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Air navigation safety through the use of surface wave radar

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ABSTRACT: Air transport is one of the keys to the economic development and stability of a country. The emergence of this sector in a State depends on the radio resources implemented to ensure the safe and rapid flow of air traffic, but above all to guarantee the safety and efficiency of air navigation. It is with this in mind that the International Civil Aviation Organization «ICAO» recommends that all State bodies responsible for providing air services within the airspace of Contracting States meet the requirements of the Management of the Air Space «ATM» and the Communication, Navigation and Surveillance system in a structured approach to the effective implementation of the system called CNS/ATM. It is in this context that we subscribe to our study which aims to contribute to the process of implementation of the CNS/ATM plan by the Régie des Voies Aériennes in the airspace of the Democratic Republic of Congo. It emerges from this ICAO recommendation that our country continues to show some shortcomings, particularly in the area of full surveillance of its airspace. Thus, we are working on experimenting with radar systems for full, reliable and optimal surveillance of the country's airspace. We have associated the current ADS-B surveillance system with other surveillance systems, primary radar «PSR» and secondary radar «SSR» to cover all regions of the airspace, and thanks to the multi-sensor function of the TOPSKY airspace surveillance, security and visualization system all surveillance data from these different systems will be merged.

KEYWORDS: Airspace, air navigation, surveillance, radar, security.

1 INTRODUCTION

Airspace management is one of the major parameters in securing air navigation. This management involves several technical factors, including the use of appropriate, adequate and efficient equipment, because the evolution of aircraft in space is only possible and secure if it is guided by Communication, Navigation and Surveillance. The installation of this equipment guarantees the safety and efficiency of air navigation [1].

CNS/ATM Systems are Communication, Navigation and Surveillance Systems using Digital (Digital) Technologies, Satellite Systems, Automation and Telecommunications Networks, with the aim of improving the Global and Continuous Management of World Air Traffic [2]. It is a New Concept which is based on the emergence of Satellite Technology which, moreover, offers many advantages, not only in terms of Communication, Navigation and Surveillance, but also and above all in Air Traffic Management and improves air traffic control services around the world, through the use of new technologies [3, 4, 5]. Given the density of traffic, air traffic controllers must have a particularly efficient surveillance system to manage Congolese airspace in a rational and efficient manner. Radar now meets this requirement [6]. This system must ensure the detection, identification and on-screen display of the various aircraft, so as to reduce the spacing between them and obtain an optimum flow of traffic [7].

2 FOUNDATIONS

2.1 GENERAL PRIMARY RADAR EQUATION

The relationship that associates the range of a radar with the characteristics of the equipment and the particular detection conditions imposes the general equation of the radar. For a peak transmission power Pc radiated uniformly by an omnidirectional antenna, the power density or power received per unit area, at a distance R from the antenna would be [8]:

$$\frac{P_C}{4\pi R^2} \quad (1)$$

The power being distributed on a spherical surface $4\pi R^2$ being the surface of the sphere of radius R.

But the antenna is directional and at maximum gain when pointed at the target. So, we find in the direction of the max gain, (G_0) a unit power (radiated power density or power per unit area)

$$P_u = \frac{P_C}{4\pi R^2} G_0 \quad (2)$$

And the overall power received by the common transmit-receive antenna of apparent surface A will be written:

$$P_{rt} = \frac{P_C . G_0 . \sigma}{4\pi R^2} . \frac{A}{4\pi R^2} \quad (3)$$

The simple expression for the antenna gain:

$$G_0 = \frac{4\pi A}{\lambda^2} \quad (4)$$

Allows us to translate this apparent surface in the previous relation. He becomes:

$$P_{rt} = \frac{P_C . G_0^2 . \lambda^2 . \sigma}{(4\pi)^3 R^4} \quad (5)$$

If, moreover, the signal received corresponds to the Minimum Perceptible or Detectable Signal (S_{min}), the distance R will logically correspond to the Maximum Range (R_{max}) of the Radar.

We write:

$$S_{min} = \frac{P_C . G_0^2 . \lambda^2 . \sigma}{(4\pi)^3 R^4 max} \quad (6)$$

For a maximum Range Rmax in free space:

$$R_{max} = \left[\frac{P_C . G_0^2 . \lambda^2 . \sigma}{(4\pi)^3 S_{min}}\right]^{1/4} \quad (7)$$

2.2 DETERMINATION OF MINIMUM DETECTABLE SIGNAL EXPRESSION

By definition, the minimum perceptible signal represents the value of the useful power that must be received at the input so that the useful power available at the output of the receiver is equal to that of the noise. So, if we generally call B_0 the average noise power at the input of a receiver, the average noise power B_1 at the output will be:

$$B_1 = B_0 G + BR \quad (8)$$

Expression in which G translates the gain of the reception chain and BR the additional overall noise provided by the active elements of the receiver. Knowing that BR=BrG

You can also write:

$$B_1 = (B_0 + B_r)\, G \quad (9)$$

By calling B_r the additional noise power of the chain brought back to the input. An average noise power equal to B_0+B_r at the input is then equivalent, representing our definition, to the power of the minimum signal necessary at the input to have at the output a signal power equal to the noise.

We write:

$$S_{min} = B_0 + B_r \quad (10)$$

2.3 SECONDARY RADAR

The secondary radar is, in fact, an identification radar which also makes it possible to know the altitude or flight level of the detected target.

A radar emits the power P_i with an antenna gain G_i (i for Interrogator) and with a frequency f_i corresponding to a wavelength $ë_i$. In the same way the transponder responds by transmitting a power Pt, an antenna gain G_t (t for Transponder) and a wavelength $ë_t$. The power density received at the transponder at a distance d from the radar is found in the expression:

$$d_{pt}=\frac{G_i P_i}{4\pi d^2} \quad (11)$$

Equivalent surface presented by the transponder antenna:

$$S_t=\frac{G_t.ë_i{}^2}{4ð} \quad (12)$$

Power received at the transponder:

$$S_t.dpt=\frac{G_t.G_i P_i.\lambda_i^2}{(4\pi d)^2} \quad (13)$$

At the reception:

The power density received by the radar at a distance d from the transponder is found in the expression:

$$d_{pt}=\frac{G_t P_t}{4\pi d^2} \quad (14)$$

Equivalent surface presented the antenna of the radar:

$$S_i=\frac{(G_i.\lambda_i^2)}{(4\pi)} \quad (15)$$

Power received at interrogator:

$$P_{ri}=S_i.d_{pi}=\frac{(P_t G_t G_{i.}.\lambda_i^2)}{(4\pi d)^2} \quad (16)$$

3 CURRENT SURVEILLANCE IN THE MANAGEMENT OF AIRSPACE IN THE DR. CONGO

3.1 ORGANIZATION OF DR CONGO AIRSPACE

The airspace or the FIR/UIR of the R.D.C. is divided into 3 sectors: Kinshasa, Lubumbashi and Kisangani. Each of these three sectors is subdivided into UTA which is a controlled upper airspace located in the UIR upper airspace and the lower airspace in which there are the following airspaces: TMA, CTR. The upper control region is the space from FL 245 to FL 460, within which aircraft benefit from the regional control service over the whole of the Democratic Republic of Congo.

The RVA is a provider of air traffic services, including: CA air traffic control service, flight information service and alerting service. The air traffic control service consists in ensuring the safety of aircraft by avoiding collisions between them and collisions with obstacles and ensuring the safe and rapid flow of traffic, by means of instruction and authorization of control. The flight information service consists of informing the captains to allow them to carry out their flight in the best conditions by communicating to them information on the evolution of the surrounding traffic, on the instantaneous or foreseeable meteorological conditions, on the use of the infrastructure and notify them of any modification likely to interest them and which may have repercussions on the progress of the flight. The alert service consists of worrying about the progress of the flight of aircraft and alerting the competent body in good time when there is reason to doubt the fate of the latter due to the lack of information about them and thereby free up search and rescue operations.

3.2 DESCRIPTION OF THE PLAN FOR THE IMPLEMENTATION OF CNS/ATM SYSTEMS IN THE DRC

The RVA (Régie des Voies Aériennes) is the national body responsible for managing airports and airspace in the Democratic Republic of Congo. It had set up its CNS/ATM implementation plan divided into three tranches or phases.

The first phase or tranche is focused on improving the fixed and mobile communications of the Kinshasa FIR, the reorganization of the management of airspace and air traffic, the training of personnel and the construction of new buildings for the area control (ACC) and new control towers at Kinshasa, Lubumbashi and Kisangani airports.

The second tranche focuses on partial implementation in parallel with the first level but with a lower priority (although equally essential) focused on the requirements arising from the transition to the new concept of the ICAO CNS/ATM system and the longer-term infrastructure development. This section concerns the extension of the ACC buildings at the airports of Kinshasa, Lubumbashi and Kisangani, the rehabilitation of the control towers of the main domestic aerodromes, the improvement of navigation aids and the implementation of the new CNS/ ICAO ATM (including GNSS approach procedures, air-ground data link communication, ATN, Automatic Dependent Surveillance, etc.) and RVA management and technical capacity building.

The third tranche is the installation of an administrative communications system and radar coverage of Lubumbashi and Goma airports.

Table 1. Statistics of international overflights by main ats and rnav routes (years 2018-2022 [9])

N°	ROUTES ATS & RNAV	Distance in Km	FREQUENCY					
			2018	2019	2020	2021	2022	*TOTAL*
1	UM731 EMSAT-DURNA	1057	2813	4158	2800	2373	3548	15692
2	UB733 ANUBI-KSA	204	2431	1703	627	727	765	6253
3	UA609 AKBON-MPK	1370	2155	2531	1249	1726	1605	9266
4	UM998 INUGA-AMSIK	685	2230	1894	452	123	418	5117
5	UA611amsik BUDEL-AMSIK	594	1048	120	1	0	0	1169
6	UA409 SOBTO-BJA	746	1643	1615	492	553	970	5273
7	UM998durna DURNA-AMSIK	844	1025	775	0	279	71	2150
8	UT143gom BATVU-GOM	1328	1033	892	524	832	1115	4396
9	UT143opero OPERO-BATVU	1358	878	1042	372	456	760	3508
10	UR784 UVORA-MOTAM	463	597	233	100	527	232	1689
11	UV30/UM998 KSA-AMSIK	411	183	610	516	925	1532	3766
12	UG862 AMPER-SIPKI	669	735	1060	635	617	755	3802
13	UA610akb PIPLO-AKBON	1390	1462	1169	78	578	882	4169
14	UT143 NALOS-BATVU	1515	131	173	344	438	133	1219
15	UM731bkv EMSAT-BUKAV	1869	0	984	242	451	220	1897
16	UA610bja PIPLO-BJA	1437	0	0	299	202	215	716
17	UM216 KINPA-BUKAVU	1265	376	70	2	0	0	448
18	UM216 bja KINPA - BJA	1603	99	0	0	0	0	99
19	UB12/UA618 BJA-DEKUM	891	333	660	414	458	269	2134
20	UA610gom PIPLO-GOM	1304	146	331	437	468	210	1592
21	UT132 GOPUR-MPK	169	0	145	64	388	639	1236
22	UA618/UB12 MOT-DEKUM	1575	158	112	111	169	151	701
23	UA618 MOTAM-BJA	992	355	213	63	194	0	825
24	UM214/UA607 ETOXO-MPK	1821	882	0	112	422	269	1685
25	UB12 DEKUM-GOM	711	63	430	182	93	0	768
26	UA617 ITNEL-KSA	163	507	378	187	282	538	1892
27	UM214/UA613 OVPAD-KSA	1637	0	144	200	266	372	982
26	MIRDA-BUKAVU	1337	0	0	0	215	321	536
28	UT143bja BATVU-BJA	1424	301	233	241	128	222	1125
29	MERON-AGTOM	739	727	679	289	120	418	2233

30	UT143/UM214 BATVU-ETOX	1543	0	349	0	59	0	408
31	UG450 BJA-INUGA	1270	939	1057	86	115	246	2443
32	UB12bkv BUKAVU-DEKM	750	703	260	101	102	137	1303
33	UM216 OVPAD-KINPA	1454	583	294	4	70	0	951
34	UB535akb AKBON-KSA	1819	0	0	0	41	41	82
35	UA613bkv BKV-KSA	1506	192	183	25	65	76	541
36	ARBAK-EMSAT	918	0	0	0	225	0	225
37	UA618/UB12 BESHO-DKM	1859	0	0	0	62	6	68
38	ARBAK-KSA	183	0	0	144	20	33	197
39	UM215/UV30 MERON-GOM	1006	0	0	92	20	0	112
40	UM731etoxo EMSAT-ET0X	1693	0	971	69	107	0	1147
41	UT143bukavu BATVU-BKV	1311	0	0	0	35	30	65
42	UG862/UT143 AMPER-NALOS	818	0	0	0	28	0	28
43	UA607 BESHO-MPK	2087	0	0	30	17	42	89
44	UA408 KENOT-BJA	596	0	0	6	22	17	45
45	UB535 SAGBU-KSA	1902	0	0	0	5	0	5
46	UG862 /UB12 AMPER-GOM	987	328	163	0	115	114	720
	Subtotal		**25 056**	**25 631**	**11 590**	**15 118**	**17 372**	**94 767**
	Other routes		**2 649**	**3 530**	**1 868**	**2 064**	**5 592**	**15 703**
	General total		**27 705**	**29 161**	**13 458**	**17 182**	**22 964**	**110 470**

3.3 CNS EQUIPMENT INSTALLED

The equipment installed is as follows:

- Communications equipment;
- Navigation equipment;
- Monitoring equipment;
- CNS equipment in airspace management

The current surveillance of the airspace of the DR Congo has not reached the maximum level, despite the various CNS equipment installed. This equipment has limitations that do not allow full and efficient surveillance of the airspace. In this, we believe that a complete surveillance of the latter requires the installation of radar surveillance systems, primary radar associated with secondary radar with the TOPSKY already installed as a visualization system. These surveillance radar systems will provide greater coverage.

4 RESULTS

Starting from the following table 1 which shows the different sectors of the Kinshasa FIR, this allows us to firstly determine the performance of the surveillance radar stations as well as the different areas terminal control (TMA) in which these stations should be located depending on the traffic but also in relation to areas that are not covered by the independent automatic broadcasting system "ADS-B". Consider a radar surveillance system with pulse width and recurrence period T; we have the form factor F = 0.001, whose performance is as follows.

Axial separation: The precision of the radar requires that it is possible to differentiate between two targets located on the same axis with respect to the station and 450 m apart from each other.

Angular separation: We must also be able to differentiate two targets located 150 km from the station and separated from each other by a lateral distance of 2.6 km. Then, we will identify the characteristics imposed on the equipment according to the previous requirements such as: the resolving power, the maximum theoretical range, the angular separation at a certain distance, the number of hits and antenna rotation speed, and the locations of the radar surveillance stations considering the maximum theoretical range.

4.1 PRESENTATION OF DIFFERENT RADAR COVERAGE ON THE DIFFERENT SECTORS

Figure 1 below represents the theoretical radar coverage of the Kinshasa (left) and Lubumbashi (right) sectors.

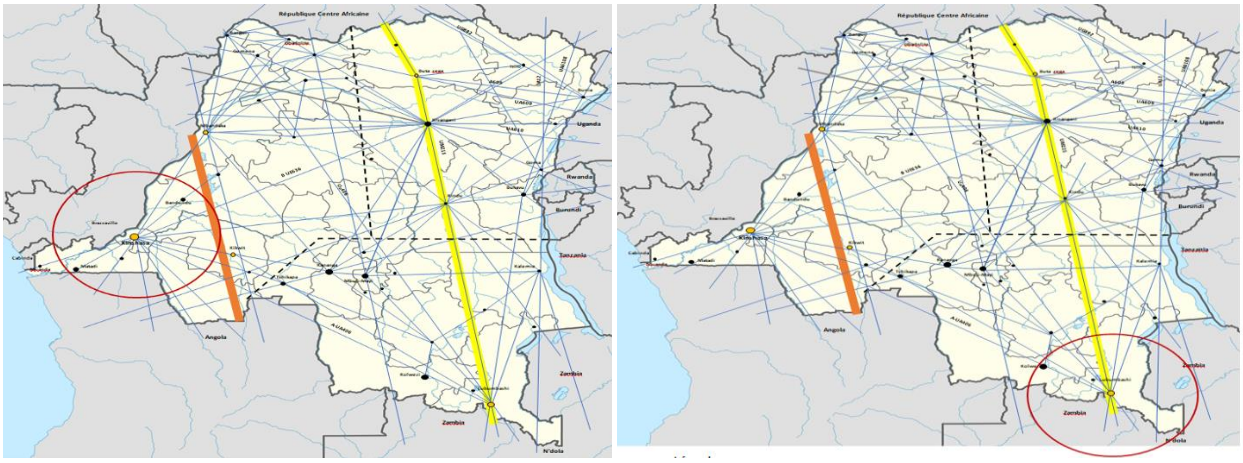

Fig. 1. Theoretical radar coverage of the Kinshasa and Lubumbashi

Figure 2 represents the theoretical radar coverage of the Kisangani (left) and kindu (right) sectors.

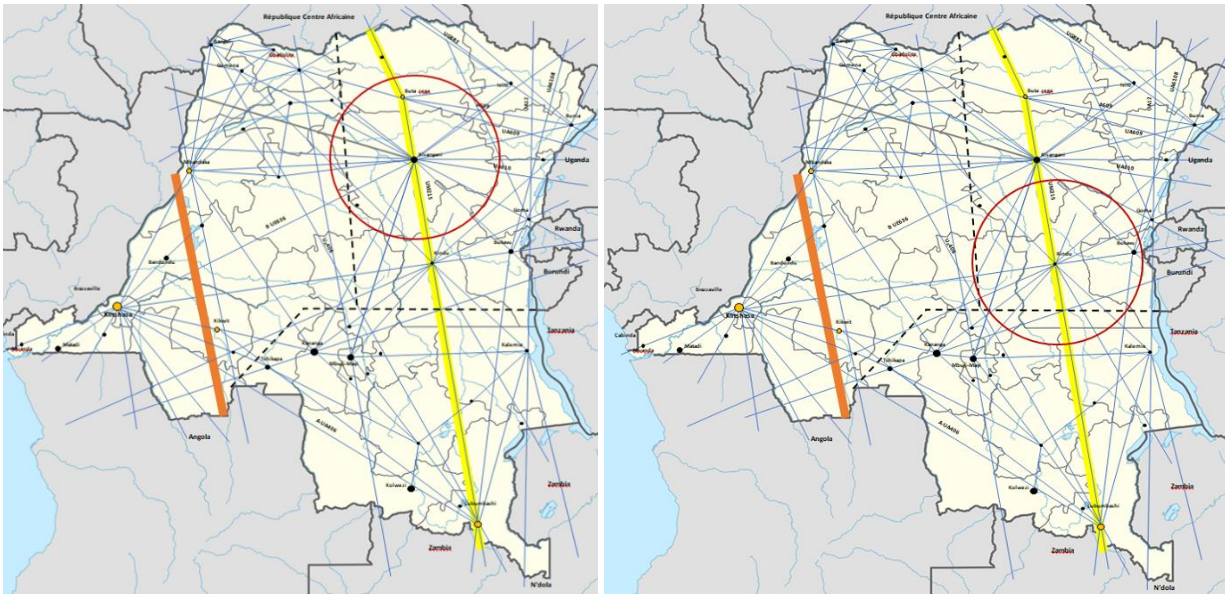

Fig. 2. Theoretical radar coverage of the Kisangani and Kindu

4.2 GLOBAL PRESENTATION OF RADAR COVERAGE ACROSS THE COUNTRY

Figure 3 illustrates the overall presentation of radar coverage across the country (left) and the mesh of ADS-B and Radar coverage (right).

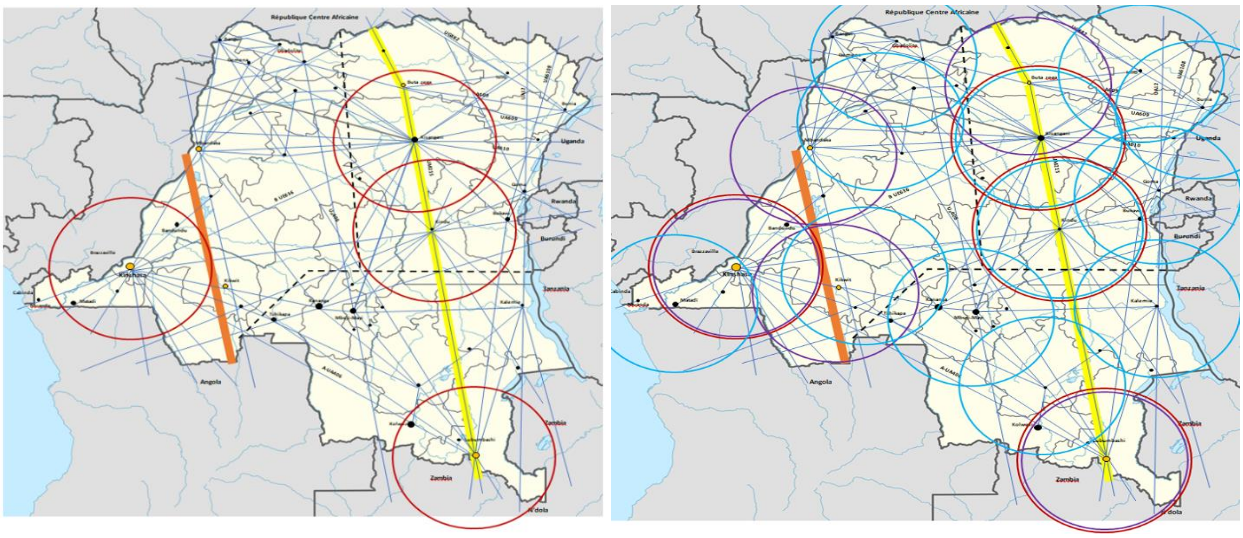

Fig. 3. Overall presentation of radar coverage across the country (left) and the mesh of ADS-B and Radar coverage (right)

With:

- *Red circle: Radar coverage*
- *Purple circle: first phase ADS-B coverage*
- *Blue circle: second phase ADS-B coverage*

As with the ADS-B surveillance system, to route Radar surveillance data to the TOPSKY processing and visualization system, VSAT stations are needed which will establish the various links for routing navigation data transmitted by aircraft. The integration of new surveillance sources (ADS-B, multilateration system and Enhanced Mode S) makes it possible to use kinematic data from sources other than classic radar detection. In particular, the new surveillance sources make it possible to provide precise position, speed and altitude from on-board equipment (ADS-B) or by differential detection time reconstruction (WAM).

5 ANALYSIS AND DISCUSSION

The integration of new surveillance sources (ADS-B, multilateration system and Enhanced Mode S) makes it possible to use kinematic data from sources other than classic radar detection. In particular, the new surveillance sources make it possible to provide precise position, speed and altitude from on-board equipment (ADS-B) or by differential detection time reconstruction (WAM). The continuous improvement of the Surveillance data processing function has resulted in the fusion mechanism, which integrates data from several sensors into a single component.

The architecture of the MST aims to ensure continuity of tracking with a very high level of precision and integrity. The MST receives the filtered and converted surveillance detections and processes each detection individually before using them to update the multi-sensor tracking. Each sensor detection is fully processed before the next one is received and processed. The position consistency check between the different sources is ensured by the fact that independent Multi-radar, ADS-B and WAM tracking is carried out. A second level of control is achieved when Multi-radar tracking is used as a reference for other detections received from other types of sensors.

Radar, WAM or ADS-B detections that would be identified as inconsistent are not used to update the system track. They are nevertheless sent to the multi-sensor tracking initialization processing to instantiate a provisional track. Multi-sensor tracking will confirm the correlation and association of each coherent detection to the monitoring track. When this is the case, the detection then contributes to enriching the state of the track.

Radar surveillance data from radar equipment must be used in common wherever such a solution is possible and advantageous, in particular on both sides of the boundaries of the regions. Some ATS units may have access to more efficient data processing systems than neighboring civil or military auxiliary units. When such a situation arises, solutions should be considered to transmit the processed data from the main body to the auxiliary bodies.

Still with a view to optimizing airspace and improving safety and air traffic flow, the new means of global ADS-B surveillance by satellite is being developed.

The location of surveillance radar stations in the different regions of the DR. Congo such as: Kindu, Kinshasa, Lubumbashi and Kisangani is essential. This approach will greatly contribute to improving the coverage of the country's airspace, and therefore the implementation of the CNS/ATM plan as the International Civil Aviation Organization wishes will be effective. These radar systems will also respond to the different areas not covered by the ADS-B system already installed, but also reinforce the safety of air navigation as a redundancy.

Space-based ADS-B represents a major advance in safety and will enable warnings and early warnings of unexpected course deviations to air traffic personnel. Also useful in a crisis situation, it can locate aircraft in distress, given the many remote regions and oceanic airspace. The more flexible and efficient use of airspace is an important benefit for air carriers. It promotes new routes and new spacing standards that lead to reduced flight time and fuel consumption, particularly for transcontinental flights in the North Atlantic and over the North Pole (to Europe and Asia). Once deployed, space-based ADS-B will facilitate the modification of airspace sectors and boundaries. The result will be increased capacity, new traffic flows that will greatly reduce fuel consumption and greenhouse gas (GHG) emissions, and improved safety in all classes of airspace.

6 Conclusion

In this article, we show that surveillance radar systems provide greater coverage. In our approach we have associated the current ADS-B surveillance system with other surveillance systems, primary radar "PSR" and secondary radar "SSR" to cover all regions of the airspace, and thanks to the function multi-sensor TOPSKY airspace surveillance, security and visualization system all surveillance data from these different systems will be merged. This study will make it possible to increase the overall capacity of the airspace of the Democratic Republic of Congo, but also by improving the service of surveillance provided, and increasing the safety of air navigation. The Democratic Republic of Congo would have a more complete system to effectively provide the surveillance service.

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