Free Flight's Big Picture Concept

Conceptual Design of a Cockpit Human-Machine Interface in a Ground-Controlled Free Flight Environment

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Abstract: In response to capacity problems in the current airspace system, regulators and the airspace industry are investigating new, more flexible uses of airspace. This has led to the concept of Free Flight, a concept in which responsibility for separation will be placed partly with the aircraft crew. This paper discusses new designs for the Primary Flight Display and the Navigation Display for use in approach and departure phases in such a Free Flight environment.

Keywords: Free Flight, aircraft displays, human-machine interaction, tunnel-in-the-sky

Implementation of Free Flight

A fundamental shortcoming of the present airspace system is inflexibility. In various forms, the Air Traffic Management System (ATM) has been in use for approximately 50 years, and it was conceived in the infancy of radar and with far lower traffic densities. In repeated attempts to gain additional demand, and in the absence of modern ground-based automation or new operational concepts, the flexibility to operate efficiently in most of the world's airspace has been sacrificed for safety purposes. In many, if not most instances, the current system dictates routes of flight, altitude and even speed to airline operators, resulting in significant financial losses. Fixed routes minimize the potential conflict locations for the human air traffic controller, but produce flight plans that do not minimize fuel usage or flight time, and requires aircraft to fly in winds that may be less than optimal. In the highly competitive air carrier environment, airlines are anxious to reduce their fuel costs and increase aircraft utilization. After all, lower operating costs could mean lower ticket prices.

Another problem is a consequence of travel growth. Air traffic is expected to double within the next 15-20 years, and the current restricted airspace architecture and management will not be able to efficiently handle this increase. The traditional method of increasing capacity by subdividing airspace into smaller control sectors to offset the increased workload has reached its viable limit in some airspace already, and this practice would not provide the levels of additional capacity needed in the future anyway.

The required improvements in both system capacity and flexibility, and with an increased amount of safety, can be achieved through the implementation of the Free Flight concept. Free Flight will offer pilots and operators the possibility to select themselves their most efficient routes, speeds and altitudes to their destination. Air Traffic control (ATC) will only interrupt and impose constraints on the preferred trajectory in case the currently flown route would conflict with other flight plans. Restrictions then are limited in extent and duration to correct the identified problem. So, while in the current situation ATC is a centralized command-and-control system between pilots and controllers, the future Free Flight concept has to be seen as a distributed system where:

- The airspace user determines the economic path.
- The ATM service provider assures separation.

Although the implementation of Free Flight may sound as a far and distant futuristic project, it is not. Already in 1996, the FAA Administrator (FAA 1996) confirmed the agency's commitment to Free Flight. Working together with aviation leaders from around time world, FAA developed a Free Flight action plan, responding to time RTCA Task Force recommendations (RTCA 1996). The FAA hopes to phase in some form of Free Flight in less than 10 years from now.

And not only in the US do airspace users feel the limitations of the current ATM system in capacity and efficiency to their operations. Europe's recently deregulated airline industry is also demanding lower costs on the industry. Therefore, Eurocontrol is pursuing the concept of a European Air Traffic Management System (EATMS). Comparison of the objectives of both programs shows no important difference between Free Flight and EATMS. For that reason, the term Free Flight' is frequently used to embrace both initiatives, with the common goal 'providing airspace users with a greater flexibility in choosing paths from one airport to another' (De Vriendt 1997).

Human Aspects of Free Flight

Implementation of Free Flight will also affect the human aspect when operating in this complex environment. A better Human-Machine Interface (HMI) will be needed not only to support the future air traffic controllers, but pilots in particular. Regardless of the fact that a major change in the design of the cockpit layout has been carried out in the last decade, it has remained unchanged that 'the human element in control of an aircraft' is blamed for almost 75% of all total jet losses (Boje 1994, NTSB 1996). Implementation of the Free Flight concept will not only bring additional information and procedures to the cockpit, thereby further increase pilot workload, but also, operating in a highly demanding Free Flight environment will also require that data needs to be presented in a way substantially increasing pilots Global and Navigation 'Situation Awareness (SA)[1]. Reproductions of earlier electromechanical instruments on sophisticated computer-generated electronic displays will no longer do. New computer graphics capabilities, the rapid progress in display media, and human factors methodologies make possible the design of large-screen, integrated pictorial formats with improved crew situation awareness and workload, safety, and operational efficiency.

Taking into account the above-mentioned objective, the conceptual design for a better cockpit HMI concentrated on improving the presentation of flight information on the two main cockpit displays: the Primary Flight Display (PFD) and the Navigation Display (ND). A complete new design for both displays is presented, based around two 20' flat panel displays. Therefore, the term 'Big Picture' not only refers to the use of larger display areas, but also to the proverbial idea of 'getting the big picture'. Special attention was paid to the flight phases descent, approach and landing, because 65% of all jet losses occur during these three phases (Boje 1994). It is obvious that the risk for a Controlled Flight Into Terrain (CFIT) is much higher when flying at low

[1] 'Global and Navigation SA' are the two main pillars of the more general term 'Situation Awareness', which has been defined by Endsley (1990) as: "the perception of the elements in the environment, concerning the performed task, within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future."

- Global SM comprises the long term, non-visual range including the location of distant traffic flows, way-points, long term flight path, terrain and map information.
- Navigation SA: comprises the short-term flight situation within visual range, including surrounding traffic within visual range of the aircraft's essential flight parameters and visual navigation. Both Global arid Navigation (Situation) Awareness depend on good Spatial Orientation/Awareness, meaning an awareness of the constantly changing aircraft orientation and position in space,

altitudes. For that reason it seemed to be appropriate to develop a flight instrument that provides a great potential to significantly improve the pilot's situation awareness in the vicinity of an airport.

Requirements of a new HMI

The development of any new display must start with the basic principle of analyzing the mission requirements. For commercial air transport pilots, these are to:

- Fly the aircraft.
- Navigate the aircraft, considering the surrounding traffic and terrain.
- Monitor aircraft systems and cope with unexpected events.

In the context of aircraft control, these three tasks involve all the control loops of Figure 1. When developing a display system, each display must relate to one of these goals. For the two cockpit displays dealt with in this particular conceptual design, the main goals are:

1. For the PFD: to provide local guidance information. For the pilot this involves staying on the desired navigation path (skill-based behaviour)
2. For the ND: to provide sufficient Global and Navigational Awareness. For the pilot this requires knowing where things are (aircraft, objects, terrain) with respect to his momentary position.

If one was to characterise the desired display features to present that information, research done at the NASA Ames Research Centre concluded that the 'ecological'[2] (Wolpert, 1990) three-dimensional forward-viewing perspective is the most intuitive in supporting local guidance tasks. Demands for Global and Navigation Awareness on the other hand are fundamentally different from those necessary for guidance and are somewhat less ecological in nature. Here, a two-dimensional depiction may be superior, with a wide viewing angle of the world. These conclusions will be taken into account for the conceptual design of the two displays.

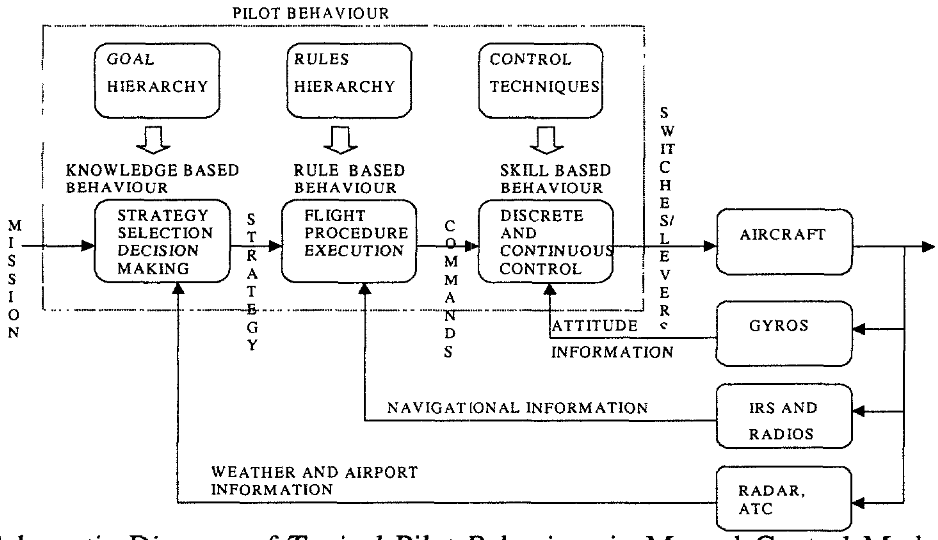

Figure 1: Schematic Diagram of Typical Pilot Behaviour in Manual Control Mode (Tanaka & Matsumoto 1986)

[2] Refers to "Ecological Psychology". Main thought of this theory is that human can function well in a specific environment (ecology) without having extensive internal model of that environment. Most of the needed information can be gathered directly from the received visual input (Vicente & Rasmussen 1990).

Further, there are four specific functions that the combination of both displays must support:

1. All-weather precise 4D Navigation capability.
2. Traffic Information with TCAS integration.
3. Terrain Information with GPWS integration.
4. Precise A/C-ATC Information Exchange, including Trajectory Negotiation capability.

All-Weather Precise 4-D Navigation Capability

By abolishing fixed routes in a Free Flight environment and offering pilots and operators the possibility of selecting themselves their most efficient flight path from one airport to another, the structure is also removed. In the airway structure, conflicts tend to show up at specific places, without the structure, conflicts occur randomly within the airspace. Resolution of these conflicts, without introducing others, requires that aircraft adhere strictly to their agreed-upon trajectory. Therefore, aircraft operating in such an environment will have to navigate much more precisely than in today's situation.

Primary Flight Display

Forty years ago, there were two separate sources of flight information: the panel instruments and the out-of the-window view. Gyroscopic instruments and precision ground-based radio navigation aids were developed to replace the out-of-the-window information during Instrument Meteorological Conditions (IMC). One such radio aid for precision instrument approaches is the Instrument Landing System (ILS). The ILS consists of two radio beams that present lateral (localizer) and vertical (glideslope) course guidance information. The primary goal of a pilot flying an ILS approach is to keep the aircraft centred on this course until a predetermined altitude, or decision height (DH) is reached. At this point, the pilot must land the aircraft using visual cues (if they are available), or execute a missed approach. The ILS display (Figure 2) that the pilot uses typically consists of two 'crosshairs', which the pilot attempts to keep in a null, or centred, position. Deviation of the crosshairs from the centre position indicates an angular offset of the aircraft from the desired course. Pilots flying small aircraft find executing an ILS approach to be a demanding, though achievable task. In larger aircraft, which typically fly at faster approach speeds and are less manoeuvrable than small aircraft, the task of performing an ILS approach with only standard instrumentation and ILS deviations becomes extremely difficult. One system developed to aid the pilot in performing the task is the flight director. A flight director calculates the required control inputs for the current flight mode, be it attitude control, altitude and heading control or control of lateral and vertical position as done in an ILS approach. Deviation of the required control input and the actual control input is presented by flight director symbology (needles or "wings") on the Attitude Director Indicator (ADI) and the pilot flies this computed trajectory by nulling some type of error indication. Instead of basing his control input on attitude, heading, altitude and lateral deviation errors, the pilot can follow the command bar from the flight director. Although a well-designed flight director can make the ILS approach task much easier, it does not lend itself well to maintaining awareness of the current aircraft state, since it does not give a direct indication of the course offset. Pilots do not have any external visual cues to assess the motion and attitude on the aircraft in space.

The 'Free Flight Big Picture Concept' aims at enhancement of a pilot's trajectory awareness by presenting a "tunnel-in-the-sky" prospective flight-path image onto the Primary Flight Display. Simply by keeping aircraft's flight path indicator (sometimes referred to as the 'velocity vector' of the aircraft and symbolised on the display as a circle with wings) into the limitations of the tunnel, the pilot then is assured to remain on a conflict-free trajectory. Dimensions of the tunnel depend on the required accuracy of navigating, which in turn rely on the moment of flight and the proximity of surrounding traffic. Therefore, tunnel-dimensions during approach, and surrounded by a high amount of traffic, are much narrower compared with those during cruise.

The advantage of a display featuring flight-path information compared with conventional flight directors is that it allows for a more natural or intuitive method of control. Since the flight-path directly indicates where the aircraft is going, at all times it provides the pilot with predictive information on the trajectory to follow. So he can anticipate and base his actions on upcoming events. Pilots then are flying in an 'active' instead of a 'reactive' mode.

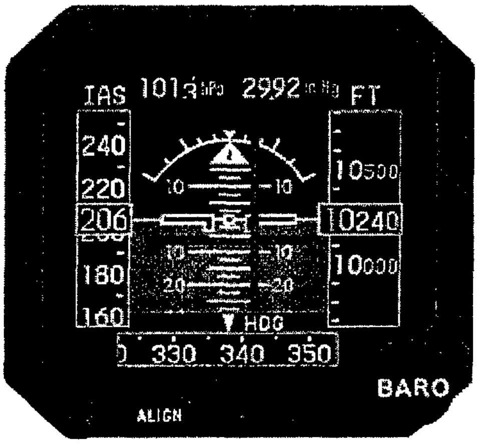

Figure 2: Primary Flight Display with Localizer and Glideslope. *Deviation of the crosshairs from the centre position indicates an angular offset of the aircraft from the desired course. (Smiths Industries)*

Using GPS, the tunnel-in-the-sky can be exactly positioned in a computer-generated three-dimensional synthetic world from on-board databases. A synthetic visual image clearly reproduces all components of the out-of-the-window view relevant for the flight task (within a viewing angle of 52^0 horizontal and 40^0 vertical of the aircraft) and integrates it with the 'basic T' components (such as aircraft's airspeed, altitude, heading, horizon, bank- and pitch angle) of current primary flight displays. To avoid the different elements on the display from hiding each other, some of them, like the tape scales, are made transparent and placed on the outer sides of the screen. The computer-generated synthetic vision image may also include sensor information. This way it is possible to account for temporary objects not included in the stored database.

The three-dimensional view out of the cockpit window is the central source of information in the newly developed Primary Flight Display. The correspondence of this presentation with human's natural way of visual perception permits the pilot to understand his actual flight situation intuitively. By integrating a synthetic world on the flight display four matters are to be achieved:

1. to present the pilot at all times a weather-independent out-of-the-window view.
2. to avoid unnecessary and time-consuming pilot eye-movements between the cockpit window and his flight displays.
3. to be able to filter unnecessary objects out of the pilot's out-of-the-window view to assure the pilot gets only the essential information, whilst giving him, by 'colour-coding', additional information about what he especially needs to pay attention to.
4. to limit the required processing power and amount of data that has to be acquired and stored by presenting the outside world in a "stylised" manner.

Using GPS as a sole means of navigation to determine aircraft's exact location as well as for positioning the tunnel-image into the (displayed synthetic world, makes it possible to fly instrument approaches independent of signals from ground based transmitters such as ILS or MLS. This would mean the same precision-approach capability at all runways all over the world independent of an airfield's own infrastructure. Moreover, it would enable new procedures and navigation techniques (such as curved approaches) which could mean more flexibility for organising the arrivals or could be very useful for noise abatement procedures around some airports.

Navigation Display

For extended route planning and to provide the pilot with the 'big picture' of terrain, obstacles and adjacent traffic along its path, the Primary Flight guidance Display (PFD) has to be complemented by a Navigation Display (ND). To assure a smooth transition between these two, the conceptual ND was designed matching the PFD's imagery, so the ND is computed from the same databases as the PFD and generates the same symbology and colour-coding.

On the new Navigation Display, the conventional horizontal perspective is extended with a vertical component. Where the Horizontal Navigation Display already has proven to be a major help for crews positional and situation awareness, Electronic Flight Instrument Systems (FFIS) produced to date have done little, if anything, to improve a crew's ability to analyse and stay aware of the *vertical* situation and *vertical* flight path (Oliver 1990).

The Primary Flight Display's 3D image of the tunnel is shown on both horizontal as vertical components of the Navigation Display in a 2D perspective. The horizontal view depicts the aircraft's position within the tunnel on a colour-coded moving map, corresponding to the altitude profile as seen in 3D on the guidance display. The vertical view displays the flight path as seen from the outside, and to the side, of the aircraft. By this combination the pilot gets, at a glance, the picture of his aircraft's position and predicted flight path into the future in relation to all relevant navigation points within the map's range. By adding the predicted flight level and time schedule at every way-point to pass, he can navigate his aircraft very accurately both in space (3D) as in time (4D). The prediction of the actual trajectory that will be flown is calculated by the on-board 4D-Flight Management System (FMS) computer. Since this prediction can be used by the aircraft to directly feed its guidance, pilots as well as air traffic controllers can have high confidence that the intended flight plan can be performed with great precision. If so, it would become possible to deliver an aircraft to the approach gate within a few seconds of the predicted arrival time, which once again would mean a tremendous advantage for organising the arrivals.

Traffic Information with TCAS Integration

A matter of major importance in raising the level of situation awareness on the flight deck is to provide the flight crew with visual information about surrounding traffic.

Using precise satellite-based positioning coupled with broadcast datalink capabilities, ADS-B's[3] advanced surveillance technology enables any aircraft to both send and receive highly accurate surveillance information both in the air and on the ground. Aircraft equipped with GPS-antennas and ADS communications will be able to broadcast their position and intended path at regular and frequent intervals to control towers and other aircraft in the vicinity. Visualising this information would help to foresee future conflicts. Providing the pilot with an electronic picture of all ADS-B information within a certain range around his own aircraft is the graphical solution to give him at a glance the 'big picture' of traffic, which would mean a great deal to his Navigational SA. Given the importance of traffic information to the pilot, we want to show it on both displays, on the Navigation as well as on the Primary Flight Display.

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[3] in the future, one of the killer-applications of datalink will probably be ADS-B. ADS-B is a co-operative system in which each aircraft uses a very accurate navigation system (such as augmented GPS) and broadcasts, at regular and frequent intervals, information about its position and possibly its intent to the ground and other aircraft in its vicinity. Performance standards for ADS-B have been developed jointly by RTCA and EUROCAE, and are nearing completion (De Vriendt 1998).

Navigation Display

In the conceptual design, the Horizontal Navigation Display becomes the presentation in which traffic, weather, terrain and navigation information seamlessly join. Above a moving map, an aircraft's positions are visualised, and heading vectors are showing intentional flight directions. This two-dimensional 'birds view perspective', completed with alphanumeric flight level information, must provide the pilot with an unambiguous 3D mental picture of his complex environment. Further, when the pilot selects a specific aircraft on his screen, selected aircraft's 4D cleared tube will be displayed next to his own, so that he can have full awareness of a potential threat.

To enhance pilot's awareness regarding closely approaching traffic even more, aircraft within a certain range (l5nmiles and 4000ft) of his aircraft are overlaid with a presentation of their Protected Zone. Sizes of Protected Zones depend on the aircraft's velocity, performance characteristics and on-board communications, navigation and surveillance equipment. Protected Zones of different aircraft must never touch. This kind of presentation integrates a 'full-situation-awareness version of the conventional Traffic Collision Avoidance System (TCAS) into the same display. When noticing an 'overlaid' aircraft on the horizontal navigation view, the pilot automatically knows that particular aircraft is within certain limits of his own aircraft and therefore needs special attention. Until now, airborne systems such as TCAS and the Ground Proximity Warning System (GPWS) control the actual flight plan and alert the pilot only if there is any risk for an impact. These tools support a crew that already has lost Situation Awareness and is no longer on the right track or is intruded by another aircraft. By generating a problem solving solution, they just help the crew to survive, not to regain Situation Awareness. However, since the introduction of TCAS in the eighties, the system probably already has saved the lives of many, so it would be unfair to condemn it now. Better is it to consider the conventional TCAS as an interim technology towards an even better system, trying to increase safety even one step before the loss of situation awareness. Our conceptual approach of TCAS tries to keep the pilot in the loop by supporting him in continuously creating and updating his mental model with the required information in an intuitive way.

Primary Flight Display

As already mentioned above, given the importance of traffic information to the pilot, surrounding aircraft are also made visible on the 3D Primary Flight Display. Aircraft entering the V-shaped sector on the Horizontal Navigation Display, marked off by two diverging lines originating from the own aircraft symbol (ownship), are entering the zone which matches the viewing angle on the Primary Flight Display. Thereby, objects visible on the PFD can easily be associated with the ones on the ND and vice versa.

Non-hazardous traffic, shown in the horizontal navigation view only by its vector (accompanying flight ID and flight level included), and entering that area, can be seen on the Primary Flight Display as flashing white spheres. The size of these depends on the relative distance of this aircraft to the ownship. Given the 3D perspective of the PFD, aircraft entering that same area, but within a certain hazardous range of the ownship (and therefore overlaid by its Protected Zone) appear as a flashing colour-coded red sphere on the Primary Flight.

The choice of presenting a colour-coded sphere instead of a 3D aircraft symbol is not coincidental. Showing surrounding aircraft's heading in a 3D-perspective cannot be done unambiguously. The reason for this is the limitations of the human eye. Therefore, the only reason for depicting traffic information also on the PFD is to make the pilot aware of hazardous traffic while possibly being concentrated on flying the tunnel. After drawing his attention the pilot then immediately needs to check the Horizontal Navigation Display for the complete mental picture.

In addition to the described graphical warning, also a textual warning message will be displayed, offering the pilot yet another source of information. In order to avoid overloading of the human visual channel, these warnings can be emphasised by call-outs, thus being present also in the auditory channel.

Terrain Information with GPWS Integration

Controlled Flight Into Terrain (CFIT) has become the most important cause of accidents, but is happily also one of the easiest to eliminate. A great deal of past and present CFIT accidents can be attributed to pilot's insufficient awareness of surrounding terrain. Just as the TCAS system, Ground Proximity Warning System is (GPWS) only alert the crew in case of a threatening impact into the very near future. GPWS does not provide the pilot with the required 'big picture' of terrain altitude so he can anticipate much more in beforehand. This has to be changed in the new conceptual design. Pilot must be allowed to fly in an active instead of a reactive mode.

Primary Flight Display

As already described in paragraph 3.1, the cleared flight-path is positioned in a 3D synthetic world of onboard databases. The weather-independent synthetic view of the outside world not only makes it possible to filter out unimportant information from the picture, but particularly by colour-coding the terrain-altitude-profile we can offer pilots increased awareness over the safe continuation of their flight. Presenting areas and obstacles that tower over aircraft's intended flight-path-altitude by a red waning colour integrates GPWS information into the display. Simply put, the tunnel-in-the-sky tells the pilot where to go, and the colour-coded terrain informs him where not to go. Additional lines downward from aircraft's tunnel-in-the-sky on to underlying terrain give an extra indication of aircraft's relative altitude to the ground. This allows pilots to estimate the altitude-above-ground at a first glance.

By keeping the flight path vector into the dimensions of the tunnel when flying an approach, a very precise indication of the required 'glide slope' altitude is provided in a pure graphical form. In addition to these graphical hints a digital readout is integrated in the altitude scale.

Navigation Display

On the map, the same colour-coding is used as on the Primary Flight Display. In this way, pilots can compare their intended flight path in relation to terrain altitude much in beforehand. Another great help for doing so is the added vertical perspective. Here, terrain altitude information is presented in relation to a 2D vertical tunnel view. A terrain surface line crossing the tunnel undeniably would mean a flight into terrain.

Trajectory Negotiation Process

For enabling the process of trajectory negotiation in a Free Flight environment, a 'trajectory Negotiation Diagram as depicted in Figure 3 is developed at the left side of the Navigation Display. Illuminating rectangular buttons indicate system's momentary state during the negotiation process, circular buttons requires the crew to make a decision. A black-coloured background is deliberately chosen in the framework of the 'dark-cockpit-concept'. It implies that any information not useful for the pilot at a particular moment of flight may not distract his attention by being colourful.

In Free Flight, aircraft will be offered the opportunity to fly their most economic trajectory, in case that trajectory does not conflict with the flight plans of other traffic. Therefore, the 'trajectory Negotiation Process must make it possible, for both airline pilots and air traffic controllers, to start negotiating with each other for route modification. Pilots then can initiate a negotiation with ATC for requesting a preferred and (more) economical flight path. ATC will start the process with a particular aircraft in case the currently flown route would meet some constraints. For the development of the Trajectory Negotiation Diagram this required two different points of departure, one for negotiations initiated by the crew, the other one for ATC--induced negotiations. This is realised by creating two separate flows, respectively originating at a rectangular "PILOTS" and "ATC" button on top of the diagram. Both flows converge however on a point where the aircraft's 4D-Flight Management System will calculate a user-preferred trajectory, according to possible constraints imposed by ATC. To give an impression of the course of a negotiation procedure, the Pilot-Induced Negotiation Process will be looked at more in detail.

By selecting the 'CHANGE' button at the upper right side of the diagram, pilots can modify the planned route, as presented on the Navigation Display, in a graphical manner. Route modifications currently can only be executed in an alphanumerical mode on a Control and Display Unit (CDU), on which the route is presented as a list of way- points. A disadvantage of modifying a route in the alphanumerical mode is the imposed mental workload by the translation process between the route presentations on the alphanumerical CDU and on the graphical Navigation Display. As a route constitutes graphical information by its nature, and a graphical presentation of that plan is highly compatible with the mental model of the pilot, modifications of the route in a graphical manner might facilitate the task.

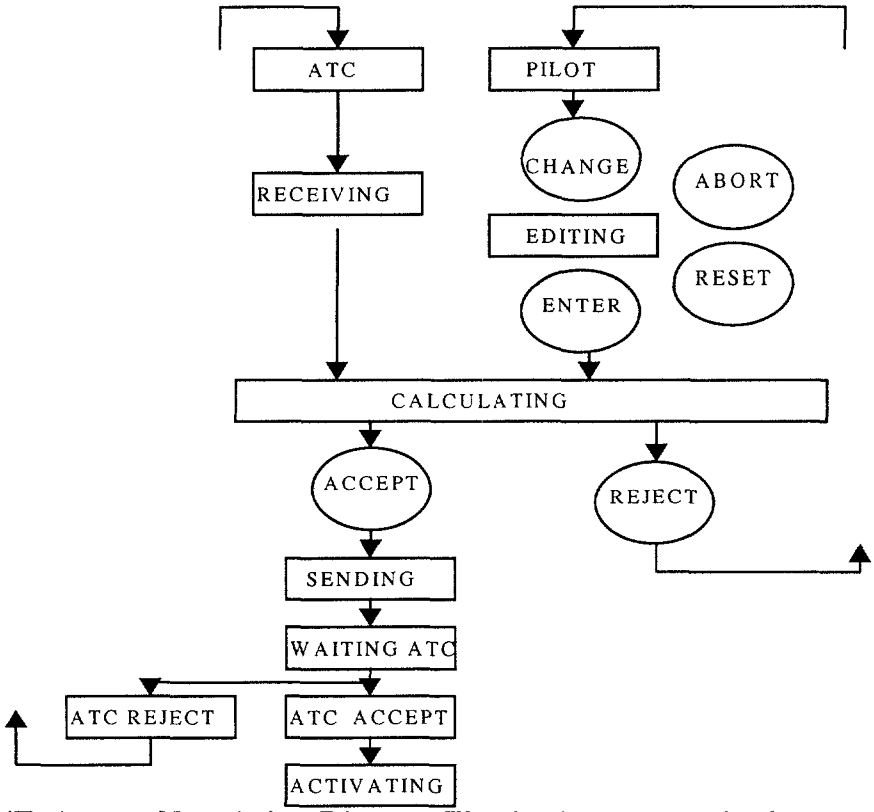

Figure 3: 'Trajectory Negotiation Diagram Illuminating rectangular buttons indicate system's momentary state during the negotiation process, circular buttons require the crew to make a decision.

For manipulation of the displayed route on the Navigation Display, a so-called 'rubber band' route editing technique can be used. The rubber band technique keeps the analogy with a rubber band, being the planned route, which is strapped around a set of nails, being the way-points. By using a cursor device, the pilot can 'pick up' the rubber band from any nail (way-point) and drag it to wherever he wants it on the screen. This technique makes possible deleting, adding and moving way-points of a route. During the entire editing process, the pilot always can reset to the original settings, or simply abort the operation. By selecting the 'ENTER' button, the pilot's preferred route modification is loaded into the aircraft's Flight Management System, which in turn will calculate an economic trajectory as close as possible to the entered proposal of the pilot. From this point on, the Negotiation Process proceeds similarly for both pilot-induced as ATC-induced negotiations.

As soon as the calculated trajectory is presented to the pilot on his Navigation Display, he can make a decision whether to accept or to reject it, by selecting one of the illuminated circular buttons on the diagram. Choosing for rejection results in the 'editing-mode' again, so the pilot can make some new modifications, or perhaps just abort the whole Negotiation Process. Accepting it means that FMS's newly calculated trajectory is down-linked to ground-based ATC for approval. ATC's computerised conflict-probe will now inspect the aircraft's proposal for possible conflict with other traffic. Only in case the ownship's Protected Zone would overlap with that of another aircraft within the not too distant future, the proposed trajectory will be rejected by ATC. Otherwise, ATC will approve. In case of rejection, a recalculation by the aircraft's FMS will happen, according to the constraints imposed by the rejected trajectory. If ATC endorses the trajectory, they will transmit a clearance tube up the datalink, around the agreed route, and consider this as the aircraft's actual flight plan. This final 'tunnel-in-the-sky' image will be presented to the pilot on his Primary Flight Display and used to feed the aircraft's guidance.

Presentation of the Conceptual Design

The elements on the newly designed Primary Flight Display are shown in Figure 4 and on the Navigation Display in Figure 5. All elements refer to specific requirements out of the previous paragraphs for an improved human-machine interface, and support aircraft's operation in a future Free Flight environment.

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Abbreviations and Symbols

ADI Attitude Director Indicator
ADS-B Automatic Dependent Surveillance Broadcast
ATC Air Traffic Control
ATD Along Track Distance
ATM Air Traffic Management
CDU Control and Display Unit
CFJT Controlled Flight Into Terrain
DH Decision Height
EATMS European Air Traffic Management System
EFIS Electronic Flight Instrument System
FAA Federal Aviation Administration
FMS Flight Management System
GPS Global Positioning System
GPWS Ground Proximity Warning System
GS Ground Speed
IMC Instrument Meteorological Conditions
MLS Microwave Landing System
HMI Human Machine Interface
ND Navigation Display
PFD Primary Flight Display
RTCA Radio Technical Commission of Aeronautics
SA Situation Awareness
TAS True Airspeed
TCAS Traffic Collision Avoidance System
UTC Co-ordinated Universal Time
α Angle of attack
γ Flight-path angle
θ Angle of pitch
X_b X axis of the aircraft body axis system or airplane axis system
X_e X axis of the moving Earth axis system or local horizon system