Tunnel-in-the-Sky

Synthetic vision simplifies the pilot's job and enhances safety

Looking down on runway 25 at Eagle-Vail airport in the Rocky Mountains, a popular ski resort area in Colorado. It is one of 58 airports in the U.S. designated as «difficult», which means that the pilot must have trained specifically for the airport. A pilot presented with this view intuitively knows that he is flying too high to make it to runway 25. If altitude were the only factor to consider, all he would have to do would be to fly a circuit and try again, but there is also a 15- knot tail wind. In real life this would mean a diversion to Colorado Springs airport. Coming in from the opposite direction to land on runway 7 is simply not an option because of Snow Mountain.

Joost van Kasteren

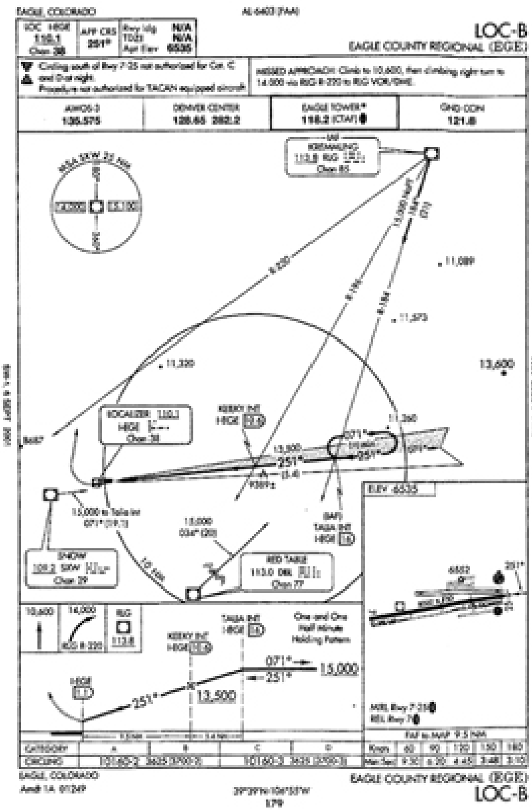
Every year, despite today's advanced electronic guidance systems, a handful of aircraft still plough into mountains in most cases killing all occupants. Such accidents are usually caused by a combination of low visibility and difficult terrain conditions. In mountainous terrain the modern precision guidance system known as the Instrument Landing System cannot be used because the ground isn't sufficiently horizontal. So landing an aircraft at these destinations puts pilots under great mental strain. New location systems, combined with a clever navigation data display system developed at Delft University of Technology, can help a lot. What's more the system can be used to reduce noise during the approach to an airport. The Electronic Positioning and Navigation Systems group at tu delft has been evaluating its system for synthetic vision

navigation in collaboration with the U.S. aerospace research organisation, nasa, and avionics manufacturer Rockwell Collins.
A series of test flights in Colorado and Virginia was successfully completed September 2001. On 18 and 19 March 2002 the Delft system was part of the demonstrations performed with the Boeing 737-900 Technology Demonstrator.

We are approaching Eagle-Vail airport, a single runway in the mountains of the U.S. State of Colorado. The airport is a popular destination because of the many surrounding ski resorts. In spite of the fact that the airport is tucked away in the Rocky Mountains, the standard approach to the runway is not very difficult. With 4.6 miles to go, at the Talia reference point (fix), you enter a right turn and start a three-degree descent, and you will find yourself nicely lined up with the runway. Child's play, provided you have the necessary flying experience. My own attempt at an approach turns out to be rather unsteady. Fortunately I'm only flying a fixed-base simulator, or the flight attendants would have been busy collecting vomit bags.
The flight procedure becomes a bit more complicated if you have to make a go-around at Eagle-Vail, according to Dr. Ir. Erik Theunissen of the Electronic Positioning and Navigation Systems group at the faculty of Electrical Engineering. At its far end, the runway faces a high mountain, Snow Mountain, which forces you to veer to the right or the left. At the same time, you have to gain height to avoid the mountain tops that dot the escape route. Things tend to become even more interesting if you have to go around with an engine failure, restricting your rate of climb.

Clinton
Going around with an engine failure was one of the scenarios enacted a number of times last August using a Boeing 757, nasa's flying laboratory. It was used to test the Synthetic Vision Information System (svis) being developed as part of nasa's Aviation Safety Programme. Theunissen's group is partnered in the programme by Rockwell Collins, one of the leading manufacturers in the field of avionics or aircraft electronics, Boeing Jeppesen for the electronic navigation charts, American Airlines for user experience, and the Federal Aviation Administration, for certification. nasa's Aviation Safety Programme came in answer to a call by former president Bill Clinton in 1997 to reduce the number of aircraft accidents by 80 percent within the next ten years. The consortium was selected by nasa in 1999 to further develop the proposal they had submitted.

Noise
Another scenario involves approaching the runway from the other end. This may be necessary due to the direction of the wind. The approach in this case is comparable to the normal procedure, but instead of touching down, you enter a short left turn followed by a right turn, bringing the aircraft on a course more or less parallel to the runway. At a certain point past the end of the runway you start a wide turn to the right, curving

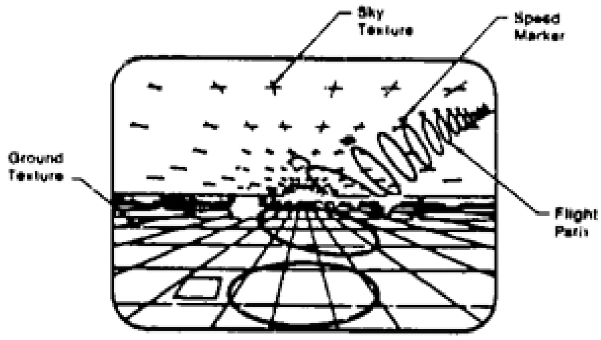


Example of an approach chart of the kind used every day by pilots all over the world when they come in to land. This is the chart used to approach Eagle-Vail airport via the Kremmling beacon and the Taila fix.

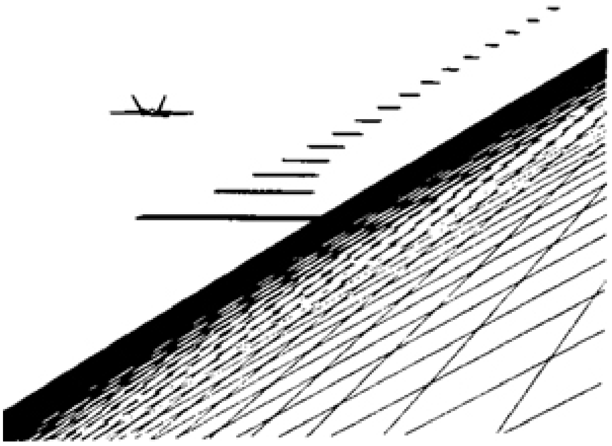
Looking down runway 25 at Eagle-Vail airport in the Rocky Mountains, a few seconds before touchdown. At the far end of the runway looms Snow Mountain, a range that complicates both takeoff and missed-approach procedures quite a bit, forcing the pilot fly around them. In situations with the rate of climb reduced by engine failure, the pilot has to follow a route through the curved valley with great accuracy until the aircraft gains safe altitude.

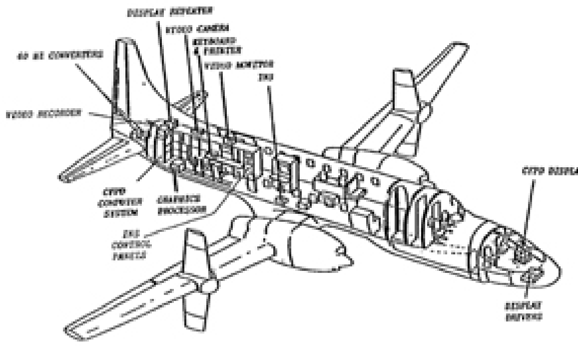
down to line up with the runway.
'It is a very complicated approach,' Theunissen says, 'because you have to perform a large number of turns while descending at the same time. Each time you have to make a roll to the right or the left, straighten out the plane, descend a little, then level off from descent to horizontal flight, then into the next roll. At the same time, you have to keep track of your speed and altitude, as you're flying at a relatively low level, hedged in by mountains. A complicated approach like this puts quite a strain on the pilots, both physically and mentally. On top of that, the approach causes quite a bit of noise on the ground, for each time you level off the plane, you have to increase thrust, which starts the engines howling.'
According to Theunissen, the synthetic vision system developed by the Delft Avionics section together with its partners, simplifies matters no end.
'The test flights we carried out in the U.S. over the past months have shown that we have managed to present the essential flight data to the pilot so as to enable him to perform the complicated approach in a smooth line. If you were to score the pilot's mental load on a scale from 1 to 10, the traditional approach would score 8 or 9, whereas our system would bring it down to something like 2 or 3, depending on the pilot's level of experience,' Theunissen claims, 'which in itself considerably improves safety. In addition, since the turn can be made at a continuous rate of descent, the approach can be started at a higher point. Throughout the approach, the distance from the ground is more than with the traditional approach. That too improves safety. An added benefit is the noise reduction, due in the first place to the increased altitude of the approach route, and in the second place to the fact that you no longer have to constantly adjust engine power. We have been able to demonstrate that our system works for Continuous Descending Curved Approaches, a system currently being discussed for Schiphol airport. That is not to say that it is ready for introduction tomorrow. The certification process for a synthetic vision system alone takes several years.'

Tunnel-in-the-Sky
The idea of synthetic vision, an artificial view of the surroundings to aid navigation, dates from the nineteen-fifties. At the time, a number of systems were conceived to provide military pilots with terrain information linked to an image of the approach.. Putting these ideas into practice has taken a couple of decades, for the simple reason that the available computers could never provide the processing power required for adequately presenting an image of the approach route's environment and the aircraft's position within it. It took a dramatic increase in processing power per given weight, together with the graphic user interface revolution of the nineteennineties, to give the schemes some chance of success. At last it became possible to display 3D information. Before then, the changes were mainly focused on imitating the previous electromechanical instruments on a computer display.

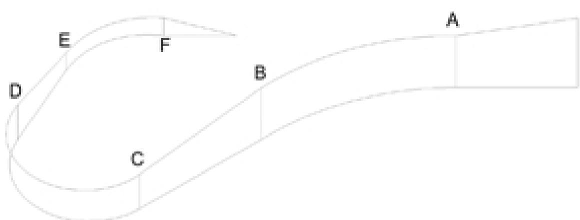


The idea for a tunnel-inthe-sky dates back to the nineteen-fifties, when U.S. Commander George Hoover led the first Pathway in the Sky (PITS) research team. This illustration shows a proposal from 1963.


On 9 February 1983, the command flight path display (CFPD) developed by Hoover and his team was implemented for the first time in the Total In-Flight Simulator (TIFS).



The TIFS is a 1953 Convair C-131D owned by the CALSPAN company, subcontractors to the US Navy. The aircraft, which was converted to a type NC-131H in the late nineteen-sixties, was jam-packed with the bulky computer equipment of the time.



Experimental psychology

Researchers at the Electronic Location and Navigation Systems department were quick to adapt to the developments.

The early nineteen-nineties saw the launch of the Delft Programme for Hybridised Instrumentation and Navigation Systems (delphins), a systematic survey to define design rules that could be used to display three-dimensional information, bearing in mind the tasks to be performed by the pilot and the resulting mental and physical load. It was a multidisciplinary programme that looked at the rapid developments in the field of graphic design, and in which human factors played a major role. 'It's not about whether or not the sky should be shown in blue and the earth in green,' Theunissen says, 'but about human beings as information-processing and acting entities, and about their place within the entire control chain of information processing and actions. It's all right to say that this or that is the information a pilot needs to fly, but you are going to have to prove it using data based on experimental psychology. Especially for avionics systems that require verification, the adage applies that every pixel has to pay its way to the screen.'

The delphins research efforts drew the attention of the aviation world, in particular that of the avionics industry, the manufacturers of aircraft electronics. So, when nasa issued a call to tender for the development of synthetic vision systems, Rockwell Collins were quick to respond.

Theunissen: 'They not only liked our way of looking at the problem, but also the fact that our system remains independent of the type of aircraft used to test it. It can be used equally well for a Boeing 757 cockpit simulator, for a large military aircraft, or for a small single-prop plane. Together with Rockwell Collins we have constructed what is called a Bridge, a software system that can be used to connect our navigation system to the systems of various aircraft types. In addition, we can use the flight data to accurately replay a flight. It is this cockpit connection that really makes our system perfect for testing in the field.'

Mental space

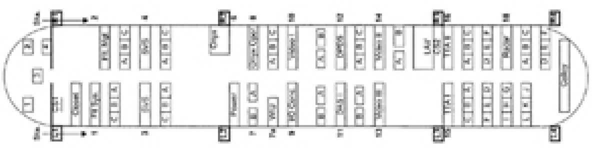
As the new cockpit design rules were developed, the main layout of the instrument panel was left unchanged. Theunissen: 'The aircraft attitude indicators are still right in front of the pilot, and the altimeter is still on the right, with the airspeed indicator on the left, and the compass at the bottom. This main layout goes back to rules of experience, but it is backed by so much knowledge that you cannot just ignore it. The thing to do is to find out which elements you can add to make flying an aircraft a simpler task. And I don't mean flying in a straight line at high altitudes, that's the autopilot's job. I mean complicated approaches like Eagle-Vail, or flying an escape route after a missed approach. As the complexity increases, the residual capacity, the mental space a pilot has to respond to unexpected events, decreases. And that is where synthetic vision systems can make a difference.'

The delphins programme focused not so much on a lifelike representation

Conventional procedure for a curved approach in stages. During the horizontal turn segments (A-B, C-D, and E-F) the aircraft changes direction, while the sections in between are used to lose altitude.

The research simulator of the Electronic Positioning and Navigation Systems group that was used to test the synthetic vision concepts. The simulator, which is also used by graduate students, was built by the group itself. Copies of the system are now in use at NASA Langley in Virginia, at Rockwell Collins at Cedar Rapids, Iowa, and at Ohio University in Athens, Ohio.

NASA Langley's Boeing 757 ARIES is the organisation's flying laboratory. During the months of August and September this aircraft was used to fly more than 100 synthetic vision approaches into Eagle-Vail airport in the Rocky Mountains.



Layout of the Boeing 757 ARIES.

of the world outside as on presenting navigational data in such a way as to actually relieve a pilot's mental strain.
Theunissen: 'To begin with, we developed an architecture in which the information can be presented in different ways, depending on the state of progress of a flight. For aircraft movements on the ground, for example, we have developed a taxi guidance system that helps the pilot to move from the gate to the start of the runway, and after landing, from the runway to the gate.' (See last page.) Within the same architecture, after take-off, the flight mode takes over. This supplies the pilot with information about the scheduled flight route and any other traffic in the air around him. In addition it contains information about the terrain the aircraft passes over. A major component of the flight mode is the display of the required flight path as an imaginary tunnel. This concept has been dubbed tunnel-in-the-sky. The idea was proposed for the first time in 1952, almost fifty years ago, but has only recently become feasible. The primary flight display, or pfd, one of a pair of displays in the Delft cockpit simulator, shows a greenish brown landscape with a purple square superimposed on it. Behind it a row of white squares of decreasing size forms the outline of a tunnel, like a fun fair caterpillar.

Going around
The purple square is used to display the flight path predictor. It takes the form of an abstract aircraft symbol, a circle with lines representing the wings and the tail fin. The trick is to use the sidestick, which is a type of joystick, to keep the plane within the purple square. The squares outlined in white behind the purple square ensure that any turns or descents can be anticipated. Under certain circumstances the proposed flight path will adapt to the current condition of the aircraft. The main parameters in this respect are the available thrust, the current speed, and the required speed. When we fly the approach to Eagle-Vail, including a simulated engine failure and missed approach, the exit flight path immediately pops up on the display. It involves exiting to the left and gaining altitude to make sure you can negotiate the mountain peaks in your path. If you are down to half power because of an engine failure, the flight path changes.
Theunissen: 'Normally, after a missed approach you follow a preplanned route that safely takes you to the prescribed altitude in the shortest possible time. The chart could show something like «Climb to 14,500 via 249 course to zodsy wp, then via 07 course to jesie wp and hold», which means «Climb to 14,500 feet in compass direction 249E, then turn to follow direction 7E to waypoint jesie, then assume the holding pattern. The latter means that you start circling until directed to proceed. The route has to be flown at a prescribed speed. The remaining engine power must be used for climbing. Our system plots the entire path in advance, and the tunnel always stays with you. If the available power turns out to be less than planned, the route is changed accordingly with the purpose of directing the aircraft out of danger as quickly as possible by


Composite photograph in which the proposed flight path has been superimposed on a view of the surrounding area at Eagle-Vail airport.


Assessment pilot Kiggins of the US Air Force uses the synthetic vision system developed at TU Delft to fly the approach to runway 7. For the test flights, a special LCD display was fitted in front of the existing pilot instruments, with the control display on the left, and the navigation display on the right. At the moment the picture was taken, with the aircraft 6 miles away from the runway, the pilot selects a new navigation display scale on the control panel to obtain a view with more detail.


Close-up of LCD display.

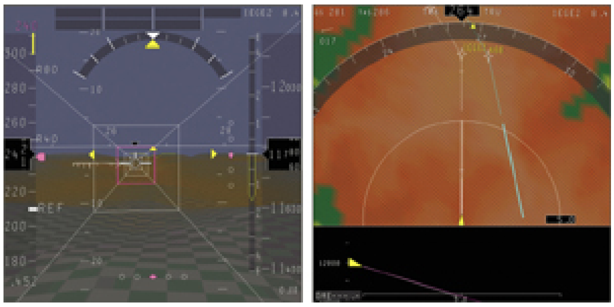
continuously optimising the route.'

Navigation error
The synthetic vision information system could play an important role in preventing what is known as «controlled flight into terrain» (cfit), in which an aircraft flies into the ground or hits a mountain. This occurs on average four times a year in civil aviation. The number of military cfit accidents is higher. The cause of these accidents often is a navigation error, in which the aircraft is somewhere quite different from where the pilot believes it to be. This usually occurs after pilots deviate from their planned course, either knowingly (for example, after missing their approach) or unknowingly. Getting lost in itself might not be such a problem, but it also means that obstacles such as mountains and high buildings are no longer where the pilot expects them to be. A synthetic vision information system would remove this source of confusion, with the computer continuously calculating the position of the aircraft relative to the required route and hazardous obstacles, and presenting the resulting image in real time to the pilot.
Theunissen: 'The pilot's navigation task includes integrating the various data on his instrument panel, such as the aircraft's attitude and its position, altitude, speed, and bearing. The task of integrating these data to obtain spatial awareness has been taken over by our system. The resulting presentation provides the visual stimuli in such a way that the pilot's spatial awareness is achieved spontaneously. One might compare it with an aircraft's computerassisted attitude control. In the old days, the pilot had to stabilise the aircraft himself, but in most modern aircraft this task has been automated, so you no longer have to worry about it.'

Geographical information
According to Theunissen, the risk of the system losing its way, or in other words, of the aircraft no longer knowing where it is, is extremely small, as long as the instruments work the way they should. An aircraft's position is determined in two different ways, by means of inertial navigation using acceleration transducers, and by means of differential gps. An aircraft's speed, attitude and altitude are also monitored in a number of independent ways. If the difference between the various measurements exceeds a previously set margin, the pilot receives a message to «check position». In addition to the flight data, there is the information about the terrain itself. The system retrieves this from two databases. The data are collected in the United States by, among others, the National Imagery and Mapping Agency (nima), a state-run agency. The first database contains large-scale data on the earth as a whole, while the second database contains geographical information about the environment of airports. The second database has two different levels of accuracy. Up to a distance of six miles the resolution is six seconds of arc (about 180 metres). Above that, up to a range of 50 miles, the resolution is 15 seconds of arc. The system also includes data on other relevant details such as high buildings, mountain peaks, and of course the runway itself.

The aircraft is now flying to the left of Eagle-Vail Airport and is about to enter into a right turn of more than 200°.

The Boeing 757 ARIES is filled with instruments, computers, and researchers monitoring the systems and pilots' actions through dozens of displays. Flights often last four and a half hours, during which time ten to eleven approaches will be flown.



The approach to runway 07 at Eagle-Vail. The navigation section of the display shows vertical and side views of the current situation. The aircraft is on a course of 264E, has started its descent, and at this point is 8.4 miles away from the reference point (IEGE2) at which the route curves to the left. The location matches position A on the aviation chart. The pilot does not have to fly over IEGE2, but at a distance of 0.7 miles before that point he has to bank left. This is where the curved part of the approach route starts. The purple square on the left-hand display shows the distance from the position the aircraft will be at in 5 seconds time. The white aircraft marker consisting of a circle with two horizontal lines and a vertical line shows the estimated position in 5 seconds time. The current airspeed is about 240 knots.

Theunissen: 'One would expect the amount of available geographical information about the surrounding countryside of airports to be substantial, but it turns out to be far from easy to obtain data of the quality we want.'

WTC

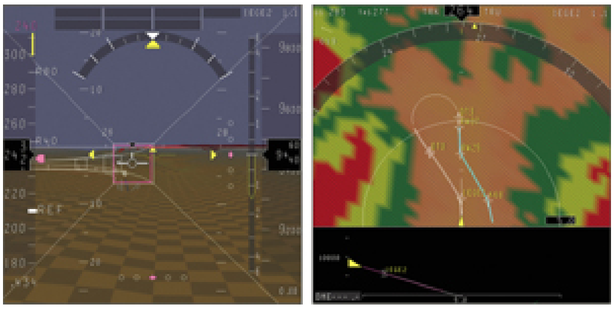
Theunissen confirms that the pilot will remain in control of the aircraft, supported by the system developed at tu delft.

'Shortly after the attack on the New York World Trade Centre, the press came with articles suggesting that the virtual tunnel in the sky concept could be used to ensure that pilots or terrorists could not deviate from their proposed route. I don't believe in that. A pilot can have a number of legitimate reasons to change course from the prescribed route. A passenger could have a heart attack, and the same goes for the pilot himself. None of them are invulnerable. Or you could have an engine failure, or a fire in the luggage hold. In each case, you would want to be able to land the plane as soon as possible. Things can also go wrong on the ground to make you change destinations, a blocked runway, for example, or some kind of ground traffic accident. In any case, the important thing is that the pilot has the last say in the matter, for he is best equipped to deal quickly and adequately in unexpected situations, something a computer finds more difficult to handle. Once you choose this set-up, you have to use it to best advantage, of course.'

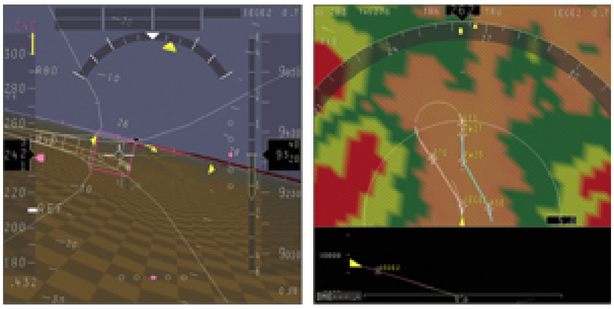
As mentioned above, the test flights with the Boeing 757 have been completed, and the system has proven its practical worth. Approaches were flown to Newport-News, Virginia and Eagle-Vail, Colorado. At Eagle-Vail, both the dynamic turn and the exit route have been flown with and without an engine failure. In a dynamic turn, the current wind conditions are used to calculate the optimum path for the pilot to follow at a constant angle of roll and speed. The video Theunissen has shot of the flights shows the mountain peaks passing eerily close to the window. In both cases the planned route using synthetic vision turned out to be more accurate as well as easier on the pilot compared with the traditional method. Another field test was conducted at Dallas Fort Worth airport in Texas, one of the world's busiest airports. The experiments included changing runways during an approach. New tests have been planned using a new type of aircraft, Boeing's V-22, a vertical takeoff and landing (vtol) aircraft. The Delft group are also engaged in a project for the U.S. Air Force, which will probably involve test flights in September 2002 using the Speckled Trout, a usaf research aircraft. All in all, the future looks good for the synthetic vision system, most of which was developed at tu delft. And Theunissen is convinced this bodes well for the further improvement of aviation safety and efficiency.

Taxi-guidance

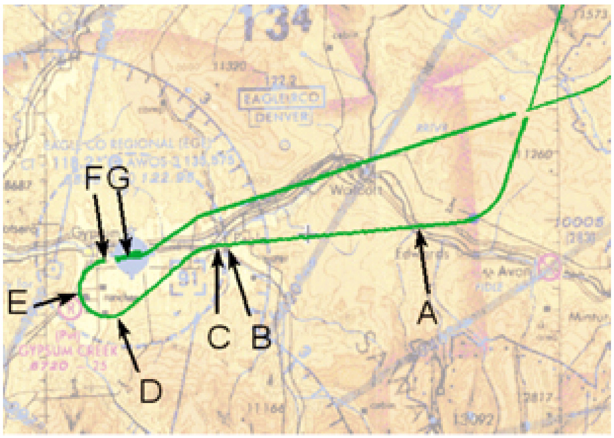
In addition to the flight mode, the synthetic vision system includes what is known as a taxi guidance mode to help the pilot find his way around an airport while on the ground. This can be a pretty daunting task, certainly



The current course of the aircraft is still 264E, but it has now progressed 7.3 miles from the situation shown in the previous figures to just before the turn to the left (position B on the chart). The red areas on the navigation display mark any terrain higher than the current aircraft altitude. The purple square on the left-hand display is at the start of the turn, and will start to move to the left shortly after this. By controlling the aircraft to keep the white aircraft marker within the purple square, a gradual transition is assured, and the route will be flown with optimum accuracy.



The aircraft is now in the turn at a distance of 0.7 miles from the IEGE2 reference point (position C on the chart). The change in course, which now reads 262E, shows that the aircraft has only just started the turn. The pale blue line on the left-hand display shows the route to be flown in the event of a go-around.

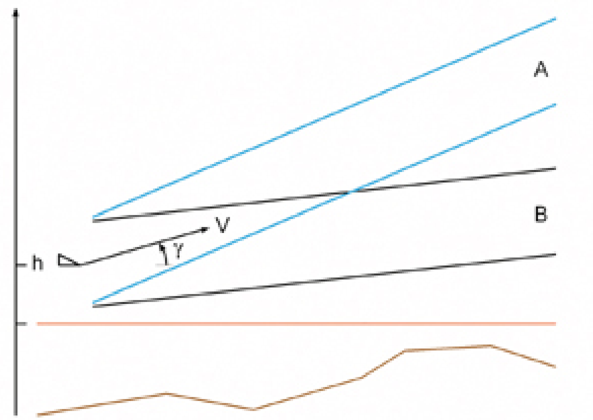


Aviation chart of the surroundings of Eagle-Vail airport in the Rocky Mountains. Erik Theunissen has marked the chart with approach and missed-approach routes specially calculated and optimised for runway 07. Marks A - G refer to the situations shown in the series of images of the control and navigation displays. At point A the aircraft has just started its descent. At point F the aircraft is lined up before the runway.

at larger airports. The usual procedure is for the pilot to be coached along by traffic control, who will also tell him when to cross or stop at a runway. In many cases, the aircraft cannot actually be seen from the traffic control tower, not even with binoculars. A pilot will also have a map of the airport, and the route will be marked by signs showing him the name of each stretch of tarmac or concrete. This is hardly the best type of information system if visibility is low, so it comes as no surprise that airports are the scene of many accidents, or near-accidents. One of the most tragic examples of a runway incursion is the collision between a KLM aircraft and a PanAm aircraft at Tenerife Airport in 1977, when the KLM aircraft started its takeoff run with the PanAm aircraft still on the runway. Another fairly well-known runway incursion occurred in 1989 when the light aircraft of Dutch astronaut Wubbo Ockels had its wing clipped by the undercarriage of an incoming Airbus A320. And then there is the recent accident at Linate airport near Milan, in which a SAS McDonnell Douglas MD-87 collided with a German Cessna. The accident, which claimed 118 lives, occurred in dense fog with the ground radar system out of order, or switched off. The taxi guidance system developed at TU Delft is to prevent such accidents in the future. The system is similar to the car navigation system found in most modern cars in the higher price range. The main differences are that the data on three-dimensional objects are actually stored as three-dimensional data, and that there is a data link connecting the aircraft to the traffic control tower. The data link is used to provide data on the position of other aircraft, and it provides an unequivocal indication of whether a runway is safe to cross or not. The display shows the layout of the airport with your own aircraft in it, as if shot by a camera hanging above and behind its tail. A route line along the bottom of the display shows the numbers of the taxi lanes to take, corresponding with the numbers on the signs outside. A red sign reading «hold» tells the pilot not to cross a runway. As soon as the path is clear, the traffic control operator presses the «cleared» button and the virtual stop sign turns green. In the simulator, Theunissen manages to get the aircraft to its take-off holding point with considerable speed, even in simulated bad visibility of only 30 metres (dense fog). 'In foggy weather, all aircraft and other traffic still have to slow down in order to avoid accidents. This causes congestion and delays at airports. Our system not only offers improved safety, but it also ensures that the aircraft can keep moving, reducing delays and saving the airlines a bundle of money.'

The taxi guidance system has recently been improved, particularly regarding the images of the instructions issued by traffic control. The work was carried out by two students, Kristel Kerstens of the Industrial Design department, and Joris Koeners, who recently graduated from the ITS Faculty. By following certain design rules and having the results tested by pilots in the simulator, they were able to reduce the risk of misinterpretation even further. At the Digital Avionics Systems conference held recently at Daytona Beach, Florida,

The DELPHINS synthetic vision system can also be used in smaller aircraft. In the context of the NASA Small Aircraft Transportation System (SATS) research program, a King Air research aircraft from Ohio University was equipped with the DELPHINS system. The picture on the right shows the synthetic vision display in use during an approach into the airport of Athens, Ohio.



their research results were selected as best student paper.

For more information, please contact Dr. Ir. Erik Theunissen, phone +31 15 278 1792,
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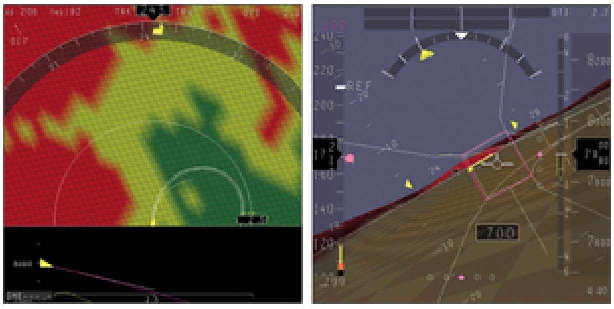
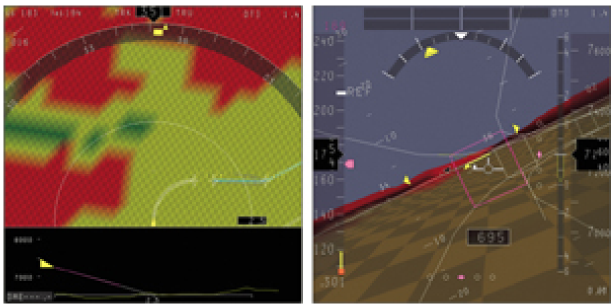
website: http://www.delftoutlook.tudelft.nl/external.html?link=www.synthetic-vision.tudelft.nltarget=/"_blank"

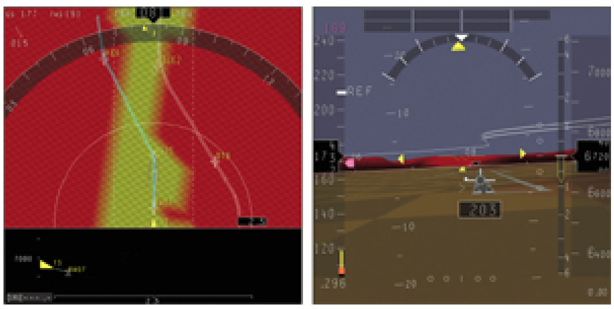
To determine the vertical path of the tunnel in the event of a missed approach procedure, the optimum path angle is continuously calculated from the current acceleration of the aircraft and the deviation from the required air speed. As long as the aircraft remains above the minimum altitude, the vertical position of the tunnel around the aircraft stays at the current altitude (h), and the calculated path angle is used to present the tunnel with the optimum climbing route. The illustration shows a side view of two possible situations. In situation A the current speed (V) is equal to the required speed, but there is also an acceleration component. As a result, the optimum path angle exceeds the current path angle, [gamma], and so tunnel A will climb faster than the current path angle. By following the tunnel, the pilot will reach a safe altitude faster. In situation B the aircraft is flying slower than the required speed. To prevent the aircraft from stalling, tunnel B will have to climb at an angle less than the current path angle.



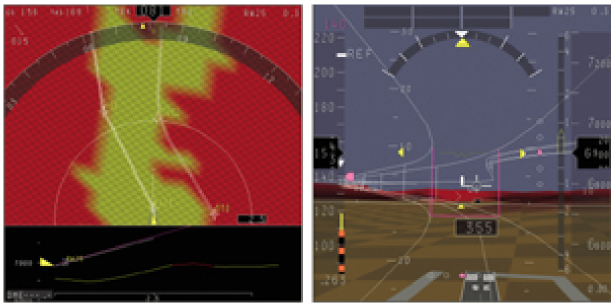
The aircraft has now reached the start of the last right turn (position D on the chart) and still has to change course through about 200E. This turn passes close in front of Snow Mountain, and the terrain colours on the navigation display show that the aircraft is by now hemmed in by mountains. The airspeed has decreased to about 170 knots.



In this view, the aircraft is halfway through the last right turn (position E on the chart) with still about 90E to go. The left-hand section of the display shows that the altitude above the terrain is still 695 feet. The navigation display already shows the airport.



The aircraft has just emerged from the turn and is right on course for the runway (position F on the chart). The altitude above the terrain is 200 feet, and a touchdown is possible. At this point, the pilot is told by traffic control to go around and fly the planned missed approach procedure. In a real situation this could be necessary if another aircraft were to taxi onto the runway by mistake.



The pilot has activated the go-around procedure. The left-hand display now shows the route to follow, the one represented earlier by a pale blue line on the navigation display. The altitude changes in this missed approach route are continuously updated to match the current rate of climb of the aircraft. By following this route the pilot can guide the aircraft to a safe altitude under the current conditions while maintaining the maximum distance from the ground.

On 8 October 2001, in dense fog, and with the ground radar out of order or switched off, a SAS MD-87 on its take-off run collided with a taxiing German Cessna at Linate airport near Milan. The lives of 118 people were lost when the SAS aircraft ploughed into a building and caught fire, as did the Cessna.

This animation shows the aircraft just after landing on runway 17R at Colorado Springs airport. The taxi route to be followed is indicated by the green line. The strip at the bottom of the left-hand display shows the current location (17R) followed by the designations of the following taxi lanes, C3 (Charlie 3), G (Golf) en M (Mike). The larger red box showing G indicates that the pilot should stop at that point and wait for permission from traffic control to proceed.

The aircraft has now reached the crossing with the Golf taxi lane and has almost reached standstill. In order to minimize the risk of the pilot continuing by accident, a sign reading «Hold» is shown in front of the crossing. In addition, both displays show the route over the crossing in red. The green dotted lines after the crossing mark the section of the route the pilot is authorised to follow once traffic control gives him permission to enter taxi lane G. As soon as this permission is given, the dotted line changes into a continuous line.

March 2002 a refined version of the Delft navigator display was fully integrated in the Boeing 737-900 Technology Demonstrator Aircraft.