European and North Atlantic Office

NORTH ATLANTIC AIR TRAFFIC MANAGEMENT GROUP

FORTY THIRD MEETING

(Prestwick, United Kingdom, 10 to 14 March, 2014)

Agenda Item 3: Update procedures and requirements

d) Variable altitude and speed

Analyses of the Speed Distribution of Aircraft that have an Assigned Mach Speed

(Presented by Iceland)

SUMMARY

This working paper analyses the speed distribution of aircraft that have been assigned a fixed Mach speed in the Reykjavik CTA. Speed information is obtained via ADS-C periodic reports and compared to the assigned Mach speed as issued in the NAT Oceanic clearance. The working paper partly addresses NAT ATMG Action Item 41-03.

1. Introduction

1.1 This working paper analyses the speed distribution of aircraft that have been assigned a fixed Mach speed in the Reykjavik Control Area (CTA). Speed information is obtained via Automatic Dependent Surveillance Contract (ADS-C) periodic reports and compared to the assigned Mach speed as issued in the North Atlantic region (NAT) Oceanic clearance.

1.2 The working paper partly addresses NAT ATMG Action Item 41-03:

> *NAT ANSPs investigate how the reference speed for fix-time calculation would be determined if an aircraft was not assigned a fixed Mach speed.*

2. Discussion

Background

2.1 All turbojet aircraft in the NAT are assigned a fixed Mach speed in the Oceanic clearance that is issued to aircraft before entry into the NAT area. This practice is governed by the following provision in the NAT section of the Regional Supplementary Procedures (SUPPs, Doc 7030):

> *6.1.1.7 The ATC-approved true Mach number shall be included in each clearance given to subsonic turbo-jet aircraft operating within Bodø Oceanic, Gander Oceanic, New York Oceanic, Reykjavik, Santa Maria Oceanic and Shanwick Oceanic control areas.*

2.2 The four-dimensional aircraft profile, including the cleared Mach speed, is stored in the Reykjavik Flight Data Processing System (FDPS) and saved to enable post-flight analyses. All Future Air Navigation Systems (FANS) equipped aircraft that log on to the Reykjavik FDPS are assigned an 18-minute periodic ADS-C contract (in addition to other types of ADS-C contracts). The periodic contract includes the Air Reference Group, which includes the Mach speed. The periodic ADS-C reports therefore include the Mach speed of the aircraft.

2.3 Aircraft manufacturers have stated that the reported Mach speed in ADS-C reports is instantaneous speed and not the target speed of the aircraft. It has been stated that because the reported Mach speed is instantaneous it could not be relied on for separation and fix-time calculations since it will show fluctuations from the target speed and may show significant fluctuations in some cases such as when the aircraft encounters turbulence (target speed = the speed that the aircraft is striving to maintain).

2.4 Because all turbojet aircraft are assigned a fixed Mach speed in the Reykjavik CTA the cleared Mach speed can also be assumed to be the target speed of the aircraft. This situation therefore provides a unique opportunity to answer the following two questions:

a) When aircraft are assigned a fixed Mach speed, how much can the speed be expected to vary from the cleared Mach speed?

b) How reliably does the ADS-C reported Mach speed represent the target speed of the aircraft?

Analyses

2.5 Data set before filtering:

- 15,128 flights.
- 124,209 periodic ADS-C reports. Of those 95,.330 were within the Reykjavik CTA
- Average number of periodic ADS-C reports per flight is 8.2.
- The average Mach number reported is M0.823.

2.6 The data set was filtered as follows:

- Spans the period 19 June 2013 – 31 August 2013.
- The flight profile data was correlated with the ADS-C periodic reports. 46 flights could not be correlated.
- Only over-flights were used, flights that departed and/or arrived within the Reykjavik CTA were excluded.
- Only flights that had the same cleared Mach speed throughout the flight in the Reykjavik CTA were retained, 520 aircraft that were issued a Mach speed change were excluded and those may be analysed further at a later date if needed.
- Only flights that maintained F285 or higher throughout the flight in the Reykjavik CTA were retained, aircraft that had any part of the flight profile below F285 were excluded.
- Only ADS-C reports within the Reykjavik CTA were examined, all ADS-C reports where the reported position was outside the Reykjavik CTA were excluded.
- Only aircraft that had 3 or more periodic ADS-C reports were retained. 2894 aircraft with 2 or fewer periodic ADS-C reports (19%) were excluded. The reason for this filtering is to try to find those aircraft that are not maintaining their cleared Mach speed (see table in Appendix A).

2.7 Data set after filtering:

- 12,234 flights.
- 92,284 periodic ADS-C reports.
- Average number of periodic ADS-C reports per flight used for this analysis is 7.5.
- The average Mach number reported is M0.822.

2.8 The number of ADS-C periodic reports from each flight after filtering is shown in **Figure 1** below:

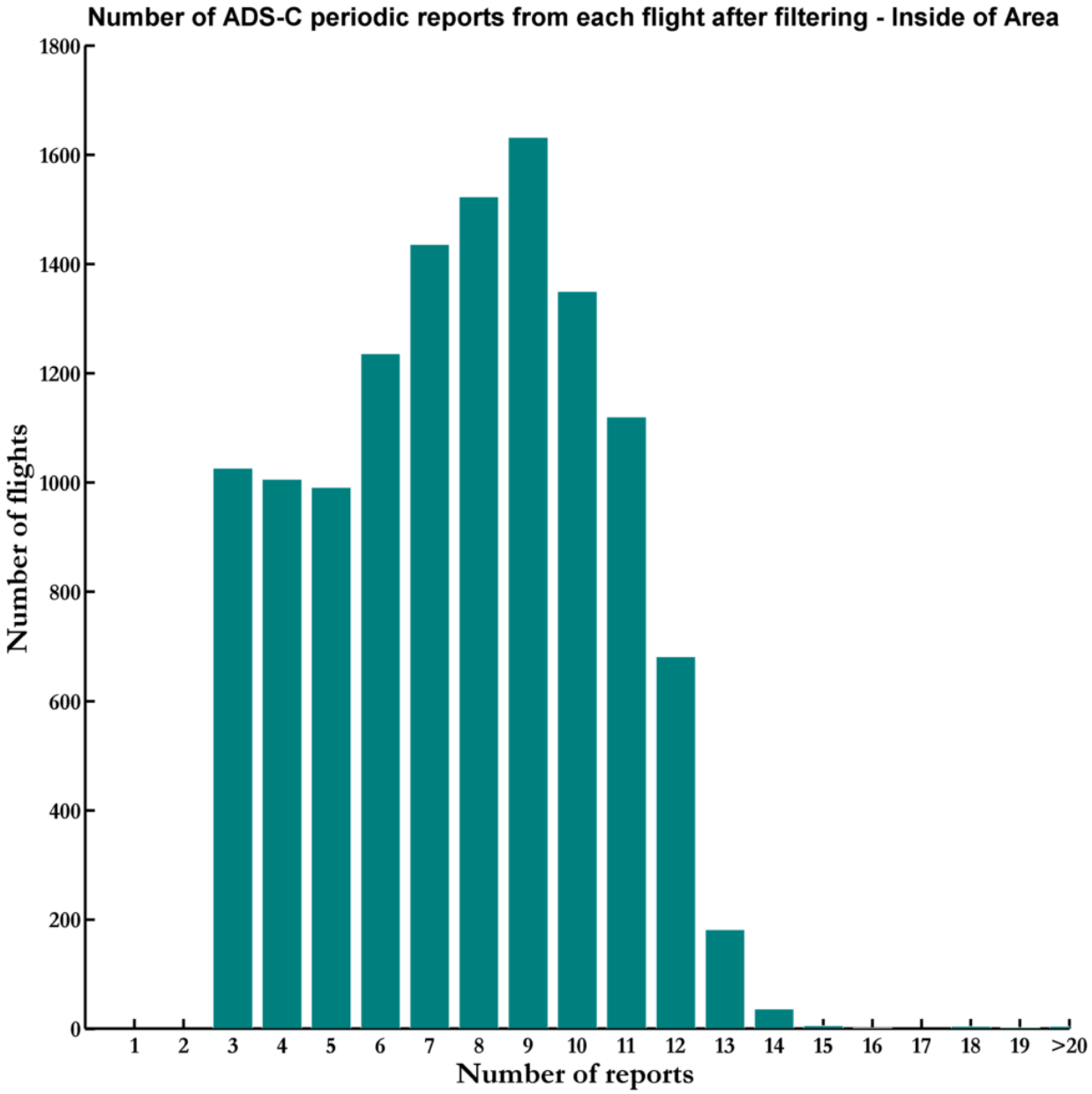

Figure 1

2.9 The distribution of the cleared Mach speed is shown in **Figure 2** below:

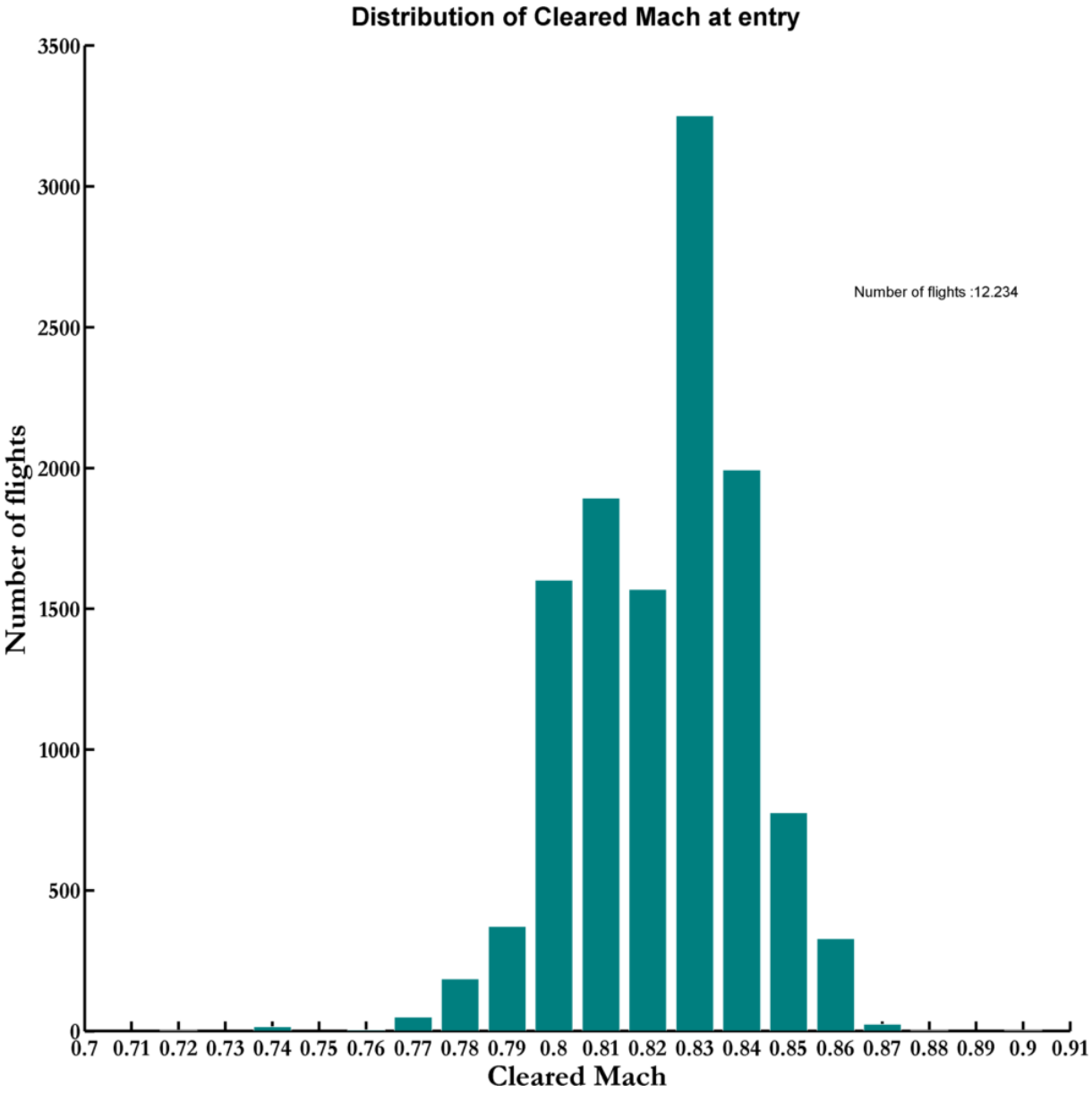

Figure 2

2.10 In the data set that is used for the analysis there were no values detected outside the M0.70 – M0.91 interval.

2.11 **Figure 3** below shows a histogram of reported Mach speed in ADS-C reports:

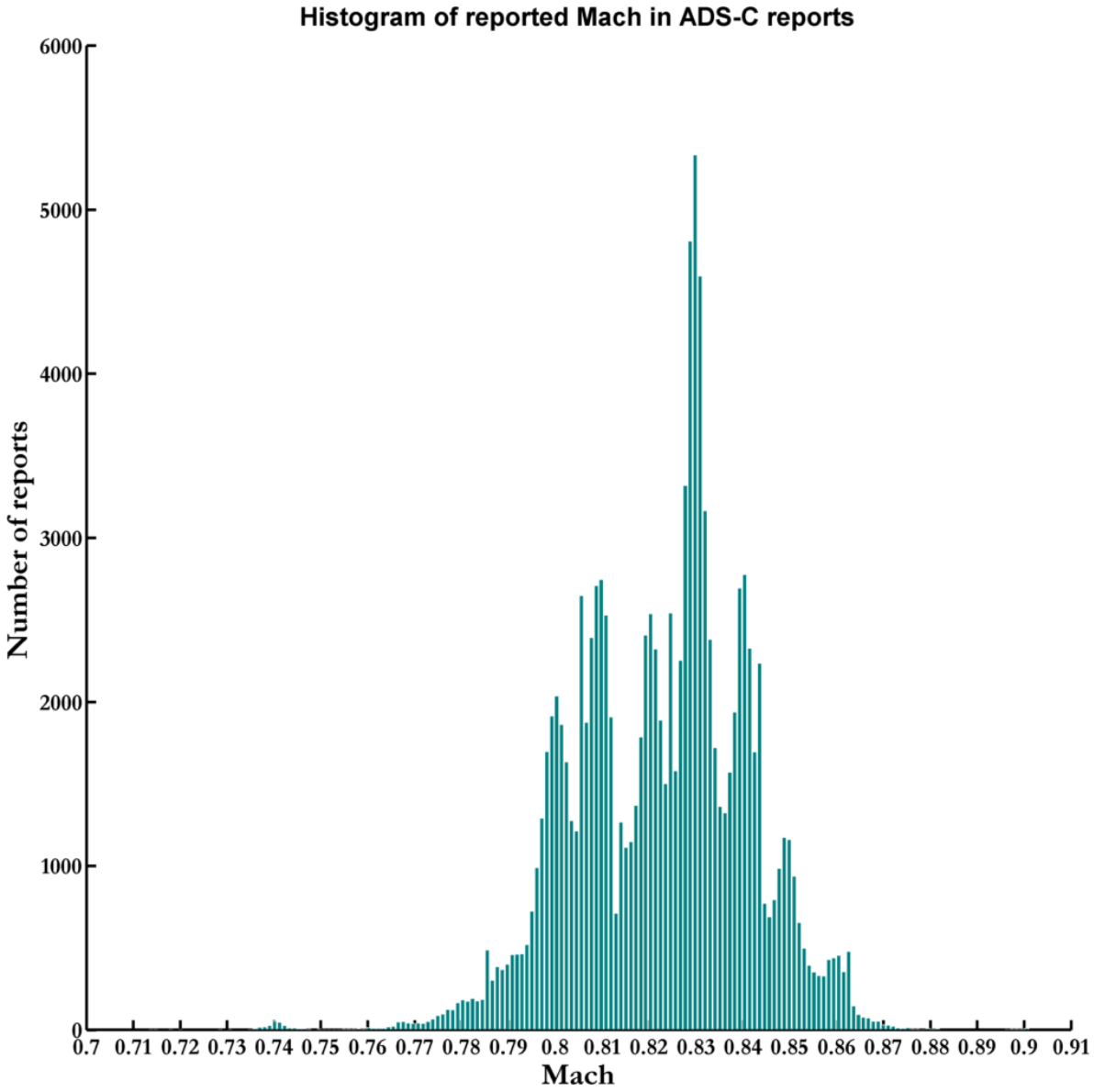

Figure 3

Results

2.12 **Figure 4** and **Figure 5** below show the results concerning reported Mach in all ADS-C reports as a difference from the cleared Mach speed:

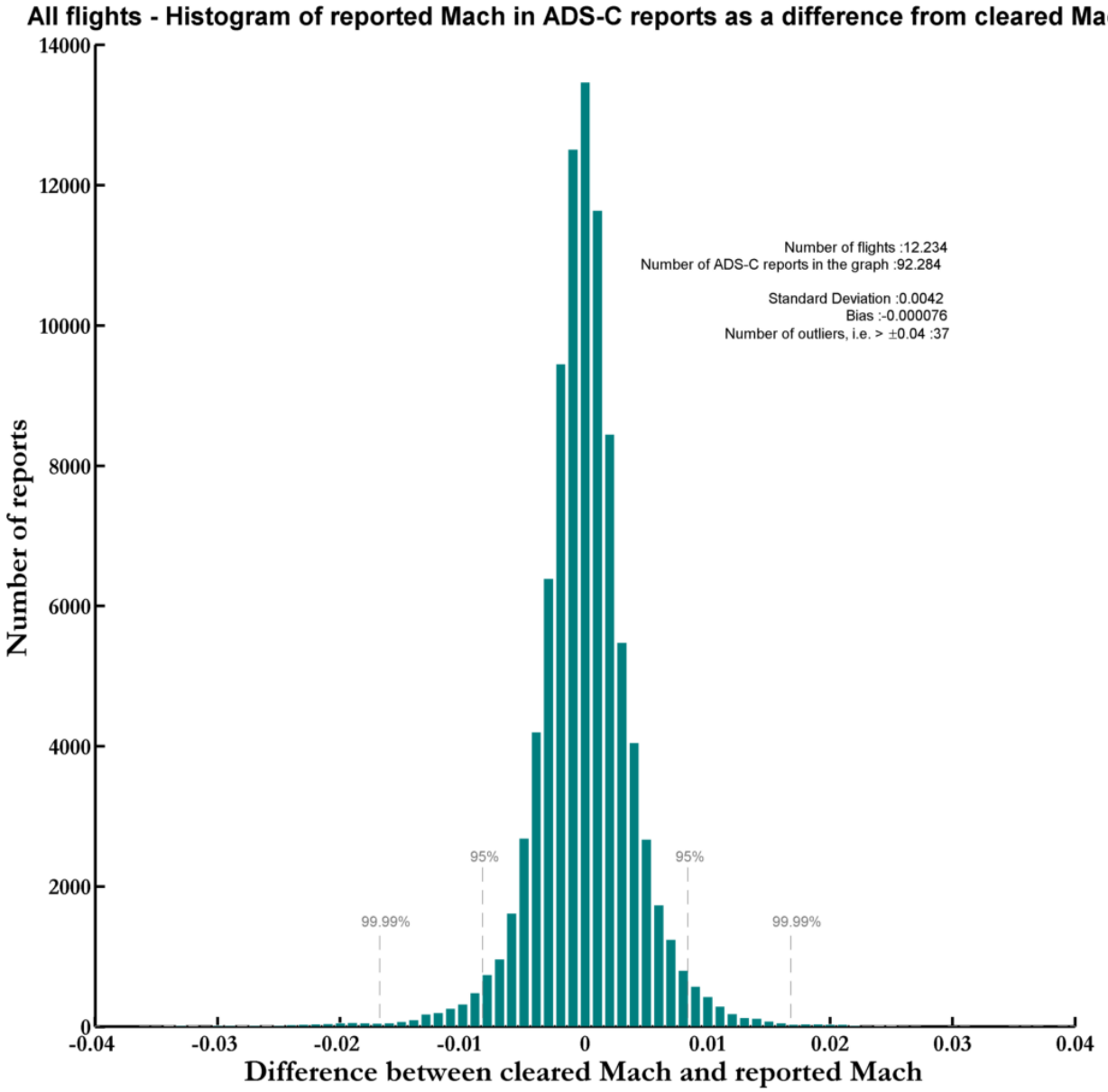

Figure 4

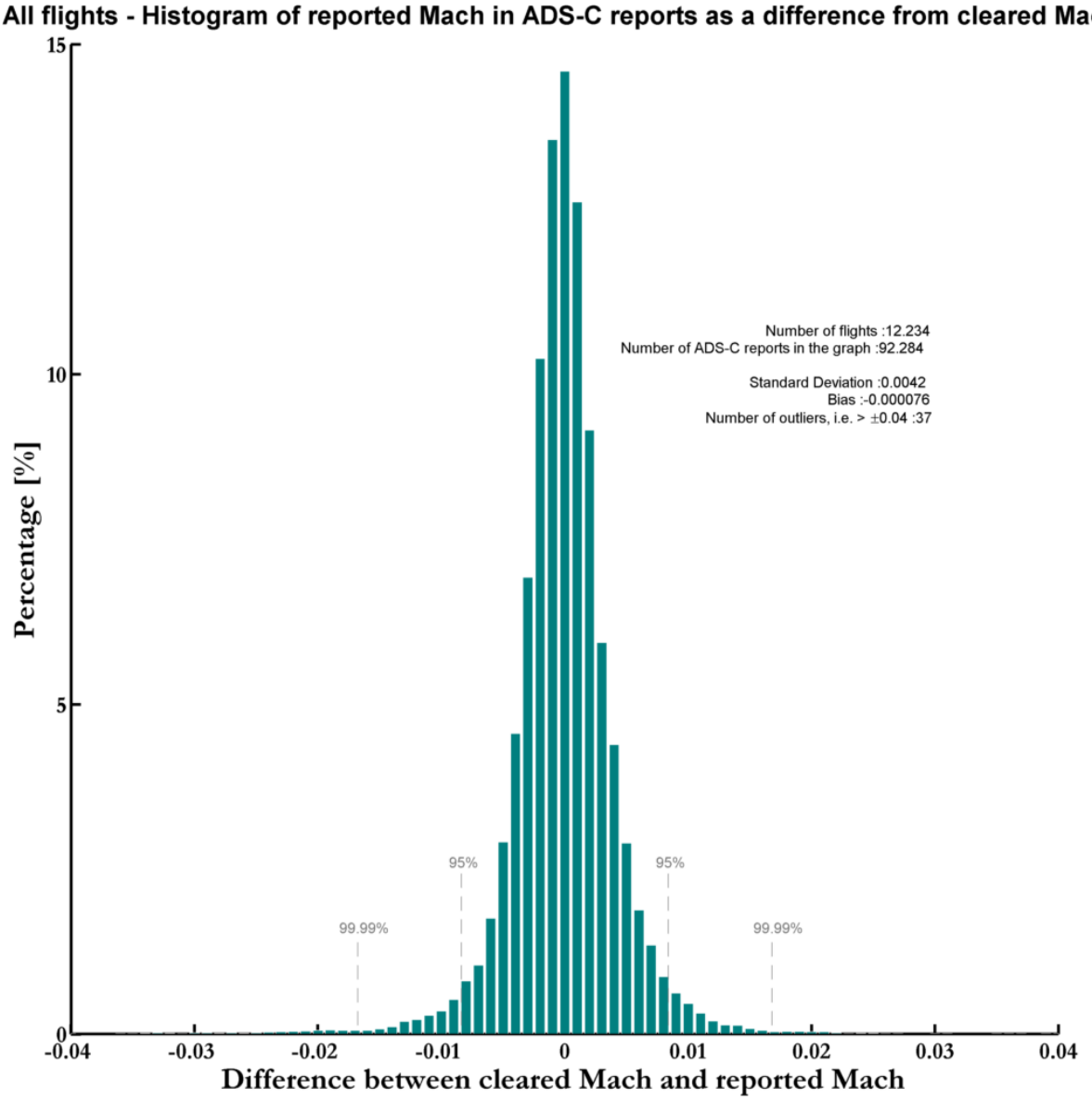

Figure 5

2.13 There are 37 outliers that are not contained within +/- M0.04 from the cleared Mach speed. They are scrutinized in the table in **Attachment A**:

2.14 **Figure 6**, **Figure 7**, and **Figure 8** below show the results concerning reported Mach in ADS-C reports as a difference from the cleared Mach speed for a few aircraft types. No noticeable difference can be seen between the different aircraft types.

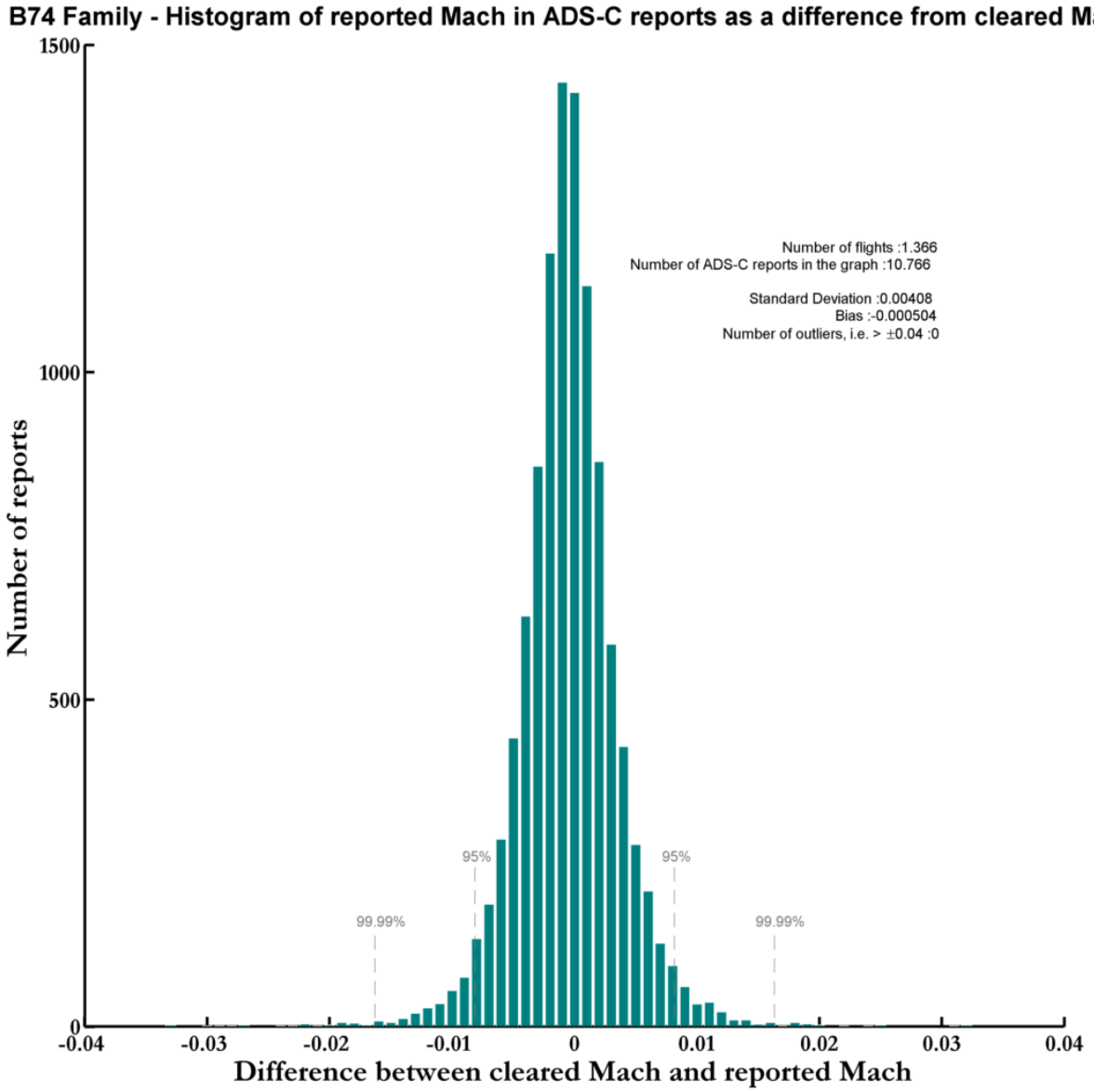

Figure 6

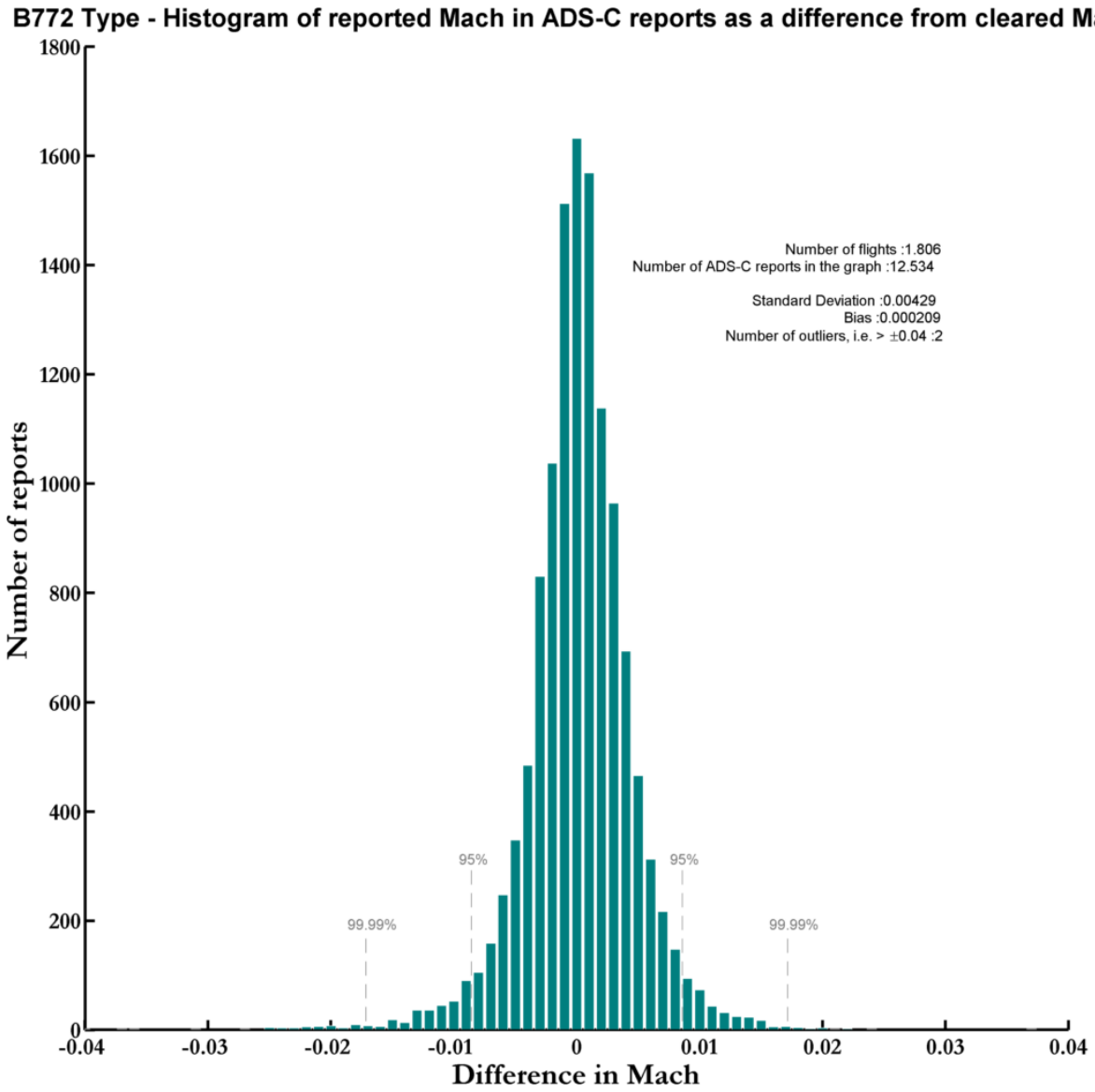
B772 Type - Histogram of reported Mach in ADS-C reports as a difference from cleared Mach
Number of flights :1.806
Number of ADS-C reports in the graph :12.534
Standard Deviation :0.00429
Bias :0.000209
Number of outliers, i.e. > ±0.04 :2
95%
95%
99.99%
99.99%
Number of reports
Difference in Mach
1800
1600
1400
1200
1000
800
600
400
200
0
-0.04
-0.03
-0.02
-0.01
0
0.01
0.02
0.03
0.04

Figure 7

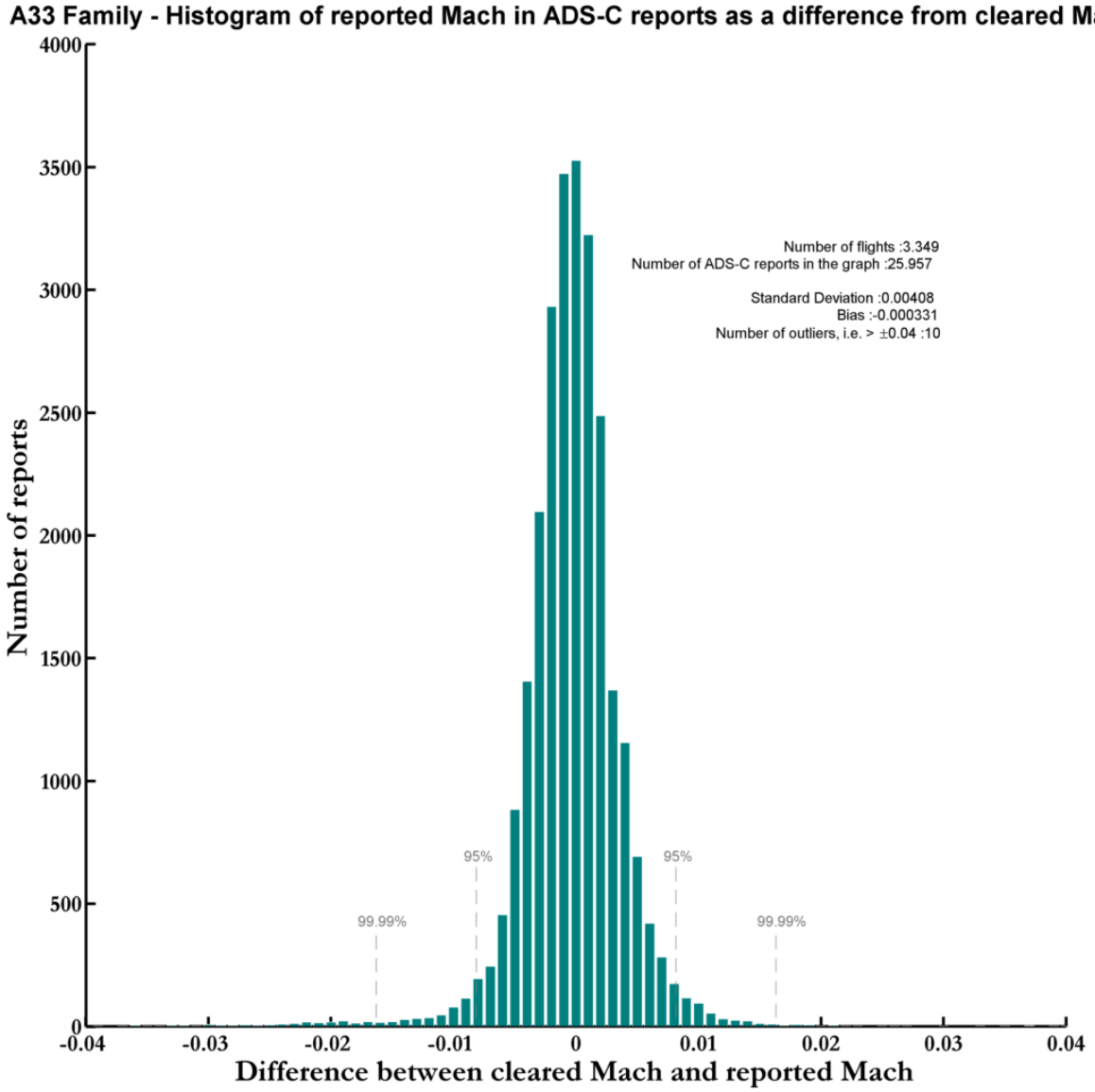
A33 Family - Histogram of reported Mach in ADS-C reports as a difference from cleared Mach
Number of flights :3.349
Number of ADS-C reports in the graph :25.957
Standard Deviation :0.00408
Bias :-0.000331
Number of outliers, i.e. > ±0.04 :10
95%
95%
99.99%
99.99%
Number of reports
Difference between cleared Mach and reported Mach
4000
3500
3000
2500
2000
1500
1000
500
0
-0.04
-0.03
-0.02
-0.01
0
0.01
0.02
0.03
0.04

Figure 8

2.15 **Figure 9**, **Figure 10**, and **Figure 11** below show the results concerning reported Mach in ADS-C reports as a difference from the cleared Mach speed for three airlines. The only noticeable difference is that for airline 2 the distribution is greater which results in increased standard deviation and that the 95% and 99.99% confidence intervals are at higher values.

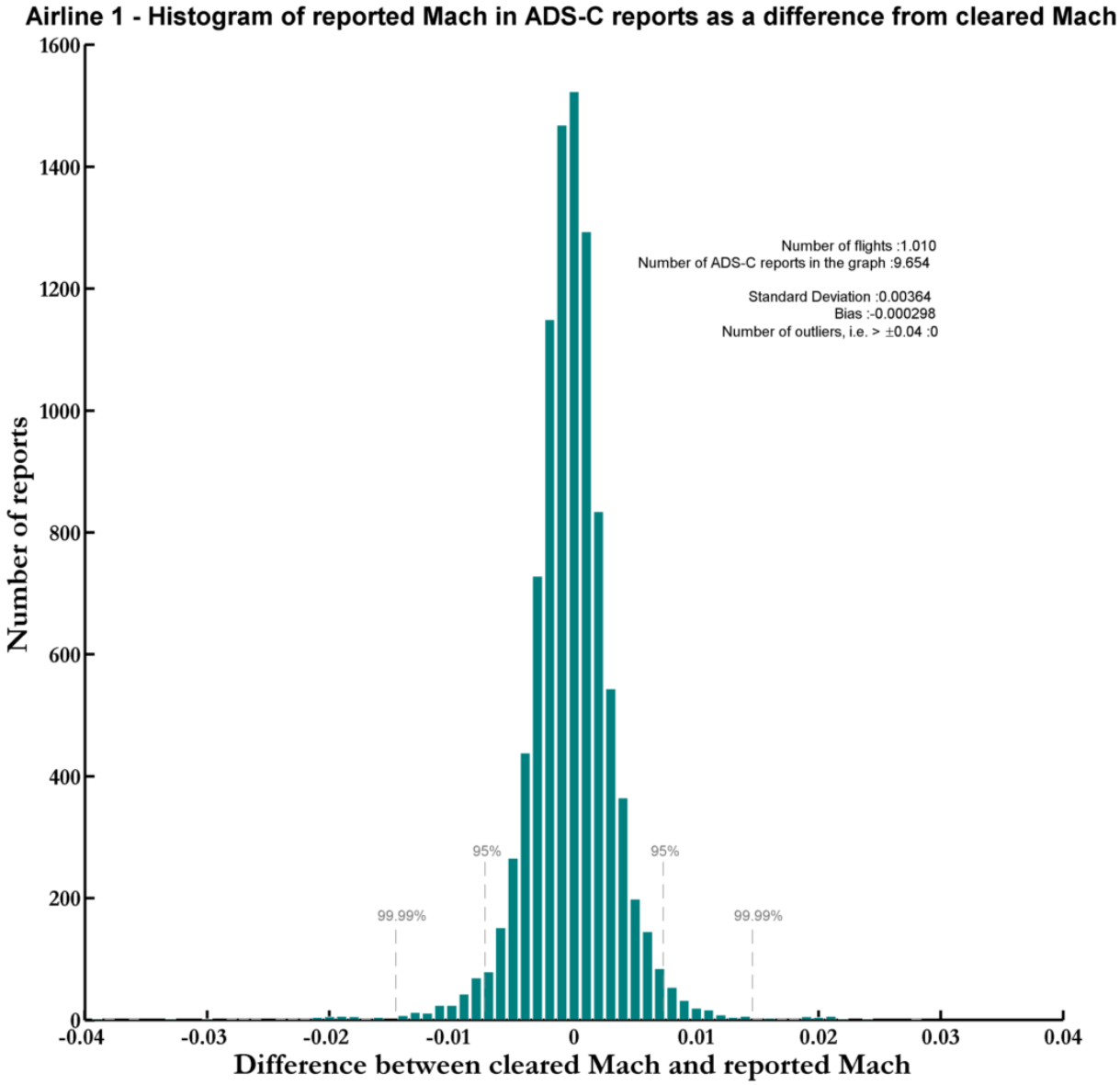

Figure 9

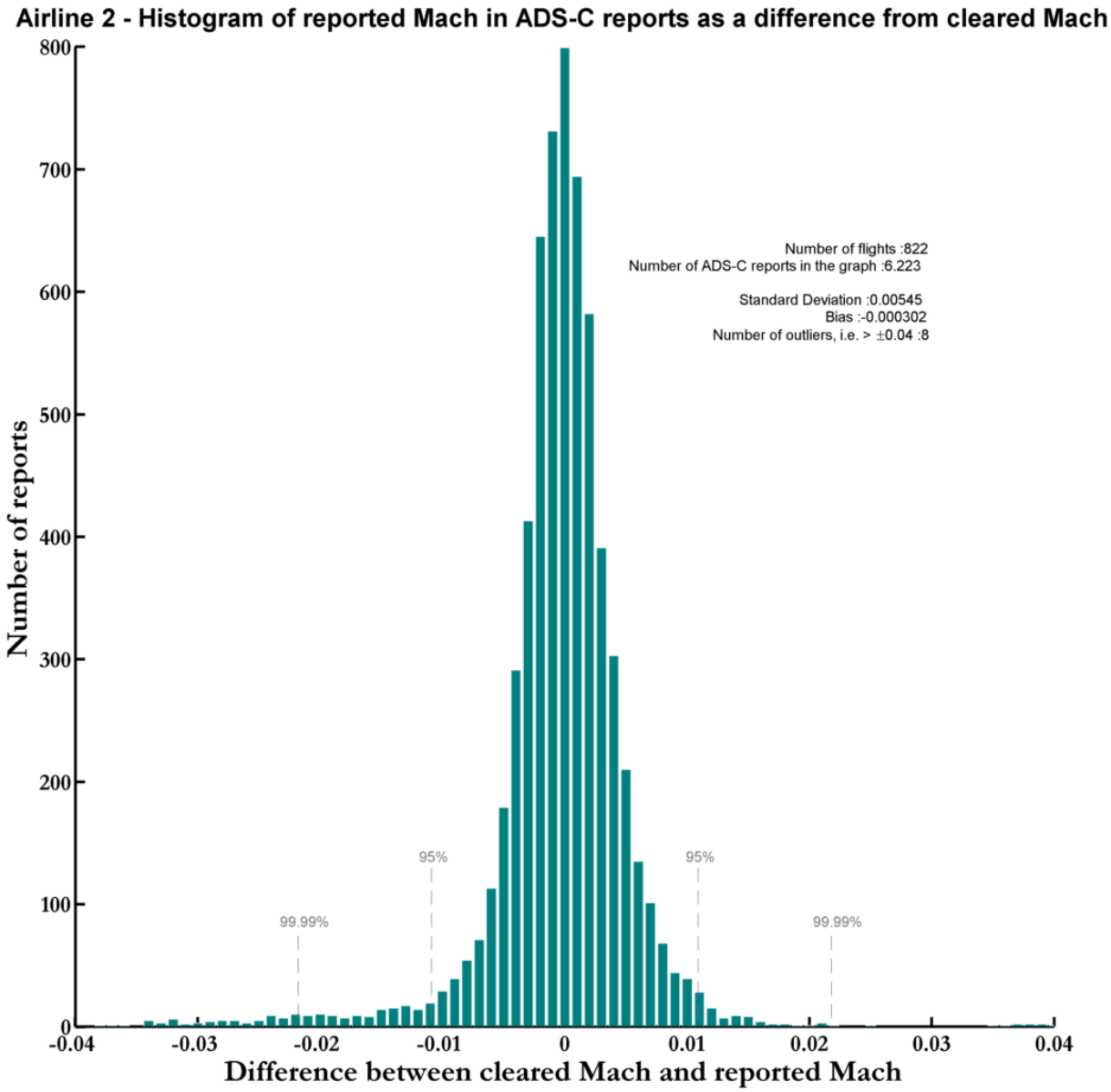
Airline 2 - Histogram of reported Mach in ADS-C reports as a difference from cleared Mach
Number of flights :822
Number of ADS-C reports in the graph :6.223
Standard Deviation :0.00545
Bias :-0.000302
Number of outliers, i.e. > ±0.04 :8
95%
95%
99.99%
99.99%
Number of reports
Difference between cleared Mach and reported Mach
800
700
600
500
400
300
200
100
0
-0.04
-0.03
-0.02
-0.01
0
0.01
0.02
0.03
0.04

Figure 10

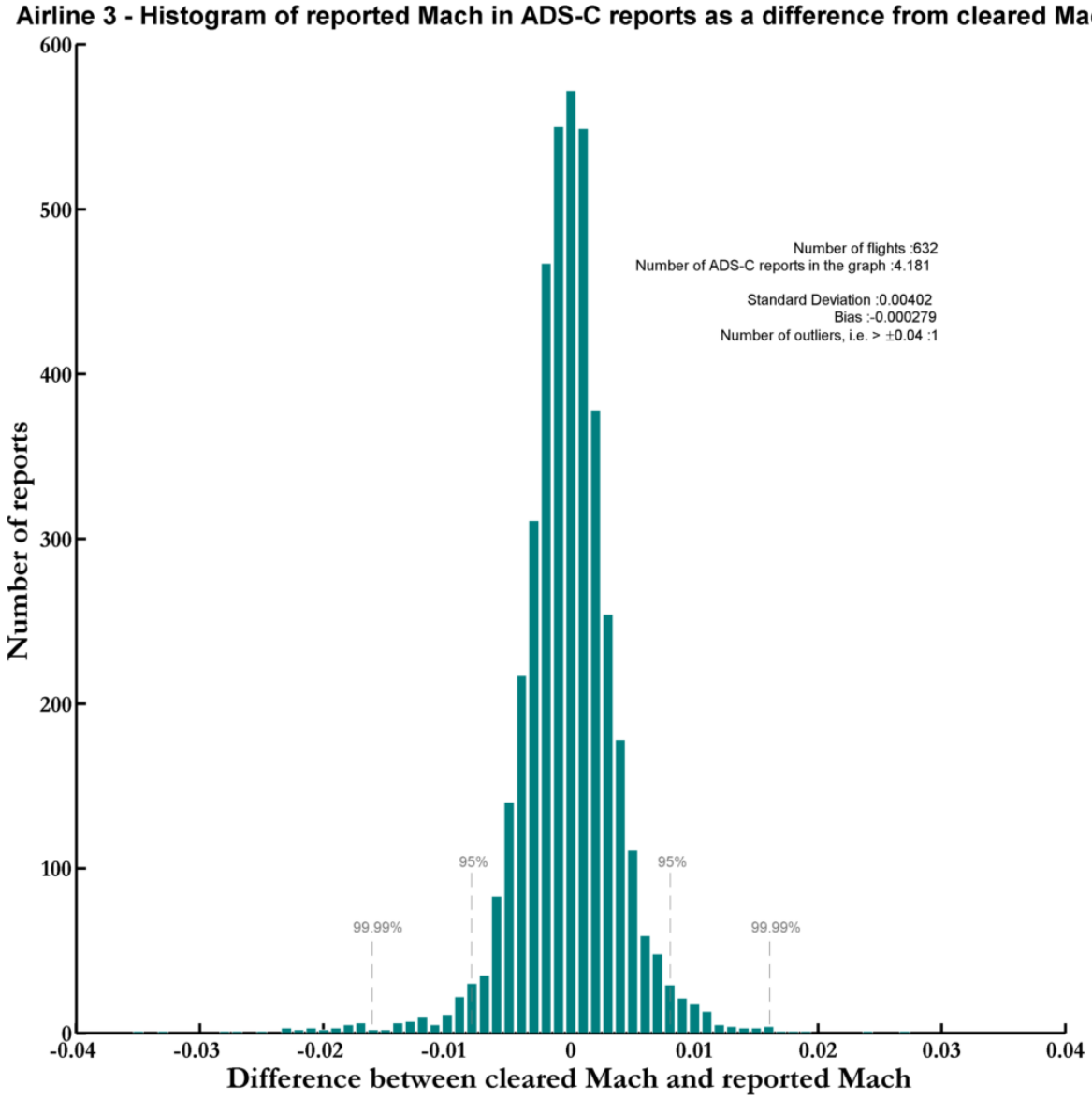

Figure 11

Variance calculations

2.16 Some limited variance calculations have been done in an effort to determine which flights are not flying their cleared Mach speed. The variance calculation has been done for every flight with 3 or more ADS-C periodic reports. The variance of the reports is calculated from the cleared Mach or in other terms from a given mean value. If the variance is over a defined threshold (0.0003) then the flight is classified as not flying cleared Mach. First results show that the configurable limit should be linked to the number of reports received and then the calculations would return better estimations. Further work could be done in this area if that is deemed to be beneficial. The results of the variance calculations can be seen in **Attachment A**.

Conclusions

2.17 Figures 4 and 5 indicate the following:

a) The speed distribution of aircraft with assigned Mach speed is more than 99.99% within +/- M0.02 (approximately 13 knots) from the assigned Mach speed.

b) Since the cleared Mach speed also represents the target aircraft speed in this research it can also be concluded that an Air Navigation Service Provider can be 99.99% confident that a Mach speed received in an ADS-C report from an aircraft is within +/- M0.02 of the aircraft target speed regardless of whether the aircraft was cleared on a fixed Mach number or not.

2.18 As a reference the following table can be used to visualize the effect of +/- M0.02 on fix-time calculations:

Route (F340)	**M080**	**M082**	**M084**	**Δt**
45N030W	00:00:00	00:00:00	00:00:00	(424 NM)
45N040W	00:54:55	00:53:35	00:52:18	-00:01:20/+00:01:17
61N030W	00:00:00	00:00:00	00:00:00	(291 NM)
61N040W	00:37:38	00:36:43	00:35:51	-00:00:55/+00:00:52
75N030W	00:00:00	00:00:00	00:00:00	(171 NM)
75N040W	00:20:05	00:19:36	00:19:08	-00:00:29/+00:00:28

2.19 The above table only takes ADS-C waypoint reports into account. The 20 minute leg between 75N030W and 75N040W would however be indicative of a 20 minutes periodic ADS-C contract anywhere in the NAT. The time estimate error over the 20 minute reporting interval would only be around 30 seconds. (This is discounting the effect of wind and temperature which would be the same regardless of whether Mach speed was assigned or not).

2.20 This indicates that if Mach speed is derived from ADS-C reports, then time based longitudinal separation can be applied without assigned Mach speed provided that speed control (Mach assignment or time restriction) is applied when estimated separation is within 1-2 minutes of the separation minima.

3. Action by the Meeting

3.1 The NAT ATMG is invited to:

a) note and discuss the information provided in this working paper;

b) discuss the effect on application of longitudinal separation; and

c) decide on any further action.

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ATTACHMENT A – ANALYSES OF OUTLIERS AND AIRCRAFT THAT MAY NOT BE FLYING THE ASSIGNED MACH NUMBER

Notes:

- There are 37 outliers where the Mach difference is more than +/- 0.04 from the cleared Mach speed. Those aircraft are indicated in the column "Outliers +/- 0.04".
- The table contains 77 flights where:
  - 72 flights are considered by the variance calculations to be flying a wrong Mach number and may contain an outlier.
  - 5 flights which are an outlier but may not be flying a wrong Mach number in accordance with the variance calculations.

#	Flight Number	Cleared Mach	Reported -Mach -speeds	Outliers +/- 0.04	Notes
1	649	0.86	-0.840 -0.841 -0.837 -0.841 -0.831 -0.838 -0.844 -0.833 -0.844		Aircraft seems to be flying 0.84.
2	803	0.79	-0.791 -**0.817** -0.789		Turbulence?
3	850	0.82	-0.819 -0.821 -0.821 -0.820 -0.823 -0.822 -0.821 -0.824 -0.816 -**0.776 -0.776** 0.817 -0.823	2	Turbulence?
4	905	0.80	0.803 -0.798 -0.802 -0.802 -0.805 -0.801 -0.804 -0.804 -**0.848**	1	Outlier. Flight which the variance calculations did not detect.
5	1267	0.82	0.821 -0.829 -0.823 -0.821 -0.814 -**0.770** -0.825 -0.821	1	Turbulence?
6	1285	0.83	-0.834 -0.828 -0.828 -0.817 -**0.775 -0.776** -0.829 -0.83 -0.836 -0.836 -0.832 -0.809	2	Turbulence?
7	1381	0.83	-0.834 -0.835 -0.836 -0.836 -**0.793**		?
8	1556	0.81	-0.789 -0.790 -0.791 -0.794		Aircraft seems to be flying 0.79
9	1957	0.79	-0.828 -0.815 -**0.832 -0.832** -0.830 -0.829 -0.826 -0.828	2	Aircraft seems to be flying 0.83
10	2094	0.83	-0.826 -**0.790 -0.776** -0.833 -0.828 -0.835 -0.831 -0.829 -0.823 -0.823	1	Turbulence?
11	2288	0.80	-0.837 -0.835 -**0.843** -0.840 -0.839 -**0.843** -0.840	2	Aircraft seems to be flying 0.84
12	2358	0.83	-0.835 -0.825 -0.828 -0.83 -0.836 -0.836 -0.83 -0.83 -0.83 -**0.755 -0.755** -0.831 -0.831 -0.829 -0.827	2	Turbulence?
13	2536	0.83	-0.801 -**0.786** -0.831 -0.825 -0.830 -0.830 -0.829 -0.829 -0.827 -0.831 -0.828	1	Outlier. Flight which the variance calculations did not detect.
14	2604	0.81.	-0.834 -0.829 -0.829 -0.829 -0.831 -0.832 -0.834 -0.830 -0.830 -0.831 -0.831		Aircraft seems to be flying 0.83
15	2699	0.85	-0.845 -0.847 -0.850 -0.846 -0.818 -**0.798** -0.824 -0.849 -0.849	1	Turbulence?
16	2852	0.84	-0.823 -0.819 -0.820 -0.817 -0.821		Aircraft seems to be flying 0.82
17	2987	0.81	-0.808 -0.814 -0.801 -0.805 -**0.777**		Turbulence
18	3032	0.84	-0.841 -0.840 -0.834 -0.843 -0.847 -0.843 -**0.790 -0.785 -0.791**	3	Pilot seems to have reduced speed.
19	3125	0.82	-0.790 -**0.774** -0.826 -0.819 -0.822 -0.817 -0.817 -0.819	1	?
20	3238	0.82	-**0.746** -0.816 -0.821 -0.823 -0.820 -0.817 -0.821 -0.821 -0.819 -0.822	1	?
21	3436	0.77	-0.776 -0.772 -**0.806**		?
22	3741	0.85	-0.851 -0.853 -0.854 -0.880 -0.878		Pilot seems to have increased speed from 0.85 to 088 mid-flight.

#	Flight Number	Cleared Mach	Reported -Mach -speeds	Outliers +/- 0.04	Notes
23	4014	0.83	-0.817 -0.829 -0.807 -0.802 -0.797 -0.803 -**0.801 -0.807**		Pilot seems to have increased speed.
24	4109	0.84	-0.819 -0.820 -0.817 -0.819		Aircraft seems to be flying 0.82
25	4154	0.83	-0.817 -0.815 -0.818 -0.816 -0.815 -0.811 -0.817 -0.794		Aircraft seems to be flying 0.82 and then slowing in the end.
26	4200	0.84	-0.841 -0.842 -**0.768** -0.842 -0.837 -0.839 -0.841 -0.839 -0.839	1	Turbulence?
27	4296	0.85	-0.845 -0.848 -0.849 -0.850 -0.848 -0.850 -0.852 -0.850 -0.852 -0.856 -0.821 -0.824 -0.820 -0.818 -0.821 -0.820 -0.823 -0.820		Pilot seems to have reduced speed from 0.85 to 082 mid-flight.
28	4330	0.79	-0.811 -0.815 -0.812 -0.808 -0.807 -0.810 -0.806 -0.806 -0.811 -0.805		Aircraft seems to be flying 0.81.
29	4530	0.82	-0.800 -0.797 -0.800 -0.802 -0.798 -0.801 -0.800 -0.797 -0.806 -0.801 -0.805		Aircraft seems to be flying 0.80
30	4796	0.83	-0.810 -0.806 -0.812 -0.808 -0.809 -0.807 -0.810 -0.808 -0.812 -0.811 -0.812		Aircraft seems to be flying 0.81
31	4912	0.84	-0.832 -0.818 -0.823 -0.822 -0.821 -0.838		?
32	5195	0.79.	-0.811 -0.816 -0.809 -0.809 -0.809 -0.812 -0.803 -0.811		Aircraft seems to be flying 0.81
33	5288	0.83	-0.811 -0.803 -0.81 -0.808 -0.81 -0.811 -0.807 -0.801 -0.809 -0.812 -0.806 -0.808		Aircraft seems to be flying 0.81
34	5298	0.81	-0.794 -0.788 -0.791 -0.788 -0.794 -0.791 -0.788		Aircraft seems to be flying 0.79
35	5510	0.85	-0.850 -0.832 -0.830 -0.829		Pilot seems to have reduced speed from 0.85 to 083.
36	5679	0.83	-0.850 -0.856 -0.830 -0.828		Pilot seems to have reduced speed from 0.85 to 083.
37	5692	0.84	-0.841 -**0.872 -0.871** -0.843 -0.833 -0.836		?
38	5859	0.83	-0.831 -**0.867** -0.829 -0.829		Turbulence?
39	5976	0.77	-0.796 -0.765 -0.777		?
40	6048	0.83	-0.819 -0.820 -0.820 -0.804 -0.801 -0.804 -0.796 -0.800 -0.800 -0.806 -0.796 -0.802		Pilot seems to have reduced speed from 0.82 to 080.
41	6309	0.82	-0.797 -0.800 -0.801 -0.800 -0.804 -0.801 -0.802 -0.801 -0.800 -0.800 -0.799		Aircraft seems to be flying 0.80.
42	6734	0.82	-0.804 -0.803 -0.803 -0.795 -0.803 -0.797 -0.807 -**0.814**		Aircraft seems to be flying 0.80 until at the last point.
43	6837	0.83	-0.832 -**0.810 -0.805 -0.803** -0.839 -0.830 -0.835		?
44	7347	0.82	-0.822 -0.821 -0.819 -0.819 -**0.740 -0.742 -0.741 -0.741** -0.819 -0.821 -0.819 -0.819	4	?
45	8244	0.80	-0.788 -0.783 -0.776 -0.781 -0.785 -0.787 -0.784 -0.783		?
46	8501	0.80	-0.799 -0.801 -**0.754** -0.799	1	Turbulence?
47	8592	0.80	-**0.758** -0.768 -0.764 -0.767 -0.804 -0.807	1	?
48	8601	0.80	-**0.757 -0.76** -0.808	2	?
49	8674	0.78	-0.811 -0.81 -0.815 -0.803 -0.809 -0.805 -0.811 -0.810		Aircraft seems to be flying 0.81.
50	8847	0.84	0.836 -0.839 -**0.812 -0.81 -0.807** -0.840 -0.840 -0.842		
51	8989	0.82	-0.799 -0.798 -0.801 -0.800		Aircraft seems to be flying 0.80.
52	9385	0.84	0.845 -**0.799** -0.850 -0.845 -0.845 -0.846 -0.842 -0.843 -0.845	1	Outlier. Flight which the variance calculations did not detect.
53	9411	0.82	-0.837 -0.842 -0.842		Aircraft seems to be flying 0.84.

#	Flight Number	Cleared Mach	Reported -Mach -speeds	Outliers +/- 0.04	Notes
54	9413	0.84	-0.840 -0.815 -0.817 -0.819		Aircraft seems to be flying 0.82 after the first point.
55	9417	0.82	0.823 -0.820 -0.818 -0.818 -0.820 -0.824 -0.816 -**0.777** -0.826 -0.823 -0.819	1	Outlier. Flight which the variance calculations did not detect.
56	9892	0.82	0.817 -0.817 -0.822 -0.822 -0.823 -0.820 -0.818 -**0.775** -	1	Outlier. Flight which the variance calculations did not detect.
57	10384	0.82	**0.810** -**0.786** -0.822 -0.819 -0.820		?
58	10419	0.80	-0.794 -**0.755** -0.805 -0.802	1	Turbulence?
59	10603	0.83	-0.839 -0.850 -0.845 -0.850 -0.850		?
60	10605	0.83	-0.854 -0.850 -0.851 -0.850 -0.852 -0.852		Aircraft seems to be flying 0.85.
61	10678	0.83	-0.834 -0.829 -0.831 -**0.801** -**0.8** -**0.799** -0.831 -0.831		
62	10685	0.79	-0.825 -**0.833** -0.827 -0.829 -**0.837** -**0.834** -0.827 -**0.833**	4	Aircraft seems to be flying 0.83.
63	10698	0.78	-0.780 -0.807 -0.801 -0.800		Pilot seems to have increased speed from 0.780 to 080 after the first point.
64	10933	0.80	-0.820 -0.826 -0.821 -0.818		Aircraft seems to be flying 0.82.
65	10960	0.84	-0.835 -0.835 -0.84 -0.839 -**0.800** -**0.803** -0.847 -0.844 -0.841		Turbulence?
66	10961	0.80	0.821 -0.817 -0.823 -0.818		Aircraft seems to be flying 0.82.
67	11089	0.80	-0.780 -0.778 -0.779 -0.776 -**0.806**		Aircraft seems to be flying 0.78 until the last point.
68	11126	0.84	-0.864 -0.860 -0.843 -0.850		?
70	11131	0.84	-0.823 -0.820 -0.821 -0.819 -0.818 -0.818 -0.820 -0.820 -0.822		Aircraft seems to be flying 0.82.
71	11292	0.80	-0.777 -0.785 -0.781		Aircraft seems to be flying 0.78.
72	11300	0.80	-0.782 -0.778 -0.783		Aircraft seems to be flying 0.78.
73	11422	0.83	-0.810 -0.809 -0.804		Aircraft seems to be flying 0.81.
74	11780	0.82	-0.788 -0.793 -0.792 -0.826 -0.82 -0.788 -0.812 -0.818 -0.822 -0.820		?
75	11915	0.82	-0.787 -0.786 -0.828 -0.825 -0.812 -0.817 -0.816 -0.822		?
76	12065	0.77	-0.787 -0.782 -0.772 -0.797 -0.809		?
77	12187	0.80	0.783 -0.779 -0.778 -0.777 -0.786 -0.787 -0.781 -0.779		Aircraft seems to be flying 0.78.

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