contained hydraulic actuation component. A PCU contains hydraulic lines, control valves, input linkage, and hydraulic actuators. The pilot input opens a valve within a PCU that directs the hydraulic fluid to the PCU's actuator, thus moving the surface.

In case of hydraulic failure, the controls can be operated through manual reversion. Sufficient force on the PCU moves the entire PCU and thus the control surface [18].

The controls have a direct impact on the ease of piloting the aircraft and therefore on the comfort of the passengers. The control redundancy is important for safety reasons and to satisfy the air regulations.

The design of powered flight controls was new to Cessna and the design engineers spent a significant amount of time on flight control design. For example, they rerouted the cables in the prototype in order to reduce friction, which caused a large number of other changes in the prototype [3].

Primary Flight Controls

The primary flight controls are the elevators for longitudinal control, the horizontal stabilizer for longitudinal trim, the roll spoilers and ailerons for lateral control, and the upper and lower rudders for directional stability and control.

Elevators

The Citation X has two elevators, one on each side of the horizontal stabilizer. The pilot’s control column controls the port elevator and the co-pilot’s control column controls the starboard elevator. The two control columns are connected by a torque tube and can be disconnected if one elevator becomes jammed. The elevators are actuated by two PCUs each. One PCU per elevator is actuated by each of the A and B hydraulic systems. If one hydraulic system fails, the other PCU on that elevator is sufficient to move the elevator. If both hydraulic systems fail, the pilot can move the entire PCU and elevator, as described above. Pitch feel is provided by bungees within the PCU and a spring-driven pitch feel system in the vertical stabilizer. The pitch feel system is moved to the lowest force position in the case of emergency manual reversion [18]. The elevator system also includes a balance spring, centering springs, input bungees, an autopilot connection, a control column shaker barrier, a control column balance bungee, and a gust lock mechanism. Since the horizontal stabilizer is movable for trim (described below), there are no trim tabs on the elevators [17].

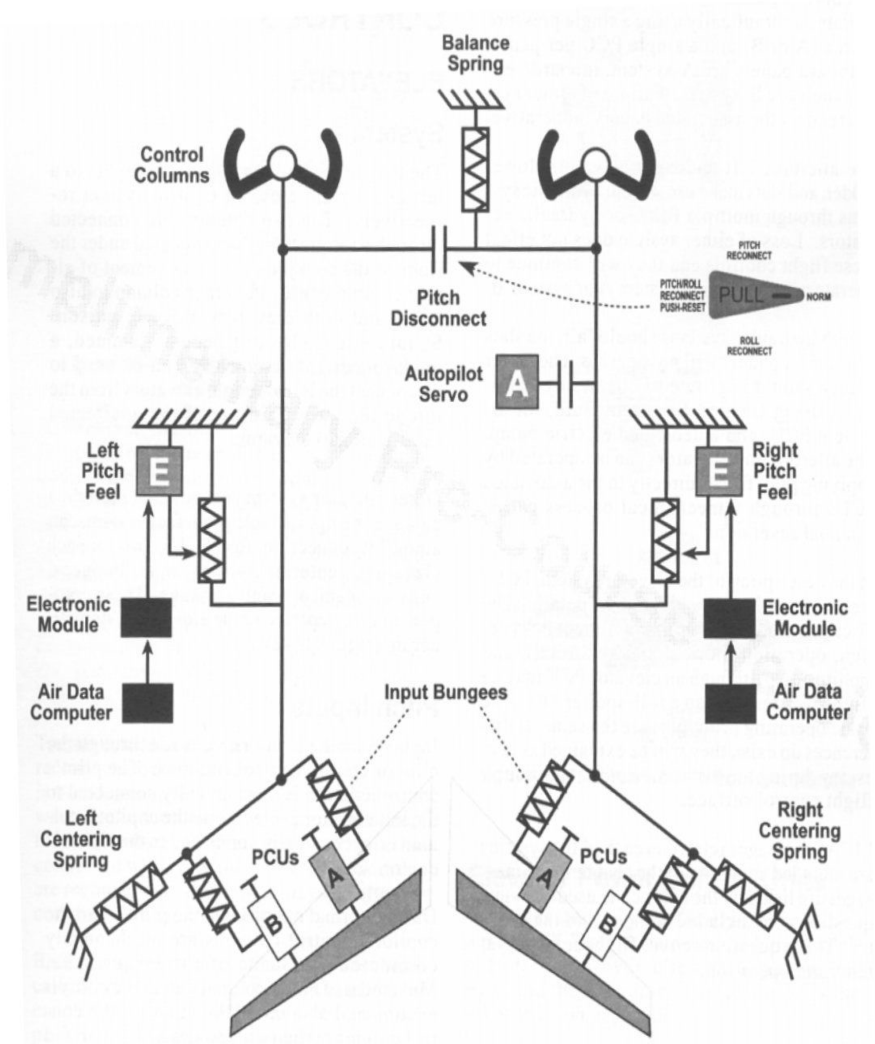

Figure 39: Elevator Control System

Horizontal Stabilizer

As mentioned above, the horizontal stabilizer is all-moving for longitudinal trim. The rotation is effected by two 28V DC motors with separate isolated electronic control modules. The primary motor requires power from the main aircraft power bus and the secondary motor uses power from the emergency bus. The autopilot and Mach trim systems both trim the stabilizer using the primary trim motor. In each motor, power is transferred by an electric clutch through a gear train that turns a jackscrew. The jackscrew controls the position of the forward end of the horizontal stabilizer. The rate of trim changes with airspeed. On the ground, the horizontal stabilizer angle can be changed across its full range in approximately 12 seconds. The flight guidance computer controls primary trim, autopilot, and Mach trim to the horizontal stabilizer. The Mach trim system relieves dynamic forces on the airframe when the airspeed is above M=0.83. It operates whether or not the autopilot is engaged [18].

Roll Control Surfaces

The pilot's control column controls the ailerons and the co-pilot's control column controls the roll spoilers. The two control columns can be disconnected as described for the elevators above. Each of the aileron system and roll spoiler system are capable of providing adequate roll control for approach and landing with a reduced crosswind tolerance. When the two systems are connected, ailerons and roll spoilers can only be operated together [18].

Ailerons

The ailerons can deflect a maximum of fifteen degrees up or down. Both ailerons are operated simultaneously by one or both of two PCUs, each operated by a different hydraulic system. Mechanical inputs from the control wheel are transferred to the PCUs, which are in turn connected to the output cables and push rods that operate the ailerons. A bungee system offers a small resistance to control wheel movement for roll feel and a centering motion for the control wheel. The trim system operates on the feel bungee, using a motor-driven gear attached to a jackscrew that shifts the neutral position of the spring canister and moves the PCU input location. The trim system is capable of trimming the system to plus or minus eight degrees of aileron deflection. The aileron control system also includes a latching mechanism for emergency control and an autopilot servo [18].

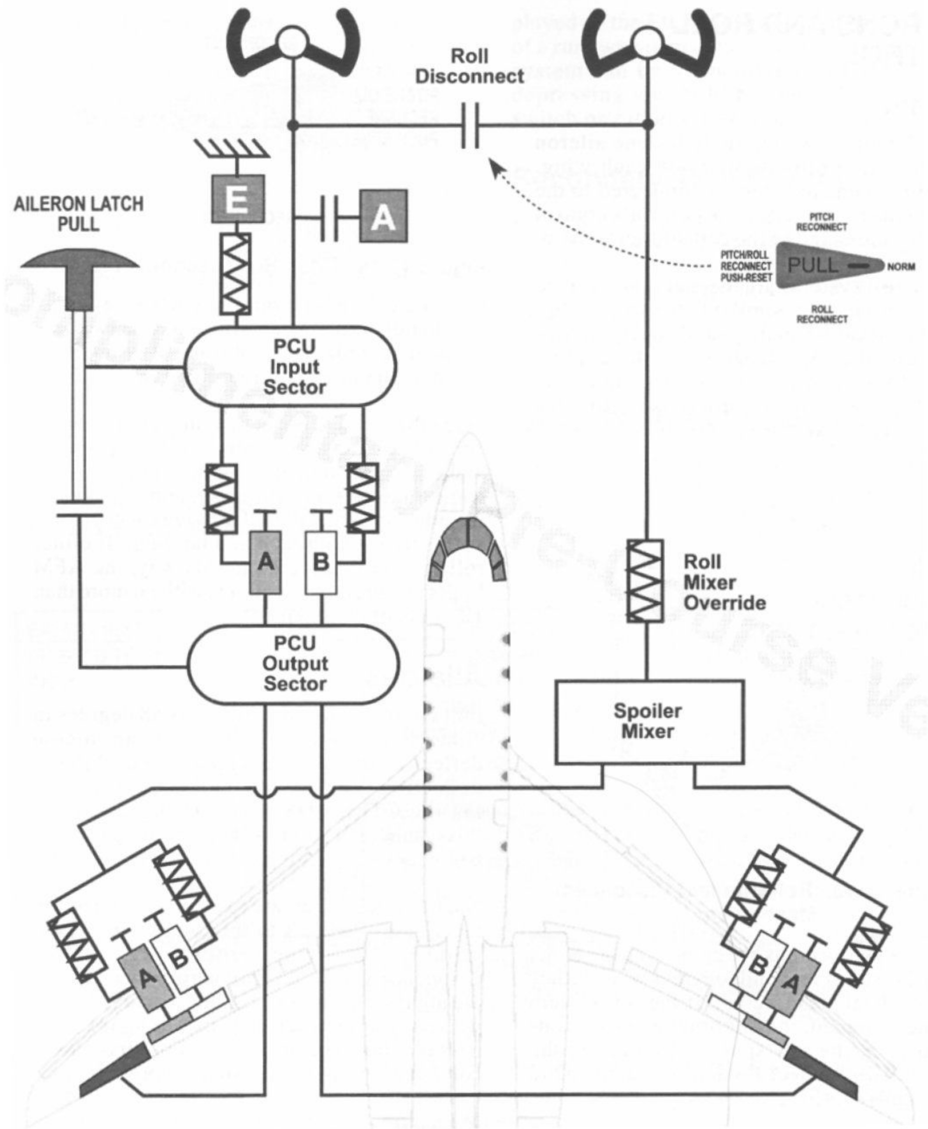

Figure 40: Ailerons and Roll Spoilers

Roll spoilers

There are two roll spoilers on each wing, each operated by a single PCU. The outboard roll spoilers are powered by the A hydraulic system and the inboard roll spoilers are powered by the B hydraulic system. The spoilers can deflect to a maximum of forty degrees. The roll spoiler input is first passed to a spoiler mixer, which mechanically delays input to the outboard roll spoilers until the ailerons have deflected by three degrees and to the inboard roll spoilers until the ailerons have deflected by six degrees. The mixer then mechanically transfers the control signal to the PCUs attached to the wing structure, each of which then moves its respective spoiler [18].

Rudders

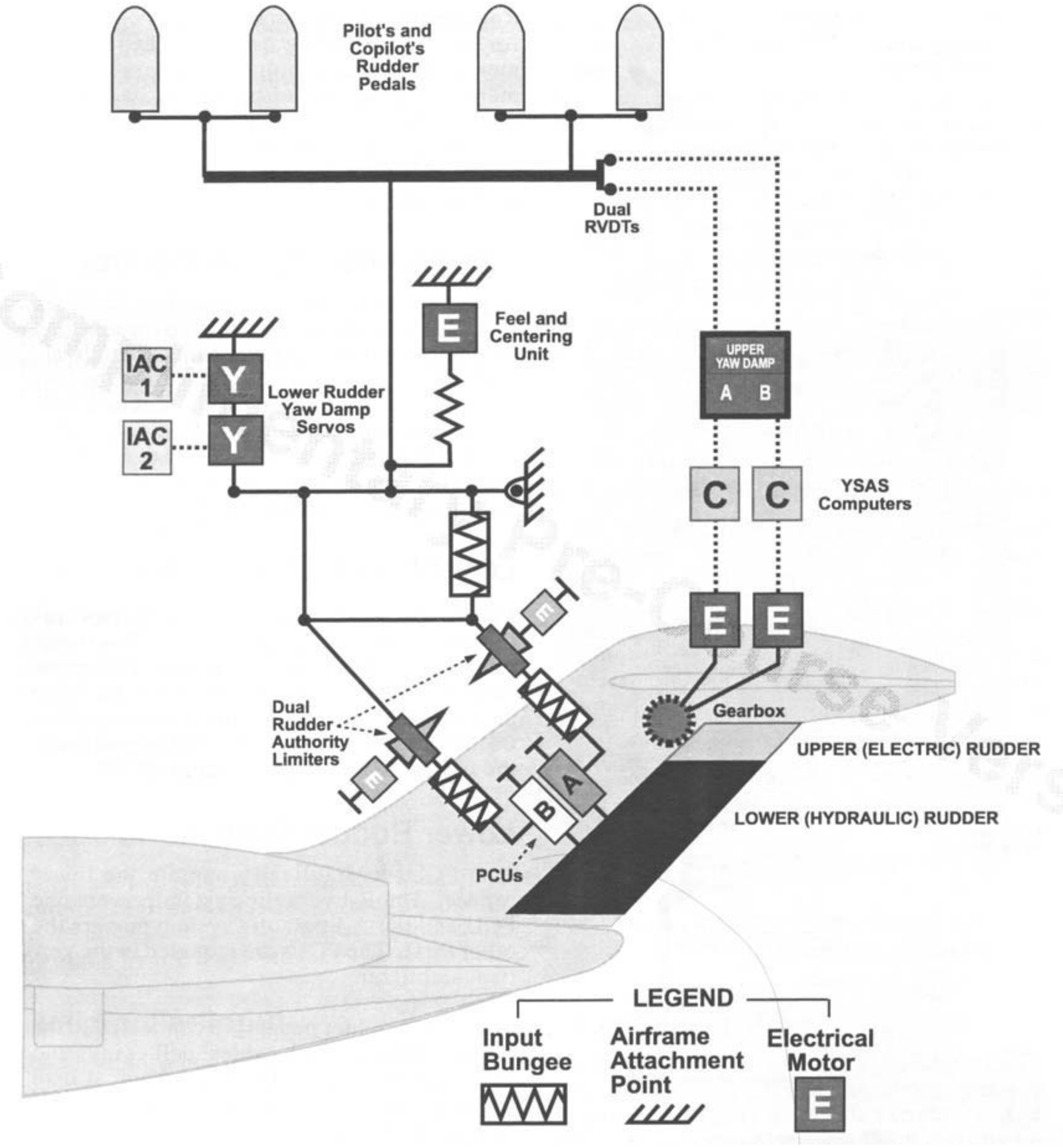

Figure 41: Upper and Lower Rudder Systems

The rudder on the Citation X is divided into an upper and a lower rudder. The rudders share mechanical inputs from the rudder pedals but have separate yaw damp control systems. The lower rudder provides approximately 88% of the yaw authority and the upper rudder provides the remaining 12% [18].

Lower Rudder

The lower rudder is operated by two PCUs, each on a different hydraulic system, located in the vertical stabilizer. The design of the lower-rudder PCUs is similar to the elevator PCUs, except that the force on the rudder is limited to lessen abrupt rudder inputs. The rudder has its own backup hydraulic pump to operate the B system in case of failure of both main hydraulic systems. The rudder can deflect up to thirty degrees in either direction at speeds less than approximately 140 knots. At higher speeds the rudder travel is limited to as little as four degrees in either direction by dual electrically operated mechanical rudder authority limiters, in order to limit the stress on the vertical tail. The rudder-feel bungee and trim system, located in the vertical tail, operate in a similar way to the aileron feel and trim system. The lower rudder is also equipped with a gust lock [18].

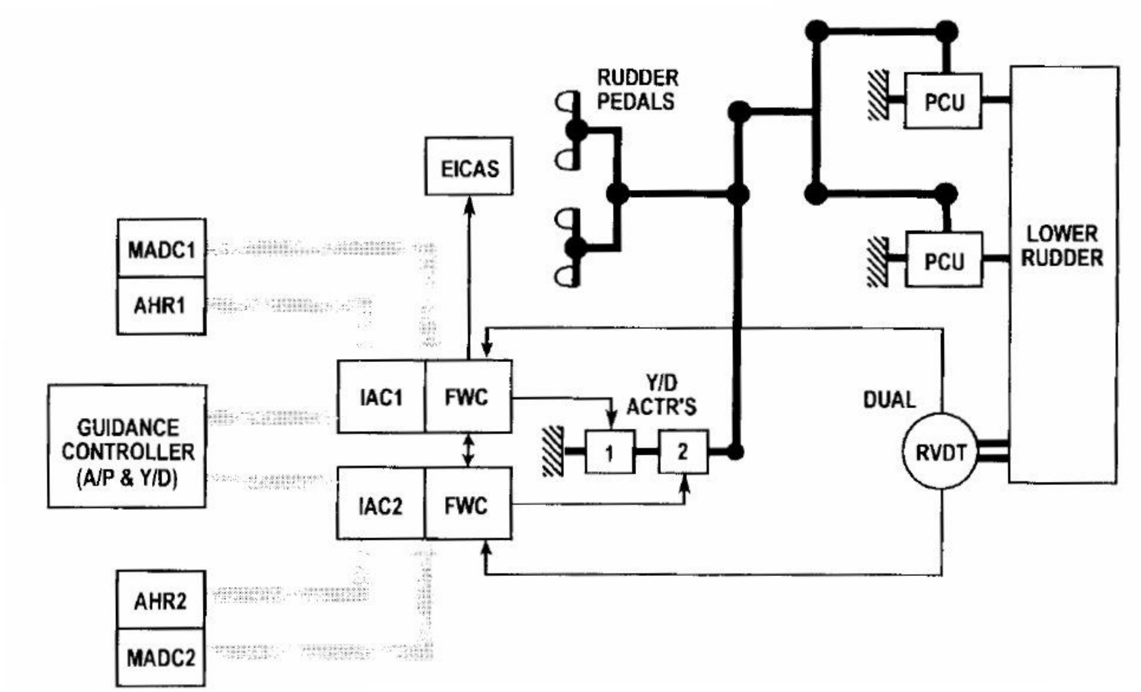

Figure 42: Lower Rudder Yaw Damper System

The lower rudder has dual electric yaw damp actuators, as shown in Figure 42, in order to provide Dutch roll damping and low-speed turn coordination. The damp actuators work in series with the linkage from the rudder pedals to the PCU inputs. Only one actuator is active at a time; the other is in standby mode. The damp actuators operate full time as long as electrical power is engaged. The flight guidance computer controls the input to the damp actuators, up to a maximum of six degrees of yaw deflection, as a function of yaw rate, roll rate, and bank angle [18]. Takeoff is permitted if one of the two lower rudder yaw damper systems is inoperative as long as both flight guidance computers are operative and some flight restrictions are followed [21].

Upper Rudder

The two functions of the upper rudder are to provide the Citation X with independent Dutch-roll damping and to provide additional yaw control when the flaps are deployed. The yaw stability augmentation system, consisting of two separate computers for redundancy, takes input from rudder pedal position sensors and from rate gyros. It computes the position of the upper rudder and outputs it to servomotors, which in turn move a gear train and jackscrew assembly connected to the upper rudder. When the flaps are up, rudder pedal input is ignored and the upper rudder moves only for yaw damping purposes [18].

The yaw stability augmentation system can deflect the upper rudder up to 15 degrees in either direction for yaw-damping purposes and up to 18 degrees in either direction for a combination of yaw damping and rudder pedal input at low speeds. As the speed increases, the maximum allowable deflection of the upper rudder decreases in order to limit the forces on the airframe. The upper-rudder yaw damping function is always operating in flight but is inhibited on the ground [18].

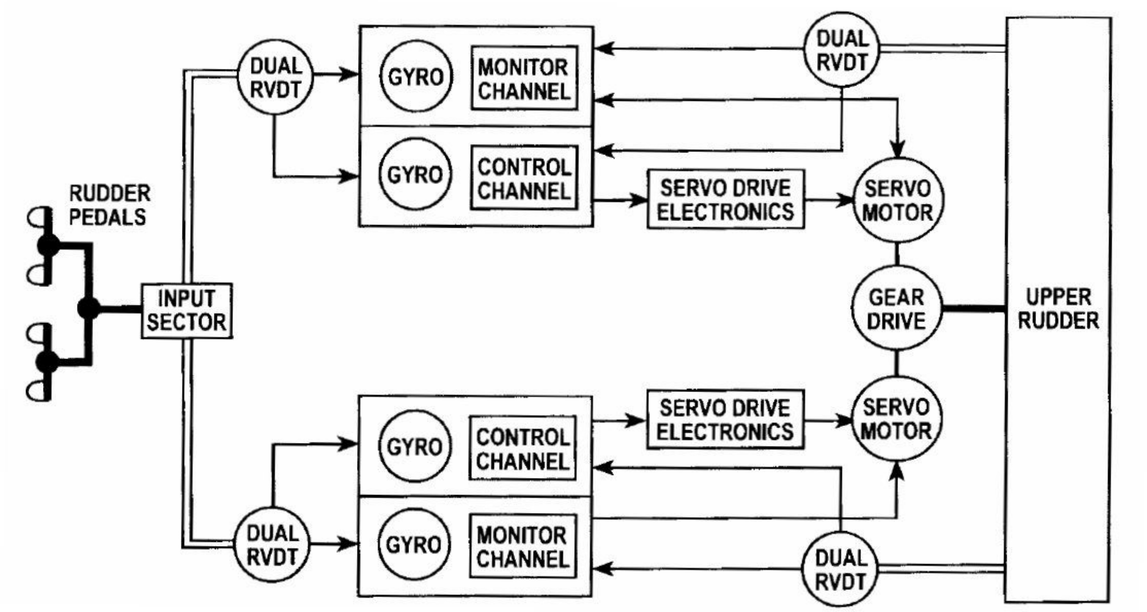

Figure 43: Upper Rudder Yaw Stability Augmentation System

Secondary Flight Controls

The secondary flight controls consist of the high lift system, meaning the flaps and slats, and the speed brakes. The high-lift system is driven by the landing speed requirements, and the speed brakes are driven by the landing distance

High Lift System

The flaps are only deployed when the slats are also deployed. When flaps are selected, the slats deploy before the flaps.

Flaps

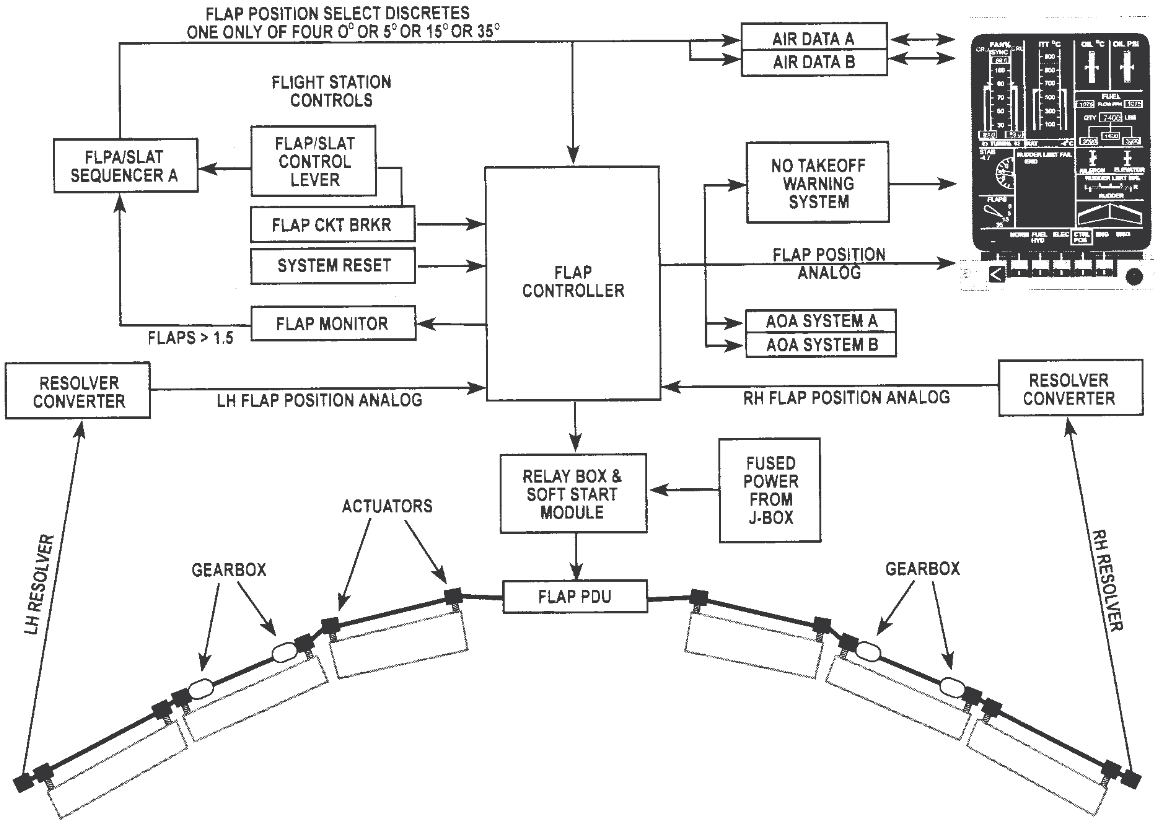

Figure 44: Flap System Schematic

There are three Fowler flaps on each wing, powered electrically by a 28V DC electric motor located in the center fuselage area. The flap system is shown in Figure 44. The flaps have a maximum deflection of 35 degrees. The motor moves flex-shaft drive trains in each wing, which then move two actuators per flap using worm gears. The worm gears vary in thread size from inboard to outboard, resulting in varying extension and retraction rates. The flaps are equipped with load limiters to protect the wing structure in case of a flap system jam [18].

The flaps are electric in order to continue to function when both hydraulic systems fail. In the case of complete hydraulic system failure, the thrust reversers do not function and the brakes are operated by their pneumatic backup system. It is therefore extremely important that the landing speed be as low as possible. This requires that the flaps be capable of deploying [3].

In order to simplify the system, the flaps extend parallel to the trailing edge of the wing, rather than parallel to the flow, which is traditional. The aerodynamicians on the team were concerned that this would decrease performance, but it works well. The team took a risk choosing the simpler design over the more aerodynamically sound and generally accepted method [3].

Slats

The regulations require that, as a stall is approached, the nose pitches down and not up. This prevents the stall from worsening and ensures that there is steady backpressure on the controls throughout the stall. While the engineers were in the process of finalizing the aerodynamic configuration and designing the flap system, they discovered that due to the highly swept, tapered wing, the Citation X had a tendency to pitch up as it approached the stall. The requirement to correct that problem drove the inclusion of slats [3].

Figure 45 is a schematic of the slat system. The slats are constructed of aluminum and located on the outboard leading edge of each wing. They are either fully deployed or fully retracted. Each slat is powered by four hydraulic actuators, two from each hydraulic system. Unlike the other control surfaces, the slats do not have PCUs; instead, they are directly attached to the actuators. The slats can be extended by the pilot and they automatically extend whenever the angle of attack exceeds 12 degrees [18].

Speed Brakes

Each wing has three speed brake panels for drag control. The outboard panel is powered by the A hydraulic system and the two inboard panels are powered by the B hydraulic system. Each speed brake panel is actuated by a single PCU, which is mechanically controlled from the cockpit. The speed brakes can be set at any angle from

0 to 40 degrees [18]. Both the speed brakes and the roll control spoilers were specifically designed to minimize pitching moment changes when they are deployed [17].

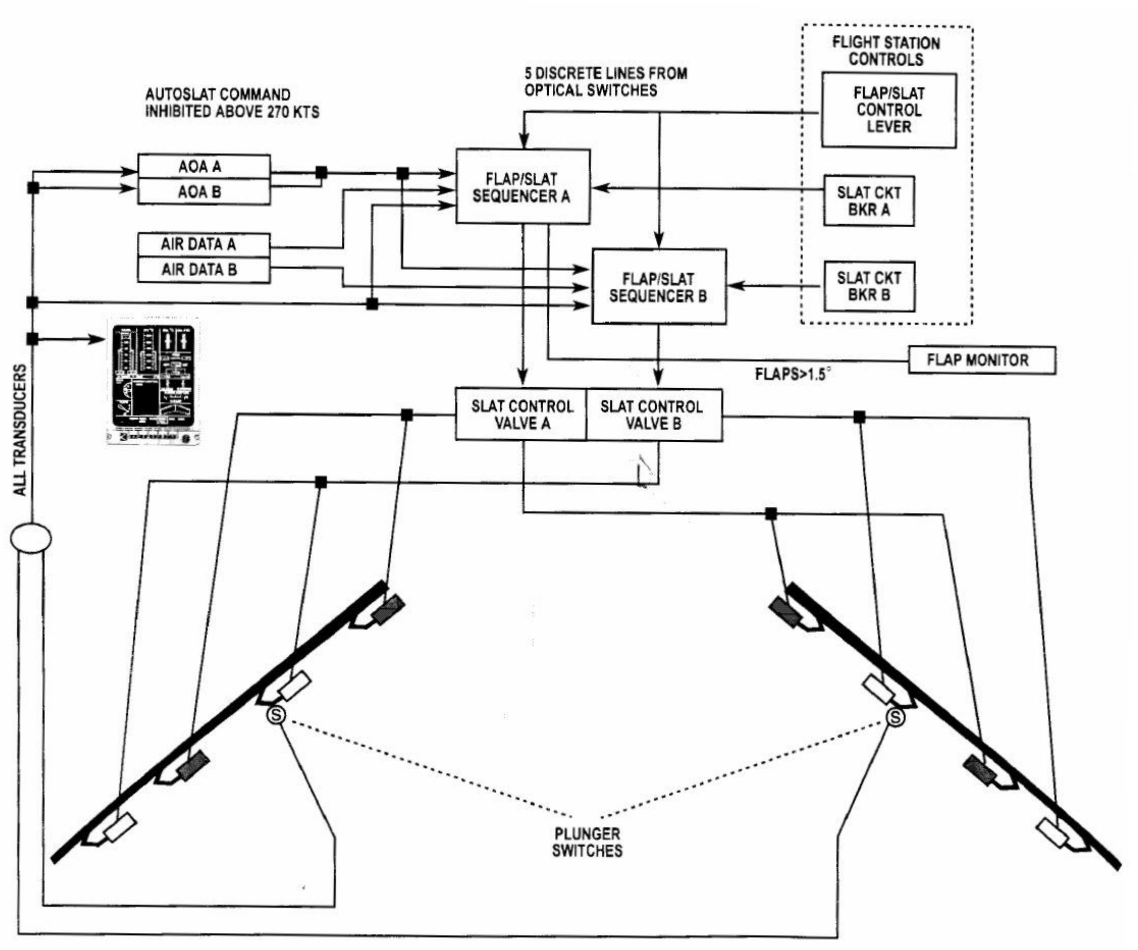

Figure 45: Slat System Schematic

6.3.13. Hydraulic System

The Citation X has two main hydraulic systems, for redundancy in order to satisfy the safety, reliability, and regulatory requirements. A schematic is shown in Figure 46. The A system is powered by the port engine and the B system is powered by the starboard engine. Each system has its own 1.7-gallon reservoir, located in an engine pylon, and there is no shared fluid. The four approved brands of hydraulic fluid are Chevron/Exxon Hyjet IVA, Chevron/Exxon Hyjet IVA Plus, Monsanto Skydrol 500B, and Monsanto Skydrol LD-4. The pressure in the hydraulic reservoirs is maintained at approximately 50 psi by bootstrap systems [18].

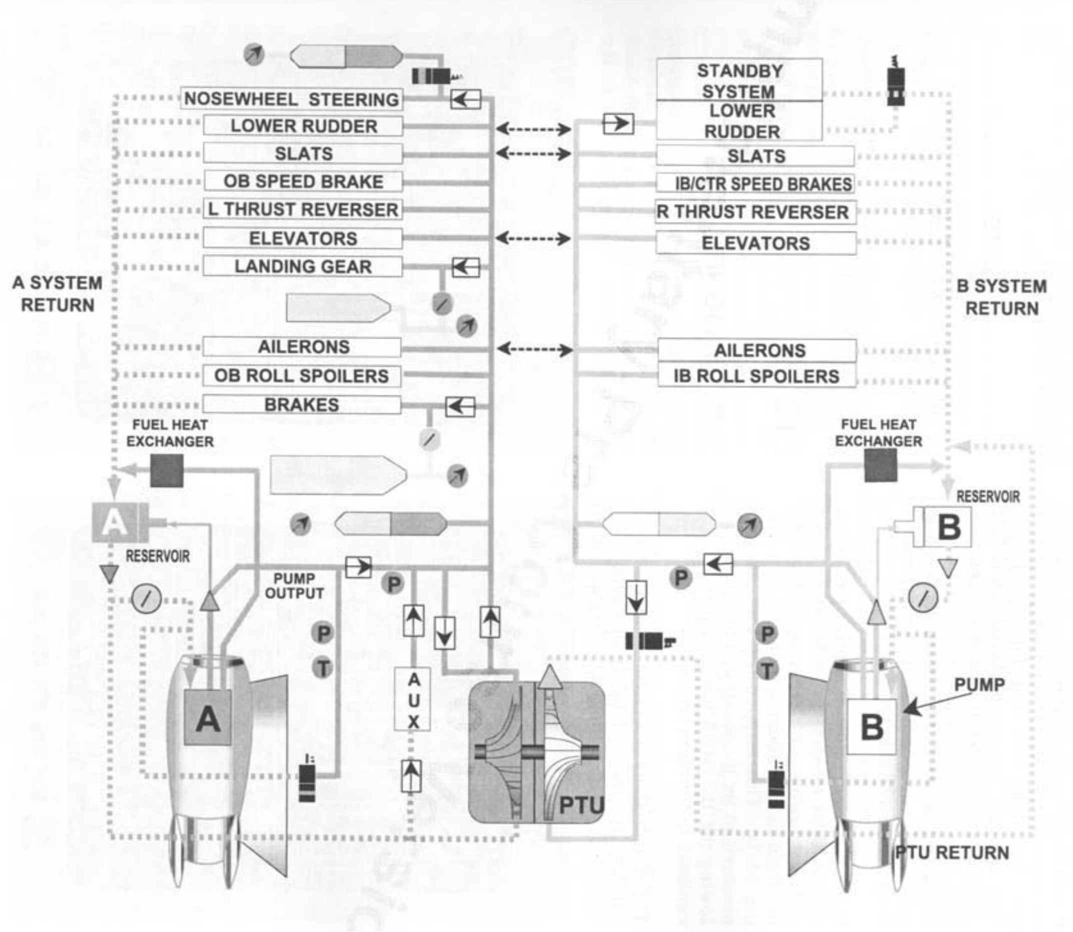

Figure 46: Schematic of Hydraulic Subsystem

The variable-displacement pumps are mounted on the accessory gearboxes in the engines. They can produce 15.5 gpm at 3000 psi. The engine-driven pumps maintain the pressure in the hydraulic lines between 3300 and 3500 psi [18].

Each system has an accumulator to dissipate fluid shock and reduce noise. The accumulators are pre-charged with nitrogen at 1500 psi. The systems are cooled with heat exchangers that pass through the fuel tanks and use fuel to cool the hydraulic fluid. The hydraulic systems also have firewall shutoff valves, unload valves, shuttle valves, and filters [18].

If the A system engine-driven pump fails, a power transfer unit (PTU), shown in Figure 47, transfers B system pressure to the A system. The PTU is located under the aft cabin and requires main DC power. It operates automatically when A system pressure drops below B system pressure by a specified amount. An electric pump can provide pressure to the A system in case of failure of both engine-driven pumps or to supplement the PTU in case of high hydraulic demand. The electric pump also is used in normal operation to set the parking brake [18]. If the B system fails, it has no backup and all the systems that depend solely on the B-system hydraulics become inoperative.

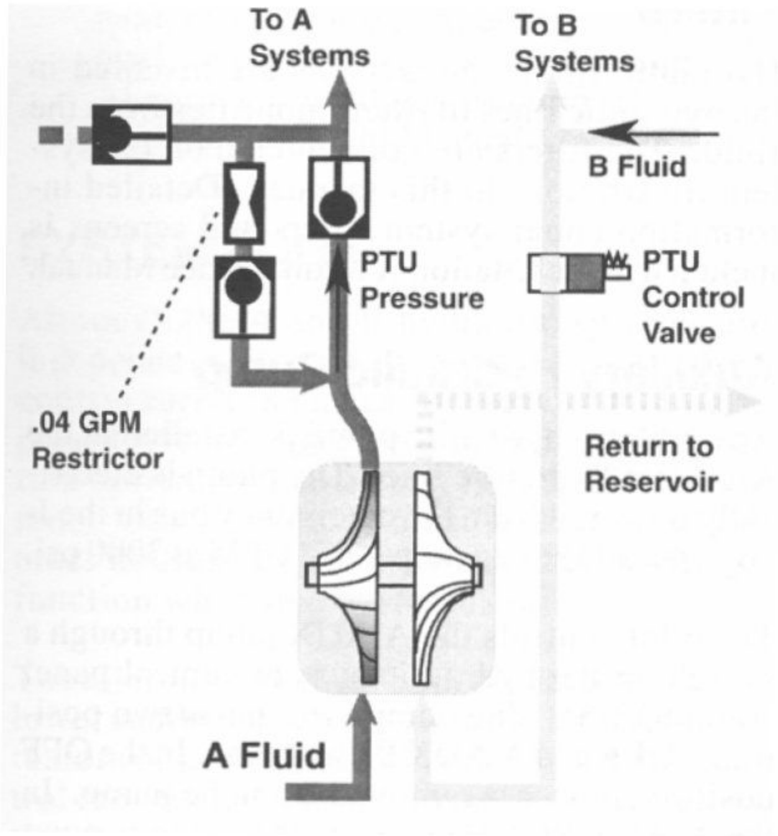

Figure 47: Power Transfer Unit

There is also a rudder standby system with its own pump-to-pump trapped B-system fluid to control the lower rudder in case both hydraulic systems fail. It is fully automated and incorporates a pressure switch, a small electric pump operated by main DC power, an accumulator, and its own reservoir [18].

Some components rely exclusively on a single hydraulic system. The left thrust reverser uses the A system and the right thrust reverser uses the B system. The landing gear, brakes, and nose wheel steering are operated by the A system. In case of A system failure, the landing gear extension and brakes can be powered by the backup pneumatic system. The ailerons, slats, elevators, and lower rudder are all redundantly operated by both hydraulic systems and would continue to operate if either system failed. The spoiler and speed-brake systems are powered in symmetric sets by each hydraulic system, as described in their descriptions [18].

6.4. Subsystem interfaces

The Citation X, like any aircraft, is a complex system characterized by a large number of subsystem interfaces. An n^2 diagram, indicating interfaces between some of the major subsystems, is in Table 15.

It is apparent from Table 15 that some subsystems are more highly coupled than others are. For instance, the electrical subsystem provides electrical power to every other listed subsystem. The structure provides physical space and protection to every other subsystem. The engines do much more than simply provide thrust. They power the hydraulic and electrical systems and provide bleed air to the environmental and ice protection systems. On the other hand, with the exception of providing the structure with separation from the ground during ground operations, the landing gear does not supply anything to any other subsystem. The fuel system also has limited interaction with the other subsystems: it only supplies fuel to the engines, and all it requires is physical space from the structure and power from both the engines and the electrical system to operate its pumps.

The number of subsystem interfaces is so large that they cannot all be described in this document. Two subsystem interfaces are briefly outlined below, in order to illustrate some of the complexities of subsystem interfaces and some of the benefits that can be derived from exploiting them. The wing/fuselage interface is notable because this is the first Citation aircraft to use this attachment method. The hydraulics/structure interface is of interest because the Citation X was the first aircraft to use hydraulics and Cessna found the integration of the hydraulics with the structure to be a significant design challenge.

6.4.1. Wing/Fuselage

While the wing and the fuselage are in the same subsystem according to the divisions in Section 6.3, their interface is notable. In previous aircraft in the Cessna Citation series, the wing was built in two pieces and connected by spars that passed through the fuselage. For instance, in the Citation Bravo, four carry-through beams pass through the fuselage: a main and aft wing spar, and two beams for the engines [24]. In the Citations III, VI, and VII, the wing is meshed into the fuselage and a structural box is built into the fuselage. This reduced the total volume of the cabin. Since in a small business jet cabin volume is of high importance, the wing carry-through spars or fuselage structural box was a significant drawback. The Citation X wing is built all in one piece. It is hung from slingers and attached in five places to the fuselage with bolts [3].

6.4.2. Hydraulics/Structure

The interaction of the hydraulics and the structural subsystem was a challenge for Cessna. In particular, finding the space within the structure to fit the hydraulic components was difficult [3]. Because no previous Cessna aircraft has powered controls, it was a new experience for the design team. The regulations require that each safety-critical control surface (the rudder, elevators, and ailerons) have a hydraulic actuator from each of the hydraulic systems, in case of failure of one hydraulic system, and a method to manually activate the control surface in the event that both hydraulic systems fail. The hydraulic lines leading to the actuators also require space. As an example, one wing contains eleven PCUs with their associated lines and controls: two for the ailerons, two for the roll spoilers, four for the slats, and three for the speed brakes. These systems are competing with the fuel tanks, fuel lines, electrical equipment and lines, electrical motors for the flaps, ice protection equipment, and structural elements for space within the wing. The design team found CATIA (Computer-Aided Three-Dimensional Interactive Application), a computer-aided-design program, to be of immense help in fitting the various parts within the aircraft.

Table 15: Subsystem Interfaces

TO \ FROM	**structure**	**engines**	**Electrical**	**Ice protection**	**Hydraulic**	**environmental**	**fuel system**	**avionics**	**Landing gear**
structure		thrust	actuates flaps	Protects surfaces	Moves most control surfaces	environmental control to cockpit, cabin, and baggage compartment			Supports structure
Engines	engines mounted on fuselage		APU provides bleed air for engine start	Protects engine intake	Actuation of thrust reversers		pressurized fuel	engine control signals	
electrical	physical space	power to the generators				cools electrical systems			
ice protection	physical space	bleed air	DC power for windshield and wing-cuff anti-icing						
hydraulic	physical space	power to the pumps	power to controllers						
environmental	physical space	bleed air	power to controllers						
fuel system	Space for tanks	power to the fuel pumps	power to boost pumps					fuel metering	
Avionics	physical space	engine monitoring data	electrical power			temperature control of avionics			
Landing gear	Space to retract		power for anti-skid system		Actuation of brakes and retraction				

6.5. Weight breakdown

The total aircraft weight for a maximum takeoff weight configuration is summarized in Table 16. In this case, the Citation X carries 1246lbs of payload and approximately 12,900lbs of fuel. The wing and empennage together make up 15% of the total take-off weight. Furthermore, the fuselage is approximately 9%, the landing gear 3%, the engines 12%, and the fuel 36% of the total take-off weight. The fixed equipment includes the avionics, the flight controls, hydraulic and electrical systems and the furnishing, and makes up about 20% of the total take off weight. A detailed weight breakdown can be found in Table 16. [25]

Item	**Weight (lbs)**	**%**
Fuel	12,887.7	36.1
Payload	1,249.0	3.5
Engines	4,212.6	11.8
Nacelles	571.2	1.6
Wing	4,069.0	11.4
Empennage	1,178.1	3.3
Landing Gear	1071,0	3.0
Fuselage	3,178.6	8.9
Fixed Equipment	7,282.8	20.4
Total Take-Off Weight	**35,300**	**100**

Table 16: Weight Breakdown

7. Program Management Approach

7.1. Organization at Cessna

Figure 48 is the organizational chart at Cessna.

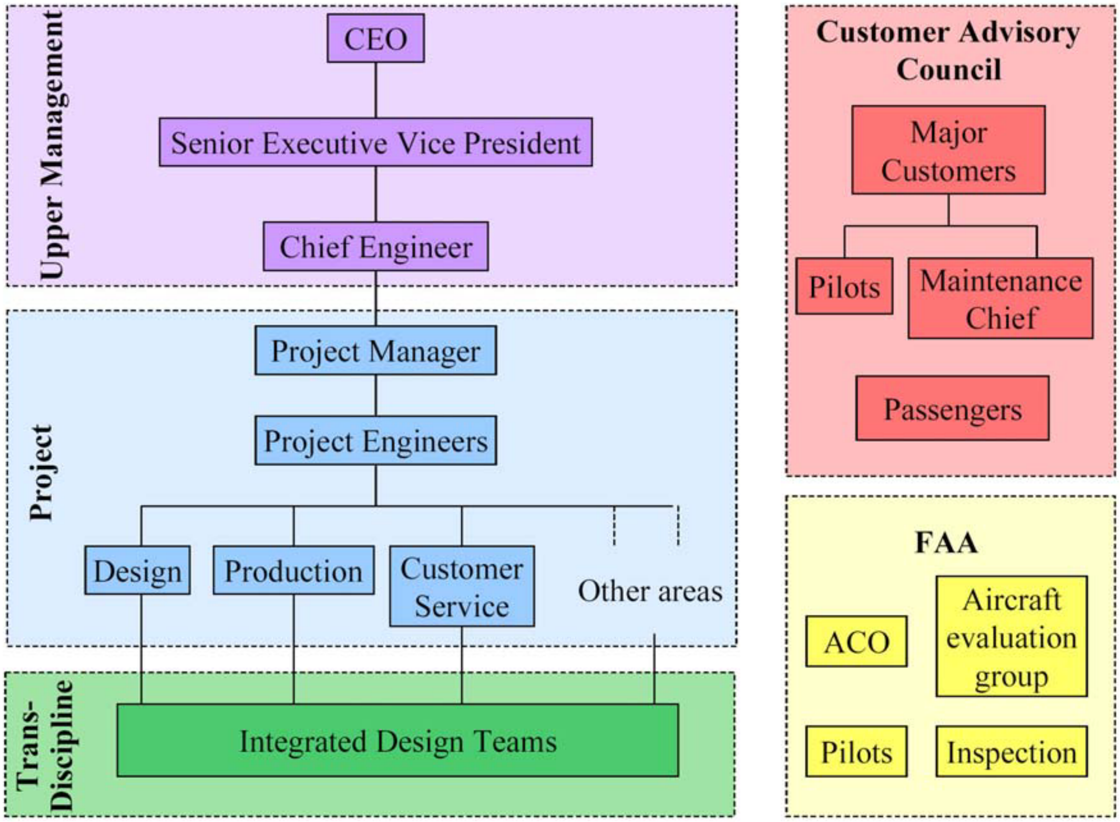

Figure 48: Organizational Chart at Cessna [32]

On the left is shown the internal organization of the company, and on the right are represented the external groups that had an influence on the Citation X project.

The majority of the decisions were made by the group leaders in each discipline. The key decisions, however, were made during design reviews, in presence of the upper management. Normally, they do not dictate any design related decision; these are left to the project management.

For the Citation X program, Cessna experienced new program management methods. It was the first time that Integrated Design Teams, the Customer Advisory Council, and Total Quality Management principles were all used on a program. These tools did not much change the functioning of some areas, but others benefited significantly from their implementation. Overall, Paul Kalberer and Dick Curtis estimated the savings in time and cost due to the new methods at about 5 or 10%[33].

Integrated Design Teams

Cessna's designers were organized into "integrated design teams" or IDTs. In the previous paradigm, engineers designed an airplane, and subsequently asked manufacturing to build it; there was little cooperation between the two groups in the design stage. On the Citation X program, manufacturing personnel and quality personnel signed off on drawings. More precisely, the IDTs were composed of design engineers, manufacturing engineers, materials engineers, pilots, representatives from marketing, customer service, maintenance groups, and others, depending on the function of the team [3], [25], [32].

IDTs have a practical disadvantage: they require a significant amount of physical space. The team members must all be located in the same room, or at least be communicating regularly. The integrated design teams are a management challenge but, according to Cessna, have been a valuable approach [3], [25], [32].

Customer Advisory Council

The customer advisory council is composed of Cessna's major customers (15), their pilots, their maintenance chiefs, and passengers. It represents a cross-section of the operators of the airplane. All the members of the council participate in the discussions and make comments to the engineers, including inspections of the mock-ups. All the comments then become "action items" that have to be closed by either completing what is requested, or explaining to the council member why it could not get accomplished [3], [25].

There were approximately two meetings per year. They were scheduled when there was enough information in order to have a productive meeting. The CAC was specific to the Citation X program. Since then, there have been other program specific Advisory Councils (Citation Excel and Sovereign, for example). The chair of the council varied with the topic discussed; for instance, when discussing a maintenance topic, a maintenance worker would lead the discussion [33].

Federal Aviation Administration

Cessna also worked closely with the FAA. Representatives were present at the design reviews with the upper management and the Customer Advisory Council.

More precisely, they often worked with pilots, ACO (Aircraft Certification Offices) specialist engineers, ACO management, the aircraft evaluation group in Kansas City (about the minimum equipment lists) and the inspection. Some issues were even discussed with the transport director [33].

7.2. Total Quality Management

TQM is, by definition, the art of managing the whole to achieve excellence. It is based on very simple rules such as “do unto others as you would have them do unto you.” Its goal is to provide a quality product to customers, which will, in turn, increase productivity and lower cost.

Cessna used Total Quality Management (TQM) during the Citation X program [3]. They implemented it with the help of a university in Wichita that offered a degree in TQM. The company contracted with this university to give each engineering employee 40 hours of training in TQM. One advantage of TQM is its similarity to the scientific method, making it easily understandable for engineers [25].

TQM is based on six basic concepts [26], [27]:

- **Focus on quality and prevention of problems**

TQM defines quality as the ratio of the performance of a product to the expectations of its consumers: when a product surpasses expectations, it is considered quality. A more complex definition could be: consistently producing what the customer wants while reducing errors before and after delivery to the customer. The TQM philosophy states that quality is not a static outcome; it is a process consisting of continually improving the quality of the company’s products. Emphasis is placed on detecting potential problems before they occur, as failure to prevent defects requires extra people, time, workload, and wastes. It also may cause loss of customer confidence, or even the customer.

In order to prevent defects, employees inspect products during manufacturing. More importantly, TQM companies "design in" quality: during the design phase of product, input from customers, marketing, and those who assemble or produce the final product is used.

- **Cooperation with suppliers and focus on customer satisfaction**

Instead of evaluating suppliers based on price alone, companies using TQM choose suppliers based on life-cycle costs and quality. Vendors are treated as business partners, with all parties working to deliver a quality product. Ideally, a relationship of confidence and cooperation replaces the too common indifference or even hostility towards the suppliers.

In TQM, customer satisfaction is the most important consideration: the customer defines quality. The companies endeavor to listen to the voice of the customer, both external and internal. An example of an internal customer for engineering is manufacturing. The quality requirements must be fulfilled even for products departments produce for other departments.

TQM emphasizes that those affected by a project must be involved in its development: customers and suppliers must be included in project teams.

- **Continuously improve and eliminate wasteful steps.**

An axiom of TQM is that technology changes perpetually, so that an innovation one day will become commonplace some time later. To meet dynamic customer needs, the organization itself must be dynamic. TQM strives to decrease delays and opportunities for error by eliminating wasteful steps. For example, a TQM company strives to deliver in less time or reduce the amount of scrap material.

- **Encourage the proper climate, empower employees**

All personnel are trained in TQM, so that they can effectively participate on project teams. The TQM philosophy believes that people must be empowered at the lowest level to perform processes in an optimum manner. In an atmosphere of trust and respect, the employees will be willing to innovate and act in order to improve service to their customers.

- **Use the problem solving/problem prevention cycle**

The three major elements of the TQM problem solving/problem prevention cycle are: the gathering of information and its analysis before actions are taken; the use of brainstorming and evaluation of the ideas generated; and the evaluation of success. This cycle can be used in:

- cross-functional teams, to clarify and refine processes that cross organizational boundaries;
- design teams, to create or change organization-wide systems;
- intact family work groups working to improve their day-to-day operations;
- newly formed and intact work groups to improve their interpersonal functioning.

- **Use measurements to back decisions**

Within TQM, quantitative data are necessary to measure the continuous quality improvement activity. Statistics allow the decision-maker to differentiate between chance occurrences and systematic factors that significantly affect product or service quality. Quantitative data can also be used to evaluate the efficiency of the workers: uptime, absenteeism, etc. The changes introduced by TQM are summarized in Table 17.

Quality Element	Previous state	TQM
Definition	Product-oriented	Customer-oriented
Priority of Quality	Second to service and cost	First among equals of service and cost
Decisions	Short-term	Long-term
Emphasis	Detection	Prevention
Errors	Operations	System
Responsibility	Quality control	Everyone
Problem Solving	Managers	Teams
Procurement	Price	life-cycle costs and partnership
Manager’s role	Plan, assign, control, and enforce	Delegate, coach, facilitate, and mentor

Table 17: Changes in a company’s philosophy introduced by TQM [27]

7.3. Human-related practices

The practices used at Cessna can be divided into human- and product-oriented practices. The human-oriented practices can in turn be divided into three categories corresponding to employees, suppliers, and customers.

Employees

- **Training**

The training of a Cessna employee takes place in a variety of areas, not only the discipline in which that employee is working. For example, Cessna subsidizes the cost of pilot training for all their employees. They believe that pilots understand the design and construction of an airplane with greater depth [32].

As mentioned earlier, each employee was required to take 40 hours of formal training to TQM principles. Each individual can then apply the principles in his own work [25].

Moreover, all new employees are trained with experienced employees, including those experienced at other companies. That way, the new employees can adapt more easily to their new job [32].

- **Decisions made at the lowest possible level**

Cessna relies heavily on the individual. The designers are granted significant autonomy, in order to encourage creativity. They have much latitude in the design, as long as the drawings are approved at the design reviews. The management intervenes in the design only during these reviews [32].

- **A more flexible workforce**

Cessna officially adopted Lean Manufacturing in 1999, as outlined in Section 7.6. Among the new practices was the creation of a more flexible workforce. The employees were trained to several jobs in order to be able to work at multiple places along the assembly line [19].

Suppliers

The suppliers of Cessna are nearly all business partners. Many of the prototype parts are received on consignment, meaning that the suppliers provide Cessna with free parts during the design of the airplane, and in exchange, Cessna develops and certifies the parts. They cooperated effectively with the engine and avionics engineers [25].

Cessna has a policy of making its suppliers responsible to the customers, as it is the customer who suffers due to supplier errors. The suppliers also give presentations to the customers, to reinforce their connection with the end users [3].

Consumers

Cessna is very customer focused. The Citation X project was born thanks to the Customer Advisory Council. Cessna had originally thought of proposing an improved 650 model, but the council wanted more than that – speed, pressurized baggage compartments, and increased range. Cessna's answer was the Citation X project, and the council approved. They had a huge influence on the design of the airplane, all the way from the mission and capabilities down to the size of the nuts and bolts. The maintenance personnel, chief of flight tests, etc. reviewed the design about three or four times a year and gave suggestions on how to improve the airplane [3], [25].

7.4. Systems Engineering practices

All the product-oriented practices can be linked to the Systems Engineering processes. Systems engineering consists of a few processes that are applied recursively at multiple levels, such as system, subsystem, and component [34]. The most important of these processes are presented below.

Tracking the requirements

The engineers track the requirements at the numerous groups meetings, in particular with their suppliers. To help them in their task, they need some tools.

- **Availability and traceability of the engineering data**

Cessna uses a computer system to reference all their documentation. An EC number is attributed to each piece of engineering and all the information about this piece is referenced under this number. Thus, all the drawings, reports, documentation about a given piece can be found easily [32].

- **FAA documentation**

The “master compliance” is an FAA documentation that explains how to comply with every regulation in detail. It often refers to a precise report or document [32].

Synthesis

- **IDTs**

IDTs permitted Cessna to incorporate the needs and requirements of all the stakeholders and disciplines, to avoid design conflicts and last-minute changes. During the meetings, the engineers could track the interfaces between the components [3], [25].

According to Dick Curtis and Paul Kalberer, every part in the airplane was influenced by the work of the IDTs. An example of effective collaboration was the design of the cockpit, for which pilots, design teams and manufacturing groups designed a final configuration that fit the requirements of all parties. This example is further discussed in Section 8 [3], [25].

- **Optimize the enterprise flow**

All the people working on the project are co-located. This permits the areas to interact continuously, without needing a formal meeting. The engineers often met to fit the different parts into the conceptual airplane and ensure no interference. Moreover, if the production disagrees with a drawing, a correction can be made rapidly, without having to go through a long process. Having all the people in the same place minimizes the intermediaries and thereby saves time [32].

Risk management

- **Design for Simplicity**

A primary design philosophy at Cessna is to design for simplicity. This means that in the design of a system, the designer starts with the simplest achievable system, and then grudgingly sacrifices simplicity to satisfy other requirements. For example, this means always trying to use a single part instead of two, keeping things in straight line, and including the fewest number of components. When this is not possible, the systems incorporate some complexity [3], [25].

This philosophy permits Cessna to limit defects by keeping systems as simple as possible, and to avoid unnecessary complexity that leads to wasteful steps.

- **Integration of advances in technology**

Computational Fluid Dynamics (CFD) provided significant advantages in the design of the Citation X. CFD was in existence for some time before the launch of the Citation X program, but it was (and is) still maturing. It was useful in the design of an aerodynamically efficient wing with less time and money than traditional wind-tunnel-tests. In addition, CATIA, the CAD system used by Cessna, was helpful in integrating the subsystems [3].

The company has been relatively quick to adopt advances made by its suppliers in engines and avionics, but slow to try many other novel technologies. For example, the company does not have a very wide use of composite materials. Only the Citation X's control surfaces are made of graphite carbon fiber and other composites. In contrast, Raytheon’s Premier entire fuselage is made of carbon-composite material laid down by computer-driven "fiber-placement" machines. Cessna executives’ arguments are that much is yet to be learned about the life of large composite parts, that the cost of composites is too high and that it can design new aircraft more quickly if not using composite materials. This argument may have some merit, evidenced by Raytheon’s program delays due to mastering a new technology and educating the FAA [19].

- **Maintain Stability in a changing environment**

Cessna limits the number of new people on a project to 25%. By keeping a large proportion of experienced workers, they limit the risk of mistakes due to ignorance or lack of vigilance [32].

Verification and Validation

- **Design reviews**

In order to facilitate the verification and validation process, Cessna had regular design reviews with the FAA, the Customer Advisory Council, and the internal management. Every subsystem was reviewed. Those groups are composed of experienced people who can often anticipate problems.

- **Parallel design/testing**

Cessna accelerates its program by testing some parts of an airplane while designing the rest. For example, they designed the airframe of the Citation X first, and began stress testing the airframe while other subsystems were being developed. Thus, by the time they flew the prototype, it already had two years of stress testing. They also had the hydraulic and electric systems cycled 100,000 times before integrating them into the plane. They did a full hydraulics mockup with flight controls, landing gear, etc. on an "iron bird." They put a television in the cockpit and simulated the behavior of the aircraft so the pilots could participate in the design. They were able to fly "iron birds" two years before prototyping, and could test hydraulics, flaps, and environmental systems. The doors were also tested 50,000 to 60,000 times before being integrated with the airplane [3], [25].

This method is especially useful when entering into areas where there is limited design information. For example, there was no available load bearing information concerning the titanium flap tracks. Therefore, the engineers ran load testing on them in their laboratory early in the design program, in order to understand how to design a long-lasting titanium track. [3], [25].

7.5. Comparison to Lean Enterprise Model

The following table compares the program management practices at Cessna with those prescribed by the Lean Enterprise Model.

	Lean Enterprise Model	Practices at Cessna
Human-related	Optimize Capability and Utilization of people	– Employees subsidized to get pilot licenses – New employees trained with experienced ones – Manufacturing: more flexible workforce
	Make decisions at lowest possible level	– Individual designers autonomous: creativity
	Develop relationships based on mutual trust and commitment	– Suppliers = business partners – Many prototype parts on consignments
	Continuously focus on the customer	– Customer Advisory Council: comments become "action items" that have to be closed
	Promote Lean leadership at all levels	– Training to TQM principles for each employee
	Nurture a learning environment	– Interchange of knowledge with the suppliers
Product-related processes	Identify and Optimize enterprise flow	– Same location: minimize intermediaries
	Assure Seamless information flow	– Traceability and availability of the engineering data – Numerous meetings (internal and external groups)
	Implement integrated product and process development	– Systems Engineering Processes
	Maintain challenge of existing processes	– Improvement of the new methods for other programs
	Ensure process capability and maturation	– Adoption of Lean Manufacturing in 1999
	Maximize stability in a changing environment	– Avoid high-risk developments – No more than 25% new people on a project

Table 18: Comparison of Cessna's practices to the Lean Enterprise Model [34]

7.6. Lean Manufacturing

Cessna adopted Lean Manufacturing in 1999. With its help, they reduced costs by 15%. They did not adopt Lean within their design process [25].

The focus of Lean Manufacturing is the absolute elimination of waste, where waste is defined as anything that prevents the value-added flow of material from raw material to finished goods. This requires abandoning the batch-and-queue mode of operation, which encourages large-batch processing and focuses on the efficiency of individual machines and workers, and adopting Lean manufacturing, which views continuous, one-piece flow as the ideal. It emphasizes optimizing and integrating systems of people, machines, materials, and facilities. The focus is set on the product and its needs rather than the organization or the equipment. This philosophy can lead to significant improvements in quality, cost, on-time delivery, and performance. The final goal is to create a value-added flow in order to give customers what they want when they want it [29].

The company implemented Lean manufacturing with the help of the University of Tennessee. Cessna first implemented it at a new plant in Independence, and then in its older plant in Wichita [19].

Cessna opened the Independence plant in July 1996 as its return to making small, single-engine piston-powered planes, a business it had abandoned ten years earlier. The new factory is still far from the first planned production target and labor hours per aircraft produced. Things were especially difficult for Cessna as it started in a new city and with inexperienced workers, recruited because tests showed them to be good team players willing to take on responsibility and not because of their skills in the area. Independence was planned as a plant that would assemble parts and pieces made and shaped elsewhere. With the help of experienced mentors (retired employees) and homegrown coaches, the plant managed to increase its efficiency by mid-1999. The emphasis then shifted from skill development to conflict resolution, problem solving, and flexibility. In 2000, some of the teams had acquired the combination of skill and cohesion to shift as needed across the assembly lines [19].

What slowed the introduction of Lean Manufacturing in Cessna's Wichita plants was both the number of fixed habits of the experienced employees and the arrival of numerous new personnel every year due to the company's rapid growth. For Cessna, the goals of Lean manufacturing are dual: cutting the time from concept to market for new aircraft, and cutting the cost and time it takes to build them. Cessna has learned to be patient through the difficulties it experienced with the CitationJet in the mid-1990s. The company lost time and money trying to fix the many mistakes due to a rushed program. Cessna aims to attain a wait time of six months between order and delivery of a Citation. This delay was 15 months in 2000; six months is a significant challenge. Changes are, however, taking place gradually on the Citation lines. Some production lines are going to stay unchanged: there is no point changing how a plane is assembled if it's going out of production in a short time [19].

8. Lifecycle considerations

8.1. Design for manufacturing, maintenance

Design for manufacturing was a crucial aspect during the development phase of the Citation X. There were a large number of details for every piece that had to be reconsidered; if a slight design change could lead to faster production rate without causing a loss in performance or additional tool development costs, Cessna would do it. Furthermore, parts had to be designed such that they could be manufactured with already available tools or low tool development costs. For example, common radius cutters with the correct aspect ratio were used for the machining of the ailerons, which fit the existing spindles in the shop.

Design for maintenance also played a major role. Wood mockups were constructed for some subsystems such that they could be moved in order to check for accessibility. When problems arose, additional access panels were added so that critical parts of the aircraft could be accessed. Maintenance was also simplified by adding many component backups. As an example of the impact of IDTs in design for manufacturing and maintenance, the pilots were also strongly integrated in the design process. Cessna, FAA and customer pilots spent months in cockpit mockups working on switch arrangements and locations and the general layout. This worked out the tradeoffs between the user-friendliness of the cockpit and the accessibility during support [30].

8.2. Prototyping

The prototyping phase was of enormous importance to identify areas for design improvement on the Citation X. Parallel design and testing, in the form of iron birds, proved to be of great importance in order to build effective prototypes. Production tools were developed exclusively for the prototype and were later used when making the first production airplanes. This allowed the prototype to have the same characteristics as the production airplane. The changes on the manufacturing tools after prototyping were varied. For example, the testing of big airframe tools started approximately a year and a half to two years ahead of the prototyping phase in order to understand fatigue issues. By the time the first prototype was built, these test articles had already experienced many hours of operation and thus needed very little change. [30]

8.3. Verification, validation, certification

The aircraft system, every subsystem , and every part must be certified. A part or subsystem can be certified either as by testing, by analysis or by similarity. Most parts have a detailed certification plan established by the FAA. After applying for a certification, a company has a 5-year period get certification, before new FAA amendments come into effect. The Citation X applied for its type certificate in 1991. Cessna's goal was to certify the Citation X both for the FAA and the JAA, but resource limitations led to choose the FAA first and JAA later on. However Cessna lost their place in line for the JAA and got a significant delay. JAA certification was achieved in 1999, three years later than FAA certification.

Cessna and the FAA jointly developed a test plan for the components. These test procedures can be large and complex; for example, the Citation X flight test plan attempts to assess the performance of most pieces and subsystems under a wide range conditions. In this ongoing process, Cessna made full use of its Designated Engineering Representatives (DER's), Cessna employees trained by the FAA to certify certain tests. These inlcude static tests, ground tests, and some flight tests. There are other areas where the DER cannot sign off, for example, on topics related to reliability. The Test Inspection Authorization (TIA), also issued by the FAA, certifies that the test is not hazardous to its employees. According to [32] most of the certifications process for the Citation X did not encounter significant problems.

Some of the testing took place in Colorado, because of its 10,000ft altitude and proximity to the development center in Wichita. Further testing location included La Paz, Bolivia for altitude and Yellowknife, Yukon, Canada for low temperature tests.

During the testing phase, the EICAS system was the most problematic subsystem. It is integrated with the whole plane and it took a long time to integrate. Other subsystems that required more validation time were the yaw damper on the upper rudder system and the flight controls, for which the cables had to be rerouted for lower friction [30].

8.4. Product support

Worldwide, there are ten Cessna-owned and 24 Cessna-authorized service centers, which provide maintenance, inspections, parts, repairs, modifications, equipment installations, refurbishment and other specialized services for the Citation family. A hot line in Cessna's headquarters operates 18 hours a day and is staffed with engineers, personnel that can track the maintenance status electronically, and administrative staff. The Citation Parts Distribution Centers have more than $50M worth of Citation inventory that can be shipped out on the same day at a competitive market price.

While these centers offer general support for the Citation family, there are also teams dedicated to a specific model. The Team X for example, is dedicated exclusively to the Citation X and is available 24 hours a day. Cessna introduced it because they realized that the Citation X was a more complex airplane than the other Citations and needed a stronger customer support group. Team X representatives went on site and could arrange alternative transportations, which was very attractive for customers. In addition, all Citation service centers carry Citation X spares. After the success of Team X, special teams for the Citation VII and others in the 650 series were established which were also valuable for both the customer and Cessna.

Cessna also provides a 5-year warranty for the Citation X that covers parts and labor, engines, avionics and the airframe. However, Cessna does not cover normal wear and tear, such as abrasion on seat fabric or tire wear [30], [35].

8.5. Ownership costs

8.5.1. Full ownership

The costs represented in this section are values given by Cessna [2] as of October 2003. These costs are therefore applicable to the upgraded version of the Citation X. Cost can be divided into acquisition cost, direct operating cost and fixed cost. 500 flight hours per year is assumed.

Acquisition Cost

The price of a Citation X was $15.6 million in 1997 and is $19.1 million in 2003 for an upgraded Citation X.

Direct Operating Cost

Prices are based on Cessna's Guide to Operating Economics. All costs are written per flight hour.

Fuel ($2.50 per gallon)	$750.00
Labor ($71.00 per hour)	$127.00
Parts (Cessna's ProParts program)	$75.00
Engine Reserves (Roll's CorporateCare)	$315.00
APU Reserves	$28.00
Total DOC per hour	$1,295.00
Total DOC per Year	**$647,460**

Fixed Cost Detail

This data is based on an industry survey. With the exception of hangar costs, which are monthly, all the costs are yearly.

Hangar ($1,800 per month)	$21,600
Hull insurance (0.3% of cost)	$57,585
Liability Insurance ($200M coverage)	$55,000
War Risk Insurance ($50M aggregate)	$20,598
Crew Salaries (2 crew plus benefits)	$220,000
Crew training (N/A for the first year)	$34,000
Total Fixed Cost (after the first year)	**$408,783**

8.5.2. Half-Ownership through Netjets

Netjets offers the Citation X and many of its competitors for fractional ownership. The price of half ownership of some of these aircraft is considered in order to compare the various components of the cost of each aircraft. Netjets separates the costs in three portions:

- Acquisition cost: this one time fee corresponds to the purchase of a portion of the aircraft. In the case of half ownership, this corresponds to half of the price of the aircraft.
- Monthly fee: this fee corresponds to the fixed costs of owning the aircraft and includes hangaring fees, crew training, insurance, etc…

- Direct Operating Cost: this is the cost per flight hour.

The comparison of these costs shows that Cessna offers an aircraft with superior speed capabilities at a competitive cost. [39]

Aircraft	Acquisition Cost	Monthly fee	DOC per hour
Hawker 800XP	$6,150,000	$54,800	$1,868
Citation X	$9,474,000	$68,400	$2,144
Gulfstream 200	$8,450,000	$74,700	$2,351
Falcon 2000	$11,905,000	$80,700	$2,635
Gulfstream IV-SP	$14,900,000	$91,600	$3,112

8.6. New 2002 version

Over the life of the aircraft, Cessna has made a number of improvements to the aircraft many through optional bulletins. These changes were therefore optionally retrofitted but were incorporated in the new aircraft that were sold. In 2002, Cessna made a major upgrade of the aircraft. While the marketing department called the 2002 version an upgrade, the engineers referred to it as a “block point change.” This was an upgrade of the two major subsystems of the aircraft. The Citation X benefited from the upgrade of the Rolls Royce engine due to its use on the Embraer regional jets. The highlights for this upgrade were:

- A 5% thrust increase from the AE3007 which reduced the take-off length requirement.
- A 400lb increase in maximum take off weight allowing the Citation X to carry up to seven passengers with full fuel.
- Enhanced Honeywell avionics.

Other improvements included changes to the aileron gear ratios to improve the low-speed roll response and an improved baggage door ladder.

9. Operating experience

9.1. Operation Experience Summary

As of September 2002, more than 160 Citation Xs were in service, and had flown more than 180,000 hours combined. [1]. Most of the operators are out of the U.S., but other operators are in Canada, Finland, Germany, Mexico, South Africa, and the UK. Most operators chose the Citation X over the competition for its high cruise speed and altitude, advanced systems, low operating costs, and Cessna's good reputation for product support.

9.2. Identified Advantages and Drawbacks

Operators of the Citation X are generally pleased with its performance. According to most operators, the Citation X's best features are speed, dispatch reliability, cabin quiet and comfort, advanced Honeywell avionics, and ease of maintenance. [12].

However, the Citation X has its share of drawbacks. The greatest drawback, according to operators, is its sluggish roll response at low speeds. This can make it difficult to land in crosswind conditions. Cessna responded to this drawback by redesigning the aileron system, and completely changing the gear ratios on the aileron. The changes were implemented starting on plane number 73, and corrected the problem. Cessna also provided a retrofit kit for the first 72 planes.

Another noted drawback was the baggage -door ladder, which was wobbly and could pinch peoples' fingers. Cessna responded to this problem by designing a new ladder, which is present on the last 130 planes.

The baggage compartment, cabin, and cockpit are said to be small. The Citation X used the cross section of the fuselage from the Citation VII, but extended the length by 5.1 feet, and lowered the seats to provide more headroom. However, when the seats are swiveled sideways to provide more elbow room, aisle accessibility becomes limited. Cessna offers a change option that allows the pilot seats to slide back, providing more leg room. Any other adjustments to enlarge the cockpit/cabin/baggage space would require major structural changes that would alter the aerodynamic configuration of the plane [25].

Cessna has issued a large number of service bulletins, which operators must comply with within 120 days of issuance. This can cause a high maintenance workload and excessive downtime.

9.3. Accidents and Incidents

As of November, 2003, there have been no hull losses of the Citation X, but the FAA reported 14 incidents from October, 1996 to May, 2003. All Cessna jets require a separate type rating. In the past, Cessna was able to group families of airplanes together under a single type rating, but as the FAA has become more and more strict, each model now requires its own. Cessna attributes its good safety record in part to the quality of pilot training.

The incidents, along with brief descriptions are listed in the table below [37].

Date	Location	Description
5-3-03	Newburgh, NY	Aborted takeoff after “no take off” warning came on at 95 to 100 knots.
4-24-03	Denver, CO	Aborted takeoff after crew received “no takeoff” light. While taxiing back to the ramp, the thermal plugs melted and both tires deflated on the right main landing gear.
1-15-03	Sacramento, CA	Left engine inlet struck by a bird on final approach. The aircraft landed safely. The inlet was replaced, and no further damage was found.
11-27-02	Santa Monica, CA	Aircraft lost hydraulic pressure in the “A” system during climb-out, then the “B” system overtemped (190C). The aircraft declared an emergency, performed emergency extension of gear, and landed at LAX with pneumatic brakes. No injuries were reported.
3-21-02	Denver, CO	Aircraft enroute to TEX diverted to Denver when pilot reported unsafe nose gear indication. Aircraft landed without incident.

3-4-02	Omaha, NE	Hydraulic failure caused crew to declare an emergency and divert to Omaha. Maintenance changed the system "A" number two hydraulic pump.
2-20-02	Ft. Lauderdale, FL	Landing gear extended without any input from the crew, stayed down for a minute, then retracted, also without any input from the crew. Several minutes later, it extended uncommanded again. The pilot declared an emergency, and landed in Fort Lauderdale. Post incident examination revealed an area of exposed wire with damaged insulation, which touched a stainless steel part of the airplane structure.
12-18-01	Teterboro, NJ	Right wingtip contacted the runway during landing due to a gust of wind that caused a high sink rate.
11-2-01	Wichita, KS	Engine oil pressure transducer failed, causing low oil pressure. Airplane landed safely and the transducer was replaced.
10-31-01	Indianapolis, IN	Emergency declared after right fuel tank overfill light came on. Fuel was seen leaking from both wings. Inspection on the ramp found fuel leaking from the access panel near the fuel vent. Cessna SB 750-28-11 had recently been installed. The original surge tank float valves were reinstalled.
12-17-00	Saint Paul, MN	Aircraft landed with the left main wheels locked. Both tires and wheels on the left side of the aircraft were destroyed during the landing roll out.
10-5-99	Lincoln, NE	Crew diverted to Lincoln when they noticed a drop in the hydraulic quantity indication. Maintenance found the #1 engine driven hydraulic pump case had small pinholes in the areas of the pressure port. The pump was replaced, and the aircraft returned to service.
4-25-99	El Paso, TX	Takeoff was aborted when the aircraft experienced power fluctuations at liftoff. A post flight inspection revealed no reason for the fluctuations. The aircraft took off again the next day, and departure was normal until landing gear was

		retracted, at which time the right engine began to operate again. The aircraft commenced to return for landing, and as gear extended, the right engine again quit. Inspection revealed a broken mixture control clamp in the right engine. When landing gear was retracted, contact with the right engine mixture control was made, causing fuel starvation and engine failure. The clamp was replaced, and the plane flew without further incident.
10-23-96	Wichita, KS	Testing emergency blow down after 5 cycles normal gear. No nose down indication. Confirmed doors slightly open by chase aircraft. Cause unknown.

9.4. Anomalies/Airworthiness directives

Cessna has four levels of bulletins. A mandatory service bulletin is issued if there is a problem with the plane that affects the safety of the flight [25]. A recommended service bulleting is issued for things that fail prematurely, and pertain to the reliability of the aircraft. An optional bulletin is issued when optional changes are available, which, while not necessary, would improve the plane. Cessna created a fourth category, called discretionary service bulletins, which have no time limit. Cessna pays for discretionary, recommended, and mandatory service bulletins, but not the optional service bulletins.

An Airworthiness Directive (AD) is issued by the FAA when a potentially unsafe condition has been found to exist in a particular aircraft, engine or system installed on the aircraft, and that condition is likely to exist or develop in other aircraft, engine or system of a similar design. [38]. Typically, the FAA will post an AD for a Cessna aircraft in response to a mandatory service bulletin issued by Cessna. This action from the FAA gives the legal version of Cessna's mandatory service bulletin.

Cessna pays for all of the ADs. The ADs for the Citation X have in general been much less expensive than the service bulletins that did not result in ADs.

Below is a table of the four ADs issued by the FAA for the Citation X [37].

AD Number	Effective Date	Description
98-05-02	3-16-98	Investigation of jamming of aileron control circuit during flight revealed that water contamination and subsequent accretion of ice on the center aileron roll feel and centering assembly can prevent free movement of the bungee shaft, which may cause jamming of aileron control circuit, which could result in reduced controllability of airplane. Requires repetitive lubrication of the aileron feel cartridge assembly shaft, until replacement of roll feel and centering bungee assembly with improved assembly is performed.
98-16-17R1	Rescinded 10-23-03	Requires repetitive in-flight functional tests to verify proper operation of the secondary horizontal stabilizer pitch trim ystem, and repair if necessary.
2001-07-04	5-15-01	Requires removal of an existing bulkhead web doubler, installation of left and right bulkhead web doublers, and enlargement of lightening holes, to prevent jamming of roll control system due to inadequate clearance between the control cable and the web, which could result in reduced controllability of the airplane.
2002-23-05	12-26-02	Requires replacement of reset circuit breakers for the auxiliary hydraulic pump system and the King KHF 950 high frequency communication system with new circuit breakers. In response to reports that trip levels for the circuit breakers were too high, which can prevent corresponding high current remote control circuit breakers from tripping when excessive electrical loads are present, which can result in fire due to overloading of wires and circuits.

10. Conclusions

This document summarizes the Citation X program, giving insights into design and performance metrics, the timeline and market context, stakeholder perspectives, the program management approach, and knowledge gained from operational experience.

First delivered in 1996, 5 years after it was announced, the Citation X is the fastest business jet on the market and can comfortably satisfy domestic range requirements. The Citation X is significantly different from its predecessors and targets mainly Fortune 1000 companies, individuals and fractional jet leasing companies. It can carry a maximum of 14 persons, including two necessary crewmembers. The key stakeholder requirements are satisfied by the performance metrics shown in Table 19 below.

Max Cruise Speed (>= 0.9)	M=0.92, 350 KIAS
Max Range (Transcontinental)	3,300nm
Max Altitude (above most traffic)	51,000ft
Max Takeoff/ Landing Weight	35,700lbs, 31,800lbs
Min Take off / Landing Distance	7,500ft at 35,700 lbs, 3,820ft at 31,800 lbs
Direct Operating Costs	$2,144/hour

Table 19: Performance Metrics

There were important technological innovations on the subsystems level. The main innovations are illustrated in the following Table 20.

Propulsion	Two Rolls-Royce AE3007C1 Turbofan, 5:1BR, Thrust 6,700 lbs
Structure	40° swept wing slung below fuselage, pressurized cabin, area-ruled fuselage, T-tail configuration
Powered Controls	Dual hydraulic systems, five spoiler panels in add. to ailerons, split hydraulic/electric rudder, separate yaw dampers on each rudder
Avionics	Honeywell Primus 2000 autopilot, flight director and EICAS

Table 20: Key Subsystems

Overall, the program was considered a success. Customer expectations of comfortably transporting passengers "from coast to coast in a hurry" were met by an aerodynamically efficient aircraft with more cabin space and quiet, large intake engines. End user expectations of good handling qualities and maintenance were satisfied by hydraulically powered primary flight controls and reliable/replaceable parts. Moreover, economic expectations of low operating costs, efficient manufacturing and a profit margin were obtained through higher fuel efficiency, a solid business plan and the introduction of lean manufacturing in 1999. The Citation X successfully penetrated a previously unexplored market niche and managed to obtain significant profit margins.

The program management style during the design stage was heavily focused on total quality management principles in order to attain employee productivity, effective communication with suppliers, meet quality expectations and improve costs. IDTs, composed of engineers, representatives from manufacturing, marketing, customer groups and maintenance ensured an overall improvement in efficiency, and that requirements of all areas are met.

The major drawbacks of the Citation X program were that the aircraft was not certified on schedule, and that some of the subsystems (such as the entry ladder and the aileron gear-ratios) were not as well designed as they could be. In addition, some subsystems, such as the split rudder, were unnecessarily complex. Cessna was aware of these drawbacks but chose not to further delay the program by redesigning the subsystems.

A valuable lesson learned, therefore, is to solve all potential problems as early in the design as possible to avoid unnecessary complexities. The major aspect missing from the program management approach is a mechanism for addressing the concerns of the design engineers early in the process, and ensuring that management takes these concerns seriously. In addition, the certification requirements should be addressed as early as possible with the regulating agencies in order to avoid certification delays.

On the positive side, Cessna did many things right in the design of this record-breaking aircraft. For instance, the company well understood he importance of evaluating the market context, and fostered close interaction between the stakeholders and the company in order to meet value expectations as closely as possible. Communications between key suppliers and partners, as well as on all internal levels in the form of IDTs, proved crucial in order to avoid significant changes in the design, delays, additional costs and sub-optimal aircraft performance. Total quality management proved to be very effective and a future focus will be on better implementing lean manufacturing principles.

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