Trigger event – a key factor in adverse Aircraft/Rotorcraft Pilot Couplings

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Abstract: *An important element that interacts unfavorably with pilot and aircraft is the triggering event. Without a trigger event (or a chain of triggering events) A/RPC does not appear. This study presents an overview of different classes of triggers that can initiate an A/RPC phenomenon. Based on extended analysis of triggering events a new definition is proposed.*

Key Words: *Aircraft/Rotorcraft Pilot Coupling, Pilot Induced Oscillations, Pilot Assisted Oscillations, biomechanical coupling, visual cues, pilot visual perception, optical illusion, Usable Cues Environment, Visual Cue Rating.*

List of Abbreviations

A/RPC – Aircraft /Rotorcraft Pilot Coupling
ASE – Advanced Supersonic Transport
DVE – Degraded Visual Environment
FBW – Fly by Wire
FOV – Field of View
FCS – Flight Control System
FDR – Flight Data Recorder
HQR – Handling Qualities Requirements
OCM – Optimal Control Model
PAO – Pilot Assisted Oscillations
PF – Pilot Flying
PIO – Pilot Induced Oscillations
RPC – Rotorcraft Pilot Coupling
UCE – Usable Cue Environment
VCR – Visual Cue Rating

1. INTRODUCTION

The future design of new aerial vehicles - such as heavy rotorcraft or large transport aircraft – is related to the development of new more flexible structures. The overall flight control system must include this effect of flexibility in its design. The reason for this is that the natural frequencies of the fuselage and wing/ rotor blade structural modes decrease as their size increase, and as consequence the lower frequency structural modes have a greater influence on the vehicle dynamic response.

Additionally, the weight reduction through use of composite materials contributes to the development of more flexible structures. The structural flexibility affects also the vehicle aero-elastic stability where the pilot biodynamic feedback and flight control system feedback can interact with vehicle structure, leading to pilot /control system assisted excitation of the structural modes.

These new problems illustrate a need for additional knowledge in developing models that include the interactions between the vehicle flight dynamics response, structural flexibility modes, the flight control system, and pilot biodynamic feedback in order to assess the aero-servo-elastic stability and to identify potential A/RPC oscillations.

Generally, A/RPC phenomena are oscillations or divergent vehicle response that is a disagreement between the vehicle characteristics and pilot control strategy. According to [1] some different definitions exist in the open literature and many times the aerospace community is unable to distinct upon whether or not it is an A/RPC. Presently PIO and PAO are considered subclasses of A/RPC.

In ARISTOTEL [2] after an exhaustive discussion between the project partners the following definition was proposed to be used through project: *"An Aircraft- or Rotorcraft-Pilot Coupling (A/RPC) is an unintentional (inadvertent) sustained or uncontrollable vehicle oscillations characterized by a mismatch between the pilot's mental model of the vehicle dynamics and the actual vehicle dynamics. The result is that pilot's control input is out-of-phase with the response of the vehicle, possibly causing a divergent motion".*

Reconsidering the A/RPC definition according to Mc Ruer [3] there should be met three simultaneous conditions for A/RPC event:

A/RPC = Vehicle Dynamics + Trigger + Closed Loop Control

This study is concerned with analysis of triggers as key factor, in order to acquire an understanding of triggering events that can develop A/RPC phenomena. Also it aims to explain the influence of the triggering events and pilot perception on modeling the pilot and the vehicle dynamics.

2. TRIGGERS DEFINTIONS AND CATEGORIES

The general cause of an A/RPC is commonly accepted to be due to a trigger event. The trigger causes the pilot to quickly alter his/her control strategy. The trigger can occur in a number of different situations such as wind, gust (exogenous trigger), changes in FCS mode or in aircraft functioning, discontinuities in the pilot perception or in the behavior of the vehicle, etc. (endogenous trigger) [3, 4, 5, 6, 7 and 8].

Trigger events may lead to A/RPC; however, not all trigger events will necessarily develop into A/RPC. Fig. 1 (after Smith [ref.4]) shows that A/RPCs occur because the aircraft dynamics allow this. Aircraft must respond to pilots input in a manner that propagates an A/RPC.

The triggers may develop under different conditions such as atmospheric turbulence, sudden change in the closed loop dynamics of the aircraft-pilot system, a nonlinear effect in flight control system, all these requiring a rapid change in pilot's control strategy. The trigger event has its effect on the pilot, but the aircraft must respond to the pilot input in a manner that propagates an A/RPC [9].

Aircraft characteristics that are known to facilitate A/RRPC behaviour include sluggish response modes, lightly damped modes, excessive phase lag or time delay, sensitive stick gradient, unusual coupling responses, and unstable modes [1, 10 - 16].

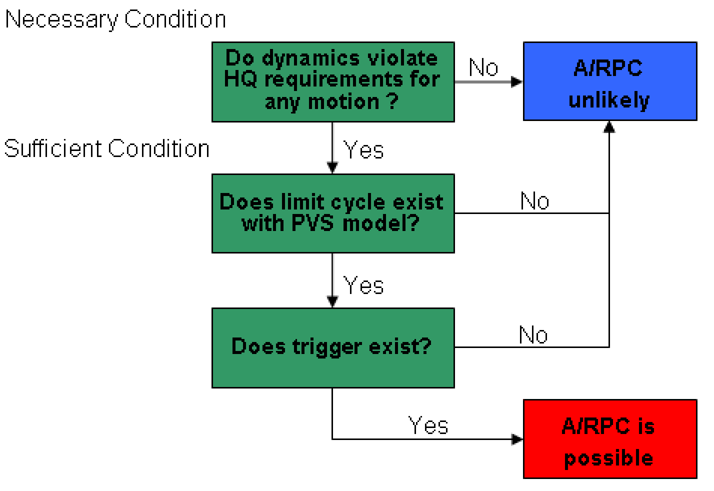

Fig. 1 Conditions for A/RPC occurring (after Smith, ref.4)
PSV= pilot vehicle system

Trigger definition – ***An inseparable element of A/RPC that activates a transition of vehicle motion from steady state to oscillatory or divergent motion when the pilot applies a correction control.***

There are considered three classes of triggers according to [3]: environmental triggers, vehicle triggers and pilot triggers. The environmental and pilot triggers were most frequent in the past, however, for modern configurations, vehicle triggers have become also a threat for vehicle's safety.

a) <u>Environmental triggers</u>

The environmental conditions can change sometimes the basic vehicle dynamics. Examples of environmental triggers are:

- Sharp wind gust, wind shear, turbulence, thunderstorm, rain or snow-blast. A wind shear associated for example with a precision landing task can force the pilot -into proper control behaviour - to induce an oscillation. The turbulence at high altitude has been joined with several A/RPC events in transport aircraft or aerial refuelling.
- Environmental conditions that change the vehicle dynamics. For example, severe icing can modify both pitch and roll characteristics.
- Other example would be a threat of imminent collision that demands a large amplitude control action, which may result in nonlinear control response.
- Other example describes an event that occurred when an Air Force F4 fighter aircraft was attempting to set a low-altitude 3000 m speed record. A longitudinal PIO developed and the aircraft disintegrated due to the aerodynamic force caused by high-dynamic pressure [17].
- A sudden and large turbulence encounter can cause a pilot to actively begin high-gain, compensatory altitude tracking when previously he was only monitoring aircraft trim to make low-gain correction to vehicle attitude.
- An environmental trigger may be associated with all stress inducing situations for the pilot, such as a spot landing.

b) Vehicle triggers

These triggers generally correspond to unpredictable failures of the aircraft systems (engine, control system, hydro system etc.) which lead to the sharp disturbance and/or the changing of aircraft handing qualities (dynamic characteristics, control sensitivity, feel system characteristics etc.). They cause changes in the effective vehicle dynamics that lead to a mismatch between the pilot control strategy and the aircraft dynamics. Three categories of vehicle dynamics triggers are distinguished:

- A Mismatch between Flight Control System and Vehicle Configurations: A usual example is a miss calibrated FCS gain or other parameter change intended to adjust the FCS properties as a function of the aircraft configurations. One significant trigger is the automatic change of the flight control system due to configuration changes (e.g. gear transition). A combination of large time delay in the FCS coupled with high gain pilot tracking activity may cause the vehicle control actuators to rate saturate or rate limit [17].
- System failures: For example, control system failures such as failure in the hydraulic system, actuator failure, uncontrolled change in aircraft trim may significant modify controllability of the vehicle. The sensor, the filter that alters the feedback dynamics to the pilot or control system may become potential triggers.
- Flight Control System Mode Shifts:
    - ▶ The potential A/RPC triggers appear through changing of the flight control laws (i.e. switch modes) to tailor the effective aircraft dynamics for different tasks. When the pilot is unaware of the mode transition, a mismatch between his mental model and the effective aircraft dynamics can appear. An example is the control law of Boeing 777 which changes between “air” mode and “ground” mode.
    - ▶ Furthermore, the transition between modes, especially in the case of failure may lead to A/RPC events. An A/RPC triggering mechanism can be developed as a result of mixed manual and automatic control modes. This is the case of elevator used manually when speed is controlled by auto throttles. More precisely, in turbulent conditions at high altitude, elevator trim motion command by stability augmentation system can interact with pilot’s manual command for pitch control.
    - ▶ Further, the nonlinear element such as rate limiter placed after the pilot’s command can introduces time lags, thereby leading the pilot to produce unreasonable inputs. It is a case of JAS39 accident which is partially attributed to this problem.
    - ▶ Finally, other situation appears when a sudden takeover from automated control, such as an autopilot disconnects in out-of-trim conditions. Sometimes, the manual takeover problems have been combined with problems of mixed manual and automatic control modes. An example is TAROM A310-300 incident at Orly airport on September 24, 1994.

c) Pilot triggers

Examples to pilot triggers correspond to: aggressive pilot control to avoid the sudden collision or to follow captain or dispatcher’s instruction; pilot stress due to sudden changing of flight condition; accidental or involuntary pilot actions; inaccurate piloting as a result of optical illusions, wrong piloting strategy and others. The pilot trigger may appear after an environmental or vehicle trigger occurs, the correspondingly A/RPC event being a result of pilot overreaction or lack of appropriate reaction. The pilot's concentration on particular cues to the exclusion of others is often necessary. However, an excessive exclusive concentration can lead to a momentary excessive gain and, subsequently, a pilot trigger upset. The stress can be task-induced when the pilot attempts a high gain task as refuelling or aircraft-carrier landing. An inappropriate or incorrect control strategies adopted by the pilot can cause a pilot-triggered A/RPC. For example, the hovering task case is one when the pilot attempts to control position directly rather than indirectly through controlling altitude. Sometimes the pilot doesn't identify the appropriate control variables to accomplish a specific control task and under stress he may focus on the wrong variables. With the increasing complexity of modern FBW/FCS it may not be possible for the pilot to have an adequate mental model of the aircraft system. In unusual or emergency situations the pilot's ad hoc mental model of the aircraft FCS may lead to inappropriate control strategies and increased potential for A/RPC phenomena.

As an illustration of the pilot triggering event let's consider the case of American Airline Flight 587 crash AA587 [17]. During climb-out the A300-600 aircraft experienced two encounters with the wake vortices of another aircraft, a Japan Airlines Boeing 747 that had departed JFK moments earlier. When the first encounter hypothesized to be the vortex emanating from the left wing tip of JAL 747, the pilot-flying(PF) responded with significant wheel inputs (30-40 deg of wheel rotation) but with a small pedal inputs. AA587 have indicated a left turn. After approximately 15 seconds, an encounter with the second vortex occurred, this one hypothesized to be emanating from the right wing of JAL747. The cockpit accelerations that occurred in the second encounter were dominated by a vertical acceleration i. e. nose down and roll acceleration to the left. The second encounter led to large wheel and pedal inputs. The Flight Data Recorder (FDR) indicated that both wheel and pedal were moved repeatedly to the maximum positions. The FDR time histories indicated that oscillatory pilot/vehicle responses were in evidence after second encounter. The plausible triggering event established in the AA587 accident were the large cockpit lateral acceleration occurring immediately after the pilot initiated pedal inputs. It was indicated an initial maximum lateral acceleration approaching 0.5 g's (nose right), occurring about 0.2 sec after the pedal was driven to its limit (right pedal) for the first time, these correspond to large accelerations for a transport aircraft. This triggering event produced by momentum behind of the large wheel and pedal inputs has been followed by pilot flying desire to bring the aircraft to a wing level attitude after initial vertical and roll acceleration in the second wake encounter. The ground test performed on an A300-600 aircraft shows that the moving of the column, wheel and pedals in a sinusoidal fashion using full and partial displacement at 0.5 Hz frequencies closely approximate the wheel and pedal displacements of the AA587 in the last seconds of flight. Figure 2 shows the applied wheel force, resulting aileron deflection, an aileron rate when both the wheel and pedal are oscillating at a frequency of 0.5 Hz and full wheel and pedal throw are required. It is clearly that aileron actuator is under nearly constant rate saturation, this means a destabilising effect. The 0.45 sec lags due to the dynamics of both the cockpit force/feel system and actuator itself was considered very large even for an aircraft of A300-600 size. Similar though smaller delay occurred with pedal input shown in fig. 3. In conclusion, a lateral-induced oscillation (APC) was evident in the moments before the crash of AA587. The lateral directional APC oscillations were likely accompanied by similar oscillations in the longitudinal axis. The rate saturations of the aileron and rudder actuators created additional time delays in the flight control system and it required an increased wheel and pedal forces of the pilot both of which contributed to the severity and duration of APC.

The sensitivity of the rudder /pedal control system of AA300-600 may constitute a control system characteristic conducive to PIO.

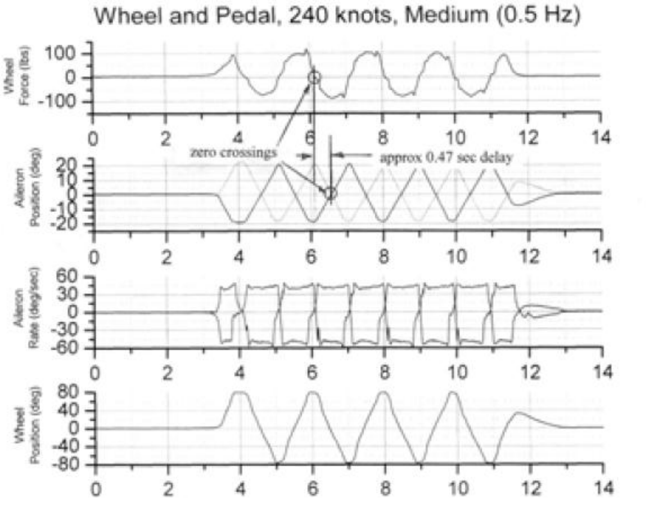

Fig. 2 A300-600 ground test results for wheel (from ref. [17])

d) Non classical triggers

Additionally to classical triggers other class of triggers mentioned as non-classical trigger can be associated with 'abnormal' forms of pilot dynamic behaviour. Ref.19 defines such an interaction of dynamic characteristics of the neuromuscular limb system, the aircraft dynamics and the mechanical controller with the flight control system. Generally, this initiation mechanism is associated to Category IV of A/RPC [18]. Sometimes named also as "limb-manipulator" or "limb-bob weight" effect, it tends to be the most common trigger in documented cases of rotorcraft pilot-assisted (augmented) oscillations (PAO). Generally, aero elastic Pilot-Augmented-Oscillation are aero elastic oscillations/mechanical vibrations that produce accelerations at the pilot station to which the pilot unintentionally couples with, sustaining or enhancing these dynamics. They correspond to unintentional closed-loop coupling and do not involve a tracking task. Following the same reference [4], a classification of aero elastic pilot-in-the-loop oscillations is formulated as:

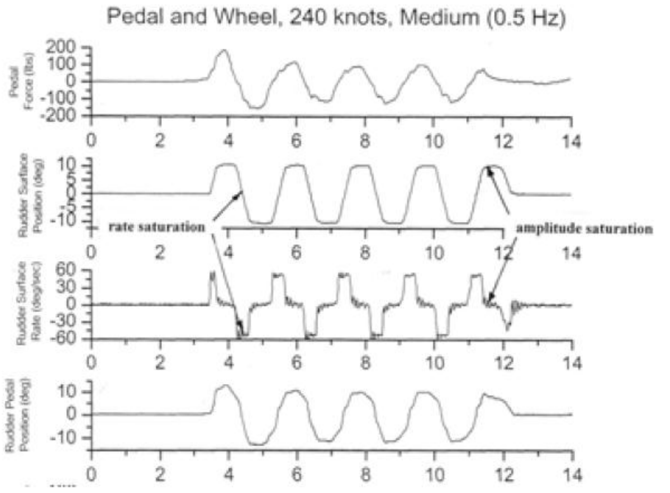

Fig. 3 A300-600 ground test results for pedal (from ref. [17])

Type I PAO– when the aero elastic structural deformation produces acceleration or altitude changes at the pilot station which results in PAO when the pilot, intentionally attempts to counter these dynamics

Type II PAO– when the aero elastic structural deformation produces an aircraft rigid body response which results in PAO when the pilot, intentionally attempts to counter these dynamics

Because the practical limit of a normal pilot input bandwidth is about 3 Hz, a physical vibration of the pilot/stick or pilot/throttle over this limit may be taken into account.

Discussing on the triggering upsets involved in Category IV A/RPC, it is generally accepted that there are two types of passive couplings responsible for A/RPCs:

- biomechanical coupling: this coupling occurs when the inertial forces on the pilot and stick cause unwanted and inadvertent pilot control inputs that reinforce and sustain motion. Two categories of A/RPC events are known to correspond to the biodynamic coupling triggering [4]: 1) "roll-ratcheting" - defined as a rapid neutrally damped roll oscillation and 2) a vehicle structural modes coupling involving airframe vibrations at typically up to 4 Hz. In both cases the pilot is not consciously engaged in the close loop.
- The second type of passive coupling appears when an airframe aero elastic mode vibrates the cockpit sufficiently to cause inadvertent pilot arm and stick inputs, resulting in control surface deflection amplifying the vehicle emotion [4].

The cockpit vibrations due to aero elasticity can degrade the pilot ratings for two different reasons:

- ▶ vibration environment has a negative impact on comfort level or ride qualities at the pilot station
- ▶ cockpit vibrations tend to influence the precision of the pilot control inputs. This aero elastic effect is referred to the transmission of vehicle motion from seat through pilot's body to stick control where it produces unintended vehicle control commands as Biodynamic Feedthrough.

For helicopters, the slung load dynamics becomes important due to the much higher sensitivity to cyclic controls associated with the increased collective control needed to support the load.

One of the famous RPC examples took place during operation with Navy CH-53E rotorcraft with external slung loads [ref. 19].

Here, pilot biodynamic interacted with the lower-frequency rotor dynamics, the slung load worsening the problem.

As an exemplification of the Category IV A/RPC biodynamic coupling, two case studies are given below (taken with modification from [ref. 20, 21]). To mention that all parties involved in the analysis were prepared for APC occurrence.

Case 1 considers a generic, large swept-wing, high speed aircraft with a conventional empennage.

The analysis is focused on the longitudinal dynamics, using a precision tracking task. The simulation was flown by several test pilots in NASA Langley's Visual Motion Simulator.

The pitch-rate-to-elevator frequency responses (rad/sec/deg) for the elastic and rigid vehicle models are shown in fig. 4.

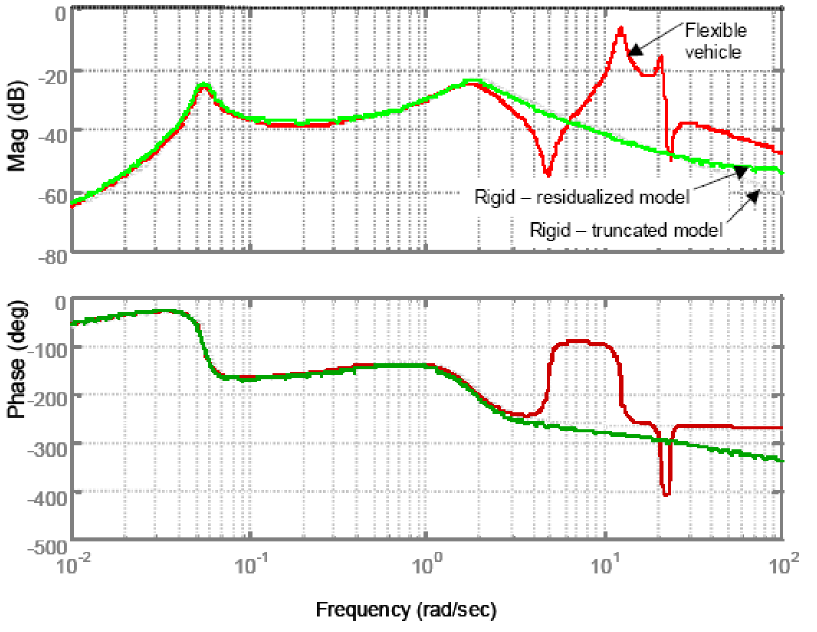

Fig. 4 Pitch rate to elevator frequency responses – flexible and rigid models (from ref. [20])

The short-period modal frequency and the first aero elastic modal frequency both near 2 Hz are evident.

A parameter in the dynamical model considered as experimental variable the in-vacuum vibration frequency of the first symmetric fuselage mode. The effect of this modal frequency on the handling characteristics is presented in fig. 5.

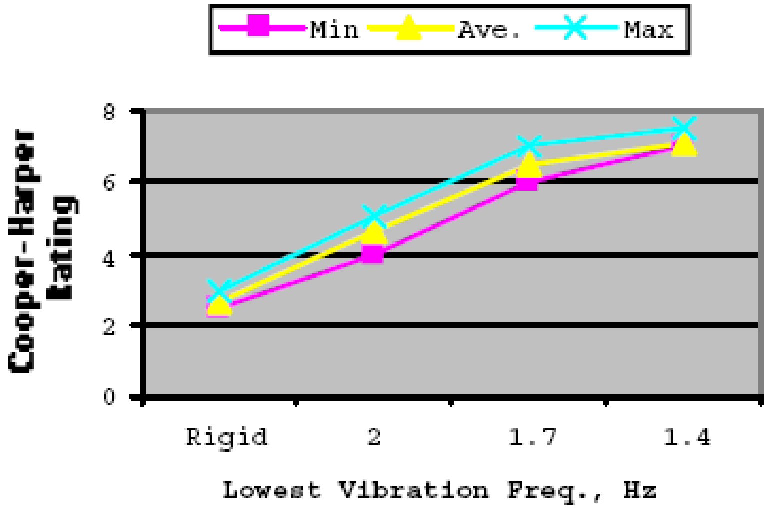

Fig. 5 Effect of increased flexibility on Handling Qualities Rating (from ref. [20])

Table 1 shows the lowest frequency of the structural vibration modes for several flight vehicles.

The above case demonstrates that these frequencies can be lower than 3 Hz, in some advanced supersonic transport (AST) configurations the frequencies being as low as 1Hz.

Some are well within the bandwidth of the pilot and primary flight control system and others may certain be excited by turbulence.

Table 1 Examples of lowest structural vibrations frequencies

Trends	in Elastic Frequencies
Aircraft	Frequency (rad/sec)
B1	13
Concorde	13+
C5 – A	11.
AST	≈ 6.5

Case 2 is a dynamic – aero elastic simulation performed in NASA Langley Research Centre's Visual Motion Simulator.

The aircraft in this case is an even larger high-speed aircraft than in case 1, a double-delta wing with its lowest vibration frequency around 1 Hz.

The generic model includes the three lowest frequency modes in each axis, for a total of six elastic modes.

The simulation results indicate that the presence of aero elastic effect in the simulation model greatly degraded the aircraft handling qualities, especially in the lateral axis in offset landing tasks performed with and without aero elastic effects.

The Cooper Harper HQR scale is presented in table 2.

Pilot comments underline that the vibrations environment had a negative impact on the ride qualities at the pilot station. The cockpit vibration tended to influence the precision of the control inputs.

Table 2 Impact of Aero elastic effects on Handling Qualities Rating – Case study 2

Longitudinal HQRs

Pilot	A	B	C	D	E	F
ASE off	3	4	4	5	4	5
ASE on	6	7	6	7	5	6

Lateral/Directional HQRs

A	B	C	D	E	F
3	3	3	4	4	5
4	7	8	6	5	7

Other case based on the analysis of flight data presents a similarly coupling phenomenon [from ref. 22].

Fig. 6 presents an analysis of lateral offset in which the pilot is implied in the biodynamic coupling while flying the aero elastic configurations (the frequency and time data have been normalized).

The time history at the top of figure shows lateral cockpit acceleration in g's and lateral stick deflections.

The plots in the lower part of fig. 5 shows the power spectral density of lateral accelerations and lateral stick deflections applied to different segments of time history. In conclusion the biodynamic coupling is evidenced by a resonant peak in the power spectral density of the pilot's stick inputs at the frequency of the one or more of the dynamic elastic modes.

All results presented in the above references suggest a biodynamic coupling and feedthrough and degradation of handling qualities [23].

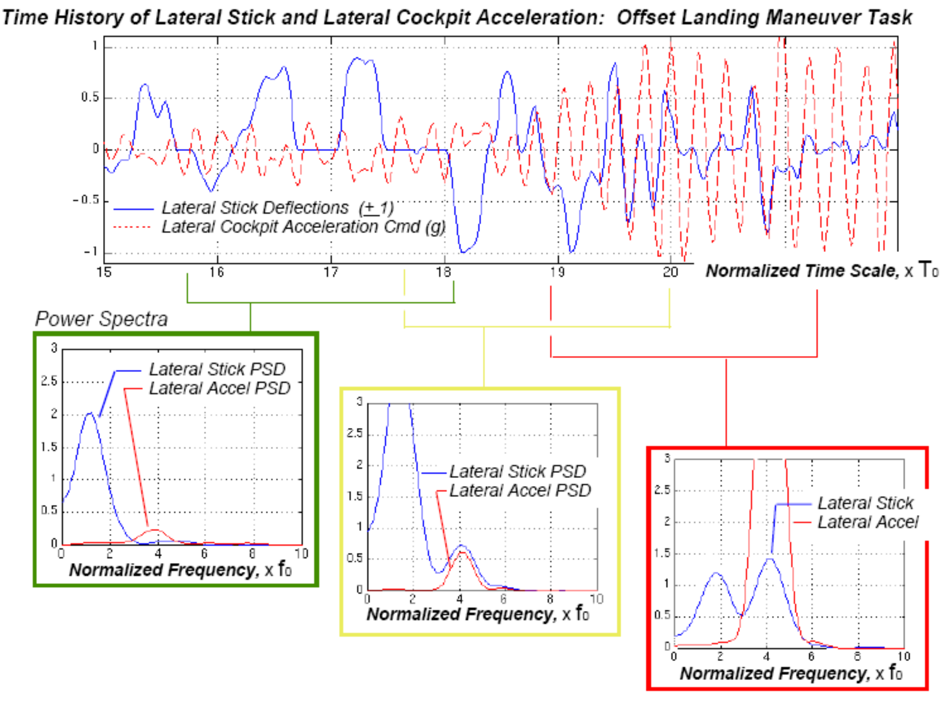

Fig. 6 Example of biodynamic coupling incident (from ref. [20])

3. PILOT VISUAL PERCEPTION AND TRIGGERS EVENTS

The human have a lot of sensors that perceives their spatial orientation [24, 25, 26]. In flying aerial vehicle the pilot self-motion, external perception and his control behaviour depend on main sensory organs which include vestibular, somatic and visual sensing and to some extent auditory sensing.

At very low frequency, human motion perception is dominated by visual cues; at high frequency, motion perception depends on a variety of sources including the vestibular system and somatic-sensory that responds to the motion through inertial space [27, 28].

At intermediate frequency all of these sensors can contribute significant to the perception of motion. In real world self-motion, all cues are coherent, although occasionally ambiguous.

The vestibular organs (the semicircular canal and otholit) are sensitive to a combination of inertial acceleration and a specific force (e.g. gravity).

Other important function of this organ is the stabilization of the eyes during head movement (see fig. 7).

The somato - sensory system consists of tactile receptors and proprioceptive sensors. The tactile receptors are sensitive to change of force on the body (e.g. through position change).

The proprioceptive sensors are sensitive to relative position of the body, also their accelerations [23, 29 and 30].

The visual perception in respect with vehicle motion is considered that the most important cues for pilot from stand point of aircraft control, close to other sensing cues (vestibular and proprioceptive).

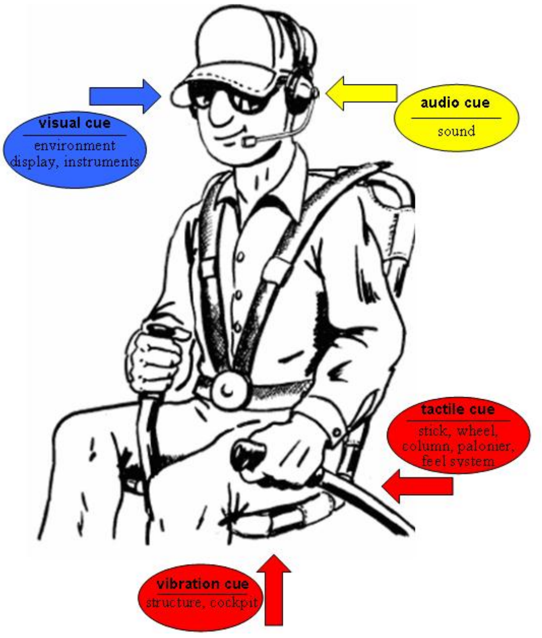

Fig. 7 Main sensory organs:
visual, vestibular, somato and audio sensing (pilot picture after ref. 31)

Perception & Visual Cues

While flying, evolution of vehicle speed and distance to a point on the ground are crucial skills and constant demands. From the perspective of human perception these skills based on the representation in the external reference frame and the distance for pilot eyes to a target [32, 33 and 34]. The most important parameters considered in the terminal phase of aircraft motion (landing) and in rotorcraft low speed tasks (hover, landing, acceleration/deceleration, etc.), are proper depth and distance perception (also sink/vertical rate and ground speed).

Many theories in psychology's domain offer some strategies adopted in motion perception based on ecological approach. James J. Gibson was first to study the concept of optical flow extensively in the 1950's and became a leader in optical flow research. Optical flow regards the combined flow of all points in the visual scene. In abstract sense the optic flow is defined that the dynamic pattern of information available in the optic array along a moving trajectory of viewpoints. The optical flow theory describes the passive perception of motion and does not take into account that fact the pilot may shifts his focus of visual attention to specific target that contain some information to the task. The optical flow cannot give information about absolute distance and trajectory speed. The optical flow pattern consists of four basic components: translation, isotropic expansion (or contraction), rotation and shear, with definition in reference [35, 36 and 37].

David Lee, student of Prof. Gibson, introduced the time-to-contact concept which makes a fundamental observation that an animal's ability to evaluate the time to pass or contact an obstacle or piece does not depend on explicit knowledge of the obstacle, its distance away or relative velocity [38]. Furthermore, David Lee is the leading proponent of the so-called "tau-coupling theory". The central idea in this theory is that human and animal movement is guided by the 'time to contact or pass' a target or obstacle - a measure known as 'tau' [39, 40]. In other words, this theory proposes that moving targets are intercepted at a specified goal zone by maintaining a constant ratio between the tau (time to closure) of the gap between the hand and the goal Tau coupling plays a main role in guiding movement. Optical flow, time-to-contact and tau coupling are in motion perception theory the main concepts that provide the pilot with information about flight parameters.

When displaying the three dimensional environment onto a two dimensional display the projected pattern consists of expanding radial lines, converging in the Focus of Radial Outflow (or Focus of Expansion) that specifies the direction of motion. Apart from Focus of Radial Outflow, optical flow theory contributes to the perception of self-motion through peripheral vision. This needs foveal attention to be perceived properly, when the optical flow works in the outer area of the Field of View (FOV). FOV become important for proper determination of vehicle attitude and speed.

An overview of literature on visual motion perception shows that the main research focuses on the different tasks for both aircraft and helicopters. The optical flow theory gives some solutions in the way the pilot receive information from the environment. Using data from piloted flight simulations, the tau-guidance strategies is useful for flare and touchdown manoeuvre in terms of rate of change of the tau of height above the runway surface [39, 40].

The tau – guidance strategy was applied also to a helicopter in low-level flight (hover in the DVE with effects of fog) [41, 42 and 43]. Its application offers an engineering basis to the design of novel display technology. The quantification of simulator fidelity have been developed using an adaptive pilot model in acceleration/deceleration manoeuvre [43]. Based on tau-guidance strategy, reference [44] investigates the applicability of 3D prediction guidance in Synthetic Vision Display during the final phase of landing through time-to-contact and tau-coupling techniques. Reference [45] investigates change of rate of width runway angle (in respect with pilot eye) through mathematical analysis using data obtained from flight simulator landings. Controlling an aircraft by human pilot remains a primary means of operation in case of unexpected or constantly changing missions or upon failure of parts of the automated system. Also the human pilot makes the final assessment of aircraft handling qualities [46]. The pilot will have to apply manual control, some or all tasks using visual information from the view of outside environment or the display. He continuously correct heading, height, horizontal and vertical speed in order to ensure a safe flight. The Usable Cue Environment (UCE) is an empirical method [fig.8] developed by large validation to identify the loss of visual cues when using synthetic vision system in a Degraded Visual Environment (DVE). In the DVE with the vision aids UCE is determined by rating the Visual Cue Rating for both translational and attitude. UCE that integrated part of ADS-33-PRF specification is a function of visual aid not a function of helicopter and it was developed to asses overall FOV requirements, ability to see and avoid large objects, or determine the suitability of simulator visual system [5, 47].

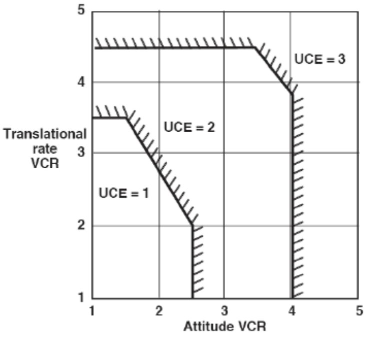

Fig. 8 UCE template (from ref. [47])

The UCE method put together handling qualities, visual perception and active control (guidance and stabilization) to provide directions for design characteristics of the control augmentation required to fly in DVE.

In different rating techniques used for handling qualities, usable cue environment (helicopters) and A/RPC susceptibility described above are typically used empirically. During simulations or flight tests values of the rating techniques are determined as a function of control system configurations or other independent variables. An exploratory analysis shows that tau-coupling technique offers a robust approach to the design of a synthetic vision system in extending UCE scale [43].

Illusion that triggers events

Optical illusion was categorized in the beginning of this study as corresponding to pilot trigger. Practically every visual cue may be susceptible to illusion stimuli acting as triggering events. Several general publications resulted from Flight Safety Foundation's Approach-and-Landing Accident Reduction (ACAR) Task Force [35] indicate the pilots should be aware of visual illusion in landing and give some advice to decrease the crew's vulnerability. Sometimes these reports are purely intended for pilots and do not offer a scientific approach to the perceptual questions.

An overview of the illusion is presented as follows:

- runway width illusion appears when landing on a narrower (wider) runway than the pilot is used to. In such case the pilot is likely to fly a lower (higher) approach as he developed a mental model where the altitude is coupled to the apparent with of the normal runway. The apparent runway width is an important cue for maintaining a proper glide path. This is a result of a theoretical study which shows that the runway width illusion may have dramatic consequences,
- sloping runway/terrain illusion – when the runway is up (down) sloping, the pilot should follow a shallower (steeper) approach path. If the pilot is not aware of the slope he will interpret the different runway perspective cues as flying at too high (low) – if maintaining the same glide path – will land/crash short of the runway (overshoot runway),
- (un)familiar size illusion – occurs when pilot estimates his altitude or distance based on the apparent size of 'familiar object' which in reality have a different size than the ones the pilot is familiar with,
- black hole illusion – this term for spatial disorientation during night approaches is due to limited optical flow and familiar size cues and the absence of horizon information. This illusion lead to a misperception of altitude or distance,
- false horizon illusion – appears when distant mountains obscure the true horizon or when a shoreline is more or less parallel to the true horizon,
- atmospheric illusion – an unusual atmospheric conditions can create several illusions that water refraction that influences perceived distance to runway and additionally gives the impression of being too high. Other example is that brighter runway lights or cleaner (no polluted) air than usual give the illusion that the airport is very near. Entering a fog layer can create the illusion of pitch up that means the pilot will suddenly steeper the approach.

The atmospheric illusions (low visibility conditions) are considered occasionally triggering events for A/RPC phenomena and may lead to a miss adaptation of the human pilot. These are considered a major source of problems as changes in external environment cause pilot attention overload, reflected in a higher pilot workload.

4. CONCLUSION

The essential elements that interact unfavourably to create a severe A/RPC event are the pilot- the aircraft-and a triggering event. Without a trigger event (or a chain of triggering events) A/RPCs do not exist. The results of the present study intend to describe the triggering events especially non classical triggers associated with 'abnormal' forms of pilot behaviour.
Based on the previous analysis of the triggering events the following definition is proposed:
An inseparable element of A/RPC that activates a transition of vehicle motion from steady state to oscillatory or divergent motion just if the pilot applies a correction control.
The severity and impact of trigger contribution are dependently of effective vehicle dynamics, pilot behavioural modes and external/internal environment.
These may be a causal chain of trigger events in which one event initiates a series of secondary triggering events.
The visual perception in respect with vehicle motion is considered that the most important cues for pilot from stand point of aircraft control, close to other sensing cues (vestibular and propioceptive).
An idea to make distinction between some contributors of different sensory organs is necessarily underlined: for very low frequency vehicle dynamics, visual system is considered that most important cues from standpoint of aircraft control and, for high frequency, the vestibular system and somato-sensory inertial space system are mainly implied.
The atmospheric illusions (low visibility conditions) are considered that occasionally triggering events for A/RPC phenomena and may lead to a miss adaptation of the human pilot. These are considered a major source of problems as changes in external environment cause pilot attention overload, reflected in a higher pilot workload.

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