Investigate IFR RPAS Control in Airports and TMA

The INVIRCAT Project
IFR RPAS Control in Airports and TMA

Gunnar Schwoch, DLR

RPAS and AI in Aviation, Rome, November 3rd, 2022

EUROPEAN PARTNERSHIP

This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 893375. The opinions expressed herein reflect the author's view only. Under no circumstances shall the SESAR Joint Undertaking be responsible for any use that may be made of the information contained herein.

Co-funded by the European Union

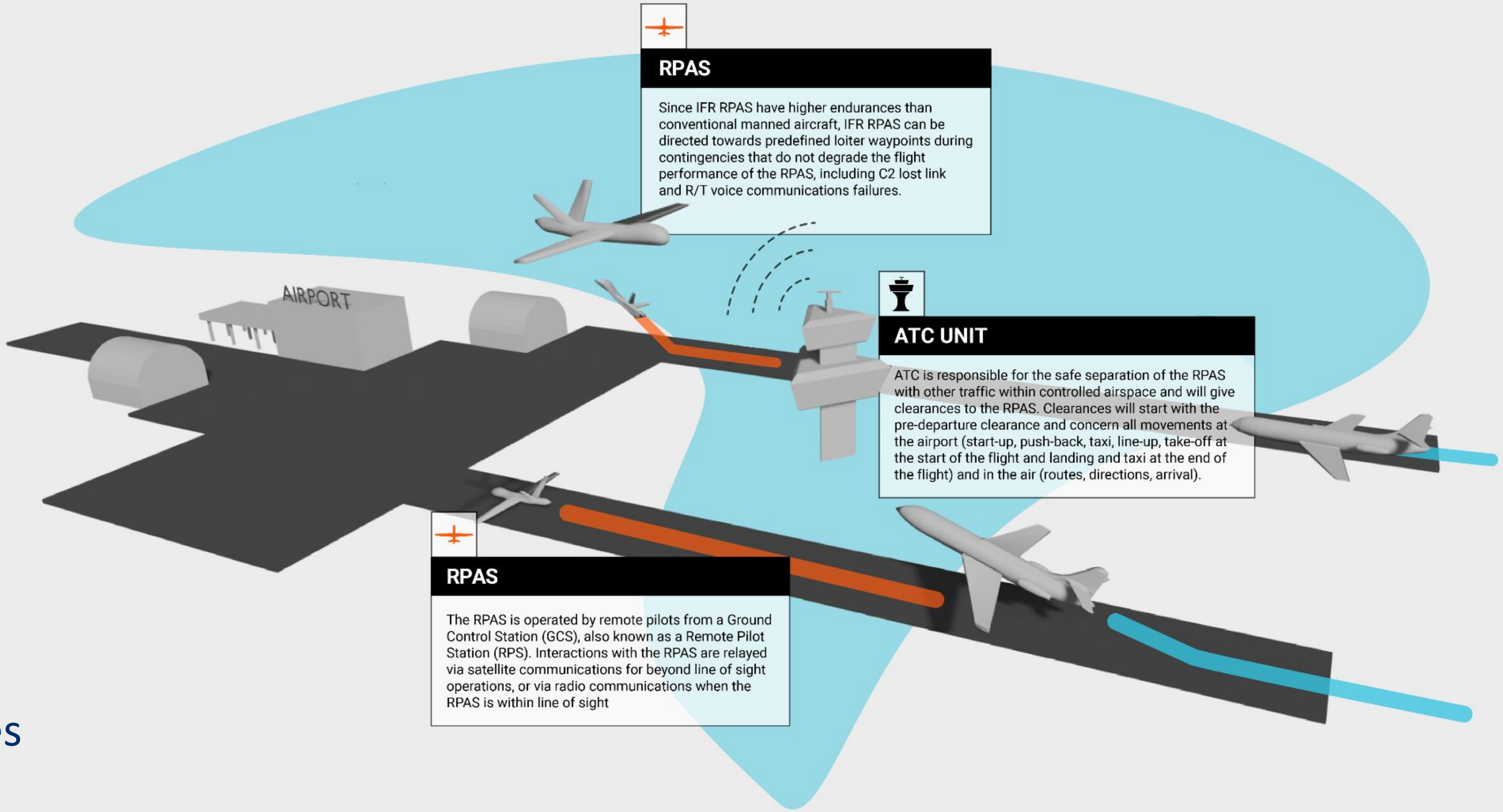
Why do we want to integrate RPAS?

Market for civil RPAS applications is growing:

- Cargo transport
- Crisis response, search and rescue (SAR)
- Communication and broadcast of information
- Monitoring of infrastructure
- Atmospheric research

Dedicated airfields not always practicable

Integration into current operations requires adequate **concept of operations**



Challenge: Different RPAS Configurations

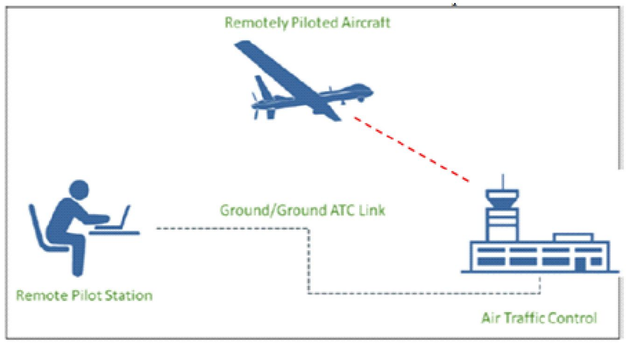
- Different performances lead to different approach speeds
- Different designs lead to different susceptibility to wake turbulence

Sources: dronedj.com, Airliners HD (Youtube)

Parameter	General Atomics MQ9A	IAI Eitan (Heron TP)	Thales Watch-keeper WK450	Euro MALE	Boeing 737-800 (opt. piloted)
Cruise Speed	169 kts	-	**70 kts**	270 kts	**455 kts**
Max. Speed	260 kts	220 kts	95 kts	-	546 kts
Range	1,900 km	4,700 km	300 km	-	5436 km
Endurance	14 hours	30+ hours	20 hours	-	-
MTOW	4,763 kg	5,400 kg	**450 kg**	11,000 kg	**79,016 kg**
Ceiling	FL500	FL460	FL180	FL450	FL410

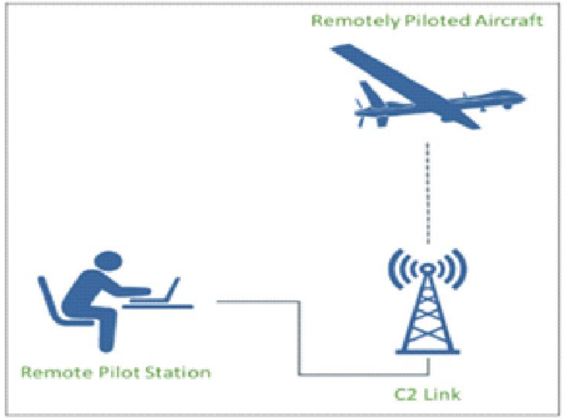
Challenge: Link Architectures

- Availability of control and communication link
- Required additions to the existing infrastructure

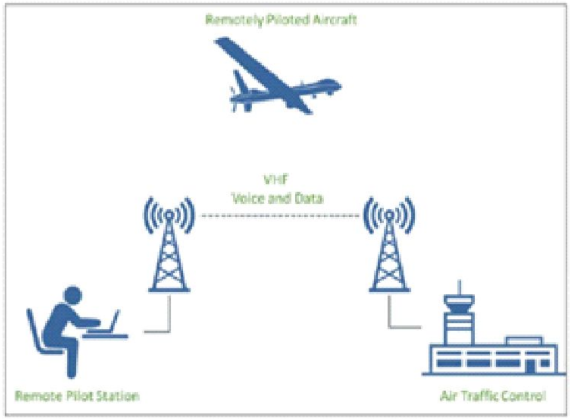


SATCOM

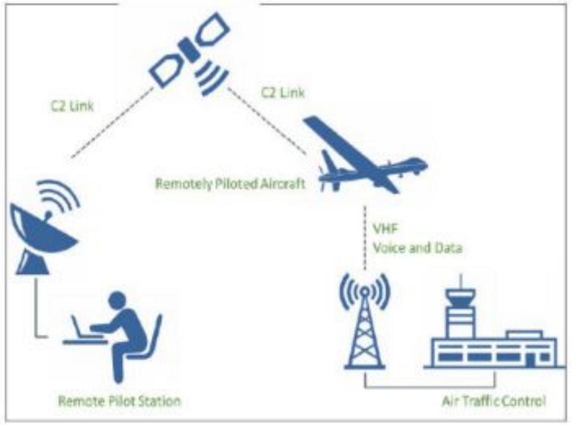
CONTROL



COMMUNICATION



RLOS

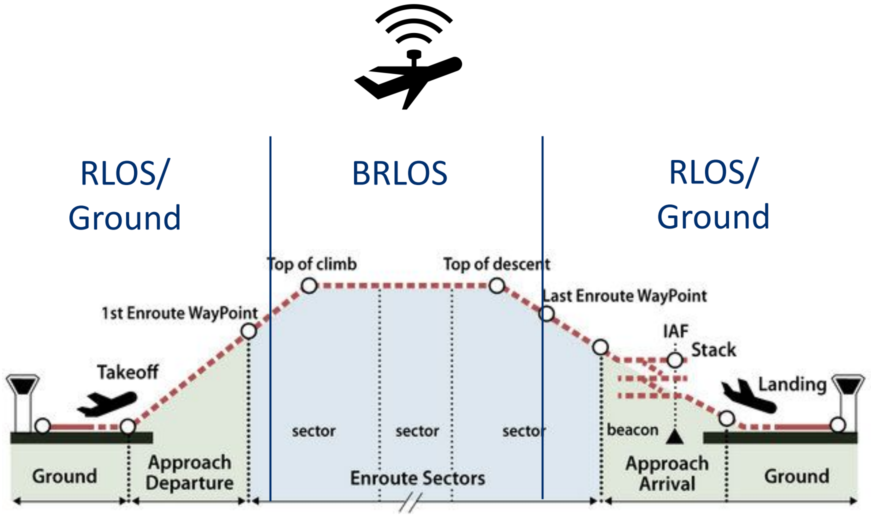


Ground/RLOS via gateway

Source: ICAO Manual on RPAS, 2015

Challenge: Latency Aspects

- Different levels of latency depending on architecture
- Impact on operations with high latency



Source: Letondal et. al., Flights in my hands […], 2013

	Remote Pilot Station location	Link	Technology	Estimated expected Latency*
RLOS	In RLOS of airport	Communication	Radio	290ms
		Control	Radio	1s
SATCOM	Remote	Communication	SATCOM	700ms
		Control	SATCOM	2s
Ground / RLOS via Gateway	Remote	Communication	Ground	150ms
		Control	Ground + Radio	1.5s

* In the TMA, Communication: one way latency, Control: round trip latency

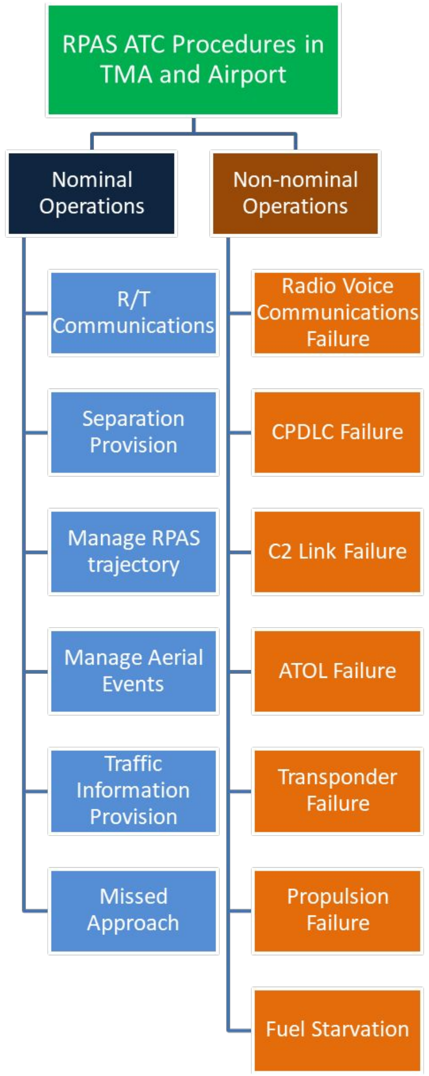
Challenge: RPAS Specialties in Operations

Nominal Operations

- Increased work load due to latency
- Reduced situational awareness due to lack of “human senses”
- No use of visual aids for direct control during take-off and landing (to avoid pilot induced oscillation)
- Reduced airspace capacity due to increased separation requirements (e.g., due to RPA performance)

Non-Nominal Operations

- Risk of RPAS specific contingencies



Project Scope

INVIRCAT develops a CONOPS to integrate RPAS into the existing ATM environment and infrastructures within the TMA and airports under IFR.

With special focus on

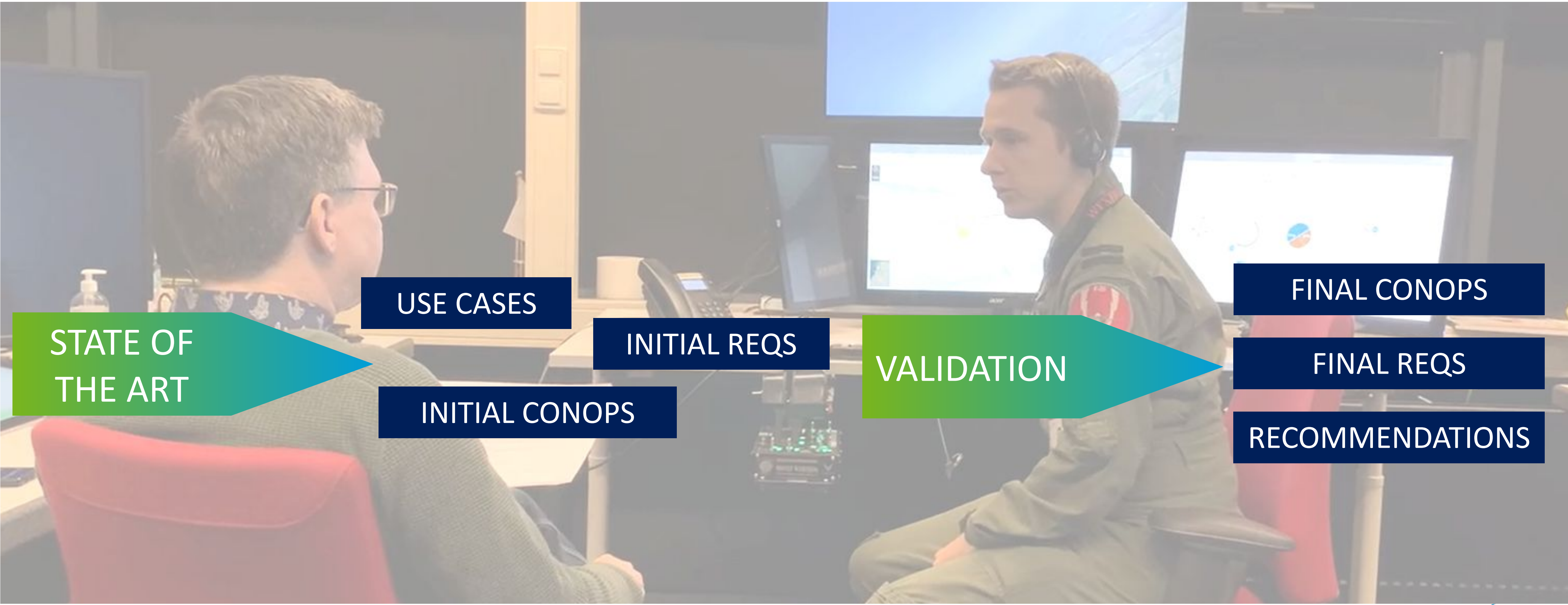
- Impact of latency,
- Automatic Take-off and Landing (ATOL), and
- Handover of RPA control between Remote Pilot Stations

INVIRCAT at a Glance

- SESAR Exploratory Research programme
- Duration: 30 months, July 2020 – December 2022
- Consortium: 7 partners from 5 EU member states

- 20 Deliverables (10 public)
- 6 Milestones

The INVIRCAT Approach



RPAS Use Cases

Nominal use cases	Non-nominal use cases
Taxi operations	(Partial) propulsion failure
Take-off	**ATOL occurrences**
Departure via SID	**C2 link failure**
Arrival via STAR	Transponder failure
Approach	Radio voice communication failure
Holding	Missed Approach*
Landing	Conflict
	Fuel Starvation

Characteristics

Description	This use case considers …
Actors	TWR ATCO (Ground), TWR ATCO (Runway), RPIL
Preconditions	The RPA is located at the apron and in a position from which it can pursue the taxi operation without external support.
Postconditions	The RPAS has received permission to line up on the runway.
Assumptions	In addition to the RPAS specific assumptions listed in section 3.3, the RPAS is equipped with a camera system …
Expected Effects of Latency	Communication with TWR ATCOs might block frequencies longer than manned aircraft due to voice latency…

Flow of activities

#	Phase	TWR ATCO (Ground)	RPIL
1	RPAS Identification	TWR ATCO (Ground) identifies the RPAS on his/her CWP. He/she recognizes the aircraft to be an RPAS…	RPIL requests taxi instructions.
2	Taxi clearance	TWR ATCO (Ground) issues clearance for taxi procedure via airport taxiways until holding position short of the runway.	RPIL reads back taxi clearance.
3	Taxiing		RPIL steers the RPA manually to the cleared taxi route …
…	…	…	…

* nominal operation performed after a contingency to recover from non-nominal to nominal operations

Concept of Operations (CONOPS)

Including

- Key assumptions
- ATC Impact
- Interfaces, Links and Latency
- Handover between RPS
- Standard Operational Procedures
- Non-nominal/emergency situations
- Links to U-space


EXPLORATORY RESEARCH
sesar
JOINT UNDERTAKING

INVIRCAT Final CONOPS "RPAS in the TMA"

Deliverable ID:	D2.4
Dissemination Level:	PU
Project Acronym:	INVIRCAT
Grant:	893375
Call:	H2020-SESAR-2019-2
Topic:	Control of IFR RPAS in the TMA
Consortium Coordinator:	DLR
Edition date:	21 July 2022
Edition:	00.01.01
Template Edition:	02.00.05

EUROPEAN PARTNERSHIP
Co-funded by the European Union

available at https://www.invircat.eu/

CONOPS - Key Assumptions

RPAS Traffic Class VI

- Describes Operations in EASA's UAS category 'Certified' under Instrument Flight Rules

Requirements

- Ability to meet the set performance requirements in the network, TMA, and airport
- Capability of flying SIDs and STARs
- Ability to meet CNS airspace requirements
- Two-way communication with ATC
- Ability to contact ATC in regard to special conditions
- DAA equipment that is compatible with ACAS systems
- Flight plan including contact details

Source: EUROCONTROL, "RPAS ATM Concept of Operations Edition 4.0," 2017.

CONOPS - Key Assumptions for RPA

- Fixed-wing structure
- Airworthiness & type certificate
- Single C2 link

IAI Heron, Source: dronedj.com

Dornier 228, Source : DLR

The RPA is

- equipped with a system that allows IFR landings without visual aid,
- equipped with an ATOL system, and
- able to conduct taxi operations on its own power.

CONOPS - Key Assumptions for Remote Pilot

The remote pilot must

- be adequately trained and certified,
- refrain from using on-board cameras for flight-critical operations,
- always fly under IFR, and not request, accept or perform any visual procedures,
- always be monitoring the RPA and override automated functions if required.

One remote pilot may only control one RPA at any given time.

U-FLY RPS, Source: DLR

Take-Off and Landing Assistance

- To avoid pilot induced oscillation the RPIL has to **refrain from the use of visual aid** during take-off and landing.
- **ATOL systems** shall automatically perform operations during take-off, initial climb, approach, landing, and missed approach flight phases

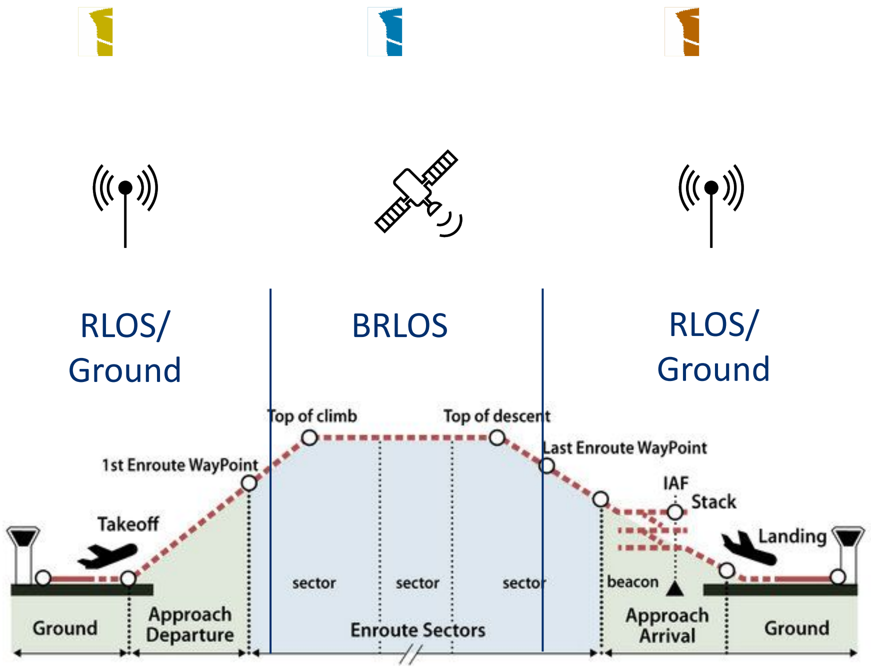
- ATOL is essential in case of C2 link fail
- ATOL helps in case of high C2 link latency

Handover RPS to RPS

- Receiving RPS must be active and available
- C2 link must be compatible
- Reliable voice communication link

- Coordination between the respective RPILs
  - RPA location and status
  - Changes or limitations to the intended flight
  - Changes or limitations to RPA performance
  - Pending or ongoing ATC instructions execution

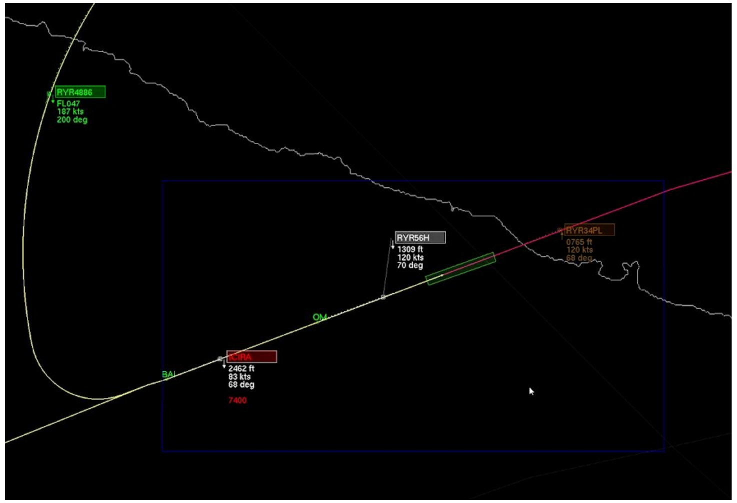
- Coordination with ATC

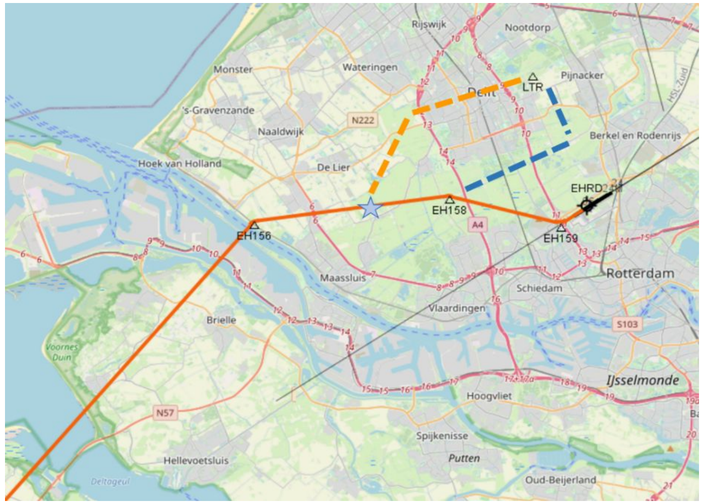


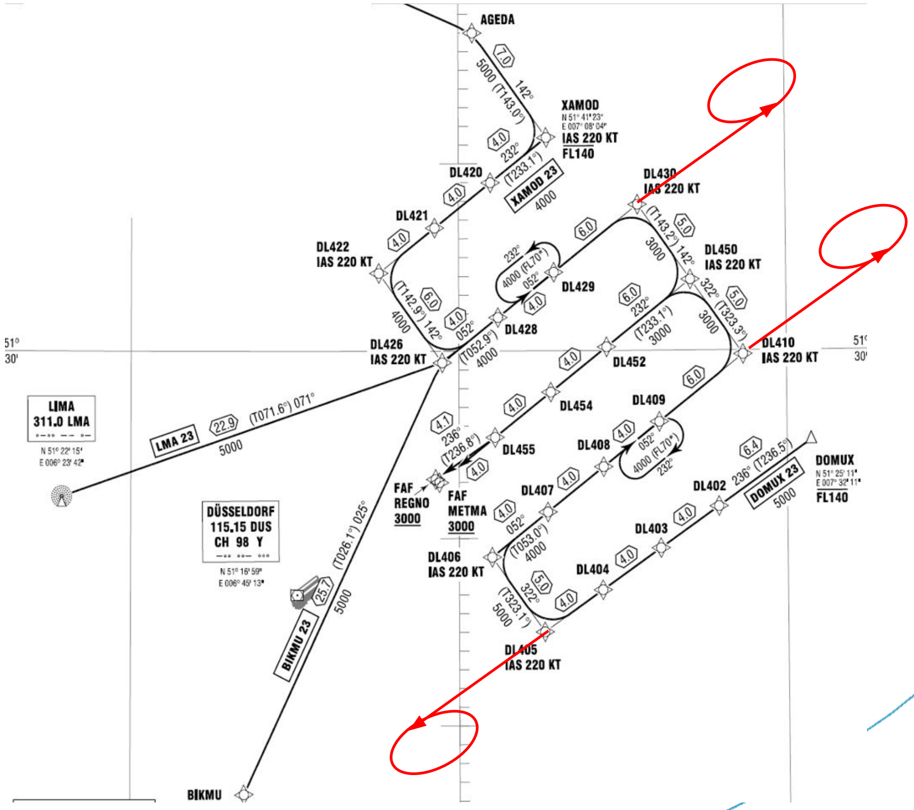
Source: Letondal et. al., Flights in my hands […], 2013

Handling of non-nominal situations

- Procedures from manned aviation, when possible
- Backup phone in case of voice communication failure
- Loiter areas in case of C2 link failure
- Controlled flight termination as ultima ratio







List of Requirements

Before validation

Definition of approx. 100 operational and functional requirements

After validation

- 95 requirements updated
- 25 requirements added

e.g., for ATC

REQ-INVIRCAT-D2.5-0009	The RPIL shall be aware of and declare contingencies to the responsible ATCO when there is a contingency situation.
REQ-INVIRCAT-D2.5-0010	The RPIL shall command the RPA in contingency situations as agreed with the relevant authorities.
REQ-INVIRCAT-D2.5-0011	ATCOs shall be aware of which aircraft is remotely piloted.

e.g., for handover

REQ-INVIRCAT-D2.5-0027	The RPIL in command shall inform the ATCO before the handover procedure is accomplished
REQ-INVIRCAT-D2.5-0028	The RPIL 1 shall brief information to RPIL 2 before handing over the RPA.
REQ-INVIRCAT-D2.5-0029	The RPIL 2 shall confirm the agreement with the briefing information to RPIL 1 before the handover is performed.

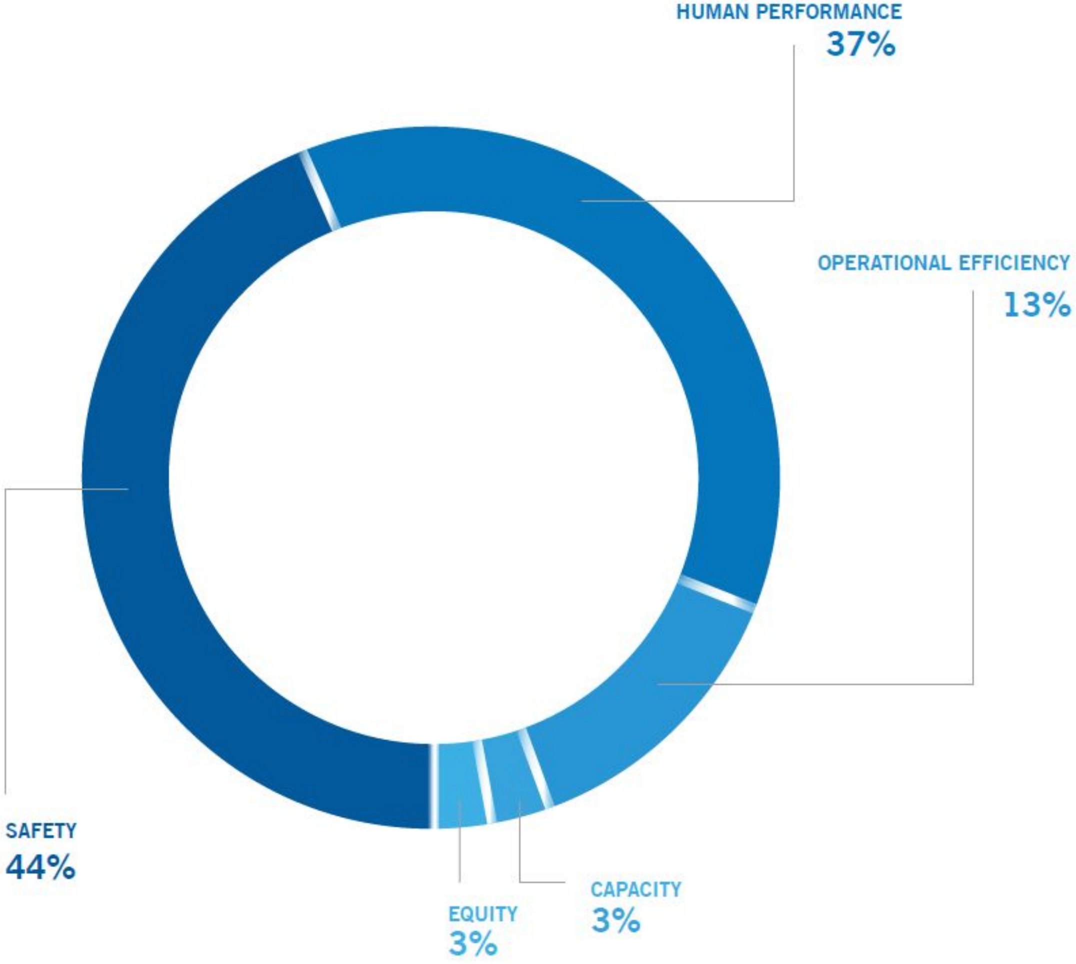
Final list of requirements: operational, functional and non-functional (safety, latency, performance) available at https://www.invircat.eu/

Validation Planning

18 Validation Objectives
5 Key Performance Areas
4 Success Criteria
3 Achievement Levels

Focus on

- ATOL system
- R/T voice
- Handover between RPS
- C2 link



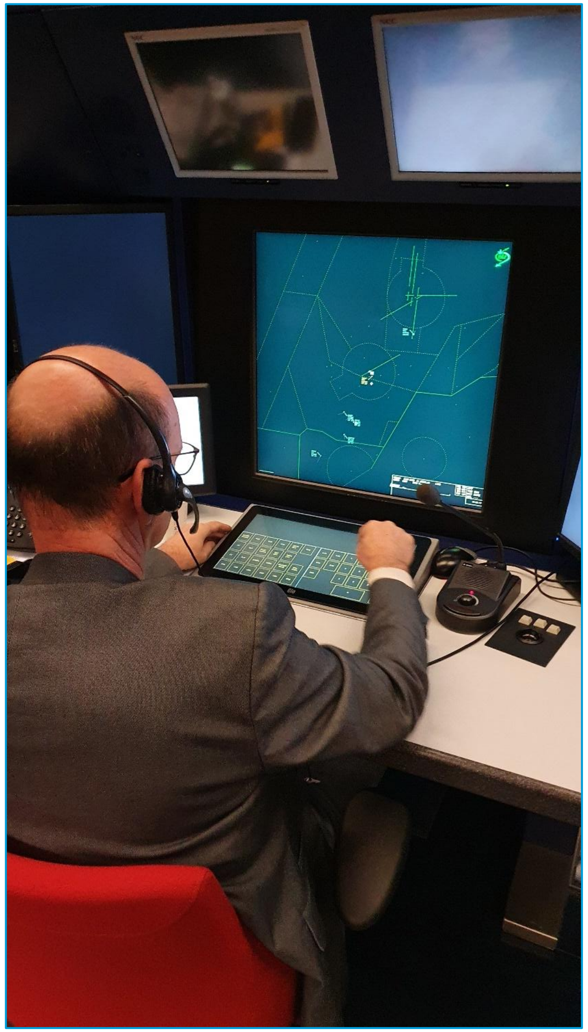
Validation Architecture

Common architectural design with different simulation components and integration opportunities

- Remote pilot stations
- Controller working positions
- Pseudo-pilot stations
- Traffic simulators

3 real-time simulations to validate the CONOPS and requirements:

- **C2 link** focus at DLR, Germany
- **R/T voice** and **handover** focus at Royal NLR, The Netherlands
- **ATOL** focus at CIRA, Italy



ATOL Focused Simulations

Final Approach & **Landing** (until RPA stops on runway)
Take-Off & **Initial climb** (from holding on runway)

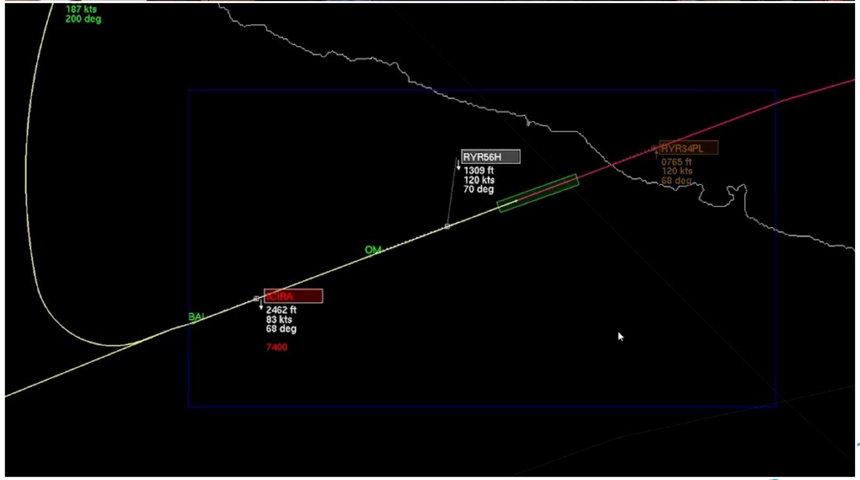
2 levels of **C2 link latency**

- **Low** 0,5 s round trip
- **High** 2 s round trip

3 contingencies

- **ATOL Failure** (during take-off/landing)
- **Runway incursion** (with RTO or MA/GA)
- **C2 link fail** (after FAF)

17 different **traffic scenarios**

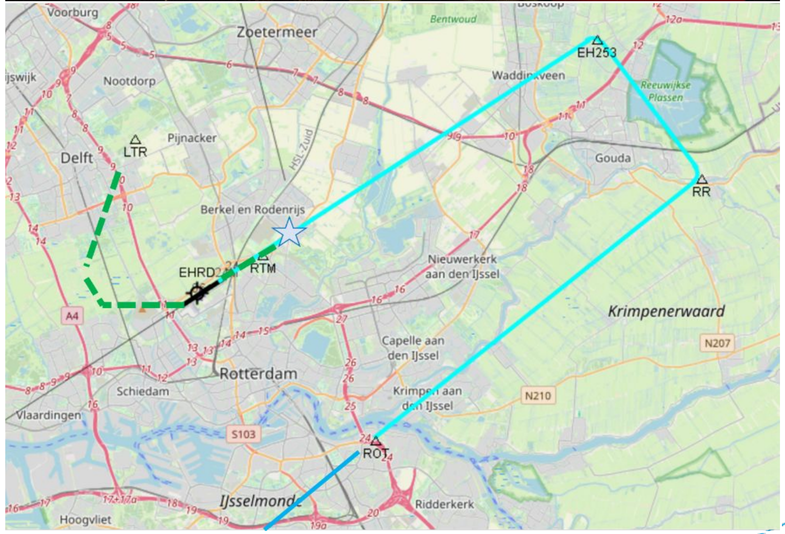


R/T Voice Focused Simulations

R/T loss in all different phases of flight with backup phone
- Departure (with loitering)
- Arrival on STAR
- Arrival in Approach
- Arrival in Landing

R/T being restored
- Departure contingency
- BRLOS Arrival
- ... and more

R/T latency depending on architecture
- 290/700 ms
- Up to 1750 ms to find the limits

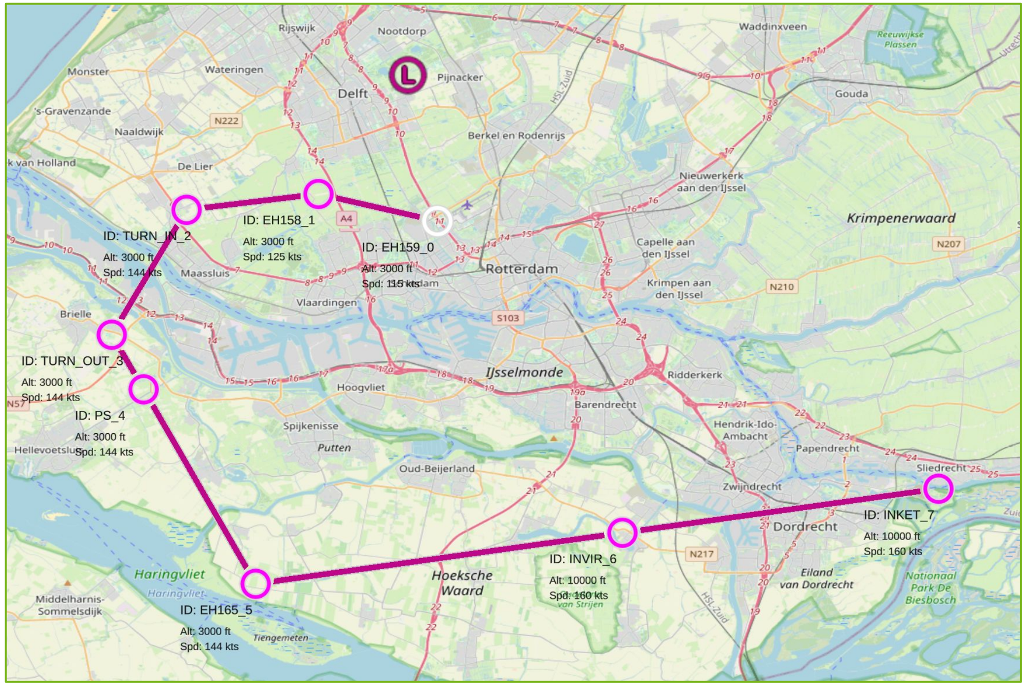


Handover Focused Simulations

Change between Remote Pilot Stations (at **INVIR**)

Three different procedures:

1. Handover during **dedicated loiter manoeuvre** with active ATC involvement (sign-out, sign-in)
2. Handover on last SID segment with **active ATC involvement** (sign-out, sign-in)
3. Handover on last SID segment **without ATC involvement**



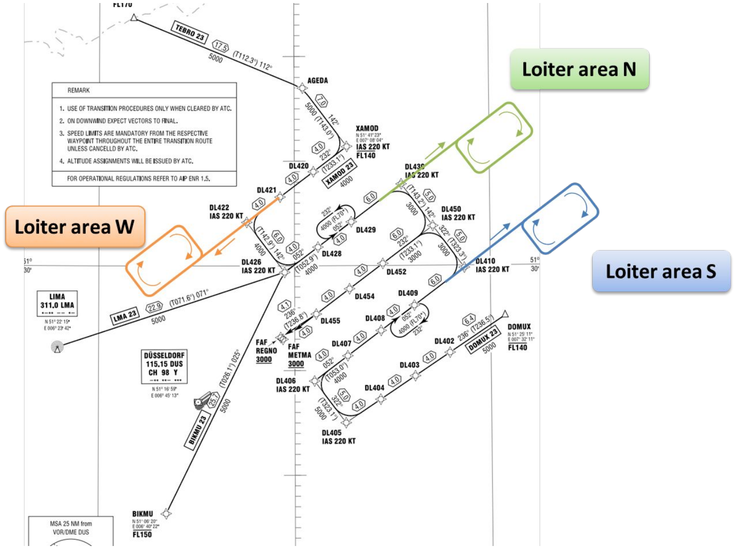
C2 Link Focused Simulations

C2 link loss for 1-3 RPAS
Using exemplary loiter areas

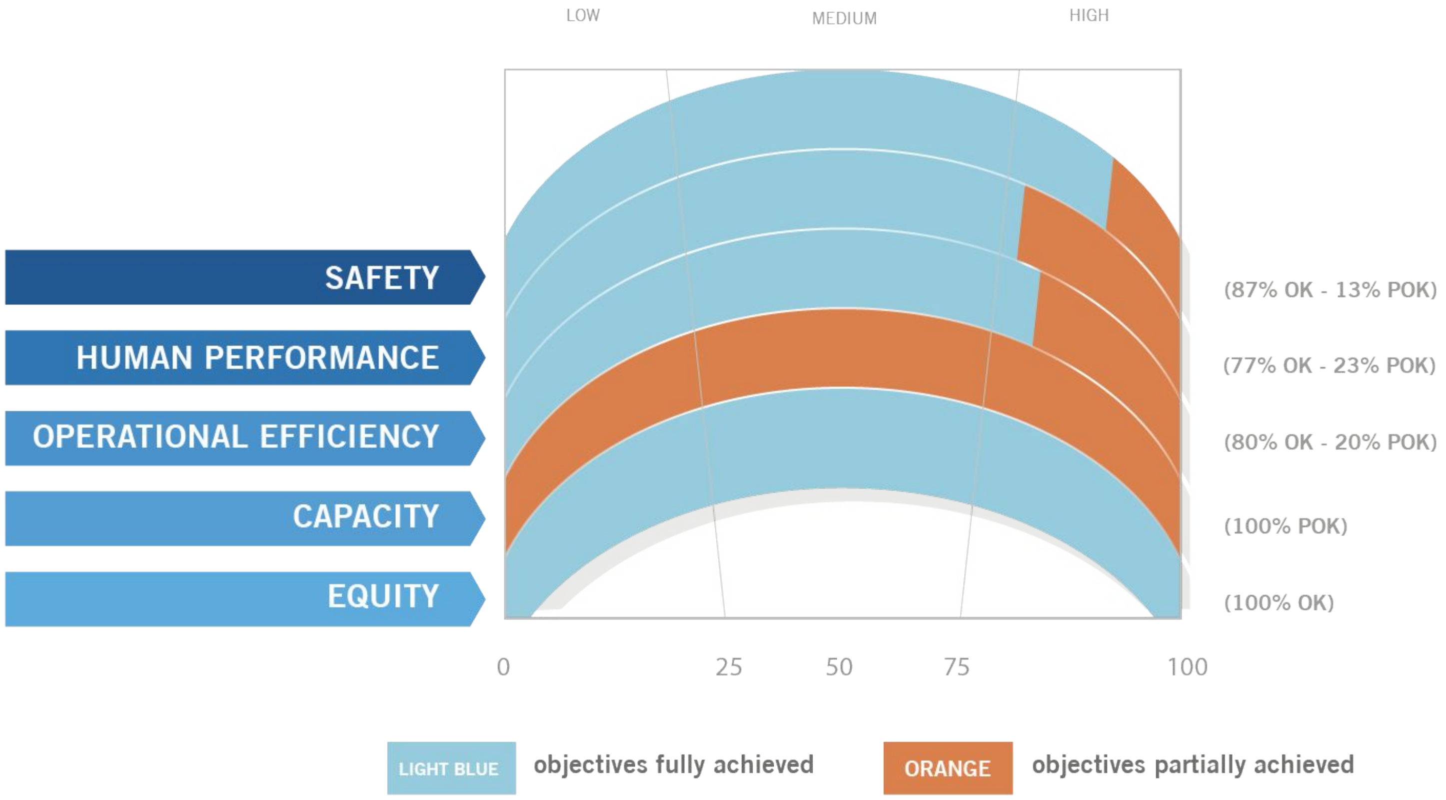
C2 link restored
Re-integration into arrival stream

High C2 latency
Up to 2 seconds

Multiple RPAS in approach
Up to 3 RPAS



Validation Results per KPA



Aggregated results of all three campaigns

SUCCESS CRITERIA

- POSITIVE FEEDBACK FROM ATCOS AND REMOTE PILOTS
- NO AIRSPACE/COMMS FREQUENCY CAPACITY RESTRICTION DUE TO LATENCY
- NO SIGNIFICANT DECREASE OF RUNWAY THROUGHPUT
- EQUITABLE (AVERAGE) DELAY OF MANNED AND UNMANNED AIRCRAFT

ACHIEVEMENT LEVEL

LIGHT BLUE objectives fully achieved

ORANGE objectives partially achieved

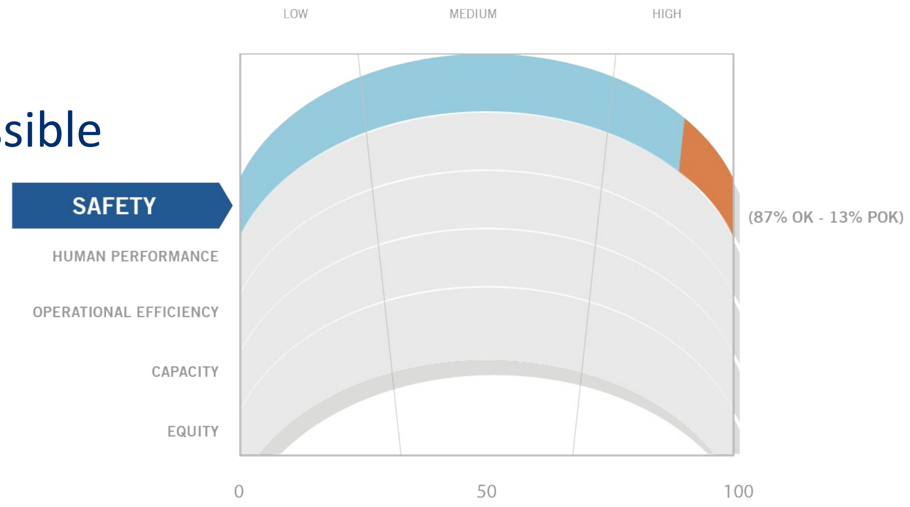
Validation Results: Safety

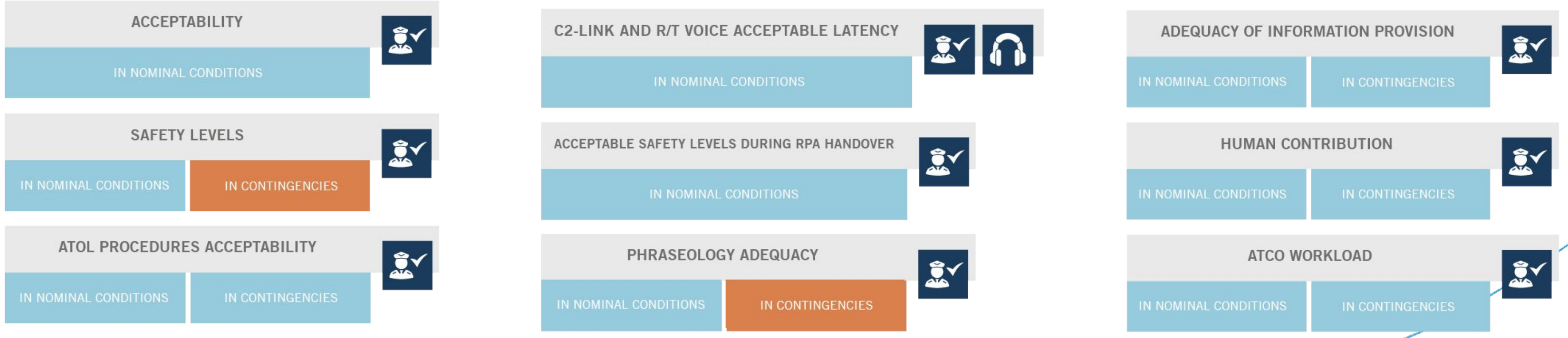
Safety in contingencies

- Follow manned IFR procedures where possible
- Additional training demand

Phraseology in contingencies

- Singular negative feedback





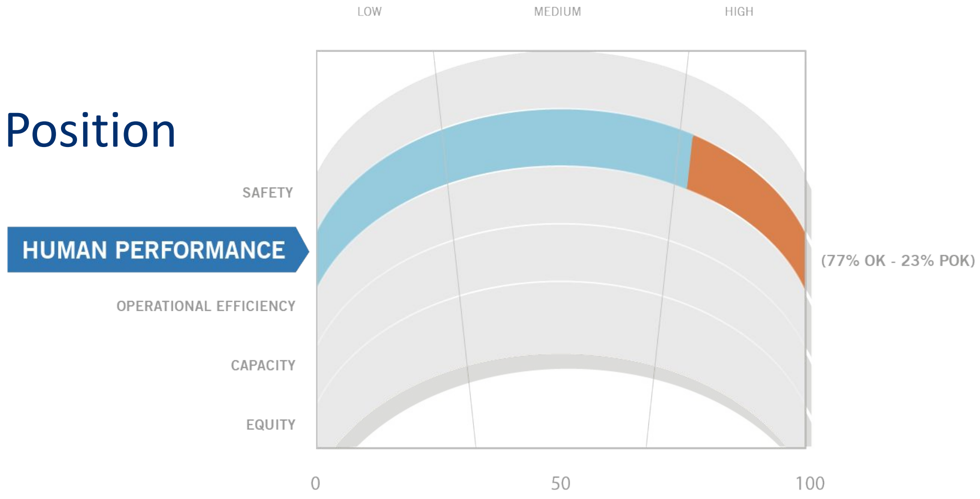
Validation Results: Human Performance

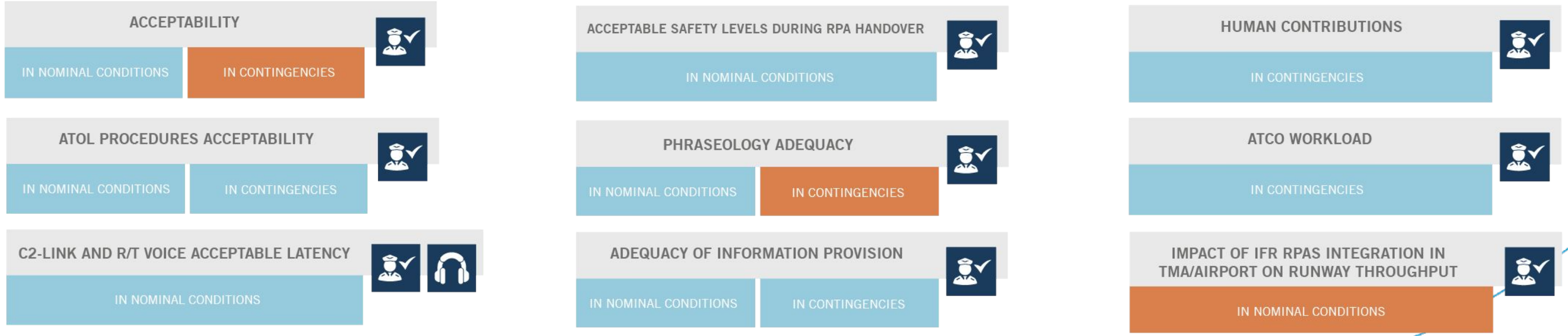
Acceptability in contingencies

- Prototype HMI and Controller Working Position
- Optimize backup communication line

Phraseology in contingencies

- Additional RPAS specific phraseology required

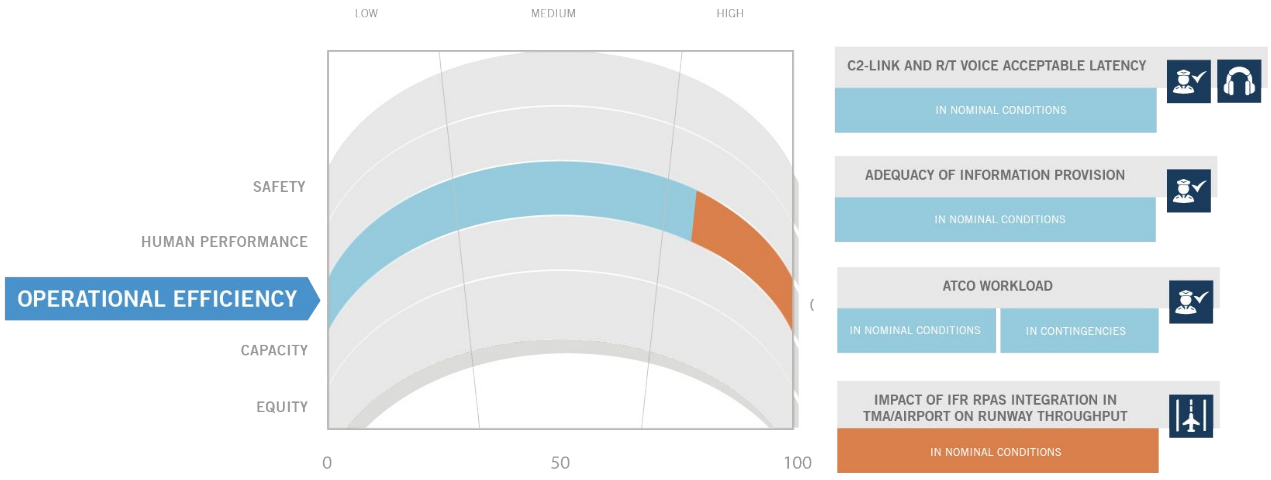


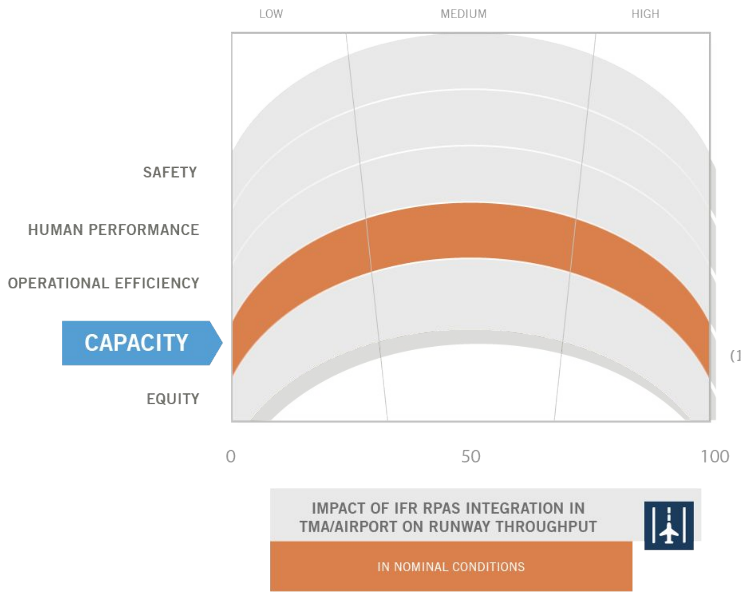


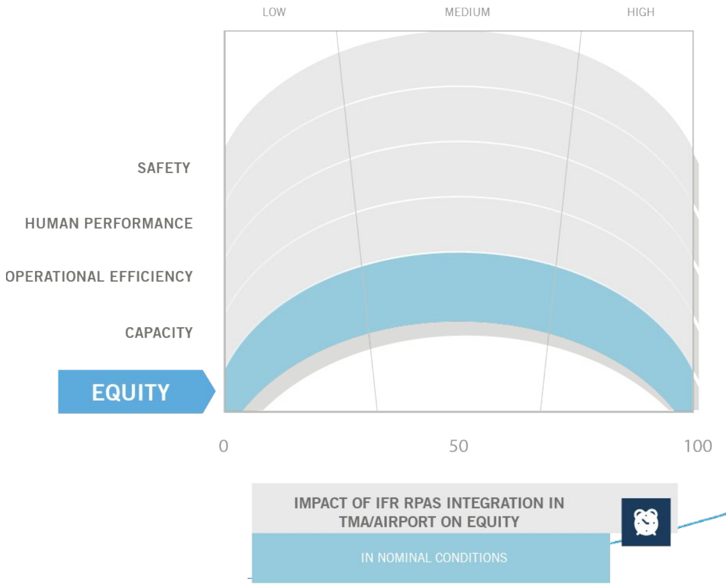
Validation Results: Operational Efficiency, Capacity, and Equity

Runway throughput

- Impacted by RPAS performance differences
- Mostly not considered an issue





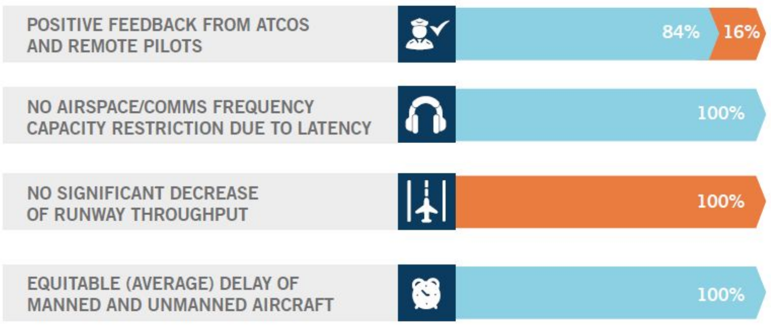


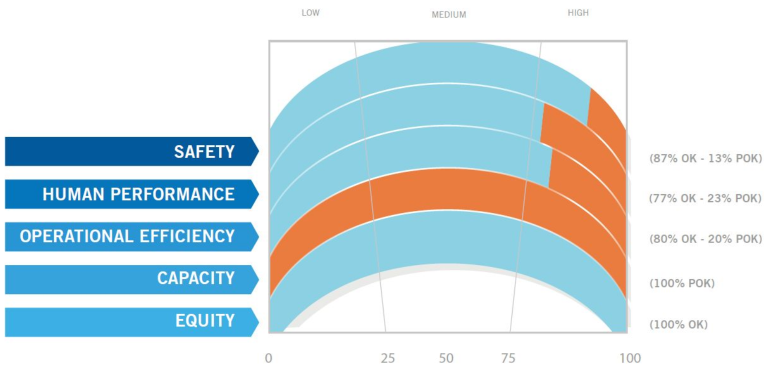
Selected Findings

- Radar vectoring for RPAS possible
- Contingency procedures should be trained
- ATOL was deemed as essential for RPAS integration in TMA

- Slower RPAS traffic on SIDs and STARs can be challenging
- Slower RPAS speeds respected and separation increased
- Slower RPAS might have more impact at high capacity IFR airports

- R/T latency was not considered to be an issue
- BRLOS should not be the first option in the TMA
- No special callsign (“unmanned”) required





⇨ Input to final versions of concept, requirements and our recommendations available at https://www.invircat.eu/

Implementation Recommendation

Phase of implementation of each technology per flight phase

Step 1

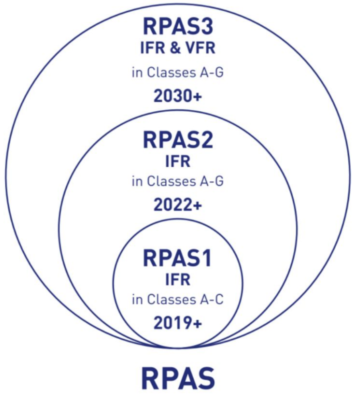
TRL ≥ 5

~ 2022 – 2030

Step 2

TRL < 5

~ 2030+



	Flight phases	Introduction in step 1	Introduction in step 2
C2 link	Taxi Take-off Departure via SID Arrival via STAR Holding Approach Landing	RLOS	RLOS via gateway[2]
	En-route	SATCOM	
Communication link	Taxi Take-off Departure via SID Arrival via STAR Holding Approach Landing	RLOS	Ground-ground
	En-route	SATCOM	
ATOL	Take-off Holding Approach Landing	Available for airports with ILS CAT III or GLS GAST c/d	Available for minor airports

Source: SESAR Joint Undertaking “European ATM Master Plan - Executive View”

Impacts and Effects on KPAs

<table>
<tr><th colspan="3">Impacts</th><th>Effects on KPAs</th></tr>
<tr><td>C2 link</td><td colspan="2">• C2 link as requirement for IFR RPAS operations with nominal/low latency
• High C2 link latency
• C2 link loss</td><td rowspan="7">• Safety
• Human Performance
• Operational Efficiency
• Capacity
• Equity</td></tr>
<tr><td>ATOL</td><td colspan="2">• New functionalities that allow Automatic Take-Off and Landing
• Automatic operations in case of ATOL detectable contingencies</td></tr>
<tr><td rowspan="3">On-board technologies</td><td>DAA</td><td>• Detection and resolution of conflicts when no pilot is on board
• Automatic conflict resolution in case of contingencies</td></tr>
<tr><td>AutoTaxi</td><td>• New RPAS functionalities that would allow automatic taxiing</td></tr>
<tr><td>WheelTug</td><td>• New support system to the taxiing process</td></tr>
<tr><td>Handover</td><td colspan="2">• New ATCO procedure and information
• Availability of voice communication links during the process
• New procedure between RPILs
• Availability of voice and data communication links between the RPSs</td></tr>
<tr><td>Commu-nications</td><td colspan="2">• Low voice communication latency
• High voice communication latency
• Loss of communication</td></tr>
</table>

Recommendations

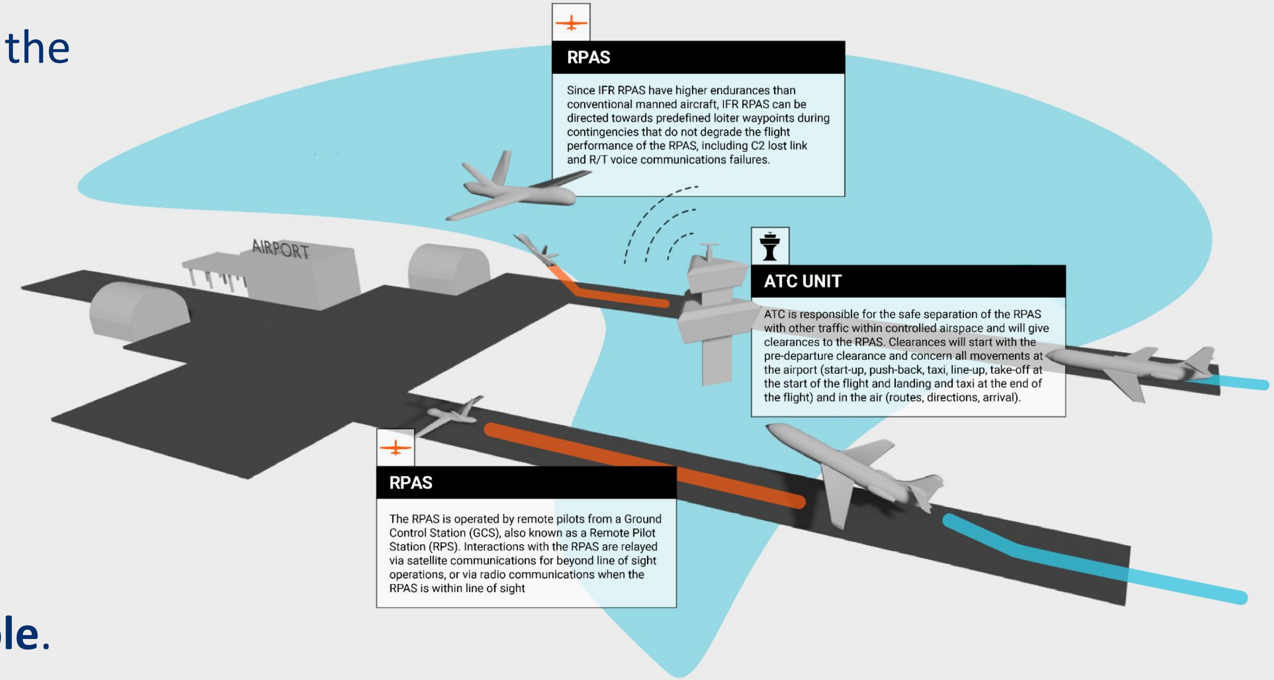
Operational recommendations	Technical recommendations	Regulatory recommendations
Specific procedures, phraseology and training for contingency situations	Identifying element/symbol for RPAS	New ATOL and RPAS propulsion failure related regulations
New procedures so DAA use is correctly understood and integrated	Report C2 link expected latency	Standardization of the handover procedure
Training for AutoTaxi and WheelTug	RPSs available at airports	Harmonization of C2 link failure procedures
The handover procedure is made known to ATC and should be outside the TMA	Compatibility between RPS and RPA during handover	Back-up line in case of communication failure
	Indication on the ATCO HMI for simultaneous handovers of multiple RPAS	Enforcement of acceptable latency limits

More in D4.3 "Final Report: Impacts and Recommendations" at https://www.invircat.eu/

Summary

INVIRCAT **results** and **products** for RPAS integration in the TMA and at airports:

- Concept of Operations
- Requirements
- Impacts on KPAs
- Implementation Strategy
- Recommendations



Validation exercises showed that the **concept is feasible**.

INVIRCAT reached **V1 maturity**.

Further reading:
https://www.invircat.eu/deliverables
https://cordis.europa.eu/project/id/893375

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THANK YOU FOR YOUR ATTENTION

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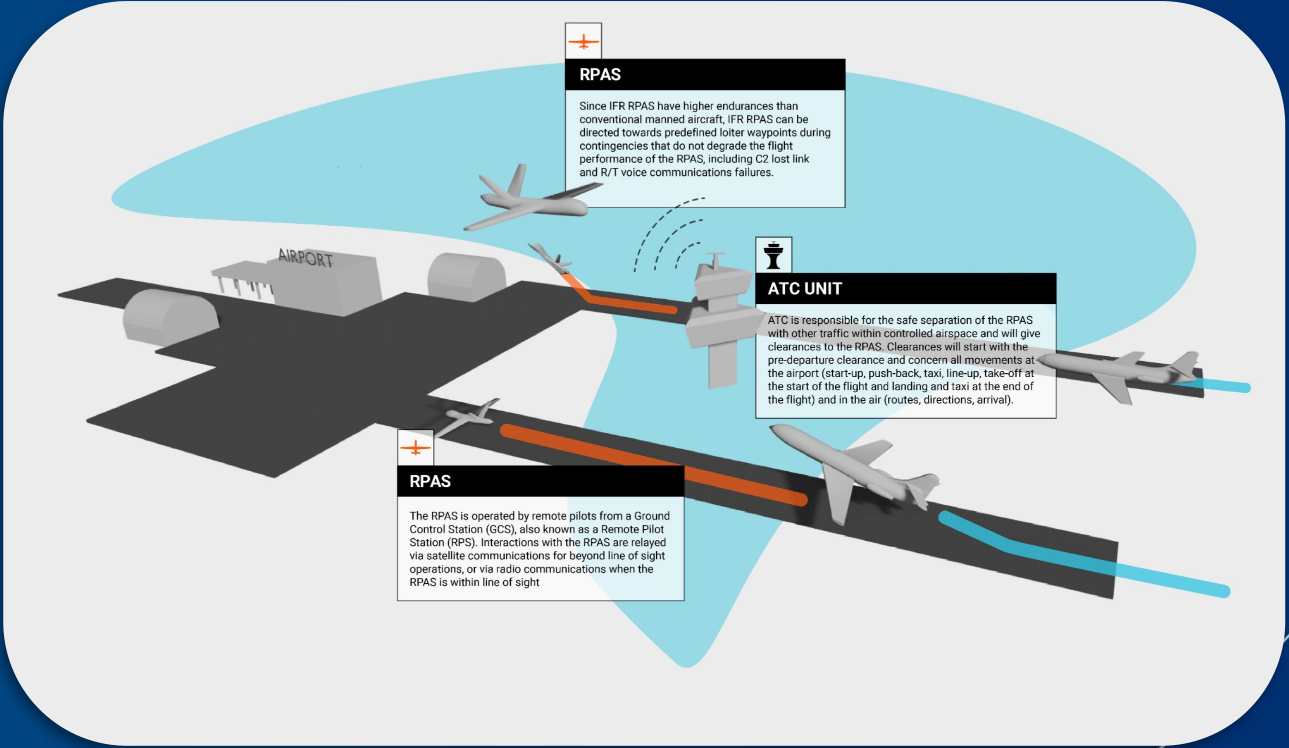

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EUROPEAN PARTNERSHIP

Co-funded by the European Union

What are RPAS at all?

RPAS are unmanned aircraft which are piloted from a remote pilot station and

- expected to be integrated into the air traffic management system equally as manned aircraft
- real-time piloting control is provided by a licensed remote pilot

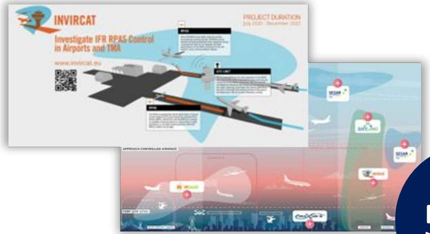
Sources: DLR, dronedj.com, Airliners HD (Youtube)

Impressions

Communication & Dissemination

Dissemination materials

Graphic materials
4 [concept images, poster, set of infographics]

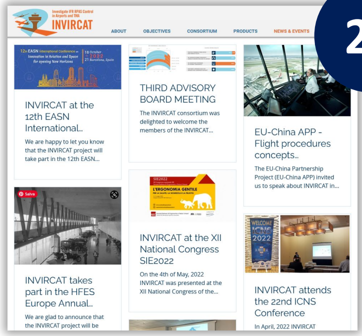


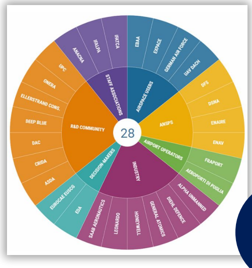
500+ **Digital distribution**
of graphic materials

Global **followers** 334

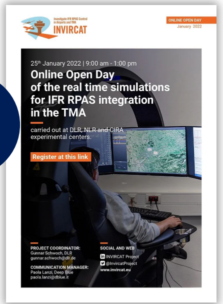
20K Social media **views**

News articles
on the project website 25

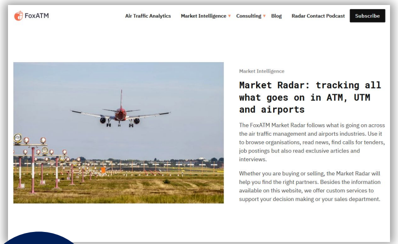




INVIRCAT workshops with the Advisory Board
for feedback gathering, reaching 50+ participants 3



1 **Open day**
for RTS results presentation, reaching 47 participants



6 Features in **third-party websites**

RPAS Projects Collaboration panel

Projects involved [INVIRCAT, URClearED, SAFELAND, ERICA, CORUS-XUAM] 5

3 Public events

Internal monthly meetings 13

3 **Newsletters**
sent to 50+ subscribers

INVIRCAT
website **sessions** 3500

1:54 average **visit duration**

8 **Scientific papers**

Third-party events attended to present INVIRCAT 12