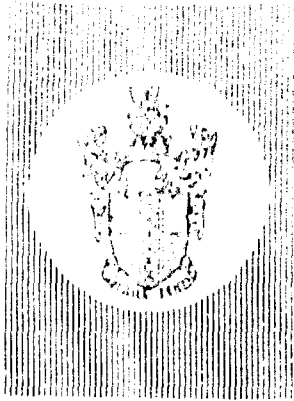


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Report No. 88004

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ROYAL SIGNALS AND RADAR ESTABLISHMENT,
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FINE RESOLUTION ERRORS IN
SECONDARY SURVEILLANCE RADAR ALTITUDE
REPORTING AMONGST AIRCRAFT TRANSMITTING
THE CONSPICUITY CODES 4321 AND 4322

Authors: P Banks, B A Wyndham, D B Jenkins

PROCUREMENT EXECUTIVE, MINISTRY OF DEFENCE
RSRE
Malvern, Worcestershire.

June 1982

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Date: June 1988

SUMMARY

The incidence of Secondary Surveillance Radar (SSR) Mode C pressure altitude encoding faults of the type caused by stuck/shorted C bits has been investigated amongst aircraft in UK airspace transmitting the SSR Mode A Conspicuity Codes 4321 and 4322. In an examination of 6808 suitable aircraft trajectories, 152 trajectories, 2.23% of the total, displayed such C bit faults on the SSR Mode C replies. The proportion of SSR plots bearing Conspicuity Codes was found to vary widely with geographical location and time. Combining a recently measured frequency for similar Mode C faults amongst non-Conspicuity Code aircraft (0.44%) with the presently measured frequencies of SSR plots and Mode C faults for Conspicuity Code aircraft leads to estimates of the overall frequency for stuck/shorted C bit faults ranging from 0.49% for the airspace covered by the Civil Aviation Authority Heathrow Tower radar to 0.70% for similar equipment at Debden.

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ALTITUDE REPORTING AMONGST AIRCRAFT TRANSMITTING THE
CONSPICUITY CODES 4321 AND 4322

P Banks B A Wyndham D B Jenkins

INTRODUCTION

The proposed implementation of ground based conflict alert systems in civil controlled UK air space, and similar airborne systems such as TCAS II, has led to concern over the integrity of Secondary Surveillance Radar (SSR) Mode C pressure altitude messages transmitted by the various classes of aircraft using UK airspace. Faults caused by defects in the operation of the C bits in the Mode C messages have been identified as having the potential to compromise the integrity of conflict alert systems. Mode C messages are used in order to calculate aircraft climb/decent rate, and defects of the present type can lead to apparent climb/decent rates erroneously high by up to a factor of three, can make climbing/decending aircraft appear to be flying level, and can lead to complete loss of aircraft height information for considerable periods of time, all with obvious repercussions for a conflict alert service using such data.

Aircraft transmitting Originating Region Code Assignment Method (ORCAM) and Domestic SSR Mode A Codes, and aircraft receiving a service from Military and Airport Approach Air Traffic Control have been examined for stuck/shorted C bit faults by Jenkins et al (1) using a method suggested by Wyndham (2,3) and first employed by Gent (4). In a study of 132,773 aircraft trajectories 0.44% were found to exhibit such a fault.

Aircraft transmitting the SSR Mode A Conspicuity Codes 4321 and 4322 were deliberately excluded from the study by Jenkins et al (1) because Conspicuity Codes are not normally used in controlled airspace. However, aircraft transmitting such Codes can approach commercial aircraft by flying close underneath or alongside airways or other civil controlled airspace and so the present study has been undertaken, using data gathered from 5 Civil Aviation Authority radar stations, at Heathrow, Gatwick, Pease Pottage, Debden and Claxby, and between 7 January and 9 November 1987.

METHOD

The method used to detect stuck/shorted C bit faults was similar to that employed by Jenkins et al (1) with one important difference: improvements in computer software enabled all aircraft transmitting non-discrete Mode A Conspicuity Codes and in the air at the same time to be tracked and used to produce trajectories, and not just the first aircraft to reply. Details of the radar data used in the present study, and the proportion of plots received and bearing Conspicuity Codes, are shown in Table 1.

RESULTS

Amongst 6808 trajectories from aircraft transmitting valid Mode C replies and transiting through at least 1000 feet 152 aircraft trajectories, 2.23% of the total, had stuck/shorted C bit faults. In spite of identification problems amongst aircraft transmitting non-discrete Mode A Codes it is possible to say that at least 10 aircraft were involved.

It was not possible to identify individual aircraft in the present study. All trajectories exhibiting the same C bit fault, unless from two aircraft in the air simultaneously, can accordingly be treated, for statistical purposes, as originating from the same aircraft and so 100% correlated. On the basis of this assumption and the methodology outlined in Appendix 3 of Jenkins et al (1) the upper bound (U/B) of the standard deviation on the observation was calculated to be 1.03%. Treating all trajectories as uncorrelated, ie as if from different aircraft, resulted in a lower bound (L/B) on the standard deviation of 0.18%.

Details of the 152 trajectories are given in Figure 1 and Table 2, where the numbers of trajectories and individually separable aircraft with each of the 9 possible C bit fault types are shown. C1- represents the C1 bit stuck off and C1+ the C1 bit stuck on fault types etc while C12 represents an inadvertent electrical interconnection (a short) between bits C1 and C2 etc.

DISCUSSION

For the present work, and with reference to Figure 1 and Table 2, only 1 in 10 faulty Conspicuity Code aircraft had shorted, as opposed to stuck, C bit faults, a value almost identical to that found for non-Conspicuity Code aircraft by Jenkins et al (1). Comparing stuck on and stuck off C bit faults, however, the picture changes. Amongst Conspicuity Code aircraft almost equal numbers of stuck on and stuck off faults were observed, for both aircraft and trajectories, whilst among non-Conspicuity Code aircraft Jenkins et al (1) found ratios of about 4 to 1, for both aircraft and trajectories, with C bit stuck off faults the more common. Whether this difference reflects equipment fits, or differing exposure to Air Traffic Control Mode C verification procedures, cannot be answered here, as examination of faulty avionics has not been possible.

The results of the present study suggest that the incidence of trajectories with SSR Mode C stuck/shorted C bit faults is considerably higher amongst aircraft transmitting the SSR Mode A Conspicuity Codes than amongst aircraft transmitting other Codes. In Figure 2 and Table 3, data published by Jenkins et al (1) are compared with the present work: nearly an order of magnitude difference exists between the groups with the lowest (ORCAM, 0.25%) and the highest (Conspicuity, 2.23%) incidence of stuck/shorted C bit faults. It is to be noted that the radar recordings used in the present study do not correspond exactly with those used by Jenkins et al (1) and therefore the numbers of trajectories and aircraft shown in Table 3 should not be compared directly. This does not, however, preclude direct comparison of fault frequencies.

In a study from which aircraft transmitting Conspicuity Codes were excluded, Jenkins et al (1) measured a frequency for stuck/shorted C bit faults of 0.44% in UK airspace, a value identical to one reported by McLaughlin (5,6) in a study of 8,189 trajectories, using a different method, and in United States airspace. The fault frequency for UK airspace will be higher when aircraft transmitting the Conspicuity Codes are included. The magnitude of the increase will however depend upon the proportion of Conspicuity Code aircraft under observation, which in turn will depend upon the volume of airspace considered, the time of day and the date, as can be seen quite clearly in an examination of Table 1, in which the number of SSR plots carrying a Conspicuity Code is shown as a proportion of the whole for each individual observational period. For example, for the total of all Heathrow Tower data recorded in the present study, in which the proportion of Conspicuity Codes received was 3.0%, the incidence of C bit faults would only be increased to 0.49%, whilst for the Debden data, in which Conspicuity Codes made up 14.3% of the whole, this figure would be increased to 0.70%.

ACKNOWLEDGEMENTS

We wish to record our appreciation for the help, advice and guidance received from Civil Aviation Authority staff at the London and Scottish Air Traffic Services Units, from staff at the radar Technical Services Facility at Gatwick, and from Civil Aviation Authority and Ministry of Defence staff in the AD4 Division at RSRE Malvern. This work was carried out under funding from, and while the authors were on secondment to, the Civil Aviation Authority.

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TABLE 1

DATES, TIMES AND SOURCES OF RADAR DATA USED IN THE PRESENT STUDY,
TOGETHER WITH THE TOTAL NUMBER OF PLOTS, AND CONSPICUITY CODE
PLOTS, RECORDED

HEATHROW TOWER

DATE	TIME	TOTAL PLOTS	CONSPICUITY CODE PLOTS
07.01.87 WED	15.15 - 16.02	50363	6604 (13.1%)
08.01.87 THU	09.05 - 11.22	141739	7191 (5.1%)
09.01.87 FRI	08.42 - 09.44	68424	4833 (7.1%)
09.01.87 FRI	10.49 - 11.49	74648	6952 (9.3%)
09.01.87 FRI	18.46 - 21.58	90952	1597 (1.8%)
14.01.87 WED	14.23 - 22.00	235012	3836 (1.6%)
15.01.87 THU	17.48 - 22.00	143068	1814 (1.3%)
16.01.87 FRI	09.40 - 11.00	101381	9061 (8.9%)
16.01.87 FRI	12.50 - 13.12	16548	792 (4.8%)
16.01.87 FRI	18.06 - 22.00	124857	1797 (1.4%)
17.01.87 SAT	10.49 - 22.00	310008	8941 (2.9%)
18.01.87 SUN	09.51 - 22.00	386992	8258 (2.1%)
19.01.87 MON	16.51 - 22.00	167691	2746 (1.6%)
20.01.87 TUE	08.34 - 12.11	178765	3621 (2.0%)
20.01.87 TUE	15.29 - 22.00	229090	5593 (2.4%)
21.01.87 WED	17.36 - 22.00	119052	542 (0.5%)
TOTALS		<u>2438590</u>	<u>74182 (3.0%)</u>

PEASE POTTAGE

DATE	TIME	TOTAL PLOTS	CONSPICUITY CODE PLOTS
22.01.87 THU	18.15 - 22.00	111441	814 (0.7%)
23.01.87 FRI	17.16 - 22.00	194802	1853 (1.0%)
24.01.87 SAT	08.23 - 22.00	563525	23806 (4.2%)
25.01.87 SUN	08.26 - 22.00	540466	19402 (3.6%)
26.01.87 MON	16.50 - 22.00	210253	8042 (3.8%)
27.01.87 TUE	17.04 - 22.00	218784	6602 (3.0%)
28.01.87 WED	17.21 - 22.00	222890	15534 (7.0%)
29.01.87 THU	17.07 - 22.00	238857	8734 (3.7%)
30.01.87 FRI	12.06 - 13.22	102098	16496 (16.2%)
02.02.87 MON	17.26 - 22.00	177529	1336 (0.8%)
03.02.87 TUE	17.08 - 22.00	166368	2151 (1.3%)
04.02.87 WED	17.23 - 22.00	184140	2696 (1.5%)
05.02.87 THU	17.20 - 22.00	229682	2655 (1.2%)
09.02.87 MON	17.25 - 22.00	181335	3012 (1.7%)
10.02.87 TUE	17.24 - 22.00	208757	12921 (6.2%)
11.02.87 WED	17.16 - 22.00	195745	6173 (3.2%)
12.02.87 THU	16.53 - 22.00	245873	8134 (3.3%)
13.02.87 FRI	18.04 - 22.00	157626	2654 (1.7%)
14.02.87 SAT	07.10 - 22.00	618562	14953 (2.4%)
15.02.87 SUN	07.13 - 22.00	712982	98506 (13.8%)
20.05.87 WED	17.37 - 21.59	258064	22104 (8.6%)
21.05.87 THU	07.42 - 12.05	395878	24176 (6.1%)
TOTALS		<u>6135657</u>	<u>302754 (4.9%)</u>

DEBDEN

DATE	TIME	TOTAL PLOTS	CONSPICUITY CODE PLOTS
07.07.87	TUE 08.00 - 20.00	571237	93822 (16.4%)
08.07.87	WED 08.00 - 20.00	1263882	214398 (17.0%)
09.07.87	THU 08.00 - 20.00	1274672	229093 (18.0%)
16.07.87	THU 08.00 - 20.00	1183475	131998 (11.2%)
02.09.87	WED 08.00 - 20.00	1016239	86780 (8.5%)
10.09.87	THU 08.00 - 20.00	1190176	177712 (14.9%)
22.09.87	TUE 08.00 - 20.00	DATA NOT	AVAILABLE
23.09.87	WED 08.00 - 20.00	1116767	156613 (14.0%)
TOTALS		<u>7616448</u>	<u>1090416 (14.3%)</u>

GATWICK

DATE	TIME	TOTAL PLOTS	CONSPICUITY CODE PLOTS
30.09.87	WED 08.45 - 15.55	392034	25062 (6.4%)
28.10.87	WED 16.25 - 36.53	841234	28161 (3.3%)
09.11.87	MON 16.52 - 32.38	391169	1721 (0.4%)
TOTALS		<u>1624437</u>	<u>54944 (3.4%)</u>

CLAXBY

DATE	TIME	TOTAL PLOTS	CONSPICUITY CODE PLOTS
13.10.87	TUE 07.00 - 20.00	1054202	116377 (11.0%)
14.10.87	WED 07.00 - 20.00	1153248	179355 (15.6%)
15.10.87	THU 07.00 - 20.00	1037351	114323 (11.0%)
TOTALS		<u>3244801</u>	<u>410055 (12.6%)</u>

Times greater than 23.59 were used when data recording was extended beyond midnight.

TABLE 2

STATISTICS OF TRAJECTORIES AND AIRCRAFT WITH C BIT FAULTS

FAULT	TRAJECTORIES	AIRCRAFT	FREQ	STANDARD DEVIATION	
				L/B	U/B
C1-	11	>= 1	0.16%	0.05%	0.16%
C2-	33	>= 2	0.49%	0.08%	0.47%
C4-	26	>= 2	0.38%	0.08%	0.37%
C1+	8	>= 1	0.12%	0.04%	0.12%
C2+	16	>= 1	0.24%	0.06%	0.24%
C4+	56	>= 2	0.82%	0.11%	0.78%
C12	0	0	0.00%	-	-
C24	0	0	0.00%	-	-
C14	2	>= 1	0.03%	0.02%	0.03%
ALL FAULTS	152	>=10	2.23%	0.18%	1.03%

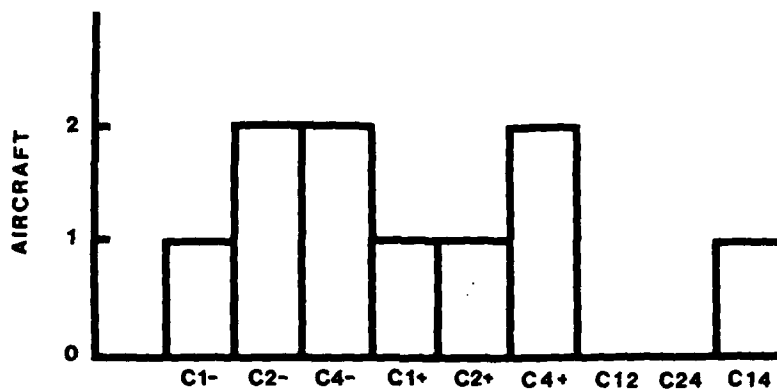
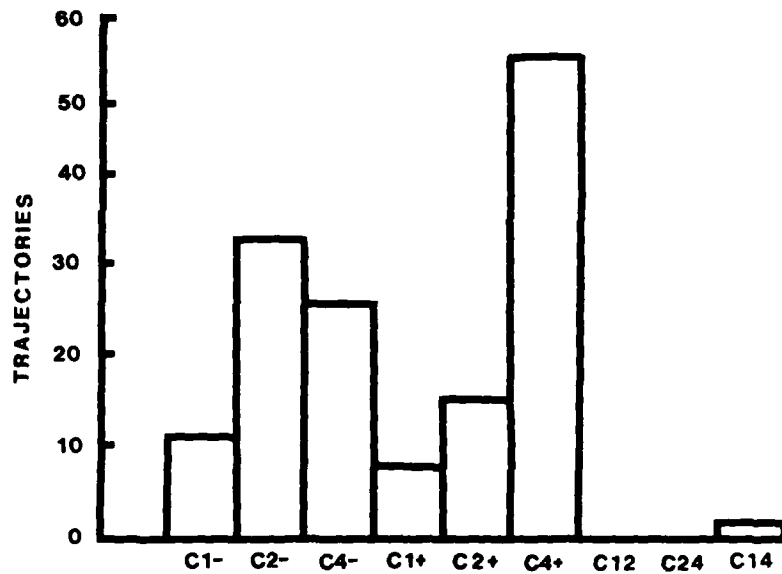
The upper (U/B) and lower (L/B) bounds of standard deviation on the frequencies of C bit faults are calculated assuming that, for all unidentified trajectories observed, the minimum and maximum possible numbers of aircraft were involved. C1- represents the C1 bit stuck off and C1+ the C1 bit stuck on fault types etc while C12 represents an inadvertent electrical interconnection (a short) between bits C1 and C2 etc.

TABLE 3

STATISTICS OF C BIT FAULTS AMONGST AIRCRAFT ENGAGED IN INTERNATIONAL AND DOMESTIC FLIGHTS, AIRCRAFT RECEIVING A SERVICE FROM MILITARY AND APPROACH ATC AND AIRCRAFT TRANSMITTING CONSPICUITY CODES 4321 AND 4322

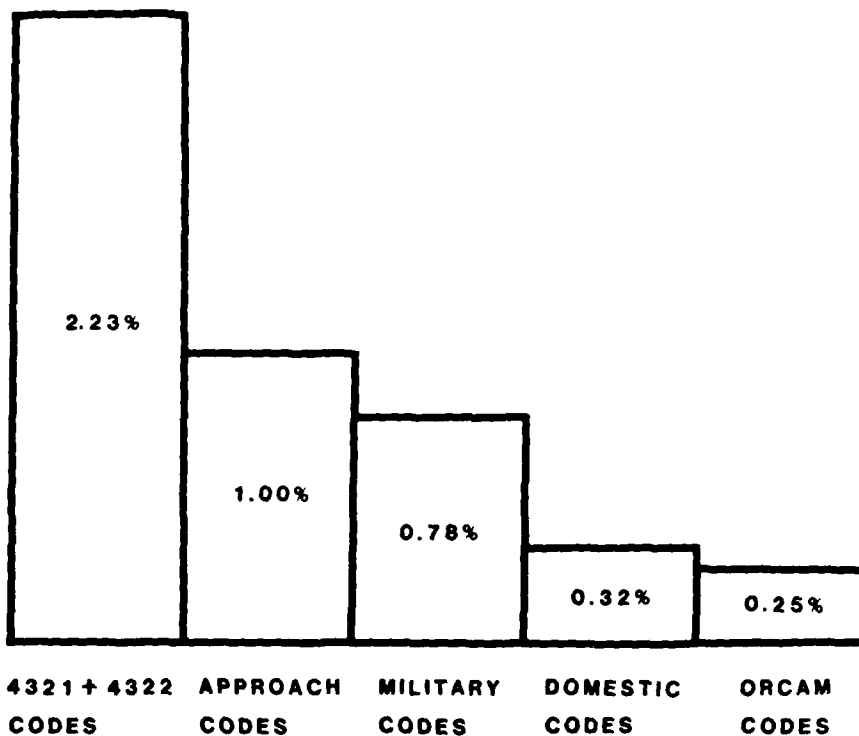
CODE	TRAJECTORIES	AIRCRAFT	FREQ	STANDARD DEVIATION	
				L/B	U/B
INTERNATIONAL	52 in 20,590	>=14	0.25%	0.07%	0.12%
DOMESTIC	47 in 14,877	>= 9	0.32%	0.20%	0.22%
MILITARY ATC	60 in 7,723	>= 9	0.78%	0.10%	0.34%
APPROACH ATC	10 in 1,001	>= 5	1.00%	0.32%	0.57%
CONSPICUITY	152 in 6,808	>=10	2.23%	0.18%	1.03%

The upper (U/B) and lower (L/B) bounds of standard deviation on the frequencies of C bit faults are calculated assuming that, for all unidentified trajectories observed, the minimum and maximum possible numbers of aircraft were involved.



Numbers of trajectories and individually separable aircraft with C bit faults identified in an examination of 6,808 trajectories observed in UK airspace and transmitting the SSR Mode A Conspicuity Codes 4321 and 4322.

FIG 1



Frequencies of C bit faults amongst aircraft transmitting SSR Mode A Conspicuity Codes 4321 and 4322, and Aircraft Identification Codes issued by Airport Approach ATC, by Military ATC, and by Civil ATC for aircraft undertaking International (ORCAM) and Domestic flights.

FIG 2

DOCUMENT CONTROL SHEET

Overall security classification of sheet UNCLASSIFIED

(As far as possible this sheet should contain only unclassified information. If it is necessary to enter classified information, the box concerned must be marked to indicate the classification eg (R) (C) or (S))

1. DPIC Reference (if known)	2. Originator's Reference REPORT 88004	3. Agency Reference	4. Report Security Classification U/C	
5. Originator's Code (if known) 7784000	6. Originator (Corporate Author) Name and Location ROYAL SIGNALS & RADAR ESTABLISHMENT ST ANDREWS ROAD, GREAT MALVERN, WORCESTERSHIRE WR14 3PS			
5a. Sponsoring Agency's Code (if known)	6a. Sponsoring Agency (Contract Authority) Name and location Civil Aviation Authority			
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7a. Title in Foreign Language (in the case of translations)				
7c. Presented at (for conference papers) Title, place and date of conference				
8. Author 1 Surname, initials BANKS P	9(a) Author 2 WYNDHAM B A	9(c) Authors 3,4... JENKINS D P	10. Date 1988.6	10. Ref. 8
11. Contract Number	12. Period	13. Project	14. Other Reference	
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continue on separate piece of paper				
<p>Abstract The incidence of Secondary Surveillance Radar (SSR) Mode C pressure altitude encoding faults of the type caused by stuck/shorted C bits has been investigated amongst aircraft in UK airspace transmitting the SSR Mode A Conspicuity Codes 4321 and 4322. In an examination of 6808 suitable aircraft trajectories, 152 trajectories, 2.23% of the total, displayed such C bit faults on the SSR Mode C replies. The proportion of SSR plots bearing Conspicuity Codes was found to vary widely with geographical location and time. Combining a recently measured frequency for similar Mode C faults amongst non-Conspicuity Code aircraft (0.44%) with the presently measured frequencies of SSR plots and Mode C faults for Conspicuity Code aircraft leads to estimates of the overall frequency for stuck/shorted C bit faults ranging from 0.49% for the airspace covered by the Civil Aviation Authority Heathrow Tower radar to 0.70% for similar equipment at Debden.</p>				