D5.4 Final Report

June 2012 to January 2014

This document is the final report of the project “the Endless Runway”, an FP7 L0 project for the European Commission. The project covers the period of June 2012 to January 2014. This report will provide a publishable summery of the project and will give the main achievements of the project. The template for final reports from EC has been followed. This document follows the guidelines for producing a final report for EC.

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Abbreviations

Acronym	Definition
ACARE	Advisory Council for Aeronautics Research in Europe
A-RAP	Adaptive Runway Aiming Points
ARP	Airport Reference Point
ATC	Air Traffic Control
ATM	Air Traffic Management
CBA	Cost Benefit Assessment
CdG	Charles de Gaulle (airport)
D-GPS	Differential Global Positioning Systems
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DOF	Degrees of Freedom
EC	European commission
ERAC	Endless Runway Aircraft
EREA	European Research Establishments in Aeronautics
GBAS	Ground Based Augmentation Systems
GPS	Global Positioning System
HUD	Head-Up Display
ILOT	Instytut Lotnictwa
ILS	Instrument Landing System
INM	Integrated Noise Model
INTA	Instituto Nacional de Tecnica Aeroespacial
kts	knots
L_{den}	Level Day Evening Night
MARS	Multi-Aircraft Ramp Systems
MIT	Massachusetts Institute of Technology
MLS	Microwave Landing System
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium
NM	Nautical Mile
ONERA	Office National d'Études et de Recherches Aérospatiales
S&T	Science & Technology
SESAR	Single European Sky ATM Research
TSFC	Thrust Specific Fuel Consumption
TMA	Terminal Manoeuvring Area

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1 Final publishable summary report

This chapter will provide a summary of the project as a project description and will state the main achievements that have been reached in the course of the project. This part of this document contains a public summary that includes five distinct parts (in line with the guidelines for providing a final report):

- An executive summary of the project
- A summary description of the project context and objectives
- A description of the main S&T results/foregrounds
- The potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and exploitation of results
- The address of the project public website

Furthermore, promotion material and information on the project beneficiaries is provided.

1.1 *The Endless Runway*: executive summary

The Endless Runway proposes a novel and radical design for a runway: a circular track, circumventing the airport. This runway is used for take-off in any direction and landing from any direction, thus offering the unique characteristic that the runway can be used under any wind condition through the possibility for an aircraft to operate always with headwind during take-off and landing. Moreover, it will allow aircraft to shorten their global trajectory through optimized departure and arrival routes and avoid runway crossings overruns. The airport terminals with all aircraft, passenger, baggage and freight facilities will be located mainly inside the circular runway.

The circle of the runway will need to be large enough to provide sufficient room for infrastructure and therefore, it will have a radius of 1.5 to 2.5 kilometres, allowing current-day aircraft to use the circle without significant structural modifications. The runway will be a 400 meters wide, banked track as a compromise between safety and limiting centrifugal forces.

Two operational concepts have been evaluated: one for the low wind case, where the complete circle can be used in any direction as there is no point on the circle where the maximum crosswind is exceeded and one concept for the high wind case, where the operation is limited to those points on the circle where crosswind is below the allowed limited. As the circle always has two points (across of each other), the high wind case provides similar operations to an airport with two parallel runways. The advantage of *the Endless Runway* is that the runways will always be available and can be "turned" with the wind, compared to conventional runways.

Several aircraft can operate the 10 km. runway simultaneously. A scheduling algorithm is proposed, where aircraft will be able to claim a number of segments, which they will need to perform their take-off or landing, depending on the aircraft characteristics and their directions of origin and destination. Safety buffers will be included, both in space and time, in between consecutive flights.

As *the Endless Runway* concerns a radical new layout for the airport, additional work has been performed to define an *Endless Runway* Aircraft Concept (ERAC) that is optimized for operations on such circular runway. It follows that take-off and landing tracks can be shortened with 10% compared to current day aircraft at straight runways.

The Endless Runway offers a sustainable airport that will allow operations in all directions independent of the wind. The total area of land use of the airport is smaller than that of an airport with straight runways and a similar number of movements. The project demonstrated a capacity similar to current-day major European hub airports. Costs for construction of the airport will be 10% to 70% higher; benefits will be gained from offering continuous capacity and shorter trajectories.

The project did not find any show stoppers and demonstrated feasibility of the concept, including the use of the airport for current-day aircraft.

1.2 Summary description of project context and objectives

1.2.1 Introduction

One of the scenarios of the European Research Establishments in Aeronautics (EREA) Air Transport System (ATS) 2050 study, the Unlimited Skies scenario, imagines an explosive growth of air traffic. If this happened, the lack of capacity at airports would be a major constraint to growth, as also recognized by ACARE, the Advisory Council for Aeronautics Research in Europe and in the Flightpath 2050 Study from EC. Airports already form a major bottleneck in the air transport system. If nothing is done, part of the demand may not be accommodated. The current activities in the scope of SESAR (Single European Sky ATM Research), although getting us closer to the capacity levels needed with its advanced technologies, might not be sufficient to obtain the capacity needed for an intended three-fold increase in air traffic, specifically under all weather conditions. More capacity is needed.

Extending existing airports or building new ones usually face the opposition of inhabitants and it takes many years between the first identification of the need and the completion of the construction. For instance, making a runway longer to accommodate larger aircraft, adding a tangent runway to an existing runway system in order not to close the airport in high crosswind, and extending the airport outside of its current limits, are all measures that may encounter strong opposition of local residents.

While airport capacity needs to be increased, authorities ask for optimised trajectories in order to reduce fuel consumption, emissions and possibly noise. Current aircraft routes based on standard procedures in the departure and approach phases are far from being direct: an aircraft flying from Toulouse-Blagnac to Paris-Orly, on a day of Autan wind (coming from the south east), will take off facing the wind from runway 14L or 14R almost in the opposite direction of its destination.

A number of physical constraints, such as wake vortex separation minima and cross- and tailwind limits, make it hard to improve the performance of conventional airport configurations significantly. Major reasons for these capacity limitations are the imposed direction of the runway system and the need to have aircraft operating along the same approach path to the same touchdown point. Directionality results in a dependency to the wind direction and speed. Using the same approach path results in trailing aircraft having to avoid wake vortices from leading aircraft.

In order to tackle the airport network capacity limitation and the efficiency requirement, an alternative design to current airports is proposed: a circular runway concept. The main underlying idea is to operate the runway in any direction safely whatever the wind direction, with any aircraft category, including those with long take-off and landing rolls.

1.2.2 Description of *the Endless Runway*

The Endless Runway is an innovative concept for airport operations in the long-term future, based on a radically new airport design encompassing a circular circumventing runway. In order to allow a sufficient number of operations, the runway inner radius is set to 1500 meters. The total runway length therefore is about 10 000 meters, comparable in length to three straight runways; long enough to allow multiple simultaneous operations on the runway and to build the airport infrastructure inside, while keeping the airport compact.

The runway width is set to 140 meters as a compromise between discomfort due to higher centrifugal forces for a narrower runway and the costs of a wider runway. To limit the effects of the centrifugal forces, the circular runway lateral profile is banked with increasing angles to the outside. As the aircraft accelerates for take-off, it moves from the flat inner part of the runway toward the outer banked part until it reaches the lateral position on the runway where the bank angle fits its lift-off speed. The same applies during landing the other way around.

The taxiway system consists of an outer and an inner taxiway ring between the runway and the terminals area. The outer taxiway, operated in the same direction(s) as the runway, is connected to runway access points through high-speed exit taxiways, where one aircraft can hold if needed. The inner taxiway is operated in the opposite direction to the outer one. Taxiways between the airport's buildings link the inner circular ring to the inner airfield area.

1.2.3 Operational concept

Three different operational cases can be identified for aircraft landing on the circular runway: strong wind, low wind, and changing wind directions.

a) In *strong wind conditions*, those exceeding 20 kts, the aircraft will fly in sequence towards *the Endless Runway* to allow for landing at the touchdown point where dependency from the wind is at a minimum (at exactly headwind). Taking-off from the runway is following the same procedure. Parts of the runway must be avoided for take-off or landing because of the crosswind. The operation is not different from today's operation, with the exception that an optimum touchdown point always exists whereas for a conventional runway a certain crosswind needs to be accepted.

b) In *low wind conditions*, aircraft can take-off and land in any direction. Aircraft are sequenced so that consecutive aircraft originate from different directions and do not interfere with each other and will not have needs for spacing according to wake turbulence categories. This enables the possibility to reduce take-off and landing intervals between aircraft.

c) With *changing wind*, the aircraft sequence can gradually "move" with the wind direction. No break in the sequence occurs as it is the case with conventional runway configurations. No costly operation for tactical runway changes or runway directions change in operation will be necessary.

1.2.4 Project's objectives

Objectives of the project have been to 1) define a concept for a major hub airport, comparable to one of Europe's large hub airports of today, and 2) to assess the capacity of *the Endless Runway* by simulating the concept defined.

The proposed concept has been evaluated with respect to airport infrastructure design aspects, aircraft performance aspects, and Air Traffic Management (ATM) aspects. For the infrastructure, the taxiways, aprons, terminals and all other facilities have been defined as they must be located inside the circle.

For the aircraft performance aspects, the first question has been to evaluate landing and take-off of current-day, conventional aircraft on the banked circular track and to evaluate the lateral forces on the landing gear and centrifugal forces for the passengers. Apart from operating *the Endless Runway* with conventional aircraft, a new aircraft design has been proposed, optimised for use on *the Endless Runway*.

For evaluation of the ATM aspects, a planning method has been set up and simulated in fast time simulations to evaluate the capacity that *the Endless Runway* could provide.

For the assessment of *the Endless Runway*, a comparison with July 1st, 2011, the busiest day ever, at Paris Charles de Gaulle (CdG) airport has been made. Paris CdG is a busy hub airport, which stresses the available infrastructure to a maximum, as the hub-function of the airport requires high arrival peak streams of traffic, high departure peak streams and a large number of gates necessary at particular transfer periods during the day. The motivation for taking one of the most demanding airports in Europe at its busiest day is that if the simulations demonstrate feasibility of the concept for this airport at this day, it will work for almost any other airport in Europe as well.

Apart from the three aspects mentioned above (infrastructure, aircraft and ATM), an assessment has been made with respect to costs and benefits for operating *the Endless Runway*, and an assessment of noise and the need for land area has been performed.

1.3 The main S&T results/foregrounds

The Endless Runway is an innovative concept for airport operations in the long-term future, based on a radically new airport design encompassing a circular circumventing runway. The lack of airport capacity is considered a major constraint to growth within the air transport system of the future, according to by ACARE, the Advisory Council for Aeronautics Research in Europe. The main idea of *the Endless Runway* is to operate the runway in any direction safely whatever the wind direction. Further gains of a circular runway are the optimisation of air and ground aircraft trajectories through the use of the best runway section and the compact airport footprint.

1.3.1 State of the art

The idea of a circular runway is not new: since the early days of aviation, people discuss and experiment new ways of take-off and landing, including the circular runway. Circular runways actually appeared since the very beginning of aviation. Clément Ader in France started with a first circular take-off at the end of the XIXth century. All along the XXth century, engineers submitted articles, reports and patents related to circular runway concepts. In the middle of the 1960s, flight trials with takes-offs and landings were even undertaken by U.S. army pilots on a circular car track in Arizona.

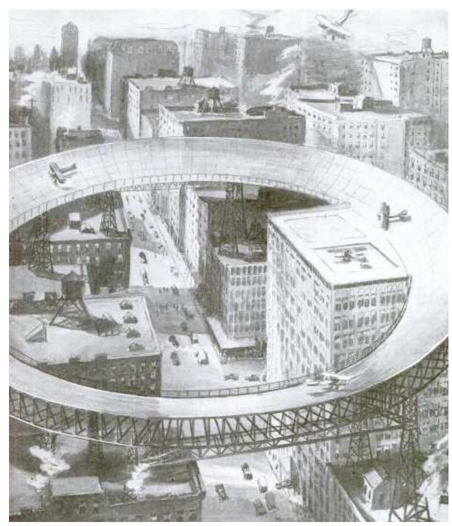

Figure 1 Circular track in Manhattan, 1919

In 1919, a circular track appears for the first time in the press, in the "Popular Science Monthly" newspaper [1]. The concern in these days was to find a way to take off and land in or near big cities such as New York with skyscrapers of different heights. An idea was found to construct a circular runway on top of the skyscrapers, without cutting off light and air from the streets below. A banked circular track, made of iron, supported by several buildings, seemed to be a solution to solve this accessibility problem.

In 1921, a first circular runway is patented by P.J. Backus [46]. He proposes a flat and small circular track way, which was adapted to light aircraft of that time.

In 1957, a refined design of the circular runway was proposed by Sir H. Tempest [1]. The problem at hand was the future evolution of jet aircraft whose speed was expected to increase more and more, causing straight runways to be longer and longer. Subsequent problem was the size of major airports. Their growth was limited by the land available, the cost of the land, and the necessary expenses for building and maintaining them. Such constraints lead to the circular runway concept (see Figure 2): with a 914 meters diameter, the runway would measure 2,870 meters and the surface of such an airport would be of about 0.66 km^2 (to be compared with the 12 km^2 from London Airport at the time). Thanks to the "endless" runway, the run on the runway could be extended, longer than its actual length, accommodating aircraft take-off and landing runs as long as needed to reach take-off speed or full stop.

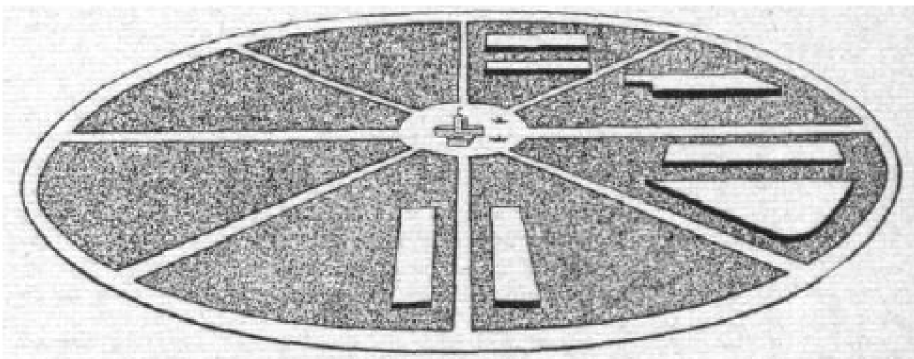

Figure 2 Perspective view of the circular runway airport, 1957

In 1964 and 1965, tests were undertaken at the General Motors Desert Proving Grounds track near Mesa, Arizona, on a circular banked track [3]. The track used had a circumference of 8047 meters, that is to say a 1281 meters radius, was 13.7 meters wide and was banked from nearly 0° on the inside to 22° on the outside. This corresponds to equilibrium speeds varying from 0 kts to about 140 kts, see Figure 3.

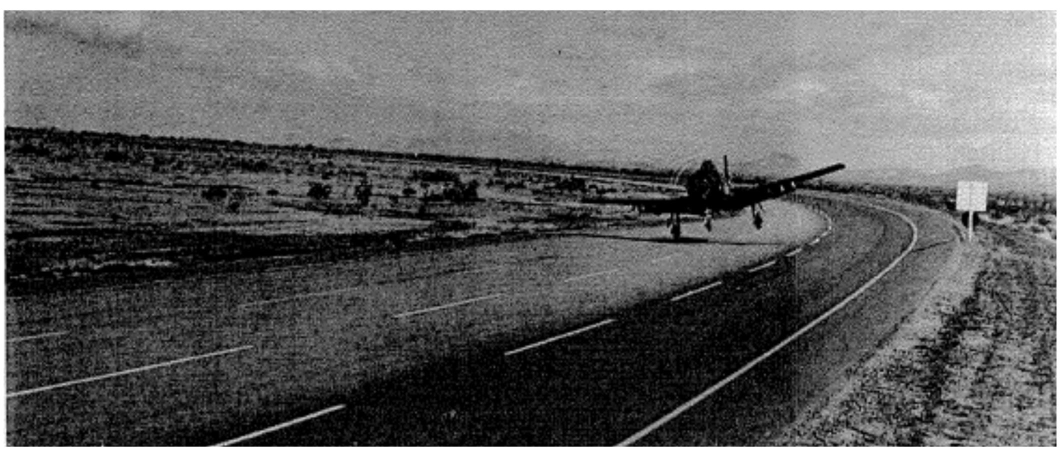

Figure 3 Flight trial on General Motors track, Arizona

Pilots reported that at first it was difficult to land with the correct roll angle and on the speed circle corresponding to the landing speed. However, pilots reported that the runway tended to correct their errors regarding landing speed, point of touchdown, and degree of bank. Aids such as a marking on the runway helped them for positioning. After a few trials, pilots mastered the knack and they reported an exceptional lateral stability, the aircraft would easily find its natural line corresponding to its speed on the runway. The stability was such that cross winds were no more a factor, removing the constraint to take off and land with headwind.

The experiments have not yet lead to the development of circular runways for operational use. One of the reasons why the circular runway remained at experimental level was probably the cost of such a runway and the need for new procedures and techniques. Construction costs would be higher than for capacity-equivalent conventional runways because of the requirement for precise banking of the runway and for larger runway width (98 meters instead of maximum 60 meters) and length (10,000 meters versus maximum 4,000 meters). Another reason was that the design studies of these concepts study did not involve devising new landing techniques and procedures, which are necessary for implementation in the air traffic environment.

Circular airports are coming back to designers' mind conceiving for the airport of the future. During the "Fentress Global Challenge: Airport of the Future" launched in the Spring 2011 and awarded early 2012, two students (one from Stanford university and the other one, Thor Yi Chun, from Malaysia's University of Science) proposed both a circular runway concept [4].

1.3.2 The concept of operation and design of *the Endless Runway*

Three different operational cases can be identified for aircraft landing on and taking-off from the circular runway: strong wind, low wind, and changing wind directions.

a) In *strong wind conditions*, those exceeding 20 kts, the aircraft will fly in sequence towards *the Endless Runway* to allow for landing at the touchdown point where dependency from the wind is at a minimum (at exactly headwind). Taking-off from the runway is following the same procedure. Parts of the runway must be avoided for take-off or landing because of the crosswind, see Figure 4. The operation is not different from today's operation, with the exception that an optimum touchdown point always exists whereas for a conventional runway a certain crosswind needs to be accepted.

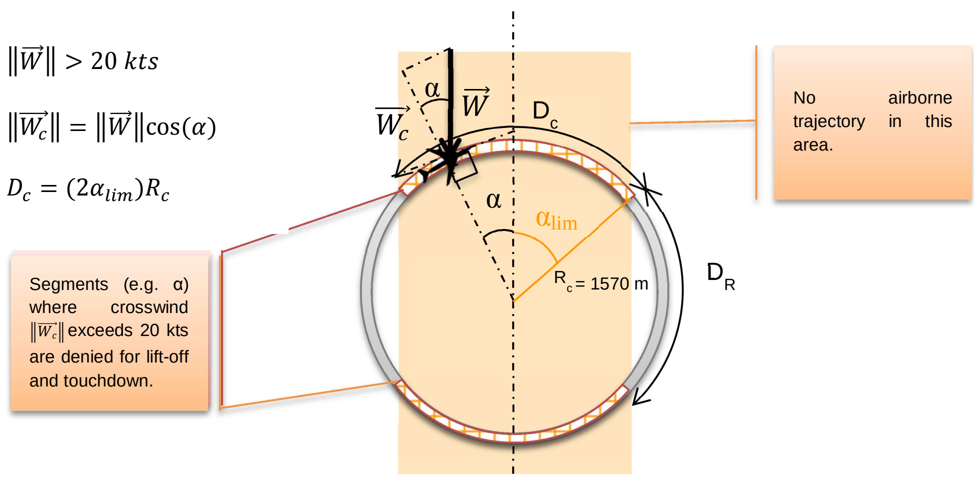

Figure 4 Closed areas at the runway with excessing crosswind

The part of the runway not allowed for lift-off and touchdown becomes shorter with increasing wind.

b) In *low wind conditions*, aircraft can take-off and land in any direction. Aircraft are sequenced so that consecutive aircraft originate from different directions and do not interfere with each other and will not have needs for spacing according to wake turbulence categories. This enables the possibility to reduce take-off and landing intervals between aircraft, see Figure 5.

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Figure 5 Flexible sequencing of aircraft

c) With *changing wind*, the aircraft sequence can gradually "move" with the wind direction. No break in the sequence occurs as it is the case with conventional runway configurations. No costly operation for tactical runway changes or runway directions change in operation will be necessary.

Objective of the project is to define a concept for a major hub airport, comparable to one of Europe's large hub airports of today. For evaluating the aspects of *the Endless Runway*, a comparison will be made to the Paris Charles de Gaulle (CdG) airport.

In order to allow a sufficient number of operations, the runway inner radius is set to 1500 meters. The total runway length therefore is about 10 000 meters, comparable in length to three straight runways; long enough to allow multiple simultaneous operations on the runway and to build the airport infrastructure inside, while keeping the airport compact.

The runway width is set to 140 meters as a compromise between discomfort due to higher centrifugal forces for a narrower runway and the costs of a wider runway. To limit the effects of the centrifugal forces, the circular runway lateral profile is banked with increasing angles to the outside. As the aircraft accelerates for take-off, it moves from the flat inner part of the runway toward the outer banked part until it reaches the lateral position on the runway where the bank angle fits its lift-off speed. The same applies during landing the other way around.

1.3.3 Evaluation of the basic principles

Although the longitudinal stretch of the banked runway will be flat with respect to the aircraft, it must be assumed that during take-off and landing, the aircraft may position itself a bit off its optimal take-off and landing point. At those moments, clearance of the tip-back angle of the aircraft must be ensured. The wingtip height will be limited on a curved runway track as indicated in Figure 6.

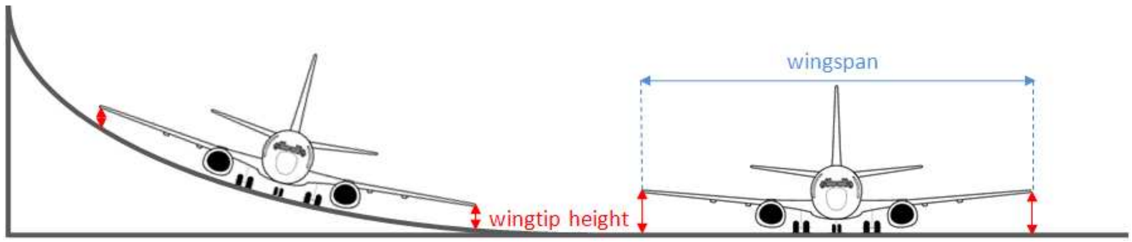


Figure 6 Wingtip clearance

To evaluate operations on *the Endless Runway*, the most constraining aircraft that is currently in operation has been selected for trial: the Boeing 747, where the outer engine will have the smallest clearance with the ground. The evaluation will be performed with a 6 Degrees of Freedom (DOF) simulation tool. There are several 6DOF simulators available (commercial and free) and all aeronautical research centers developed their own proprietary systems over the years. Flight Gear was selected for use in the project.

The objective of the simulations is to take an existing passenger aircraft and to operate it on an *Endless Runway* airport to both assess its behavior and define the attainable level of performance. The outcome of these evaluations is a direct comparison of the aircraft behavior on the tracks, the determination of the level of take-off and landing performances and the identification of the most promising runway cross section. The approach that has been used is illustrated in Figure 7.

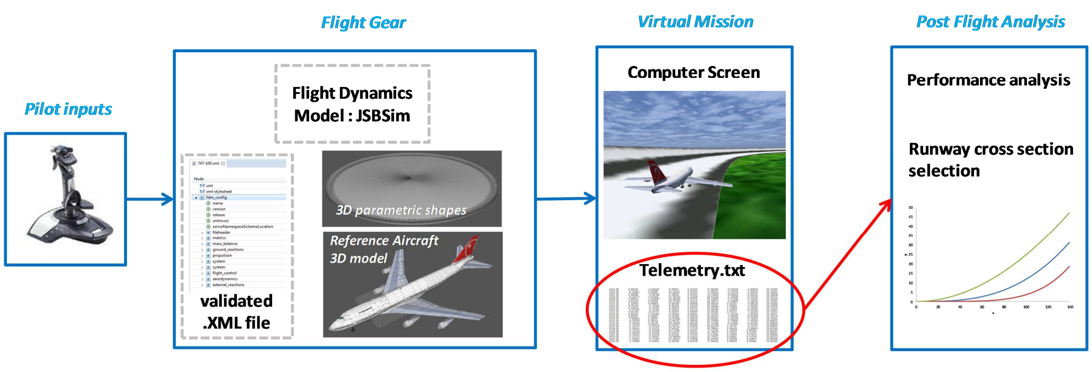


Figure 7 Approach used for the aircraft performance evaluation

Three different runway cross-sections have been compared, classified according to the speed variation they provide along the circle radius (x):

- Linear speed distribution: $V = K.x$
- Square speed distribution: $V = K.x^2$
- Root square speed distribution: $V = K.\sqrt{x}$

The first parametric study consists in fixing the reference runway width to 140 meters and applying the different formulas to calculate the corresponding cross section. The B747-100 rotation speed was fixed to 160 kts. Figure 8 shows runway cross section shapes based on the different speed distribution, whereas Figure 9 gives the corresponding speed distributions.

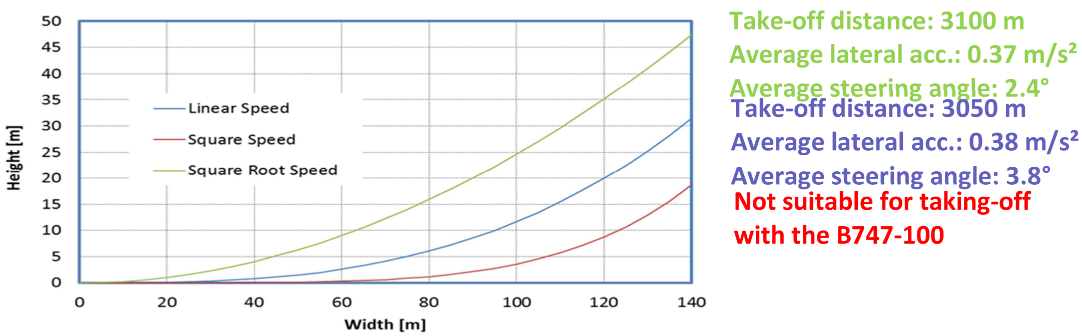


Figure 8 Runway profiles associated to different speed distributions

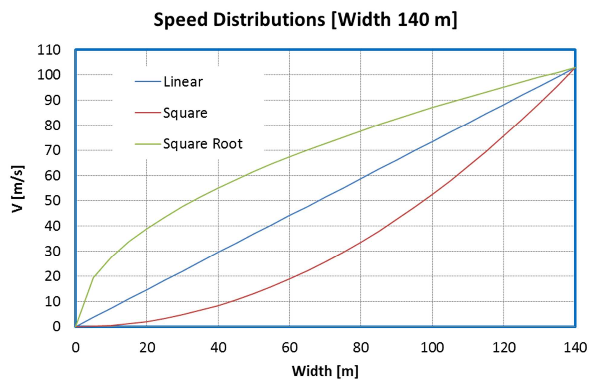


Figure 9 Speed distributions

To compare the two possible speed distributions, the assessment has been made based on the maximum runway height and runway volume and the three main performance criteria as given in Table 1.

Table 1 Comparison of the runway cross section parameters

		Conventional runway	Linear speed distribution	Square root speed distribution
Take-off distance	[m]	2860	3100	3050
Average absolute lateral acceleration	[m/s²]	-	0.37	0.38
Average steering angle	[deg]	-	2.4	3.8
Runway maximum height	[m]	0	31	47
Runway volume	[m^3]	-	11 274 459	22 652 185

Even if the square root speed distribution performs better than the other distributions, the difference is negligible while differences regarding the size of the runway (and thus cost) are not. For these reasons, the runway cross section following a linear speed distribution is selected as the most promising solution.

Since the width does not have a strong impact on the take-off distance, the value of 140 meters is acceptable to limit the overall size of *the Endless Runway*. A smaller width is not recommended because of the resulting higher lateral acceleration. During take-off and landing operations performed with the B747-100 model in Flight Gear, the landing gear struts always operated within the defined ranges.

From the simulations and the subsequent data analysis, the B747-100 take-off distance on a circular runway is increased of about 10% with respect to its reference value (in a curved abscissa). The B747-100 landing distance on a circular runway is increased of about 13% with respect to its reference value (in a curved abscissa).

When the aircraft moves on the circular runway, in the lateral plane, the forces applied are the weight $\vec{W}$, the reaction of the track on each wheel of the landing gear, summed up as $\vec{N}$, and the friction $\vec{F}$. A comparison with trains, shows that they are designed so that passengers do not sustain a lateral acceleration higher than 1,2 m/s^2, which corresponds to 0,23 g. An appropriate aircraft acceleration and deceleration during the ground roll could help optimizing passenger comfort.

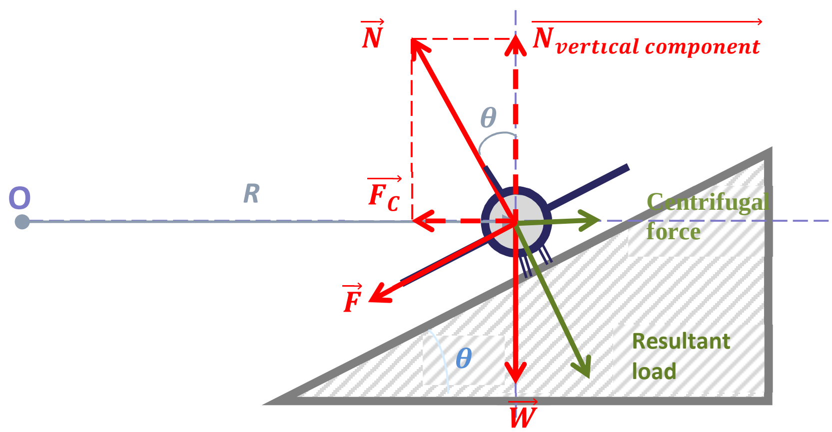


Figure 10 Forces operating on the aircraft on ground on a circular banked track with friction depicted

Regarding the passenger comfort, the simulations show that the average value of the acceleration is 0.66 m/s², below the accepted limits.

With the circular runway models integrated in Flight Gear, it is then possible to perform take-off simulations with the validated B747-100 model. Figure 11 illustrates the take-off simulation.

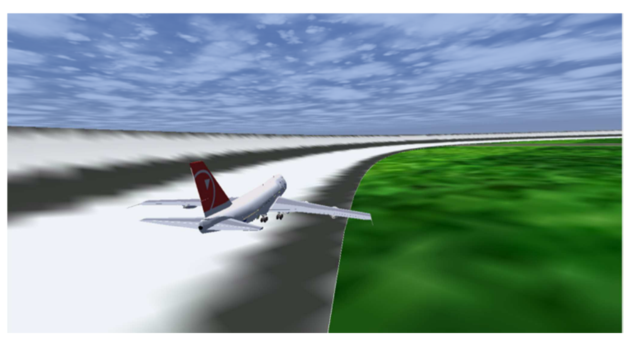


Figure 11 Take-off simulation with the B747-100 on a circular runway

1.3.4 Airport design

The basis airport design principles are presented in Figure 12. The taxiway system consists of an outer and an inner taxiway ring between the runway and the terminals area. The outer taxiway, operated in the same direction(s) as the runway, is connected to runway access points through high-speed exit taxiways, where one aircraft can hold if needed. The inner taxiway is operated in the opposite direction to the outer one. Taxiways between the airport's buildings link the inner circular ring to the inner airfield area. Finally, a dual taxiway system is available on the inner part of the terminals. This taxiway design aims at avoiding bottlenecks and at providing a short routing between the aircraft stands and the runway entry or exit point.

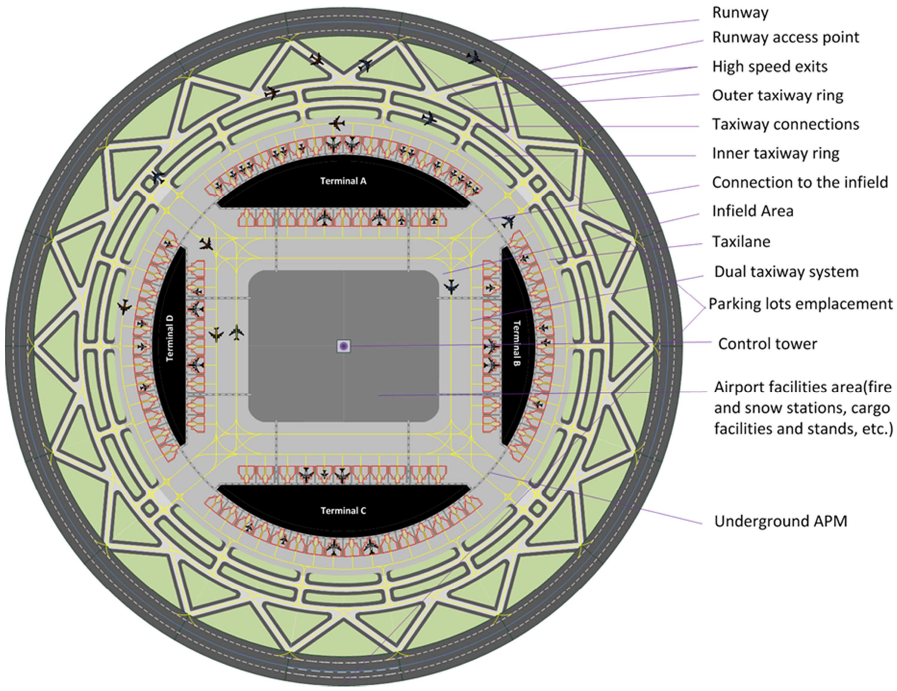


Figure 12 Basic airport design

One to four terminals with connected generic gates called Multi-Aircraft Ramp Systems (MARS) can be built depending on the airport category (hub or seasonal), with additional remote stands in the latter case. The choice for midfield buildings is justified as to occupy less space, on the order of 30 or 40 metres, as compared to the 100 to 150 meter depth for standard airport terminals, leaving more space available inside the circle for further expansions. There will be one main (larger) terminal building which will contain baggage claim areas, ticketing, airline offices and security processing facilities. If the airport facilities need to be expanded, a linear configuration can be easily extended with the addition of piers. The number of stands depends on the aircraft categories operating the airport: 99 positions are available for wide-body aircraft or 198 for narrow-body aircraft, or a certain number in between if both are mixed. Additional remote stands should be added in the central area to accommodate all wide-body aircraft in peak hours.

Taking into account 10 000 passengers per peak hour and 20 m^2/passengers hour, the necessary terminal area size will be around 200 000 m^2. The actual available space in the four terminals accounts to slightly over one million square meters.

Furthermore, all essential facilities, such as fire stations, control tower and hangars can be included inside the circle. Non-related aeronautical facilities are located on the outside, occupying an estimated surface of 2,360,000 m^2. The total area available for *the Endless Runway* hub airport is approximately 11,545,000 m^2.

Access from the outside to the inside facilities is provided to employees and suppliers through tunnels passing under the runway, and to passengers through an APM (Automated People Mover) connecting the main terminal to the intermodal station located outside and to the parking lots that may be constructed under the runway (see Figure 13).

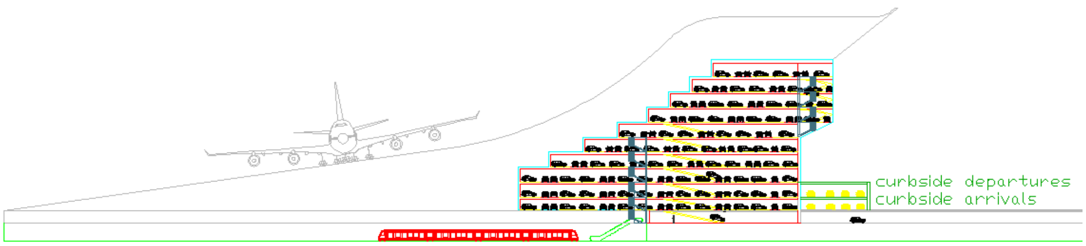


Figure 13 Parking area under the runway

Arriving aircraft will access the two concentric taxiways using high-speed exits under a 45º angle with the runway, as can be seen in Figure 12. These curves allow mitigating passenger discomfort when the aircraft enters a high-speed exit and a smooth steering of the aircraft. The selected taxiway configuration is advantageous from an operational perspective. If the aircraft uses the optimum high-speed exit, the linear distance from the outer taxiway ring to the terminal façade is only 347.5 m. Therefore it can be concluded that taxiing time can be significantly reduced if gates are adequately assigned. The apron length has also been reduced using the MARS system, which substantially increases gate flexibility.

1.3.5 ATM procedures

From the Air Traffic Management (ATM) perspective, the circular runway will be split in segments: an aircraft will use a set of contiguous runway segments for take-off and landing, and several aircraft will be authorized to use distinct runway strips simultaneously. With a high number of segments, flexibility will be increased as the required runway strip can be optimized based on the required landing and take-off distances; with a low number of segments, unnecessary parts of the runway might be blocked. On the other hand a high number of segments lead to more infrastructural, coordination and calculation needs.

Eighteen segments were chosen as a good compromise: low enough to minimize the taxiway construction and maintenance costs, movement area design and traffic complexity, and high enough to optimize throughput, runway occupancy time and route efficiency.

Of course, a higher number of segments leads to even smaller delays. On Charles de Gaulle, 18 segments give 38 seconds of average aircraft delay, 36 segments 18 seconds. As *the Endless Runway* airport application is a hub airport aiming to have a capacity similar to Paris Charles de Gaulle (115 movements per hour as declared capacity in 2011), 18 segments seems a fair value in terms of delays.

Figure 14 shows the defined segments from 00 to 17, numbered in a clockwise direction. The Airport Reference Point (ARP) is chosen to be the centre of the circle. The 00 segment is centred on the "clock point" and represents headings from 350 to 010 degrees. The length of the segment on the inner side of the runway (1,500 m radius) is 524 m (marked in red). With a 140 m wide runway the length of the outer side of a segment is 572 m (marked in green). The positioning of entry and exit taxiways at each segment start and end correlates very well with the recommendations given by runway design manuals.

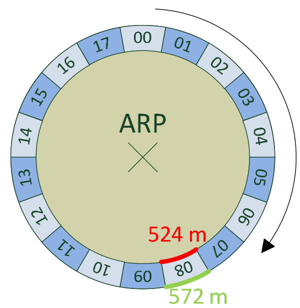


Figure 14 Runway segments

For each of the 18 runway segments, arrival and departure routes have been defined. Departure routes start at the end of the respective runway segment climbing straight out to a height of 5000 feet with an angle of 5°. Arrival routes end at the beginning of a runway segment with a straight path coming from a height of 3000 feet and a glide path angle of 3°. The starting point of the arrival routes and the end point of the departure routes are indicated by TMA (Terminal Manoeuvring Area) entry and exit points.

A booking system for allocating flights to runway segments has been defined following a time based approach. With the scheduled flight plans for the day of operation, a conflict free runway allocation for all expected flights will be set up and taken as a basis. Knowing the take-off and landing distances, including additional length needed because of the banked nature of the runway (as indicated before), a runway management system computes the number and ideal position of the runway adjacent segments needed for the operation, including buffers for safety. In the high wind case, the buffer will not be used; instead some runway segments will be closed. The concept for the use of the circular runway as a number of segments is as follows:

- A number of segments linked together form a temporary runway strip.
- Each flight can claim a number of segments for a certain time for departure or arrival. The number of segments is related to the required take-off or landing distance.
- A safety distance of one or two segments between claimed segments is added by ATC.
- Each segment is reserved to one flight at a specific time. It can be freed after a short safety period for the next movement. This concept has to be defined in terms of safety and operational feasibility.

Next, the system takes as an input a list of desired runway segments and associated timeframe for all the flights operating on *the Endless Runway*. To avoid overlap in assignment of segments, the following sequential strategy is defined.

- The first aircraft of the day gets the desired runway segments at the desired timeframe.
- For following aircraft, if the requested runway segments are available, the runway segments will be allocated to the flight.
- In the low wind case, for following aircraft, if the required adjoining segments are not available within the preferred timeframe, the runway management system looks for the closest available ones. If none is available, it will delay the flight to a later slot.
- In the high wind case, for following aircraft, if the runway is not available during the timeframe, the aircraft will be delayed to the end of the previous aircraft timeslot.

For each agreed flight allocation to runway segments, a contract between the airport and the aircraft will be put in place.

A graphical view of the runway segments reservation over time can be set up. In Figure 15, the time in the middle of the Endless Runway radar view is the start time. The blue boxes represent departure flights, the orange ones the arrivals, with a green line as the boundary of the first booked segment and a red line as the end of the last booked segment.

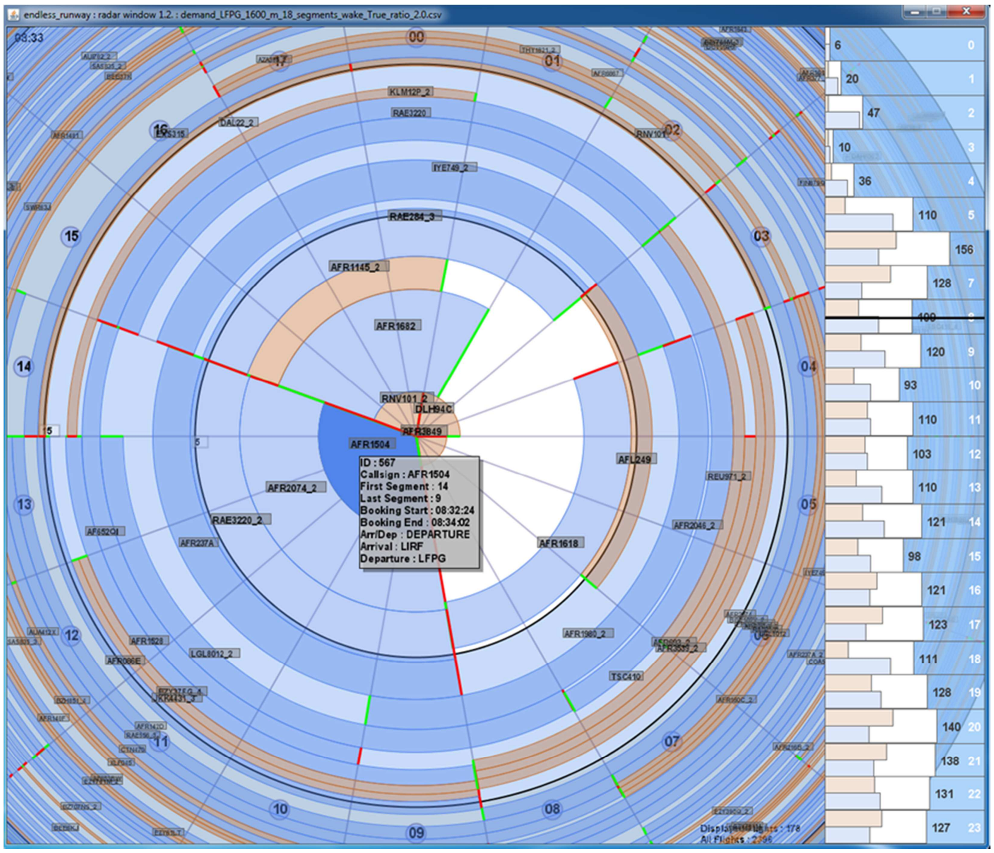


Figure 15 Runway segments booked in a time representation

Procedures for TMA operations, ground operations and special procedures for missed approaches have been defined.

The TMA will cover a circular area around the centre of the airport with a radius of about 10NM. Like in current traffic, arrivals will descent with an angle of 3°, while departures use an average climb angle of 5°; the ceiling of the TMA thus will be 5000 ft.

The easiest way to construct routes within the TMA is to use straight flight-paths for arrival and departure routes tangential to the segments they are connected to. Figure 16 shows the 18 segments (00-17) of the runway, the routes and the start/end points at the borders of the segments. As the aircraft are taking-off and landing in a bank angle, they will operate a curve at the moment of lift-off and touch down, leading to routes that are slightly offset of the direction of the segments.

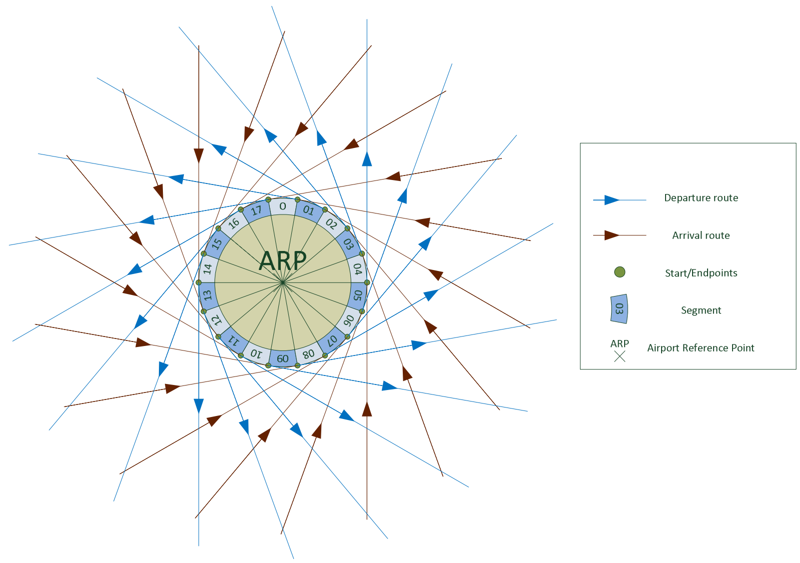


Figure 16 Arrival / departure route design (counter clockwise operation)

The high wind case, where the circle is divided into two parts, has a slightly different TMA concept, see Figure 17. The two parts of the runway can be considered as two parallel runways. Today, parallel runways are considered independent from the wake vortices perspective if their runway centrelines are separated from more than 760 meters. Taking into account that wake vortices appear only in the airborne part of the aircraft trajectory, to have the most efficient use of *the Endless Runway* in the high wind case, the new configuration should make certain that the aircraft departure and final approach trajectories from both parts are never closer than 760 meters, this to ensure that aircraft operations from both sides are independent.

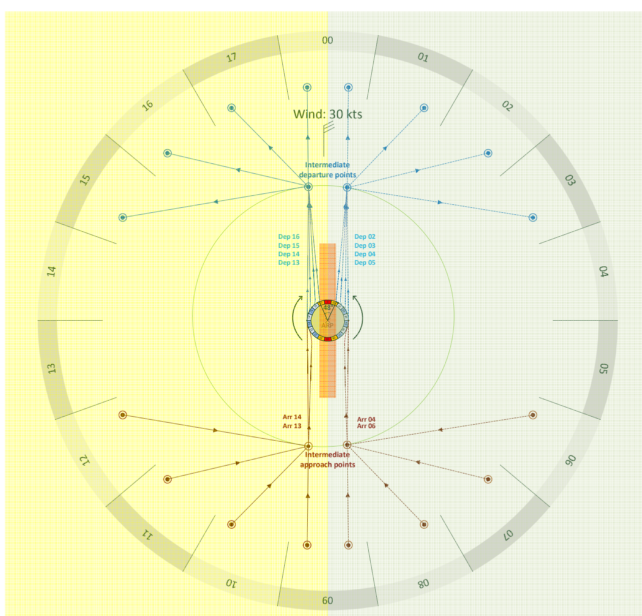


Figure 17 Arrival and departure routes in strong wind conditions (> 20 kts)

After landing, the aircraft will leave the runway as quickly as possible. The taxiway system consists of two parallel rings that are used to coordinate the traffic to and from the runway. While the outer ring is operated in the same direction as the runway, the inner taxiway ring is operated in the opposite direction. The connection to the apron is provided by a number of taxiways, whereas four main entries to the inner part of the apron are available. All elements of the airport layout, like taxiways and stands have been considered and the ground movement concept set up. Special attention has been given to modelling of the turnaround. The turnaround (rotation) of an aircraft has a significant effect on the capacity of the ground structure as stands may be blocked for longer times.

The missed approach procedure is defined as follows. The pilot continues the flight in the cone shaped TMA until reaching a height of a 1000 ft. Then the aircraft will make an outward turn and continue within the cone to a height of 1000 ft. and then will take an outward radial and climb to a height of 4000 ft. Figure 18 provides an idea of this procedure.

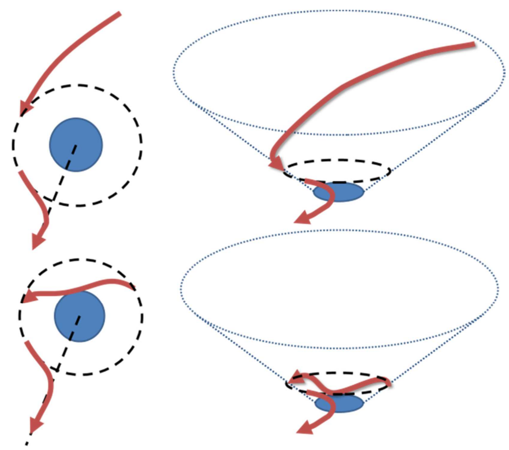


Figure 18 Representation of the missed approach procedure

With a fully flexible and dynamic definition of the threshold (touchdown point), a marking or light installation will need to be significantly different from current navigation aids. Splitting the runway circle in a discrete number of segments provides threshold markers and gives visual guidance to the pilot.

Conventional navigation aids as ILS are not suitable anymore as they cannot support curved approaches, but other ground based or space based navigation systems, like Microwave Landing Systems (MLS) and Differential Global Positioning Systems (D-GPS) can provide a high number of different approach paths. The highest flexibility is given by a satellite based system.

ATM procedures will require a high level of automation. Air traffic controllers will need assistance for calculating the optimum take-off and touchdown point for each aircraft, taking other traffic and meteorological conditions into account. Augmented reality combines real and virtual elements to provide high situational awareness. As a basic form of this technology are already available head-up displays (HUD) and can be used for additional on-board guidance to present approach information to the pilot.

Finally, simultaneous aircraft movements for arrivals and departures, both in clockwise and counter-clockwise directions may be possible, where more than one aircraft can occupy the runway at the same time. This further optimisation of the use of *the Endless Runway* has not been evaluated in the project.

1.3.6 Simulations

The concept of *the Endless Runway* has been evaluated by use of simulations. In a first step it had to be checked, whether available simulations can be used and adapted to *the Endless Runway* idea. It turned out, that some tools can be used and some have to be developed for the project. Three different areas have been identified to be evaluated, the runway itself, the surrounding TMA and the ground movement area. For the runway a special tool was set up, the TMA was simulated with the DLR in-house solution TrafficSim and the ground area was implemented in Simmod *Pro!*.

The base for the simulations is a real traffic data file for flights to and from Paris Charles de Gaulle on 1st of July 2011, the busiest day of the year. By using the developed runway scheduler tool these data were processed to a get an optimised and conflict free flight plan file for *the Endless Runway* airport. This flight plan was then taken by the other simulation tools as an input. This approach leads to an optimized runway schedule but has the effect that TMA and ground might not operate at the optimum. Figure 19 gives an overview of the simulation setup.

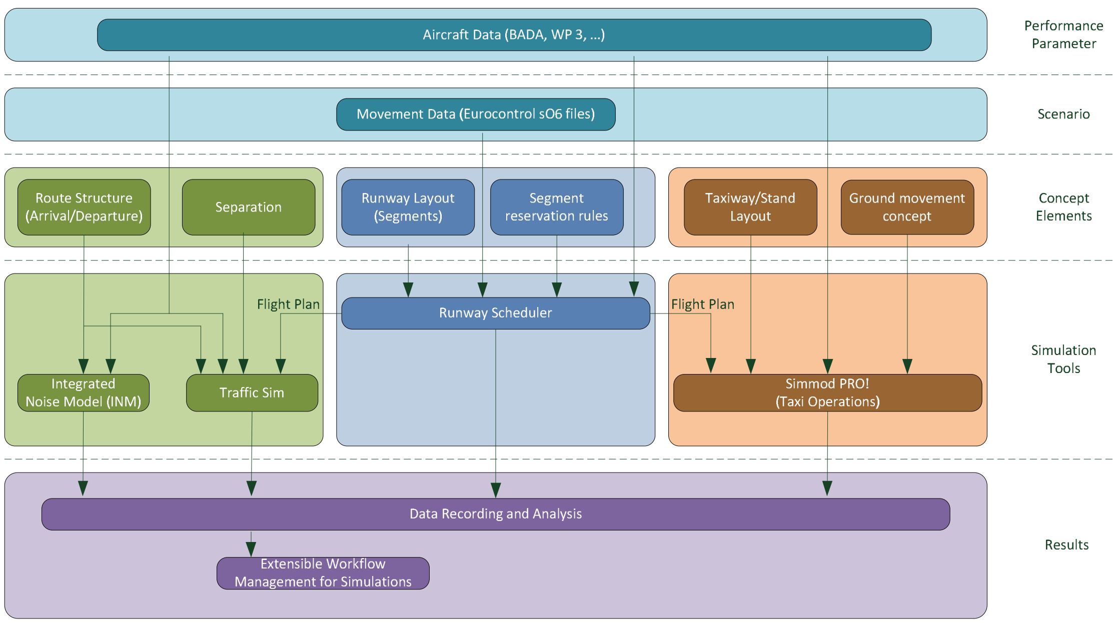


Figure 19 ATM simulation set up

To evaluate the capacity of *the Endless Runway* different scenarios with different traffic demands have been setup. By adding virtual flights to the original flight schedule from Charles de Gaulle, traffic scenarios of up to twice the demand of July 1st, 2011, have been generated.

As described in the ATM procedure set up, the requested segments and timeslots will be known for all aircraft in the simulation. Timeslots will be extended if wake turbulence separation applies, e.g. when an aircraft of a lighter category takes-offs or lands behind an aircraft of a heavier category, the segments will booked for a longer period. ICAO wake turbulence separation minima are used for this. As the algorithm focusses on runway scheduling, conflicts may appear in the TMA and the following actions are taken to resolve those:

- Each conflict is represented by two aircraft, the duration of the conflict and the position of the conflict. Parameters that describe the conflict include altitude and the track of both flights.
- Conflicts will be resolved through adding vertical separation, hence applying a steeper climb or descent angle. A maximum angle is applied.

- Conflicts that occur shortly after departure cannot be resolved through a higher climb rate and a method was used to solve the conflicts by deleting one of the conflict partners. As some flights are involved in more than one conflict, an algorithm deletes that one of a conflicting pair that has more following conflicts than the other one.

For the final scenario, the traffic was simulated conflict-free with a separation of 1.5 NM lateral or 500 ft vertical.

1.3.7 Analysis

The output of the runway scheduler is a flight plan, with a detailed description of the every single flight. With increasing demand, the runway system is not able to handle the traffic anymore without delaying some of the flights. This delay is recorded and can be used as a parameter to determine the runway capacity. Different traffic scenarios were used in the simulation leading to the results as depicted in Table 2.

Table 2 Average and maximum delay for different density scenarios

Traffic ratio	Number of flights	Max fligts per hour	Average delay with wake rule (h:min:s)	Max delay with wake rule (h:min:s)
100.0%	1570	110	00:00:21	00:04:16
110.0%	1727	121	00:00:33	00:07:18
120.0%	1887	127	00:01:16	00:09:23
130.0%	2042	131	00:03:41	00:20:11
140.0%	2198	146	00:12:53	00:41:58
150.0%	2365	150	00:27:31	01:04:09
200.0%	3140	179	02:37:43	05:11:33

From this table, it can be concluded that a 100% scenario compared to the traffic at Paris CdG can be operated at *the Endless Runway* without problems, hence a capacity of 110 movements per hour can be regarded a realistic figure. Paris CdG gives a declared capacity of 115 movements per hour in their current four-runway configuration (N.B. size of *the Endless Runway* is comparable to three runways). Up to 140%, with movement rate of 146 movements per hour, can be realised with an average delay below 15 minutes. This quarter of an hour is usually regarded the limit for indicating delay in traffic – any delay below 15 minutes can be absorbed through slack in the flight schedule.

The TMA simulation was run with three traffic scenarios. The 1.0 traffic demand, the 1.5 fold increase and the doubled traffic scenario. The separation criteria have been set to 1.5NM lateral and 500ft vertical. Because of the complex crossing route structure in the TMA a number of conflicts between flights occur. A straight forward method was used, to eliminate the conflicts by deleting the flights of a conflicting pair. This leads to conflict free scenarios in TMA but reduces the number of movements that can be handled. The maximum number of movements per hour in the TMA was handled with the 2.0 traffic demand as an input reduced by the conflicting flights. A number of around 110 movements could be achieved also in the TMA under best circumstances. This is comparable to the runway limit.

The ground simulation has only been run with the traffic scenario 1.0 which is the original traffic file from Paris CdG. As a first result the number of stands appeared to be a problem as the ground simulation shows blockings and deadlocks for moving aircraft. Long aircraft turnaround times block the stands and limit the number of available stands for new arrivals. One solution could be to include additional stands in the centre of the airport and move some facilities to the outside. To actually obtain results from the ground simulation, the traffic scenario was modified and all heavy aircraft replaced with medium types so that the simulation ran successfully. As a result, taxi in and taxi out times could be analysed, where it shows that all values are comparable to today's operations or even better, especially for the hub operations.

All simulations together have given a first indication that the concept as proposed for *the Endless Runway* is feasible and capacity compared to today's high traffic operation can be achieved. A few assumptions in terms of separation had to be made, to allow the multiple use of the runway. The chosen traffic demand of Paris Charles de Gaulle with a number of 1570 movements per day and a maximum of 110 movements per hour seems to be close to the limits of *the Endless Runway*. A higher number of movements tend to not acceptable delays for flights and a high number of conflicts in the TMA. Further study to optimise runway use and to integrate planning of the ground movements and TMA movements into one planning system will need to be performed. A consistent simulation environment with optimisation taking into account runway, TMA and ground, could lead to harmonized traffic picture and better results.

1.3.8 Aircraft optimised for use of *the Endless Runway*

Since *the Endless Runway* concept offers a real discontinuity with today's airport layout, the project also defines an innovative aircraft that would be tailored to the circular runway and its specific procedures. For this "*Endless Runway* Aircraft Concept" (ERAC), the 2050 concept of operation is assumed where the resulting vehicle configuration is the result of both a concept exploration and an analysis of the specific constraints. Subsequently, ERAC is sized according to the classical approach used in conceptual design. The last step in defining a tailored aircraft consists of performing simulations within the same environment as has been done for the B747, to assess the ERAC from a performance point of view.

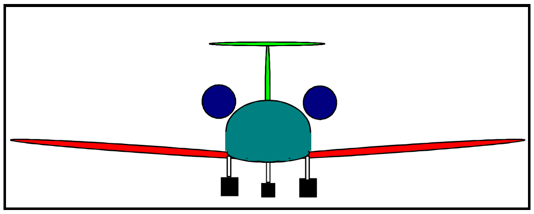
From a mission point of view, based on the expected 2050 mission characteristics, the ERAC is capable to transport 450 passengers at Mach 0.8 over a distance of 8000 Nm.

The major constraints of operating the B747 on *the Endless Runway* concerned the limited engine clearance (mostly the outer engines) of the under-the-wing engines. The concept exploration therefore has to consider a limited wing span, and, where possible, different wing and engine positions related to the fuselage of the aircraft.

In addition, the ATM simulations have shown that the ground handling of the aircraft is one of the critical concerns, because of the limited number of gates inside the circle, and ERAC must therefore provide possibilities for fast aircraft turn around. Finally, because of the complex manoeuver at low speed, just after take-off and just before landing, ERAC has to be designed for better control in this flight regime. After down selecting different options, the most promising concept for ERAC is the one indicated in Figure 20, where its main features are summarised as follows:

- A double bubble fuselage (as the D8 series proposed by MIT), enabling a larger landing gear track and providing a certain lift.
- A T-tail empennage.
- Engines providing a thrust-to-weight ratio of 0.32 located in the rear part of the fuselage decreasing thus the risk of contact with the runway.
- Larger control surfaces to increase its maneuverability during low-speed phases.

7	Configuration		Classic
	Fuselage		Double Bubble Section
	Engine	number	2
		location	Tail
	Wing		Low
	Tail		T
	Landing Gear		Multi-Bogey



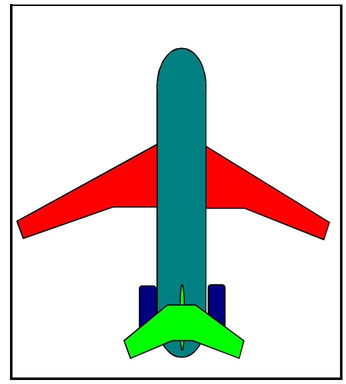


Figure 20 Most promising concept for ERAC

ERAC is based on the innovative fuselage called Double Bubble proposed in [5]. Two fuselages are connected to each other to from one (more or less) oval shape which become the outer hull of the airplane. The structural cross section of the fuselage is thus composed of two bubbles. The conservative sizing resulted in a large aircraft of about 266.4 tons of which higher ground clearance reduce in an important manner the risk of ground contact during take-offs and landings with respect to a B747.

The complexity of such structure cannot be captured by existing flight performance models, however, the earlier study give some indications on parameters to set for simulations. To take into account the evolutions to be made on this engine in the next decades, designers decided to keep the geometry, mass and thrust level constant and to reduce the Thrust Specific Fuel Consumption (TSFC) by 15%. The sizing process considers then an engine with the following characteristics:

- Maximum thrust at sea level : 416.5 kN.
- Maximum diameter : 3.4 m.
- Total length : 7.3 m.
- Weight : 7550 Kg.
- TSFC : 0.458 lb/h/lbf.

In the final iterations of the design process, the aerodynamics properties have been determined and a 3D model has been drawn, so that simulations could be performed. The acquired additional information allows a refinement of the concept that has been used in simulations. Figure 21 and Figure 22 illustrate the final sketch of the ERAC.

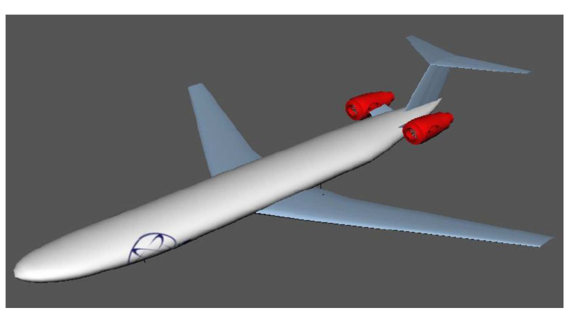


Figure 21 ERAC 3D model for Flight Gear (.ac format)

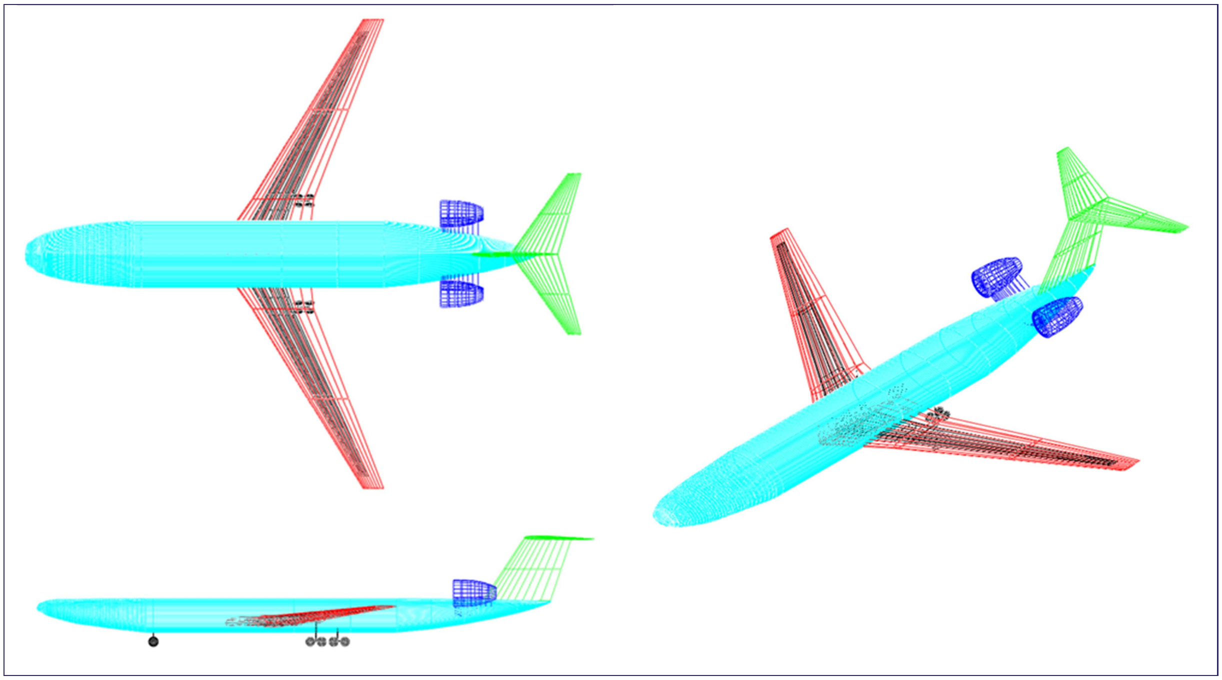


Figure 22 ERAC 3D sketch

Results from simulations with the ERAC show that the take-off distance in the nominal case (all engines operative) on *the Endless Runway* will reduce with about 21%, without generating critical accelerations for the passengers. Furthermore, the ERAC needs as expected the same landing distance as the Boeing 747, however, it must be noted that the landing speed at which the simulation have been performed is a conservative choice. The landing distance could then be smaller. Also, improvements on the sustained accelerations must be noted. The tailored ERAC offers a level of take-off performance on a circular runway that is better than the B747 on a classical runway. Such an improvement is a key element in achieving a higher airport capacity as the ATM calculations have been performed with take-off and landing performances of current-day aircraft.

Another observation is that the ERAC size according to given constraints leads to a higher thrust-to-weight ratio than today's airplanes. This increase is required given the limitation on decreasing the wing load (aircraft span is limited because of the ground clearance).

Ground clearance of the wingtips is good: the inner wing has a minimum distance of 2.48 meters; while the outer wingtip has a minimum distance to the ground of 2.67 meters.

1.3.9 Impact of *the Endless Runway*

An assessment has been made concerning the impact that *the Endless Runway* would have on societal aspects as noise. From the proposed arrival and departure routes, it is clear that the airport will generate noise in any possible direction. A calculation has been made using the Integrated Noise Model (INM) software, where traffic on the busiest day Paris Charles de Gaulle has been used to determine the noise impact over the year. The accumulated noise is corrected for the total number of flights in 2013 (472,000 movements) as the busiest day multiplied with 365 would give about 20 % more movements than actually realized in 2013. In this manner, a comparison between the noise contours of *the Endless Runway* and the actual noise contours of Paris Charles de Gaulle in 2013 can be made, see Figure 23. Noise is indicated in L_{den} (Level day-evening-night), the standard European noise metric for measuring noise around airports.

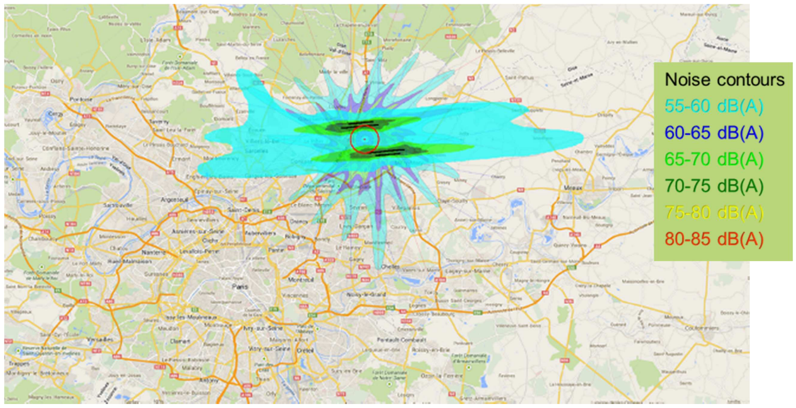


Figure 23 Noise contour comparison between the Endless Runway and Paris CdG airports

For the comparison of the two airports (*the Endless Runway* vs. the 2013 Paris Charles de Gaulle scenario), precautions must be taken as the location of the current Paris Charles de Gaulle airport and runways was decided in consideration with the environment and surrounding communities. Therefore, highly populated areas appear affected by *the Endless Runway* airport, which would normally be built further from the agglomeration.

Finally, regarding ground airport noise, the height of the banked runway should avoid it to spread outside of its boundary.

A cost analysis was done based on a basic cost model, developed in Figure 24 which distinguishes several cost factors. Estimations had to be made, like the cost of constructing the banked runway. Figure 24 compares the costs between a standard airport and a minimum and a maximum estimate for the Endless Runway airport.

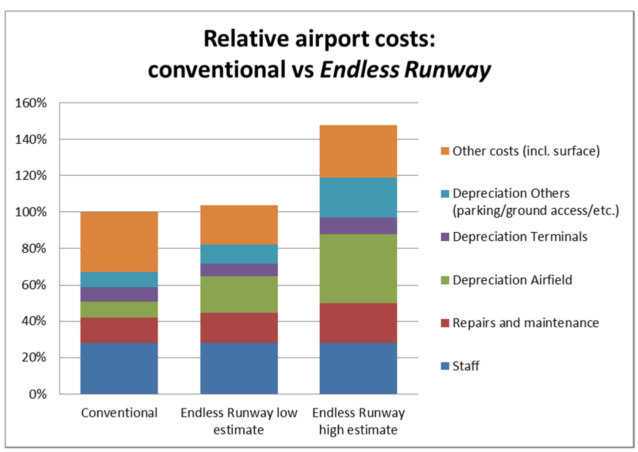


Figure 24 Relative airport development costs

It appears that an *Endless Runway* airport would be between 1.1 and 1.6 times more expensive than a conventional one.

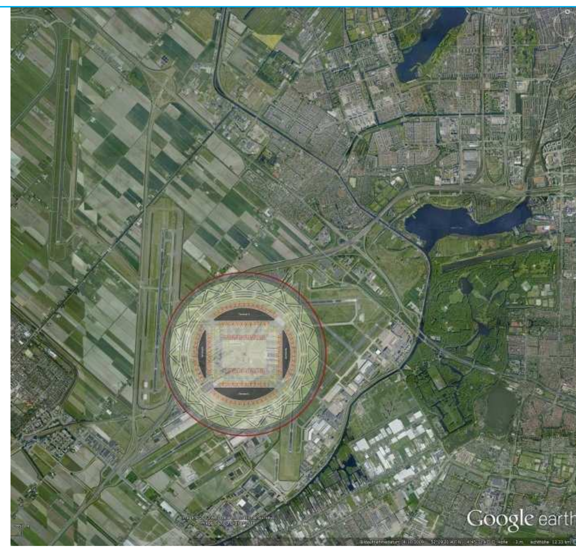
On the benefits side, smaller ground acquisition costs due to the compactness of the infrastructure (36 % of Paris Charles de Gaulle), and shorter flying and taxi times leading to more efficient flights and less fuel consumption are in favour of *the Endless Runway* concept.

Finally, the overall sizing of the airfield will be considerably different from current-day airports, where the land acquisition is mostly necessary for constructing long runways. Figure 25 gives an impression on the footprint of *the Endless Runway* compared with some existing European airports.

Paris CDG

Frankfurt Main

Madrid Barajas



Amsterdam Schiphol

Figure 25 Comparison the Endless Runway to actual European airports.

The presented comparison concerns the runway and the inner area of *the Endless Runway* only. All external facilities have to be placed around the circle, so additional space, compared to what is shown in the figure, will be needed. But just as well for the images of the existing airports it is not obvious which space is really needed for the airport itself and what area is used for support or as industrial area.

1.3.10 Transition from today to the future

Many aspects will have to be considered when constructing an airport with an *Endless Runway*. The motivation for a location will be different, as aircraft will fly in any direction and more noise near the airport can be expected.

The technological challenges that will have to be solved for operating an *Endless Runway* are actually mostly already under way. Increased automation in the aircraft and on-ground will aid in planning the runway segments to be used and in determining exactly what take-off or touch-down point will be optimal. To exactly follow the plan, automation will also help. Research performed in *the Endless Runway* can benefit current developments in for example the application of Adaptive Runway Aiming Points (A-RAP).

Regulations, standards and certification will need to be adapted to *the Endless Runway*. As far as possible, current regulations and standards have been followed within the project, but the new runway shape will certainly require changes. The main issues will be the circular shape and the bank angle of the runway and the complexity of the TMA operations.

1.3.11 Final considerations

A concept for operating a circular runway has been evaluated from various perspectives: the aircraft, the airport and the operations. *The Endless Runway* has proven to be a feasible concept at least in the nominal conditions studied in the project timeframe. Several other considerations will be given in this section.

One important element of operating *the Endless Runway* is the need for guidance to ATC and to the pilot. As current radio navigation aids (especially ILS), visual aids and runway markings are not applicable anymore, other technologies and concepts will have to be implemented. Precision approaches will be necessary, which refer to cases where the aircraft is guided in both the lateral and the vertical plane, with sufficient accuracy to meet requirement for up to CAT II and CAT III approaches.

New navigation technologies, like satellite navigation, make it possible to carry out precision approaches. Together with Ground Based Augmentation Systems (GBAS), these are one of the most promising technologies for pilot guidance systems. GPS (Global Positioning System) only provides sufficient accuracy for non-precision approaches. GBAS, which consists of a reference station located at or near the airport coupled with a monitor station that together measure GPS errors and transmit corrective information to aircraft, allows augmenting the positioning accuracy of the GPS to meet requirements for precision approaches.

A new method for determining a runway aiming point, called the Adaptive Runway Aiming Point (A-RAP), is proposed recently where a (shifted) aiming point is determined which shifts the touch-down point along the runway in the downstream direction and which can be used by different precision approach landing aids. A precise calculation of the aiming point is carried out which is moreover adapted to the actual conditions encountered at the time of the landing, regarding both the external environment (meteorological conditions) and the runway used (state, slope, . . .). Automatic calculation makes it possible to reduce the work load of the pilot. Current research towards Adaptive Runway Aiming Points will enable curved approaches to every separate segment on *the Endless Runway*.

A way of assisting the pilot in the operation with the circular shape of the runway is to transfer the guidance to the cockpit. Augmented reality systems are already available and with future developments, the technology could be used as one of the main guidance systems. With the further development of this type of technology, the combination of all kinds of navigational support like synthetic terrain data, navigational waypoints, approach information, markings, and aircraft information will contribute to the required situational awareness of the pilot.

To schedule a full day of traffic, a multi-objective planning system will need to be designed that covers planning of flights at the runway, the TMA and ground movements in one system. One of the current trends in use of complex planning systems is the research towards cooperation between planning systems through optimisation techniques, negotiation techniques and through cooperative distributed planning. The latter is an interesting technique that allows different planners to make their own plan and then through coordination align the overall plan, without the need for an overall “super planner”. Figure 26 gives the overview of envisaged automation of the ATS system, according to ACARE.

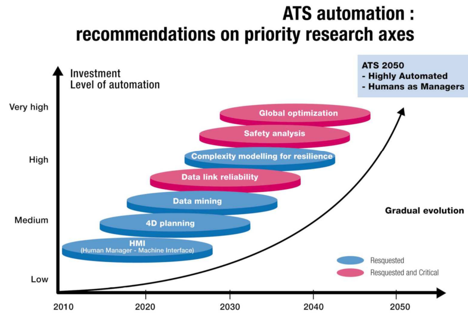


Figure 26 Increasing automation towards 2050

It can be concluded that no show stoppers for a further evaluation of *the Endless Runway* have been identified while setting up the airport design, aircraft concept and the ATM operational procedures, but some points of concern are mentioned and several possible options need further study.

The efforts provided by the consortium to achieve these goals are valuable and the associated development of competences will be used in future European projects. Moreover, this project demonstrated that a true revolutionary solution for the future of air transport is viable only if solutions are achieved through a holistic development approach from the perspective of the aircraft, the airport and air traffic management.

1.3.12 References

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[6] Dupeyrat M., Aubry S., Schmollgruber P., Remiro A., Loth S., Vega Ramirez M., Hesselink H., Verbeek R., Nibourg J., *D1.2 The Endless Runway State of the Art, runway and airport design, ATM procedures and aircraft*, version 2.0, November 2011
[7] Hesselink H., Verbeek R., Welman C., Dupeyrat M., Schmollgruber P., Aubry S., Loth S., Remiro A., Vega Ramirez M., *D1.3 The Endless Runway concept description: High-level overview*, version 2.0, December 2012
[8] Remiro A, Welman C., *D2.2 The Endless Runway Airport Infrastructure*, version 1.0, September 2013
[9] Schmollgruber P., De Giuseppe A., and Dupeyrat M., *D3.2 The Endless Runway Aircraft Aspects*, version 1.0, September 2013
[10] Loth S., Dupeyrat M., Hesselink H. and Verbeek R., *D4.2 The Endless Runway ATM Operational Concept*, version 1.0, June 2013
[11] Loth S., Dupeyrat M., Hesselink H. and Verbeek R., *D4.3 Simulation of the Endless Runway: Modeling and Analyses,* version 2.0, September 2013
[12] S. Loth, Hesselink, H. Dupeyrat, M. Welman, C. Verbeek, R. *D5.2 Assessment of the Endless Runway*, version 1.0, April 2014
[13] Remiro, A, Hesselink, H., *D5.3 Transition from Today to the Future*, version 1.0, April 2014

1.4 Potential impact and the main dissemination activities and exploitation of results

The project has evaluated the potential impact of *the Endless Runway* in a dedicated deliverable [12]. The impact has been assessed with respect to capacity of the airport, the noise impact, the airport footprint, a technological assessment and a cost benefit assessment has been performed. These will be summarised in this section.

1.4.1 Capacity

One of the main motivation items for the project has been to study the capacity impact of an airport that will operate *the Endless Runway*:

> *The Endless Runway* concept can generate a breakthrough in sustainable airport capacity by avoiding the physical constraints of conventional runways through shifting the lift-off and touchdown points of individual aircraft.

Capacity has been mentioned as *sustainable* capacity, wherewith is meant that a certain operational capacity of the airport can be maintained at high level, with every meteorological (mainly wind) condition.

The basic concept of operating the runway is to allow flexible lift-off and touchdown points that will enable every aircraft to lift-off or touchdown at any point on the circle depending on

1. Current wind conditions – the aircraft will take-off and land with headwind and minimum crosswind.
2. Direction of flight – the aircraft will depart or arrive in the direction of their destination.

This leads to two operational scenarios: the low wind case and the high wind case. In the low wind case, cross- and tailwind will be limited, allowing the aircraft to operate the runway at any point, from any direction. In the high wind case, a dedicated operational mode has been developed where the runway is separated into two parts, each operating as one runway with only headwind operations. Simulations have been performed using the 1st of July, 2011, at Paris Charles de Gaulle (CdG) as reference scenario. It was the busiest day of that year.

In order to make an assessment of the capacity of *the Endless Runway*, a comparison to today's runways and today's airports is necessary. Assuming a traffic mix in aircraft types, in general, the number of movements that can be achieved on one runway will be around 35 (for segregated mode) to 40 (for mixed mode) movements per hour. A capacity of 80 movements per hour can be realised on a two-runway configuration, where the capacity increases to 110-120 on three or four simultaneously used runways. Theoretical studies indicate that the maximum capacity that can be achieved in a three runway configuration will be around 130 movements, although in practice the traffic mix will not allow this number of movements. As the length of the runway proposed for *the Endless Runway* can be compared to three conventional runways (about 10.000 meters), it seems realistic to set the target capacity at 110-120 movements.

Table 3 gives an overview of average and maximum delay that was found on operating the runway in a low wind case. The table gives increasing traffic load, based on the baseline scenario of July 1st, 2011. Aircraft have been separated based on time and wake turbulence separation and a safety distance is included between consecutive aircraft.

Table 3 Capacity measures with different traffic density

Traffic ratio (1 July 2011)	Number of flights	Max flights per hour	Average delay (hh:mm:ss)	Max delay (hh:mm:ss)
100.0%	1570	110	00:00:21	00:04:16
110.0%	1727	121	00:00:33	00:07:18
120.0%	1887	127	00:01:16	00:09:23
130.0%	2042	131	00:03:41	00:20:11
140.0%	2198	146	00:12:53	00:41:58
150.0%	2365	150	00:27:31	01:04:09
200.0%	3140	179	02:37:43	05:11:33

From Table 3, a first conclusion is that the nominal number of operations, compared to a busy day at Paris CdG can be accommodated without problems in the low wind case. More traffic can be considered; a doubling of traffic however, will not be feasibly.

It can be noted that usually, delay is only considered as delay if the flight schedule cannot be realised with a fifteen minutes margin; anything below this fifteen minutes can be absorbed through slack in this flight schedule. On an average day, a realisation of 90% flights on time, which means a delay of fifteen minutes or less, is regarded normal and figures as obtained from the simulations would allow operations until fifteen minutes delay on average as acceptable. This would allow 146 movements per hour, with 12:53 minutes delay on average. Capacity of *the Endless Runway* can be regarded similar to higher than today, i.e. in between 110 and 146 movements per hour.

Although the major European airports hardly ever close completely because of storms, in several occasions, airports have to deal with limitations in operations because of the wind. At Amsterdam Airport Schiphol, strong winds limited the operations during the winter season of 2013/2014 four times, where the airport was forced to operate a one-runway configuration. In one of these occasions, the Royal Dutch Airlines, KLM, reported to have cancelled 20 flights.

In the high-wind case, therefore, we may assume the capacity of *the Endless Runway* to be consistent at the same capacity as that of a conventional airport with two parallel independent runways, i.e. 80 movements per hour, although the strong winds may limit the operation thus reducing capacity.

1.4.2 Noise impact

An assessment has been made concerning the impact that *the Endless Runway* would have on societal aspects as noise. From the proposed arrival and departure routes, it is clear that the airport will generate noise in any possible direction. A calculation has been made using the Integrated Noise Model (INM) software, where traffic on the busiest day Paris Charles de Gaulle has been used to determine the noise impact over the year. The accumulated noise is corrected for the total number of flights in 2013 (472,000 movements) as the busiest day multiplied with 365 would give about 20 % more movements than actually realized in 2013. In this manner, a comparison between the noise contours of *the*

Endless Runway, see Figure 27, and the actual noise contours of Paris Charles de Gaulle in 2013, see Figure 28, can be made. Noise is indicated in L_{den} (Level day-evening-night), the standard European noise metric for measuring noise around airports.

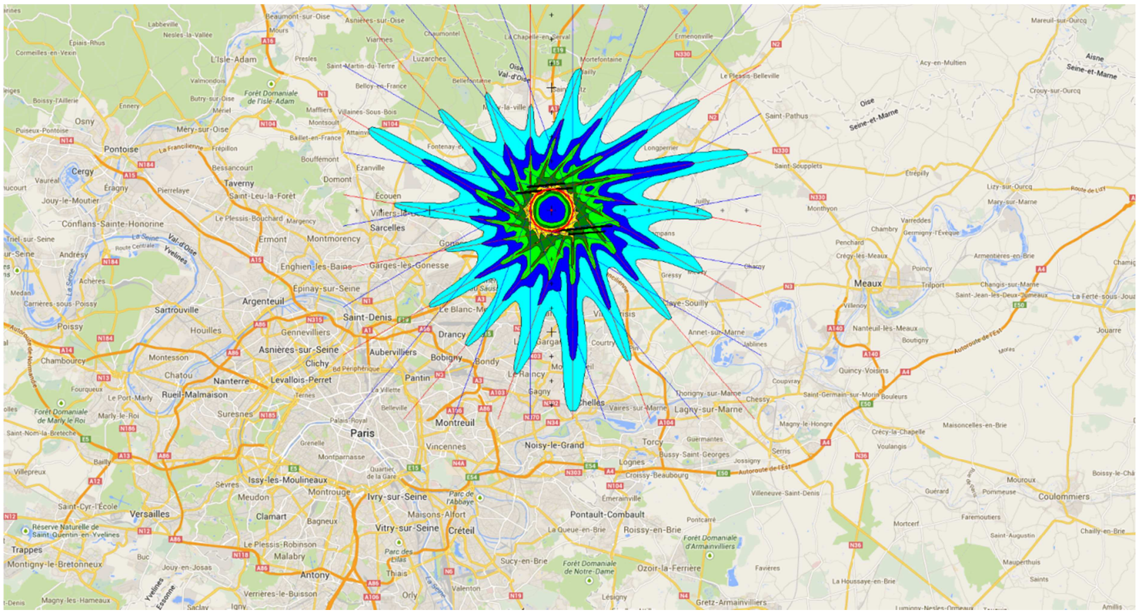


Figure 27 INM noise contours for the Endless Runway

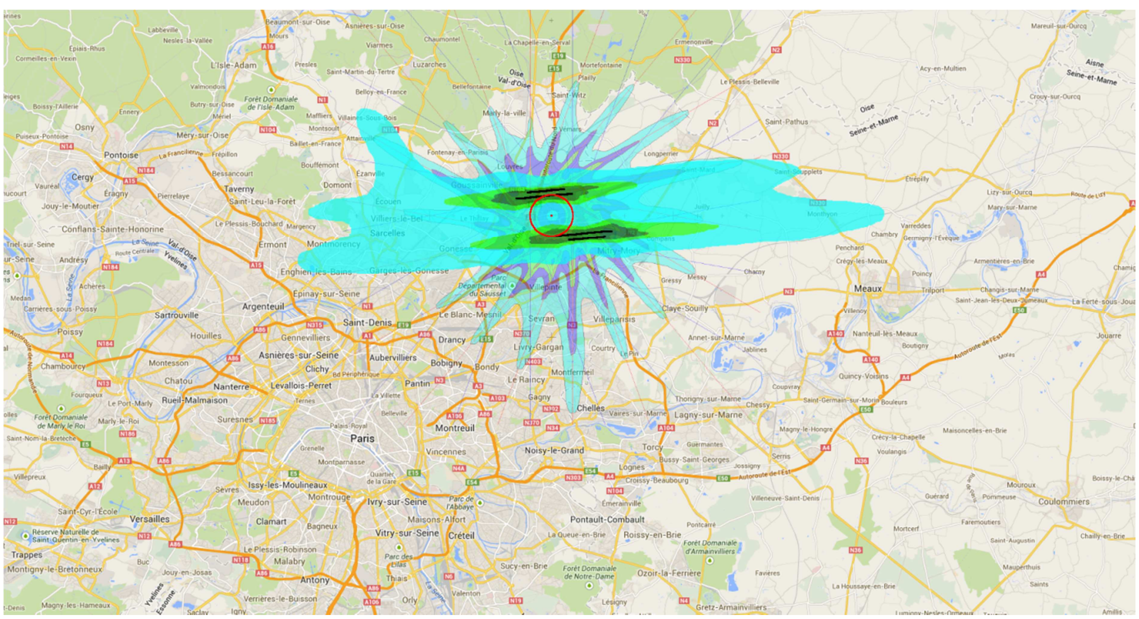


Figure 28 Noise contours comparison between the Endless Runway and Paris Charles de Gaulle airport

For the comparison of the two airports (*the Endless Runway* vs. the 2013 Paris Charles de Gaulle scenario), precautions must be taken as the location of the current Paris Charles de Gaulle airport and runways was decided in consideration with the environment and surrounding communities. Therefore, highly populated areas appear affected by the Endless

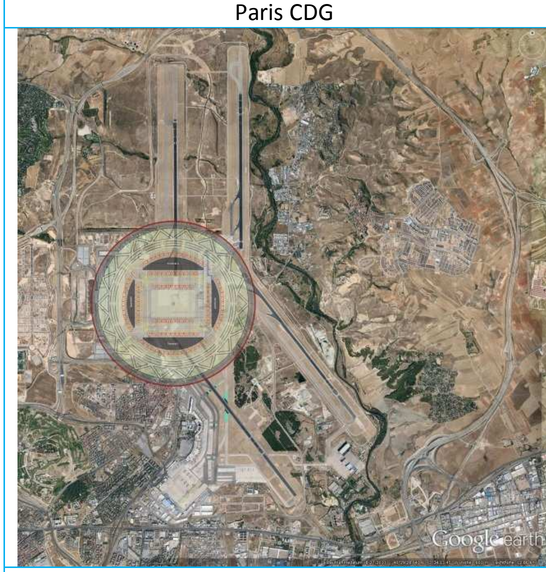
Runway airport, which would normally be built further from the agglomeration. The question behind those contours maps is whether more people would accept to be impacted by the airport noise nuisances but with less frequency, or whether they prefer to know exactly where the corridors are, with strong nuisances for the population below. Several discussions with local residents lead to the conclusion that the second option is preferable in dense areas, but no hint is given for remote airports. Finally, regarding ground airport noise, the height of the runway should avoid it to spread outside of its boundary.

1.4.3 Airport footprint

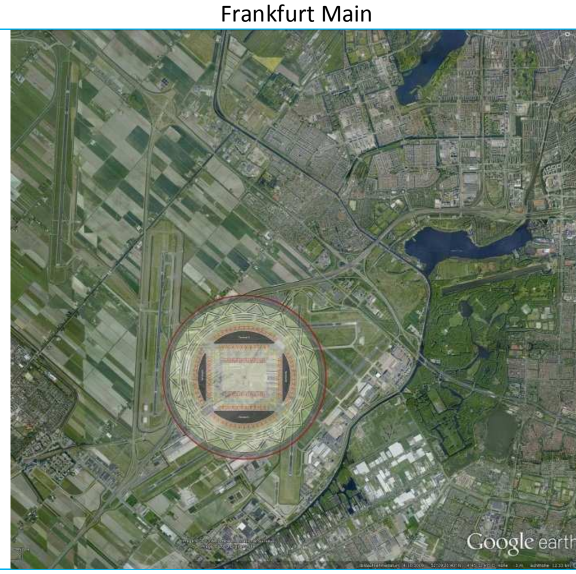
Figure 29 gives an impression on the footprint of *the Endless Runway* compared with some other European airports.

Paris CDG

Frankfurt Main



Madrid Barajas



Amsterdam Schiphol

Figure 29 Comparison the Endless Runway to actual European airports.

The comparison includes the runway and the inner area of *the Endless Runway* only. All external facilities will have to be placed around the circle, so additional space is needed. But just as well for the images of the existing airports, it is not obvious which space is really needed for the airport itself and what area is used for support or as industrial area.

1.4.4 Technological assessment

The ever more complex air transport system facing more and more ambitious goals is naturally evolving towards automation[1]. This automation of the air transport system will be built on three pillars: the automated air traffic management, the automated aircraft and the connection between the both: the ATM contract.

Air Traffic Management will be assisted by a range of sensors that will enable operations under all weather conditions, including high wind and low visibility to detect aircraft movements, movements of other vehicles and a view of all other relevant objects, like birds and debris on the runway. Control towers will be replaced by remote towers. This transition towards automated ATM has been ongoing for several years already: controllers are supported by conflict detection systems and planning tools that allow increasing efficiency, predictability and throughput. This transition will lead to a shift from a human decision maker supported by assistance systems towards advanced automated decision systems managed by a human.

Aircraft operations will see the same shift in responsibility, where the pilot will monitor the aircraft instead of taking active actions. The key aspect of aircraft automation is the complete implementation of the 4D contract concept. Aircraft will be “responsible” for monitoring their commitment to the 4D contract that was signed with the ground ATM centre. Aircraft will collect and manage information on other air traffic, weather, communications, navigation and surveillance infrastructure status, airports, terrain and obstacles. Figure 30 gives the overview of envisaged automation of the air transport system.

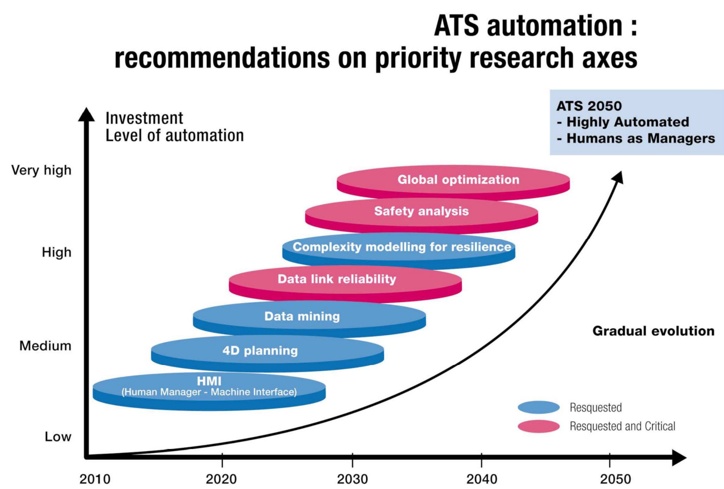


Figure 30 Air Transport System automation towards 2050

Due to the straight arrival segment of the TMA structure, instrument landing systems like ILS could theoretically be used on all segments and for each direction. From practical and economic points of view this is not really an option and therefore not considered as a solution. GPS (Global Positioning System) provides position information, be it with only sufficient accuracy for non-precision approaches. Ground Based Augmentation Systems (GBAS), which consists of a reference station located at or near the airport coupled with a monitor station that together measure GPS errors and transmit corrective information to aircraft, allows augmenting the positioning accuracy of the GPS to meet requirements for precision approaches (up to CAT II and CAT III). With GBAS, no separate installation for vertical and lateral guidance (as with an Instrument Landing System (ILS) localizer and glide path antennas) will be necessary.

[1] EREA ATS 2050 Phase 2, *From Air Transport system 2050 Vision to Planning for Research and Innovation*, published by the Association of European Research Establishments in Aeronautics, May 2012.

Independent from the final technical solution, the most important part is the definition of the required navigation performance for arrival and take-off for *the Endless Runway*. Any technology that is capable of achieving these values can be used.

1.4.5 Cost benefit assessment

A cost analysis was done based on a basic cost model, which distinguishes several cost factors. The analysis tries to estimate only the cost and benefits of an *Endless Runway* airport relatively to a conventional hub airport with four runways. No absolute Cost Benefit Analysis (CBA) can be provided as there are too many uncertainties and unknowns in respect to the airport concept, the needed technologies and the cost of materials, energy and workers for the 2050 context.

Estimations had to be made, like the cost of constructing the banked runway. Where no absolute figures would be available, a low and a high estimate have been made. The following types of costs have been considered: development, operational, recurring and non-recurring costs. This methodology is good enough to get a general feeling about the costs of an *Endless Runway* airport compared to a conventional airport.

Figure 31 compares the costs between a standard airport and a minimum and a maximum estimate for the Endless Runway airport. It appears that an *Endless Runway* airport would be between 1.1 and 1.6 times more expensive than a conventional one.

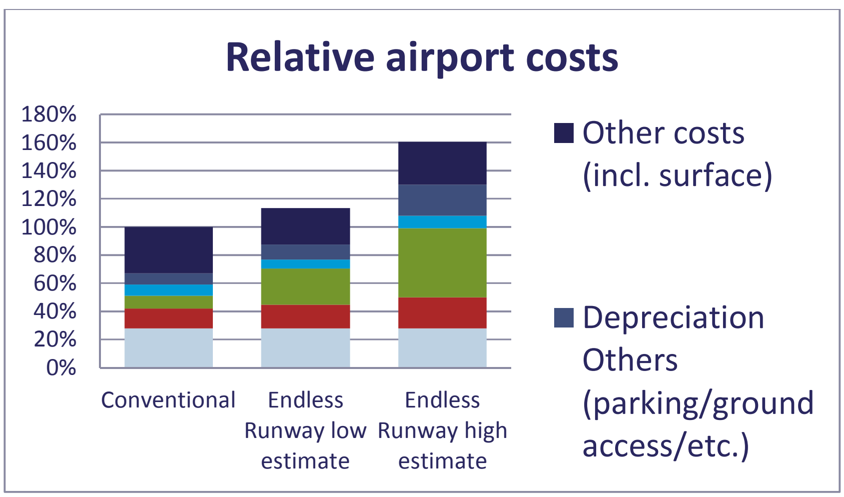


Figure 31 Relative airport development costs

On the benefits side, smaller ground acquisition costs due to the compactness of the infrastructure (36 % of Paris Charles de Gaulle), and shorter flying and taxi times leading to more efficient flights and less fuel consumption are in favour of *the Endless Runway* concept.

The expected total costs and revenues for a conventional airport is €1.87 Billion. The expected total cost for an *Endless Runway* airport is therefore €1,87 Billion * [104%-148%]=[€1,94 Billion - €2,76 Billion]. The difference is between €0.07 and €0.90 Billion per year of higher airport costs per airport when operating an *Endless Runway* airport. Return on investment can therefore be expected in between two and forty years.

The Endless Runway offers, even in strong wind conditions, two landing and take-off points, where nowadays airports have to use fallback scenarios with operating one runway. The financial benefits of the operation will depend on the airport and the type of operation of the airline; a hub airline will have more costs for cancelling flights than an airline offering point-to-point connections. At major airports, costs for cancelling 50% of the flights of the main carrier can get up to .5M€ per day. Here, the benefit of a sustainable capacity, which is offered by *the Endless Runway*, is significant.

1.4.6 New developments

Several recent developments can benefit from the work performed for *the Endless Runway*.

Adaptive Runway Aiming Point

New navigation technologies, like satellite navigation, make it possible to carry out satellite-guided precision approaches. A new method for determining the runway aiming point is proposed recently where a (shifted) aiming point is determined, called the Adaptive Runway Aiming Point (A-RAP), which shifts the touch-down point along the runway in the downstream direction and which can be used by different precision approach landing aids. A precise calculation of the aiming point is carried out which is moreover adapted to the actual conditions encountered at the time of the landing, regarding both the external environment (meteorological conditions) and the runway used (state, slope, . . .). Automatic calculation makes it possible to reduce the work load of the pilot.

Current research towards Adaptive Runway Aiming Points will enable curved approaches to every separate segment on *the Endless Runway*. The work performed for *the Endless Runway* on planning runway segments can be used for A-RAP.

Free Flight in the TMA

One interesting aspect for TMA operations of *the Endless Runway* is based on a full free flight concept as presented in Figure 32. Every aircraft can book a number of segments at the runway at a given time and approach the airport from the direction it wants without a pre-defined route. This approach requires a high degree on automation and high performance in terms of navigation and communication capabilities. Separation is transferred completely to the aircraft and a high load of communication between aircraft will be necessary to coordinate all movements within the TMA.

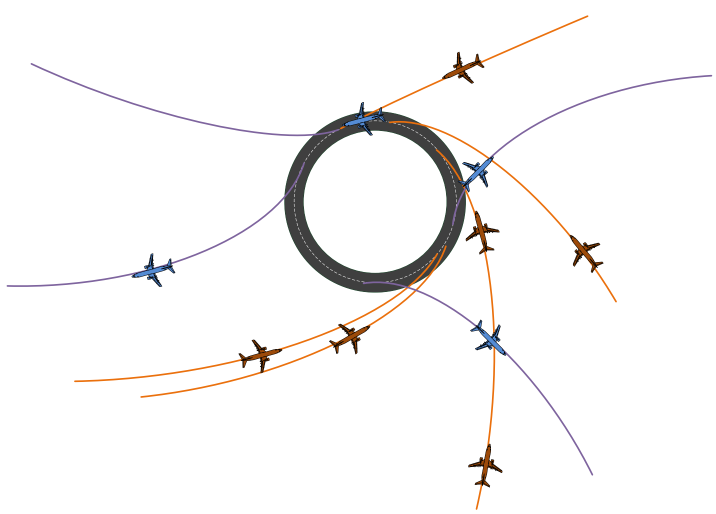


Figure 32 Free flight concept for the Endless Runway in the TMA

For *the Endless Runway* an intermediate step was taken towards free flight operations, as each aircraft will fly a straight line from TMA entry to the runway (and vice versa), close to the original idea of a highly flexible airspace and the requirement of effective routing. The application of the free flight concept could also give room to a capacity increase in the TMA. This development performed within *the Endless Runway* complements the current work in free flight, which is currently solely dedicated to en-route traffic.

Table 4 summarises the pros and cons of *the Endless Runway* as has been evaluated in this document and in other parts of the project.

Table 4 Overall assessment of the Endless Runway project

Description	Assessment
Advantages	
Capacity of *the Endless Runway* is similar or higher than that of a conventional airport with three or four runways.	A three or four runway airport in Europe typically operates at a capacity of 115 movements per hour; *the Endless Runway* has demonstrated a capacity of 110 to 146 movements per hour, depending on accepted (mean) delays and on available ground infrastructure.
The Endless Runway has a sustainable capacity of 80 movements per hour	As the runway has two touchdown/take-off points in any wind direction, a capacity of 80 movements per hour can be achieved.
Taxi times are significantly reduced	A reduction of 40% to 95% of taxi times is observed.
The average flight distance can be reduced by 1 % to 2 % based on an average 700 NM flight thanks to the TMA routes structure.	Based on an average 700 NM flight, the total flight distance can be reduced by 1% to 2%.
The Endless Runway airport's land use is significantly smaller for large airports.	The airport's size for *the Endless Runway* has been compared with several large airports in Europe, where a reduction can be expected up to one third in surface necessary for aircraft operations.
Noise footprint for an airport with an *Endless Runway* is smaller.	The noise footprint is more dispersed in all directions, but overall more compact.
New A-RAP procedure possible.	Results of the project could be applied to research towards the Adaptive Runway Aiming Point.
Full Free Flight procedures possible.	Results of the project could lead to the application of free flight in the TMA.
The Endless Runway can bring air services to places that nowadays have no airport facilities	Small islands, remote sites (a.o. in less developed areas and countries), and small communities may benefit from a small *Endless Runway*.
The Endless Runway can be implemented as a feeder airport	The four hour door-to-door ACARE goal may benefit from the implementation of small feeder *Endless Runway* airports.
Disadvantages	
Cost of constructing an *Endless Runway* is higher.	The cost benefit analysis shows that costs for constructing an airport with an *endless runway* is typically 110% to 160% of that for a conventional airport.
Lack of flexibility in the inner infrastructure.	All required airport facilities must be located within the circle where only limited space is available. The project has demonstrated that the main

	infrastructure will fit the circle size of 1500 meters radius.
Extensions to the airport will be difficult	Contrary to today's airports, *the Endless Runway* cannot be extended to the outside. Also, contrary to today's airports, the runway radius is fixed and therefore the runway cannot be stretched out, and the room available for the infrastructure within the runway boundary remains limited.
Hub airport is very demanding	The mix of traffic and the peaks in arrival and departure operations makes the demand on the operation of *the Endless Runway* very high. The airport may show improved performance if it was designed for a dedicated purpose only. More research towards this will be necessary.
The only aircraft found that would not be able to operate the banked runway is the Blended Wing Body (BWB).	Size and shape of the BWB may make it impossible to operate at *the Endless Runway* as the wingtips will touch the ground on the banked track.

1.5 The address of the project public website, if applicable as well as relevant contact details

www.endlessrunway-project.eu

1.6 Project logo

Figure 33 Project logo

1.7 Diagrams or photographs illustrating and promoting the work of the project

Figure 34 to Figure 39 Experience driving a circular track shows some photos taken during the project. The project has been promoted at several exhibitions, for which the latest poster is included in Figure 40.

Figure 34 SESAR Innovation Days

Figure 35 ACI Airport Exchange

Figure 36 The team (1)

Figure 37 The team (2)

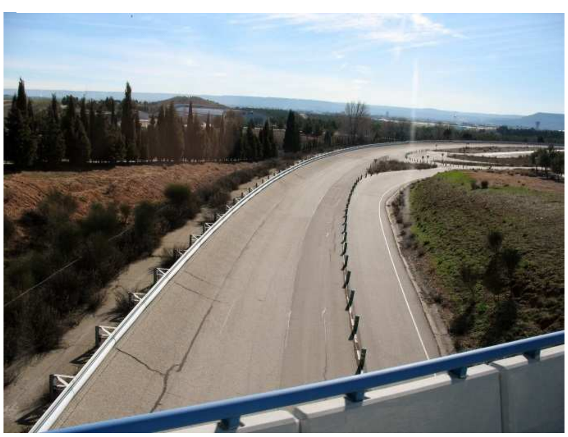


Figure 38 View on a circular (car) track

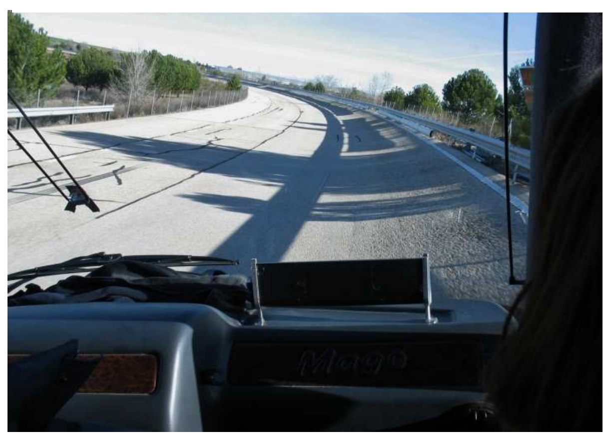


Figure 39 Experience driving a circular track

Figure 40 Project poster (presented at SESAR Innovation Days, November 2013)

1.8 List of all beneficiaries with the corresponding contact names

Consortium

The project is carried out in a consortium of NLR, DLR, ONERA, INTA, and ILOT. Contact person for the project is

Henk Hesselink
henk.hesselink@nlr.nl
+31.88.511.3445

Contacts for the beneficiaries are indicated in Table 5

Table 5 Points of contact

Project points of contact	
NLR	Mr. Henk Hesselink Tel. +31.88.511.3445 henk.hesselink@nlr.nl
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ILOT	Mr. Marián Jez Tel: +48 22 609 704 603 marian.jez@ilot.edu.pl

2 Use and dissemination of foreground

Section A (public)

This section includes two Tables

- Table A1: List of all scientific (peer reviewed) publications relating to the foreground of the project.
- Table A2: List of all dissemination activities (publications, conferences, workshops, web sites/applications, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters).

These tables are cumulative, which means that they should always show all publications and activities from the beginning until after the end of the project. Updates are possible at any time.

TABLE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES

NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[2] (if available)	Is/Will open access[3] provided to this publication?

[2] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).

[3] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

1											

TABLE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities[4]	Main leader	Title	Date/Period	Place	Type of audience[5]	Size of audience	Countries addressed
1	*Conference presentation:* *Evaluation of Operations at an Airport with a Circular Runway*	*ONERA (M. Dupeyrat)*	*ICAS 2014 (International Council of the Aeronautical Sciences)*	*7-12/09/2014*	*St. Petersburg (Russia)*	*Scientific*	*Hundreds for the total conference; 10 – 50 per session*	*worldwide*
2	*Conference presentation:* *An Innovative Airport Concept (Operating an Endless Runway)*	*NLR (H. Hesselink)*	*CEAS 2013 (Council of European Aerospace Societies): "Innovative Europe",*	*16-19/09 /2013*	*Linköping (Sweden)*	*Scientific*	*Hundreds for the total conference; 10 – 50 per session*	*Europe*
3	*Workshop presentation:* *A Vision for the Airport in 2050: The Endless Runway*	*ONERA (M. Dupeyrat)*	*Aerospace 2050, Scientific workshop to honor Professor Marc Pélegrin, ISAE (Institute Supérieur de l'Aéronautique et de l'Espace),*	*19/12/2013*	*Toulouse (France)*	*(Retired) scientists*	*50*	*France*

[4] A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

[5] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias, Other ('multiple choices' is possible).

4	*Workshop presentation: The Endless Runway*	*ONERA (M. Dupeyrat)*	*CORAC Airport Flow group at Airbus*	*20/12/2013*	*Toulouse (France)*	*Managers*	*50*	*France*
5	*Seminar presentation: The Endless Runway*	*ILOT (M. Jez)*	*Polish Agency for Air Navigation*	*2/2014*	*Warsaw (Poland)*	*Scientists*	*25*	*Poland*
6	*Exhibition poster*	*NLR*	*ACI Airport Exchange*	*27-28 /11/2012*	*Amsterdam (The Netherlands)*	*Scientists and managers*	*500*	*World-wide*
7	*Exhibition running presentation*	*ONERA*	*ACI Airport Exchange*	*27-28 /11/2012*	*Amsterdam (The Netherlands)*	*Scientists and managers*	*500*	*World-wide*
8	*Exhibition poster*	*NLR*	*SESAR Innovation Days*	*26-28/11/2013*	*Stockholm (Sweden)*	*Scientists*	*200*	*Europe*
9	*Meeting with air traffic controller and Air France pilot*	*ONERA*	*Blagnac Airport*	*02/04/2013*	*Toulouse*	*End user*	*1*	*France*
10	*Several meetings with Modlin and Radom managers: civil airport director, military airport manager, sports airport manager, Polis CAA*	*ILOT*	*Modlin and Radom airports*	*2013*	*Warsaw*	*End user*	*4*	*Poland*

Section B (Confidential[6] or public: confidential information to be marked clearly)
Part B1

The applications for patents, trademarks, registered designs, etc. shall be listed according to the template B1 provided hereafter.

The list should, specify at least one unique identifier e.g. European Patent application reference. For patent applications, only if applicable, contributions to standards should be specified. This table is cumulative, which means that it should always show all applications from the beginning until after the end of the project.

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights[7]:	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)

[6] Note to be confused with the "EU CONFIDENTIAL" classification for some security research projects.

[7] A drop down list allows choosing the type of IP rights: Patents, Trademarks, Registered designs, Utility models, Others.

Part B2

Please complete the table hereafter:

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
	Ex: New superconductive Nb-Ti alloy			*MRI equipment*	*1. Medical* *2. Industrial inspection*	*2008* *2010*	*A materials patent is planned for 2006*	*Beneficiary X (owner)* *Beneficiary Y, Beneficiary Z, Poss. licensing to equipment manuf. ABC*

In addition to the table, please provide a text to explain the exploitable foreground, in particular:

- Its purpose
- How the foreground might be exploited, when and by whom
- IPR exploitable measures taken or intended
- Further research necessary, if any
- Potential/expected impact (quantify where possible)

[19] A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.

[9] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

4.1 Report on societal implications

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:	ACP2-GA-2012-308292-ENDLESS RUNWAY
Title of Project:	The Endless Runway
Name and Title of Coordinator:	Drs. Ing. H.H. Hesselink

B Ethics	
1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***0Yes ◙No***
2. Please indicate whether your project involved any of the following issues (tick box) :	***NO***
RESEARCH ON HUMANS	
• Did the project involve children?	
Did the project involve patients?	
Did the project involve persons not able to give consent?	
Did the project involve adult healthy volunteers?	
Did the project involve Human genetic material?	
• Did the project involve Human biological samples?	
• Did the project involve Human data collection?	
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	
• Did the project involve Human Foetal Tissue / Cells?	
• Did the project involve Human Embryonic Stem Cells (hESCs)?	
• Did the project on human Embryonic Stem Cells involve cells in culture?	
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual	

lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	
• Did the project involve tracking the location or observation of people?	
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	
• Were those animals transgenic small laboratory animals?	
• Were those animals transgenic farm animals?	
• Were those animals cloned farm animals?	
• Were those animals non-human primates?	
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	
DUAL USE	
• Research having direct military use	0 Yes ◙ No
• Research having the potential for terrorist abuse	

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator		1
Work package leaders	2	2
Experienced researchers (i.e. PhD holders)		
PhD Students		
Other		

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	
Of which, indicate the number of men:	

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?
- ○ Yes
- ◙ No

6. Which of the following actions did you carry out and how effective were they?

	Not at all effective → Very effective
❑ Design and implement an equal opportunity policy	○ ○ ○ ○ ○
❑ Set targets to achieve a gender balance in the workforce	○ ○ ○ ○ ○
❑ Organise conferences and workshops on gender	○ ○ ○ ○ ○
❑ Actions to improve work-life balance	○ ○ ○ ○ ○
○ Other:	

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?
- ○ Yes- please specify
- ◙ No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?
- ○ Yes- please specify
- ◙ No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?
- ○ Yes- please specify
- ◙ No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?
- ◙ Main discipline[10]: 2.1 Civil engineering
- ○ Associated discipline[10]:
- ○ Associated discipline[10]:

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*
- ○ Yes
- ◙ No

[10] Insert number from list below (Frascati Manual).

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

- ◙ No
- ○ Yes- in determining what research should be performed
- ○ Yes - in implementing the research
- ○ Yes, in communicating /disseminating / using the results of the project

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ ◙	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

- ◙ No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- ○ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ◙ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ○ No

13b If Yes, in which fields?

Agriculture	Energy	Human rights
Audiovisual and Media	Enlargement	Information Society
Budget	Enterprise	Institutional affairs
Competition	Environment	Internal Market
Consumers	External Relations	Justice, freedom and security
Culture	External Trade	Public Health
Customs	Fisheries and Maritime Affairs	Regional Policy
Development Economic and Monetary Affairs	Food Safety	**Research and Innovation**
Education, Training, Youth	Foreign and Security Policy	Space
Employment and Social Affairs	Fraud	Taxation
	Humanitarian aid	**Transport**

13c If Yes, at which level?

- ○ Local / regional levels
- ○ National level
- ○ European level
- ◙ International level

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	-
To how many of these is open access[11] provided?	
How many of these are published in open access journals?	
How many of these are published in open repositories?	
To how many of these is open access not provided?	
Please check all applicable reasons for not providing open access:	
❑ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[12]: ……………	
15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*	-

16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	-
	Registered design	-
	Other	-

17. How many spin-off companies were created / are planned as a direct result of the project?	-
Indicate the approximate number of additional jobs in these companies:	

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

❑	Increase in employment, or	❑	In small & medium-sized enterprises
❑	Safeguard employment, or	❑	In large companies
❑	Decrease in employment,	v	None of the above / not relevant to the project

[11] Open Access is defined as free of charge access for anyone via Internet.
[12] For instance: classification for security project.

❑	Difficult to estimate / not possible to quantify		

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:*
Difficult to estimate / not possible to quantify	❑

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes ◙ No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes ◙ No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

❑	Press Release	❑	Coverage in specialist press
❑	Media briefing	❑	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
√	Brochures /posters / flyers	√	Website for the general public / internet
❑	DVD /Film /Multimedia	❑	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

❑	Language of the coordinator	√	English
❑	Other language(s)		

***Question F-10*:** Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES

1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]

1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)

1.3 Chemical sciences (chemistry, other allied subjects)

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)
1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY
2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)
2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]
2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES
3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)
3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)
3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES
4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)
4.2 Veterinary medicine

5. SOCIAL SCIENCES
5.1 Psychology
5.2 Economics
5.3 Educational sciences (education and training and other allied subjects)
5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES
6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)
6.2 Languages and literature (ancient and modern)
6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]

3 FINAL REPORT ON THE DISTRIBUTION OF THE European Union FINANCIAL CONTRIBUTION

This report shall be submitted to the Commission within 30 days after receipt of the final payment of the European Union financial contribution.

Report on the distribution of the European Union financial contribution between beneficiaries

Name of beneficiary	Final amount of EU contribution per beneficiary in Euros
1. NLR	
2. DLR	
3. ONERA	
4. INTA	
5. ILOT	
Total 5 beneficiaries	