Test will verify and validate the accuracy to which a receiver can determine its position with respect to a known location.

f) Dynamic Navigation Accuracy: The same as Static Navigation Accuracy, except the receiver is undergoing motion in any or all of the three axes of movement x, y, z.

g) Timing Accuracy: This Test will verify and validate the accuracy to which the receiver can determine the time based on timing information received in the satellite signal – for accuracy of time stamping of photographs or video footage.

All of these tests can be also performed quickly, accurately and repeatability in the lab using a GNSS Galileo simulator to simulate the position data emitted by overhead satellites and monitor the effects on the receiver. However, real time in-flight tests are preferred since they will produce more realistic and accurate data for specific environmental and mission condition.

1.8) The Expected Test Results for the Scenario A:

a) To obtain, verify and validate the UAS communications functional and operational performance data against the Requirements of D2.3 "System Requirements Specification", section 5.3 UAV: UAS/ RPAS-PIT Station Segment System Requirements Document;
b) To obtain, verify and validate the UAS control functional and operational performance data against the Requirements of D2.3 "System Requirements Specification", section 5.3 UAV: UAS/ RPAS-PIT Station Segment System Requirements Document;

c) To obtain, verify and validate the UAS Navigation functional and operational performance data against the Requirements of D2.3 "System Requirements Specification", section 5.3 UAV: UAS/ RPAS-PIT Station Segment System Requirements Document;
d) To obtain, verify and validate the UAS DAA functional and operational performance data against the Requirements of D2.3 "System Requirements Specification", section 5.3 UAV: UAS/ RPAS-PIT Station Segment System Requirements Document;
e) To obtain, verify and validate the specific Inspection Mission Payload instrumentation functional and operational performance as per supplier specification and related HELMET user requirements;
f) To obtain, verify and validate Safety and Security functional and operational performance data against the Requirements of D2.3 "System Requirements Specification", sections 4.3 and 5.3 UAV: UAS/ RPAS-PIT Station Segment System Requirements Document; (Flight Testing for Safety Tasks are specifically treated in later subsections of this section).

2) Flight Test Scenario B: Rail and Road Assets Monitoring Services Field Operations

2.1) Test Case 1B: UAS/RPAS Monitoring of Railway and Road Assets Operational Mission:

A small Fixed Wing Hybrid UAS/RPAS of the HELMET Support Services Network (which includes the PIT stations installed along the Railway and Road Test Site(s)) is involved in Monitoring Flight Test Operations of a railway line and road in the following specific sub-case missions:

a) Accident/Incident Occurrence;
b) Situational Awareness,
c) Difficult Terrain, Safety, or Manoeuvrability,
d) Natural Disaster Event;
e) Fatal Crash Scene Mapping

Under the simulated conditions UTM airspace of open sky or restricted or urban/local environmental operational conditions. The UAS/RPAS will be mainly equipped with a Video HD sensor performing the above test operations (missions) in scheduled flights and transmitting in real-time and/or near-real-time the recorded events to the test team for verification and validation of its operational capabilities. The UAS/RPAS involved can be fully supported by the PIT Station(s) distributed for the tests in strategic locations which are serviced by the HELMET Network. In addition, the flight test will verify and validate the UAS/RPAS fail-safe flight mode performance and its capability to fly at a BVLOS mode patrolling a restricted area within the railway and road assets perimeter (in actual operations it will fly sometimes at 20-30km distance from its base). The Flight tested UAV must have an approved flight plan by the local UTM and it won't exceed 120m altitude AGL during flight operations within the established geo-fencing restrictions.

2.2) Test Case 2B Flight Phases, Mission Endurance and Range:

This Test Case involves all Flight Phased Operations for all UAS/RPAS involved and these are Pre-Flight, Take-off, Arrival to the mission area, Performance of the Planned Aerial Work and Return to Base (Landing), Post-Flight Operations. However, there are some slight differences on the planned aerial work. For the first two, most of the aerial work is at hovering conditions at low altitude from 0.5m-20m (vertical) and lateral movements (25cm-10m) focusing at the inspection zone of the asset, while the third UAS/RPAS will have more complex flight trajectory going from straight flight up to 1km and back, to loitering and hovering periods around the target area at altitudes that can vary from 5m to 100m. All operational steps described in D2.2 CONOPS, section 3.3.4 document are applicable. Taking into account of the single UAS/RPAS involved in the above flight test mission profiles and performance capabilities the mean endurance will be 90min (without PIT Station Support) while the range will be variable from 500m to 2.5km (total minimum test site dimensions).

2.3) Test Flight UAS/RPAS Inspection Operational Performance Measurable Requirements for GNSS Galileo Services Verification and Validation (see Table 10 below) for all Cases in Scenario B

Table 10. Requirements for GNSS from Viewpoint of UAS/RPAS Monitoring Operations

MONITORING MISSION (RAIL/AUTOMOTIVE)	ACCURACY HOR	ACCURACY VER	INTEGRITY	TIME-TO-ALERT	CONTINUITY	AVAILABILITY	
Position/Navigation (Urban/Non-Urban)	1 m /10m	1 m /10m	1 – 2× 10–7	1s	1–1×10–4/h to 1–1×10–8/h	0.95-0.99	UR_015
GEO-Awareness	1m	1m	1 – 2× 10–7	1s	1–1×10–4/h to 1–1×10–8/h	0.95-0.99	

2.4) Flight Test Main Services Provisions Required for the Scenario B:
As per Scenario A subsection 1.4

2.5) Organizations and Experts Involved during the Flight Tests for the Scenario B :
As per Scenario A subsection 1.5

2.6) Other Flight Test Operational Applications under the Scenario B:(Railway and Road Infrastructural Monitoring):

- ✓ Visual location of victims on the accident scene
- ✓ Aerial damage assessment
- ✓ UA/RPA resource (food/water) delivery
- ✓ Medical first aid kit delivery
- ✓ UA/RPA with LiDAR damage monitoring and assessment
- ✓ Monitoring Natural Disaster

2.7) Scenario B Flight Phases Main Test Tasks List:
As per Scenario A subsection 1.7

2.8) The Expected Test Results for the Scenario B:

a) To obtain, verify and validate the UAS communications functional and operational performance data against the Requirements of D2.3 “System Requirements Specification”, section 5.3 UAV: UAS/ RPAS-PIT Station Segment System Requirements Document;
b) To obtain, verify and validate the UAS control functional and operational performance data against the Requirements of D2.3 “System Requirements Specification”, section 5.3 UAV: UAS/ RPAS-PIT Station Segment System Requirements Document;
c) To obtain, verify and validate the UAS Navigation functional and operational performance data against the Requirements of D2.3 “System Requirements Specification”, section 5.3 UAV: UAS/ RPAS-PIT Station Segment System Requirements Document;
d) To obtain, verify and validate the UAS DAA functional and operational performance data against the Requirements of D2.3 “System Requirements Specification”, section 5.3 UAV: UAS/ RPAS-PIT Station Segment System Requirements Document;
e) To obtain, verify and validate the specific Monitoring Mission Payload instrumentation functional and operational performance as per supplier specification and related HELMET user requirements;
f) To obtain, verify and validate Safety and Security functional and operational performance data against the Requirements of D2.3 “System Requirements

Specification", sections 4.3 and 5.3 UAV: UAS/ RPAS-PIT Station Segment System Requirements Document; (Flight Testing for Safety Tasks are specifically treated in later subsections of this section).

3) Flight Test Scenario C: UAS/RPAS Rail and Road Traffic Management Operational Scenario

The UAS/RPAS Traffic Management of Railway and Road Operational Scenario is a subset of the Monitoring Operations. However, Traffic Management has some peculiarities within the Monitoring task and thus will be Tested and Assessed separately.

3.1) Flight Test Scenario C - Test Case 1C:

A small Fixed Wing Hybrid or a Multi-Rotor UAS/RPAS will be employed for test flight operations for this scenario and it shall verify and validate the HELMET Support Services Network in Traffic Management mainly for roads in the following specific missions or a representative number of them depending on the availability of realistic traffic simulations test sites:

1) Live traffic monitoring and control
2) Work zone management
3) Traffic data collection
4) Incident management at real time
5) Real-time traffic impact assessment
6) Monitoring congestion of roadways
7) Monitoring activities at traffic intersections
8) Assessment of traffic patterns
9) Crash investigation
10) Forensic mapping
11) Support Intelligent Transportation
12) System (ITS) application of highway and transportation infrastructure monitoring
13) Urban highway traffic monitoring
14) Level of Service (LOS) determination
15) Estimation of average annual daily travel
16) Measuring origin-destination flows
17) Traffic-related pollution monitoring

Under the conditions UTM airspace of open sky or restricted or urban/local environmental operational simulated conditions. The UAS/RPAS will be mainly equipped with a Video HD sensor or LIDAR performing the above flight test operations (missions) in scheduled flight planning and transmitting in real-time and/or near-real-time the recorded events to the test team actors for the verification and validation of the mission data. The UAS/RPAS involved can be fully supported by a representative number of PIT Stations placed in strategic locations within the test area. The tests will verify and validate the UAS/RPAS fail-safe flight mode capabilities and it will fly at its most representative flight modes in EVLOS and BVLOS patrolling an area within mainly the selected test site perimeter chosen for this purpose. In addition the flight test operations will have an approved flight plan by the local UTM and the UAV won't exceed 120m altitude AGL during flight operations within the established geo-fencing restrictions.

3.2) Test Case 2C Flight Phases, Mission Endurance and Range:

The Test Scenario C Flight Phases for the UAS/RPAS involved are Pre-Flight, Take-off, Arrival to the mission area, Performance of the Planned Aerial Work and Return to Base (Landing), Post-Flight Operations. UAS/RPAS will have a complex flight trajectory composed of straight flight, loitering and hovering periods around the target area at altitudes that can vary from 30 to 120m. All operational steps described in section 3.3.4 are applicable. Taking into account of the single UAS/RPAS involved in the above missions performance capabilities the mean endurance will be 120min (without PIT Station Support) while the range will be variable from up to simulated 30km.

3.3) Test Flight UAS/RPAS Traffic Management Operational Performance Measurable Requirements for GNSS Galileo Services Verification and Validation (see Table 11 below) for all Cases in Scenario C

Table 11. Requirements for GNSS from viewpoint of UAS/RPAS Traffic Management Operations

TRAFFIC MANAGEMENT (RAIL/AUTOMOTIVE)	ACCURACY HORIZONTAL	ACCURACY VERTICAL	INTEGRITY	TIME-TO-ALERT	CONTINUITY	AVAILABILITY
Position/Navigation	10m / 30m	10m / 30m	1 – 2× 10–7	1s	1–1×10–4/h to 1–1×10–8/h	0.95 to 0.99
GEO-Awareness	1m	1m	1 – 2× 10–7	1s	1–1×10–4/h to 1–1×10–8/h	0.95 to 0.99

3.4) Flight Test Main Services Provisions Required for the Scenario C:
As per Scenario A subsection 1.4

3.5) Organizations and Experts Involved during the Flight Tests for the Scenario C :
As per Scenario A subsection 1.5

3.6) *NOT USED*

3.7) Scenario C Flight Phases Main Test Tasks List:
As per Scenario A subsection 1.7

3.8) The Expected Test Results for the Scenario C:

a) To obtain, verify and validate the UAS communications functional and operational performance data against the Requirements of D2.3 “System Requirements Specification”, section 5.3 UAV: UAS/ RPAS-PIT Station Segment System Requirements Document;
b) To obtain, verify and validate the UAS control functional and operational performance data against the Requirements of D2.3 “System Requirements Specification”, section 5.3 UAV: UAS/ RPAS-PIT Station Segment System Requirements Document;
c) To obtain, verify and validate the UAS Navigation functional and operational performance data against the Requirements of D2.3 “System Requirements Specification”, section 5.3 UAV: UAS/ RPAS-PIT Station Segment System Requirements Document;
d) To obtain, verify and validate the UAS DAA functional and operational performance data against the Requirements of D2.3 “System Requirements Specification”, section 5.3 UAV: UAS/ RPAS-PIT Station Segment System Requirements Document;
e) To obtain, verify and validate the specific Traffic Management Mission Payload instrumentation functional and operational performance as per supplier specification and related HELMET user requirements;
f) To obtain, verify and validate Safety and Security functional and operational performance data against the Requirements of D2.3 “System Requirements Specification”, sections 4.3 and 5.3 UAV: UAS/ RPAS-PIT Station Segment System Requirements Document; (Flight Testing for Safety Tasks are specifically treated in later subsections of this section).

5.2.2.4 UAS Hazards-Based Flight Test Scenarios for Safety Assessment

The IMTM operation of UAS in high-risk environments (e.g., suburban, urban, and congested population densities) will require the development and implementation of hazards mitigation systems and contingency management strategies for reducing risk. Implementing these systems and strategies for safety-critical applications will necessitate a thorough evaluation of their effectiveness and clear identification of any limitations. Such verifications and evaluations will require the development and application of a realistic set of hazards-based test scenarios. This subsection summarizes an approach for the development of hazards-based test scenarios for the IMTM UAS rail and road operations and presents an initial set of test scenarios developed for a selected hazard. The scenarios are based on UAS IMTM Mission Task Elements (MTEs) and include nominal and emergency conditions. The technical approach logic for developing hazards-based test scenarios for evaluating hazards mitigation strategies for UAS IMTM operations is illustrated in Figure 11 below.

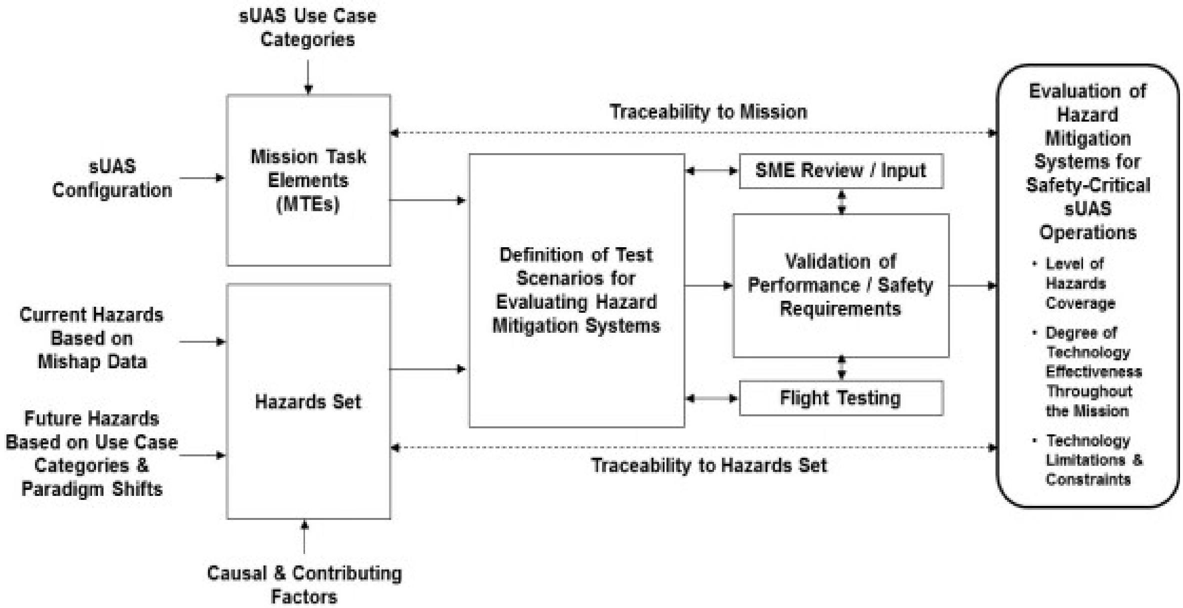


Figure 11. Hazards-Based Test Scenario Development Approach Logic for UAS IMTM Operations (AIAA AVIATION Forum, 17th AIAA Aviation Technology, Integration, and Operations Conference 5-9 June 2017, Denver, Colorado)

Flight testing is required to support the safety assessments being performed for small UAS (sUAS) operations in the context of HELMET Network. A key aspect of this testing is the assessment of sUAS dynamics and control characteristics under off-nominal conditions (e.g., system failures). The flight test results will be also used in verifying and validating vehicle simulation models being developed prior to testing for characterizing off-nominal condition effects. Other testing will focus on evaluating the effectiveness of hazard mitigation systems at the UAS level and contingency management systems and strategies at the operational level. Flight testing will also be used in assessing the effectiveness of real-time risk assessment and safety assurance systems. Ultimately, a multi-sUAS flight test environment will be established for developing and validating safety requirements for multi-sUAS operations within the HELMET Network Services to rail and road segments. The remainder of this subsection focuses on flight testing of sUAS under system failures.

5.2.2.4.1 Flight Test Approach, Failure Emulation, and Expected Initial Flight Test Results

A series of flight tests will be performed to assess failure responses in three different platforms, two multi-rotors and one hybrid type of sUAVs. For the multi-rotors, two likely failure scenarios will be developed, one where a motor fails or degrades while the sUAV is in a stable hover and the other where a motor fails or degrades while the vehicle is navigating a waypoint pattern. For the hybrid platform, scenarios will developed that emulated control surface failures of neutral, positive and negative deflections. Additionally, the on-board Navigation system would be selectively disabled during a waypoint following function. All three platforms will use COTS sUAV autopilot.

In order to obtain realistic failure results, COTS sUAS platforms will be modified to allow for emulating a failure under controlled conditions. For multi-rotor sUAS, provisions should be made able to switch the throttle signal going to one of the rotor motor controllers to a value selectable by the radio-control transmitter. This will allow for the test to implement both a complete failure of a rotor emulating loss of motor controller, motor failure, or prop failure, and a "partial" failure emulating a control signal issue where the control signal pulse width modulation to the motor controller will be frozen via a "hold last valid setting" by the motor controller. In the case of hybrid sUAS, provisions should be made able to fail control surfaces (e.g., right aileron, right side elevator, and rudder) at selectable positions to emulate a servo failure or a mechanically jammed control surface. In addition, the hybrid sUAV will be outfitted to incorporate the ability to selectively disable the on-board GNSS Galileo Navigation Subsystem.

Experimental Test Flights will be defined with the multi-rotors for failing a motor in both fixed, stable hover and waypoint navigation modes. In these tests, the throttle settings will include nominal hover, +/-25%, +/-50%, -75%, and -100% (i.e., full off). Note that during testing, it will be determined for both types of multi-rotors that a +50% throttle setting or above maybe unrecoverable in hover as resulted in similar tests in the past.

Failure durations will be ranged from 1 to 30 seconds, depending on the effect, with longer durations applied to the hybrid sUAV. That is, if the failure do not cause visible distress to the component or the vehicle it may be allowed to persist for several seconds. If the failure effect is visibly significant or destabilizing, the failure should be reversed more quickly to prevent entry into an unrecoverable state. The multi-rotors would be generally able to ignore a nominal hover throttle setting "failure" in hover as observed in related experimental testing programs in the past. However, even this benign condition may make navigating a waypoint pattern problematic. In such performed tests has resulted that a sUAV multi-rotor wasn't able to recover from a +50% or higher "stuck" throttle setting. In some cases, a multi-rotor were unable to hold a single fixed position but would instead fly a very tight circle around the hover position. In addition, the tested multi-rotor sUAV would exhibit a fairly dynamic response to a complete shutdown of one rotor.

The hybrid sUAV will be tested for verifying and validate its behaviour and if affected by a frozen-neutral aileron setting. Waypoint navigation with the right aileron fixed will be tested for verifying if it will be indistinguishable from nominal flight path. The ± 25% failures will show the degree of deviation from the assigned flight path in a box pattern. Additional testing with larger off-nominal settings will be performed in the case the failed aileron is stuck to either +/- 100%, as would be the case with a jam and verify if the UAV can manoeuvre around the waypoint pattern. In this case, it should be verified if the remaining operational aileron will be deflected in fully the opposite direction leaving only the rudder to effect a turn. Testing a rudder failure on the hybrid UAV must be conducted as well. The patterns must be re-used with the waypoints arranged in a clockwise fashion to necessitate a right turn at the corners. A neutral rudder failure must be verified for impact on the ground track. However, a full left rudder deflection must be made so as to verify the right turn functional performance. Conversely, tests must be performed having a full right rudder failure to verify UAV behaviour in turns taking a normal amount of time and cross-track error.

The elevator testing must be similarly selected to represent half the elevator failed in a specific deflection between -100% and +100%. With the half elevator failed full down, the test must verify the UAV attitude and handling behaviour in terms of recovery above the safety floor altitude. At power-off the test must verify attitude when the half elevator would fail full up and the other half elevator is deflected full down. In addition the test must verify if the UAV under elevator failing conditions can navigate the waypoint pattern. Furthermore, with the Navigation subsystem power turned off, the test must verify the ability of the UAV to maintain altitude, course, and if attitude degraded very rapidly.

A number of additional tests may include testing more vehicle types, such as an octo-copter and a different fixed-wing sUAS. Tests should be also performed to evaluate the ability of multi-rotor sUASs to descend in the presence of failure and to navigate when the GNSS Galileo Navigation System has failed. Different types of autopilots will also be tested to determine whether the phenomenon captured during these tests is autopilot specific. Other flight test activities will support the sUAS dynamics modelling and development for off-nominal conditions, as well as the evaluation of hazard mitigation systems. The evaluation of hazard mitigation systems will include support in the development of a comprehensive set of test scenarios including the validation of performance requirements. A potential outcome of the overall HELMET UAV verification and validation testing effort is the development of safety recommendations and recommended “best practices” for improving the robustness of both the hardware platform and the airborne software, as well as for developing and evaluating resilient systems for off nominal conditions. These recommendations would allow system designers to develop safer, more reliable vehicles even in the event of component failures, which will be mandatory on future sUAS that operate BVLOS and under high-risk safety-critical conditions.

5.2.2.4.2 UAS Hazards-Based Initial Test Scenarios

A set of realistic hazards-based test scenarios are needed in order to evaluate the effectiveness of hazard mitigation strategies for reducing risk in safety-critical sUAS operations. Document D2.2 CONOPS, Section 5.3.4 “Overview of Hazards Identification and Assessment for UAS/RPAS Operations” provides a summary of the combined hazards and a set of risk mitigation strategies for a selected hazard, and describes the incorporation of hazards into the MTEs developed for sUAS vehicles by configuration. A preliminary set of test scenarios for off-nominal conditions are presented for this selected hazard and a subset of the associated causal & contributing factors. Table 12 summarizes the combined hazards.

Table 12. Combined Vehicle-Level Hazards Set Based on Analyses of Current and Future Hazards
(AIAA Forum, 17th AIAA Aviation Technology, Integration, and Operations Conference 5-9 June 2017, Denver, Co)

Hazard No.	Hazard Description
VH-1	Aircraft Loss of Control (LOC)
VH-2	Aircraft Fly-Away / Geofence Non-Conformance
VH-3	Lost of Communication / Control Link
VH-4	Loss of Navigation Capability
VH-5	Unsuccessful Landing
VH-6	Unintentional / Unsuccessful Flight Termination
VH-7	Failure / Inability to Avoid Collision with Terrain and/or Fixed /Moving Obstacle
VH-8	Hostile Remote Takeover and Control of UAS
VH-9	Rogue / Noncompliant UAS
VH-10	Hostile Ground-Based Attack of UAS (e.g.UAS Counter Measure Devices, etc.)
VH-11	Unintentional / Erroneous Discharge of Explosives, Chemicals, etc.
VH-12	Erroneous Autonomous Decisions / Actions by UAS Compromise Vehicle / Operational Safety
VH-13	Cascading Failures in Multi-UAS and Collaborative Missions

The technical approach for developing hazards-based test scenarios for evaluating hazards mitigation strategies for sUAS operations is illustrated by the logic in Figure 11.
The goal is to be able to evaluate mitigation system effectiveness over the entire mission and for all key causal and contributing factors associated with the hazard being mitigated. Coverage of all aspects of the mission is accomplished through the use of mission task elements which will be developed from the use case categories and specified by vehicle configuration. Coverage of the causal and contributing factors associated with the hazard will be accomplished by designing them into the test scenarios. The performance / safety specifications being proposed in this subsection will need to be validated via simulation evaluations, experimental flight testing, and input obtained from subject matter experts (SMEs). Thus, the flight test will support the verification and validation

of the performance / safety requirements being specified in these scenarios. It is emphasized again that the scenarios presented in this subsection are considered preliminary. The test scenarios should also be comprehensive enough to facilitate the identification of limitations in the mitigation system – either relative to hazard coverage or mission coverage. A set of preliminary hazards-based test scenarios is presented in D2.2 CONOPS, Section 5.3.4, Tables 29 through 37 while Table 13 provides an example of initial hazards based test scenarios for the VH-1 Case for Aircraft Loss of Control.

Table 13. Example of Initial Hazards-Based Test Scenarios for VH-1: Aircraft Loss of Control

Scenario	Hybrid Rotorcraft (HR)	Multi-Rotor (MR)
Robustness under Wind & Turbulence Conditions	•Varying Wind Speed & Direction •Varying Turbulence Levels	• Varying Wind Speed & Direction • Varying Turbulence Levels
Resilience to Flight Control Component Failures	• Loss of Control Effectiveness (Elevator, Rudder, Aileron, Thrust) • Stuck Actuator (Elevator, Rudder, Aileron)	• Loss of Control Effectiveness (Rotors) • Stuck Rotor Speed
Resilience to Shifts in Center of Gravity (C.G.) Position	• Longitudinal C.G. Shifts • Lateral C.G. Shifts • Vertical C.G. Shifts	• Longitudinal C.G. Shifts • Lateral C.G. Shifts • Vertical C.G. Shifts
Resilience to Vehicle Impairment Conditions	• Lifting / Control Surface Contamination Effects • Lifting / Control Surface Damage Effects (with and without associated C.G. shifts)	• Vehicle Contamination Effects • Vehicle Damage Effects (with and without associated C.G. shifts)
Resilience to Control Component Failures, Vehicle Instabilities, and Vehicle Impairment Conditions	• Flight Control Component Failures • C.G. Shifts • Vehicle Impairment Conditions • Wind / Turbulence Conditions	• Flight Control Component Failures • C.G. Shifts • Vehicle Impairment Conditions • Wind / Turbulence Conditions

Table 14. Example Hazards-Based Test Scenario for Resilience to Flight Control Component Failures

Hybrid Rotorcraft (HR)	Multi-Rotor (MR)
Resilience to Flight Control Component Failures	
Objectives: •Evaluate ability to detect / mitigate flight control component failures during all mission tasks. •Identify resilience coverage and limitations under flight control component failures (in terms of failure type / severity and MTE effectiveness). •Determine control limits and maneuverability constraints under control component failures.	**Objectives**: • Evaluate ability to detect / mitigate flight control component failures during all mission tasks. •Identify resilience coverage and limitations under flight control component failures (in terms of failure type / severity and MTE effectiveness). • Determine control limits and maneuverability constraints under control component failures.
Description: • Initiate each nominal MTE and randomly inject an emulated control component failure (elevator, rudder, aileron, and engine thrust), as follows (and in accordance withthe aircraft configuration being tested).	**Description**: • Initiate each nominal MTE and randomly inject an emulated control component failure (rotor failures), as follows (and in accordance with the aircraft configuration being tested).
• Evaluate loss of control effectiveness (elevator, rudder, aileron, and engine thrust) incrementally from 0% to 100%. • Evaluate resilience (i.e., mitigation effectiveness) to stuck control surface effects incrementally from neutral to hard over positions (elevator, rudder, and aileron). • Evaluate with no winds and nominal wind conditions (no turbulence)	• Evaluate loss of control effectiveness (rotor speed) incrementally from 0% to 100%. • Evaluate resilience (i.e., mitigation effectiveness) to stuck rotor-speed effects incrementally from neutral to maximum levels. • Evaluate with no winds and nominal wind conditions (no turbulence)
Flight Conditions: • All FW Nominal Common MTEs • Selected FW Nominal MTEs, as Appropriate	**Flight Conditions**: • All MR Nominal Common MTEs • Selected MR Nominal Specialized MTEs, as Appropriate
Hazard Condition: Single Component Failure	**Hazard Condition**: Single Rotor Failure

• Loss of Control Effectiveness (elevator,rudder, aileron, and engine thrust): 0%, 10%, 20%, …, 100% • Stuck Control Surface (elevator, rudder, aileron) Increments from Neutral: ±2 deg, ±4 deg, …, ± hard-over	• Loss of Control Effectiveness (rotor speed): 0%, 10%, 20%, …, 100% • Stuck Rotor Speed Increments from Nominal: ±10%, ±20%, …, ± 100% (positive and negative values represent increments above or below the nominal value)
Environmental Conditions: • No wind • Varying levels and directions of sustained wind conditions up to 10% above the rated wind level for vehicle operation	**Environmental Conditions**: • No wind • Varying levels and directions of sustained wind conditions up to 10% above the rated wind level for vehicle operation
Desired Performance: • ≥ 80% of Nominal Performance (Suburban) • ≥ 90% of Nominal Performance (Urban / Congested)	**Desired Performance**: • ≥ 80% of Nominal Performance (Suburban) • ≥ 90% of Nominal Performance (Urban /Congested)
Adequate Performance: • ≥ 70% of Nominal Performance (Suburban) • ≥ 80% of Nominal Performance (Urban / Congested)	**Adequate Performance**: • ≥ 70% of Nominal Performance (Suburban) • ≥ 80% of Nominal Performance (Urban / Congested)
Test Variations: • Tests at varying initial conditions within each MTE • For Dual-Engine Vehicle Configurations, Include Single Engine Out Conditions • Multiple Failures can be Considered to Determine Level of Available Control Redundancy	**Test Variations**: • Tests at varying initial conditions within each MTE • Multiple Rotor Failures Can be Considered to Evaluate Level of Available Control Redundancy • Failures Involving Reversal of Rotor Rotational Direction Should be Considered if a Failure Mode Resulting in this Behavior is Identified
Notes: Evaluations should predominantly be performed using a simulation capable of characterizing off-nominal condition effects; Selected simulation results should be validated in flight testing	**Notes**: Evaluations should predominantly be performed using a simulation capable of characterizing off nominal condition effects; Selected simulation results should be validated in flight testing

5.2.2.4.3 Flight Testing for Multi-UAS Operations

As stated previously, the operation of UAS within the UTM system is expected to migrate toward high-risk environments associated with suburban and urban settings serving Rail and Road IMTM needs. It is also anticipated that future demand will necessitate a shift toward multi-UAS operations in which a single operator will be responsible for the safe operation of multiple UAS simultaneously as it is also for HELMET. This subsection discusses the need for establishing a multi-UAS flight test environment that facilitates integrated research and technology evaluations involving autonomy, real-time risk management and safety assurance, human-automation teaming, Verification and Validation of increasingly autonomous systems.

Associated with the proliferation of civil applications for UAS is a paradigm shift to BVLOS operations with
increasing use of autonomous systems and operations under increasing levels of urban development and airspace usage. It is also anticipated that increasing demand for sUAS operations in multiple application domains will necessitate a paradigm shift towards multi-UAS operations and the use of advanced technologies that enable real-time risk assessment and safety assurance and effective dynamic human-automation teaming for real-time contingency management at the operational level. Multi-sUAS operations may involve simultaneous operation of heterogeneous vehicle types, collaborative missions, and coordinated missions involving manned air and ground vehicles. As risk increases for ensuring the safety of manned aircraft and persons on the ground (e.g., in suburban and urban environments), these operations become safety-critical and may require advanced technologies for ensuring safety under off-nominal conditions (both anticipated and unexpected). These technologies include resilient autonomous systems, real-time risk assessment

and safety assurance systems, and effective human-automation teaming systems that are effective under off-nominal and hazardous conditions. Evaluation of these technologies will require new methods and tools that facilitate the exposure of system limitations and weaknesses in a research and development environment – so that weakness are not exposed in practice during a safety-critical operation. One such method is a flight test environment that enables integrated technology development and evaluations for multi-UAS safety-critical operations. In order to define a multi-UAS flight test capability, the kinds of testing that would require support must be considered. Table 13 illustrates two examples of multi-UAS flight testing aimed at safety / risk evaluations, and Table 14 provides a phased build-up of these flight test capabilities from single UAS operations to the multi-UAS operations illustrated in Table 15 As illustrated in these tables, various features of the flight test capability are considered, including the Basic Idea, Use Cases supported, Hazards being considered, Mitigation / Contingency Systems being evaluated, and safety / risk indicators to be monitored (and managed). Moreover, the two examples of multi-UAS testing support increasing levels of operational complexity (in terms of density of operations) and increasing levels of operational risk (in terms of population density).

Table 15. Examples of Multi-UAS Flight Testing for Safety / Risk Evaluations

Flight Test Features	Multiple Heterogeneous Vehicles in Suburban Operations	High-Density Urban Operations
Basic Idea	• Multiple Vehicle Flight Test (BVLOS) • Use of BRS or Second Ground Station for Safety / Risk Monitoring • Other Vehicles in Close Proximity - Actual sUAS - Simulated Manned Aircraft	• Higher-Density Multiple Vehicles (BVLOS) • Use of MOS for - Multiple Vehicle Operations - Safety / Risk Monitoring / Management • Use of BRS for Large-Scale Safety / Risk & Contingencies Management
Use Cases	• Infrastructure Inspection • Public Safety (Emulated Search / Surveillance)	• Infrastructure Inspection • News Gathering / Traffic Monitoring • Package Delivery
Hazards	• Mid-Air Collision (MAC) • sUAS LOC and Impact of LOC Trajectory on other sUAS / Aircraft • sUAS Fly-Away under LOC or GPS Failure • Others	• Mid-Air Collision (MAC) • sUAS LOC and Impact of LOC Trajectory on other sUAS / Aircraft and Urban Environment • Widespread GPS Malfunction / Failure (e.g., Loss or Corrupted Data) • Others
Mitigation / Contingency Actions	• Sense and Avoid (SAA) / Detect and Avoid (DAA) / Collision Avoidance System • Flight Termination / Land System Pre Programmed with Safe Landing Zone(s) • Return to Base & Land (Commanded by UTM System) • Resilient Flight Control System for LOC Prevention / Recovery • Other	• SAA / DAA / Collision Avoidance System • Flight Termination / Land System that Identifies Safe Landing Zone in Real Time • Rerouting of nominal UAS to accommodate uncertain trajectory of off-nominal UAS • All Land (Commanded by UTM) • Resilient Flight Control System for LOC Prevention / Recovery • Others
Safety Indicators	• Vehicle Health • Flight Path Compliance • Geofence / Flight Termination Containment • Current / Predicted Trajectory under LOC • Predicted Collision Point / Probability	• Current / Predicted Trajectories of Multiple UAS (Nominal & Off-Nominal) • Current / Predicted Proximity to other UAS / Aircraft • Others
Risk Indicators	• Current / Predicted LOC Trajectory • Predicted Impact Point / Area Relative to Ground Assets and People • Predicted Collision Point / Area for MAC	• Current / Predicted LOC Trajectory Relative to Ground & Other UAS • Predicted Flight Termination Path Relative to Other UAS

Table 16. Multi-UAS Phased Flight Testing for Evaluation of Real-Time Risk Management Technologies

Phased Flight Testing	I. Single Vehicle	II. Multiple Vehicles	III. Multiple Heterogeneous Vehicles in Suburban Operations	IV. Higher Density Urban Operations
Basic Idea	• Single Vehicle Flight Test (VLOS/BVLOS) • Use of Second Ground Station for Safety / Risk Monitoring	• Two Vehicle Flight Test -- #1: Autonomous / BVLOS -- #2: Hand-Flown / VLOS • Use of BRS or Second Ground Station for Safety /Risk Monitoring	• Multiple Vehicle Flight Test (BVLOS) • Use of BRS or Second Ground Station for Safety/Risk Monitoring • Other Vehicles in Close Proximity - Actual sUAS - Simulated Manned Aircraft	• Higher-Density Multiple Vehicles (BVLOS) • Use of MOS for - Multiple Vehicle Operations - Safety / Risk Monitoring / Management • Use of BRS for Large-Scale Safety / Risk & Contingencies Management
Use Cases	• None	• Infrastructure Inspection • Fire Spotting	• Infrastructure Inspection • Public Safety (Emulated Search / Surveillance)	• Infrastructure Inspection • News Gathering / Traffic Monitoring • Package Delivery
Hazards	• Onboard System Failure • Vehicle Loss of Control (LOC) • Nav System Failure • Others	• Changing No-Fly Zone(s) • Mid-Air Collision (MAC): Non-Cooperative Vehicle #2 Entry into Vehicle #1 Airspace • Departure from Geofence - Onboard System Failure - NAV System Failure	• Mid-Air Collision (MAC) • sUAS LOC and Impact of LOC Trajectory on other sUAS / Aircraft • sUAS Fly-Away under LOC or Nav Failure • Others	• Mid-Air Collision (MAC) • sUAS LOC and Impact of LOC Trajectory on other sUAS / Aircraft and Urban Environment • Widespread GPS Malfunction / Failure (e.g., Loss or Corrupted Data) • Others
Mitigation / Contingency Actions	• Return to Base & Land • Flight Termination	• SAA / DAA / Collision Avoidance System • Flight Termination / Land System • Risk-Based Operational Mitigation	• SAA / DAA / Collision Avoidance System • Flight Termination / Land System Pre-Programmed with Safe Landing Zone(s) • Return to Base & Land (Commanded by UTM System) • Resilient Flight Control System for LOC Prevention / Recovery • Other	• SAA / DAA / Collision Avoidance System • Flight Termination / Land System that Identifies Safe Landing Zone in Real Time • Rerouting of nominal UAS to accommodate uncertain trajectory of off nominal UAS • All Land (Commanded by UTM) • Resilient Flight Control System for LOC Prevention / Recovery • Others
Safety Indicators	• Vehicle Health • Flight Path Compliance • Geofence / Flight Termination Containment	• Vehicle Health • Flight Path Compliance • Geofence Containment • Proximity to Vehicle(s)/Infrastructure	• Vehicle Health • Flight Path Compliance • Geofence / Flight Termination Containment • Current / Predicted Trajectoryunder LOC • Predicted Collision Point / Probability	• Current / Predicted Trajectories of Multiple UAS (Nominal & Off-Nominal) • Current / Predicted Proximity to other UAS / Aircraft • Others
Risk Indicators	• Current / Predicted Trajectory • Predicted Impact Point / Area Relative to Ground Assets and People	• Current / Predicted Trajectory • Predicted Collision Point / Probability • Predicted Impact Point / Area Relative to Ground Assets and People	• Current / Predicted LOC Trajectory • Predicted Impact Point / Area Relative to Ground Assets and People • Predicted Collision Point / Area for MAC	• Current / Predicted LOC Trajectory Relative to Ground & Other UAS • Predicted Flight Termination Path Relative to Other UAS

5.2.3 Flight Test Data Processing

5.2.3.1 General

Taking into consideration the immense amount of information produced during flight testing, it is evident that it is needed to count on specific tools that expedite or even automate parts of the data post-processing. A typical data acquisition system may log more than 100 parameters at non-synchronised, variable rates that range from 100 Hz to 1 Hz. A single 10-minute flight produces thousands of raw samples that need to be synthesised and interpreted to enable a rational analysis of the test results.

Data requirements are directly dictated by the details of the UAS Flight Test program and its reporting requirements. The entire purpose of a flight test program is to provide data to facilitate system development, verification, validation, evaluation, qualification, certification, and ultimately, use. Definition of data requirements is a multiple step process that includes specifying the tests and test conditions, identification of the parameters that must be measured, the rate and accuracy needed, definition of data turn-around time and data reduction and/or analysis methods, and the data presentation formats required.

In the sequence of events that make up a flight test program data processing comes between data acquisition and data analysis. It typically starts with the receipt of the flight test data, whether recorded on tape or received in real time by telemetry link, and it ends with the delivery of the processed data to the data analyst.

There are many kinds of "data processing" that occur and the Flight Test Engineer (FTE) must ensure that he/she understands what these various processes are and which data that he/she can expect from each step. Some examples of these data processing steps are:

(1) Conversion of raw binary data into Engineering Unit (EU) data
(2) Presentation of EU data as numerical values (tables) or graphical time histories, x-y plots, bar charts, etc.
(3) Pictorial presentation of the flight path and aircraft attitude and other flight or aircraft parameters
    Calculations in the frequency domain (Fast Fourier Transform)
(4) Data analysis with dedicated software for:
    - ✓ Signal analysis
    - ✓ Signal filtering
    - ✓ Determination of transfer functions
    - ✓ Parameter identification
    - ✓ "Image processing" of video and radar data

5.2.3.2 Summary Flight Test Data Processing Elements

The objective of the Flight Test Quantitative Data Processing obtained by an instrumentation system during a flight test program are almost never in a form that is directly usable by the Flight Test Engineering Team (FTET) or the organization that has requested the test. Therefore it is necessary to convert this data into a more usable form. The data processing requirements must be spelled out as early as possible during the planning for a test. This planning is an iterative process that starts with a generalized idea of the information needed and progresses ultimately to the preparation of the detailed data processing plan. The FTE must be prepared to specify in great detail how the data that is measured and recorded (See Sections 6 and 8) is to be processed, to specify what data products will be required, and the format in which they are to be presented. He/she must understand the inter-relationships between the instrumentation system, its capabilities and limitations, and the overall capabilities of the data processing system. The objective of the data processing requirements planning, therefore, is to describe the data products that will satisfy test objectives without over-specifying needs for accuracy, sampling rates, etc. The following List contains a summary of elements that, together, constitute "Data Processing":

a) PREPROCESSING
   (1) Data format
      - ✓ PCM
      - ✓ PCM with asynchronous sub-frames
      - ✓ PCM with embedded with custom data formats
   (2) Replay of flight and telemetry tapes
      - ✓ Bit, frame, and word synchronization
   (3) Data selection
      - ✓ Selection of processing periods
      - ✓ Selection of parameters
      - ✓ Redundancy removal
   (4) Conversion to computer compatible format
   (5) Application of calibrations
      - ✓ Approximation method
         - ▪ Best fit straight line
         - ▪ Multi-section linear fit (linear interpolation between calibration points)
         - ▪ Table look-up
         - ▪ Polynomials (nth order)
         - ▪ Splines
      - ✓ Type of calibration
         - ▪ Over-all (end-to-end) (in-situ) calibrations
         - ▪ Aggregate calibrations
         - ▪ Component calibrations
         - ▪ Discrete
   (6) Application of corrections
   (7) Time
      - ✓ Synchronization
      - ✓ Correlation
      - ✓ Tagging
   (8) Dealing with delay times
      - ✓ Pitot-static lines
      - ✓ Filter delays
      - ✓ Processing delays
   (9) Indent tagging
   (10) Instrumentation checking
      - ✓ Parameter quick-look
      - ✓ Presentation of raw data
   (11) Standard calculations
      - ✓ Computation of standard derived parameters: Mach, indicated airspeed, altitude, position error
      - ✓ correction
      - ✓ Computation of other simply derived parameters
      - ✓ Correction of systematic errors
   (12) Data validation
   (13) Delivery of data to post-processing environment

b) POSTPROCESSING AND ANALYSIS (real-time and/or post-mission)
   (1) Interactive processing/batch processing
   (2) Curve fitting

(3) Data smoothing or filtering
(4) Data compression
(5) Reduction to standard atmosphere
(6) Standard routine calculations
(7) Custom algorithms
(8) Calculations specific to the type of test:
- ✓ Trajectory
  - Aircraft
  - Stores
- ✓ Performance
- ✓ Stability and control
- ✓ Thrust
- ✓ Air data
- ✓ Loads
- ✓ Wind
- ✓ Fly-over noise
- ✓ Engine inlet distortion

(9) Coordinate conversions
(10) Standard algorithm library
(11) Signal filtering
(12) Image processing of video and radar data
(13) Parameter identification
(14) Statistical analysis
(15) Power spectral density
(16) Fast Fourier Transform
(17) Transfer function analysis
(18) Frequency response analysis

c) <u>TEST DATA PRESENTATION</u>

(1) Colour/black & white
(2) Display screen
(3) Hard copy
(4) Post-flight/quick-look/real-time
(5) Time histories
- ✓ Numerical tables
- ✓ Graphical plots

(6) X-y cross plots
(7) 3D-plots
(8) Bar charts
(9) Annunciator panel
(10) Limit failure
(11) Pictorial display
- ✓ Flight path
- ✓ Aircraft attitude
- ✓ System schematic
- ✓ Spin
- ✓ Take-off/landing performance

(12) Predicted threshold
(13) Positional map
(14) Other flight or aircraft parameters

d) <u>TEST DATA PROCESSING FACILITIES</u>

(1) Telemetry (pre-processing) ground station
(2) Tracking antenna, single or dual axis
(3) Pre-processing stations

(4) Data processing computers
(5) Operating system
(6) Throughput capacity
(7) Storage capacity
(8) Data communication network
(9) Workstations
(10) Printers
(11) Plotters
(12) Equipment for processing and analysing trace, photo, film, and video recordings

e) TEST DATA BASE FOR AUXILIARY DATA
  (1) UAV identification
  (2) Test flight number, date and time
    - ✓ UAV configuration
    - ✓ Mass
    - ✓ Centre of Gravity
    - ✓ Modification standard
    - ✓ Equipment suite
  (3) Configuration of stores
  (4) Configuration of avionics data buses
    - ✓ Configuration of data acquisition system
    - ✓ PCM formats
    - ✓ Location of measured physical quantities
    - ✓ Programming information
    - ✓ Transducers and signal conditioners
    - ✓ Aircraft signal sources
  (5) Parameter info, definition, technical data
  (6) Calibrations

f) DATA BASE FOR FLIGHT TEST DATA AND RESULTS
  (1) On-line data and results files for flight test data users
  (2) (Historical) archiving of flight test data and results

5.3 TEST PROGRAM MANAGEMENT AND ORGANIZATION

5.3.1 Test Program Management Tasks and Organization

Figure 12 of this subsection depicts the main Organizational Structure and its Interfaces dedicated to carry-out and perform all the HELMET Network UAS Segment Ground and Flight Testing Verification and Validation tasks during the overall System Development Phase Effort. The main objective of the T&E Team Organization is to:

a) Plan, Schedule, Organize and Conduct all HELMET UAS Segment Developmental Ground and In-Flight Test Program;
b) Verify and Validate through testing on the Ground and in-Flight the Physical Integrity, Functional Capabilities and Performance of the UAS Segment within its Operational Mission Environment (Simulated or not) and provide experimental data to the HELMET-UAS Development Program Effort;
c) Obtain, Elaborate and Issue Test Data to Support Risk Management and Executive Decisions;
d) Develop Operational Site Plans and Specifications, Identify, Acquire, Inspect and Prepare the Test Site(s) Infrastructure and related Facilities;

e) Plan, Develop, Organize and Implement a Program of Integrated Logistic Support Effort to assist all Ground and Flight Test Tasks;
f) Interface with the HELMET Project and System Engineering Management by providing Test Data and Reports in support to the overall Development Program through Scheduled and/or Non-Scheduled Meetings and Internal Project Reviews. Support Project Management in Formal Reviews and closure of milestones regarding the Test Program.

The main Tasks and Responsibilities of the Test Team can be summarized as follows:

a) HELMET UAS TEST & EVALUATION MANAGER (TEM): is the sole responsible toward the HELMET System Engineering Manager (SEM) for the planning, directing and controlling the total UAS Segment Ground Testing, Flight Testing and Test Support Program Effort. In addition, the TEM participates as a permanent member in the T&E Program Committees and chairs all the T&E Program meetings and related Reviews whether are internal and/or external to the HELMET UAS Project Segment.
b) UAS GROUND V&V TEST TEAM LEADER (GTTL): is the sole responsible toward the TEM for all Ground Verification and Validation Test Activities their planning, directing and controlling. The GTTL participates in all TEM Meetings, Reviews (internal and/or external to the Project) and Reporting for all aspects of the UAS Segment Ground V&V Testing. In addition, to the GTTL respond all allocated to the T&E Program GT Engineering, Technician, and Quality Control personnel and for the time the effort goes on.
c) UAS FLIGHT TEST TEAM CHIEF TEST PILOT (CTP): is the sole responsible toward the TEM for all In-Flight Verification and Validation Test Activities their planning, directing and controlling. The CTP participates in all TEM Meetings, Reviews (internal and/or external to the Project) and Reporting for all aspects of the UAS Segment In-Flight V&V Testing Phase. In addition, to the CTP respond all allocated to the T&E Program FT Test Pilot, Test Co-pilot, FT Observer, FT Engineering, FT Technician, and FT Quality Control, personnel and for the time the effort goes on.
d) UAS TEST & EVALUATION FIELD SUPPORT TEAM LEADER (TFSTE): is the sole responsible toward the TEM for all Ground and In-Flight Test Program Field Logistic Support Activities, their planning, directing and controlling. The TFSTE participates in all TEM Meetings, Reviews (internal and/or external to the Project) and Reporting for all aspects of the UAS Segment In-Flight V&V Testing Phase Integrated Logistic Support such Maintenance/Overhaul, Test Facilities and Sites Support, Supply Support, Tools and Test Equipment, Data Acquisition Support, Training Support and Support Data. In addition, to the TFSTE respond all allocated to the T&E Support Program Technicians, Logistician, Site/Facilities Inspector dedicated to UAS Project personnel and for the time the effort goes on.

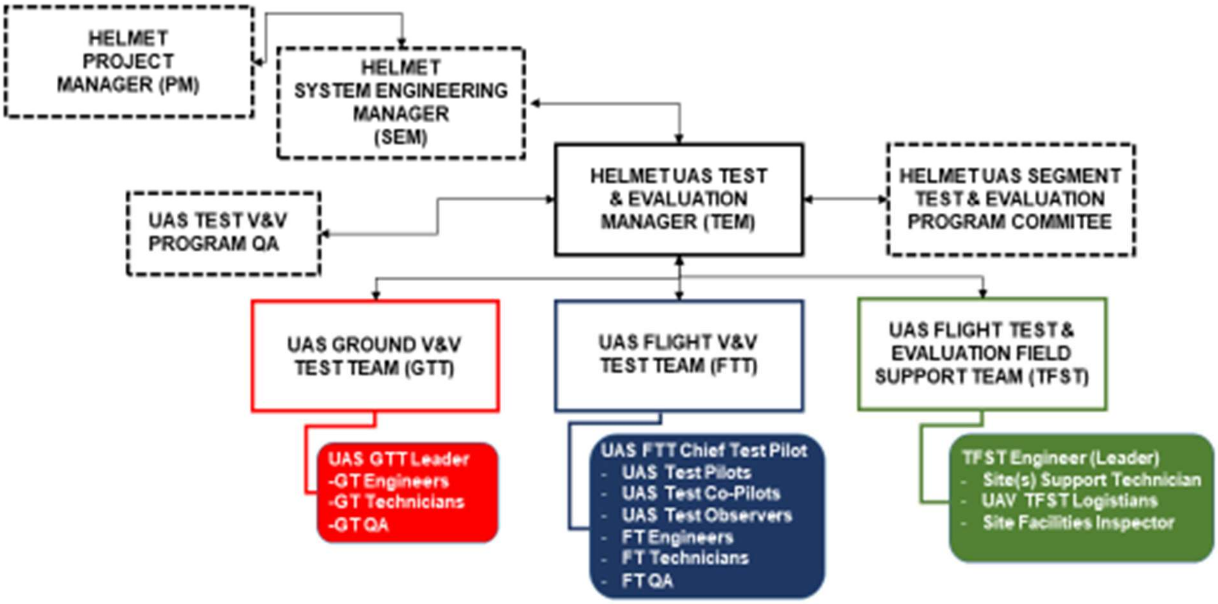


Figure 12. HELMET UAS Segment Test and Evaluation Organizational and Interface Scheme

5.2.1 UAS Test Program Master Schedule Activities List

Task No.	Test Program Main Activity Description	Start-Finish (Months)
1.0	Test Program Kick-Off	T0
2.0	Test Program Management	T0-T16
2.1	Program Detailed Planning and Scheduling	T0-T2
2.2	Site and Facilities Plan	T1-T3
2.3	Test Site(s) Identification, Acquisition and Furnishing	T2-T6
3.0	UAS Ground Testing Readiness Review (G-TRR)	T6
4.0	UAS Ground Testing and Data Acquisition and Reporting	T6-T10
5.0	UAS In-Flight Testing Readiness Review (F-TRR)	T10
6.0	IMTM UAS In-Flight Testing and Reporting	T10-T15
7.0	IMTM UAS Acceptance Test Readiness Review and Reporting	T15
8.0	Test Program Final Review and Report-End of Program	T16

6 REFERENCES

[1] RTCM, RTCM 10410.1 Standard for Networked Transport of RTCM via Internet Protocol (Ntrip) Version 2.0 with Amendement, RTCM, 2011.

[2] RTCM, RTCM 10403.3, Differential GNSS (Global Navigation Satellite Systems) Services - Version 3, RTCM, 2016.

[3] A. Neri, R. Capua und P. Salvatori, „High Integrity Two-tiers Augmentation Systems for Train Control Systems," in *PNT 2015*, 2015.

[4] J. Saastamoinen, Atmospheric Correction for the Troposphere and Stratosphere in Radioranging of Satellites, in the Use of Artificial Satellites for Geodesy, Geophys. Monogr. Ser, 1972.

[5] O. García Crespillo, M. Joerger und S. Langel, „Overbounding GNSS/INS Integration with Uncertain GNSS Gauss-Markov Error Parameters," in *Position, Navigation and Timing Symposium (PLANS)*, 2020.

[6] O. Garcia Crespillo, M. Joerger und S. Langel, „Tight Bounds for Uncertain Time-Correlated Errors with Gauss-Markov Structure," unpublished.

[7] HELMET, „D3.2 Functional Architecture Design Document," 2020.

[8] HELMET, „D3.1 High Level Design Document," 2020.

[9] HELMET, „D3.3. Detail Design Document," 2020.