AERODINAMIC ANALYSIS OF HELICOPTER FENESTRON VERTICAL TAIL

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Abstract: *The Eurocopter EC135 (now Airbus Helicopters H135) is a twin-engine civil light utility helicopter produced by Airbus Helicopters (formerly known as Eurocopter). It is mainly used for helicopter emergency medical services then for corporate transport, law enforcement, offshore wind and military flight training. This publication contains the theoretical aspects and analyzes aerodynamically the performance of fenestron vertical tail with XFLR5 freeware.*

Keywords: *Airbus H135, fenestron tail, XFLR5 6.06, aerodynamic analysis.*

Simbols and acronyms

OEI	One Engine Inoperative	AEO	All Engines Operative
MTOW	Maximum Takeoff Weight	HMI	Human Machine Interface
FADEC	Full-Authority Digital Engine Controls	TOP	Takeoff-Power
LLT	Lifting Line Theory	VLM	Vortex Lattice Method
AoA	Angle of Attack	C_l, C_m, C_n,	Moments coefficients (pitch, roll, yaw)

1. INTRODUCTION

The H135 is light twin-engine multi-purpose helicopter in the 3 ton class, with up to 8 seats for pilots and passengers. The H135 delivers exceptional power reserves including full class 1 & class 2 performances, enhanced safety margins, best-in-class payload and the industry benchmark for control response and precision flying thanks to the hinge and bearing less main rotor system. All composite main rotor blades, with an advanced tip geometry design, in combination with the fenestron anti-torque system make the H135 the quietest helicopter in its class, with certified sound levels well below the ultra-stringent ICAO limit, (see figure 1). The H135 can be powered by either Safran Helicopter Engines Arrius 2B2 or Pratt & Whitney Canada PW206B3 engines - both are FADEC controlled and provide efficient fuel burn characteristics. These powerful and reliable engines, combined with the improved dynamic lifting system components, provide outstanding performance and vital power reserves especially in One Engine Inoperative (OEI) scenarios and in all flight regimes including demanding High & Hot conditions, [1, and 2].

FIG. 1 Airbus H 135 helicopter

Airbus developed new, optimized aerodynamic elements for H135 granting optimal mission capability. More in detail: the vertical fin is extended in its upper section to extend the envelope of the autopilot.

Table1 Airbus H135 features, [1, 2]

Features	Value	Features	Value
Fuselage geometry	10,2x2,0x3,50 m	Ceiling (TOP)	4570 m
Rotor diameter	10,4 m	(MTOW)	2,900 kg
Max speed (2200 kg)	287 km/h	Takeoff-Power (TOP)	528 KW

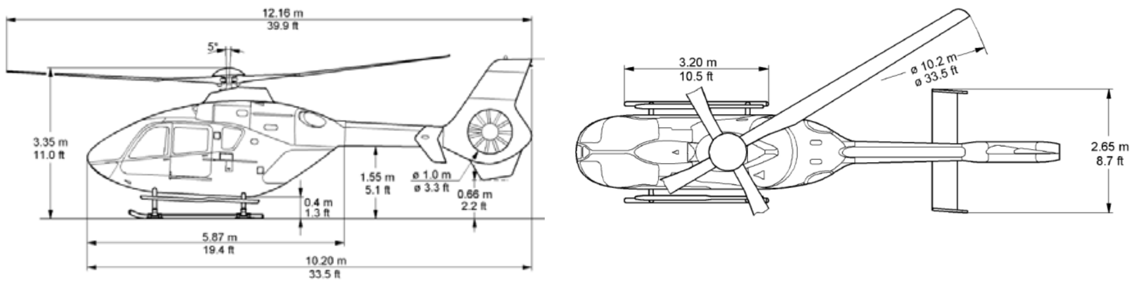

FIG. 2 H 135 external dimensions, [1]

2. HELICOPTER VERTICAL STABILIZER

The primary role is providing stability in yaw, while the stability in yaw is provided by the tail rotor, the vertical stabilizer can: alleviate the rotor thrust therefore reducing the power; replace the tail rotor in case of failure. The counter clockwise sense of rotation of the main rotor results in a clockwise torque acting on the main gear box and the fuselage.

Thus in hover or in flight with low forward speed the H/C nose tends to turn to the right. To counteract this movement the tail rotor thrust has to keep the H/C nose straight by creating a force on the tail boom to the right with the airflow from right to left.

With higher forward speeds flying straight and level, the power demand to the tail rotor decreases significantly due to the aerodynamic shape of the vertical fin and the angle between endplates and the flight direction. The rear structure is the aft section of the fuselage. It stabilizes the helicopter in flight by means of the vertical fin with the integrated Fenestron tail rotor and provides the lever arm on which the thrust of the tail rotor counteracts the torque of the main rotor system. The rear structure of the H135 consists of the following assemblies: tail boom, horizontal stabilizer, vertical fin with fenestron structure, see figure 3 and 4, [3].

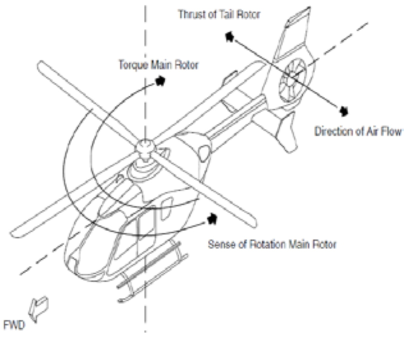

FIG.3 Fenestron concept

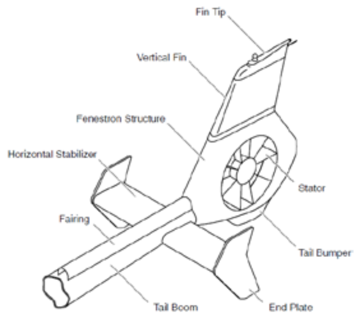

FIG.4 Tail Unit

Fenestron Vertical Fin

The vertical fin together with the integral Fenestron structure forms a unit. The upper region of the vertical fin has an aerodynamic function, while the Fenestron structure below it encloses the tail rotor system. The yaw control of the helicopter is made possible by the Fenestron, see Fig. 4.

3. AERODYNAMIC ANALYSIS

3.1. Freeware XFLR5

Aerodynamic analyzes were performed with the XFLR5 freeware tool. XFLR5 is an analysis tool for airfoils, wings and planes operating at low Reynolds Numbers. It includes: XFoil's direct and inverse analysis capabilities; wing design and analysis capabilities based on the Lifting Line Theory (LLT), on the Vortex Lattice Method (VLM), and on 3D Panel Method, [4, 5, 6 and 8].

3.2. Helicopter design H135

2D geometry.

For helicopter design I used tree airfoils: NACA 0012, NACA 0021 and NACA 2411, (see Fig.5), [4, 5 and 7].

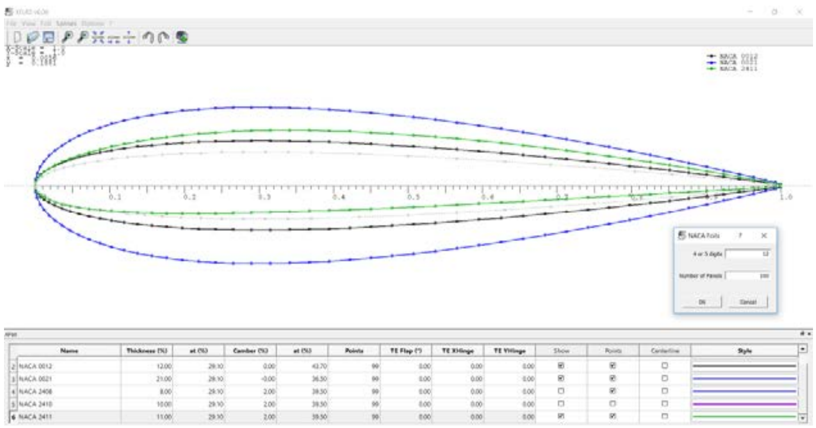
FIG.5 Direct Foil Design

The case study includes a comparative analysis of the aerodynamic aspects of the H135 fuselage without the influence of the lifting rotors. We have travelled a series of stages with XFLR5, as follows: a similar geometric configuration of the H135 helicopter in a 1:10 scale was considered, (see Fig. 6).

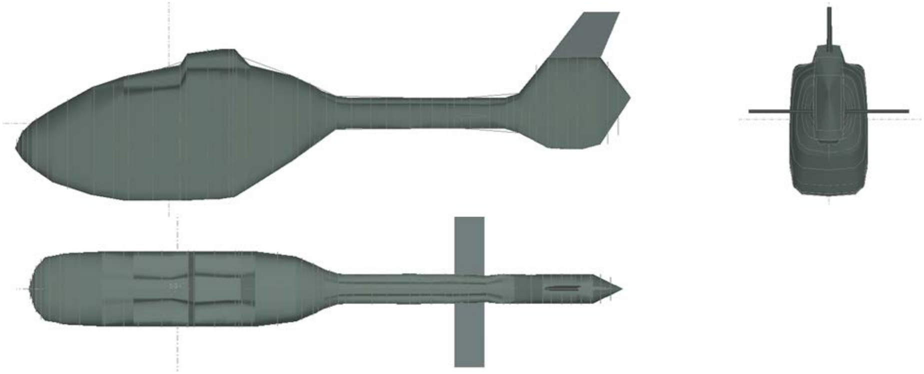

FIG.6 Airbus H135 XFLR5 design

For the design of the fuselage we have activated *Wing and Plane Design*, in *Body* and then in *Define a New Body*, from which we entered the spatial coordinates for each *Frame Positions* on the OX axis. Each *Frame Positions* has as spatial coordinates the OY and OZ axes from where we changed their positions through the *Current Frame Definition* window, see figure 7. On the OX axis we have defined the length of the helicopter at a scale of 1:10. On the OY and OZ axis we define the helicopter's maximum width and height and shape.

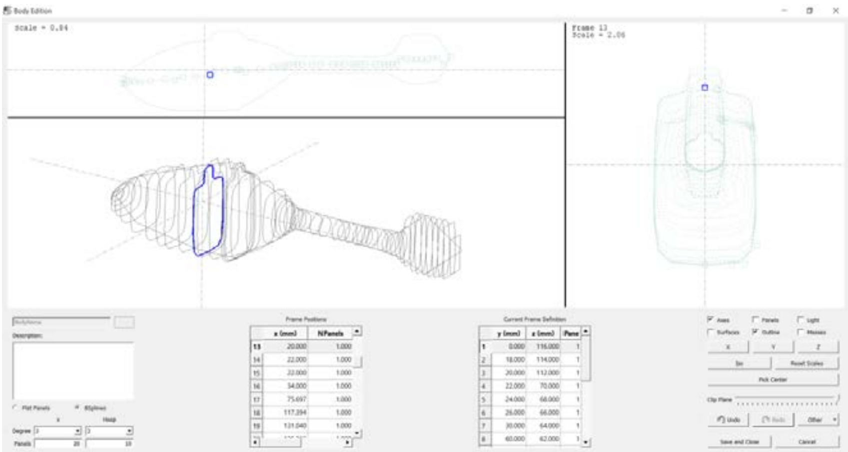

FIG.7 Body Design

Coupling the fuselage with the tail

We have introduced the elevator and fin where which we have modified by defining the desired dimensions (see figure 8) and positioning them by modifying values coordinate on axis, to could couple them with the fuselage. The working time for Airbus H135 design in xflr5 was 30 hours.

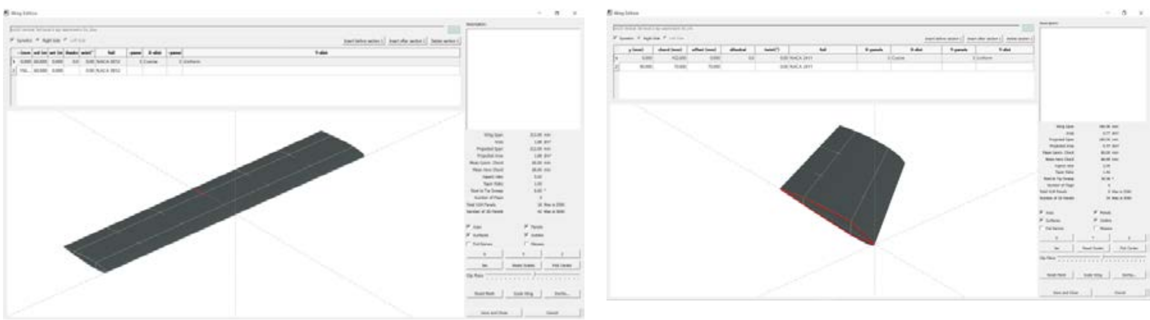

FIG. 8 Elevator and fin design

3.3. Aerodynamic analysis

Aerodynamic analyzes considered the initial conditions outlined in Table 6.

Table 6. Initial conditions

Parameter	Value	Parameter	Value
Speed	10 m/s	Inertial values	no
Air density	1.225 kg/cm^3	Viscosity	1.5e-05 m^2/s
Max. iterations	200	Method	3D/VLM
Alpha Precision	0.0100	Polar	constant speed
AoA interval	$-15^0 \div 15^0$, $\Delta=1^0$	Relax. factor	20

The analysis has two cases on two different geometries of different vertical tail and different twists, for the analysis conditions of the tables 6, the selected numerical data refer to C_l, C_m, C_n, and C_y, see Table 7.

Table7. Analysis cases

NACA0021 / NACA0012		NACA2411	
Twist 0^o	Twist 7^o	Twist 0^o	Twist 7^o

4. THE RESULTS

4.1. Vertical fin analysis with NACA2411.

According to figure 9 the pitch coefficient (C_m) variation for the two values of twist, has a similar slope is used for all incidence (see also Annex 1), the absolute difference for a zero incidence being 0.11 (-12.48 vs. -12.59), the twist of 7^o having an influence on the pitch coefficient, especially with the increase in speed. In figure 10, it is observed that an increase in the absolute value of the rolling coefficient (C_l) with the increase of the twist is expected, for a zero incidence (AoA) we have a difference of approximately 0.50.

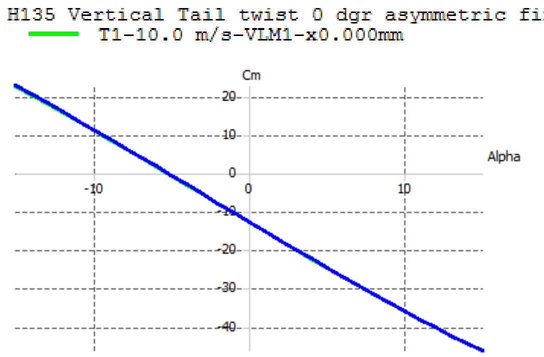

FIG.9 C_m vs AoA

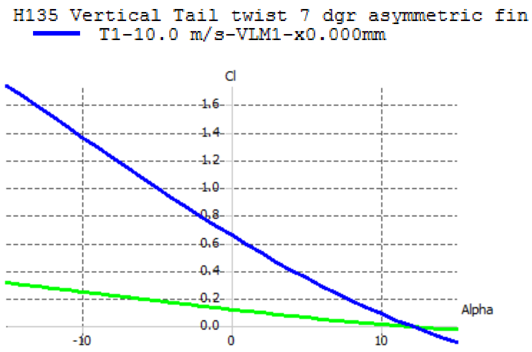

FIG.10 C_l vs AoA

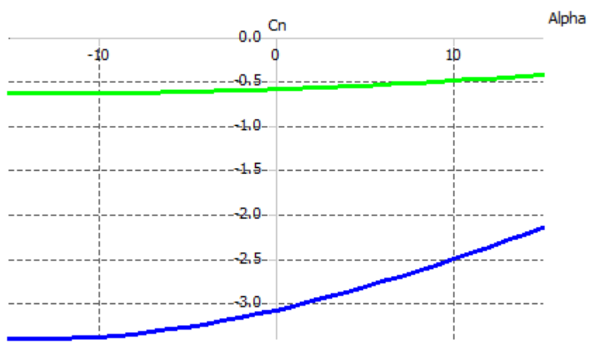

FIG.11 C_n vs AoA

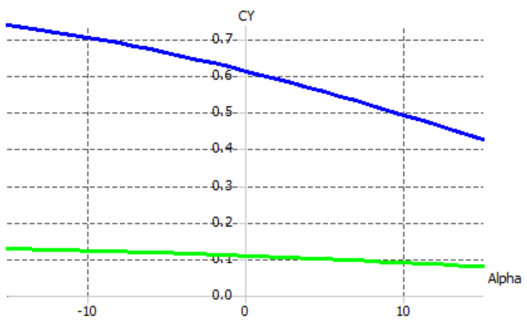

FIG.12 C_y vs AoA

The yaw coefficient (C_n) highlighted in Fig. 11 increases in absolute value with increasing speed indicating the great influence on lateral movement/yaw by a difference of 5 times greater (approximately 2.5) considered at zero incidence, coefficient of lateral force C_y see figure 12, with the same increase.

4.2.Vertical fin analysis with NACA 0021 and NACA 0012.

According to figure 13, the variation of the pitch coefficient (C_m) for the two twist values has a similar slope over the all incidence (see also Annex 2), the absolute difference for a zero incidence being 0.07 (-12.50 vs. -12.57), the twist of 7^o having an influence on the pitch coefficient, especially with the increase of the velocity.

In Fig.14, it is observed that an increase of the absolute value of the rolling coefficient (C_l) with the increase of the twist, for a zero incidence we have a difference of about 0.60

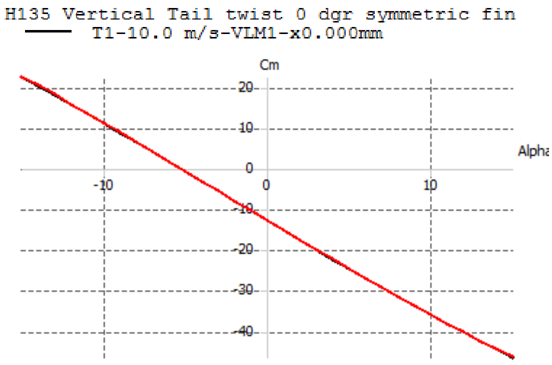

FIG.13 C_m vs AoA

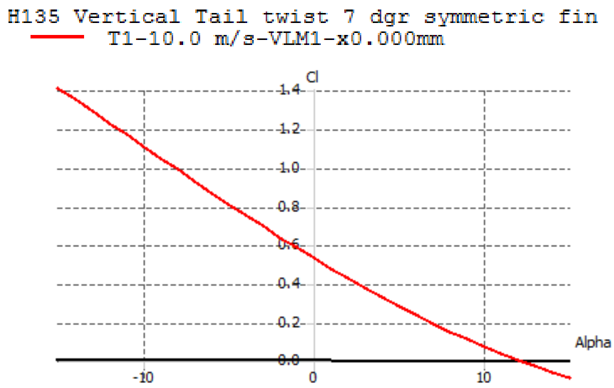

FIG.14 C_l vs AoA

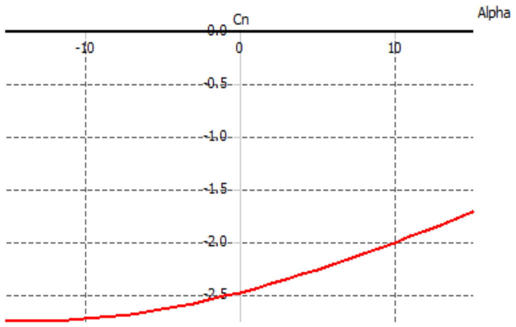

FIG.15 C_n vs AoA

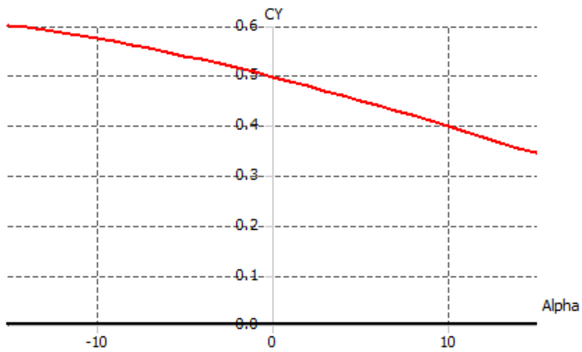

FIG.16 C_y vs AoA

The yaw coefficient (C_n) highlighted in figure 15 increases in absolute value with increasing speed, highlighting the great influence on lateral / yaw movement by a difference of 5 times greater (approximately 2.5) considered at zero incidence, influencing obviously the coefficient of the loop force C_y see figure 16, with the same sense of growth.

CONCLUSIONS

Design efforts to optimize the tails of modern helicopters have specific approaches based on the aerodynamic concept chosen to cancel the gyroscopic torque of the bearing rotor.

Although the analysis of the presented paper did not take into account the functioning of fenestron and was limited only to the influence of the geometrical characteristics of the vertical tail by using an open source aerodynamic analysis code (XFLR5), it was possible to highlight the degree of influence of the selected 2D geometries with a high degree to trust the results.

The results can be used successfully in the pre-dimensioning and general optimization steps and then be taken over in CFD commercial tools for refined optimizations.

The article can be used in the educational field to conceptualize the aerodynamic phenomena that arise due to geometrical changes.

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ANNEXES

Annex 1. Vertical fin analysis with NACA2411

Wing name : H135 Vertical Tail twist 0 dgr asymmetric fin
Wing polar name : T1-10.0 m/s-VLM1-x0.000mm
Freestream speed : 10.000 m/s

alpha	CL	ICd	PCd	TCd	CY	Cm
-15.000	-3.577065	0.394408	0.000000	0.394408	0.127295	22.571976
-14.000	-3.378706	0.348491	0.000000	0.348491	0.126553	20.366787
-13.000	-3.174651	0.304949	0.000000	0.304949	0.125736	18.129532
-12.000	-2.965228	0.263913	0.000000	0.263913	0.124847	15.862936
-11.000	-2.750780	0.225507	0.000000	0.225507	0.123886	13.569760
-10.000	-2.531661	0.189848	0.000000	0.189848	0.122854	11.252800
-9.000	-2.308237	0.157042	0.000000	0.157042	0.121753	8.914877
-8.000	-2.080887	0.127188	0.000000	0.127188	0.120584	6.558839
-7.000	-1.849998	0.100375	0.000000	0.100375	0.119348	4.187558
-6.000	-1.615966	0.076683	0.000000	0.076683	0.118048	1.803921
-5.000	-1.379197	0.056183	0.000000	0.056183	0.116683	-0.589166
-4.000	-1.140102	0.038935	0.000000	0.038935	0.115257	-2.988787
-3.000	-0.899099	0.024990	0.000000	0.024990	0.113771	-5.392021
-2.000	-0.656610	0.014388	0.000000	0.014388	0.112227	-7.795938
-1.000	-0.413062	0.007161	0.000000	0.007161	0.110626	-10.19760
0.000	-0.168883	0.003326	0.000000	0.003326	0.108971	-12.59411
1.000	0.075496	0.002896	0.000000	0.002896	0.107263	-14.98251
2.000	0.319643	0.005868	0.000000	0.005868	0.105505	-17.35992
3.000	0.563129	0.012232	0.000000	0.012232	0.103699	-19.72343
4.000	0.805526	0.021967	0.000000	0.021967	0.101846	-22.07016
5.000	1.046406	0.035040	0.000000	0.035040	0.099950	-24.39726
6.000	1.285349	0.051411	0.000000	0.051411	0.098013	-26.70189
7.000	1.521937	0.071027	0.000000	0.071027	0.096036	-28.98123
8.000	1.755760	0.093826	0.000000	0.093826	0.094023	-31.23252
9.000	1.986415	0.119737	0.000000	0.119737	0.091976	-33.45302
10.000	2.213505	0.148679	0.000000	0.148679	0.089896	-35.64000
11.000	2.436646	0.180561	0.000000	0.180561	0.087788	-37.79082
12.000	2.655460	0.215283	0.000000	0.215283	0.085653	-39.90285
13.000	2.869583	0.252738	0.000000	0.252738	0.083494	-41.97351
14.000	3.078662	0.292809	0.000000	0.292809	0.081314	-44.00029
15.000	3.282358	0.335370	0.000000	0.335370	0.079115	-45.98072

Wing name : H135 Vertical Tail twist 7 dgr asymmetric fin
Wing polar name : T1-10.0 m/s-VLM1-x0.000mm
Freestream speed : 10.000 m/s

alpha	CL	ICd	PCd	TCd	CY	Cm
-15.000	-3.625169	0.446570	0.000000	0.446570	0.734481	22.687935
-14.000	-3.428159	0.400487	0.000000	0.400487	0.728967	20.483150
-13.000	-3.225427	0.356737	0.000000	0.356737	0.723029	18.246223
-12.000	-3.017298	0.315453	0.000000	0.315453	0.716674	15.979881
-11.000	-2.804112	0.276760	0.000000	0.276760	0.709910	13.686882
-10.000	-2.586219	0.240774	0.000000	0.240774	0.702745	11.370020
-9.000	-2.363985	0.207603	0.000000	0.207603	0.695187	9.032119
-8.000	-2.137782	0.177346	0.000000	0.177346	0.687247	6.676026
-7.000	-1.907998	0.150094	0.000000	0.150094	0.678933	4.304613
-6.000	-1.675025	0.125927	0.000000	0.125927	0.670256	1.920768
-5.000	-1.439267	0.104917	0.000000	0.104917	0.661226	-0.472604
-4.000	-1.201132	0.087124	0.000000	0.087124	0.651855	-2.872587
-3.000	-0.961036	0.072602	0.000000	0.072602	0.642153	-5.276257
-2.000	-0.719399	0.061390	0.000000	0.061390	0.632133	-7.680686
-1.000	-0.476645	0.053522	0.000000	0.053522	0.621807	-10.082944
0.000	-0.233202	0.049017	0.000000	0.049017	0.611187	-12.480104
1.000	0.010502	0.047888	0.000000	0.047888	0.600286	-14.869247
2.000	0.254037	0.050135	0.000000	0.050135	0.589118	-17.247461
3.000	0.496975	0.055748	0.000000	0.055748	0.577696	-19.611849
4.000	0.738889	0.064707	0.000000	0.064707	0.566035	-21.959528
5.000	0.979353	0.076982	0.000000	0.076982	0.554147	-24.287642
6.000	1.217948	0.092532	0.000000	0.092532	0.542049	-26.593351
7.000	1.454257	0.111308	0.000000	0.111308	0.529753	-28.873846
8.000	1.687870	0.133249	0.000000	0.133249	0.517277	-31.126352
9.000	1.918384	0.158285	0.000000	0.158285	0.504634	-33.348122
10.000	2.145406	0.186337	0.000000	0.186337	0.491840	-35.536446
11.000	2.368548	0.217314	0.000000	0.217314	0.478911	-37.688663
12.000	2.587435	0.251121	0.000000	0.251121	0.465863	-39.802151
13.000	2.801702	0.287650	0.000000	0.287650	0.452710	-41.874332
14.000	3.010996	0.326785	0.000000	0.326785	0.439471	-43.902683
15.000	3.214978	0.368403	0.000000	0.368403	0.426159	-45.884735

Annex 2. Vertical fin analysis with NACA 0021 and NACA 0012

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Wing name :        H135 Vertical Tail twist 0 dgr symmetric fin
Wing polar name :  T1-10.0 m/s-VLM1-x0.000mm
Freestream speed :  10.000 m/s
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alpha	CL	ICd	PCd	TCd	CY	Cm
-15.000	-3.576003	0.394141	0.000000	0.394141	0.000000	22.589949
-14.000	-3.377699	0.348133	0.000000	0.348133	0.000000	20.384899
-13.000	-3.173693	0.304499	0.000000	0.304499	0.000000	18.147772
-12.000	-2.964313	0.263371	0.000000	0.263371	0.000000	15.881289
-11.000	-2.749900	0.224874	0.000000	0.224874	0.000000	13.588217
-10.000	-2.530810	0.189124	0.000000	0.189124	0.000000	11.271345
-9.000	-2.307410	0.156228	0.000000	0.156228	0.000000	8.933499
-8.000	-2.080076	0.126284	0.000000	0.126284	0.000000	6.577527
-7.000	-1.849197	0.099383	0.000000	0.099383	0.000000	4.206297
-6.000	-1.615169	0.075605	0.000000	0.075605	0.000000	1.822700
-5.000	-1.378397	0.055019	0.000000	0.055019	0.000000	-0.570360
-4.000	-1.139294	0.037688	0.000000	0.037688	0.000000	-2.969968
-3.000	-0.898277	0.023661	0.000000	0.023661	0.000000	-5.373201
-2.000	-0.655768	0.012980	0.000000	0.012980	0.000000	-7.777130
-1.000	-0.412194	0.005675	0.000000	0.005675	0.000000	-10.178825
0.000	-0.167984	0.001766	0.000000	0.001766	0.000000	-12.575363
1.000	0.076431	0.001264	0.000000	0.001264	0.000000	-14.963822
2.000	0.320619	0.004166	0.000000	0.004166	0.000000	-17.341293
3.000	0.564150	0.010464	0.000000	0.010464	0.000000	-19.704880
4.000	0.806596	0.020135	0.000000	0.020135	0.000000	-22.051701
5.000	1.047530	0.033149	0.000000	0.033149	0.000000	-24.378899
6.000	1.286530	0.049462	0.000000	0.049462	0.000000	-26.683636
7.000	1.523179	0.069025	0.000000	0.069025	0.000000	-28.963108
8.000	1.757066	0.091774	0.000000	0.091774	0.000000	-31.214535
9.000	1.987788	0.117639	0.000000	0.117639	0.000000	-33.435173
10.000	2.214947	0.146538	0.000000	0.146538	0.000000	-35.622318
11.000	2.438159	0.178382	0.000000	0.178382	0.000000	-37.773308
12.000	2.657045	0.213070	0.000000	0.213070	0.000000	-39.885521
13.000	2.871243	0.250494	0.000000	0.250494	0.000000	-41.956379
14.000	3.080397	0.290538	0.000000	0.290538	0.000000	-43.983364
15.000	3.284168	0.333077	0.000000	0.333077	0.000000	-45.964005

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Wing name :        H135 Vertical Tail twist 7 dgr symmetric fin
Wing polar name :  T1-10.0 m/s-VLM1-x0.000mm
Freestream speed :  10.000 m/s
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alpha	CL	ICd	PCd	TCd	CY	Cm
-15.000	-3.612519	0.427772	0.000000	0.427772	0.600512	22.659481
-14.000	-3.414994	0.381791	0.000000	0.381791	0.595821	20.454559
-13.000	-3.211759	0.338160	0.000000	0.338160	0.590784	18.217512
-12.000	-3.003138	0.297011	0.000000	0.297011	0.585405	15.951067
-11.000	-2.789474	0.258466	0.000000	0.258466	0.579692	13.657985
-10.000	-2.571117	0.222644	0.000000	0.222644	0.573651	11.341059
-9.000	-2.348435	0.189651	0.000000	0.189651	0.567291	9.003113
-8.000	-2.121802	0.159585	0.000000	0.159585	0.560618	6.646995
-7.000	-1.891604	0.132538	0.000000	0.132538	0.553641	4.275576
-6.000	-1.658236	0.108589	0.000000	0.108589	0.546368	1.891744
-5.000	-1.422103	0.087809	0.000000	0.087809	0.538809	-0.501596
-4.000	-1.183613	0.070259	0.000000	0.070259	0.530972	-2.901528
-3.000	-0.943183	0.055991	0.000000	0.055991	0.522867	-5.305128
-2.000	-0.701234	0.045045	0.000000	0.045045	0.514504	-7.709467
-1.000	-0.458192	0.037453	0.000000	0.037453	0.505893	-10.111617
0.000	-0.214483	0.033235	0.000000	0.033235	0.497045	-12.508651
1.000	0.029462	0.032401	0.000000	0.032401	0.487970	-14.897648
2.000	0.273215	0.034953	0.000000	0.034953	0.478679	-17.275698
3.000	0.516345	0.040879	0.000000	0.040879	0.469184	-19.639902
4.000	0.758425	0.050159	0.000000	0.050159	0.459496	-21.987383
5.000	0.999030	0.062762	0.000000	0.062762	0.449628	-24.315277
6.000	1.237740	0.078647	0.000000	0.078647	0.439590	-26.620752
7.000	1.474137	0.097764	0.000000	0.097764	0.429396	-28.900995
8.000	1.707812	0.120050	0.000000	0.120050	0.419057	-31.153231
9.000	1.938362	0.145437	0.000000	0.145437	0.408587	-33.374714
10.000	2.165392	0.173843	0.000000	0.173843	0.397998	-35.562737
11.000	2.388516	0.205179	0.000000	0.205179	0.387303	-37.714638
12.000	2.607359	0.239346	0.000000	0.239346	0.376515	-39.827789
13.000	2.821555	0.276237	0.000000	0.276237	0.365647	-41.899624
14.000	3.030752	0.315736	0.000000	0.315736	0.354713	-43.927612
15.000	3.234611	0.357719	0.000000	0.357719	0.343725	-45.909283