AIRLINES FLEETS RENEWAL FOR GLOBAL SUSTAINABILITY

H. Karam[1], E. Anwama[1], L. G. Zelaya Cruz[2], H. Alfazari[3], F. Krykhtine[4], F. Mora-Camino[1,2,5*]

[1]Durban University of Technology, DUT - South Africa
[2]Universidade Federal Fluminense, UFF – Brazil
[3]Sohar University, Sultanate of Oman
[4]Universidade Federal do Rio de Janeiro, UFRJ – Brazil
[5]Ecole Nationale de l'Aviation Civile, ENAC, France

*** Corresponding author e-mail address**: moracamino@hotmail.fr

PAPER ID: SIT2288

ABSTRACT

In this paper, the resilience of an airline in the face of huge investment needs to get an impressive reduction of carbon emissions is considered. A hard scenario is considered where new national/international regulations are introduced with an immediate quota on flights and fleet and mandatory milestone for fleet upgrade. An original fleet upgrading optimization model is developed. The economic sustainability conditions attached to such a constrained situation and the forced fleet renewal program are established and financial and operational sustainability objectives are discussed.

Keywords: Aviation sustainability, Airlines Resilience, Fleet Renewal, Dynamic Programming.

1. Introduction

This study addresses the issue of the aviation sustainability which has become an essential issue for the aviation sector which is a direct polluter of the Earth's atmosphere through its emissions of CO_2, NO_x and other particles, noise as well as the creation of contrails contributing to the greenhouse effect. More than a decade ago, apart from aeronautical noise, reducing environmental impact was not a top priority for the aeronautical sector. In the last decade, aircraft manufacturers and airlines have faced increasing pressure from governments, customers, and investors to act assertively on environmental issues and to promote and achieve sustainable environmental goals and targets. It is considered that to reach audacious sustainability objectives in the next decades, new regulations and penalties will be applied to air transport operators and then new aeronautical technologies must be introduced to maintain the activity of this sector. This will have as consequence a rather complete renewal of civil aviation fleets in the next decades. Then airlines will soon be faced with the necessity to implement heavy investment programs for the renovation of their fleets, entailing significant financial costs which in turn could lead to higher ticket prices and a contraction in demand. The survival of airlines during this apparently turbulent period could be put seriously to the test.

In this paper, the resilience of an airline in the face of such high investment needs, but also in the face of the uncertainty with respect to future operational costs and demand, is analyzed.

A long-term fleet planning period is considered for a generic airline with her initial fleet, operated network, and demand. A hard scenario where new national/international sustainability regulations are introduced with an immediate double quota policy and two milestones:

1) The double quota is relative to flights and fleets: satisfied demand and operating fleet are immediately restricted to the levels of year base 1.
2) The milestones are such that after the first one, T_L, environment non-compliant aircraft operating will be subject to a penalty and after the second milestone, T_E, such aircraft cannot be sold to another airline to be operated elsewhere.

The economic sustainability conditions attached to such a constrained situation and the forced fleet renewal program are established and financial and operational sustainability objectives are discussed.

2. Methodology

The proposed approach is based on an oriented modelling of the airline operation. This means that at this stage of the study, part of the decision space available to an airline is frozen. In that case, the structure of the supply, represented here in an original way through monthly tours to take into consideration seasonal effects on the airline performance, is considered unchanged during the whole horizon of analysis. The same is done with demand, represented by flows between connections. This results in a constant revenue through the years while ticket prices remain untouched. Then the focus in this study is on the operation of the fleet and its changing composition to face as well as possible new environmental regulations with respect to carbon emissions. The adopted scenario is an extreme one, where before considering the introduction of more performant technologies with respect to carbon emissions, the traffic volume and air transport activity are limited to their values at the base year.

The aim of the proposed model is to investigate what could be a feasible timing for the upgrading of an airline fleet in such a context with the objective of achieving a relevant reduction of carbon emissions.

3. The proposed model

Here the time horizon considered in a monthly basis is *T* (several decades), starting from time t=1 (initial situation) and *t*= t^{th} year period, *m* = 1 to 12 are month numbers.

Operations assumptions

An airline operates in year *t* *FA* aircraft between a set *A*(*t*) of $|A(t)|$ airports from a single base where the maintenance operations of its *FA* aircraft are performed.

The offer of transportation service is composed of the multiple tours realized by each aircraft of the fleet during each month of a given year. Let *TR*(*t, m*) be the set of these tours with $r \in \{1, \dots, FA\}$. A tour is composed of a sequence of elementary flights with possible repetition during the month. Let *EF*(*t, m*) be the set of elementary flights offered by the airline during month *m* of year *t* and let *NEF*(*t, m ,r, f*) the number of times that flight *f* is present in tour *r*, $r \in TR(t,m)$.

Let *LC*(*t, m, r*) the set of connections offered by the airline to its customers in month *m* of year *t* and built from the flights of tour *r* (a connection realized in a tour may be composed of one flight or a succession of flights of this tour). Then, let *LC*(*t, m, r, l*) be the set of flights building connection *l*.

Let $\pi_l(t,m)$ be the ticket price (minus airport taxes) and $D_l(t,m)$ the satisfied demand for connection $l \in LC(t,m,r)$.

Let $CA_r(t)$ be the capacity in terms of passengers (only one class of passengers is considered in this study) of aircraft *r* at period *t*, it must be such as (capacity constraint for flight *f*):

$$NEF(t,m,r,f) \cdot CA_r(t) \geq D_l(t,m) \quad l \in LC(t,m,r), r \in TR(t,m) \forall t, \forall m \quad (1)$$

4. Costs and revenues from the fleet

The revenue of the airline for year *t* retrieved from aircraft *r* is given by:

$$R_r(t) = \sum_m \sum_{l \in LC(t,m,r)} D_l(t,m) \cdot \pi_l(t,m) \quad rTR(m,t) \quad (2)$$

The revenue of the airline for year *t* is given by:

$$R(t) = \sum_{rTR(m,t)} R_r(t) \quad (3)$$

Let the cost of flight *f* operated by aircraft *r* in year *t* (it is supposed here that it remains the same during a given year month by month) be given by $C_{fr}(t,t_r)$. Here t_r is the year at which the propulsive technology of aircraft *r* has been upgraded, then if $t < t_r$ the aircraft uses the older technology, cost C_{fr}^1 and, when $t \geq t_r$, it uses the new technology with eventually smaller operating costs C_{fr}^2 while performing flight *f*.

Then the total operations cost of aircraft *r* at year *t* is given by:

$$CO_r(t) = \sum_{m=1}^{12} \sum_{f \in EF(m,t)} NEF(m,t,r,f) \cdot C_{fr}(t,t_r)\, r = 1, \cdots, FA \quad (4)$$

The total operations cost of the airline for year *t* is such that:

$$CO(t) = \sum_{r=1}^{FA(t)} CO_r(t) + COV(t) \quad (5)$$

where it is assumed that:

$$COV(t) = \varphi\big(FA(t), D(t)\big) \quad (6)$$

$\varphi(.,.)$ being an increasing function of the fleet size *FA*(*t*) and of the total number of processed passengers *D*(*t*), with:

$$D(t) = \sum_m \sum_{l \in LC(t,m,r)} D_l(t,m) \quad (7)$$

At initial situation, all the aircraft of the airline use the same propulsive technology and carbon emissions with this technology is given by:

$$CE(t) = \sum_{r=1}^{FA(t)} \sum_{m=1}^{12} \sum_{f \in EF(m,t)} NEF(m,t,r,f) \cdot CE_{fr}(t,t_r) \quad (8)$$

Here if $t < t_r$ the aircraft uses the older technology, carbon emissions CE_{fr}^1 and, when $t \geq t_r$, it uses the new technology with less carbon emissions CE_{fr}^2, while performing flight *f*.

5. Economic assumptions

A long-term inflation rate *a* over *T* is considered for the surrounding economy. According to this inflation rate, corrected ticket prices and nominal operational costs are adjusted to maintain initial value:

$$\pi_l^c(t,m) = \pi_l) \cdot (1+a)^{t-1} \quad (9)$$

and

$$C_{fr}(t,t_r) = C_{fr}^1 \cdot (1+a)^{t-1} \text{if } t < t_r \quad (10.1)$$

$$C_{fr}(t,t_r) = C_{fr}^2 \cdot (1+a)^{t-1} \text{if } t \geq t_r \quad (10.2)$$

To acquire a new aircraft, it is supposed that the airline has to make a loan to be reimbursed all

along years of operation well beyond *T*. This loan is only possible if the level of the debt of the airline is expected to remain during the repayment period less than β times its capital value (with $\beta > 0$). It is supposed that the acquisition of aircraft *r* has resulted ($t \leq T_L \wedge willresult(t > t_r)$ in a fixed financial charge $L_r(t)$ for the airline:

$$\text{if } t < t_r \text{ , } L_r(t) = L_r^1 \text{ and if } t \geq t_r \text{ ,}$$
$$L_r(t) = L_r^2 \quad (11)$$

It is supposed that shareholders of the airline receive every year a return proportional to the annual net revenue with $0 < \mu < 1$:

$$RS(t) = \mu \cdot \big(R(t) - CO(t) - L(t)\big) \quad (12)$$

At time T_L, a new legislation about carbon emissions is enforced. It is such that:

3) By T_E ($T_L \leq T_E \leq T$) airlines must have renewed their fleet so that a new technology is adopted to operate their flights with reduced carbon emissions $CE_{fr}^2$with:

$$CE_{fr}^2 < CE_{fr}^1 r \in FA(t),$$

$$f \in EF(m,t), m\{1,\cdots,12\}, t \geq T_L \quad (13)$$

4) While this objective is not achieved at T_E by tour r, the airline (and others) has to pay every year a penalty $P_r(t)$ computed by:

$$P_r(t) = max\{\alpha \cdot R_r(t), P_r^{min}\} \quad (14)$$

This expression avoids the situation in which a tour has small revenues leading to an ineffective penalty, then the penalty will be at least P_r^{min}.
Then, if $t < T_E$ the financial charge is given by:

$$L(t) = \sum_{r=1}^{FA} L_r(t) \quad (15)$$

and if $t \geq T_E$, the financial charge is given by:

$$L(t) = \sum_{r:t_r<t} L_r(t) + \sum_{r:t_r \geq t}\big(L\big|\ \big|r(t)\big|\ \big| + P_r(t)\big) \quad (16)$$

It is supposed here that the lifetime of the initial fleet of aircraft is higher than *T*, so a minimal situation is the case in which no aircraft is renewed until *T*, then at T this airline is out of operation.
The new technology is characterized by parameters (capacity, operating cost (base year 1), carbon emissions): CA_r^2, CO_{fr}^2 and CE_{fr}^2. At time t_r (with $T_L \leq t_r \leq T$) an old aircraft *r* is removed from service and a new one with enhanced environmental technology enter in operations servicing connections *LC*(1, *m*, *r*), *m* =1 to 12.

6. The optimization problem

The considered optimization problem is stated at time T_L to establish a planning of the fleet renewal during the time horizon from T_L to *T*. Here the objective can be to maximize the present value of the return to the shareholders of the airline while different constraints are considered:

$$\max_{t_r, r=1,\cdots,FA} \sum_{t=T_L}^{T} RS(t) \cdot (1+a)^{-} \quad (17)$$

with the constraints:

$$\sum_{t=T_L}^{t=T} CE(t) \leq (1 - \varepsilon/100) \cdot \sum_{t=T_L}^{t=T} \sum_{r=1}^{FA(t)} \sum_{m=1}^{12} \sum_{f \in EF(m,t)} NEF(m,t,r,f) \cdot CE_{fr}^1 \quad (18)$$

$$\sum_{\tau=T_L}^{t} (1-\mu) \cdot \big(R(\tau) - CO(\tau) - L(\tau)\big) \cdot (1+a)^{-(t-T_L)} + R_{T_L} \geq K \cdot \sum_{r=1}^{FA} L_r(t) \cdot (1+a)^{-} \quad (19)$$

$$NEF(t,m,r,f) \cdot CA_r(t) \geq D_l(t,m)$$
$$l \in LC(t,m,r), r \in TR(t,m) \forall t, \forall m \quad (20)$$

$$T_L \leq t_r \leq Tr = 1,\cdots,FA \quad (21)$$

Constraint (18) imposes that the total carbon emission is reduced by at least $\varepsilon\%duringtheconsideredperiod$. Then, R_{T_L} is the initial financial reserve of the airline, *K* is an integer and constraint (19) is a financial condition for the airline to be able to acquire new aircraft. Constraint (20) is relative to the capacity which must remain sufficient to cope with the

planned demand in all its components, finally constraint (21) implies that by time T all the aircraft of the airline fleet have been upgraded.

7. Conclusion

The first issue to be tackled using this model is the feasibility issue: what is the maximum value of ε so that this problem is feasible? It appears easily that depending of the relative importance of the penalties $P_r(t), r = 1, \cdots, FA$ with respect to the difference of financial charges between two generations of aircraft, the aircraft should be upgraded as soon as possible (T_E), or as late as possible (T). The proposed problem does not adopt a standard formulation although it is a linear integer optimization problem (decision variables: $t_r \in \{T_L, T_L + 1, \cdots, T\}$ $, r = 1, \cdots, FA$). Different heuristics based on the productivity and pollution characterizing each tour, could be designed to get with limited calculation some acceptable solutions. The proposed model could be also integrated in a multilevel optimization process where the pricing of flights and penalties to aircraft are fixed. Finally, a new version of this model could incorporate demand reactiveness to prices to allow the design of a pricing policy associated with the fleet renewal process.

References

ATAG 2021, Balancing growth in connectivity with a comprehensive global air transport response to the climate emergency: a vision of net-zero aviation by mid-century, Waypoint 2050. Edition September 2021.

Ploetner, K., Rothfeld R., Urban M., Hornung M., Tay G., and O. Oguntona, 2017. Technological and Operational Scenarios on Aircraft Fleet-Level towards ATAG and IATA 2050 Emission Targets. AIAA Aviation 2017, Denver, USA.

Turan H. H., E. Sondoss and M. J. Ryan, 2020, A long-term fleet renewal problem under uncertainty: A simulation-based optimization approach, Expert Systems with Applications, Volume 145, 1 May 2020, 113158.

Belobaba P., A. Odoni and C. Barnhart editors, 2009, The global airline industry, AIAA, John Wiley and Sons.

.