RIDE CONTROL FOR THE PERSONAL PLANE

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Abstract

The small and personal aircraft are used by – so called - less-skilled pilots may introduce large accelerations and maneuver loads and flying in region between 2 – 4 km altitudes, that is the area of large air turbulence. Therefore the passengers' ride control improvement is very important goal of introducing the personal planes.

This paper defines the discomfort indexes, analyzes the possible methods of ride controls and describes the developed ride control philosophies and methods for the personal planes. The novelties of these methods are (i) developing a discomfort index for the personal planes, (ii) developing a limitation system for the aerodynamic control system, (iii) improving the ride control systems developed for small aircraft, (iv) integration of the ergonomic and psychological factors into the ride control developments.

Abbreviations

a, b, c ...	constants, parameters,
a_z, $\bar{a}_z$	- vertical acceleration at the aircraft centre of gravity and its root mean squared (rms) value,
$\bar{c}$, $\bar{c}_g$	mean (aerodynamic) and geometrical mean chord of wing,
C_L, C_D	- lift and drag coefficients,
C_L^α	- lift coefficient derivative respectively to angle of attack, slope of airplane lift coefficeint,
C_m^α	- partial derivative of the aircraft moment coefficient respectively to the angle of attack,
CVo	- cabin volume (used by (16) in cu.ft),
CFP	- cubic feet of available space per passenger,
DDS	- door-to-door speed (used in (16) in knots),
FBD	- fuel burn in lbs per day
g	- acceleration of gravity,
g_{rms}	- root mean squared values of the passengers' seat accelerations
I_{yy}	- moment of inertia generated around the axis *y*,
J	- index,
k	- constant of proportionality,
K	- gain (of transfer function),
k_q	- gust alleviation factor,
M	- mass of aircraft, moment, pitching moment,
M_w	- partial derivative of the pitching moment respectively to *w* velocity component.
Δn_z	- changes in (*z* direction component of) load factor influenced by the gust,
P/SATS	- peresonal/small aircraft transportation system,
PH	- passenger headroom in ft,
q, $\bar{q}$	- pitch rate angular velocity, and its root mean squared values,
R_{ground}, R_{block}	- ground and block ranges,
RFPL	- range with full payload and required fuel reserves, (used by (16) in nm),
S	- aircraft wing area,
s	- Laplace variable,
SMD	- number of seat-miles that are generated per day,
RDI	- ride discomfort index,
U_0	- aircraft velocity component (*u*) along the *x* axis at the initial condition,
$V = [u\ v\ w]^T$	- aircraft velocity and its componenets,
VAP	-value-added paeameter,
W	- aircraft weight,
W/S	- wing load factor,
w_g	- gust velocity,
$\mathbf{x}$, x	- state vektor, elements of state vector
x_{CV}	- a weighted function of the desired states (not the state itself),
x_{AC}	- distance between the aircraft aerodynamic centre and centre of gravity.
Z_w	- changes in normal forces (force components in *z* direction) induced by changes in velocity, *w*,
Z_{δ_i}	- effect the ith control element deflection on the force component to the *z* direction
α	- angle of attack
$\Delta\alpha = w_g / V$	- changes in angle of attack, α, induced by gust having velocity, w_g
δ_i	- deflection angle of the *i*th control element (elevator, flaps),
θ	- climb angle,
μ	- airplane mass ration,
ρ	- air density,
ω	- frequency,
ς	- damping,

indexes

0	- trim condition before disturbance.
CV	- controled variable (element of state vector),
com	- command,
des	- desired,
fq	- flying quality,
m	- measured,
RD	- ride discomfort,
rq	- ride quality,
n.des	- natural desired,

Intorduction

In quit general form the comfort is a subjective state of well-being in relation to an induced environment including all type of disturbances such noise, mechanical vibration, maneuver loads, large acceleration or decelerations, etc. Ride comfort is the comfort inside the vehicles experienced by both drivers (pilots) and passengers. As usually the ride quality is evaluating by discomforts or by specially developed ride quality rating models. The ride control improves the ride control.

In case of using the small and so called personal aircraft by the pilots owners or renters of the planes who may have not so large experiences (less-skilled pilots [1]), the ride comfort improvements has goal of increasing the flight safety, too [2, 3]. Such small and personal aircraft are used in region of altitude 2 – 4 km, that is the area of large air turbulence. Therefore the passengers' ride control improvement is very important goal of introducing the personal planes.

Generally, the personal plane ride control must deal with the following discomfort sources:

- large maneuvering loads (accelerations) generated by the less-skilled pilots (or even by the professional pilots controlling aircraft remotely) initiating large and sudden deflection of the control surfaces,
- loads (accelerations) induced by the air turbulences,
- load because the possible flights in bad weather conditions,
- structural vibrations and cabin noise and
- cabin interior, dimensions.

This paper defines the discomfort indexes, analyzes the possible methods of ride controls and describes the developed ride control philosophies and methods for the personal planes. The novelties of these methods are the followings:

- developing a discomfort index for the personal planes,
- developing a limitation system for the aerodynamic control system (that might be adjusted by the pilots depending on their needs from "young dynamic maneuverability up to "old lady" style controllability),
- improving the ride control systems developed for small aircraft,
- integration of the ergonomic and psychological factors into the ride control developments.

The paper distributes results of ride control analysis and development realized by the EU supported projects EPATS (European Personal Air transportation System), PPLANE (Personal Plane) SATS-Rdmp (Small Aircraft transportation System – Roadmap, Hungarian National project SafeFly developing safety philosophy for 4 seats small aircraft and it supported by Hungarian talent care and cultivation TAMOP project.

1. Needs in ride control system

Generally, [4] comfort is a subjective state of well-being in relation to an induced environment including all type of disturbances such as noise, mechanical vibration, maneuver loads, large acceleration or decelerations. Ride comfort is the comfort inside the vehicles experienced by both driver (rider) and passengers. As usually, the ride quality is evaluating by discomforts or by specially developed ride quality rating models. Ride control uses the passive methods (as canard configuration) and active control elements.

The first ride controls had been developed for military aircraft (as for B-1 for improving the crew ride quality [5, 6] especially at the terrain following missions [7] and for B-52 because its flexible structure - [8]).

The passenger ride comfort problems were investigated at first at wide body aircraft. A Gust Response Suspension System has been developed for the Boeing 747 to improve passenger ride qualities in the aft section [7].

The ride control plays a very important role in flying at transition mode, as using the V/TOL aircraft having high coupling in different control channels [9, 10].

The new small personal aircraft applying the latest results of sciences and technologies will be used widely by the common people having large sensitivity to the comfort [11]. Passengers of personal aircraft may fill discomfort because

- the aircraft will be operated at lower altitude, in the airspace that usually accounts for most of intensive air turbulences,
- possible flights in bad weather conditions,
- structural vibrations and cabin noise as well as
- cabin interior, dimensions.

The loads generated by the air turbulence may cause the most serious problem. Gusts usually appear in highly stochastic manner. The probability of meeting a gust with different velocities had been measured and defined by aviation authorities. For example Figure 1. shows the probability of appearing different gusts in function of various altitudes [12].

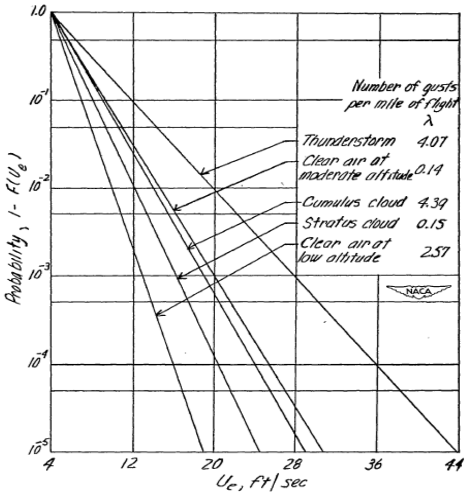

Fig. 1. Chracterisation of the gust appereances (U_e gust velocity (ft/sec))

Gust loads are usually evaluated by the load factor (*n*) generated by the gust (or air turbulences). Because of the human sensitivity, the ‘vertical’ load may generate the maximum discomfort. Here ‘vertical’ means the *z* direction in a wind reference coordinate system. As known, according to the FAR Part 23, in horizontal flight with constant altitude and speed, the ‘vertical’ load factor equals to one and the vertical gust generates extra load factor:

$$\Delta n_z = k_g \frac{C_L^{\alpha} \Delta\alpha_g \rho V^2 S}{2W} \quad , \qquad (1)$$

$$\text{where } k_g = \frac{0.88\mu}{5.3+\mu}, \qquad \mu = \frac{2W}{C_L^{\alpha} \rho S \bar{c}_g g} .$$

Table 1. Typical characteristics for a medium size passenger and a small aircraft

	wing spain	takeoff weight (N)	wing are (m2)	C_L^{α}	altitude 3 000 m: aircraft velocity (m/s)	altitude 3 000 m: air density (kg/m3)	altitude 10 000 m: aircraft velocity (m/s)	altitude 10 000 m: air density (kg/m3)
medium size passenger aircraft	31	600 000	105	5,60	200	0,909	245	0,41
4-seats small aircraft	11	11 600	16	5,30	70	0,909		

Changes in load factors influenced by the gusts can be determined by use of (1) and the data given in Table 1. As the Figure 2. demonstrates, small aircraft flying at 3 000 m has 6.5 times greater sensitivity to the gust than the medium size passenger aircraft at its cruise phase.

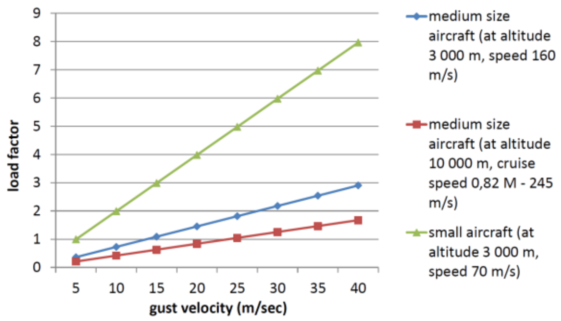

Fig. 2. Changes in load factor influenced by the gusts

The probability of meeting a larger gust at low altitude is higher than at the cruise altitude of the conventional passenger aircraft (see Figure 1.) However, the most important factor is the wing-load. The compared small and medium size aircraft have a wing-load of 725 and 5715 n/m^2, respectively. Therefore, the changes in the load factor generated by the gusts (15 m/s for altitude 3 000 m and 11 m/s for altitude 10 000 m) defined by the FAA (as design requirements) may initiate an extra load of 2,99 g and 0,46 g, respectively. Therefore, small aircraft should have 1 + 2,99 = 3,99 g load factor, even in conventional flight.

Seeing the facts above, it is clear that the ride control being able to decrease the loads generated by the turbulence could play an important role in the public acceptance of the novel small and personal air vehicles.

2. Ride control evaluation

Passenger comfort is not a simple task to measure. Even so, the literature proposes several methods. The most widely used are (i) the ride discomfort index (RDI), and the (ii) value-added parameter (VAP), which is especially seen to be popular in small or personal aircraft related investigations.

2.1. Ride discomfort indexes

As discussed in chapter 1., vertical acceleration (load caused by gusts) is a critical factor in human ride comfort. Therefore, the RDI should contain the acceleration in direct or indirect form.

After the extensive analysis of the effects decreasing human comfort and the study on the passenger perceptions of ride quality and motion sickness in air vehicles [13], various simplified empirical formulas were developed to evaluate the ride comfort, or discomfort.

One of the most simple RDI scaling method was introduced by Richards [14] and his colleague with use of:

$$J_{RD} = 2.1 + 17.2\bar{a}_z , \tag{2}$$

where

$$\bar{a}_z = \frac{1}{g}\left(U_0\dot{\alpha} - U_0 \cos(\alpha_0)q + g \sin(\theta_0)\theta\right). \tag{3}$$

By considering the longitudinally disturbed motions, Erkelens [15] recommended a special modified formula to determine the RDI:

$$J_{RD} = 1.8 + 17.5\bar{a}_z + 2.45\bar{q} . \tag{4}$$

Principally, this equation is the approximation of a frequency dependent ride discomfort function.

McLean [16] assessed another RDI:

$$J_{RD} = k\frac{C_L^{\alpha}}{W/S} . \tag{5}$$

Here, the wing lift slop, C_L^{α} involves the stability derivative [17], Z_w:

$$Z_w = -\frac{\rho SV}{2M}\left(C_L^{\alpha} + C_D\right) . \tag{6}$$

Generally,

$$C_L^{\alpha} \succ\succ C_D , \tag{7}$$

and the equation (6), using (7) could be reformulated to the following simplified form:

$$Z_w \cong -\frac{\rho SV}{2M}C_L^{\alpha} = -\frac{\rho Vg}{2k}J_{RD} . \tag{8}$$

By considering only the longitudinal motions of the aircraft, only, the following equations can be used:

$$\dot{w} = Z_w w + U_0 q + \sum_{j=1}^{m} Z_{\delta_i}\delta_i , \tag{9}$$

$$\bar{a}_z = \dot{w} - U_0 q = Z_w w + \sum_{j=1}^{m} Z_{\delta_i}\delta_i . \tag{10}$$

Using (8) and (10), the *z* direction (vertical) acceleration of the aircraft centre of gravity is defined as the linear function of RDI and deflection angle of control elements:

$$\bar{a}_z = -\frac{\rho U_0 g}{2k} w J_{RD} + \sum_{j=1}^{m} Z_{\delta_i}\delta_i . \tag{11}$$

From (11), it is clear that the reduction of the acceleration related to the aircraft's centre of gravity and effort of control elements' deflections reduces the ride discomfort. The practical analysis of this RDI [16, 17] indicate the following conclusions defined by [18, 19], too: if ride $J_{RD} \le 0.1$, than passengers would not feel any discomfort, while $J_{RD} \ge 0.28$, would already indicate signs of discomfort, which could be easily solved by minor modification in the flight conditions (altitude or speed).

As known from flight mechanics

$$\frac{C_m^{\alpha}}{C_L^{\alpha}} = -\frac{x_{AC}}{\bar{c}} . \tag{12}$$

By using (12) RDI defined by (5) could be also reformulated to the following:

$$J_{RD} = \frac{k}{W/S}\bar{c}\frac{C_m^{\alpha}}{x_{AC}} . \tag{13}$$

According to the flight dynamics and control [18, 20], the longitudinal derivative, C_m^{α} could be determined by following formula:

$$C_m^{\alpha} = \frac{2I_{yy}}{\bar{c}\rho U_0 S}M_w . \tag{14}$$

Therefore, the RDI as below:

$$J_{RD} = k\frac{2I_{yy}}{\rho U_0 S}\frac{M_w}{x_{AC}} , \tag{15}$$

depends on the derivatives M_w (15) and Z_w (8). For minimization of the ride discomfort, these derivatives must be minimized [17]. With this, the characteristics of the aircraft longitudinal short periodic motion must be changed. As a result, the ride control system must be developed together with the direct control system improving the longitudinal stability of the aircraft.

Comment: While the literature indicates that humans are more sensitive to lateral acceleration than to longitudinal motions, unfortunately there is no good and well acceptable definition for lateral discomfort indexes. Even so, if the discomfort related to the lateral disturbance should be decreased, one could use the vertical canard or deflection of the vertical stabilizer.

2.2. Value-added parameter

The NASA SATS project shows that small aircraft needs a simple ride control system to increase the ride quality. However, step changes in general aviation as personal air transportation system needs another requirements of quality, called as value added parameters (VAP).

Roskam has recommended the possible introduction of the VAPs [21] especially for small and personal aircraft. He has underlined: "the personal transportation airlines envisioned in the SATS program must represent clear value to costumer to be marketable". He defined a special value-added-parameter including the most favorite characteristics of costumers as door-to-door speed (DDS), range with full payload (RFPL) at economical cruising speed and NBAA reserves as well as cabin volume (CVo):

$$\mathrm{VAP} = \mathrm{DDS} \times \mathrm{RFPL} \times \mathrm{CVo}\,. \qquad (16)$$

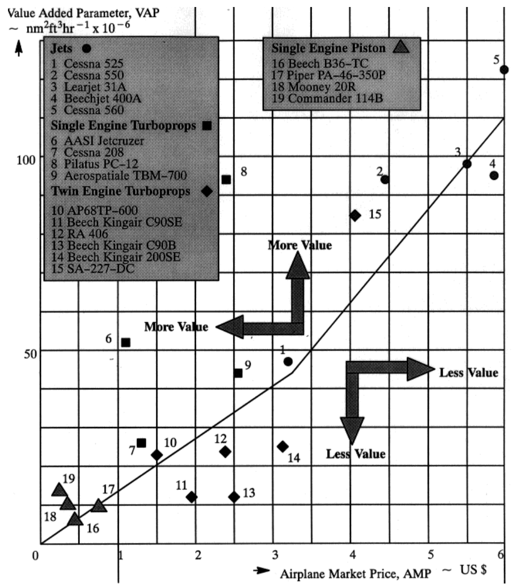

Fig. 3. The value-added-parameter (16) as function of market price (in million US $)

According to the analysis (Fig. 3.) used by Roskam [21] based on a modified data bank [22], a six-passenger personal transportation jet can only be effective in the market place once its VAP is around 50 (10^6) or more. Assuming a minimum required DDS of 200 kts (370 km/h) and a range of $R_{ground}/R_{block} = 0.1$ results in a design cruise speed of about 300 kts (456 km/h). The maximum flight time of airplanes without sanitary facilities is 3 – 3.5 hours [21]. Therefore, the RFPL can be defined as 900 miles (1850 km) for such aircraft category. Therefore, once the VAP is equal to 50, than the required cabin volume is about 185 cu.ft (5 m^3).

From this short analysis, it seems that it is a challenge to design a twin jet six-seats personal jet with a primary cost of 1.5. – 2 MUSD, a range up to 900 miles, a cruise speed around 300 kts, which is convenient for travelling as well as for working.

The evaluation of the value from the user point of view could be applied to all type of small aircraft. For example, many scientists believe that small aircraft transportation also accounts for airplanes being able accommodate up to 19 or even up to 22 – 26 passengers. Such regional planes could be evaluated (from the user point of view) by the value factor (VF) introduced by Norris [23]:

$$\mathrm{VF} = (\mathrm{SMD} \times \mathrm{CFD} \times \mathrm{PH})/\mathrm{FBD}\,. \qquad (17)$$

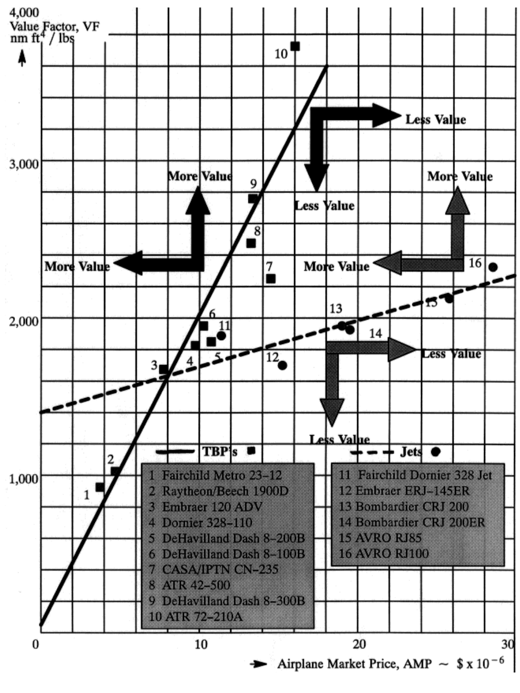

Fig. 4. The value factor VF (7) as function of market price

According to the results presented in the Figure 4. turboprop regional airplanes account for a better value factor, once their primary cost is greater than 8 million USD. This is the main reason for many airlines to rapidly change their fleet of regional jets to turboprops.

Of course, the different size of aircraft have different VAP. For example, the 4 seats single engine personal aircraft should have VAP more than 15 M and price less than 0,6 MUSD.

2.3. Human sensitivity to the ride control

The Human as individual has subjective sensitivity to the ride comfort. For example, according to our measurements, noise generated nearby airport as usually has smaller level than noise generated in metro. (But nobody wants to close the metro!).

Preliminary investigations on passengers' acceptance on disturbance effects [24] show, that human is very sensitive to low frequency excitations from 2 up to 12 Hz (Fig. 5.). The idea behind the improving the ride quality is therefore to keep the frequency of the disturbing effects under 2 or higher than 12.

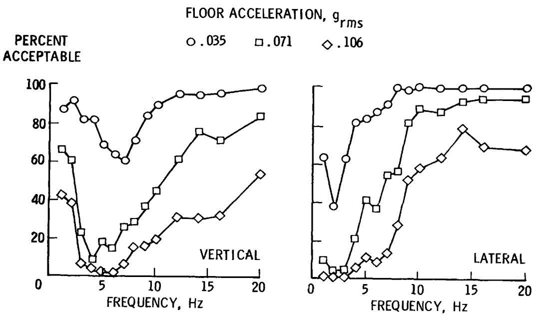

Fig. 5. Aircraft tourist class passengers acceptance of vibration

3. Ride control systems for personal aircraft

There are three different methods that could improve the ride quality of small and personal aircraft. These are the passive, quasi-passive or semi active and active methods.

3.1. Passive methods

Possibly the less complex method to improve ride control, and which is generally associated to conventional methods of aerodynamic design. We have to reduce the amplitude of oscillation or vibration and to keep the frequency in range from 2 to 12.

This could be reached by analyzing two different facts. The first is defined by the aircraft short period disturbed motion that is investigated by flight stability and control very well. The second is influenced by the structural vibrations initiated e.g. by flow separation or working elements on the aircraft as engine as well as by the aeroelastic phenomena as flatter and buffer (buffeting).

In case of low frequency, the geometrical characteristics must be selected to keep the aircraft oscillation frequency below 2. If possible, the wing load and fuselage length must be increased. As for problems generated at higher frequency, potential solution include for example the canard configuration, and engines installed in/on the wings.

3.2. Quasi passive / semi active method

Theoretically, the highly undesirable passenger accelerations could be always alleviated by an automatic control system using appropriate sensors, computers, and rapid-actuation controls. Unfortunately, the complexity, costs, and maintenance of such systems are beyond the financial capabilities of typical small airplane owners. Despite the long-term interest of designers in reducing the effects of turbulence on ride quality, and the continuing dissatisfaction of public passengers with undesirable accelerations due to turbulence, no current general aviation small aircraft are equipped with gust-alleviation systems.

NASA investigated the aircraft response to gusts and its reduction for the last 40 - 50 years [25]. They studied several concepts for gust alleviation even for small aircraft applications [26]. Between 1975 and 1976, a series of analytical and experimental studies were performed on a 1/6-scale model of a typical general aviation airplane equipped with an aeromechanical gust alleviation system. The gust alleviation system consisted of two auxiliary aerodynamic surfaces that deflected the wing flaps through mechanical linkages to maintain nearly constant airplane lift when a gust was encountered. The test with the dynamic model, modeling a four-seat, high wing, single-engine light airplane showed that the gust-alleviation system reduced the model's root-mean-square normal acceleration response by 30 percent in comparison with the response in the flaps-locked condition. Despite these promising results, the so called semi active aeromechanical concept was not deployed because the complexity of the solution.

A decade later, NASA had developed an active, computer-based gust alleviation system for general aviation aircraft [25]. After the analytical studies, the concept was demonstrated on a Cessna C-402 twin-engine research airplane. Unfortunately, even at that time, the response characteristics required of the control actuators could not be accommodated within the budget and time allotted for the project, and the activity was terminated.

Nowadays, the semi active methods could be combined with active control systems.

The extreme accelerations and large discomforts for passengers could be controlled or reduced by developing a special control system in which the control effectiveness could be changed.

The control effectiveness could be characterized by the deflection and deflection rate of control surfaces, as well as by the initiated changes in aerodynamic characteristics for unit control force or unit deflection of control sticks.

The effectiveness can be enhanced by modifying the control systems with

- changing in mechanical systems (for example changes in lengths of control rods, use of changeable mechanical limiters of control surface deflections),
- changing in actuator characteristics (for example changes in supply pressure of hydraulic actuators), and
- changes in (automatic) control laws.

These methods are semi actives, as they might not be used continuously, but only on a switch on - switch off basis.

3.3. Active methods

All the active ride control techniques are the different applications of the direct and active control methods. There are numerous methods that could be applied to reduce the gust effects, the gust load alleviation to improve the ride control and extend the aircraft's technical life. The gust load alleviation control technology could be either reactive or predictive. In a traditional reactive control framework, flight control systems could be designed to provide sufficient aerodynamic damping characteristics that suppress vehicle dynamic response as rapidly as possible upon a turbulence encounter. Unfortunately, the simple increase of the damping ratios, might result in poor flight control performance.

Predictive control could provide a novel gust load alleviation strategy for future aircraft design, especially with light-weight flexible structures. Novel look-ahead sensor technology like lidar radar can measure or estimate turbulent intensity to provide such information to a predictive gust load alleviation control system which in turn would dynamically reconfigure flight control surfaces once an aircraft enters a turbulent atmospheric region. The predictive gust load alleviation control must include:

- novel sensor methods as Optical Air Data Systems based on LIDAR or other novel detection methods that can measure near-field air turbulent velocity components directly in front of an aircraft in the order of one-body length scale to provide nearly instantaneous predictive capability to significantly improve the effectiveness of a gust load alleviation control system, as well as
- a predictive gust load alleviation control approach or other effective methods that can reliably reconfigure flight control surfaces dynamically based on the sensor information of the near-field turbulence to mitigate the vehicle structural dynamic response upon a turbulence encounter.

The gust alleviation system is a special control system that could be synthesized with the aircraft motion models describing the aircraft dynamics and/or airframe (structure) aeroelastic motion.

One of a special method of applying this system to improve the ride control could be based on the desired dynamics.

Generally, the aircraft motion model (system of equations) as the aircraft dynamic model could be used to study the stability, dynamics and controllability of the aircraft motion. However, integration of this system of equation needs detailed and exact information e.g. on the real parameters of aircraft, or all type of disturbances. Once the available data on the exact performance of systems, actuators, etc., is limited, the given system cannot provide to required solution. In such case, the inverse dynamics introduces errors or uncertainties into the system, such as changes in system parameters (anomalies), no modeled actuator and sensor dynamics, and/or errors in both of these components. The reduction of the disturbance effects and low sensitivity can be achieved by synthesis robust outer-loop controller with the dynamic-inversion inner loop (Fig. 6.). Therefore, the elements of $\mathbf{x}$ state-vector must be measured ($\mathbf{x}_{\mathrm{m}}$) and a special controlled variable (x_{CV}) must be determined from the measurements to define the $x_{CV_{des}}$ desired controlled value as different in $x_{CV_{com}}$ command and x_{CV} actual controlled values:

$$\dot{x}_{CV\,des} = T\left(x_{CV_{com}} - x_{CV}\right). \qquad (18)$$

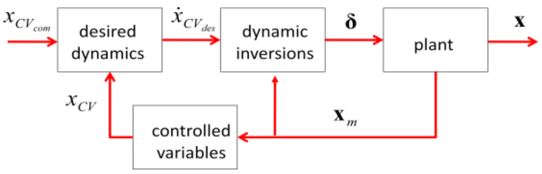

Fig. 6. Dynamic inversion

The different T transfer functions define the different roles of desired dynamics. For example, the desired controlled values for flight quality and ride control can be determined by the transfer functions shown in Figure 7.

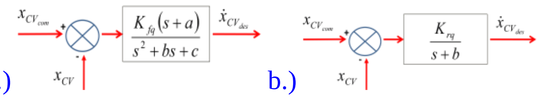

Fig. 7. Desired dynamics (a.- flying quality, b.- ride quality)

Therefore, the flying quality desired dynamics can be represented as

$$\dot{x}_{CV_{des}} = \frac{K_{fq}(s+a)}{s^2+bs+c}\left(x_{CV_{com}} - x_{CV}\right), \qquad (19)$$

where $\quad b = 2\varsigma_{des}\omega_{n.des}$

and $\quad c = \omega_{n.des}^2 - K_{fq}$

for the desired damping, ς_{des}, and natural frequency, $\omega_{n.des}$. Of course, in the transfer function the gain K_{fq} and the zero location are real constant values.

Because the aircraft dynamics including the actuator dynamics, dynamic inversion, aircraft dynamics, and sensor, might be represented by an integrator elements,

$$x_{CV} = \frac{1}{s}\dot{x}_{CV_{des}} \qquad (20)$$

and the closed-loop transfer function for the flying quality dynamics is given by

$$\frac{x_{CV}}{x_{CV_{com}}} = \frac{K_{fq}(s+a)}{s3 + bs^2 + \left(c + K_{fq}\right)s + K_{fq}a}. \qquad (21)$$

By the same approach, the closed-loop function for the ride control can be defined by the following model:

$$\frac{x_{CV}}{x_{CV_{com}}} = \frac{K_{rq}}{s^2 + bs + K_{rq}}. \qquad (22)$$

This approach can be implemented into the active control synthesis and after determining the transfer functions related to the given aircraft, it could be used to define a developed ride control.

4. Recommendations

As it was described, the ride control, ride quality of the small and personal aircraft depends on

- form, structural solution, aerodynamics, flight performances, stability and controllability of aircraft,
- unwanted disturbances (air turbulence),
- disturbance generated by pilots (maneuvers),
- structural vibration (aeroelasticity, working of elements like engines, actuators),
- noise (aerodynamic, working elements like engine, actuators),
- discomfort (cabin dimensions, traffic complexity, etc.).

The ride quality is a subjective state of well-being, that depends on the individual sensitivity to the disturbances, the forms and values of disturbances and stochasticity of the disturbances. Therefore, even the definition of the ride comfort, or discomfort is quite complex task and the ride control may improved by use of different methods that may have a complex interactions.

The requirements in analysis and improving the ride quality was defined by first works on personal air transport developments [27]. Since, several projects (EPATS, PPLANE, SafeFly) have investigated the ride control [28] together the safety aspects [1]

Our analysis and developments of the personal airplanes [11] and their safety [2, 3] has resulted to the following recommendations.

Ride discomfort index

Because the higher sensitivity of small aircraft to gusts, operation of aircraft by less-skilled pilots and human subjective evaluation of the comfort, the ride discomfort index might be defined by following simplified formula:

$$J_{RD} = a_0 + a_1\bar{a}_{z_g} + a_2\bar{a}_{z_c} + a_3\dot{q} + \\ + b_1\left(f - b_2\right) + b_3\left(VAP - b_4\right), \qquad (23)$$

where first part deals with the physical disturbance (dividing the vertical acceleration into two elements initiated by air turbulence, gusts and by pilot controlling the aircraft motion) and the second part take into account the human sensitivity to the comfort.

The coefficients in the (23) are different for the different size of aircraft and their real characteristics and performance as wing load factor, cruise speed, cruise flight altitude, size of cabin, noise, etc. For example the b_2=6 and b_4=20 for small 4 seats aircraft.

Aircraft development

For further improving the ride control of personal aircraft by passive methods, as limitation on the wing load factor, using the unconventional forms, decreasing the structural vibrations, minimization of the additional acceleration by establishing the seats very close to the centre of gravity, introducing a special system adjusting and keeping centre of gravity in the fixed point, etc.; a special project must be initiated.

Generally, it is strongly recommended to certify the personal aircraft in utility category [2], however, the sensitivity to the large gust loads must be reduced.

Pilot assisting system

Because the personal aircraft will be piloted by so called less-skilled pilot, therefore a special pilot assisting system must be developed. On one hand, such system may generally assist the pilots as virtual (digital) co-pilot system [2, 28] and may support the pilot situation awareness and decision [1].

On the other hand, such system can be applied as semi active method for improving the ride control, too. There are two major problems must be solved. At first the aircraft control must be simplified for reducing the pilot workload. For example the engine (throttle) and elevator control must be harmonized by developing a special coupled control system (Fig. 8. [2, 27, 29, 30]).

At second, the pilot induced overloads may or better to say must be reduced by implementing a special electro-mechanic elements controlling ratio of elevator deflection and rule displacement. Such system may vary the controllability and maneuverability from the so called "old lady type control" up to "young ace".

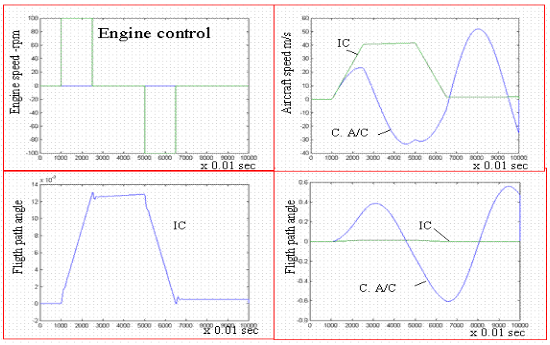

Fig. 8. A case of harmonisation of the engine and elevator control: pilot uses the engine control for change the aircraft speed, only.

This solution seems very simple, however, it generates a series of problems, because the

Both of these solutions are new, original and applicable, however they must be tested from safety point of view. Especially, the changes in ration of elevator and rule deflection nay, as quasi dynamic method of improving the ride quality, may cause not only flight dynamic, but legal and society acceptation problems, too.

Gust elimination system

Well know and well developed technology used as dynamic method for increasing the ride control, as it shortly described by point 3.3. The system must be harmonized with the changes previously described control line integrations (harmonization) and using an adjustable ratio in engine and elevator control. Of course, all the system improving the aircraft stability have direct influences on the air craft ride control, too. therefore all the applied methods for increasing the ride control must be harmonized.

Noise and vibration reduction

For reaching this goal several many different solutions can be applied from the passive methods (shape designed for minimization of flow separations, structural solutions with control on own frequency, etc.) up to active noise and vibration control (for example using the MEMS (Micro-Electro-Mechanical Systems) technology for active flow, flow separation control).

Increasing the society acceptances

Generally, the acceptance of the new technologies as new personal aircraft and establishing the new personal air transportation system is a very complex process involving into solutions all the stakeholders. This process more or less depends on the human subjective sensitivity to accepting the new technologies. This sensitivity is a function of the society attitude to the innovative and radically new, disruptive technologies and added values of the new technologies.
Solutions of problems associated by the society acceptation of the personal air transport are generated partly on the basis of technology development, physical solutions and partly on the sociology, psychology, etc.
The working on the society acceptation must starting with the future user (young generation) and the possible users.

Conclusions

The personal aircraft and personal air transport system introduces new and large business in aviation. The diffusion of this new system into the economy depends on its society acceptance. The ride quality is one of the very important factor that may increase the society acceptance.

The comfort is a subjective state of well-being in relation to an induced environment including all type of disturbances. Ride comfort is the comfort inside the vehicles experienced by both pilots and passengers.

The ride comfort of small and personal aircraft depends on the

- loads induced by disturbances from surrounding (like air turbulences),
- loads originated from inside the control system (endogenous disturbances) initiated by the pilots (so called less-skilled pilots having limited practice),
- structural solutions (minimizing the noise and vibrations) and
- human subjective sensitivity (on the size, importance of door-to-door speed, safety, etc.).

After investigation of the possible increasing the ride control several recommendation had been worked out, namely

- a special ride discomfort index was developed for the personal aircraft,
- the passive methods (form of aircraft, structural solution for decreasing the unwanted increases in load factor) were defined,
- pilot assisting system including the simplification of the aircraft control system (as harmonization of the engine and elevator control) and semi active control on maneuverability (control on ratio of control surface and control stick deflections),
- gust elimination (smoothing) system (as active, dynamic on line control of gust loads),
- reduction of noise and vibration by use of active control methods,
- increasing the society acceptance by increasing the comfort (with improving the "psychological" factors).

The described recommendations need further investigations.

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