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Special Committee 147

MINIMUM OPERATIONAL PERFORMANCE STANDARDS FOR TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEMS AIRBORNE EQUIPMENT

The 99th meeting of RTCA SC-147 and 68th meeting of EUROCAE WG-75 was held on 9 September 2020; this was a virtual (WebEx) Plenary hosted by RTCA.

The following Leadership was present:

J. Stuart Searight	Co-Chairman, Federal Aviation Administration
Garfield Dean for Bill Booth	Co-Chairman, EUROCAE WG-75
Sheila Mariano	Government Authorized Representative
Donna Froehlich	Secretary, Aurora Innovations
Al Secen	Program Director RTCA
Alex Engel	Technical Program Manager EUROCAE

Agenda for Wednesday 9 September 2020:

1. Chairmen's Opening Remarks / Introductions
2. Anti-Trust Statement & RTCA/EUROCAE Policies
3. Approval of Minutes From the 98th meeting of RTCA SC-147 and 67th meeting of EUROCAE WG-75 (4 June 2020)
4. Approval of Agenda
5. Review of ACAS Xu FRAC
   a. Overview of SWG and TWG Comment Categories
   b. No Non-Concurs
   c. Review of SWG and TWG High Priority Comments
   d. Opportunity for Questions/Discussion
6. Approval of FRACed ACAS Xu MOPS, DO-386/ED-275
7. Future Meeting Schedule
8. Adjourn

1. Chairmen's Opening Remarks / Introductions

Mr. Stuart Searight welcomed everyone to SC-147 virtual plenary. He continued indicating that the committee has already reviewed and commented on the ACAS Xu MOPS (to be published as: RTCA DO-386/EUROCAE ED-275). He also noted that the committee leadership had received the joint committees' consensus approval of the disposition/approach for all comments against the ACAS X MOPS. Mr. Searight continued by indicating that the main objectives of this plenary are to review results of the comment implementation, to confirm approval of the FRACed ACAS Xu MOPS, and to refer the document to RTCA PMC and EUROCAE Council for publication approval.
Then Mr. Stu Searight indicated he had some small points of business to share. Mr. Searight congratulated the Coordination Working Group and other contributors for their recent accomplishment. He stated Mr. Alex Engel recently sent an email announcing EUROCAE approval of CAS Interoperability MASPS (EUROCAE ED-xxx). Mr. Searight indicated that Mr. Ruy Brandao sends his regrets that he cannot attend due to other urgent business. Mr. Garfield Dean announced that Mr. Bill Booth is not able to attend and that he (Mr. Dean) is representing WG-75 for this meeting.
At this point Mr. Searight indicated that Mr. Charles Leeper will lead the review of the finalization of FRAC comment resolutions, completion of some ACAS Xu MOPS materials, and the presentation of final system behavior and performance which will be the majority of this meeting.

Anti-Trust Statement & RTCA/EUROCAE Policies

Al Secen congratulated everyone on the Council approval of EUROCAE WG-75 CAS InterOp MASPS. He then reviewed the RTCA Anti-Trust Policy, which, he noted, applies equally for Plenary and WG sessions. Then Mr. Secen reviewed the RTCA Proprietary Policy, noting that RTCA has a strong commitment to avoid inclusion of proprietary information in their standards and other documents. Mr. Alex Engel indicated that EUROCAE has basically the same Anti-Trust and Proprietary information policies as RTCA. Mr. Engel also congratulated both WG-75 and SC-147; he noted the second FRAC of this MASPS improved the document organization and presentation and made the MASPS a much better document all around. Then Mr. Secen reviewed RTCA Committee Participation Membership Plenary and Membership Guidance and Mr. Engel reviewed EUROCAE Participation policy noting that EUROCAE Plenary meetings do not typically allow guests, but since this is joint the RTCA Policy is applicable for this meeting.

2. Approval of Minutes From the 98th meeting of RTCA SC-147 and 67th meeting of EUROCAE WG-75 (4 June 2020)

Mr. Charles Leeper moved to approve the minutes from 4 June 2020. Mr. Wes Olson seconded the motion. There was no comment nor request for discussion. As there were no objections, the minutes were approved.

4. Approval of Agenda

Mr. Leeper moved to approve the agenda for today's Plenary. Mr. Stacey Rowlan seconded. There was no discussion; no additions were requested at the time. The agenda was approved.

5. Review of ACAS Xu FRAC

Mr. Charles Leeper presented the Xu MOPS Schedule slide and noted our progress and plan to get from FRAC to PMC approval for publication. Mr. Leeper indicated the key points he wanted to cover are:

a. Overview of SWG and TWG Comment Categories
b. No Non-Concurs
c. Review of SWG and TWG High Priority Comments

d. Opportunity for Questions/Discussion

Mr. Leeper noted that when we submit to PMC we will not request an out-of-cycle review of the ACAS Xu MOPS. He explained the plan to deliver the document to our Program Director for submission to RTCA PMC in early to mid-November (not later than 11/17) to provide enough time for the 30 day review. Similarly, Mr. Alex Engel will submit the document to the EUROCAE Council in early December to provide a 14 day review and scheduled for completion in synch with PMC approval. Mr. Leeper continued: This change from an out-of-cycle to the review for the December PMC meeting will give Mr. Al Secen time to shepherd Volumes 1 and 2 through the editor cycle and get the document formatted and ready for the production/release process. At this time, the presentation transitioned to reviewing the MOPS comment resolution.

Mr. Brian Ulm presented Volume 1 comment resolution for SWG. Mr. Ulm started by presenting the main categories of comment. – There were: 0 (zero) non-Concur, 24 High, 97 Medium, 213 Low and 11 Duplicate comments. – Then Mr. Ulm reviewed the Major updates to ACAS Xu MOPS Sections 1 and 2, including the test sections (2.4.2.10.5 and 2.4.2.11) as well as several of the Appendixes. Mr. Ulm elaborated for Appendix C, Degraded Surveillance, the contents were overhauled for ACAS Xu and for Appendix I, ATAR Appendix, the SWG is able to report the requirements are finalized and confirmed.

Mr. Leeper presented an Overview of Volume 1 TWG comment resolution. – There were: 0 (zero) non-Concur, 48 High, 129 Medium, 138 Low and 0 (zero) Duplicate comments. – Mr. Leeper noted some high comments were against the Operational Environment section and the fact that ACAS Xu did not have its own Operational Services and Environment Definitions (OSED) document; clarifying that ACAS Xu dependency on and reference to SC-228's OSED cleared up these concerns. Mr. Leeper continued describing FRAC resolutions. He indicated the editors ensured that the comment resolution maintained consistency with the CAS Inter-Operability MASPS and the data fields in the various messages.

At this point, Mr. Searight congratulated the committee on this accomplishment. Working on 2 documents at the same time (DO-386/ED-275, ACAS Xu MOPS, and DO-382/ED-264, CAS Interoperability MASPS) but actually coordinating across at least 5 documents going through FRAC and to publication in similar timeframe, Mr. Searight recognized the committee's contributions to the UAS DAA MOPS revision (DO-365B) as well as both the Transponder MOPS (DO-181F/ED-73F) and ADS-B Extended Squitter MOPS (DO-260C/ED-102B) both being done within the Combined Surveillance Committee, which consists of members from RTCA SC-209, SC-186, and EUROCAE WGs 49 and 51. Mr. Brandon Suarez seconded this sentiment noting how well SC-228 and SC-147 coordinated though the past few years.

Mr. Leeper continued the summary of MOPS comments, indicating there were a lot of comments on the test section. The inclusion of Systems Tests and Automatic Performance Monitor were part of a special effort to enhance the comprehensive nature of the test information. Mr. Leeper mentioned that the TRM Overview was improved based on FRAC comments. Another section that was greatly improved by FRAC comments was Provisions for Potential Modification (Appendix L of Volume II): this deviations appendix provides some software hooks and guidance to allow a manufacturer to have better success in approach and integration of some anticipated enhancements to an ACAS Xu implementation.

Mr. Leeper then reviewed updates to the introduction in the MOPS Volume I, Section 1 Then Monitoring messages, RF Transmissions for Monitoring (ARA fields). He then stated RWC Broadcast Interrogation was determined to be excluded from Interference Limiting (like RA Coordination Interrogation).

Next, Mr. Leeper discussed RA Tables; we received a number of comments on the copious number of notes in the table. We ended up addressing the necessary information in SC-228 DAG. Mr. Leeper noted that Ms. Ann Drumm has been the focal point of our message coordination efforts and our primary interface with the Combined Surveillance Committee. He continued by indicating, since the display requirements are in the DAA MOPS, our system description "ends" with the outputs and a description of the outputs and the message/bit formats for the output messages. With tests being updated to check the output messages and the values within

Comments from Mr. Tom Hanrahan and several others requested information on how to use the outputs or for guidance on how to "drive" the display. In response to these comments, we added a new section and table 2-44. The team also incorporated the intruder symbol pictures/definitions from SC-228 (DO-365) to provide the last bit of needed details on how to drive the display, depicting traffic in addition to the guidance and alerting information.

Mr. Leeper indicated there was a two-week review breakout to address some of the comments that needed coordination across a core team of SMEs. A list of the comments and their topics (slide 16) showed the breadth of this two-week review. For the MOPS references comment, we made sure we coordinated with SC-228 to get the latest updates to DAA MOPS under revision (DO-365B pre-FRAC revision) and incorporated the appropriate information in our ACAS Xu MOPS since the two documents will be published in same timeframe and it would be in the best interest of both committees to have the "sister" documents in synch. Regarding the providing guidance for SC-228 about the non-directional arrow, we incorporated information about how to determine if our target is non-directional by examining fields in TRM Report. Mr. Leeper summarized: The core team agreed with the feedback and was successful in finalizing the language for each update with the original commenter(s). Finally, the two week review also included editorial comments against Volume II, ADD. Mr. Leeper indicated these comments were accepted and that Mr. Chris Edwards is working with Mr. Al Secen to get Volume II prepped for the RTCA document publication cycle.

Mr. Leeper then displayed a summary of all comments against the Volume II, ADD. The comments fell into the following categories: 0 (zero) non-Concur, 29 High, 55 Medium, 37 Low, 0 (zero) Duplicate, and 111 Editorial. Comments that requested changes to the algorithms, their variables or resulting performance were captured in the Program Office Change Proposal (CP) process. The CP process provides documentation of changes considered, the rationale for implementation (or not), whether the change was approved, and if so, information regarding how the change was implemented and verified. Mr. Leeper indicated Mr. Adam Panken would brief the committee on CPs to the STM while Mr. Sam Wu would brief on CPs to the TRM.

As Mr. Adam Panken began his briefing on the ACAS Xu Volume II changes to STM functionality, he gave credit to a lot of contributors especially Ms. Jessica Lopez and team that were running and re-running tests. Next he gave a quick summary of the types of changes that were requested for ACAS Xu, these were Tracking and Correlation Improvements, Degraded Mode Fixes, and System Robustness & Rare Events. Then, Mr. Panken began describing the Tracking and Correlation Changes:

- Xu-0298 – STM may not attempt to decorrelate a UAT track once it has correlated. This CP did not elicit discussion and was accepted as presented.
- Xu-0200 – Tracked intruder bearing differences at close ranges may cause undesirable decorrelations. Mr. Panken elaborated that CP was analyzed to ensure that the uncertainty factor doesn't collapse as the intruder gets very close; this was done by using range uncertainty and applying that in all directions. He added that extensive integration and regression testing was performed which included the tests that identified the issue as well as performance testing.
- Xu-0299 – ATAR tracks coast frequently and decorrelate when both ownship and intruder are maneuvering. This was addressed by inflating ATAR uncertainty and outlier thresholds (to account for bias), using 'reactive' IMM track in correlation algorithms, and preventing decorrelations during ATAR re-initialization.

Next, Mr. Panken described the Degraded Mode Changes:

- Xu-0279 – STM Source selection handling of NAR/Geo w/o ATAR is incorrect
- Xu-0264 – Add ownship degraded flag and modify max coasts for ownship baro altitude (align with Volume 1 requirements, added output flag)
- Xu-0267 – Ownship WGS84 Input does not correctly handle NaN geo alt when lat/lon if valid
- Xu-0286 – WGS84/ECEF Coordinate conversion mismatch when using both geodetic and barometric altitudes

The Degraded Mode Changes were accepted without need for additional discussion or clarification. Mr. Panken proceeded to describe the CPs that are characterized as System Robustness and Rare Events:

- Xu-0285 – Individual IMM tracks are not linking correctly to main IMM structure when initializing a bearingless track
- Xu-0266 – Precision issues in WrapToPi – this was observed when reviewers performed their assessments (tests) in non-Julia implementations
- Xu-0302 – Stuck VRC in RA Report when no CVC sent
- Xu-0278 – non-PSD error in IMM bearingless mode – was resolved by adding protection for stable matrixes in the IMM

Finally, Mr. Panken summarized the kinds of improvements that resulted in resolving the Volume II STM comments. The Tracking and Correlation updates improve correlation performance in challenging geometries. While Degraded Mode Changes addressed fixes needed and general robustness to improve final system reliability. At the end of this presentation, Mr. Garfield Dean asked about the delay, the lag, in ADS-B data; he wanted to know what if the lag varies?" Mr. Panken indicated that we looked at the lag, and the analysis is discussed in the degraded mode appendix. Mr. Dean followed up asking if there can be up to 600 ms delay. Mr. Panken replied that type of delay is built into our analysis.

Mr. Sam Wu presented a summary of the changes to the TRM functionality in the Volume II ADD. The changes can be categorized into five categories: Architectural, Horizontal TRM, Online Costs Balancing, Target Track Angle Update Optimization, and DAA Operational Improvements. Mr. Wu proceeded to describe the CPs that are characterized as Architectural TRM changes:

- Xu-0099b and Xu-0253 – Complete ARA processing and output
- Xu-0283 – Degraded surveillance and state transition TRM Processing to align with MOPS table
- Xu-0301 – Bug fix to ensure proper processing of multiple intruders data between cycles in the vertical TRM

Mr. Wu addressed the CPs that are characterized as Horizontal TRM

- Xu-0261 – Bug fix to properly perform lookups into horizontal coordination table
- Xu-0289 – Proper management of highest threat intruders contributing to horizontal RA in mixed-equipage, multi-threat scenario

Then, Mr. Wu described the CPs that are characterized as Online Costs Balancing

- Xu-0256 – Online cost turning for vertical RAs to improve operational suitability in vertical sandwich scenarios
- Xu-0262 – Online cost tuning for vertical RAs to improve single threat scenarios

Mr. Wu also described the CPs that are characterized as Target Track Angle Update Optimization.

- Xu-0268 – 50% reduction in TTA updates. This change had no safety trade-off; the logic still provides guidance to safe TTA. He then showed graphs (slides 8&9) to support this assertion

Finally, Mr. Wu summarized the CPs that are characterized as DAA Operational Improvements

- Xu-0281 Band saturation reduction mechanism is applied when horizontal bands area saturated
- Xu-0296 Apply hysteresis on horizontal band cleared by band saturation reduction.
- Xu-0282 Improvement of DAA preventive alerting

Mr. Wu summarized the improvements from the FRAC Comment CPs as follows:

- Xu DO-386 ADD Architectural changes to align with MOPS for clarity
- Xu DO-386 TRM Updates address edge case scenarios
  – Threat data management in mixed equipage, multi-threat scenarios
  – Tuned online costs for improved performance in specific geometries
- Xu DO-386 Updates refine operational features
  – Significant reduced nuisance horizontal RA updates
  – DAA logic refined for improved operational suitability
  – Maintains safety integrity

Mr. Charles Leeper explained that in order to address any Operational Suitability or Safety concerns that might arise from modifying the Volume II ADD, the TCAS/ACAS X PO provided the results of the various performance and safety analyses using the update ADD. The next few presentations will be from each of those analyses.

Starting off with the Metrics Matrix briefing, Mr. Sam Wu began by describing the simulation configurations. The (Unmanned) baseline for comparison is the ACAS Xu DO-386 (post-FRAC ADD) vs DAIDALUS V1 Class 2 system (with TCAS II operational). As a reminder, Mr. Wu compared the Xu performance baseline with the (Manned) configuration that has been used as baseline for ACAS Xa/Xo performance analyses: Unequipped Mode S (25' altitude increments) vs. TCAS II V7.1. Mr. Wu also pointed out the simulation assumption(s) for Pilot Response Rate include the same 5 & 3 second response to an RA as used in the baseline simulations for manned ACAS Xa/Xo.

Mr. Wu then reviewed the CPs that resulted in significant ADD changes and affected the Metrics (slide 4). With that background established Mr. Wu provided some framework of the metrics being discussed and the color coding of the comparative charts. For the color coding: Medium Green and Light Green show degrees of improvement while Red and Pink typically show a reduction in performance; however, upon further analysis, the Metrics Matrix team has provided explanations for each occurrence of Red/Pink explaining why this raw number is not detrimental (due to improvement or offset by another more relevant metric). The Blue background indicates the simulation results have less than 95% confidence factor. Slides 8-11 provide the baseline comparison of the Safety Metrics.

Then, Mr. Wu reviewed the SRMD Severity Categories and their Definitions (slide 12-18). Mr. Wu noted that we graph Minimal, Minor, Major, Hazardous, but not for Mid-Air Collision (MAC) – We only simulate the degrees of severity of Near Mid-Air Collisions In Major and Hazardous categories, Xu outperforms the DAIDALUS baseline. – Xu and DAIDALUS both meet all safety guidelines. The absolute likelihood of violation of the Severity categories – we are well below the acceptable threshold. When looking at the severity categories DAIDALUS has better safety results at Minimal and Minor Severity Violations, ACAS Xu outperforms DAIDALUS when assessing Major and Hazardous Severity categories. Mr. Leeper indicated that the data bars (below red horizontal/threshold) bars on slide 18 indicate the performance tradeoff that both SC-147 and SC-228 made in order to make the alert timing operationally suitable, maintain the safety measures, and further demonstrate safety by preserving the results for the metric Severity of Loss of Well-Clear (slides 19-21).

Mr. Wu began discussing the Operational Suitability (OpSuit) Metrics; this analysis and its results were derived from historical NAS Data called National Offload Program (NOP) data. The first set of configuration assumptions for the 2 aircraft encounters were: Ownship equipped with ADS-B and Unequipped (no CAS) Intruder with Mode S (slide 23). The results demonstrated a significant reduction in warning alerts per encounter; there were a few more late corrective alerts but this is a very small fraction of the total corrective alerts and considered tolerable compared to the improvements. The analysis with a TCAS intruder showed less impact to the Late Corrective Alerts metric and similar improvements to the other OpSuit measures. Then Mr. Wu proceeded to describe the results where ownship has Active Surveillance and Intruder is Unequipped (no CAS) with Mode-S intruder. The team observed that there are slightly more corrective alerts per encounter than the baseline DAIDALUS analysis. Mr. Wu indicated that this is an acceptable tradeoff to the 3x PNMAC in safety slides calculated for DAIDALUS with active ADS-B (see slide 18).

After pointing out that the row titled Average Warning Alert Time prior to CPA (8^{th} item on slides 23-27), the ACAS Xu performance is depicted in white, not red or green, Mr. Tom Hanrahan asked whether there was a comparison with TCAS or ACAS Xa. Mr. Leeper stated that in general, Xu tends to issue RAs a few seconds earlier than TCAS does. Mr. Suchy added: In one of our briefings we provided comparisons at higher altitudes, and in that analysis, TCAS alerted around 31 (seconds) and Xu alerted around 28 or 29 seconds prior to CPA.
In summary: ACAS Xu (DO-386) demonstrates safety integrity against collision risk and DAA loss of well clear. P(LoWC) greater than DAIDALUS with ADS-B is acceptable and demonstrates low rate of high severity risk. Additionally, ACAS Xu DO-386 demonstrates optimize trade-off between safety and operational suitability. It exhibits reduced nuisance alerting (RAs and DAA corrective alerts) compared to the DAIDALUS baseline. The results also demonstrate significant improvements to target track angle updates.

Mr. Garfield Dean asked about how many times you would issue corrective alerts compared to TCAS. Mr. Leeper indicated this was not an "apples to apples" analysis due to DAA definitions. He continued: Although we could not establish a comparable metric of ACAS Xu performance vs TCAS TAs, one study showed that ACAS Xu corrective alerts occurred about 8 times more often than TCAS RAs.

Stress Test Results for ACAS Xu System Performance Envelope presented by Mr. Michael Owen. Mr. Owen began by providing some Simulation Notes (slide 2); these describe assumptions made for the simulations:

- Each figure shows risk ration as a function of platform maneuverability for surveillance source, equipage, dynamics limits and pilot response delay
- Pilot response does not include response to DAA guidance – i.e., there is no response analysis in these results
- Each figure summarizes results from 300 million LLCEM encounter simulations. [LLCEM=Lincoln Labs Correlated Encounter Models]

Then (slide 3) Mr. Owen provided a "tour" of the layout of his slides to make it easier to understand what is being depicted in each graph, including: surveillance source, dynamic limits, equipage, turn rate, acceleration, and pilot response. Then he proceeded to show the risk ratio graphs. When moving on to the ADS-B symmetric, equipped-unequipped encounter (slide 4) Mr. Owen pointed out the dip in the dark blue risk ratio curve near the 2 degree/second turn rate, he noted the Xu horizontal logic sensitivity is increased as maneuverability decreases. He added that the risk ratio decreases for the decreased platform maneuverability. He then walked through the other slides showing the risk ratio of each of the groupings of encounters with different surveillance, equipages etc. Reviewing the slides, one can compare

- ADS-B vs. RADAR vs. Active surveillance
- Symmetric vs Asymmetric encounters
- EU vs EE

as well as turn rates and response times

When he reached the Active Asymmetric EU (1.0, 1/4g, 5/3 turn rate and response rate) encounter set results (slide 9), Mr. Owen pointed out the delayed pilot response causes the

decrease in risk ratio in as the maneuverability increases - He clarified, we have to remember this is delayed pilot response to understand the performance.
As he moved on to Equipped-Equipped encounter sets (starting with slide 13), Mr. Owen indicated that he changed the scale of the risk ratio in the graph. These slides demonstrate a trend of risk reduction across all comparisons. [As demonstrated by the preponderance of dark blue in the graphs and the risk ratio color scale focusing on a smaller range of values.
Summary:

- Xu risk ratio robust to platform maneuverability
- Some cases where increasing alert rate (increased logic sensitivity) reduces pNMAC as maneuverability decreases
- EE risk ratios are substantially lower than EU risk ratios as expected due to coordination between both aircraft
- Increased acceleration limit outweighed by effects of pilot response delay

Mr. Randall Sleight, from Johns Hopkins Applied Physics Laboratory, then presented the [FTEG and Stress Testing Analysis for ACAS Xu](#).
Mr. Sleight began the presentation with FTEG analysis – FTEG is FAA Fast-Time Encounter Generator. – The purpose of this FTEG analysis is to analyze ACAS Xu performance with a challenging set of encounters meant to stress a CAS system. In this analysis traditional FTEG classes were upgraded to include horizontal maneuvers that would stress horizontal guidance provided by ACAS Xu and other DAA systems. He continued explaining indicating the FTEG analysis is intended to independently:

- Assess the safety of the system's collision avoidance-level advisories relative to baseline systems
- Help characterize its behavior
- Identify areas for improvements

Mr. Sleight then proceeded to give an overview of the new, horizontal, DAA FTEG classes. He noted that these horizontal classes are needed for complete stress testing included in the Metrics Matrix. A team from TCAS PO settled on 13 horizontal classes involving various combinations of parallel and crossing tracks, upon which SMEs from JHU APL modified the existing encounter generation tool to generate all 13 horizontal classes (H0-H12) and 10 vertical classes (V0-V9). Then, Mr. Sleight displayed the generalized tracks (ownship and intruder) for each of the vertical classes (slide 7) and each of the horizontal classes (slide 8); accompanied by a table describing ownship and intruder tracks (vertical or horizontal aspect of track) as appropriate for vertical or horizontal FTEG analysis. Mr. Sleight then reviewed the vertical and horizontal parameters used in the FTEG analysis (slides 10-11). Next, Mr. Sleight noted that these results are based on the final DO-386 logic (ADS-B and Active surveillance) and only responding to a collision avoidance alert; that is, responding to a Resolution Advisory (RA), not a Remain Well Clear (RWC) advisory. An RWC advisory is comparable to the DAIDALUS Warning alert which occurs on Class II DAA systems, on average, 15 seconds prior to an ACAS Xu RA. Mr. Sleight also provided additional comparisons of the two baseline (comparison) systems: TCAS II (V7.1) and to DAIDALUS, responding only to warning level horizontal and vertical rate bands as well as TCAS RAs (slides 13-15). Slide 17 provides a graph depicting an overview of stress testing runs for all

Vertical and Horizontal Encounter Classes; at this perspective the risk ratio is quite low for all encounter classes. Mr. Sleight then went over some additional material needed to understand the analysis results. Slides 19 - 22 provide decoding information for acronyms in the results table; while slide 23 presents the full table of results. Mr. Sleight demonstrated the interactive report and then summarized the DAA FTEG Findings (slide 25):

- Xu outperformed TCAS and Class2 baseline NMAC counts in the majority DAA FTEG classes given the CAS equipage and surveillance variations under consideration:
    - Xu-Unequipped, and Xu-TCAS, with
    - ADS-B with Active, and Active-only surveillance, with
    - Xu as the master and slave.
- No performance or Xu logic issues have been identified
- Equipped-Unequipped classes where Xu NMAC performance is borderline compared to Class2 (NMAC count not high enough to be of serious concern) were investigated within the Low Power Climb and Turn analysis

Mr. Sleight noted: the pre-FRAC analysis was performed before the TCAS PO had completed the cost tuning. In those results there were more borderline cases. – The tuning has eliminated the hot spots we wanted to investigate and reduced the borderline cases to the point that we are better than DAIDALUS in these cases.

The next part of the presentation is Stress Testing. There are four areas of stress testing that are discussed:

- Horizontal Coordination
- Multi-Threat
- SA01
- Low Power Climb and Turn

Mr. Ed Lorenzo presented the Horizontal Coordination (HC) analysis part of the Stress Testing. He summarized the effort as follows:

- HC analysis began with evaluating feasibility of HC in Xu; the safety benefit of coordinating horizontally has continued to improve with each Xu version
- Analysis focuses only on stressing horizontal coordination by its own merits; vertical RAs are not responded to in this analysis.
- HC improves safety compared to no HC:
    - Aggregating all classes: HC results in 45.6% fewer NMACs compared to no HC. Also, HC results fewer NMACs for 11 of 13 classes – Note that H3 and H8 encounter classes H3 and H8 showed on average 15.9% safety degradation with HC
- NMACs exhibit sensitivity to absolute and relative airspeeds. The NMACs in H3 (where NMAC|HC > NMAC|!HC) were concentrated near extremely low / likely unrealistic airspeeds <100 fps and NMACs in H8 (where NMAC|HC > NMAC|!HC) do not fall in a particular airspeed category
- After closely examining NMACs examples, they generally fall under categories not attributed to coordination. That is they have very low airspeed that are likely “too” stressing and unrealistic (<100 fps), or they are Attributed to action selection, not coordination selection

Then, Mr. Lorenzo outlined the simulation assumptions (slide 28) while reviewing the Horizontal Encounter Classes. Then, he covered the safety results of the analysis. The first graph (slide 30) summarized the number of NMACs with and without Horizontal Coordination (HC) for all 13 Horizontal Encounter Classes; noting that HC improved the results for almost all Horizontal Encounter Classes. You can see the difference in the next graph (slide 31) where H3 and H8 show a minimal degradation of safety (due to a negative %NMAC difference); however, it was noted that H3 and H8 are not considered Hot Spots (which was defined as > 25% degradation and >50 NMACs). Then, Mr. Lorenzo reviewed the results of multi-threat analysis The NMAC Triplets graph demonstrates good decision to implement and keep the Horizontal Coordination in ACAS Xu.

As the presentation transitioned to Multi-Threat encounter set analysis, Mr. Ryan Gardner took over description of analysis result of Multi-threat encounter sets. First he described the star geometry (250K encounters) and compared it to the Star sandwich geometry (250K encounters) (slide 34-35). Then, Mr. Gardner reviewed the LA Basin geometry (slide 37) and reminded us: All encounters are simulated with response to CA only using standard pilot response and aircraft performance. Mr. Gardner then reviewed the results for the Star Encounter Set (slides 38-40) and the results for Star Sandwich Encounter Set (slides 41-43). Both Encounter Sets show significant improvement is safety (reduction in NMACs) with use of ACAS Xu; he also highlighted instances where the horizontal RA resolved situations that would not have been resolved with only vertical advisories. Finally, Mr. Gardner reviewed the results from the LA-Basin Encounter Set (slides 42-44). It should be noted that LA-Basin is a dense and complicated airspace and the simulated encounters reflect that. ACAS Xu outperformed the comparative systems. However there are some encounters that ACAS Xu is unable to resolve; Mr. Gardner walked-through the simulation results of one.

Next, Mr. Gardner presented the Alerting and Guidance Statistics for the three different multi-threat encounter sets. Mr. Gardner characterized these as “Refined Display” statistics. More specifically, these statistics for Xu alerting show the average number of seconds the relevant event happened per Xu-equipped aircraft per encounter (slide 45). First, Alert Quantity (slide 46) depicts the average number of seconds in duration for each type of advisory, these were presented for the three different encounter geometries (Star, Star Sandwich and La Basin). A more detailed look shows the average number of seconds the horizontal and vertical display bands are saturated (slide 47) and simulation results of an extended vertical RWC band saturation in a Star Sandwich encounter (slide 48). Then, Mr. Gardner presented statistics on the average number of seconds where a commanded target track angle or vertical rate (RA) does not coincide with an open RWC band segment and additional details regarding cause of some of these (slide 49). Mr. Gardner proceeded to Band saturation without Collision Advisory (CA), and then the number of seconds where there are residual RWC bands after CA Clear of Conflict (COC) (slides 50-52). The next slide depicted Discontinuous bands for multi-threat encounter (slides 53-54); Mr. Gardner clarified that this is an OK situation – discontinuous bands can occur in multi-threat and the results presented are not concerning. Mr. Gardner also presented jitter and inverse jitter, (slides 55-56). When it appears, it is usually for 1-2 seconds, and has been attributed to sensor noise. Mr. Gardner closed with the following summary: ACAS Xu drastically reduced number of NMACS in these stressing encounters. ACAS Xu significantly outperforms TCAS in extremely challenging multi-threat scenarios. Alerting and guidance metrics confirm the correct operation of recent CPs and agreements with SC-228; the analysis reveals no areas of concern.

Mr. Ben Zintak began presenting the results from the Stress Testing encounter set that represents SA01-lilke encounters. The encounters in this analysis are characterized by limited climb ability in crossing encounters. He noted there was interest in this analysis from Ms. Ann Drumm of our committee's Coordination Working Group as well as from a Triton representative on our committee. Then, Mr. Zintak characterized the 100,000 encounters in this analysis set (slide 60) and the examination of adjusting the SA01 heuristic parameter, Rmin (slide 61). The results of the analysis (slide 64) indicate that in situations with limited climb performance ACAS Xu DO-386 improves (decreases) significantly or maintains NMAC count from the TCAS baseline and improves NMAC counts from the previous version (ACAS Xu V5R3) in all but one of the tested configurations.

Mr. Randall Sleight began describing aircraft performance levels include in the Low Power Climb and Turn analysis (slides 74-75). Mr. Sleight noted: The lower-power limits are intended to represent a common, generic high altitude long endurance platform (HALE) and these limits were imposed on the RA response and nominal encounter climb/turn rates for ownship aircraft. Various Master/Slave Low Power Climb and Turn Combinations were assessed (see bottom of 75). He added: the TCAS (High Performance) was included as a point of interest, not as part of baseline, then he observed: ACAS Xu (reassuringly) performs well with that also. The results of these analyses were presented on the next two slides (76-77). The results indicated ACAS Xu outperforms the baseline in a majority of cases (slide 78). Specifically, in the EU case, Xu has some classes with more NMACs compared to Class 2. This occurs when both Xu and Class 2 have ADS-B and Active surveillance, in nominal vertical rates, mid altitudes, and high altitudes. However, across the board, Xu has less NMACs when compared to the TCAS baseline (slides 81-82). The exception is that DAIDALUS has a slight advantage in some cases, due to alerting earlier than TCAS (slides 83-87). Then, Mr. Sleight explored the NMACs resulting in the Equipped vs Unequipped encounter; he noted the red cells designate a "hot spot" (slide 88) but further analysis determined these "hot spots" were not very significant. He explored this a little further, and highlighted that there was noisy surveillance response due to the turning intruder, in this instance ownship turned right and got closer to the intruder (other encounters in the "hot spots" had similar explanations).

Mr. Randall Sleight summarized findings from the Stress Testing effort:

- Horizontal coordination provides a general benefit compared to no horizontal coordination
- In Multi-Threat encounters, Xu vastly outperforms TCAS in extremely challenging
- For SA01 encounters we found Xu performs well in the particular crossing / inability-to-climb scenario suggested by our Coordination SME
- For Low Power Climb and Turn:
    - Previous area of investigation (master/slave balance) has been corrected
    - The few areas in Low Power Climb and Turn scenarios where Xu does not

perform as well as baselines are due to known advantages of baseline systems (i.e. DAIDALUS taking advantage of early alerting, TCAS not having a horizontal dimension at all)

- No new areas of concern were identified in final logic version

Mr. Sleight concluded: the full Metrics Matrix report will be available around the publication of the ACAS Xu MOPS.

Mr. Sean Yen and Mr. Charles Leeper reviewed the ACAS Xu performance test results versus the DAA (e.g., Class 1, 2) performance test results versus the ACAS Xu Class 3 performance test results. This comparison is referred to as the DAA Report Card.
Mr. Leeper began by slide giving history of agreement between SC-147 and SC-228 that ACAS Xu would be a Class 3 DAA system and how the ACAS implementation would require some variations in the performance requirements due to the operational tuning built into the ACAS Xu system. Mr. Yen continued by presenting the 7 significant areas where DAA and ACAS Xu timing of alerts varies: Preventive Alerts (slide 3), Corrective Alerts (slide 4), ATAR Only Special Case (slide 5), No Bearing Special Case (slide 6), No Altitude Special Case (slide 7), Un-validated ADS-B (slide 8) and Un-validated ADS-B Special Case (slide 9). Mr. Leeper indicated that SC-147 captured all agreements with SC-228 (exemptions) and packaged a description of the exemptions and related analyses to show compliance with intent and good product. This documentation is captured as DO-365B Appendix K (to be reviewed in SC-228 DO-365B FRAC) and is referred to as the DAA Report card and Summary.

Sean Yen then presented an Overview of the ACAS Xu Simulator (ASIM Xu) (slides 10-16).
Mr. Yen explained that ASIM Xu is a software tool that allows users to run encounters through the compiled Julia logic. ASIM Xu can also plot encounters to allow users to inspect the encounter geometry and other aspects of the encounter. He then presented the Overview tab of ASIM showing how you can analyze performance for an encounter scenario that is provided as an input file. He then proceeded to show how the Interactive Legends (slide 13) allow the ASIM user to enable and disable display of ownship and intruder tracks in order to improve clarity of the X-Y-Z encounter plot. Then Mr. Yen demonstrated how an ASIM user could use the DAA Zone Tab (slide 14) to compare ACAS Xu performance against the DAA. Another ASIM tab that Mr. Yen demonstrated is the DAA Tube Tab (slide 15); it depicts (an enclosed) tube of vertical separation 500 feet above and below ownship altitude marking the Hazard zone, then space beyond that depicting the edge of the Non-Hazard Zone. Another feature described was related to Coordination and Surveillance, the information presented on this tab allows the user to examine the timing of the horizontal and vertical coordination messages. These tabs have been added to provide more visibility into the ACAS Xu performance for the scenario – encounter data file use as input.

Ms. Barbara Kobzik-Juul then presented an overview of the ACAS Xu Test Suite (ASIM)
Ms. Kobzik-Juul indicated the ACAS Xu Test Suite was developed to allow Manufacturers to compare their implementation of the ACAS Xu application against the expected outputs established by the TCAS/ACAS X Program Office result using the DO-386 distribution set and the tolerances published with the Test Suite (slide 3). Then Ms. Kobzik-Juul explained that the test suite was designed to cover functional tests, as well as to provide branch coverage. She noted that some tests for branch coverage are look weird, this is because they are contrived (set-up) to test whether specific branches are reachable/reached.

She then outlined the organization of the Test Groups and their description (slides 6-7).

Ms. Kobzik-Juul revisited the Test Group Overview (slides 13-19) and provided an overview of the HAZOP encounters. These were generated through finalization of system, so they could not be finalized until last of algorithm changes were implemented. – She noted that the HAZOP team actually identified some detailed requirements for ACAS Xu and generated Change Proposals (CPs) for incorporation into the algorithms. Ms. Kobzik-Juul also noted that Correlation tests for section 4.2.11 were devised and included based on Jessica Lopez's work to ensure proper coverage for surveillance.

Mr. Kobzik-Juul pointed out that for ACAS Xu, DO-386, the Test Suite includes 48 scripts for Coverage Determination, Functionality Verification and Format/Timing/Precision check for Input files. The distribution includes Ca2600 encounters (1300 of which are for correlation bench tests), Input files, Expected result files, including: STM reports, TRM report, Costfiles (slides 19-21). This will be part of the TCAS PO Supporting Items and will be available to Committee members about the time that ACAS Xu MOPS, DO-386 is published.

Mr. Charles Leeper and Mr. Brandon Suarez reviewed SC-228 Status of DO-365B (Slide #24). Mr. Suarez noted that FRAC of DO-365B is scheduled to start September 16 and run to Oct 14. Mr, Leeper asked the committee to please review and comment on this revision of the MOPS. He noted that Revision B significantly expands the classes and refines performance definitions for different classes of UAS, with ACAS Xu, DO-386, represented as a Class 3 UAS. As mentioned earlier, Appendix K captures the agreed upon performance for ACAS Xu with explanations for any exceptions/exemptions to DAA performance requirements. Appendix K has been warmly received by SC-228 leadership, and can only benefit from SC-147 comments/contributions if such is needed. Mr. Suarez encouraged SC-147 to review and comment on DO-365B and asked people to contact himself or Mr. Leeper if they wanted to review DO-365B and needed assistance with getting a copy of the document and/or submitting comments.

Then Mr. Charles Leeper presented a slide that listed the MOPS, Supplementary and Supporting documents/files that represent the DO-386 analysis. The MOPS Volume I and Volume II are available through RTCA and EUROCAE and with the purchase of the DO-386 MOPS, RTCA will supply the Supplementary documents listed on the left of the page (slide 27, see screenshot below). Supporting documents and products are available to members of joint SC-147/WG-75 and can be accessed via a link provided to members upon publication of the MOPS.

MOPS (Supporting) Products vs non-MOPS (Supplementary) Products:

MOPS vs non-MOPS Products

DO-386 Items (available from RTCA Store)	FAA TCAS Program Office Supporting Items
DO-386 Volume I Text [.pdf]	ASIM User Guide [.pdf]
DO-386 Volume II Text [.pdf]	ASIM Application (includes executable ACAS library) [.zip]
DO-386 Volume II Horizontal Logic Tables [.dat] *Includes horizontal coordination table [.bin]*	Requirements Mapping and Justification Matrix (RMJM) [.xlsx]
DO-386 Volume II Vertical Logic Tables [.dat] *Includes entry tables [.dat] and vertical RWC table [.dat]*	Requirements Mapping and Justification Report (RMJR) [.pdf]
DO-386 Parameters File [.txt]	Metrics Matrix [.pdf]
DO-386 Test Suite Text [.pdf]	Operational Validation Report [.pdf] *Includes DAA Report Card and System Performance Envelope*
DO-386 Test Suite Encounters [compressed .txt]	Offline Table Generation ADD [.pdf]
	HAZOP Report [.pdf]
	FTEG Report [.pdf]
	Stress Testing Report [.pdf]
	ACAS Xu Safety Assessment [.pdf] *Developed as part of RTCA safety work, approved by TCAS PO. References HAZOP Report [.pdf], FTEG Report [.pdf], and Stress Testing Report [.pdf]*

Mr. Leeper explained that the right hand column lists the non-MOPS supporting documentation package supplied by TCAS PO for use by SC-147 Members. This additional analysis is part of our Op Suit and Safety analysis with the culmination of the ACAS Xu Safety Assessment. The final, DO-386, version will be available in a folder in our workspace. This folder/file location will be announced closer to DO-386 publication.

6. <u>Approval of FRACed ACAS Xu MOPS, DO-386/ED-275</u>
Mr. Stu Searight followed up the technical briefings by saying that we have receieved lots of good information in these preceding presentations. Then he asked the committee members if they had any questions or comments or questions. No discussion was needed, and Mr. Searight proceeded by asking if we had a motion to approve the ACAS Xu MOPS. Mr. Charles Leeper made a motion to approve the MOPS and send to PMC for approval for publication. Mr. Neal Suchy seconded the motion. There were no objections, and the committee approved the ACAS Xu MOPS.

Mr. Al Secen stated that the ACAS Xu MOPS was an example of exemplary work done quickly and professionally; Mr. Alex Engel concurred.

7. <u>An ALPA Representative (Mr. Ed Hahn) requested to address the committee</u>.
Mr. Searight had received a request from our ALPA representative, Mr. Ed Hahn, to address the committee. After being recognized, Mr. Hahn thanked the committee for their time and said: “As you might know, there is an ongoing issue at Denver International Airport, with nuisance TCAS

RA events during turns to parallel runway approaches due in part to Denver's altitude placing TCAS in a higher Sensitivity Level than is usual for an airport environment. There are currently efforts underway to alleviate this problem, but these will require either atypical controller action or approach procedure design."

He continued: "One of the questions that has arisen is whether a "patch" to v7/7.1 is a possibility, similar to what was done to reduce nuisance alerts back in the early 1990s when TCAS equipage first became widespread. This led in part to TCAS v6.04/04a [a summary report of this change can be found on FAA Tech Center pages: http://www.tc.faa.gov/its/worldpac/techrpt/rd92-23.pdf]."

Then Mr. Hahn concluded: "We recognize the FAA and aviation community are focused on ACAS development, but we are asking as part of due diligence on this issue."

Mr. Suchy observed: The committee has approved, RTCA has published, ACAS Xa/Xo; its design actually included addressing that problem. Another committee member contributed that: TCAS was not patched for several reasons including the difficulty to maintain the aging code. Mr. Olson: Indicated that updating TCAS isn't just the effort of updating the software. If we make changes to TCAS there will be substantial testing to ensure operational suitability, coordination and safety of this new system. Mr. Suchy added: The last TSO made ACAS X the standard for Collision Avoidance Systems in the NAS (where it said any upgrades or replacements to TCAS system would use of ACAS Xa/Xo. Ms. Mariano contributed: We would like Manufacturers and Operators to go forward to ACAS Xa. We would like Operators to make a request of, and work with, the manufacturers to get ACAS Xa/Xo in production and rolled into the environment.

Hahn: I appreciate the conversation. We needed to explore this possibility as part of our due diligence. This is good feedback to takeback to the group when discussing the Denver airspace.

Mariano: We appreciate ALPA bringing the feedback and we will ask flight standards to work with the airport to help with this issue until ACAS Xa can get into the environment.
Mr. Searight thanked Mr. Hahn for bringing this to our attention; he indicated that our committee always benefits from ALPA's participation, and expertise in this work.

8. Future Meeting Schedule

- 10 September 2020 — RTCA PMC
- 15-17 September 2020 — SC-147 Working meetings for ACAS sXu
- 29 and 30 September 2020 — sXu SWG and sXu TWG will resume the traditional SWG (Tues afternoon) and TWG (Wednesday morning) slots
- 9-10 December 2020 — SC-147 Working meetings for ACAS sXu
- 17 December 2020 — RTCA PMC

9. Adjourn @ 2:30

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