THE AUGUR PROGRAM FOR BRNAV

An Internet-based tool providing aircraft operators with advance notification of GPS integrity.

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The Navigation Division of the EUROCONTROL Agency, with STASYS Ltd. and Delft University, has developed the Augur Programme for B-RNAV. Augur performs complex calculations and yet provides an easy-to-interpret interface to aid aircraft operators with the use of the United States Air Force' Global Positioning System (GPS).

Introduction

The European Civil Aviation Conference (ECAC) took a significant step forward on April 23rd 1998 when the carriage of Basic Area Navigation (B-RNAV) equipment became mandatory on the Air Traffic Services (ATS) route network in the ECAC area (with the exception of some domestic routes), as scheduled under the ECAC Strategy for the 1990s. B-RNAV equipment automatically determines aircraft position by processing data from one or more sensors (e.g. DME, VOR, INS, Loran C) and guides the aircraft with a track-keeping accuracy equal to or better than 5 NM (RNP 5) for at least 95% of the flight time.

EUROCONTROL, together with the Joint Aviation Authorities (JAA), has been preparing for the implementation of RNAV since 1991 through the development of the necessary standards and the definition of certification and operational approval requirements. Following the termination of the Omega service, a hyperbolic system used for navigation, the two organisations also worked together to examine the safety of the use of GPS for B-RNAV operations in ECAC airspace. The results of extensive studies indicated that safety could be maintained, subject to a number of conditions.

The Requirement

After a detailed review of aircraft systems, it was deemed by the JAA that the use of GPS by aircraft flying under Instrument Flight Rules (IFR) within European airspace to perform B-RNAV operations can meet the requirements to operate as a stand-alone means of navigation as long as the equipment conforms to the JAA Temporary Guidance Leaflet (TGL) No.2. This requires that the GPS receiver has the ability to detect when a satellite is out of tolerance (this is known as the availability of GPS integrity). The operational limitations on the use of GPS stand-alone RNAV equipment include the following requirement:

"...given a GPS constellation of 23 satellites or less (22 or less for GPS stand-alone equipment that incorporates pressure altitude/baro aiding), the availability of GPS integrity (RAIM) should be confirmed for the intended flight (route and time). This should be obtained from a prediction program either ground-based... or from an alternative method that is acceptable to the Authority."

This confirmation should be done during the pre-flight planning phase, and dispatch should not be made in the event of predicted continuous unavailability of RAIM (Receiver Autonomous Integrity Monitoring) of more than 5 minutes for any part of the intended flight. RAIM unavailability depends upon the geometry of satellites relative to the user. Geometries

that may be satisfactory for navigation may not be able to provide the failure detection capability within the required specifications.
There are a number of PC-based prediction programs currently available that can provide this information for an individual route, but they require the manual interpretation of GPS status information. Thus EUROCONTROL placed a contract with STASYS Ltd. to design a system, called "**Augur**", which predicts the effect of RAIM availability upon a route using automatically-obtained status information, and without the need for the operator to perform time-consuming calculations. Augur aims to provide all of the information necessary to advise on GPS integrity for European aviation operations. The program helps aircraft operators using stand-alone GPS equipment to operate in accordance with JAA requirements. It informs a user of the number of operational satellites and provides a means by which the availability of GPS integrity can be confirmed for an intended flight for the whole of ECAC airspace.

It is of paramount importance that the information provided by the prediction program is available to all airspace users. Following an initial study, EUROCONTROL determined that the most appropriate method of achieving this was to make the programme available at a site on the World-Wide Web (WWW). Other key advantages of using the Web are: the site can also provide a focal point for discussion (via built-in discussion fora), and mass access to information on other related topics. The facility (http://augur.ecacnav.com), partially available since 23rd April 1998, has been fully operational as from 31st July. Currently, the EUROCONTROL Navigation domain web site created for Augur also provides information and Discussion Groups on B-RNAV and RVSM, as shown by Figure 1.

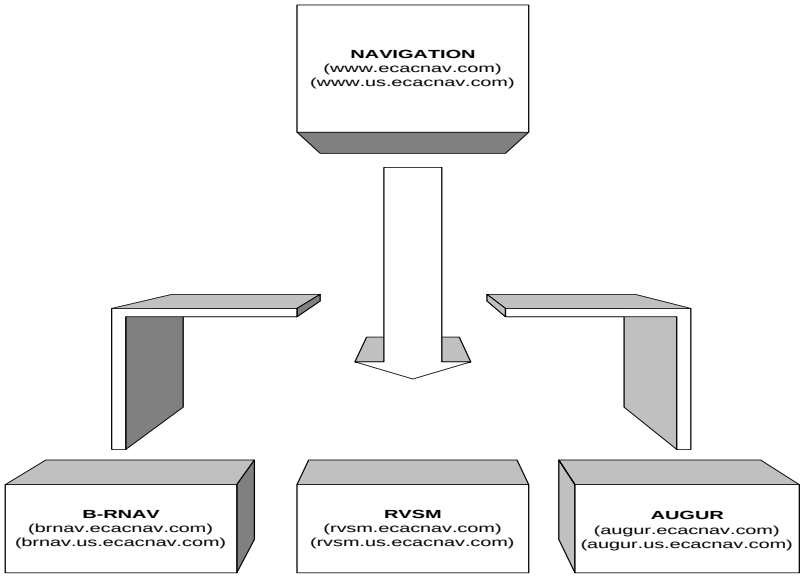

Figure 1 – Web Structure Block Diagram

The Predictive RAIM availability algorithms developed by Delft University for Augur were researched to such an extent that two scientific papers have been produced, one for each of the two premier satellite navigation conferences, see ref.s [ION 98] (US) and [GNSS 98] (Europe). However, the majority of the project involved providing a reliable and fully-tested service, available even to those with the most basic Web-browsing software.

The enormous computational capacity necessary, coupled with the requirement to handle a potentially large number of enquiries, led to the purchase of a large Web server consisting of

two quad processor computers, linked in a fail-over cluster with 256 MegaBytes of RAM and 24 GigaBytes of usable hard disk space utilising RAID 5 technology, with a dedicated 256 KiloBit/second optical link to the Web. In order to provide a continuous, 24 hour per day service, a mirror site duplicating the functionality of the primary site exists in the United States (the logo at the top of the page indicates to users to which site they are connected - compare Figure 4 with Figure 5).

How to Use Augur

Augur is predictive, and so its accuracy relies on the latest information on the status of each satellite signal. But the number of operational satellites can be reduced without warning at any time. Hence, it is advisable to use Augur as late as possible prior to the intended flight.

Augur consists of:

- a prediction of the number of operational satellites in two modes: STATUS Mode and VISIBILITY Mode;
- a prediction of RAIM outages over an area (AREA Mode) or a specified route (ROUTE Mode).

and is intended to be used in the following way:

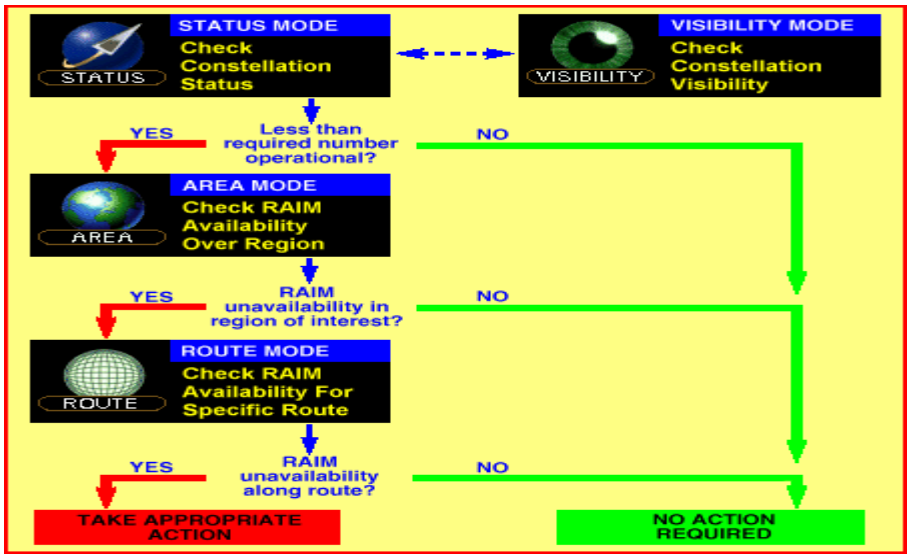

Figure 2 "How to use Augur" Flowchart

From the Home Page (shown by Figure 3), choose STATUS Mode.

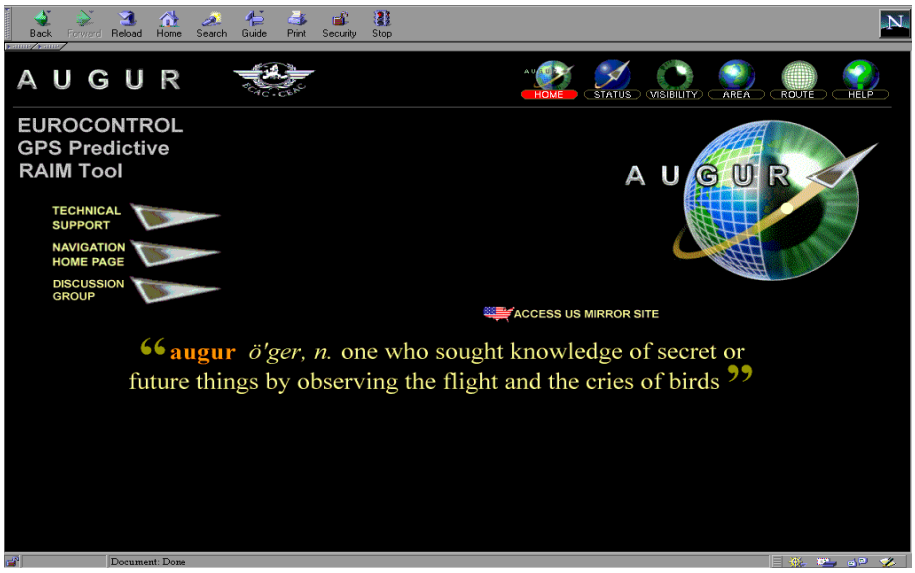

Figure 3 The Augur Home Page

If this indicates that there are insufficient operational satellites during the period of the intended flight, then proceed to AREA Mode. Here, an instant, intuitive view of the effect of any RAIM availability can be found. If this indicates that there are problems in the region of the intended flight in the appropriate time period, then choose ROUTE Mode to discover whether or not the specific route is likely to be affected. VISIBILITY Mode gives an indication of satellite visibility about a point. Each mode is described in more detail below.

Augur Modes

STATUS Mode

This mode gives a graphic and text display, from which the first part of the JAA requirement, the determination of the number of operational satellites can easily be seen.

The graphic display (Figure 4) shows the number of operational satellites in the constellation. If this number (indicated by the blue line) dips below the (maroon or red) bound on the plot, then the user should proceed through the AREA and ROUTE Modes to determine the predicted RAIM availability for the flight. The maroon bound represents the JAA requirement for the number of operational satellites for non-baro aided stand-alone GPS, and the red bound represents the JAA requirement for baro-aided stand-alone GPS. The text display gives the number of operational satellites and the time(s) of occurrence of any change, and is suitable to be printed off and included in flight documentation.

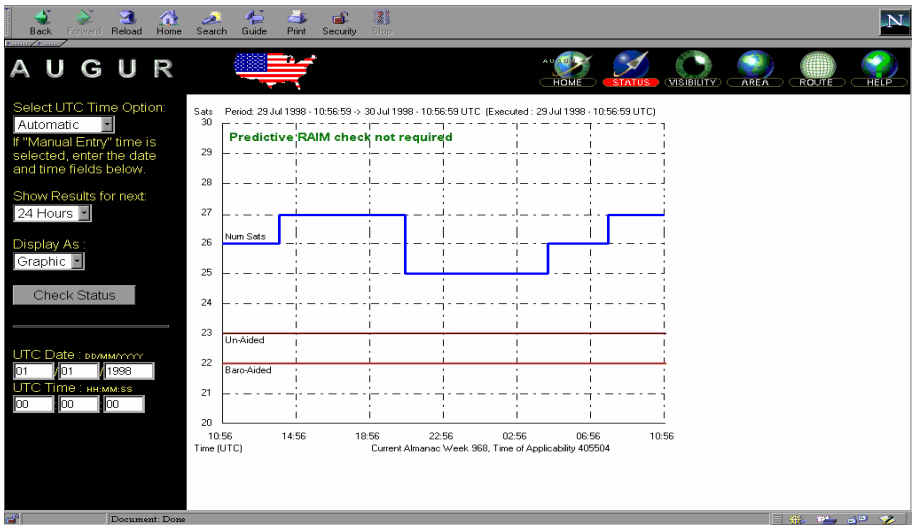

Figure 4 Example STATUS Mode Graphic Output (US mirror site)

If results are required over a 24 hour period starting at the current time, then the user simply needs to press “Send Data”. On visiting this page for the first time, the user can make use of the Web browser function “bookmark”, so that in future the STATUS Mode page can be found instantly, and sufficient information to comply with the JAA requirement found with the press of one button, “Send Data”. This simple action will complete the GPS predictive RAIM check for the majority of cases. Alternatively, the user may enter start time (in UTC), and select the duration from 1, 6, 12, 24, or 48 hours in the "Show Results for next" box.

STATUS automatically considers not only the latest almanac, but also any Notice Advisories to Navigation Users (NANUs) which are in force. The latter give notice of short-term outages due to maintenance and manoeuvring. This information is automatically obtained from the United States Coast Guard NAVCEN GPS web site, http://www.navcen.uscg.mil.

The STATUS Mode (i.e. the number of operational satellites) is also available via an automatic information line, available via telephone (+44 1252 717044).

Note: According to the JAA requirements in TGL-2, there is no need to run a prediction of GPS RAIM availability if the number of operational satellites in the entire constellation is more than 23 (or 22 for GPS stand alone equipment with baro-aiding). However areas affected by RAIM unavailability exist, even when there are more operational satellites than the number specified in TGL-2, due to the constant variation of the constellation geometry relative to the user. AREA Mode aims to give a conservative indication of where such problems are likely to occur.

VISIBILITY Mode

VISIBILITY Mode is supplementary to STATUS Mode. Whereas STATUS Mode gives the number of operational satellites in the entire constellation, the VISIBILITY Mode gives a sky plot of satellites visible about a fixed point for a given time duration. The user is requested to enter location, altitude, time, mask angle, and the number of samples required. Figure 5 shows typical graphic output and, from this figure, the area of the sky below the stated mask angle can be seen to be represented by a hash outer ring. This mode also allows a table of the azimuth and elevation at each specified interval for each satellite to be viewed and downloaded.

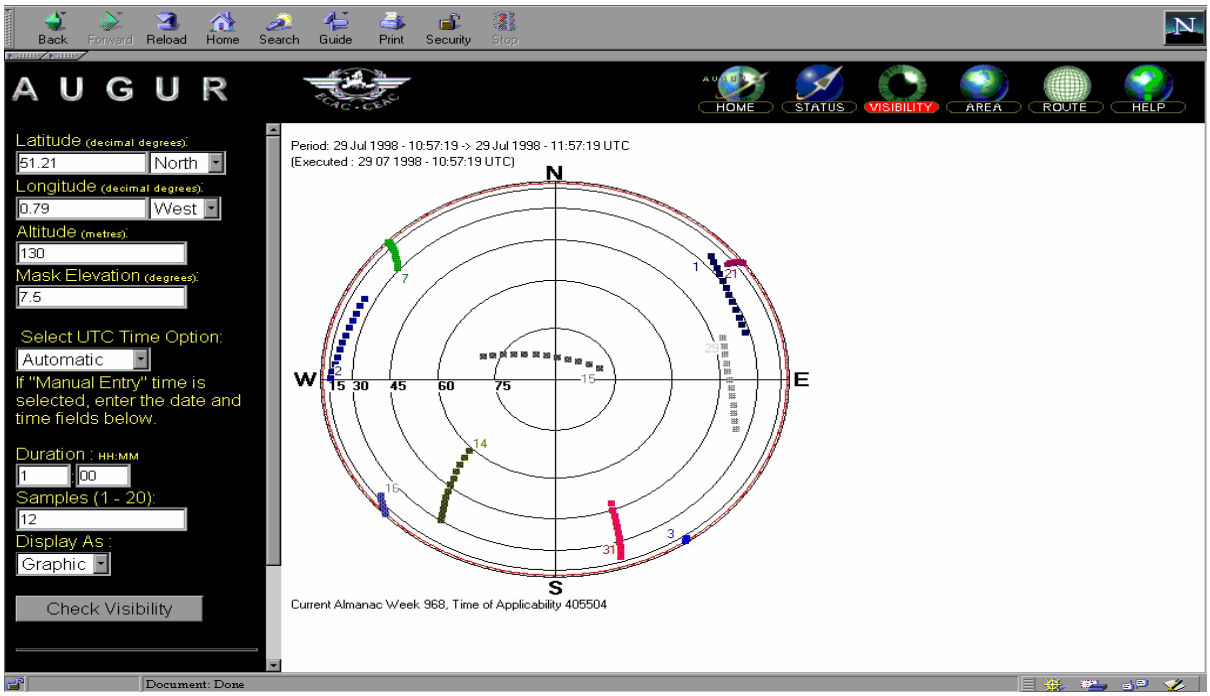

Figure 5 Typical VISIBILITY Mode Graphic Output

AREA Mode

AREA Mode is a unique feature which provides a graphical overview of RAIM availability across the ECAC region, and hence allows the users to readily determine whether or not their flight may be affected. The RAIM availability (for both unaided and baro aided user equipment) is calculated on a grid of 15 minutes of arc intervals over the entire region at a 2.5 minute time resolution. This amounts to 16 million RAIM availability calculations for a 24 hour period! The GPS User Equipment is assumed to have a fixed mask angle of 5 degrees, and be at an altitude of 6500 metres. In most cases the aircraft mask angle is less than 5 degrees, which increases the RAIM availability.

AREA Mode gives an indication of where GPS integrity problems are likely to occur. As the actual receiver algorithms used are not available, due to commercial reasons, the one used by Augur is more conservative (e.g. the 5 degree mask angle), hence showing more extensive RAIM holes than an operator is likely to experience. Conversely a pilot may not see a loss of RAIM availability indication with his on-board user equipment for a variety of other reasons, but the points of RAIM unavailability, as defined by the public domain algorithm used by AREA mode, are still there.

AREA Mode provides results for four periods of 6 hours' duration, for each day, starting at 00:00 (all times in UTC). Predictions are available up to 48 hours ahead. The AREA Mode graphic output shows all RAIM outages of 5 minutes or greater.

The area to be viewed can be selected from five pre-defined choices. The latter four views overlap their neighbours by approximately 25%.

- All Europe
- North West Europe
- North East Europe
- South West Europe
- South East Europe.

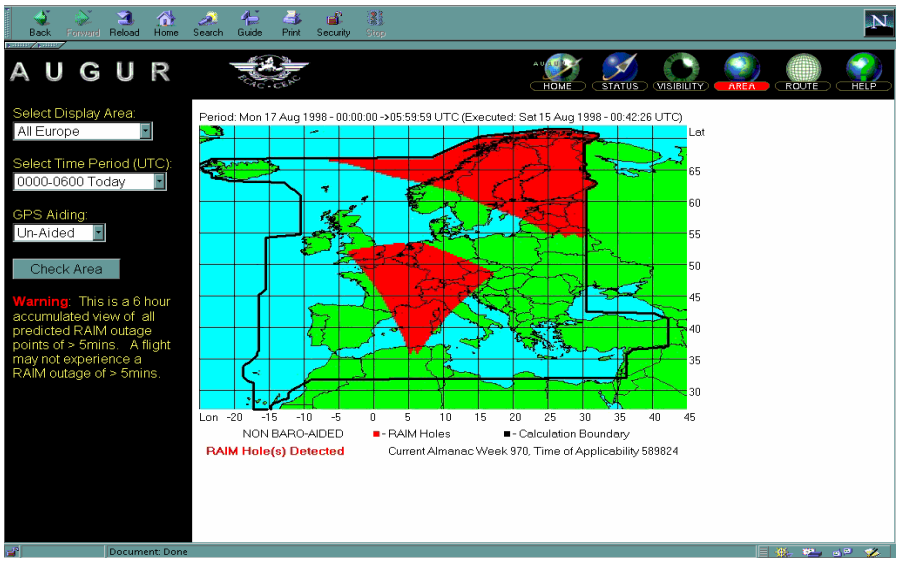

Figure 6 Typical AREA Mode Output

Figure 6 shows typical results for the ECAC area (outlined) using AREA Mode. This example plot indicates that, in the areas shaded red, there was at least one predicted RAIM outage of greater than 5 minutes during the 6 hour period.

ROUTE Mode

To see whether or not a specific route is affected, ROUTE Mode should be used. A route may be submitted to Augur by selecting route nodes using ICAO waypoint identifiers and specifying the time of arrival at each in terms of time elapsed since the time at the first waypoint (see Figure 7). The RAIM availability is calculated at a 2.5 minute time resolution for the entire route, assuming a constant speed between each waypoint. The GPS User Equipment is assumed to have a fixed mask angle of 5 degrees, and be at an altitude of 6500 metres. The ROUTE Mode graphic output shows all RAIM outages of 5 minutes or greater, and states the duration of the outage (see Figure 8).

ROUTE Mode provides novel features:

• A graphical plot showing RAIM availability at plus and minus 15 minute intervals in 5 minute steps about the nominal departure time. This permits an instant “heads-up” view to be gained of the effect of a small change to the nominal departure time.

• Latest almanac and applicable NANUs automatically taken into account.

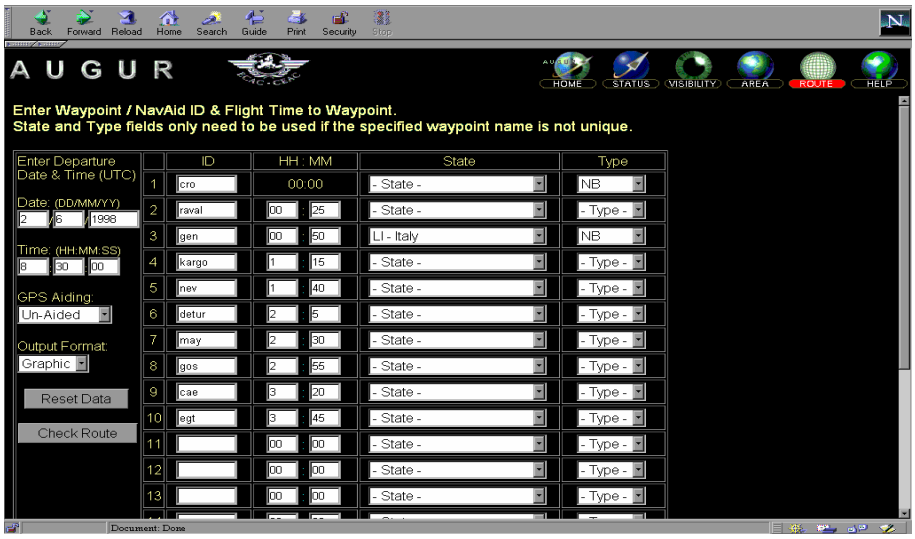

Figure 7 The ROUTE Mode Input Screen

Figure 8 Typical ROUTE Mode Output

Should the user choose to use Augur in addition to any ground-based (or receiver-incorporated) prediction function, then be aware that they may give different results. This may be due to one, or a combination of, the following:

- The algorithms used are different.
- The parameters used within the algorithm may be different.
- The sample time may be different.

Augur and the associated information pages at the EUROCONTROL Navigation Website are intended to be the components of an operational tool, and therefore to help aircraft operators and aircrews. There is no doubt that satellite navigation will become increasingly important in the future, and from the feedback already received, web sites such as Augur are extremely important to provide assistance and education to aviation users. Further comments are always welcome, preferably by e-mail to the Augur Helpdesk : **augur.helpdesk@ecacnav.com**.

References

[TGL-2] Temporary Guidance Leaflet no. 2 (formerly AMJ 20X-2), 13 June 1997, Preliminary Draft, Joint Aviation Authorities.

[TSO-C129] Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS), Department of Transportation, FAA Aircraft Certification Service, 12 October 1992, Washington DC, USA.

[ION98] P.B. Ober, “RAIM performance: How algorithms differ” to be published in *The proceedings of the 11th International Technical Meeting of The Satellite Division of The Institute of Navigation, ION GPS-98, September 15-18, 1998, Nashville, Tennessee.*

[GNSS98] D.A.G. Harriman, STASYS Ltd., P.B. Ober, Delft University of Technology***,*** *Algorithm Selection For Augur - EUROCONTROL's Predictive RAIM Tool.*