Interoperability Cross Atlantic Trials (ICATS)

Scott E Landriau
System Architect
Lockheed Martin IS&GS Civil – Transportation & Financial Solutions

Lee Weinstein
Chief Engineer
Lockheed Martin IS&GS Civil – Transportation & Financial Solutions

Jose Manuel Asensio
Project Manager
Indra Sistemas, S.A.

Amalia Garcia Alonso
Senior R&D Engineer
CRIDA, A.I.E.

Andrea Villa
R&D Engineer
CRIDA, A.I.E.

Abstract

Interoperability Cross Atlantic Trials (ICATS), a two year Demonstration project, was launched in September 2013, under the framework of the Single European Sky (SES) initiative, and co-financed by the SESAR Joint Undertaking (SJU). ICATS primary objective is to quantify operational benefits enabled by the International Civil Aviation Organization (ICAO) inter-region exchange of flight object data including 4D Trajectories for trans-Atlantic flights.

ICATS successfully demonstrated the feasibility of integrating two different regional implementations of the flight object by means of a Flight Information Exchange Model (FIXM) based Global Flight Object (GFO) concept and associated technical infrastructure. The infrastructure was deployed at Indra and Air Navigation Service Provider (ANSP) facilities in Europe and at the Florida NextGen Testbed (FTB) at Embry Riddle Aeronautical University in Daytona, Florida for conduct of the ICATS Live Flight Trial in spring 2014.

The ICATS Live Flight Trial successfully demonstrated significant operational improvements both in terms of Fuel Efficiency and CO2 Emissions, as well as improved accuracy and predictability of key data derived from the flight object for Air Traffic Control (ATC) use. ICATS met or exceeded a number of the quantitative benefit targets established during the initial project definition and planning activity.

KEYWORDS

SESAR, NextGen, FIXM, flight object, SWIM, 4D trajectory, benefits, international

ICATS Project

Interoperability Cross Atlantic Trials (ICATS) was a two year Demonstration project launched in September 2013, under the framework of the Single European Sky (SES) initiative, and co-financed by the SESAR Joint Undertaking (SJU). ICATS primary objective was to quantify operational benefits enabled by the inter-region exchange of flight object data including 4D Trajectories for trans-Atlantic flights by means of a Live Flight Trial.

The main project activities included:

- Establishing meaningful Success Criteria targets to support the ICATS objective of quantifying operational benefits in the form of measurable metrics for certain Key Performance Areas (KPAs),
- Planning of Live Flight Trial activities to quantify the Success Criteria metrics,
- Design and deployment of a suitable infrastructure to support the Live Flight Trial,
- Organizing the Live Flight Trial and collecting the required data, and
- Analysis of the data and assessment of results.

The project was performed by the consortium shown in Figure 1 comprising European Air Navigation Service Providers (ANSPs): AENA from Spain and NAV-Portugal from Portugal; Air Traffic Management (ATM) solution providers: Lockheed Martin and Indra, Air Europa as the airline; and CRIDA, a Spanish ATM R&D company, in charge of the analysis of the data from the trials and provision of the results. Throughout conduct of the project the SJU monitored program execution.

Figure 1 ICATS Consortium Members

Key Demonstration Objectives and Success Criteria

The objectives of the project were organized in two different sets (Exercises in SJU terminology), each one with its specific use case, metrics and supporting air traffic scenario, as depicted in Table 1.

For Exercise 1, selected Air Europa flights between Madrid and Caribbean and Latin American airports (Havana, Cancun, Santo Domingo, San Juan Puerto Rico, Caracas, etc) were examined by the AOC to identify opportunities to optimize the route of flight (e.g., via route, level or speed changes). The ICATS technical infrastructure supported collaborative assessment of AOC proposed trajectory optimizations. Air Europa Flight Crews subsequently worked with ATC to implement any trajectory optimization assessed to be acceptable. To quantify the resulting operational benefit, a baseline reference scenario derived from a sample of Air Europa

Flights from 2013, was elaborated for direct comparison with ICATS results.

Exercise 2 included all transatlantic flights from Central America to Madrid crossing the Santa Maria Oceanic and New York Oceanic airspace. The main focus was direct comparison of ICATS data with operational data provided by AENA in order to quantify the associated operational benefits. The subject data for comparison was captured by AENA using their in-service tools (PIV, Posicion *de Información de Vuelo*, Flight Information Position).

The detailed demonstration objectives and success criteria targets for each Exercise are shown in Table 1 below.

An underlying objective supporting the Key Performance indicators was to validate the feasibility of integrating two different regional implementations of the flight object by means of the Global Flight Object concept and associated technical infrastructure.

Table 1 ICATS Live Flight Trial Objectives and Success Criteria

Exercise ID	**Demonstration Objective**	**Demonstration Objective Description**	**Success Criterion**
Exercise 1: Flight Efficiency improvement by means of airline proposed Trajectory optimizations	Objective 3	Capacity - Coordination Revision/Rejection: the number of Coordination revisions or rejections for a given amount of flights.	Reduction of at least 5% comparing with a non-ICATS baseline scenario.
	Objective 4	Efficiency - Fuel Consumption.	>= 1% fuel savings
	Objective 5	Environment – CO2 Emissions: the use of optimized flight profile will lead to a reduction of CO2 emissions and reduced environment impact.	>= 1% reduction of CO_2 Emissions
	Objective 6	Safety – Tactical Conflicts: an earlier activation of the conflict detector and conflict probe tools due to a more accurate traffic situation and an earlier resolution of conflicts delivers safety improvement by reducing Tactical Conflicts.	Reduction of at least 10 % of the Tactical Conflicts as compared to a baseline non-ICATS scenario
Exercise 2: Predictability / Accuracy improvements in the entry sector	Objective1	Capacity - Load-Hourly Sector Entry Rate (Hourly Entry Rate): the number of aircraft predicted to enter the sector within one hour (i.e. in a sliding window of one hour from current time onwards).	Improve the accuracy of sector load calculations by 15% of oceanic traffic

Exercise ID	Demonstration Objective	Demonstration Objective Description	Success Criterion
workload calculation	Objective 2	Capacity - Load-Sector Occupancy: this is the number of aircraft in the sector airspace per hour.	Reduction on a 10% of unexpected sector overload due to Oceanic traffic as compared to the non-ICATS baseline scenario
	Objectives 7 and 8	Predictability and Accuracy: more timely and accurate updates derived from 4D trajectories enhances data predictability	1. Data provided by the ICATS Human Machine Interface (HMI) is closer to the actual times than the PIV data. 2. ICATS HMI Data is more predictable than the current PIV Data

Live Flight Trial Operational Context

Figure 2 below depicts the operational context for the ICATS Live Flight Trial and provides a framework for high level discussion of the Operational Concept for the Trial and how it was supported by the ICATS architecture.

As shown, the architecture incorporates an Operational Chain (shown across the top of the figure in green) that consists of existing operational systems in both the European Union (EU) and the United States (US). A parallel Interoperability (IOP) Chain (shown across the bottom of the figure in yellow) incorporates automation systems for both ANSP and Airline Operations Center (AOC) users, the regional System Wide Information Management (SWIM) systems in both the EU and US, and the Inter-Regional SWIM (I-SWIM) infrastructure that provides global inter-regional interoperability.

The Interoperability Chain automatically receives all data necessary to maintain situational awareness from the Operational Chain by means of data feeds in both the EU and US regions. The continuous and automatic flow of data to the Interoperability Chain ensures that it always contains up to date data that mirrors the current operational situation in the Operational Chain. The Interoperability Chain further implements flight object based data sharing by means of its EU and US regional SWIMs, EU and US adapters, and the I-SWIM interoperability infrastructure. This provides the Interoperability Chain with access to timely, high quality flight object data whereas the Operational Chain contains the same data that it does today. The Interoperability Chain, with access to high quality and timely flight object data, provides the environment for exploring and measuring the operational benefits associated with SWIM based information exchange of flight object data.

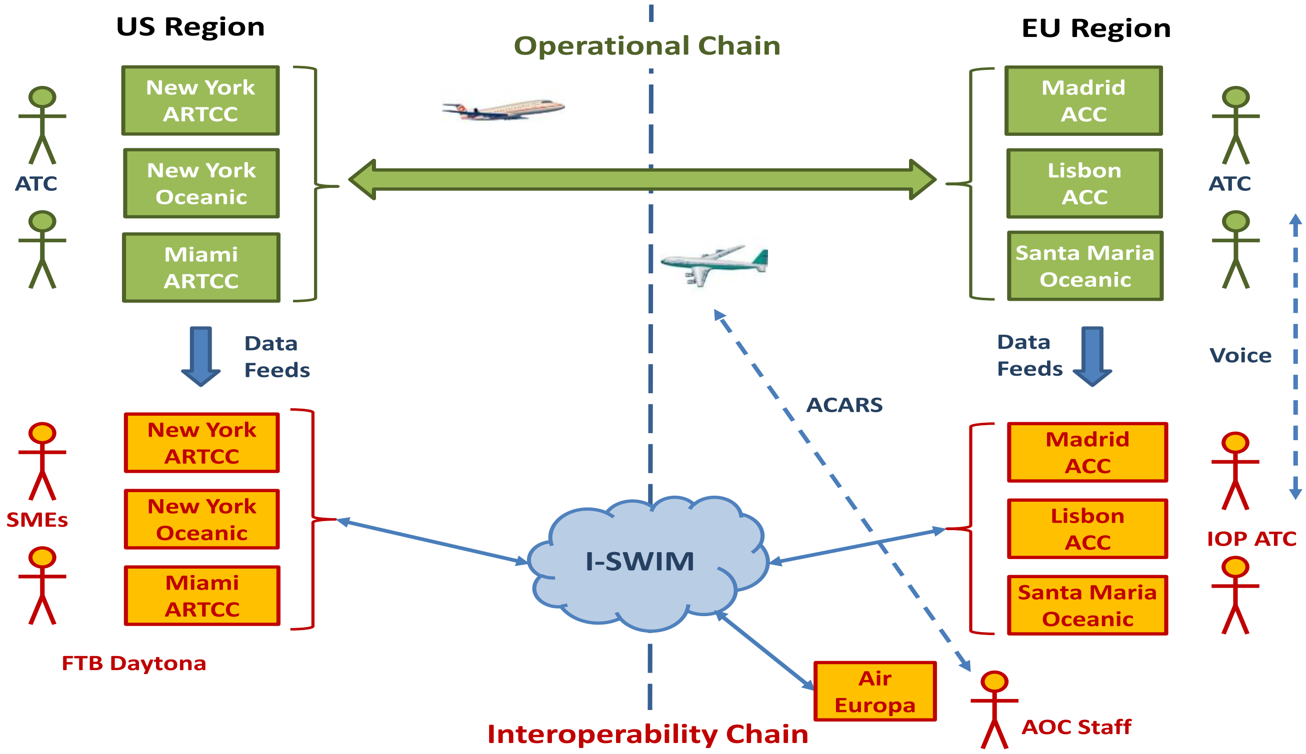


Figure 2 ICATS Live Flight Trial Operational Context

Using the up to date and accurate flight object data in the Interoperability Chain, the IOP controllers on the EU side, Subject Matter Experts (SMEs) on the US side, and AOC Users can more effectively and efficiently spot and assess changes of route, level or speed that would optimize the planned and actual movement of flights. Such optimizations are identified using the automation systems in the Interoperability Chain in conjunction with existing tools in order to enhance safety and efficiency, proactively assure separation, or reduce fuel burn and environmental impact.

The Interoperability Chain supports the AOC in developing "What-if" type flight path changes to route, level or speed that can be proposed, distributed for evaluation, and assessed in the Interoperability Chain by IOP controllers on the EU side and SMEs in the FTB on the US side. In the EU half of ICATS, the side by side physical integration of the IOP controllers with Operational Chain ATC staff permits the proposed changes to be verbally evaluated, assessed, and coordinated. When a "What-if" change proposal is fully assessed as acceptable and conflict free by all impacted parties, the change can be proposed to the Operational Chain by the AOC and the Flight Crew using Aircraft Communication Addressing and Reporting System (ACARS) and Controller Pilot Data Link Communications (CPDLC) as is done today. To ensure safety, Flight Crew and Operational Chain ATC provide the final evaluation and implementation of any such proposed change to ensure that it is still viable and acceptable. Once the Operational Chain systems and data are updated, the change is reflected through to the Interoperability Chain to complete the cycle.

AOC proposed changes have a high probability of success in the Operational Chain because of the "pre-evaluation and coordination" of changes in the Interoperability Chain using the What-if change proposal mechanism. Further, the four step cycle of: 1) identify and propose a what-if change that optimizes flight movements, 2) pre-evaluate and coordinate the change to determine whether it is acceptable, 3) implement the change in the Operational Chain when it is acceptable, and 4) update the Interoperability Chain with the results of the change - can be repeated as often as needed for any given flight of interest.

In addition, the side by side parallel Operational and Interoperability Chains provide a means for comparison of the data available in both chains. Recorded data in the Operational Chain is readily available and can be compared with data recorded in the Interoperability Chain in order to characterize the improvements in accuracy, precision, and timeliness that can be achieved using flight object based information exchange.

Supporting Infrastructure

The ICATS Supporting Infrastructure includes a set of hardware and software components that integrate separate regional SWIM implementations in the EU and the US. At the start of the project we recognized that such integration would need to allow for different regional SWIM implementations in the EU and US. The key to achieving interoperability between heterogeneous regional SWIM implementations was use of a standardized means for information exchange – specifically, the FIXM Standard which was in its early stages of evolution at the time.

The ICATS Supporting Infrastructure in the ICATS Interoperability Chain, shown in Figure 3 below, implements flight object information exchange using a GFO that was collaboratively defined by the combined EU and US based engineering team. The GFO data model is based on FIXM 1.1, the current version of the FIXM Standard at the time that ICATS engineering work was performed. The GFO combines the FIXM standard for exchange of basic flight plan information with a series of ICATS specific extensions that were developed to implement scope that had not yet been addressed by the FIXM standard but were nonetheless necessary for the successful implementation of ICATS. Of particular significance, the ICATS GFO employs a cross region trajectory data structure that is standardized by means of an ICATS specific extension (since FIXM 1.1 did not address the flight object's 4D trajectory). In practice, the inter-region trajectory is constructed cooperatively by the participating EU and US regions where each region contributes a regional trajectory segment and the segments are integrated by means of well-defined boundary points that link the regional segments. This approach is readily extensible to a larger number of participating regions and does not require multiple regions to have global knowledge of airspace definitions that are normally encapsulated by each participating region.

Management, update, and distribution of GFOs is provided by an I-SWIM layer in the Interoperability Chain that is implemented by means of a distributed network of cooperating I-SWIM nodes that provide callable services for creation, update, and deletion of GFOs. Network interconnectivity between EU Interoperability Chain Systems in the various European facilities and US Interoperability Chain systems deployed in the Florida NextGen Testbed in Daytona was provided by Virtual Private Network (VPN) secured internet connections linking the distributed set of I-SWIM nodes. To match individual regional SWIM implementations to the I-SWIM provided services for GFOs, a regional adapter function is utilized in each region to translate between Regional Flight Object (RFO) and GFO.

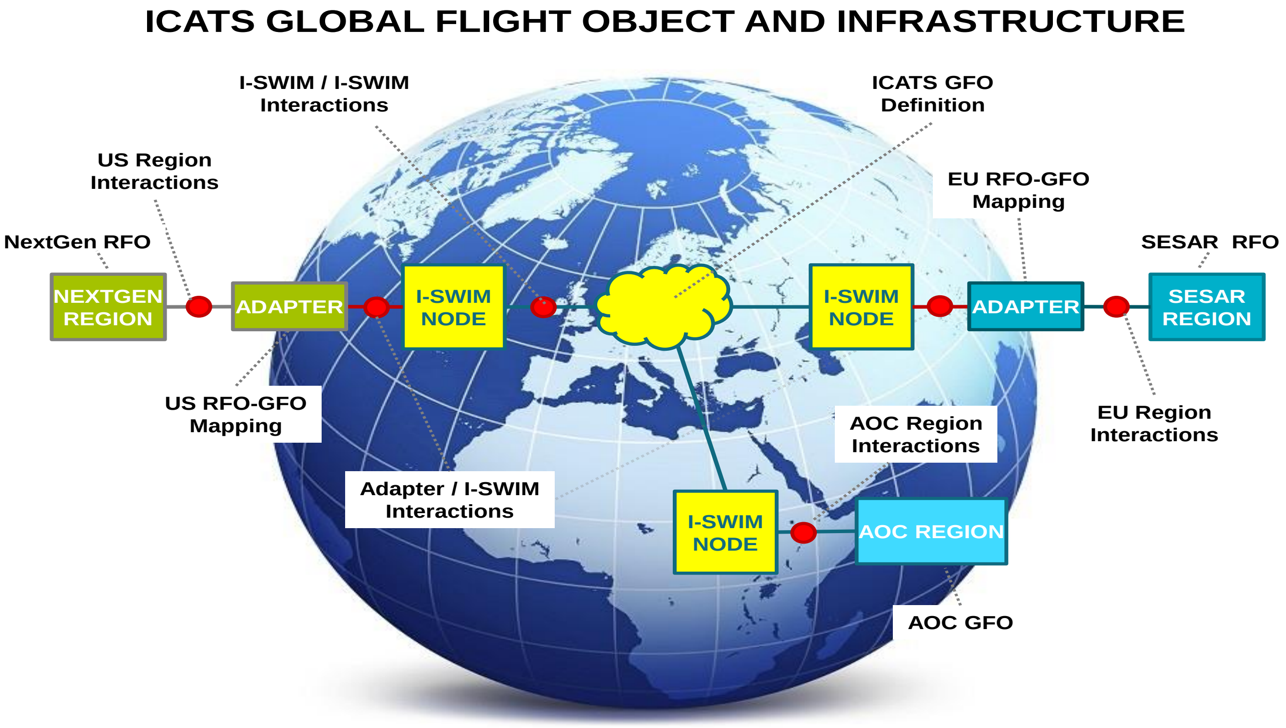


Figure 3 ICATS Global Flight Object and SWIM Infrastructure

The infrastructure incorporates a number of European Organisation for Civil Aviation Equipment (EUROCAE) ED-133 concepts into the basic definition and the approach for management of GFOs including the concepts listed below:

- ***GFO Information Clustering*** – the full GFO structure divides its information content across a series of information clusters for efficiency and to constrain the communication bandwidth needed for update activity.
- ***GFO Manager and Contributor Roles*** – the ED-133 Manager and Contributor roles are defined for the GFO and are dynamically managed for each GFO as the corresponding flight progresses along its trajectory. A simple handoff protocol between regions is used to pass the Manager role between regions when appropriate.
- ***GFO Services*** – the limited set of services was defined to permit update of the GFO by either region. The services combine Publish/Subscribe delivery of updates from the Manager to all stakeholders and Request/Response updates from Contributors to the Manager. All GFO services were defined using Web Services Definition Language (WSDL).

Live Flight Trial Conduct

The live flight trial was conducted over a nine week period between April 8, 2014 and June 7, 2014 consisting of the two exercises and supported by the parallel ground ATC infrastructure. Each exercise had a different scope and set of objectives.

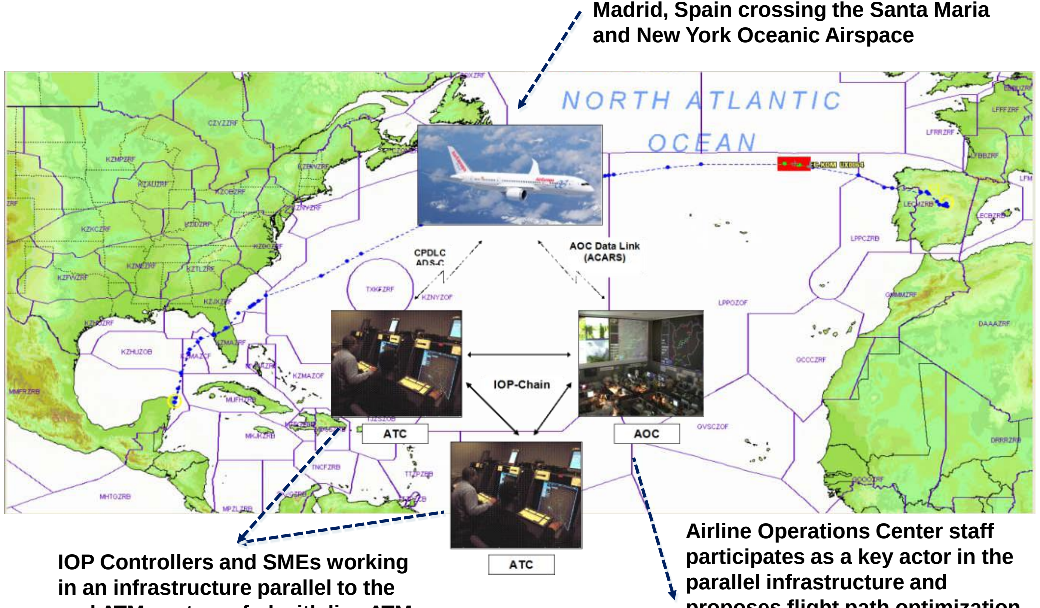
Exercise 1 concentrated on the first four hours of flight, where the possibility of trajectory improvements is most likely to emerge. Due to staff constraints we did not plan sessions of westbound and eastbound flights in the same day and only allowed a maximum of up to four flights to participate in each session. On days that we focused on flight traveling eastbound, from the United States to Europe, the trial was conducted 00:00 – 4:00 UTC while westbound trial days were conducted 14:00-18:00 UTC.

Exercise 2 only analyzed flights traveling eastbound and required data for all phases of flight and therefore was conducted 00:00 – 10:00 UTC when the majority of passenger carriers fly between the United States and Europe.

Successful execution of the trials required active participation from many individuals across multiple organizations. Figure 4 depicts a high level ICATS live flight trial context and the major roles required for trial execution: IOP Controllers and SMEs and Operational Controllers with their respective ATM systems, transatlantic flights and their flight crews, and Air Europa AOC staff serving the following roles:

ICATS TRIALS SCENARIO

Trials using transatlantic traffic from/to Madrid, Spain crossing the Santa Maria and New York Oceanic Airspace



IOP Controllers and SMEs working in an infrastructure parallel to the real ATM systems fed with live ATM data for synchronization

Airline Operations Center staff participates as a key actor in the parallel infrastructure and proposes flight path optimization that may trigger a trajectory change in the real ATM systems

Figure 4 ICATS Live Flight Trial Scenario

- ***IOP Controllers*** in Lisbon and Santa Maria provided by Nav-Portugal. In these locations, the IOP Controllers were able to consult with operational ATC to evaluate the proposed changes in the Interoperability Chain and verbally coordinate proposed changes with Controllers in the Operational Chain.
- ***Subject Matter Experts (SMEs)*** in the Florida NextGen Testbed at Embry Riddle Aeronautical University in Daytona, Florida provided by Lockheed Martin. Here the SME evaluated the

proposed changes in the Interoperability Chain.

- ***Airline Operation Center (AOC) Staff*** provided by Air Europa. The AOC team proposed changes to route, level or speed for evaluation and assessment in the Interoperability Chain by IOP controllers and SMEs. The AOC team also communicated an IOP approved change via ACARS to the Flight Crews for submission to Air Traffic Control using CPDLC.
- ***Flight Crews*** on transatlantic flights provided by Air Europa. Flight Crews on select flights by Air Europa were pre-briefed on the ICATS objectives and the live trial protocol. These Flight Crews were instructed to be ready to request route, level or speed changes to Air Traffic Control when requested by the AOC.
- ***Operational Controllers*** in Madrid, Lisbon, and Santa Maria in Europe and in New York and Miami in the United States. Operational Controllers evaluated route, level or speed amendments from Air Europa Flight Crews as they would any other request from any Flight Crew and provided clearances when operationally appropriate.
- ***Madrid ACC Staff*** located in Madrid, Spain provided by AENA. SYSRED (AENA Unit responsible for maintaining a global overview of the status of Air Navigation Services across the Spanish Air Navigation Network) staff and Flight Data Position staff at the ACC collected system information for analysis.
- ***Engineering Staff*** located in Madrid, Spain and Maryland and Minnesota, United States provided by Indra and Lockheed Martin, respectively. The engineering team was on call to investigate and resolve issues when necessary.

Daily execution of Exercise 1 began with Air Europa identifying the target flights and providing flight dispatching information for each flight. When a flight was airborne, Air Europa AOC staff surveyed the airspace situation and proposed a trajectory change. Figure 5 depicts an example flight optimization as seen by the AOC staff. The blue flight path indicates the original flight plan and the red flight path incorporates the trajectory change to realize an optimization.

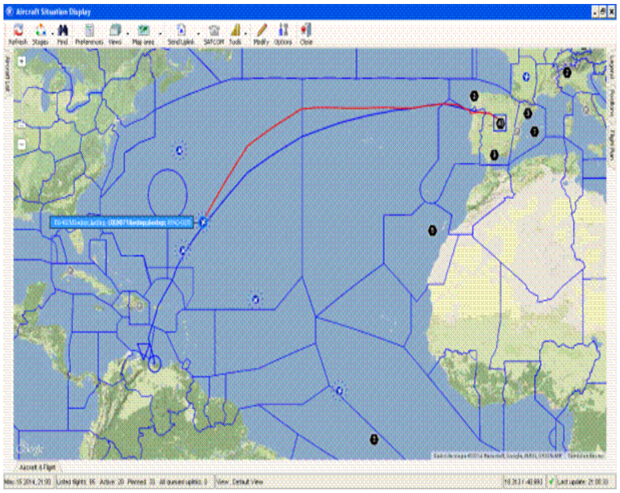


Figure 5 ICATS Flight Path Optimization of AEA071 Madrid - Caracas May 15, 2014

The trajectory change proposed by the airline was evaluated by the affected IOP Controllers (Lisbon and Santa Maria) and SMEs (Florida), and once the change proposal was fully assessed as acceptable and conflict free by all impacted parties, the change was confirmed to the AOC via the IOP chain. The AOC then informed the flight crew via ACARS of the change proposal. To ensure safety, the Flight Crew then formally requested the trajectory change via CPDLC (or voice in the case of the Lisbon ACC) to the controller at the appropriate operational position. The operational controller had the final evaluation and implementation of the proposed change. If the operational controller accepted the change request, the change would be reflected in the Interoperability Chain through the live data feeds to complete the cycle.

Exercise 2 required a reduced level of active involvement by all parties. The exercise required that the IOP systems were kept running with live data feeds include Meteorological (MET) data. At 00:00, 02:00, 04:00, 06:00, 08:00, 10:00 UTC, Madrid ACC personnel downloaded the Air Traffic Service Unit (ATSU) Estimated Entry times for all Eastbound flights, via the ICATS HMI Web. At the same time, the Flight Data and Flow Management personnel of the Madrid ACC captured the flight and Flow data from PIV positions. This data was stored for analysis at a later time by CRIDA.

Additionally, some qualitative analysis was necessary to address objectives 1 and 6. A set of participant questionnaires focused on Pilots, IOP Controllers/SMEs, and Operational Controllers were developed in order to gather additional inputs on the effectiveness of the trial regarding the new system and procedure from the point of view of the various actors. The questionnaires were distributed to the pilots before each flight and completed after the execution of each flight. In the Controllers case, the questionnaires were completed after each day of trials, summarizing the full ICATS day of operations.

Data Analysis and Results

During the nine week trial execution period, 41 flights trials were performed under Exercise 1 (both Westbound and Eastbound). Figure 6 shows the number, origin and destination of the ICATS Target flights and the number of optimized trajectories for ICATS Exercise 1. In some cases, although some optimization was found it was not applied due to technical issues.

A detailed explanation of the ICATS Trajectory Optimization Outcomes above is given in Figure 7.

From those flights with an optimization found and successfully performed a variety of information was provided by the different actors involved in the trials. This accumulated information provided the raw inputs used for subsequent analysis that produced quantitative and qualitative results for the Live Flight Trial.

Airline

- Initial Flight Plan for all flights.
- Flight Operations Quality Assurance (FOQA) data describing the actual flight for most flights.
- Data link communications between the Flight Crew and ATC.
- Completed Questionnaires for pilots.

ANSPs

- Data Link Communications between Flight Crew and ATC and between ATC from different units.
- Completed Questionnaires for IOP Controllers.
- SACTA PIV Estimated HFIR Entry Time for all flights (today information from the Spanish ANSP) entering Spanish Airspace
- ICATS HMI (from the ICATS Server) Estimated HFIR Entry Time for oceanic flights entering Spanish Airspace updated every 2 hours.

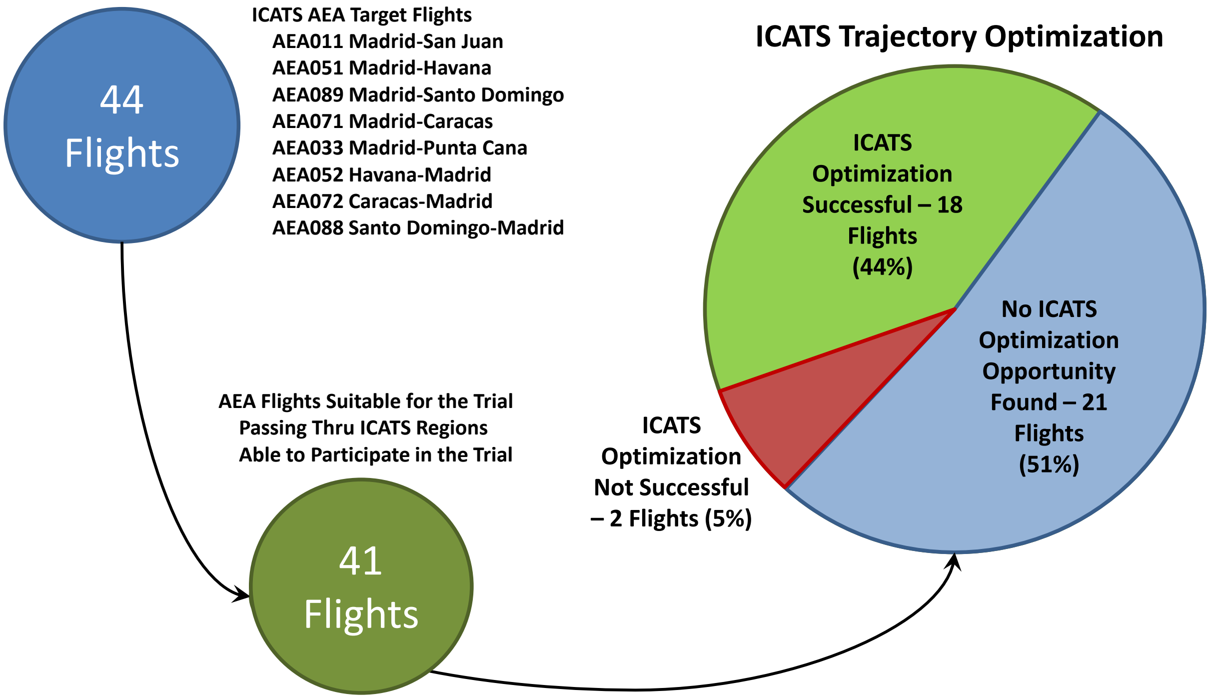


Figure 6 Exercise 1 Flight Path Optimization Results

ICATS Optimization Successful	•What If Proposal Processed by ICATS IOP Chain •What If Accepted in both ICATS Regions (EU &US) •Flight Change Proposal Implemented in the Operational Chain
ICATS Optimization Not Successful	•What If Proposal Processed by ICATS IOP Chain •What If Rejected or Timed Out in at least one ICATS Region (EU or US)
No ICATS Optimization Opportunity Found	•Flight Details (route, level, speed) were examined by the AOC •No opportunity for reduced fuel burn or flight time was identified •No What If Proposal was generated

Figure 7 ICATS Exercise 1 Trajectory Optimization Outcomes

Some months prior to the start of the Live Flight Trial, a baseline scenario was developed to provide a baseline reference for examining the benefits achieved by ICATS for Exercise 1 objectives. The participating airline and the ANSPs routinely measure similar data to that used during the trials using source data such as data link communications logs, Initial Flight Plans, and FOQA data. The baseline scenarios were developed for objectives 3, 4, and 5 using information from more than 15 days of airline/ANSP operations. It was not possible to create a baseline scenario for objective 6 due to the lack of information from current operations. In the case of the Exercise 2, as the information obtained from the ICATS Interoperability Chain was compared directly with the corresponding information from the current Operational Chain, a baseline scenario was not needed.

This information was processed using different tools and techniques, i.e. statistical techniques to process the questionnaires results or FUSA, a Matlab tool, to process the FOQA data. Examining the data collected from the demonstration exercise, the final indicators, metrics and results obtained from its analysis in terms of achievement of the demonstrations are summarized in Table 2.

Table 2 ICATS Live Flight Trial Objectives and Results

Objective ID/KPI	Metric	Measuring Process and Criteria	Expected Benefit	ICATS Results
Objective 1 / Capacity – Hourly Sector Entry Rate (Hourly Entry Rate)	1.1. Estimated (PIV) Sector load per hour - Estimated (PIV compared with ICATS) Sector Load per hour	Source of the reference data and trials data for comparison: ANSP	Improve the accuracy of sector load calculations by 15% of oceanic traffic	The ICATS HMI results provide improved accuracy of sector load calculations that exceeds 15% expectation. This is limited to the cases where ICATS HMI provides better results than the PIV system, which happens only in the 47% of the cases. For those cases, ICATS HMI Data is also more predictable than the PIV data. **Result: Objective partially achieved**
Objective 2 / Capacity – Sector Workload / Occupancy	2.1. Estimated (PIV) Oceanic Traffic per hour - Actual Oceanic Traffic per hour 2.2. Estimated (ICATS) Oceanic Traffic per hour - Actual Oceanic Traffic per hour	Source of the reference data and trials data for comparison: ANSP	Reduction on a 10% of Unexpected sector overload due to Oceanic traffic	ICATS improvement to sector workload / occupancy overload exceeds the 10% expectation. However, this is limited to the cases when ICATS HMI data is better than PIV system, which occurs in 49% of the cases. **Result: Objective partially achieved**

Objective ID/KPI	Metric	Measuring Process and Criteria	Expected Benefit	ICATS Results
Objective 3 / Capacity - Coordination Revision / Rejection.	Two sources of data to analyze: 3.1. Using Questionnaires distributed to Pilots and ATCOs and qualitative analysis of results 3.2. Using the data link communications files from the Airline & ANSP to examine the actual number of rejections against a baseline number of rejections	Source of the reference data and trials data for comparison : ANSP and Pilots	Reduction of at least 5%	Quantitative Analysis: 4.78% improvement to current situation using the baseline scenario. Qualitative Analysis: high and positive impact of ICATS **Result: Objective successfully achieved.**
Objective 4 / Efficiency - Fuel Consumption	Source of the reference data and trials data for comparison: 4.1. Estimated fuel (TRIP) as per the FPL - Actual Fuel (from Take-off to Landing) and FOQA Data (corrected for an +8.5% error observed in the FOQA data)	Source of the reference data and trials data for comparison: Airline Logging of estimated fuel burn from the Operational Flight Plan Logging of the actual fuel burned from the Flight Data Monitoring Calculate the difference	>= 1% of fuel saving	Quantitative Analysis: 1.40% of fuel savings for the optimized flights **Result: Objective successfully achieved**
Objective 5 / Environment - CO2 Emission	The CO_2 emissions are derived from the Estimated / Actual fuel using a conversion factor defined by Eurocontrol: CO_2 = 3,149 Kg per Kg fuel. 5.1. Estimated CO_2 Emissions as per the FPL - Actual CO_2 Emissions as per the corrected FOQA data	This figure is calculated using a conversion factor from the fuel burned.	>= 1% of reduction of CO_2 Emission	Quantitative Result: 1.40% of reduction of CO_2 emission for the optimized flights **Result: Objective successfully achieved**

Objective ID/KPI	Metric	Measuring Process and Criteria	Expected Benefit	ICATS Results
Objective 6 / Safety - Tactical Conflicts	6.1. Qualitative analysis of the questionnaires.	Source of the reference data and trials data for comparison: ANSP	Reduction of at least 10 %	Quantitative Analysis: No means to measure this result. Qualitative Analysis: positive impact of ICATS.
Objective 7 / Predictability – Data Predictability	All the following metrics apply to the 6 calls done (at 00:00, 02:00, 04:00, 06:00, 08:00, 10:00 UTC). 7.1. PIV HFIR (Flight Information Region Entry Time) - Log time 7.2. ICATS HFIR - Log time	ICATS HMI Data is more predictable than the current PIV Data	Improvement in data predictability	The statistical analysis shows that ICATS HMI is slightly more predictable than PIV system in 5 of the 6 queries done (calls). The average improvement for ICATS is about 18 minutes in predictability.
Objective 8 / Predictability – Data Accuracy	Direct comparison of the HFIR data from the current system HMI with the ICATS HMI 8.1. PIV HFIR - Actual HFIR 8.2. ICATS HFIR - Actual HFIR	ICATS HMI Data accuracy is higher than the current PIV Data. This metric should be considered jointly with Objective 7.	Improvement in data accuracy	The statistical analysis shows that ICATS HMI is slightly more accurate than PIV system in 4 of the 6 queries done (calls). The average improvement for ICATS is around 8 minutes in accuracy.

Conclusions

Based on analysis of data from the Live Flight Trials, the main conclusions are the following:

- ***Environment*** - the airlines would obtain an important benefit in terms of fuel savings and reduction of CO2 emissions that would also result in a direct reduction of their operating costs. ICATS flight path optimization produced an estimated average fuel saving of about 1100 kilograms per oceanic flight. This equates to a reduction of CO2 emissions of approximately 3464 kilograms per oceanic flight.
- ***System Capacity*** - the ANSPs increased system capacity is partially proven due to the ICATS system limitations. Considering only the cases when ICATS data is more accurate (closer to the actual data) than the PIV data, the results show a clear benefit by improving the accuracy of the sector load and a reduction of the unexpected variations oceanic traffic workload.
- ***Data Predictability and Accuracy*** - ICATS realized the expected benefit for the cases analyzed. These include cases with a positive predictability and where there was directly comparable

information in both systems (ICATS HMI and current system PIV).

- ***Safety*** - no significant conclusions can be extracted due to the qualitative analysis.
- ***Flight Efficiency*** - there is a positive subjective response from the pilots and most of the controllers who participated in the Live Flight Trial regarding the benefits that ICATS could provide in order to facilitate the users preferred trajectory.
- ***Coordination*** - the analysis of ICATS results shows that the number of trajectory change requests rejected was reduced by improved information sharing. This is linked with the Flexibility of the system, which allows trajectory changes without impacting the rest of the operations.
- ***Interoperability*** - the demonstration and Live Flight Trials have shown that the ATM systems developed by two industrial partners, used by two ANSPs located in different ICAO regions, and providing ATM service to one Airline crossing between those ICAO regions, have been successfully connected, were able to exchange information through IOP Chain infrastructure, and were interoperable.

Further Recommendations

While the results demonstrate that the ICATS project was highly successful in meeting its defined objectives, this type of trial should be extended in several dimensions to progress a number of key NextGen and SES objectives. Some recommendations follow:

Extend the trials to a larger set of Stakeholders – The ICATS capability was designed focusing on the needs of the ICATS project. In doing so flight object Data Exchange capabilities were provided to support interactions between a small number of stakeholders of the EU region, the US region, and the Air Europa AOC. At the same time, the capabilities were designed to ensure that it could be extended to a larger community of stakeholders without a large and expensive level of re-design or new development. It would be interesting to conduct a larger trial that includes additional regions and AOCs. Such an activity would produce a larger cross section of data supporting the user benefits case and would effectively demonstrate that the basic ICATS flight object management and distribution function can be extended to a larger set of participating stakeholders.

Integrate the Airline and ATC via Trajectory Optimization Automation – As ICATS results have shown benefits for the airline, it is worth considering a concept of an integrated Trajectory Optimization tool that makes use of both ATC and AOC provided information and automates identification of Trajectory Optimization opportunities. Such a tool would integrate the basic ATC positional and intent data with information provided by the AOC/airlines (e.g., flight diversion routes, constraints, etc), to optimize operations (e.g., turn around, flight crew). While ICATS has shown that ATC based flight object is of interest to the AOC, information available at AOC may also be of great interest for ATC processing (aircraft actual position, aircraft intent, airline constraints and preferences, etc). Such a Trajectory Optimization tool would help automate the identification of potential flight path, speed, level optimizations for all stakeholders, thus increasing the likelihood that flights would take an optimum path through the airspace.

Involve Traffic Load tools for Predictability Exercise – For ICATS the analysis of improvement in the sector entry/workload was performed by off line calculation using the data captured during the Live Flight Trial. To provide a more automatic and error free process and to manage additional indicators and metrics, the involvement of tools such as Traffic Monitoring System (TMS) is recommended. These tools would be fed with live flight object data to perform the calculations.

Examine Additional Use Cases and Operational Concepts Supported by Flight Object – Other operational Use Cases that can benefit from the use of the flight object as a key enabling technology should be explored, such as Extended Sequencing from the last part of En Route Oceanic phase, Improvements to current coordination/information mechanisms, etc.

Incorporate Metering into the System and Demonstration – A major focus of ICATS was the delivery of user benefit through optimization of flight path. The project concentrated mainly on optimization in Domestic and Oceanic airspace and did not consider the impact that metering constraints at the point of arrival may have on optimizations performed while En-Route. Future trials should incorporate knowledge of metering constraints into the optimization process. Ideally, a goal of En-Route optimization should be to ensure smooth traffic flows all the way to the destination airport and that necessarily will include knowledge and consideration of metering adjustments to the flight path.

About the Authors

Scott Landriau is a Certified System Architect with Lockheed Martin in Rockville, Maryland and has over 25 years of experience designing and deploying ATM solutions both in the US and in Europe.

Lee Weinstein is a Chief Engineer with Lockheed Martin in Rockville, Maryland and has over 9 years of experience designing, developing, testing and deploying ATM solutions in the US.

Jose Manuel Asensio, a Telecommunications engineer and Project Manager with Indra in Madrid, has worked since the mid-1980s in project/technical management for ATM systems in Europe.

Amalia Garcia Alonso is a Senior R&D Engineer with CRIDA, A.I.E. in Madrid. She has over 9 years of experience working in Spanish and European projects related to the future ATM Concepts Validation.

Andrea Villa is a R&D junior engineer and PhD student at CRIDA, A.I.E. She has participated in AENA and European Framework Program projects mainly related to airspace