THE LONG RANGE REGIONAL LINER

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1 Introduction

As the big hub airports become increasingly congested and the delay for the passengers increases, alternative solutions have to be found. One possible solution is to move the intercontinental segment of the air transportation market to the regional airports which are close the hub airport. This project set-up consists of two parts. The first part is the design of a small to medium size aircraft which is able to fly long range. The second part of the project is the completion of a business case in which the economical feasibility of the aircraft is investigated. The two parts are performed in parallel as the results of the business case are continuously implemented in the design of the aircraft.
The following requirements were established at the beginning of the project:

- Provide a viable feasibility study.
- The aircraft should be capable to transport 100-130 passengers with luggage.
- The aircraft should have minimum range of 10000 km.
- The aircraft should meet the latest regulations on noise and pollution.
- The operation of the aircraft should be competitive with the current way of travel via international airports.

These were translated into the following mission need statement:

"Conduct a feasibility study and design a long range aircraft capable of transporting approximately 100 passengers by using regional airports."

2 Conceptual design and trade-off

After the construction of a design option tree from which the obvious losers were eliminated, four possible concepts remained to be further investigated during the conceptual design phase. Two of them are conventional ones namely a modification of an existing aircraft and a conventional design from scratch, while a design based on the Prandtl-plane concept and a delta wing are more exotic.

The following approach was used. First some general parameters were established which are practically the same for all the concepts. Examples of these general parameters are the payload weight and fuselage interior requirements like the amount of m^3 one has to reserve for toilets and galley's etc. Also an initial weight estimation method was constructed which is used by all the concept designs so they can be compared on weight during the final trade-off.

Modification of an existing aircraft: LRRL-757 design concept

There are three possible options when choosing an aircraft to modify to the needs of the mission need statement: either an aircraft with similar capacity is modified to reach the desired range, or an aircraft with acceptable range is modified to have the desired capacity, or a combination of the two. A range of suitable donor aircraft was researched, from the airbus A319 to a Boeing 767-300. The most suitable aircraft was found to be a B757-200 as it is possible to replace space for payload with fuel to reach the required range. As the 757-200 can provide seats for 239 passengers, a part of the fuselage is cut out. Two cabin layouts, a business and an economy class, were created as can be seen in figure 1. In table 1 at the end of the section the dimensions and other characteristics of the LRRL-757 can be found.

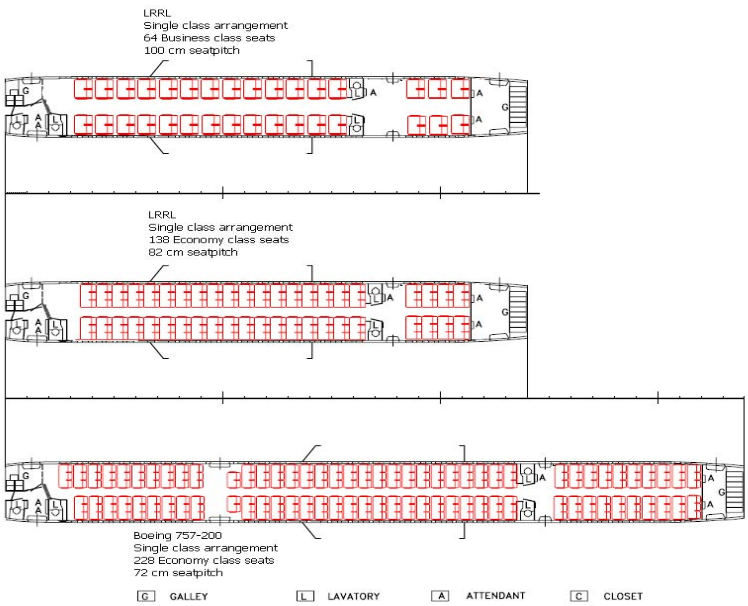

Figure 1: cabin lay-outs of the LRRL-757

Scratch design concept

The configuration of the scratch design is a very conventional one. It is very similar to the Boeing 757, with a low wing, wing mounted engines and a conventional tail. This design from scratch opted for a 4 abreast seating configuration which makes the fuselage longer in comparison with the modified design but this also reduces the wetted area which results in a lower drag. In table 1 the characteristic parameters of the scratch design concept can be found.

Prandtl-plane design concept

The Prandtl-plane design concept is one of the two exotic designs. A Prandtl plane is also known as a joined wing system. This system does not consist of a main wing together with a horizontal tail plane but consists of a front wing which generates 70% of the lift and a back wing which generates 30% of the lift. A concept drawing of the Prandtl-plane concept can be found in figure 2.

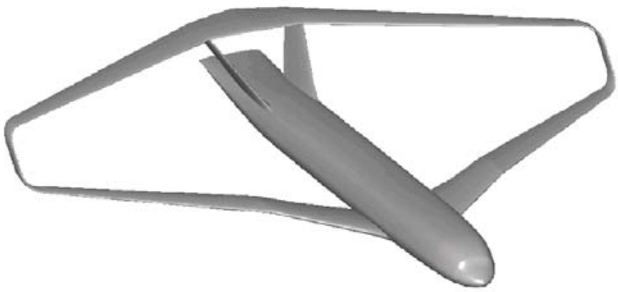

Figure 2: Prandtl-plane concept drawing

A literature study on the possible advantages and disadvantages of the Prandtl-plane concept in comparison with a conventional aircraft turned out the following results:

- lighter weight
- higher stiffness
- lower induced drag
- Good static stability and control
- higher buckling loads which result in a weight penalty
- existence of interference drag between the wings
- possible flutter problems which can result in a weight penalty

Delta wing design concept

A configuration based on the use of a delta wing is considered, because of the potentially high wing volume offered. There were three options for the configuration, namely:

- The aircraft cruises supersonically
- The aircraft cruises subsonically or supersonically at will
- The aircraft cruises subsonically

The configuration where the aircraft cruises subsonically was chosen since this fits the requirements. Furthermore, passenger aircraft may not fly supersonically over land which diminishes the economical feasibility of a supersonic configuration. The analysis of this configuration is particularly difficult due to the unavailability of data related to this aircraft. Because of this problem a reference aircraft is used, which is the Avro Atlantic. As statistical data is not applicable to this aircraft, it is the only way of giving an initial estimate of the weight. The characteristics of the Delta wing design concept can be found in table 1.

Weights	**Modify**	**Scratch**	**Prandt-plane**	**Delta**
MTOW [kN]	1113	1167	889	883
OEW [kN]	546	569	392	244
MLW [kN]	946	992	755	750
MAX Thrust [kN] per engine	222	252	190	445
Fuel [kN]	395	439	328	472
Performance:				
CL @ begincruise	0.622	0.642	0.438	0.200
CL @ endcruise	0.413	0.427	0.268	0.130
CL design, cruise	0.518	0.535	0.353	0.165
CL cruise (begincruise-endcruise)	0.209	0.215	0.170	0.070
cruise speed km/h	832	903	903	903
A/C dimensions:				
Fuselage length [m]	35	43	46	46
Fuselage width [m]	4.0	4.2	3.0	3.0
Fuselage height [m]	4.1	4.2	3.5	3.5
Slenderness, height/length [-]	0.116	0.098	0.076	0.076
Wing span [m]	38.1	37.3	20.3	33.2
wing surface [m2]	185	167	150	368
Fuselage:				
Cabin layout, seats abreast	6	4	4	4
Seat pitch [cm]	82	82	82	82

Table 1: Overview characteristics of the four concept designs

Trade-off

Before the trade-off can be carried out, a trade-off logic has to be created in order to perform the trade-off as objective as possible. Firstly, all the trade-off criteria are gathered and some of them are divided in sub criteria because a criterion can be made up out of multiple performance parameters which all have to be taken into account. Examples of these criteria are take-off/landing and cruise performance, stability, fuel efficiency, passenger comfort and available technology. The trade-off of these configurations is done per trade-off criteria. For each criterion, first the conventional aircraft is graded, after which the other configurations are compared to the conventional aircraft. In this manner it is possible to compare the different configurations both to a fixed grade, the conventional aircraft, and to the other configurations, as these are graded with respect to the conventional aircraft as well. Since a ten points scale (one worst, ten best) is used, a value of six is taken as a commonly accepted average. Each fluctuation around this value represents a favorable or unfavorable characteristic of the specific design.

From the outcome of the final trade-off it was not possible to directly conclude which configuration should be chosen for further investigation, as all except the delta wing are close to a score of 70%. However, when taken into account the level of detail and the related credibility that can be achieved for each configuration in the final phase of this project, a conventional design concept (which includes both the scratch- and modified design) will be the most logical choice as for these concepts the available technology scores very high. When also taking into account that both the Modify and the Scratch score a 6 or higher for all trade-off criteria, whereas the Prandtl-plane has lowest grading, which is a 4, an extra argument for choosing the conventional design is added.

3 Final design

In the last phase of the design synthesis exercise, the conventional design was detailed. In figure 3 a 3-view technical drawing can be found of the LRRL.
In the following section some important performance characteristics are explained in depth.

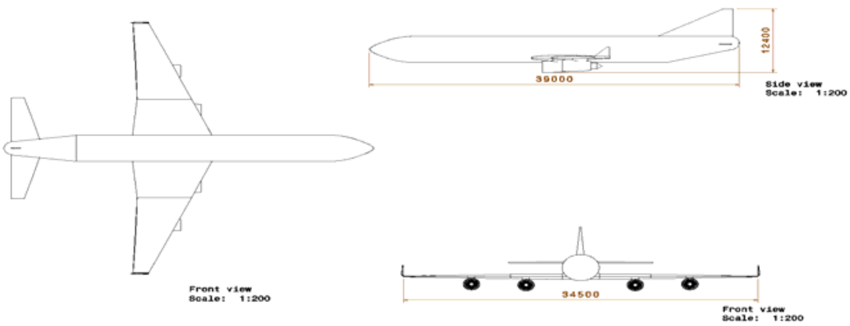

Figure 3: 3-view drawing of the LRRL

The performance

The performance of the aircraft is calculated by means of a Payload-Range diagram and the balance field length. To understand the relation between the weight fractions of the aircraft and the range it can fly, a weight-range diagram is constructed. The construction of the weight-range diagram is based on a climb flight to the cruise altitude of 11 km, one extra climb flight to be able to start a diversion flight and the cruise phase. The corresponding values for the SFC, thrust and speed are allocated to the flights climb and the cruise stages.

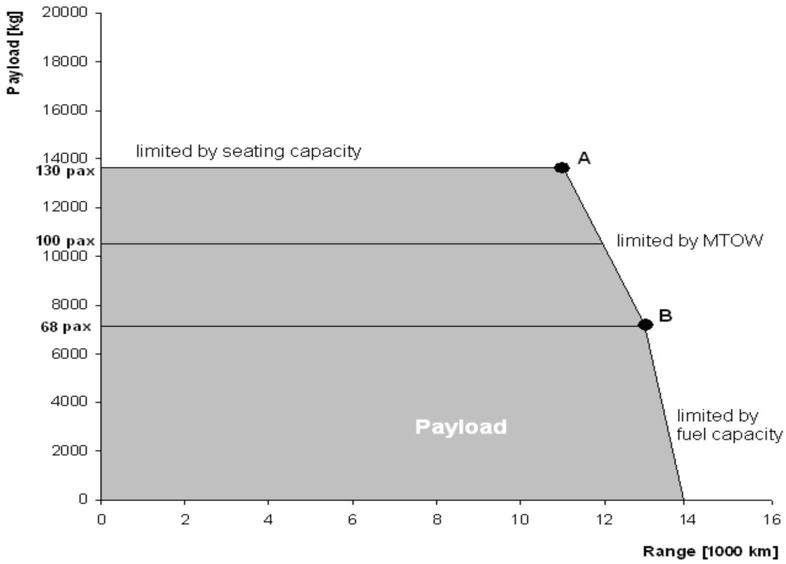

Figure 4: Payload-Range diagram

The Payload-Range diagram, figure 4, is built up by three main weights plotted against range. The lower horizontal line represents the OEW, which is constant over range because the aircraft configuration does not change. The following line indicates the maximum zero fuel weight (MZFW), which is the weight of the aircraft including the payload but without fuel. The top line is the TOW line, evolving into a horizontal line representing the MTOW and ending as the TOW line once again.

The second tool used for performance calculations is the balanced field length. As the aircraft has to take-off from regional airports which in general have shorter runways than hub airports, the balanced field length becomes an important criterion which the aircraft has to meet. From the performance calculation it became clear that the design point which was chosen on a $C_{L take\text{-}off}$ of 2.2 does not comply with the balanced field length criterion. When it is increased to 2.5 it does meet the balanced field length requirements, so it is set to that value which is taken into account when calculating the necessary flapped area of the wing. The V1 of the LRRL is equal to about 69 m/s. The balanced field length is situated on 1661 m.

4 Market implementation

The customer market for the LRRL can be divided into several sub markets: Traditional scheduled airlines (TSA), Low cost carriers (LCC), business travel market, charter airlines, leasing companies and cargo airlines. Especially the first three sub markets are particularly interesting for the LRRL. It estimated that 573 aircraft will be sold in a 5 year span.

Since the appearance of the low cost carriers, the focus of aviation on cost reduction is mainly on reducing indirect operating costs; therefore this category is not thought to bring significant cost gains anymore. In the nearby future, the cost of the actual flight operations, the direct operating costs (DOC), will therefore become more important. The main parts of DOC are the aircraft depreciation cost (DC), fuel cost (FC), labor cost (LC) and maintenance cost. To compare the financial performance of the LRRL and determine its economic viability, nine arbitrarily chosen long-haul flights are analyzed. To include load factors and different capacities specific to each aircraft, the obtained data is scaled down to represent a cost per passenger. This cost per passenger is then compared to the modeled cost of the same flight, only when performed with the LRRL.

One of the assumptions used in making this comparison is the fact that the load factor for existing networks is 0.75. As average load factors for an airline are in the range of 0.6 to 0.8, the value of 0.75 represents an established airline operating a profitable route. The load factor for the LRRL, however, is taken at 0.9, as the low capacity of the aircraft allows to get a higher load factor. Another assumption is that aircraft fly at their average cruise speed throughout the flight. They do not speed up or slow down during take-off or landing. This approximation is argued to hold as these flight phases are significantly shorter than the cruise phase on long-haul flights. Also delays haven't been taken into account. Although delays are common in the HS network, they are left out of consideration, as they are too unpredictable to incorporate in an analysis of this scale. To compensate for the fact that the LRRL cannot fly in a straight line to its destination because of ATC requirements/instructions, a 10% flight distance penalty is applied to the LRRL. In table 2 a comparison based on cost between the LRRL and the Hub and spoke network is worked out.

Aircraft type	Flight stage	Airport Charges Hub	Airport charges regional	Total cost per hour	cost per pax per hour	flight time per pax	Total DOC per pax
B738	PRG-AMS	-	$2,345	$11,524	$96	$2	$160
B747	AMS-KUL	$14,795	-	$44,906	$140	$12	$1,632
LRRL	PRG-KUL	-	$2,345	$16,736	$143	$12	$1,667

Table 2: A cost comparison between a HS-flight and the LRRL

From the market study follows that the LRRL will provide an average decrease in DOC of 20%. It also became clear that the LRRL can provide a travel time reduction of 43% in comparison with the HS-network.

5 Conclusions and recommendations

The LRRL is capable of carrying up to 130 passengers over 10000 km with a cruise speed of 900 km/h and can take off and land from regional or secondary airports that have a minimum runway length of 2200 m.

The final aircraft design consists of a conventional, low-wing aircraft, powered by four turbofan engines each delivering 105 kN. These engines, the PW6000, are newly developed and fall in the best emission class, living up to today`s as well as future noise requirements. They will enable flights into many airports that have curfews and noise quota, which are often imposed at secondary airports. The aircraft belly is only 1,5 m from the ground, enabling easy access and ground handling without the need for extra equipment. By incorporating overcapacity in the center fuel tank, it is possible to diversify the capabilities of the LRRL. Airlines can opt to decrease the number of passengers, exchanging passenger weight for fuel and thus extending the range. Other options for airlines include having a multi-class or all business class configuration and even a conversion to an all cargo version.

The LRRL is designed to operate in the point to point network, and will most likely take away 30% of the market away from the hub and spoke network. It is estimated that about 570 aircraft will be sold in the first 5 year. Even with the oil prices soaring to an all time high, the LRRL still offers an economical advantage over the current existing networks.

It should also be remarked that the LRRL is capable of flying on biojet with only minor adjustments to the structure and the engines.

With the ever increasing fuel prices it is important to fly as fuel economical as possible. Though the LRRL is designed to fly within the next ten years, the application of composite materials or a next generation of aircraft engines might be extremely beneficial to the aircraft as they have a direct influence on the structural weight and the amount of fuel that is burnt. This does not only enhance the economics of the aircraft but with less hazardous emissions, it will improve the sustainability of the aircraft and thus society's view on the LRRL. The progress of these technologies should be followed during the upcoming years, and their benefits for the LRRL re-analyzed.