Final Project Report

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Abstract

The SESAR 09.01 'Airborne Initial 4D Trajectory Management' project was an enabling project to the overall 'Initial 4D Trajectory Management' concept and operations by providing the airborne contribution with following maturity objectives: V2 (feasibility) from a regional perspective and V3 (pre-industrial development and integration) from a mainline perspective.

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This deliverable consists of SJU foreground.

Acronyms

Acronym	Definition
ADS-B	Automatic Dependent Surveillance - Broadcast
ADS-C	Automatic Dependent Surveillance - Contract
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
ATS	Air Traffic Services
ATSU	Air Traffic Service Unit
ARINC	Aeronautical Radio, Incorporated
A/C	Aircraft
CLS	Control Loading System
CPDLC	Controller Pilot Data Link Communication
CTA	Controlled Time of Arrival
CTO	Controlled Time Over
DLSG	Data Link Steering Group
ED	EUROCAE Document
EUROCAE	European Organisation for Civil Aviation Equipment
FANS	Future Air Navigation System
FMS	Flight Management System
FOC	Flight Operations Centre
ICAO	International Civil Aviation Organization
INTEROP	Interoperability
MASPS	Minimum Aviation System Performance Standards
NEAN	Northern European ADS-C Network
NM	Network Manager

NUP 2+	NEAN Update Programme 2+
OSED	Operational Service and Environment Definition
PCP	Pilot Common Project
RTA	Required Time of Arrival
RTCA	Radio Technical Commission for Aeronautics
SC	Special Committee
SESAR	Single European Sky ATM Research
SPR	Safety and Performance Requirements
TMA	Terminal Manoeuvring Area
VLD	Very Large scale Demonstration
WG	Working Group
4D	4 Dimensions
4DTRAD	4-Dimensional Trajectory Data link

1 Project Overview

The SESAR 09.01 'Airborne Initial 4D Trajectory Management' (also called 'i4D' for Initial 4 Dimension) project aimed to define, prototype, verify and validate the airborne part of the overall '4D Trajectory Management' concept and operations.

The airborne definition corresponding to the 'Initial 4D Trajectory Management' concept and operations can be defined through two sub-functionalities:

1) The sharing and synchronization of air and ground trajectories (enhanced datalink communication capabilities) in order to enable more efficient handling and certainty of the flight profiles.

2) The use of a time constraint (enhanced navigation capabilities) in order to enhance the management of aircraft sequences by the air traffic controllers.

The SESAR 09.01 objectives were to consolidate, on aircraft side, requirements needed for the management of a time constraint; to demonstrate navigation performance (time guidance accuracy and robustness to meteorological uncertainties); to consolidate the data downlinked by the aircraft that are required by the ground tools; to evaluate the accuracy of the FMS (Flight Management System) and ground 4D trajectories over time in collaboration with operational projects; and to evaluate pilots' acceptability of the i4D cockpit operations,

The SESAR 09.01 project was composed of following members: Airbus and Leonardo (formerly known as Alenia Aermacchi) as aircraft manufacturers for the aircraft definition, integration and validation; Honeywell and Thales as equipment manufacturers for the development and verification of avionics prototypes; and EUROCONTROL for the ATM expertise. In addition, all partners contributed to the overall concept definition and provided their expertise in the area of trajectory management.

In addition, the 'Airborne Initial 4D Trajectory Management' project was an enabling project and was conducted in close collaboration with related operational projects (e.g. SESAR 04.03 'Integrated and Pre-operational Validation & Cross Validation' and SESAR 05.06.01 'Ground and Airborne Capabilities to Implement Sequence' projects).

1.1 Project progress and contribution to the Master Plan

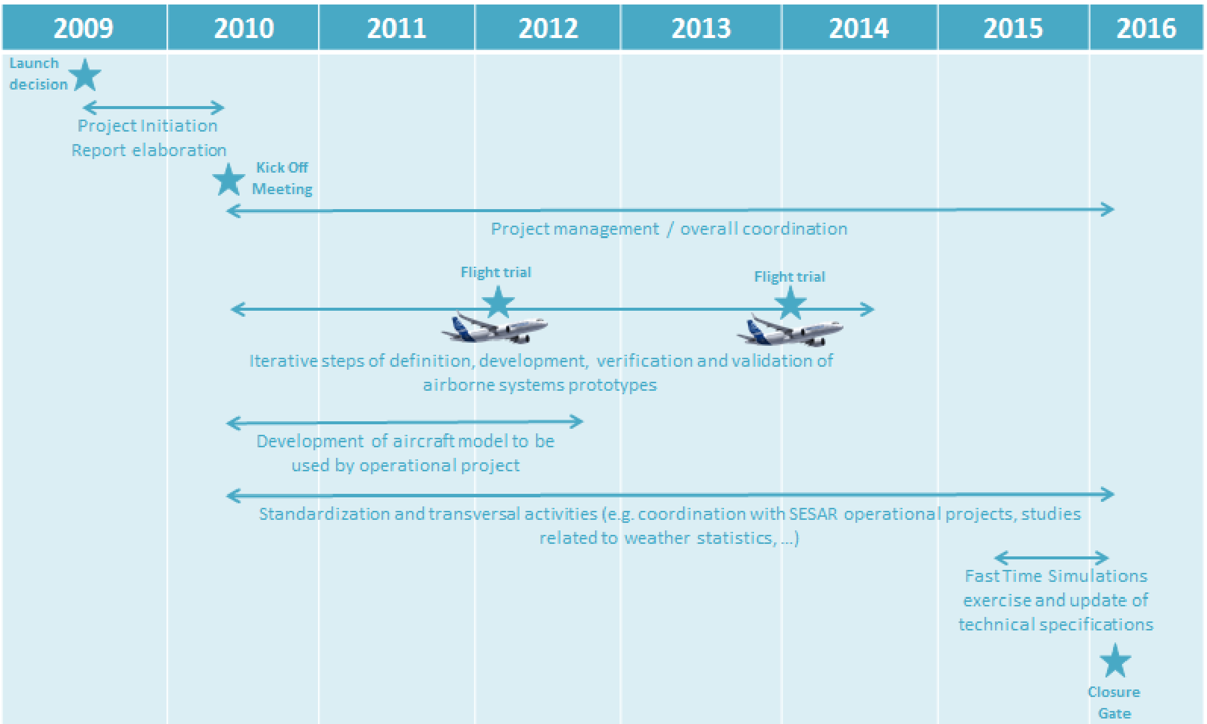
In order to meet the objectives of this 'Airborne Initial 4D Trajectory Management' project, a stepped approach has been considered in order to efficiently progress on the clarification of the concept. Indeed, iterative sessions have been considered as the most appropriate technique to assess the feasibility and acceptability of the different elements of the concept building in complexity and focus.

This stepped approach has been composed of two cycles of simulations and two flight trials and has been closely coordinated with relevant SESAR operational projects with the objective to mature the definition of the airborne function for both mainline and regional aircraft (including coordination with rotorcraft and military aircraft SESAR projects for the elaboration of consolidated airborne specifications of 'Initial 4D Trajectory Management' function) through following activities: mock-up integration in research simulator for both mainline and regional aircraft; development, verification and integration of airborne systems prototypes for both mainline and regional aircraft; verification and integration of the airborne systems prototypes and ground simulators in order to make sure that they are interoperable for both mainline and regional aircraft; validation by pilots and controllers using cockpit simulators coupled with ground simulators with relevant operational projects for both mainline and regional aircraft; and flight tests with relevant operational projects for mainline aircraft.

In addition, it was key to ensure the good integration between Initial 4D function and other aircraft functionalities with common FMS areas (e.g. computation of vertical and speed profiles). For this purpose, studies have been performed for integration between Initial 4D and Continuous Descent Approach (CDA); and integration between Initial 4D and "at" and "at or above" speed constraints (i.e. constraint requested "at" or "at or above" a defined speed).

In parallel, following transversal activities have been performed: elaboration of one fast time simulation and several studies related to weather statistics, CTA spacing analysis …; and participation to standardisation working groups providing them with technical inputs on the overall concept. These activities have allowed contribution to feasibility and benefits assessment, contribution to the release of standardisation documents and elaboration of recommendations for future work related to the Airborne Initial 4D Trajectory Management.

In addition, SESAR 09.01 prototypes have been used in the SESAR PEGASE (Providing Effective Ground and Air data Sharing via EPP (Extended Projected Profile)) project in order to assess the potential usage of aircraft predicted trajectory (EPP) information by ATC centres thanks to Airbus delivery flights equipped with SESAR 09.01 prototypes.



The SESAR 09.01 project contributed as an enabling project to support SESAR Solution #06 Controlled Time of Arrival (CTA) in medium density / medium complexity environment (part of 'Advanced Air Traffic Services') and is aligned with the Integrated Roadmap Dataset 15 (ref. [4]).

Aircraft (A/C) enablers code	Name	Project contribution	Maturity at project start	Maturity at project end
A/C-11	Flight management and guidance for improved single time constraint achievement (Controlled Time of Arrival /	Consolidation of requirements needed for the management of a time constraint (including coordination with rotorcraft and military projects linked	Middle of V2(*) / TRL2	V3 / TRL6 for mainline aircraft

	Controlled Time Over)	the Initial 4D concept). Development of pre-industrial prototypes (FMS, ATSU, and EIS) and integration in flight simulators. Demonstration of navigation performance (time guidance accuracy and robustness to meteorological uncertainties) in a relevant end-to-end environment, i.e. simulator sessions (including coupled ones with ATC centres) and flight trials. Contribution to standardization working groups related to the time constraint.		V2 / TRL4 for regional aircraft
A/C-31a (**)	Data link communication exchange for ATN (Aeronautical Telecommunication Network) baseline 2 (FANS 3/C)	Consolidation of requirements needed for the data link exchanges between the aircraft and the ATC centres in order to share and synchronize air and ground trajectories.		
A/C-37a (**)	Downlink of trajectory data according to contract terms	Development of pre-industrial prototypes (FMS and ATSU) and integration in flight simulators. Evaluation of trajectory data accuracy. Contribution to standardisation working groups related to ATN Baseline 2.		

(*) The maturity at project start was considered in the middle of phase V2 because Initial 4D operational concept and OSED (Operational Service and Environment Definition) was provided by previous projects (CASSIS, 4DTRAD, NUP2+, Episode 3, TMA 2010+ and PETAL 3) and standardisation working groups; validation activities were performed at navigation performance level (CASSIS, NUP 2+) at ATC operational level (Episode 3, TMA 2010+), at ground tool level (Episode 3), and at airborne level (Episode 3); a first level of aircraft and system specification was available through SPR/Interop from standardisation working groups (EUROCAE/RTCA SC-214/WG-78): and partial benefit analysis was performed (EUROCONTROL / Airbus fast time study).

(**) In the scope of SESAR 09.01 project, the data link communication has been considered as the package that includes CPDLC (Controller Pilot Data Link Communication) and ADS-C (Automatic Dependent Surveillance-Contract). As the consequence, the enablers A/C-31a 'data link communication exchange for ATN baseline 2 (FANS 3/C)' and A/C-37a 'downlink of trajectory data according to contract terms' have been merged together in the table here below (as considered together during all SESAR 09.01 activities).

1.2 Project achievements

The SESAR 09.01 'Airborne Initial 4D Trajectory Management' project has allowed having:

From mainline aircraft perspective: early coordination with ATC / ANSP (Air Navigation Service Provider) to define air/ground data exchange protocol; definition and development of an aircraft function on real systems prototypes: 2 FMS (Flight Management System), 1 ATSU (Air Traffic Service Unit) and 1 EIS (Electronic Instrument System); validation of the aircraft function through use of 4 types of simulation means (simulator, simulator connected to TMA (Terminal Manoeuvring Area) and En-Route ATC centres, Airbus tests aircraft, and aircraft models provided to ANSP partners for mixed fleet tests) with successful technical results and a function validated and operationally accepted on-board (*), and end-to-end operational evaluations performed with relevant operational projects; maturation of requirements (including compatibility with other airborne functions).

(*) From a technical point of view, new functionalities have been defined at airborne level in order to match with operational requirements and needs with a limited impact on avionics (i.e. software modifications only): possibility to define a time constraint with an accuracy of +/- 10 seconds (up to now, only +/- 30 seconds of accuracy was available); definition of a new algorithm to meet the time constraint with reliability and robustness to meteorological uncertainties; implementation and downlink of a temporal window (also called ETAmin/max) in order to define a time constraint that is achievable by the aircraft; and automatic downlink of the aircraft capabilities and intention / predictions through ADS-C Extended Projected Profile (EPP).

Regarding the integration between Initial 4D and other aircraft functionalities with common FMS areas, following achievements have been reached: regarding i4D and CDA, a new guidance mode has been defined in order to optimize flight along a pre-defined vertical and speed profile that includes a time constraint; regarding i4D and "at" speed constraints, definition of a design considering these types of constraints (not implemented in FMS today) has been done in terms of display and guidance (priority rules, acceptable number of speed adjustment, …) with a minimum impact at cockpit level. Note that time performance with "at" speed constraints may not be achievable in some cases, further work is necessary to determine in which case and to which extend both concept can be mixed. It has to be noted that “at” and “at or above” speed constraints were first defined in the ED-75D and the next supplement of ARINC 702A is expected to be more detailed in the way to manage and integrate these speed constraints in a homogeneous way between all aircraft and FMS manufacturers.

From regional aircraft perspective: definition of the applicable datalink and navigation requirements at regional aircraft level for supporting the i4D requirements; definition and development of necessary regional flight simulator and ATC simulator modification for supporting the i4D requirements and for allowing the final tests. For what concerns the regional flight simulator itself, the algorithms for controlling the CLS (Control Loading System) have been improved and the autopilot system tested and trimmed for having the expected behaviours. For what concerns the ATC simulator, the CPDLC and ADS-C messages were managed by a simulated ATC developed by Leonardo (formerly known as Alenia Aermacchi) and integrated with the regional flight simulator; final tests successfully executed as per plan and associated verification and validation scenarios.

The verification and validation activities have demonstrated associated navigation and datalink performance. In particular, the flight trials have allowed demonstrating the technical feasibility of the Initial 4D Trajectory Management concept with very high degree of conditions and environment representativeness (except on future traffic representation) and contributing to the overall operational acceptability. Indeed, it was possible to connect the systems air/ground as intended, all time constraints have been achieved within +/- 10 seconds, airborne data availability on ground has been considered essential during the different flight trials, and both controllers and pilots provided positive feedbacks.

1.3 Project Deliverables

The following table presents the relevant deliverables that have been produced by the project.

Reference	Title	Description
D13	Technical verification and validation report - regional aircraft	This deliverable contains a synthesis of all the V&V tests and results, as well as conclusions and recommendations regarding the maturity of 'Initial 4D Trajectory Management' regional aircraft function.

D52	Yearly synthesis of standardization contribution 2015	This deliverable contains the sum up of standardization activities performed by project members for the following standardization subgroups: RTCA (Radio Technical Commission for Aeronautics) SC-214 / EUROCAE (European Organisation for Civil Aviation Equipment) WG-78 'Advanced Data Communications Baseline 2 Standards' group, EUROCAE WG-85 '4D Navigation' group, and ARINC (Aeronautical Radio, Incorporated) 702A updates.
D53	New overall step C validation report (flight trial and coupled simulations) - mainline aircraft	This deliverable presents the results of validation exercises jointly done by 'Airborne Initial 4D Trajectory Management' project and relevant operational projects. This document covers internal Airbus and coupled simulation sessions with EUROCONTROL MUAC and the second i4D flight trial in co-operation also with NORACON.
D56	Fast simulation report	This deliverable is the report for the CTA Fast Time Simulations done by EUROCONTROL. This FTS investigates the application of RTA to a real sequence of arriving aircraft into Stockholm Arlanda airport. Assuming that the actual arrival times were CTAs assigned to each aircraft, the study examines if the airborne RTA solution would work and investigates potential benefits.
D57	Aircraft and system performance and functional requirements	This deliverable provides the definition of aircraft and system performance and functional requirements related to the airborne Initial 4D Trajectory Management. This captures the on-board operational needs and requirements, and provides the main assumptions taken by the airborne side. In addition, the traceability between airborne requirements and 05.06.01 OSED and SPR (Safety and Performance Requirements) (ref.[43]) is provided in this document.
D58	Interface requirements between the aircraft and the ATC systems	This deliverable specifies the set of datalink messages (ADS-C and CPDLC) that are implemented on aircraft to cope with the needs expressed by relevant operational projects and that defines the interoperability requirements to be met by the airborne and ground systems to support Initial 4D Trajectory Management operations. In addition, the traceability between airborne requirements and 05.06.01 INTEROP interoperability) (ref.[44]) is provided in this document.

1.4 Contribution to Standardisation

From an ATM perspective, standardisation is a key element to ensure global interoperability by maintaining consistency with development and implementation of the concepts developed in SESAR. The 'Airborne Initial 4D Trajectory Management' project kept a close relationship with standardisation activities in order to:

- To ensure prototypes definition remain compliant with latest (intermediate) standardization versions,

- To provide standardization groups with relevant studies (weather statistics, CTA spacing analysis …) and with relevant SESAR validation results in order to improve maturity of the requirements,

- To ensure also that the standardization progress are in line between each other (e.g. to contribute to coordination paper between SC-227 / WG-85 and SC-214 / WG-78 regarding the ADS-C frame containing FMS predictions),

With the following standardisation working groups:

RTCA SC-227 / EUROCAE WG-85 "4D Navigation / Standards of Navigation Performance": this document includes the navigation requirements related to the CTA Controlled Time of Arrival (also called TOAC, Time Of Arrival Control) to be applied in order to ensure that the system and each subsystem will perform its intended function satisfactorily under conditions normally encountered in aeronautical operations.

ICAO (International Civil Aviation Organization) DLSG (Data Link Steering Group) / ICAO 9694 Part III 'Manual of Air Traffic Services Data Link Applications' related to ADS-C application and RTCA SC-214 / EUROCAE WG-78 'Advanced Data Communications Baseline 2 Standards': the current datalink standards and implementations (i.e. ED-110/ED-122 / FANS1/A(+) deployed in many remote/oceanic areas and ED-110/ED-120 / FANS 2/B(+) being deployed in Europe) are not interoperable and require dual implementation to support both environments (costly, different procedures, no seamless operational transition …). The global objective of these standardization groups is to ensure operational and technical convergence (global harmonization of datalink procedures) and to cover all flight phases (airport, terminal, en-route) and airspace types (domestic, remote/oceanic). In particular, the 4DTRAD (4-Dimensional Trajectory Data link) service supports the datalink capabilities linked to '4D Trajectory Management' concept (air-ground synchronisation, RTA and speed schedule clearance, 4D route revision, clearance request, 4D trajectory intent conformance monitoring)

ARINC 702A 'Advanced Flight Management Computer System': this supplement introduces winds temperature data definitions to ARINC Characteristics 702A.

You will find here below the latest status of the standards defined through the standardisation groups defined here above and related to the 'Airborne Initial 4D Trajectory Management' project (here below are listed the European standardization documents only):

ED-75D 'MASPS (Minimum Aviation System Performance Standards): Required Navigation Performance for Area Navigation': this document has been approved by the Council of EUROCAE on 29 October 2014.

ED-228 / ED-229 'Safety, Performance and Interoperability Requirements Standard for Baseline 2 ATS (Air Traffic Services) Data Communications': these documents have been approved by the Council of EUROCAE on 18 March 2016. In addition, these documents will be considered as the official baseline for PCP (Pilot Common Project) AF6 (ATM Functionality) 'Initial Trajectory Information Sharing'.

ARINC 702A Supplement 4: this document has been published by ARINC Industry Activities on 15 December 2014. Note that a Supplement 5 is currently in progress in order to be fully aligned with navigation and datalink RTCA/EUROCAE standards.

Note all these released documents are in line with 09.01 outcomes.

1.5 Project Conclusion and Recommendations

As a conclusion, the SESAR 09.01 project has developed the airborne contribution of the Initial 4D Trajectory Management concept and operations. Maturity objective has been reached:

From a regional viewpoint, technical feasibility has been assessed with successful tests on flight simulator (that included validation of the technical objectives and assessment of the operational acceptability of i4D procedures and functions).

From a mainline viewpoint, technical feasibility, pre-industrial development and integration have been validated and considered as operationally acceptable. Moreover, mainline definition is considered being ready for transition to the industrialisation and deployment phase.

Thanks to maturity acquired during SESAR 09.01 project, some members have launched industrial development process that will allow to support the SESAR 2020 Very Large scale Demonstrations and PCP AF#6 'Initial Trajectory Information Sharing' (refer to recommendations here below).

Moreover, the standardisation documents related to the Airborne Initial 4D Trajectory Management concept have been released (and in line with SESAR 09.01 outcomes).

In addition, SESAR 09.01 project has been a key enabler for the assessment and validation activities performed by several operational projects and for the definition of PCP AF#6 Initial Trajectory Information Sharing.

Recommendations for future work are outline here below:

From a regional viewpoint, additional activities (additional scenarios with different temperature and wind profiles, other types of constraints, … in a fully simulated environment and, potentially, assessment of new display features for a better awareness in the cockpit) should be considered before industrialisation of the function.

The CTA concept should be further tuned in high density / complexity environment. Based on Fast Time Simulations performed in the scope of SESAR 09.01 project (ref.[40]), preconditioning of traffic using ATC support tools, traditional vectoring or alternative path control techniques would be required to accommodate additional delay and to resolve conflicts for dense traffic scenarios.

Finally, the integration of downlinked trajectory data into ATC / FOC (Flight Operations Centre) / NM (Network Manager) systems should be further investigated, matured and closely followed in SESAR 2020 projects on the way towards deployment (PCP AF#6 'Initial Trajectory Information Sharing').

The SESAR 09.01 'Airborne Initial 4D Trajectory Management' project activities, conclusions and recommendations should contribute and be taken into account for the SESAR 2020 projects focused on Controlled Time of Arrival (CTA) concept and integration of downlinked trajectory data into ground systems and for the Pilot Common Project AF6 (ATM (Air Traffic Management) Functionality) 'Initial Trajectory Information Sharing'.

Note that the conclusions and recommendations provided here above are limited to the airborne viewpoint only. Additional conclusions and recommendations should be identified at the concept level (i.e. not only from an airborne perspective) and should be provided in Final Project Reports of relevant operational projects.

2 References

[1] SESAR Programme Management Plan, Edition 03.00.01

[2] European ATM Master Plan

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[7] SESAR 09.01 project, Technical Verification & Validation Plan - Mainline Aircraft - step 1 (WA2.1), D03, 04 December 2010

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[16] SESAR 09.01 project, Technical Verification & Validation Scenarios - Regional Aircraft Issue 1 (WA2.2), D12, 30 October 2012

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[21] SESAR 09.01 project, Delivery form and description of Aircraft behaviour model - Mainline Aircraft - step 1 (WA2.1), D16, 17 November 2011

[22] SESAR 09.01 project, Integration simulator delivery form - Mainline Aircraft - step 1 (WA2.1), D19, 22 November 2011

[23] SESAR 09.01 project, Technical Verification & Validation report of integration simulator and flight tests - Mainline Aircraft - step 1 (WA2.1), D20, 30 January 2012

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[27] SESAR 09.01 project, Preliminary studies Report - Regional Aircraft - Issue 01 (WA2.2), D25, 30 March 2011

[28] SESAR 09.01 project, Specifications report - Regional aircraft (WA2.2), D26, 25 March 2013

[29] SESAR 09.01 project, Preliminary Technical Verification & Validation Report - Regional aircraft (WA2.2), D27, 08 October 2013

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[31] SESAR 09.01 project, Technical Verification & Validation Scenarios - Regional Aircraft Issue 02 (WA2.2), D47, 08 November 2013

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[36] SESAR 09.01 project, Yearly synthesis of standardisation contributions 2015 (WA1), D52, 28 April 2015

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[44] SESAR 05.06.01 project, Deliverable Step 1 - fully validated INTEROP, D85, 15 July 2016

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