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Flexibility within flight operations as an evaluation criterion for preliminary aircraft design

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ABSTRACT

Airlines explain the purchase of oversized aircraft by flexibility within flight operations despite potentially higher fuel consumption and operating costs. In this paper assessment and attributes of flexibility as a criterion is presented and evaluated. A survey was sent to airlines worldwide to explore the motivation for flexibility and desired aircraft characteristics, fleet structure, and flexibility parameters. The results show that flexibility is considered a vital feature and almost as important as direct operating costs. It is also shown that an aircraft's range capacity and commonality in particular facilitate many flexible applications. Overall, higher flexibility is accompanied by higher operating costs.

1. Introduction

The aircraft design process is based on a set of top-level aircraft requirements (TLAR) that define the design mission after which the specific aircraft is sized accordingly. Range, payload, cruise altitude, cruise mach number as well as the required take-off and landing distance belong to the most important requirements specified by particular customers (see Fig. 1). The actual and final transport capacity of the specific aircraft which is derived from the design process is usually represented by a payload-range-diagram. Demonstrating each range-payload-combination it envelopes all possible missions that can be flown by the aircraft (see Fig. 2). Apart from technical requirements economic factors like direct operating costs (DOC) are considered as absolutely essential for developing new aircraft designs so as to each design is evaluated by its economic performance. Today's air traffic is characterized by a strong market competition due to customers demanding a broad variety of services and an increasing pressure from rising costs and ecological regulations (Doganis, 2010). Airlines and other operators therefore pay attention to economic aspects in particular when purchasing new aircraft. To meet customers' expectations and market demands operators usually aim for a fleet composed of different types of aircraft, such as short and long distance aircraft developed by different manufacturers (Holdren, 2010).

However, the evaluation of flight data statistics indicates that many airlines operate a large number of aircraft outside the determined design space which might cause higher weights, operating costs, and emissions of greenhouse gases. Higher expenditures due to operations of larger aircraft on short distances and fewer payloads still are accepted by operators as long as the overall profitability is guaranteed or even increased.

Both the actual mission range and mission payload frequently deviate from the values fixed during the design process as a result of fluctuating passenger respectively cargo volume and changing flight plans. The American Research and Innovative Technology Administration (RITA) publishes data on flown distances, loaded payload and operated aircraft type of daily flight operations of the American air traffic.[1] The corresponding payload-range-diagrams of two common single-aisle aircraft are illustrated in Fig. 3 and Fig. 4 (Airbus A320-200 and Boeing 737–800 respectively).[2] For instance, a design range of 2000 NM as well as 2600 NM respectively and a design payload of 16,500 kg as well as 14,600 kg respectively have been defined in the design process for the aircraft A320-200. The payload and range distribution is plotted for both aircraft types to illustrate daily operations patterns (Airbus, S.A.S., 2013).

It clearly can be observed that most flights have been operated with maximum payload, or maximum number of passengers, since the majority of all flights carried about 12,000 kg of paid weight. In addition, most flights have been flown on relatively short distances of about 1000 NM which, in fact, cover many inner-European, inner-American and inner-Asian connections but deviate massively from the design value.

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[1] Data relating to the year 2010.
[2] Airbus A320-200 has been operated on 560,000 flights; Boeing 737-800 has been operated on 460,000 flights.

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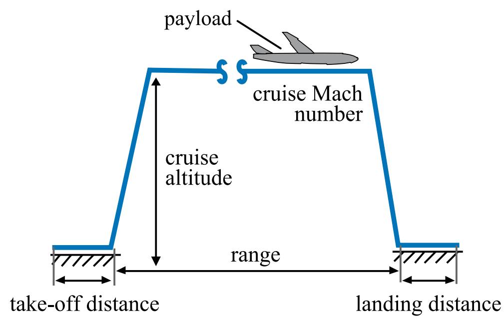

Fig. 1. Aircraft design mission and definition of top-level aircraft requirements.

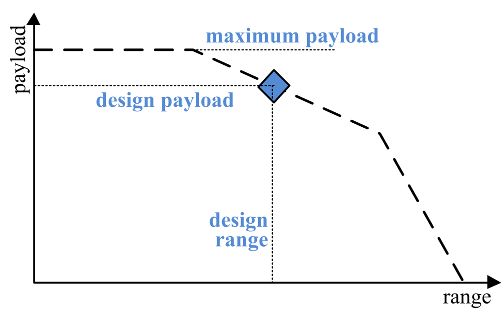

Fig. 2. Payload-range-diagram derived from design mission.

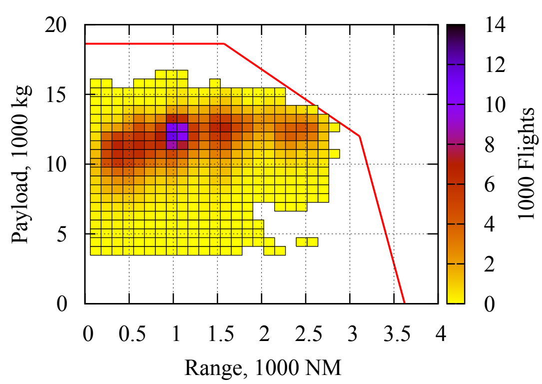

Fig. 3. Payload-range-diagram of Airbus A320-200.

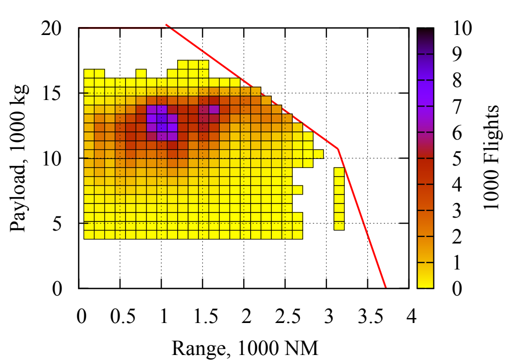

Fig. 4. Payload-range-diagram of Boeing 737-800.

Both illustrations demonstrate the initial presumption of operating oversized aircraft. Thus, it has to be assumed that airlines expect a certain level of operational flexibility that allows covering a broad market segment. More specifically, one aircraft must be operated on different connections serving variable numbers of passengers and cargo units. Furthermore, operating two single aircraft designed for different missions is expected to generate more expenses than one aircraft with flexibility. Here, flexibility is treated as an evaluation criterion by finding parameters that influence an aircraft's operational performance. Evaluating a survey answered by worldwide operating airlines is expected to elucidate the motivation for high flexibility. Particular attention is paid to different airline groups, such as national, regional and low cost carriers to identify potential differences.

2. Flexibility within flight operations

Aviation has unpredictable external influences, which affect the configuration of air traffic. Management of air traffic flows and demand is therefore considerably restrictive in contrast to other modes of transport such as trains due to the nature of unpredictable changes in work environment such as storms or strikes (Mensen, 2013). Moreover, an aircraft's capacity is limited to a certain amount of payload referring to passengers and cargo volume. Maintenance stops, unexpected failures due to system malfunction or changing regulations enforced by authorities are further issues that make fleet planning more difficult. To maximize potential profitability – the actual principal objective of each business enterprise – operators have to focus on current market demands so as to choose the right aircraft type on appropriate routes in the right time (Clark, 2007). When demand outmatches supply an exchange of the specific aircraft has to be made or, even worse, a second flight has to be offered. In this case, a degradation of the seat load factor is common, which leads to higher expenses. Consequently, operators require aircraft that are characterized by a high flexibility, thus, such aircraft that can be adapted to changing market conditions without much effort (Patterson et al., 2012).

2.1. *Definition of flexibility*

Flexibility generally is defined as the system's ability to meet exogenous requirements while ensuring retention of existing characteristics (Hanlon, 2007). In terms of aviation flexibility deals with an aircraft's potential of adapting its characteristics to changing requirements over time. In order to get a better understanding when defining flexibility it has to be distinguished between predictable and unpredictable events an aircraft is confronted with (Golden and Powell, 2000):

- Predictable events such as the aggravation of valid technical and environmental regulations are quite easily taken into account since there is usually sufficient time to plan ahead. Aircraft that are capable of being flexible towards those occurrences are classified as *versatile.*
- Unpredictable events complicate daily operations massively, since any reactions responding to those events must be simple to deal with. Aircraft that are capable of being flexible towards those occurrences are classified as *robust.*

Aviation flexibility therefore implies the scope of missions that can be flown efficiently over a broad range of flight speed, flight altitude, and flight distances while carrying various amount of payload. Depending on current demand of a specific route, the load factor can be increased easily while related operating costs are decreased. Consequently, operators attach increasing importance on operational flexibility when purchasing new aircraft (Armbruster, 1996; Boling, 2014; Patterson et al., 2012).

2.2. *Flexibility parameters*

Before evaluating operational flexibility particular specifications that have significant influence on an aircraft's flexibility must be identified first. However, in contrast to many other evaluation criteria, such as direct operating costs (DOC), there is no adequate criterion to measure or compare an aircraft's flexible constitution. Finding the actual level of flexibility therefore is rather difficult. Nevertheless, several