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# INTEGRATED FIX INFORMATION

## INTRODUCTION

The ECAC (European Civil Aviation Conference) states signed the basic document — the EUROCONTROL Airspace Strategy — describing the future evolution of the ECAC airspace organisation up to 2015 and then beyond. In the context of the Strategy, the airspace users community encompasses a wide range of quite different interest groups involved either in Commercial Air Transport Operations, Military Operations, General Aviation & Aerial Work Operations or Test Flights & Unmanned Aerial Vehicles Operations.

Current forecasts show a more then doubling of commercial air transport flights thoughout Europe by 2015 based on 1995 traffic levels.

The future airspace organisation management processes have to address all of the expectations of these different user communities and therefore have to find trade-offs between the needs peculiar to each airspace user or Air Traffic Management (ATM) service provider category.

The strategic intent for the future ECAC airspace organisation is *"to progressively move towards an uniform airspace organisation leading to one continuum of airspace … providing maximum freedom for all airspace users consistent with the required level of safety in the provision of ATM services, while making due allowance for the security and defence needs of individual States."*

The desirable method of navigation within the European airspace is the Area Navigation (RNAV) – *„a method of navigation which permits aircraft operation on any desired flight path within the coverage of station-referenced navigation aids or within the limits of the capability of self-contained aids, or a combination of these (ICAO)"*.

Air traffic/air operation of different users within a limited airspace is possible only if the engaged navigation and surveillance systems fulfil all the main operational requirements – accuracy, availability, continuity and integrity. A final flight safety level is limited by measurement accuracy of immediate aircraft positions in space ("fixes"), by their repetition rate and also by reliability of those measurements.

Then any desirable growth of air traffic density is impossible apart from the previous corresponding increase of fix measurement accuracy in the given airspace segment.

Determination of true aircraft fixes within the given airspace depends upon several factors — the surveillance/fix measurement accuracy, the fix measurement repetition rate, surveillance systems working areas, the moments at which fixes of the same target are taken by different surveillance systems, the co-ordinate systems accepted e.t.c. Fortunately, the known differences in co-ordinate values as well as time and repetition rate effects can be processed and almost eliminated. What remain are the fix accuracy limitations, which depend upon operation possibilities of the navigationas well as surveillance systems engaged.

Air Traffic Control (ATC) ground surveillance/control systems still rely upon one kind of so called independent air traffic surveillance systems only. They are ground surveillance radars. Secondary Surveillance Radars (SSRs) represent fundamental sources of aircraft fix information for civilian air traffic services (ATS). Primary Surveillance Radars (PRSs) serve as basic sources of fix information for military anti-aircraft defense systems (AAD) and for surveillance of the aircraft not equipped with SSR transponders.

Lacks of detection of some sorts of targets, a limited fix measurement accuracy as well as a relatively low fix repetition rate of the radars mentioned above call for parallel use of other kinds of surveillance systems which should cover the radar network “weak points” and help to improve a final accuracy and reliability of identification/surveillance/guidance of different aircraft/targets operating under RNAV flight conditions within the given airspace.

A complex of highly accurate and reliable ground reconnaissance/ surveillance/control systems has been established and tested in recent years. The complex is highly effective and useful for exploitation especially at newly emerging common civilian/military ATS centres, named the Integrated Air Control Centres (IACCs), which are recently being planned and built throughout Europe. There are two kinds of alternative systems, which can serve as parallel no-radar means of ground surveillance. One of them is a system of independent surveillance — the Passive Surveillance System (PSS). The other is the Automatic Dependent Surveillance System (ADS).

## GEOMETRY OF THE SYSTEMS

### Radar Systems

Both SSR and PSR use the same method — the distance-angle method (see Fig. 1) — for measurement of aircraft fixes. Then the lines of constant values of aircraft azimuth $\Theta$ always cross the circles of constant radar-aircraft horizontal distance (R) at the same angles $\gamma=90^{o}$ and the system geometry is then hold as ideal.

There are two kinds of errors which determine the final radar error of the fix measurement. They are equal to

$$a = \Delta\Theta \cdot R \quad (1)$$

$$b = \Delta r \quad (2)$$

where 2ΔΘ is the width of radar antenna beam and Δr is equal to the error of the radar distance-meter. Since Δr is relatively small and remains almost constant for all slant fix distances the final fix error depends above all upon the radar-aircraft horizontal distance and ΔΘ values.

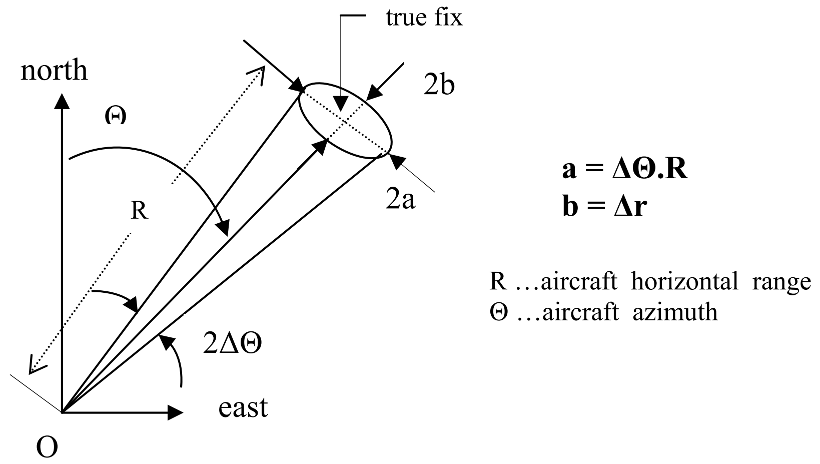


Fig. 1. Geometry of radars position lines (R, Θ)

Beam widths of most of radar types tend to be 1° or more. For example at distances about 100 km this brings max. fix error value approx. a=1.7 km and special complex and costly technical measures as monopulse or/and adaptive technologies must be employed to lessen it to the acceptable value. For example, if an aircraft position error be not allowed to exceed 500 m (see the EUROCONTROL standard of en-route flight path error), the maximum values of the accepted radar-aircraft distance have to be much smaller. This fact essentially influences multiradar processing in such a sense, that for the sake of avoiding too big errors of the final multiradar fixes (so called Joint Multi-Radar Information — JMRI) some appropriate weighting algorithms have to be implemented in the tertiary radar processor software which avoid negative influences of farther radar stations.

## Passive Surveillance Systems

Three or more stations of a PSS are located at different places. Geometry of this location depends upon the system role/use. A typical example of 3D PSS with its central master station **C**, three slave stations **1,2,3** and two position curves $\Delta R_1$ and $\Delta R_2$ are seen in Fig. 2. Corresponding distance difference values are equal to

$$\Delta R_i = R_{i,\alpha} - R_{i,\beta} = c \cdot \Delta t_i = 2a_i = 2 \cdot \sqrt{\left(e_i^2 + b_i^2\right)} \qquad (3)$$

where $\Delta t_i$ is the time difference between target signal arrivals at the C (master) station and at the given side station (TDOA — Time-Difference of Arrival value).
Hyperbolic position curves cross each other at the fix. The final fix error depends both upon the errors of single hyperbola measurements (distance difference $\Delta R_i$ values or simply on the time delays $\Delta t_i$), and also upon the crossection angle $\gamma$.

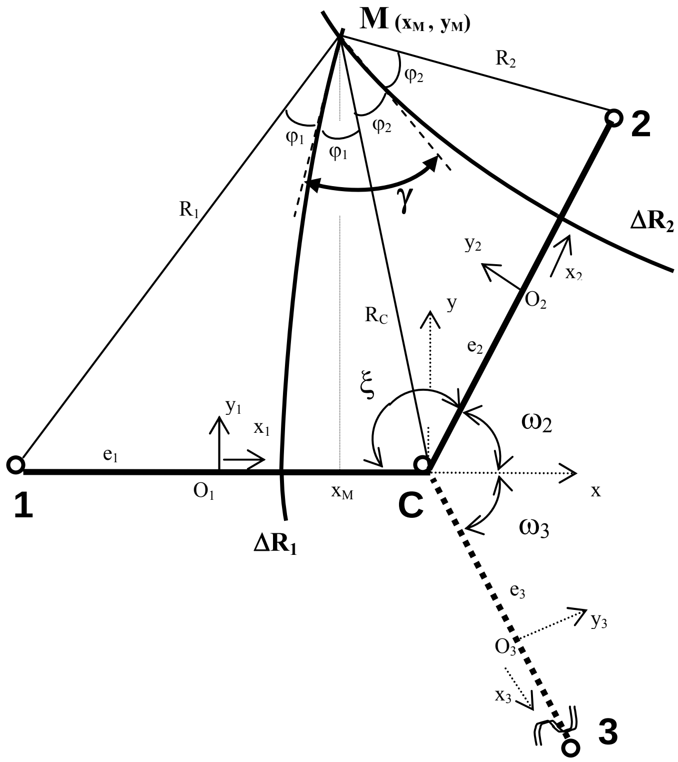


Fig. 2. Geometry of the PSS position lines ($\Delta R_i$, $\gamma$)

If

$$x_1 = x + e_1 \qquad x_2 = x \cdot \cos\omega_2 + y \cdot \sin\omega_2 - e_2 \qquad x_3 = \frac{x}{\cos\omega_3} - e_3$$

$$y_1 = y \qquad y_2 = y \cdot \cos\omega_2 - x \cdot \sin\omega_2 \qquad y_3 = x \cdot \sin\omega_3 + y \cdot \cos\omega_3$$

and

$$e_i = \sqrt{\left(a_i^2 + b_i^2\right)} \qquad b_i = \sqrt{\left(e_i^2 - a_i^2\right)}$$

$$R_{i,\alpha} = \left[\left(x_i + e_i\right)^2 + y_i^2\right]^{0,5} \qquad R_{i,\beta} = \left[\left(x_i - e_i\right)^2 + y_i^2\right]^{0,5}$$

then the hyperbolae and their tangents

$$\frac{x_i^2}{a_i^2} - \frac{y_i^2}{b_i^2} = 1 \tag{4}$$

$$y_i' = \pm \frac{b_i}{a_i} \frac{x_i}{\sqrt{\left(x_i^2 - a_i^2\right)}} \tag{5}$$

yield

$$\gamma_{1,2} = \left| arctg \;\; y_1' - \left[ arctg \;\; y_2' + \omega_2 \right] \right| \tag{6}$$

$$\gamma_{1,3} = \left| arctg \;\; y_1' - \left[ arctg \;\; y_3' + \omega_3 \right] \right| \tag{7}$$

$$\gamma_{2,3} = \left| arctg \;\; y_2' - \left[ arctg \;\; y_3' + \left(\pi - \omega_2 - \omega_3\right) \right] \right| \tag{8}$$

and

$$\varphi_i = \frac{1}{2} \cdot \arccos \frac{R_{i,\alpha}^2 + R_{i,\beta}^2 - \left(2.e_i\right)^2}{2 \cdot R_{i,\alpha} \cdot R_{i,\beta}} \tag{9}$$

$$\sigma_{\Delta\ell} = \frac{\sigma}{2 \cdot \sin\gamma} \cdot \sqrt{\left(\frac{1}{\sin^2\varphi_1} + \frac{1}{\sin^2\varphi_2}\right)} \tag{10}$$

where $\sigma_{\Delta l}$ is a root-mean square value of the aircraft position (fix) error and σ is the root-mean square value of the distance - difference (c.$\Delta t_i$) error. Low cost, high sensitivity and accuracy, and a good experience with their long-time remote operation under bad weather conditions have allowed the PSS to play important roles in both en-route 3D or 4D air reconnaissance//air surveillance as well as in precise approach and airfield surface navigation.

## Automatic Dependent Surveillance

Position measurement errors of airborne GPS receivers operating on the Standard Positioning Service (SPS) are of values 30–100 m. Accuracy of the military Precise Positioning Service (PPS ) receivers is higher. Differential GPS (DGPS) mode fix errors can drop down to submeter values. A standard GPS fix repetition rate is one fix per second. This gives a good chance for simple reconstruction of the aircraft flight trajectory at the ADS receiver output. Addressed ADS messages allow a reliable identification of any individual aircraft at ground ATS centres. There are two ways of getting ADS messages to ground ATS sites – one is via the SSR mode S format and the other is via a VHF Data Link (VDL). ADS signals can serve either as calibration information for the given SSR stations or as regular fix messages for ATC controllers.

FIX INTEGRATION

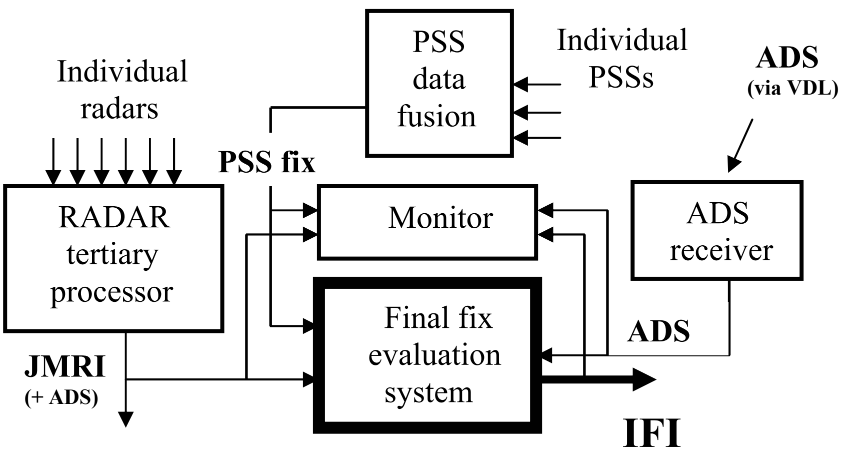


Fig. 3. Final fix integration/monitoring system

A large amount of fix data is being parallely generated by simultaneously operating radar stations. The radar network affords a very useful recconaissance, navigation, and surveillance/control information. A given radar network is also able to operate continuously for a long-time. In spite of these advantages the network final product (JMRI) does not contain all the information needed. Moreover — accuracy of JMRI fixes is dependent upon many factors (technical quality of a radar station, its location with respect to the aircraft path measured, different fix repetition rates of individual radars, target identification limits of PSR as well as SSR e.t.c).

PSS network is a very potential source of reconnaissance, surveillance, and navigation informations. Narrow-band PSSs are intended for detection of airborne radar transponder signals. Broad-band PSSs are able to detect any electromagnetic signal. Passive operation, broad-band detection, high sensitivity, a very good ability of target identification (not only of different types but also of individual aircraft which had been detected before), high fix measurement accuracy, large operation areas, low cost and reliable remote operation/control of PSS slave stations succesfuly help „to fill the gaps“ of the JMRI and of radar operation. But a rather long fix repetition period of up-to-date PSS (similar to that of radars) still prevents timely and reliable detection of quickly changed positions and flight directions of highly manoeuvering aircraft.

ADS is intended to serve both as a time-and-fix calibration signal and as a regular source of aircraft fixes. Possible time gaps which may occur in ADS signal reception can be easily covered by radar and PSS networks.

## CONCLUDING REMARKS

1. Both the safety of civilian air traffic and the readiness of Air Force and Air Defence unit significantly depend upon levels of accuracy and reliability of the aircraft immediate position measurement.
2. Up-to-date aircraft position measuring ATC surveillance systems (radars) still do not offer all the information necessary to fulfil all tasks of newly intended Integrated Air Control Centres (IACC).
3. The PSS and the ADS have been recognized as very powerful aids which can strengthen ATS/ATC/Air Force/Air Defence capability.
4. Radar, PSS and ADS data fusion results in the IFI (Integrated Fix Information) suitable for good and prompt civil/military air co-operation.

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