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Flutter problems of electrically powered aircraft

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The aircraft flutter is self-excited harmonic oscillation of structure. It occur without any warning and leads to destruction within a second. Flutter is cause by interaction of inertia, stiffness and aerodynamic forces. There have to be considered the feedback between force and deformation of structure during mathematical analysis of problem. A producer of airplane have to proof that each prototype of airplane is free from flutter up to certain velocity given by airworthiness requirements.

There have to be carried out a ground vibration test (next as GVT) [1] of an airplane for obtaining input data to flutter analysis in form of modal parameters. Any analytical methods for evaluation modal parameters of complex structure such as airplane fail. The GVT is based on excitation of aircraft structure by electromagnetic exciter with force meters and sensing a response by accelerometers. The measured data are process by Fast Fourier Transformation and Frequency response Function is subsequently determined for the purpose of modal parameters evaluation. The flutter analysis can be carry out on a finite element model tuned at the modal parameters from GVT [2] and [1]. Alternatively, by mathematical model derived directly in modal coordinates where eigen-vectors are not calculate on behalf of tuned finite element model, but directly imported from GVT measured data [3]. There were used the second method in this paper.

An electrical propulsion of an aircraft becoming more and more popular in last few years. A companies focused at aircraft production are experimenting with installation an electrical propulsion unit (next as EPU) to their aircraft. There is also a company aimed on developing and certification of such as propulsion unit, for serial production as an alternative to Rotax engine, which is popular among sports aircraft producer. In these days, a thrust produced by electrical engine installed in such as airplane is enough for safety take-off and fast enough to cruise. Nevertheless, a maximum velocity or endurance of airplane with EPU is far less than for combustion engine. In addition, the EPU installation can quite affect a flutter velocity of an airplane in negative way.

The subject of presented work is two-seater all-metal low-wing sports airplane with wingspan 9m. A fuel stores are situating in wings. A luggage compartment is situate in wings and fuselage. The airplane is certified according CS-23, thus a minimal flutter velocity has to be higher than 1,2 multiple of design velocity of airplane (next as V_D). The airplane has standard combustion engine Rotax. Moreover, there was did a modification of this airplane in sense of installing an EPU. There were performed the GVTs with 94 measuring points and 13 excitations locations together with flutter analysis for both version of airplane.

The flutter analysis for airplane with Rotax engine was carried out for light (one light pilot, no fuel, no luggage) and heavy (two heavy pilots, full fuel tanks, full luggage compartment) mass configuration with free and blocked control. On behalf of CS-23

Table 1. Flutter summary for Rotax version (light mass configuration, altitude 0m); A1: 1st Anti. wing bending; 1.AR-KR: 1st Anti. aileron rotation; 1.TT: 1st Fuselage torsion; 1.R-SK: 1st Rudder rotation

Flutter type	Modes involved	Flutter velocity	Flutter frequency	Control
Aileron flutter	A1 (Node in 48%) + 1.AR-KR	1,48V_D	19,3 Hz	Free
Rudder flutter	1.TT + 1.R-SK	1,35V_D	15,8 Hz	Blocked

requirement, the limits of all variables that can affect the flutter velocity have been examine. Analysed flutter velocities for nominal state are present in Table 1. All flutter velocities are above 1,2V_D, thus the airplane meets the requirement to flutter resistance for nominal state.

The modification of airplane for a purpose of EPU installations is based on removing combustion engine and installing the electrical one, which is lighter and smaller than combustion one. The batteries are install in the wing. The fuel storage and wing luggage compartment were replace by battery bed structure. Each half-wing contains three battery segments, distributed from root rib up to 55% of wingspan. The mass of all batteries installed is 185kg, which is about 45% more than for mass of maximum fuel and luggage in wing compartments. The structure of airplane gets heavier due to installation of EPU by 40kg e.g. 9,5%, without considering the mass of batteries.

The result of nominal state flutter analysis for modified airplane with EPU is present in Table 2. All flutter velocities are above 1,2V_D, except first Aileron flutter for Free control, where the flutter velocity is inside a flight envelope at 0,88 V_D. This flutter does not occur for Rotax version of airplane and is cause by battery installation. There are two symmetric and two antisymmetric 1st wing bending modes for EPU version. The Rotax version of airplane has only one mode for each, as usual airplanes have. See Fig. 1 for first wing bending modes comparison. The second wing bending modes for both airplane versions have no such as anomaly and they are similar in frequency and eigen-shape. The installation of battery bed have to be well stiff to battery will not stress by bending moment, together with add mass of battery it cause that new modes similar to first bending modes appear. They differ from standard structural modes in position of node point. Symmetric battery mode is not a problem because even that it have eigen-frequency higher than structural one it is still quite far away from eigen-frequency of symmetrical aileron rotation, which is about 30Hz, for free and blocked control. Unfortunately, eigen-frequency of antisymmetric battery mode is about half of structural one, and thus gets closer to antisymmetric aileron rotation mode, which is 7,5Hz for free control. Those two modes pairs together at certain velocity and causing the flutter occurrence in flight envelope.

Table 2. Flutter summary for EPU version (light mass configuration, altitude 0m); A1: 1st Anti. wing bending; 1.AR-KR: 1st Anti. aileron rotation; S2: 2nd Sym. wing bending; 1.SR-KR: 1st Sym. aileron rotation; 1.TT 1st Fuselage torsion; 2.R-SK: 2nd Rudder rotation; 1.SOT 1st Fuselage side bending

Flutter type	Modes involved	Flutter velocity	Flutter frequency	Control
Aileron flutter (Battery mode)	A1(Node in 26%) + 1.AR-KR	0,88V_D	13Hz	Free
Aileron flutter	S2 + 1.SR-KR	1,48V_D	42 Hz	Free & Blocked
Rudder flutter	1.TT + 2.R-SK + 1.SOT	Free: 1,29V_D Blocked: 1,27V_D	Free: 20,5Hz Blocked: 19,8Hz	Free & Blocked

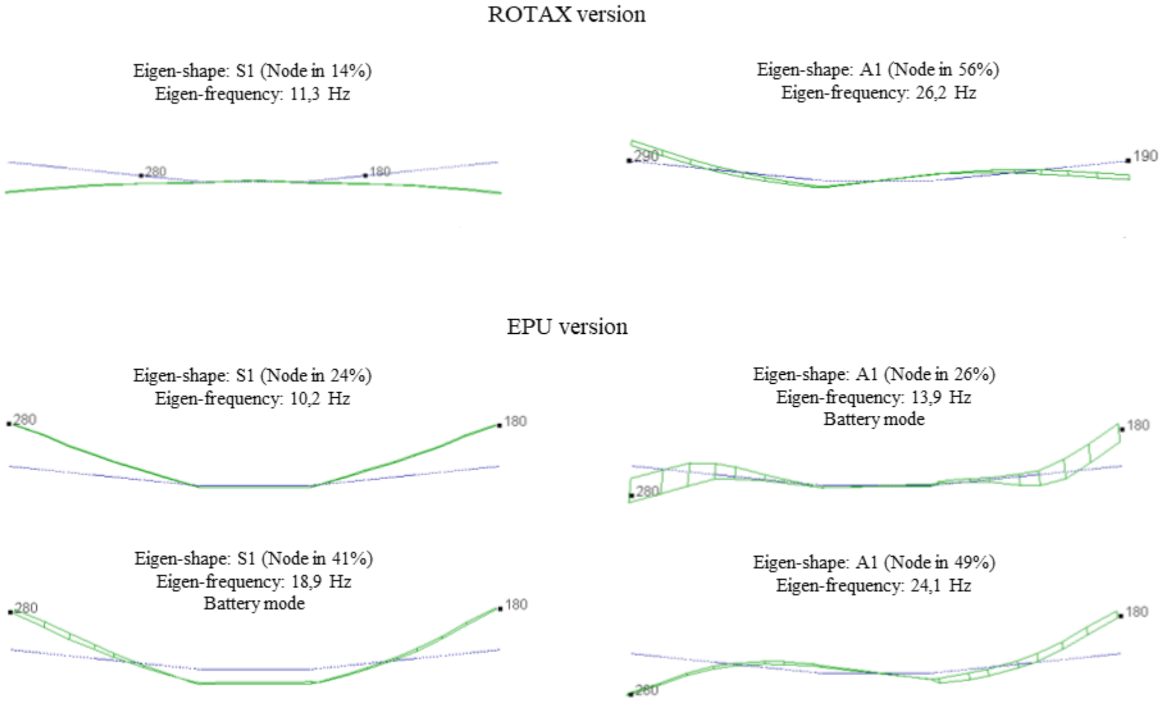

Fig. 1. First wing bending modes comparison. Symmetric modes – left column. Antisymmetric – right column

The installation of large amount of battery to wing can negatively affect the flutter velocity of aircraft. The presence of battery mass together with stiff battery bed will cause appearance of battery eigen-modes in bending. It was observed that the frequency of symmetric shape of battery mode get higher than structural 1st wing bending, and for antisymmetric shape of battery mode the frequency get lower than structural one. The exact frequency shift will depend on total mass of battery and stiffness of battery bed. In this case, it was about double for symmetric and half for antisymmetric shape. However, there is high

Table 3. Statistic of selected eigen-modes, for two seats sports airplane with combustion engine

Eigen-frequencies of antisymmetric modes [Hz]			
Airplane	**1st Aileron rotation Free control**	**1st Aileron rotation Blocked control**	**1st Wing bending Light mass config.**
NG5	3,9	24,0	25,5
Magic	4,9	12,0	30,7
Faeta NG	5,3	22,1	16,1
Rotax version	6,2	23,0	26,2
SkyLane	6,7	10,8	19,4
Lambada	7,1	13,2	10,5
EPU version	*7,5*	*24,6*	*24,1*
Sting	8,2	9,2	17,2
Sparrow	8,5	15,8	18,7
Piper Sport	10,5	14,4	23,7
Vampire	14,6	14,6	15,0
Minisport	15,0	24,2	21,7
SkyLane NG	12,2	15,3	21,7
VIA	16,2	16,3	27,6
GP-ONE	17,4	21,5	15,8
Legend	16,2	18,0	12,5
Viper	20,4	21,4	13,4
Average value	*10,6*	*17,7*	*20,0*

probability that eigen-frequency of antisymmetric battery mode will get close to 1st antisymmetric aileron rotation in free control configuration. This mode act as kinematic mechanism thus the eigen-frequency is low. Based on statistic of 17-measured two seats sports airplane with combustion engine, presented in Table 3, the average antisymmetric aileron eigen-frequency is about 10,6 Hz. Meanwhile average antisymmetric wing bending eigen-frequency is about 20,0 Hz, which will be reduce by battery installation. With increasing velocity of flight, the aileron eigen-frequency will rise and can easily meet the antisymmetric battery mode, coupled each other and cause the flutter at low velocities. Thus, the installation of EPU with large mass of batteries in the wing can be quite dangerous from flutter point of view.

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