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THE BIG IRON

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Abstract

There are research activities in the United States evaluating various concepts of Free Flight. One such concept looks at autonomous flights for fully equipped aircraft operating in the National Airspace System. The flight deck of such aircraft will be fully equipped to uplink and downlink data (such as traffic, weather, etc.) and will be equipped with decision support tool(s) to process information for conflict detection and resolution and communicate with other flight decks and the service provider.

This document presents an alternative architecture, a centralized information assembly and processing, and a decision support system called the "Big Iron" that can be implemented in long-term NAS operations under the Free Flight Concept. Such a system would provide a homogeneous decision support tool and homogeneous assembly of information coming from different communication means with differing levels of accuracy and latency. Consequently, appropriately equipped users would possess consistent common information.

There are two potential problems identified under this approach: (1) delay in receiving the decision support analysis and (2) added strain on communication links expressed through additional bandwidth requirements. Both problems stem from having to transmit solutions and/or requests as opposed to processing them locally. Assumptions were made regarding the types of services necessary to support the autonomous operations that will be available and their associated communication links. The purpose of this research is to determine how much and what kind of information can be transmitted in time to enable safe and efficient operations under such centralized information and decision support processing and the timeframe in which this could be realized.

Concept of Future NAS Operations

One of the ideas for future National Airspace System (NAS) operations is to shift the authority for separation and trajectory alterations to appropriately equipped aircraft and their flight crews [1-4]. Since equipping an aircraft with all devices necessary for autonomous maneuvering is costly and requires a long lead time, it is expected that there still will be aircraft in need of traditional Air Traffic Control (ATC) services flying simultaneously and in the same airspace as equipped aircraft [1-8]. The main advantage of flying an (appropriately) equipped aircraft will be *direct access* to the information necessary to safely *determine and execute* adjustments in its own flying trajectories while still satisfying all constraints imposed by the system, such as weather, Special Use Airspace (SUA), flow constraints, etc.

The system is founded on four key players:

- ATSP, responsible for guiding all non-equipped aircraft, providing advisories for all aircraft flying in its sector, monitoring the traffic situation and intervening in operations of equipped aircraft on an as-needed basis;
- Appropriately equipped aircraft, responsible for conducting safe autonomous operations, and for keeping ATSP and other equipped aircraft informed about their intent;
- Non-equipped aircraft, responsible for conducting safe operations as commanded by ATSP; and,
- Airline Operations Centers (AOC), providing mainly strategic assistance to their crews.

The feasibility of the system supporting the autonomous operation is strongly dependent on the implementation of new technologies, policies, and procedures to support the distributed approach to safe aircraft separation and decision management. In addition, Free Flight operations in the NAS cannot be successful without coordination and collaboration among all users/system elements, Air Traffic

Management (ATM) decision support, reliable air/ground communication system, and NAS wide harmonious information system offering timely, consistent and unambiguous information [1, 9]. Furthermore, planning and scheduling of NAS operations are just the starting point; they continue with real-time coordination due to many unpredictable influences (weather being the largest).

The Big Iron Concept

Since safety and efficiency of a Free Flight environment necessitates the accuracy of common information, it is natural to direct the information flow through some centralized unit that would process it in a uniform fashion and then make it accessible to all users. In addition, since the concept is founded on autonomous operations of equipped users, the assumptions about how other users might react to the same contemplated event (bad weather cell, traffic congestion, SUA) are simply educated guesses, even if assisted by decision support tools. Their accuracy, however, is crucial for the safety and efficiency of the outcome. Having an ability to process the decision support requests centrally can additionally decrease the risk of inaccuracies and misinterpretations, and thus improve the overall system operations.

The Big Iron is envisioned as a centralized information assembly and processing resource, and a system-wide available decision support system that can provide homogenous information and decision support.

The main benefits Big Iron might provide include the following:

- Homogenous aeronautical information as opposed to a local processing of the information provided by various communication means with various accuracy and latency levels;
- Access to new applications and resources as they become available and without having to change expensive on-board automation;
- Potential cost-effectiveness, resulting from enhancement of the existing decision support tools (that would have to be provided for the ATSP use) and coupled by inexpensive airborne browsers instead of costly on-board automation.

The autonomous flight operations with the Big Iron concept employed would be transparent to users. Responsibilities, procedures and available information would remain the same as for concepts with airborne DSTs. The only difference is the location where these decision support applications reside: a ground based centralized DST as opposed to many airborne local ones. Free maneuvering aircraft crews would receive their trajectory re-planning options either fully automatically or on request, depending on the situation, and would choose the preferred solution that would automatically be available for everyone's use.

Consistent algorithm for decision support, as opposed to many similar but still different ones that are based on preferences and objectives of its user (ATSP, free maneuvering aircraft, AOC) provides predictable solutions to everyone, which is an additional advantage as well. However, one could argue that being able to tailor each solution to user preferences provides user-benefits.

There are many possible functions that can be assigned to the ground based DST; the whole set doesn't even have to be fully defined and can be attuned as the autonomous maneuvering evolves: assembly of different graphical interpretations of weather, SUA and terrain on a chosen user preferred flight path for each flight or a leg or a segment of a flight; calculations of various kinds, such as trajectory re-planning, forecasting of traffic situations on tactical or strategic level; ability to download some airborne software improvements; etc.

Perhaps the most significant advantage of having such a centralized decision support tool and information processing capability accessible to all (equipped) users is its versatility. Since air/ground communications are prerequisite, an aircraft would only require some sort of a browser or interrogation device to access it. Furthermore, the applications available through the Big Iron can improve and grow in time without a need to change any airborne equipment; the appropriate communications channel and the same "old" browser would still be enough equipment needed to obtain the new and/or improved applications. The applications' change and/or improvement would be implemented locally but available globally, which would likely be a cost effective alternative to the current approach of hard-coding on-board applications and devices.

The Air/Ground Communications Simulation Model

This research is an initial exploration into the (high-level) communications operational feasibility of the Big Iron concept. The main goal was to study the bandwidth requirements resulting from such a centralized approach to air/ground decision support and information processing. Subsequently, we have found the following assumptions to be justified: (1) the Big Iron has enough capacity to handle simultaneous requests from all users and (2) each conflict can be resolved in such a manner that the ATSP does not need to revoke the autonomous operations.

We developed a discrete-step simulation of the air/ground communications under the long-term autonomous NAS operations, fully implementing those features anticipated with the Big Iron. We examined three test cases based on the morning rush operations forecasted for 2015 within the following centers: ZID (Indianapolis, IL), ZAU (Chicago, IL), and ZOB (Cleveland, OH). In each of the cases we varied the overall fleet equipage level from 20% to 100% in increments of 20% and the average size of supplementary aeronautical messages from 0 Kb to 125 Kb, in increments of 25 Kb. (This information was considered supplementary to the information provided by the other aeronautical information services, such as TIS and FIS). In addition, we assumed that upon each sector entry a crew of an equipped aircraft would request additional information with a probability of 0.25. With no better information available, assuming such an arbitrary value was a sound approach to studying the range of communication requirements under the described concept.

Additional requests from Big Iron might include various weather or turbulence maps, traffic or weather conditions at the destination airport or in airspace further down the flight path. Some message types could be very large and compression would be required to preserve the available bandwidth. Several research efforts have already addressed this issue [9] and they have concluded that the most likely compression ratios for the weather information will be between 10:1 and 50:1. Applying these ratios to our largest simulated message, a conservative average message size for the custom-requested information will be about 6.25 Mb.

Assumed air traffic was extracted from a forecast of average daily operations within the NAS in 2015. All flights followed wind-optimized flight paths avoiding Special-Use Airspace (SUA). We did not model trajectory modifications due to separation assurance, but the required communications were modeled. In addition, because of the lack of information about the likely airspace configuration supporting the coexistence of autonomous and ATC managed flights, we assumed the current FAA sector definition. This is a conservative assumption for this analysis since re-sectorization would likely *decrease* the bandwidth requirements.

The air/ground communications model assumed that all regular aeronautical services providing weather, traffic and flight information required for successful autonomous operations were working properly via their own assigned communication links. Voice and data controller-pilot communications and the supplementary information requests to the ground based DST (information not included in the regular TIS and FIS broadcasting) were transmitted via the appropriate VDL Mode 3 channel. We assumed the 1V3D configuration that provided access to one voice and three data channels in one 25 kHz frequency assignment. In other words, each sector had one frequency assigned with each frequency "divided" into 4 sub-channels: one used exclusively for controller-pilot voice communications, one for controller-pilot data link communications and the remaining two for all equipped aircraft crew inquiries, including requests regarding trajectory alterations.

The communication link and message transmission were modeled by the RTCA's specification standards for the VDL Mode 3 [10, 11]. VDL mode 3 uses Time Division Multiple Access (TDMA) technology to provide access to a channel. Each flight can have a single channel assigned at any given moment. The nominal data rate of a single VDL Mode 3 channel is 31.5 kbps. However, the basic channel resource for message transmission is one TDMA slot (30 ms) during which only 576 bits (192 symbols) of user data can be processed, indicating an effective data rate of 19.2 kbps. Four consecutive TDMA slots compose a TDMA frame, which determines the effective sub-channel data rate of 4.8 kbps.

All simulated messages were first segmented consistently with the TDMA frame specifications and then processed via the appropriate sub-channel and in accordance with their transmission request times and priorities. To allow otherwise wasted bandwidth to be utilized, the air/ground communication model considered all message frames waiting for transmission for frame grouping. The model performed frame grouping for a transmission within the same channel with respect to acknowledgement and with respect to the frame with the highest priority. The model allowed the addition of the lower priority frames only if that would not delay the reception of the frames with the higher priority.

The assumed message set was based on standard air/ground communications within the high altitude En Route sectors (FL240 and above). (The model can easily be adjusted to include the communications typical for other sector types as well.) The model assumes that appropriately equipped aircraft crews, in charge of solving all conflicts on its path, would have direct access to Big Iron resources. In addition, each sector had a controller/service provider who was responsible for resolving conflicts and communicating the appropriate information to all involved pilots of the non-equipped aircraft. The model assumed that the equipped crew had up to 5 minutes before a conflict to perform a corrective action; if the conflict was not resolved by that time, the Big Iron would send a warning to all involved aircraft crews as well as appropriate trajectory alteration(s) granting conflict free paths. If a pilot accepted the trajectory alteration offered by the ground-based computer, he would send an acknowledgement message to Big Iron (the aircraft's ADS-B would broadcast the same trajectory alteration information as well); otherwise, the pilot would request other trajectory alteration solutions. We assumed that in 10% of cases pilots would request additional options.

Summary of the simulation results

The following is a description of the results obtained by running 50 iterations for each test case defined by center, applied equipage level and supplemental information size[1].

Assuming average daily NAS operations under normal weather conditions, there were 765, 631 and 627 simulated flights within ZID, ZOB and ZAU centers, respectively, during the 3 morning rush periods. Air/ground communications within ZID, ZOB and ZAU were performed via 28, 24 and 32 channels, respectively, corresponding to the appropriate number of sectors within each center. The maximum sector traffic load was 33 aircraft in ZID (traffic load was 7 aircraft on average per sector), 18 in ZOB (6 average), and 18 in ZAU (5 average).

The controller/pilot communications were simulated via separate sub-channels so as to provide seamless connection and to assure continuity of service for high priority communications. As a result, incorporating supplemental messages requested from Big Iron did not influence the processing of CPDL messages.

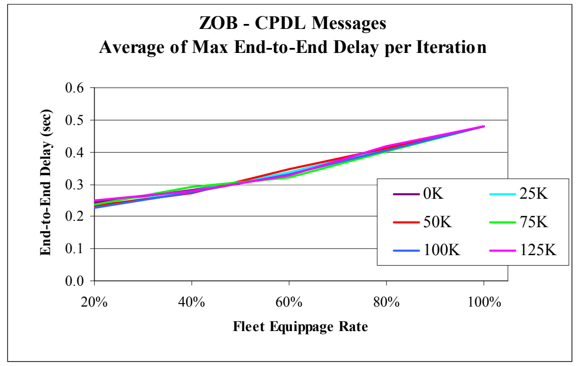

Figure 1. ZOB-CPDL Message Average of the Maximum End-to-End Delay per Iteration versus Equipage Rate

On average, the mean end-to-end delay was less than 0.15 seconds in all three centers even assuming 100% equipage; the standard deviation was below 0.1 second, the average of maximum delays across all iterations was below 0.5 seconds (as shown for the ZOB test case in Figure 1), and a CPDL message was delivered within 0.22 seconds at the 99.7% confidence interval.

The change in the CPDL message statistics with the equipage rate did not indicate communication overload: the increase in the average of maximum end-to-end delay per iteration from the case of 20% to 100% equipage rate was below 0.3 seconds in all three test cases (the highest one was 4.8 seconds in ZOB), whereas average end-to-end delay increased about 0.005 seconds (the highest was 0.127 seconds in ZOB), and standard deviation about 0.016 (the highest was 0.031 seconds in the same test case. However, since our research was concentrated on the communications between airborne users and Big Iron, we didn't incorporate all the messages that might be transferred by the CP data link. Including various temperature, pressure and other recurring reports collected by the on-board gauges into the simulated message set (with the appropriate frequencies of transmission, [12]) would probably increase the end-to-end delay of the CPDL messages. This issue would become important for the evaluation of Big Iron concept only if the same channel was to be used for the transmission of both CPDL and DST types of messages; at this time it is reasonable to assume that the CPDL messages would be

[1] Due to the spatial limitations, we could not include all figures created for each examined case; the figures we incorporated in this report were selected as the best representative ones.

transmitted separately due to safety of the high priority CP communications and that the capacity of the appropriate connection is sufficient. As a result, the communications with Big Iron can be analyzed independently.

The simulated communications with the Big Iron included two message types: (1) requests and their potential solutions regarding flight trajectory modifications, and (2) requests for additional information and associated answers.

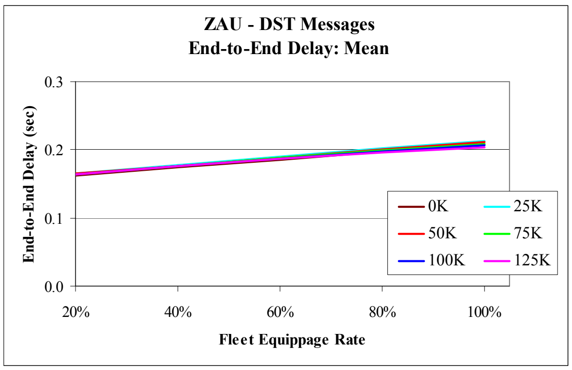

Figure 2. ZAU-Mean of the High Priority DST Message End-to-End Delay by Equipage Rate

Messages regarding trajectory modifications were given higher priority; informational requests/answers could be transmitted only if there were no higher priority messages waiting to be processed.

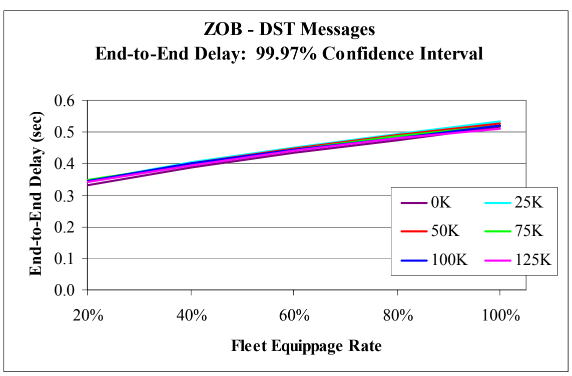

Figure 3. ZOB-99.7% Confidence Interval for the High Priority DST Message End-to-End Delay by Equipage Rate

After each processed TDMA frame, the model would check for TDMA frames with high priority and only if none were waiting for the channel release, would the model look for the TDMA frames with lower priority messages. Additionally, frame grouping was allowed only if it would not disturb the transmission of high priority messages (and also with respect to acknowledgement). As a consequence, incorporating lower priority decision support messages did not result significant change in the end-to-end delay of the high priority communications (as shown for the ZAU test case in Figure 2).

The model indicated that decision support messages regarding trajectory modifications would be delivered within 0.6 seconds at the 99.7% confidence level (as shown for the ZOB test case in Figure 3). The average iteration max end-to-end delay was bellow 0.8 seconds in all three simulated cases (as shown for the test case ZOB in Figure 4) including the 100% equipage scenario; the maximum experienced end-to-end delay across 50 iterations was 5.08 seconds in ZOB, 3.96 seconds in ZID (Figure 5) and 0.92 seconds in ZAU.

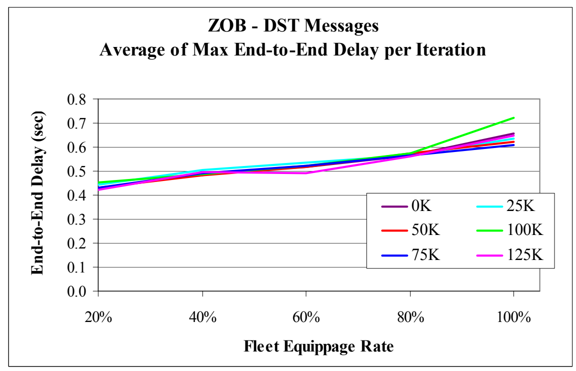

Figure 4. ZOB-High Priority DST Message Average of Max End-to-End Delay per Iteration by Equipage Rate

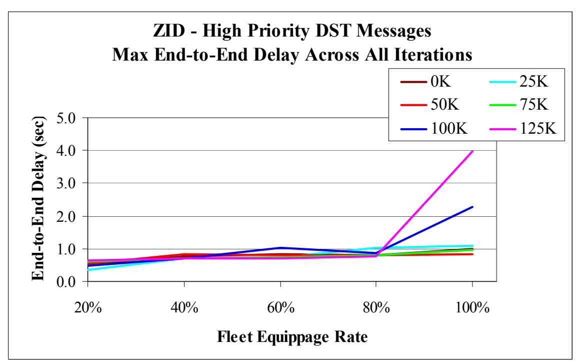

Figure 5. ZID-High Priority DST Message Max End-to-End Delay Across all Iterations by Equipage Rate

The end-to-end delay of supplemental messages, however, was not as sensitive to the equipage rate as to the size of communicated information. On average, 25 Kb messages were delivered within 3 seconds. Larger messages took about 3 additional seconds for each 25 Kb increment in size to complete transmission, regardless of the equipage rate.

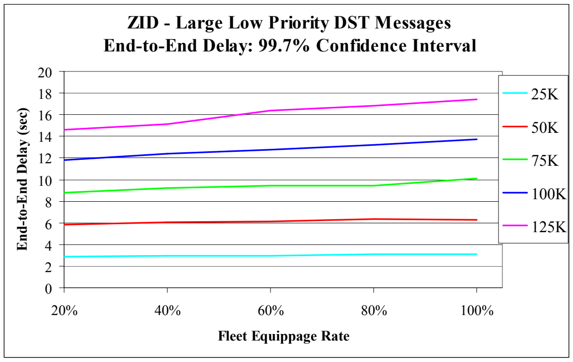

Figure 6. ZID-99.7% Confidence Level for the Low Priority DST Message End-to-End Delay by Equipage Rate

Overall, the highest average end-to-end delay was just above 14 seconds in all three centers, the highest average of maximum delays across all iterations was 23.53 seconds (in ZID test case, Figure 7) and the highest experienced was 30.96 (in ZOB test case, Figure 8) seconds. However, the model indicated that these messages would reach their destination in less than 18 seconds within ZID (as shown in Figure 6), and just above 16 seconds within the other two centers at the 99.7% confidence level.

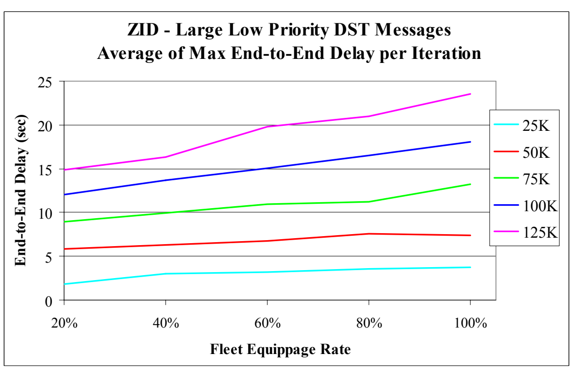

Figure 7. ZID-Low Priority DST Message Average of Iteration Max End-to-End Delay by Equipage Rate

The standard deviation was also affected by the supplemental information message size. This is understandable because as the equipage rate increases, the communication load due to high priority messages will also increase (same number of conflicts, but voice-com control would be replaced by DST), which will in turn increase the likelihood of interruptions (thus increasing the standard deviation as well) of the lower priority informational messages. Additionally, larger informational messages will require more TDMA frames, again increasing the likelihood of message interruptions. Combining the two, causes higher overall delay of the large low priority messages.

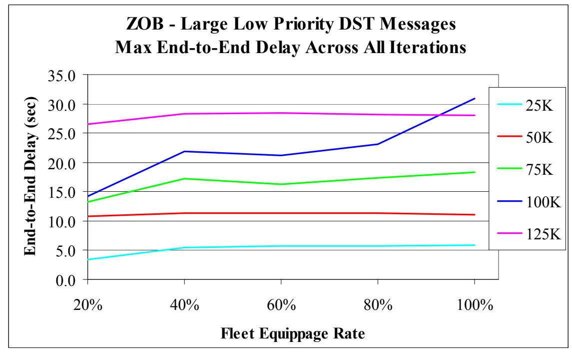

Figure 8. ZOB-Low Priority DST Message Max End-to-End Delay Across All Iterations by Equipage Rate

The RTCA's Minimum Aviation System Performance Standards (MASPS) for the VDL Mode 3 states that the maximum allowable message delay for the 96th percentile shall be 22 seconds and that a high priority data message of 192 bits or smaller shall be delivered within one second with a probability of 95%. Our model indicates that both standards are likely to be satisfied within the Big Iron concept, even with large low priority supplemental information messages (as shown for the ZID test case in Figure 9).

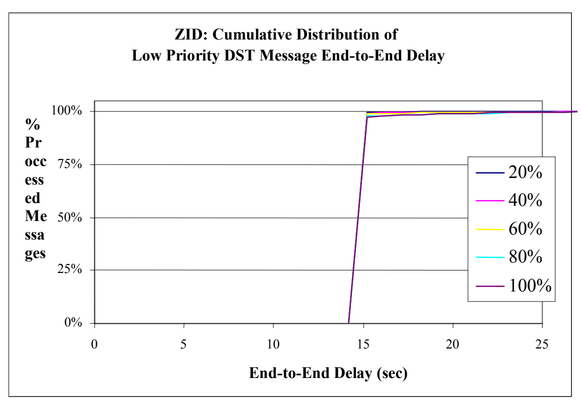

Figure 9. ZID: Cumulative Distribution of the Low Priority DST Message by Max End-to-End Delay and Equipage Rate

The next step in Big Iron research should be to incorporate the whole message set for each of the communication links considered, as well as timing and type of information available by other aeronautical services. It would also be interesting to conduct a survey of what type of additional information pilots might request from the Big Iron and how often that information would be required. As a consequence, a richer set of the supplemental information messages could be composed and incorporated. That would provide a better practical understanding of the capabilities and limitations of the Big Iron concept.

Finally, the center with the highest traffic and air/ground communications load does not necessarily experience the highest delays. End-to-end delay is highly sensitive to the time distribution of requests for message transfer. The closer the message inter-arrival times are the higher end-to-end delays tend to be. Therefore, we need to also examine the theoretical worst case scenario, that is, how many simultaneous messages can be allowed to wait for transmission in the same channel before the last one's delay reaches the maximum acceptable value (Table 1).

Table 1– Max Number of Simultaneous Messages by End-to-End Delay and Message Size

Delay	Message Size (bit)							
(sec)	192	528	1,056	2,112	3,696	5,280	6,336	7,440
1	8	8	4	2	1	0	0	0
2	16	16	8	4	2	1	1	1
3	25	25	12	6	3	2	2	1
4	33	33	16	8	4	3	2	2
5	41	41	20	10	5	4	3	2
6	50	50	25	12	7	5	4	3
7	58	58	29	14	8	5	4	3
8	60	60	33	16	9	6	5	4
9	60	60	37	18	10	7	6	5
10	60	60	41	20	11	8	6	5
11	60	60	45	22	13	9	7	6
12	60	60	50	25	14	10	8	6
13	60	60	54	27	15	10	9	7
14	60	60	58	29	16	11	9	7
15	60	60	60	31	17	12	10	8
16	60	60	60	33	19	13	11	8
17	60	60	60	35	20	14	11	9
18	60	60	60	37	21	15	12	10
19	60	60	60	39	22	15	13	10
20	60	60	60	41	23	16	13	11
21	60	60	60	43	25	17	14	11
22	60	60	60	45	26	18	15	12

The maximum number of octets allowed per transmission i.e. per packet of information is 930, i.e., 7,440 bits. Assuming a single sub-channel data rate of 4800 bps and knowing that a single TDMA frame can transfer up to 576 bits (48 of which is reserved for the header), we can conclude that up to 8 simultaneous single TDMA frame requests for transmission can be allowed to guarantee 1-second delivery. If 9 messages requiring one frame per message request transmission at the exact same time and for the exact same (sub-) channel, the 9th message would experience end-to-end delay of 1.08 seconds.

This is a theoretical approach that assumes that the messages requesting transmission by the same channel are all the same size; however, it provides a valuable insight into how many messages can be delivered in a certain amount of time. This reasoning should be combined with the appropriate frequencies and sizes of certain types of messages, especially the highest priority ones, to determine the probabilities that the message would experience delay if transmitted by a given communication link.

Cost-Benefit Analysis

An important potential benefit of the Big Iron concept is its possible cost effectiveness over other similar concepts providing autonomous operations through *airborne* decision support tools. This potential is based on the assumption that installation, maintenance, certification and upgrade of many airborne decision support tools would be more expensive than for the ground-based DST. In other words, the ground-based DST assumed to be available to ATSP in all concepts of long-term NAS operations, is a good foundation for the Big Iron. However, an enhancement would be required to provide simultaneous service to both ground-based and airborne users, but the basic functionality would not have to be altered. In addition, future enhancements of the DST algorithms (i.e., expansions of the available message set, or other improvements that would enhance or introduce capabilities), would not necessarily entail airborne equipment hardware or software changes. Since the communication links are already required and available, an aircraft would only need some sort of airborne "browser" to access Big Iron instead of a complete airborne DST. As new features are developed, these would be available to everyone with the same "old" browser. It is also likely that the most frequent changes in airborne equipment would be optional and would provide enhanced data access. Properly implemented, this would not disable access to the Big Iron by users who do not wish to implement the new features. In the worst case it might only prohibit access to the new capabilities but not influence the existing ones. Some software improvements may be desired from time to time, but even these would be generally inexpensive compared to the improvements in on-board hard-coded devices. The whole idea can be compared to the ability to access the World-Wide-Web through older browsers: downloading or processing information might be slower, but it is certainly possible in most cases.

Since the overall benefits of autonomous operations are the same regardless of the location of the DST, and the expected cost of equipping for Big Iron is lower to the users, the Big Iron should result in faster equipage by the users. However, it would still be beneficial to know how long it would take for the anticipated benefits to pay back the initial system investment.

For the purpose of studying the costs and benefits associated with ground-based versus on-board DST equipment, we developed a model that determined the number of years that would be necessary for the benefits to outweigh the required investment for the typical, best and worst case. The typical case was determined by the initially assumed data representing costs and benefits of an investment; the worst case was 2.5 times more costly and required more frequent updates in the case of the approach with on-board automation available, while the best case assumed 50% less expensive installation costs and half as many updates. The model does not account for the differences in message costs nor the differences in equipment that may be required by a specific aircraft type. This simplification is acceptable because the model was built to help us understand the *major* aspects of the cost-benefit interaction. Incorporating too many details could produce misleading results given the lack of empirical data and the numerous intangibles that simply cannot be accounted for.

The cost-benefit analysis was performed at the aircraft level, the U.S. airline level and the National Airspace System level. The model was based on the current fleet characteristics of the U.S. airlines and assumed three groups of aircraft: classic aircraft (those incapable of being retrofitted), glass-cockpit aircraft (those that can be equipped during regularly scheduled “C” or “D” maintenance check), and newly purchased aircraft (custom-built). U.S. airlines currently own about 6000 aircraft; about 44% of them have glass-cockpit and are considered candidates for autonomous operations. In addition, we assumed that the average useful aircraft life is about 30 years and that on average there are about 250 new aircraft entering the overall airline fleet per year.

We assumed that the FAA investment for ground-based DST would be $1 billion if access is available only to ATSP and about 10% more if access is provided to airborne users as well. The retrofitting cost to provide an on-board DST would be $150K and forward-fitting cost would be about 30% of this amount. Both retrofitting and forward-fitting of a browser supporting Big Iron access were assumed to be about 10% of the on-board cost. Furthermore, every five years after initial equipage of on-board DST, there would be an additional cost associated with the software or hardware improvements equal to about 10% of the retrofit installation costs.

The cost data assumed by this analysis were based primarily on historical data from the recent FAA investments in the host replacement program as well as investments in developing and installing ERAM [15-17]. Similarly, the historical cost data available for the analogous airline investments, such as FMS or TCAS, were also considered, as well as various cost and benefit data assumed by similar models found through a literature survey [13, 14]. Ultimately, the applied cost-benefit data were based on judgment and should accordingly be considered approximate. Once new and more accurate information becomes available, it can easily be incorporated into the model and quickly produce more accurate estimates of the costs and benefits associated with both approaches.

Finally, we assumed that both alternatives would be available in 2015 and would provide a savings of 4% in direct operating costs on average. Also, we assumed that, on average, cruise consists of about 30% of the average utilization time (expressed in daily block hours) and that the average direct operating costs are just under $2,000 per hour.

As expected, the model indicates that the Big Iron approach breaks even sooner than the airborne DST approach. At the aircraft and the overall airline level, it would take a little less than a year for the anticipated benefits to outweigh the costs for the Big Iron, as opposed to two years indicated for the latter approach. On the overall NAS level, it would take about four years for the initial investment in Big Iron to pay-off, as opposed to seven years for the alternative. In the best case, the system investment payoff period would be reduced to two years with Big Iron approach and three years for the alternative. However, in the worst case, the payoff period might be increased to 7 years in the case of Big Iron approach, whereas in the case of the approach with the on-board DST to 34 years.

Due to the approximate cost and benefit data applied to this analysis, the conclusions have to be considered approximate as well. The cost-benefit model, however, points out that airlines might equip their fleet faster if Big Iron concept is employed, because its benefits could return the required investment within the first year of operations.

Conclusions

Advanced autonomous operations in the NAS cannot be successful without coordination and collaboration among all users/system elements, ATM decision support and reliable air/ground communication. Having access to a NAS-wide harmonious information system would be beneficial due to the timelines and consistency of aeronautical information. Moreover, planning and scheduling of NAS operations are just the starting point; they have to continue with real-time coordination due to many unpredictable influences. Also, in order to conduct safe and efficient flights, free maneuvering aircraft need a complete picture of traffic and weather situations in addition to a clear understanding of airspace constraints and flying procedures.

Directing the complete air traffic information through a centralized ground based resource such as Big Iron, coupled with the harmonious decision support available to all users, and enabled by the new (soon to be) available technology, is a sound approach to maintaining uniform aeronautical information required for highest safety and efficiency. The Big Iron concept assures the uniformity of the aeronautical information through the centralized information assembly and processing. The concept does necessitate higher air/ground communications load. However, the initial research indicates that the additional increase in air/ground message traffic due to handling the airborne trajectory re-planning requests to the ground based decision support can be accommodated and would not decrease the quality of the air/ground communications. In addition, the concept is a cost-effective alternative enabling advanced autonomous flight operations within the NAS.

Finally, we would like to emphasize that this research does not invalidate the long-term operational concept of on-board automation; it merely points out the great potential of an operationally equivalent alternative.

Keywords:

Air/ground Communications, CPDL, DST, VDL-Mode 3, End-to-End Delay, Cost-Benefit Analysis, free maneuvering, autonomous flight operations

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Biographies

Almira Williams is system analyst at CSSI, Inc. Her responsibilities include developing an air/ground communication model under long term NAS operations and determining the potential sources of demand for future transportation technologies by analyzing demographics, mode choice, and demand distribution determinants. Prior to CSSI, she served as an assistant faculty in the Department for Airports and Air Traffic Control at the Belgrade University (YU). Upon receiving her M.S. in Transportation from UC Berkeley, she worked as an independent consultant performing mostly airport and airspace simulation modeling.

Dr. Stephane Mondoloni is chief scientist at CSSI Inc. in Washington, DC. For the past nine years, he has been developing simulation models and conducting analyses for the Federal Aviation Administration and the National Aeronautics and Space Administration. Recent tasks have focused on conflict detection and resolution, aircraft trajectory optimization, and evaluation of alternative operational concepts. He received his Ph.D. in 1993 from MIT in Aeronautics and Astronautics.

Diana Liang works for the Office of System Architecture and Investment Analysis for the Architecture and System Engineering Division. She is responsible for the development of the NAS Architecture Tool and Interface called CATS-I, directing analyses in support of NAS Concept Validation, and the development of Modeling Tools and Fast-Time Simulations to support that validation. This work includes several models she is developing jointly with NASA and cooperative efforts with Europe via Eurocontrol. Prior to working for ASD, Ms. Liang worked in the Office of Energy and Environment for two years as the lead for the Emissions and Dispersion Modeling System (EDMS), updated the FAA's Air Quality Handbook and reviewed Environmental Impact Statements related to emissions. Ms. Liang holds a BS in Computer.

Steve Bradford is the chief scientist for Architecture and NAS Development in the FAA’s Office of System Architecture and Investment Analysis (ASD). In this role he has participated in the development of the RTCA NAS Operational Concept and the ICAO ATMCP Global Concept. His organization is also responsible for leading the effort to validate the future concepts, develop the FAA's ATC Information Architecture and leads several co-operative efforts via action plans with Eurocontrol. Prior to his current position, Mr. Bradford was the Manager of the NAS Concept Development Branch. Earlier, Mr. Bradford was lead on several simulation and analytic software development efforts, and conducted early analysis of Free Flight Concepts. From 1987 to 1991 he worked for CACI, Inc. where he led the SIMMOD model development and taught simulation language and modeling courses. He has also worked for the US Navy developing logistic planning models.

Richard Jehlen is the division manager for Air Traffic Operational Planning in the FAA’s Air Traffic Services (ATS) organization. His office serves as the principal Air Traffic element responsible for operational concepts such as the NAS Operational Concept and the ICAO Global Concept. It is also responsible for Air Traffic’s validation of the concepts, international harmonization efforts for the future and ultimately the efficient integration of new systems. Prior to his tenure in this office, Mr. Jehlen was the ATS requirements lead for future decision support tools, which were incorporated into the FAA’s Free Flight initiative. Over 22 years in ATC, his responsibilities have included Airspace & Procedures, Military Liaison, Automation and direct operational oversight.