Deviation Request ETSO-C145c#5 for an ETSO approval for CS-ETSO applicable to Airborne Navigation Sensors Using the Global Positioning System Augmented by the Satellite Based Augmentation System (ETSO-C145c)

Consultation Paper

1 Introductory Note

The hereby presented deviation requests shall be subject to public consultation, in accordance with EASA Management Board Decision No 7-2004 as amended by EASA Management Board Decision No 12-2007 products certification procedure dated 11th September 2007, Article 3 (2.) of which states:

"2. Deviations from the applicable airworthiness codes, environmental protection certification specifications and/or acceptable means of compliance with Part 21, as well as important special conditions and equivalent safety findings, shall be submitted to the panel of experts and be subject to a public consultation of at least 3 weeks, except if they have been previously agreed and published in the Official Publication of the Agency. The final decision shall be published in the Official Publication of the Agency."

2 ETSO-C145c#5 Airborne Navigation Sensors Using the Global Positioning System Augmented by the Satellite Based Augmentation System

2.1 Summary of Deviation

Clarification on the limited validity of equation (A-22) and (A-22a) proposed by DO-229(A,B,C,D) for the ionospheric pierce point location computation and provision of a formula which does not have that limitation.

2.2 Original Requirement

In RTCA DO229D Appendix A in section A.4.4.10.1 it is stated:

> Considering the satellite and user locations, the user must first determine the location of the ionospheric pierce point of the signal path from the satellite. The location of an ionospheric pierce point (IPP) is defined to be the intersection of the line segment from the receiver to the satellite and an ellipsoid with constant height of 350 km above the WGS-84 ellipsoid. The following equations provide a method for determining the latitude and longitude of that pierce point. First, the latitude is computed as
>
> $$\phi_{pp} = \sin^{-1}\left(\sin\phi_u \cos\psi_{pp} + \cos\phi_u \sin\psi_{pp} \cos A\right) \text{ radians} \qquad \text{(A- 20)}$$

where, as illustrated in Figure A-17, Ψ_{pp} is the earth's central angle between the user position and the earth projection of the pierce point computed as:

$$\psi_{pp} = \frac{\pi}{2} - E - \sin^{-1}\left(\frac{R_e}{R_e + h_I}\cos E\right) \text{ radians} \qquad \text{(A- 21)}$$

A is the azimuth angle of the satellite from the user's location (ϕ_u, λ_u) measured clockwise from north. E is the elevation angle of the satellite from the user's location (ϕ_u, λ_u) measured with respect to the local-tangent-plane. R_e is the approximate radius of the earth's ellipsoid (taken to be 6378.1363 km). h_I is the height of the maximum electron density (taken to be equal to 350 km). The longitude of the pierce point is:

If $\phi_u > 70°$, and $\tan \psi_{pp} \cos A > \tan(\pi/2 - \phi_u)$

or if $\phi_u < -70°$, and $\tan \psi_{pp} \cos (A + \pi) > \tan(\pi/2 + \phi_u)$

$$\lambda_{pp} = \lambda_u + \pi - \sin^{-1}\left(\frac{\sin \psi_{pp} \sin A}{\cos \phi_{pp}}\right) \text{ radians} \qquad \text{(A- 22)}$$

Otherwise,

$$\lambda_{pp} = \lambda_u + \sin^{-1}\left(\frac{\sin \psi_{pp} \sin A}{\cos \phi_{pp}}\right) \text{ radians} \qquad \text{(A- 22a)}$$

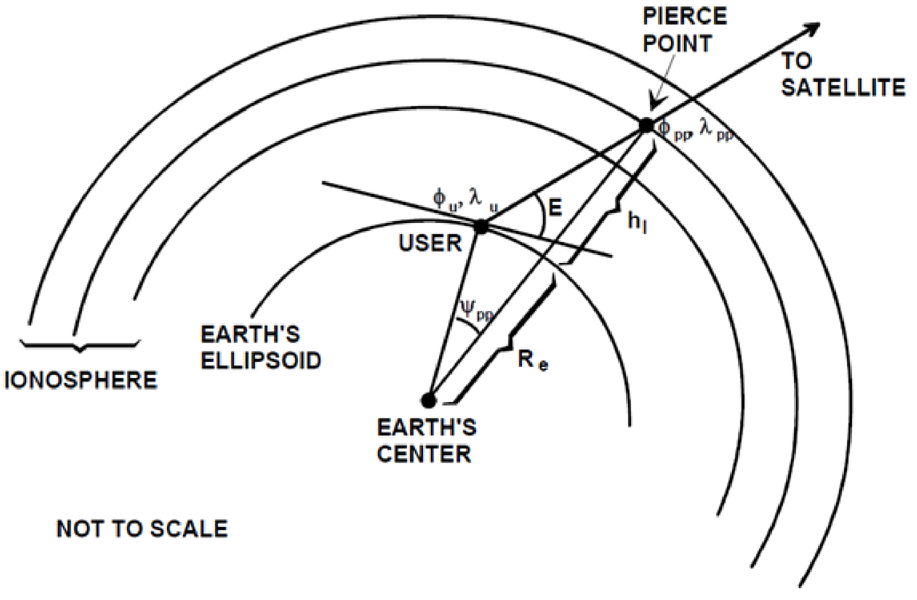


FIGURE A-17 IONOSPHERIC PIERCE POINT GEOMETRY

2.3 Statement of Problem

Equipment implementing the computation of the ionospheric piece point with equations (A-22) and (A-22a), without further mitigation, failed to provide position solutions at high latitudes.

It has to be noted that the requirement for the ionospheric pierce point location computation is the first 2 sentences of RTCA DO229D Appendix A section A.4.4.10.1. Formulae (A-20) to (A-22a) provide no means to compute the location of the ionospheric pierce point over an ellipsoid as required by the requirement but only an approximation which provides the ionospheric pierce point over a sphere if the pierce point is not too far from the equator.

As can be seen by simple inspection, equations (A-22) and (A-22a) are only well defined for

$$\frac{\left|\sin\left(\psi_{pp}\right)\sin(A)\right|}{\left|\cos(\phi_{pp})\right|} \leq 1,$$

which is equivalent to

$$\left|\sin\left(\psi_{pp}\right)\sin(A)\right| \leq \left|\cos\left(\phi_{pp}\right)\right|.$$

According to equation (A-21) the maximum Earth central angle between the user and the ionospheric pierce point ψ_{pp} for satellites used in the position determination is 14.2°, due to minimal allowed satellite elevation of 5° (DO-229D 2.1.4.11 and 2.1.5.11) for LNAV/VNAV or LPV operation. For all other modes of operation the maximum Earth central angle between the user and the ionospheric pierce point ψ_{pp} is 18.6°, as there is no minimal allowed satellite elevation. In these other modes of operation only the performance targets have to be met with a masking angle of 5°.

Just as a reminder the maximum Earth central angle between the user and a GPS satellite is 71.2° for a masking angle of 5° and 76.1° at the horizon, if the Earth is treated as a sphere. So a user with a modulus of the latitude larger than 54.8° can see a satellite directly over the pole, if a masking angle of 5° is used. If a masking angle of 0° is used, users with a modulus of the latitude larger than 48.9° can see a satellite directly over the pole. If a user can see a satellite directly over the pole, the user can see satellites at low elevations in all directions.

For the equations (A-22) and (A-22a) to be well defined it is required that

$$\left|\sin\left(\psi_{pp}\right)\sin(A)\right| \leq \left|\cos\left(\phi_{pp}\right)\right|,$$

which is only guaranteed for all azimuths for latitudes of the ionospheric pierce points ϕ_{pp} which fullfill

$$\sin\left(\psi_{pp}\right) \leq \cos\left(\left|\phi_{pp}\right|\right), \text{ or}$$

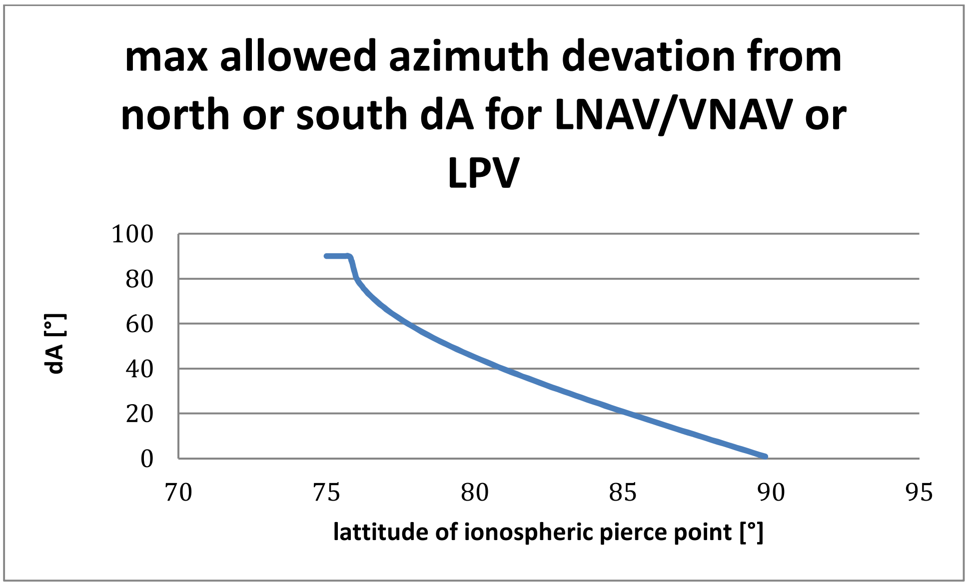
$$\operatorname{acos}\left(\sin\left(\psi_{pp}\right)\right) \geq \left|\phi_{pp}\right|,$$

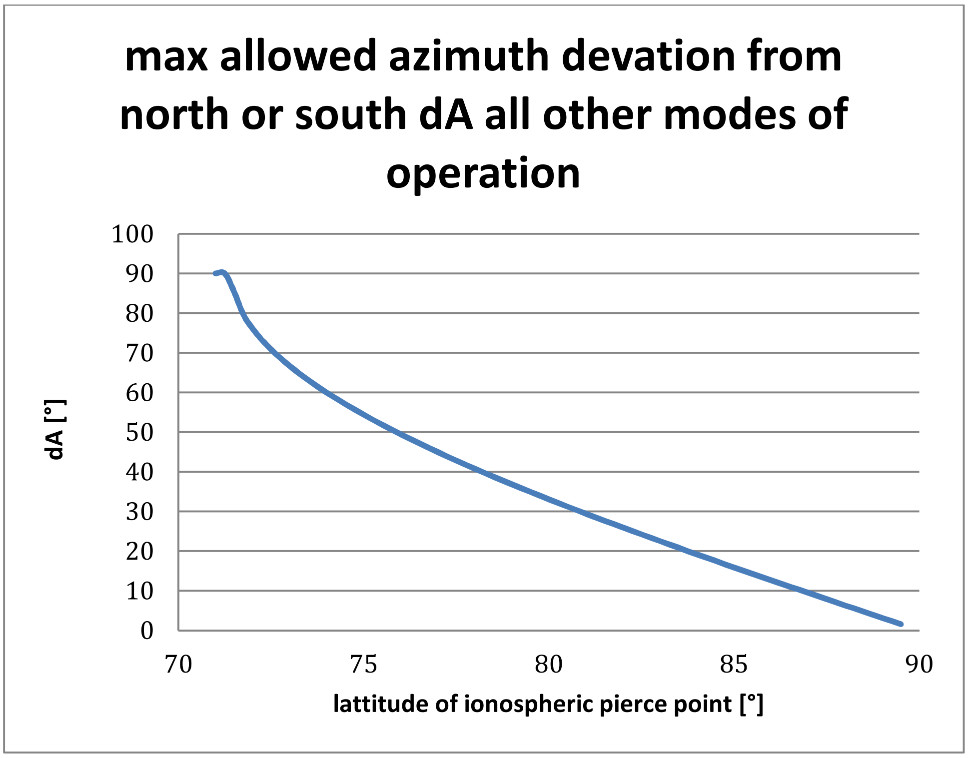
or in words with a modulus of the latitude of the ionospheric pierce point ϕ_{pp} smaller than 75.8° for LNAV/VNAV or LPV respectively 71.3° or all other modes of operation.

In more detail considering also the azimuth dependency, equations (A-22) and (A-22a) are only well defined if the minimum azimuth deviation from north or south dA fulfils

$$dA \equiv \min(|A|, |A-\pi|, |A-2\pi|) \leq \operatorname{asin}\left(\min\left(1, \frac{\left|\cos\left(\phi_{pp}\right)\right|}{\sin\left(\psi_{pp}\right)}\right)\right).$$

Note that in the above equation the azimuth is in rad.





When equations (A-22) and (A-22a) are ill-defined the position of the ionospheric pierce point is not defined, and therefore the user receiver might compute any longitude on Earth as the longitude of the ionospheric pierce point. Different implementations of the equations will most likely result in different locations of the ionospheric pierce point, which will then lead to erroneous position solutions and wrong computations of the protection levels, as the ionospheric pierce point as well as the position solution are input to the various equations which define the protection levels at the end. In some implementations the equipment will just hang, and a reboot of the equipment is necessary.

So currently the latitude of the ionospheric pierce point for systems using equations (A-22) and (A-22a) can only be trusted without additional checks, if the modulus of the user latitude is smaller than 61.6° for LNAV/VNAV or LPV operation and 52.7° for all other modes of operations. The maximum modulus of the user latitude which does not require an additional check is computed as the maximum modulus of the latitude of the ionospheric pierce point for which the problem cannot exist minus the maximum Earth central angle between a user and the ionospheric pierce point (see also figure A-17 of DO229D above).

Strictly speaking it would be sufficient to checked that only satellites are used in the position solution where every individual satellite fulfils

$$\min(|A|, |A-\pi|, |A-2\pi|) \leq \operatorname{asin}\left(\min\left(1, \frac{|\cos(\phi_{pp})|}{\sin(\psi_{pp})}\right)\right).$$

Note that in the above equation the azimuth is in rad.

If equations (A-22) and (A-22a) are replaced by

$$\lambda_{pp} = \lambda_u + \operatorname{atan2}(\sin(\mathrm{A}) * \sin(\psi_{pp}) * \cos(\phi_u), \cos(\psi_{pp}) - \sin(\phi_u) * \sin(\phi_{pp}))$$

the problem does not exist, but the computed ionospheric pierce point is still the one over a sphere and not over an ellipsoid. For a definition of atan2 see below.

$$\operatorname{atan2}(y,x) = \begin{cases} \arctan\left(\frac{y}{x}\right) & \text{for} \quad x > 0 \\ \pi + \arctan\left(\frac{y}{x}\right) & \text{for} \quad y \geq 0, x < 0 \\ -\pi + \arctan\left(\frac{y}{x}\right) & \text{for} \quad y < 0, x < 0 \\ \operatorname{sgn}(y)\frac{\pi}{2} & \text{for} \quad y \neq 0, x = 0 \\ \text{undefined} & \text{for} \quad y = 0, x = 0 \end{cases}$$

2.4 Equivalent Level of Safety

Limitation of the usage area for equipment which is using equations (A-22) and/or (A-22a) of RTCA DO-229A, DO-229B, DO-229C or DO-229D to latitudes with a modulus smaller than 61.6° for LNAV/VNAV or LPV operation and 52.7° for all other modes of operation.

An alternative to the first equivalent level of safety is to check that for all satellites used in the position solution, where equations (A-22) and/or (A-22a) of RTCA DO-229A, DO-229B, DO-229C or DO-229D are used, that equation

$$\min(|A|, |A-\pi|, |A-2\pi|) \leq \operatorname{asin}\left(\min\left(1, \frac{|\cos(\phi_{pp})|}{\sin(\psi_{pp})}\right)\right)$$

is fulfilled. Note that in the above equation the azimuth is in rad.

A third method to provide an equivalent level of safety is to replace equation (A22) and (A22a) with

$$\lambda_{pp} = \lambda_u + \operatorname{atan2}(\sin(\mathrm{A}) * \sin(\psi_{pp}) * \cos(\phi_u), \cos(\psi_{pp}) - \sin(\phi_u) * \sin(\phi_{pp}))$$

to allow worldwide coverage for the function including high and low latitudes operation during which the equipment systematically fails without this replacement.

2.5 EASA position

We accept the deviation.