

Small Airplane Considerations for the Guidelines for Development of Civil Aircraft and Systems

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ABSTRACT

On September 30, 2011, certification authorities released Advisory Circular 20-174[1], *Development of Civil Aircraft and Systems*, which recognizes the Society of Automotive Engineers (SAE) Aerospace Recommended Practice (ARP) 4754A and the European equivalent ED-79A [2], in order to address “the concern of possible development errors due to the ever increasing complexity of modern aircraft and systems.” ARP4754A/ED-79A describes a process of development assurance which helps reduce the risk of design errors in the development of aircraft systems. This process is necessary for complex systems not easily comprehended by deterministic analyses or tests.

This ARP was developed “in the context of Title 14 of the Code of Federal Regulations (14 CFR) part 25,” a category which includes complex systems such as full fly-by-wire flight controls. However, this paper shows that such systems are the exception to most, recent civil airplane designs. Of new airplanes designed in the last 10 years, most implement systems which are simple and easily comprehended. Many of these simpler aircraft are in the part 23 category, which the AC also associates to this ARP. This paper shows that the ARP, as written, does not consider simple systems and may unnecessarily burden the development of such systems through this lack of recognition.

This paper reviews the current diversity of system complexity, discusses the regulatory and technical drivers for this diversity, and provides recommendations for incorporating such considerations in the ARP while preserving its original intent.

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INTRODUCTION

Revision A of ARP4754/ED-79 broadened that document's scope beyond the former boundaries of “highly-integrated or complex aircraft systems” to encompass the development of all aircraft systems, no matter their characteristics. It explicitly associates rigorous development assurance activities to these systems' maturity starting from the perspective of the aircraft down to that of its systems' components/items. The ARP does so by providing a method to document that the aircraft functions and requirements are appropriate and are implemented correctly as they are passed from the aircraft to systems and then again down to those systems' items. At the item level the ARP interfaces with development processes such as those described by RTCA/DO-178B/ED-12B *Software Considerations in Airborne Systems and Equipment Certification* [3] and RTCA/DO-254/ED-80 *Design Assurance Guidance for Airborne Electronic Hardware* [4].

This explicit understanding of aircraft functions and their related system functions and requirements is fundamental to insuring that the implementation is correctly addressing aircraft needs, and that no errors are being made as the levels of detail increase. This perspective is particularly important with systems that utilize multiple systems interactions to produce an aircraft level function or that participate in multiple aircraft functions where these system behaviors and interactions may become too complex to be easily understood. The ARP is focused on mitigating the concern that increasingly complex systems will yield a greater opportunity for design errors.

To prevent these errors, the revised scope of ARP4754A implies an assumption that all aircraft systems are or will be complex or highly integrated in the near future. The ARP contains several references to a trend of increasing integration between aircraft functions and systems. While the concern regarding errors in the development of complex and integrated systems is valid, the perception that all systems

will soon follow this complexity trend is shown in this paper to be questionable. Unlike the ARP, advisory material related to processes which interface with ARP4754A, which are also concerned with the growing complexity of systems, recognize and provide an alternate path for simple systems.

Simple systems include cable operated flight controls, wheel brakes without anti-skid functionality, and non-FADEC engines. This paper shows that in general current civil airplanes embody such systems for the sake of size or may consist of a combination of simple and complex systems for robustness. The combination of simple and complex systems is often implemented as a means to provide architectural dissimilarity for aircraft level functions. Such high level dissimilarity is obvious and easily understood from its initial design definition and may be considered more robust than following a path of redundant, complex, and integrated systems for the same function.

Protecting against design errors for complex systems is warranted, but a path regarding simple systems would ensure these more reliable and simple systems are not replaced with systems which are made more complex to fulfill the process needs of auditable "artifacts." The ARP can and should still provide methods for adequate safety coverage of highly integrated or complex systems while also supporting traditional techniques for simple systems. Such considerations will also prevent AC20-174 from conflicting with 14 CFR Part 23 regulations and guidance including the latest revision of AC23.1309-1E, *System Safety Analysis and Assessment for Part 23 Airplanes* [5], and the depth of analysis flow chart in the Systems Design and Analysis Harmonization Working Group recommended version of AC 25.1309-1B, *System Design and Analysis* [6], which are discussed later in this paper.

This paper investigates the current state of system complexity, mainly between part 25 and part 23 airplanes, and examines the drivers of that system diversity. It will discuss the association of ARP4754A to those drivers and recommend methods to include these complexity considerations into the ARP.

SYSTEM COMPLEXITY STUDY

Understanding the state and trend of system complexity in civil aviation is critical to understanding the applicability of ARP4754A. The ARP clearly states that it was written from the perspective of the part 25 category, which is reflected in there being only two part 23 companies represented of the 57 persons mentioned in its acknowledgments. This bias in perspective may have set up the recommended practice in such a way that it inherently challenges its potential association to part 23 and other parts. By understanding the state of system complexity between these parts and its drivers, this paper will identify how the ARP may be improved to better accommodate this range of system complexity.

To understand the trend of complexity in aircraft systems, a quantification of that attribute must be made. In July of 2009, the FAA released *Part 23 - Small Airplane Certification Process Study* [7] with the intent to "assess the adequacy of the current airworthiness standards throughout a small airplane's service life while anticipating future requirements." A portion of the study is dedicated to the discussion of the diversity of systems which can be found in the part 23 category. It finds that this varied set of aircraft can be grouped into three major categories:

1. Low Performance, Low Complexity,
2. Medium Performance, Medium Complexity, and
3. Unlimited Performance, Unlimited Complexity.

The challenge with the study is that it does little to quantify this "complexity," and in fact, gives the same example (Conventional Flight Control System (Cables, Pushrods, etc.)) for both the Low and Medium Complexity flight control systems, while merely stating "unlimited" in the final category. The relevance of the study and its association to ARP4754A/ED-79A is the recognition that part 23 does have the widest range of system complexity among the certification categories potentially affected by AC20-174 and the ARP. A more quantifiable understanding of this complexity helps to justify the consideration of simple versus complex within the ARP.

As mentioned previously, there are several systems, including flight controls, propulsion, fuel, and brakes where the inability to differentiate complex from simple systems could have unintended consequences. A study of airplane flight control systems was selected as a means to establish a complexity scale. Airplane flight control systems are of particular interest because they are in all cases safety critical, share a set of common aircraft level functions between both part 23 and part 25 categories, and embody a range of complexity from single pilot, manually-powered systems to dual pilot, fully powered, full fly-by-wire systems. The following discussion provides perspective of the current state of system complexity and its primary drivers through the following investigations:

- A survey of part 23 and part 25 flight control systems on airplane designs certified in the last 10 years.
- A study of regulatory and guidance material complexity drivers
- A discussion of the state-of-technology which drives flight control system complexity.

A Study of Flight Controls Systems of Recently Certified Airplanes

Over the past 10 years, 2002 through 2012, there have been 42 unique, first issuances/revisions, Type Certification Data Sheet (TCDS) issued to the aircraft parts (not including engines and propellers) that would have been impacted by



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AC20-174. Of this set, 23 TCDS's (52%) were issued to part 23 aircraft as shown in [Figure 1](#).

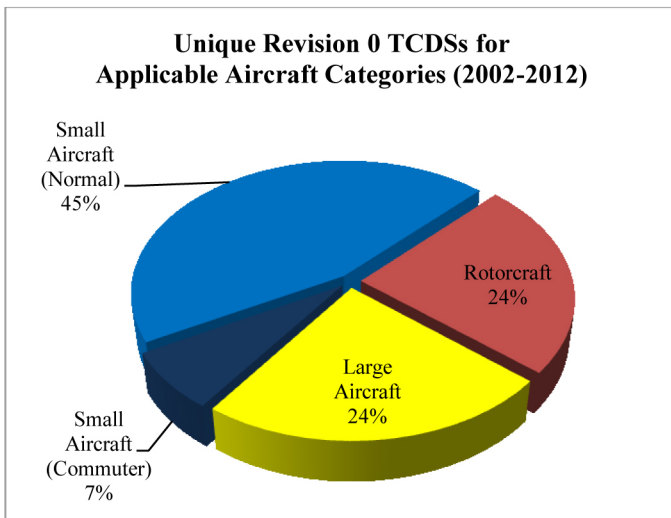


Figure 1. Unique Revision 0 TCDSs from 2002 to 2012 by Aircraft Category

Reflective of the FAA's study, this set of part 23 aircraft exemplifies a range of system complexity. To ensure a complete array of system complexity would be represented in this paper's study, the entire range of part 23 (52%) and part 25 (24%) revision 0 TCDS's was chosen for analysis.

Complexity can be characterized by a number of variables including functionality, interactions, redundancy, etc. The quantification method for this study scored each aircraft by the means by which the design provided power and control to common types of flight control systems. The scoring method was applied to a subset of the revision 0 TCDSs-aircraft with publicly available flight control system descriptions.

Common flight control system types were identified on a relative scale. While not all aircraft evaluated need to implement all system types, there should be no system type which is not listed. For example, not all aircraft need to implement slat systems, but slat systems should be represented for those that do. The ten common flight control system types used were:

- Ailerons
- Aileron trim
- Rudder
- Rudder Trim
- Elevator/Stabilator
- Pitch Trim
- Slats
- Flaps
- Spoilers

• Speed Brakes

For this study thrust reversers, thrust attenuators, nor reverse pitch propellers, which can be categorized as "thrust controls," were not considered part of the flight controls system.

Through the evaluation, it was discovered that indeed not all system types were found on all aircraft, and as Maximum Takeoff Weight (MTOW) decreased so did the number of those implemented system types. This finding is an indication of the diversity not only of system complexity but of aircraft level functionality important to ARP4754A/ED-79A. The evaluation also confirmed that none of these aircraft had flight control systems which were outside of the identified types, though some implementations may be more complex than others. Since this categorization was a general grouping of system types, all types scored similarly no matter how many control surfaces, independent control channels, or control means were part of that system type. This generalized approach means the mechanisms which move the single aileron surfaces on each wing of a Diamond DA42 would have the same scoring basis as the mechanisms which control the multiple left and right aileron surfaces on an A380.

For each system type, an aircraft was then scored based on very general system characteristics. These characteristics were the two ways for the aircraft to acquire points:

1. the system type being powered and
2. the manner by which the system type was controlled.

If a system type was powered hydraulically or electrically, it received one point. The consideration of powered verses unpowered controls implies specific complexities in an aircraft's power distribution systems. Instead of evaluating those power distribution systems directly for interdependence, any aircraft flight control system with any association to a power source was equally scored towards being complex even if the power sources may have been different types (electrical or hydraulic) or independent origins. This scoring was biased toward an assumption of higher complexity than may be implemented on a given aircraft.

If a system type was controlled electrically or electronically, as opposed to mechanically, it received one point. This distinction is necessary since there are several flight control systems which are powered, yet mechanically controlled. Mechanically controlled systems tend to be federated systems due to the mechanical complexity, weight, and volume challenges of mechanical mixing. Electronically controlled systems, however, have a greater opportunity to share common resources. This study did not evaluate if all electrically or electronically controlled systems types on a given aircraft actually shared common computing resources, but the scoring did not differentiate between interdependent computing systems and simple circuits. Therefore, despite the fact that the Cessna Citation Mustang has simple electrical aileron trim, rudder trim, pitch trim, flaps, and speed brakes with no common computing hardware, the scoring

association between these systems is the same as for those types on the Boeing 787 and the Airbus A380. This scoring characteristic shows that this evaluation, like that of the means of power, skewed towards a higher complexity determination.

The points for the power and control of each type were summed for each aircraft. Zero points were given to system types which were not present on the aircraft. In total, the most complex flight control systems—full fly-by-wire aircraft—could tally a maximum of 20 points, and the simplest systems—fully mechanical flight controls—could tally a minimum of 0 points. To illustrate the diversity of complexity across small and large airplane categories over the last 10 years, these scores were plotted against each aircraft's certified MTOW, shown in Figure 2; the data presented is available in the Appendix.

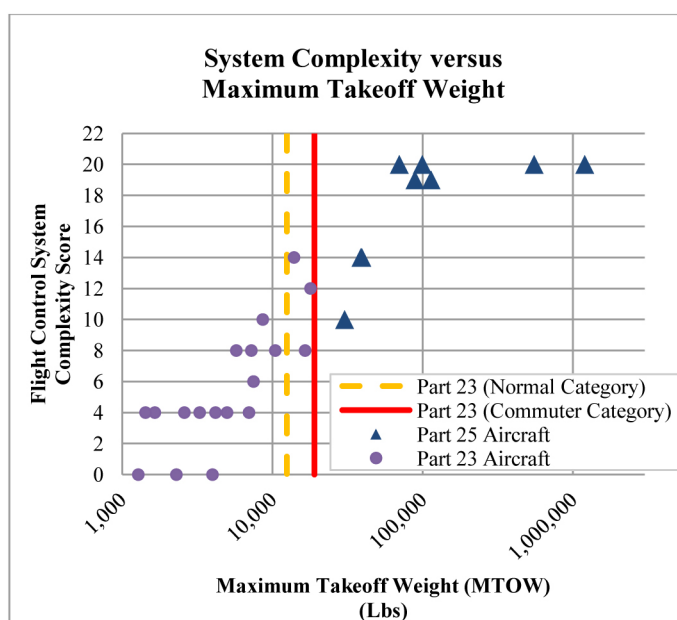


Figure 2. System Complexity vs. Maximum Takeoff Weight

Figure 2 demonstrates that, despite the biases inherent in this evaluation towards a higher complexity score, the majority of recently designed airplanes are neither highly complex nor integrated. In fact, system types on aircraft receiving 6 points or lower in general represent aircraft with conventional mechanical and analog electromechanical flight control systems. These electromechanical systems are normally trim systems and flap systems that use limit switches. These systems are typically no more complex than a doorbell or garage door opener. It should be noted that not all part 25 aircraft achieved a score of 20; three even scoring the equivalent or lower complexity to some part 23 commuter aircraft.

To identify a trend in the growth of complexity, these scores were plotted against the TCDS issuance date, as shown in Figure 3. While the few part 25 data points may roughly be considered a trend, the part 23 data set clearly has no

discernable tendency. The study of regulatory drivers of system simplicity which follows this section demonstrates that this simplicity may persist so long as the rules remain as written.

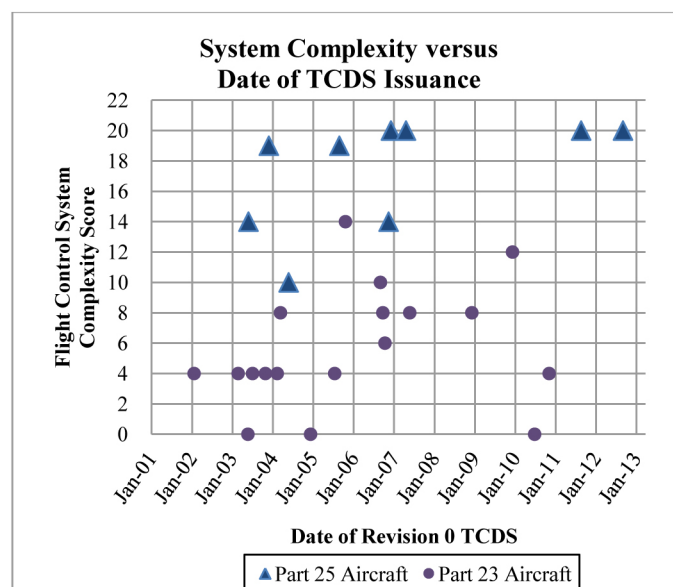


Figure 3. System Complexity vs. TCDS Issuance Date

Regulatory and Guidance Drivers of Flight Control System Complexity

For flight control systems and many others, the regulatory differences between part 23 and part 25 are key drivers towards the diversity of systems described above. Part 23 is geared towards simpler flight controls systems which accommodate the category's aircraft size and performance. Similarly, associated advisory and guidance material support more traditional approaches to developing those simpler systems. An overview of these drivers reveals the governing landscape within which ARP4754A must operate to be useful to part 23 and systems with mixed levels of complexity. This section will focus on how these regulations and supporting material interact with system designs and the ARP implications of those interactions.

Regulations which drive simple flight control systems

A significant difference between part 23 and part 25 aircraft is the need for a second in command. According to 14 CFR 91.531 [8] a second in command is not required for part 23 Normal category aircraft or part 23 Commuter category aircraft so long as the aircraft “has a passenger seating configuration, excluding pilot seats, of nine or less ... if that airplane is type certificated for operations with one pilot.” Part 135 has a complementary rule to this stating “No certificate holder may operate an aircraft without a second in command if that aircraft has a passenger seating configuration, excluding any pilot seat of ten seats or more.”