sesar JOINT UNDERTAKING

ITARO

INTEGRATED TMA • AIRPORT • RUNWAY OPERATIONS

PJ.37 ITARO Online Event - NLR Activities

- Welcome & Introduction
- By Mr. Wilfred Rouwhorst NLR (AT-ONE) – Project coordinator

Online, *08th of June* 2023

EUROPEAN PARTNERSHIP

Co-funded by the European Union

Agenda

- Welcome & Introduction
- Introduction to project ITARO by Wilfred Rouwhorst
- NLR’s ATM Real-Time Simulations by Wilfred Rouwhorst:
  - *Combining IM, Continuous Descent Operations (CDOs), RNP-based approach operations, Time Based Separation (TBS) and* Optimised Runway Delivery (*ORD) tool*
- Flight Test Campaign by Nico de Gelder
  - *Demonstration of prototype Interval Management (IM) system in a Flight Trial*
- NLR’s Piloted Real-Time Simulation by Bart Heesbeen
  - *Cockpit tools for vertically separated departure routes*
- Concluding Remarks, Next Steps, Q&A

Introduction to project ITARO

- ITARO = ***I***ntegrated ***T***MA, ***A***irport and ***R***unway ***O***perations
- SESAR2020 - Wave 3 project
- Project started: 01 Jan 2021
- Project ends: 30 June 2023
- Total EU funding budget ~4.29 Milj Euro
- PJ.37 Coordinator: NLR (AT-One)
- Partners:

Main Project Aims

- Contribute to Greening **aviation**

- Increase the ***Maturity Levels* and *Technology Readiness Level*** (TRL) of particular SESAR "Solutions"

- Strive towards **integration and pre-deployment** of SESAR "Solutions"
  - As such a Very Large Demonstration *– like project*
  - Targeting TRL7-ongoing

V1	V2	V3	TRL7

ITARO Project Structure

Three main project parts (i.e. **Solution Tracks**):

1. Integrated Runway Throughput and Terminal Efficiency - (VLD-*like*)
   - Led by NLR (AT-One), supported by NATS
   - **Arrival work of NLR performed under this part**
2. Complementary Industrial Research (IR) - work performed for Solution PJ.07-W2-39 (Collaborative framework managing delay constraints on arrivals)
   - Led by EUROCONTROL, supported by DSNA
3. Complementary Industrial Research (IR) - work performed for Solution PJ.01-W2-08B (Enhanced Arrival and Departures)
   - Led by NATS, supported by EUROCONTROL and NLR
   - **Departure work of NLR performed under this part**

First Solution Tracks

Further divided into two sub-parts:

- Integrated Runway Throughput and Terminal Efficiency (VLD-*like*) – Departure Operations ⇔ Online presented on 08 November 2022

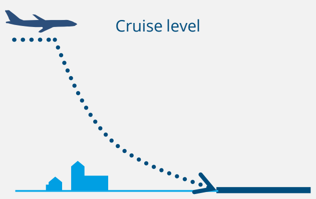
  - by NATS

- Integrated Runway Throughput and Terminal Efficiency (VLD-*like*) – Arrival Operations ⇔ **presented Today**

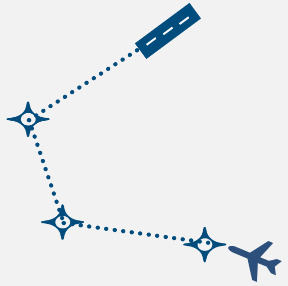
  - by NLR (AT-One)

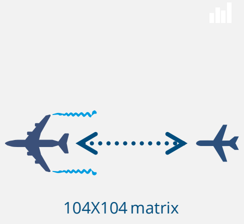
First Solution Track - VLD-*like*
Integrated Arrival Operations

- Addresses Greening of flight operations
- Whilst retaining high-capacity at airports
- Combining Operational Improvements from SESAR Solutions
  - Required Navigation Performance (RNP)-approaches
  - Continuous Descent Operations (CDOs)
  - Interval Management (IM)
  - Reduced Separation Minima, like Pair-Wise Separation (PWS)
- Investigated elements are also part of the Dutch Airspace Redesign Program (DARP)



Idle Continuous Descent Approach


Fixed Arrival Routes



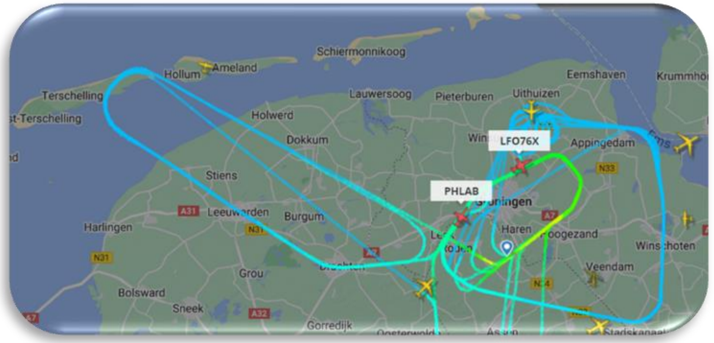
RECAT-PWS

Interval Management

NLR DEMO / Validation Exercises

To address the question ‘whether and how the SESAR Solutions (improvements) will work together’, NLR has performed

- Two Real-Time Simulations (RTSs) in the Schiphol TMA environment on NLR’s ATC Research Simulator (NARSIM)
- A flight trial at Groningen Airport Eelde using an NLR and DLR aircraft and Honeywell Flight-deck IM equipment



Validated SESAR Solutions

SESAR Solutions to be validated	OI Step
PJ.02-01-04 Wake Turbulence Separations (for Arrivals) based on Static Aircraft Characteristics	**AO-0306** Static Pairwise Separations (S-PWS) for Arrivals
PJ.02-01-01 Optimised Runway Delivery (ORD) on Final Approach	**AO-0328** Optimised Runway Delivery (ORD) on Final Approach
PJ.02-08-03 Increased Runway Throughput based on local runway occupancy time (ROT) categorisation	**AO-0337** Increased Runway Throughput based on local ROT characterization
PJ.01-05 Airborne Spacing Flight Deck Interval Management (FIM)	**TS-0108** Airborne Spacing Flight Deck Interval Management (FIM)

Third Solution Track
Complementary IR - work performed for Solution PJ.01-W2-08B

SESAR Solution Vertical guidance mode to support Optimised profile Climbs (PJ.01-W2-08**B6)** ⇔ **presented Today by NLR**

- *Cockpit tools for vertically separated Departure routes*

- NLR performed a Fast Time Simulation (FTS) & Validation Exercise on their APERO flight Simulator
- Real Time Simulation (RTS) with real Pilots, supported by a single ATCo
- Main objective:
  - More efficient use of TMA airspace

Agenda

- Welcome & Introduction
- Introduction to project ITARO by Wilfred Rouwhorst
- **NLR's ATM Real-Time Simulation by Wilfred Rouwhorst**
    - *Combining IM, Continuous Descent Operations (CDOs), RNP-based approach operations, Time Based Separation (TBS) and* Optimised Runway Delivery (*ORD) tool*
- Flight Test Campaign by Nico de Gelder
    - *Demonstration of prototype Interval Management (IM) system in a Flight Trial*
- NLR's Piloted Real-Time Simulation by Bart Heesbeen
    - *Cockpit Tools for vertically separated departure routes*
- Concluding Remarks, Next Steps, Q&A

sesar JOINT UNDERTAKING

ITARO
INTEGRATED TMA • AIRPORT • RUNWAY OPERATIONS

PJ.37-W3-ITARO: NLR’s ATM Real Time Simulations

- By Mr. Wilfred Rouwhorst NLR (AT-ONE) – Project coordinator

Online, *08th of June* 2023

Co-funded by the European Union

Arrival Operations at Schiphol Airport TMA

Daytime (peak hrs) Operation at Schiphol Airport TMA:

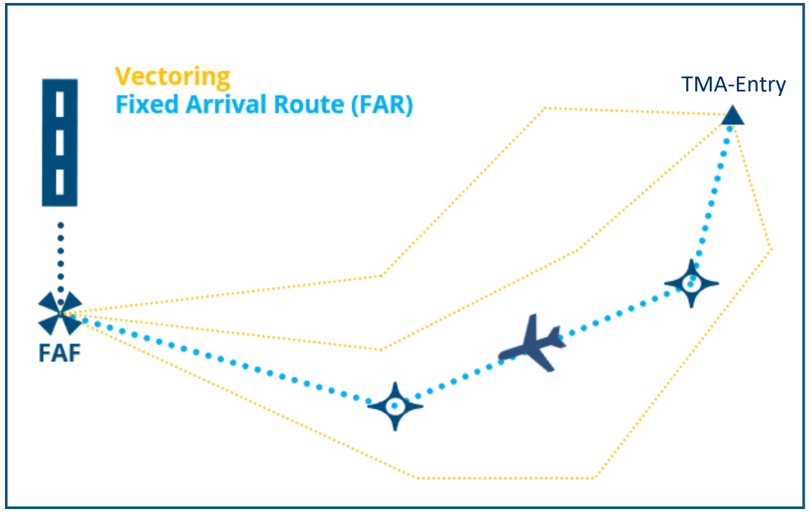
- Generally step down kind of approaches
- Radar Vectoring
- 3 TMA Entry Points (at FL100 descending FL70)
- Minimum Radar Separation (MRS) at final: 3.0 NM
- Since Jan 2023 (after RTS2) operational:
  - Time Based Separation (TBS) instead of distance based arrival separations
  - RECAT-EU Wake Turbulence criteria implemented instead of ICAO WT categories

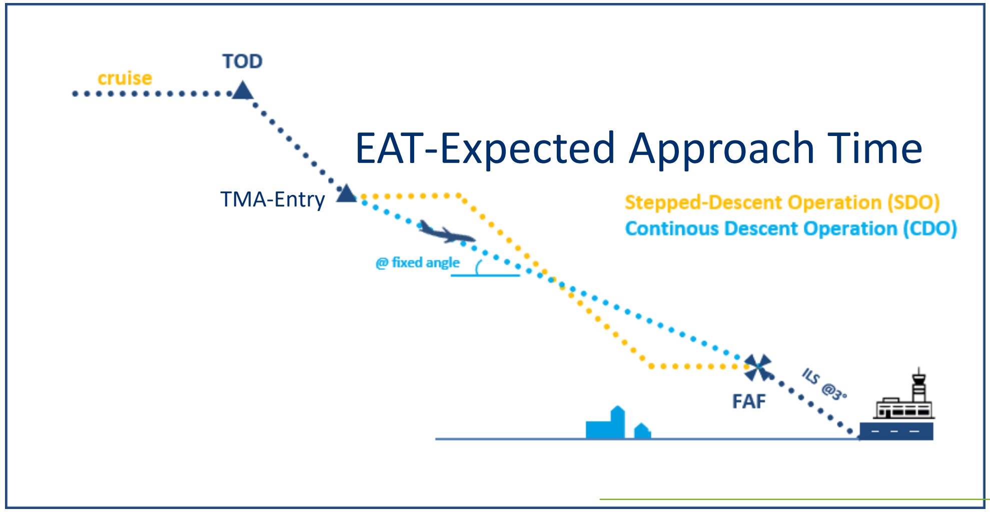
Within NL-FIR:

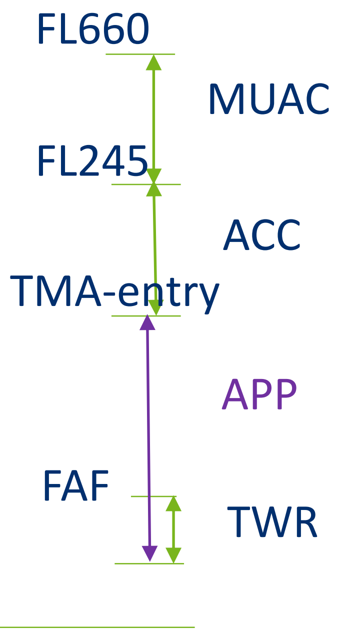
- ACC controls a/c between FL245 and the TMA Entry (IAF) / Exit Points, as well as the holding areas
- APP controls a/c from IAF till Final Approach Fix (FAF), and till runway for separation assurance, and Departures
- TWR controls a/c from about FAF till landing

New Integrated Arrival Operations Concept for Schiphol Airport TMA (1)

Combining FARs + CDOs + IM + RECAT-EU-PWS + TBS (/ROT/MRS)





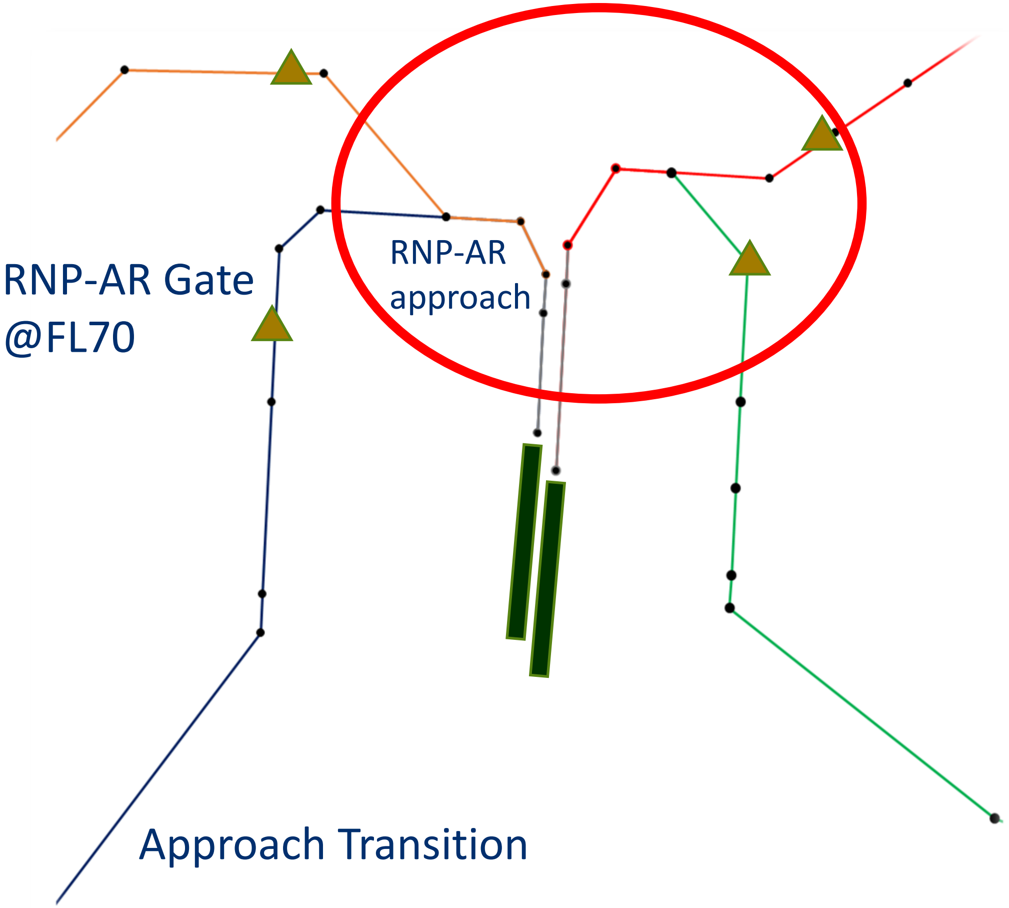


- **FARs incl Established RNP (-AR) give more precise route flying (less spread) hence better predictability and more confined environmental impact**
- **CDOs during peak hrs daytime with fixed profile gradients for greening the operations and provide better predictability**
- **4 TMA Entry points used in new concept**

New Integrated Arrival Operations Concept for Schiphol Airport TMA (2)

Required Navigation Performance (RNP) - Authorisation Required (AR)

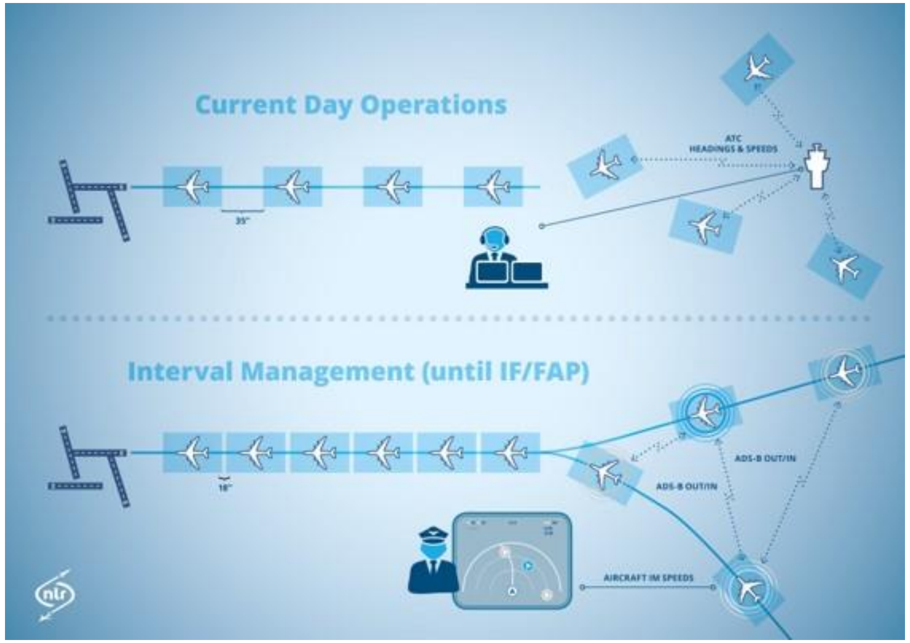
- RNP-AR APCH provides very small lateral path errors (0.3, 0.2, 0.1 NM), high accuracy, even during curved paths and descends
- Highly Important for Safe operations of Independent Parallel Approach procedures (IPA)
  - Established on RNP (EoR)
  - No 1,000 ft separation → enabling CDO
- New ATCO & Pilot procedures and R/T required
- Additional pilot reporting at
  - Pilots to report “Established on RNP” when passing RNP-AR Gate = ▲



New Integrated Arrival Operations Concept for Schiphol Airport TMA (3)

Interval Management (**IM**). Why at Schiphol Airport?

- CDOs improve the environmental impact but reduce runway throughput during peak hrs day time operations
- The goal of IM Operations is precise inter-aircraft spacing in a stream of traffic to retain runway throughput
  - given other elements such as fixed routes and more accurate delivery/metering at the TMA Entry Points

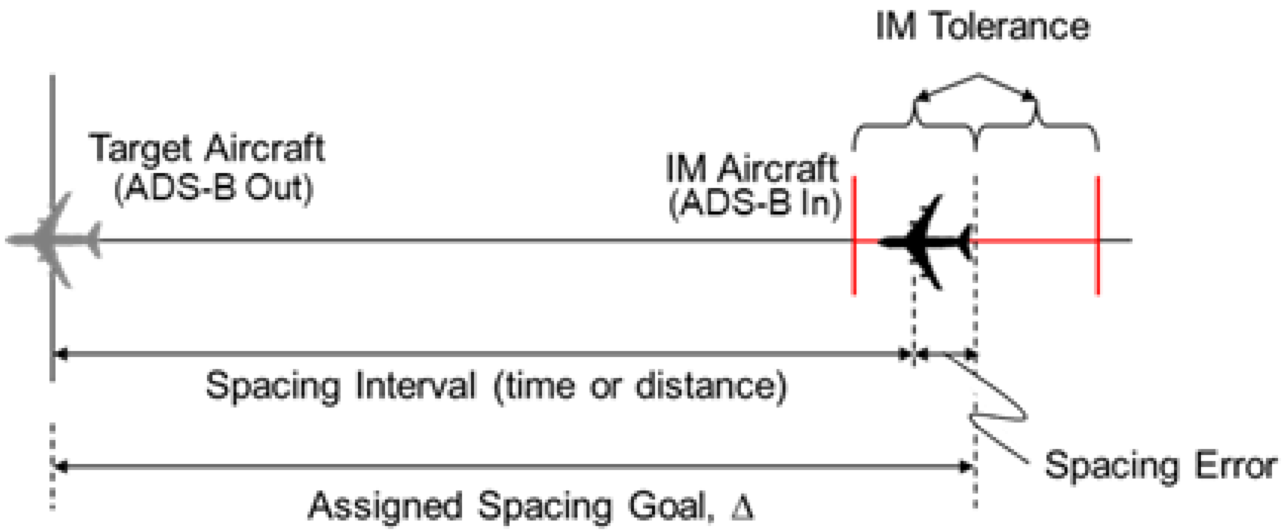


IM is regarded an enabler for efficient, high-capacity Continuous Descent Operations (CDOs)

New Integrated Arrival Operations Concept for Schiphol Airport TMA (4)

Interval Management (**IM**). How?

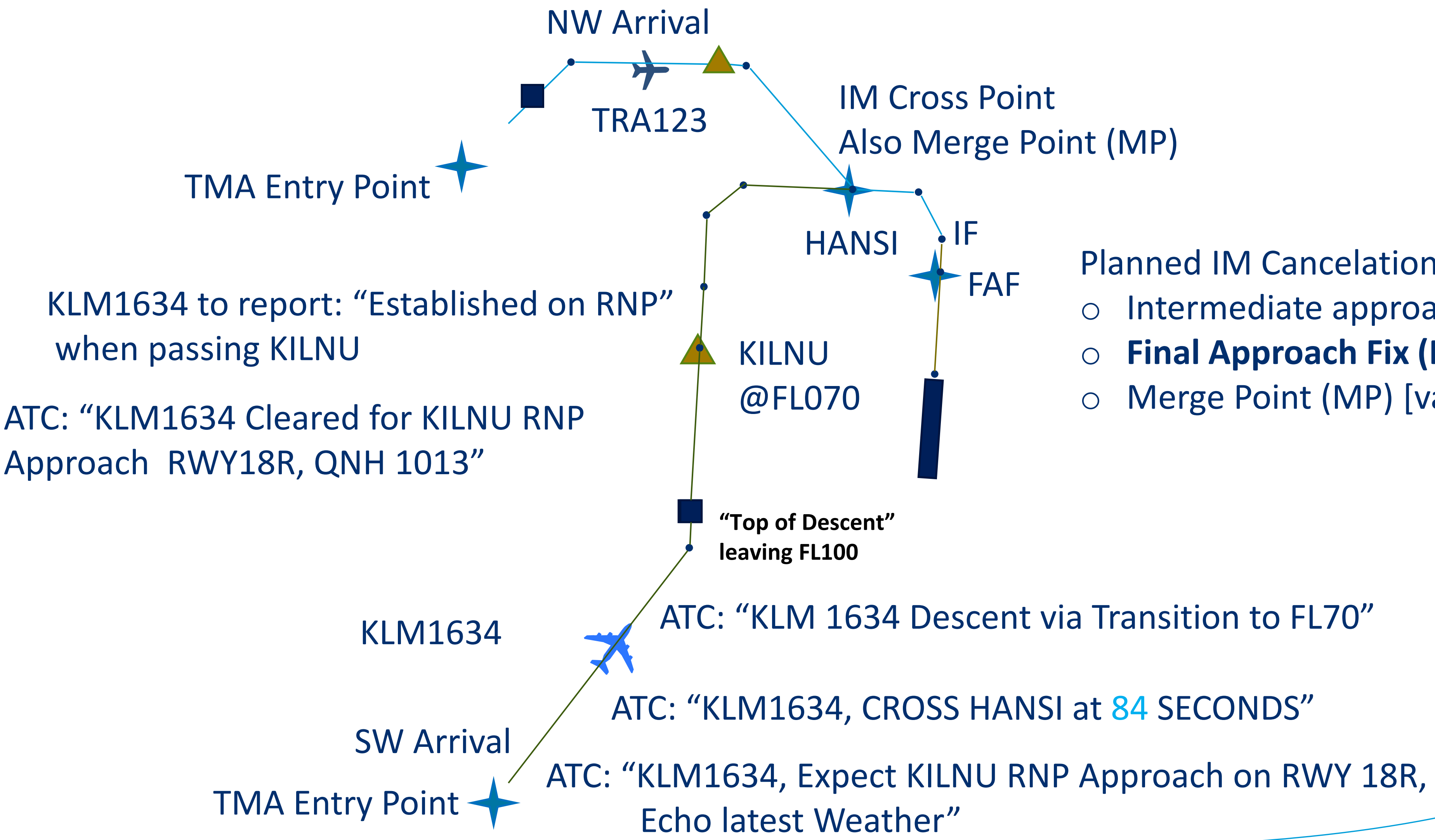
- IM is partly a ATCo tool to support (merging and spacing of) inbound flights on fixed routes, in daytime capacity-constrained operations
- And partly by means of on-board avionics: Flight-deck Interval Management (FIM) function using ADS-B IN and pilot & ATCo procedures



TMA Entry Point

New Integrated Arrival Operations Concept for Schiphol Airport TMA (5)

Interval Management (**IM**) and RNP-AR. Where?

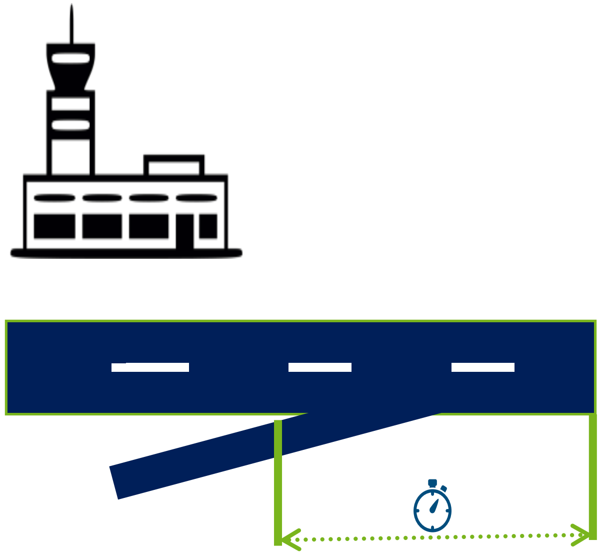


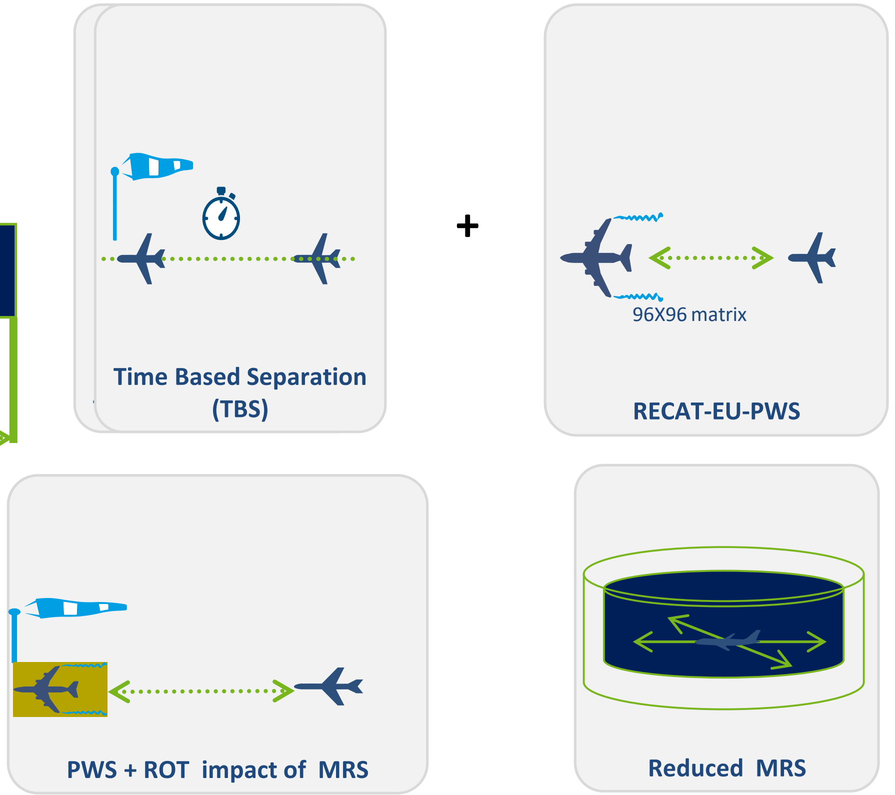
Planned IM Cancelation Point (PCP) at:

- Intermediate approach Fix (IF) [variant 1],
- **Final Approach Fix (FAF)** [variant 2], or
- Merge Point (MP) [variant 3]

New Integrated Arrival Operations Concept for Schiphol Airport TMA (6)

Combining FARs + CDOs + IM + RECAT-EU-PWS + TBS(/ROT/MRS)



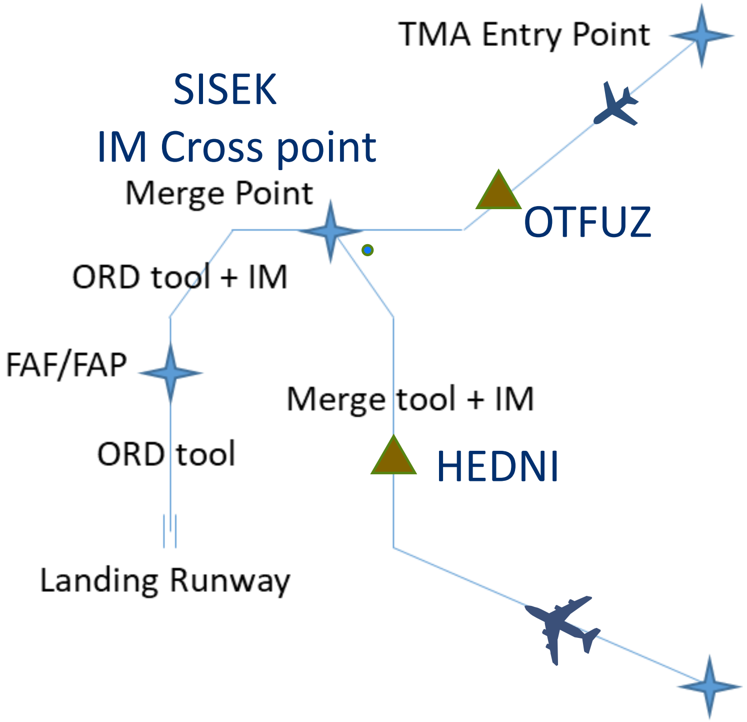


Providing:

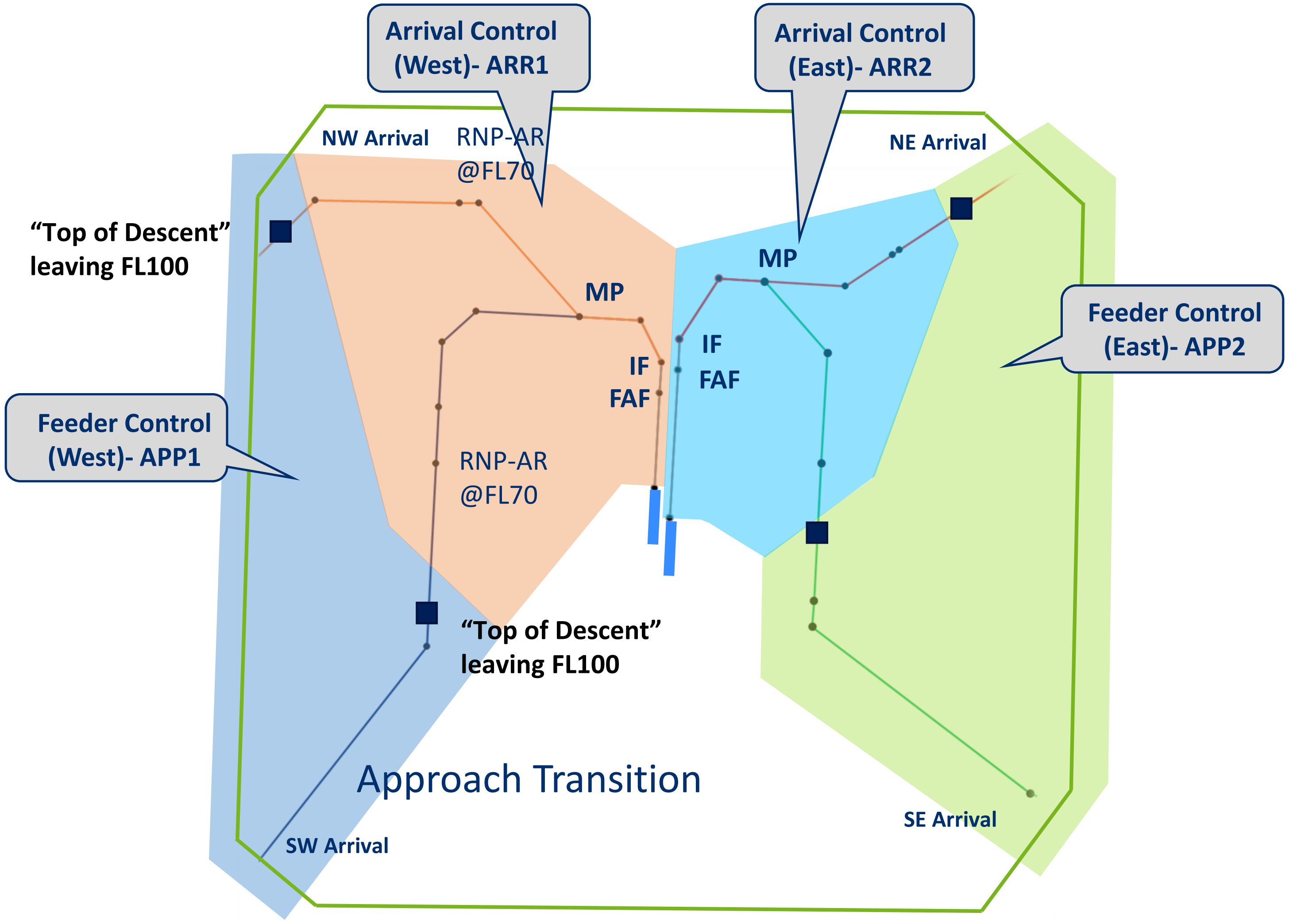
- **New ATCo Tools (like IM & Traffic Merge & ORD tool)**
- **Predictability, Safety**
- **Fuel Efficiency, Environmental reductions**
- **Runway Capacity & Human Performance**

Scope of NLR Arrival Exercises

- CDOs + FARs: RNP-RNAV operations + Established on RNP-AR
- Controller support tools
  - Optimised Runway Delivery (ORD)
    - Target Distance Indicators (TDIs) indicator displayed on FAR instead of extended centreline
    - Connection line between pair (ON/OFF via Touch Input Device, TID)
  - Merge support
  - Spacing support (IM)
- 4 TMA entries and all RNP-AR approaches starting at FL70
- First part of IM clearance, target and lead aircraft route already assumed provided by ACC
- Second IM clearance part, assigning the IM spacing goal and IM cross point provided by FDR/DCO
- Reduced separation minima on final
  - Time-Based Separation (TBS)
  - RECAT-EU Static Pair-Wise Separation (S-PWS), EASA Table 104x104 A/C
  - Runway Occupancy Times (ROT) aspects
- MRS set at 2.5 NM



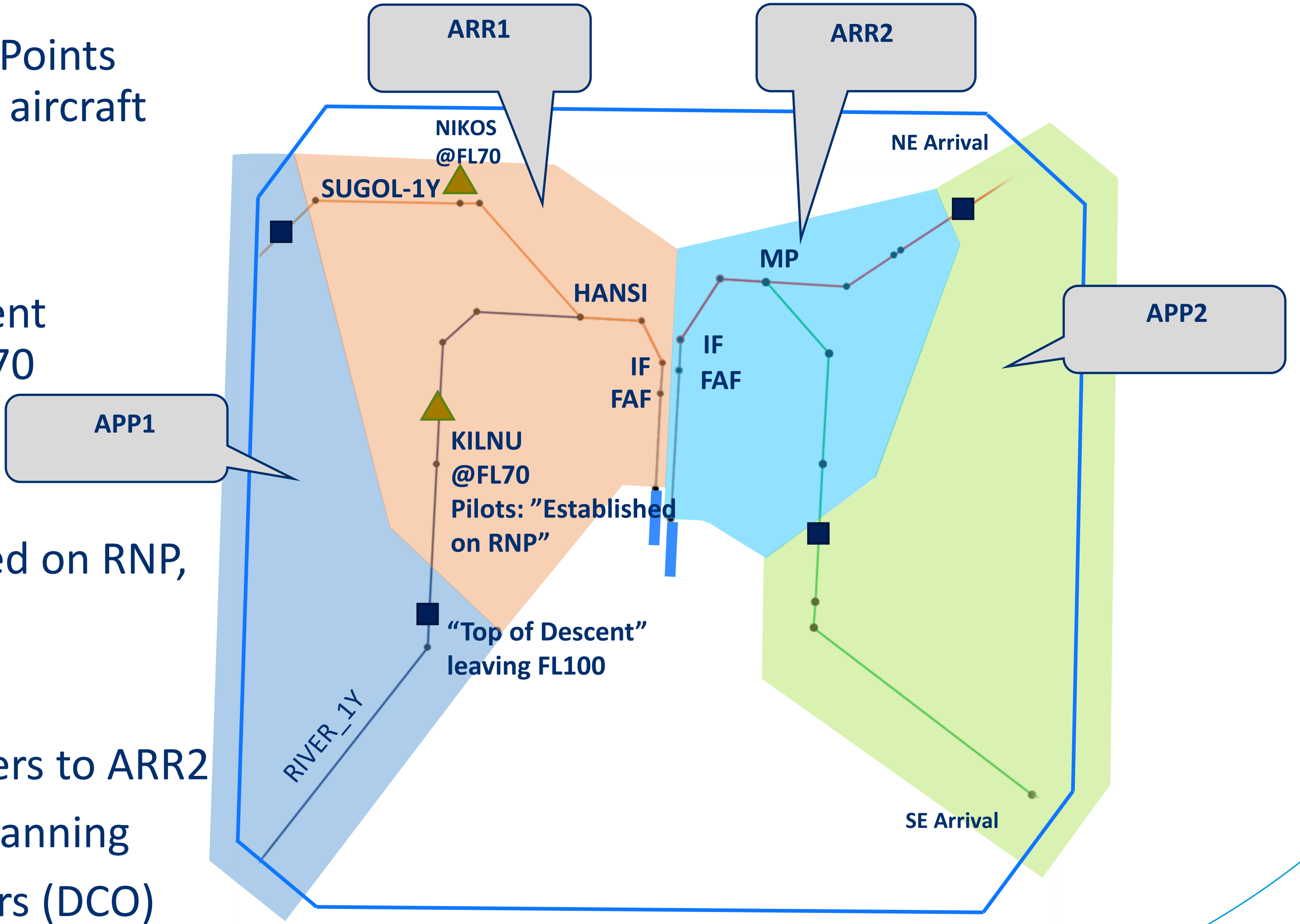
NLR RTS2 - Schiphol Operational Environment

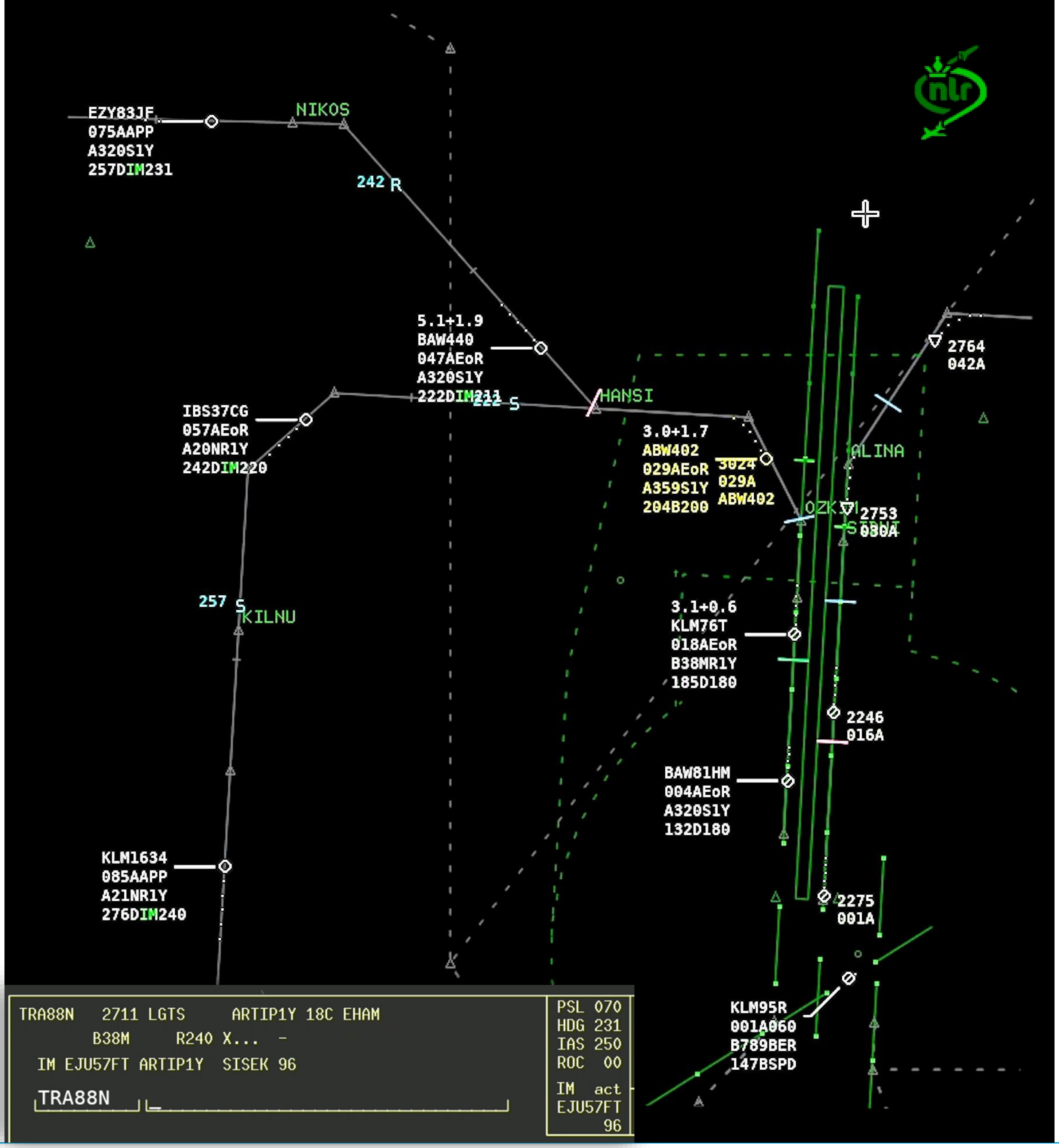


- Standard two arrival (18R+18C) runways
- Two departure (24+18L) runways were in use:
  - 4x ATCOs + 1x Planner + 4x Sim Pilots
  - 2x APP (FDR/DCO) + 2x ARR
- ATCOs varied over Controller Working Positions
- Aircraft automatically delivered to TMA entries (by ACC) using E-AMAN) with prescribed high EAT accuracy
  - EAT adherence [+/- 30 s]

Routes and ATC Roles

- Scripted ACC role
  - Accurate +/-30 sec delivery at TMA Entry Points
  - First part of IM clearance, target and lead aircraft route
- **All West-inbound traffic will first go to APP1**
  - ACC traffic from RIVER/SUGOL → APP1
    - IM clearance + spacing goal assignment
    - Descend via transition to flight level 70 (KILNU/NIKOS)
  - Transfer to ARR1
    - RNP APPROACH clearance, Established on RNP, merge and final approach tasks
- Similar for East-inbound traffic:
  - Scripted ACC delivers to APP2 who transfers to ARR2
- Planner to assist on/use (E-AMAN) inbound planning
- APP1 & APP2 also act as Departures Controllers (DCO)



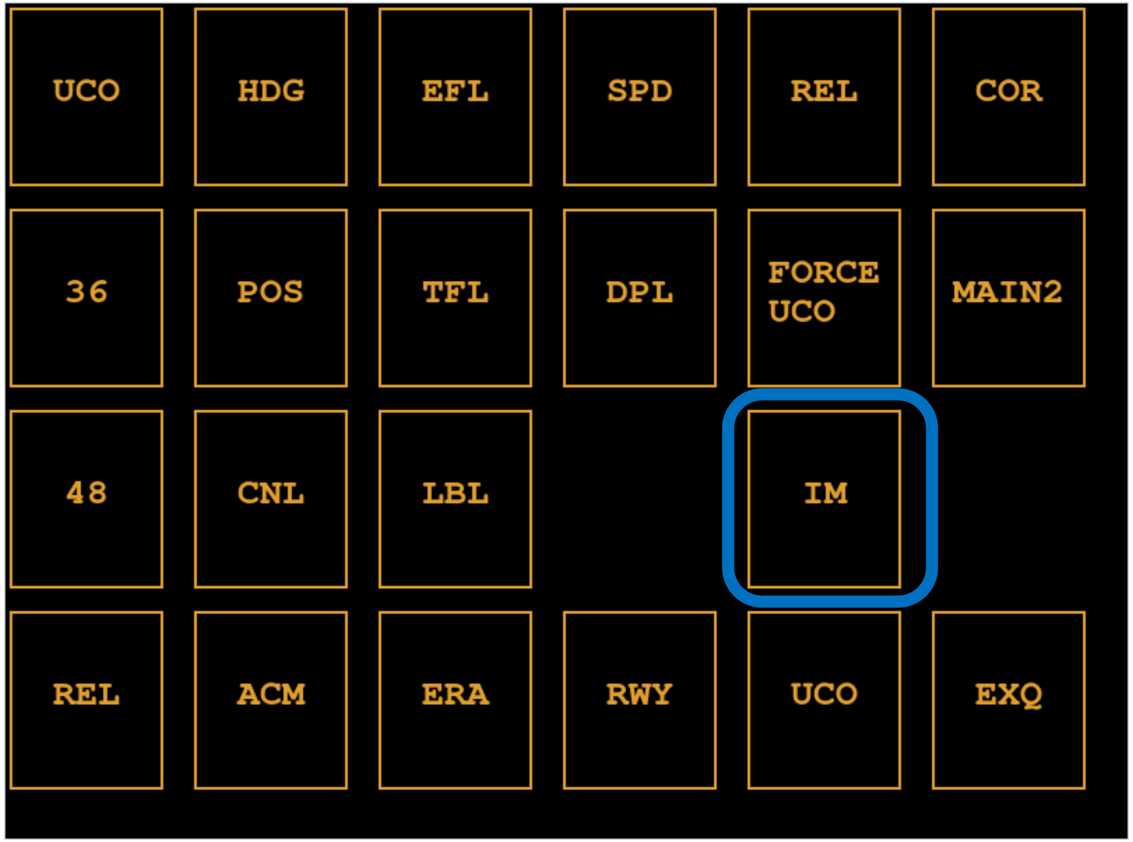


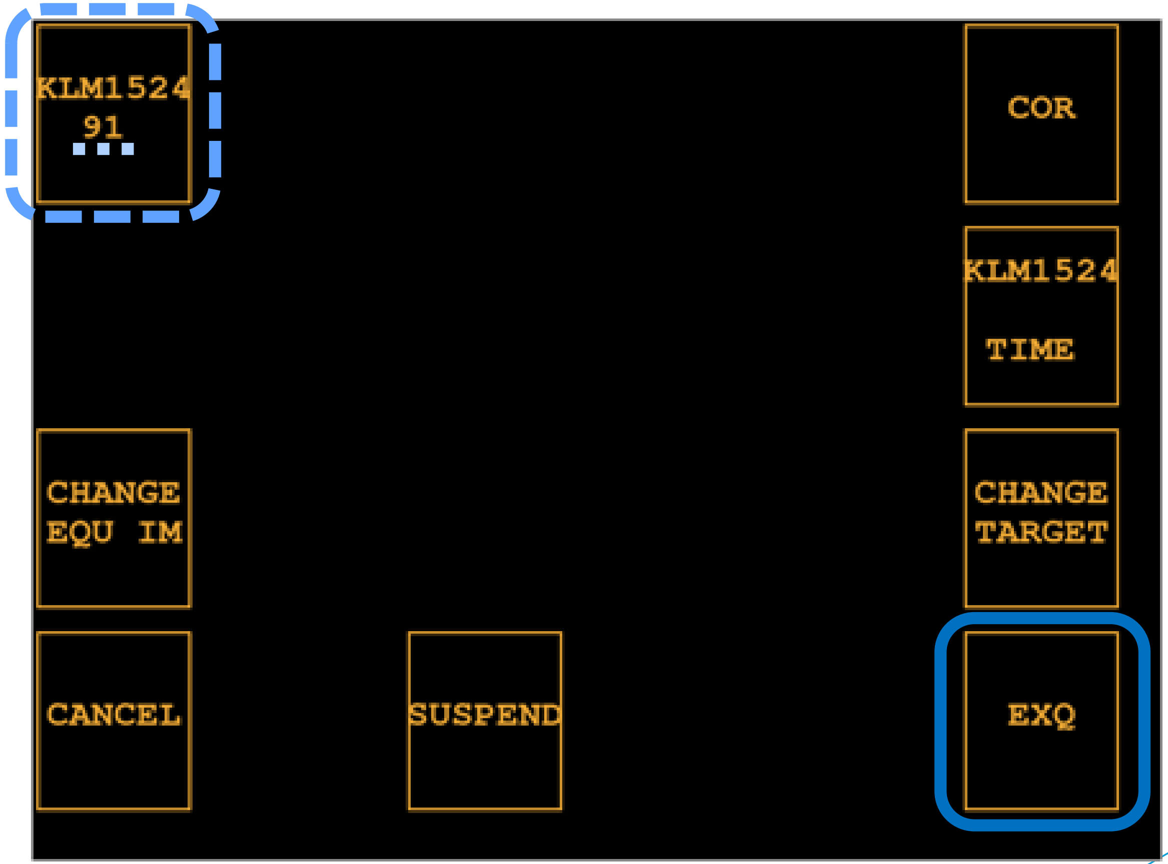
ATCo - ARR HMI

- Controller support tools
  - Optimised Runway Delivery (ORD)
    - Target Distance Indicators (TDIs)
    - Connecting line (on/off)
  - Merge support
    - Ghost blip indicators (position & ground speed)
  - IM operations
    - Green – IM Active
    - Cyan – IM Pending
    - Orange – IM Warning
    - Frosted Mint – IM advisory
- ORD: TDIs displayed on FARs instead of extended centreline only
  - Magenta = WTC related
  - Cyan = MRS related
  - Green = ROT related

ATCo TID HMI

TID: Touch Input Device





Short ATCo screen video examples

APP1_River_1Y (~2.5 min)

- Expect KILNU RNP Approach
- Cross HANSI at 84 secs
- Also departure traffic => crossings arrivals/departures
- Via Transition descend FL70
- Contact ARR

ARR1_Merge & ARR1_Merge & Final18R (~3 min)

- Cleared KILNU RNP Approach, QNH 1013
- Establish on RNP => (APP => EoR in A/C label)
- Contact TWR

Schiphol TMA Arrival Exercises

- After development periods, check-outs, training sessions and final acceptance tests
  - First NARSIM Real Time Simulations in period Jan-Feb ’22

    (3 measurement days)
  - Second **NARSIM RTS** in period Jul-Nov’22

    (3 measurement days)

NLR RTS2 - Experimental set up (1)

- NLR's Human Factors & Safety & NARSIM & Operational support involved (via SME ATCO)
- Two main conditions compared: REF versus SOL

• REFerence conditions

1. Accurate a/c delivery at TMA entries
2. RNP-Based Operations in TMA
   - CDOs with fixed descent gradients
   - "Established on RNP" for IPA
3. Optimised Runway Delivery (ORD) on Final Approach
   - Time Based Separation (TBS)
   - **RECAT-EU** (Wake Recategorization)
   - Reduced separation based on local Runway Occupancy Time (ROT) characterisation
   - MRS 2.5
4. No Interval Management
5. 4 IAFs

• SOLution conditions

1. See REF
2. See REF
3. See REF
   - Time Based Separation (TBS)
   - Wake Turbulence Separation (for Arrivals) based on Static Aircraft Characteristics (RECAT-EU-PWS)
   - Reduced separation based on local Runway Occupancy Time (ROT) characterisation
   - MRS 2.5
4. Interval Management
5. See REF

NLR RTS2 - Experimental set up (2)

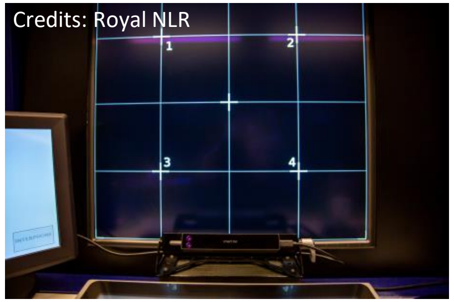
Scenario	IM equipage (%)	Wind	Events
REF / SOL	0 / 20 / 80 / 100	Calm (5 kts) uniform / Strong headwind (15 kts on the ground and 50 kts at FL100)	Go Arounds / EAT adherence / Unplanned

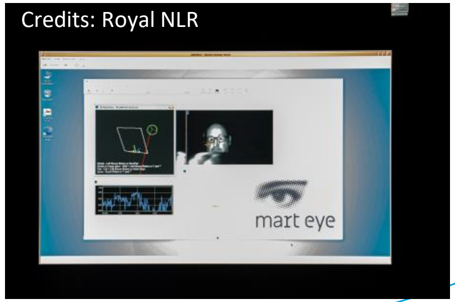
- 10 scenario runs set up
- Through put: 40 a/c per runway per hour
- MRS 2.0 used in a single demonstration run, jointly with IM speed bracket variation at +/-10% (instead of +/-15%)

NLR RTS2 - Data Gathering

- Subjective data:
  - Run & day session ATCo debriefing comments
  - ATCo post-run and final questionnaires filled
  - ATCo filled rating scales for Situation Awareness (SASHA), Workload (NASA-TLX) and Safety observation questionnaires
  - Observation data (by observers)
- Objective data
  - All simulator recorded data (sim, audio & video)
  - Coupling to FANAMOS for environmental impact assessment (noise & emissions along FARs/CDOs)
  - Complementary objective measurements made via Eye Tracker
- Very limited number of runs!

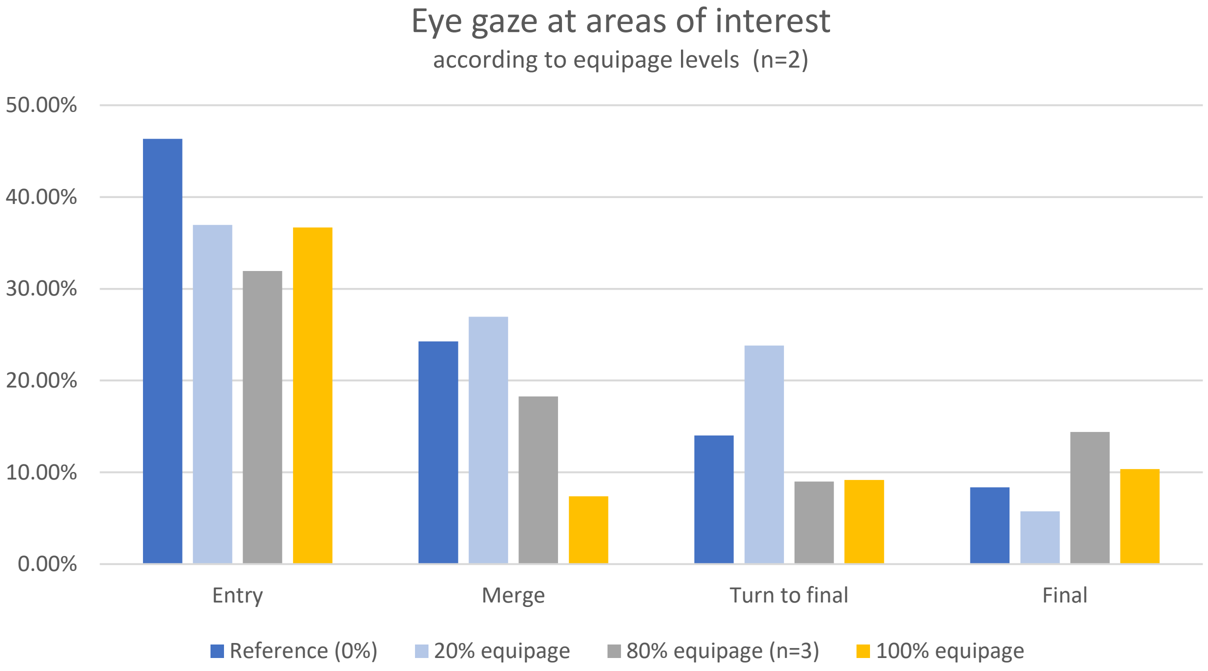
Eye-tracker calibration of ATCo behind radar screen

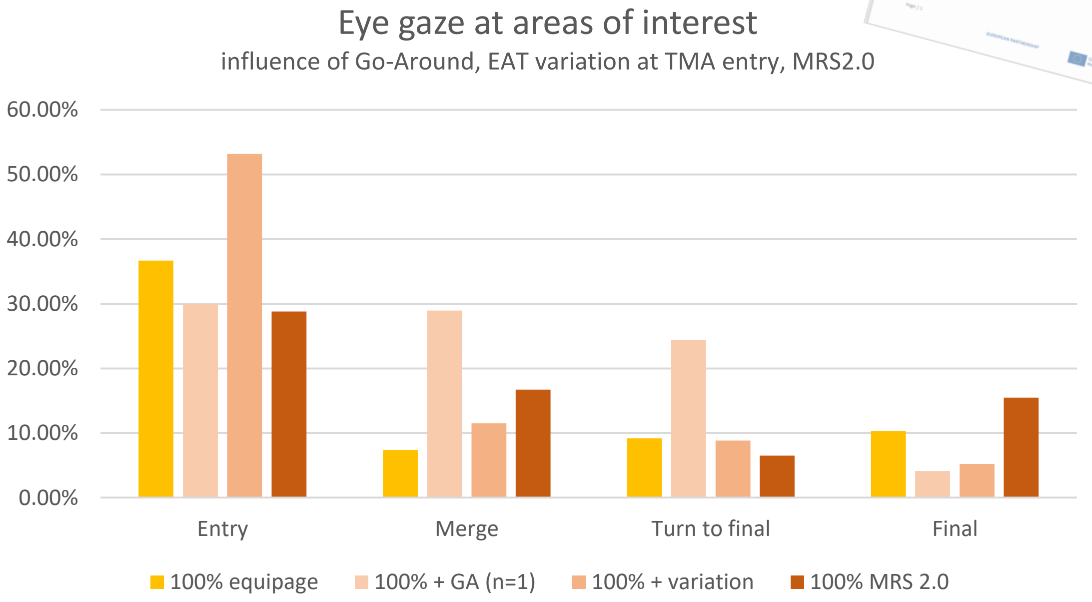




NLR RTS2 - Eye tracking results

- Eye tracking data

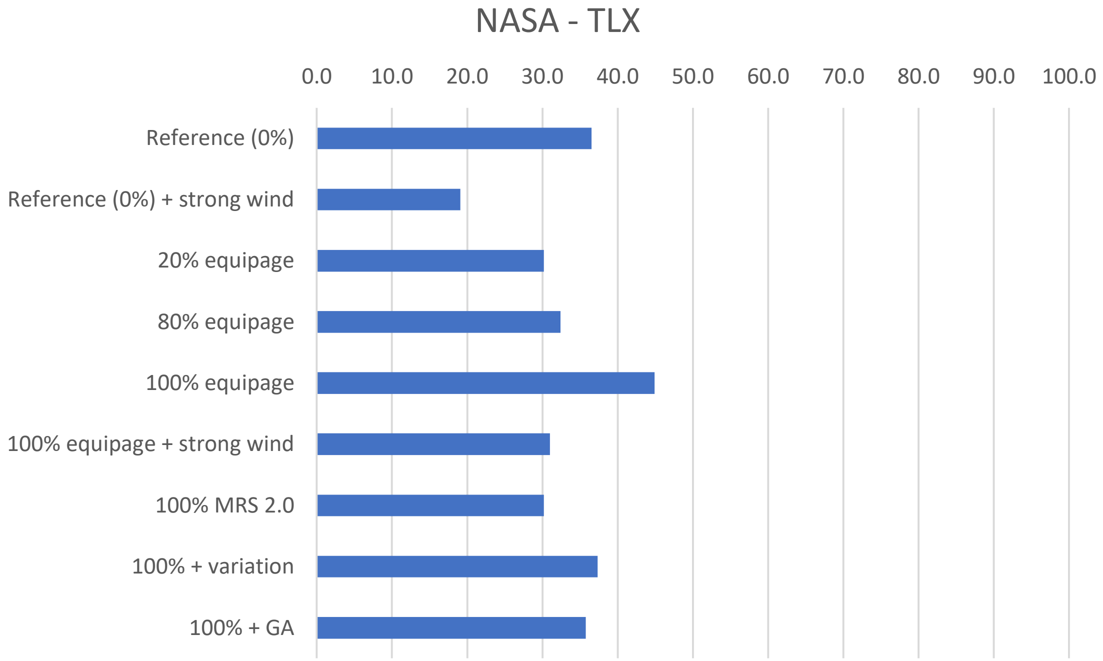




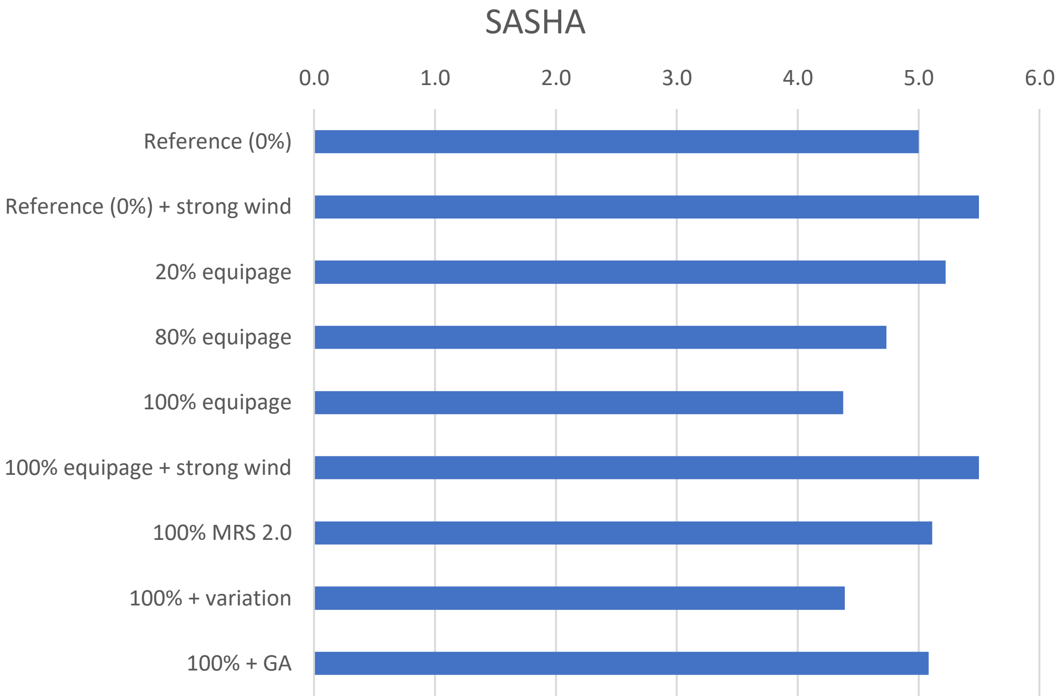
ATCOs had the feeling not to have sufficient time for monitoring the traffic and being able to instruct interventions when necessary for traffic that is turning in for final (especially in RTS1)

NLR RTS2 - Workload and SA results

- Workload (NASA-TLX)



- Situation Awareness (SASHA)



Concept is acceptable but only when the delivery of aircraft into the TMA is sufficiently accurate (within plus or minus 30 seconds), the pilots are timely following up instructions and equipage levels are substantial (e.g., 80%).

NLR RTS2 - Environmental Results

- SOL versus REF scenarios comparison:
  - No increase in the 55 dB noise contour area for nominal situations
  - Decrease in the CO_2 emission (fuel usage) for nominal situations

- Today's vectoring operation at Schiphol Airport TMA was not inside the reference scenario, hence the obvious environmental benefits of FARs and CDOs were not part of the demonstration

- The tested runway throughput was significantly higher than the today's sustained runway throughput (40-43 versus 34-36)


VERY LARGE-SCALE DEMONSTRATION

sesar JOINT UNDERTAKING

D1.5 - PJ.37-W3-DEMOR - Part IV ENVAR, Track PJ.37-W3-01A

Deliverable ID:	D1.5
Dissemination Level:	PU
Project Acronym:	PJ37-W3-ITARO
Grant:	101017622
Call:	H2020-SESAR-2020-02
Topic:	SESAR-WAVE3-05-2020, SESAR-WAVE3-06-2020
Consortium coordinator:	NLR (AT-One)
Edition date:	25 May 2023
Edition:	01.00.00
Template Edition:	02.00.05

EUROPEAN PARTNERSHIP

Co-funded by the European Union

NLR RTS2 - Safety results

- Analysis Results (SOLution versus REFerence scenarios):
  - No increase in the number of go arounds due to insufficient spacing
  - No increase in the number of losses of separation
  - A bit of concern expressed on:
    - The interoperability of the different tools, especially w.r.t E-AMAN and IM aspects for incorrect A/C pairings and illogical sequences
    - The perceived controllability of the operation by the controller (mostly when non-nominal)
- Some Safety Recommendations:
  - Implement a mechanism to alert controllers in case of compatibility issues between tools
  - Expand the demonstration, for instance to include ACC airspace and a Runway Controller


VERY LARGE-SCALE DEMONSTRATION

sesar JOINT UNDERTAKING

D1.5 - PJ.37-W3-DEMOR - Part II - Safety Report, Track PJ.37-W3-01A

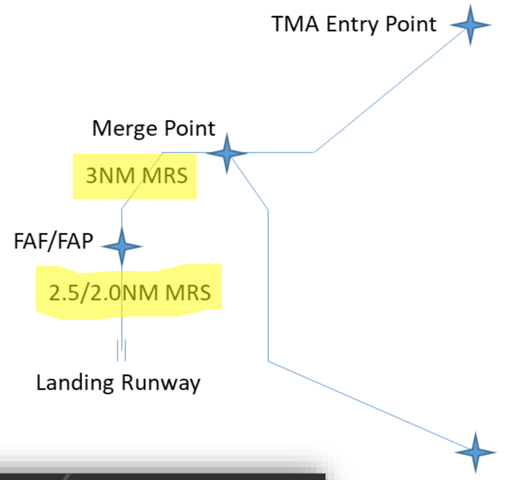
Deliverable ID:	D1.5
Dissemination Level:	PU
Project Acronym:	PJ37-W3-ITARO
Grant:	101017622
Call:	H2020-SESAR-2020-2
Topic:	SESAR-WAVE3-05-2020, SESAR-WAVE3-06-2020
Consortium Coordinator:	NLR (AT-One)
Edition Date:	25 May 2023
Edition:	01.00.00
Template Edition:	00.00.04

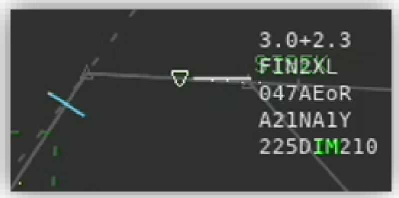
EUROPEAN PARTNERSHIP

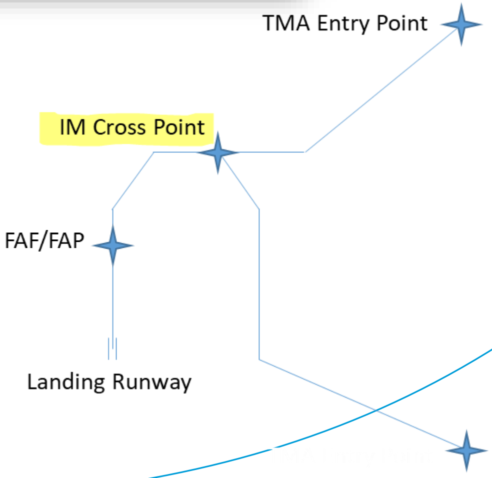
Co-funded by the European Union

Main Findings Real-Time Simulations

- ✓ Operational Improvements worked well together
  - ✓ No acceptance issues were identified by the ATCos
  - ✓ There is no negative effect on the runway throughput
- ✓ No real Human Performance, Safety or Environmental issues identified
- Some integration issues have been identified, and partly addressed (from RTS1 to RTS2)
  - ✓ Target Distance Indicator display & calculations (e.g. turns, winds and speed profiles) along route
  - ✓ IM cross point in support of ATCo merge task
  - Transition from MRS 3 NM to MRS 2.5/2.0 NM impacts ORD & TDI
  - ATCo-need to faster create a gap during heavy traffic loads
  - Interoperability of ATCo tools can be further improved
  - (E-)AMAN requires adaptation, especially for reduced separation aspects, like MRS reduction and S-PWS tables







Integrated Arrival Operations for Schiphol Airport
RTS2 Conclusions & Recommendations

- Combining the SESAR Solutions (FAR+CDO+IM) does work!
  - FARs (+ RNP-AR) + CDOs contribute to greening flight operations
  - Assessed controller tools (i.e. merge, IM and ORD) and IM operations are promising to retain very high capacity at airports
  - No showstoppers found
  - A few integration issues identified
- It is strongly recommended to:
  - Expand scope with ACC + TMA (APP/ARR) + TWR controllers involved
  - Further develop and test identified issues
  - Continue Interval Management (IM) in R&D

Agenda

- Welcome & Introduction
- Introduction to project ITARO by Wilfred Rouwhorst
- NLR's ATM Real-Time Simulation by Wilfred Rouwhorst
  - *Combining IM, Continuous Descent Operations (CDOs), RNP-based approach operations, Time Based Separation (TBS) and* Optimised Runway Delivery *(ORD) tool*
- **Flight Test Campaign by Nico de Gelder**
  - *Demonstration of prototype Interval Management (IM) system in a Flight Trial*
- NLR's Piloted Real-Time Simulation by Bart Heesbeen
  - *Cockpit Tools for vertically separated departure routes*
- Concluding Remarks, Next Steps, Q&A

PJ.37 ITARO Online Event – IM Flight Trial

- By Mr. Nico de Gelder, NLR (AT-One) – Technical Lead PJ.37-W3-01A

Online, *8th of June* 2023

EUROPEAN PARTNERSHIP

Co-funded by the European Union

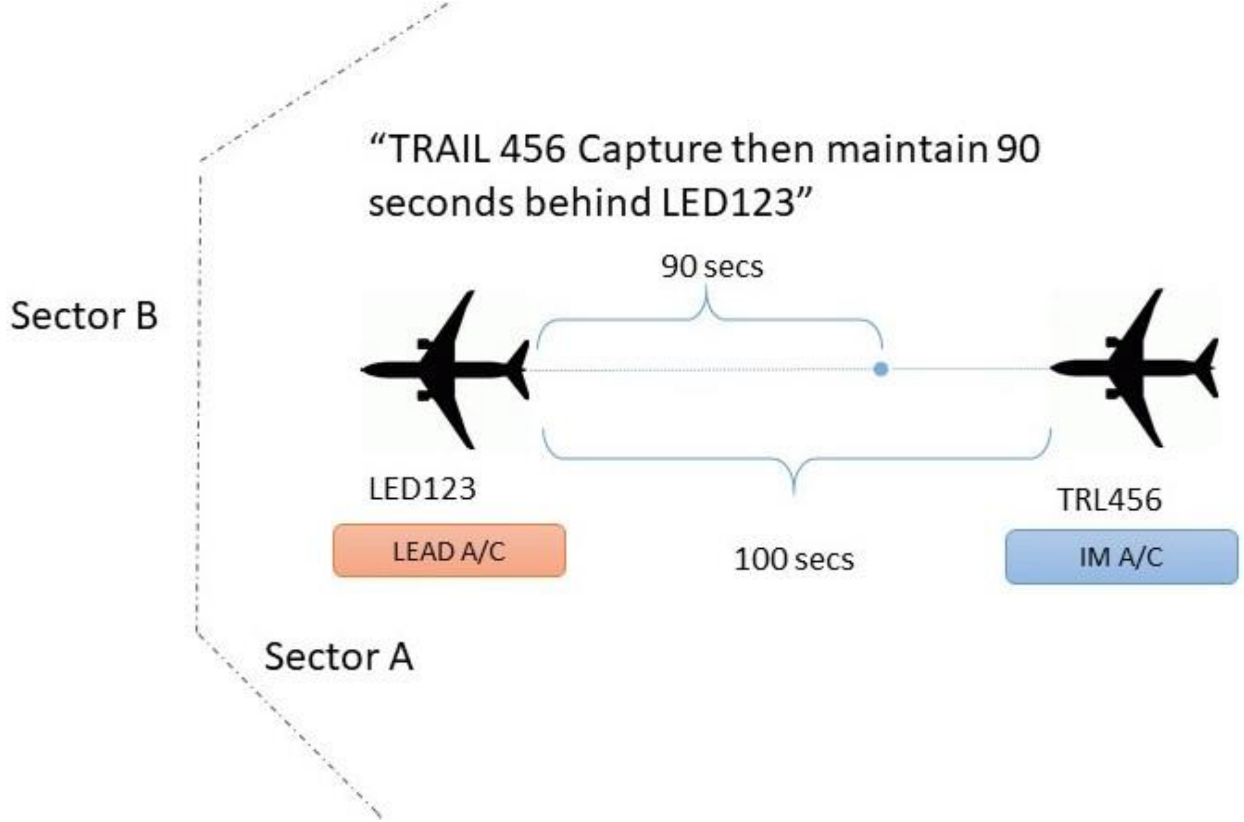

From radar vectoring ...
... to fixed RNAV RNP routes

IM Flight Trial at Groningen Airport Eelde

- ITARO (2021-2023) performed a limited flight trial
  - To get experience with IM operations in the NL TMA environment and to reduce the risk of a large-scale trial/implementation
  - Initial plan included airline involvement, but due to COVID-19 this plan had to be adapted → NLR test aircraft was modified with FIM avionics
  - Flight test campaign executed in 2022 with 36 flight hours
  - NLR Citation II was the FIM-equipped aircraft and performed the IM operations
  - Honeywell provided the prototype FIM avionics
  - DLR FALCON 2000LX and PH-WIS were the IM lead aircraft

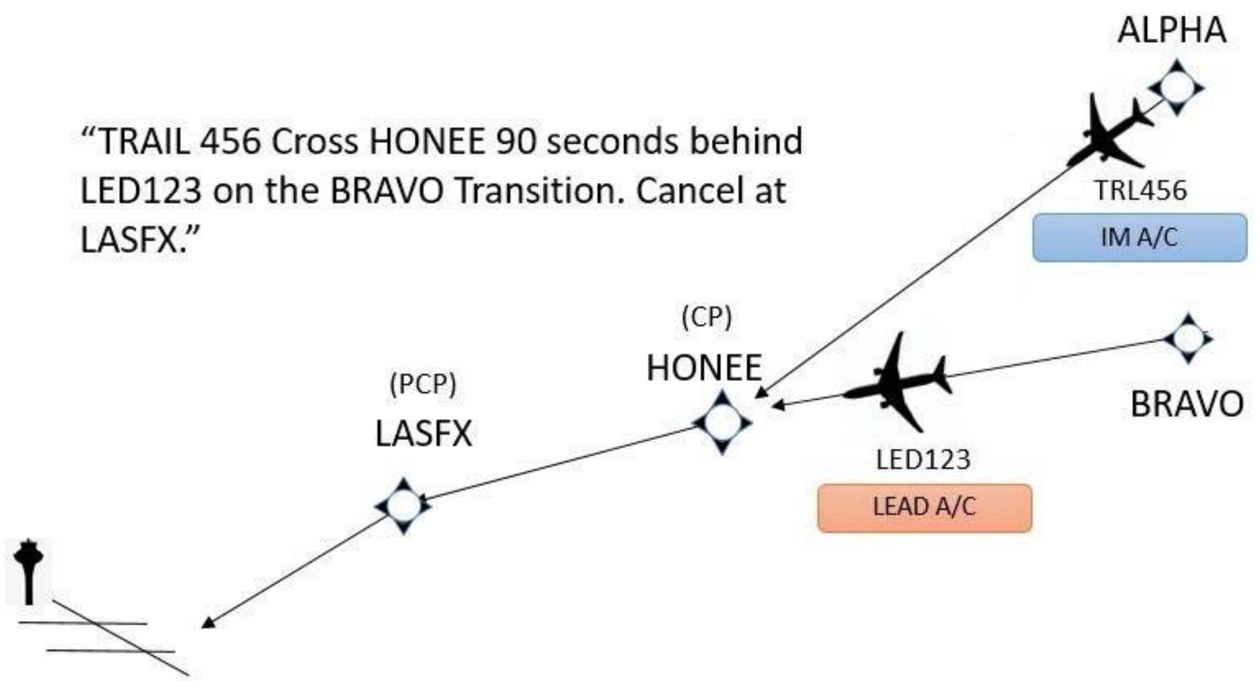
IM Clearance Types (1)

- Capture then Maintain (aka Maintain)
  - On same route
  - Sample R/T - “TRAIL 456, MAINTAIN 90 seconds behind LED123”
  - The IM flight crew flies IM Speeds to capture spacing goal as soon as practical



IM Clearance Types (2)

- Achieve-by then Maintain (aka Cross)
  - Sample R/T - "TRAIL 456, CROSS HONEE 90 seconds behind LED123 on the BRAVO Transition"
  - The IM flight crew flies IM Speeds to achieve spacing at Cross Point (merge point) HONEE, then
  - The IM flight crew flies IM Speeds to maintain spacing until Planned Cancellation Point LASFX



IM Procedure (FAA AC 90-114B CHG 1, Draft ICAO Doc 9994)

1. ATC identifies IM pair

- *Using automation support tools, ATC identifies the potential IM lead aircraft and IM aircraft, assigned spacing goal, crossing point (when applicable), and planned cancellation point*

2. ATC checks feasibility

3. ATC issues IM clearance

4. IM flight crew reads back clearance

- ... and enters the IM clearance information into the FIM avionics

5. IM flight crew verifies lead aircraft

- Flight crew verifies that they have selected the correct lead aircraft and that they have entered the IM clearance elements correctly

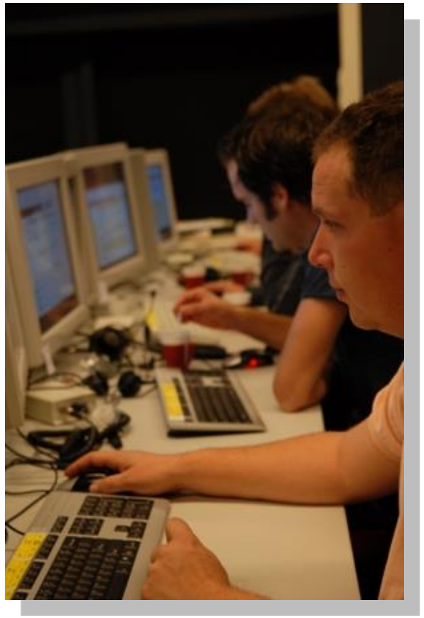
6. FIM avionics internal check

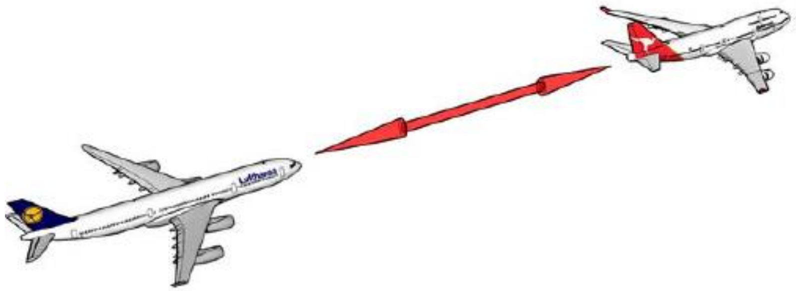
7. IM flight crew evaluates IM speed

8. IM flight crew flies IM speeds

9. IM cancellation

- IM aircraft flight crew complies with IM speeds until the procedure is cancelled





IM Aircraft

Cessna Citation II test aircraft, PH-LAB

- Jointly operated by NLR and TUD
- Collins ProLine 21 cockpit
- Equipped with Honeywell FIM avionics (industrial-based prototype)

Credits: Royal NLR

Credits: Royal NLR


Credits: Royal NLR


Credits: Royal NLR

IM Lead Aircraft

Citation CJ4, PH-WIS

- Private ownership
- Engineering flights

Dassault Falcon 2000LX, ISTAR test aircraft, D-BDLR

- Operated by DLR
- Measurement flights

Both lead aircraft

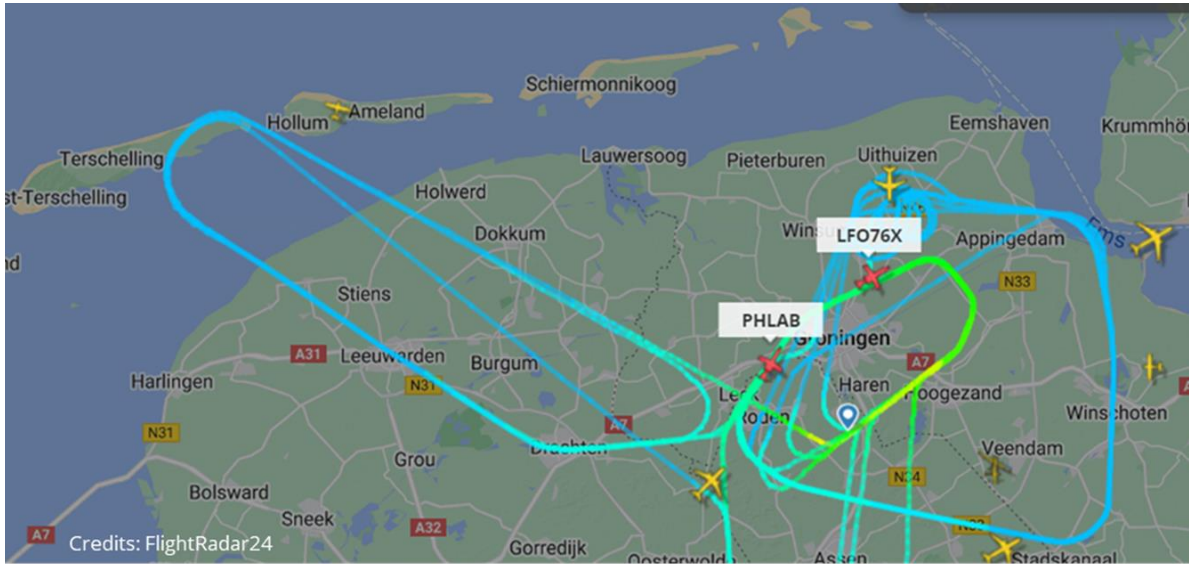
- ADS-B OUT Version 2
- LNAV/VNAV capabilities

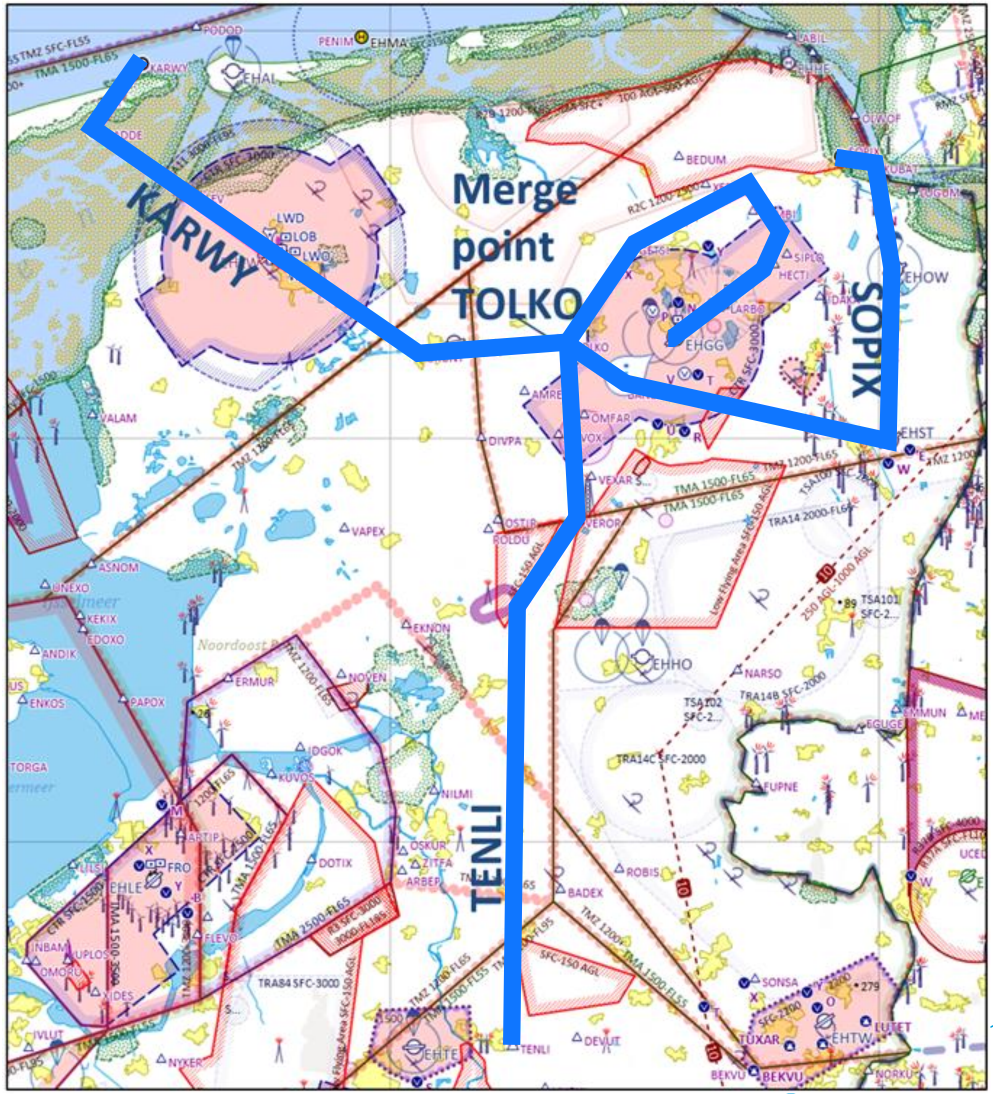
Experimental Flight Procedures

All flight procedures use an overlay of the published TOLKO 2G Approach

- KARWY 20X/25X – TMA A
- SOPIX 20X/25X – Eelde TMA
- TENLI 20X/25X – CTA East 1 *

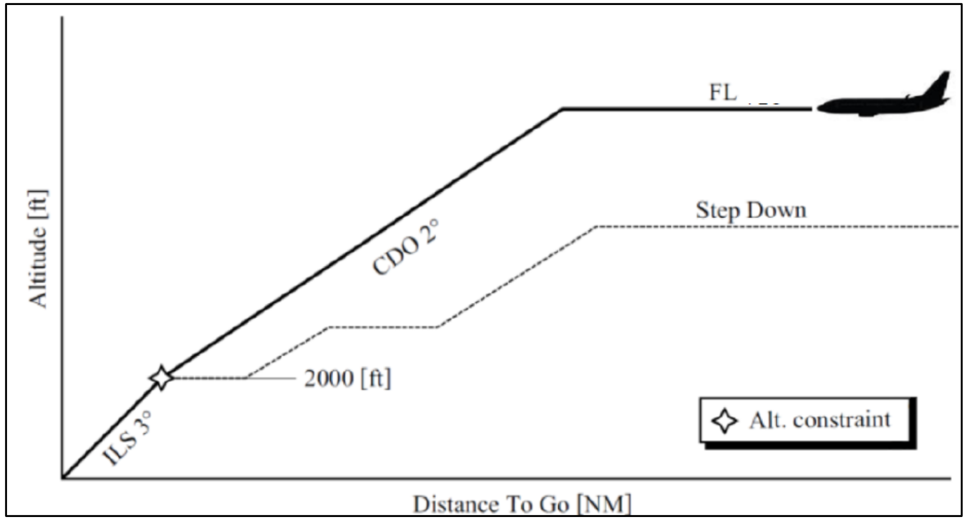
(*) Overlay of published TENLI 2G Arrival



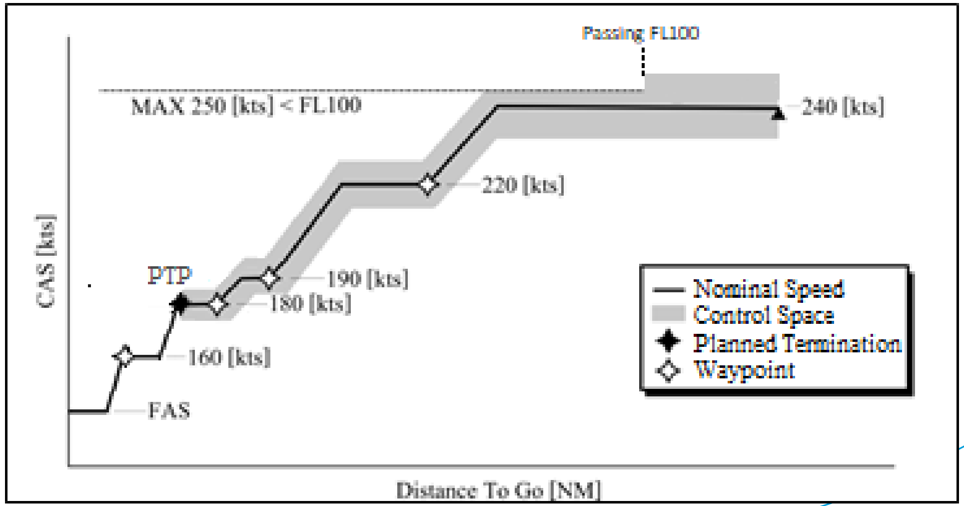


Vertical Path & Speed Profile

- Fixed profile descent path
- From FL140 down to 2,000 ft at the Final Approach Point (FAP)
  - 2.0 degrees
  - 2.5 degrees
- Then 3.0 degrees on final approach segment



- Nominal speed profile
- IM aircraft speed control authority
  - 10% Airspeed Profile Limit
  - Max 250 knots below FL100
  - Aircraft min/max speeds



Flight Deck Displays supporting IM

Flight Trial Timeline

Kick-off NLR-Honeywell	Oct ‘21
Design Review	Dec ‘21
Integration Test Review	1 Apr ‘22
Shipping Equipment to NLR	4 Apr ‘22
Flight Test Plan	5 Apr ‘22
Integration, Ground Testing	7–22 Apr ‘22
Shakedown Flight	22 Apr ‘22
1st Slot, Engineering Flights	25–26 Apr ‘22
Check Flight	9 June ‘22
2nd Slot, Measurement Flights	14–17 June ‘22
Data Analysis & Reporting	June–Dec ‘22

Runs

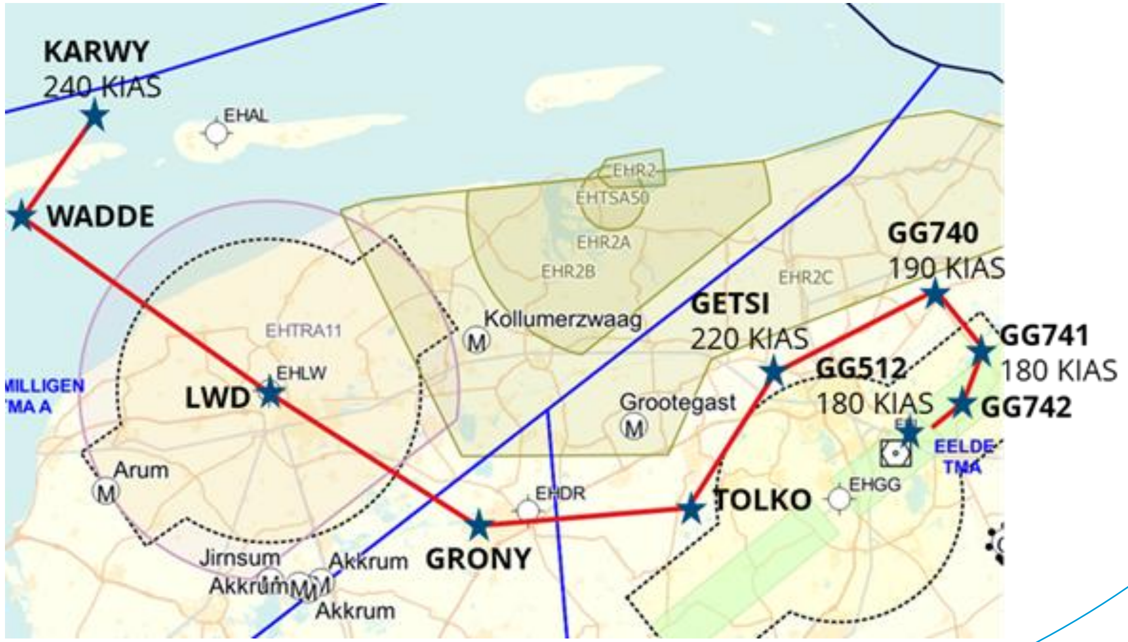
Engineering Flights 3 flights → 16 runs → 13 OK

Measurement Flights 8 flights → 45 runs → 36 OK

- NOK runs → line-up and technical implementation issues (e.g. no IM Speed, erroneous spacing), ... however not due to ATC interventions

A mix of runs

- CAPTURE → 6 runs
- CROSS_TOLKO → 34 runs
  - Cross Point at merge point TOLKO
- CROSS_GG742 → 9 runs
  - Cross Point at GG742, intercept of the final approach track, 2 NM prior to the FAP



Results

Results are shown in the next five slides:

- Data Entry – HMI
- FIM Functions
- Spacing Performance at the Planned Cancellation Point (PCP)
- IM Speed Changes
- ADS-B IN Range

Results - Data Entry

5 pilots participated, 4 of them fly with commercial airlines

Consolidated pilot feedback on HMI → generally OK, but should be improved in one area:

- Many manual entries required, even besides wind entries
  - IM Aircraft (Own) Route
  - IM Lead Aircraft ID, IM Lead Route
  - IM Clearance Type, Spacing Goal, Cross Point, Planned Cancellation Point
- As the entries will require cross-checking and this will need to be done typically just before a STAR clearance (in descent, busy), this can become a CRM and workload issue
- <u>Current data entry is considered to be on the verge of acceptable</u>
- Lots of possibilities to get most, if not all, data from NavDB, FMS and/or CPDLC uplinks. This would dramatically ease the workload required to set up the IM clearance

→ The data entry by pilots should be refined

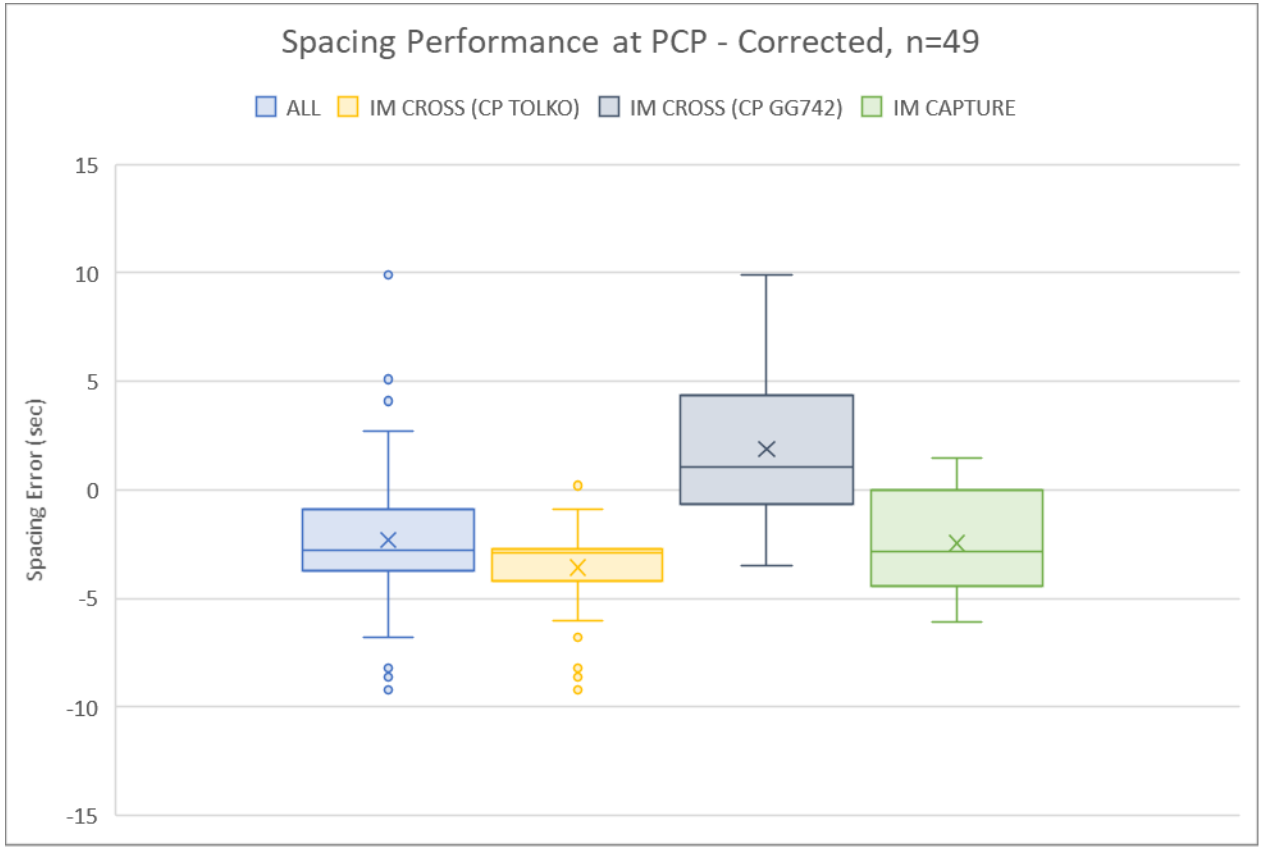
Results - FIM Functions

- The vast majority of the FIM functions worked as intended
  - A few topics, related to implementation, need further attention / refinement
- One of the main topics is the early waypoint sequencing
  - Occurred frequently during line-up for the SOPIX arrival
    - Flying outbound ‘close’ to (inbound) legs of the initial approach procedure
  - Occurred frequently during line-up for the TENLI and KARWY arrivals
    - Flying outbound sometimes crossed (inbound) legs of the arrival/approach procedure
    - Also flying outbound ‘close’ to the (inbound) legs of the arrival procedure
  - Pilots had to re-enter data → to be avoided, especially given data entry requirements
  - Seen as test set-up artefacts, but similar situations may occur in actual operations

→ The FIM equipment should be robust regarding waypoint sequencing and should have an easy option for restoring waypoints that should not have been sequenced

Results - Spacing Performance at PCP

IM Operation	# Runs	Mean (sec)	Std Dev (sec)	Percentage within 9.3 sec tolerance
ALL RUNS	49	-2.32	3.34	98.0%
IM CROSS (CP TOLKO)	34	-3.47	2.15	100%
IM CROSS (CP GG742)	9	2.10	3.94	88.9%
IM CAPTURE	6	-2.45	2.68	100%



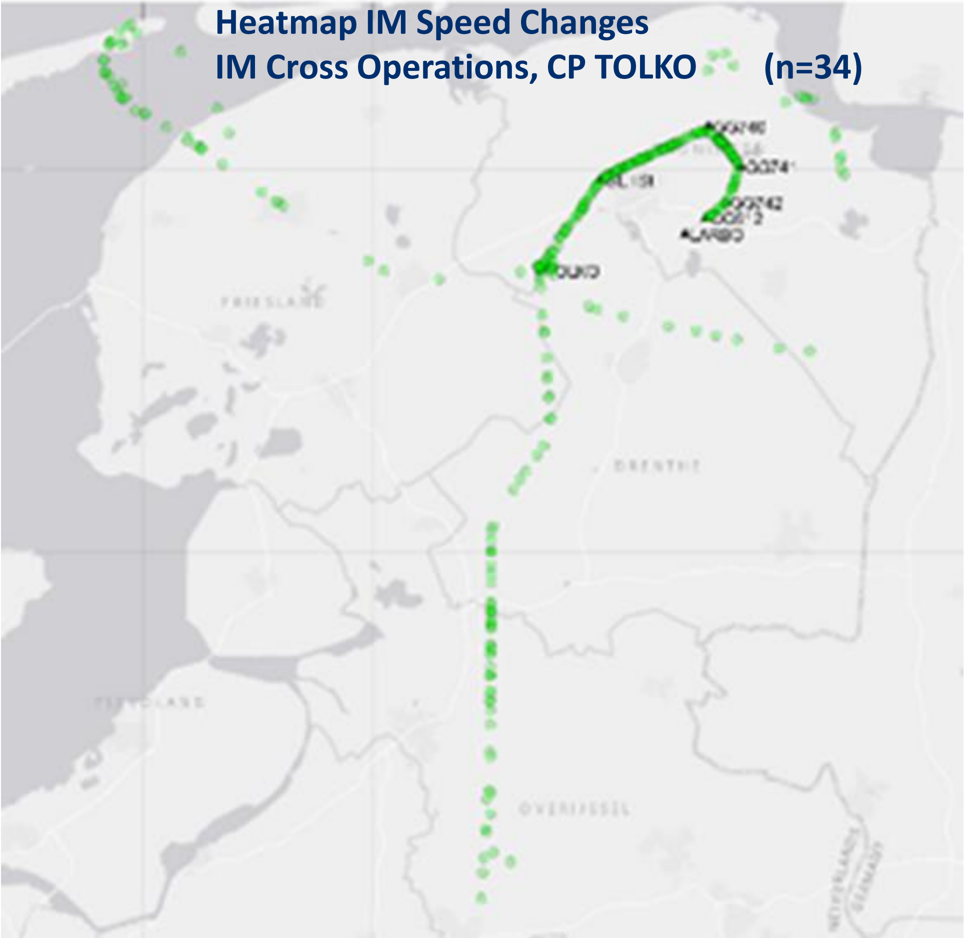
IM performance is very impressive → 98% within 9.3 sec tolerance (target is 95%)

The one 9.9 sec case was due to an ATC speed instruction a few miles prior to PCP

Consolidated pilot feedback: Very good performance! Typically within seconds of the target spacing

Results - IM Speed Changes

Heatmap for IM Cross with CP at TOLKO (34 runs)



For all runs:

- Maintain stage
  - 0.84 speed changes per minute, or
  - 1 min and 11 sec between speed changes
- Achieve stage
  - 0.30 speed changes per minute, or
  - 3 min and 22 sec between speed changes

Consolidated pilot feedback: IM speed guidance is acceptable, however the number of IM speed changes in last ~10 NM [of the maintain stage] should be improved

Results - ADS-B IN Range

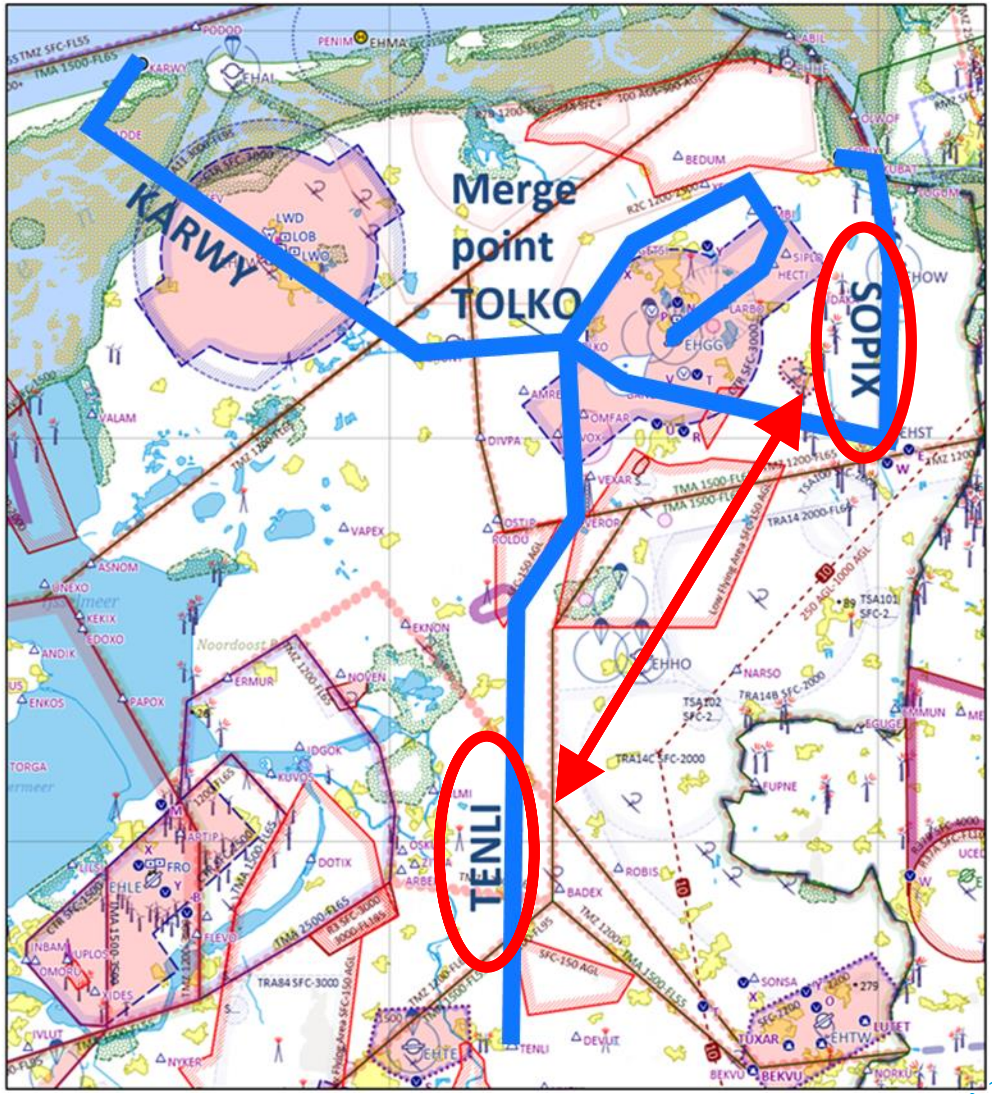
An example

- IM Lead Aircraft on SOPIX Arrival
- IM Aircraft on TENLI Arrival

IM Lead Position frequently only visible at range of 35-45 NM (expected at least 70 NM)

After an extensive analysis, it was concluded that the issue must be related to the specific aircraft installation, most likely the antenna locations and possibly also RF interference

Recommendation: set up a test to demonstrate adequate ADS-B IN range performance



General Conclusions

- The live trial has demonstrated that IM operations on fixed routes with fixed descent profiles work very well together (from a pilot perspective)
- IM spacing performance is very impressive
- No integration issues have been identified
- A lot of useful data has been gathered on IM operations
- Several recommendations on ADS-B IN and the FIM avionics itself have been identified

- Great co-operation between all organizations and persons involved to make this complex ITARO IM flight trial a success

Recommendations

It is strongly recommended:

- To develop and test some limited improvements of the FIM prototype avionics
  - Data entry, maintain stage algorithm in the last ~10 NM, early waypoint sequencing
- To set up and perform a live trial in Europe focusing on TBO in Terminal Airspace
  - Demonstrate SESAR Solutions supporting TBO (RNP+CDO) in Terminal Airspace.
    - Separation Minima on Final Approach (PJ.02-01-01, PJ.02-01-04, PJ.02-08-03)
    - Interval Management (PJ.01-05)
  - Airliners equipped with FIM avionics that is approved under TSO-C195c
  - An ATC centre/sector actively supporting and using IM operations
  - Prerequisite is availability and usage of a PBN route structure
  - Deployment: the operational trial could seamlessly be continued in operations

Agenda

- Welcome & Introduction
- Introduction to project ITARO by Wilfred Rouwhorst
- NLR's ATM Real-Time Simulation by Wilfred Rouwhorst
  - *Combining IM, Continuous Descent Operations (CDOs), RNP-based approach operations, Time Based Separation (TBS) and* Optimised Runway Delivery *(ORD) tool*
- Flight Test Campaign by Nico de Gelder
  - Demonstration of prototype Interval Management (IM) system in a Flight Trial
- **NLR's Piloted Real-Time Simulation by Bart Heesbeen**
  - *Cockpit Tools for vertically separated departure routes*
- Concluding Remarks, Next Steps, Q&A

sesar JOINT UNDERTAKING

ITARO
INTEGRATED TMA • AIRPORT • RUNWAY OPERATIONS

PJ.37 ITARO - Departure Operations: Cockpit tools for vertically separated departure routes

- By Mr. Bart Heesbeen, NLR (AT-One) – Technical Lead PJ01-W2-08B6

Online, *08th of June* 2023

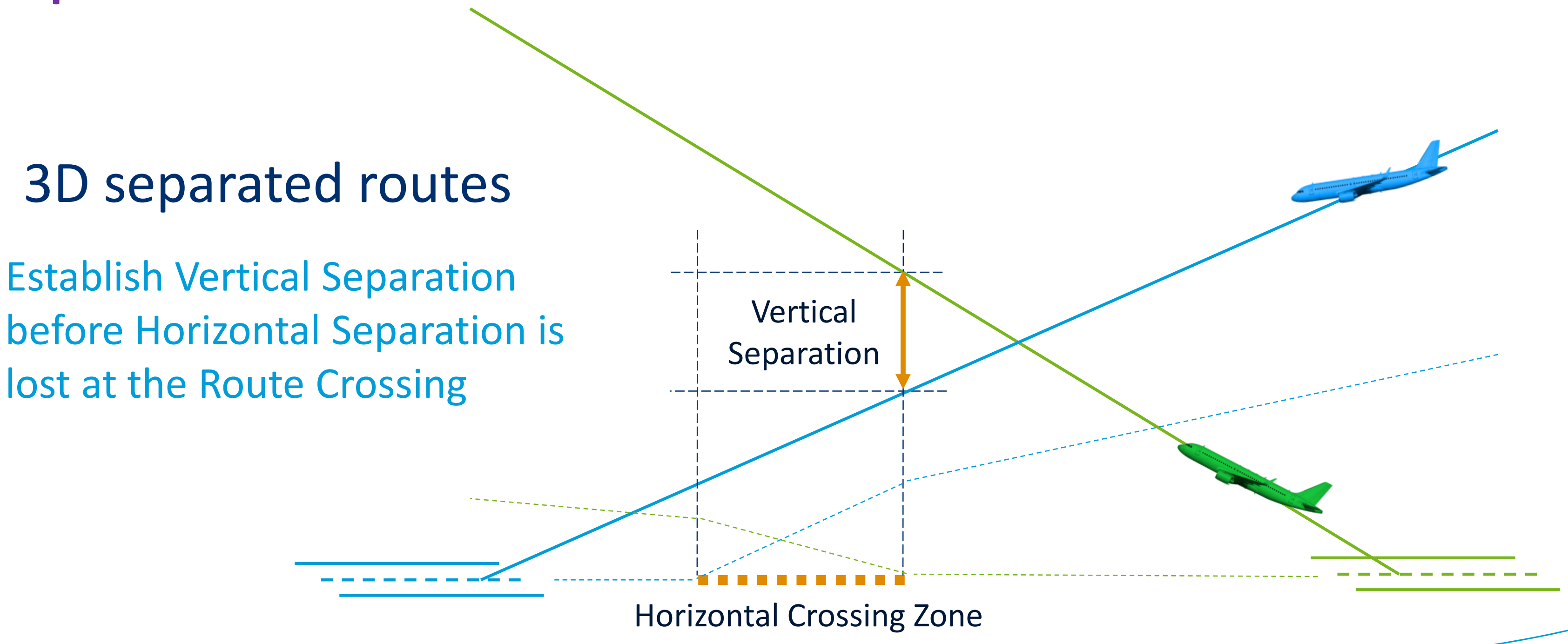
EUROPEAN PARTNERSHIP

Co-funded by the European Union

ITARO - Departure Operations

- Main Objective: More efficient use of TMA airspace

- Proposed SESAR Solution: Strategically separated departure and arrival routes with altitude/vertical path constraints to make them independent



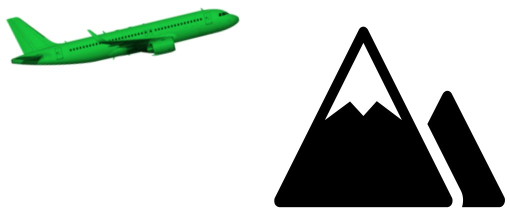
ITARO - Departure Operations

- Expected Benefits of Solution:
  - No conflicts at route crossings if altitude constraints are respected
  - Strong reduction in potential conflicts that need intervention by ATC
  - Reduced workload for ATC (less interventions required)
  - More predictable traffic pattern in lateral and vertical path
  - Independent arrival and departure routes enable Continuous Descent Operations (CDOs) and Continuous Climb Operations (CCOs)
  - Reduction in fuel consumption

Proposed Solution - Enablers (1/2)

Enablers for Proposed Solution:

- For the Solution to work it is required that the altitude constraints are always respected



"Hard Constraint"

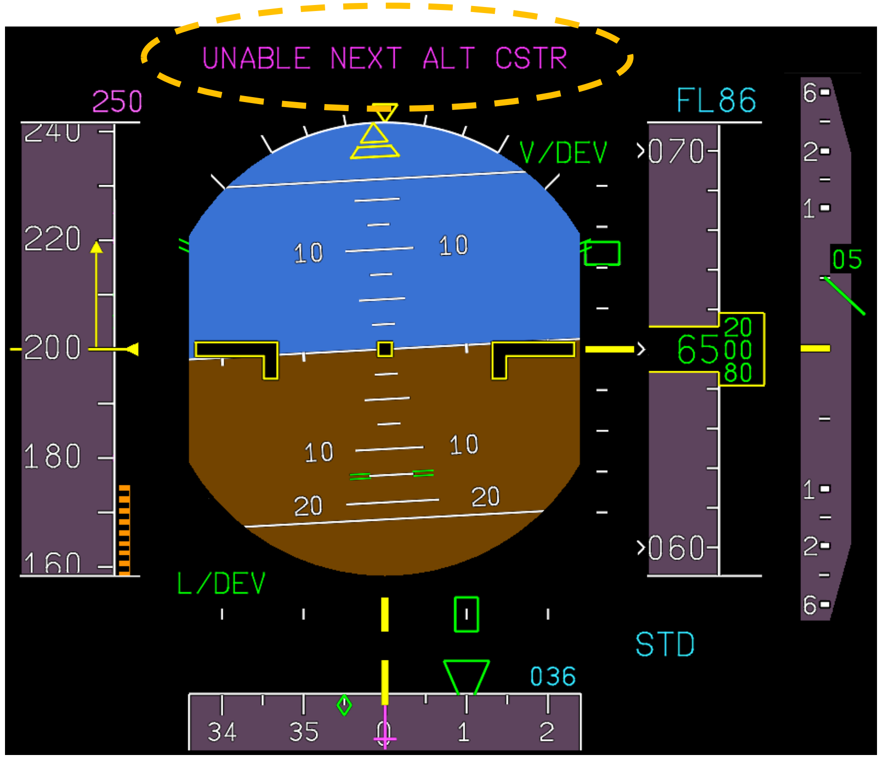
- The arrival and departure procedures need to stress that these altitude constraints are "Hard Constraints" in place to ensure separation with traffic on other routes

- Present-day FMS functionality with altitude constraints and prediction on respecting these constraints ... "UNABLE NEXT ALT"

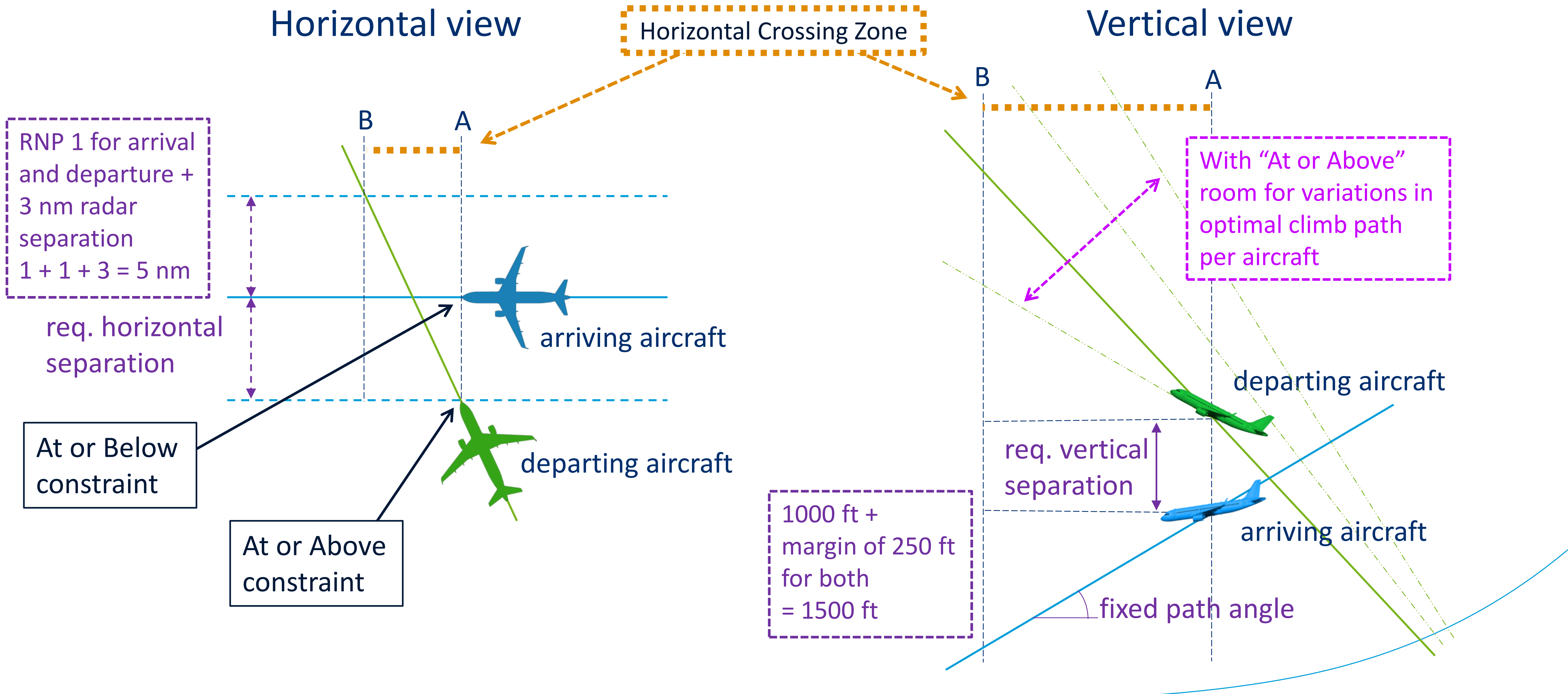
Proposed Solution - Enablers (2/2)

Enablers for Proposed Solution:

- Current indication on cockpit displays limited to: "UNABLE NEXT ALT CSTR"
- Additional indications on cockpit displays assist in monitoring the vertical path performance with respect to the altitude constraints
- These also provide live information on the predicted margin at the constraints



Strategically separated arrival and departure routes

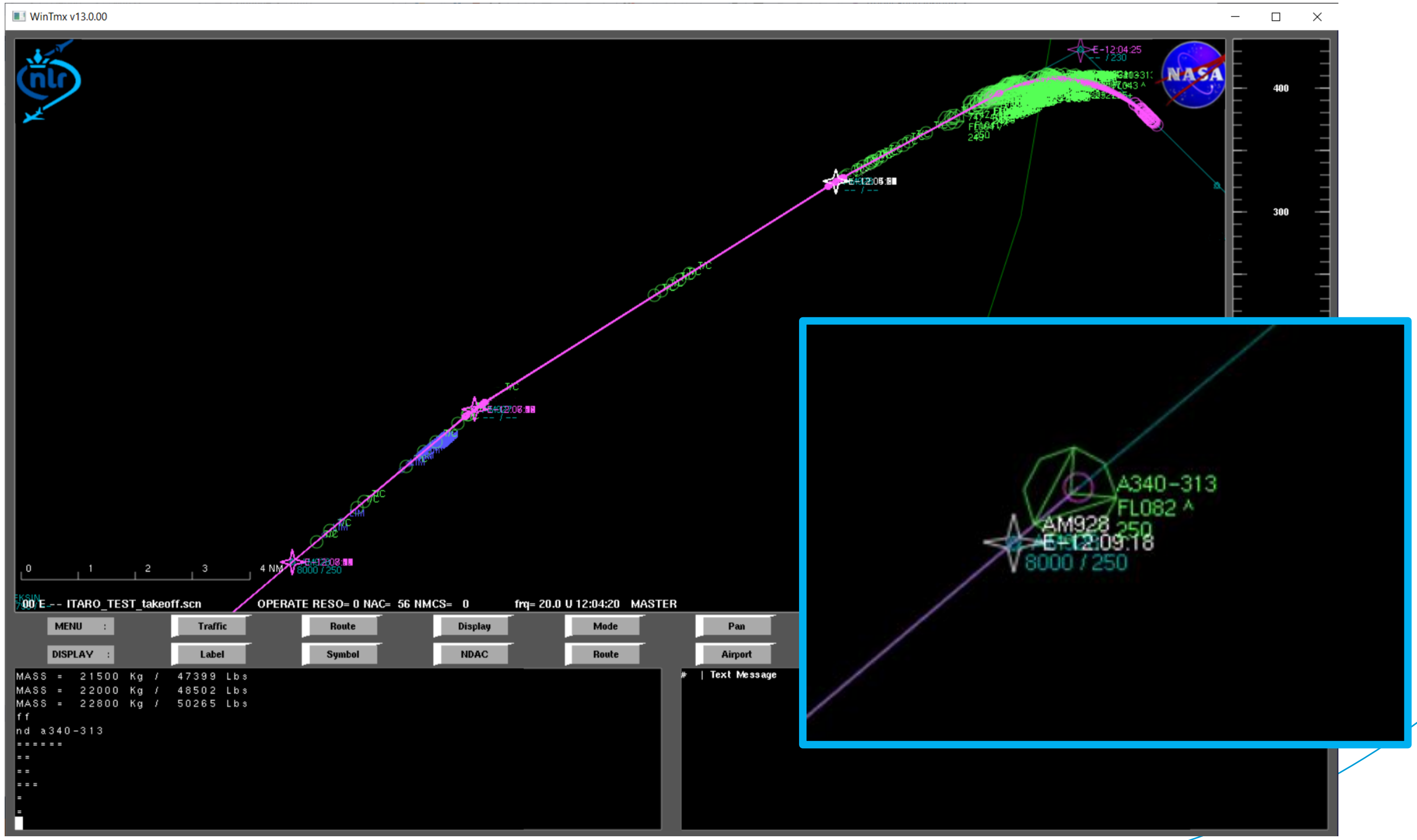


Fast-Time Simulations with Traffic Manager (1)

Traffic Manager simulation tool of NLR was used to evaluate the climb performance and fuel consumption using different climb techniques

At-or-Above constraints preferred for departures

- The optimum climb angle differs for each aircraft type and also depends on Take-Off Weight
- At-or-Above constraints provide room for different optimum climb angles



Fast-Time Simulations with Traffic Manager (2)

- Different scenarios were simulated with different Take-Off Weights, Climb Thrust, Speed Profiles and Wind Conditions
- Distribution of these conditions based on average probability of each condition
- Distribution of different aircraft types based on real traffic sample at Schiphol in 2022
- In total 23,520 batch simulation runs
- The Fast-Time simulations were also used to construct scenarios with ”critical route crossing geometries” for the Piloted Simulation

Independent Variable	Variations / Range
Departure Scenarios	- Standard departure - Departure with vectoring - At-or-Below departure
Take-Off Weights	80 / 85 / 90 / 95 / 100 % Max Take-Off Weight
Climb Thrust Ratings	80 / 90 / 100 % Max Climb Thrust
Speed Profiles	[250] kts [230 / 250] kts [210 / 250] kts [210 / 230 / 250] kts
Wind Conditions	0 / 20 / 40 / 60 kts (Tail wind in climb)

Fast-Time Simulations Results

Strategically Deconflicted Route Crossings versus Vectoring

On average for all departures a 0.4% reduction in fuel consumption can be achieved if strategically deconflicted routes are used and vectoring is no longer required.

Departure Speed Profile

Accelerating to the optimum initial climb speed (typically 250 kts) as soon as possible is the most efficient. Delayed acceleration or a stepped acceleration uses 2% to 4.5% more fuel.

Climb technique for At-or-Below constraints

A reduced climb rate during departures with At-or-Below constraints can reduce the fuel burn with 1% during the initial climb.

Real-Time Simulation in Cockpit Simulator

Piloted simulations were performed in the APERO simulator at NLR

Participants: 4 airline pilots in 4 separate sessions

ATC interaction: An experienced Air Traffic Controller in the same room

Simulated Aircraft:
Airbus A340-300

Cockpit displays: Airbus A340 with experimental indications on the Primary Flight Display (PFD)

Scenarios: Departures from Amsterdam Airport Schiphol

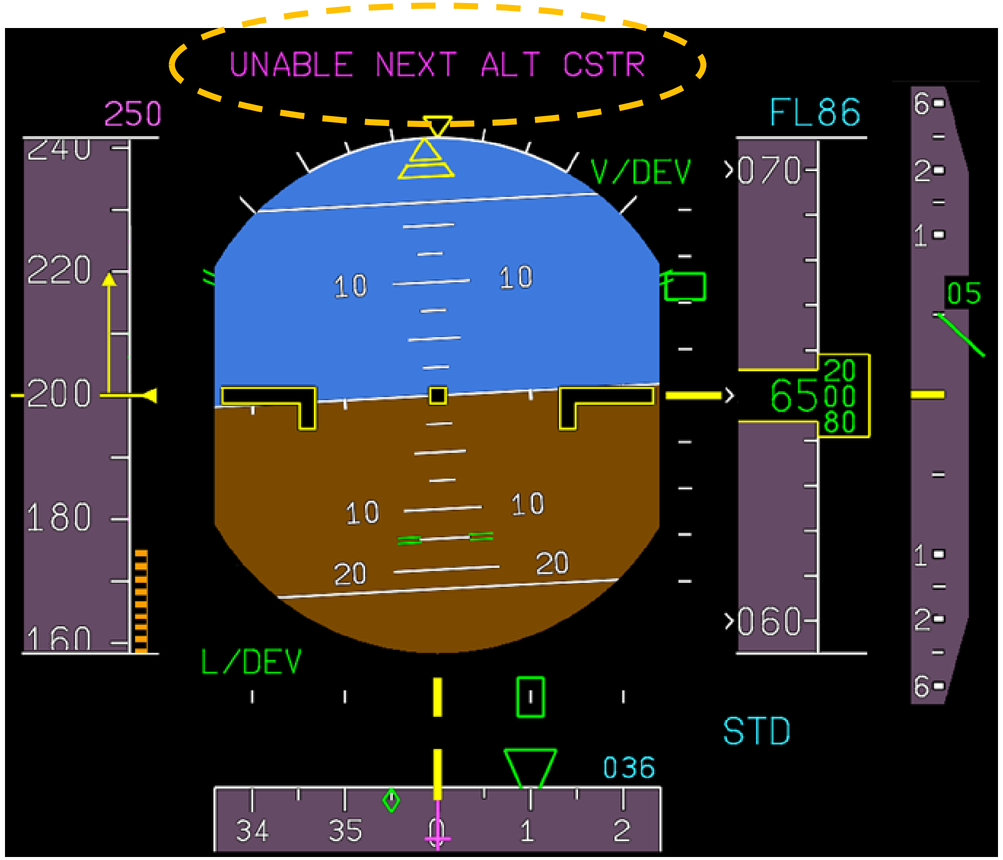
APERO =
Avionics Prototyping Environment for Research and Operations

Current FMS functionality and indications

ITARO INTEGRATED TMA • AIRPORT • RUNWAY OPERATIONS

sesar JOINT UNDERTAKING

"UNABLE NEXT ALT CSTR" can suddenly pop-up during flight without any prior warning or indication of a reducing margin to the altitude constraint



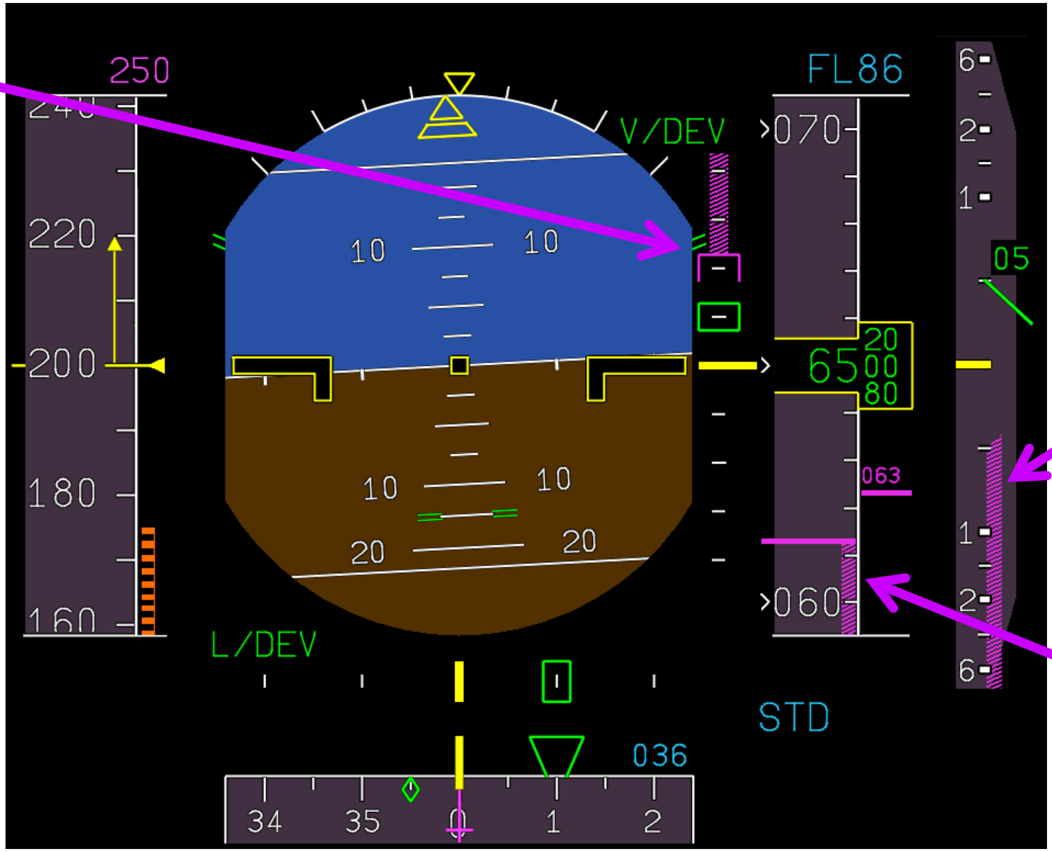
"ALT ERROR" value only available on specific MCDU page

"UNABLE NEXT ALT" only when altitude constraint no longer is respected

Additional cockpit tools to monitor the margins to altitude constraints

3 types of experimental indications on the Primary Flight Display

Bar on V/DEV scale
Available margin on V/DEV that still will respect the next Altitude constraint

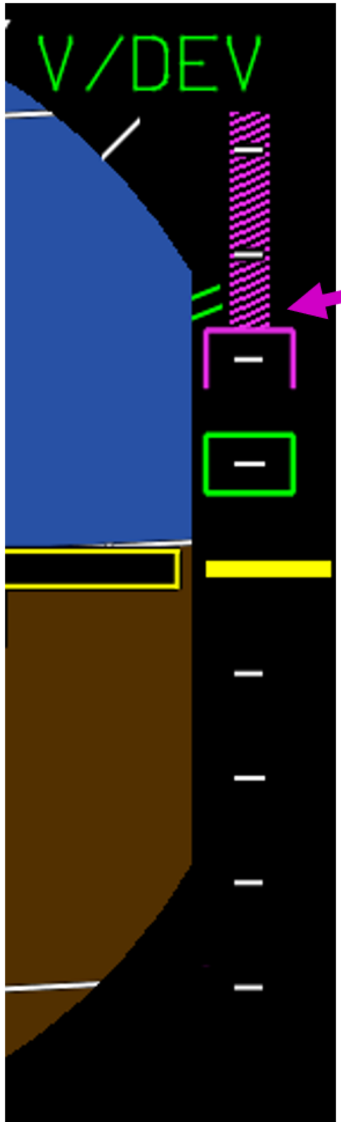


Bar on Vertical Speed scale
Minimum Vertical Speed required to respect the next Altitude constraint

Bar on Altitude tape
Rising minimum Altitude with a fixed path gradient towards the next Altitude constraint

Experimental Indication 1 - V/DEV scale

Indications on the V/DEV scale

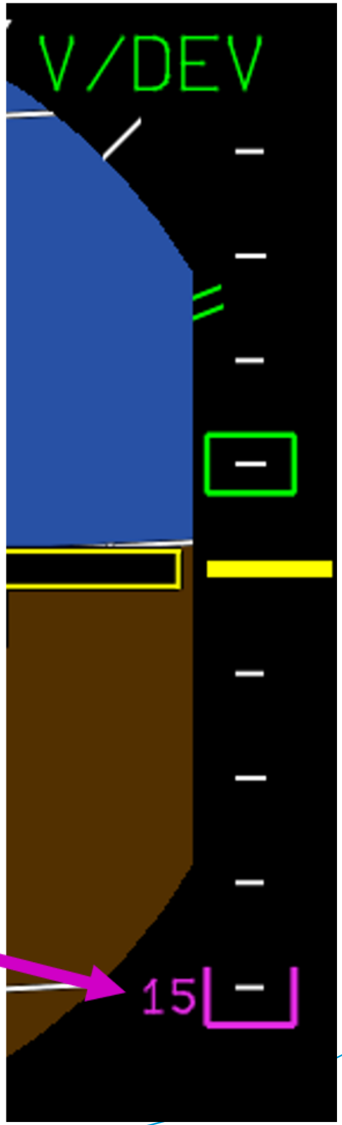


V/DEV Limit for "At or Above" altitude constraint
The V/DEV should remain below this mark (- 200 ft)

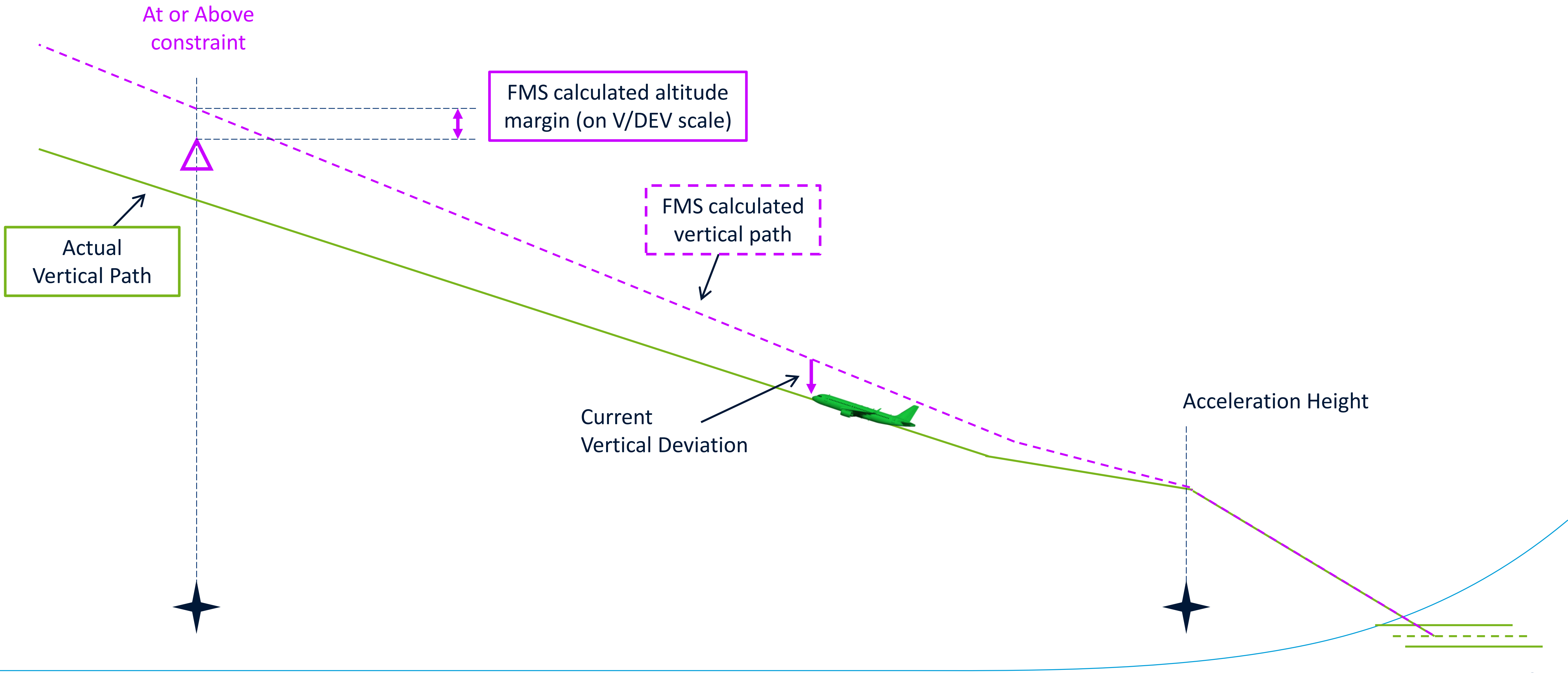
V/DEV - current Vertical Deviation from the FMS path
(-100 ft = 100 ft below FMS path)

V/DEV Scale (each tic represents 100 ft)

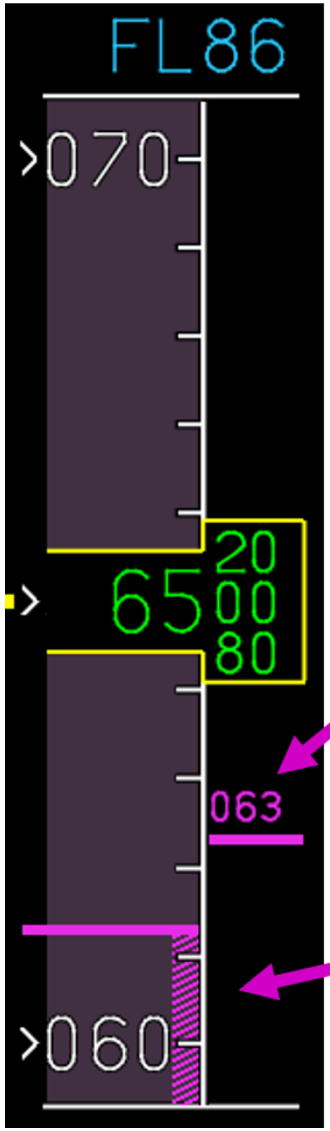
V/DEV Limit for "At or Below" altitude constraint
(the indication is off the scale at +1500 ft)



Vertical Deviation margin at constraint



Experimental Indication 2 - Altitude tape



Indications on the Altitude tape

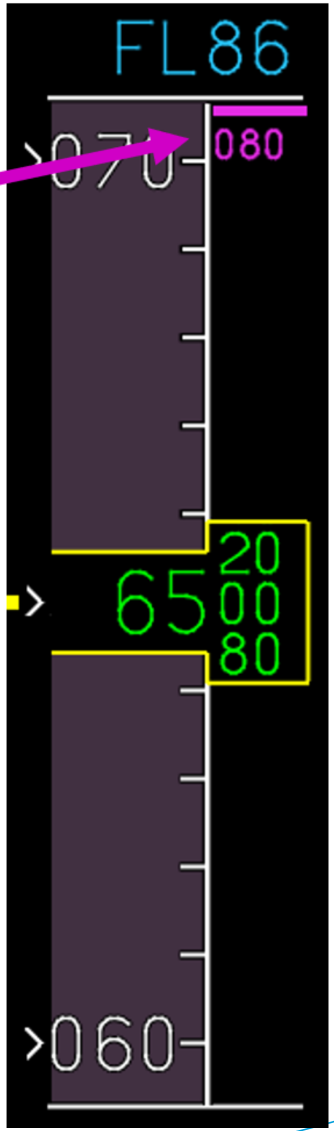
"At or Below" Altitude constraint

(the indication is off the scale at FL 080)

"At or Above" Altitude constraint

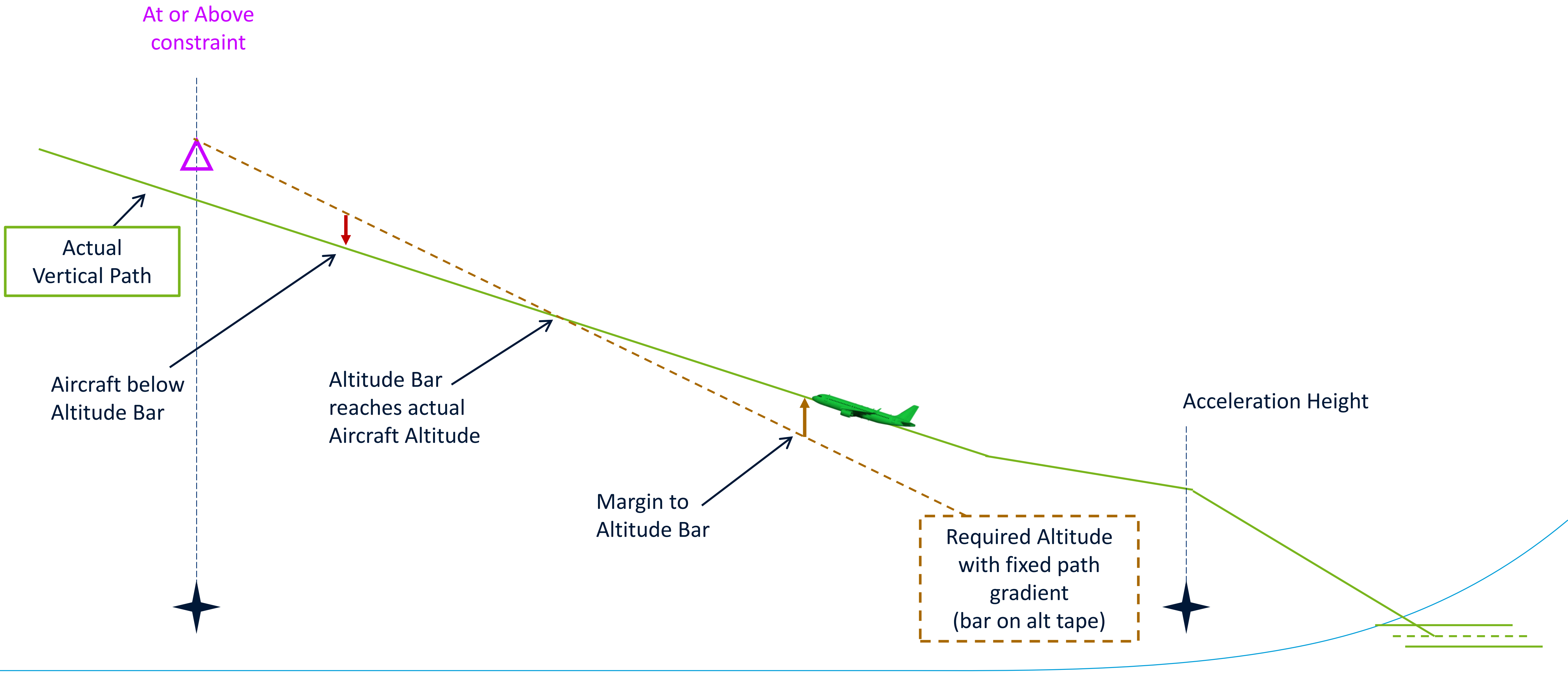
(constraint altitude indicated as FL 063)

Altitude bar that rises with a fixed vertical path gradient towards the "At or Above" altitude constraint

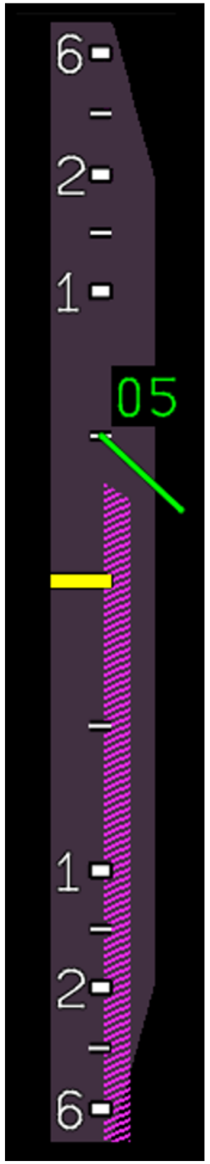


Calculation of indications - Altitude Tape

Rising Altitude Bar



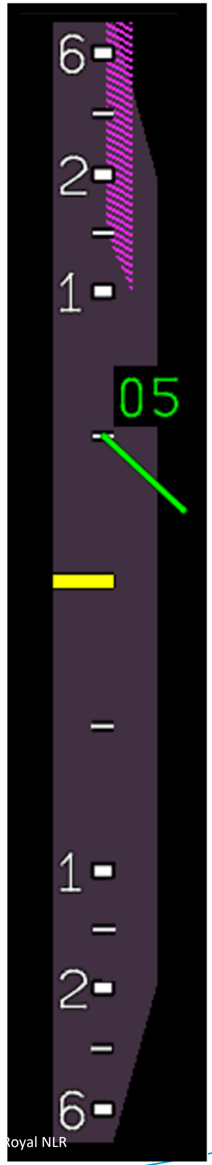
Experimental Indication 3 - V/S scale



Indications on the Vertical Speed scale

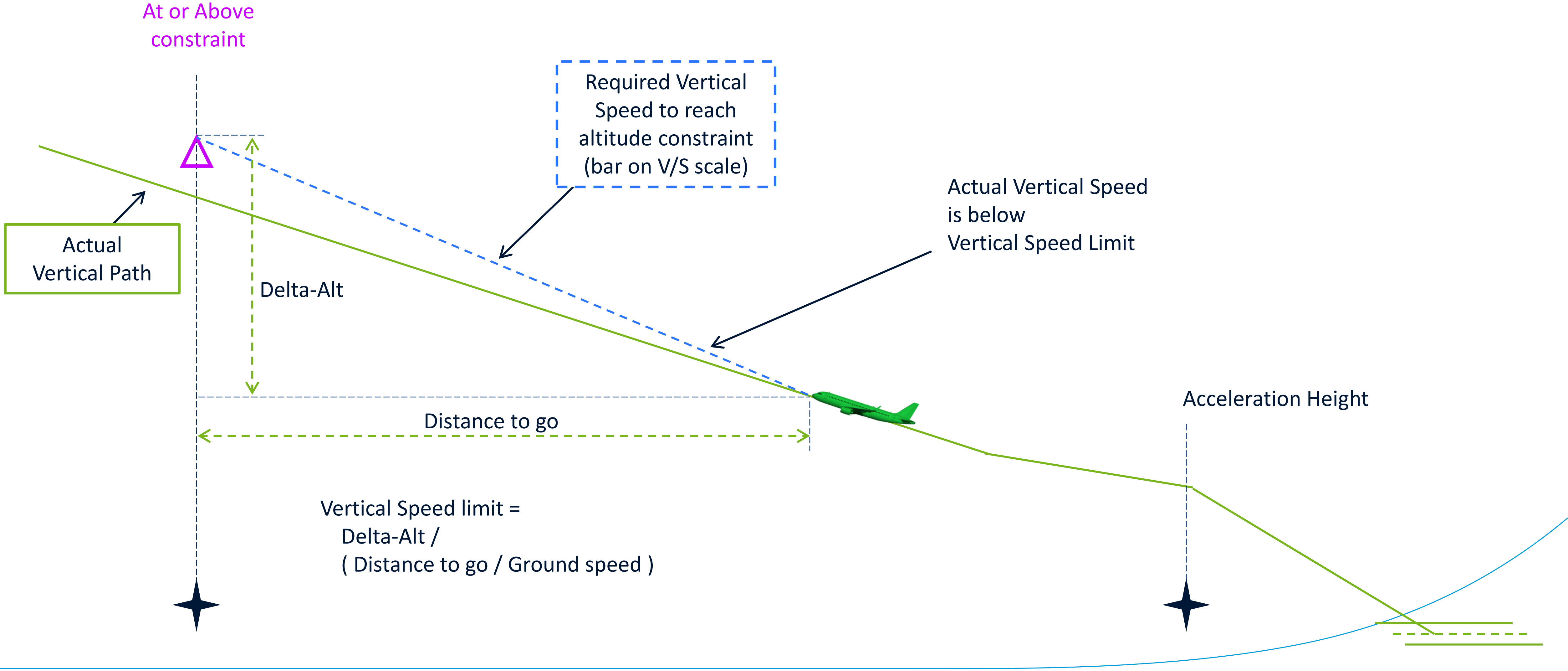
Maximum Vertical Speed (up)
"At or Below" Altitude constraint

Minimum Vertical Speed (up)
"At or Above" Altitude constraint



Calculation of indications - V/S scale

Vertical Speed Limit Bar



Vertical Speed limit =
Delta-Alt /
(Distance to go / Ground speed)

Piloted Simulations Results

Feedback from Pilots:

- Additional indications on the cockpit displays about the required climb performance for meeting the altitude constraints is very useful
- Most pilots favored the indication on the Vertical Speed tape

Feedback from Air Traffic Controller:

- The Air Traffic Controller would like to have more information from the cockpit down-linked, reducing the need for RT to request this information
- From the Controller perspective it is important that he is timely informed if the altitude constraint will not be met, there needs to be sufficient time for the Controller to resolve a potential conflict

Solution Results

- Expected Benefits of Solution:

✓ No conflicts at route crossings if altitude constraints are respected

✓ Strong reduction in potential conflicts that need intervention by ATC

? Reduced workload for ATC (less interventions required)
  => insufficient data, follow-up research required

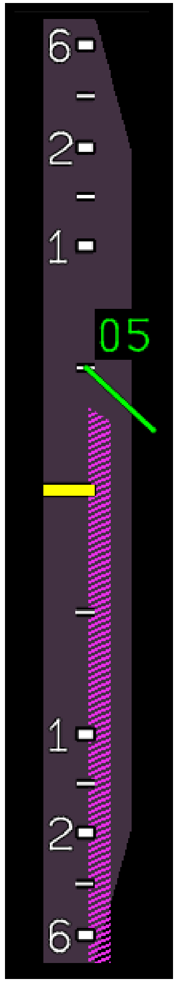
✓ More predictable traffic pattern in lateral and vertical path

✓ Independent arrival and departure routes enable Continuous Descent Operations (CDOs) and Continuous Climb Operations (CCOs)

✓ Reduction in fuel consumption

General Conclusions

- Strategically separated departure and arrival routes improve the efficient use of the TMA airspace.
- The average fuel consumption per flight is reduced.
- Additional indications on the Vertical Speed scale provide the best feedback on the climb performance required to respect the altitude constraints.



Recommendations

It is strongly recommended:

- To perform follow-up research to reach a higher maturity level.
- To execute additional RTS validation exercises that include a full interactive environment with multiple pilots and ATCos.
  This will provide data on the workload of ATCos and pilots and feasibility of related operational procedures.


Credits: Royal NLR

Agenda

- Welcome & Introduction
- Introduction to project ITARO by Wilfred Rouwhorst
- NLR's ATM Real-Time Simulation by Wilfred Rouwhorst
  - *Combining IM, Continuous Descent Operations (CDOs), RNP-based approach operations, Time Based Separation (TBS) and* Optimised Runway Delivery (*ORD) tool*
- Flight Test Campaign by Nico de Gelder
  - Demonstration of prototype Interval Management (IM) system in a Flight Trial
- NLR's Piloted Real-Time Simulation by Bart Heesbeen
  - Cockpit Tools for vertically separated departure routes
- **Concluding Remarks, Next Steps, Q&A**

JOINT UNDERTAKING

ITARO

INTEGRATED TMA • AIRPORT • RUNWAY OPERATIONS

Concluding Remarks and Next Steps

Concluding Remarks & Next Steps

Concluding Remarks

- The ‘Integrated Arrival’ concept is feasible but depending on ACC delivery accuracy, hence the concept needs to be broadened to “time based operations” along the full fixed descent route
- Within SESAR this concept and more precisely the associated main Solutions (PJ.02-01-04, PJ.02-01-01 and PJ.02-08-03) received Maturity level TRL-7 ongoing. PJ.01-05 remained at the V2 level
- The ‘constrained departure’ concept (Solution PJ.01-W2-08B6) reached V2-ongoing. It requires further maturing and involvement of a full ATCO simulator environment and improved ATCO tooling before full conclusions can be drawn on the benefits

Next Steps

- To bring the concepts further a new SESAR2020 proposal “GO-START” has been submitted to SJU and passed the selection threshold: but not directly awarded. Placed on reserve list by SJU
- NLR internally picked up a few developments, related to E-AMAN improvements and arrival streaming
- Next SESAR IR-call (2024?) potentially allows to set up a live trial in Europe with airlines aiming to continue Interval Management (IM) in R&D and/or bringing it closer to deployment

More info desired?

- Visit the ITARO project website
- DEMO results Report (D1.5) will be made public
- Follow us on LinkedIn:

- Read our Open Access Government (OAG) Publications:
  - Lowering environmental impact: Combining SESAR solutions in an operational environment
  - Integrating SESAR Solutions in an Operational Environment to foster the Green Deal

- Or, look into our Video outings (on the NLR YouTube channel)!
  - Constrained Departure exercise APERO (youtu.be/dy95RaWv3JI)
  - IM Flight trials at Eelde Airport TMA (youtu.be/LxzMK5gQYaQ)
  - RTS2 (video is upcoming soon!)

A big thank you to all involved!

- All participating ATCOs, SIM pilots and actual pilots!
- SME ATCO
- NLR project Team
- NARSIM Team
- Human Factors & Safety Team
- Honeywell Inc (USA)
- NLR and DLR Flight Test Teams
- NLR’s Aircraft RADO, RATO and Technical Team
- LVNL
- Military / Dutch Mil
- Groningen Airport Eelde
- Dutch Airspace Redesign Programme (DARP) group
- Ministry of Infrastructure and Water Management

SESAR JOINT UNDERTAKING

ITARO
INTEGRATED TMA • AIRPORT • RUNWAY OPERATIONS

Questions and Answers

sesar JOINT UNDERTAKING

ITARO

INTEGRATED TMA • AIRPORT • RUNWAY OPERATIONS

THANK YOU FOR YOUR ATTENTION