3 Requirements and Certification

3.1 Origin of Requirements for Aircrafts

Requirements for aircrafts originate from the flight mission the aircraft has to achieve. The flight mission follows from *market research*, *customer requests* and through *consultations with potential customers* (see Section 1). Apart from the aircraft performance, most important are two figures that are key to civil aircraft requirements: payload, m_{PL} and range, R.

Payload – as the name implies – is everything that gets transported for money. Payload comprises of

1. number of *passengers* to be transported (number of seats in each class)
2. mass and volume of *carry on baggage* per passenger (in each class)
3. mass of *check in baggage* per passenger (in each class)
4. mass of (additional) *cargo* as there is:
    - cargo on main deck
    - cargo on lower deck
        i. in container
        ii. on pallet
        iii. as bulk cargo

Range is the distance that an aircraft can fly under defined (practical) conditions considering sufficient fuel reserves. Required range depends on the average and longest stage length the aircraft is intended for.

There are different ways to determine payload/range requirements. Three approaches are discussed here. In practice these three approaches are not strictly separated, but are rather different sides of the same object.

1. Analysis of the seat-range diagram,
2. Analysis of the route network of an airline,
3. Analysis of a full market survey.

3.1.1 Analysis of the Seat-Range Diagram

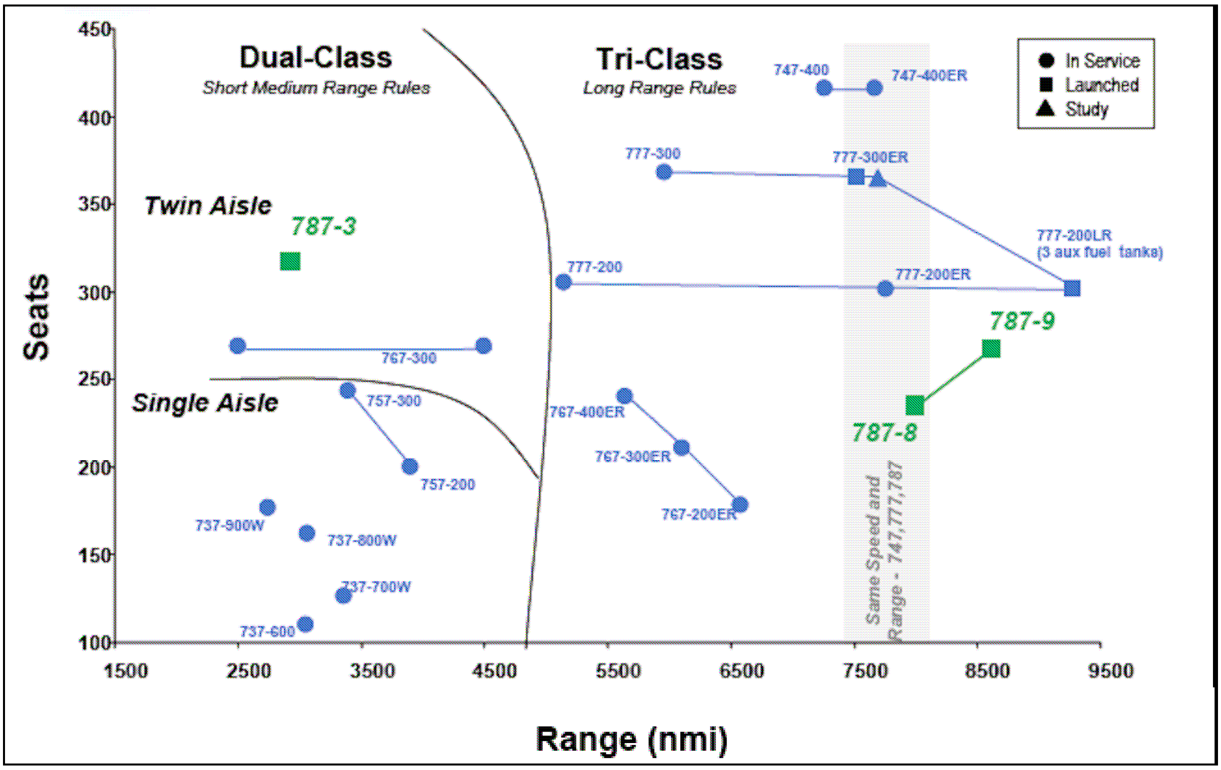

Fig. 3.1 Seat-range diagram of Boeing aircraft (**Boeing 2007**)

The seat-range diagram (**Fig. 3.1**) shows the number of seats of an aircraft versus its aircraft range. Many aircrafts are shown in the same seat-range diagram. A quick view on the diagram reveals which combinations of "number of seats" and "range" is not covered. These void areas may warrant a newly designed aircraft or a variant of an existing one in form of a stretch or shrink. However, reasons may be present for a void in the diagram. So these questions demand an answer:

1. Are there technical or economic reasons for the void?
2. Is it possible to overcome these past problems?
3. Are there enough city pairs for the identified range?
4. How many passengers are likely to fly these city pairs?
5. How much are these passengers prepared to pay for the flight?
6. Can enough traffic be generated that a new aircraft design is justified?

A large aircraft manufacturer will try to cover the whole seat-range design space with its products. Starting from limited aircraft types and limited fuselage cross sections the design space will be covered with *stretched and shrunk derivatives* to account for different payloads (number of seats). *Extended range versions* will account for range requirements. In this way an aircraft family is generated that offers much flexibility to customer's needs.

In order to offer optimal fitting products, the difference in seat numbers from one aircraft in the family to the next may not be too big. On the other hand, it is not economic to built to many different types. Therefore note:

Aircraft families have proved to be economical if the number of seats is increased from one model to the next bigger one by 20 % ... 25%.

3.1.2 Analysis of the Route Network of an Airline

Looking just at one or a few airlines, it may be a good idea to analyse a selected part of the route network and to derive requirements for a proposed new aircraft from the findings. Of interest could be either the regional, internationalen oder inter-continental route network depending on the proposed aircraft in question.

Data of interest are passenger demand and *distance of the city pairs*. The demand has to be divided by the number of flights per day to yield the *average passenger demand per flight*. If for regional flights several flights are offered during the day, flights in the morning and the evening are under heavy demand, whereas flights in the middle of the day are less sought after.

Load factor
It would be unrealistic to expect that an aircraft is always 100 % occupied. This is simply not possible for logistic reasons. Reversely this means that an aircraft has to be selected can carry more than the average number of passengers to be transported. An important economic figure is:

load factor = sold payload / offered payload

The load factor is higher with longer range. Long haul flights are more economical. The load factor also depends on general traffic demand and hence on the global economy (**Fig. 3.2**).

Range flexibility
We need some flexibility when it comes to the number of seats. Very similar also range flexibility is needed. The airlines wish to have aircraft that can not only fly the average mission but also some missions with longer flight distances.

range flexibility = aircraft range / demanded flight distance

Range flexibility is quite large on short range aircrafts: up to 4 or 5. Long range aircrafts make better use of their capabilities and show range flexibilities of only 2 to 3.

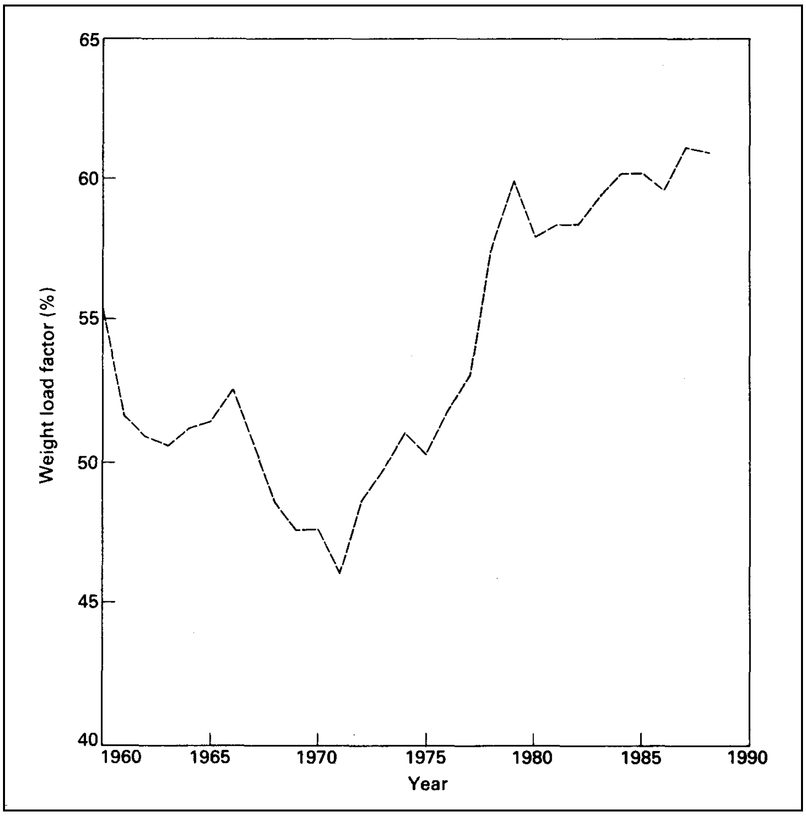

Fig. 3.2
Average load factor calculated from all ICAO - airlines 1960 bis 1988 (**Doganis 1991**)

3.1.3 Analysis of a Full Market Survey

Detailed market studies yield the best data for strategic company decisions for or against an new product. These studies are based on large computer models consisting of two main parts:

- generic forecast,
- product forecast.

Generic forecast

The generic forecast estimates the demand of new aircrafts for the worldwide fleet of aircrafts. The results are published for different aircraft sizes, and time intervals. A generic forecasts is built up in 6 steps:

1. traffic forecast expressed in revenue passenger-kilometers (RPK). RPK depend on the gross national product (GNP) and the estimated future revenues of the airlines in US$/RPK.
2. different growth rates on different routes
3. growth limits due to capacity limits at airports

4. replacements of older aircraft?
5. larger aircraft or more flights?
6. with 1 to 5: calculation of required number of new aircraft:
   1. in each seat category
   2. during selected time interval

Continuous growth also for the next years will be at 5% for passenger flights and even a little more for cargo flights.

Product forecast

The product forecast estimates the percentage one aircraft manufacturer will claim from the global demand for new aircrafts. The product forecast consists of 6 steps:

1. Evaluation of *aircraft performance* (payload, range, take-off distance, ...)
2. Evaluation of *aircraft economics* (DOC, ...)
3. Evaluation of *sales support* (export garanties, lease possibilities, ...)
4. Evaluation of *product development* (aircraft family, reported new aircraft types, ...)
5. Evaluation of *manufacturer* (image, product support, ...)
6. Evaluation of *political sales support*.

3.2 Calculation of Required Payload

Payload m_{PL} is calculated from:

1. number of seats n_{seat}
2. mass of cargo m_{cargo}

$$m_{PL} = m_{PAX} \cdot n_{seat} + m_{baggage} \cdot n_{seat} + m_{cargo} \tag{3.1}$$

Table 3.1: Assumptions on mass of passengers und their baggage (**Roskam I**)

average mass of	short and medium range	long range
passenger, m_{PAX}	79.4 kg	79.4 kg
baggage, $m_{baggage}$	13.6 kg	18.1 kg
Sum	93.0 kg	97.5 kg

3.3 Payload-Range Diagram

The dependencies of payload and range are depicted in the payload-range-diagram. It is based on

$$m_{TO} = m_{OE} + m_F + m_{PL} \tag{3.2}$$

with

m_{TO} take-off mass,

m_F fuel mass,

m_{OE} operating empty mass.

A generic payload-range diagram is **Fig. 3.3**

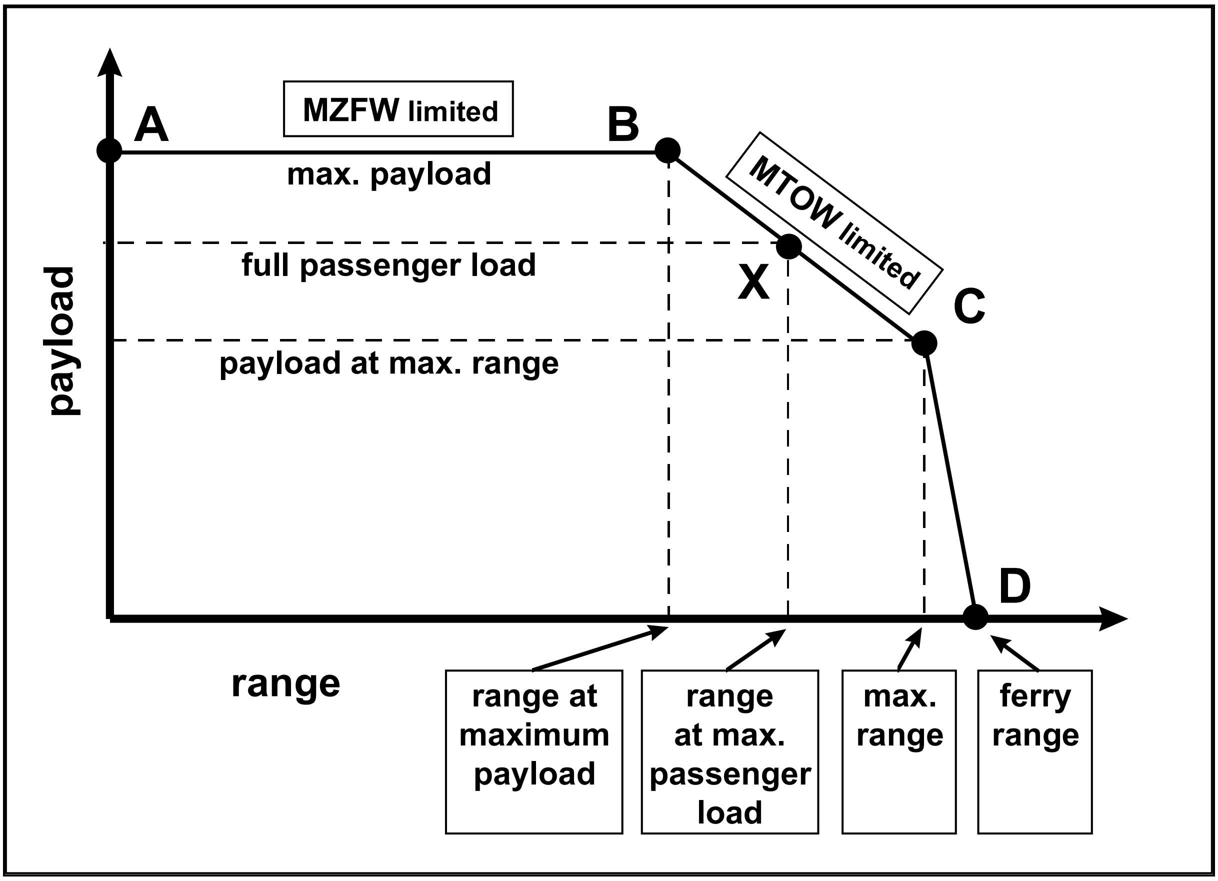

Fig. 3.3 Generic payload-range diagram

MZFW limits between points A and B

An aircraft must not exceed a maximum payload, m_{MPL}. Otherwise loads, like the wing bending moment at the wing root, would get too high.

Point A: Range = 0 NM (theoretical), no fuel is necessary. Take-off mass would equal maximum zero fuel mass, m_{MZF}.

Point B: Maximum take-off mass, m_{MTO} may not be exceeded. The fuel mass is $m_F = m_{MTO} - m_{OE} - m_{MPL}$. The fuel yields the *range at maximum payload*.

MTOW limits between point B and C

Payload gets exchanged for fuel: with increased fuel to longer range.

Point C: *maximum fuel mass*, m_{MF} is on board. m_{MF} depends on available tank volume. Payload at this point is *payload at maximum range* and is calculated from $m_{PL} = m_{MTO} - m_{OE} - m_{MF}$. The longest range for a commercial flights.

OEW limits at point D

The aircraft can fly further even without additional fuel. This is possible because a lighter aircraft uses less fuel.

Point D: Of importance for ferry flights (without payload)
Point X: Range at full passenger payload.
This is in general the design point for preliminary sizing.

The payload-range diagram is constructed by drawing straight lines from point A to B, C and D.

3.4 Certification

Certification requirements are important for aircraft design. An aircraft may only be operated if it is certified. That in turn demands the observation of certification requirements.

After World War II German aircraft were certified based on US-American regulations the *Federal Aviation Regulations* (FAR). The other European countries had there own certification regulations. In order to reduce expenditure of time and money, Europe started to harmonize its certification specifications in the 70s. The *Joint Aviation Regulations* (JAR) were written based on the FAR with some modifications especially by the *British Civil Airworthiness Requirements* (BCAR). In 1983 the BAe 146 has been the first aircraft certified by JAR-25. **Table 3.2** shows a list of JAR. Recently the European Aviation Safety Agency (EASA) was founded. The *certification standards* stayed the same but are now called CS.

Table 3.2 Regulations of the Joint Aviation Authorities

JAA MAINTENANCE AND AIRWORTHINESS PUBLICATIONS	
JAR-1	**DEFINITIONS AND ABBREVIATIONS**
JAR-21	CERTIFICATION PROCEDURES FOR AIRCRAFT AND RELATED PRODUCTS AND PARTS
JAR-22	SAILPLANES AND POWERED SAILPLANES (Basic Code Luftüchtigkeitsforderungen für Segelflugzeuge und Motorsegler)
JAR-23	**NORMAL, UTILITY, AEROBATIC, AND COMMUTER CATEGORY AEROPLANES** (Basic Code FAR Part 23)
JAR-25	**LARGE AEROPLANES** (Basic Code FAR Part 25)
JAR-27	SMALL ROTORCRAFT (Basic Code FAR Part 27)
JAR-29	LARGE ROTORCRAFT (Basic Code FAR 29)
JAR-36	AIRCRAFT NOISE
JAR-145	APPROVED MAINTENANCE ORGANISATION
JAR-APU	AUXILIARY POWER UNITS (Basic Code TSO C77a)
JAR-AWO	ALL WEATHER OPERATIONS
JAR-E	ENGINES (Basic Code BCAR Section C)
FCL-1	FLIGHT CREW LICENSING (AEROPLANE)
FCL-3	FLIGHT CREW LICENSING (MEDICAL)
JAR-P	PROPELLERS (Basic Code BCAR Section C)
JAR-STD	1A AEROPLANE FLIGHT SIMULATORS
JAR-TSO	JOINT TECHNICAL STANDARD ORDERS
JAR-VLA	VERY LIGHT AEROPLANES
JAR-OPS Part 1	**COMMERCIAL AIR TRANSPORTATION (AEROPLANES)**
JAR-OPS Part 3	COMMERICAL AIR TRANSPORTATION (HELICOPTERS)

Most important for aircraft design are JAR-23 and JAR-25 (today: CS-23 and CS-25). The sub-division of these certification specifications are:

1. Subpart A--General
2. Subpart B--Flight
3. Subpart C--Structure
4. Subpart D--Design and Construction
5. Subpart E--Power plant
6. Subpart F--Equipment
7. Subpart G--Operating Limitations and Information.

Table 3.3 shows the correct choice of the relevant certification specifications depending on the characteristics:

1. number of passengers
2. maximum take-off mass
3. type of power plant

Table 3.3 Selection of the certification specifications by the characteristics of the aircraft

aircraft type	**normal, utility and aerobatic aeroplanes**	**commuter aeroplanes**	**large aeroplanes** (JAR) transport category airplanes (FAR)
characteristics	passenger seats = 9 MTOW = 5700 kg	passenger seats = 19 MTOW = 8600 kg propeller driven twin-engined	MTOW > 5700 kg
airworthiness standard	**CS-23, FAR Part 23**		**CS-25, FAR Part 25**
interpretative material	**FAR:** Advisory Circular AC23-?		**EASA:** Advisory Circular Joint (ACJ) Advisory Material Joint (AMJ) included in CS-25 **FAR:** Advisory Circular AC25-?

To register an all new aircraft the following procedure has to be followed in Europe:

1. A certified *design organisation* develops and manufactures a new Aircraft. The organisation has to hold a Design Organisation Approval in accordance with CS-21 Subpart J. The organisation has to show the conformity of the aircraft with certification specifications and environmental requirements. If this was successfully shown the organisation becomes the type certificate holder (TCH).
2. A *production organisation*, holder of a Production Organisation Approval can now produce the aircraft in series accordance to the standards of the type certificate. The manufacturer himself certifies the airworthiness and compliance with the type certificate in a "Statement of Conformity" (EASA Form 52).
3. An Aircraft will be certified for traffic, if it has:
   - A certificate of airworthiness
   - A statement of conformity
   - A noise certificate
   - An ensured holder
4. During operation of an aircraft a certified *maintenance organisation* has to keep the aircraft airworthy.

Fig. 3.4 shows the design organization, production organization and maintenance organization.

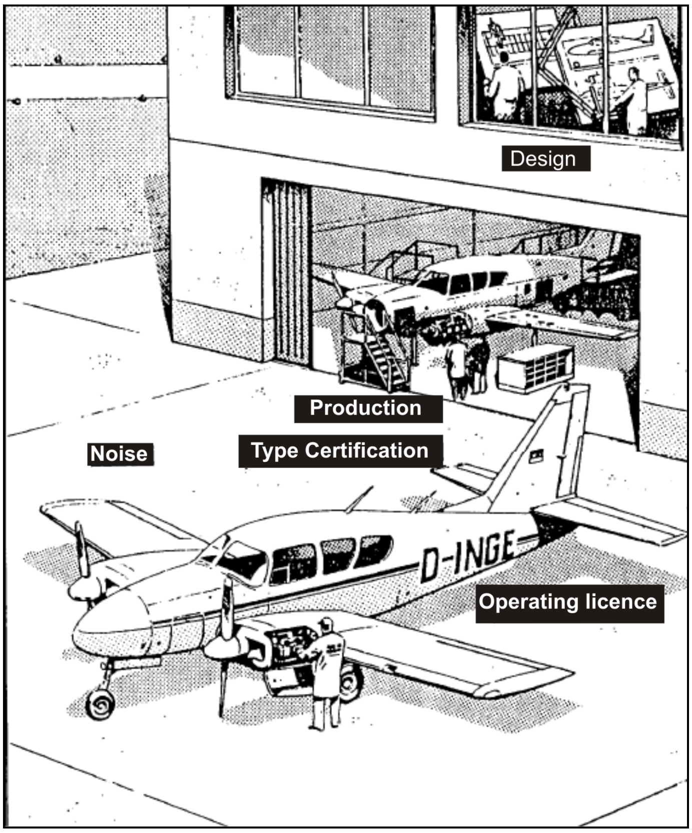

Fig. 3.4 Design organization, production organization and maintenance organization.

For type certification in the USA the *Federal Aviation Administration* (FAA) will be engaged. The type certificate will based on the *Federal Aviation Regulation* (FAR, see **Table 3.4**). Because of the fact that the JAR and CS are based on the FAR the changes for a US American type certificate will be comparatively marginal. Differences between the CS and the FAR are marked in the CS.

Table 3.4 Federal Aviation Regulations

Federal Aviation Administration

TITLE 14 OF THE U.S. CODE OF FEDERAL REGULATIONS FEDERAL AVIATION REGULATIONS
PARTS 1 THROUGH 199 INDEX OF FAR PARTS

FAR PART 1--DEFINITIONS AND ABBREVIATIONS
FAR PART 11--GENERAL RULE-MAKING PROCEDURES
FAR PART 13--INVESTIGATIVE AND ENFORCEMENT PROCEDURES
FAR PART 14--RULES IMPLEMENTING THE EQUAL ACCESS TO JUSTICE ACT OF 1980
FAR PART 15--ADMINISTRATIVE CLAIMS UNDER FEDERAL TORT CLAIMS ACT
FAR PART 16--RULES OF PRACTICE FOR FEDERALLY-ASSISTED AIRPORT ENFORCEMENT PROCEEDINGS
FAR PART 21--CERTIFICATION PROCEDURES FOR PRODUCTS AND FAR PARTS
FAR PART 23--AIRWORTHINESS STANDARDS: NORMAL, UTILITY, ACROBATIC, AND COMMUTER CATEGORY AIRPLANES
FAR PART 25--AIRWORTHINESS STANDARDS: TRANSPORT CATEGORY AIRPLANES
FAR PART 27--AIRWORTHINESS STANDARDS: NORMAL CATEGORY ROTORCRAFT
FAR PART 29--AIRWORTHINESS STANDARDS: TRANSPORT CATEGORY ROTORCRAFT
FAR PART 31--AIRWORTHINESS STANDARDS: MANNED FREE BALLOONS
FAR PART 33--AIRWORTHINESS STANDARDS: AIRCRAFT ENGINES
FAR PART 34--FUEL VENTING AND EXHAUST EMISSION REQUIREMENTS FOR TURBINE ENGINE POWERED AIRPLANES
FAR PART 35--AIRWORTHINESS STANDARDS: PROPELLERS
FAR PART 36--NOISE STANDARDS: AIRCRAFT TYPE AND AIRWORTHINESS CERTIFICATION
FAR PART 39--AIRWORTHINESS DIRECTIVES
FAR PART 43--MAINTENANCE, PREVENTIVE MAINTENANCE, REBUILDING, AND ALTERATION
FAR PART 45--IDENTIFICATION AND REGISTRATION MARKING
FAR PART 47--AIRCRAFT REGISTRATION
FAR PART 49--RECORDING OF AIRCRAFT TITLES AND SECURITY DOCUMENTS
FAR PART 61--CERTIFICATION: PILOTS AND FLIGHT INSTRUCTORS
FAR PART 63--CERTIFICATION: FLIGHT CREWMEMBERS OTHER THAN PILOTS
FAR PART 65--CERTIFICATION: AIRMEN OTHER THAN FLIGHT CREWMEMBERS
FAR PART 67--MEDICAL STANDARDS AND CERTIFICATION
FAR PART 71--DESIGNATION OF CLASS A, CLASS B, CLASS C, CLASS D, AND CLASS E AIRSPACE AREAS; AIRWAYS; ROUTES; AND REPORTING POINTS
FAR PART 73--SPECIAL USE AIRSPACE
FAR PART 77--OBJECTS AFFECTING NAVIGABLE AIRSPACE
FAR PART 91--GENERAL OPERATING AND FLIGHT RULES
FAR PART 93--SPECIAL AIR TRAFFIC RULES AND AIRPORT TRAFFIC PATTERNS
FAR PART 95--IFR ALTITUDES
FAR PART 97--STANDARD INSTRUMENT APPROACH PROCEDURES
FAR PART 99--SECURITY CONTROL OF AIR TRAFFIC
FAR PART 101--MOORED BALLOONS, KITES, UNMANNED ROCKETS AND UNMANNED FREE BALLOONS
FAR PART 103--ULTRALIGHT VEHICLES
FAR PART 105--PARACHUTE JUMPING
FAR PART 107--AIRPORT SECURITY
FAR PART 108--AIRPLANE OPERATOR SECURITY
FAR PART 109--INDIRECT AIR CARRIER SECURITY
FAR PART 119--CERTIFICATION: AIR CARRIERS AND COMMERCIAL OPERATORS
FAR PART 121--CERTIFICATION AND OPERATIONS: DOMESTIC, FLAG, AND SUPPLEMENTAL AIR CARRIERS AND COMMERCIAL OPERATORS OF LARGE AIRCRAFT
FAR PART 125--CERTIFICATION AND OPERATIONS: AIRPLANES HAVING A SEATING CAPACITY OF 20 OR MORE PASSENGERS OR A MAXIMUM PAYLOAD CAPACITY OF 6,000 POUNDS OR MORE
FAR PART 129--OPERATIONS: FOREIGN AIR CARRIERS AND FOREIGN OPERATORS OF U.S.- REGISTERED AIRCRAFT ENGAGED IN COMMON CARRIAGE
FAR PART 133--ROTORCRAFT EXTERNAL-LOAD OPERATIONS
FAR PART 135--AIR TAXI OPERATORS AND COMMERCIAL OPERATORS
FAR PART 137--AGRICULTURAL AIRCRAFT OPERATIONS
FAR PART 139--CERTIFICATION AND OPERATIONS: LAND AIRPORTS SERVING CERTAIN AIR CARRIERS
FAR PART 141--PILOT SCHOOLS
FAR PART 142--TRAINING CENTERS
FAR PART 145--REPAIR STATIONS
FAR PART 147--AVIATION MAINTENANCE TECHNICIAN SCHOOLS
FAR PART 150--AIRPORT NOISE COMPATIBILITY PLANNING
FAR PART 151--FEDERAL AID TO AIRPORTS
FAR PART 152--AIRPORT AID PROGRAM
FAR PART 155--RELEASE OF AIRPORT PROPERTY FROM SURPLUS PROPERTY DISPOSAL RESTRICTIONS
FAR PART 156--STATE BLOCK GRANT PILOT PROGRAM
FAR PART 157--NOTICE OF CONSTRUCTION, ALTERATION, ACTIVATION, AND DEACTIVATION OF AIRPORTS
FAR PART 158--PASSENGER FACILITY CHARGES (PFC'S)
FAR PART 161--NOTICE AND APPROVAL OF AIRPORT NOISE AND ACCESS RESTRICTIONS
FAR PART 169--EXPENDITURE OF FEDERAL FUNDS FOR NONMILITARY AIRPORTS OR AIR NAVIGATION FACILITIES THEREON
FAR PART 170--ESTABLISHMENT AND DISCONTINUANCE CRITERIA FOR AIR TRAFFIC CONTROL SERVICES AND NAVIGATIONAL FACILITIES
FAR PART 171--NON-FEDERAL NAVIGATION FACILITIES
FAR PART 183--REPRESENTATIVES OF THE ADMINISTRATOR
FAR PART 185--TESTIMONY BY EMPLOYEES AND PRODUCTION OF RECORDS IN LEGAL PROCEEDINGS, AND SERVICE OF LEGAL PROCESS AND PLEADINGS
FAR PART 187--FEES
FAR PART 189--USE OF FEDERAL AVIATION ADMINISTRATION COMMUNICATIONS SYSTEM
FAR PART 191--WITHHOLDING SECURITY INFORMATION FROM DISCLOSURE UNDER THE AIR TRANSPORTATION SECURITY ACT OF 1974
FAR PART 198--AVIATION INSURANCE