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研究課題名（和文）Development of the "Pilot's Individualized Learning using Objective Data PILOD)" training method for increased training efficiency and objective assessment of manual flight skills

研究課題名（英文）Development of the "Pilot's Individualized Learning using Objective Data PILOD)" training method for increased training efficiency and objective assessment of manual flight skills

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研究成果の概要（和文）：本研究では、40名の実験参加者にフライトシミュレータで基本操作訓練を行い、データを収集した。さらに、20名が予備実験や部分的な実証実験に参加した。データ分析の結果として、訓練生の進歩を示す主要な指標を抽出することができた。これには、最終的なパフォーマンス指標だけでなく、訓練生の理解度、操作パターンや学習スタイル、ストレスと努力のレベルなどの潜在的な指標も含む。
自動分析ツールと、特訓用のソフトも開発した。分析結果は、訓練フライト直後わかりやすい形で表示するため、教官の支援や訓練生の自主的な練習にも役立つ。
分析モジュールや特訓ソフトの様々な部分が産業界から関心を集めている。

研究成果の学術的意義や社会的意義
Due to the increasing use of automation the time spent on practicing basic manual flying skills is decreasing. This research can improve flight safety by providing cost-efficient and effective training support tools. The research also shows new ways to make use of the large amount of data available.

研究成果の概要（英文）：In this project I trained 40 students basic flight manual skills in our simulator while systematically collecting their data. Another 20 participants took part in smaller side-experiments and exploratory studies. Through the analysis of this data, I was able to extract key indicators that show a student's progress. This includes not only final performance measures, bus also latent indicators of for example the trainee's level of understanding, his/her control and learning style, and stress and effort levels.
I developed tools to largely automate the analysis as well as additional modules to train specific sub-tasks in an efficient and effective manner. The visualized analysis results can be available immediately after a training flight and help the instructor to decide which exercise to start next. It can also help trainees to practice independently, and ask for a `check ride' when they feel ready.
Various parts of the analysis and training modules have gained interest from industry.

研究分野：Aviation human factors

キーワード：Flight training　Flight simulator　Human pilot　Visual information　Manual control skill　Objective evaluation　Aviation psychology

１．研究開始当初の背景

Developments in the aviation market have led to 3 big challenges in pilot training:

- **Quantity:** There is a pilot shortage that will only get worse due to the rapid globalization and increased wealth, especially in Asia.
- **Quality:** With the increased use of cockpit automation, pilots' manual control skills have degraded. Manual aircraft control has become a factor in the majority of fatal accidents.
- **Cost:** More efficient pilot training will be needed to assure safety in the increasingly competitive market where Low Cost Carriers (LCCs) and government-supported airlines from the Gulf-states (Middle East) put pressure on airlines and pilots to cut costs.

This leads to a need for more effective as well as more efficient training methods. The key to achieve this is, in my opinion, to acknowledge that not everyone is the same.

Authorities around the world are starting to shift from prescriptive regulation to performance based regulation such as AQP and EBT, focusing more on the training outcomes than on the training methods (Figure 1). This is an important enabler for more flexible training programs, where the training methods and the amount of time spent on various topics may be varied according to each trainee's needs.

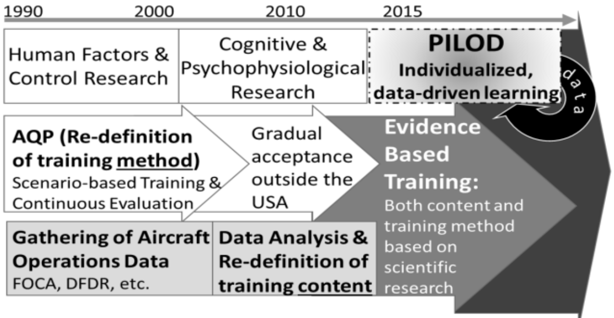

Figure 1 Developments in research and pilot training

２．研究の目的

Since the amount of training may be reduced when sufficient proficiency is demonstrated, it is important to:

- Clearly define what indicates proficiency
- Provide ways to measure proficiency as well as progress towards proficiency
- Assure flight instructor concordance (inter-rater reliability)
- Provide new cost-effective training tools to help trainees reach proficiency more quickly

Therefore, the main objective of the "Pilot's Individualized Learning using Objective Data" (PILOD) project was to research and develop new methods to analyze flight training data to provide objective feedback to trainees and to assist instructors in selecting suitable training exercises based on each trainee's specific strengths and weaknesses. I proposed various analyses of (see also Figure 2):

- flight performance data (current practice)
  (result oriented)
- various other training simulator data, including the pilot's control inputs
  (skill/method oriented)
- pilot's psychophysiological data such as heart rate, heart rate variability, eye tracking, pupil dilatation, and brain waves
  (stress, effort, 'readiness' oriented)
- Correlations between the above
  (situational-awareness, competency oriented)

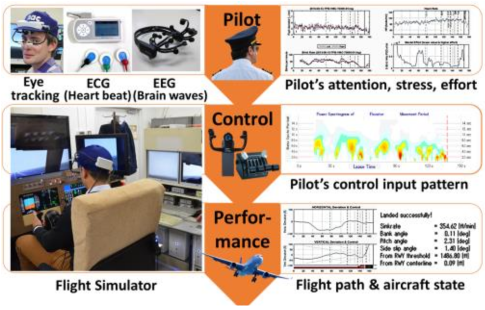

Figure 2 Overview of the measurements and analyses in the PILOT project.

After identifying the most suitable data analysis methods, I aimed to improve their robustness and ease-of-use and test them on a large number of subjects.

A second objective was to verify the effectiveness of several small training exercises and training tools I developed for practicing specific basic flight skills. Combining these two objectives, the final objective was a proof-of-concept of the PILOD training method, where each trainee receives need-based training exercises.

３．研究の方法

A large part of this research consisted of acquiring and analyzing experiment data. For the main experiment, participants received 7 times 1 hour of basic flight skill training in the fixed-base flight-training device ("simulator") at The University of Tokyo while I measured various data. Together with a retired veteran airline pilot, I developed a training syllabus for these training sessions, as well as a number of small training modules to practice specific skills on a needs-basis. I adapted our simulator hardware and software to synchronize data capturing among the various recording systems, and added several new features needed for the additional training modules. I also built a more immersive simulator (Figure 11).

There have been several phases of data gathering and analysis over the duration of the project. The initial experiments were exploratory. I tried to find patterns in the differences between the 1st, 4th and 7th day data recordings, and relate them to specific skills and competencies. During this period, we also experimented with different ways of providing feedback and various additional training modules. After refining the analysis methods, I verified their suitability and defined certain proficiency levels through experiments with a number of licensed pilots who flew the same set of scenarios as the student trainees. In the main experiment, we trained more students, some of who received personalized feedback and needs-based training, while others received only general feedback and training. In addition, I carried out a number of side-experiments to verify the effectiveness of the additional training modules, and to quantify proficiency levels for certain competencies.

The experiment protocols have been reviewed and approved by the ethics committee of The University of Tokyo's School of Engineering. All subjects participated voluntarily and signed an informed consent form.

４．研究成果

Data analysis methods

In this research I developed the following original data analysis methods. A unique feature of all these analyses I that they are carried out on a time scale of several seconds, whereas most existing methods analyzing similar data operate on a complete flight phase such as "climb", "cruise", or "landing".

- *Control input pattern analysis.*
  This spectrogram-based analysis shows how detailed and how strong the pilot's control inputs are. Figure 3 shows how individual control- or learning-style differences become visible, which can be help to formulate appropriate feedback.
- *Mental Effort analysis*
  I developed an index of "Mental Effort" (ME) based on heart rate variability (HRV) (Figure 5). Some would call this an index of "workload", but workload is often confused with "taskload" (the amount of work that *should* be done). Also, when attention is dispersed and shallow (causing large overhead limiting resources for on-task effort), rather than comprehensive and focused, workload will be high. The ME index can indicate whether a trainee is focused at critical moments, such as during the flare.
- *Heart Rate analysis*
  I discovered a change of the pattern over the training period that is common to almost all trainees (Figure 6)
- *Blink analysis*
  When concentrated on the flare, there are no eye blinks.
- *Pupil size analysis*
  I discovered that professional pilots and several well trained subjects showed a rapid increase of pupil size during the flare maneuver. Their natural spontaneous fluctuations of pupil size also became clearly finer.
- *Secondary task*
  I found a simple "press the button when you hear a beep" task effective to find out whether trainees have any spare capacity (remaining resources).

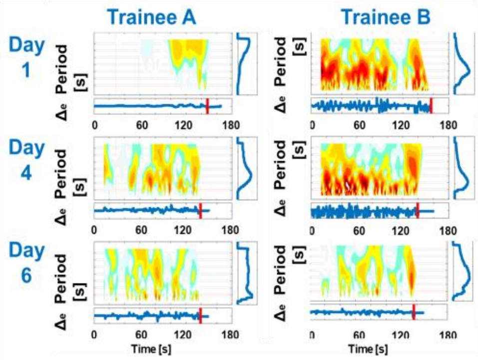

Figure 3 Trainees A and B initially have different control styles, but with personalized feedback, they both quickly develop a similar style

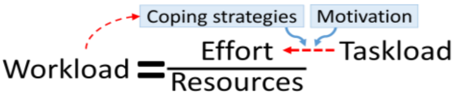

Figure 4 My interpretation of workload, taskload, resources, and effort.

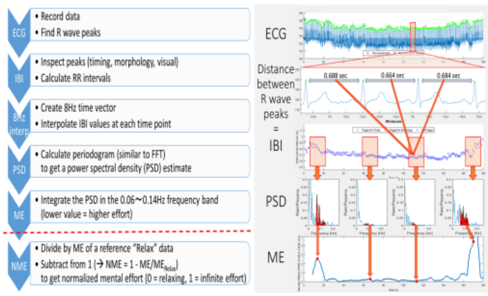

Figure 5 Calculation of the Mental Effort Index using power-spectrum density

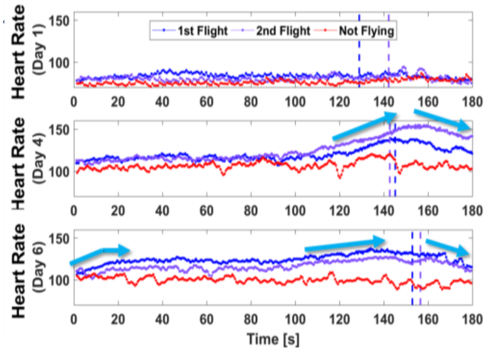

Figure 6 Typical progress of heart rate patterns over the first 6 training sessions.

- *Combined analyses*
  The correlations between various types of data provides higher level information about the trainee's situational awareness and understanding. For example, combining vertical deviation (performance), elevator input (control) and mental effort (psychophysics) may help to clarify questions like: *Was the trainee concentrated on the task? Was he working on the right task at the right time? Was his reaction appropriate?* As another example, the combination of heartrate and ME index shows how well the trainee has internalized the skill. As shown in Figure 7, the four different regimes call for different actions from the instructor to tune the training plan and match the trainee's personal level.

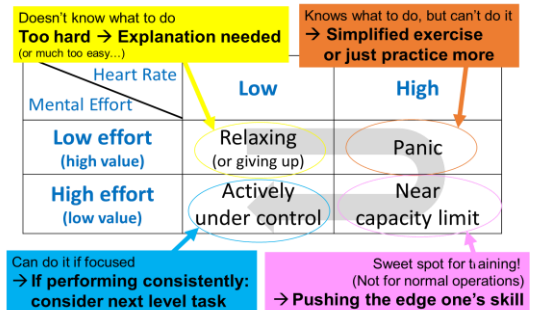

Figure 7 Using the combination of heartrate and mental effort index to guide training decisions.

Although the explanations in this report are descriptive, most of the described characteristic features are extracted and quantified automatically. This forms the basis for highlighting points of interest in the results (Figure 8) and for the skill balance chart (Figure 9).

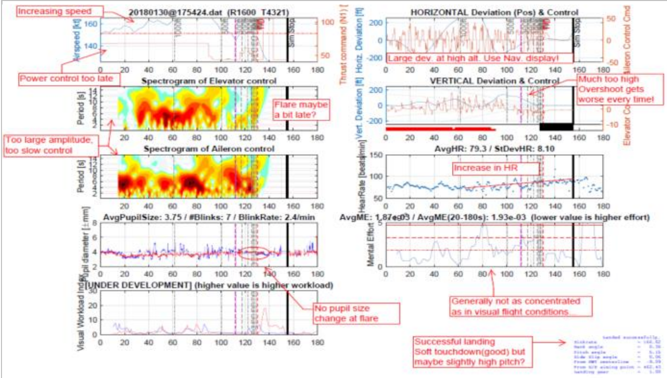

Figure 8 Visualization of flight performance, control input, and psychophysiological data of a single landing approach, with interpretation (feedback comments to the trainee).

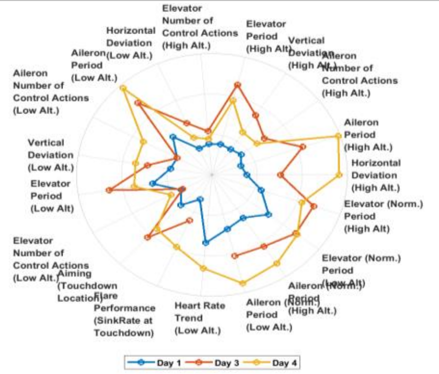

Figure 9 Skill balance chart showing a trainee's progress after automatic data analysis.

Training tools

To efficiently train the weak points, I created a number of specific training exercises.

- *Independent training tools*
  - *Aiming Training Tool (software for laptop and plugin for flight simulator)*
    The trainee can practice finding the center of expansion of the optical flow, which is the point one is heading to (Flight Path Vector). The stand-alone software is shown in Figure 10 and the simulator plugin in Figure 11.
  - *Flare Training Tools*
    This helps to improve flare skills by training the use of visual information from the runway sidelines in peripheral vision ($\dot{\theta}$, "Theta-dot"). First $\dot{\theta}$ values must be recognized and estimated (Figure 12) then it can be applied to achieve a proper flare profile (Figure 13).
  - *Augmented cues: Audio alert*
    To train "scanning" (regularly checking the various cockpit instruments), an alert siren sounds when certain flight parameters are outside a predefined range.

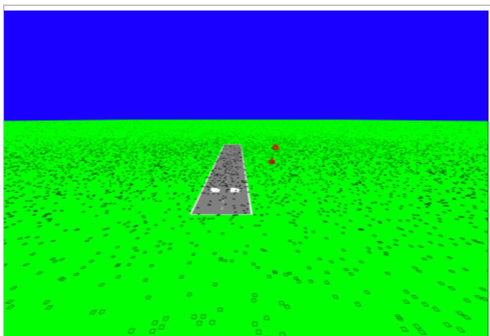

Figure 10 Aiming Training software tool

Figure 11 X-Plane flight simulator plugin version of the Aiming Training software (in the new cockpit).

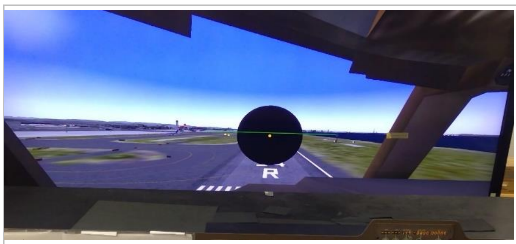

Figure 12 Step 1 of the Flare training. The central part (foveal vision) is obscured to train using information from the visual periphery.

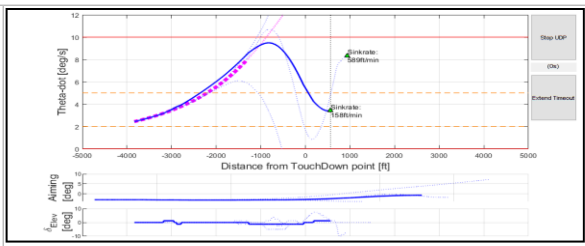

Figure 13 Step 2 of the Flare training. The trainee gets immediate feedback of his $\dot{\theta}$ values during the landing.

   - *Secondary task*
     A simple reaction time task can make trainees aware of how much time it takes to perceive, process, and react to a stimulus, and therefore how much they have to "think ahead" when planning their control actions. It can also be used during a flight to "gamify" scanning practice.
- *Landing sub-task practice scenarios*
   - *High-altitude longitudinal control*
     This trains understanding of the relationship control stick → pitch angle → sinkrate → vertical position (glideslope indicator) and the time delays involved.
   - *High-altitude lateral control*
     This exercise trains understanding of the relationship control wheel → bank angle → heading → lateral position (localizer indicator) and the time delays involved.
   - *Low-altitude longitudinal control*
     The simulated aircraft is set up for landing at a height between 300~500ft above the runway, with a slight offset from the glideslope. The trainee should use mainly use outside visuals (including PAPI) and only reference cockpit instruments sparsely to get the aircraft back on the glideslope.
   - *Low-altitude lateral control*
     The simulated aircraft is set up at a height of 50ft at the centerline at the runway threshold. Speed and Altitude are frozen, only lateral motion can be controlled. The trainee's task is to make the aircraft fly stably above the left runway sideline, achieving that, make it fly stably above the right sideline, etc.

Conclusion

The PILOD project resulted in a large number of novel data analysis methods and training tools as described above. I have been able to identify common patterns that can be used to evaluate a trainee's progress in new ways, focusing on the personal development rather than only on the final result. In addition, I have been able to extract these patterns automatically from the data in a robust way, and used them as practical indices for simplified feedback & decision-making.

In the project proposal, I set the goals as listed in the table below. As can be seen, the PILOD project was successful in reaching its main goals.

Minimum	Realistic	Ideal (aim)
・Detailed algorithms and suggestions for individualized training.	・Analysis software toolbox and guidelines for individualized training.	・Easy to use analysis software package and guidelines for result interpretation and individualization of training.
・Concept verification with 30-40 university students as trainees and a few professional pilots as reference.	・Validation using university students and 20-30 real pilot trainees, as well as several professional pilots.	・Validation using a varied group of students and others, 30 or more real pilot trainees, as well as 10 professional pilots.
・Interest from the academic society.	・Interest from both academia and industry.	・Trial or adoption of the method by industry.
・Participants understand pilot operations and human factors research better.	・Participants show improved skills.	Participants get their license quicker and have better career perspectives.
・Knowledge about training and objective evaluation.	・Improved quantitative measures for skill and safety.	・Fundamental insight in human control & performance

■ Achieved ■ Partly achieved ■ Work in progress (early phase) □ Unverified

５．主な発表論文等

〔雑誌論文〕　計0件

〔学会発表〕　計8件（うち招待講演　0件／うち国際学会　6件）

１．発表者名 Jorg Onno ENTZINGER
２．発表標題 INDIVIDUALIZED LANDING FLARE TRAINING USING BOTH FLIGHT PERFORMANCE AND PSYCHOPHYSIOLOGICAL MEASURES
３．学会等名 International Symposium on Aviation Psychology（国際学会）
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１．発表者名 1.上村常治、エントジンガー・ヨルグ オノ、松永大一郎、土屋武司
２．発表標題 伝承された操縦手法を操縦システム開発で解明した： ピッチと推力の目標値の重要性
３．学会等名 日本航空宇宙学会　第57 回飛行機シンポジウム
４．発表年 2019年

１．発表者名 J.O. Entzinger, T. Uemura, S. Suzuki
２．発表標題 INDIVIDUALIZING FLIGHT SKILL TRAINING USING SIMULATOR DATA ANALYSIS AND BIOFEEDBACK
３．学会等名 31st Congress of the International Council of the Aeronautical Sciences（国際学会）
４．発表年 2018年

１．発表者名 Jorg Onno Entzinger
２．発表標題 INDIVIDUALIZED LANDING FLARE TRAINING USING BOTH FLIGHT PERFORMANCE AND PSYCHOPHYSIOLOGICAL MEASURES
３．学会等名 International Symposium on Aviation Psychology（国際学会）
４．発表年 2019年

1．発表者名
Jorg Onno Entzinger, Tsuneharu Uemura, Shinji Suzuki

2．発表標題
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3．学会等名
31st Congress of the International Council of the Aeronautical Sciences (ICAS2018)（国際学会）

4．発表年
2018年

1．発表者名
Jorg O. ENTZINGER, Tsuneharu UEMURA, Shinji SUZUKI

2．発表標題
On the use of secondary tasks in addition to other objective measures of pilot workload

3．学会等名
2016 Asia-Pacific International Symposium on Aerospace Technology（国際学会）

4．発表年
2016年

1．発表者名
ヨルグ・オノ・エントジンガー、土屋 武司

2．発表標題
研究用フライトシミュレータの構築 及び操縦評価への応用例

3．学会等名
第５８回飛行機シンポジウム

4．発表年
2020年

1．発表者名
Kosuke Okubo, Jorg Onno Entzinger

2．発表標題
An Overview of Flare Techniques and Flare Training Methods

3．学会等名
32nd Congress of the International Council of the Aeronautical Sciences (ICAS2021)（国際学会）

4．発表年
2021年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

The following bachelor theses resulted from this research project:
1) 堰口直樹 "パイロットの上達度の評価指数と効率的な訓練方法の提案", 学士論文, 東京大学工学部航空宇宙工学科システムコース, 2016年11月28日提出
2) 深沢拓人 "パイロットの上達度指標に基づくシミュレーター操縦訓練手法に関する研究", 学士論文, 東京大学工学部航空宇宙工学科システムコース, 2017 年11 月27 日提出
3) 大久保皓理 "視覚情報の有効利用訓練によるパイロットの着陸技量の向上", 学士論文, 東京大学工学部航空宇宙工学科システムコース, 2020年11月28日提出

A project description and related files can be obtained from the following website:
"Pilot's Individualized Learning using Objective Data" (PILOD)
客観的データを用いたパイロットの個別学習 プロジェクト
https://www.flight.t.u-tokyo.ac.jp/?page_id=484

Related publications can be found at:
エントジンガーの研究論文一覧
https://scholar.google.com/citations?user=Dcu0MvcAAAAJ

6．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

7．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

8．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関