ADS-B/OUT/M — NI/04
14/08/19

Reunión de implementación de la Vigilancia dependiente automática – emisión (ADS-B OUT) para las regiones NAM/CAR
(ADS-B/OUT/M)
Ottawa, Canadá, del 21 al 23 de agosto de 2019

Cuestión 5 del Orden del Día: **Otros asuntos**

POSIBLE IMPACTO DE PEQUEÑOS UAS TRANSMITIENDO SOBRE 1090MHZ

(Presentada por el Secretario del Grupo de expertos de Seguridad)

RESUMEN EJECUTIVO	
Esta Nota de información resume las discusiones del Grupo de expertos de vigilancia de la OACI sobre el posible impacto de pequeños UAS transmitiendo en 1090 MHz.	
Objetivos Estratégicos:	• Seguridad Operacional • Capacidad y eficiencia de la navegación aérea • Desarrollo económico del transporte aéreo
Referencias:	• Información del Grupo de expertos de Seguridad de la OACI

1. Introducción

1.1 El Grupo de expertos de Seguridad (SP) está a cargo de la Comisión de navegación aérea para realizar estudios específicos y desarrollar disposiciones técnicas y operacionales de la OACI para sistemas de vigilancia aeronáutica, sistemas anticolisión y sus aplicaciones como se describe en el Plan Mundial de Navegación Aérea (GANP). En la 8ª y 9ª reunión del Grupo de trabajo de vigilancia aeronáutica (ASWG) del Grupo de expertos de vigilancia, que se llevaron a cabo en septiembre de 2018 y marzo de 2019 respectivamente, se presentaron diversos documentos relacionados con algunas limitaciones técnicas asociados con un gran número de pequeños Sistemas de aeronaves no tripuladas (UAS) intentando utilizar aviónica de vigilancia Modo S actual.

2 Sumario de discusión en la ASWG/8 y ASWG/9

2.1 SP3-ASWG8-WP/15 - Problemas de dirección y espectro para pequeños UAS (Apéndice A)

2.1.1 El WP/15 se presentó en respuesta a la Cuestión del Orden del Día ASWG/7-27 para el Sub-grupo técnico (TSG) a fin de investigar e informar problemas con direcciones de aeronaves de 24-bits y espectros 1090 asociados con pequeños UAS. Esta primera parte del WP estipuló que basados en las proyecciones del crecimiento de pequeños UAS en Estados Unidos, la FAA concluyó que no hay suficientes direcciones de la OACI para todos los pequeños UAS (sUAS) previstos.

2.1.2 La última parte del WP/15 explicó dos análisis separados que se llevaron a cabo por Corporación MITRE y la NASA sobre los problemas de espectro asociados con pequeños UAS, asumiendo que dichos vehículos estaban equipados con transmisores ADS-B usando 978 MHz.

2.1.3 Con base en el análisis descrito en el WP/15, se reconoció que: a) el esquema de dirección de aeronaves de 24-bits en el Anexo 10, Volumen III, Capítulo 9 de la OACI, no está diseñado para la alta densidad de los vehículos en un espacio aéreo que se prevé pequeño para los UAS; b) incluso con a niveles de potencia de transmisión de radiofrecuencia (RF) que son equivalentes a los teléfonos celulares (1W), los pequeños UAS operando en una típica área grande urbana en densidades de espacios aéreos de un vehículo por kilómetro cuadrado y equipados con vigilancia dependiente automática – emisión (ADS-B OUT) se esperaría que invalidara cualquier sistema de vigilancia estándar de la OACI operando sobre 978 MHz o 1090 MHz. Por lo tanto, la WP concluyó que el equipo ADS-B OUT extendido (como se define en RTCA/EUROCAE MOPS y documentos de la OACI) de pequeños UAS no es una alternativa fehaciente.

2.2 **SP3-ASWG8-WP31 – Análisis inicial de posibles impartos de pequeños UAS transmitiendo sobre 1090 MHz en Europa *(Apéndice B)***

2.2.1 Después de la presentación de la WP/15, se presentó la SP3-ASWG8-WP/31 que mostró un estudio inicial para investigar cuál sería el impacto de las operaciones de sUAS equipados con ADS-B en la detección de aeronaves con Modo S. la WP/31 presentó esos resultados y preguntó al grupo revisar posteriormente este asunto para tener un acuerdo común.

2.2.2 En todos los casos descritos en la WP/15, la adición de transmisiones de sUAS en 1090 MHz resultó es una reducción de distancia de la estación terrestre ADS-B para mantener la misma probabilidad de actualización (98.5%). Para niveles de potencia de 0.1W, la reducción de distancia fue del 3% para un escenario con 1 UAS/Km2 y hasta 8% para un escencario con 3 UAS/Km2. Esto puede ser considerado como un “mínimo impacto” a pesar de que incrementará el costo de una red de receptor ADS-B terretre. Para niveles de potencia de 1W, la reducción de distancia es más significativa, subiendo hasta 41% en una actualización de 5 segundos de intervalo y 38% para una actualización de 8 segundos de intervalo en un ambiente Charles De Gaulle (CDG) (escenario 6). Sin embargo es una gran reducción para el escenario 5 (1UAS/Km2), en un periodo de actualización de 5 segundos la distancia de CDG permanece en un valor similar a la distancia del ADS-B en Frankfurt en 2016 sin UAS. Ambientes con un número mayor de aeronaves (alta densidad de aeronaves) tienen transmisiones ADS-B “menos visibles” por sUAS. La WP/13 concluyó que el impacto debería ser mayormente investigados para otros escenarios incluyendo los receptores a bordo 1090.

2.2.3 La Nota de estudio SP3-ASWG8-WP/15 y SP3-ASWG8-WP/31 están bajo otros documentos en la siguiente página electrónica: https://www.icao.int/NACC/Pages/meetings-2018-adsbout.aspx.

2.3 Discusión y conclusión en la ASWG/8 y ASWG/9

2.3.1 Muchos miembros del SP acordaron con las preocupaciones indicadas en ambas Notas de estudio descritas en los párrafos 2.1 y 2.2, especialmente con lo relacionado a los problemas de espectro asociados con pequeños UAS. También surgieron muchas preocupaciones relacionadas con la gestión de los Estados de las direcciones de aeronaves de 24-bits. Sin embargo, también se señaló que dependiendo de los Estados hay diversas maneras de gestionar las direcciones de aeronaves y no es fácil categorizar UAS solamente dependiendo de su peso. Hay escenarios en los que inclusive sUAS tienen necesidades específicas para utilizar direcciones de aeronaves de 24-bits. Por tanto, muchos Estados tienden a evaluar las situaciones caso por caso cuando reciben una aplicación de una comunidad UAS. Se sugirió que el SP debería proporcionar alguna directriz a los Estados para gestionar direcciones de aeronaves de 24-bits apropiadamente.

2.3.2 Basados en la conclusión del ASWG/8 descrita en el párrafo 2.3.1, el Sub-grupo técnico del Grupo de expertos de vigilancia redactó un material de orientación para los Estados, que se presentó en la Reunión ASWG/9, llevada a cabo en marzo de 2019. La Reunión ASWG/9 revisó el borrador del material de orientación y lo actualizó durante la reunión.

2.3.3 Dada la urgencia para comunicar esta información a los Estados, la Secretaria de la OACI fue encargada para redactar una Comunicación a los Estados sobre este asunto, en coordinación con otros grupos de expertos como el Grupo de expertos sobre sistemas de aeronaves pilotadas a distancia (RPASP) y el Grupo de expertos sobre gestión del espectro de frecuencias (FSMP).

3 Discusión

3.1 Esta Nota de información incluye un borrador del material de orientación, inicialmente desarrollado por el Grupo de expertos de vigilancia de los Estados, bajo iniciativas activas de la OACI para la operación confiable y segura de sistemas de vigilancia para validar la utilización de 1090 MHz y para la no asignación de la dirección de la aeronave de 24 bits para UAS volando exclusivamente en altitud muy baja.

3.2 Las frecuencias 1030 y 1090 MHz actuando como frecuencias pares, apoyan muchos sistemas de vigilancia aeronáutica, incluidos el radar secundario de vigilancia (SSR), multilateración, Sistema anticolisión de a bordo (ACAS) y la Vigilancia dependiente automática – radiodifusión (ADS-B).

3.3 La utilización adecuada y eficiente del ancho de banda disponible y capacidad de 1090 MHz es un elemento clave para una operación segura de los sistemas de vigilancia. Los estudios realizados por el SP identificaron problemas y limitaciones técnicas potenciales sobre la operación de los sistemas de vigilancia con la presencia d un número considerable de aeronaves no tripuladas (UA) equipadas con transmisores ADS-B OUT de 1090MHz, pero operando exclusivamente a muy baja altitud.

3.4 Reconociendo el impacto que podría resultar en una operación de aeronaves adversa en seguridad operacional, se ha desarrollado material de orientación para los Estados a fin de validas la utilización de 1090MHz y para la no asignación de la dirección de aeronaves de 24-bits a UAS. Se anexa dicho material de orientación en el **Apéndice C**).

3.5 Considerando la importancia de este asunto, esta Nota de información tiene como objetivo proporcionar información anticipada a las regiones para aumentar la conciencia sobre este tema.

Nota – el borrador del material de orientación anexo a esta Nota de información todavía está en discusión y revisión de otros grupos de expertos. La Comunicación a los Estados sobre este asunto que incluye la versión final del material de orientación será proporcionada oportunamente.

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SP3-ASWG8-WP/15
24/9/2018

International Civil Aviation Organization

WORKING PAPER

THIRD MEETING OF THE SURVEILLANCE PANEL (SP/3)

Eighth meeting of the Aeronautical Surveillance Working Group (ASWG/8)

Montreal, Canada, 24 – 28 September 2018

SP3 Agenda item 3: Aeronautical surveillance systems and Airborne Collision Avoidance systems

ASWG8 Agenda Item 6: Mode S and Extended Squitter

Address and Spectrum Issues for Small UAS

(Prepared by **Doug Arbuckle** and **Bob Pomrink**)
(Presented by **Doug Arbuckle**)

SUMMARY

This Working Paper has been prepared in response to Action Item ASWG/7-27, "TSG to investigate and report back on 24-bit aircraft address and 1090 MHz spectrum issues associated with small UAS."

ACTION ITEM AND WP TYPE

Response to Action Item ASWG/7-27

TSG WP Type: B. Draft CP Material or proposal for WG discussion and comment

1. INTRODUCTION

1.1 Various papers presented at ASWG/7 engendered discussions about some of the technical and practical limitations associated with large numbers of small UAS attempting to make use of current Mode S surveillance avionics. As an outcome of these discussions, the TSG was requested (via Action Item ASWG/7-27) to investigate and report back on 24-bit aircraft address and 1090 MHz spectrum issues associated with small UAS.

2. Discussion

2.1 Availability of 24-bit aircraft addresses for small UAS

2.1.1 The 24 bits allocated in Mode S for aircraft address allows a unique address to be allocated to 16,177,214 aircraft, aerodrome surface vehicles, obstacles or fixed Mode S target detection devices for surveillance and/or radar monitoring purposes. See ICAO Annex 10, Volume III, Chapter 9. ICAO has allocated much of the available addresses to the various ICAO contracting States. For example, the Russian Federation and the U.S. have each been allocated 1,048,576 addresses (the largest block allocated by ICAO).

2.1.2 Within the U.S. allocation, most of the available addresses (over 910,000) are allocated for civil aircraft use; the remainder are allocated for testing (just over 1,000) and for use by State aircraft (over 100,000). There are over 350,000 registered civil aircraft in the U.S. and over 10,000 State aircraft. If there were no growth in these fleets, then a maximum of 600,000 aircraft addresses would be available. As of 2 April 2018, there were over 154,000 registered small UAS in the U.S. – these small UAS are registered under Part 107 of the U.S. Code of Federal Regulations, section 14. Additionally, there are over 880,000 "hobbyist" small air vehicles registered in the U.S.

2.1.3 Projections of small UAS growth in the U.S. indicate that it is likely that there will be over a million such vehicles by 2025. The FAA has therefore concluded that there are insufficient ICAO addresses for all of the envisioned small UAS. Note that FAA does not issue ICAO addresses to small UAS registered under Part 107 of the U.S. Code of Federal Regulations, section 14. Also, the FAA does not issue ICAO addresses to "hobbyist" small air vehicles registered in the U.S. Only aircraft/vehicles registered via the FAA's Civil Aircraft Registry are issued an ICAO address.

2.2 Spectrum issues associated with small UAS

2.2.1 At FAA's request, MITRE Corporation's Center for Advanced Aviation System Development (CAASD) conducted analyses which led to an AIAA paper entitled, "ADS-B Surveillance System Performance with Small UAS at Low Altitudes." An earlier study, published in 2016, explored the impact of very high densities of small UAS (sUAS) transmitting ADS-B using the Universal Access Transceiver (UAT). The AIAA paper reports on an analysis which examined a broader range of operating scenarios characterized by various sUAS traffic densities and transmission power levels. The AIAA paper considered the implications of varying sUAS traffic density and transmission power on air-to-air and air-to-ground uses of ADS-B. The AIAA paper was presented at the AIAA Science and Technology Forum and Exposition (SciTech) in January 2017 and is referenced below. Note that although this paper is cited below (for its analysis results), the FAA does not agree with many of the statements made in sections V (Key Findings) and VI (Conclusion and Future Work) of the paper. Table 5 of the AIAA paper shows the impact on FAA ground stations of various assumed levels of UAS traffic (in addition to the assumed manned aircraft within line of sight to the ground station). RF experts within the FAA believe that avionics manufacturers cannot accurately control RF transmit power below 1W, nor can FAA/FCC effectively regulate RF transmit power levels below 1W. Therefore, FAA focuses on the 1W results in the AIAA paper, which shows that even the minimum analysed density of 0.5 sUAS per square kilometre / 1.75 sUAS per square mile (1400 sUAS operating within 800 square miles) causes FAA ground stations to become blinded from seeing manned aircraft ADS-B reports.

2.2.2 NASA performed a separate analysis from the MITRE CAASD study referenced above, using an independent model developed by NASA. See reference below; this paper is also attached since it is not yet available online. One key finding, based on NASA's probability of detection threshold of 80% or better, was that a 1W ADS-B transmitter for sUAS on the Air-to-Ground link would not meet this threshold.

2.2.3 Note that the MITRE CAASD and NASA analyses are based on models and do not include the impact of real world interference that the FAA has observed on both 978 MHz and 1090 MHz frequencies at numerous ground station locations. Therefore, FAA expects that the MITRE CAASD and NASA analysis results are optimistic relative to what would be observed in implemented systems.

2.2.4 The 1090 MHz frequency is currently more congested than the 978 MHz frequency, since 1090 MHz is also used by ATCRBS and Mode S systems (TCAS, SSRs and multilateration systems). Therefore, any impacts on 1090 MHz from sUAS ADS-B transmissions on this frequency are expected to be significantly worse than those calculated for UAT on 978 MHz.

3. Conclusion

3.1 The 24-bit aircraft address scheme in ICAO Annex 10, Volume III, Chapter 9 was not designed for the high density of vehicles in an airspace that is foreseen for small UAS.

3.2 Even at RF transmit power levels which are equivalent to cell phones (1W), small UAS operating in a typical large urban area at airspace densities of one vehicle per two square kilometres and equipped with ADS-B Out would be expected to cripple any ICAO standard surveillance system operating on 978 MHz or 1090 MHz.

3.3 Therefore, the FAA believes that widespread ADS-B Out equipage (as defined in RTCA/EUROCAE MOPS and ICAO documents) by small UAS is not a feasible alternative.

4. Actions on the meeting

The meeting is invited to consider this information and provide it to other entities as appropriate.

REFERENCES

Michael Guterres, Stanley Jones, Greg Orrell, and Robert Strain. "ADS-B Surveillance System Performance With Small UAS at Low Altitudes", AIAA Information Systems-AIAA Infotech @ Aerospace, AIAA SciTech Forum, (AIAA 2017-1154)
https://doi.org/10.2514/6.2017-1154

Konstantin J. Matheou, Rafael D. Apaza, Alan N. Downey, Robert J. Kerczewski, and John Wang. "ADS-B Mixed sUAS and NAS System Capacity Analysis and DAA Performance", ICNS Conference Paper 2B3, 2018.
[[see attached]]

ADS-B MIXED SUAS AND NAS SYSTEM CAPACITY ANALYSIS AND DAA PERFORMANCE

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I. Abstract

Automatic Dependent Surveillance-Broadcast (ADS-B) technology was introduced more than twenty years ago to improve surveillance within the US National Airspace Space (NAS) as well as in many other countries. Via the NextGen initiative, implementation of ADS-B technology across the US is planned in stages between 2012 and 2025. ADS-B's automatic one second epoch packet transmission exploits on-board GPS-derived navigational information to provide position information, as well as other information including vehicle identification, ground speed, vertical rate and track angle. The purpose of this technology is to improve surveillance data accuracy and provide access to better situational awareness to enable operational benefits such as shorter routes, reduced flight time and fuel burn, and reduced traffic delays, and to allow air traffic controllers to manage aircraft with greater safety margins. Other than the limited amount of information bits per packet that can be sent, ADS-B's other hard-limit limitation is capacity. Small unmanned aircraft systems (sUAS) can utilize limited ADS-B transmission power, in general, thus allowing this technology to be considered for use within a combined NAS and sUAS environment, but the potential number and density of sUAS predicted for future deployment calls into question the ability of ADS-B systems to meet the resulting capacity requirement. Hence, studies to understand potential limitations of ADS-B to fulfill capacity requirements in various sUAS scenarios are of great interest. In this paper we, validate/improve on, previous work performed by the MITRE Corporation concerning sUAS power and capacity in a sUAS and General Aviation (GA) mixed environment. In addition, we implement its inherent media access control layer capacity limitations which was not shown in the MITRE paper. Finally, a simple detect and avoid (DAA) algorithm is implemented to display that ADS-B technology is a viable technology for a mixed NAS/sUAS environment even in proposed larger mixed density environments.

II. Introduction

ADS-B modelling and simulation work has been on-going at NASA's Glenn Research Center (GRC) for the past few years. The motivation to simulate ADS-B technology is due to its acceptance by the Federal Aviation Administration (FAA). Due to the emergence of smaller drones being sold throughout the US and the rapid evolution of drone technology, many safety, commercial, and recreational types of applications will drive the number of drones (aka sUASs) to populate the skies, such that the inclusion of ADS-B technology on future drones may be a logical safety-enhancing extension. Thus, work on two tasks are presented that show simulation results in a mixed sUAS capacity environment, and further extends the analysis to display initial DAA algorithmic results.

III. Inspiration and Approach

Thus, the first step is to understand ADS-B performance in a mixed, sUAS and NAS, capacity environment. This has been completed previously by Guterres, Jones, Orrell, and Strain [1]. In work supporting UAS Traffic Management (UTM) research, GRC leveraged the work in [1], validating the results with GRC's ADS-B simulation model. GRC's model includes theoretically proven channel includes theoretically proven channel model algorithms for UTM including: 1) AWGN, 2) link budget, 3) multipath propagation (Fresnel coefficient), and 4) 900-1090MHz band co-cannel interference, a somewhat different approach from [1]. In implementing individual channel models, the GRC model specific channel impairments to be analyzed, thus allowing better checks to the overall model.

The ADS-B waveform is a Time Division Multiple Access (TDMA) based communications modulation [2]. Due to this slotted modulation design, there is an inherent capacity limit at the MAC layer. For air-to-air (A2A) and air-to-ground (A2G) ADS-B communications, there are a total of 3,200 Message Start Opportunity slots (MSOs) [3]. Theoretically the most aerial vehicles (AVs) at one time that can communicate are 3,200. But due to the random way the MSO's are chosen once the link budget is closed, another added layer of throughput interference is inherently added – MSO collisions. This additional functional throughput MSO Collisions algorithm has been added to the GRC ADS-B model. Thus, a more true 'probability of decoding' framed information coming over the air using ADS-B technology can be predicted for high capacity ADS-B usage. This is a performance feature extends the analysis in [1].

From [1], three transceiver types are implemented: 1) ADS-B, 2) Mode S, and 3) Air Traffic Control Radar Beacon System (ATCRBS). All these 3 technology modes share the 900-1090MHz spectrum, thus the need for co-channel interference algorithm in the GRC model. Also, the GRC model allows for various 'radius ranges' and various heights per 'radius range' that can be altered. The model currently only allows an average constant air speed per AV per 'radius range'. All the above parameters can be altered including transmit power for sUASs. The GRC ADS-B model will be discussed in more detail in the next section.

IV. ADS-B Model Details

The 'ADS-B Capacity' model was coded for air-to-air (A2A) and air-to-ground (A2G) analyses. The simulation was modelled similarly to [1]. The airport is located in the center, bottom of the cylinder at the 3-dimensional point (0, 0, 0). The 3 dimensions are: 1) distance x, 2) distance y, and 3) altitude. The National Air Space (NAS) general aircraft (GAs) are simulated to have an average altitude of 20,000 ft. and all have an average speed of 300nm/hr. The sUASs, on the other hand, are all randomized in altitude ranging between 50 to 400 ft. The sUAS average speed was chosen to be 50nm/hr. for all sUASs. All sUASs and GA's initial distance x and distance y placement were randomized at the beginning of the simulation to be between 2-21 nm from the center radially. This range was chosen to allow the high density 5 $^{AVs}/_{km^2}$, medium density 3 $^{AVs}/_{km^2}$, and low density 1 $^{AV}/_{km^2}$. Finally, all AV's are incoming/enroute towards the airport radially in a straight line fashion.

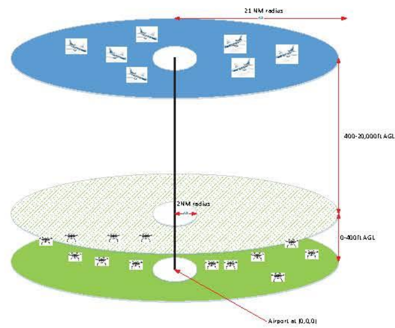


Figure 1- NAS/sUAS Airspace Simulation Approach

It is important to define the types of flying objects referred to in this paper. AV's are the most generalized type of flying objects that include GA and sUASs. GA is the type of aircraft that flies in the NAS, while sUAS are referred to as drones that is not part of NAS.

In table 3 from [1], there are 16 density scenarios listed. For this paper, scenarios 1 through 12 have been simulated. For traffic density, the AV mix between lower flying sUASs and NAS type flying planes (GA) for all simulations are: 95% sUAS, 5% GA, where the types of radar technology for the 5% GA planes are split as follows: 3% ADS-B, 1% Mode S, and 1% ATCRBS. This mix again was chosen due the approach in [1].

Table 1-MITRE 12 Scenarios

	Transmit Power (W)				Traffic Density (AVs/km^2)		
	1.00	0.10	0.05	0.01	5	3	1
Scen 1	X				X		
Scen 2		X			X		
Scen 3			X		X		
Scen 4				X	X		
Scen 5	X					X	
Scen 6		X				X	
Scen 7			X			X	
Scen 8				X		X	
Scen 9	X						X
Scen 10		X					X
Scen 11			X				X
Scen 12				X			X

The basis of this paper's analysis is to understand how the power of sUAS in various high density scenarios affects communications performance in two ways: 1) probability in closing the communications link and 2) capturing a MSO and completing the MAC layer process to fully send framed information data to the receiver. Once the signal strength is good enough to enter the ADS-B receiver and there is an available MSO slot in a high ADS-B density scenario, the incoming framed information of the ADS-B signal can be used to begin 'smart' algorithm, one type of which is referred as Detect and Avoid (DAA).

The DAA approach was inspired by [2]. To understand capacity limitations is important, but an initial type of DAA algorithmic analysis should be done to better understand full UTM processing capacity and system performance of ADS-B technology.

V. DAA Model Details

Once the framed information passes through the MAC layer (network layer 2), the incoming bit-framed information can be processed. Detect and avoid (DAA) algorithms are processed at higher levels of the network stack. But due to channel impairments, AV ADS-B transceiver capacity, and inherent waveform capacity limitations due to TDMA modulation, the probability of the incoming frame being processed every second epoch will be less than 1.0. As shown in the results sections, the probability of a frame getting through the first time per certain capacity situations can vary from 0.20 to 0.95. Thus, an analysis using a DAA algorithm may increase the probability to 'track' other adjacent AVs utilizing ADS-B technology. But as always, there is a compromise in other performance parameters that may be lessened. For example, when the detection of a nearby ADS-B transceiver takes longer due to DAA processing, the situation may be too late and a crash may occur.

The DAA approach and design parameter definitions were inherited from [4]. The following DAA design parameter definitions are provided:

1) *Measurement Received* – means that the link budget of the ADS-B receiver was met and there were no MSO collisions. Thus, the received framed measurement information is then assumed to have been decoded.
2) Set Number – the count of *Measurement Received* times. Set number minimum is 2.
3) *Track* - when a number of *Set Number* times is counted within a *Maximum Size Set.*
4) *Maximum Set Size* – maximum number of measurements that can be missed between two received measurements and allow them to still form a track.
5) *Kill Track* – the number of times missed MSO slot before stopping to track an AV.

For example, when *Max Set Size* = 6, this means a maximum count of 4 MSO slots can be missed between 2 MSO caught slots before a *Track* is created. When Kill Track =1 means that the first missed *Measurement Received,* the *Track* will cease to exist and the whole process needs to start over. Using this DAA algorithmic terminology, an analysis of this is done within the next section.

VI. Channel Model Details

There are 4 algorithmic channel models being implemented within this model: 1) AWGN, 2) Link Budget, 3) Multipath Interference, and 4) Co-channel Interference.

Any communications system is normally baselined using an Average White Gaussian Noise channel. The energy per symbol over noise (S) is used as a parameter within the Link Budget model as shown below equation. For reference, the ADS-B modulation waveform is 8-DPSK. Thus, a total of 3 bits per symbols are sent over the air. Equation 1 sums up the link budget model where, either the minimum symbol power needs to be met, or the maximum transmitter distance can be found within an AWGN channel [3].

$$R_{max} = \left(\frac{P_t G_t^2 \sigma \lambda^2}{(4\pi^3) S_{min}}\right)^{1/4} \qquad \textit{eq. 1}$$

Table 2 is a link budget table example that shows parameters and real values for a link budget. In this particular case an ADS-B transmitter power Pt=20dB with a certain grazing angle within a smooth surface multipath environment should be able to close the link within 90 nm (blue and red highlighted values are linear, not dB).

Multipath interference model has been duplicated from [1] and [2] using the below equation.

$$M(E,A) = 20log\left[C_o(E)exp\left(-2\left(\frac{2\pi}{\lambda}\right)^2 s^2 sin^2(E)\right)\right] + g_T(E,A) + g_R(E,A) \qquad \textit{eq. 2}$$

Figure 2 is the reproduced Fresnel coefficient value, C, for a smooth surface (worst case) multipath scenario which is the one used in [1].

Table 2-Link Budget Example

			Comments
NUMERATOR	Pt(dB)	20.0	Power of transmitter in dB
	Pt	100.0	value
	Gt	1	Gain of tramsitter antenna
	Sigma	0.5	Surface area of target (ADS-B level 3)
	wavelength	0.3	wavelength of carrier wave
	Gr	1	Gain of receiver antenna
	tau	1.00E-06	pulse timeframe in seconds
	F Ratio	0.72	dependent of Grazing angle
DENOMINATOR	k	1.38E-23	Boltzman's constant
	Ts	967	System temperature of transceiver
	D0(1)(dB)	13	Detectability factor in dB
	D0(1)	19.95	Detectibility factor in linear value
	Lalpha(dB)	-5.14	Multipath in dB - Depends on Grazing Angle
	Lalpha ratio	0.31	Multipath linear value
	Lt(dB)	1	Line Transmission Loss
	Lt Ratio	1.26	Line Transmission loss linear value
	Rm=	90.0	Maximum needed range in NM (For Level 3)

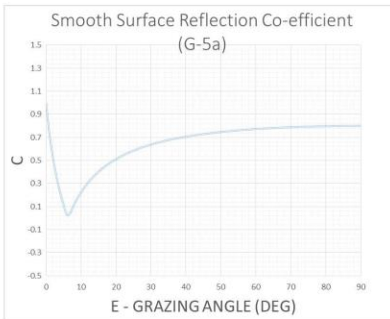


Figure 2 – Fresnel Coefficient Plot for Smooth Surface

ADS-B and the other 2 legacy technologies used currently in the NAS, Mode S, and ATCRBS, utilize the same 980-1090MHz spectrum. [1] implemented a Co-Channel interference model, where the equivalent was implemented with the GRC model. The algorithm output is shown Figure 3.

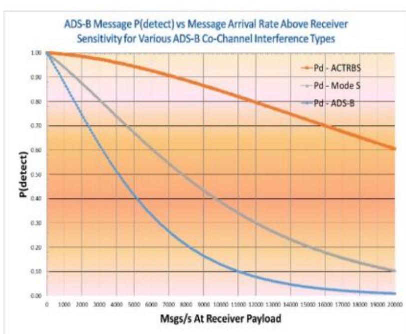


Figure 3 – ADS-B P(detect) vs Message Arrival Rate for Various Co-Channel Interference Types

VII. Results and Analysis

The following sections will present the simulation output and will be contrasted and compared to previous work and then will follow with additional information not presented in previous findings. The UAT system is modelled as an AWGN communication system where additional channel algorithm impairments are used to acquire the probabilistic values for both A2A and A2G implementations. The sections are split by A2A and A2G findings.

A. A2A Analysis

A2A analysis considers the communications between AVs only. In general, there are more multipath affects due to the AV's altitude, speed, and grazing angle. Likewise, depending on AV speed and distance away from each other, the transmission link between AVs may or may not close. The purpose of these simulations is to understand capacity limitations for future mixed sUAS and NAS GA environments. The percentages chosen were to compare to the MITRE previous results. The authors believe these percentages to be different than the ones used, but were kept the same for comparison reasons. Again, the mixed AV environment is a 95% sUAS using ADS-B UAT, to 3% GA ADS-B UAT, to 1% GA Mode S UAT, to 1% GA ATCRBS. A total of 20,000 AVs for High Density, 12,000 medium Density, and 4,000 AVs for Low Density.

1. High Density Detailed Analysis

It was determined a high density environment of $5\ ^{AVs}/_{km^2}$ to be implemented with the defined percentage breakdown. sUAS 'communications link' distance was varied while sUAS transmitted power was kept the same for all sUASs. As the distance is varied, the receiving end antenna receiver captures a certain Es/No symbol power (S) level which either closes the link or the link stays open, thus never communicating with the adjacent AV's receiver.

A parameter than was deliberately chosen to be different than [1] was the transmitter power of the GA. The GA ADS-B transmitter power was at 100W, as opposed to 25W that was in [1]. The simulation performance output results in Table 3 show the worst case performance between: 1) 'Close Link Budget' which includes co-channel interference, AWGN, and multipath and 2) all channel impairments adding the MSO collisions which is referred to as 'Probability of Decoding'. The values from [1] are in bold.

Table 3 - A2A Worst Case Probabilities

	A2A			
	High Density			
Scenario	1	2	3	4
Worst Case Prob of Decoding	0.28	0.50	0.58	0.68
Worst Case Prob of Link Closing	0.65	0.65	0.65	0.80
From Mitre Table	**<0.25**	**0.1**	**0.3**	**0.78**
sUAS Distance MAX	3.5	2.0	1.5	1.0
	BLOS	BLOS	LOS	LOS

We are assuming that the MITRE paper analysis only went as far to 'Probability of Closing Link'. When we add MSO collisions, the probabilities seem to match a little better, but not exactly correlated. It is the opinion of the authors that due to running actual channel algorithms, thus capturing many nuances, our results are more accurate. They also distinguish between the two types of probabilistic performance, 'Probability of Decoding' and 'Probability Closing Link'.

Figure 4 shows the simulation results of the 1.0W baseline high density performance output of the GRC simulation. The x axis shows the 'head-on' distance between sUAS and another sUAS or GA. The power of the sUAS transmitter stays constant, but the 'head-on distance' increases. As the distance increases, the probability of a sUAS 'closing the link' starts reducing. This is the black line labelled 'sUAS ABOVE Receiver Operating Point'. Notice the more power, the longer 'Head-On Distance' the sUAS can communicate – see Table 3.

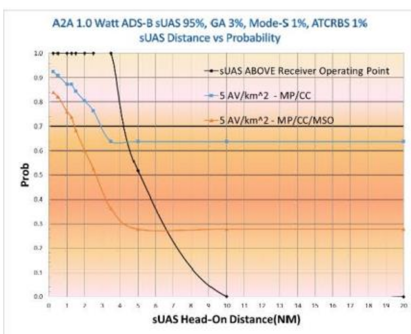


Figure 4 - A2A High Density 1.0W sUAS Transmit Power – Scenario 1

The blue line called 'MP/CC' represents the probability of closing the link when co-channel and multipath channel impairments are added. Finally, the additional MAC layer capacity performance (MSO collisions), once the link is closed after co-channel and multipath, is added. This is the red line called MP/CC/MSO which is the worst case probability of getting an ADS-B frame to the higher network layer levels of the receiver called 'Probability of Decoding'. It is important to note that once the sUAS's head-on distance is too long where the black link budget line is 5-10% or higher, the probability lines/curves retain their last value. This is because there are no more sUASs to cause more impairments than the last probability value measured.

Figure 5-Figure 7are the remaining High Density scenario plots that map worst case values in Table 3.

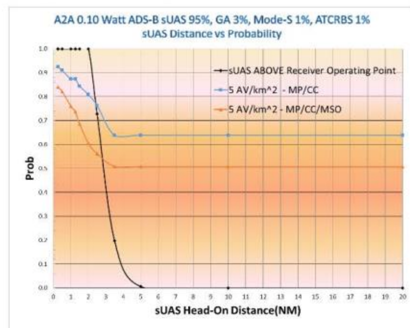


Figure 5 - A2A High Density 0.1W sUAS Transmit Power – Scenario 2

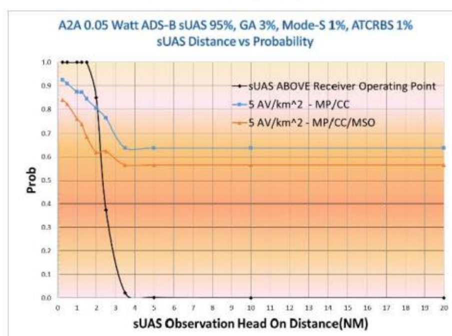


Figure 6 - A2A High Density 0.05W sUAS Transmit Power – Scenario 3

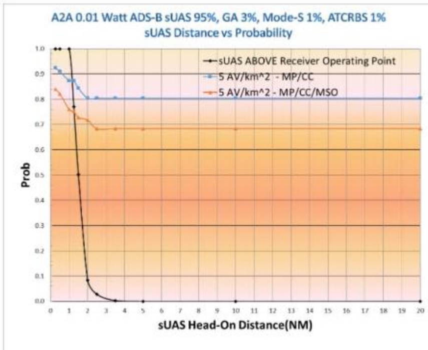
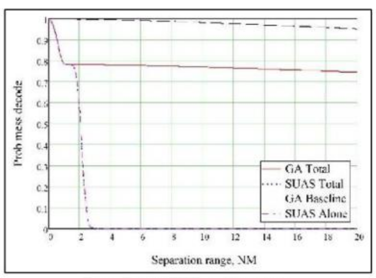


Figure 7 - A2A High Density 0.01W sUAS Transmit Power – Scenario 4

Figure 8 is Scenario 4 from [1]. When you compare the 0.78 'Probability message decode' to the GRC blue line which we assume is equivalent in meaning, they are very similar – 0.78 vs 0.80, but this does not include MSO collisions. When you add the additional MSO collisions probability, the actual 'Probability of Decoding' really is at a worst-case of 0.68 for a high density sUAS environment using 0.01W of transmitter power.



Shared-use UAT performance

Figure 8 – MITRE's A2A High Density 0.01W sUAS Transmit Power – Scenario 4

The GRC ADS-B model is a Monte-Carlo simulation that uses various channel algorithm models to estimate an Es/No value to close the link. This EsNo value is then compared to the ADS-B receiver operating point of 8dB Es/No, which per the standard, is sufficient to meet a BER of 1e-5 [2]. Figure 9 shows the tracking of the Es/No values that show best case and worst case Es/No receiver values. This plot is for Scenario 4.

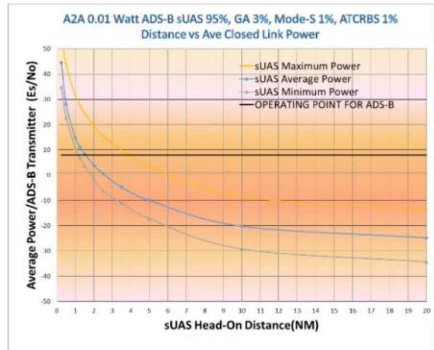


Figure 9 – Scenario 4 Average, Minimum, and Maximum Es/No Levels per sUAS Head-On Distance

Figure 9 shows, on average, any head-on distance between sUAS and any other type of ADS-B AV that is less than ~1.5nm will close the link. To be conservative as what is reflected in the table, the minimum curve is used, thus 1.0 nm will guarantee the 'closing of the link' 100% of the time. Of course, we will need to see what the ADS-B MSO collision probability is at this point to ensure that the frame will go through the MAC layer.

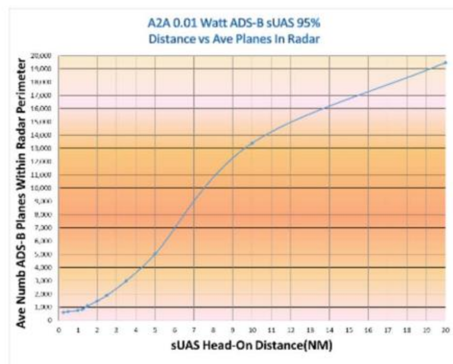


Figure 10 – Scenario 4 Average Number of ADS-B AVs Within Radar Range per sUAS Head-On Distance

Figure 10 shows how many average number of ADS-B AVs, which includes all sUASs and GAs, which are within each sUAS closing link perimeter.

2. Medium and Low Density Analysis

The remaining medium and low density analyses are shown in Table 4. Notice that the GRC simulations results are much more optimistic than those of [1] for 'Probability of Link Closing'.

Table 4 - A2A Worst Case Probabilities for Medium and Low Densities

	A2A							
	Medium sUAS Traffic				Low sUAS Traffic			
Scenario	5	6	7	8	9	10	11	12
Worst Case Prob of Decoding	0.48	0.70	0.79	0.84	0.55	0.66	0.72	0.95
Worst Case Prob of Link Closing	0.68	0.80	0.88	0.91	0.68	0.75	0.78	0.98
From Mitre Table	<0.25	0.27	0.48	>0.78	0.25	0.68	0.8	>0.8
sUAS Distance MAX	3.5	2.0	1.5	1.0	3.5	2.0	1.5	1.0
	BLOS	BLOS	LOS	LOS	BLOS	BLOS	LOS	LOS

B. A2G Analysis

The A2G analysis is very similar to the A2A analysis except, the ground station is considered to be always at low altitude, thus the multipath interference will be more constant. See Tables 5and 6.

Table 5 - A2G Worst Case Probabilities for High Density

	A2G			
	High sUAS Traffic			
Scenario	1	2	3	4
Worst Case Prob of Decoding	0.14	0.28	0.40	0.51
Worst Case Prob of Link Closing	0.18	0.33	0.52	0.60
From Mitre Table	<.25	<.35	<.1	0.38
sUAS Distance MAX	3.5	2.0	1.5	1.0
	BLOS	BLOS	LOS	LOS

Table 6 - A2G Worst Case Probabilities for Medium and Low Densities

	A2G							
	Medium sUAS Traffic				Low sUAS Traffic			
Scenario	5	6	7	8	9	10	11	12
Worst Case Prob of Decoding	0.30	0.48	0.60	0.74	0.72	0.78	0.81	0.89
Worst Case Prob of Link Closing	0.38	0.58	0.72	0.82	0.85	0.89	0.91	0.92
From Mitre Table	<.25	<.35	0.1	0.58	0.25	0.35	0.5	0.82
sUAS Distance MAX	3.5	2.0	1.5	1.0	3.5	2.0	1.5	1.0
	BLOS	BLOS	LOS	LOS	BLOS	BLOS	LOS	LOS

Again, the GRC simulation has a more optimistic worst case probabilities of closing the link.

C. DAA Analysis

The following analysis is for DAA algorithm utilizing ADS-B technology. The statistics that are being derived for the Probability to *From a Track* – A2G only. The definitions of the DAA parameters were defined in the above section. The P(Form a Track) cannot be captured as a closed form equation, thus simulations are run to capture this DAA statistic.

The first DAA simulation varies the total number of AVs between 100 and 3,000 only utilizing ADS-B technology and is run for a total of 180 seconds, where each ADS-B transmitter will send out its automatic message every second. The 4 defined ADS-B power levels are equally split per ADS-B level categories of 3, 2, 1, and sUAS. Thus, if there a total of 1,000 AVs, 250 AVs are dedicated to ADS-B power level 3 which is 250W. This mix of sUAS to NAS-type GA aerial vehicles, in this task simulation, are 75% GAs to 25% sUASs all equally randomized across a 100NM radius. This is to contrast the previous approach. Due to the larger radar perimeter regions of GA transmitter power levels, most GAs will communicate with the ground station, but not all sUASs will due to their limited ~1nm radar perimeter. Again, all AVs are enroute radially to the center where the airport/ground station is placed. For clarity, an example of 1000 AVs parameters are shown in Table 7. Since there are larger powered transmitters in the region, the total number of AVs being detected by the ground station will be close to the total from the beginning of the simulation. Once the simulation begins and the simulation comes close to the 180th second since all AVs are enroute and radially flying towards the center of the plot, it would be probable that all AVs are being detected by the ground station.

Table 7 - A2G DAA Simulation Input Parameters

ADS-B Level	Power(dB)	Amount Randomly Placed Within 100-5NM Radius	AGL(ft)	Speed (NM/hr)
3	24	250	20000	300
2	20	250	20000	300
1	14	250	20000	300
sUAS	-20	250	50-500	50

Table 8 shows the results of the P(Form a Track) as we adjust both, increasing AVs and increasing *MaxSetSize*. For example, when MaxSetSize=1, this means that it only takes one Received Message to form a track. We can double-check the situation when AVs=1000 and MaxSizeSet=1 the following way. Since all planes have ADS-B technology, we can refer to the 'co-channel interference' plot and the 'first time MSO collision' plot to validate the P(Form). From looking at the co-channel interference plot first, ~13% of the AVs do not make it through. Thus, there remain 870 AVs that have to compete for MSOs. The '% of First Time MSO Receiver Collisions' for 870 AVs is ~12%. Finally, even though 1,000 AVs are randomly placed within the 100nm radius, not all AVs will be captured by the ground station, especially since the power of the sUASs is only 0.01W. So, when taking that small percentage off the total, the P(Form) matches the simulation's computed output of ~77%. Unfortunately, this double check cannot be done for MaxSetSize>1 due to more intense combinational computations. Thus, the reason for a simulation, since a reasonable closed form approach cannot be created.

The simulation results in Table 8 show that as we increase the MaxSetSize variable, the P(Form) always increases. However, by increasing the MaxSetSize value, the DAA algorithm eventually will not be able to detect the incoming AV as quickly, since we are spending more time to ensure that the probability of forming a track is increased. These are design decisions that will eventually need to be tested and implemented in real flight cases. The purpose of these simulation results is to display the estimated performance of DAA algorithms as we adjust certain parameters.

Table 8 - A2G DAA P(Form) – AVs vs MaxSetSize

MaxSetSize	1	2	3	4	5
ADS-B AVs	P(Form)	P(Form)	P(Form)	P(Form)	P(Form)
100	97%	100%	100%	100%	100%
200	94%	100%	100%	100%	100%
300	92%	99%	100%	100%	100%
400	90%	99%	100%	100%	100%
500	87%	98%	100%	100%	100%
1000	77%	95%	99%	100%	100%
1500	68%	89%	96%	100%	100%
2000	60%	84%	93%	98%	99%
3000	47%	54%	70%	81%	89%
4000	38%			38%	38%
5000	31%				

The 'Probability of First Time MSO Receiver Collisions' plot is shown in Figure 11 to display the difference between the estimated closed form equivalent [4] versus the GRC simulation output.

Now we analyze the P(Losing Track). We incorporate the initial step of forming a track, but now we add another DAA parameter called 'Kill Track' where depending on its value will alter the probability of retaining the track. For this analysis, 1,000 ADS-B AVs, all enroute, utilizing the same above simulation parameters. The 1,000 AV amount was chosen because when the DAA parameter MaxSetSize>1, a P(From) of 95%will occur. The simulation was run for 180 seconds where an MSO is created per ADS-B per second.

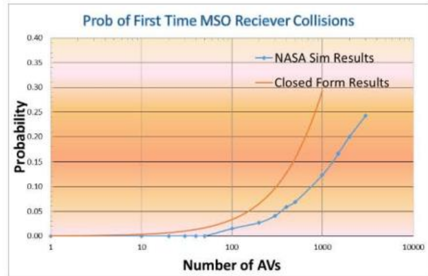


Figure 11 – Probability of First Time MSO Receiver Collisions

Table 9 - A2G DAA P(Losing Track)

MaxSetSize	measKillTrack	Prob_losing_Track
2	1	9.4%
3	1	8.8%
4	1	8.1%
5	1	0.0%
MaxSetSize	measKillTrack	Prob_losing_Track
2	2	5.1%
3	2	4.9%
4	2	4.7%
5	2	4.5%
MaxSetSize	measKillTrack	Prob_losing_Track
2	3	3.5%
3	3	3.4%
4	3	3.3%
5	3	3.2%
MaxSetSize	measKillTrack	Prob_losing_Track
2	4	2.6%
3	4	2.5%
4	4	2.5%
5	4	2.4%
MaxSetSize	measKillTrack	Prob_losing_Track
2	5	2.1%
2	6	1.7%
2	7	1.4%
2	8	1.2%
2	9	1.1%
MaxSetSize	measKillTrack	Prob_losing_Track
3	5	2.0%
3	6	1.7%
3	7	1.4%
3	8	1.2%
3	9	1.1%

As shown in Table 9, increasing the MaxSetSize from 2 to higher values does not affect the 'Probability of Losing Track'. It is very small difference, but it probability needs to be run longer to get the equivalent statistical value. We do notice by altering the 'Kill Track' parameter to higher values does affect the Probability of Losing Track.

The next DAA simulation will increase AV capacity. By looking at the previous data, the DAA parameter to close the Track will be held constant at MaxSetSize=2. The DAA parameter 'Kill Track' will be varied to an extreme. Due to higher capacity, simulation time has been reduced to one minute which may affect the statistical soundness.

Table 10 - A2G DAA P(Losing Track) with Increased Capacity

ADS-B AVs	MaxSetSize	measKillTrack	TimeRun(min)	Prob_losing_Track
1500	2	2	3	7.2%
1500	2	3	3	5.1%
1500	2	4	3	3.9%
1500	2	20	3	0.6%
ADS-B AVs	MaxSetSize	measKillTrack	TimeRun(min)	Prob_losing_Track
2000	2	2	3	9.0%
2000	2	5	1	3.0%
2000	2	6	1	3.1%
2000	2	8	1	2.1%
2000	2	20	1	0.1%
ADS-B AVs	MaxSetSize	measKillTrack	TimeRun(min)	Prob_losing_Track
3000	2	2	1	10.7%
3000	2	6	1	4.4%
3000	2	20	1	1.1%

For the highest capacity of AVs run of 3,000, the most feasible parameter setup not to lose tracking is measKillTrack=20, as shown in Table 10. But MaxSetSize must be increased to >5 to get to P(Form)>%90. But again, waiting 20 seconds and depending on speed of each AV, the DAA parameter may be too large for overall safety. A more itemized and critical analysis needs to be done to understand the best sweet spot per capacity amount.

VIII. Key Findings

There are two main tasks that were presented in this paper. The initial task was to simulate scenarios found in [1] concerning capacity in a mixed sUAS and GA environment and to compare results between the two implementations. Added to the first task was further inherent TDMA capacity performance called MSO collisions. Once the mixed sUAS capacity environment was analyzed up to the MAC layer environment, the second task was to begin DAA analysis using a simple algorithm found in [4].

A. Task 1 Key Findings

- The GRC simulation results – 'Worst Case Probability Closing Link' - do not match with the [1], are much more optimistic for all 3 density cases for both A2A and A2G results
- An 80% 'Probability to Decode' lower limit has been set by the author to identify worst case performance
- When adding the MSO collisions to the capacity to the simulation, the 'Probability to Decode' is always lower in percentage than the 'Worst Case Probability Closing Link' for both A2A and A2G results
- 68% 'probability to decode' for the lowest power sUAS transmitter of 0.01W in a high density A2A environment is not acceptable
- 51% 'probability to decode' for the lowest power sUAS transmitter of 0.01W in a high density A2A environment is not acceptable
- 84% and 95% 'probability to decode' for medium and low density A2A environments using the low power 0.01W transmitter is a plausible performance findings
- For A2G, only the low density 'probability to decode' for sUAS transmitter power levels of 0.01W and 0.05W have plausible performance results
- For a mixed sUAS/GA mixed environment due to the low power transmitters are able to meet the 80% 'probability to decode' cutoff, all sUAS are assumed to be within the Line of Sight (LOS) range – 1NM or less – for both A2A and A2G environments

B. Task 2 Key Findings

- For P(Form)≥99% with a capacity of ~1,000 ADS-B for A2G link, the DAA parameter MaxSetSize≥3. Thus, it will take 3 seconds to detect an ADS-B nearby transmitter
- For P(Losing the Track)≤1% with a capacity of ~1,000 ADS-B for A2G link, the DAA parameter KillTrack≥10. Thus, it will take 10 seconds for the ADS-B receiver to drop the nearby ADS-B AV

IX. Conclusion and Future Work

This paper presented ADS-B modelling that is being done at GRC. The model is constantly being improved from a computational efficiency, to validating its algorithmic results to ensure the probabilities being produced will hopefully closely mimic future real-world high capacity mixed environment scenarios.

As suggested in [1], for others to confirm their results, it is suggested to confirm this paper's results either in a similar algorithmic fashion or in a more efficient, less computational, closed form approach where higher capacity simulations can be found in a quicker timeframe. Now that this work has been published, it would be preferred to collaborate with interested parties to better various to identify the best results.

Due to the algorithmic approach that was taken with the GRC ADS-B capacity model, the results given are with confidence and are more optimistic than the results in [1].

For the DAA algorithmic probability analysis, more work needs to be done to better understand the performance. But at this time, the paper identifies parameter starting points for future real-time on-board DAA processing.

For future work:

1) Incorporate actual NAS and sUAS flight paths and speeds instead of using computer generated AV related data for speed, altitude, and flight path

2) Simulate various sUAS vs GA capacity mixes for A2A DAA simulations

3) Expand the simulation to accept ADS-B frames and extract information to run DAA algorithms with actual ADS-B data

4) Perform DAA A2A analysis similar to the DAA A2G analysis in this paper

5) Perform DAA analysis of speed, altitude, and angle using the ADS-B framed information to understand other DAA concepts as described in the DAA paper

References

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24/9/2018

International Civil Aviation Organization

WORKING PAPER

THIRD MEETING OF THE SURVEILLANCE PANEL (SP/3)

Eighth meeting of the Aeronautical Surveillance Working Group (ASWG/8)

Montreal, Canada, 24 – 28 September 2018

SP3 Agenda item 3: Aeronautical surveillance systems and Airborne Collision Avoidance systems

ASWG8 Agenda Item 6: Mode S and Extended Squitter

Initial analysis of possible impact of small UAS transmitting on 1090MHz in Europe

(Prepared by **Eric Potier** and presented by **Eric Potier**)

SUMMARY

This paper provides some initial results of the modelling of the impact of small UAS transmitting on 1090 MHz.

ACTION

The SP3-ASWG/8 is invited to:

a) Note the information contained in this WP and
b) To develop a common understanding of the impact of small UAS transmitting on 1090 MHz.

1. INTRODUCTION

1.1 There are ongoing discussions on whether small UAS could use 1090 MHz ADS-B to report their position.

1.2 EUROCONTROL is performing a study to investigate what would be the impact of ADS-B equipped SUAS operation on Mode S aircraft detection.

1.3 This paper presents some initial results of an investigation of the possible impact of the use of 1090 MHz by small UAS and asks the group to further review this subject in order to have a common understanding.

2. DISCUSSION

2.1 A RF model has been used to investigate the possible impact of transmissions on 1090 MHz from small UAS. The model has used some assumptions on transmissions that could be made by small UAS including their density and their transmitted power. Using these assumptions the model has looked at the impact on the reception of an ADS-B extended squitter transmitted by a normal aircraft, more particularly on the range reduction to keep the same level of probability of update of an ADS-B position.

2.2 The RF model has used different air environments coming from a real situation on a peak day in 2016 and a future environment with increased traffic (2025 scenario) together with 2016-ground infrastructure. The airborne scenarios are based on the surveillance radar data recordings for Friday 09/09/2016 at 09:15 UTC. Friday 09/09/2016 was a peak day in Europe with 35,594 flights. The study has looked at 3 air scenarios:

- 2016-CDG: one omni-directional antenna located at Charles de Gaulle (CDG) airport seeing 567 aircraft at -84dbM with a 7dB gain.
- 2016-FRA: one omni-directional antenna located close to Frankfurt (FRA) airport seeing 583 aircraft at -84dbM with a 7dB gain.
- 2025-FRA: one omni-directional antenna located close to Frankfurt (FRA) airport seeing 807 aircraft at -84dbM with a 7dB gain. It was build using STATFOR predictions and corresponds to 20% additional traffic.

2.3 In a first step, the study has looked at the impact on the decoding of an aircraft by a ground receiver surrounded by a set of small UAS. Additional steps are foreseen to look at different places in Europe and to look at the reception of an aircraft flying other a small UAS cloud.

2.4 The RF model used a degarbling performance as specified in ED-102A/DO-260B and a power gain of 7dB to not be limited by the distance (132NM without gain). As a consequence the obtained maximum range must be taken with precaution however the shape of the curves of probability of update remains the same.

2.5 The probability of update between 80 and 100NM obtained with the model for the CDG scenario is equivalent to the probability of update between 80 and 100NM measured on the Bretigny ADS-B station at another rdate.

2.6 The transmission rates of ADS-B extended squitters was set at:

- 5.6/s for each aircraft in the air,
- 2.2/s on average for aircraft on the ground (weighted average between 2.6/s moving and 0.5/s not moving),
- 4.6/s for DF18 rate from SUAS is set to 4.6 in the RF Model:
  - 2 Airborne Position / sec
  - 0.2 ACID / sec
  - 2 Airborne Velocity / sec
  - 0.4 Aircraft Operational Status / sec

2.7 The approach used was to look at the delta performance created by the addition of the new transmissions generated by the small UAS (SUAS).

2.8 The variables that were used during the modelization are:

- the density of small UAS around the receiver,
- the power transmitted by small UAS.

2.9 The UAS density is no known with certitude therefore different small UAS densities have been used as specified the table below. A case was reported in Germany with 1000 drones detected in the Hamburg CTR.

SUAS Scenario	SUAS Density (number of SUAS per Km² (/NM²))	ADS-B Output Power	Number of SUAS detected by the omni-directional antenna at -84 dBm	Max range of UAS received at -84dBm in NM with 7db gain
1	0.5 (1.75)	0.1W (20dBm)	93	4.2
2	1 (3.5)	0.1W (20dBm)	390	4.2
3	3 (10.5)	0.1W (20dBm)	563	4.2
4	0.5 (1.75)	1W (30dBm)	933	13.3
5	1 (3.5)	1W (30dBm)	1898	13.3
6	3 (10.5)	1W (30dBm)	5736	13.3

Table 1 – SUAS Environments

2.10 The range for different received level is given for different powers in the following graph when using a 7dB antenna gain.

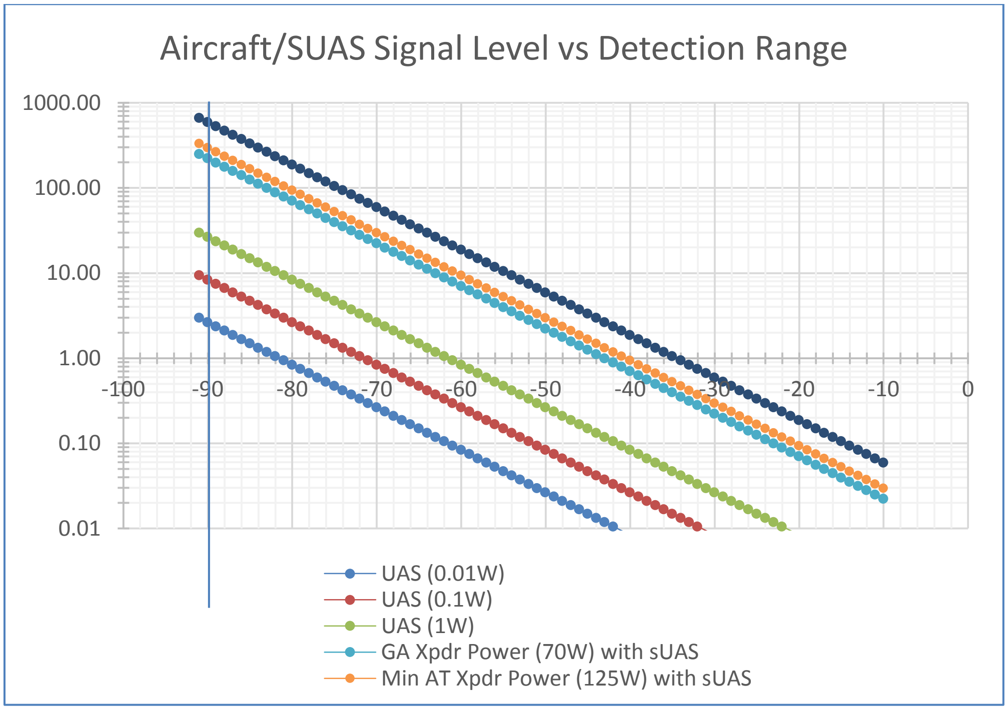

Figure 1 – Detection range for -84dbm with + 7 db gain for different transmitted powers

2.11 The study looked at the decoding probability of a signal S transmitted by one aircraft. The interfering signals could come from other aircraft using high powers therefore located in a large area (green star) or from systems using lower transmission power such as small UAS contained in a smaller volume around the receiver (blue circles).

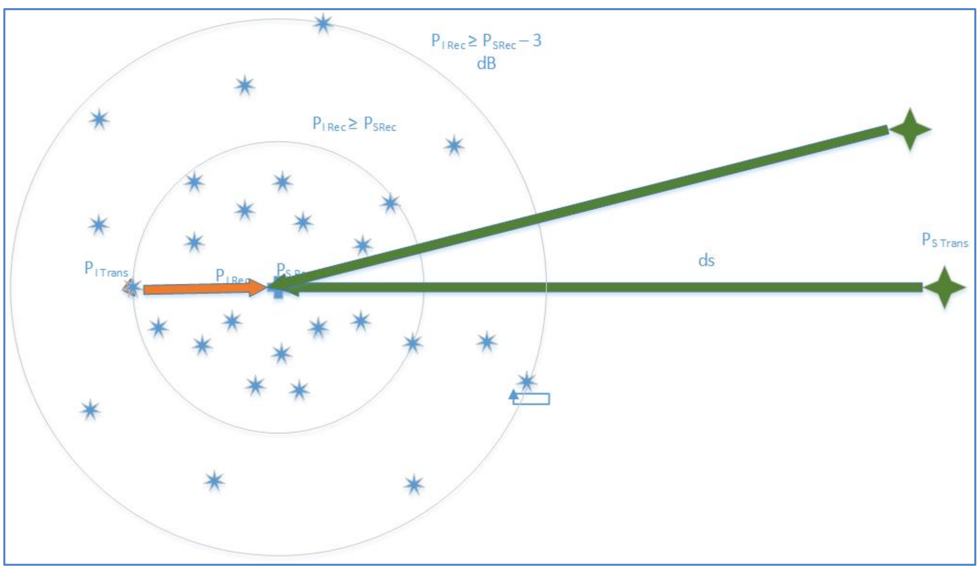

Figure 2 – SUAS cloud impacting the detection of a transmission from 1 aircraft

2.12 For example using the previous graph an aircraft transmitting 500W (dark blue curve) located at 105NM is impacted by messages received at same power from small UAS transmitting 1W within 4.7 Nm around the receiver or by messages received at (power-3dB) from small UAS transmitting 1W within 6.7 NM .

2.13 Result for FRA-2016 1W 3UAS /km^2 – PoU 5s

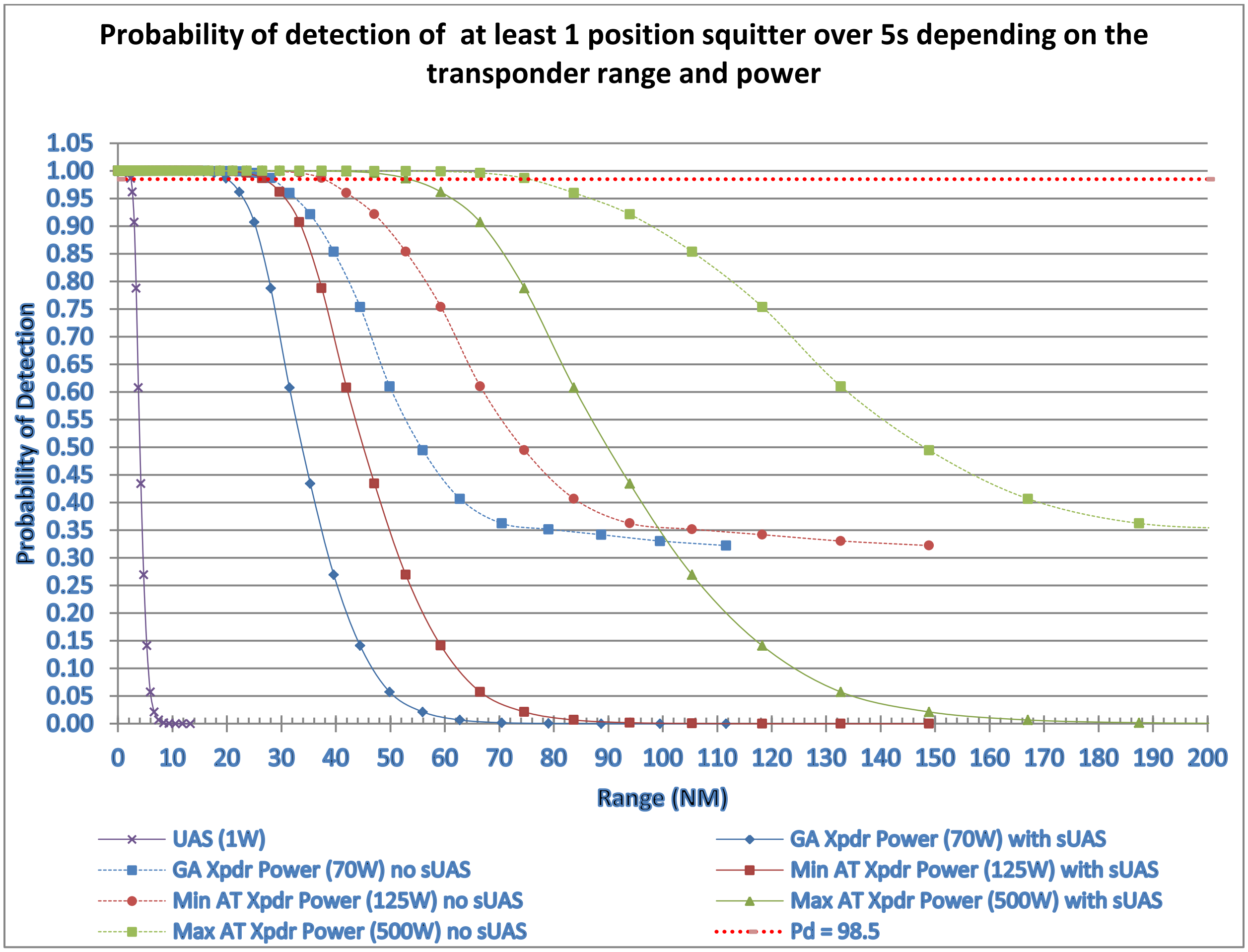

Figure 3 – Comparison probability of detection versus range no UAS – UAS over 5s – FRA 2016- 1W – 3UAS

2.14 The range of aircraft/SUAS to get a probability of detection = 98.5 is:

- 75.3NM for Air Transport with max transponder power NO SUAS
- 53.3NM for Air Transport with max transponder power - with SUAS 1W
  ➔ **Range reduction = 22NM**
- 37.7NM for Air Transport with min transponder power – NO SUAS
- 26.7NM for Air Transport with min transponder power – with SUAS 1W
  ➔ **Range reduction = 11NM**
- 28.3NM for General Aviation – NO SUAS
- 20NM for General Aviation – with SUAS 1W
  ➔ **Range reduction = 8.3NM**
- 2.4NM for SUAS 1W

2.15 This scenario, 1W and 3UAS per km2, creates a big range reduction.

2.16 Result for FRA-2016 0.1W 3UAS /km^2 – PoU 5s

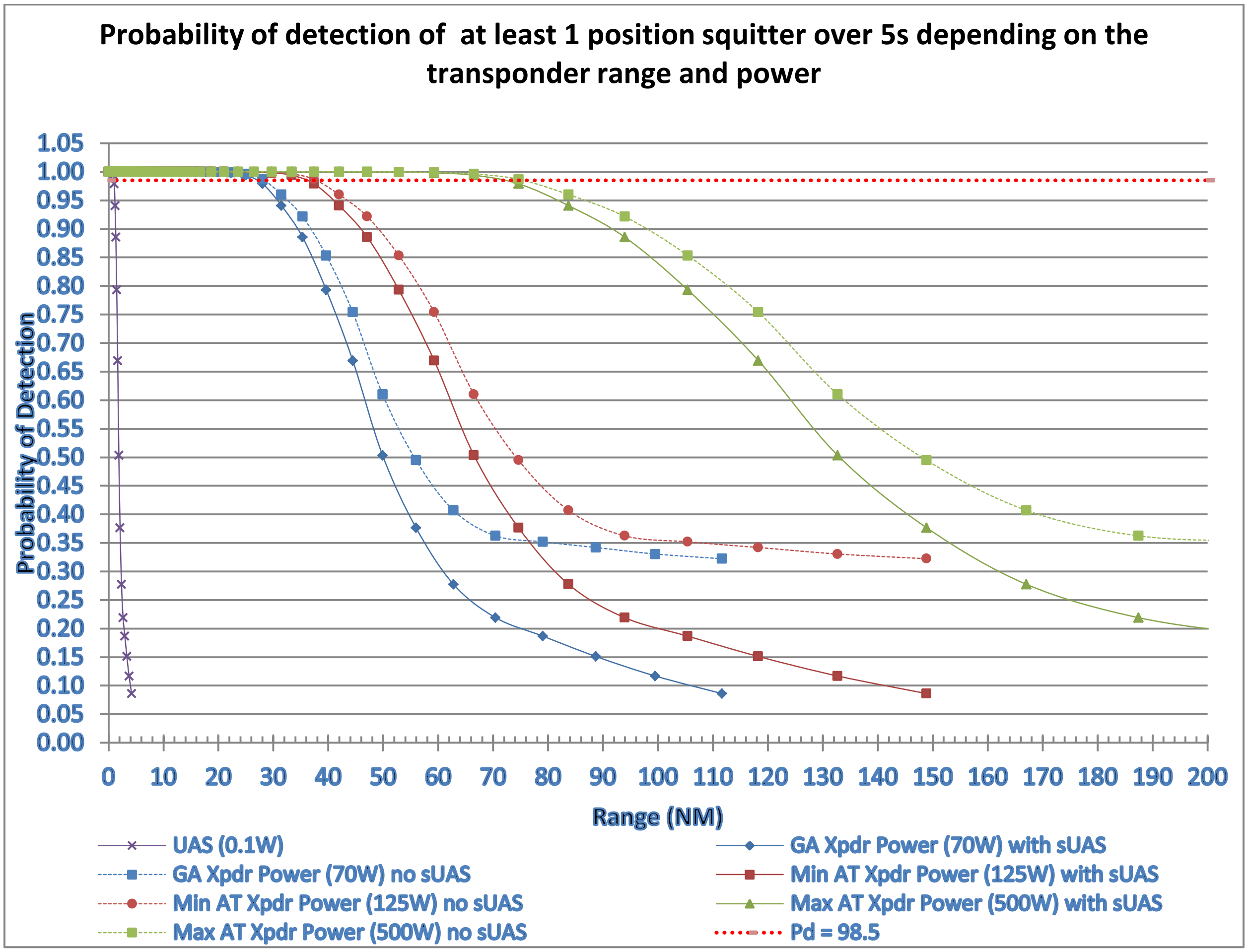

Figure 4 – Comparison probability of detection versus range no UAS – UAS over 5s – FRA 2016- 0.1W - 3UAS

2.17 The range of aircraft/SUAS to get a probability of detection = 98.5 is provided below:

- 75.3NM for Air Transport with max transponder power - NO SUAS
- 71.4NM for Air Transport with max transponder power - with SUAS 0.1W
  - ➔ **Range reduction = 3.9NM**
- 37.7NM for Air Transport with min transponder power – NO SUAS
- 35.8NM for Air Transport with min transponder power – with SUAS 0.1W
  - ➔ **Range reduction = 1.9NM**
- 28.3NM for General Aviation – NO SUAS
- 26.8NM for General Aviation – with SUAS 0.1W
  - ➔ **Range reduction = 1.5NM**
- 1NM for SUAS 0.1W.

2.18 The reduction of the transmitted power has a big effect on the impact that is reduced a lot, from 22NM (1W) to only 3.9NM (0.01W).

2.19 Result for FRA-2016 1W 1UAS /km^2 – PoU 5s

If the number of small UAS is reduced to 1/km^2 The figure below provides the probability of detection of at least 1 position squitter per 5 second period

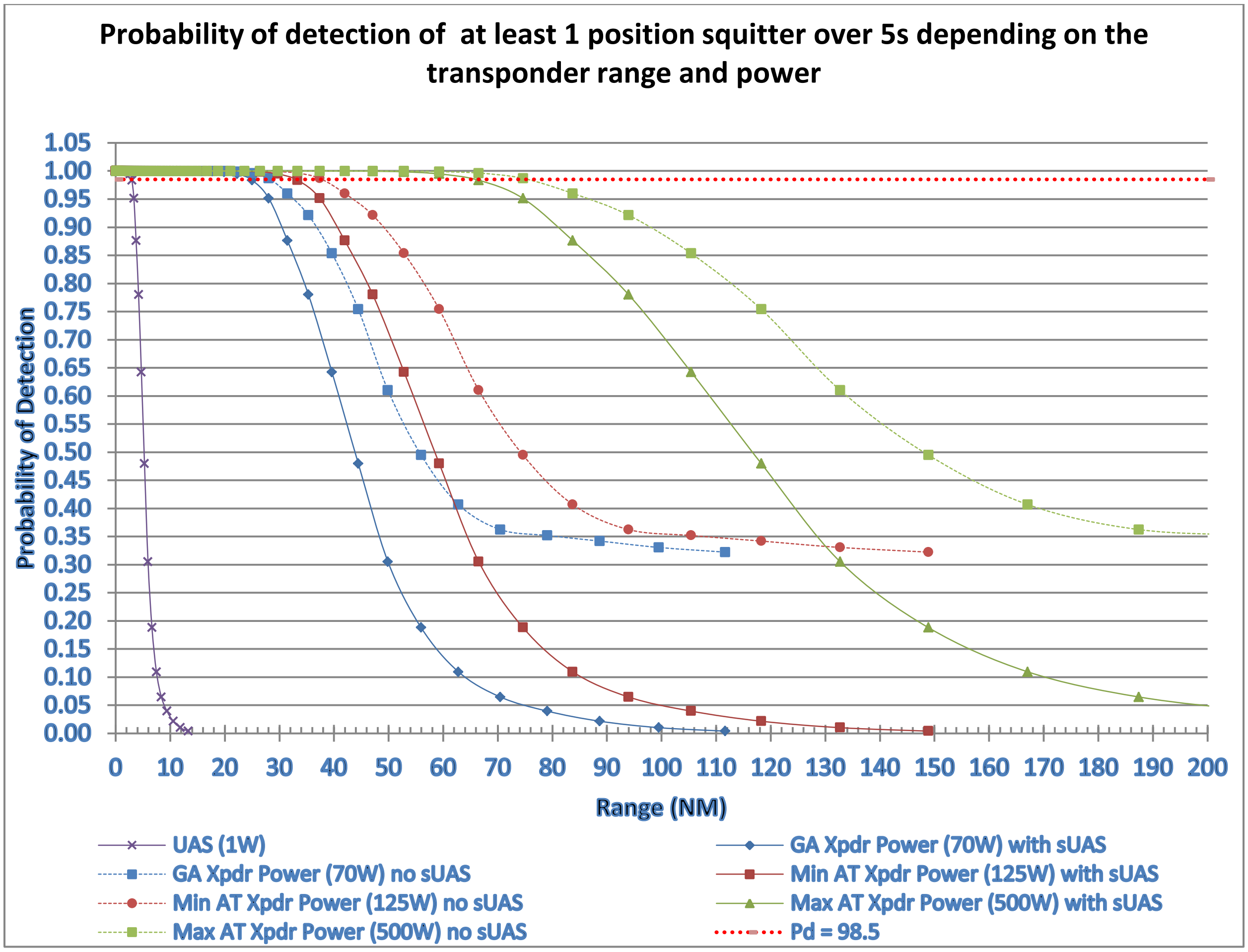

Figure 5 – Comparison probability of detection versus range no UAS – UAS over 5s – FRA 2016- 1W – 1UAS

2.20 The range of aircraft/SUAS to get a probability of detection = 98.5 is provided below:

- 75.3NM for Air Transport with max transponder power - NO SUAS
- 65.6NM for Air Transport with max transponder power - with SUAS 1W

  ➔ **Range reduction = 9.7NM**

- 37.7NM for Air Transport with min transponder power – NO SUAS 1W
- 32.9NM for Air Transport with min transponder power – with SUAS

  ➔ **Range reduction = 4.8NM**

- 28.3NM for General Aviation – NO SUAS
- 24.6NM for General Aviation – with SUAS 1W

  ➔ **Range reduction = 3.7NM**

- 2.9NM for SUAS 1W

2.21 Reducing the small UAS density from 3 to 1 /km^2 has also a big impact alleviating the performance reduction from 22NM to 9.7 NM reduction in range.

2.22 Result For CDG-2016 1W 3UAS /km2 – PoU 5s

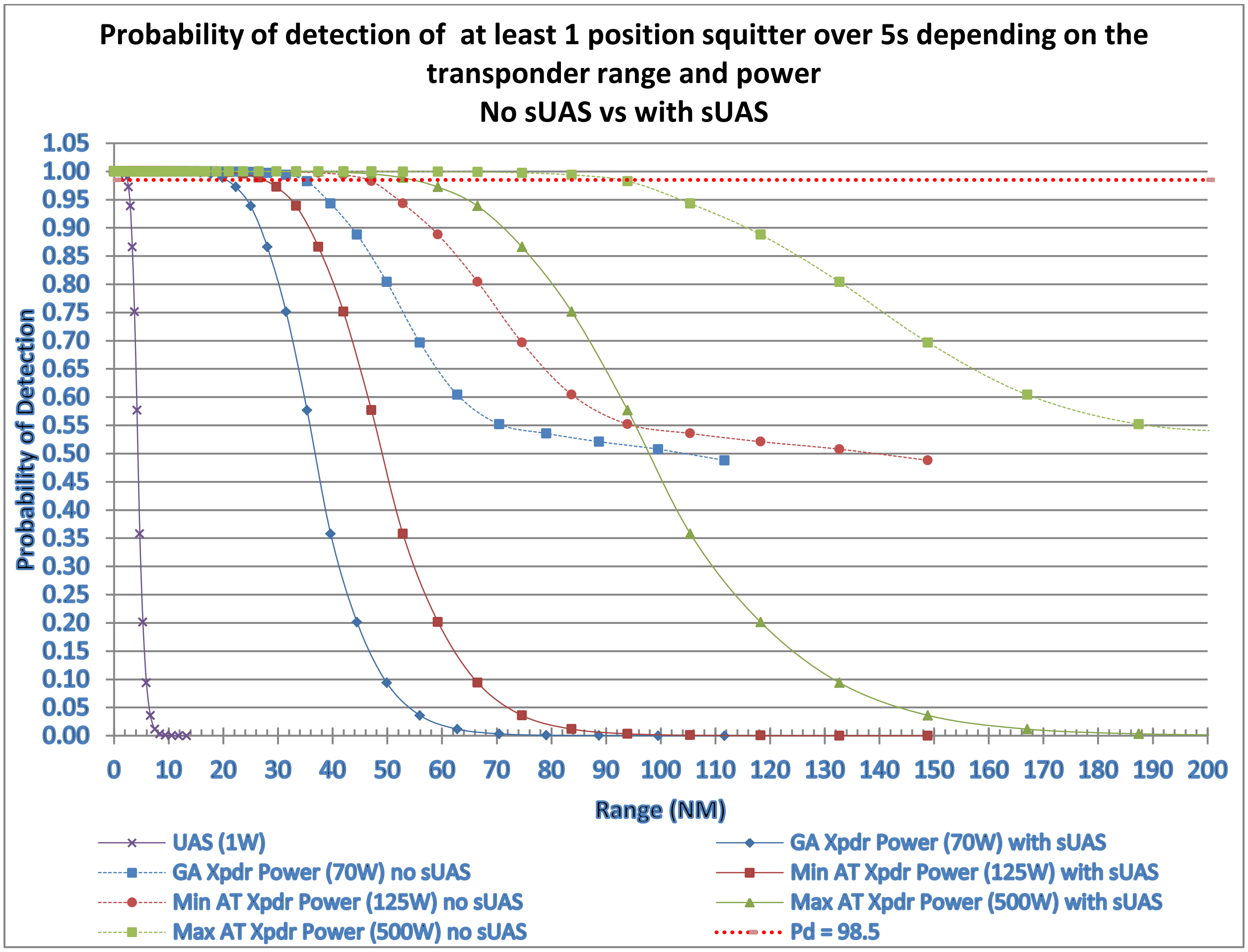

Figure 6 – Comparison probability of detection versus range no UAS – UAS over 5s – CDG 2016- 1W

2.23 The range of aircraft/SUAS to get a probability of detection = 98.5 is provided below:

- 91.8NM for Air Transport with max transponder power - NO SUAS
- 54.3NM for Air Transport with max transponder power - with SUAS 1W

  ➔ **Range reduction = 37.5NM**

- 46NM for Air Transport with min transponder power – NO SUAS
- 27.2NM for Air Transport with min transponder power – with SUAS 1W

  ➔ **Range reduction = 18.8NM**

- 34.5NM for General Aviation – NO SUAS
- 20.4NM for General Aviation – with SUAS 1W

  ➔ **Range reduction = 14.1NM**

- 2.4NM for SUAS 1W

2.24 The impact of 3 small SUAS/km^2 transmitting at 1W is in proportion more important in area with low traffic density. However, the achieved range is similar to what is estimated in higher density areas, 53.3 NM at FRA to be compared to 54.3NM in CDG area.

2.25 Result for FRA-2025 1W 1UAS /km2 – PoU 5s

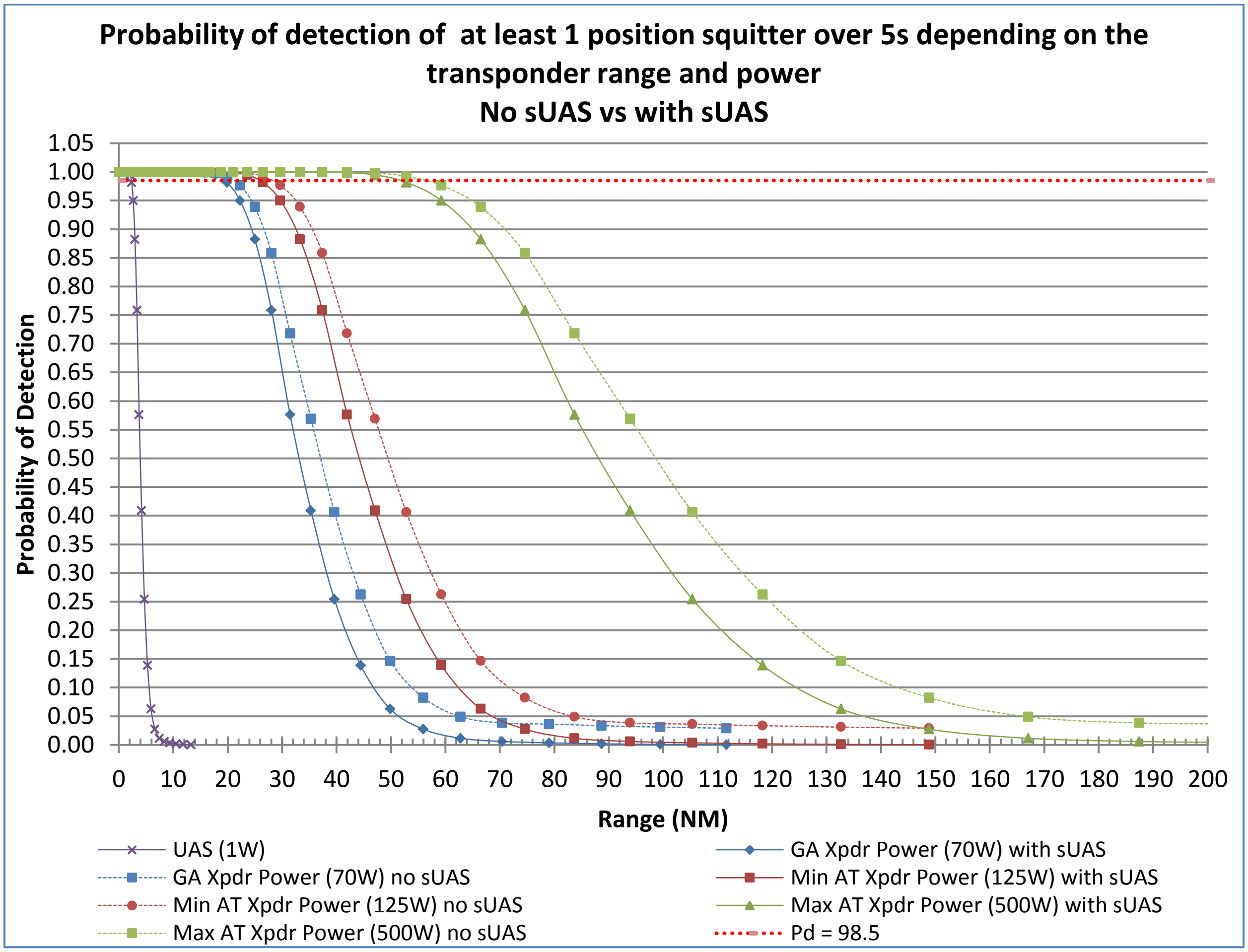

Figure 7 – Comparison probability of detection versus range no UAS – UAS over 5s – FRA 2025- 1W

2.26 The range of aircraft/SUAS to get a probability of detection = 98.5 is provided below:

- 51.4NM for Air Transport with max transponder power - with SUAS 1W
- 55.8NM for Air Transport with max transponder power - NO SUAS
  - ➔ **Range reduction = 4.4NM**
- 25.8NM for Air Transport with min transponder power – with SUAS 1W
- 28.0NM for Air Transport with min transponder power – NO SUAS
  - ➔ **Range reduction = 2.2NM**
- 19.3NM for General Aviation – with SUAS 1W
- 21NM for General Aviation – NO SUAS
  - ➔ **Range reduction = 1.6NM**
- 2.3NM for SUAS 1W

2.27 UAS transmission on 1090 has less impact (e.g 4.4NM) in the future when the range reduction will be first generated by the additional aircraft transmissions.

3. SUMMARY

3.1 The table 2 compares the maximum detection range of aircraft and SUAS to get a probability of update of 98.5% over a 5 second period.

	Max detection range (in NM) PD of 1 position squitter in 5 second = 98.5% (Range Reduction in % compared to the scenario with NO SUAS)			
SUAS Scenario	SUAS	GA Transponder Power 46dBm - 70W	Min Air Transport Transponder Power 51dBm - 125W	Max Air Transport Transponder Power 57dBm - 500W
FRA 2016 - NO SUAS	**N/A**	**28.3**	**37.7**	**75.3**
FRA 2016 - 1	1.1 (0.1W)	28.1 (0.71%)	37.5 (0.53%)	74.9 (0.53%)
FRA 2016 - 2	1.1 (0.1W)	27.9 (1.41%)	37.2 (1.33%)	74.3 (1.33%)
FRA 2016 - 3	1 (0.1W)	26.8 (5.30%)	35.8 (5.04%)	71.4 (5.18%)
FRA 2016 - 4	3.1 (1W)	26.1 (7.77%)	34.8 (7.69%)	69.4 (7.84%)
FRA 2016 - 5	2.9 (1W)	24.6 (13.07%)	32.9 (12.73%)	65.6 (12.88%)
FRA 2016 - 6	2.4 (1W)	20 (29.33%)	26.7 (29.18%)	53.3 (29.22%)
CDG 2016 - NO SUAS	**N/A**	**34.5**	**46**	**91.8**
CDG 2016 - 1	1.3 (0.1W)	34 (1.45%)	45.3 (1.52%)	90.4 (1.53%)
CDG 2016 - 2	1.3 (0.1W)	33.5 (2.90%)	44.6 (3.04%)	89 (3.05%)
CDG 2016 - 3	1.2 (0.1W)	32 (7.25%)	42.7 (7.17%)	85.1 (7.30%)
CDG 2016 - 4	3.6 (1W)	30.4 (11.88%)	40.6 (11.74%)	81 (11.76%)
CDG 2016 - 5	3.3 (1W)	27.4 (20.58%)	36.6 (20.43%)	73 (20.48%)
CDG 2016 - 6	2.4 (1W)	20.4 (40.87%)	27.2 (40.87%)	54.3 (40.85%)
FRA 2025 - NO SUAS	**N/A**	**21**	**28**	**55.8**
FRA 2025 - 1	0.8 (0.1W)	20.9 (0.48%)	27.8 (0.71%)	55.5 (0.54%)
FRA 2025 - 2	0.8 (0.1W)	20.8 (0.95%)	27.7 (1.07%)	55.2 (1.08%)
FRA 2025 - 3	0.8 (0.1W)	20.4 (2.86%)	27.3 (2.50%)	54.4 (2.51%)
FRA 2025 - 4	2.4 (1W)	20.2 (3.81%)	26.9 (3.93%)	53.6 (3.94%)
FRA 2025 - 5	2.3 (1W)	19.3 (8.10%)	25.8 (7.86%)	51.4 (7.89%)
FRA 2025 - 6	Not run			

Table 2 – Max detection range – PD=98.5% at 5s

3.2 The following graph represents the ranges for the reception of message transmitted from 500W and 70 W transponders.

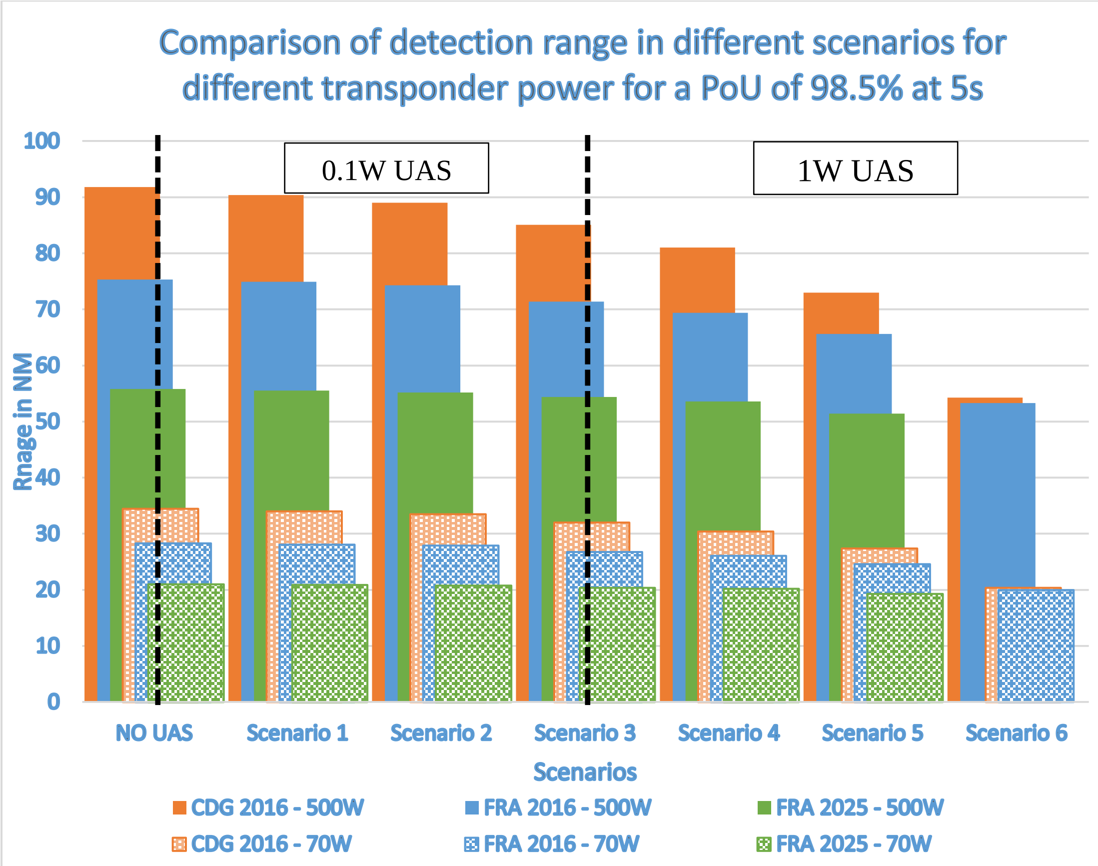

Figure 8 – Comparison of detection range in different scenarios for different transponder power for a PoU of 98.5% at 5s

3.3 In all cases, the addition of UAS transmission on 1090 results in a range reduction of the ADS-B ground station to maintain the same probability of update (98.5%).

3.4 For 0.1W power transmission, the range reduction is up to 3% for scenario with 1 UAS /km2 and up to 8% for scenario with 3UAS/km^2. This might be considered as “limited impact” although it will increase the cost of ground ADS-B receiver network.

3.5 For 1W power transmission, the range reduction is more important going up to 41% for 5s and 38% for a 8s update interval in CDG environment (scenario 6). This is a large reduction however for scenario5 (1UAS/km2) at 5s update period the range of CDG remains at a value similar to the range of an ADS-B at Frankfurt in 2016 without UAS.

3.6 The environments with a higher number of aircraft (high density of aircraft) are “less visible” by the ADS-B broadcast by SUAS.

3.7 The impact should be further investigated for other scenarios including airborne 1090 receivers.

4. ACTION BY THE MEETING

4.1 The SP/3-ASWG/8 is invited to:

a) Note the initial results of a study investigating the impact of small UAS transmitting on 1090 MHz with up to 40% reduction of reception range depending on scenario,

b) Note that a better definition of scenarios and more analyses are required,

c) task the TSG to develop a common understanding of the impact of small UAS transmitting on 1090 MHz.

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APÉNDICE C
BORRADOR DEL MATERIAL DE ORIENTACIÓN PARA PROBLEMAS DEL ESPECTRO 1090 MHZ Y GESTIÓN APROPIADA DE LA DIRECCIÓN DE AERONAVES DE 24-BITS ASOCIADA A AERONAVES NO TRIPULADAS OPERANDO EXCLUSIVAMENTE EN ALTITUDES MUY BAJAS

1. Antecedentes

1.1 Las frecuencias 1030 y 1090 MHz actuando como frecuencias pares, apoyan muchos sistemas de vigilancia aeronáutica, incluidos el radar secundario de vigilancia (SSR), multilateración, Sistema anticolisión de a bordo (ACAS) y la Vigilancia dependiente automática – radiodifusión (ADS-B). Las aeronaves son interrogadas por un SSR/MLAT terretre (u otra aeronave, en el caso de ACAS) en 1030 MHz y responden (o transmiten) en 1090 HMz con información tal como la posición, la altitud y el vector de velocidad.

1.2 En incremento de la densidad en los sistemas terrestres y a bordo de vigilancia utilizando frecuencias 1090/1090 MHz actualmente está creando preocupación, especialmente en espacios aéreos densos. Resultaría, finalmente, en una reducción del desempeño del ACAS así como de los sistemas SSR/MLAT y ADS-B. Además, el uso creciente de aplicaciones ADS-B OUT para servicios de seguridad de vida y la evolución potencial de esas aplicaciones, como lo es la ADS-B basada en el espacio, han levantado seria preocupación de posible congestión en 1090 MHz. A fin de asegurar operación continua y segura de la aeronave, se requiere una operación apropiada y eficiente del ancho de banda disponible en 1090 MHz. Esto incluye acceso limitado para usuarios evitables.

1.3 Además, es importante notar que esos sistemas de vigilancia confían en un esquema de capacidad limitada para dirección de aeronave de 24-bits. La asignación de dirección de aeronave de 24-bits y su correcta configuración en una aeronave es un elemento clave para una operación segura de una aeronave y de los protocolos asociados usados para apoyar los sistemas de comunicación y vigilancia.

1.4 Como se define en el Anexo 10, Volumen III, las direcciones de aeronaves se designan en bloques al Estado de registro o a la a autoridad de registro común a través de la OACI. Usando el bloque de direcciones asignado, el Estado de registro o la autoridad de registro común son requeridos a asignar una dirección de aeronave individual a cada aeronave equipada adecuadamente ingresada en un registro nacional o internacional.

1.5 Es esencial para los Estados reconocer que su bloque asignado de direcciones de aeronaves de 24-bits es un bien finito y valioso. En total, hay 16,777,214 direcciones de aeronave y la mayoría de estas direcciones ya han sido asignadas a los Estados de registro o a la autoridad de registro común. Se pronostica que el crecimiento del tránsito aéreo será duplicado en los próximos 15 años. Por lo tanto, a fin de gestionar estas direcciones de manera sostenible, los Estados deben validar si las nuevas solicitudes de asignación de direcciones de aeronaves por parte de los explotadores de aeronaves se ajustan a las condiciones definidas en el Anexo 10, Volumen III.

2 Problemas identificados en relación a la operación de aeronaves no tripuladas

2.1 Como se describe en la Sección 1, se han generado preocupaciones sobre la congestión de la frecuencia 1090 MHz y escasez de direcciones de aeronaves de 24-bits. Sin embargo, el rápido crecimiento de la población de aeronaves no tripuladas está haciendo que estas preocupaciones sean más severas o intensas.

2.2 Incremento exponencial de los riesgos de la seguridad operacional debido a la congestión de 1090 MHz.

2.2.1 Un estudio reciente llamó la atención de un grupo de expertos de la OACI muestra que un gran número de UAs (un UA por cada 2 Km2) operando en altitudes bajas (menos de 500 pies sobre el nivel del suelo) en un espacio aéreo terminal típico de alta densidad (760 aeronaves equipadas con ADS-B operando en un radio de 200 MN y a nivel del suelo de FL180) puede interferir en la recepción de una estación terrestre ADS-B de los informes ADS-B de una aeronave cuando la potencia de transmisión de cada RPAS es de 1 Watt o superior.

Nota – Es importante anotar que grupos de expertos cree que ni los fabricantes de aviónica ni los reguladores serán capaces de regular efectivamente el nivel de potencia de transmisión RF menor a 1W, que es una potencia baja comparada con la aviónica que cumple con el Anexo 10, Volumen IV, de la OACI, que transmite a una potencia más elevada (70-125W). Por tanto, quizá no sea posible controlar la interferencia de UAs equipados con 1090 MHz Modo S o ADS-B hacia otra aeronave en un espacio aéreo controlado.

2.2.2 Todos los estudios proporcionados por grupos de expertos concluyen que la operación de la ADS-B OUT por un gran número de UAs levante preocupaciones serias para la seguridad operacional de otras aeronaves en el mismo espacio aéreo.

2.3 Agotamiento futuro de direcciones de aeronaves de 24 bits

2.3.1 El esquema de direcciones de aeronaves de 24 bits no fue designado para un gran número de vehículos, con base en la actual proyección de crecimiento de UAs, será imposible la asignación para todos los UAs bajo el mismo esquema.

2.3.2 Debido a que en algunas situaciones los UAs requerirán ser asignados por direcciones de aeronaves de 24-bits, si un UA vuela en un espacio aéreo controlado o en proximidad con una aeronave tripulada por ejemplo, los Estados necesitarán evaluar dichas situaciones caso por caso, cuando reciban una nueva solicitud de dirección de aeronave de la comunidad UA.

2.4 A fin de resolver los problemas discutidos en las secciones 2.2 y 2.3, en la Sección 3 se describe el procedimiento para asegurar una adecuada utilización de 1090 MHz y para la no asignación de direcciones de aeronaves (24-bits) a UAs.

Nota – como se describe en el Manual sobre sistemas de aeronaves pilotada a distancia (RPAS) (Doc 10019), una aeronave cuya intensión de ser operada sin piloto a bordo se clasifica como una aeronave no tripulada (UA) y una aeronave no tripulada que es pilotada desde una estación remota es una RPA (refiérase a la siguiente figura).

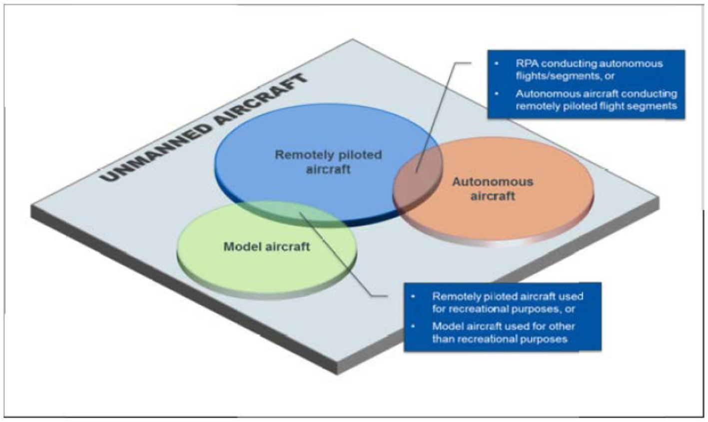

Figure 1-1. Unmanned aircraft

3 Procedimiento para asegurar la utilización apropiada de 1090 MHz y para la no asignación de direcciones de aeronaves (24-bits) para UAs

3.1 Hay una presión creciente para el uso de aplicaciones 1090 MHz Modo S o ADS-B OUT por parte de UAs. Dado el gran número de UAs previstos y al hecho de que las transmisiones de sus transpondedores o instrumentos ADS-B OUT impactarán el ya congestionado uso de 1090 MHz por sistemas existentes de vigilancia aeronáutica y de anticolisión, los Estados deben:

1) realizar un análisis del espectro de radio frecuencia para analizar el grado de congestión de 1090 MHz y con base en los resultados de este análisis, considerar cómo operaciones 1090 MHz ADS- B de UAs pueden impactar el desempeño de los sistemas de vigilancia operados por los ANSP en el espacio aéreo de interés así como los sistemas anticolisión a bordo de la aeronave;

2) formular las circunstancias y definir procedimientos para determinar los potenciales requerimientos para equipamiento 1090 MHz ADS-B OUT en UAs, a fin de permitir o prohibir dicho equipamiento según sea el caso. Durante este proceso, el Estado debe considerar:

   - el grado en que las UA requerirán o no servicios de tránsito aéreo. Por ejemplo, una UA operando en un espacio aéreo controlado quizá no requiera cumplir con los sistemas de vigilancia aeronáutica de la OACI.

   - el grado en que la operación de UAs interoperaría o no en el espacio aéreo con aeronaves tradicionales tripuladas. Por ejemplo, si una UA no está operando en la proximidad de una aeronave tradicional tripulada, entonces el cumplimiento en el equipamiento de sistemas de vigilancia de la OACI por dicha UA quizá no sea justificable.

•

3) En dichos casos donde las UAs no requieran equipo que cumpla con el equipamiento de vigilancia aeronáutica de la OACI, guiar a los explotadores y fabricantes de esas UAs que operan exclusivamente a baja altitud para que no utilicen ADS-B OUT a 1090 MHz para esas UAs. Por esta circunstancia, los Estados no deben asignar direcciones de aeronaves de 24-bits a dichos UAs.

Nota – Si es necesario, la asignación de direcciones de aeronaves de 24-bits debería ser parte de una certificación en el proceso de registro de UAs. Esto aseguraría una inspección cuidadosa de la dirección de aeronave de las UAs antes de su operación en tiempo real. Para material de orientación sobre el uso adecuado de las direcciones de aeronaves de 24-bits, refiérase al Anexo 10, Vol. III y al Doc 9924.

— FIN —