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14. ABSTRACT

This working paper analyzes Mode S Register data collected in 2021 and provides insights into which registers are commonly available. The purpose of this paper is to use collected data to determine which BDS registers are typically implemented on Mode S transponders, and which registers might be of interest to an interrogator.

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WORKING PAPER

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HYBRID meeting, 13 June through 17 June 2022
at EUROCONTROL, Brussels, Belgium

Mode S Register Equipage and Capabilities

(Prepared by **Jack Field** and **Alex Ivans**)

(Presented by **Jack Field**)

SUMMARY

This working paper analyzes Mode S Register data collected in 2021 and provides insights into which registers are commonly available.

ACTION

The meeting is invited to review the paper and recommend additional work.

1. Introduction

1.1 Mode Select (Mode S) transponders used for cooperative surveillance and air traffic control can provide data to an interrogating system upon request. The interrogating system uses the ground-initiated Comm-B (GICB) protocol to request one of the 255 Comm-B Data Selector (BDS) registers. Each BDS register contains 56 bits of data.

1.2 An important design consideration for an interrogating system is to determine which BDS registers to implement. Interrogating systems should only implement the ability to request registers that will be of utility, will be implemented by transponders, and are defined. Implementing registers that will not be utilized creates unnecessary design, integration, and test requirements, which leads to additional cost and complexity.

1.3 The purpose of this paper is to use collected data to determine which BDS registers are typically implemented on Mode S transponders, and which registers might be of interest to an interrogator. Those designing interrogator systems may desire to use this information to decide which Registers to implement. Additionally, this paper looks at the characteristics reported by aircraft transponders in Register 10_{16}. This information may be useful for modelling aeronautical surveillance frequency congestion (i.e., 1030/1090 MHz), which depends on transponder characteristics, such as percent of aircraft equipped with collision avoidance systems.

2. Discussion

2.1 Data were collected using a Mode S interrogator in the Northeast United States in February, August, and on two occasions in September 2021. During the data collection in February, the interrogator requested that each aircraft within range reply with BDS register 17_{16}. During the data collections in August and September, the interrogator requested that each aircraft within range reply with BDS registers 17_{16}, 18_{16}, 19_{16}, $E5_{16}$, and $E6_{16}$. Some aircraft also provided responses to interrogations for Register 10_{16} during the data collection period.

2.2 Register 10_{16} provides information about the capabilities of the aircraft. Register 17_{16} details which of a subset of commonly used registers contains valid data. Registers 18_{16} and 19_{16} indicate which of registers 01_{16} through 70_{16} the transponder is capable of filling, but do not provide any information as to whether those registers currently contain valid data. Registers $E5_{16}$ and $E6_{16}$ are not included in Registers 17_{16}, 18_{16}, or 19_{16}; however, it can be determined which aircraft implement these registers by observing which do not populate them with all zeros.

2.3 Each BDS register provided in the data sets was associated with a unique 24-bit aircraft address. The three sets of data were combined and all instances of duplicate identical entries for a single aircraft address were removed. In the few cases where the same aircraft reported different data across multiple interrogations, the response indicating more register capabilities was retained. Register 10_{16} data for each aircraft were processed to determine each aircraft's capabilities. Register 17_{16}, 18_{16}, and 19_{16} data for each aircraft were processed to determine which BDS registers are supported by each aircraft.

2.4 In total, data were collected from 2593 unique aircraft from 15 countries across the four occasions. Table 1 summarizes the country of origin (based on the ICAO 24-bit Aircraft Address allocations) and number of aircraft providing each of Registers 10_{16}, 17_{16}, 18_{16}, and 19_{16}. One aircraft used an address that is not assigned to any country and is therefore listed as "Unknown".

Table 1: Aircraft Summary

Country	Number of Aircraft	Register 10_{16}	Register 17_{16}	Register 18_{16}	Register 19_{16}
Canada	18	17	18	13	13
Ethiopia	2	2	2	1	1
Germany	1	1	1	0	0
Iceland	2	2	2	1	1
India	1	1	1	0	0
Malta	1	0	1	1	1
Morocco	1	1	1	1	1
Portugal	1	0	1	1	1
Qatar	1	1	1	1	1
Spain	1	0	1	1	1
Trinidad and Tobago	1	1	1	1	1
Turkey	1	1	1	1	1
United Arab Emirates	3	3	3	2	2
United Kingdom	2	1	2	2	2
United States (Civil)	2523	689	2502	2374	2357
United States (Military)	32	31	27	26	26
Unknown	1	1	1	1	1
Total	**2592**	**752**	**2566**	**2427**	**2410**

2.5 Registers 17_{16}, 18_{16} and 19_{16}

2.5.1 Table 2 shows processed data for all registers filled by at least one aircraft during the four collection periods as reported by Registers 17_{16}, 18_{16} and 19_{16}, as well as data for aircraft that filled either Register $E5_{16}$ or $E6_{16}$ with anything other than all zeros. Any register from 01_{16} through 70_{16}, as well as $E1_{16}$, $E2_{16}$, and $F1_{16}$ (which are included in Register 17_{16}), not listed in Table 2 was not indicated as a capability by any aircraft.

2.5.2 As seen in Table 2, all 2427 aircraft that provided Register 18_{16} indicated that they were capable of providing Registers 10_{16}, 17_{16}, and 18_{16}. All but one aircraft indicated they were capable of providing Register 20_{16}, used to report Aircraft Identification (ID) (also known as callsign or Flight ID), which is a requirement for Elementary Surveillance (ELS). Over 88% of the aircraft indicated they were capable of Enhanced Surveillance (EHS), as indicated by Registers 40_{16}, 50_{16}, and 60_{16}.

2.5.3 Over 99% of the aircraft indicated that they were Automatic Dependent Surveillance – Broadcast (ADS-B) Out capable. This can be determined by the presence of Registers 05_{16}, 06_{16}, 08_{16}, 09_{16}, 61_{16}, and 65_{16}, which are the minimum registers required for ADS-B Out Version 2 in the US. Additionally, 93.7% of aircraft indicated they were capable of filling Register 62_{16}, an optional ADS-B Out register required in Europe for those aircraft required to transmit ADS-B Out.

Table 2: Summary of Results

Register [1]	Airspace Requirement	Register 17_{16} Data			Register 18_{16}/19_{16}/$E5_{16}$/$E6_{16}$ Data		
		Capable	Total	Percent [2]	Capable	Total	Percent [2]
05_{16}	ADS-B Out	2549	2566	99.34%	2410	2427	99.30%
06_{16}	ADS-B Out	2547	2566	99.26%	2409	2427	99.26%
07_{16}		2549	2566	99.34%	2409	2427	99.26%
08_{16}	ADS-B Out	2552	2566	99.45%	2412	2427	99.38%
09_{16}	ADS-B Out	2548	2566	99.30%	2409	2427	99.26%
$0A_{16}$		2539	2566	98.95%	2406	2427	99.13%
$0F_{16}$					412	2427	16.98%
10_{16}	Mode S Level 2				2427	2427	100.00%
17_{16}	ELS				2427	2427	100.00%
18_{16}	ELS[3]				2427	2427	100.00%
19_{16}	ELS[3]				2420	2427	99.71%
$1A_{16}$	ELS[3]				15	2427	0.62%
$1B_{16}$	ELS[3]				15	2427	0.62%
$1C_{16}$	ELS[3]				2018	2427	83.15%
$1D_{16}$	EHS[3]				93	2427	3.83%
$1E_{16}$	EHS[3]				1	2427	0.04%
$1F_{16}$	EHS[3]				1	2427	0.04%
20_{16}	ELS[3]	2565	2566	99.96%	2426	2427	99.96%
21_{16}		564	2566	21.98%	533	2427	21.96%
25_{16}					86	2427	3.54%
30_{16}	Level 2/ACAS				1346	2427	55.46%
40_{16}	EHS	2276	2566	88.70%	2138	2410	88.71%
50_{16}	EHS	2369	2566	92.32%	2217	2410	91.99%
51_{16}		1087	2566	42.36%	1005	2410	41.70%
52_{16}		1087	2566	42.36%	1005	2410	41.70%
53_{16}		327	2566	12.74%	315	2410	13.07%
$5F_{16}$		2107	2566	82.11%	1976	2410	81.99%
60_{16}	EHS	2325	2566	90.61%	2182	2410	90.54%
61_{16}	ADS-B Out				2397	2410	99.46%
62_{16}	ADS-B Out (EU)				2259	2410	93.73%
65_{16}	ADS-B Out				2394	2410	99.34%
$E5_{16}$					911	2403	37.91%
$E6_{16}$					906	2393	37.86%

Note 1: All registers from 01_{16} through 70_{16} (inclusive) not listed in this table, as well as registers $E1_{16}$, $E2_{16}$, and $F1_{16}$, were not indicated as capabilities by any aircraft observed.
Note 2: The color-coding scale is based on percent of aircraft and is not an indication of whether an interrogator should implement a given register. Green indicates a high percentage of aircraft implement the given register, while red indicates a low percentage.
Note 3: Registers 18_{16} through $1F_{16}$ are only required if the aircraft has any of the capabilities indicated within those registers.

2.5.4 The most commonly observed registers include those used for capability reporting (10_{16}, 17_{16}, 18_{16}, 19_{16}, $1C_{16}$)[1], ELS/EHS (20_{16}, 30_{16}, 40_{16}, 50_{16}, $5F_{16}$[2], 60_{16}), and ADS-B Out (05_{16}, 06_{16}, 07_{16}[3], 08_{16}, 09_{16}, $0A_{16}$[3], 60_{16}, 61_{16}, 62_{16}, 65_{16}).

2.5.5 Registers 51_{16} and 52_{16} contain data that are already available in ADS-B Out registers. All aircraft that indicated they could provide Registers 51_{16} and 52_{16} also indicated they could provide the associated ADS-B Out registers. Register 53_{16} contains data that are already available in EHS registers. All aircraft that indicated they could provide Register 53_{16} also indicated they could provide the associated EHS registers.

2.5.6 Registers 21_{16} and 25_{16} are related to aircraft registration and characteristics and may be of interest to certain interrogator systems. However, Register 21_{16} was only available for 22% of aircraft and Register 25_{16} was only available for 3.5% of aircraft.

2.5.7 Register $1C_{16}$ lists whether the aircraft is capable of providing any of Registers $E1_{16}$ through FF_{16}. Approximately 83% of aircraft provided Register $1C_{16}$, likely because they populate any of Registers $E3_{16}$ through $E6_{16}$, which contain details regarding the transponder and collision avoidance system hardware part numbers and software versions. Less than 40% of aircraft populated Registers $E5_{16}$ and $E6_{16}$ with non-zero data. Therefore, the additional aircraft reporting Register $1C_{16}$ capability are likely populating Registers $E3_{16}$ and/or $E4_{16}$ with the transponder hardware part number and software version.

2.5.8 Any registers from 01_{16} through 70_{16}, as well as $E1_{16}$, $E2_{16}$,, and $F1_{16}$, that were not referenced in Table 2 were not reported as available by any aircraft. This includes several registers that may have been of interest to certain interrogator systems, such as 41_{16}, 42_{16}, and 43_{16} (next waypoint); 44_{16} and 45_{16} (meteorological data); 48_{16} (Very High Frequency (VHF) channel); and 54_{16}, 55_{16}, and 56_{16} (Waypoints 1, 2, and 3).

2.5.9 In addition to the registers discussed above, the interrogator system also received data for Register $1D_{16}$ for 591 aircraft. Of those, 28 aircraft reported Uplink Mode S Protocol (MSP) Channel 2 capability and two aircraft reported Uplink MSP Channel 5 capability.

[1] Registers $1A_{16}$, $1B_{16}$, $1D_{16}$, $1E_{16}$, and $1F_{16}$ are also used for capability reporting, but less than 1% of aircraft reported implementing those registers. Registers $1A_{16}$ and $1B_{16}$ correspond to an ability to fill any register in the ranges 71_{16}-$A8_{16}$ and $A9_{16}$-$E0_{16}$, respectively. Registers $1D_{16}$, $1E_{16}$, and $1F_{16}$ are used for reporting MSP services (e.g., dataflash).

[2] RTCA DO-181E/EUROCAE ED-73E were not clear on whether Register $5F_{16}$ was required for EHS; DO-181F/EUROCAE ED-73F clarify that it is not.

[3] Registers 07_{16} and $0A_{16}$ are ADS-B Out registers but are not required to be transmitted.

2.6 Register 10_{16}

2.6.1 Data from Register 10_{16} was collected from 752 unique aircraft. Since Register 10_{16} does not change frequently, it is infrequently extracted by interrogator systems. The interrogator used for this data collection likely received Register 10_{16} data from the remaining aircraft outside of the collection period.

2.6.2 Figure 1 provides details on the number of aircraft with operating Airborne Collision Avoidance System (ACAS) (bit 16 in Register 10_{16}), whether the ACAS is Hybrid (bit 37 in Register 10_{16}) and whether the aircraft is equipped with extended squitter (bit 34 in Register 10_{16}).

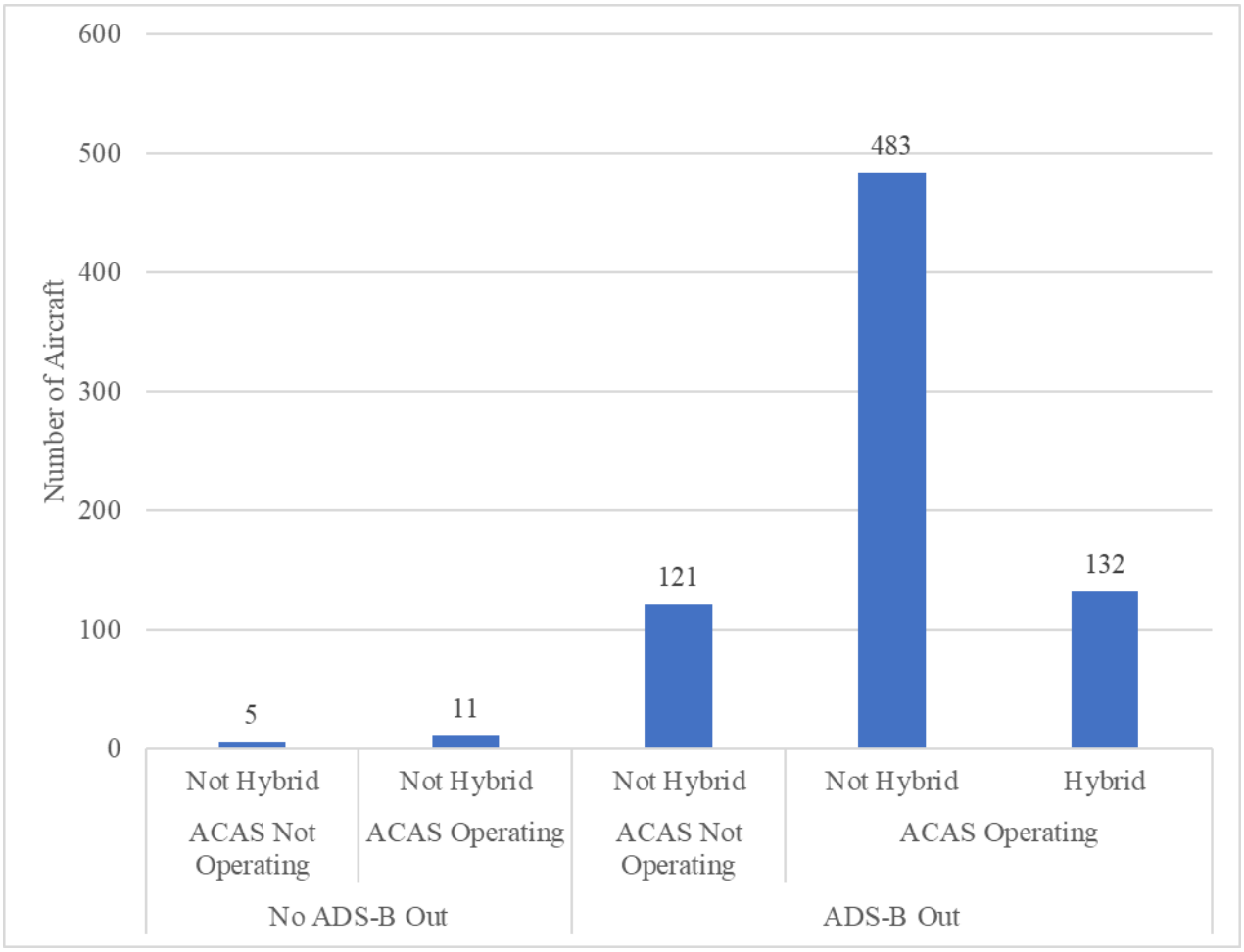

Figure 1: ACAS and ADS-B Out Capabilities

2.6.3 Figure 2 provides details on the ACAS version number (bits 39-40 in Register 10_{16}) and the Mode S Subnetwork Version number (bits 17-23 in Register 10_{16}).

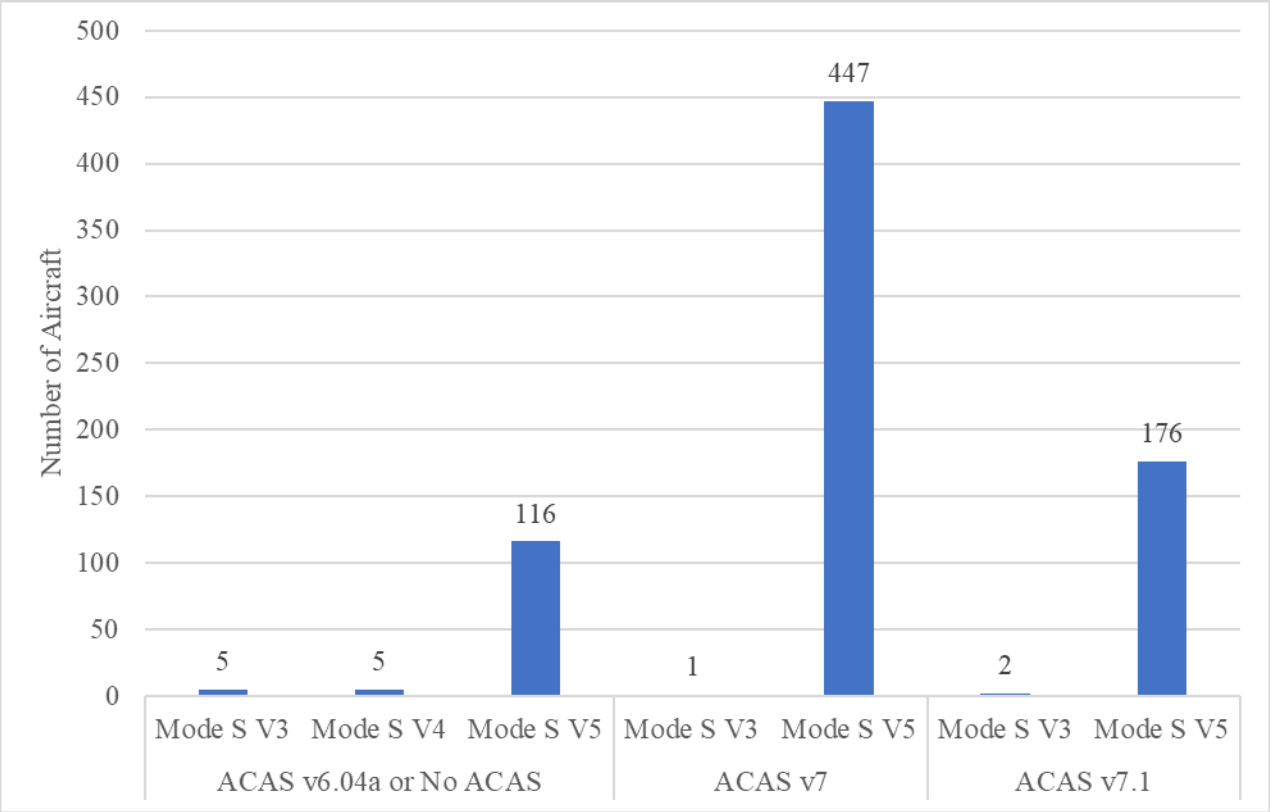

Figure 2: Mode S Subnetwork Version and ACAS Version

2.6.4 In addition to the figures provided, the following observations were made from the Register 10_{16} data:

- No aircraft reported the Continuation Flag (bit 9).
- 615 aircraft reported the Overlay Command Capability (bit 15), and 121 aircraft did not.
- No aircraft reported the Transponder Enhanced Protocol Indicator (bit 24), i.e., all transponders were Level 2 to 4.
- Eight aircraft did not report the Mode S Specific Services Capability (bit 25). However, three of those eight aircraft reported the Squitter Capability (bit 34), indicating that one of the two bits may have been set erroneously for those three aircraft.
- No aircraft reported the Uplink Extended Length Message (ELM) (bits 26-28) or Downlink ELM (bits 29-32) capabilities.
- All but two aircraft reported the Aircraft ID Capability (bit 33). One of the aircraft that reported no Aircraft ID Capability did report Register 20_{16} capabilities, but not Register 08_{16}, in Register 17_{16} and 18_{16}. Data from Register 17_{16} and 18_{16} were not available for the second aircraft. Additionally, no Register 10_{16} data were available for the one aircraft that did not report Register 20_{16} capability in Registers 17_{16} and 18_{16} (in Table 2), therefore three total aircraft reported no Aircraft ID capability.
- All aircraft reported the Surveillance Identifier (SI) Code Capability (bit 35).
- No aircraft set any of bits 10-14 (reserved) or 41-56 (Support Status of Data Terminal Equipment (DTE) Sub-addresses 0 to 15).

- One aircraft reported ACAS Operational (bit 16) with the ACAS Version (bits 39-40) set to zero, indicating either a pre-Version 7.0 ACAS or an incorrectly set bit.
- One aircraft reported ACAS Non-Operational (bit 16) with bit 38 indicating that ACAS was generating both Traffic Advisories (TAs) and Resolution Advisories (RAs) or a non-zero version in bits 39-40.

3. Conclusion

3.1 This analysis shows Mode S register equipage and aircraft capabilities for a representative sample of aircraft. It is possible that a larger set of data, or data from another location, may provide different results. This paper may be useful to aid in deciding which Registers to implement in an interrogator system. and for modelling aeronautical surveillance frequency congestion (i.e., 1030/1090 MHz).

3.2 Most aircraft for which data were collected did not populate many registers beyond those required for or associated with ELS, EHS, and ADS-B Out.

3.3 No aircraft reported a capability to fill any of Registers 41_{16}, 42_{16}, or 43_{16} (next waypoint); 44_{16} or 45_{16} (meteorological data); 48_{16} (VHF channel); or 54_{16}, 55_{16}, or 56_{16} (Waypoints 1, 2, and 3).

3.4 All aircraft reported SI Code capability.

4. Actions on the meeting

The meeting is invited to review the analysis provided in this paper and recommend additional work.