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SAFETY CASE OF AN UNMANNED CARGO AIRCRAFT DURING AN INTERNATIONAL TEST FLIGHT

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Presentation based on graduate theses of Patrick van der Spek, Erik Waller, Luuk Jonker & Joep Heesakker

CREATING TOMORROW

BENEFITS OF UNMANNED CARGO AIRPLANES (UCA)

- Lower transportation costs
  - Reduction in number of pilots (from two to 1/10th) per aircraft
  - No pressurized cabin
  - No duty time restrictions
  - Lower cruising speeds improving fuel efficiency and enabling new technology
- More air cargo destinations
  - Point-to-point is economically viable between regions not currently served by air cargo
  - Aircraft more versatile to landing terrain (amphibious, short take-off & landing)

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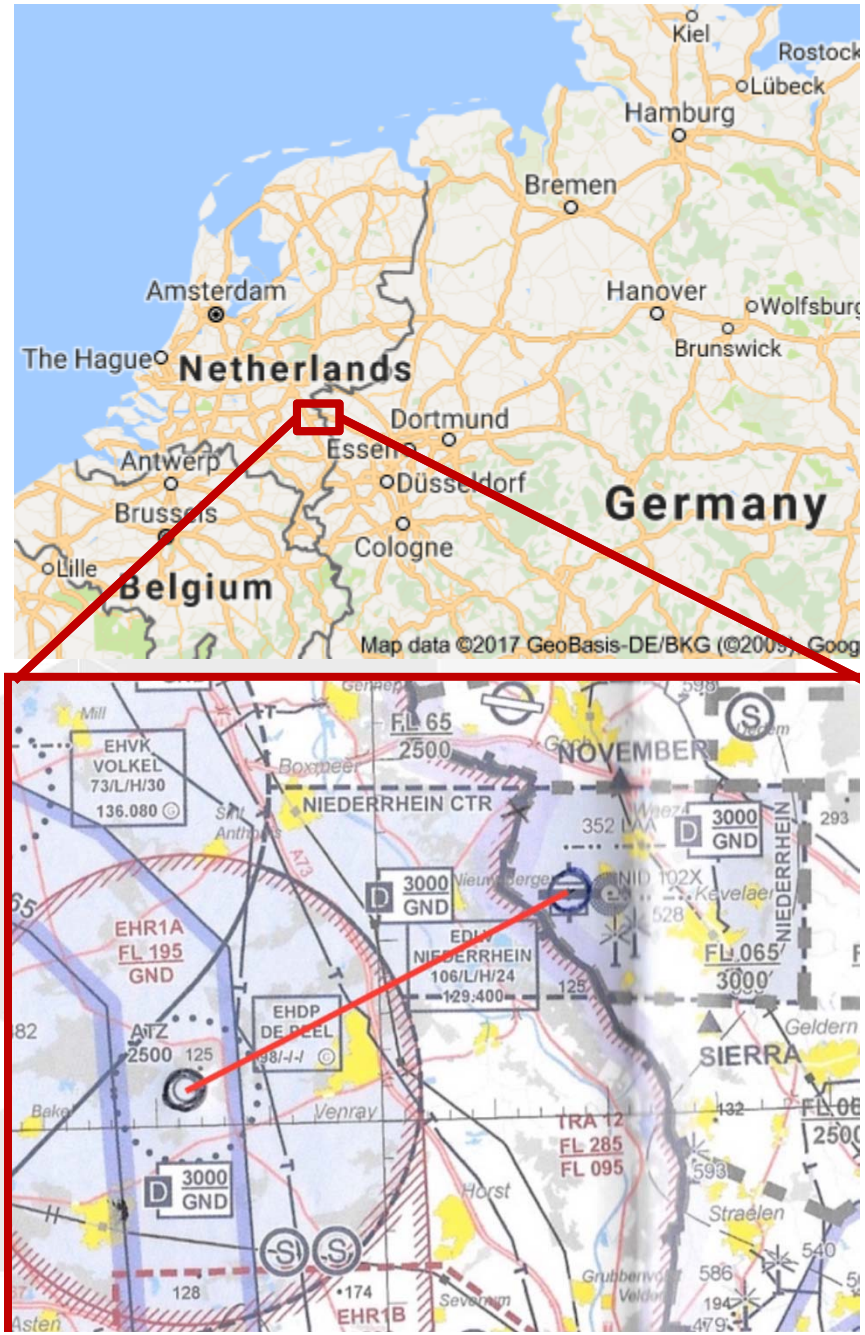
GOAL OF A UCA TEST FLIGHT

- Prove UCA can operate safely within Europe
  - With a view to the EASA RPAS legislation (2018)
  - Speed-up development of legislation
- Stimulating the development and interest of UCA
  - Gain publicity
  - Find funding / investment
- Prove UCA are economically viable
  - Lower costs than existing (air) cargo transportation
  - Faster mode of transportation than road transport



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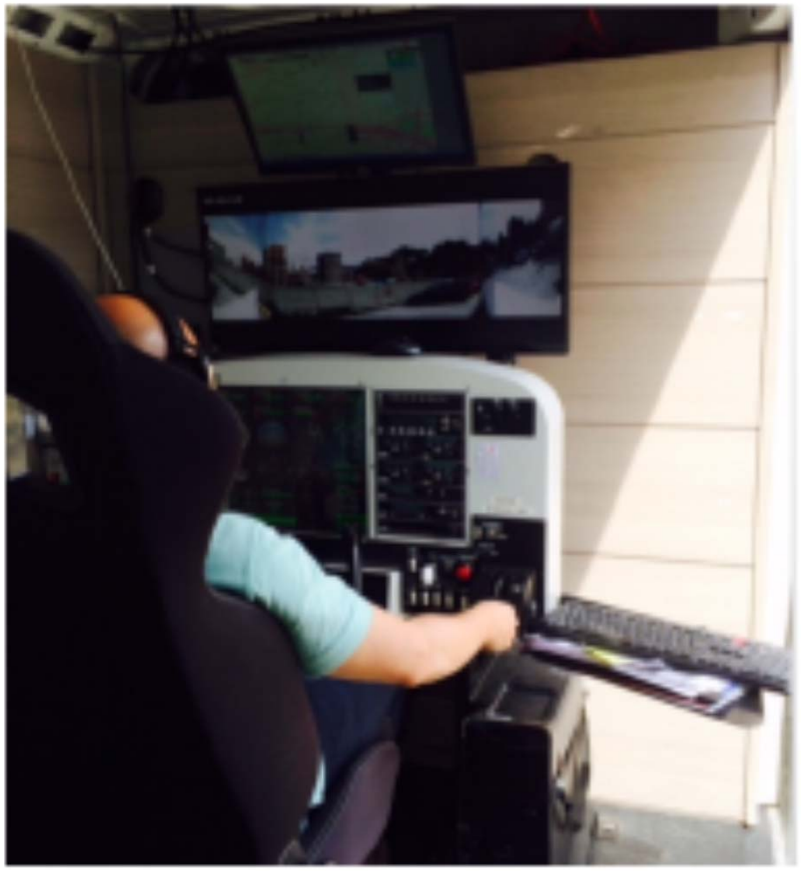
SINGULAR
AIRCRAFT

Dimensions	
Wing span	14,0 mts
Overall length	11,5 mts
Tail height	3,60 mts
Weights	
Maximum Take-Off Weight (MTOW)	3.800 kg
Operating Empty Weight (OEW)	1.750 kg
Payload capacity	2.050 kg
Take-off & Landing	
Take-off roll	300 m
Landing roll	350 m
Rate of Climb	2.000 ft/min
Rate of Climb (N-1)	440 ft/min
Cruise	
Max. Operational Altitude	24.000 ft
Optimum altitude	10.000 ft
V. Cruise 80 % Power	131 kts
V. Cruise 65 % power	126 kts
V. Cruise 55 % power	111 kts
V. Cruise optimum OEW	90 kts
V. Cruise optimum MTOW	115 kts
Max cruise range	4.500 Nm
Max cruise range MTOW	400 Nm

CONCEPT OF OPERATIONSA UCA TEST FLIGHT

- Automatic (not autonomous) flight mode
- Controlled by two ground stations
  - Master / Slave mode
  - 270-degree external view
  - Full aircraft instrumentation
- Navigation:
  - Mode-S transponder
  - 2 *Differential Global Positioning Systems* (DGPS)
  - 9 accelerometers
  - *Detect and Avoid* (DAA) in preparation
- Passive fire protection system; fire extinguisher optional.
- Transported in a standard 40’ container and assembled in less than four hours.



Singular Aircraft, 2016

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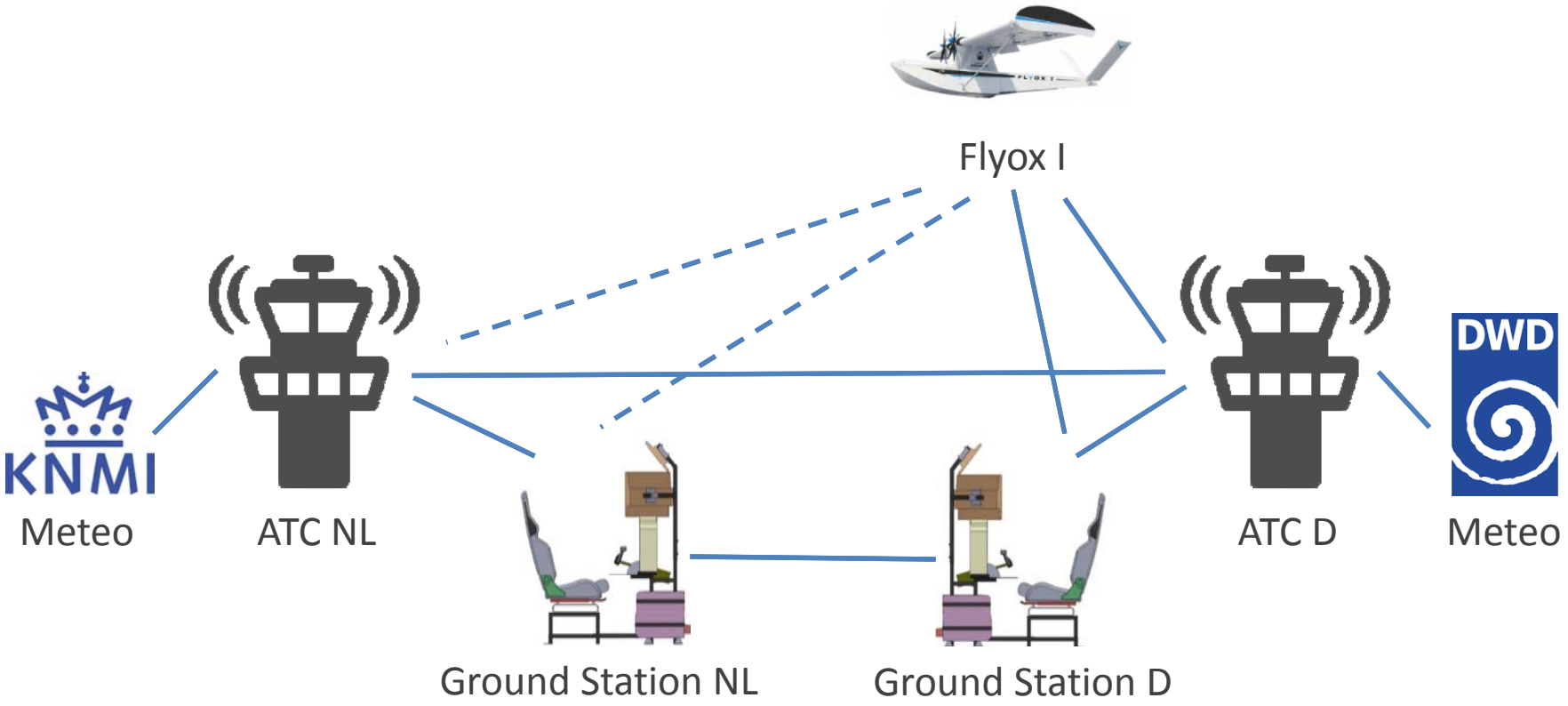
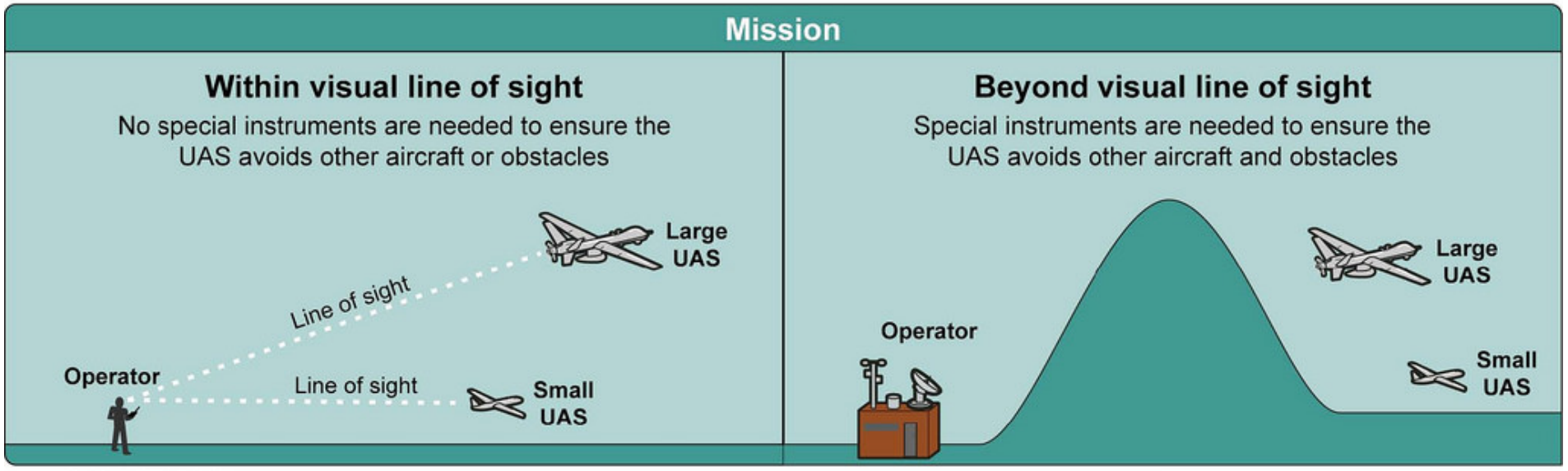
THE FLYOX I AND WIDER SYSTEM DURING THE TEST FLIGHT



BUT….

- There is no legislation in Europe covering large remotely piloted aircraft
- There is no legislation covering Beyond Visual Line of Sight missions



Source: G

How to ensure a level of safety equal to conventional aviation?

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COMPARISON OF UNMANNED AND CONVENTIONALLY PILOTED TEST FLIGHTS

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THE SYSTEM COMPONENTS ARE AS SAFE AS CPA EXCEPT THE FLYOX I

- Rainproof IP 67
- No icing conditions

yox I

- Same functionality as conventional aviation
- Pilots qualified as conventional pilots
- DA
- Au c flight

ATC

DWD

Mete

Ground Station D

FLYOX 1 DOES NOT MEET CONVENTIONAL CERTIFICATION REQUIREMENTS

Safety Requirements	Frequent	Probable	Remote	Extremely remote	Extremely improbable
FLYOX	$>10^{-3}$	$<10^{-3}$	$<10^{-4}$	$<10^{-5}$	$<10^{-6}$
Conventional planes <9000 kg	-	$<10^{-3}$	$<10^{-5}$	$<10^{-7}$	$<10^{-8}$

RISKS AND MITIGATIONS FOR COMPONENT FAILURES

- 10^2 x safety difference in certification base:
  - Correct for fact that there are no people on board
  - Project track over low population densities
- Unsuitable weather conditions (rain, icing conditions, x-wind):
  - Rely on official weather bulletins
  - Delay or abort flight if weather deteriorates
- Flight path programming errors
  - Double check on flight path programming
  - Flight path monitoring by ground stations & ATC
  - Manual correction en-route if required

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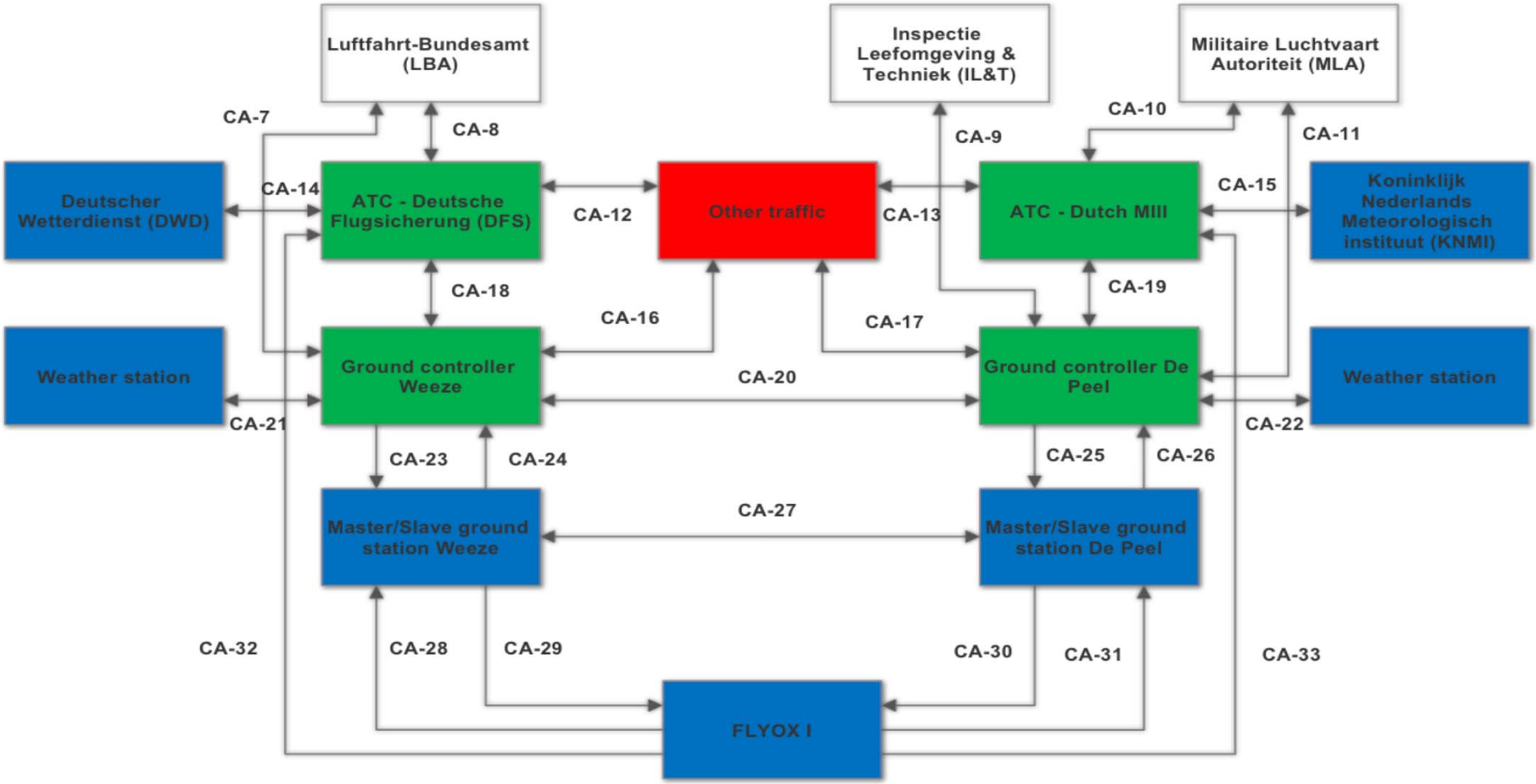
THE SYSTEM INTERACTIONS ARE INVESTIGATED THROUGH STAMP

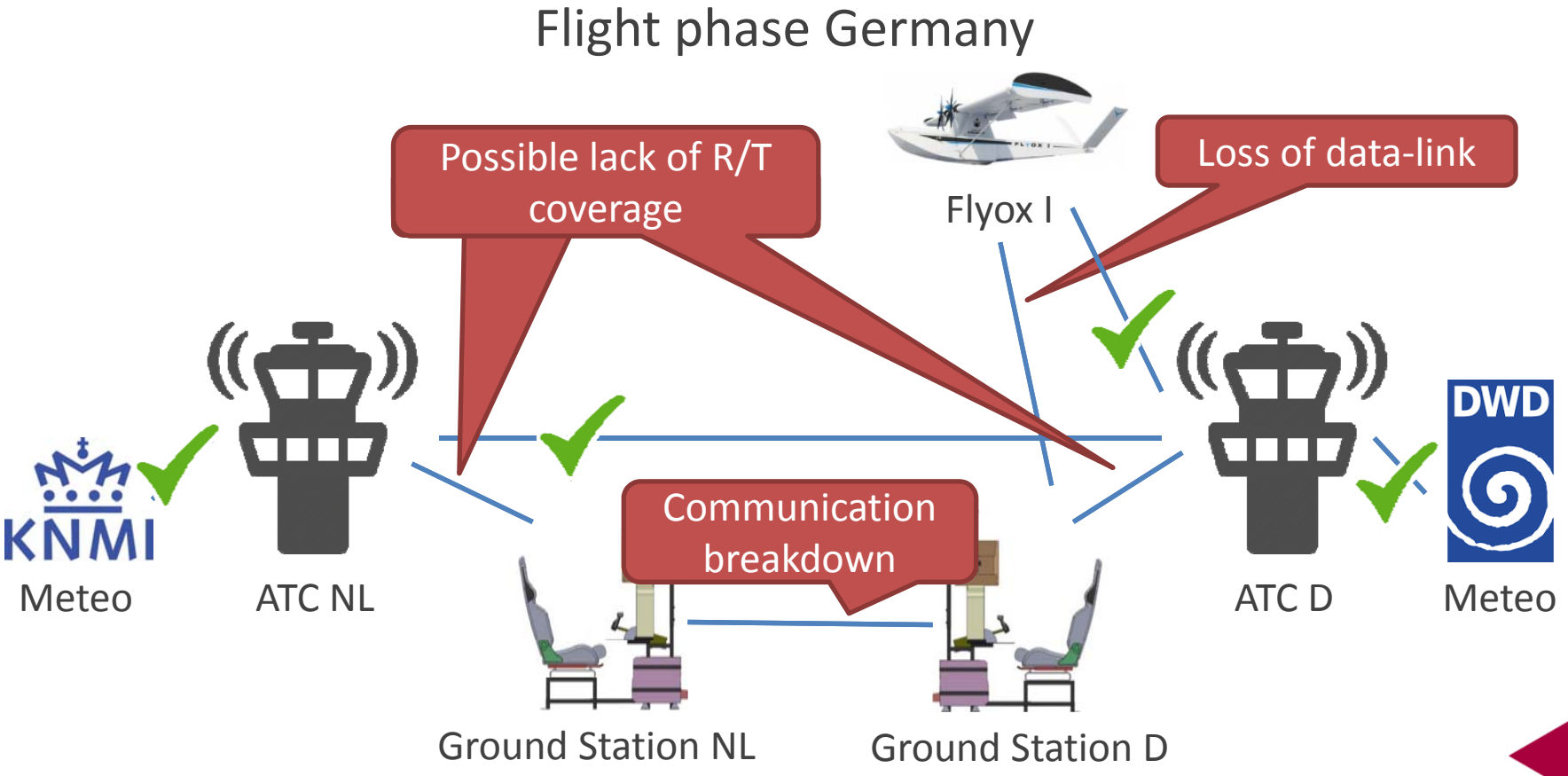


MULTIPLE SCENARIO'S ANALYZED

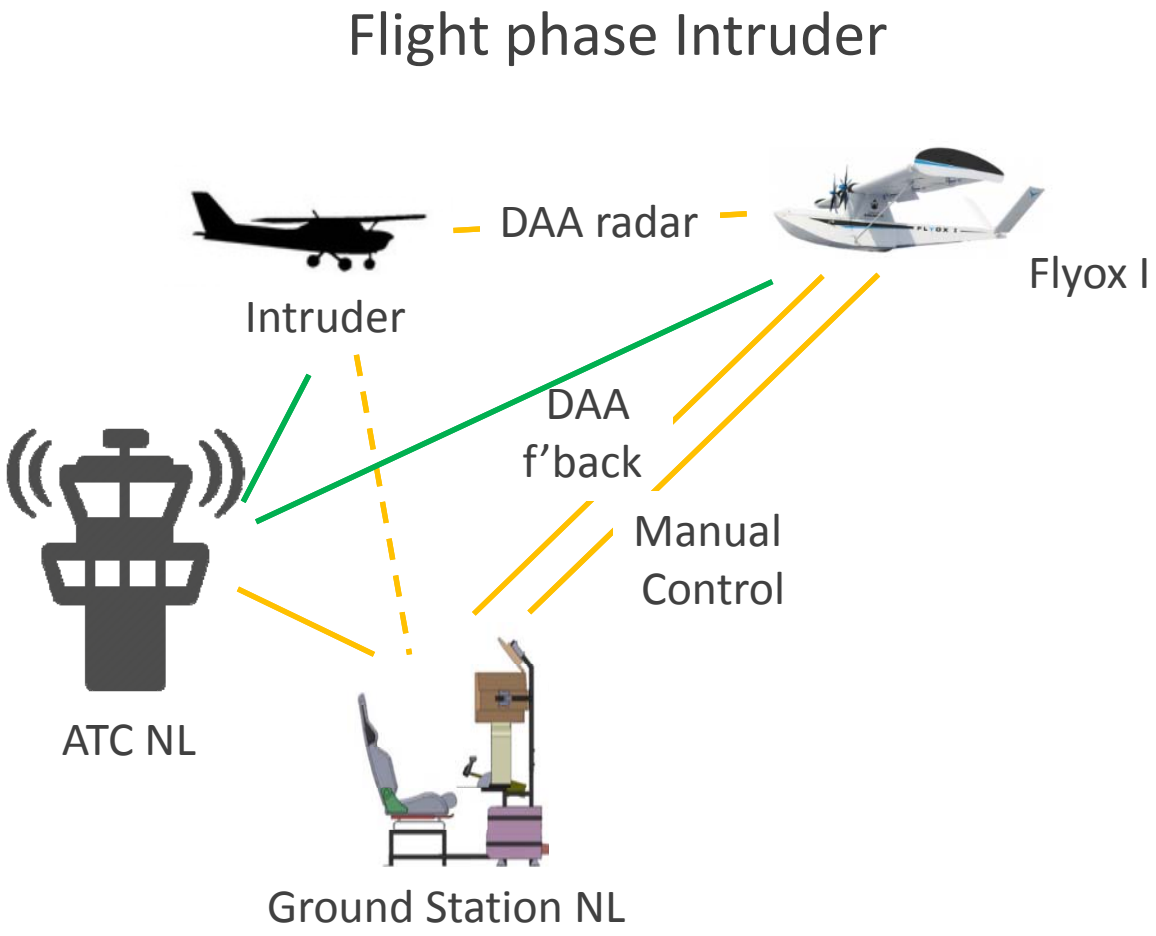
- Take-off and flight Germany
- Handover to ground station Netherlands
- Flight and landing Netherlands
- Intruder

#	Control Action	Unsafe Control Actions		
		Not providing causes hazard	Wrong timing or order causes hazard	Stopped too soon or applied too long uses hazard
CA-15	Weather reports Dutch Mill	No hazard - When there is no weather report the flight will be cancelled	When the weather report is provided wrong the information could be outdated or incorrect this could lead to an exceedance of the certification base and disturbance during the flight **H-3 H-6**	
CA-16	Communication between Weeze and other traffic	Normally radio communication between two pilots is air to air. In this case the pilot is on the ground so the radio communication is ground to air. This increases the risk of interference caused by structures or the terrain. When communication is disturbed, it is possible that the separation minimum is violated **H-1**	When the communication between the ground controller and the intruder is provided incorrect or at the wrong time (before the ATC) a hazard can occur because of conflicting messages. This could lead to a violation of the separation minimum and disturbance during the flight **H-1 H-6**	When the contact is stopped too soon it is possible that not all information has come through and the separation minimum is violated **H-1**
CA-17	Communication between De Peel and other traffic	Normally radio communication between two pilots is air to air. In this case the pilot is on the ground so the radio communication is ground to air. This increases the risk of interference caused by structures or the terrain. When communication is disturbed, it is possible that the separation minimum is violated **H-1**	When the communication between the ground controller and the intruder is provided incorrect or at the wrong time (before the ATC) a hazard can occur because of conflicting messages. This could lead to a violation of the separation minimum and disturbance during the flight **H-1 H-6**	When the contact is stopped too soon it is possible that not all information has come through and the separation minimum is violated **H-1**
CA-18	Communication between ground control Weeze and DFS	Normally radio communication between a pilot and the ATC is air to ground. In this case the pilot is on the ground so the radio communication is ground to ground. This increases the risk of interference caused by structures or the terrain. When there is no communication, an intruder can stay unnoticed, clearances are not received and weather information is not provided **H-1 H-3 H-6**	When the communication is incorrect or in the wrong order, this could lead to a violation of the separation minimum, exceedance of the certification base and disturbance during the flight **H-1 H-3 H-6**	When the communication is stopped too soon it is possible that a part of the communication is not received. This could lead to a violation of the separation minimum, exceedance of the certification base and disturbances during the flight. **H-1 H-3 H-6**

MANY SYSTEM INTERACTIONS ARE CRITICAL IN COMPARISON TO CPA FLIGHTS



HOWEVER, LIMITED SAFETY RISK DUE TO NON-COOPERATIVE TRAFFIC



RISKS AND MITIGATIONS FOR SYSTEM INTERACTIONS

- Lack of R/T link between ATC and ground station
  - Pre-flight trials
  - Back-up with phone line
- Communication breakdown between ground stations (technical or procedural)
  - Pre-flight practice and trials
  - Back-up with phone line (technical)
- Loss of data link between Flyox I and ground station
  - Back-up by second ground station [& satellite]
  - No effect on flight path due to automatic flightpath
  - Requirement for flight path changes due to intruder, weather or programming errors in combination with data link loss estimated to be negligible

Note focus on preparation phase versus execution

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CONCLUSION

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THIS SAFETY CASE DEMONSTRATES THAT RISKS HAVE BEEN MITIGATED

- ATC, Ground Station, pilots etc. certified against conventional norms
- Mitigations have been identified for
  - Aircraft safety requirement (10^{-2} lower than conventional aviation)
  - Unsuitable weather conditions (rain, icing conditions, x-wind)
  - Flight path programming errors
  - Lack of R/T link between ATC and ground station
  - Communication breakdown between ground stations (technical or procedural)
  - Loss of data link between Flyox I and ground station

- ➢ The test flight can be as safe as conventional aviation
- ➢ Legislation needs to accept automatic / near-autonomous nature of flight and focus on flight preparation rather than execution

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THANK YOU FOR YOUR ATTENTION
(AND HOPING FOR A SUCCESFUL TEST FLIGHT)

- Professor of Aviation Engineering: Robert J. de Boer, rj.de.boer@hva.nl
- Website: http://www.hva.nl/aviation

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CA-16	Communication between Weeze and other traffic	Normally radio communication between two pilots is air to air. In this case the pilot is on the ground so the radio communication is ground to air. This increases the risk of interference caused by structures or the terrain. When communication is disturbed, it is possible that the separation minimum is violated **H-1**	When the communication between the ground controller and the intruder is provided incorrect or at the wrong time (before the ATC) a hazard can occur because of conflicting messages. This could lead to a violation of the separation minimum and disturbance during the flight **H-1 H-6**	When the contact is stopped too soon it is possible that not all information has come through and the separation minimum is violated **H-1**
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#	Control Action	Unsafe Control Actions		
		Not providing causes hazard	Wrong timing or order causes hazard	Stopped too soon or applied too long causes hazard
	** are long term control actions*	Control actions shaded blue could be unsafe but are equal to those of CPA flight and have no additional safety requirements	Control actions shaded green have an acceptable safety requirement	Control actions shaded red differ from a CPA flight and require corrective safety measures.
CA-1	The LufthVG (*)	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**
CA-2	'Wet luchtvaart' and 'Luchtvaart wet' (*)	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**
CA-3	Supervision on LufthVG (*)	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**
CA-4	Supervision on 'Wet Luchtvaart' and 'Luchtvaart wet' (*)	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**
CA-5	'Wet Luchtvaart', MAS and MLE (*)	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**
CA-6	IL&T and MLA (*)	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**
CA-7	LBA supervising the ground controller (*)	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**
CA-8	LBA supervising the DFS (*)	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**

#	Control Action	Unsafe Control Actions		
		Not providing causes hazard	Wrong timing or order causes hazard	Stopped too soon or applied too long causes hazard
CA-9	IL&T supervising the ground controller (*)	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**
CA-10	MLA supervising Dutch Mill (*)	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**
CA-11	MLA supervising the ground controller (*)	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**	No short-term safety hazards. **H-7**
CA-12	Communication between DFS and other traffic	When the communication is not possible, the intruder cannot be informed that it is in closed airspace, this could lead to a violation of the separation minimum **H-1**	When the communication is wrong timed this could mean that the separation minimum is already violated before the communication starts. The wrong order could lead to a misunderstanding **H-1**	When the communication is stopped too soon this could lead to a misunderstanding **H-1**
CA-13	Communication between Dutch Mill and other traffic	When the communication is not possible, the intruded cannot be informed that it is in closed airspace, this could lead to a violation of the separation minimum **H-1**	When the communication is wrong timed this could mean that the separation minimum is already violated before the communication starts. The wrong order could lead to a misunderstanding **H-1**	When the communication is stopped too soon this could lead to a misunderstanding **H-1**
CA-14	Weather reports DFS	No hazard - When there is no weather report the flight will be cancelled	When the weather report is provided wrong the information could be outdated or incorrect this could lead to an exceedance of the certification base and disturbance during the flight **H-3 H-6**	No hazards

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#	Control Action	Unsafe Control Actions		
		Not providing causes hazard	Wrong timing or order causes hazard	Stopped too soon or applied too long causes hazard
CA-19	Communication between ground control De Peel and Dutch Mill	Normally radio communication between a pilot and the ATC is air to ground. In this case the pilot is on the ground so the radio communication is ground to ground. This increases the risk of interference caused by structures or the terrain. When there is no communication, an intruder can stay unnoticed, clearances are not received and weather information is not provided **H-1 H-3 H-6**	When the communication is incorrect or in the wrong order, this could lead to a violation of the separation minimum, exceedance of the certification base and disturbance during the flight **H-1 H-3 H-6**	When the communication is stopped too soon it is possible that a part of the communication is not received. This could lead to a violation of the separation minimum, exceedance of the certification base and disturbances during the flight. **H-1 H-3 H-6**
CA-20	Communication between ground controllers	Normally radio communication between two pilots is air to air. In this case the pilots are on the ground so the radio communication is ground to ground. This increases the risk of interference caused by structures or the terrain. When there is no communication, the master/slave transition of the ground stations can go wrong. This could lead to a disturbance during the flight **H-6**	When the communication is wrong there can be a misunderstanding about who controls the FLYOX, this could lead to a violation of the separation minimum exceedance of the certification base and a disturbance during the flight **H-1 H-3 H-6**	When the communication between the ground controllers is stopped too soon there could be a misunderstanding about who is controlling the FLYOX I **H-6**
CA-21	Weather information ground station Weeze	No hazards, weather information from the ATC is used	When the weather information is provided wrong there is the possibility that when this is used this could lead to an exceedance of the certification base **H-3**	No hazards, weather information from the ATC is used
CA-22	Weather information ground station De Peel	No hazards, weather information from the ATC is used, see **section 4.4**	When the weather information is provided wrong there is the possibility that when this is used this could lead to an exceedance of the certification base **H-3**	No hazards, weather information from the ATC is used, see **section 4.4**
CA-23	Controlling ground station Weeze	When the ground controller cannot intervene the FLYOX it is possible that the separation minimum is violated and the certification base is exceeded **H-1 H-3**	When the intervention of the ground controller is at the wrong time or order, it is possible that the separation minimum is violated, the FLYOX deviates from the intended flight path, exceeds the certification base and disturbance during the flight **H-1 H-2 H-3 H-6**	When the intervention of the ground controller is stopped too soon it is possible that the FLYOX violates the separation minimum, deviates from the intended flight path, exceeds the certification base and disturbance during the flight **H-1 H-2 H-3 H-6**

#	Control Action	Unsafe Control Actions		
		Not providing causes hazard	Wrong timing or order causes hazard	Stopped too soon or applied too long causes hazard
CA-24	Information ground station Weeze	When the flight information is not provided, it is possible that the certification base is exceeded and there is a disturbance during the flight **H-3 H-6**	When the wrong information is provided, it is possible that the certification base is exceeded and there is a disturbance during the flight **H-3 H-6**	No hazards
CA-25	Controlling ground station De Peel	When the ground controller cannot intervene the FLYOX it is possible that the separation minimum is violated and the certification base is exceeded **H-1 H-3**	When the intervention of the ground controller is at the wrong time or order, it is possible that the separation minimum is violated, the FLYOX deviates from the intended flight path, exceeds the certification base and disturbance during the flight **H-1 H-2 H-3 H-6**	When the intervention of the ground controller is stopped too soon it is possible that the FLYOX violates the separation minimum, deviates from the intended flight path, exceeds the certification base and disturbance during the flight **H-1 H-2 H-3 H-6**
CA-26	Information ground station De Peel	When the flight information is not provided, it is possible that the certification base is exceeded and there is a disturbance during the flight **H-3 H-6**	When the wrong information is provided, it is possible that the certification base is exceeded and there is a disturbance during the flight **H-3 H-6**	No hazards
CA-27	Communication between the ground stations	When there is no communication between the ground stations it is unclear which station is the master and which is the slave. This could lead to control problems and eventually to a deviation from the indented flight path, exceedance of the certification base, and disturbance during the flight. **H-2 H-3 H-6**	When there is wrong communication between the ground stations it is unclear which station is the master and which is the slave. This could lead to control problems and eventually to a deviation from the indented flight path, exceedance of the certification base, and disturbance during the flight. **H-2 H-3 H-6**	No hazards
CA-28	Downlink from the FLYOX I to Weeze	When the downlink is not provided, there is no flight information available. it is possible that the certification base is exceeded and there is a disturbance during the flight **H-3 H-6**	When the downlink is available but the information is provided in the wrong order it is possible that the certification base is exceeded and there is a disturbance during the flight **H-3 H-6**	No hazards
CA-29	Uplink from Weeze to the FLYOX I	When the uplink is not available the FLYOX cannot be controlled by the ground controller. This could lead to a violation of the separation minimum, exceedance of the certification base and a disturbance during the flight **H-1 H-3 H-6**	When the uplink is available but the information is provided in the wrong order it is possible that the flight deviates from the flight path, exceeds the certification base and there is a disturbance during the flight **H-2 H-3 H-6**	No hazards

#	Control Action	Unsafe Control Actions		
		Not providing causes hazard	Wrong timing or order causes hazard	Stopped too soon or applied too long causes hazard
CA3-30	Uplink from De Peel to the FLYOX I	When the uplink is not available the FLYOX cannot be controlled by the ground controller. This could lead to a violation of the separation minimum, exceedance of the certification base and a disturbance during the flight **H-1 H-3 H-6**	When the uplink is available but the information is provided in the wrong order it is possible that the flight deviates from the flight path, exceeds the certification base and there is a disturbance during the flight **H-2 H-3 H-6**	No hazards
CA-31	Downlink from the FLYOX I to De Peel	When the downlink is not provided, there is no flight information available. it is possible that the certification base is exceeded and there is a disturbance during the flight **H-3 H-6**	When the downlink is available but the information is provided in the wrong order it is possible that the certification base is exceeded and there is a disturbance during the flight **H-3 H-6**	No hazards
CA-32	FLYOX I to DFS	When the mode-s transponder is not available the ATC gets no flight information from the FLYOX I, this could lead to a violation of the separation minimum and disturbance during the flight **H-1 H-6**	When the mode-s transponder provides the information in the wrong order the information could be incorrect, this could lead to a violation of the separation minimum and disturbance during the flight **H-1 H-6**	When the connection is broken too soon, the flight information is not available anymore, this could lead to a violation of the separation minimum and disturbance during the flight **H-1 H-6**
CA-33	FLYOX I to Dutch Mill	When the mode-s transponder is not available the ATC gets no flight information from the FLYOX I, this could lead to a violation of the separation minimum and disturbance during the flight **H-1 H-6**	When the mode-s transponder provides the information in the wrong order the information could be incorrect, this could lead to a violation of the separation minimum and disturbance during the flight **H-1 H-6**	When the connection is broken too soon, the flight information is not available anymore, this could lead to a violation of the separation minimum and disturbance during the flight **H-1 H-6**