Ref. Ares(2017)4852899 - 04/10/2017

ACASIAS

Requirements and Specification Document

WP1

J. Verpoorte
September 22, 2017
Version 0.44

Grant Agreement number:	723167
Project acronym:	ACASIAS
Project title:	Advanced Concepts for Aero-Structures with Integrated Antennas and Sensors
Funding scheme:	RIA
Start date of the project:	01/06/2017
Duration:	36 months
Project coordinator (organisation):	Harmen Schippers (NLR)
Phone:	0031 (0)88-5114635
E-mail:	Harmen.Schippers@nlr.nl
Project website address:	www.acasias-project.eu

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723167

DOCUMENT INFORMATION

Document Name	Requirements and Specification Document
Version	0.44
Version Date	September 22, 2017
Author	J. Verpoorte (NLR) WP1 members (see list below)
Security	PU (with classified annex)

APPROVALS

	Name	Company	Date	Visa
Coordinator	H. Schippers	NLR	22-9-2017	
WP1 Leader	J. Verpoorte	NLR	22/9/2017	
Task Leader	Z. Řezníček	Evektor	22.9.2017	
Task Leader	M. Müller	NLR	22-09-2017	

DOCUMENTS HISTORY

Version	**Date**	**Modification**	**Authors**
0.1	19-06-2017	Initial draft version	J. Verpoorte
0.11	21-06-2017	Added GPS antenna in some sections	J. Verpoorte
0.12	23-06-2017	Added RF characteristics and requirements in chapter 2	J. Verpoorte
0.13	25-06-2017	Added requirements for winglet antenna from Evektor/VZLU in chapter 1 and 2.	J. Verpoorte
0.14	29-06-2017	Section2 1.2 and 2.4 updated with information of Evektor and NLR	J. Verpoorte
0.15	29-06-2017	Section 1.4 and 1.5 updated with inputs of Evektor and Fokker	J. Verpoorte
0.16	07-07-2017	Table of Contents "repaired". Chapter 1 "Introduction" added Environmental requirements moved from Chapter 2 (RF req.) to Chapter 6 (environ. req.).	J. Verpoorte
0.17	12-07-2017	Sections 2.3, 4.2.2 and 4.3 updated based on input from DLR.	J. Verpoorte

Version	Date	Modification	Authors
0.18	12-07-2017	Sections 2.3, 3.3.6, 4.2.3 and 4.3 updated based on input from Invent.	J. Verpoorte
0.19	13-07-2017	Updated based on input from NLR (sections 2.2, 4.3 and 5.2.2)	J. Verpoorte
0.20	14-07-2017	Section 2.6 updated by CIMNE	X. Martinez
0.21	17-07-2017	Section 2.4 and 5.2.1 updated based on input of Invent	J. Verpoorte
0.22	18-07-2017	Added boundary conditions for acoustic panel based on input from DLR	J. Verpoorte
0.23	21-07-2017	Section 5 (Criteria for assessment) updated	J. Verpoorte
0.24	25-07-2017	Section 2.4 (winglet antenna) updated by Evektor	J. Verpoorte
0.25	26-07-2017	Section 2.5 updated by FAE Section 5.2.1 updated by NLR	A.J. de Graaff M. Müller
0.26	27-07-2017	Section 3.5 (link budget) updated by NLR	J. Verpoorte
0.27	28-07-2017	Section 4 and 6 updated by Evektor	J. Verpoorte
0.28	28-07-2017	Update of section 5 layout	J. Verpoorte
0.29	02-08-2017	Feedback of FAE, FE and IMST	J. Verpoorte
0.30	02-08-2017	Section 4 and 6 updated by Evektor	Řezníček Zdeněk
0.31	04-08-2017	Feedback of FAE and NLR incorporated	J. Verpoorte
0.32	09-08-2017	Feedback of Evektor (P. Tobola) incorporated	J. Verpoorte
0.33	09-08-2017	General editing	J. Verpoorte
0.34	14-08-2017	Feedback of Evektor (P. Tobola) incorporated	J. Verpoorte
0.35	14-08-2017	Editing of some WP2 and WP5 sections.	J. Verpoorte
0.36	21-08-2017	Feedback of Evektor on Maintencance included.	J. Verpoorte
0.37	22-08-2017	Feedback of DLR included.	J. Verpoorte
0.38	25-08-2017	Feedback of Evektor included. General editing.	J. Verpoorte

Version	Date	Modification	Authors
0.39	28-08-2017	Feedback of DLR and Evektor included.	J. Verpoorte
0.40	01-09-2017	Feedback of Evektor (ZR/PT) included.	J. Verpoorte
0.41	04-09-2017	Feedback of Evektor (PT) included.	J. Verpoorte
0.42	18-09-2017	Creation of classified annex (data taken from sections 2.3, 2.4 and 2.5)	J. Verpoorte
0.43	19-09-2017	Update of classified annex (data taken from sections 2.3, 2.4, 2.5 and 4.2.1)	J. Verpoorte
0.44	22-09-2017	Small corrections	J. Verpoorte

LIST OF AUTHORS

Full name	Organisation
Xavier Martínez	CIMNE
Stephan Algermissen	DLR
Řezníček Zdeněk	Evektor
Pavel Tobola	Evektor
Bas Veldman	Fokker Aerostructures
Arent-Jan de Graaf	Fokker Aerostructures
Charly Heuts	Fokker ELMO
Rens Baggen	IMST
Stefan Steeger	Invent
Jaco Verpoorte	NLR
Marcelo Müller	NLR

DISTRIBUTION LIST

Full Name or Group	Organisation
All partners	

CONTENTS

ACRONYMS AND ABBREVIATIONS

Acronym	Meaning
A/C	Aircraft
AC	Advisory Circular
ACARS	Aircraft Communications Addressing and Reporting System
ADL	Aeronautical Data Link
AES	Aeronautical Earth Stations
AFP	Automated Fibre Placement
AIR	Aerospace Information Report
AM	Amplitude Modulation
AMC	Acceptable Means of Compliance
AMS	Aerospace Material Specification
APSK	Amplitude and Phase Shift Keying
ARINC	Aeronautical Radio, INCorporated
ARP	Aerospace Recommended Practice
ASAC	Active Structural Acoustic Control
ATC	Air Traffic Control
AWGN	Additive White Gaussian Noise
BNC	Bayonet Neill–Concelman Connector
BPSK	Binary Phase Shift Keying
BSS	Broadcasting Satellite Service
BVID	Barely Visible Impact Damage
C/N	Carrier-to-Noise ratio
CACRC	Commercial Aircraft Composite Repair Committee
CAD	Computer Aided Design
CbB	Connexion by Boeing
CDMA	Code Division Multiple Access
CFD	Computational Fluid Dynamics
CFRP	Carbon Fibre Reinforced Plastic
CMA	Common Mode Analysis
CMH	Composite Materials Handbook
CMOS	Complementary Metal-Oxide-Semiconductor
CMR	Certificate of Maintenance Review
CRFP	Carbon Fibre Reinforced Plastic
CRI	Certification Review Item
CROR	Contra-Rotating Open Rotor
CRS	Certificate of Release to Service
CS	Certification Specifications
CSMA	Carrier-Sense Multiple Access
dBd	dB (with reference to the dipole radiation)
dBi	dB (with reference to the isotropic source)
dBm	dB (with reference to the power of 1 mW)
dBW	dB (with reference to the power of 1 W)
DC	Direct Current
DLL	Design Limit Load
DO	Document

Acronym	Meaning
DSB	Double Side Band
DUL	Design Ultimate Load
DVB	Digital Video Broadcast
DVB-S2	Digital Video Broadcasting Over Satellite 2
EASA	European Aviation Safety Agency
Eb	Energy per bit
ED	EUROCAE Document
EIRP	Equivalent Isotropically Radiated Power
EM	Electromagnetic
EMC	Electromagnetic Compatibility
EN	European Norm
ERP	Effective Radiated Power
ETSI	European Telecommunications Standards Institute
ETSO	European Technical Standard Order
EUROCAE	European Organisation for Civil Aviation Equipment
EUTELSAT	European Telecommunications Satellite Organization
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FEM	Finite Element Model
FH	Fuselage Height
FML	Fibre Metal Laminate
FR	Fuselage Curvature
FS	Fuselage Station
FSS	Fixed Satellite Service
FW	Fuselage Width
G/T	Figure of Merit (in dB/K)
GA	Grant Agreement
GFRP	Glass Fibre Reinforced Plastic
GFSK	Gaussian Frequency Shift Keying
GLARE	Glass Laminate Aluminium Reinforced Epoxy
GNSS	Global Navigation Satellite Service
GPS	Global Positioning System
I0	Interferer spectrum density
ICAO	International Civil Aviation Organization
IDAL	Item Development Assurance Level
IM	Intermediate Modulus
ITU	International Telecommunication Union
LL	Limit Load
LNA	Low-Noise Amplifier
LOV	Limit Of Validity
LSP	Lightning Strike Protection
MOPS	Minimum Operational Performance Standards
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
N0	Noise spectrum density
NDI	Non-Destructive Inspection
NDT	Non-Destructive Test
OASPL	Overall Sound Pressure Level

Acronym	Meaning
OEM	Original Equipment Manufacturer
OML	Operational Multi-pilot Limitation
PA	Power Amplifier
PAE	Power Added Efficiency
PCB	Printed Circuit Board
PDC	Dc Power
PL	Panel Length
PS	Panel Surface Area
PSK	Phase Shift Keying
PU	Public
PVC	Polyvinyl Chloride
PW	Panel Width
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RHCP	Right-Hand Circular Polarisation
RIA	Research And Innovation Action
RMS	Root Mean Square
RTCA	Radio Technical Commission For Aeronautics
RX	Receiver
SAE	Society of Automotive Engineers
SANDRA	Seamless Aeronautical Networking Through Integration of Data Links, Radios, and Antennas (FP7)
SES	Société Européenne des Satellites
SES	Satellite Earth Stations and Systems
STC	Supplemental Type Certificate
STDMA	Self-Organized Time-Division Multiple Access
TAS	True Air Speed
TBC	To Be Confirmed
TBD	To Be Done
TBL	Turbulent Boundary Layer
TC	Type Certificate
TCDS	Type Certificate Data Sheets
TDMA	Time Division Multiple Access
TRL	Technology Readiness Level
TSO	Technical Standard Order
TX	Transmitter
UHF	Ultra-High Frequency
UL	Ultimate Load
VDL	VHF Data Link
VHF	Very High Frequency
VOR	VHF Omnidirectional Range
VSWR	Voltage Standing Wave Ratio
w.r.t.	with respect to
WBS	Work Breakdown Structure
WP	Work Package
WPL	Work Package Leader
XWB	Extra Wide Body

REFERENCES

[1] EUROCAE ED-84B, Aircraft Lightning Environment and Related Test Waveforms

[2] SAE ARP5412B, Aircraft Lightning Environment and Related Test Waveforms

[3] EUROCAE ED-91B, Aircraft Lightning Zoning Standard

[4] SAE ARP5414B, Aircraft Lightning Zoning Standard

[5] EUROCAE ED-105, Aircraft Lightning Test Methods

[6] SAE ARP5416, Aircraft Lightning Test Methods

[7] EUROCAE ED-14G, Environmental Conditions and Test Procedures for Airborne Equipment

[8] RTCA DO-160G, Environmental Conditions and Test Procedures for Airborne Equipment

[9] EUROCAE ED-136, Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems

[10] SAE ARP4761, Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems

[11] EUROCAE ED-79A, Guidelines for Development of Civil Aircraft and Systems

[12] SAE ARP4754A, Guidelines for Development of Civil Aircraft and Systems

[13] EUROCAE ED-23C, MOPS for airborne VHF receiver - transmitter operating in the frequency range 117.975-137.000 MHz

[14] RTCA DO-186B, Minimum Operational Performance Standards (MOPS) for Airborne Radio Communications Equipment Operating Within the Radio Frequency range 117.975 – 137.000 MHz

[15] EUROCAE ED-152, Aircraft Precipitation Static Certification

[16] SAE ARP5672, Aircraft Precipitation Static Certification

[17] SAE ARP1870A, Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety

[18] SAE CMH17, Composite Material Handbook 17, ISBN of 978-0-7680-7814-5

[19] EUROCAE ED-113, Aircraft Lightning Direct Effects Certification

[20] SAE ARP5577, Aircraft Lightning Direct Effects Certification

[21] AC 20-107B, Composite Aircraft Structure, 2008-09-08

[22] AC 20-155A, Industry Documents To Support Aircraft Lightning Protection Certification, July 16, 2013

[23] Earth Station Performance Requirements, SES 2006

[24] ETSI EN 302 307 V1.2.1 (2009-08), European Standard (Telecommunications series), Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications (DVB-S2)

[25] ETSI EN 302 186 V1.1.1 (2004-01), Satellite Earth Stations and Systems (SES);Harmonized EN for satellite mobile Aircraft Earth Stations (AESs) operating in

the 11/12/14 GHz frequency bands covering essential requirements under article 3.2 of the R&TTE Directive

[26] ICAO Annex 10 Volume III: Communication Systems – Part II: Voice Communications Systems

[27] FP7 project SANDRA (http://sandra.aero/2013/index.php/about-sandra)

[28] EUROCAE WG-62 "Minimum Operation Performance Standard for GNSS antennas draft", v2.1 October 2014

[29] SAE ARP5089, Composite Repair NDT/NDI Handbook

[30] SAE ARP5605A, Solid Composite Laminate NDI Reference Standards

[31] SAE ARP5256, Mixing Resins, Adhesives and Potting Compounds

[32] SAE AIR5431, Repair Tooling

[33] SAE ARP4916, Masking and Cleaning of Epoxy and Polyester Matrix Thermosetting Composite Materials

[34] SAE AE-27, Design of Durable, Repairable, and Maintainable Aircraft Composites, ISBN 0768000203

[35] SAE AIR6291, Guidelines for Repair Process Evaluation of Aluminium Bonded Structure

[36] SAE AIR5367, Machining of Composite Materials, Components and Structures

[37] Moir I., Seabridge A., Jukes M.: Civil Avionics Systems, Second Edition, John Wiley&Sons 2013, ISBN 9781118341803

[38] CAP 411 Light Aircraft Maintenance Schedule – Aeroplanes, Issue 2, ISBN 0 11790 406 6, CAA, Fifth Edition April 2005

[39] https://en.wikipedia.org/wiki/Airband

[40] https://en.wikipedia.org/wiki/VHF_Data_Link

1. Introduction

The overall objective of the ACASIAS project is to contribute to the reduction of energy consumption of future aircraft by improving aerodynamic performance and by facilitating the integration of novel efficient propulsion systems such as contra-rotating open rotor (CROR) engines.

The aerodynamic performance is improved by the conformal and structural integration of antennas. The installation of CROR engines is facilitated by installation of an Active Structural Acoustic Control (ASAC) system in the fuselage. The integration of such a system in fuselage panels will annoying noise in the cabin caused by multi-harmonic sound pressure level which is radiated by CROR engines. CROR engines are able to realize up to 25% fuel and CO_2 savings compared to equivalent-technology turbofan engines.

The ACASIAS project focuses on challenges posed by the development of aero-structures with multifunctional capabilities. The following structural concepts are considered:

- A composite stiffened ortho-grid fuselage panel for integrating Ku-band SATCOM antenna tiles.
- A fuselage panel with integrated sensors and wiring for reduction of CROR cabin noise.
- A smart winglet with integrated blade antenna (integrated substrates into special foam, partly covered by a 1 mm glass/quartz epoxy layer).
- A Fibre Metal Laminate GLARE panel with integrated VHF communication slot antenna and GPS antenna.

The Work Breakdown Structure (WBS) of ACASIAS is shown in Figure 1. The objective of WP1 is to derive the mechanical, electromagnetic and thermal requirements and specifications for the four areas of research:

- Fuselage panel with embedded antenna tiles (WP2).
- Fuselage panel with sensors and actuators for reduction of cabin noise (WP3).
- Winglet with integrated VHF antenna (WP4).
- Fibre metal laminate panel with VHF slot antenna and GPS antenna (WP5).

WP1 is divided into 5 tasks. Each task will have its own requirements or criteria. WP1 provides the requirements for WP2 to WP5. In addition, the assessment criteria for WP6 are provided. This document (D1.1 "Requirements and Specification Document") is the only deliverable of WP1 and requirements for each task are given in the next chapters:

- Task 1.1 Define loads and boundary conditions of structures with integrated functions [Section 2 of this document].
- Task 1.2 Describe RF characteristics and requirements of airborne antennas to be integrated [Section 3 of this document].
- Task 1.3 Identify expected trade-offs for several types of civil aircraft [Section 4 of this document].
- Task 1.4 Define criteria for assessment of performances of structures with integrated functions [Section 5 of this document].
- Task 1.5 Tailor antenna requirements within industry standards, e.g. EUROCAE ED-14, RTCA DO-160 and ARINC 791 standards (environmental, EMC, RF, installation) [Section 6 of this document].

The main objective of this document is to identify the important parameters for the requirements. In some cases, actual values can already be provided for these parameters (as part of WP1). In other cases, the value will be derived during the design of the

appropriate integrated structure (WP2 to WP5). Therefore some TBDs are still present in this deliverable.

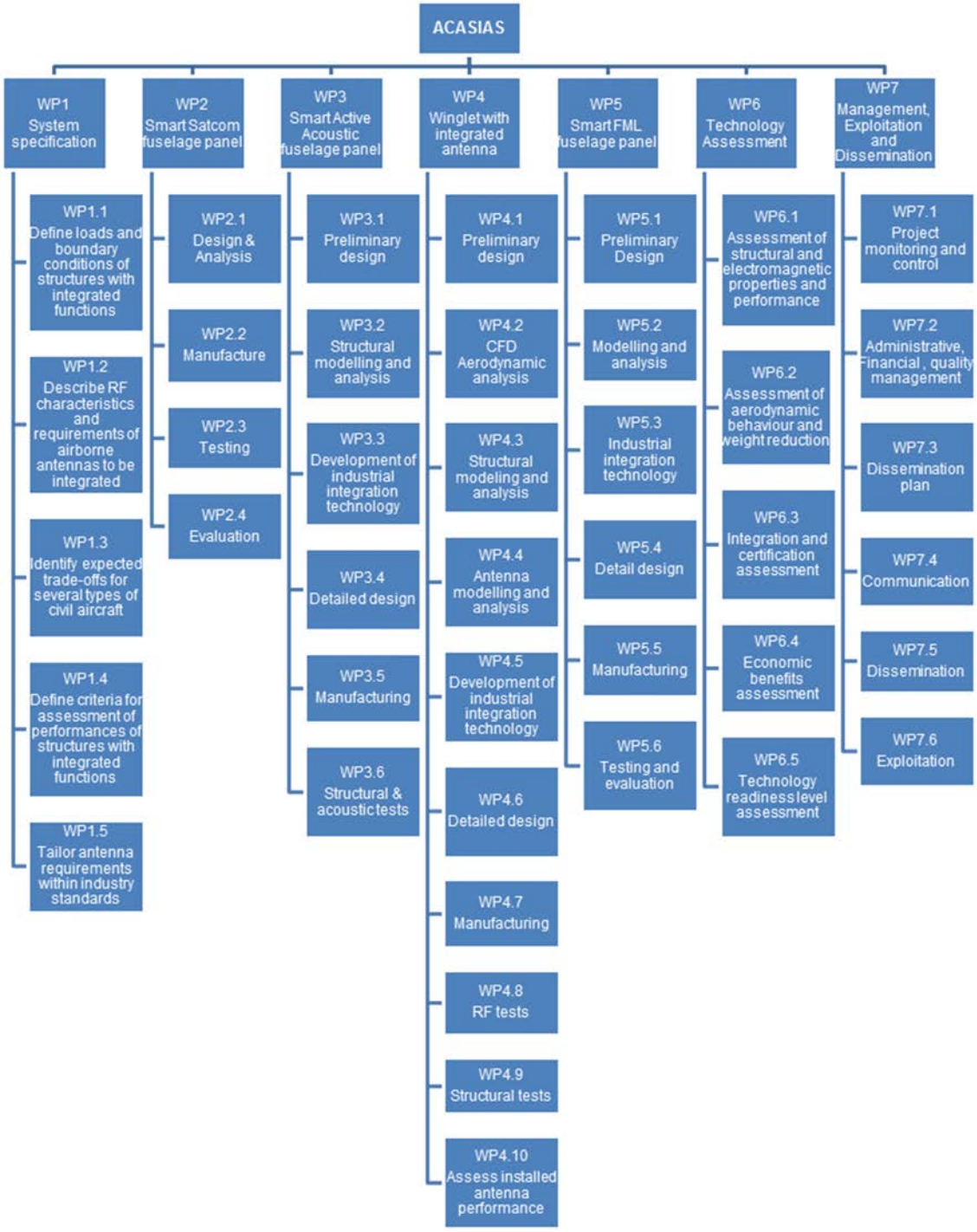

Figure 1. Work Breakdown Structure of ACASIAS.

2. Loads and boundary conditions of structures with integrated functions

2.1. Objective

The objective of this task is to define loads and boundary conditions for structural analysis of aircraft components with integrated functions. These conditions will be discussed for the four innovations of ACASIAS in the next sections.

Loads and boundary conditions are related to the chosen material and geometry, therefore materials and geometry as well as other related information are also included in the following sections where necessary. Every innovation has different requirements which will be discussed in the relevant sections if applicable.

As loads and boundary conditions mainly serve as an input for the design and analysis of the innovative structures, some more details on them are given in section 2.6.

2.2. Fuselage panel with embedded antenna tiles

Target aircraft: Fokker 100
Target location: Preferably in the fuselage forward section or (not preferred) in the aft fuselage section on the top or side of the aircraft.

The aim is to develop an ortho-grid stiffened fuselage panel with embedded antenna tiles. The panel shall consist of carbon fibre reinforced composite ortho-grid ribs and an EM transparent skin made using glass fibre reinforced composite.

The work is focussed on tension loadings with internal pressure. A subscale flat (shear) panel to evaluate design and manufacturing method is envisaged to investigate other representative load cases.

Location
The location of the ortho-grid panel is preferred to be in a section of the fuselage with relative low loads. More details are provided in Appendix 1.

Loads
Flat shear panel:
Relevant loads at the chosen shear location. This location may be different from the curved panel.

Integrated ortho-grid panel:
In the forward section of the Fokker 100 aircraft, the dominant load is a tension in the fuselage crown section. There will be a more shear loading in the panel rotated w.r.t. zenith. No aerodynamic loads are included.

The anticipated loads are given in Appendix 1.

The standard safety factor of 1.5 for ultimate load will be used for the loads. Further, other safety factors related to materials or conditions will be discussed and applied if necessary.

Boundary conditions

Flat shear panel:

Conditions relevant to the chosen shear location will be considered.

Integrated ortho-grid panel:

The boundary conditions similar to the conditions at the position of the panel in the aircraft should be considered for the design of the panel section. The boundary conditions for a test are defined as follows, see also Figure 2:

- Curved sections: Axial loading, free in the circumferential direction
- Straight sections: Pressure and frame loading, free in the axial direction

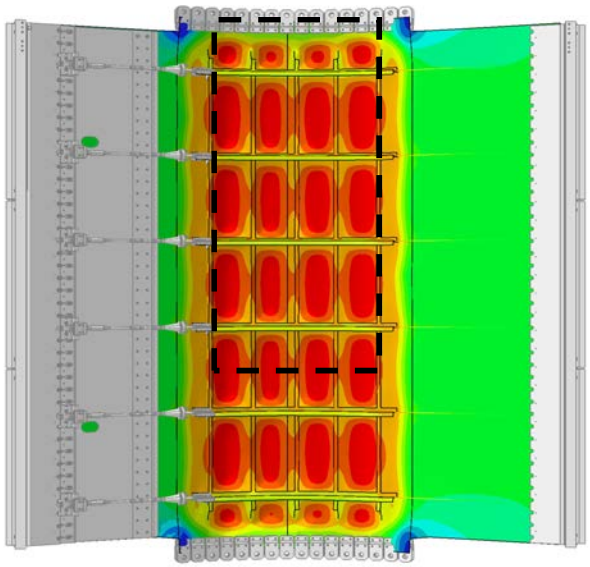

Figure 2. View on the curved panel setup and boundary conditions. The axial load is applied in the vertical direction.

Variation of temperature conditions is not foreseen in this project.

Damage tolerance

A damage tolerant design shall be adopted as much as possible within the available budget. For a typical monolithic composite, the maximum damage tolerant design strain is around 3000 – 3500 microstrain for the limit load. This range shall be observed in the design. As the programme concerns a new design, new features may need a detailed investigation by testing. This shall be evaluated during the review of the designs.

A damage tolerance shall be investigated for the grid fuselage panel. The impact damage poses a threat for the composite structure and connection between the skin and grid. It may be necessary to investigate typical damages by impact testing.

Materials and processes

The panel shall be laid-up using automated fibre placement and cured in an autoclave.

The panel shall be manufactured from thermoset prepreg materials. These materials shall be suitable for aerospace structural applications. It is aimed to apply commonly used material systems when expecting a better availability of these materials.

The ortho-grid ribs will consist of carbon fibre reinforced material. An epoxy based prepreg with standard modulus fibre is envisaged.

Possible candidates:
- Hexcel: 8552 resin AS4 fibre
- Cytec: 977-2 resin AS4 fibre

Intermediate or high modulus fibre may be considered if the preliminary design shows that this is necessary to obtain an efficient structure.

The EM transparent skin will consist of glass fibre reinforced composite material. Quartz glass is preferred reinforcement material from the EM point of view, but S2 glass shall also be considered if cost and availability are an issue.

Test rig
The Fuselage panel will be tested in the NLR test rig. The panel with integrated antenna tiles must fit in this test rig.
Specifications of the test rig are:
- Maximum panel dimensions: 3030 (length) x 1300 (width) mm
- Net test section: 2800 x 1200 mm
- Panel diameters: between 2693 and 5640 mm. Maximum of 6 frames can be tested with no limit for the amount of stringers.
- Axial load: up to 900kN
- Delta P tangential skin load: up to 340N/mm
- Delta P cabin pressure: 1.4 bar (static)
- No stringers, stiffeners or frames can be located outside the net test section - only skin and, if applicable, doublers.

Input for WP2:
- Reference geometry (Fokker 100) at the chosen panel location given using CAD files. The envisioned final test is for a stiffened panel with the length of 3030 mm and width of 1210 mm, radius 1650 mm (Fokker 100).
- Running loads (in N/mm for tension, compression, shear), pressure (ΔP) and load cases in the limit load and ultimate load,
- Connections e.g. among skin and stringers for the reference,
- Materials for reference and for the new design (CFRP, adhesives)
- Interface within the fuselage and for the final test panel,

See also the section 2.6 for more details on the required input for the design and analysis of the panel.

2.3. Fuselage panel with sensors and actuators for reduction of cabin noise

Target aircraft: Airbus A350
Target location: Side fuselage panel, side lining panel

The target aircraft Airbus A350 has a CFRP fuselage section structure. A fuselage section comprises upper and lower panel as well as the side panels. The reinforcement of the panel shell is created by omega shaped hollow stringers and C- or Z-shaped frames. The uncured prepreg shell is cobonded with cured stringers, while the frames are connected to the stiffened shell with a sealing and rivets using thermoplastic clips. The panels are connected with straps, shovels at stringer run-out or stringer coupling and frame couplings during the assembly of a section.

The local thickness and ply book of the panels and structural elements of each section is tailored to the structural loads and specific surrounding: pressurized fuselage, empennage or wing box section, door surrounding, window surrounding, possibly engine pylon of CROR.
The structural material of the A350 fuselage is IM carbon fibre prepreg (Hexcel's M21E-IMA). Functional layers like LSP and antistatic surface films or glass fibre plies for corrosion protection or damage propagation protection are included when required by engineering.
The secondary structure including the interior linings is mounted with brackets and clips on the frames. The linings are made from thin GFRP facesheets on honeycomb sandwich sheets. They cover the structure in different shapes. Table 1 lists the typical geometry of the structure and alternative representative solutions for the ACASIAS application.

Table 1. Typical geometry of the structure and alternative representative solutions for the ACASIAS application.

Target location Side panel	**Target aircraft**	**Representative acoustic panel**
Structural prepreg skin	M21E IMA (limited to OEM and A350 supply chain contractors)	M21 T800S or equivalent
Skin thickness	Normal skin panel ~2,2mm Window surrounding ~7mm Door surrounding ~8mm	Same
Skin functionality	Structure only	Structure with integrated sensor
Outer radius	2,98m	Same
Side panel size	>6 x 4m²	Sized to existing curing tool and acoustic test stand; ~1,3 m x 1,7 m, width could comprise two windows and three frames
Stringer pitch	~210mm	Same
Stringer thickness	~1,5 - 2,2mm	equivalent shape and mass dummy
Frame pitch	~690mm	same
Frame thickness	~2,0 – 4,0mm	equivalent shape and mass dummy

Setups:
Placement of actuators and sensors
- Combined (one actuator combined with one sensor)
- Distributed (independent placement of actuators and sensor with respect to observability and controllability of structural modes)

Location of ASAC system
- Fuselage panel
- Lining panel (in case of low performance of the fuselage)

Loads:
CROR acoustic
- Frequencies: f_1=120 Hz, f_2=150 Hz, plus higher harmonics and their mixed products
- Location: Outer side of the fuselage panel
- Sound pressure level on the outer side: app. 100 dB in CROR frequencies f_1 and f_2, decreasing with higher frequencies

Masses
- Actuator: Weight=4-60 g

- Sensor: Weight=1-20 g

Sizes:
Actuators
- Max. base size=50x50 mm^2

Sensors
- Max. base size=20x20 mm^2

Fuselage panel or lining panel
- Diameter: app. 6 m
- Width x Height: app. 1.3 m x 1.7 m

2.4. Winglet with integrated VHF antenna

Target aircraft: Evektor EV-55
Target location: Winglets

The present EV55 winglets were not designed for integration of any kind of antenna equipment, so it is necessary to adjust it appropriately to the task. The main obstacles are tightly related with the winglet's actual material composition and its basic dimensions.

The present winglet is composed from carbon fibre reinforced Plastic (CFRP) material. Such a material is conductive enough to be recognized as a good shielding material at all radio communication frequencies. In addition, similar materials near the antenna structure may unfavourably influence antenna performance if situated in its immediate vicinity. For the reasons specified above, the winglet's material composition shall be changed from CFRP to glass fibre reinforced plastic (GFRP).

VHF communication antennas operate on relatively low frequencies: 118 – 137/156 MHz (i.e. wavelengths range is approx. 2 to 2.5 m). Basic winglet dimensions used on a small aircraft usually do not exceed 1 x 0.5 m, so design and integration of a VHF communication antenna into its structure may easily become a challenging engineering task.

Considering the above mentioned, it is necessary to redesign actual winglet of EV55 to the state sufficient for integration of VHF antenna. Keeping actual aerodynamic performance parameters, the new winglet will be made of GFRP (or similar material) and its dimensions will be optimized in a way to decrease possible problems with antenna design and integration on a reasonable level.

The winglet has to be designed (optimized) so that strength limits of wing and winglet itself should not be exceeded. The load generated on current (not-optimized) winglet surface is relatively small and there are two aspects that should be kept in mind:

- Minor local aspect: Introduction of the winglet load into the wing tip structure. This can be covered by sufficient strength reserve factors of current interface between winglet and wing tip structure or by a local reinforcement of structure.

- Major general aspect: In terms of strength of the wing as a whole part, the critical factor of winglet design is its influence on load distribution along the wing, especially on bending moment distribution. In general, the winglet shifts resultant air force towards the tip of the wing and consequently increases the bending moment of the wing.

  Current wing+winglet configuration generates critical bending moment on the wing that cannot be exceeded (without structural modification of the wing). It means that

the **optimized winglet shall not generate higher forces** affecting bending moment of the wing in comparison to current winglet.
Ultimate values of bending moment distribution are given for critical load case (positive gust on wing) in Table 21 and Figure 24 in Appendix 1.

Introduction of the winglet load into the wing tip structure can be carried out by applying aerodynamic loads obtained from CFD analyses for a selected critical load case as a maximum resultant force at a specified reference point. In the example, coordinates of the reference point are [6 596, 1 141, 8 024] in [mm] (see Figure 25 and Figure 26 in Appendix 1). In the case if the winglet is not optimized, the evaluated load cases and maximum limit loads at the specified reference point for the load case A04+ are presented in Table 22 and Table 23 in Appendix 1.

It is necessary to check the metallic structure of the wing for design ultimate load (DLL x 1.5) and composite winglet for increased ultimate load (DLL x 1.5 x 1.5 x 1.07) during the design of optimized winglet structure. A detailed FEM model including winglet and wing tip structure shall be prepared to consider local strength of winglet area (an example of the FEM model is presented in Figure 27 in Appendix 1).

Regarding the FEM model depicted above, the aerodynamic load of critical load case A04+ (CFD results transformed to Nastran pressure PLOAD4) was applied on the whole winglet and also on 2D-elements representing a narrowed wing tip.

Aerodynamic simulations and design of a new winglet with integrated VHF antenna will be performed for the cruise flight condition. The flight envelope is shown in Figure 28 in Appendix 1. The new winglet will be based on the present winglet and the shape of the new winglet will be suitable for housing of the VHF antenna within the specific characteristics.

Current winglets were installed on the wing to improve lateral stability of aircraft EV55 with extended flaps. For the reasons mentioned above, the requirement for winglet design was specified as follows:

- The lateral stability of aircraft with winglets and extended flaps must be at least the same as the lateral stability of the wing without winglets and clear configuration.

This requirement must be respected also for the optimized winglet intended for integration of antenna equipment.

Lateral stability was evaluated by the value of the stabilizing moment about axis x of the aircraft (M_x). As mentioned above, the moment M_x for wing without winglets and clear configuration (see Figure 29 in Appendix 1) is considered as the reference value of minimal stabilizing moment for all the flaps positions.

The EV-55 airplane provided by new optimized winglets with integrated VHF antennas must meet this reference course of moment M_x, especially with the fully extended flaps. Higher values of M_x can be expected for other configurations.
Based on the stability and design requirements, an actual shape of the not-optimized winglet was defined (see Figure 3). In the next step, the winglet was optimized for the best performance and low additional wing loads.

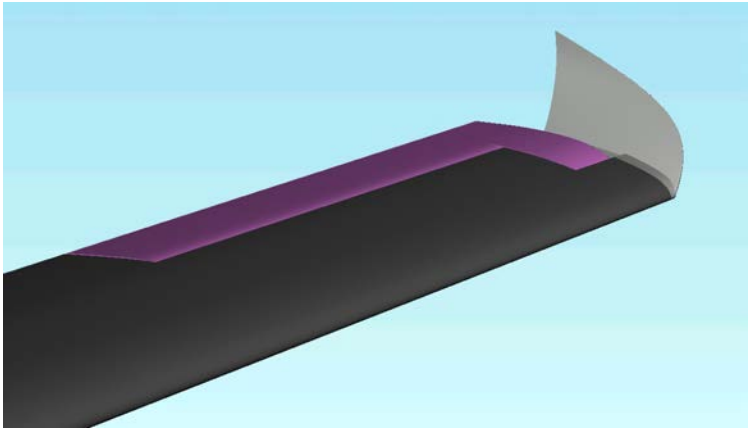

Figure 3. Wing part with a final shape of the winglet.

A winglet structure may adversely affect final controllability and manoeuvrability of an airplane. So a possible influence of the optimized winglet part has to be re-evaluated regarding requirements of CS-23 regulations, Section B (aerodynamics) and Section C (stress and structural behaviour). Meeting the requirements is usually demonstrated by flight tests supported by numerical analyses.

2.5. Fibre metal laminate panel with integrated antenna

Target aircraft: Airbus A320
Target location VHF antenna: Upper side of the fuselage
Target location GPS antenna: Top of the fuselage

The aim is to develop a Fibre metal laminate fuselage panel with integrated antennas. The panel will consist of a FML skin with FML stiffeners and aluminium frames.

Location
The preferred location of this fuselage panel is in a prismatic section of the fuselage with standard panel and frame design. Reinforcements due to doors, windows and other local design features will be avoided to simplify the design of the integrated antenna configuration. See also Figure 30 in Appendix 1 for potential antenna locations.
The antenna shall fit in the maximum of 2 stringer pitches and 2 frame bays of the target Aircraft.

For the demonstrator, the same panel design will be used to demonstrate both the integrated VHF and the GPS antenna. Note that the location in the actual fuselage for the VHF antenna will be in the side and the GPS will be at the top of the aircraft.

The tests for the fibre metal laminate fuselage panel are not defined yet. In case when a full-scale panel needs to be tested for static pressure loads, the panel shall fit in the NLR curved fuselage panel facility, see section 2.2.

Loads
Fibre metal laminate panel with integrated antenna:
In the forward and aft upper section of the Airbus A320, the dominant load is a tension. There will be a more shear loading in the panel rotated w.r.t. zenith. Aerodynamic loads can be neglected. The following loads are anticipated:

Pressure: 1.0 – 2.0 ΔP

Tension axial (N/mm): load flow in the panel at Limit load (to be determined in WP5)
Fatigue loading: to be discussed (only a static test is foreseen within the project)

The standard safety factor of 1.5 for ultimate load will be used for these loads. Further, also safety factors related to materials or conditions will be discussed.

Boundary conditions
Fibre metal laminate panel with integrated antenna:
For the design of the panel section, the boundary conditions should be similar to the conditions at the position of the panel in the aircraft. In case when a full-scale panel needs to be tested for static pressure loads, the boundary conditions are defined in the same way as for the composite panel with integrated antenna tiles - see also Figure 2 in the section 2.2:

- Curved sections: axial loading, free in circumferential direction
- Straight sections: Pressure and frame loading, free in axial direction

Variation of temperature conditions is not envisioned.

Damage tolerance
A damage tolerant design shall be adopted as much as possible within the available budget.
As the programme concerns oneself with a new design, new features may need a detailed investigation by testing. This shall be evaluated during the review of the designs.

A damage tolerance shall be investigated for the fuselage panel.
It may be necessary to investigate typical damages by impact testing.

Other load cases should be investigated to determine shear and compression behaviours. Currently the focus is on tension loading with internal pressure. A subscale flat (shear) panel to evaluate design and manufacturing method is envisaged to investigate other representative load cases.

Input for WP5 is the following:

- Representative load cases.
- Reference geometry, CAD files. The envisioned final test is a stiffened panel with the length of 3030 mm and width of 1210 mm, radius 1975 mm (Airbus A320).
- Running loads (N/mm in tension, compression, shear), pressure (ΔP) and load cases in limit load and ultimate load,
- Connections e.g. among the skin and stringers for the reference,
- Materials for the reference and for the new design (Glare, adhesive, aluminium)
- Interface within the fuselage and for the final test of the panel.

2.6. Structural modelling of boundary conditions, loads and restrains

To conduct the structural analysis of the different technologies addressed in the ACASIAS project, there are several parameters that have to be defined beforehand in order to define the numerical model. The information required can be classified in different groups which are: geometry, new elements integrated in the geometry, boundary conditions (restrains and loads), material properties and failure criteria. These are described in detail in the following sections.

2.6.1. Geometry

Numerical analyses on any structural component require a detailed description of the component geometry. The geometry description consists on known basic dimensions such as length, width, thickness (and thickness variations if any), curvature, etc. A detailed description of any existing elements included in the structural component such as stiffeners, holes, rivets, etc. is necessary as well.

2.6.2. Antennas, wiring, actuators and other components

New functional elements will be added to fuselage panels or other airplane structural parts in the ACASIAS project. Antennas, wiring, actuators, and other components are to be embedded into the laminate structure. The numerical models will require knowing the geometry, weight, materials and, in general, basic characteristics of these elements. It will be also necessary to know exact locations of these elements in appropriate panel or structural part.

2.6.3. Boundary conditions & loads

Any structural analysis requires boundary conditions. They are specified in knowing how the structure is attached to the medium around it and in the loads that are applied by this medium over the structure. Therefore, it is required to know the restricted displacements and rotations in the panel boundaries, either if they are zero or a given value; as well as the loads that must be applied to the structural component. These loads can be the external ones (pressure, force on one side, etc.) or the internal ones (self-weight or vibrations of elements included in the panel).
Most of ACASIAS components are structural panels or parts belonging to a larger structure in the airplane, such as the fuselage or wings. In this situation, boundary conditions and loads over the structure part considered in the project might be obtained from a larger numerical analysis conducted previously over the structure that contains it. It is assumed that this larger analysis has been already done and it is not envisioned to perform it in this project.

2.6.3.1 Fuselage panel with sensors and actuators for reduction of cabin noise

<u>Geometry:</u>

- Fuselage panel
  - Single-curved panel
  - Diameter: app. 6 m
  - Width x Height: app. 1.3 m x 1.7 m

<u>Antennas, wiring, actuators, etc.</u>

- Actuators
  - Electro-dynamic actuator
    - Mass-spring-damper system
    - Discrete actuator, point force
  - Piezo electric actuator
    - Crystal with piezo effect
    - Distributed actuator, strain based
- Sensors
  - Accelerometer (encapsulated monolithic block)
- Wiring

    - all actuators and sensors are electrically connected

Boundary conditions & loads

- Boundary conditions for fuselage panel
    - four mounting points (fixed), one in each edge, app. 10 cm out of edge
    - sides are free but acoustically sealed ("water-proof")
- Loads for fuselage panel
    - Distributed pressure loads due to acoustic excitation
    - Inertial loads of actuators and sensors

Material properties

- Fuselage panel
    - (Glass or carbon) fiber-reinforced plastics
    - (optional) honeycomb core or similar

2.6.4. Material properties

Material properties are of utmost importance when performing numerical analysis of structural parts. In the ACASIAS project, the most of the structures are made from composite materials and the numerical models will use multiscale procedures to obtain the material performance. In a multiscale analysis, the composite response is obtained from a micro-model of the composite material. Therefore, the material properties required are those of the constituents, instead of global properties of the composite. Under this scenario, the material properties required are:

- Composite architecture: fibre and matrix materials used, volume fractions of fibre and matrix, layer thickness, layer orientation and stacking sequence.
- Fibre Properties: Elastic properties (Young modulus, Poisson modulus, Shear modulus), specific weight, damping values (viscosity), failure stress, force-displacement response in order to obtain its fracture energy.
- Matrix properties: Elastic properties (Young modulus, Poisson modulus, Shear modulus), failure stress, force-displacement graph in order to obtain its fracture energy. Having this graph for tensile, compression and shear stresses will provide most valuable information that will improve the model capabilities.

In order to calibrate and validate the model, a full characterization of the lamina used in the laminate will be also required. The characterization includes: Young's modulus (longitudinal and transverse direction), Poisson modulus, tensile and compressive strength (longitudinal and transverse direction), Shear modulus and strength and fracture energies (or force-displacement graphs to obtain them).
If the panel contains any other material, such as aluminium in the case of GLARE, mechanical properties of this material (elasticity and failure endurance) will be taken into consideration.

2.6.5. Failure Criteria

There are several factors that can lead to the conclusion that the structure does not longer fulfil its design requirements. Commonly these are divided in Ultimate Limit State, the structure cannot bear the loads applied to it, or Service Limit State, in which the structure is no longer functional.
The results obtained from a numerical model can be analysed to verify if these limit states are fulfilled. However, to do such work, it is necessary to know them; or, in other words, it is necessary to know the requirements of the final user of the structure. Therefore, this final user must define the maximum displacement admissible on the

structure, the maximum loads (usually characterized as a proportion of the failure strength of the material), etc.

2.6.6. Final considerations

In any design process, such the one that has to be carried out in ACASIAS, there are some parameters that will be unknown at the very beginning of the project. In example, ribs on the panel can change their configuration and position in order to fulfil the operational and structural requirements; or the laminate configuration might change to be able to bear the applied loads. In such cases, the initial analyses will require a first assumption on the unknown parameters and further analysis will refine them.

3. RF characteristics and requirements of airborne antennas to be integrated

3.1. Objective

The objective of this task is to derive RF requirements such as frequency, gain, directivity (directional/omnidirectional), field of view, impedance, bandwidth, polarization and lightning protection for integrated antennas in:

- A composite stiffened ortho-grid fuselage panel for integrating Ku-band SATCOM antenna tiles.
- A smart winglet with integrated blade antenna (integrated substrates into special foam, partly covered by a 1 mm glass/quartz epoxy layer).
- A Fibre Metal Laminate GLARE panel with integrated VHF communication slot antenna and GPS antenna.

In addition some information is given about the Ku-band satellites and services that will be used in the link budget calculations.

3.2. Fuselage panel with embedded antenna tiles

3.2.1. Ku-band service

A Ku-band service based on the DVB-S2 standard (Digital video broadcasting satellite - second generation) is assumed (ETSI 302 307 [24]).

3.2.2. Ku band modulation

The DVB-S2 standard specifies BPSK, QPSK, 8PSK, 16APSK and 32APSK modulations.

3.2.3. Ku-band satellites (positions, transmit power, gain and distance)

An example of a target satellite for the Ku-band satcom antenna the is Eutelsat 5 West A satellite (formerly Atlantic Bird 3) which is located at 5° W and the Eutelsat-16C (formerly SESAT 1) located at 16° E. The satellite EIRP ranges from 38 dBW to 52 dBW. The EIRP charts for these satellites are shown in Figure 4, Figure 5 and Figure 6. Being on geostationary orbits, these satellites will be located at 35,786 km above the ground.
In Figure 7, the satellite G/T is specified for Eutelsat 5 West A.

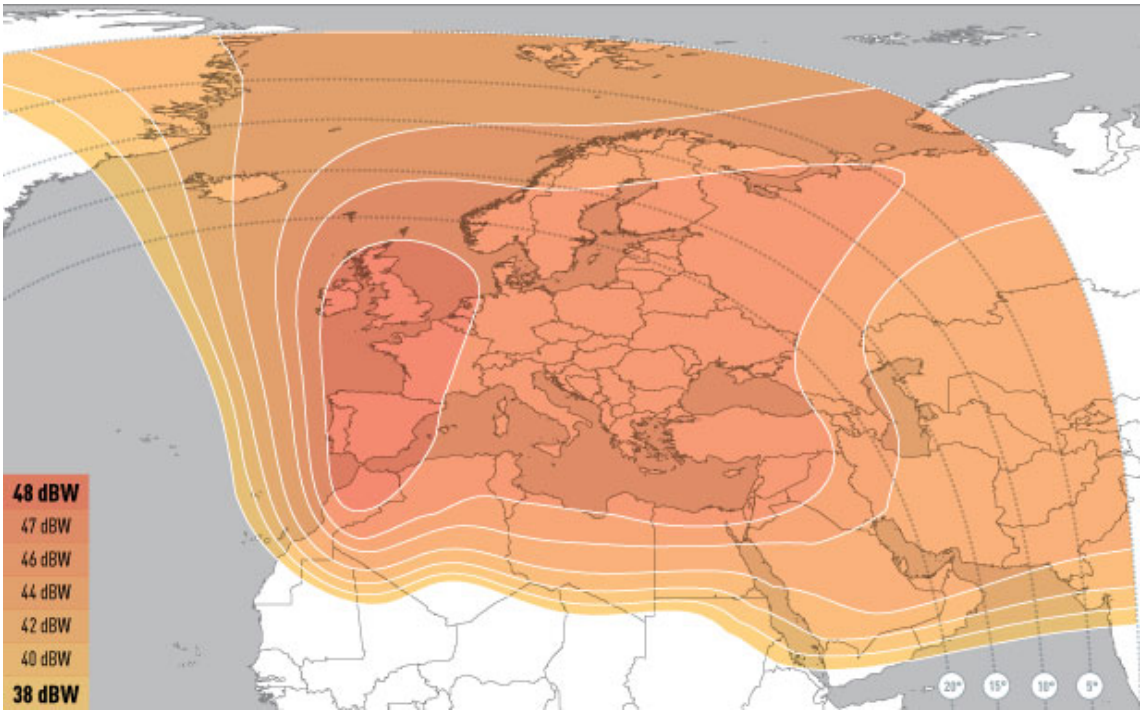

Figure 4. Chart of EIRP for the Eutelsat 5 West A (formerly Atlantic Bird 3). {Source EUTELSAT}

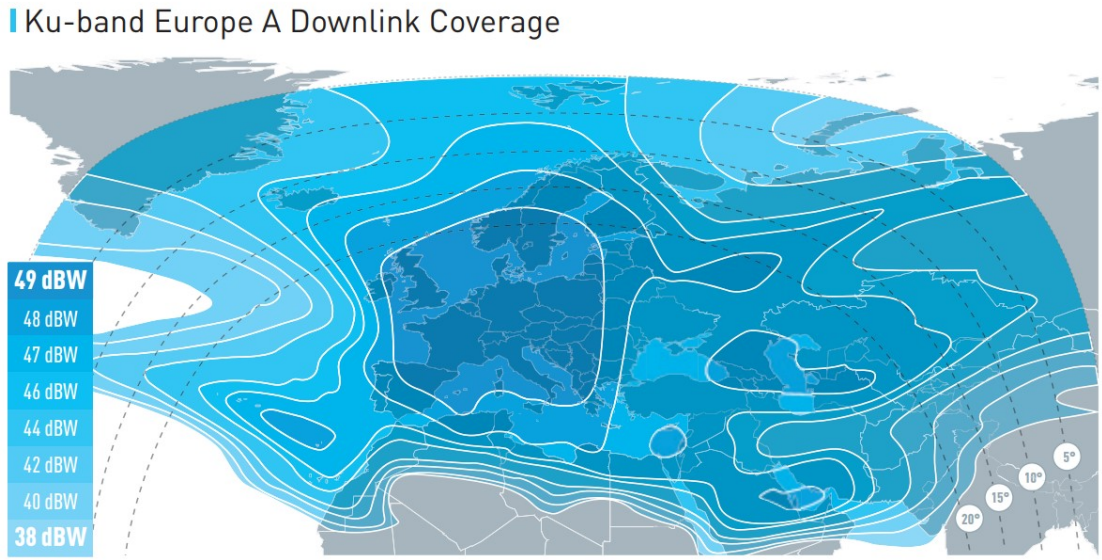

Figure 5. Chart of EIRP for the Eutelsat-16A. {Source EUTELSAT}

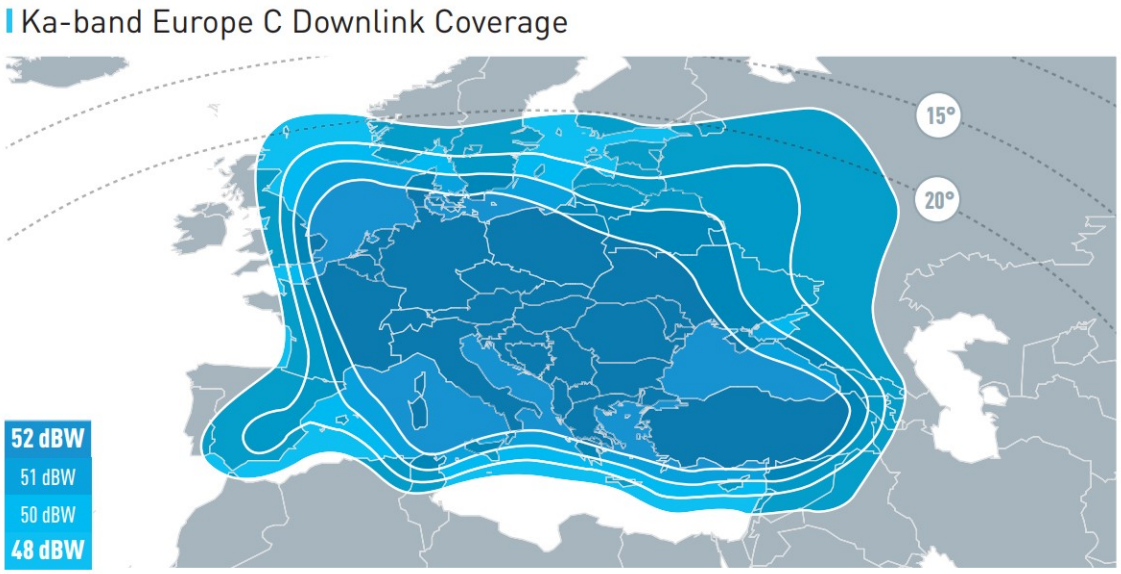

Figure 6. Chart of EIRP for the Eutelsat-16C (formerly SESAT 1). {Source EUTELSAT}

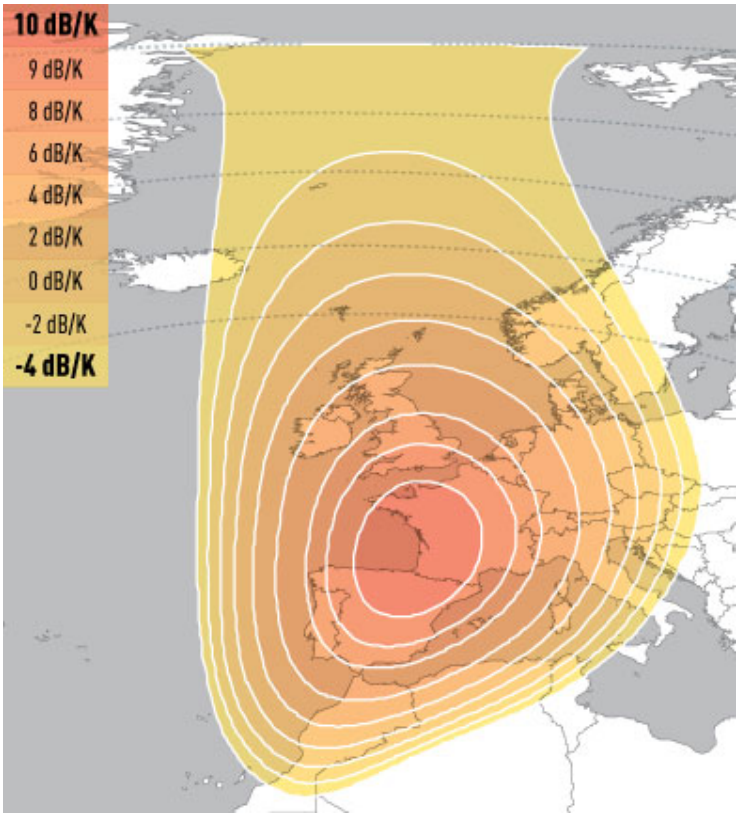

Figure 7. G/T for Ku-band Spot 1 (Western Europe) Uplink {Source EUTELSAT}.

3.2.4. Ku-band frequency range and bandwidth

The antenna shall receive over the range 10.7 – 12.75 GHz with the breakdown of this band as shown in Figure 8. The antenna shall transmit in the range 14.0 to 14.5 GHz. The required bandwidth for the RX antenna is 2 GHz and for the TX antenna 500 MHz.

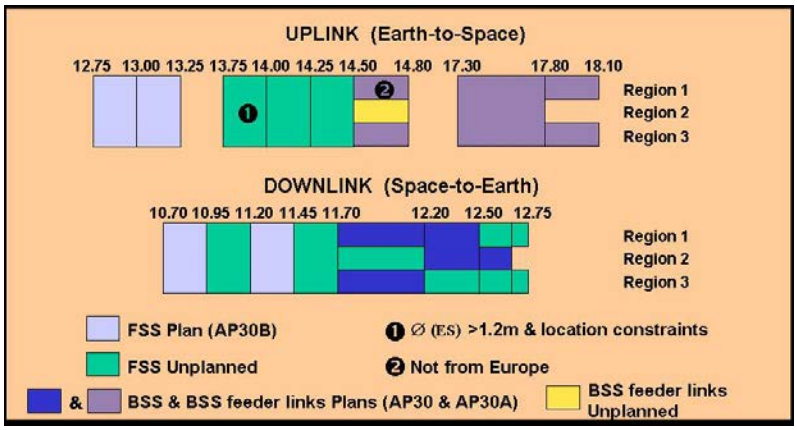

Figure 8. Ku-band FSS & BSS frequency bands.

3.2.5. Ku-band ideal antenna coverage volume

The ideal Ku band coverage volume extends from 10° to 90° in elevation and 360° in azimuth {assuming geostationary satellites and maximum latitude of operation 70°}.

3.2.6. Ku-band gain

The required RX antenna gain coming from link budget analyses in the SANDRA project is [27]:

- 30.7 dBi at 10.7 GHz
- 32.3 dBi at 12.7 GHz

The required TX antenna gain is to be decided in WP2 but typical values are in the range of 38 dB – 40 dB.

3.2.7. Ku-band beamwidth

We base the beamwidth on the specifications of the Connexion by the Boeing system. The CbB specifications demand a beamwidth of 2° by 3° at broad side and accept a $\frac{1}{\cos\theta}$ spreading with steering angle.

3.2.8. Ku-band sidelobe level

The maximum EIRP in any 40 kHz band in any direction φ degrees from the AES antenna main beam axis shall not exceed the following limits within 3° of the geostationary orbit:

33 - 25 log (φ+δφ) - H dB(W),	where 2,5° ≤ φ+δφ ≤ 7,0°
+12 - H dB(W),	where 7,0° < φ+δφ ≤ 9,2°
36 - 25 log (φ+δφ) – H dB(W),	where 9,2° < φ+δφ ≤ 48°
-6 - H dB(W),	where 48° < φ+δφ ≤ 180°

where φ is the angle, in degrees, between the main beam axis and the direction considered.
The value of δφ (relative to the target satellite) is equal to the RMS antenna pointing accuracy.
For AESs designed to transmit always at $EIRP_{max}$, H (in dB) is the maximum number of AESs which may transmit at $EIRP_{max}$ as declared by the manufacturer.

{Ref. section 4.2.4.2 of ETSI EN 302 186 [25] }

3.2.9. Ku-band polarisation

The DVB-S2 system employs linear polarisation. The antenna requires polarisation tracking to correctly discriminate the desired signal from interference.

3.2.10. Ku-band cross polar rejection

The cross polar rejection should be 35 dB [23]. This is a requirement for fixed reflector antennas larger than 2.5 m diameter. The value should only be considered as a very first design objective for smaller mobile antennas where typical values of 20-25 dB are common.

The required values should be met at antenna boresight and within

- ±15% of the half power beamwidth or
- the linear sum of the antenna installation, pointing and tracking errors; whichever is greater

3.2.11. Ku-band required carrier-to-noise ratio

The required carrier-to-noise ratio is given in Figure 9. The standard EN 302307 [24] specifies a C/N versus spectrum efficiency for each modulation method.

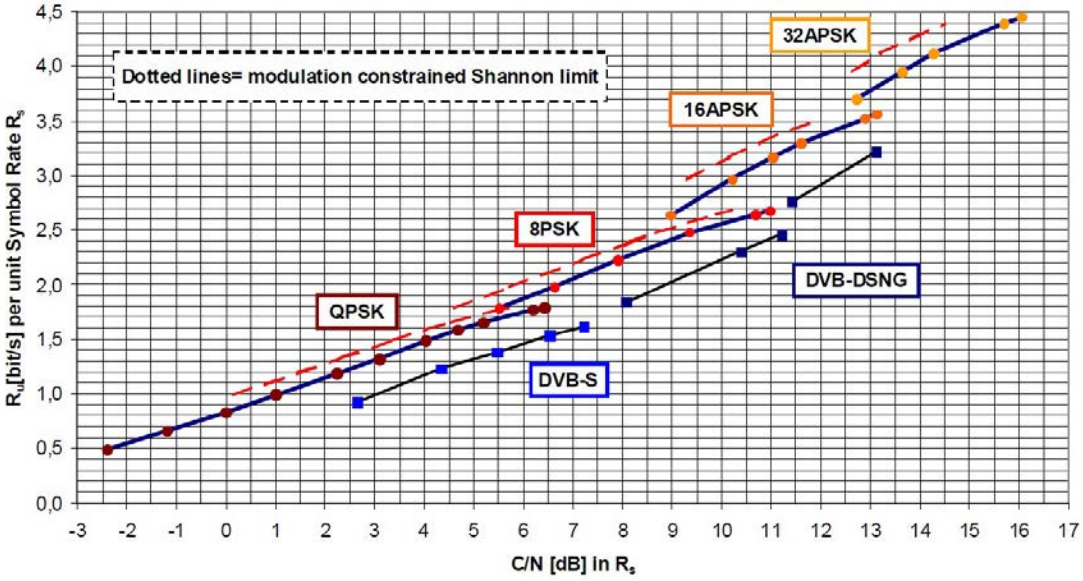

Figure 9. Required C/N versus spectrum efficiency, obtained by computer simulations on the AWGN channel (ideal demodulator) (C/N refers to average power). {Source ETSI EN 302 307 V1.2.1 (2009-08) [24]}

3.2.12. Ku-band G/T

G/T should in general be better than 11.2 dB/K (12.7 dB/K nominal) for all useful elevations. Lower values are also possible but will reduce the quality of service {SANDRA project [27]}.

3.2.13. Ku-band beam positioning accuracy

The beam should be positioned with an accuracy of 0.2° in azimuth and 0.4° in elevation.

3.3. Winglet with integrated VHF antenna

3.3.1. Operating frequency range

Basic operating frequency range for VHF radio communication is 117.975 – 137 MHz. VHF communication equipment used for voice and data transmission utilizes amplitude modulation and operates on assigned channels spaced 25/8.33 kHz apart within the above specified frequency range. EUROCAE ED-23: [13], DO-186B: [14]
However, new airborne VHF digital radio transceivers / receivers are already using extended frequency range up to 156 MHz and, according to DO-186B Chap.1.1, there is a possibility that in the future: "part or all of the frequency band 108.000 to 117.975 MHz may become available for ground-to-air and / or air-to-ground communication" too.
Considering the above said, a possible broadening of the basic VHF communication range should be taken into consideration too (i.e. trade-off analysis – frequency band vs. complexity of antennas design).

3.3.2. Signal characteristics for VHF communication

Signals transmitted and received by a VHF communication system can be of both analogue and digital nature. Communication (ATC) is not bound to just one communication channel but can run on multiple channels at the same time (i.e. VHF radio communication, maintenance and operational data exchange (ACARS, VDL, etc.), international distress frequency at 121.5 MHz) [39],[40].
Modulation of a signal is dependent on the type of information / service used for the communication: Voice provision is usually carried out using analogue and digital signals with DSB-AM (A3E, legacy), D8PSK (VDL3) modulations and TDMA protocol. Data provision (VDL) is usually carried out using digital signals with D8PSK (VDL 2/3), GFSK (VDL 4) modulations and CDMA/ TDMA+CSMA / STDMA protocols (VDL 2/3/4).
The signal for VHF communication services is assumed to be vertically polarized, so all VHF comm. antennas should be appropriately positioned/oriented with respect to this fact. At the end, it is worth mentioning that VHF navigation systems (i.e. VOR) are using horizontally polarized signals at frequencies just next to the VHF communication range (108 to 117.975 MHz).

3.3.3. Radiation pattern and antenna positioning

VHF communication antennas are generally situated on the top or/and bottom of an airplane's fuselage (see Figure 10). The reason is to ideally achieve characteristics similar to vertically oriented dipole in free space (i.e. omnidirectional pattern in azimuthal plane and typical doughnut-like pattern in 3D space). Airplane may use VHF systems for both air-to-ground and air-to-air communication, so the final radiation pattern should sufficiently cover both lower and upper hemisphere (see Figure 11).
Antennas positioned on top and bottom side of airplane's fuselage tends to have similar radiation patterns like a vertically oriented monopole antenna to be able to cover most of a hemisphere. According to the DO-186B [14], the field strength, which is tightly related with the uniformity of radiation pattern, shall not vary more than 6dB in azimuthal plane.

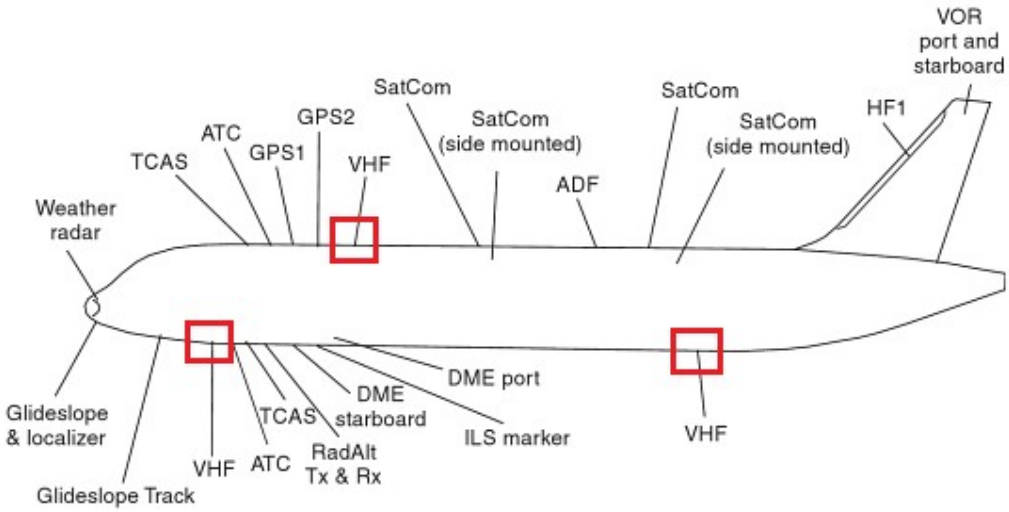

Figure 10. Illustrative antenna layout for Boeing 777. [Source: "Civil Avionics Systems" by I. Moir, [37]]

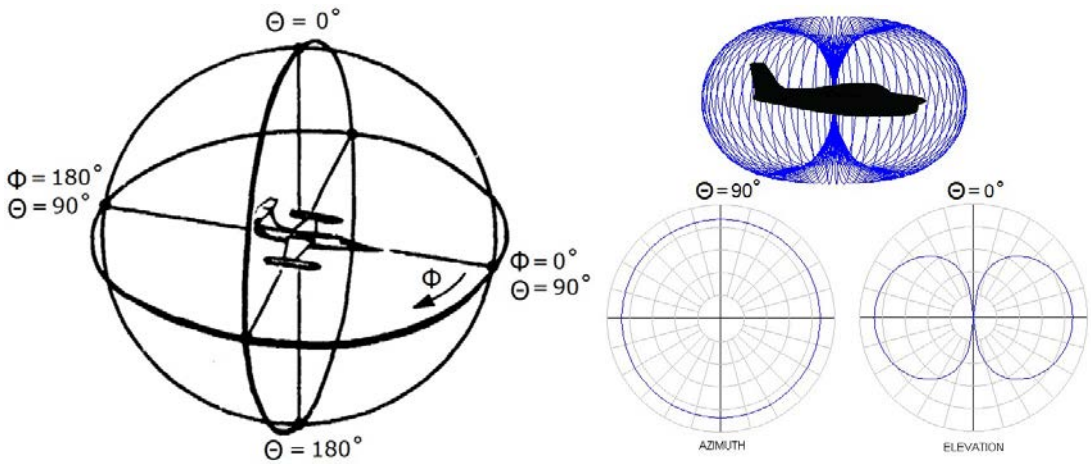

Figure 11. Reference coordinate system and idealized radiation pattern (vertical dipole).

The above described requirements may represent a challenging task if the VHF antenna is situated inside a winglet part at the tip of an airplane's wing. The first reason is related with the fact that the winglet's reference plane (i.e. body of winglet's antenna) may be oriented in a way that the antenna couldn't be able to radiate sufficiently in all the required directions. The second reason is lack of a good conductive mirror / ground plane situated in a way to help the antenna to radiate in all desired directions. The last reason may represent a necessity to adjust the antenna radiation pattern to the actual shape of winglet body. Besides a possible (minor) problem with slight movements of the antenna caused by actual aerodynamic conditions around the winglet during the flight, there are many different shapes of winglets used on aircraft that may have significantly different elevation angle against the wing's plane. This means that the design of a winglet antenna is always tightly related with the actual shape and material complexity of a winglet to fulfil all the necessary requirements connected with its radiation pattern.
Taking into account the fact that there will be an antenna integrated in each winglet, it is possible to sketch the most important areas where a good antenna reception / transmission performance should be provided: see Figure 12.

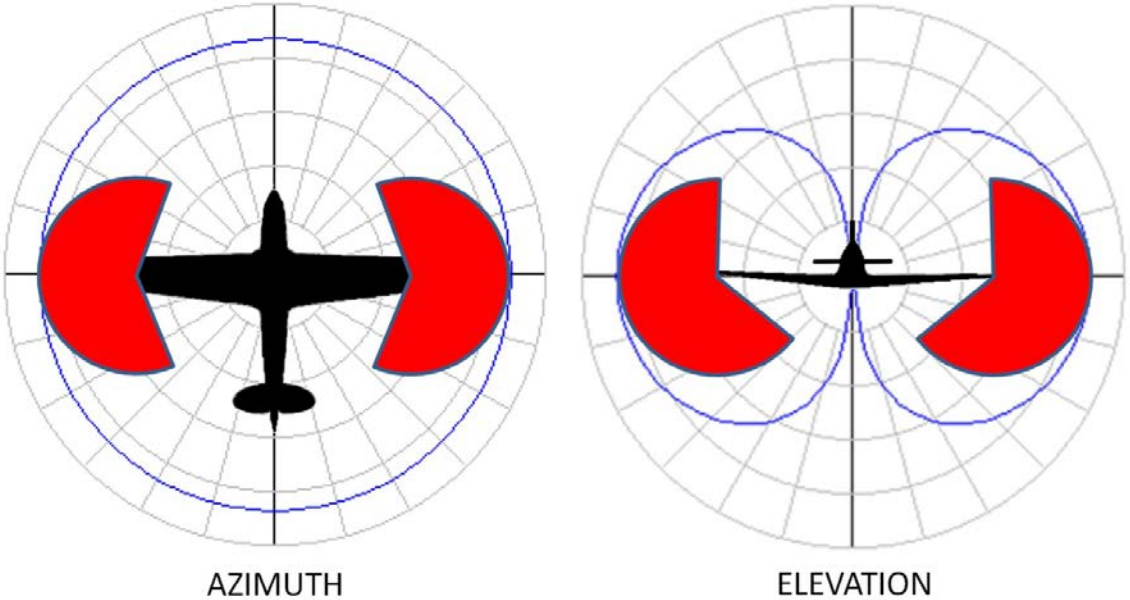

Figure 12. Idealized representations of areas with good reception / transmission performance of winglet antennas on an airplane.

3.3.4. Gain, VSWR and Rx/Tx parameters

Generally, there is a direct proportion between the gain of VHF communication antennas and their directivity. This means that the maximum gain for an antenna with the omnidirectional radiation pattern should not be significantly different form the gain of the dipole antenna in free space (in ideal case, if we don't sacrifice the directivity at higher and lower elevation angles for higher gain in the azimuthal plane). This means that the maximum gain for an omnidirectional VHF communication antenna should be in the range between -3dBd to 0dBd (i.e. -0.85 dBi to 2.15 dBi). The lower limit corresponds to the gain of ¼ wavelength monopole antenna.
Regarding the antenna efficiency described in DO-186B, "the field strength in the horizontal plane when compared to that provided by a standard vertically polarized monopole antenna shall not be down more than 6 dB". Ref. DO-186B [14]
Another parameter that may significantly influence Rx/Tx performance of VHF communication system is an antenna VSWR (i.e. measure of impedance mismatch between the antenna and adjacent transmission line). The maximum allowable VSWR for VHF communication antennas is 3:1. VSWR is usually referenced to the characteristic impedance of 50 Ohms.

3.3.5. Other systems integrated in winglet

The common engineering practice dictates to keep in mind other possible systems that are situated in the vicinity of the system to be designed (i.e. antenna) and may influence its performance (see Chapter 4.4). In our case, it is necessary to take into account the following possible systems:

- Position / anticollision lights
- Protection measures against a lighting strike
- Protection measures against the precipitation static (P-static)

The winglet may be subject to lightning attachment. The winglet lightning zone is 1A / 1B (Figure 13).

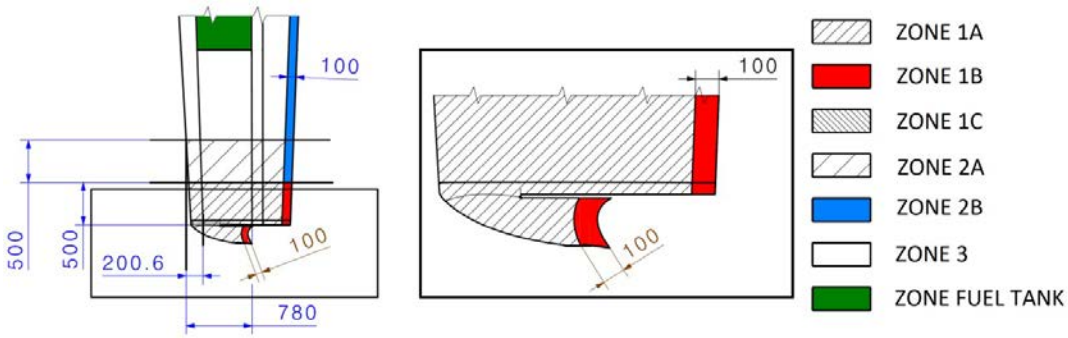

Figure 13. Winglet lightning zoning for EV55 aircraft.

3.3.6. VHF winglet antenna summary

Basic antenna parameters for winglet antenna (preliminary):

- Electrical:
  - Frequency: 117.975 – 137/156 MHz (EUROCAE has extended VHF frequency range to 156 MHz.)
    - Frequency band coverage: no continuous scanning / several frequencies should be operated at the same time (VHF communication, maintenance and operational data exchange (ACARS, VDL), international distress frequency at 121.5MHz)
  - Max. VSWR: 3:1 / Opt. VSWR: < 2.5
  - Max. Gain (target): -3 up to 0 dBd (i.e. -0.85 up to 2.15 dBi) / max. difference: 6dB.
  - Polarization: vertical
  - Radiation pattern: To be decided in WP4.
  - Impedance: 50 Ohm
  - Power: 16 W (for EV55), max. power: up to 25W (other A/C)
- Mechanical:
  - Target weight: max. 1 kg.
  - Max. dimensions (expected): To be decided in WP4.
  - Finish / enclosure: To be decided in WP4.
  - Connector type: BNC female (preferred)
- Environmental:
  - Temperature: -55ºC to + 85ºC
  - Altitude: max.: 50 000ft / 15 km
  - Airspeed: max.: 600 Knots TAS @ 35,000 ft.
- Specifications:
  - Environmental: DO-160G
  - MOPS: DO-186B
  - ETSO/TSO: ETSO 2C169a / FAA TSO 169a (historical: C37d, C38d)
  - AMC 25.581 lightning protection
  - AMC 25.899 electrical bonding and protection against lightning and static electricity

3.4. Fibre metal laminate panel with VHF slot antenna GPS patch antenna

3.4.1. VHF communication

3.4.1.1 Frequency range

The operating frequency range for VHF communication is 117.975 to 137 MHz. The channel separation is 8.33 kHz or 25 kHz. {Ref. EUROCAE ED-23C [13]}

3.4.1.2 Sensitivity (Signal-Plus-Noise to Noise Ratio)

Single Carrier Sensitivity: The level of a single carrier RF input signal, modulated 30 % at 1000 Hz, required to produce a signal-plus-noise to noise ratio of 6 dB shall not exceed -93 dBm with an audio output power not lower than 10 dB below the declared audio output power. {EUROCAE ED-23C [13]}

The sensitivity of the receiving function should be such as to provide on a high number of occasions an audio output signal with a signal-to-noise ratio of 15 dB, having a field strength of 75 μV/m (-109 dBW/m^2). {Ref. ICAO Annex 10 Volume III [26]}

3.4.1.3 Output power

The transmitter output modulated and unmodulated, on all frequency channels for which the equipment is designed, shall not be less than the manufacturer's declared value.

NOTE 1: Table 2 indicates the minimum modulated output power which will normally be necessary for given radio-line-of-sight distances. In the determination of the required output power, it has been assumed that a properly installed and matched antenna system is used.

Table 2. Minimum modulated output power.

Classes	Distance (Nautical Miles)	Minimum Output Power (Watts)
3 & 5	200	16
4 & 6	100	4

NOTE 2 : It is recommended that the output power be limited to 25 watts to minimise interference.
{Ref. EUROCAE ED-23C [13]}

The effective radiated power shall be such as to provide a field strength of at least 20 μV/m (-120 dBW/m^2) on the basis of free space propagation, at the ranges and altitudes appropriate to the operational conditions pertaining to the areas over which the aircraft is operated.
{Ref. ICAO Annex 10 Volume III [26]}

3.4.1.4 Polarisation

The polarisation of emissions shall be vertical. {Ref. ICAO Annex 10 Volume III: [26]}

3.4.1.5 Field of view

The VHF antenna should have an omnidirectional view in the horizontal plane.

3.4.2. GPS patch antennas

3.4.2.1 Frequency of Operation

The antenna unit shall operate over the bands outlined in Table 3. The frequency of operation is defined in terms of the 3 dB points of the total antenna response. It should be noted that currently the E5b band is only optional.

Table 3. GNSS frequency bands.

Frequency Band of:	Central frequency f_c [MHz]	Lower frequency limit [MHz]	Upper frequency limit [MHz]	Bandwidth [MHz]
E5a Gallileo	1176.45	1166.45	1186.45	20
E5b Galileo (option)	1207.14	1197.14	1211.14	14
E1 Galileo	1575.42	1563.144	1587.696	24.552
L5 GPS	1176.45	1164.22	1188.68	24
L1 GPS	1575.42	1565.19	1585.65	20.46

{Source Minimum Operation Performance Standard for GNSS antennas [28]}

3.4.2.2 Antenna Unit Radiation Patterns

The antenna radiation patterns shall refer to a coordinate system depicted in Figure 14 a-b. The definition of azimuth and elevation angles is also denoted. These are the angles traditionally defined in conjunction with radiation patterns in antenna engineering. The antenna is assumed to be placed at the origin of the coordinate system O (Figure 14 b). The GNSS antenna quantity defined is the relative radiation pattern that is the radiation pattern normalised to its peak value expressed in dB. The peak normalisation reference value is the maximum value based on all available of azimuthal cuts restricted within an elevation angle cone of 15° from zenith.

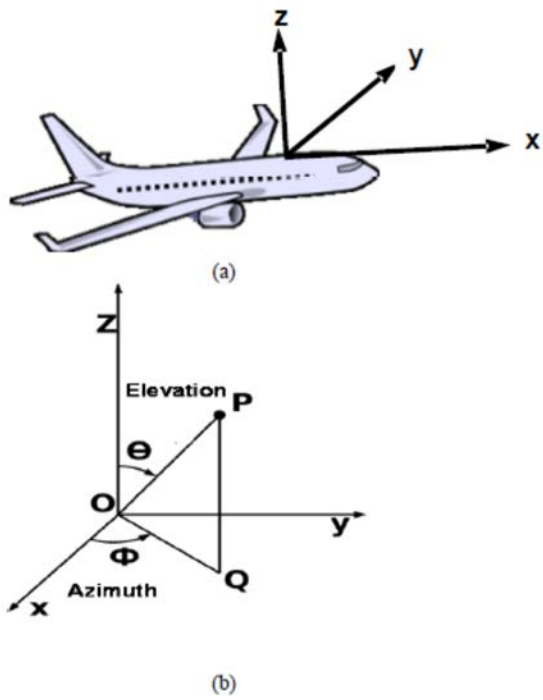

Figure 14. Coordinate systems for radiation patterns.

It is assumed that the radiation patterns are measured with an increment of the maximum of 1° in elevation and the maximum of 3° in azimuth. It is also assumed that the antenna to be measured is mounted over a circularly shaped ground plane of a diameter at least 1200 mm with a diffraction reduction treatment beyond its rim. Such treatment may be implemented with a rolled section with a diameter of at least 100 mm. The relative radiation pattern measured at the GNSS band centres (Table 3) shall comply with the maximum and minimum gain templates described in Table 4. These templates are assumed to form in a linear piecewise fashion with break points defined by the values of Table 4 as shown graphically in Figure 15.

Table 4. Relative Radiation Pattern template.

Elevation Angle [degrees]	Minimum [dB]	Maximum [dB]
-90	-11	-7
-85	-8.5	-5
-80	-7	-3
-75	-5.5	-1
-60	-3.5	-0.75
-15	-2.5	0
15	-2.5	0
60	-3.5	-0.75
75	-5.5	-1
80	-7	-3
85	-8.5	-5
90	-11	-7

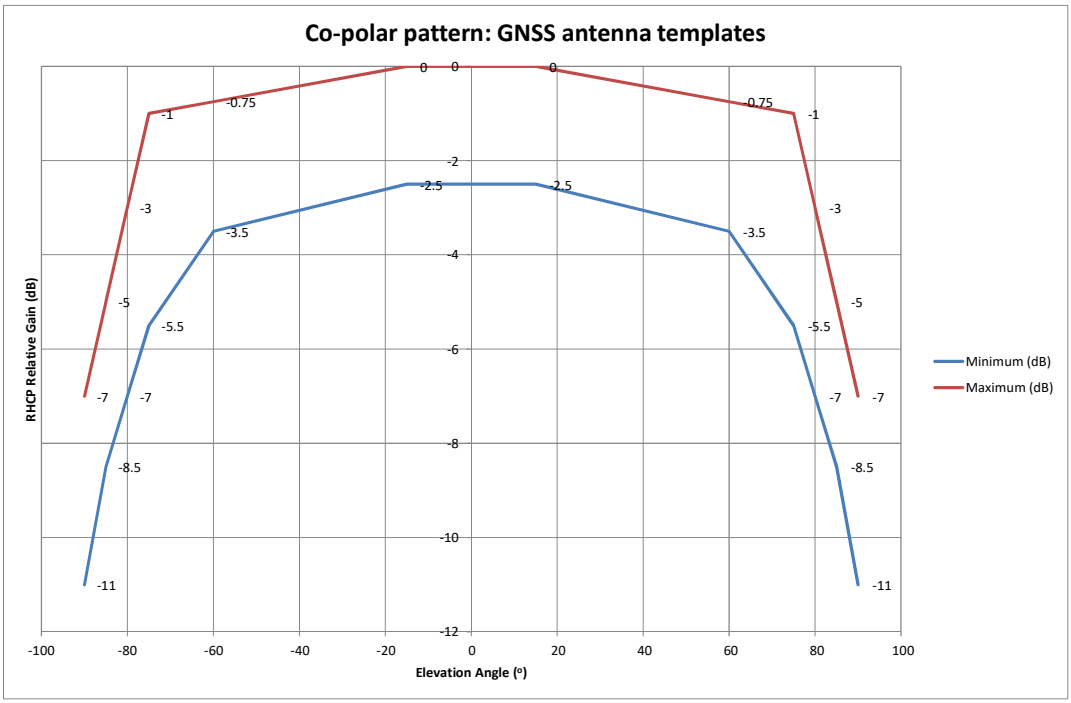

Figure 15. Relative Radiation Pattern template.

Note 1: Small deviations may still be considered acceptable provided that their magnitude does not exceed the value of 1 dB and the percentage of the angular regions of deviation do not exceed 5% of total angular directionality measured when taking into account the above guidance for the elevation-azimuth grid of points.
Note 2: The relative antenna gains shall not vary by more than 1 dB taking into account the full operational temperature range.
{Source Minimum Operation Performance Standard for GNSS antennas [28]}

3.4.2.3 Polarisation

The antenna shall receive a nominally Right Hand Circularly Polarised (RHCP) wave and its polarisation purity will be defined by an Axial Ratio (AR) at bore sight that should be 3 dB or better.
{Source Minimum Operation Performance Standard for GNSS antennas [28]}

3.4.2.4 Antenna Sensitivity: The G/T Ratio

The antenna, irrespective of its implementation, shall ensure delivery of a minimum acceptable C/N_o GNSS signal to the receiver. The quantity for ensuring this (as used traditionally with other satellite communication systems) is the G/T.
The GNSS antenna has to demonstrate that its G/T value is at least -31.8 dB/K for all elevation angles Θ when: $0° < \theta < 85°$ and for all frequencies within f_C±8MHz; with the band centres f_c as defined in Table 3.

The antenna gain-to-noise temperature ratio G/T is usually computed at the interface between the passive antenna and the input of the antenna front-end (low noise amplifier). However, the G/T value is the same at any interface in the antenna system.
The G/T is computed by dividing the antenna gain at the input of the antenna front-end (i.e. the gain of the passive antenna element) by the antenna system noise temperature at the input of the antenna front-end:

$G/T = G_{passive\ antenna} / T_{antenna\ system}$

The antenna system noise temperature is the sum of the antenna noise temperature and the equivalent noise temperature at the input of the antenna front-end electronics:

$T_{antenna\ system} = T_{sky} + T_{equivalent\ noise\ temperature}$

T_{sky} is computed by evaluating the sky noise temperature taking into account the radiation pattern of the antenna. For an antenna with a hemispherical coverage in the L-band, this temperature (T_{sky}) is no more than 100 K.

The gain of the antenna decreases with the elevation angle. Since the G/T requirement is also applicable down to 5° elevation angle, the maximum equivalent noise temperature can be determined by using the absolute gain at this elevation. In Figure 15, the relative gain requirement at 5° elevation is given by the minimum of -8.5 dB and the maximum of -5 dB). A minimum figure for the absolute gain for this type of antenna at the 5° elevation is -4.5 dBi. This implies a maximum antenna system noise temperature of 537 K.

The maximum equivalent noise temperature of the front-end is then 437 K. The noise figure of the front-end and of the total antenna system can be computed using the relationship:

$T_e = (F-1)\ T_0$ with $T_0 = 290$ K

Therefore the maximum noise figure of the antenna front-end shall be N_{FE} = 4.0 dB and the maximum total antenna system noise figure shall be N_{AS} =4.6 dB.

Note 1 Compliance to the minimum G/T figure quoted has to be unequivocal including all operational temperatures.
Note 2: Demonstration of the G/T performance can be achieved either by measuring the G/T directly or its constituent parts G and T.
Note 3: The G/T requirement is equally applicable both to passive and active antennas with the former as already indicated including any attached cables.
{Source Minimum Operation Performance Standard for GNSS antennas [28] }

3.5. Link budget calculation

A link budget calculation has been carried out to support the requirements.

3.5.1. GPS downlink

The link budget for the reception of GPS L1 signals is given in Table 5.

Table 5. Link budget GPS downlink.

Item	Symbol	Source	Downlink	Units
Frequency	F	Input	1.575	GHz
Transmitter power	P		25	W
Transmitter power	P	10*log (P)	14.0	dBW
Transmitter line loss	Llt	Input	-1.25	dB
Transmit antenna beamwidth	Theta t	Input	32.2	deg
Peak transmit antenna gain	Gtp		14.0	dB
Transmit antenna Pointing Loss	Lpt		0.0	dB

Transmit antenna gain	Gt		14.0	dB
Eq. Isotropic Radiated Power	EIRP		26.7	dBW
Propagation path length	S	Input	20200	km
Space loss	Ls		-182.5	dB
Propagation (atm.) & polarization loss	La		-2	dB
Multipath loss	Lm		0	dB
Power flux density near receiver	Pfd		-128.4	dBW/m2
Peak Receive antenna gain	Grp		0.0	dB
Receive antenna beamwidth	Theta r		161.2	deg
Receive antenna Pointing error	er		0.01	deg
Receive antenna Pointing Loss	Lpr		0.0	dB
Receive antenna gain	Gr		0.0	dB
Receiver line loss	Llr		0.1	dB
System noise temperature	Ts		500	K
Figure of merit	G/T		-27.0	dB/K
Received power	Pr		-127.7	dBm
Bandwidth transponder	B		2.046	MHz
Signal-to-noise ratio	S/N		-19.2	dB
Carrier to noise density ratio	C/No		43.9	dB-Hz
Carrier to noise ratio	C/N		-19.2	dB

3.5.2. VHF transmit

The link budget for the aircraft-to-ground or aircraft-to-aircraft VHF transmission is given in Table 6.

Table 6. Link budget VHF transmit.

Item	Symbol	Source	Downlink	Units
Frequency	f	Input	0.138	GHz
Transmitter power	P		16	W
Transmitter power	P	10*log (P)	12.0	dBW
Transmitter line loss	Llt	Input	-1	dB
Transmit antenna beamwidth	Theta t	Input	114.2	deg
Peak transmit antenna gain	Gtp		3.0	dB
Transmit antenna Pointing Loss	Lpt		0.0	dB
Transmit antenna gain	Gt		3.0	dB
Eq. Isotropic Radiated Power	EIRP		14.0	dBW
Propagation path length	S	Input	370.4	km
Space loss	Ls		-126.6	dB
Propagation (atm.) & polarization loss	La		-3	dB
Multipath loss	Lm		0	dB
Power flux density near receiver	Pfd		-121.3	dBW/m2
Peak Receive antenna gain	Grp		0.0	dB
Receive antenna beamwidth	Theta r		161.2	deg
Receive antenna Pointing error	er		0.01	deg
Receive antenna Pointing Loss	Lpr		0.0	dB
Receive antenna gain	Gr		0.0	dB
Receiver line loss	Llr		0.1	dB
System noise temperature	Ts		500	K
Figure of merit	G/T		-27.0	dB/K

Received power	Pr		-85.5	dBm
Bandwidth transponder	B		20	MHz
Signal-to-noise ratio	S/N		13.1	dB

3.5.3. Ku-band downlink

The link budget for the reception of Ku-band satellite signals is given in Table 7.

Table 7. Link budget Ku-band downlink.

Item	Value	Units
Earth station latitude	65	°
Earth station longitude	28.5	°
Satellite latitude	0	°
Satellite longitude	-12.5	°
Frequency	11428250000	Hz
Distance	40659569.37	m
Path Loss	205.800425	dB
Elevation angle	10.04979459	°
Satellite EIRP	45	dBW
Aircraft antenna receive gain	32.8	dB
Pointing Loss etc	0.74	dB
Receive power at aircraft	-128.740425	dBW
Aircraft antenna noise temperature	128.82	K
Aircraft antenna noise temperature	21.09983295	dB K
Antenna G/T	11.70016705	dB K^-1
Data rate	25742000	bps
Data rate	74.10642286	dB bps
Eb	-202.8468479	dBW
N0	-207.5001671	dBW
Eb/N0	4.653319147	dB
Satellite separation	3.1	°
Neighbour EIRP	45	dB
Discrimination ratio	16.1	dB
I0	-218.2068479	dB W
Eb/I0	15.36	dB
N0+I0	-207.1459378	dB
Eb/(N0+I0)	4.30	dB
Demodulator threshold Eb/(N0+I0)	1.45	dB
Provision for uplink	0.2	dB
System margin (Extra safety margin)	1.7	dB
Required Eb/(N0+I0)	3.35	dB
Margin (should be +ve)	0.95	dB

4. Expected trade-offs for several types of civil aircraft

4.1. Objective

This chapter is discussing the basic design trade-offs relevant for each of the systems to be developed in the ACASIAS project. Their trade-offs will be discussed with respect to the target A/C platforms, used for the development of each individual system, as well as to other "typical" platforms, which may be applicable for each of them too. All A/C platforms under consideration are specified in Table 8.
Starting TRLs are discussed in detail for each of the systems at the end of their trade-off discussions.

Table 8. Overview of dimensions and characteristics of target aircraft and reference aircraft.

	Reference platform	Typical	Target Aircraft
WP2 (Smart panel for Ku-band SATCOM)	Regional Jet aircraft Single aisle passenger aircraft Business jet aircraft	Bombardier C-series Airbus320 Dassault Falcon	Target A/C for development is Fokker100
WP3 (Smart acoustic panel)	Single aisle passenger aircraft	Airbus A320	Target A/C for development is A350
WP4 (Smart winglet)	Small civil aircraft Regional Jet aircraft Single aisle passenger aircraft Business jet aircraft	Evektor EV55 Bombardier C-series Airbus320 Dassault Falcon	Target A/C for development is Evektor EV55
WP5 (Smart FML panel)	Regional Jet aircraft Single aisle passenger aircraft Business jet aircraft	Bombardier C-series Airbus320 Dassault Falcon	Target A/C for development is Airbus320

An overview of basic parameters for all the mentioned A/C platforms can be found in Table 9. A brief description of all target platforms is provided in the following sub-chapters together with their schematic views. Provided information may help reader to familiarize with the A/C platforms to be used in the project and highlight different design aspects and technical or design risks that are related with the integration of the systems into them. Such information will allow us to discuss possible trade-offs in more specific and detailed way.

Table 9. Overview of dimensions and characteristics of target and reference aircraft platforms

A/C platform:	A319	A320	A350	EV55	Fokker 100	Dornier 728	Dassault Falcon	CS 100	CS 300
Passengers (Max.):	160	150/ 180	440	9/14	122	-	8	133	160
Length [m]:	33.84	37.57	60.54	14.35	35.53	27.40	11.79	35.0	38.7
Wingspan [m]:	35.8	34.09	64.75	16.1	28.08	27.12	25.94	35.1	
Height [m]:	11.76	11.76	17.05	4.66	8.50	9.05	7.47	11.5	

A/C platform:		A319	A320	A350	EV55	Fokker 100	Dornier 728	Dassault Falcon	CS 100	CS 300
Fuselage diameter (basic) [km]:		3.93 / 4.14	4	5.96	1.75	3.30	3.25	2.8	3.7	
Range of flight (Max.) [km]:		6 950	6 850	15 270	2 050	2 450	3 300	9 630	5 741	6 112
Speed	Maximum [km/h]:	871	870	961	407	856	915	1 102	871	
	Travel [km/h]:	829	829	918	380	800	904	980	829	
Altitude (Max.) [m]:		12 500	12 131	13.137	7 320	10 668	11 280	15 545	12 497	
Outside temperatures range:		-55°C / +75°C	-55°C / +75°C	-60°C / +60°C	-55°C/ +50°C	-	-	-55°C / +80°C	-	
Cabin pressurization:		yes	yes	yes	no	yes	yes	yes	yes	

4.1.1. Fokker 100

The Fokker 100 is a medium-sized, twin-turbofan airliner from Fokker. It was the largest jet airliner built by Fokker before its bankruptcy in 1996. Design of the Fokker 50 and Fokker 100 aircraft started in 1983. The first flight was made in November 1986. A total of 283 aircraft have been delivered. By July 2016, 116 Fokker 100 aircraft remained in airline service with 26 airlines around the world. Although airlines are currently retiring the aircraft, there are still large numbers in operation in both Australia and Iran.

The dimensions of the Fokker 100 are given in Table 9 and Figure 16. The Fokker 100 has no winglets.

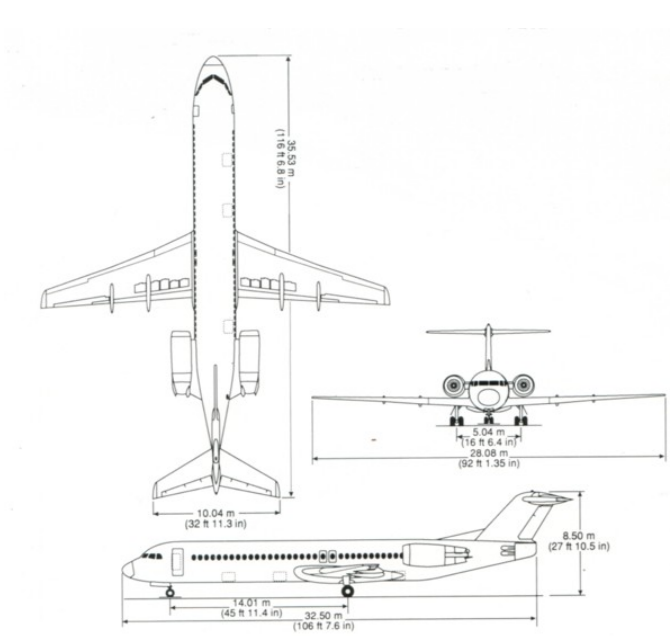

Figure 16. Fokker 100 dimensions.

4.1.2. Airbus A350

The Airbus A350 XWB is a family of long-range, twin-engine wide-body jet airliners developed by European aircraft manufacturer Airbus. The A350 is the first Airbus aircraft with both fuselage and wing structures made primarily from carbon-fibre-reinforced polymer. Its first flight was made in June 2013, while the production started in 2014. Up to June 2017, 92 of the 847 ordered aircraft were delivered to the customers.

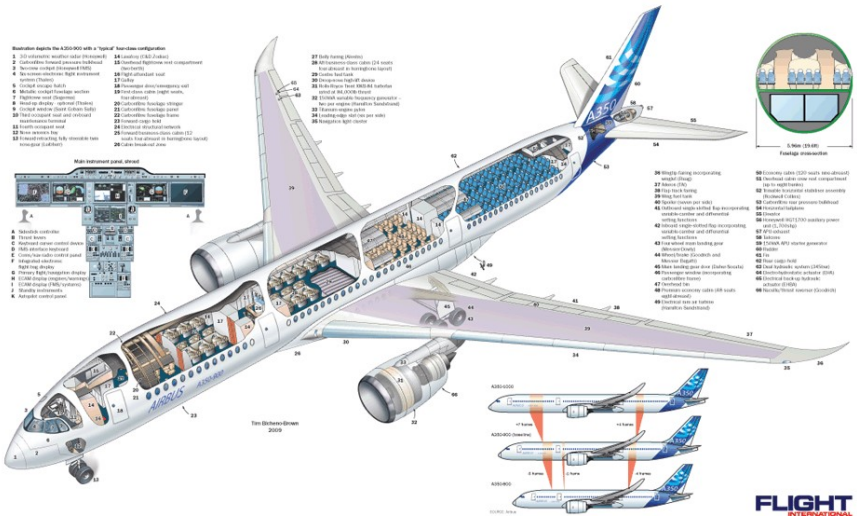

Figure 17. A350 cutaway. Source: www.flightglobal.com from 21. July 2017

4.1.3. Evektor EV55

The EV-55 aircraft is a high-wing, twin engine, turboprop, multipurpose aircraft developed by Evektor, spol. s r. o., Czech Republic. It is specified for transportation of passengers and/or cargo and equipped with a retractable landing gear and a T-shaped tail unit. Although the fuselage is mostly made of aluminum alloys, EV-55 is considered to be a semi-composite aircraft due to its composite nose, nacelles and fairings. At this time, a certification process with EASA is in progress while two flying prototypes of EV-55 are operated.

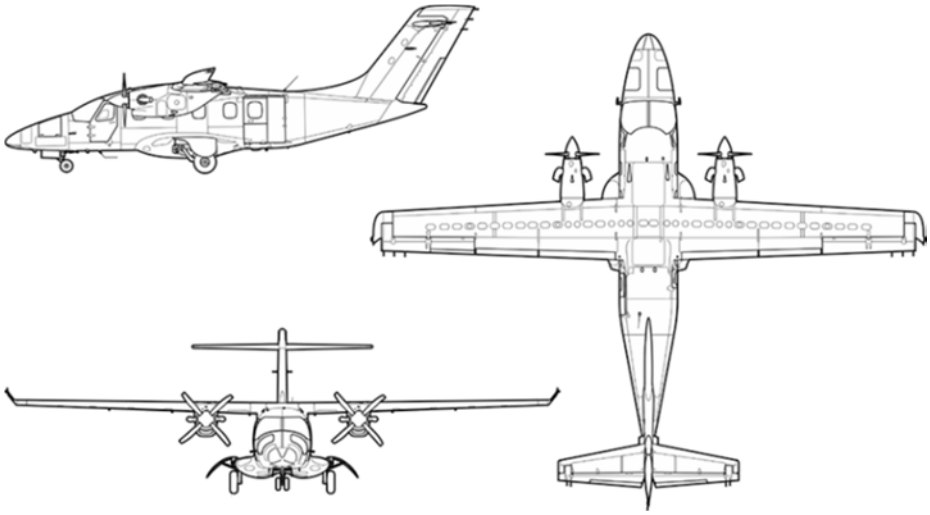

Figure 18. Schematic view of EV-55 aircraft.

4.1.4. Airbus 320

The Airbus A320 aircraft is a narrow body, short-medium range aircraft, made in 4 different models: A318, A319, A320 and A321. The first flight was carried out on 22nd February 1987 and it is the Airbus cash cow. Already 8500 of A320's have been delivered. Recently the A320neo was introduced. The A320neo is equipped with sharklets, more efficient engines and redesigned cabin interior to meet state of the art requirements for efficiency and cabin comfort.

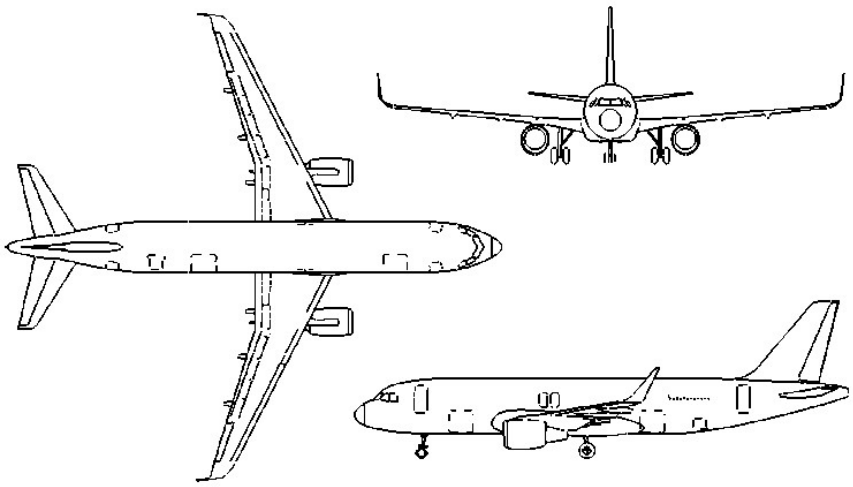

Figure 19. Schematic view of A320 aircraft.

4.2. Fuselage panel with embedded antenna tiles (WP2)

4.2.1. Trade-offs relevant for Fokker 100

In WP2 an ortho-grid stiffened panel with embedded antenna tiles will be developed. The panel will consist of carbon fibre reinforced composite ortho-grid ribs and an EM transparent skin made of glass fibre reinforced composite.

The main criteria for selection of the location of the antenna on the aircraft are:

- Aerodynamic and structural loads
- Field of view
- Available space
- Isolation from other antennas

The location of the antenna is preferably in an area where loads are not high, e.g. in the crown panel. A compromise may be required to find a suitable location for the field of view and the expected stress. Most likely this will be different for different types of aircraft.

The panel will be tested to verify its performance. The requirement for a successful test will be that there is no damage to the panel if tested to design limit load (DLL) and no failure when tested to design ultimate load (DUL, which is 1.5 x DLL). The antenna panel shall withstand limit load without incurring damage.

As mentioned, the location of this grid panel is preferred to be in a section of the fuselage with relative low loads. These locations are given in Figure 23 (Appendix 1).

The antenna will be oriented to Ku-band satellites above the equator. For an aircraft operation at high latitudes one antenna at each side of the aircraft is preferred.

The maximum dimensions of the integrated Ku-band antenna are 60 x 60 cm. The maximum dimensions of the fuselage panel in WP2 are related to the capabilities of the NLR curved fuselage panel facility which will be used to test with static pressure loads. This setup allows attachments for the maximum dimensions of 303 x 129 cm.

The antenna size is mainly dictated by the required gain of the antenna. This gain depends on the steering angle of the antenna ($1/\cos(\theta)$). The maximum steering angle depends on the location of the antenna on the aircraft and the maximum latitude at which the aircraft will be operated. Currently, a maximum of 6 x 6 antenna tiles with dimensions of approximately 10 x 10 cm are foreseen. The minimum antenna tile size can dictate the spacing between the ribs of the ortho-grid. Depending on the location in the aircraft fuselage, this can limit the applicability for certain aircraft.
The thickness of the antenna will depend on the mechanical structure and the cooling provisions to be integrated.

The antenna is based on a modular approach. The maximum 6 x 6 antenna tiles can be replaced if they need repairs.

The benefit of the antenna tile concept is that tiles can be made as a module that can be integrated into the fuselage. Within certain boundaries, it may be used in different types of aircraft with only minor adjustments to the tile outer geometry.

The fuselage structure of the panel developed in WP 2 antenna tiles should be able to withstand LL and UL as described earlier. The antenna tiles must be able to withstand these loads as well without ceasing to function.

Baseline of the WP2 structure is an S2-glass fibre skin with carbon fibre reinforced ortho-grid. It may be necessary to adapt the design depending on the actual load on the structure. Different pressures lead to different load cases and the final design of the panel must be adapted to that.

As the antenna contains active electronics, the chance exists that during the lifetime malfunctions occur. It must be possible to access the tiles from the inside of the cabin for repairs.

The antenna panels are placed inside the fuselage in WP 2, therefore environmental effects are limited and only basic protection as for other electronics inside the fuselage is required.

The antenna should be installed in a lightning zone with low probability of lightning strike.

Weight is an issue as the solution found should not make the entire aircraft heavier to such a degree that any fuel saving resulting from removing protruding antennas is lost to an increase in aircraft weight.

Interference with other nearby structures / systems / antennas:
The tail of the aircraft could block the reception of satellites if the antenna is located at position 3. For all antenna positions, the wings may block reception if the aircraft is banking and flying at high latitudes.
No detailed information is available about other RF systems or antennas on the Fokker 100. However, given the small beamwidth of the antenna it is not expected that coupling with other antennas will be a problem. Most other systems operate at lower frequencies. Harmonics of these systems may fall in-band of the Ku-band antenna.

With respect to the certification of an integrated antenna: the less conventional the design of the structure is, the more demonstration and validation will be required to eventually certify the structure. Within ACASIAS, certification is not a goal. However, it must be taken into account that any development should be certifiable in the end.

Dimensions and curvature are the same for all three locations (Figure 23). The dimensions are given in Table 10.

Table 10. Dimensions and curvature Fokker 100.

A/C platform:	Dimension:	Symb.	Value:	Info:
Fokker 100	Fuselage width	FW	3300 mm	Fuselage diameter
(location 1, 2, 3)	Fuselage height	FH	3300 mm	Fuselage diameter
	Fuselage curvature	FR	1650 mm	Fuselage radius
	Panel width	PW	1210 mm	Maximum width
	Panel length	PL	3030 mm	Maximum length
	Panel surface area	PS	3.67 m^2	Maximum area

4.2.2. Trade-offs relevant for other aircraft types

For WP2 antenna location and antenna size are most important. The location of the antenna on the aircraft is important to be able to connect with satellites. Since a good field of view to the satellites should be available also when flying at high latitudes, a position at both sides of the fuselage (30 to 45 degrees from zenith would be best). The antenna size is mainly dictated by the required antenna gain and the maximum scan angle of the antenna.

Since all other target aircraft (except the EV55) are larger than the Fokker 100, antenna size and location should not be a problem unless interference with other antennas becomes a problem. Also the loads at certain locations on other aircraft could be higher. Installing the Ku-band antenna on aircraft with similar dimensions as the EV55 may be a problem. The dimensions of this aircraft are about half the dimensions of the Fokker 100 aircraft. Finding a location on this aircraft for a 60 x 60 cm antenna may be difficult.

4.2.3. Actual TRL of the proposed system

In the LOCOMACHS project, a rib stiffened compression panel was designed, manufactured and tested. Separate research into the development of antenna tiles was conducted by NLR in the past. From that point of view, basic research that can be turned into an application or a concept under a research and development program was carried out. In this case the concept concerns the integration of antenna tiles into a structure. This can be regarded as the concept having reached TRL 1.
However, in the current ACASIAS project, an idea is proposed for the practical application of current research. There are no experimental proofs or studies for the specific structure in mind to support the idea at the start of the project as they will be developed during the project. As such, the current TRL for WP 2 is TRL 2.

4.3. Fuselage panel with sensors and actuators for reduction of cabin noise (WP3)

4.3.1. Trade-offs relevant for Airbus A350

In WP3 a fuselage panel with integrated sensors and wiring for reduction of CROR cabin noise based on the integration of smart layer with attached sensors and actuators will be developed. The panel will be manufactured from fibre reinforced plastics including ribs and frames. Actuators, sensors and wiring for the ASAC system will be integrated during the manufacturing process. The objective of the ASAC system is the reduction of transmitted sound power through the fuselage to the passenger. Therefore, a side panel close to the passengers has to be selected as test section for ACASIAS. In Figure 20 possible side panels for the integration of an ASAC system are highlighted.

Figure 20. Possible locations (red) of an ASAC system in the Airbus A350 fuselage.

The number of actuators and sensors is dependent from the stiffness, mass and geometric complexity of the underlying structure. In general, an increase of all three parameters leads to an increase of actuators and sensor per area fuselage. The final number of actuators and sensors has to be determined by simulations and experiments of the target structure. To give an overview, the masses and sizes of usual actuators and sensors for ASAC systems are given below:

- Size and weight of acoustic sensors and actuators
  - Actuators:
    - Electro dynamic exciters: Weight=25-60 g, Max. base size=50x50 mm^2
    - Piezo actuators: Weight=4-8 g, Max. base size=61x35 mm^2
  - Sensors:
    - Accelerometers: Weight=1-20 g, Max. base size=20x20 mm^2

4.3.2. Trade-offs relevant for other aircraft types

In general an ASAC system can be installed on every kind of fuselage or lining structure independent from its radius. With increasing size and geometrical complexity the number of actuators and sensors increase. Previous experiences with ASAC systems show, that the number of actuators and sensors scales linear with the size of the structure while the complexity (number of stringers or ribs) is fixed. Thus, the mass of actuators and sensors per area can be kept fix. In summary, the lessons learned in ACASIAS will enable an estimation of additional mass for an ASAC system at other aircraft types. The portability of the algorithms is given, but the parameters of the controller have to be evaluated for each type of structure. Since the ASAC system developed for ACASIAS depends on CROR excitation, the transferability is given only for aircraft with comparable engines. Nevertheless, the functionality of the ASAC system heavily depends on the implemented controller. Therefore, the fuselage with integrated actuators and sensors can be used for other types of noise reduction problems such as the reduction of turbulent boundary layer (TBL) noise as well.

4.3.3. Actual TRL of the proposed system

In the FP6 Integrated Project (IP) INMAR (Intelligent Materials for Active Noise Reduction) fundamental knowledge about ASAC systems including sensor/actuator materials and control technology was acquired. In national (SYLVIA, DIANA, etc.) and DLR funded (CoSiCab, ECCO, CENT, etc.) projects several application scenarios for ASAC systems like the reduction of CROR noise transmission were investigated. In all projects the actuators, sensors and wiring were attached to the structure. In ACASIAS the integration of all components into the structure is planned. Since now, no experimental

proof of concept is built to even demonstrate this integration technology. Regarding all aspects of integration and functionality of the active system the "Integration of smart layers in the fuselage for the reduction of transmitted noise" has currently the state of TRL 2.

4.4. Winglet with integrated VHF antenna (WP4)

Since the winglet VHF antenna is not generally used as a solution in aeronautical industry, it is necessary to consider all cons and pros following from such a specific situation.
There are several aspects that should be taken into account during the design of such an antenna. All of them can be divided into three specific groups of problems:
The first group is related with the antenna's specific location on the airframe, the second group relates to the issues connected with basic spatial needs of an integrated antenna in a winglet structure and the last group is discussing relevant design trade-offs that can be met in similar cases.
All the above presented groups will be discussed in the following sub-chapters for the target aircraft (EV-55) and other possible platforms specified in Table 8 (according to the GA, Table 5). A final recapitulation of actual TRL levels for the individual developed systems follows the trade-offs' discussions at the end of the chapter.

4.4.1. Trade-offs relevant for EV55

The target aircraft for winglets with integrated VHF antenna is a small twin-turboprop aircraft EV-55. The EV-55 had been chosen as a target aircraft for its relatively small winglets that may represent the most challenging design problems regarding antenna performance, temperature management and level of antenna's integration into the winglet structure. Successful design of similar system under aforementioned conditions will naturally prove its principal applicability to all A/C platforms with bigger winglet structures.
Regarding the specific position of the antenna on airplane, one of the most evident trade-offs is related with antenna's radiation pattern positioned at tip of a wing compared with more common locations like upper or bottom part of an airplane fuselage. An antenna situated at the bottom / upper part of the fuselage is usually designed in a way to provide radiation characteristics similar to a monopole antenna above good conductive plane (i.e. fuselage). This means that the antenna has an omnidirectional like far-field pattern in horizontal plane (Φ = 0-360 °, Θ = 90°; see Figure 10, Figure 11) and it is able to cover most of the upper/bottom half of a space around the aircraft (upper hemisphere: Φ = 0-360°, Θ =0- 90°, bottom hemisphere: Φ = 0-360°, Θ =90-180°).
Contrary to above mentioned, the winglet antenna may not be able to cover the same parts of space, but it can be designed in a way to sufficiently cover left and right hemispheres from the aircraft perspective (i.e. left hemisphere: Φ = 180-360°, Θ =0-180°; right hemisphere: Φ = 0-180°, Θ =0-180°; see Figure 12). This means that one winglet antenna cannot cover whole the desired space in the horizontal plane and two winglet antennas, one for each side of an airplane, are necessary to cover the whole area defined by MOPS specified in RTCA DO-186B [14]. Such a solution may represent a problem if one of those antennas will stop working properly (a similar problem, applicable for different directions, can be expected for the generally used option too). However, the combination of VHF antennas integrated in winglets and fuselage panels (i.e. systems to be developed in WP2 and WP5) may represent a very reliable way how to provide a fail proof solution with a good signal coverage in all necessary directions.

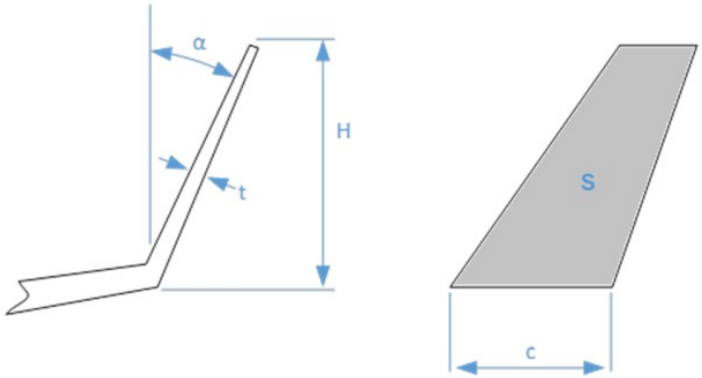

Figure 21. Illustrative representation of simplified winglet shape.

Table 11. Overview of basic winglet dimensions for different A/C platforms.

A/C platform:	Dimension:	Symb.	Value:	Info:
CS 100/ 300	Width	c	141 cm	Approximate value
	Thickness	t	3 cm (tip) 15 cm (root)	Approximate value
	Height	H	130 cm	Approximate value
	Angle	α	50°	Estimate
	Area	S	-	Total surface area in a winglet's plane (estimate)
A 320	Width	c	164 cm	Approximate value
	Thickness	t	3.4 cm (tip) 16.6 cm (root)	Approximate value
	Height	H	243 cm	Approximate value
	Angle	α	6.5°	Estimate
	Area	S	-	Total surface area in a winglet's plane (estimate)
EV55	Width	c	80 cm	Approximate value
(not optimized)	Thickness	t	2.7 cm (tip) 5.4 cm (root)	Approximate value
	Height	H	50 cm	Approximate value
	Angle	α	40°	Estimate
	Area	S	0.26 m^2	Total surface area in a winglet's plane (estimate)
Dassault Falcon	Width	c	TBD	Approximate value
	Thickness	t	TBD	Approximate value
	Height	H	TBD	Approximate value
	Angle	α	TBD	Estimate
	Area	S	TBD	Total surface area in a winglet's plane (estimate)

Strictly from the complexity of the design point of view, the difficulty of the winglet antenna design may be increased due to the angle of inclination between the main plane of the winglet's structure and the main vertical plane of an airplane (see Figure 21; EV55 has α=40°, see Table 11). Different aircraft structures use different winglets and higher angles of inclination between the antenna reference plane and the main vertical plane of an airplane can increase possible problems with finding optimal solutions for integrated antenna structures that should have good receiving/transmitting characteristics for vertically polarized VHF signals, but should not interfere with VHF navigation systems that are operating with horizontally polarized signals at nearby frequencies. This means that a winglet antenna should be designed in a way to not unintentionally radiate at horizontal plane in frequency range between 108 to 117.975 MHz (the mentioned problem may be more important in future if VHF communication services possibly start using the same frequency range too. See chapter 2.4 for more information).

Another possible issue related with the position of the winglet antenna can be seen in the fact that cables connecting the antenna with VHF communication units may be easily two times longer compared to those connecting a VHF antenna installed on an aircraft fuselage. Then it is logical to expect that such a solution will introduce more losses (insertion/cable loss) into the transmission chain between the antenna and receiving/transmitting unit. Increased insertion loss naturally has a negative impact to final performance of the whole VHF communication system (i.e. link budget calculation).

The last but the most important trade-off issue linked with a VHF antenna situated at the tip of an airplane's wing is a logical prerequisite of the antenna to operate in the most severe electromagnetic environment. The winglet structure is by default situated in lightning zones 1A, 1B, 2A, 2B (see Figure 13 elaborated using ARP 5414B: [4]). This means that a significant part or the whole winglet is likely to experience initial lightning attachment and first return stroke at least. In addition, the winglet, as a structural extremity, tends to hold the lightning channel (at its trailing edge) and there is a high possibility that both winglets will become a part of the lightning channel at the same time. In other words, winglet antennas and neighbouring circuits on both sides of an aircraft can be subjected to high currents (220 kA) and resulting high field intensities and induced currents / voltages in all possible forms - from signals with relatively long and flat waveforms up to bursts of very high and sharp peaks- at the same time (see SAE ARP 5412B: [2]).

Due to the above said, the winglet antenna has to have better and more complex protection against similar events, compared to the antennas situated on an aircraft fuselage.

Generally, such a protection would need to protect the winglet antenna from structural damage caused by a lightning strike (§23.867, §25.581) and, more importantly, prevent or suppress introduction of possible strong induced signals into the rest of aircraft electrical system (§23.1309, §25.1316). The most effective way, how to design similar protection, is to consider the winglet with integrated antenna as a whole complex system and to make the design certifiable (see ARP5577: [20], AC 20-107B: [21], AC 20-155A: [22]).

Another interesting trade-off issue may represent a conundrum how to fit a VHF antenna into a winglet with relatively small dimensions, like the one used on EV55 aircraft (see Figure 21, Table 11). Antenna's dimensions and geometry are tightly related with its operating frequencies (i.e. wavelengths), so its spatial needs represent a strict limiting factor if good RF performance is mandatory. In addition, winglet antenna will serve as a transmitter too, so it has to be adjusted for operation with relatively high power levels (input power generally ranges from 8 to 50 W when the VHF communication antennas operate with an input power up to 25 W). This means to take into consideration a good temperature management during its design too. Providing a good temperature management solution for the antenna could be difficult in tight spaces similar to those inside the winglet structure.

Another spatial trade-off issue may represent other systems that are usually integrated into a winglet structure. Those systems are position and navigation lights, P-static dischargers and lightning protection means (i.e. diverters). Lights are usually situated

near the winglet support and the lightning diverter is usually going along the winglet's leading edge from the front side of the support to the winglet's tip. It is advisable to keep a reasonable distance between the antenna and all the mentioned systems (ergo, the final space for integration of VHF antenna is even smaller).
The last but not least item to discuss is a design decision about modularity (or compactness) of the whole winglet system with integrated antenna. Such a design decision is tightly linked with parameters like the target aircraft platform, its maintenance plan, robustness of the final antenna system integrated into the winglet structure and its final financial aspects. It is clear that the end-user would not be inclined to buy an expensive winglet system knowing the winglet has to be replaced each time the antenna stopped working properly. On the other hand, a winglet structure (shell) may represent the least expensive part of the system for a small aircraft and its replacement may be relatively quick, compared to large transport airplanes. Therefore, the compactness (modularity) of the final solution has to be always adjusted to the target platform.
As an example, integrated VHF antenna can be designed as a modular part of the winglet for large transport aircraft like A320, mainly due to better maintenance options and time and financial demands connected with its possible replacement, or as an inseparable part of the cheap winglet for a small aircraft platforms like EV55.
Considering the less expensive design solution, a possible substitution of E-glass for Quartz glass should be assessed with respect to the final RF performance of integrated antenna and winglet's structural behaviour too.
Although Quartz glass has a better and more stable RF properties compared to E-glass including a better thermal stability and high in-use temperatures, E-glass has a higher strength and modulus as Quartz glass. So, except the fact that using E-glass solution may decrease the final cost of the design, it is possible that strength loads and conditions on a winglet structure may prevent us from using Quartz glass in specific design situations.

4.4.2. Trade-offs relevant for other platforms

Generally, all the trade-offs mentioned in previous chapter (Chapter 4.4.1) are applicable for other platforms under consideration too (see the Table 8). Differences of applicable trade-offs for the target platform and other platforms are mainly related with their different operational conditions and varieties of shapes and basic dimensions of a winglet structure.
The bigger dimensions will allow us to design VHF antenna with a better RF performance, because maximum space allowed for VHF antenna integration will not be as strict as for winglets used on a small aircraft. Similarly, an EMC engineer will have more space to propose a better and more robust protection against possible disturbing electromagnetic events (like a lightning strike) when making a design of the winglet structure and all the electronic devices integrated inside.
A correct combination of a better RF performance and protection will allow us to provide more reliable and performance oriented solution.
Contrary to the above said, there is one particular issue, which significance may rise up with increasing winglet dimensions, more specifically with its surface area: P-static interferences.
Aircraft can be charged due to vehicle's presence in a thunderstorm or due to triboelectric charging (friction) caused by different particles in airflow (snow, rain, dust, etc.). Materials with surface resistivity higher than 1 kΩ/square tend to develop significant electrostatic charges, because the charge will not bleed off from the target surface area. Charged areas may cause corona discharges from sharp edges, streamer discharges on dielectric surfaces or arc-overs between electrically isolated metallic sections. All the mentioned effects may cause P-static problems and are logically applicable to our case.
The above mentioned problems may become more severe not just because of the size of winglet's surface area, but due to inappropriate material choices too. To suppress possible P-static problems on winglet or VHF antenna structure, it is advisable not to

situate materials with different triboelectric charging potentials next to each other (e.g. Glass vs. Teflon, PVC, silicon, etc).

4.4.3. Actual TRL of the proposed system

Several technologies define the TRL for WP4; technologies on components level, on configuration level or on process level. The integration/manufacturing processes and the antenna technology have each different TRLs but for the complete winglet with integrated antenna, the ultimate TRL is dependent on the lowest TRL. Thus, one can state that the lowest TRL, when referring to the table in section 5.4.3, is at best **TRL 2**. This is the assessed TRL for the technology solution of WP4.

At this point, the following critical design aspects have been identified:

- Fitting the antenna within the space available. This will be a main challenge regarding the operating frequency relative to the available winglet space. A possible solution could be when considering a larger aircraft.
- Taking into account the lighting diverters in close proximity. The whole topic of the diverters and other lightning-protective provisions will be quite challenging because of the following aspects:
    - Such structures are usually made of metal which conducts/scatters EM-waves in an excellent way.
    - The lightning-protective devices are very close to the antenna structure, relative to the wavelength, hence coupling between the latter devices and the antenna is to be taken into account when designing the antenna.
    - The structures will considerably limit the available space within the winglet for the antenna due to the minimum safe distances between the lightning structures and the antenna.

4.5. Fibre metal laminate panel with VHF slot antenna and GPS patch antenna (WP5)

The antenna system will be integrated in the design of a Fiber Metal Laminate fuselage. General design requirements for such an integrated structure are defined in Appendix 2. From these requirements, the driving requirements will be selected to perform the trade study.
The requirements are based upon the target aircraft. For this study, the target aircraft is the Airbus A320 series. The specification of this aircraft is shown in Appendix 3.

4.5.1. Antenna and FML panel trade-offs

For WP5, the fuselage panel construction (FML) and the antenna types (patch and slot types) with their application and frequency ranges are given. Therefore, the following general trade-offs (development choices and evaluations) remain as in Table 12.

Table 12. Trade-offs for target aircraft.

Trade-Off Variable	Trade-Off Requirement	Criteria	TRL
Antenna type + location	Antenna application	RF wave propagation plane / Field of View	2+
Slot Antenna slot shape	Antenna performance	Radiation pattern	3
	Antenna installation Footprint	Generic FML Panel 'Cell' size	3
	Weight	Structural discontinuities	4
Patch Antenna Stacking (Multi-	Antenna performance	Radiation pattern	3
	Antenna installation	Generic FML Panel 'Cell' size	3

Trade-Off Variable	Trade-Off Requirement	Criteria	TRL
Antenna)	Footprint		
	Weight	Structural discontinuities	4
Patch Antenna border width	Antenna performance	Radiation pattern	3
	Antenna installation Footprint	Generic FML Panel 'Cell' size	3
	Weight	Structural discontinuities	4
Antenna Access Side	Aerodynamic smoothness	OML evenness OML transverse disturbances OML longitudinal disturbances	4
Antenna Depth	Enhanced Antenna installation Footprint	Generic FML Panel 'Cell' size	3
Lightning Protection	Antenna performance	Radiation pattern Direct/Indirect Strike Risk	4
Load bearing of antenna	Weight	Antenna stiffening weight	4
	Antenna performance	Radiation pattern under load	4
FML panel structural discontinuities	Weight	Stiffener/Reinforcement weight	3
FML fuselage panel 'window'	Lightning protection	Direct/Indirect Strike Risk Panel 'window' size Antenna surface depth below OML	4
FML fuselage panel 'window' finish	Erosion protection	OML evenness Transparency material Erosion resistance	4+
	RF transparency	Transparency material RF absorption	3
	Aerodynamic smoothness	OML evenness OML transverse disturbances OML longitudinal disturbances	4+
Antenna structural inclusion	Accessibility and Maintainability	Removable modules and components Component reliability and service life Antenna MTBF	4+
(Any) Component reliability	Component Weight	Operational / Functional margins Component reliability and service life Antenna MTBF	4+
	Component Cost	Fuselage panel Manufacturing cost Fuselage panel Direct Maintenance Cost	4+

Table 13. Panel definitions.

Definition	Description
Fuselage Panel 'Cell'	Fuselage panel section defined as between two adjacent frames and two adjacent stringers.
Panel 'Window'	Cutout made in the undisturbed fuselage panel skin for antenna installation purposes – providing a radiation window
Panel structural component	Load bearing fuselage structure component, such as: frame, stiffener and skin.

4.5.2. Aircraft application trade-offs (general)

For any aircraft, not just the target WP5 aircraft, the same trade-offs will apply – differing only in the trade-off criteria that are aircraft specific (Table 14).

Table 14. Trade-offs for other aircraft.

Trade-Off Variable	Trade-Off Requirement	Criteria	TRL
Antenna Location	Antenna performance	Blind spots	5+
	Aircraft System performance	Attenuation	6+
	Aircraft System Weight	Interconnection length and specific weight	6+
	Lightning Strike Risk	Lightning Zone Category Lightning Protection	5+
	Damage Susceptibility	Potential Erosion/Collision Areas Erosion Protection	5+
Antenna configuration	Structural Continuity	Fuselage Panel 'Cell' size Antenna Installation Footprint	6+
	Direct Maintenance Costs	Reliability figures Material costs Maintenance/Repair procedures	6+
Aerodynamic drag reduction	Fuselage interior space	Antenna depth Antenna access space	5+
	Weight	Estimated net fuel burn	5+
	Cost	Estimated net operating cost	5+

NOTE: Since WP5 has the indicated end state of TRL4, it has to be determined which one of these trade-offs applies.

Table 15. Antenna configuration.

Definition	Description
Antenna configuration	Type of antenna (conformal, slot, patch, dipole, monopole), integration method (embedded, separate) and build-up (by components)

4.5.3. TRL assessment of current technology solutions.

For WP5, several technologies define the integrated solution. Therefore the ultimate TRL is dependent on the lowest TRL. Technologies for the integrated technology solution are either for components, configuration method or for technology application.

The components of the technology solution are the two types of conformal antennas to be integrated, as well as the fuselage panel hybrid construction from Fibre Metal Laminate and whole-metallic components.

The integration method of the technology solution is to integrate the antennas into the fuselage panel as an integral component. This means that both the fuselage panel as well as the antenna become more multi-functional components; antennas will perform (partially) as structural components, and the fuselage panel will perform some antenna functions. Most important aspect of the integration will be a more efficient method of

restoring the fuselage panel strength which will be lost by the required antenna windows in the fuselage skin.

The technology solution may have been applied to other vehicles before, such as land or sea vehicles, but not as such for CS23/25 or FAR23/25 aircraft.

The lowest TRL in Table 16 is **TRL2** – this is then also the assessed TRL for the technology solution of WP5.

Table 16. TRL assessment for WP5.

Category	Technology Item	1	2	3	4	5	6	7	8	9
Technology Components	slot antenna	x	x	x	x	x	x	x	x	
	patch antenna	x	x	x	x	x	x	x	x	
	FML fuselage panel structure	x	x	x	x	x	x	x	x	
Technology Method	Integral installation of fuselage panel and antenna	x	x							
	Integral antenna unction sharing between fuselage panel and antenna	x	x							
	Integral load sharing between fuselage panel and antenna	x	x							
Technology Application	CS23/25, FAR23/25 type aircraft	x	x							

The technology components are assumed to have reached at least TRL8; examples of patch antennas and slot antennas can be found for other applications than for aircraft, and FML material has been already used for in-service aircraft fuselage constructions.

All other Technology Items have yet to have their requirements validated, as well as their key technologies defined and tested. These Technology Items have not yet been developed into working prototypes, nor have these been tested as breadboard.

Table 17. Interpretation of TRL levels.

TRL	Meaning / Intent	Proof / Evidence (Sort)
1	Concept – Principle defined	Working principle analysis
2	Concept – Requirements Defined	Functional Analysis Requirements validation
3	Concept – Component samples and coupons	Key technology functions 'breadboard' tested and verified
4	Prototype – Functional performance	Working prototype laboratory tested for baseline and variance performance
5	Prototype – Environmental robustness	Prototype subjected to relevant environmental conditions and performance tested.
6	Prototype – System interface validation	Prototype tested as part of a real life system for performance, working and system interactions
7	Product – Build and Qualified	Product designed and developed for based on industrialization requirements, and qualified for the intended

TRL	Meaning / Intent	Proof / Evidence (Sort)
		application.
8	Product – Function-tested and Certified	Product has been implemented in the intended application (system) and successfully completed operational (certification) tests
9	Product – Operationally validated	Product has been in service and accumulated significant data.

5. Criteria for assessment of performances of structures with integrated functions

5.1. Objective

The objective of this chapter is to define essential criteria for assessment of performances for the newly developed structures with integrated functions.
The criteria, which are very heterogeneous, will be used at the end of the project to assess the progress of the research carried out.

5.2. Criteria

5.2.1. Load bearing capabilities

5.2.1.1 Fuselage panel with embedded antenna tiles

The panel with integrated antennas will be tested to verify its performance. The requirement for a successful test will be the that there is no damage to the panel and antenna tiles if tested to design limit load (DLL) and no failure when tested to design ultimate load (DUL, which is 1.5 x DLL).

5.2.1.2 Fuselage panel with sensors and actuators for reduction of cabin noise

The fuselage panel will be designed according to known basic dimensions and thicknesses. The integration of actuators, sensors and wiring between different fibre layers will not weaken the structure significantly. The prototype fuselage that will be built in this project will not be subject of full scale load or fatigue tests.

5.2.1.3 Winglet with integrated VHF antenna

As specified in the subchapter 2.4 of this document, the new winglet with integrated VHF antenna will be designed not to generate more loads than the existing winglet of EV-55. A compliance with this requirement can be proven using CFD calculations and/or wind tunnel. Considering the shape and material complexity when the winglet is from composite material (GRFP) and wing body is from aluminum alloy, the test of an assembly consisting from the winglet and part of wing is necessary to include a stiffness effect of adjacent structure. As the metallic wing must be designed for 1.5 multiple of operational load (CS 23.303, 23.305), but the composite winglet up to 1.5x1.5x1.07 multiple of operating load (see also CS 23.603, 23.605, 23.613, 23.619 + AMC 20-29, AMC CS-VLA 619(b)), the metallic structure might be collapsed sooner than the necessary load for the winglet compliance is achieved. Antecedent suitable FEM analysis can verify whether the metallic structure is able to carry increased load required for strength proof of composite winglet.

It is necessary to find the best compromise between the endurance test of the winglet itself and its mechanical attachment to the end of wing as the minimum and the effect of the new winglet on the wing in its entirety (whole the wing span) as the maximum if allowed by the project budget. If the winglet is not considered as an EV-55 primary structure, a proof of compliance with CS 23.573 (Damage Tolerance and Fatigue Evaluation of Structure) is not necessary.

5.2.1.4 Fibre metal laminate panel with integrated antenna

The panel with integrated antennas will be tested to verify its performance. The requirement for a successful test will be that there is no damage to the panel and antenna tiles if tested to design limit load (DLL) and no failure when tested to design ultimate load (DUL, which is 1.5 x DLL).

5.2.2. Production costs

5.2.2.1 Fuselage panel with embedded antenna tiles

The cost of an external Ku-band phased array antenna is in the order of € 100.000. These costs are primarily determined by the costs of the active electronics, the multilayer PCBs and the cooling solutions. The integrated antenna will have the same active electronics and multilayer PCBs as an external antenna. Dedicated cooling solutions will be implemented as well. Therefore it is expected that the costs of the integrated Ku-band antenna will be in the same order of magnitude as the costs of an external antenna.

Using an automated manufacturing method such as fibre placement can bring labour cost down while enabling weight reduction through optimisation of the lay-up and increase quality through improved repeatability. The rib stiffening method offers the possibility to manufacture a stiffened panel without additional support tooling and intermediate steps, e.g. preforming of hat stiffeners for subsequent co-cure.

5.2.2.2 Fuselage panel with sensors and actuators for reduction of cabin noise

For the integration of actuators, sensors and wiring into the fuselage, additional steps in the manufacturing process are necessary. The so-called smart-layer must be manufactured in advance and finally be integrated "in one-shot" during the fuselage process. Therefore, the cost can be subdivided into two parts: the costs of the smart-layer and the integration of the layer into the fuselage. The costs of the smart-layer are driven by the number of actuators and sensors. The integration costs depend upon the working hours needed. Nevertheless, the increase of costs of the fuselage due to the smart-layer should not exceed 5 %.

5.2.2.3 Winglet with integrated VHF antenna

The following assumptions are taken from the DoA:

- *Manufacturing costs are recurrent cost related to labour costs and material costs.*
- *The manufacturing cost of these smart structures is estimated to be approximately 5 –25% less than the costs of the separate components and the cost of installation thanks to the fact that less manufacturing steps are required and the fact that the system contributes to the airframe structure. Moreover, the cost of manufacturing a separate UHF antenna and a separate winglet will be*

larger than the costs of a winglet with integrated antenna, because the non-integrated UHF antenna does require a separate radome for the packaging of the PCB with antenna. The same holds for the other smart structures.

- *For out-of-autoclave manufacturing 25-35% of costs can be saved by using innovative CFRP tooling including an injection monitoring system. Another aspect contributing to the cost reduction is the approach to realize an integrated structural design, where no downstream assembly processes are required.*
- *The labour costs for assembly of the smart structures with integrated systems will be also less than the assembling cost of the separate systems.*

Table 18. Production costs.

Production costs criteria	**Satcom fuselage panel**	**Active Acoustic fuselage panel**	**Winglet with integrated antenna**	**FML fuselage panel**	**Impact on labour / material ratio**
Replacement of existing solution	Yes	No, higher production costs, benefits in fuel consumption (CROR) and ergonomics (cabin noise)	Yes	Yes	50/50
Additional new system introduced	No	Yes	No	No	50/50
Additional system provisions (additional labour)	No	Yes	No for antenna, yes for cable in wing		100/0
Reduced system provisions (reduced labour)	No	No	Separate antennas, gaskets, brackets in fuselage		100/0
Material consumption	Less	More	Less		0/100
Material costs	Same or less	More	Same or less	Same or less	0/100
Energy consumption	Same	More (sensor actor, controller production,…)	Less, compared antenna-winglet to winglet plus antennas		50/50
Number of individual items	Less		Less		20/80
Limited supplier base due to complexity (costs of labour)	No (can be made using different materials and by		No		100/0

Production costs criteria	Satcom fuselage panel	Active Acoustic fuselage panel	Winglet with integrated antenna	FML fuselage panel	Impact on labour / material ratio
	different suppliers)				

Production costs criteria in the table are always linked to the comparison with the existing technical solution. The innovative structure development and engineering shall have these criteria as a minimum target. For example w.r.t. materials: the materials to be selected are the same as for the existing solutions or are available from similar aircraft structures. Do not select material with limited sources or higher material costs as a benefit would be from eased production and therefore cost reduction potential. For example w.r.t. energy consumption: assuming the optimum process was selected for the existing solution. The integrated solution is based on that process driven by the process needed for the primary structure.

Overall production costs of the aircraft could be reduced based on OEMs procurement policies as the integrated smart structures can be assembled or can be delivered in subassemblies in the supply chain at different tier level.

This should not be mixed up with maintenance or operational costs. For the assessment in WP6 each innovative structure shall provide a breakdown of the criteria at item level compared to the existing solution. The breakdown can also validate the ratio of labour and material. In order to achieve an acceptable level of detail the breakdown is limited to primary structure, integrated smart system, interfaces from structure to smart system and interfaces from smart structure to the aircraft.

5.2.2.4 Fibre metal laminate panel with integrated antenna

The costs of classical protruding VHF and GPS antennas (compliant with the aviation requirements (environmental, MOPS, TSO) are in the order of € 500 to € 1000.
The production costs of the integrated VHF and GPS antennas shall be in the same order of magnitude. The costs can be slightly higher because it is expected that the antennas have a longer lifetime and less maintenance is needed (TBC).

5.2.3. Maintainability

The maintenance of aircraft is highly regulated, in order to ensure safe and correct functioning during flight. National regulations are coordinated under international standards, maintained by bodies such as the International Civil Aviation Organization (ICAO). The maintenance tasks, personnel and inspections are all tightly regulated and staff must be licensed for the tasks they carry out.

The Maintenance Planning Document MPD is the source document providing maintenance planning information necessary for operators to generate a dedicated or customized Aircraft Maintenance Program AMP. The MPD should not be considered the final document in determining appropriate maintenance and each operator has direct responsibility to decide what maintenance must be performed and when it should be done.
However in the case of both Airworthiness Limitations (AL) or Airworthiness Limitation Items (ALI) and Certification Maintenance Requirements (CMR), the operator must ensure full compliance with all requirements – A CMR is a required periodic task

established during the design certification of the airplane as an operating limitation of the Type Certificate (TC).

Each Maintenance task must be described fully in Instructions for Continued Airworthiness ICAW, for example the Aircraft Maintenance Manual (AMM). Airworthiness Limitations (AL) are a regulatory approved means of introducing inspections or maintenance practices to prevent problems with certain systems. Mandatory replacement times, inspection intervals and related inspection procedures for structural safe-life parts are included in the AL document. As well as the scheduled tasks the various requirements of Service Letters (SL), Service Bulletins (SB) and Airworthiness Directives (AD) The operator must have a process to analyze the information and ensure appropriate compliance.

5.2.3.1 Fuselage panel with embedded antenna tiles

Maintainability and repair:
The Ku-band antenna will have a modular configuration. It shall be possible to replace antenna tiles (10 x 10 cm, 64 antenna elements) from the inside of the fuselage panel. Repairs to the cooling system should also be possible from the inside.

As the antenna contains active electronics, the chance exists that during the lifetime malfunctions occur. It must be possible to access the tiles from the inside of the cabin for repairs.

Presently installed Ku-band antennas use mechanical steerable dishes or mechanically steerable antenna arrays. It is well-known that such systems are also subject to mechanical vibrations, which can cause damage. The Ku-band SATCOM antenna array in the ortho-grid stiffened fuselage is less vulnerable for vibrations because it is more compact and has no moving parts. Furthermore, this integrated antenna array can be made accessible from within the cabin which allows quick mounting and dismounting of antenna tiles.

Periodic check of critical antenna functions:
The Ku-band antenna will have a controlling unit that performs a check at start-up and that performs the internal calibration of the antenna. Any malfunctioning of the antenna will be notified to the crew. Periodically, e.g. during C-checks every 18 months, a more comprehensive test can be carried out. This test can include a stationary test of reception of the satellite link under controlled conditions.

Non-destructive inspection (NDI) of composite fuselage walls from the outside is required during regular maintenance checks, but also in case of accident on-ground (e.g. collision with ground cargo). Damage due to collisions is visible on aluminium walls, but usually not on CFRP walls due to the elasticity of the material; it returns to its original form while there can be considerable internal damage due to delamination. This mechanism plays an essential role in composite certification: barely visible impact damage (BVID) and associated allowable strain levels need to be taken into account during design. NDI must be used to assess the damage and ensure the integrity of the structure. E.g., inspections of critical areas using ultrasonic methods should not be made impossible by the presence of intermediate PCB layers in the composite laminated structure.

5.2.3.2 Fuselage panel with sensors and actuators for reduction of cabin noise

Maintainability and repair:

The integration of the actuators and sensors guarantees for a lifetime protection from environmental damage. Due to the integration, a repair of single components is not possible. In case of damage (impact or component failure) the affected part of the fuselage has to be replaced with a new one or new actuators and sensors have to be placed and wired on the inner side of the fuselage.

Periodic check of critical functions:
The Active-Structural-Acoustic Control (ASAC) system can be checked before each take-off by the controller using the actuators and listening to the sensors. Every sixth month or more in-depth test should take place.

Non-destructive inspection:
A section-wise check of functionality can be done by system identification of the controlled plant. In this test the actuators are driven by uncorrelated noise signals while the sensor signals are recorded. Failures of the structure, especially at locations where actuators and sensors are integrated, can be detected using Structural Health Monitoring (SHM).

5.2.3.3 Winglet with integrated VHF antenna

During the lifetime of an antenna integrated in a winglet replacement of the complete winglet shall always be possible, e.g. after a lightning strike on the aircraft. Repair of the antenna is not possible because it is completely embedded in the winglet.

With respect to the integrated antenna in the winglet, several aspects of maintenance are considered. Defined wiring and structural interfaces are designed, tested and assessed. This allows for defined repair kits that can be stored and employed in case of manufacturing and repair at certified maintenance locations. Furthermore, repair during manufacturing processes is allowed and risks for loose wiring or contacting are compensated and, thus, the advantageous potential of integrated antennas in winglets is maintained.

Periodic check of critical antenna functions: As specified in the generic Light Aircraft Maintenance Schedule CAP 411 [38] from the British CAA, there are two maintenance tasks referred to VHF antenna system in the Section 8 of this document. They are Task 37 (Inspection of aerials, insulators, controllers, instruments, displays, microphones, headsets, jackplugs and sockets) and Task 39 (Operational check of VHF ground functions), both with the period of 50 flight hours or 6 months.

Non-destructive inspection: As the acceptable guidelines for non-destructive testing and inspections after a winglet repair can be used ARP5089 [29] and ARP5605A [30] elaborated by CACR committee of SAE, when respecting all the CMR and CSR requirements given in the Part 66 and Part 145 issued by EASA or FAA.

5.2.3.4 Fibre metal laminate panel with integrated antenna

During the lifetime of an antenna integrated in a fuselage panel small repairs (e.g. of the connector or the feed PCB) shall be possible. These repairs will be possible from the inside of the fuselage.

Protruding VHF antennas are visually inspected during so-called C-checks which are performed at least every 18 months. Most often inspected damage during regular C-checks is corrosion of connectors and imperfect sealing of the antenna foot. In addition, blade antennas on the lower side of the fuselage are sometimes damaged due to collisions with ground cargo, and then require replacement.

The installed cabling and wiring seems to be sensitive to damage at suspension points due to vibrations.

Non-destructive inspection (NDI) of composite fuselage walls from the outside is required during regular maintenance checks, but also in case of accident on-ground (e.g. collision with ground cargo). Damage due to collisions is visible on aluminium walls, but usually not on CFRP walls due to the elasticity of the material; it returns to its original form while there can be considerable internal damage due to delamination. This mechanism plays an essential role in composite certification: barely visible impact damage (BVID) and associated allowable strain levels need to be taken into account during design. NDI must be used to assess the damage and ensure the integrity of the structure. E.g., inspections of critical areas using ultrasonic methods should not be made impossible by the presence of intermediate PCB layers in the composite laminated structure.

5.2.4. Lifetime etc.

5.2.4.1 Fuselage panel with embedded antenna tiles

The lifetime of an antenna in a fuselage panel shall be in the same order as the minimum lifetime of the aircraft because replacement of a fuselage panel is very costly. Therefore the minimum lifetime of these integrated antennas shall be 30 years. During this period small repairs (e.g. of the connector) should be possible.

The fuselage structure of the panel developed in WP 2 antenna tiles should be able to withstand LL and UL as described in paragraph XX. The antenna tiles must be able to withstand these loads as well without ceasing to function.

5.2.4.2 Fuselage panel with sensors and actuators for reduction of cabin noise

The lifetime of the actuators depends upon the cycles they have seen during operation. The sensors should have nearly unlimited lifetime compared to the entire aircraft. They are well capsulated and hidden from environmental damage. The actuators may lose performance and have to be checked within the D-check.

5.2.4.3 Winglet with integrated VHF antenna

The lifetime of an antenna in a winglet shall be at least 6 years but preferably 12 years (TBC). The performance of the antenna should be checked during D-check (every 6 years) and replaced if necessary. Replacement of the winglet antenna should always be possible, e.g. after a lightning strike on the aircraft.

5.2.4.4 Fibre metal laminate panel with integrated antenna

Same as 5.2.4.1.

5.2.5. Means of verification for primary aerospace structures

For primary aerospace structures, no actual detailed standard is available as for antenna electronics in which a very detailed set of requirements is defined. Aerospace structures must comply with the regulations to ensure the application meets the safety requirements set by the responsible aviation regulatory authority. The safety requirements are set out in e.g. the Certification Specifications (CS) by EASA in Europe or Federal Aviation Regulations (FAR) by the Federal Aviation Administration (FAA) in the USA.
The manufacturer must present the project to the certification authority and propose the set of rules that will apply for the certification of this specific component (Certification Basis), which has to be approved by the certification authority.
The certification authority and the manufacturer must then define and agree on the means to demonstrate compliance of the aircraft structure with each requirement of the Certification Basis.
The manufacturer must demonstrate compliance of its product with regulatory requirements. In this case, the structure is analysed against the Certification Basis. This compliance demonstration is often done by testing supported by analysis. Experts from the certification authority perform a detailed examination of this compliance demonstration, by means of document reviews and by attending some of these compliance demonstrations, witnessing the tests in person.
If technically satisfied with the compliance demonstration by the manufacturer, the certification authority accepts the results from demonstration and the structure can be used.

The previous is only a very brief summary of the certification process. Within ACASIAS it is not the aim to certify a structure, only to demonstrate it in a laboratory environment (TRL 4) or relevant environment (TRL 5).

5.2.6. RF performance

5.2.6.1 Fuselage panel with embedded antenna tiles

The parameters to be assessed for the RF performance of the integrated antenna are frequency and bandwidth, (installed) radiation pattern (gain) and polarisation. The requirements for these parameters are given in section 3 ("RF characteristics and requirements of airborne antennas to be integrated"). The verification of these parameters will be through measurements of the antenna performance in the facilities of the partners.

In addition the antenna shall be able to withstand lightning strikes. The design of the antenna shall include a lightning protection. The requirements for direct lightning effects are given in section 6 (Tailoring of antenna requirements within industry standards). The verification of these lightning requirements will be trough tests at an external facility.

5.2.6.2 Winglet with integrated VHF antenna

As specified above, the essential parameters to be assessed for the RF performance of the winglet integrated antenna are frequency and bandwidth, radiation pattern (gain) and polarisation to be evaluated together with appropriate integrated part of the airframe location (or the airframe in its entirety). The requirements for these parameters are given in Section 3 (see the subchapter 3.3 Winglet with integrated VHF antenna). The verification of these parameters will be through measurements of the antenna

performance in the facilities of the partners and verified using a test flight (radiation pattern).

In addition the antenna shall be able to withstand lightning strikes if its design shall include a lightning protection. The requirements for direct lightning effects are given in the section 6 (Tailoring of antenna requirements within industry standards). The verification of these lightning requirements will be through tests at specialized external facility.

5.2.6.3 Fibre metal laminate panel with integrated antenna

The parameters to be assessed for the RF performance of the integrated antenna are frequency and bandwidth, (installed) radiation pattern (gain) and polarisation. The requirements for these parameters are given in section 3 ("RF characteristics and requirements of airborne antennas to be integrated"). The verification of these parameters will be through measurements of the antenna performance in the facilities of the partners.

5.2.7. Noise and vibration reduction

5.2.7.1 Fuselage panel with sensors and actuators for reduction of cabin noise

Reduce sound transmission through the fuselage/lining by up to 8 dB in the first five CROR frequencies.

5.2.7.2 Airframe Integrated Antennas (in general)

Even if the antenna integration into the airframe skin as well as winglets has surely positive effect also for an aerodynamic noise and possible vibration, its effect is negligible, when the CROR engines are in operation. That means no criteria are established for this possible reduction.

6. Tailoring of antenna requirements within industry standards

6.1. Objective

Appropriate industry standards are often referred in AMCs or ACs as guide materials for airframers to prove a compliance with individual regulation items when they apply for TC or STC and also in ETSOs or TSOs for any airborne equipment to be installed in various air vehicles. They simplify a communication among airframers, airborne equipment manufacturers and civil aviation authorities to define requirements for aircraft or equipment airworthiness.

Systems to be developed have to obey general airworthiness demands put on them through aircraft certification, guidance and advisory materials and, along with the demands, have to provide additional functionalities endowed to them during their design specification. A selection of airworthiness materials applicable to antenna installations is provided in Table 19, where industrial standards are specified at the appropriate regulation items and possible AMCs and ACs.

Other types of equipment requirement specifications are TSOs and ETSOs, where the environmental and operational requirements are specified. The environmental requirements are generally specified in terms of the industry standard ED-14G or DO-160G and its categories ([7], [8]). The wording of its European and US version is the same when simultaneously updated by EUROCAE and RTCA respectively.

Other situation seems to be for referred industrial documents, if the operational requirements are to be specified, when only the reference to MOPS (like DO-186B, [14]) in TSO is applicable for antenna requirements.

The reliability parameters for antennas (mean time between failures and mean time to repair) can be specified using standard procedures discussed in the EUROCAE / SAE ARP standards ED-136 / ARP4761 and ED-79A / ARP4754A on the base of a system criticality (IDAL) for the system which is the antenna part of (see [10], [11], [12], [13]).

Applicability of composite materials to newly developed antenna structures is bringing new requirements also for their workmanship, maintainability, repairability and testing. A standardisation in these fields is always in progress and activities of SAE and its CACRC committee were flown into applicable industrial standards and handbooks. They refer to material specifications (CMH17 [18], AMS3970A series and AMS 2980B series), standard methods of their processing (AE-27 [34], ARP4916 [33], ARP5256 [31]), guidelines for repair procedures, tooling and non-destructive testing and inspections (AIR5367 [36], AIR6291 [35], AIR5431 [32], ARP5089 [29] and ARP5605A [30]).

Requirements for the individual antennas with reference to industrial standards are specified in the following sections.

Table 19. Regulation Items and Industry Standards Applicable for External Airborne Antennas.

Regulation Sections	Items of A/C Building Regulations		Acceptable Means of Compliance		Referred Industry Standards	
	CS-25/FAR-25	CS-23/FAR-23	AC (FAA)	AMC (EASA)	EUROCAE	SAE / RTCA
Structure	25.301 Loads	23.301 Loads		AMC 25.301		
	25.303 Factor of Safety	23.303 Factor of Safety				
	25.305 Strength and Deformation	23.305 Strength and Deformation				
	25.307 Proof of Structure	23.307 Proof of Structure	AC 25.307-1	AMC 25.307 AMC 23.307		
	25.365(e) Pressurized Compartment Loads	23.365(e) Pressurized Cabin Loads		AMC 25.365		
	25.571 Damage Tolerance, Fatigue Assessment, Parts Departing Aircraft, Birdstrike – section 25.571(e)(1)	23.573 Damage Tolerance and Fatigue Evaluation of Structure	AC 25.571-1D AC 20-107B	AMC 25.571 AMC 23.573 AMC 20-29		
	25.581 Direct Effects of Lightning	23.867 Electrical bonding and protection against lightning and static electricity	AC 25.899-1	AMC 25.581	ED-84B [1] ED-91B [3] ED-105A [5] ED-152 [15] ED-113 [19]	ARP5412B [2] ARP5414B [3] ARP5416A [6] ARP5672 [16] ARP5577 [20] ARP1870A [17]
Design and Construction	25.601 General	23.601 General				
	25.603 Materials	23.603 Materials and workmanship	AC 20-107B	AMC 20-29		CMH-17 [18]
	25.605 Fabrication Methods	23.605 Fabrication Methods				
	25.609 Protection of Structure	23.609 Protection of Structure		AMC 20.609		
	25.611 Accessibility Provisions	23.611 Accessibility Provisions		AMC 23.611		
	25.613 Material Strength Properties and Material Design Values	23.613 Material Strength Properties and Design Values	AC 25.613-1	AMC 25.613 AMC 23.613		
	25.629 Aeroelastic Stability Requirements	23.629 Flutter	AC 25.629-1B AC 23.629-1B	AMC 25.629		
	25.631 Bird Strike Damage	N/A	N/A	AMC 25.631		
	25.841 Pressurized Cabins	23.841 Pressurized Cabins				
	25.901 Power Plant Installation	23.901 Power Plant Installation	AC 20-135	AMC 25.901		
	25.1419 Ice Protection	23.1419 Ice Protection	AC 25.1419-1A AC 23.1419-2D AC 20-73A	AMC 25.1419		
Equipment	25.1301 Function and installation	23.1301 Function and installation	AC 43.13-2B AC 43-13-1B	AMC 25.1301	ED-23C [13]	DO-186B [14] ARP1870A [17]
	25.1309 Equipment, systems and installations	23.1309 Equipment, systems and installations	AC 25.1309-1A AC 23.1309-1E	AMC 25.1309	ED-79A [11] ED-136 [9] ED-14G [7]	ARP4754A [12] ARP4761 [10] DO-160G [8]
	25.1316 Electrical and electronic system lightning protection	23.1306 Electrical and electronic system lightning protection	AC 20-136B AC 20-155A	AMC 25.1316 AMC 20-136	ED-105A [5] ED-14G [7]	ARP5416A [6] DO-160G [8]

Note : Some applicable industry standards are not referred in the appropriate ACs or AMCs, but they are referred directly by authorities using CRIs or Issue Papers.

6.2. Fuselage panel with embedded antenna tiles

Introduction

It is assumed that the antenna tiles are accessible from the inside of the aircraft. So the antenna tiles are in a pressurized and temperature controlled environment. The antenna contains active electronics with thermal cooling solutions. The function performed by the antenna (Ku-band satellite communication for passenger entertainment and airline logistics) is not a critical function.

In ACASIAS the antenna will be developed up to TRL 5. Technology validated in a relevant environment (industrially relevant environment in the case of key enabling technologies). Testing for TRL 5 will focus primarily on the aerodynamic and mechanical loads to be expected during operation. For testing of fuselage panels up to TRL5, NLR has a test rig with capability to subject fuselage skin sections to biaxial loading conditions which are typical for fatigue and static design loads of the fuselage crown section of civil aircraft. In addition tests will be carried out to verify the thermal cooling solutions. No environmental tests such as temperature, pressure or vibration are planned. However, the requirements for the environmental conditions should be taken into account in the design.

In Table 20 the applicability of specific sections of EUROCAE ED-14G [7] is given.

Table 20. EUROCAE ED-14G "ENVIRONMENTAL CONDITIONS AND TEST PROCEDURES FOR AIRBORNE EQUIPMENT".

EUROCAE ED-14	Applicability
Section 4.0 Temperature and Altitude	Applicable
Section 5.0 Temperature Variation	Applicable
Section 6.0 Humidity	Applicable
Section 7.0 Operational Shocks and Crash Safety	Applicable
Section 8.0 Vibration	Applicable
Section 9.0 Explosion Proofness	Not applicable
Section 10.0 Waterproofness	Applicable
Section 11.0 Fluids Susceptibility	Not applicable
Section 12.0 Sand and Dust	Not applicable
Section 13.0 Fungus Resistance	Not applicable
Section 14.0 Salt Spray	Not applicable
Section 15.0 Magnetic Effect	Applicable
Section 16.0 Power Input	Applicable
Section 17.0 Voltage Spike	Applicable
Section 18.0 Audio Frequency Conducted Susceptibility - Power Inputs	Applicable
Section 19.0 Induced Signal Susceptibility	Applicable
Section 20.0 Radio Frequency Susceptibility (Radiated and Conducted)	Applicable
Section 21.0 Emission of Radio Frequency Energy	Applicable
Section 22.0 Lightning Induced Transient Susceptibility	Applicable
Section 23.0 Lightning Direct Effects	Applicable
Section 24.0 Icing	Not applicable
Section 25.0 Electrostatic Discharge	Applicable

EUROCAE ED-14	Applicability
Section 26.0 Fire, Flammability	Applicable

6.2.1. Lightning protection

The antenna should be protected against direct lightning effects according to EUROCAE ED-14G/RTCA DO-160G section 23. The lightning zone for the VHF antenna and the GPS antenna is 2A (TBC). An overview of the lightning zones is given in Figure 22.

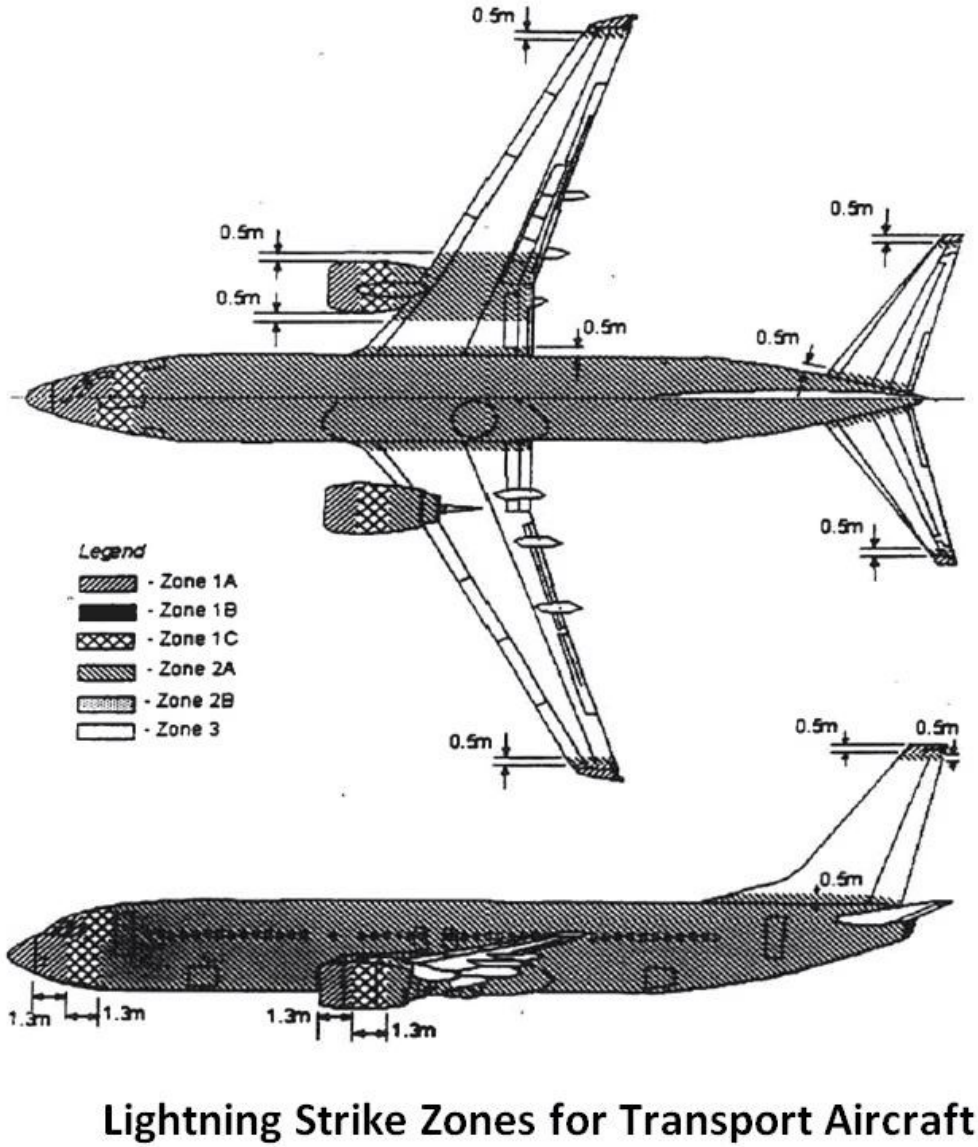

Figure 22. Lightning Strike Zones for Transport Aircraft (EUROCAE ED-14G).

6.2.2. Thermal requirements

Operational requirements, antenna power consumption, heat sink options/restrictions for the Ku-band antenna of WP2.

6.2.2.1 Operational requirements

Based on our discussions with satellite internet providers and research surveys, an antenna for in-flight entertainment (Internet-in-the-sky) is normally only operated when the plane is at cruising altitude. During take-off and landing, the system should be switched off or on stand-by.

6.2.2.2 Duty cycle of the antenna

The worst case duty cycle of the antenna is assumed to be 100%. It is however expected that due to the large amount of electronic components, a start-up time is required in order to achieve a thermal equilibrium before the antenna can be operated.
The operational temperature is in general determined by the operating conditions of the RF-components. At the moment, GaAs still has superior performance with respect to SiGe and CMOS regarding power output, noise figure and linearity, hence it is assumed for ACASIAS that the PA's and LNA's used will be GaAs-based. The normal operating range of these components goes from -40° to +85° C (this is a typical range determined by the maximum junction temperature of the transistor). As a result, the system cannot reach a temperature above 85° at the locations of the GaAs-chips without risking permanent damage.

6.2.2.3 Power consumption

At this point it is not exactly clear, how large the antenna will be. Therefore all calculations are performed on basis of an antenna tile size of 8x8 antenna elements. Power consumption and heat dissipation can then simply be scaled up with the number of tiles for a full size antenna.
Also, only assumptions can be made regarding the power consumption because no components have been selected yet. In order to arrive at a first, estimated figure, the following assumptions have been made:

- Example PA HMC994APM5E: PDC = 2.5 W
- One Tx-tile of approximately 8 x 8 cm2 contains 64 PA's (based on operating frequency 14 – 14.5 GHz)
- Example LNA CHA2066: PDC = 0.2 W
- One Rx-tile of approximately 9 x 9 cm2 contains 64 LNA's (based on operating frequency 10.7 – 12.75 GHz)

Therefore the power consumption Tx-tile = 160 W & Power consumption Rx-tile = 12.8 W
This power budget does not include any up/down converters, digital components, and modem components yet.
It is clear from the figures above that Tx will pose the largest thermal challenge from RF-point of view. It will be the aim to select l a Ku-band PA that has the lowest possible DC consumption because a distributed PA architecture is used (i.e. each antenna element has its own PA) and the power radiated per antenna element can be relatively low. Alternatively, one could consider also the application of LNA as PA if its P1dB is sufficiently high, thus reducing the total power consumption.

6.2.2.4 Antenna efficiency

The antenna efficiency will be determined for the larger part by the efficiency of the PA and LNA components. These components are the most efficient when operated at their P1dB. This is however not always possible because a margin (back-off) has to be taken into account when using certain modulation schemes. Also, the efficiencies of the PA and LNA are of importance. The PA selected as a preliminary reference (HMC994APM5E) has a PAE (Power Added Efficiency) of 23% (assumed when operated close to the P1dB compression point), i.e. 23% of the consumed DC-power is transferred into RF-power,

the remaining part is dissipated. For the LNA, no value is stated but for an operation near the P1dB point, a PAE of 5% can be calculated based on the datasheet information. The total power dissipated in form of heat for Tx & Rx will be 160 x 0.75 + 12.8 x 0.95 = 132 W/tile.

6.3. Winglet with integrated VHF antenna

6.3.1. Environmental conditions

Environmental conditions for testing of the winglet-integrated antenna are given using environmental categories specified by the industrial standards ED-14G / DO-160G ([7], [8]). Applicability of these categories for any airborne equipment in general depends on the aircraft type, nature of the equipment and location of its installation.
If taking into consideration the special case of VHF antenna integrated inside the winglets of EV-55, categories of the Sections 4 up to 8 and Sec.10 (temperature, altitude, humidity, shock, vibration and waterproofness) are specified with traceability to the general flight profile and supposed use of the aircraft when Sections 9 and 11 up to 15 (explosion, fluids, sand and dust, fungus, salt spray and magnetic effects) are not applicable. If the antenna is passive equipment (PA and LNA are integrated in appropriate transceivers), the Sections 16 up to 22 (power supply and spurious signal susceptibilities/generation) and 25 (electrostatics) are not applicable too. On the other hand, categories of the Sec. 23 and 26 (direct lightning and flammability) are to be considered in accordance with the installation locations of the antenna.

When installing the winglet-integrated antenna in another aircraft, applicability of all the ED-14 / DO-160 sections has to be evaluated again namely when amplifiers are integrated in the winglet together with the radiation elements (see the Sections 16 up to 22 and Sec. 25).

6.3.2. Operational requirements

Operational requirements for VHF communication system (by means of which the winglet –integrated antenna is a part) are to be kept under all the supposed tests given using the previously mentioned environmental categories (see Chapter 6.3.1). These requirements (frequency range, modulations, channel spacing, etc.) are specified by the industrial standard RTCA DO-186B [14][1] that is referred by TSO-C169a.

As the document refers to the VHF communication system in its entirety, only the requirements for VHF antennas are selected and their importance and applicability for winglet-integrated antenna are evaluated. They are: frequency range, output power, antenna VSWR and antenna efficiency.

- Frequency Range

The requirements for frequency range of all the communication system including antennas (117.975 – 137.000 MHz) are specified in two subchapters of this document: 1.3 Operational Applications and 1.4 Operational Goals.

- Output Power

The requirements for output power of a transmitter (16 W for EV-55) is specified by the item 2.3.1 Output Power of this document.

[1] Despite the similar name and purpose of the industrial standard EUROCAE ED-23C [13], the European document is not applicable for VHF antenna requirements as referred for the receiver-transmitter equipment only (see item 1.4 Composition of Equipment in this document).

- Antenna VSWR

The requirements for antenna VSWR (3:1 max.) is defined in the items 2.2.14 and 2.3.9 of DO-186B [14] for the receiver as well as transmitter respectively.

- Antenna Efficiency

The requirement for antenna efficiency (6 dB max. defined in sense of the polarization mismatch factor) is defined in the items 2.2.15 and 2.3.10 of DO-186B [14] for the receiver as well as transmitter respectively.

The above mentioned MOPS have to be in accordance with a more general Radio Regulations of ITU (in its Chapter VIII Aeronautical Services) with no applicable operational requirements for antenna installations.

6.3.3. Installation and maintenance requirements

Installation and maintenance requirements of antennas are not specified by a special industrial standard, but they are subjected to the drawings and documents gathered for obtaining TC or STC when installing particular airborne equipment in particular aircraft. This set of documents includes partly limitations and recommendations of the antenna manufacturer (Installation manual) and partly comprehensive technical specification of the particular installation together with the proof of its compliance with the valid construction and operational regulations which refer to the appropriate types of aircraft and antennas.
All applicable individual paragraphs of the regulations have to be proven in general for the new type of antennas in a specified type of aircraft as stated in Table 19. Requirements for structural strength, aerodynamics, weight and its distribution, safety and reliability analyses, EMC and other categories are explicitly or implicitly expressed using these regulations. Proofs of antenna's compliance with them will create a formal base of air transport safety. Desired as well as undesired interactions among individual airborne systems, human factors and environmental effects have to be taken into consideration by chief designer and cooperating system engineer, designers and material engineers when creating TC or STC application and vindicating them against objections of the Authority.

If the design of winglet-integrated VHF antenna cannot be separated from the design of appropriate aircraft, no classic installation manual is applicable and the requirements for installation (and maintenance) of the antenna have to be combined with all the other parts or systems to be integrated together in a particular winglet of a particular aircraft. In the case of EV-55, the following parts are to be co-integrated in the winglet with the VHF antenna:

- Position and anti-collision lights
- Protection against direct lightning stroke
- Protection against precipitation statics

As mentioned in Chapter 4, the more systems to be integrated into the same space, the more compromises have to be done. Considering the applicable certification specifications (CS and FAR) as well as their approvable means of compliance (AMCs and ACs), we can find many references to industrial standards respectable by authorities as aids for proofs of compliance. By such a way, a compliance with individual paragraphs of CS and FAR are proven at airframers (TC or STC) or airborne equipment manufacturers (TSO or ETSO) in the case when the authority does not require other proof of compliance. Documents of EUROCAE, SAE, RTCA and ARINC are often referred and used for these purposes. For example, the documents ED-14G and DO-160G ([7], [8]) are referred for airborne equipment environmental specification or the documents [1], [2], [3], [4], [5], [6], [19], [20] are referred if the lightning protection if necessary. Some industrial

standards are not referred in applicable ACs and AMCs, but they can be specified directly by the certification authority or using CRIs or Issue Papers.

Other couple of industrial standards are referred, if the reliability parameters (Mean time between failures and Mean time to repair) are to be specified for any airborne equipment. These quantitative assessments are explained in the ARP 4761 and ARP 4754A ([10], [12]) from SAE or their EUROCAE equivalents ([9], [11]) and can be used for aircraft of various categories. In the case of CS/FAR 23 (EV-55), they are referred by AC 23-1309-1E, when AC 25-19A is used for CS/FAR 25 category of aircraft.

Considering the reliability parameters of winglet-integrated VHF antenna from the system point of view, two complementary radiation patterns (for the left and right hand winglets) are to be taken into consideration as a substitution of one classical VHF antenna protruding from an aircraft fuselage in the reliability calculations.

When applications of composite materials for the winglet-integrated antenna are unavoidable, also the handbooks CMH17 [18] and [34] from SAE are referred by ACs, AMCs, CRIs or Issue Papers to prove a compliance with the material items of building regulations (25.603 and 23.603).

6.4. Fibre metal laminate panel with VHF slot antenna and GPS antenna

Introduction

It is assumed that the VHF and GPS antennas are completely integrated in the skin of the aircraft. Connection to the antenna is from the inside of the aircraft. The GPS antenna contains some active electronics (LNAs) but no thermal cooling solutions. The VHF antenna contains no active electronics (unless additional amplification is needed). The function performed by the antennas, Air Traffic Communication and satellite navigation, are essential functions for the aircraft.

In ACASIAS the antenna will be developed up to TRL 5. Technology validated in a relevant environment (industrially relevant environment in the case of key enabling technologies). Testing for TRL 5 will focus primarily on the aerodynamic and mechanical loads to be expected during operation. For testing of fuselage panels up to TRL5, NLR has a test rig with capability to subject fuselage skin sections to biaxial loading conditions which are typical for fatigue and static design loads of the fuselage crown section of civil aircraft. No environmental tests such as temperature, pressure or vibration are planned. However, the requirements for the environmental conditions should be taken into account in the design.

In Table 20 the applicability of specific sections of EUROCAE ED-14G [7] is given.

6.4.1. Lightning protection

The VHF and GPS antennas should be protected against direct lightning effects according to EUROCAE ED-14G/RTCA DO-160G section 23. The lightning zone for this antenna is 2A (TBC). An overview of the lightning zones is given in Figure 22.