

SPACEKEYS

Latest Evolution of RAIM and A-RAIM Prediction Systems

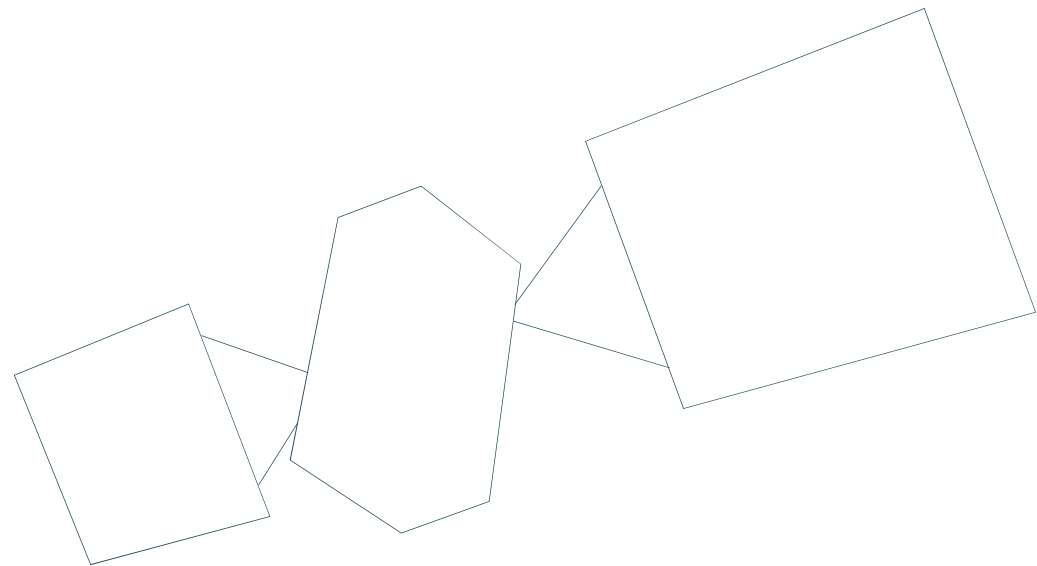


SPACEKEYS is a project funded by the European Space Agency

Topics

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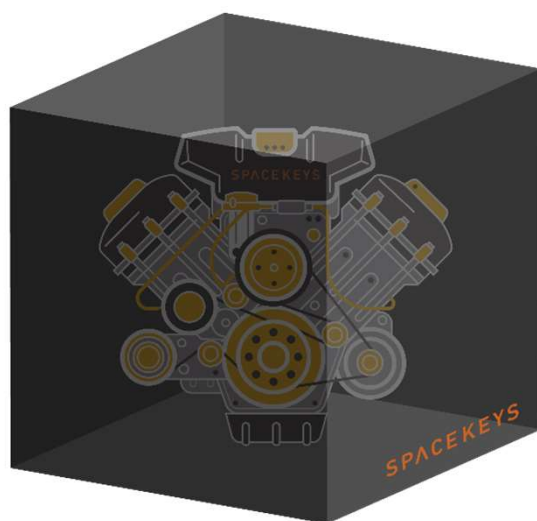
- Rationale
- Requirements
- Objectives
- Results
- Achievements



SPACEKEYS Rationale

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As the GPS satellites themselves have evolved over the years, so have the systems that allow operators to take the benefit of satellite navigation. SPACEKEYS presents the ultimate evolution of GNSS RAIM prediction solution for aviation. It provides for worldwide RAIM predictions for all aircraft types and for all navigation and surveillance specifications. SPACEKEYS is a project partly funded by European Space Agency (ESA) under the NAVISP programme ([NAVISP EL2-007](#)).



Black Box Design



- Airlines
- CAA/ANSPs
- Flight Planning
- Flight Following
- Weather
- Business Jets
- General Aviation



Create competition and add multi-constellation



SPACEKEYS NAVISP Project Context

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- Phase 1 - All Worldwide traditional RAIM prediction requirements met, including ADS-B.
- Phase 2 – Addition of multi-GNSS (Galileo) and A-RAIM as an R&D project. Built on a solid Phase 1.
- Major emphasis on requirements capture from users (Airlines, Integration Companies).
- Agile software development process, development, verification and validation are significantly overlapping. Quick iterations minimize the refactoring efforts at the end of the development task.
- Rigorous Validation and Verification with **ESA unrivalled expertise in subject matter and external Quality Assurance review.**

SPACEKEYS NAVISP Phase 1 Project Activities

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- Phase 1 - All Worldwide traditional RAIM prediction requirements met, including ADS-B.
 - Requirements gathering.
 - Major problem for Flight Planning re RAIM hole detection.
 - Partly user-driven
 - User Workshops held through 2018.
 - User Group Meeting 1-3 October 2019, Vienna.
 - System design.
 - Implementation.
 - Validation/Verification. FAA Volpe SAPT, Independent MATLAB implementation.
 - Deployment.
 - Maintenance.
 - Already significant user base.
 - Number of bespoke 'per-user' adaptations made.

RAIM Requirements (standards)

Large variety of receiver and operational standards:

- RTCA Minimum Operational Performance Standards (MOPS).
 - US: FAA ACs , TSOs, orders and notifications.
 - Europe: EASA's AMCs.
 - JAA's TGLs.
 - ICAO.
 - ... other third-country documents.
-
- In total over 50 standardization documents were analyzed...
 - ... but none of them standardizes the RAIM algorithm as such.

RAIM Requirements (GNSS Receivers)

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The RAIM solution performs predictions for all currently known receiver types in commercial aviation. This includes receivers compliant with TSO-C129, TSO-C196 and TSO-C145/146. The system is Future Ready For Multi-Constellation Receivers and Advanced Horizontal RAIM.

The following GNSS receiver parameters are supported:

Parameter	Options	Details
Algorithm	FD or FDE	
Barometric Aiding	ON, OFF or ON only on Failure	The option „On only on Failure“ provides the user the possibility to apply BA only in case the RAIM prediction resulted in an outage excluding BA. This is only available in the Spacekeys RAIM prediction solution.
Selective Availability	ON or OFF	
Mask Angle	-25° to 30°	
HAL Multiplier	Any certified value	Some aircraft are certified to apply a horizontal alert limit bias during RAIM predictions.

RAIM Requirements (Navigation)

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The RAIM solution performs predictions in compliance with the following navigation specifications. Terrain screening is performed as required for RNP AR predictions.

	RNAV 10 RNP 10	RNAV 5 Basic-RNAV	RNAV 2 US RNAV Type A	RNAV 1 Precision-RNAV US RNAV Type B	RNP 4	RNP1	RNP Approach	RNP AR Approach	MNPS
FAA (U.S.A.)	AC 90-105A (replaces Order 8400.12C)	AC 90-96A	AC90-100A	AC90-100A	AC 90-105A (repl. order 8400.33)	AC 90-105A	AC 90-105A (LNAV, LNAV/VNAV) AC90-107 (LP, LPV)	AC 90-101A AC20-138D	N8110.60
EASA (EU, EFTA and other countries)	AMC 20-12	AMC 20-4 JAA TGL 2	AMC 20-16 JAA TGL 10	AMC 20-16 JAA TGL 10		AMC 20-16 JAA TGL 10	AMC 20-27 (LNAV, LNAV/VNAV) AMC 20-28 (LP, LPV)	AMC 20-26	
CASA (Australia)	AC 91U-2(0)	CAAP B-RNAV-1	AC 91U-II-3-B	AC 91U-II-3-B	AC 91U-3(0)	AC 91U-II-C-3(0)	AC 91U-II-C-5 (LNAV) AC 91U-II- Attachment (LNAV/VNAV)	AC 91U-II-C-5 (RNP AR) AC 91-U-II-C-6	
SVRSOP (Latin America)	AC 91-001	AC 91-002	AC 91-003	AC 91-003	AC 91-004	AC 91-006	AC 91-008 (LNAV) AC 91-010 (LNAV/VNAV)	AC 91-009	
Transport Canada		AC 700-015							

Requirements (Surveillance)

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The RAIM solution performs predictions in compliance with the FAA ADS-B 2020 specification AC90-114A Change 1. As other Worldwide surveillance requirements are developed the system will ensure all requirements are complied with.



**U.S. Department
of Transportation**
Federal Aviation
Administration

Advisory Circular

Subject: Automatic Dependent
Surveillance-Broadcast Operations

Date: 3/7/16

AC No: 90-114A

Initiated by: AFS-400

Change: 1

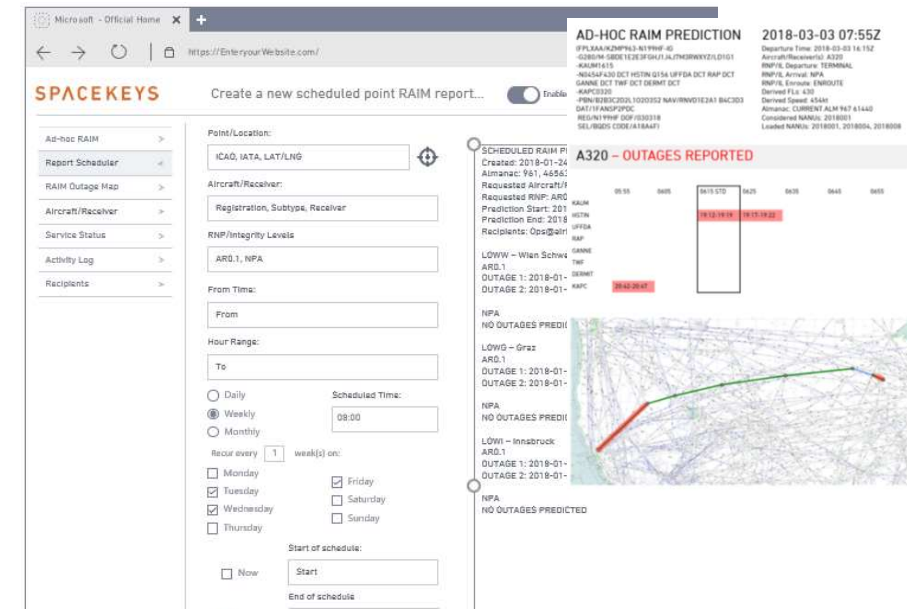
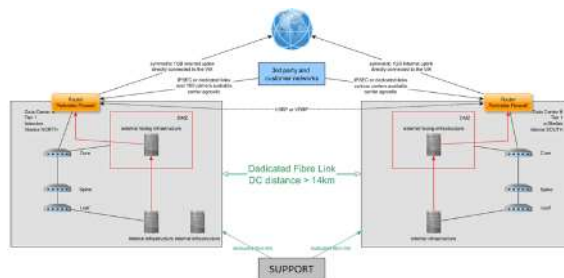
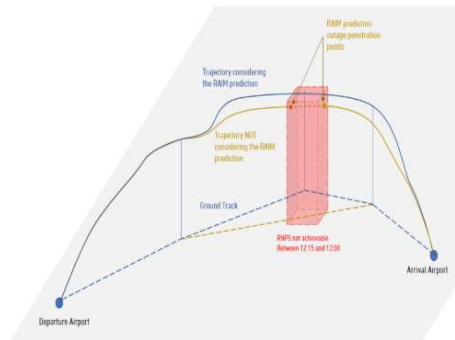
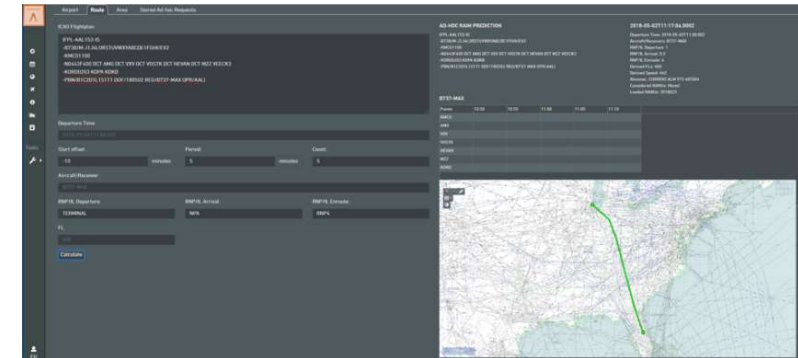
1. PURPOSE. The intent of this advisory circular (AC) is to facilitate operations using Automatic Dependent Surveillance-Broadcast (ADS-B) technology in compliance with Title 14 of the Code of Federal Regulations (14 CFR) part 91, §§ 91.225 and 91.227, which are required after January 1, 2020. The appendices provide guidance for the authorization of additional ADS-B Out and ADS-B In operations and their associated aircraft qualification and maintenance requirements.

2. PRINCIPAL CHANGES. This change incorporates new ADS-B guidance related to a technical amendment to § 91.225; equipping type certificated (TC) aircraft, light-sport aircraft (LSA), and experimental aircraft; and preflight requirements in U.S.-designated airspace. This change also modifies guidance for Cockpit Display of Traffic Information (CDTI) Assisted Visual Separation (CAVS).

SPACEKEYS Objectives

- All Worldwide prediction requirements met, including ADS-B.
- Modern System To System APIs.
- Sophisticated Web User Interface – including flight plan cut/paste.
- Daily Reports – Users Customisable .

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System Integration / API

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Spacekeys RAIM supports real time integration with third party systems such as flight planning and flight following systems. Both SOAP and REST APIs are provided for system developers to develop integrated solutions. The APIs are load and stress tested and deliver outstanding performance.

The following integration options are possible:

- API to request a location RAIM prediction for any airport with specific RNP levels (departure, destination, destination alternates,...).
- API to request a trajectory RAIM prediction for any trajectory of a flight (main, alternates,...).

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Web-Based User Interface

SPACEKEYS

A full suite of web tools to allow the user to perform RAIM predictions:

- Manual ad-hoc operations including ad-hoc location predictions or route predictions.
 - ICAO flightplan copy/paste.
 - Supported by an interactive map.
- Storing of ad-hoc predictions for future re-usage.
- Configure automated reports.
 - Providing the capability to set specific schedule parameters.
- Configure aircraft types, aircraft registrations and receivers.
- XML Flight Plan Import (e.g.: ARINC 633).
- Full Worldwide area map display (with navigational data overlay).
- Activity Log / RAIM Prediction History.
- Service Status Monitor.

² Utilizing the unique FLIGHTKEYS 5D dynamic aircraft parameter inheritance system

The screenshot displays the SPACEKEYS web interface. At the top, there's a browser window showing the URL 'https://EnterYourWebsite.com/'. The main header includes the 'SPACEKEYS' logo and a button to 'Create a new scheduled poi'. On the left, a sidebar lists navigation options: Ad-hoc RAIM, Report Scheduler, RAIM Outage Map, Aircraft/Receiver, Service Status, Activity Log, and Recipients. The central area is divided into two main sections. The top section, titled 'AD-HOC RAIM PREDICTION', shows flight plan details for a route from KAUM to KAPC, including aircraft type (A320), registration (N6454F), and various RAIM parameters. The bottom section, titled 'A320 - OUTAGES REPORTED', displays a table of outage data for the A320 aircraft, with columns for time (05:55 to 06:55) and status (STD, 19:12-19:19, 19:17-19:22). Below this, there's a map showing a flight route over a geographical area. The bottom of the interface features a configuration section for 'Aircraft' and 'Receiver' settings, including fields for Identifier, Registration, MSN, Operator, and GNSS Receiver, along with a 'New...' button. A sidebar on the left lists aircraft types: Airbus (A319, A320, OE-ABC, OE-ABD), Boeing, and Embraer.

SPACEKEYS Tools

SPACEKEYS

- Constellation Service Status. 
- Ad-hoc Predictions. 
- Scheduled Predictions. 
- Receiver/Aircraft Settings. 

Constellation Service Status

SPACEKEYS

SPACEKEYS

Service Status

Current Almanac

GPS Week

20

GPS TOA

503808

Number of Satellites (current/total)

31/31

Current NANUs

Number	SVN	PRN	Start	Stop	Type
2019142	55	15	2019-09-05T19:25:00Z	2019-09-06T07:25:00Z	FCSTDV
2019136	61	2	2019-08-29T14:45:00Z	2019-08-30T02:45:00Z	FCSTDV

This RAIM prediction system currently performs RAIM predictions based on GPS GNSS system only.

Ad-hoc Predictions - Airport

SPACEKEYS

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RM

Airport

Route

Area

📍 Point/Location

AUH,SJC,EGLL

✈️ Aircraft/Receiver

757/717_only

📏 RNP/Integrity Levels

NPA, RNP-AR-0.25

🕒 Time Period

12:00

Calculate

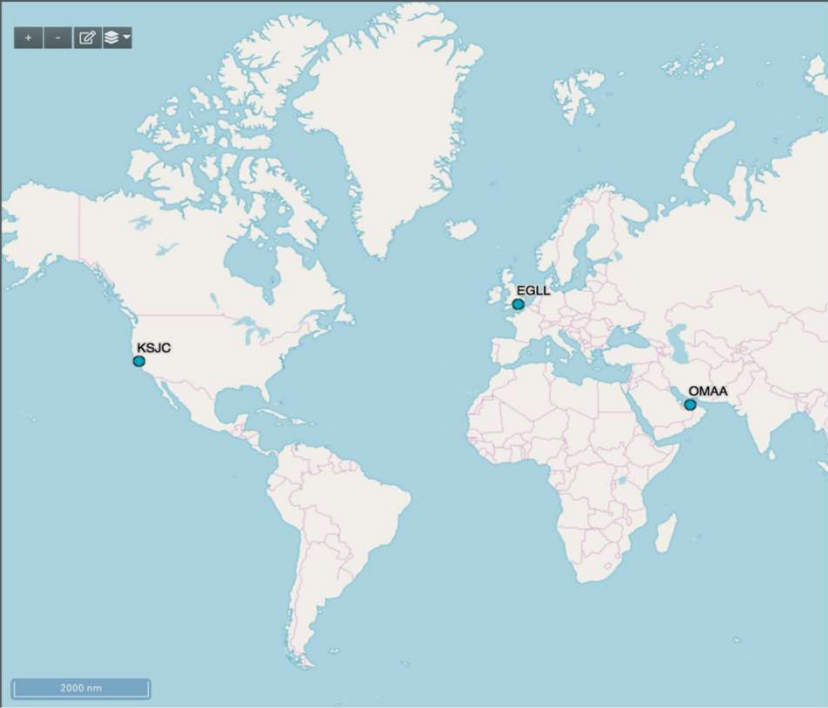
Schedule

+

-

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AD HOC RAIM PREDICTION NEXT 12H FROM 2019-08-28T14:12:59.650Z

EGLL RNP/RNP-AR (0.25 NM) 757/717_only ACCEPTABLE EXCEPT FOR THE FLWG PERIOD(S):

2019-08-28T19:45:29.650Z - 2019-08-28T19:49:29.650Z

4 MIN

2019-08-28T20:49:29.650Z - 2019-08-28T20:59:29.650Z

10 MIN

EGLL RNP Approach (0.3 NM) 757/717_only ACCEPTABLE EXCEPT FOR THE FLWG PERIOD(S):

2019-08-28T20:49:29.650Z - 2019-08-28T20:55:29.650Z

6 MIN

KSJC RNP/RNP-AR (0.25 NM) 757/717_only ACCEPTABLE EXCEPT FOR THE FLWG PERIOD(S):

2019-08-28T14:48:29.650Z - 2019-08-28T14:54:29.650Z

6 MIN

-----EGLL-----

EGLL RNP/RNP-AR (0.25 NM) 757/717_only OUTAGES PREDICTED

2019-08-28T19:45:29.650Z - 2019-08-28T19:49:29.650Z

4 MIN

2019-08-28T20:49:29.650Z - 2019-08-28T20:59:29.650Z

10 MIN

EGLL RNP Approach (0.3 NM) 757/717_only OUTAGES PREDICTED

2019-08-28T20:49:29.650Z - 2019-08-28T20:55:29.650Z

6 MIN

-----KSJC-----

KSJC RNP/RNP-AR (0.25 NM) 757/717_only OUTAGES PREDICTED

2019-08-28T14:48:29.650Z - 2019-08-28T14:54:29.650Z

6 MIN

KSJC RNP Approach (0.3 NM) 757/717_only ACCEPTABLE

-----OMAA-----

OMAA RNP/RNP-AR (0.25 NM) 757/717_only ACCEPTABLE

OMAA RNP Approach (0.3 NM) 757/717_only ACCEPTABLE

REPORT DETAILS

REQUESTED: 2019-08-28T14:12:59.972Z

ALMANAC: 20 503808

NANUs:

Ad-hoc Predictions - Route

SPACEKEYS

SPACKEYS

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AirportRouteArea

ICAO Flightplan

-A32/M-SDFGIRY/H

-EKCH1635

-N0454S1070 ADAMA Z648 VEDER DCT ALAMU DCT EPARI DCT NARKA T621 RONBU/N0451F350 P975 ARTAT UP975 PIPUR/N0459F370 UP975 ERGUN UL124 EVSAS UM688 OTIDO DCT RER DCT

-ORER0243 LZIB

-PBN/B1D1S1S2 DOF/180302 REG/OEABC RVR/200 OPR/AUA)

✈

Departure Time

2018-03-02 16:35

✈

Start offset

-10minutes

Period

5minutes

Count

5

✈

Aircraft/Receiver

787

✈

RNP/IL Departure

TERMINAL

✈

RNP/IL Arrival

NPA

✈

RNP/IL Enroute

0.07

☰

Flight Level

310

ADS-B Check

None

Calculate

Schedule

AD-HOC RAIM PREDICTION

(FPL-AUA940Q-IS

-A32/M-SDFGIRY/H

-EKCH1635

-N0454S1070 ADAMA Z648 VEDER DCT ALAMU DCT EPARI DCT NARKA T621 RONBU/N0451F350 P975 ARTAT UP975 PIPUR/N0459F370 UP975 ERGUN UL124 EVSAS UM688 OTIDO DCT RER DCT

-ORER0243 LZIB

-PBN/B1D1S1S2 DOF/180302 REG/OEABC RVR/200 OPR/AUA)

2019-07-25T11:28:49.753Z

Departure Time: 2018-03-02T16:35:00Z

Aircraft/Receivers: 787

RNP/IL Departure: 1

RNP/IL Arrival: 0.3

RNP/IL Enroute: 0.07

Derived FLs: 310

Derived Speed:

Almanac: 15 589824

Considered NANUs: (None)

Loaded NANUs: 2019113

787 - OUTAGES REPORTED

Points	16.25	16.30	16.35	16.40	16.45
ASMOB					
RELTU					
APTOX					17:58-18:04
TEPKI			17:54-17:59	17:59-18:04	18:04-18:09
PIPUR		17:54-18:00	17:59-18:05	18:04-18:10	18:09-18:15
ORMAN	17:55-18:01	18:00-18:06	18:05-18:11	18:10-18:16	18:15-18:21
ERGUN	18:01-18:06	18:06-18:11	18:11-18:16	18:16-18:21	
ASVOD	18:06-18:12	18:11-18:17	18:16-18:22		
KONUK	18:12-18:17	18:17-18:22			
EVSAS					
BAYIR					

📍

📏

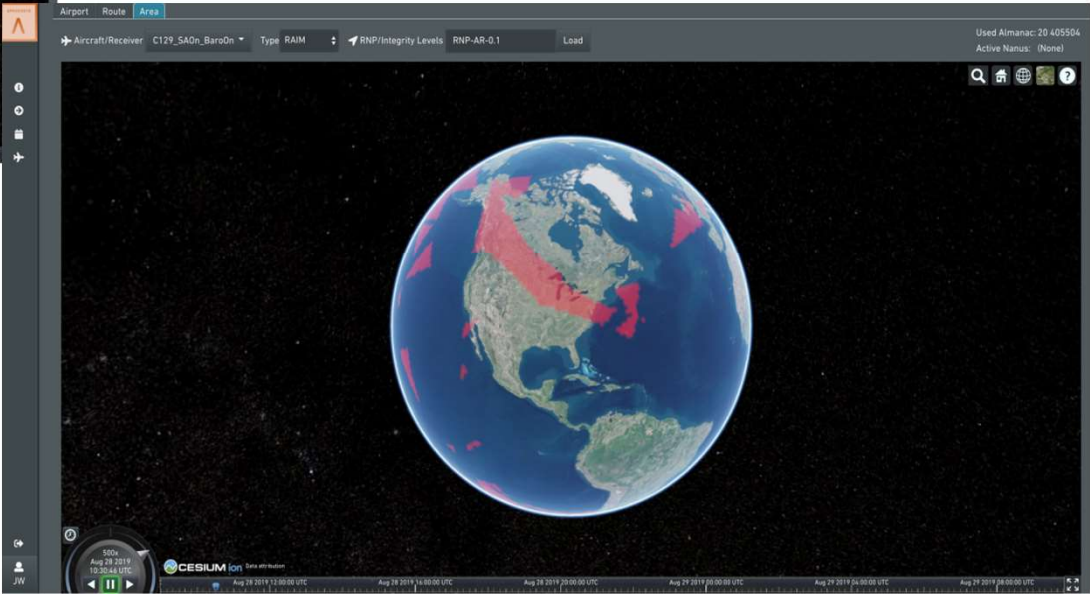
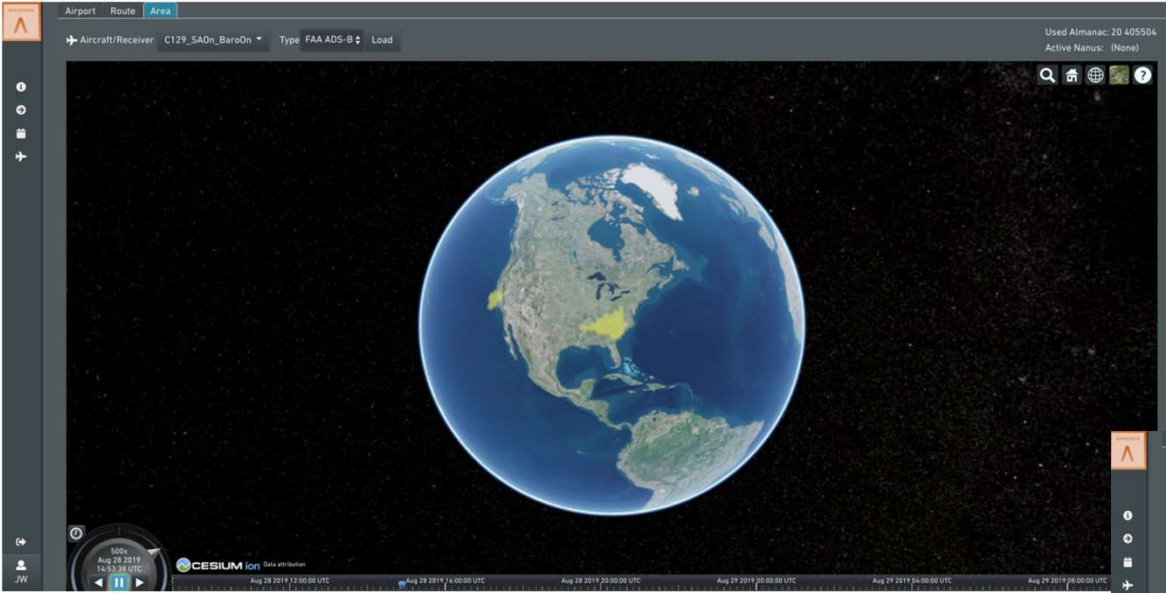
📶

📶

500 nm

Ad-hoc Predictions - Area

SPACEKEYS



Scheduled Predictions

SPACEKEYS

↑

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👤

BS

Airport

Route

Stored Airport Schedules

Stored Airport Schedule:

C085 RAIM PREDICTION

Name

C085 RAIM PREDICTION

Status

Enabled

Description

C085 RAIM Check

Report Type

RAIMREPORT_HTML_01

Point/Location

AWK, PNI, YAP, CXI, KWA, MAJ, MDY, ROP, ROR, TTK

Aircraft/Receiver

B737.30C

RNP/Integrity Levels

0.3

Time Period

24:00

From

00:00

Scheduled Time

11:45

☒ Monday

☒ Tuesday

☒ Wednesday

☒ Thursday

☒ Friday

☒ Saturday

☒ Sunday

Recipients

john@spacekeys.aero

Brian.D.Smith@united.com

Save

Test Now

Cancel

RAIM PREDICTION C085 RAIM PREDICTION

RUN AT 2019-08-28 14:51 UTC

VALID FROM 2019-08-28 14:51 UTC FOR A 24 HOUR VALIDITY

RAIM SCHEDULE DESCRIPTION: C085 RAIM Check

PTPN (POHNPEI ISLAND/POHNPEI INTL)

LOCATION: 6°59'06.3"N 158°12'35.3"E

RNP Approach (0.3 NM)

B737.30C

NOT ACCEPTABLE

3 MIN

PTYA (YAP ISLAND/YAP INTL)

LOCATION: 8°29'56.1"N 158°04'57.0"E

RNP Approach (0.3 NM)

B737.30C

NOT ACCEPTABLE

1 MIN

PGRO (ROTA ISLAND/BENJAMIN TAISACAN)

LOCATION: 16°12'27.7"N 145°14'28.0"E

RNP Approach (0.3 NM)

B737.30C

ACCEPTABLE

PKMJ (MAJURO ATOLL/MARSHALL ISLANDS)

LOCATION: 7°03'52.0"N 171°15'19.3"E

RNP Approach (0.3 NM)

B737.30C

ACCEPTABLE

PKWA (KWAJALEIN/BUCHOLZ AAF/KWAJALEI)

LOCATION: 8°43'12.0"N 167°43'54.0"E

RNP Approach (0.3 NM)

B737.30C

ACCEPTABLE

PLCH (CHRISTMAS ISLAND/CASSIDY INTL)

LOCATION: 1°59'10.4"N 157°30'59.1"W

RNP Approach (0.3 NM)

B737.30C

ACCEPTABLE

PMDY (MIDWAY ATOLL/HENDERSON FLD)

LOCATION: 28°12'56.5"N 177°22'52.3"W

RNP Approach (0.3 NM)

B737.30C

ACCEPTABLE

PTKK (WENO ISLAND/CHUUK INTL)

LOCATION: 7°27'42.0"N 151°50'34.0"E

RNP Approach (0.3 NM)

B737.30C

ACCEPTABLE

PTRO (BABELTHUAP ISLAND/BABELTHUAP/K)

LOCATION: 7°22'02.0"N 154°30'38.0"E

RNP Approach (0.3 NM)

B737.30C

ACCEPTABLE

PWAK (WAKE ISLAND AIRFIELD)

LOCATION: 19°15'57.0"N 169°38'13.0"E

RNP Approach (0.3 NM)

B737.30C

ACCEPTABLE

REPORT DETAILS

REQUESTED: 2019-08-28 14:51 UTC

ALMANAC: 20 803608

MANU: 2019106

Receiver/Aircraft Settings

SPACEKEYS

SPACEKEYS

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BS

Available Receivers:

737	Type: 129, Algorithm: FD, Selective Availability: Unaware, Mask Angle: 30, RNP Multiplier: 1, Barometric Aiding: no, Barometric Aiding Policy: always on	✎ 🗑️
737C300	Type: 129, Algorithm: FDE, Selective Availability: Unaware, Mask Angle: 5, RNP Multiplier: 1, Barometric Aiding: no, Barometric Aiding Policy: always on	✎ 🗑️
737MAX	Type: 145/146, Algorithm: FD, Selective Availability: Aware, Mask Angle: 30, RNP Multiplier: 1, Barometric Aiding: yes, Barometric Aiding Policy: always on	✎ 🗑️
787	Type: 129, Algorithm: FD, Selective Availability: Aware, Mask Angle: 5, RNP Multiplier: 1, Barometric Aiding: no, Barometric Aiding Policy: always on	✎ 🗑️
A319A320	Type: C129, Algorithm: FD, Selective Availability: Aware, Mask Angle: 5, RNP Multiplier: 1, Barometric Aiding: yes, Barometric Aiding Policy: always on	✎ 🗑️
B737.30C	Type: C129, Algorithm: FDE, Selective Availability: Aware, Mask Angle: 5, RNP Multiplier: 1.8, Barometric Aiding: no, Barometric Aiding Policy: always on	✎ 🗑️
B737NG	Type: C129, Algorithm: FD, Selective Availability: Aware, Mask Angle: 5, RNP Multiplier: 1.8, Barometric Aiding: no, Barometric Aiding Policy: always on	✎ 🗑️
B757B767	Type: C129, Algorithm: FD, Selective Availability: Aware, Mask Angle: 5, RNP Multiplier: 1, Barometric Aiding: no, Barometric Aiding Policy: always on	✎ 🗑️
B777B787	Type: C129, Algorithm: FD, Selective Availability: Aware, Mask Angle: 5, RNP Multiplier: 1.5, Barometric Aiding: no, Barometric Aiding Policy: always on	✎ 🗑️

➕

 Add new receiver

Receiver Name:	Type:
737MAX	145/146
Algorithm:	Selective Availability:
FD	Aware
Mask angle:	RNP Multiplier:
30	1
Barometric Aiding:	Barometric Aiding Policy:
Yes	Always Considered
Save Cancel	

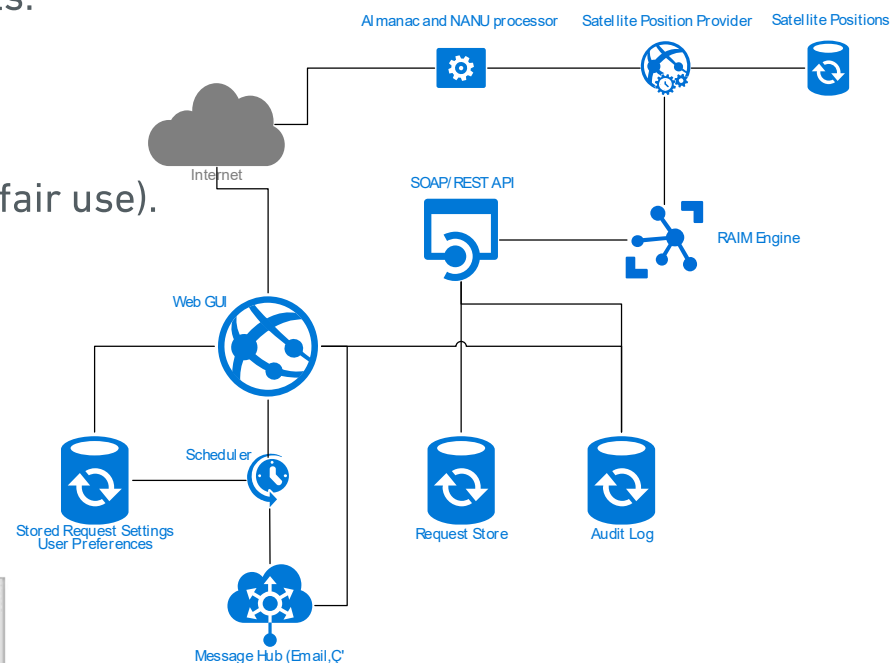
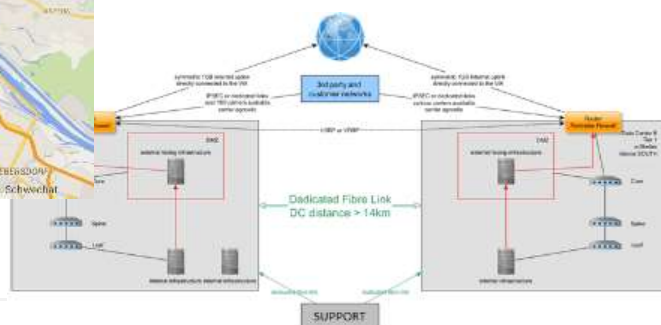
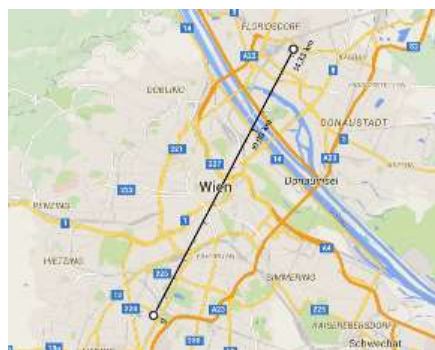
Architecture and SLA

SPACEKEYS

The system architecture has been created using latest technologies with the main focus on stability, scalability and performance. Each component is resilient and deployed over multiple physical locations. Deployment in a commercial cloud provider's infrastructure (AWS, Azure,...) is supported out of the box.

Spacekeys guarantees the following Standard Service Levels:

- 99.95% system uptime.
- New Almanac Processing within 2 minutes.
- New NANU processing within 60 minutes.
- Average 500 requests per aircraft registration and day (fair use).
- 24/7 support.



Achievements – RAIM/ADS-B

SPACEKEYS

- NAVISP
 - Phase 1: RAIM - Design, implementation and validation/verification.
 - Phase 2: A-RAIM - Galileo and A-RAIM experimental test bed.
- SPACEKEYS Success
 - EUROCONTROL Augur. A cut down functional system to meet EUROCONTROL requirements. Created from Phase 1 success.
 - Airlines in Europe, US and Asia. British Airways, American Airlines, Virgin Atlantic, Delta Airlines, SouthWest Airlines, Volotea, ARINC Direct, SAS, Cathay Pacific, Brussels Airlines....
 - Two major Worldwide flight planning companies direct API integration.
 - Integration with two Flight Following systems.
 - SPACEKEYS sit on US Congressional ADS-B review committee.
- A case study – Europe on October 16th 2018.....a major aviation GPS event never seen in 20 years.
 - One satellite out for maintenance.
 - Bad geometry – GPS outage for approach over most of Europe.

EUROCONTROL AUGUR - A SPACEKEYS Achievement

SPACEKEYS

augur.spacekeys.aero



- Service Status
- Terminal/Approach Tool
- Help

TERMINAL/APPROACH TOOL

Airports

egll,loww

Mask Angle

5.0°

Algorithm

FD

Selective Availability

Aware

Integrity Level

APPROACH (RNP 0.3)

Barometric Aiding

Off

Predict RAIM



Disclaimer

SCENARIO

Begin 2018-05-29T00:00:00Z
End 2018-06-01T00:00:00Z
Created 2018-05-29T09:19:55.784Z
Almanac CURRENT.ALM 979 405504
NANUs (None)

CONFIGURATION

Mask Angle 5.0
Algorithm FD
Integrity Level APPROACH (RNP 0.3)
Selective Availability Aware
Barometric Aiding Off

EGLL LONDON/HEATHROW - 51.48 / -0.46 / 25

NO PREDICTED OUTAGES

LOWW VIENNA/SCHWECHAT - 48.11 / 16.57 / 183

NO PREDICTED OUTAGES

Download Report

SPACEKEYS NAVISP Phase 2 Project Activities

SPACEKEYS

- Phase 2 – Addition of multi-GNSS (Galileo) and A-RAIM as an R&D project. Built on a solid Phase 1.
 - Requirements gathering (literature study).
 - System design.
 - Special care to be taken as phase 1 system went live during phase 2.
 - Implementation.
 - Algorithmic testing.
 - Integration.
 - Integration testing.

An aerial photograph of a vast, arid desert landscape under a bright, low sun. The horizon is visible, and a satellite is seen in orbit above the desert floor. The scene is bathed in a warm, orange glow from the sun.

THANK YOU!

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