Aircraft Systems – Reliability, Mass, Power and Costs

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1 Introduction

Although *aircraft system design* is part of aircraft design, it seems not to be given much emphasis in *preliminary aircraft design*. Aircraft systems are considered briefly when it comes to aircraft mass prediction. The landing gear is taken account of in preliminary design, as is the problem of fuel storage. The type of flight control system (fully powered or manually actuated) may be considered. Anything else is often left to the level of more detailed design activities. **The aim of this paper is: To extend the view on aircraft system design beyond the preliminary aircraft design level** by stressing the focal points of aircraft system design: Reliability, mass, power and costs**.**

Significance of Aircraft Systems

The mass of aircraft systems accounts for about 1/3 of the aircraft's empty mass. Similarly, aircraft systems have a high economical impact: More than one third of the development and production costs of a medium range civil transport can be allocated to aircraft systems – and this ratio can even be higher in case of military aircraft. In the same proportion, the price of the aircraft is driven by aircraft systems. Aircraft systems account roughly for one third of the Direct Operating Costs (DOC) and Direct Maintenance Costs (DMC).

Historical Trends

Since the 1960th stability in aircraft silhouettes and general design concepts can be observed. Nevertheless, remarkable progress has been achieved since that time: In the same way as aerodynamics, structures, and power plants have been optimized, also aircraft systems have been gradually improved in economics, reliability, and safety. This has been made possible by a constant evolution and optimization through in service experience, research & development and also by employing new technologies. Probably the most important impact to the changes has been made by digital data processing.

2 Definition

Aircraft System:	A combination of inter-related items arranged to perform a specific function on an aircraft.

3 Breakdown

Aircraft systems are distinguished by their function. It is common practice in civil aviation to group aircraft systems according to **ATA iSpec 2200** successor of the well known Specification 100 of the Air Transport Association of America (ATA).

Table 1 Aircraft systems (**ATA iSpec 2200**)

identifier	**name of system**
21	air conditioning
22	auto flight
23	communications
24	electrical power
25	equipment / furnishings
26	fire protection
27	flight controls
28	fuel
29	hydraulic power
30	ice & rain protection
31	indicating / recording systems
32	landing gear
33	lights
34	navigation
35	oxygen
36	pneumatic
37	vacuum
38	water / waste
41	water ballast
44	cabin systems
45	central maintenance system (CMS)
46	information systems
49	airborne auxiliary power
50	cargo and accessory compartments

4 Certification

Certification requirements for aircraft systems of large aircraft can be found in various paragraphs of JAR-25 and FAR Part 25. The certification requirements are grouped into Subparts. Subpart F "Equipment" contains requirements for aircraft systems:

§ 1301 General
§ 1302 ... Instruments and Navigation
§ 1351 ... Electrical System
§ 1381 ... Lights
§ 1411 ... Safety Equipment
§ 1431 ... Miscellaneous Equipment (incl. Cockpit Voice Recorder, Flight Recorder)

Subpart E "Power Plant" also contains requirements for power plant related systems:
§ 951 ... Fuel System
§ 1195 ... Fire Protection (detection and extinguishing related to the power plant)

Subpart D "Design and Construction" contains requirements for aircraft systems:
§ 651 ... Flight Control
§ 721 ... Landing Gear
§ 771 ... Equipment / Furnishings (personnel and cargo accommodations)
§ 831 ... Air Conditioning (ventilation, heating, pressurization)
§ 851 ... Fire Protection (detection and extinguishing related to the cabin)

5 Safety and Reliability

The *safety requirements* for aircraft systems are stated in § 1309 of the certification requirements JAR-25 and FAR Part 25. The reliability $R(t)$ and the probability of failure $F(t)$ can be calculated from the failure rate λ

$$R(t) = e^{-\lambda t} \quad , \quad F(t) = 1 - e^{-\lambda t} \quad .$$

For low failure rates, as they are common in aviation, the probability of failure calculated for a period of one hour ($F(t)$/FH) equals almost exactly the failure rate λ. *Redundancy* is the existence of more means for accomplishing a given function than would simply be necessary. The *steady state availability* is defined as the probability that a system will be available when required, or as the proportion of total time that the system is available for use.

6 Mass

Mass estimation of aircraft systems is part of the mass (or weight) estimation of the whole aircraft. The mass of all aircraft systems m_{SYS} amounts to 23% ... 40% of the aircraft's operating empty mass. The figure "23%" is true in case of a modern long-range airliner, whereas 40% is about right for a smaller aircraft like a business jet. We follow a *top down approach* and get (**Scholz 2002**):

$$m_{SYS} = 0.92\, m_{MTO}^{\ 0.85}$$

for system mass m_{SYS} and maximum take-off mass m_{MTO} in kg .

Some aircraft systems, like the landing gear system (ATA 32) and the equipment and furnishings (ATA 25) account for a large percentage of total aircraft system mass. A number of systems are of minor importance for aircraft system mass predictions.

7 Power

Propulsive power for any conventional flying depends on fuel. This fuel is used in the aircraft main engines. *Secondary power* systems (hydraulic power, electrical power, pneumatic power) in turn draw on engine power to supply their client systems with *non-propulsive power* in all those cases where functions are not directly actuated by the pilot's muscles. Secondary power is also needed, due to safety requirements and the need for autonomous operation of the aircraft on the ground with engines shut down. Various *secondary power sources* are available in the air and on the ground: ground power, auxiliary power unit (APU), ram air turbine (RAT) and aircraft batteries. *Secondary power loads* may be grouped into two major categories: technical loads and commercial loads. *Power conversion* transforms secondary power from one form into another.

8 Costs and Trade-Off Studies

Trade-off studies play an important roll in the aircraft system design. *Trade-off studies* try to find the best among several system design proposals. *Safety* aspects allow no compromise because certification regulations have to be closely followed. Also *performance* aspects do not leave much room, for the reason that usually only as much performance as necessary to do the job will be allowed for. More powerful aircraft systems will unnecessarily produce *costs* – costs that add to the overall costs of the aircraft. Clearly, costs need to be reduced as much as possible to come up with a viable product. Therefore, it is the costs aspect that mostly decides in trade-off studies which system design will get on board the aircraft.

At the aircraft system level, evaluations are done in the early design stage by looking separately at various aspects:

- mass
- maintainability
- reliability
- system price
- other specific criteria depending on the aircraft system in question.

Based on these separate evaluations, the simplest way to come up with one single figure of merit for a proposal is to subjectively define a *weighted sum* of the results *based on* the *individual criteria*.

In contrast to the above approach, at the aircraft level an evaluation is traditionally based primarily on one single figure: the Direct Operating Costs, DOC. Also DOC take account of criteria like mass, maintainability, and aircraft price, but DOC combine these separate parameters unambiguously by calculating their economical implications. Subjective manipulations of the results are largely avoided in this way.

Unfortunately, aircraft DOC-methods cannot be taken "as is" to apply this advantage to an aircraft system evaluation. In contrast to aircraft DOC methods, a DOC method on the systems level must incorporate many system-specific parameters. Therefore, a *DOC method for aircraft systems* called DOC_{SYS} has been developed (**Scholz 1998**) which follows the principles of aircraft DOC methods as closely as possible, while taking aircraft system peculiarities into account as much as necessary.

In contrast to the method outlined above, a method by **Shustrov 1999** combines system mass effects and effects related to the system's energy consumption to a quantity called *starting mass*.

Literature

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