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Perspective Guidance Displays Show the Way Ahead

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A LITTLE over two decades ago, programmable electronic flight instrument display systems (EFIS) were introduced in commercial aviation aircraft such as the Boeing B757/767. The introduction comprised three new instruments: the primary flight display (PFD), replacing the traditional attitude director indicator (ADI); the navigation display (ND), replacing the horizontal situation indicator (HSI); and the engine indicating and crew alerting system (EICAS), replacing the engine gauges and a whole slew of other indicators and controls. This introduction changed the face of the cockpit flight instrument panels in civil aviation, earning its nickname of "glass cockpit". However, more than the mere looks of the flight deck changed. The flight management system (FMS) got a central role in the flight practice, and piloting changed, from interaction with the aircraft supported by some automation to interaction mainly with the automated systems.

The introduction of the glass cockpit and the new way of flying civil transport aircraft through automation was reluctantly accepted by the pilot community. Besides early complaints about the readability of EFIS displays, the main issues were the problems of keeping the pilot in the loop, and explaining what the automation is doing at any time, supporting the flight crew "mode awareness". Still, as accident statistics now show, safety has increased and nowadays flight decks with EFIS and FMS are the norm for commercial and business aviation, and are introduced even in general aviation.

With the introduction of the glass cockpit came an increased level of navigational situation awareness, in particular through the added functionality of the navigation display. Its forebear, the HSI, showed an abstract presentation of relative bearings to selected beacons and the distance expressed in dots to VOR radials or the localizer. The ND replaced this by a much more intuitive display of relative geographical position with respect to waypoints on the planned route, approach fixes, markers, and the runway centerline. A planned approach was now visible on the display rather than just on an approach plate. As altitude and speed constraints could be assigned to waypoints in an approach procedure, the energy management during an approach, which depended so far on rough mental computations, was significantly improved as well.

Although the electronic instruments offer much more functionality and integrated information than their electro-mechanical counterparts, they still are not more than two-dimensional "orthogonal" presentations of attitude and geographical position which the pilot must mentally integrate. There must be a world of possibilities in the electronic instrumentation that we have only begun to explore. Unlike autonomous robotic vehicles, humans are capable of interpreting and moving through dynamic three-dimensional environments with little or no conscious mental effort. This talent to intuitively do things right, to not become disoriented or collide with obstacles while moving through the most complex of environments, is a product from ages of evolution. Besides mental reasoning, judgment and a talent for producing solutions when confronted with unforeseen situation (in other words, improvisation) this represents one of the important assets of the human pilot. However, it was up to now not exploited to its fullest potential because of the "unnatural" way of presenting the information to the pilot. Therefore, the current practice to have different abstract, two-dimensional presentations of the aircraft guidance and navigation situation needs to be revised. A future primary flight display should present the aircraft's spatio-temporal situation, i.e. its motion in space and time, in a way that is intuitively understandable, that supports pilots in their manual and supervisory control tasks, enhances their situation awareness even more, and is compatible with the various tasks imposed by the air traffic management system, now and in the future.

Advances in this field have been made with perspective flight-path displays such as the "tunnel-in-the- sky," the "pathway-in-the-sky," or the "highway-in-the-sky". These displays integrate the guidance information with

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information on the current aircraft state, and are widely recognized for their potential to help pilots control their aircraft along complex curved trajectories.[1-34] By presenting to the pilot the trajectory to follow in an intuitive, three-dimensional fashion, while at the same time including the guidance constraints, the display directly portrays the pilot's primary aircraft guidance and control task. The combination of guidance and primary flight information in the same display can increase the pilot's situation awareness and improve the flight safety, in particular for complex and therefore more critical operations. As a result, these displays may allow complex routings to be issued, which pilots may fly manually or through supervision of their automation. These new capabilities open up opportunities for air traffic management, in the areas of noise abatement and external safety during departure and approach.

The concept of a perspective flight-path display is often confused with another powerful but more recent innovation, synthetic vision systems (SVS). Low-cost, high-performance graphics cards, often derived from COTS PC hardware, are now capable of rendering a synthetic substitute of a pilot's out-the-window view during all phases of flight. Synthetic vision is now commercially available, and it is likely to dominate in particular the general aviation market.[35-39] Synthetic vision by itself, however, does not present any trajectory guidance information, and is primarily intended to increase the pilot's situation awareness of terrain, with potential benefits to decrease controlled-flight-into-terrain (CFIT) related accidents. Of course, the synthetic outside view can be combined with trajectory guidance, and because this is often done, the concept of synthetic vision, enhancing terrain situation awareness, and the concept of a perspective flight-path display, providing trajectory guidance, have become intertwined.

The concept of these perspective flight path displays is not new. On the contrary, since World War II many attempts to build such displays have been reported.[31,40] At that time, however, the available technology posed severe limitations on the display format, and most of these early concepts have never reached farther than the designer's drawing table. The rapid advance of digital computer technology in the 1960s and 1970s led to a boom in perspective display research, which since then has expanded to a point where it is difficult to keep in touch with all the concurrent developments in laboratories all over the world. A number of up-to-date literature reviews provide a historical overview and describe the current status.[31,41]

Notwithstanding the progress from past decades, a considerable number of issues with perspective guidance displays remain to be addressed. The effects of tunnel geometrical design and the related fight on clutter,[42,43] the scale of the tunnel,[34] the ways to augment the display with symbology like the flight-path predictor[13,44-46] and their effects on pilot performance and workload, all have been extensively reported in the literature, but it is still unclear how these results affect the operational use of the display. Problems have been reported when accurately flying curved trajectories in the presence of wind and in situations where the nominal tunnel trajectory requires rapid changes in the aircraft flight condition.[26,34,47,48] Surprisingly, also the gain in global situation awareness is debated, as some believe that the compelling nature of the three-dimensional display leads pilots to focus too much on the guidance tasks related with the display and ignore other aspects of flight. This is referred to as 'cognitive funneling', or 'cognitive capture'.[49] Also, cost-effective methods of testing these new displays need to be demonstrated. Nearly identical studies of tunnel displays in flight tests (not easily affordable) and fixed-based, part-task simulator tests (affordable at a reasonable cost) have sometimes led to quite different results.[34,50]

Finally, and most importantly, it is not very clear how a perspective flight-path display "fits in" with the air navigation system that is employed throughout the world. That is, how do we employ these tunnel displays in the current air traffic management system? The research conducted in the past decades has clearly shown that perspective displays are an excellent tool to enable pilots to manually fly or monitor complex curved approaches. But in the current air traffic management system, it is unlikely that such "fixed" approach paths are flown, in particular near large terminal areas. Here, the common procedure is that air traffic controllers issue vectors to pilots to safely guide them through the airspace and to sequence them before making the final approach. These 'vector' commands include (indicated) airspeed, altitude and heading angle, and, important to note: none of these are referenced to the ground surface. The tunnel display, on the other hand, shows a ground-referenced trajectory, that is, the required track angle and position. It is still not sufficiently clear how these two different perspectives on handling the air traffic can be matched.

Despite these issues, however, and paraphrasing Newman's stand on head-up displays,[51] perspective flight-path displays in all respects show the way ahead. Literally speaking, through the presentation of the near-future guidance constraints in an intuitive, pictorial format that allows the pilot to stay "ahead" of the situation, thus reducing workload and enhancing situation awareness. And in a figurative sense, because the perspective guidance displays tap into hitherto unused capabilities of pilots, enabling the accurate tracking of complex trajectories in space and time. This will pave the way for enhanced procedures, in particular in the terminal area, and for increased safety and efficiency in air transportation.

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