RTCA Special Committee 186, Working Group 3
ADS-B 1090ES MOPS Maintenance
Meeting #24

Honeywell Aerospace, Phoenix Arizona
13 – 15 January 2009

Discussions on the Total and Uncompensated Latency in ADS-B
Revision 1

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Summary
It is the view of the FAA that the material in the current revision of the STP MOPS (RTCA/DO-302) is guidance material that represents a way to integrate navigation sources, but is not the only acceptable way to integrate navigation sources. Additionally, there are some specific details of the STP MOPS that may not hold true for all instances of a given sensor type (i.e., RNP FMS or WAAS GPS). During the RTCA SC-186 Plenary on 24 April 2008, a small Ad Hoc Group was tasked to review the STP MOPS for possibly including some of the requirements in Change 3 to DO-260A, and potentially Change 2 to DO-282A. This task also included the review of Latency in the ADS-B system, and the production of proposals for any changes to FAA Advisory Circulars (AC). **This Working Paper** is presented as proposed resolution to the issue of Total and Uncompensated Latency in the ADS-B system. Working Paper 1090-WP24-08 is presented as a matrix which proposes to allocate specific paragraphs of the STP MOPS to (1) the Navigation AC, (2) the ADS-B OUT AC, or (3) ADS-B Link MOPS.

1 Total Latency and Uncompensated Latency in ADS-B

As applications using ADS-B data are being developed, it has become apparent that tighter control is needed than what is currently afforded in the 1090 MHz MOPS regarding the Total and Uncompensated Latency of transmitted position and velocity information. In particular, the latency of data needs to be considered in whole, from the original generation of that data within the Navigation system to transmission.

1.1 Description of the Problem

The long-used functional architecture is depicted in Figure 1.

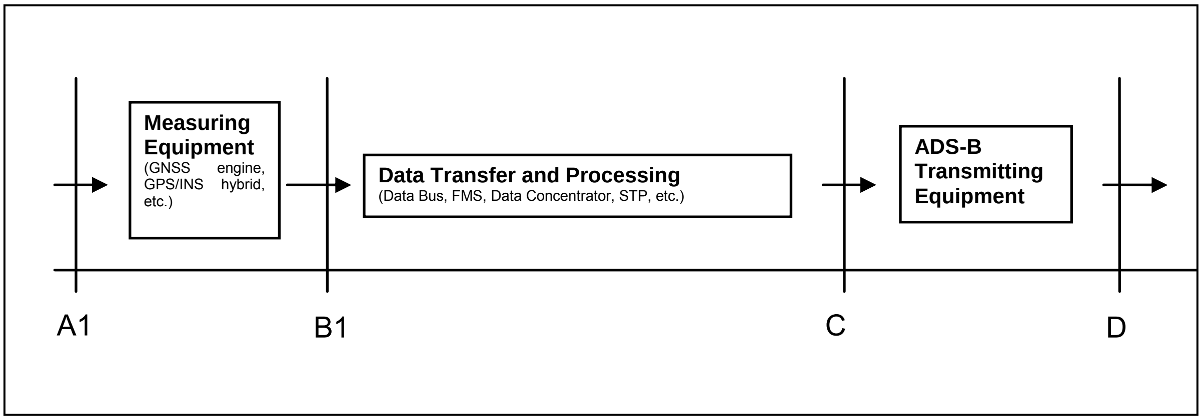

Figure 1: Functional Architecture Diagram

The interfaces are defined as follows:

- A1: Input to the Measuring Equipment
- B1: Output of the Measuring Equipment
- C: Input to the ADS-B Transmitting Equipment
- D: Output of the ADS-B Transmitting Equipment (i.e. the transmission)

1.1.1 Timing Notation

For a piece of data in the stream and an interface X, let T_X be the time that the data crosses interface X. Let TOA_X be the time of applicability of that data. It is to be understood that TOA_X represents the truth—i.e., it is the ideal time of applicability of the data at interface X.

In the case of position data, as it moves through the data stream it may be advanced in the direction of travel to compensate for timing. For interfaces X and Y define $\Delta T_{X \to Y}$ to be the total amount of time compensated for by the equipment between interfaces X and Y.

Key examples of this notation are listed below:

- For a GNSS position source TOA_{B1} is the GNSS time mark, and this is the ideal time of applicability.
- The GNSS industry standard is a not-to-exceed value of $T_{B1} - TOA_{B1} < 200$ ms.
- Because extrapolation is not usually performed on the position between interfaces B1 and C, $\Delta T_{B1 \to C}$ is typically zero.
- $\Delta T_{C \to D}$ is the total amount of extrapolation performed by the ADS-B Transmitting Equipment.

The general timing diagram is presented in Figure 2:

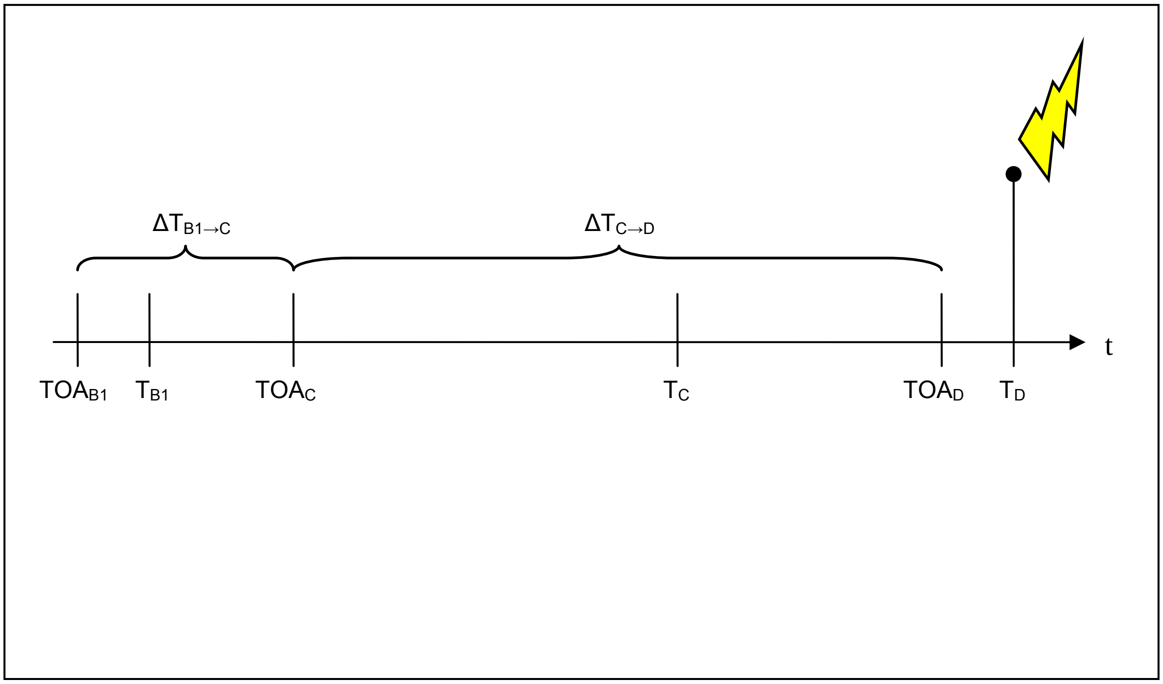

Figure 2: The general timing diagram

Note: $\Delta T_{B1 \to C}$ *is depicted as being positive in Figure 2. In general, it is not necessary that* $TOA_C = TOA_{B1}$.

Lastly, let $TTOA$ be the transmitted time of applicability. This is the time that is expected to be decoded by the ADS-B Receiving Equipment. The transmitted time of applicability varies according to the T-bit:

- When the T-bit is set to ZERO (0), the receiver takes the transmitted time of applicability of the received data to be the time of reception, so $TTOA = T_D$.
- When the T-bit is set to ONE (1), $TTOA$ is the nearest 200 ms UTC epoch to the time of transmission. Presumably, $TTOA = TOA_D \pm$ clock errors.

1.1.2 Latency Definitions

Using the above notation, Total Latency is defined as:

$$TL = T_D - TOA_{B1}.$$

The measurement of Total Latency begins at the time of applicability of the data output by the Measuring Equipment and ends at the time of transmission.

Uncompensated Latency is defined as:

$$UL = TTOA - TOA_D = TTOA - (TOA_{B1} + \Delta T_{B1 \to D}).$$

As TOA_D is truth data, Uncompensated Latency is simply the error in $TTOA$.

- For non-UTC coupled transmissions, $TTOA = T_D$. So,
  $$UL = T_D - (TOA_{B1} + \Delta T_{B1 \to D}) = TL - \Delta T_{B1 \to D}.$$
  Intuitively, Uncompensated Latency is Total Latency minus the amount of compensation performed.

- For UTC-coupled transmissions, Uncompensated Latency is on the order of clock errors and is considered negligible.

1.2 STP MOPS Ad-Hoc Subgroup consensus and findings

1.2.1 General Consensus

- It is widely recognized that Total Latency can and should be limited to 1.5 seconds. It is proposed that further development of ADS-B standards and rulemaking should require that $TL < 1.5$ seconds, 95%.

  Note: There may be a need to specify total delay, which begins at the time of measurement of position (or other) data rather than at the time of applicability of that data. It is recommended that within the MOPS and MASPS defining ADS-B Transmitting Equipment, the notion of Total Latency is adopted as defined above. Additional allocations may be made out to the time of measurement if necessary.

- The accuracy category transmitted in an ADS-B message should be encoded directly from the output of the Measuring Equipment. In particular, NAC_P should not be adjusted to take care of any effects of Uncompensated Latency. It is more useful to have knowledge separately of position errors and time errors.

1.2.2 Findings for Uncompensated Latency

The scope of the discussion is the unsynchronized case, i.e., when the 'T'-bit is set to ZERO in 1090 MHz. If the ADS-B Transmitting Equipment has the UTC time mark then Uncompensated Latency is assumed to be ZERO.

Note: It is true however that when an ADS-B receiver does not have the UTC time mark and receives a message with the 'T'-bit set to ONE, then there will be timing errors incurred on the receive side. This is out of scope here, but is expected to be taken into account where applicable.

Requirements in DO-260A address only that portion of UL which comes from the ADS-B Transmitting Equipment extrapolating the position data such that at the time of transmission, the position data is accurate to be within 200 ms, under the assumption that $T_C = TOA_C$ of the transmission time. In setting this timing requirement certain assumptions were made about $T_C - TOA_C$, but the difference could be unbounded in principle. In an effort to specify UL in its full context, it is generally acknowledged that:

- Uncompensated Latency of less than 600 ms, 95% is available and easily achievable, though there do exist installations that do not currently meet such a requirement.
- Current applications can support UL < 600 ms, 95%.
- For any given installation, Uncompensated Latency is a random quantity with a mean μ and standard deviation σ.

Even with all aircraft compliant with a requirement of 600 ms, 95%, the mean μ can be expected to vary significantly among installations, or even during the course of a flight. In the RAD application, for example, 600 ms, 95% is assumed and modeled as $\mu = 300$ ms for a single aircraft on average.

Note: At the time of this draft, it is not clear the full nature of the modeling of UL in RAD. It may be that the 300 ms is further assumed to be compensated for in either the Airborne or Ground domain.

It is observed that in many cases it is possible for the ADS-B Equipment to compensate for the mean latency in a particular installation, i.e., to know what $T_C - TOA_C$ is on average and to compensate for it in the transmission. The committee discussed the advantages and drawbacks of requiring mean-compensation. From the perspective of designing applications, a mean-compensated UL is preferable. Concerns with such an approach include:

- The need to know aspects of GNSS performance beyond the current requirement of $T_{B1} - TOA_{B1} < 200$ ms
- Difficulty in controlling the mean in some cases, e.g. data concentrator. Dynamic input to the ADS-B Equipment is untenable
- Even when the mean is stable, there may be difficulties in characterizing and certifying ADS-B installations
- It is difficult to see why the ADS-B Equipment should account for what is happening outside of the box, and maintaining coordination between the ADS-B Equipment and the installation for years could be problematic. In short, Iif it is not our problem, then why should we fix it?

While not determined to be a practical requirement, mean-compensation is certainly a good technique for reducing the effects of Uncompensated Latency.

The STP MOPS Ad Hoc Subgroup arrived at the conclusion that UL should be controlled as an overall requirement.

1.2.3 Proposal for bounding Uncompensated Latency

It is critical that the bounds placed on UL be future-proof. The suite of applications that have been developed to date are able to accommodate 600 ms, 95%, but the requirements set on UL will need to support the coming development of future applications. While the possibility of down-linking timing categories to allow for greater design freedom has been discussed, we believe that a single common bound is sufficient and practical. As such, this required bound on UL should be as tight as possible without placing unnecessary burden on the installers and manufacturers.

An allocation to three components of UL is considered. Note that the contribution to Uncompensated Latency between interfaces B1 and C is $(T_C - T_{B1}) - \Delta T_{B1 \to C}$, where the term in parentheses is the transit time of the data and $\Delta T_{B1 \to C}$ is the amount of compensation that is performed by the equipment between B1 and C, according to the notation defined. Similarly, the contribution to Uncompensated Latency from the ADS-B Equipment is $(T_D - T_C) - \Delta T_{C \to D}$. The following allocation is considered a reasonable starting point.

- Accept 200 ms from the position source. I.e., $0 < T_{B1} - TOA_{B1} < 200$
- Assume that all but ±100 ms of the transit time be compensated for between B1 and C, i.e., $-100 < (T_C - T_{B1}) - \Delta T_{B1 \to C} < 100$ ms, 95%

  Note: A 95% value is given here rather than a not-to-exceed in order to accommodate the widest range of solutions.

  Note: It is expected that compensation for transit time be performed by the system architecture between interfaces B1 and C, as this is where the uncompensated latency is incurred. Compensating for this time within the ADS-B Equipment could prove problematic should changes to the hardware or software architecture between B1 and C occur without coordination.

- Improve upon the current requirement in DO-260A so that the transmitted time of applicability is within ±100 ms of the time of applicability of the data (assuming $T_C = TOA_C$), i.e. that the ADS-B Transmitting Equipment compensates for all but ±100 ms of the time that the position data is within the box, ~~the transmitted time of applicability is within ±100 ms.~~ i.e., $-100 < (T_D - T_C) - \Delta T_{C \to D} < 100$ ms.

  Note: There are at least three ways to meet this requirement. (1) The position can be extrapolated 100 ms into the future, (2) the random transmission time can be determined ahead of time, and (3) the position can be extrapolated at a higher rate.

It is easy to see that the sum of these three comprise UL as defined. Note that the sum of the first two allocations result in:

$$-100 < T_C - TOA_C < 300 \text{ ms, 95\%.}$$

This is the key improvement over the current situation, in which $T_C - TOA_C$ is essentially unbounded.

The overall requirement met for Uncompensated Latency under this example allocation is:

$$-200 < UL < 400 \text{ ms, 95\%.}$$

This seems to be a reasonable value for future ADS-B applications to work with. Further deliberation is needed on the final requirement on UL, and on how to set requirements with respect to allocation.