INTRODUCTION

Voice analysis in aeronautical situations contributes to the study of human factors in flight incidents. The latter do not always imply tragic consequences for passengers. With the development of technology, the number of airplane accidents has decreased but the number of flights continues to increase. Human factors are involved more and more often in accidents. Knowledge of the pilot's condition is of great interest in evaluating the effects of fatigue, stress and workload. By using the medium of sound recordings, the evaluation is not invasive in a context where all the communications involve the use of a microphone and are recorded.

This paper reports the results of several experiments in relation with the main psycho-physiological disturbances of pilots. Two of them deal with situations encountered by pilots during both short and long flights: fatigue or drowsiness due to consecutive short flights in a day and the ability to react rapidly after a period of sleep (long flights, sleep inertia). The third one involves a day of driving. The corresponding workload could be similar to the pilots'. Finally, the cockpit voice recorder of a crashed plane is analyzed.

A large number of measurements on vowel signals have been performed for most of these experiments (Ruiz et al. 1996, 2008, 2010). But the chaotic aspects of speech have not been studied. It is the purpose of this paper. Vowels uttered by a troubled speaker can show irregularities and instabilities due to nonlinearities of the phonatory system (J.J.Jiang, 2006). Maximal Lyapunov exponent λ can analyze these irregular and chaotic activities.

The study of λ takes part in the research of voice acoustic features which have variations linked to psycho-physiological disturbances.

MAXIMAL LYAPUNOV EXPONENT

The maximal Lyapunov exponent λ is a signature of chaos in the field of nonlinear dynamics. If the trajectory of a dynamical system diverge exponentially λ is positive, i.e. chaos. Otherwise λ is null for a stable limit cycle or less than zero if the trajectories approach a fixed point.

With experimental data without an associated mathematical model, the set of time states of a dynamical system is not determined by equations and initial conditions. There is no theoretical calculation of Lyapunov exponent and a practical method is necessary. The algorithm introduced by Rosenstein et al. gives the maximal Lyapunov exponent of time-series data set (M.T.Rosenstein 1993, H.Kantz 2005).

A laboratory Matlab™ program gives an estimation of λ. The two parameters for the calculation are the embedding dimension m and the reconstruction delay τ. Neighboring points in the trajectory are located between a sphere of radius ε to eliminate background noise and a sphere of radius δ (A.Giovanni 1999).

Tests on chaotic attractors (Henon and Logistic) and vowels signals lead to the following choices: m=3, τ equal to the first zero of the autocorrelation function. ε and δ are percentages of the peak-to-peak amplitude of the signal. ε =2% and δ=4% for all the experiments and ε =15% and δ=25% for the CVR analysis because of higher noise levels.

EXPERIMENTS

Except for the Cockpit Voice Recorder (CVR) analysis, sound recordings are made with a headset proximity microphone to maintain constant distance between the lips and the transducer for all head movements (AKG C555L). The recorder is a Sony Pro D.A.T with a sampling frequency of 44.1 kHz and a 16 bit resolution.

Vowels are segmented with an audio editing software so as to only keep quasi-stationary part of the signal. The attack, the decay and the transition with adjacent phonemes are suppressed. The monophtongs are analyzed during their stable period to measure the maximal Lyapunov exponent.

For all the experiments the phonetic material consists of the same five aeronautical sentences (but for the CVR, segmentation is done on natural speech).

Day of Short-Haul Rotations

The cause of voice disorders is related to fatigue or drowsiness due to consecutive short flights in a day. Pilots can also be in a sleepy state late in the day or even during early morning flights. A pilot's work period is sometimes made up of several flights from an airport to another within the French territory. The same crew carries out this flight plan for three days running. Flight personnel explain that major fatigue occurs during the first day because of the sudden change in daily rhythm after a period of rest. The following days they adapt themselves. Fatigue and drowsiness are induced because:

- pilots have to wake up early in the morning (the first flight takes off early and the airport is some distance from the city centre),
- each flight (about one hour) is too short to have any rest time and air space is very crowded,
- each stopover is short (less than one hour) and the pilots stay in the cockpit to prepare the next flight.

The recordings are done on the first day. Both pilots in the cockpit crew read the same eight sentences at each stopover and also on arrival in the morning. The signal to noise ratio is significant and large enough to ensure good measurement of the acoustic features.

Among all the daily short-haul rotations, the following recording periods are chosen: recording 1 on departure (06h00), recording 2 at one stopover (08h00), recording 3 on arrival (15h00).

The corpus consists of 190 vowels: 94 for pilot 1 (32 for recording 1, 31 for each recording 2 and 3) and 96 for pilot 2 (24 for recording 1, 33 for recording 2 and 39 for recording 3).

Day of Driving

Driving all along a day can induce a workload similar to the one pilots have in their daily short-haul rotations. The highway trip of 900 km begins early in the morning until the end of the afternoon. The first recording of the speaker is performed the day before, a second one before driving, followed about every hour at rest-stops along the way.

380 vowels are segmented and analyzed (about fifty for each recording).

Sleep Inertia

Sleep inertia refers to the feeling of grogginess and slowness that occurs immediately upon awakening. Difficulties can be severe enough to impair thinking, decisions and performance. The vulnerability of pilots is important when they take turns sleeping during long flights. If a technical problem occurs, like an alarm in the cockpit, it is important they react as rapidly as possible not only to evaluate the issue but also to solve it.

The question that arises is whether the ability to concentrate and work efficiency is always at an optimum level. The purpose of the experiment is to create such a situation in the laboratory in order to record speech before and after a sudden awakening.

The experiment is conducted with a pilot in a French hospital (sleep disorder department). Three recordings are made: recording 1: upon arrival in the lab (11 AM), recording 2: after lunch (2 PM), recording 3: the pilot is taken to a room where his sleep is monitored. A few minutes after falling asleep he is suddenly awakened by a very powerful light. He then has to perform a number of tasks on a computer similar to those usually performed in flight (3 PM). He reads the same five sentences, similar to flight ones, in each of the three recordings.

The acoustic conditions are those of a quiet room with limited background noise and no noticeable presence of standing waves.

The phoneme corpus consists of 108 vowels: 37 for recording 1, 30 for recording 2 and 41 for recording 3.

Cockpit Voice Recorder

Pilot, copilot and flight engineer utterances are extracted from a Cockpit Voice Recorder (CVR). The timing firstly shows the occurrence of a failure in flight commands. The incident arouses discussions between the crew members, about its severity and its causes. At the end of the recording, the plane crashes.

The corpus obviously contains a stressful phase (at the end of the flight) and other phases with lower stress (during discussions relating to technical problems); a rest period exists before the flight incident.

Therefore, three possible emotional states can be considered: one of important stress, at the end of the flight, one of weaker stress, during the discussions about the problem, and one of absence of stress, corresponding to verbal exchanges not involving any technical problem, and taking place during quiet moments. They are referred to as levels 2, 1 and 0 of the independent variable stress.

The corpus of segmented vowels consists of 500 phonemes for the pilot, 338 for the copilot and 175 for the flight engineer.

RESULTS

The maximal Lyapunov exponent values of each vowel are plotted from the beginning to the end of each experiment. But the horizontal axis of the plots is not a real time axis because λ values are equidistant. Such a choice leads to an overview of local variations.

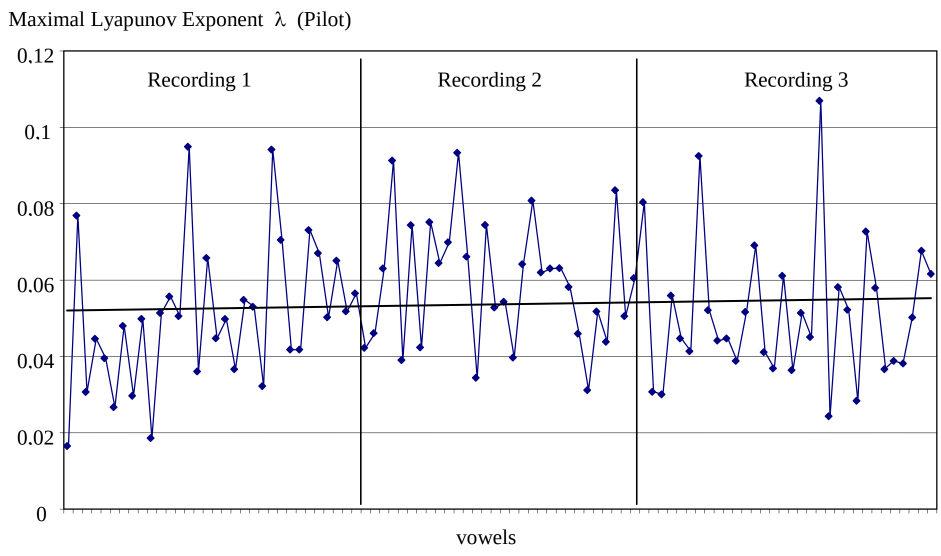

FIGURE 1. Maximal Lyapunov exponent for the vowels uttered by the pilot in short-haul rotations and regression line.

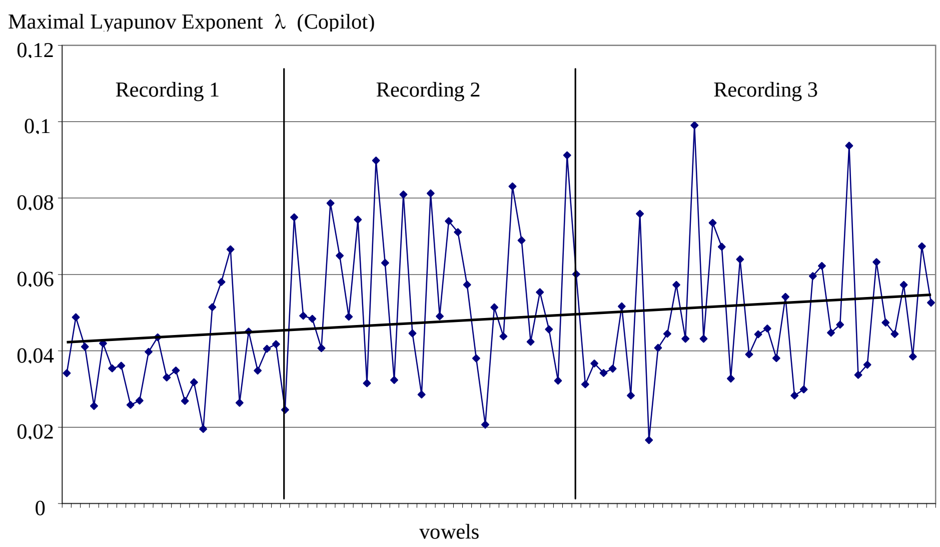

FIGURE 2. Maximal Lyapunov exponent for the vowels uttered by the copilot in short-haul rotations and regression line.

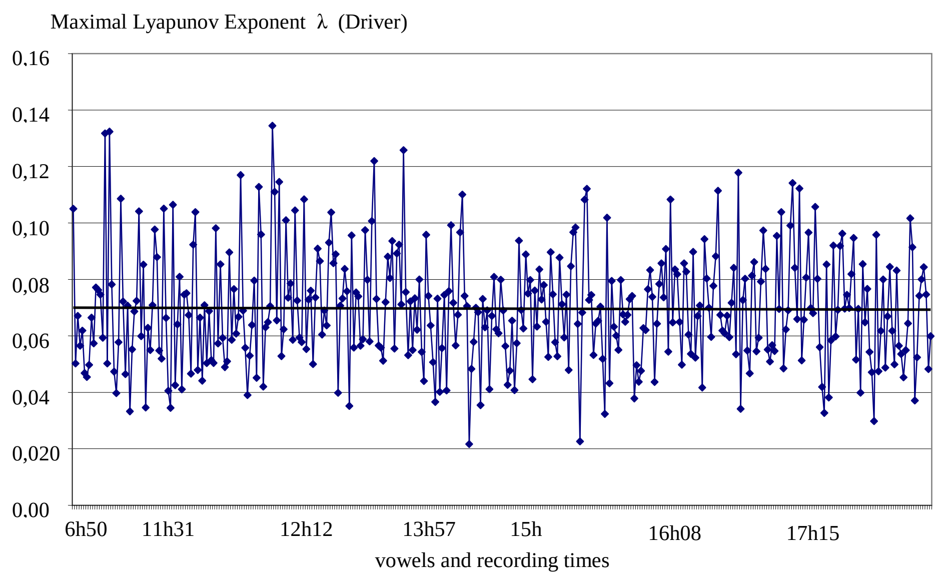

FIGURE 3. Maximal Lyapunov exponent for vowels uttered by the driver during the day of driving and regression line.

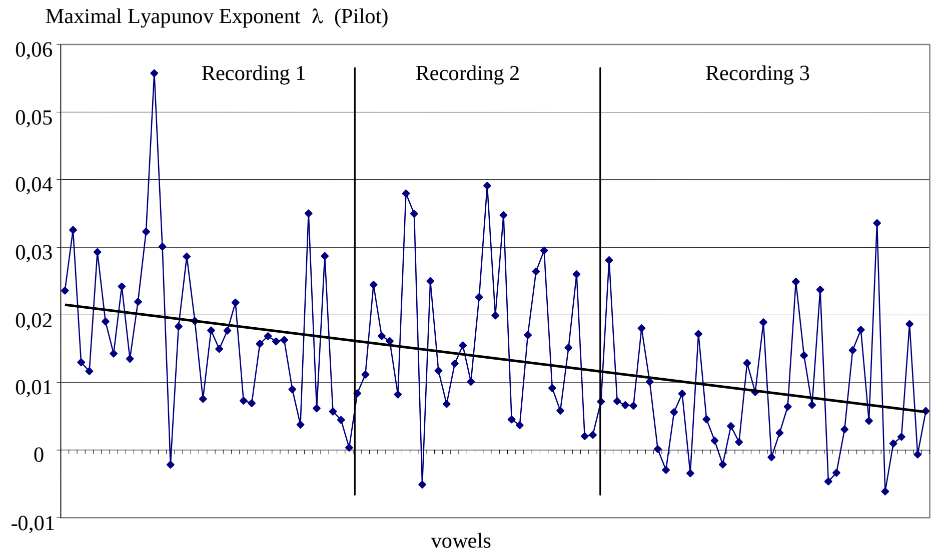

FIGURE 4. Maximal Lyapunov exponent for vowels uttered by the pilot during the sleep inertia experiment and regression line.

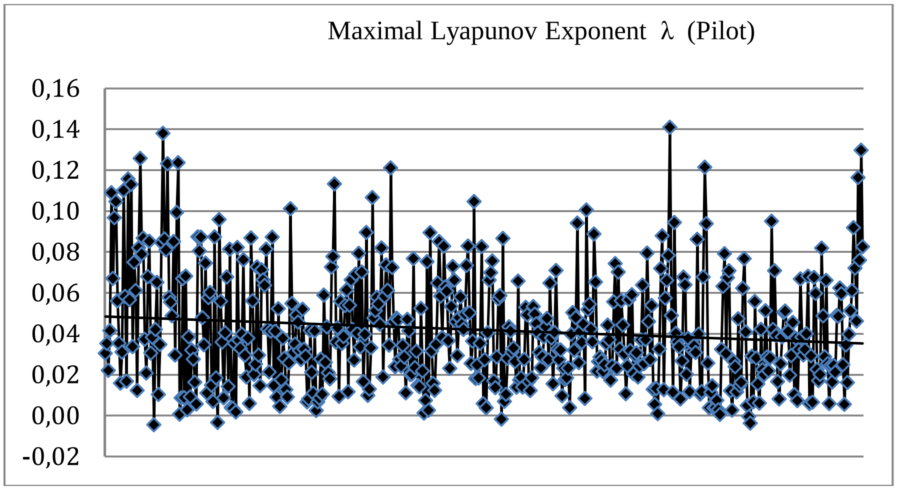

FIGURE 5. Maximal Lyapunov exponent for the vowels uttered by the pilot of the CVR and regression line.

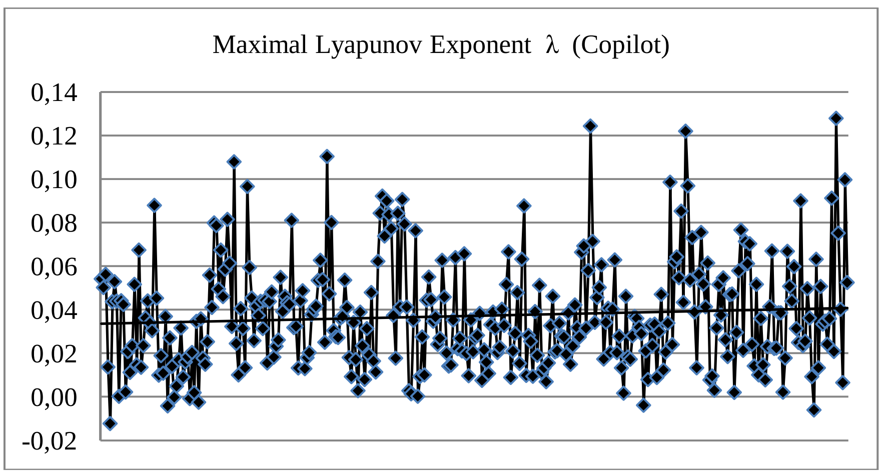

FIGURE 6. Maximal Lyapunov exponent for the vowels uttered by the copilot of the CVR and regression line.

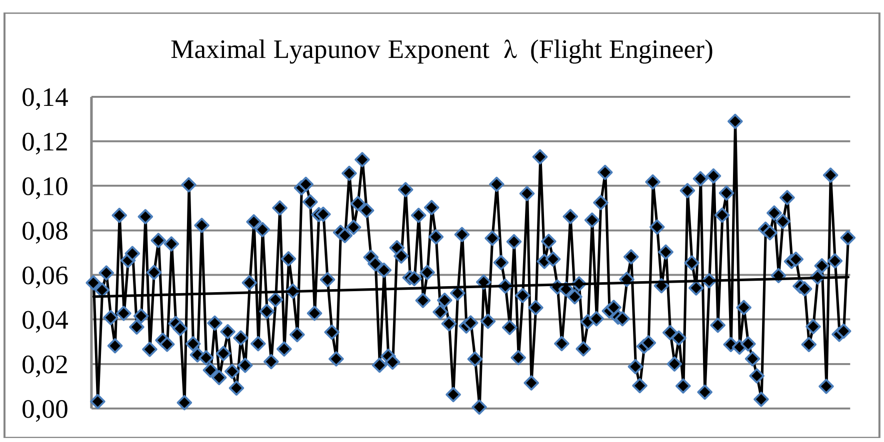

FIGURE 7. Maximal Lyapunov exponent for the vowels uttered by the flight engineer of the CVR and regression line.

Examination of the figures leads to four main results.

Firstly, except for a few values, the maximal Lyapunov exponent is always positive. Theoretically it means that the vowel signals exhibit chaotic behavior. But, because experimental data sets are short and noisy, Lyapunov exponent may indicate chaos where there is none (J.Theiler, 1992). Here, without a specific method for identifying nonlinearity, values of λ are not discussed in terms of chaos. The purpose is only to study their variations over time.

Secondly, λ values have a great dispersion. It is difficult to observe and to define ranges of variation or thresholds in relation with the psycho-physiological disturbances. For example, levels 0, 1, 2 are not visible on plots of the CVR analysis (Figs. 5, 6, 7). On the other hand, for the sleep inertia experiment (Fig. 4) and for the copilot of the short-haul rotations (Fig. 2), noticeable, but not significant, changes are observed between recordings.

Thirdly, even if the adjacent values of λ are not equidistant in a real time axis, the regression line indicates the general tendency. Its slope is different from an experiment to another, from a speaker to another. λ increases, decreases or can be relatively constant.

Fourthly, an overview of the time patterns (Fig. 1 to 7) shows that λ is not insensitive to the experimental conditions.

CONCLUSION

All measurements done do not allow us to conclude that maximal Lyapunov exponent is an indicator of vowel disorders. Too much dispersion and different directions of variation are observed for the 4 experimental conditions with 7 speakers and 1691 segmented vowels. λ has a great intra – and inter - speaker variability. This conclusion is based on these experiments, the number of speakers involved, the choice of the calculation parameters and the phonetic material used. Nevertheless, the results show a sensitivity of λ to psycho-physiological disturbances without giving a tendency and an extent.

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