Using Ecological Interface Design for Energy Management During Idle-Thrust Approaches

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Alternative approach procedures are being developed, in order to create aircraft operations that have less impact on the environment. In these low-power, low-noise approaches, level flight segments are avoided, and low or flight idle thrust settings are used until the aircraft reaches a stabilization point at low altitude, close to the runway. Electronic automation tools and handbook charts are currently tested and used in these procedures. This paper takes a different approach, and applies the principles of Ecological Interface Design to create interfaces that enable the pilot to fly these procedures in a flexible manner. Interfaces for two of these procedures, the Free-Path Total Energy Approach (FPTEA) and the Modified Three-Degree Approach (MTDA) were developed and evaluated in a fixed-base flight simulator. Pilots were able to plan and fly the approach with both displays, and indicated that the displays provided good awareness of the approach.

Introduction

The growing volume of air traffic leads to concerns on the impact on noise and pollution. For the long term, quieter and more energy efficient aircraft are being developed. However, for shorter-term improvements, modified approach procedures should lead to a use of aircraft that minimizes the environmental impact. Advanced Noise Abatement Procedures (ANAP) are being developed, in which low or idle thrust settings are used for most of the trajectory, and low flying on level flight segments is avoided. In general, in these procedures, a continuous descent is initiated from a fairly high altitude, typically 7000 ft above airport elevation, and engine power is set to low or idle thrust setting when appropriate. After selection of low engine power, the descent and deceleration of the aircraft are controlled by means of aircraft configuration changes, flap settings and gear extension. For safety reasons, close in to the airport (typically at 1000 ft), thrust is restored, and the descent is continued at a constant approach speed (Ren and Clarke, 2003).

A major disadvantage of these procedures is their unpredictable character from the view of air traffic controllers. Each aircraft will have its own deceleration profile along the descent, and since also the weight of the aircraft plays a role, type information alone is not enough to determine the deceleration profile. Thus, since controlling the spacing between the aircraft during the approach interferes with their optimum profiles, and because the timing of the approach is uncertain to ATC, conservative spacings have to be applied before aircraft can begin the descent and approach. Both support by (paper) charts, and automated assistance, which gives cues to the pilot for configuration changes and throttle settings, have been investigated (Ren and Clarke, 2003; Erkelens, 1998; in ’t Veld, Mulder, van Paassen and Clarke, 2004; in ’t Veld, Mulder, van Paassen and Clarke, 2003; de Prins, Schippers, Mulder, van Paassen, in ’t Veld and Clarke, 2005; Ho, 2004; Koeslag, 1999; de Gaay Fortman, van Paassen, Mulder and in ’t Veld, 2007). These support tools can to a large extent automate the control of the deceleration. To decrease the spacing needed between aircraft, and increase runway capacity, methods of self-spacing are introduced. The automated support tools are extended with functionality to meet a specified arrival time (de Gaay Fortman et al., 2007) or to maintain a specified separation from the predecessor (de Prins et al., 2005; in ’t Veld et al., 2004; in ’t Veld et al., 2003).

This paper takes a different approach, and applies Ecological Interface Design to create interfaces that enable the pilot to fly these procedures without following instructions from an automated cuing system. Two approaches are considered. The first is the Modified Three-Degree Decelerating approach (MTDDA), which has also been applied in (Ren and Clarke, 2003; in ’t Veld et al., 2004; in ’t Veld et al., 2003) In this approach, the aircraft follows a three degree flight path. Close to the runway, this path is defined by the glide slope of the instrument landing system, and at larger distances, area navigation capability defines the path. The second procedure is called the Free Path Total Energy Approach (FPTEA). In this procedure, the vertical path of the airplane is not specified, which leads to
greater flexibility. The display should enable pilots to use this flexibility to adjust the timing of the arrival.

In the following section, an engineering analysis of the MTDDA and FPTEA is presented. This analysis is the input for the work domain modeling. The display designs are presented and explained. A simulation with the displays was set-up and evaluated by four pilots.

Engineering Analysis

The decelerating three-degree approach to the runway can be performed in a large number of ways. In this design, the approach started with a relatively high initial altitude of 7000 ft. At a distance of 43.8 km from the runway, the 3 degree descent is started. The point where the thrust is cut to flight idle is the main variable that influences the duration of the approach. For the aircraft considered in this study, the Cessna Citation II, this has been investigated in an off-line simulation. The results of this simulation are visible in Figure 2, in which the speed of the aircraft is plotted against the distance from the runway. The leftmost red line in this figure represents the fastest approach. The aircraft flies along the 3 degree path at the initial speed of 250 kts indicated airspeed, until only 14 km away from the airport, and then deploys flaps and landing gear at the highest airspeeds allowed. The rightmost red line shows the opposite, where deceleration is most gentle and starts early. One should realize that, once the choice has been made to reduce thrust, the options for further changing the deceleration profile are limited to configuration changes; flaps settings and gear extension. The changes in timing that can be produced by changing the configuration alone are in the order of 10 seconds and thus fairly limited.

Work domain analysis

For the work domain analysis, we will start with an Abstraction - Decomposition Space (ADS) derived from the analysis in (Amelink, Mulder, van Paassen and Flach, 2005). The production goal is to fly an approach. Economy is achieved by reduced use of fuel, and a low noise production. Safety is realized by an flight that steers clear from dangerous constraints, such as terrain, over-speed, under-speed or stall, and a stabilized last portion of the approach is needed to enable pilots or automation to make a safe landing (Figure 3). The abstract functions are:

- Locomotion, which in the MTDDA must be constrained to a 3 degree path, while in the FPTEA it is more flexible, however, the end constraint is still that a three degree path is followed to the runway from 1000 ft.

- Energy management. The aircraft must be brought from a high energy state (at high altitude and a fairly high speed), to a specified low energy state, with the final approach speed at 1000 ft on
the three degree path. In the case the MTDDA, a fixed altitude path is followed. Since potential (height related) energy along the path is specified, the speed at a point along the path is an alternative to define the energy.

At the generalized function level, drag, thrust, lift and maneuvering provide the means to locomote and to manage energy. It may be obvious that the airplane drag can be influenced by the flap and gear selection. The limitations of the gear and flaps, as described at the physical function level, pose constraints on the speeds at which gear and flap settings are possible. However, energy dissipation is a product of drag and speed. Speed is thus an important component in energy management, and it links both locomotion and energy management together.

The physical function level the “tools” of the aircraft are modeled. A number of additional constraints is found at this level, following (van Paassen and Mulder, 2004). For most airplanes, the speeds at which flaps and gear can be extended are limited, and this limits the control options the pilot has for generating drag and thus for decreasing energy. Also, a minimum speed must be maintained to generate lift and ensure controllability of the aircraft. These constraints, in the form of maximum and minimum speeds, should also be visualized in the interface.

To keep the difference between current flight practice and flight supported by the displays limited, the current sequence of configuration changes for the aircraft is maintained. Thus, along the approach, flap extensions and gear selection, in a fixed order, are considered.
matic speed obviously influences the duration of the approach. However, to keep the display compatible with current flight practice, indicated airspeed (IAS) is used in the display. The IAS depends on kinematic speed, wind speed and air density. The duration of the approach depends on the kinematic speed and the distance to fly. The duration cannot be read off the display, and it is not feasible to add it in an intuitive way. To provide the timing information a nominal profile and a number of derived profiles, at “intervals” of 10 seconds faster or slower, is presented (Figure 7).

Approaches flown with the FPTEA have greater flexibility. While the MTDDA display can show a projection of the velocity along the approach, this projection does not function in the FPTEA approach, since the altitude may – within bounds – be freely chosen, and the speed will also depend on altitude, instead of only on a limited number of configuration changes. Instead, the FPTEA path is better visualized in energy terms. The endpoint in the approach, expressed in energy, is the sum of the potential energy at the 1000ft point, and the kinetic energy associated with the final approach speed. This energy is plot against the distance to the runway, see Figure 8.

The other “fixed” point in the energy is the current flight condition of the aircraft. The locomotion and energy management goals can now be achieved by moving the current flight condition in this energy space to the end point. For safety, one should also consider the constraint imposed by the physical functions; minimum and maximum speed, and by underlying terrain. These are not yet included in this display design, and must be deduced by the pilot from combination with the other flight instruments.

Constraints imposed by the aircraft energy dissipation are also shown in the display. These are extrapolated from the two points mentioned above, the end point and the current flight condition (Figure 8). For both points the path in distance-energy space with the highest energy dissipation rate, and the path with the lowest energy dissipation rate is drawn. Together, these span the plane of points in the distance-energy plane that are both reachable from the current energy state and from where the desired end state can still be reached.

The influence of airspeed on energy dissipation is shown dynamically, i.e. by the visible changes in a flow conditions.
Figure 9: Energy dissipation shown for the optimal speed at the current flap setting, current speed, and for following configuration changes. The gray line shows the energy rate for the final configuration.

display when the airspeed is changed. The energy dissipation at the current airspeed is also shown in the display (Figure 9). The effect of the configuration options is given by showing the minimum (and thus as optimal speed) energy dissipation for other possible aircraft configurations at the current speed. A final constraint is that the aircraft must be in its final configuration (flap setting, gear down) at the 1000 ft point. This means that the 1000 ft point is not only defined by its altitude and speed / energy, but also by the airplane configuration. This constraint is shown by a line starting at the 1000 ft point showing the energy dissipation at the final speed and in the final configuration.

As an additional cue, the line color for the different configuration options depends on indicated air speed. If a configuration is allowed at the current airspeed, the line is shown at full intensity. If current airspeed is too high for a certain configuration, the line corresponding to that configuration is shown in a dim tone.

Evaluation

The display designs were programmed in a fixed-base real-time simulation (Figure 10). A model of the university’s research aircraft, the Cessna Citation II, was used. Simulated approaches were flown, which started at an altitude of 7000 ft. Pilots flew with either:

- FPTEA display, the task was to perform a descent (without timing constraints).
- The MTDDA display, also to perform a descent without timing constraints.
- The MTDDA display with timing information, while the task also included timing the arrival.

For each of the displays, three topics were investigated. The first was the relevance of different elements of the display; for this, repeated runs were made with different display elements removed. The second was the effect of scaling and zooming. Non-zooming, stepwise zooming and continuously zooming display variants were shown. The third topic was the capability of the display and support automation to enable flight near the constraints of the work domain, for example a descent that started very close to the runway. Four pilots participated in the experiment, all pilots had logged over 1000 hours.

Results of the evaluation are based on pilot comments on the displays. The main results for FPTEA were:

- It proved perfectly possible to fly any strategy (high, low on the approach, rapid descent) with the FPTEA.
- One pilot commented that the display appeared too cluttered. Other pilots quickly made sense of the lines.
- All pilots preferred a zooming display, two preferred stepwise zooming, while the other two preferred continuous zooming.
- On the information content, pilots agreed that tick marks or values on the energy axis were not missed, probably since the absolute energy values...
had no meaning to them. Information on ground clearance was missed, and one pilot suggested that the information could possibly be integrated in an existing display.

- Pilots agreed that the display offered possibilities that would not fit in today’s air traffic control environment.

The main results for the runs with the MTDDA display without timing information nor task were that zooming functionality, discrete or continuous, was preferred. Within the constraints imposed by the procedures, the pilots were also able to choose the limit cases (fastest and slowest approach) without any problem.

For the MTDDA with the added timing information and task, it proved to be possible to fly an approach with both idle thrust and adhere to the specified time of arrival. One pilot complained about the clutter in the display. Selection of the thrust cut-back point proved to be most effective in influencing the timing of the arrival, any changes in flap selection can only provide small adjustment. This was also found for automated flap and gear selection cueing (de Gaay Fortman et al., 2007).

Conclusions and recommendations

The present paper describes the development and initial evaluation of two displays for performing low-power, low-noise approaches. Previously, research on and development of automated support systems that provide thrust, flap and gear cues to the pilot showed the feasibility of these procedures. The prototype interfaces presented here show that, when provided with the appropriate information and in the appropriate format, pilots have no problems performing this previously automated task. The advantage of this approach is that pilots will have a better situation awareness.

Several recommendations resulted from the evaluation sessions with the four pilots. Aside from specific recommendations on the display format, the main recommendation is that the information should be integrated in existing flight desk displays. Currently, work is in progress on combining the MTDDA display with the vertical situation display used in modern flight decks.

References


