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SCIENCE AND TECHNOLOGY ORGANIZATION
S&T organization

Unmanned Aircraft Systems Risk Assessment: Review of Existing Tools and New Results

MAJ Diogo Duarte

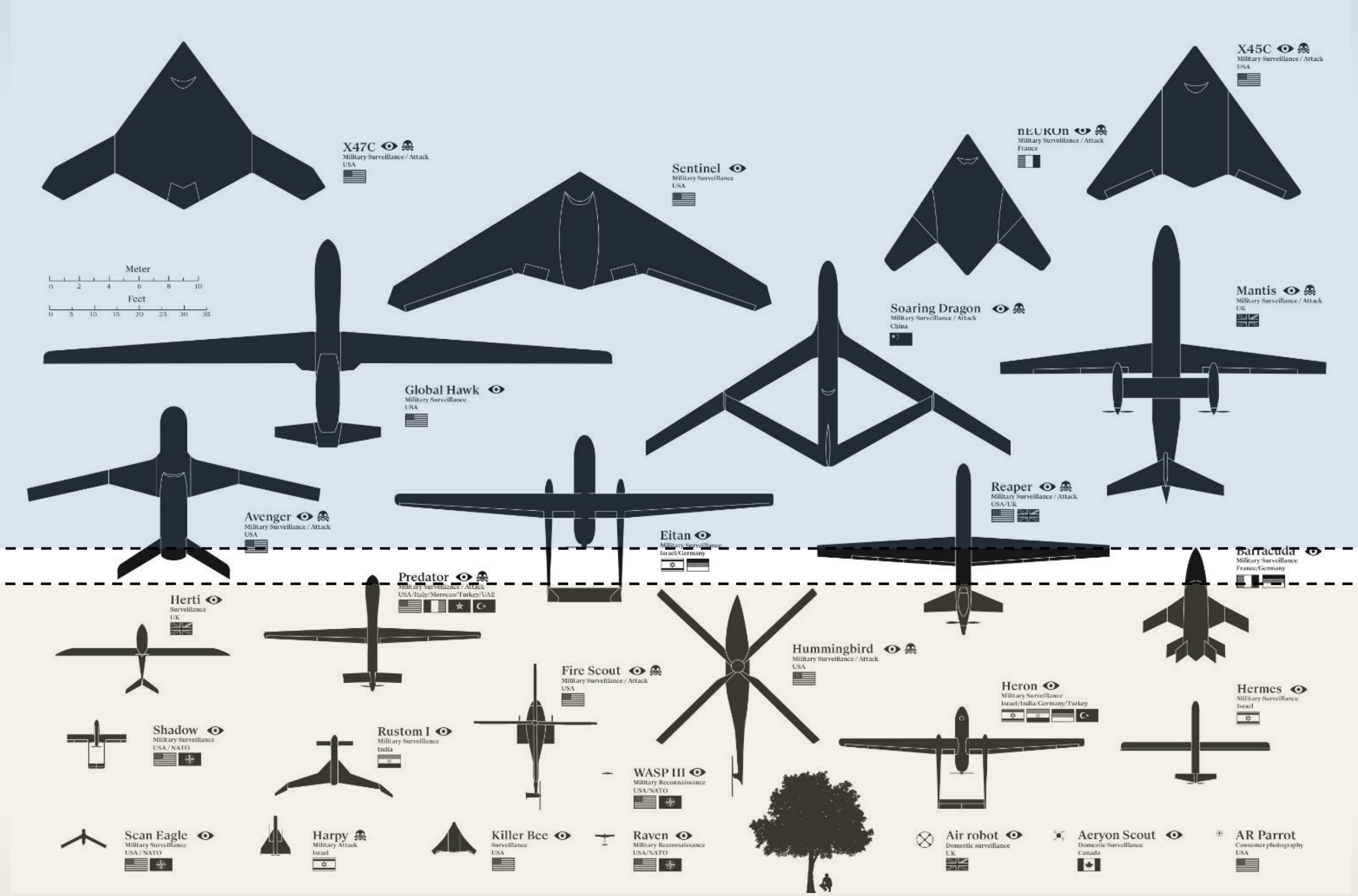
Pt Air Force

GOAL

To present a new Risk Assessment Tool for the operation of dual-use Unmanned Aerial Systems and compare its potential with other available Risk Assessment Tools.

Outline

INTRODUCTION



[4]

Unrestricted Operation

High Investment in tests
High Certification Periods

Designed for specific operations

Lower complexity
Lower Investment in tests
Lower approval times

INTRODUCTION

1. *Specific Operations Risk Assessment (SORA)*

2. *FAA ORDER 8130.34D*

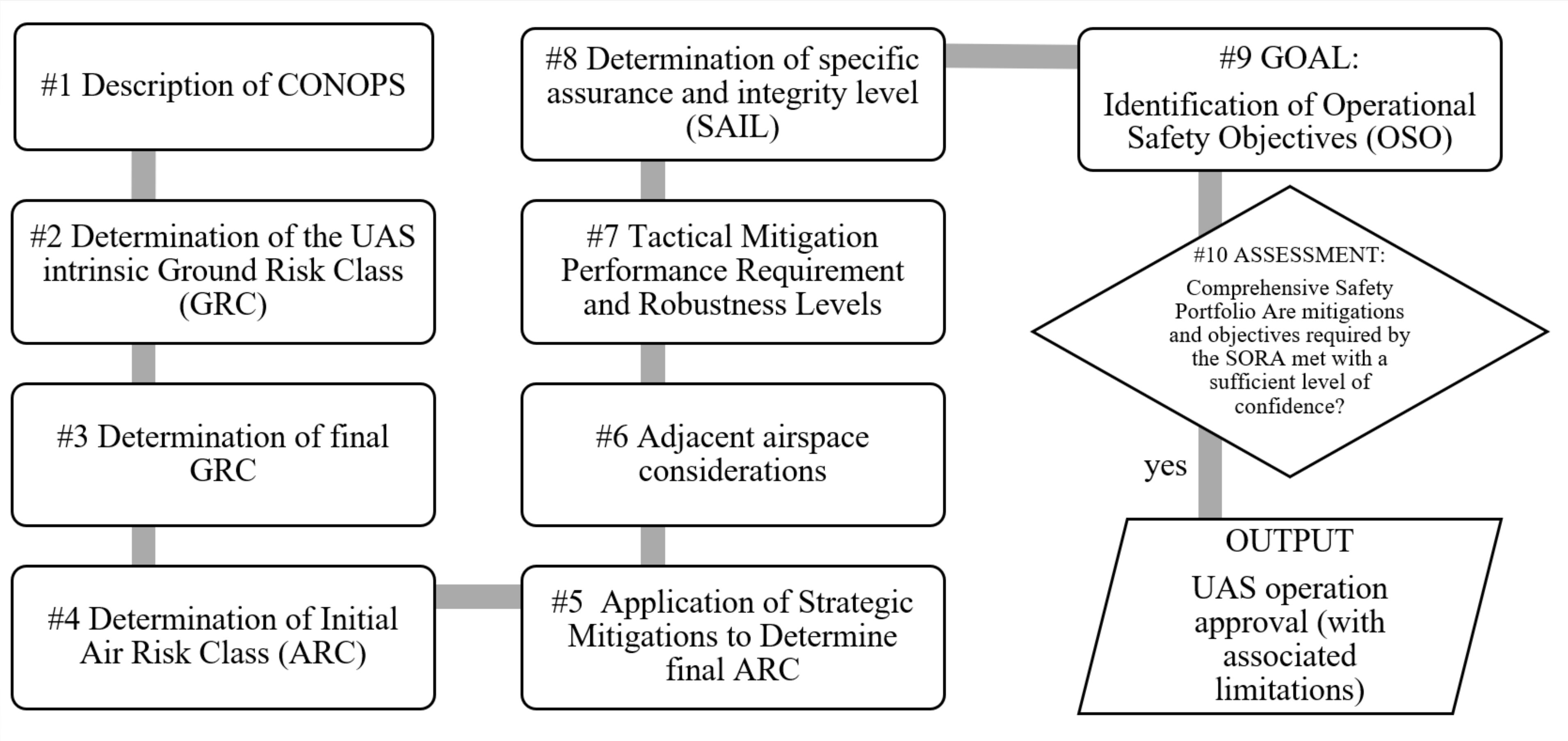
3. *Risk Assessment Tool* (RAT)

4. *New/Proposed RAT*

01

SORA

1. SORA



#1 Description of CONOPS
#2 Determination of the UAS intrinsic Ground Risk Class (GRC)
#3 Determination of final GRC
#4 Determination of Initial Air Risk Class (ARC)
#5 Application of Strategic Mitigations to Determine final ARC
#6 Adjacent airspace considerations
#7 Tactical Mitigation Performance Requirement and Robustness Levels
#8 Determination of specific assurance and integrity level (SAIL)
#9 GOAL:
Identification of Operational Safety Objectives (OSO)
#10 ASSESSMENT:
Comprehensive Safety Portfolio Are mitigations and objectives required by the SORA met with a sufficient level of confidence?
yes
OUTPUT
UAS operation approval (with associated limitations)

1. SORA

Holistic approach: Ground and air risk classes;

Probability of catastrophic failure not calculated

No consideration with the population density

02

FAA Order 8130.34D

2. FAA ORDER 8130.34D

Airworthiness Certification of Unmanned Aircraft Systems

Risk Category	Incremental Element	Value
MTOW	Up to 4.5 lbs	0
	4.5 up to 55 lbs	5
	55 lbs up to 300 lbs	10
	300 lbs up to 1,000 lbs	15
	Greater than 1,000 lbs	25
Maximum Speed	Less than 87 kts	0
	87 kts to 250 kts	10
	Greater than 250 kts	20
Maximum Operating Altitude	Less than 200 ft AGL	0
	200 ft AGL up to 500 ft AGL	5
	500 ft AGL up to 5,000 ft AGL	10
	5,000 ft AGL up to 17,999 MSL	15
	Class A and above	25
Flight History	previous flight time ≥ 50 hrs	0
	previous flight time < 50 hrs	2
	Unknown – first flight	6

Night Operations
IMC
Beyond or Extended Visual Line of Sight (BVLOS/EVLOS)
Chase Aircraft
Operations Closer Than 2 Miles From Towered Airport

Group Category	Total Score
Group I	0 to 16
Group II	17 to 39
Group III	40 and above

Applicant Task	Group I	Group II	Group III
Charted Flight Area	Should be completed by applicant	Should be completed by applicant	Should be completed by applicant
Safety Checklist	N/A	Should be completed by applicant	Should be completed by applicant
Safety Evaluation	FAA only reviews program letter; questions resolved via email or phone	FAA determines if safety evaluation is necessary and the appropriate format	Should be completed
Initial Flight Test Plan	N/A*	Should be completed by applicant; Comprehensive review by FAA not required*	Should be completed by applicant*

Operational Limitations

03

RAT: Risk Assessment Tool

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RAT General Description

The RAT combines the probability of the loss of the UAV versus the probability of hitting people on the ground.

The calculation of the probability of the loss of the UAS is calculated as a function of a UAS Design Integrity Score which derives from the assessment of the Design Integrity over 11 safety relevant domains.

This score is then correlated with the probability loss of the UAS, allowing for the calculus of the probability of hitting people on the ground in accordance with the population density.

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RAT General Description

MAWA ARF Group

EDA

EUROPEAN DEFENCE AGENCY

Phase I → Phase II → Phase III

Phase I	Phase II	Phase III
1. Design Integrity Assessment Checklist 2. Score[0;100]	1. Correction Factor 2. Probability of Cat. Failure	1. Probability of hitting people on the ground 2. Final Decision

[1/10 ; 1/10000]HV

Prob < 5E-5 (1/20000HV)

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RAT General Description

Phase I → Prelim SCORE → **Phase II** → Final SCORE

Phase I

Design Integrity Assessment Checklist
DIAC

Domains:

65 Questions

1) Organization / Manufacturer;
2) Adopted Design Standards;
3) Tested Usage Spectrum;
4) Stability, Control and Emergencies;
5) Remote Control Station;
6) Structural Integrity;
7) Propulsion and Feeding System Integrity;
8) Integrity of Systems and Equipment;
9) Safety Demonstration;
10) Software Integrity;
11) Continued Airworthiness and Operational Suitability

Phase II

Correction Factors
(Negative Impact on Score)

1. No Technical Occurance Tracking
2. Human Machine Interface not Considered
3. No Evidence of Structural Integrity
4. No Evidence of Propulsion Integrity
5. Inadequate E3
6. No Software Life Cycle Assurance
7. No Training Syllabus

Final SCORE

$$P_{cat} = 0.1\, e^{-0.069.Score}$$

Phase III

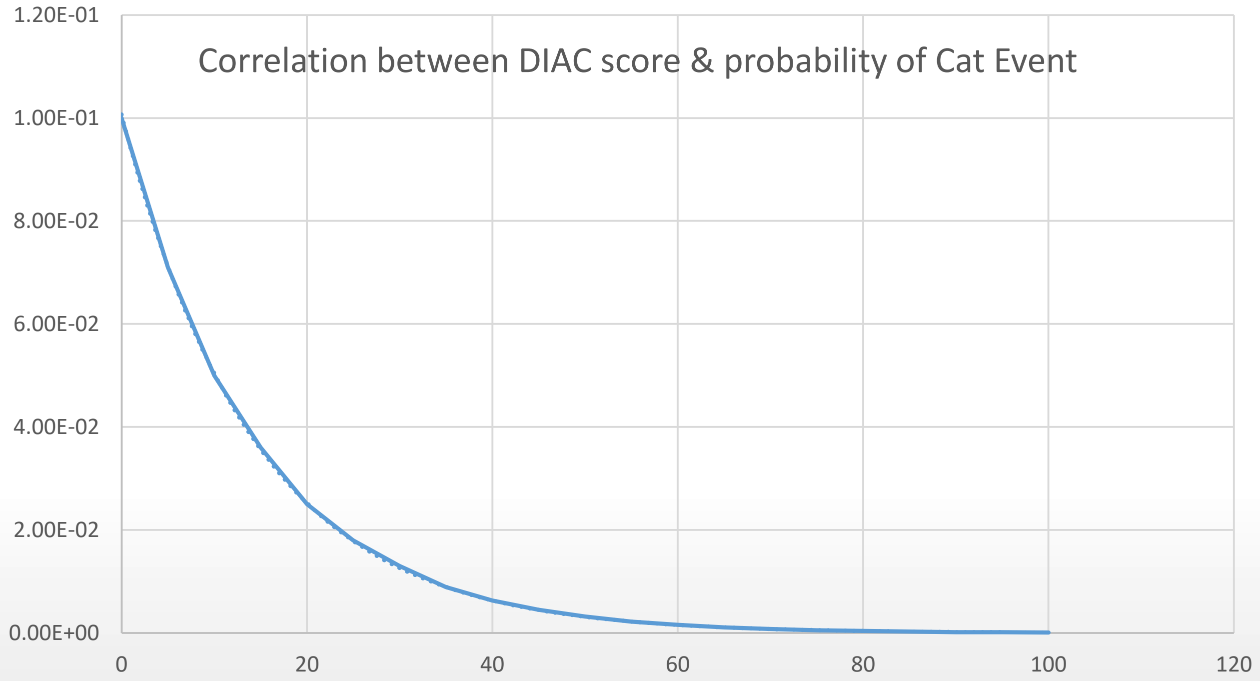
$$R = P_{cat} \times P_{HIT} \times (1 - S)$$

S – shelter factor

$$P_{Hit} = A_{debris} \times P_{Den}$$

RAT: Concepts & Terms

The correlation between the UAS design integrity score and the probability of a catastrophic event was derived by the UK NMAA and by the Italian NMAA and resulted in the following correlation:



$$f_{(score)} = 0.1e^{(-0.069*Score)}$$

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RAT: Concepts & Terms

The basic equation of the RAT is :

$$CE = PF \times (PD \times AL) \times PK \times S \; ^{(1)}$$

where each variable is defined as:

CE = Casualty Expectation
PF = Probably of Failure or Mishap per flight hour
PD = Population Density per square mile.
AL = Lethal Area
PK = Probability of a Fatality given a hit (usually assumed to be 1)
S = Shelter factor (if applicable)

(1) Note: The equation is published in "Range Safety Criteria for Unmanned Air Vehicles , Rationale and Methodology Supplement, April 2001" issued by the Range Commanders Council/range Safety Group.

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RAT: Concepts & Terms

The probability of hitting people on ground is function of the wingspan, speed, maximum take-off weight of the platform and population density. The probability of hitting people on the ground is calculated as:

$$P_{Hit} = A_{debris} \times P_{Den}$$

P_{HIT} – Probability of hitting people on the ground;
A_{debris} – Crash/Impact area [m^2];
P_{Den} – Population density [people/m^2].

$$A_{debris} = K \times b^2$$

b - Wingspan [m];
K – Dimensionless coefficient.

$$K = \min[50; E \times 17{,}5 + 3{,}2858] \qquad (2)$$

(2) Note: This correlation was derived from experimental work conducted by the UK NMAA and the Italian NMAA.

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RAT: Concepts & Terms

The RAT tool is based on the risk matrix which combines the probability of the loss of the UAS versus the probability of hitting people on the ground. The risk equation is calculated as:

$$R = P_{cat} \times P_{HIT} \times (1 - S)$$

Where
R- Risk equation;
P_{HIT} – Probability of hitting people on the ground;
P_{Cat}– Probability of UAS catastrophic event;
S - Shelter factor.

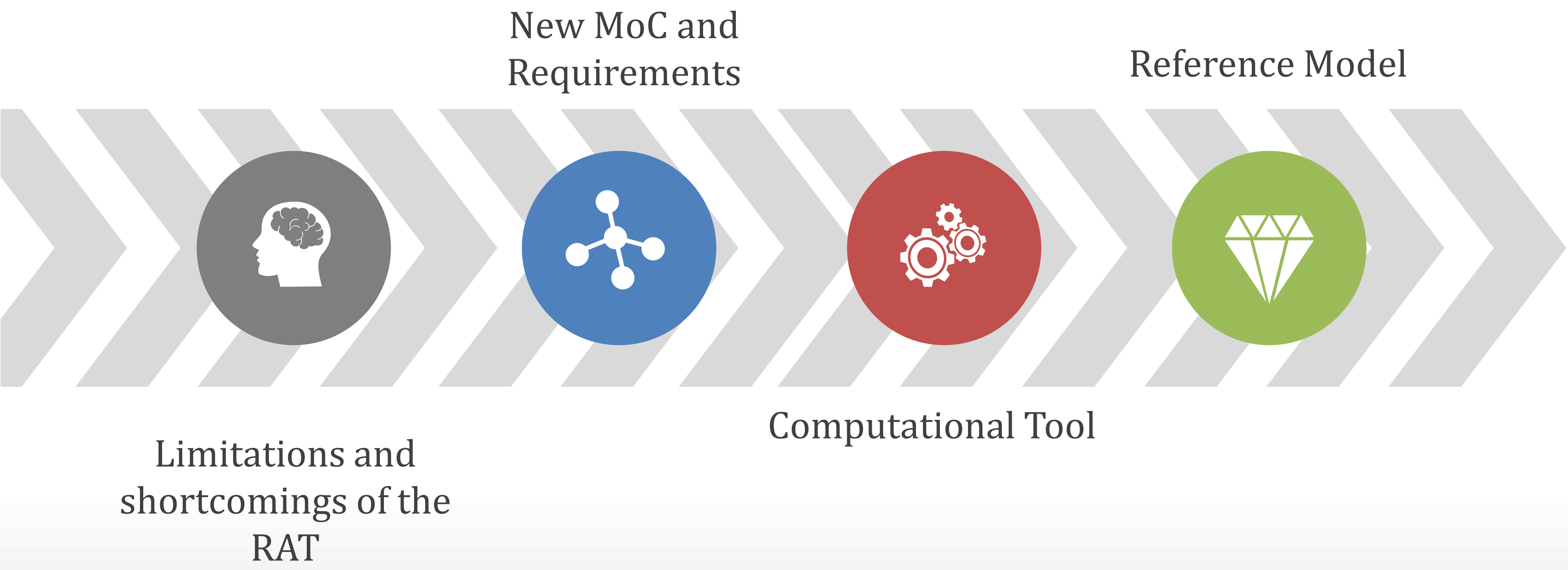
This probability is then correlated with the kinetic impact energy of the UAS, allowing each NMAA to define different ranges of risk, that may be used as ranges of the risk matrix.

Risk criticality	Example of Risk criticality ranges
Unacceptable	>1E-3
Very High	>1E-4
High	1E-5 to 1E-4
Medium	1E-6 to 1E-5
Low	1E-7 to 1E-6
Very Low	<1E-7

04

PRAT: Proposal for new RAT

Development



4. New/Proposed RAT

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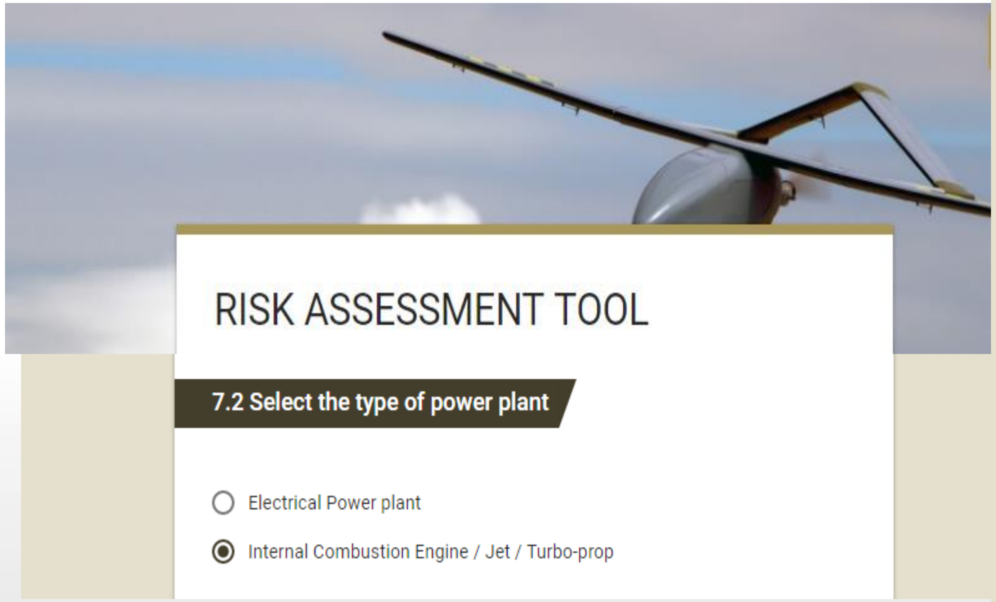
<u>OBJECTIVE:</u> Change the ***Risk Assessment Tool*** in order to allow the **standardization** of the airworthiness evaluations of these systems in the European Space.

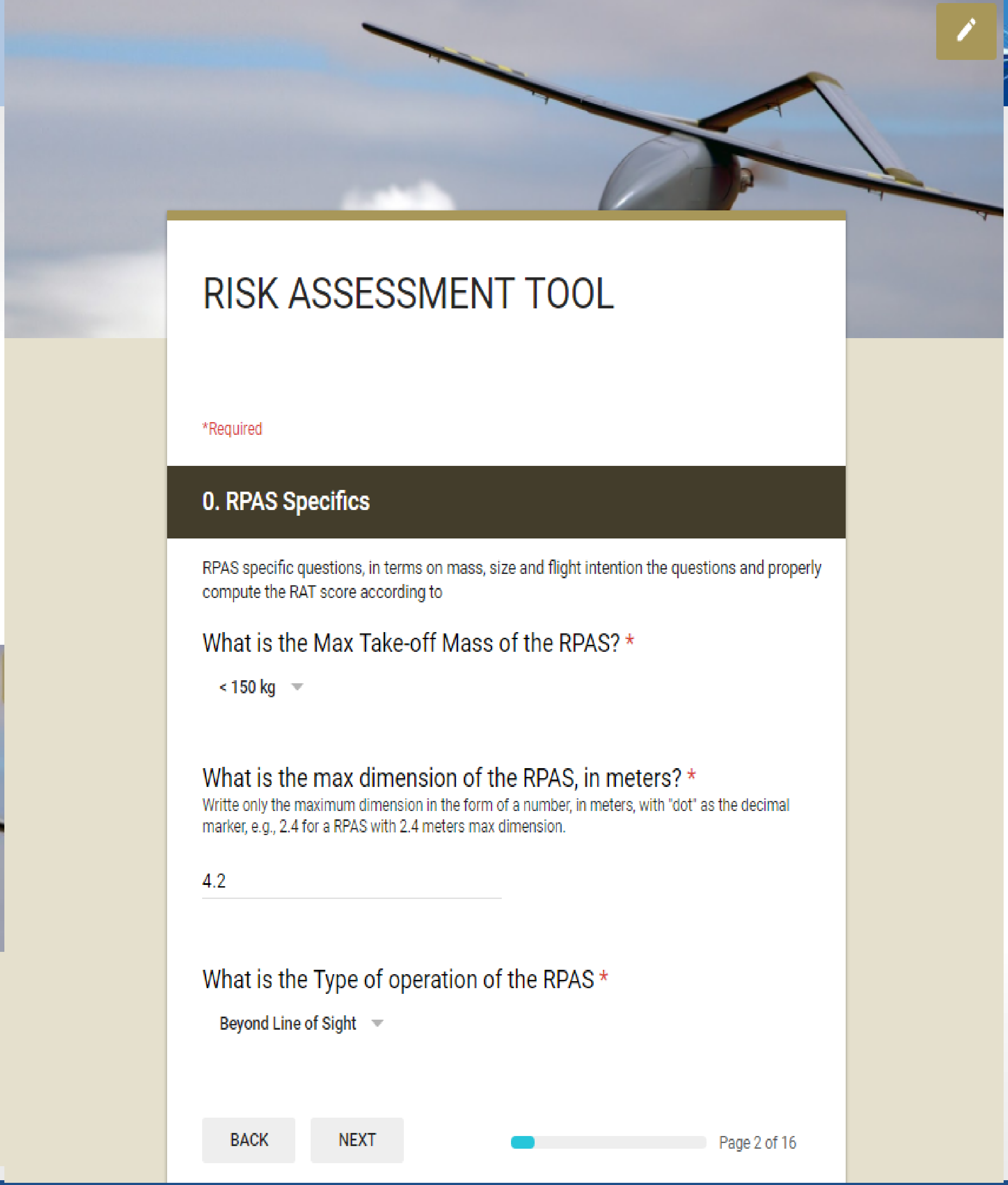
- 1 – Identify the limitations of the RAT that have led the Nations not to invest in trying to use the RAT in a consensual manner.
- 2 – Define requirements and respective MoCs in a clear and unambiguous way so that the evaluators could achieve consensual answers.
- 3 –Transform the tool in a way that it could be used by different specialists, stationed in diferente locations, and share in a common platform their results.
- 4 – Define a reference scenario that can be used to answer in an immediate way the allowable operation areas (in the National Territory) for a given UAS (with a specific design integrity score).

4. New/Proposed RAT

The Tool

- Open Source
- Multi-platform
- Automatic Saving
- Document Upload
- Remote access





PRAT: Validation

Case Study

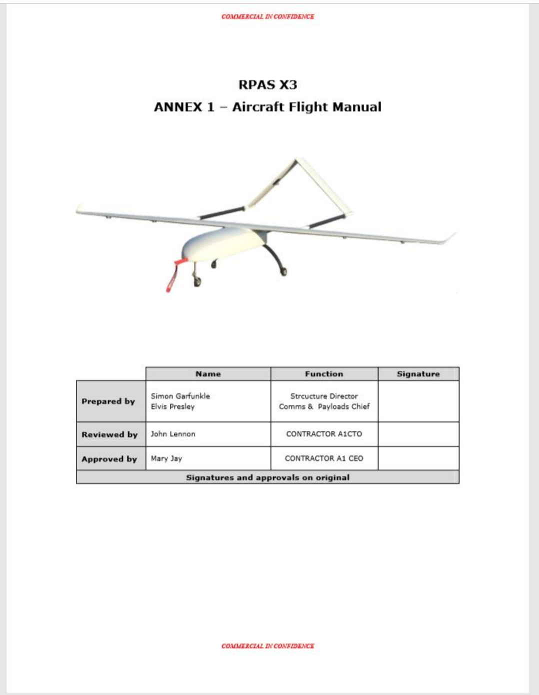
UAS

SPAN of 4.2 m

MTOW 35 kg

Answers by:

MAWA ARF Group **EDA**



COMMERCIAL IN CONFIDENCE

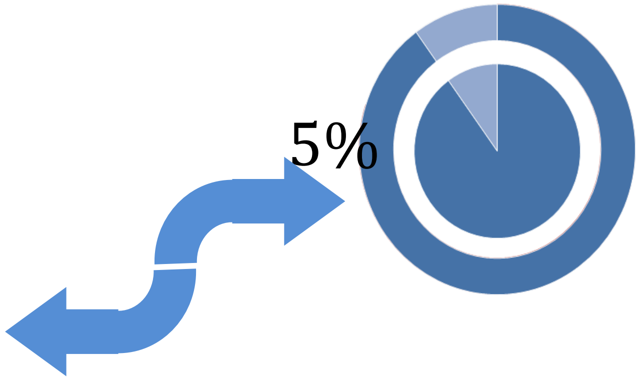
RPAS X3

ANNEX 1 – Aircraft Flight Manual

	Name	Function	Signature
Prepared by	Simon Garfunkle Elvis Presley	Strcucture Director Comms & Payloads Chief	
Reviewed by	John Lennon	CONTRACTOR A1CTO	
Approved by	Mary Jay	CONTRACTOR A1 CEO	
Signatures and approvals on original			

COMMERCIAL IN CONFIDENCE

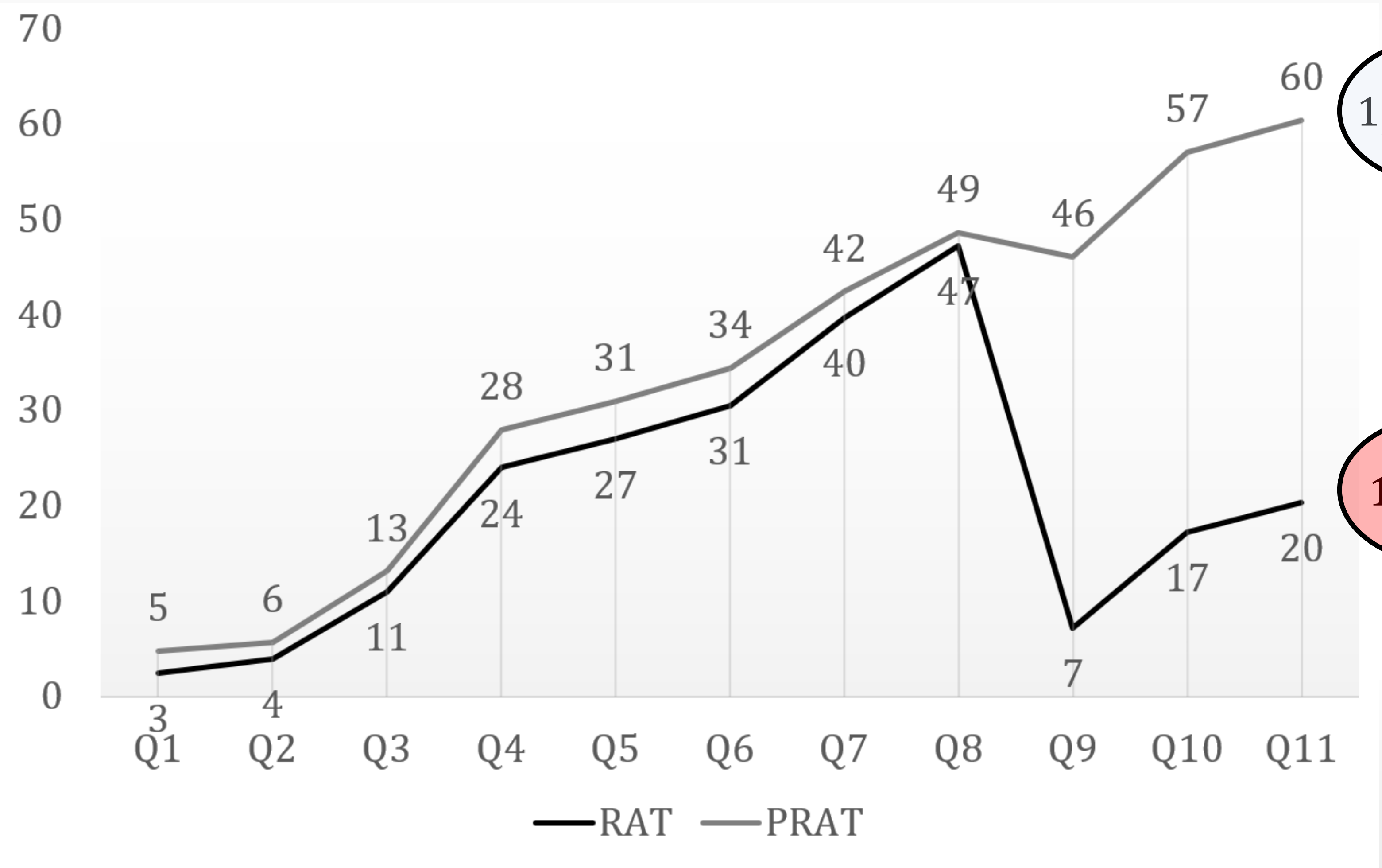
Specialist	Score
E1	65
E2	39
E3	56
E4	52
E5	73
E6	44
Average	55
Baseline	60



EUROPEAN DEFENCE AGENCY

AAN AUTORIDADE AERONÁUTICA NACIONAL

PRAT: Validation



1/625 HV

Using the New Version with the new Scoring method that accounts for the weights of the UAS in the penalization

More realistic value

1/40 HV

Using the New Version but implementing the scores a nd penalizations as define d in the Original RAT

Irrealistic Value
The real operational experience of the UAS shows a probability of catastrophic failure significantly lower (design related)

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PRAT: Comparison to the RAT for different weights

Study of the applicability of the RAT to different types of UAS.
This study considered that the scenario evaluated by the NMAAs in the field exercise was the same for the different types of systems. Specifically, the same conditions and experience of the manufacturer, the same systems and same documentation was assumed to have been delivered for evaluation.

Model	UAV ref	m [kg]	V_{impact} [m/s]	b[m]	*Score*	Probability of Catastrophic failure	Pop. density people/Km2
RAT	Raven	2	23	1.5	10	4.9E-02	13
PRAT					57	2.0E-03	330
RAT	ANTEX X02 Alfa	13	30	2.4	10	4.9E-3	5
PRAT					64	1.2E-3	200
RAT	Scan Eagle	20	35	3	10	4.9E-02	3
PRAT					52	2.7E-03	50
RAT	Wingo	35	35	4.2	10	5.0E-02	1.5
PRAT					50	3.0E-03	25
RAT	Shadow	200	75	6	10	4.9E-02	0.21
PRAT					32	1.1E-02	0.9
RAT	Hermes 900	1000	200	20	10	4.9E-02	0.005
PRAT					5	7.1E-02	0.0035






SMALL UAS:

The new version of the RAT seems to produce scoring results that when transformed into values of probability of catastrophic failure make more sense than the ones obtained with the application of the scoring based on the initial version.

LARGER UAS:

The diferences obtained using both methods are insignificante.

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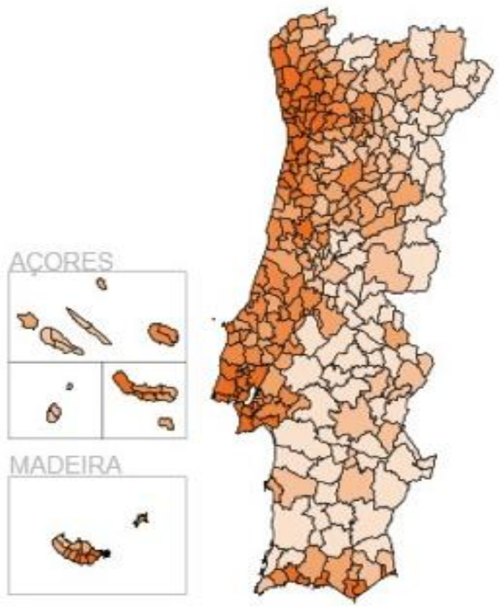
PRAT: Building The Reference Model

The definition of the usage spectrum was made with the simulations provided by the new version of the RAT, which were complemented with engineering judgeme nts that derived from the development of this work:

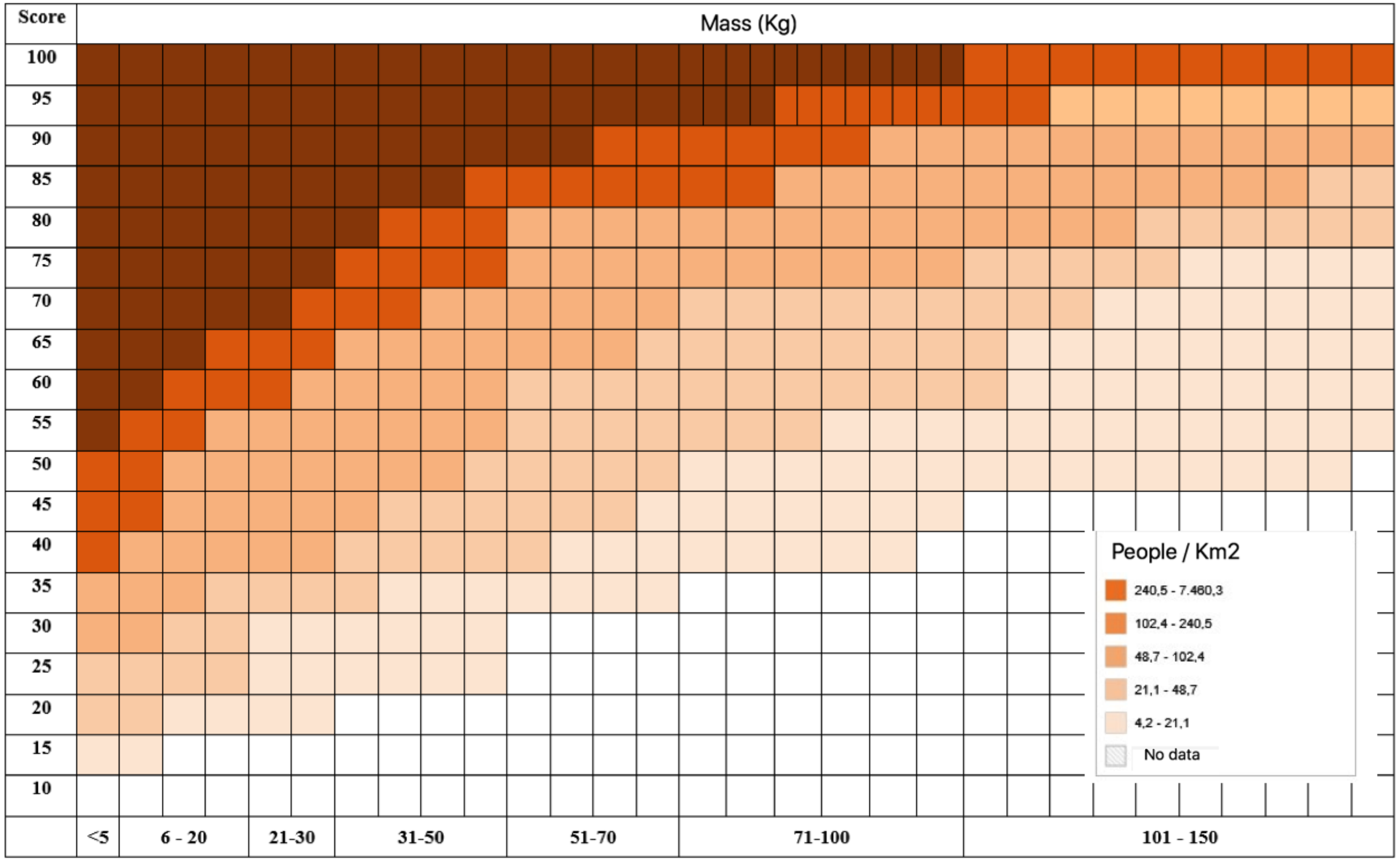
- Harmless UAS (as defined in SLAT) they could fly without restrictions;
- The study showed that a 10 % of variation between results of evaluators must be "absorbed" by the methodology;

- For the case of evaluations of medium/large UAS, scores that result superior to 90%, require that the safety assurance level that must be demonstrated to comply with this tool is so high, that probably the certification of those platforms in the light of STANAG 4703 would be possible, if such a process was endorsed.

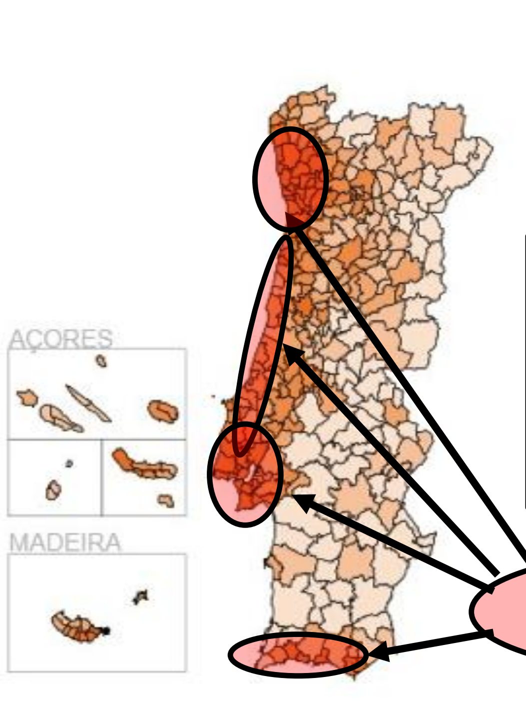
PRAT: Building the Reference Model



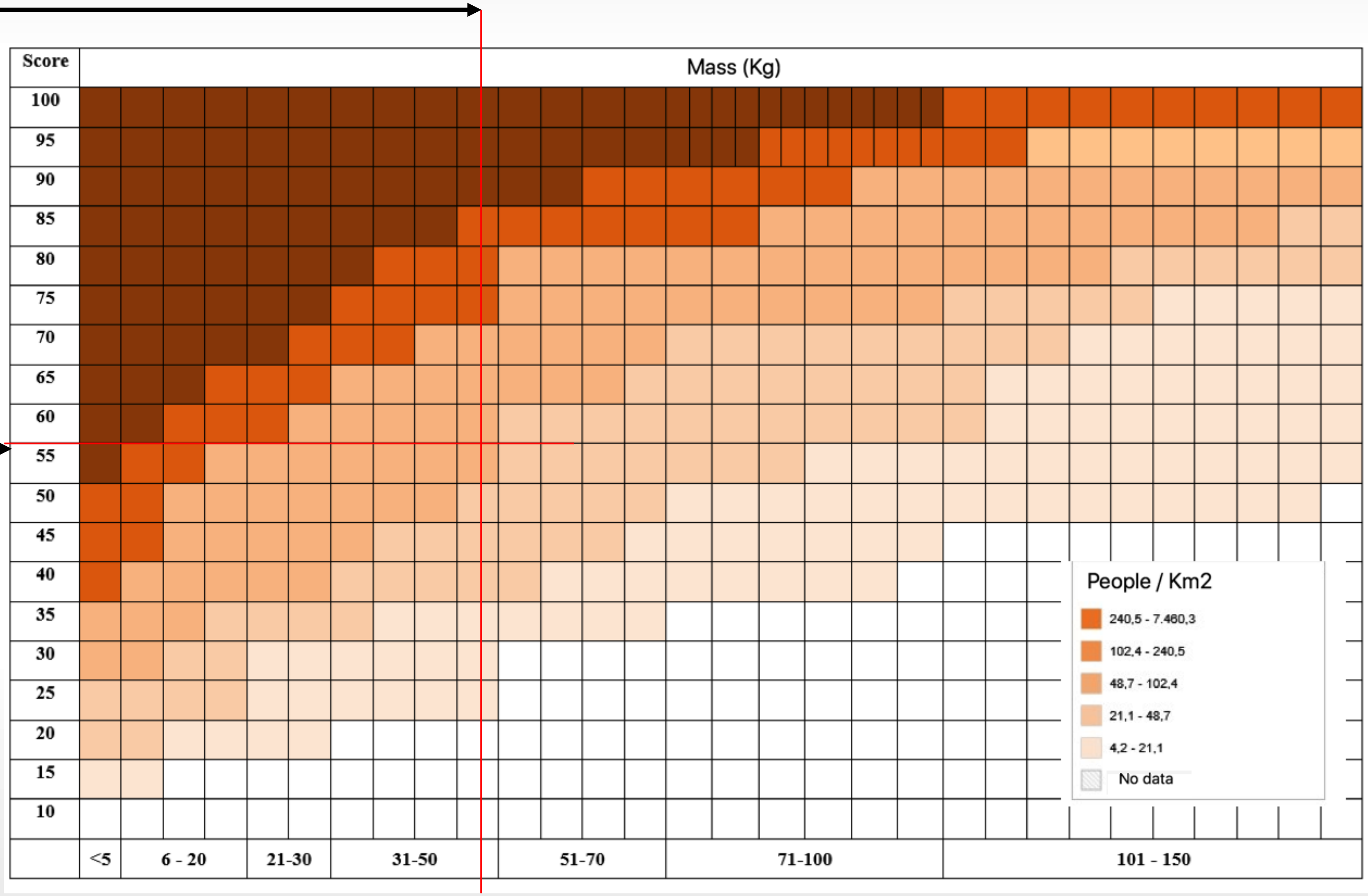
2 kg		35 kg		100 kg		150 kg	
Score	Hab/ km^2	Score	Hab/ km^2	Score	Hab/ km^2	Score	Hab/ km^2
80	1650	90	400	100	160	100	130
60	420	80	200	90	120	90	65
40	100	60	52	75	45	75	21
20	26	40	13	50	8	50	4
10	13	20	3	40	4	40	2



PRAT: Building the Reference Model



Mass: 48 Kg
Score: 55 Points



2 kg		35 kg		100 kg		150 kg	
Score	Hab/ km²	Score	Hab/ km²	Score	Hab/ km²	Score	Hab/ km²
80	1650	90	400	100	160	100	130
60	420	80	200	90	120	90	65
40	100	60	52	75	45	75	21
20	26	40	13	50	8	50	4
10	13	20	3	40	4	40	2

05

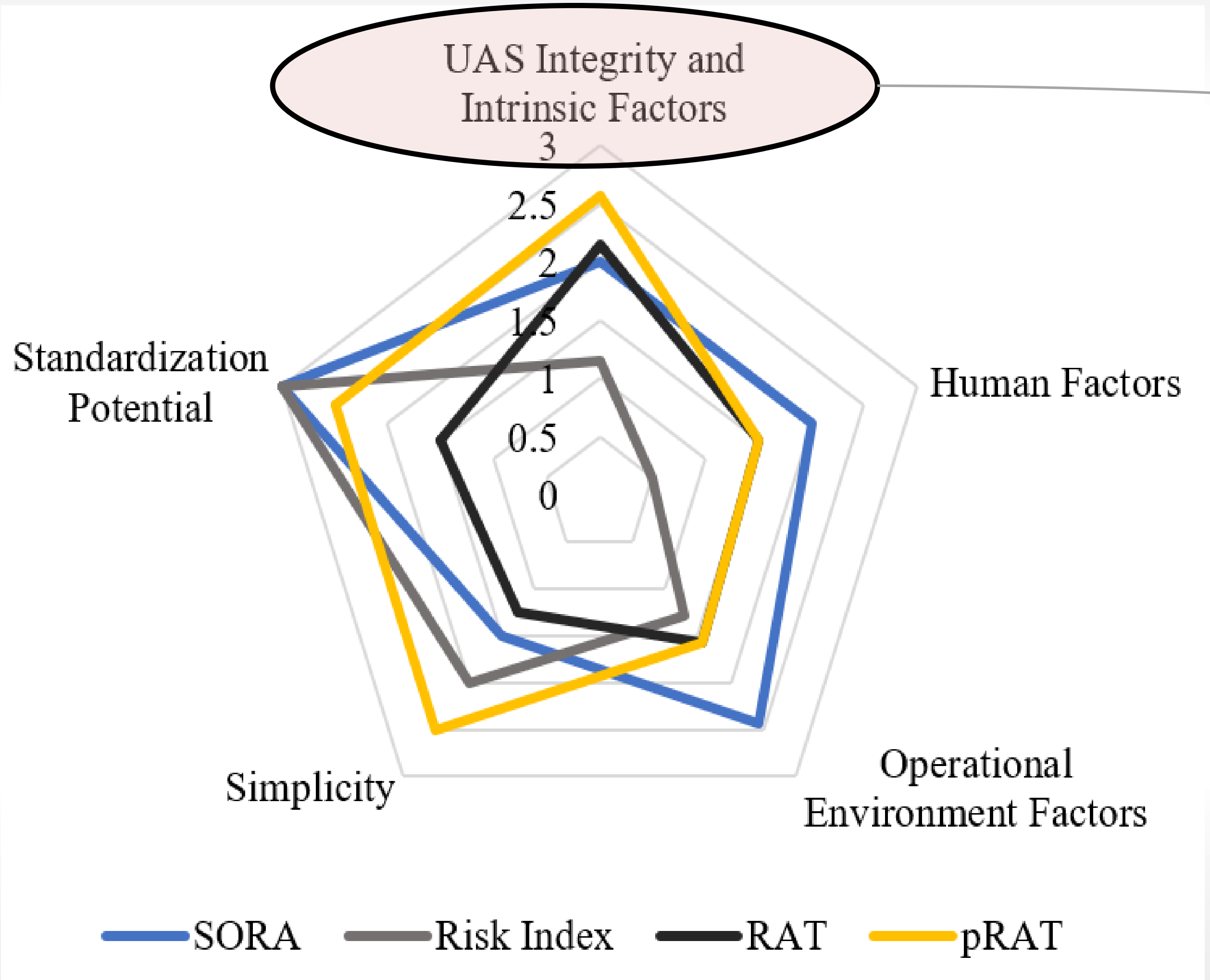
Comparison

5. Discussion

Factor Group	Description	Framework: SORA	Framework: Risk Index	Framework: RAT	Framework: pRAT
Intrinsic Factors (quality, safety)	Applicability (class or category)	Specific	R&D crew training, market survey production flight testing	*Open* and *Specific*	*Open* and *Specific*
	UAS characteristics	+++	++	+	+++
	Structural Integrity and Safety	++	+	+++	+++
	Software and System's Integrity	+	+	+++	+++
	Operational/testing flight time	+	-	+++	+++
	Life cycle estimation and support	++	++	+++	+++
	Probability of Catastrophic failure	++	++	++	+++
	Collision avoidance	+++	-	-	-
Human Factors	Operator Training and Qualifications	++	+	++	++
	Human Error	++	-	+	+
Operational Environment	Operations outside design standards	+++	+	++	++
	Probability of failure to operational reasons (weather, environment)	+++	+	+	++
	Infrastructure Damage estimation	++	+	-	-
	Populational density	++	+++	+++	+++
	Probability of causing death of people on the ground	+	+	+++	+++
	Probability of collision in flight	+++	++	-	-
	Geofencing	+++	-	-	-
Complexity[1]		+++	++	+++	++
Standardization Potential		+++	+++	+	++

[1] + low complexity; ++ medium complexity; +++ high complexity;

5. Discussion



Main strength

The RAT (when compared with other risk assess ment tools) covers in a very objective and thorough way the most important aspects addressed in the STANAG 4703.

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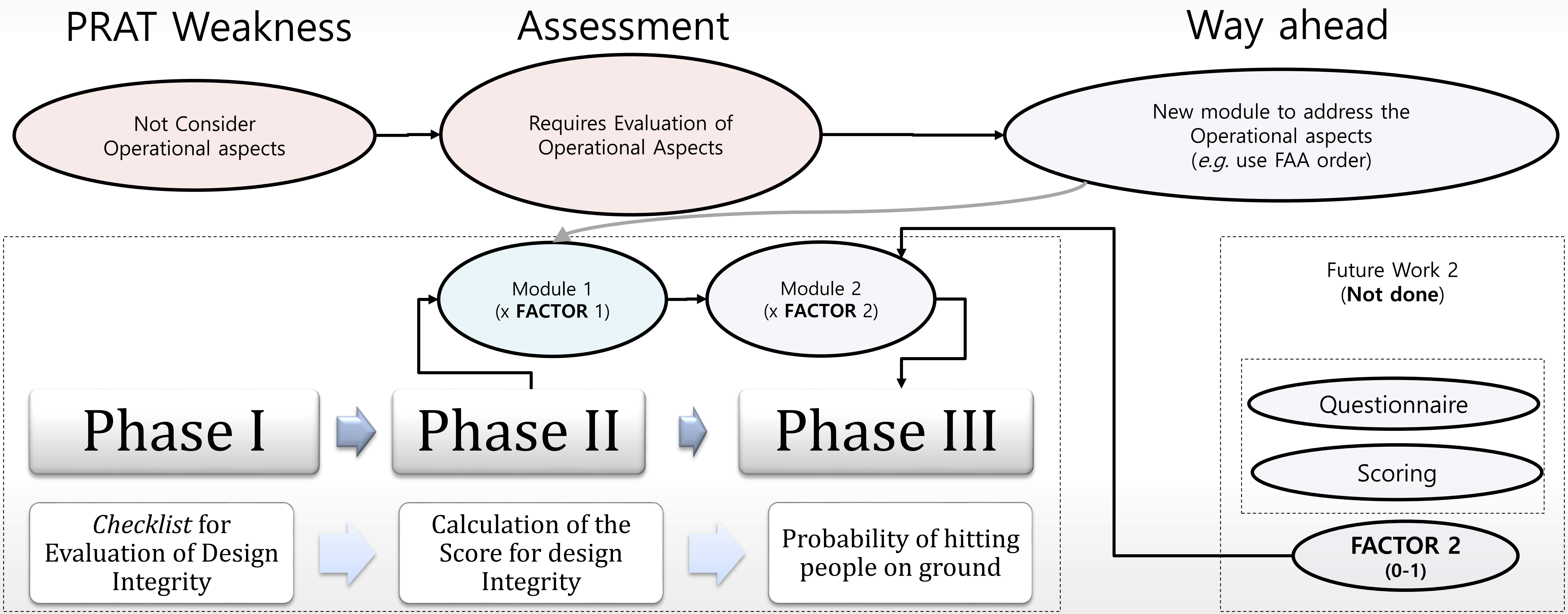
PRAT: Improving the Tool



06 Conclusions

6. Conclusion

- The Proposed tool, without further developments:
  - Is considered to be amongst the best tool available to compare different UAS, as it provides a very thorough evaluation of the UAS;
  - Is considered to be in conditions of being incorporated in the UAS documentations as one of the reference Risk based methodologies to be used as an adequate Means of Compliance for the UAS-MIL Specific category.

- The new Version of the RAT is a very good Tool for the assessment of the design integrity;
- The new version is more user friendly;
- The results obtained in the validation exercise show that the tool allows for the scoring of system with reduced variability;
- The RAT was developed only for the assessment of the design integrity, which is a weak point when compared to other methodologies, which are more inclusive;
- This tool can be easily upgraded in order to respond to aspects as human factors and operational consideration(in the same manner as the design assurance was accounted for);
- The consideration of these factors through a typified analysis could make the RAT possible to be used in a broader scope;

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THANK YOU

"Now this is not the end.

It is not even the beginning of the end. But it is, perhaps, the end of the beginning."

Winston Churchill