

Chapter 7 Computers and Aviation

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Although animal flight has a history of 300 million years, serious thought about human flight has a history of a few hundred years, dating from Leonardo da Vinci,¹ and successful human flight has only been achieved during the last 110 years. This is summarized in the attached figures 7.1-7.4. To some extent, this parallels the history of computing. Serious thought about computing dates back to Pascal and Leibnitz. While there was a notable attempt by Babbage to build a working computer in the 19th century, successful electronic computers were finally achieved in the 40s, almost exactly contemporaneously with the development of the first successful jet aircraft. The early history of computers is summarized in figures 7.5-7.8. Tables 7.1 and 7.2 summarize the more recent progress in the development of supercomputers and microprocessors.

Although airplane design had reached quite an advanced level by the 30s, exemplified by aircraft such as the DC-3 (Douglas Commercial-3) and the Spitfire (figure 7.2), the design of high speed aircraft requires an entirely new level of sophistication. This has led to a fusion of engineering, mathematics and computing, as indicated in figure 7.9.



Figure 7.1a Orville and Wilbur Wright, 1903 (Courtesy of USAF, United States Air Force).

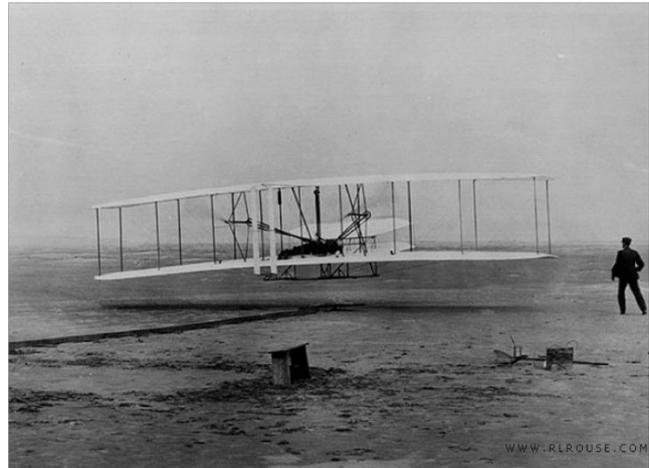


Figure 7.1b The Wright Flyer, 1903 (Courtesy of John T. Daniels, Library of Congress, US).²

¹ L. da Vinci, *Notebooks*, Oxford University Press, 2008

² The Wright Flyer is the first successful powered aircraft, designed and built by the Wright brothers. They flew it four times near Kill Devil Hills, about four miles south of Kitty Hawk, North Carolina, US.



Figure 7.2a Douglas DC-3, 1935 (Courtesy of Douglas Aircraft, The Boeing Company).



Figure 7.2b Supermarine Spitfire, 1936 (Courtesy of Franck Cabrol, GNU Free Documentation).



Figure 7.3a Messerschmitt ME-262, 1941 (Courtesy of USAF, United States Air Force).



Figure 7.3b Lockheed SR-71, 1964 (Courtesy of Judson Brohmer, USAF).



Figure 7.4a Boeing 747, 1969 (Courtesy of Andre Chan, Stanford University, US).



Figure 7.4b Airbus 380, 2005 (Courtesy of Andre Chan, Stanford University, US).



Figure 7.5a Pascal's Pascaline, 1642 (Courtesy of André Devaux, Calmecca, France).

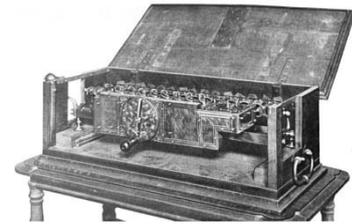


Figure 7.5b Leibniz's stepped reckoner, 1672.³



Figure 7.6a Babbage's difference engine, 1822 (Courtesy of Jitze Couperus, Flickr).

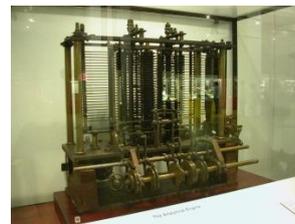


Figure 7.6b Babbage's analytic engine, 1822 (Courtesy of Bruno Barral, Wikipedia).



Figure 7.7a Mark I, 1944 (Courtesy of John Kopplin and Michael Rothstein, Kent State University, US).⁴



Figure 7.7b Cray-1, 1976 (Courtesy of Cray Research, US).⁵



Figure 7.8a NEC Earth Simulator, 2002 (Courtesy of JAMSTEC, Japan Agency for Marine-Earth Science and Technology).



Figure 7.8b IBM Blue Gene, 2005 (Courtesy of Argonne National Laboratory, US).

³ J. A. V. Turck, *Origin of Modern Calculating Machines*, The Western Society of Engineers, p.133, 1921

⁴ Mark I, a computer which was built as a partnership between Harvard and IBM in US, was the first programmable digital computer made in the US. But it was not a purely electronic computer.

⁵ The Cray-1 was a supercomputer designed, manufactured and marketed by Cray Research founded in 1972 by computer designer Seymour Cray in Seattle, Washington, US, After the Cray Research purchase in 2000, Cray was formed: www.cray.com.

During the last five decades, computers have fundamentally transformed every aspect of aviation and aerospace. These impacts fall into three main classes. First, computing has completely transformed the design and manufacturing processes. Second, the advent of microprocessors with ever increasing power has transformed the actual aircraft and spacecraft themselves, with computers taking over every aspect of the flight control and navigation systems. This parallels similar developments in automobiles, which are no longer directly controlled by their drivers, but instead use microprocessors to optimize engine performance and manage functions such as anti-skid breaking. The third way in which computers have transformed aviation is that the major aspects of aircraft operations are now controlled by computing systems such as electronic reservation and ticketing systems and automatic check-in. We shall discuss each of these aspects in more detail in the following sections.

Table 7.1 Supercomputers timeline

Year	Model	Performance
1964	CDC 6600	3 MFLOPS ⁶
1976	Cray-1	250 MFLOPS
1993	Fujitsu Numerical Wind Tunnel	124.5 GFLOPS
2002	NEC Earth Simulator	35.86 TFLOPS
2007	IBM Blue Gene/L	478.2 TFLOPS
2009	Cray Jaguar	1.759 PFLOPS
2012	IBM Sequoia	20 PFLOPS

Table 7.2 Microprocessor timeline

Year	Model	Manufacturing Process	Transistor	Clock	Bits	Core
1971	Intel 4004	10 μm	2,250	108 kHz	4	1
1978	Intel 8086	3 μm	29,000	4.77 MHz	16	1
2000	Intel Pentium IV	0.18 μm	42 M	1.5 GHz	32	1
2008	Intel Core i7	45 nm	774 M	2.993 GHz	64	4

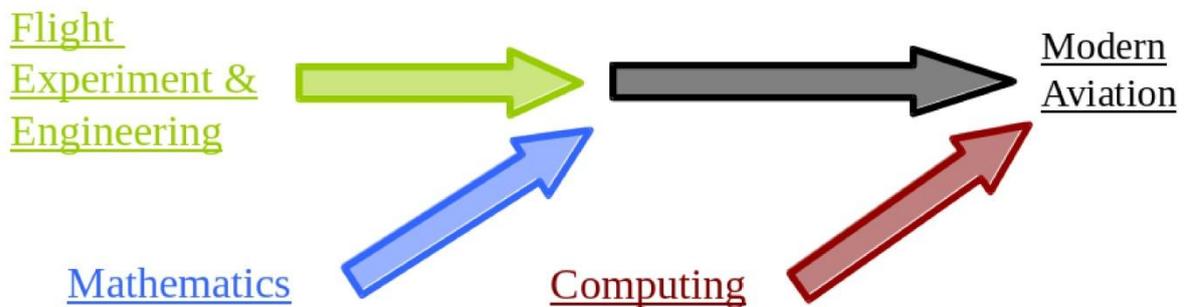


Figure 7.9 Fusion of flight experiments, mathematics and computing.

⁶ In computing, FLOPS (FLOating-point Operations Per Second) is a measure of computer performance, useful in fields of scientific calculations that make heavy use of floating-point calculations. For such cases it is a more accurate measure than the generic instructions per second.

7.1 Computing in structural and aerodynamic analysis

The first inroads of computing in the aerospace industry were in the design process, beginning with structural analysis based on the finite element method. In fact, the origins of the finite method may be found in the aerospace industry, in The Boeing Company, where it was developed under the leadership of Turner in the period 1950 - 1962.⁷ Important early contributions were made by Argyris who was a consultant to Boeing.^{8,9,10,11} The NASTRAN (NASA STRucture ANalysis) software for structural analysis was developed under NASA (National Aeronautics and Space Administration) sponsorship between 1964 and 1968, and became a standard tool.

Computing methods for aerodynamic analysis follows soon behind, giving birth to the new discipline of CFD (Computational Fluid Dynamics). The Aerodynamic Research Group of the Douglas Aircraft Company,¹² led by Smith, developed the first panel method for three dimensional, linear, potential flows in 1964.¹³ Nonlinear methods were needed to enable the prediction of high speed transonic and supersonic flows. A major breakthrough was accomplished by Murman and Cole in 1970, who demonstrated for the first time that steady transonic flows could be computed economically. The first computer program that could accurately predict transonic flow over swept wings, FLO22, was developed by Jameson and Caughey in 1975, using an extension of the method of Murman and Cole, and rapidly came into widespread use. At this time (1976), swept wing calculations challenged the limit of the available computing resources. The most powerful computer available, the Control Data 6600, had 131,000 words of memory. This was not enough to store a full three-dimensional solution, which had to be read back and forth from disk drives. It had a peak computational speed of about 3 Megaflops, and a complete swept wing calculation took about 3 hours with a cost around 3,000 dollars. Nevertheless, Douglas found it worthwhile to run 6 or more calculations using FLO22 every day. The first major application was the wing design of the C17 (Cargo aircraft model 17). FLO22 was also used for the wing design of the Canadair Challenger. This was the first application of CFD to the wing design of a commercial aircraft. FLO22 is still used today for preliminary design studies. It is useful in this role, as the calculations can now be performed in 10 seconds with a laptop computer.

With the advent of the first supercomputers in the early 80s, exemplified by the Cray-1, which achieved sustained computational speeds of around 100 Megaflops, it became feasible to solve the full fluid flow equations (the Euler equations for inviscid flow and the Navier-Stokes equations for viscous flow) for complex configurations. The first Euler solution for a

⁷ M.J. Turner et al., *Stiffness and deflection analysis of complex structures*, Journal of the Aeronautical Sciences, Volume 23, N. 9, p. 805, 1956

⁸ J.H. Argyris, *The open tube: A study of thin-walled structures such as interspar wing cut-outs and open-section stringers*, Aircraft Engineering and Aerospace Technology, Volume 26, Issue 4, p. 102, 1954

⁹ J.H. Argyris, *Flexure-torsion failure of panels: A study of instability and failure of stiffened panels under compression when buckling in long wavelengths*, Aircraft Engineering and Aerospace Technology, 26, p. 174, 1954

¹⁰ J.H. Argyris, *Energy theorems and structural analysis: A generalized discourse with applications on energy principles of structural analysis including the effects of temperature and non-linear stress-strain relations*, Aircraft Engineering and Aerospace Technology, Volume 26, Issue 11, p. 383, 1954

¹¹ J.H. Argyris and S. Kelsey, *Energy theorems and structural analysis: A generalised discourse with applications on energy principles of structural analysis including the effects of temperature and nonlinear stress-strain relations*, Butterworth, 1960

¹² The Douglas Aircraft Company was an American aerospace manufacturer based in Southern California. It was founded in 1921 by Sr. Donald Wills Douglas and later merged with McDonnell Aircraft in 1967 to form McDonnell Douglas: www.mdc.com

¹³ J.L. Hess and A.M.O. Smith, *Calculation of the non-lifting potential flow about arbitrary three dimensional bodies*, Douglas Aircraft Report, N. E.S. 4062, 1962

complete aircraft was accomplished by Jameson, Baker and Weatherill in late 1985, who were provided remote access to a Cray-1 by the Cray company.¹⁴ By the 90s, computer performance had advanced to the point where Navier-Stokes simulations could be routinely performed using meshes containing several million cells. This period saw the emergence of NASA developed codes such as OVERFLOW (OVERset grid FLOW solver), CFL3D (Computational Fluids Laboratory Three-Dimensional), USM3D (Unstructured Mesh Three-Dimensional) and FUN3D (Fully Unstructured Navier-Stokes Three-Dimensional). During the 80s and 90s, there was a parallel development of commercial CFD software targeted at a wide range of industrial applications. The first commercial CFD software was Spalding's PHOENICS (Parabolic Hyperbolic Or Elliptic Numerical Integrated Code Series) code. Fluent, CFX¹⁵ and STAR-CD (Simulation of Turbulent flow in Arbitrary Regions Computational Dynamics) emerged as the most widely used commercial software packages, but most aerospace companies still prefer to use codes specifically developed for high speed flow simulations.

The current use of CFD in aircraft design is illustrated in figures 7.10-7.11. Figure 7.10 shows a simulation of the compressible viscous flow over an Airbus A380. Figures 7.11a and 7.11b illustrate the extent of CFD use in the designs of the A380 and the Boeing 787.

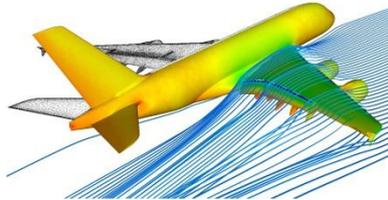


Figure 7.10 CFD simulation of A380 (Courtesy of DLR, the German Aerospace Centre).¹⁶



Figure 7.11a CFD contributions to A380 (Courtesy of DLR).¹⁷



Figure 7.11b CFD contributions to B787 (Courtesy of The Boeing Company).¹⁸

7.2 Computer aided design and manufacturing

Historically, engineering parts have been defined by engineering drawings and 'blueprints'. These required meticulous preparation by large teams of draftsman working at drawing boards. By the 60s, it was apparent that there was an opportunity for significant cost reductions if this process could be computerized. This required, however, the development of a new set of mathematical tools which provide the foundations of modern computational geometry, and have enabled the development of CAD (Computer Aided Design) and CAM (Computer Aided Manufacturing) systems.

¹⁴ www.cray.com

¹⁵ Fluent and CFX are computational fluid dynamics software marketed by Ansys Corporation: www.ansys.com.

¹⁶ DLR (Deutsches Zentrum für Luft- und Raumfahrt e.V.): www.dlr.de

¹⁷ Ibidem

¹⁸ www.boeing.ch

The early development of geometric modelling technology was driven by the automotive and aircraft industries due to their unique engineering requirements for a wide range of curves and surfaces for their parts. Manually defining and manufacturing these components was becoming increasingly time-consuming and costly. By the early 60s, numerically controlled machine tools became more readily available. There was the need to generate the digital information to drive these machines. CAD systems began to emerge in this era. Some of the first development took place at Citroën where de Casteljaou developed CAD methods, and introduced the de Casteljaou algorithm in reports that were not published outside Citroën,^{19,20} and at Renault, where Bézier led the development of the UNISURF system,²¹ and introduced the concept of the Bézier curve.^{22,23,24}

As in the case of CFD, CAD system development also experienced rapid changes as computer hardware became more capable. In the 60s, CAD software was run on mainframe computers. The earliest CAD systems were used primarily for replacing the traditional drafting practice. Though limited at that time to handle only two-dimensional data, using CAD for engineering drawing helped to reduce drawing errors and allowed the drawings to be modified and reused. Large aerospace and automotive companies with the resources to cover the high costs of early computers became the earliest users of CAD software. Most CAD development in that period was conducted internally in those companies. An example was the CADAM (Computer-Augmented Design And Manufacturing) system developed by the Lockheed²⁵ aircraft company. This system, which automated the production of two-dimensional drawings was marketed by Lockheed after 1972. Dassault purchased a license in 1974, and also acquired UNISURF from Renault in 1976. Subsequently, this evolved into the three-dimensional modelling system CATIA (Computer Aided Three-dimensional Interactive Application), which was originally used in conjunction with CADAM. Dassault began marketing CATIA in 1981, and it has become the most widely used CAD tool in the aerospace industry. In the 70s, the emergence of powerful minicomputers made CAD software more affordable and accessible, and helped create the commercial CAD software market. Very rapid growth of commercial CAD changed the way CAD was used and developed in big automotive and aerospace companies as they began to use commercial software in conjunction with their internally developed CAD systems. Simultaneously, there were significant advances in the geometric algorithms that CAD software was based on, including B-Spline (Basis Spline),^{26,27} and NURBS (Non-Uniform Rational B-Spline).²⁸ In the 80s, low-cost, low-maintenance, and high-performance workstations using UNIX²⁹ operating system were introduced. This again revolutionized the CAD software market, and effectively replaced the mainframe and mid-range computers as the preferred hardware for

¹⁹ P. de Casteljaou, *Outillages méthodes calcul*, Technical report, André Citroën Automobiles SA, 1959

²⁰ P. de Casteljaou, *Courbes et surfaces à pôles*, Technical report, André Citroën Automobiles SA, 1963

²¹ UNISURF was a pioneering surface system, designed to assist with car body design and tooling, developed in 1968, and full in use at the company in 1975. By 1999, around 1,500 Renault employees made use of it.

²² A. Bézier curve is a parametric curve frequently used in computer graphics and related fields.

²³ P. Bézier, *Définition numérique des courbes et surfaces I*, *Automatisme*, 11, N. 12, p. 625, 1966

²⁴ P. Bézier, *The mathematical basis of the UNISURF CAD system*, Butterworth-Heinemann, 1986

²⁵ Lockheed, the Lockheed Corporation (originally Loughhead Aircraft Manufacturing Company) was an American aerospace company founded in 1912 and later merged with Martin Marietta to form Lockheed Martin in 1995.

²⁶ In mathematics, a Basis Spline is a sufficiently polynomial function with derivatives of all orders that is defined by multiple subfunctions.

²⁷ R. Risenfeld, *Applications of B-Spline Approximation to Geometric Problems of CAD*, Ph.D. thesis, Syracuse University, 1973

²⁸ K.J. Versprille, *Computer-Aided Design Applications of the Rational B-Spline Approximation Form*, Ph.D. thesis, Syracuse University, Italy, 1975

²⁹ Originally UNICS, UNiplexed Information and Computing System

CAD systems. At the same time, three-dimensional CAD software and solid modelling techniques matured and became a commercial reality. As the computer hardware and maintenance costs continued to fall and CAD software became more available and powerful, commercial CAD systems spread throughout industry.

In 1988, Boeing made the decision to use the commercially available CATIA to design and draft the new B777 airplane, which became the first CAD based 'paperless' design of a commercial aircraft. This decision proved to be very successful, leading to reduced product development time and cost. From the 90s to the present time, the same trend repeated itself, with more cost-effective and powerful personal computers replacing the less cost-effective workstations, and with a corresponding migration of CAD software from the UNIX system to the mainstream Windows and Linux operating systems. The function of CAD systems also evolved from pure geometric modelling tools into a system of computer aided engineering solutions that consists of computer aided manufacturing, digital assembly, and virtual production management.

Using information technology such as computer aided manufacturing and production can effectively restore close interaction and communication among a large number of people in the design process. In a computer assisted environment, the airplane designer has access to manufacturing processes and tools in the form of virtual environments. These will allow the designer to virtually manufacture the product while designing it. A more optimal design trade and resource allocation between production and airplane performance can be achieved early in the design stage.

To conclude this section, some statistics are presented from the study of the digitally designed Boeing 777, which demonstrate the great benefits from design automation achieved through CAD system. Boeing used CAD systems that combined geometric modelling using CATIA, finite element analysis using ELFINI (Finite Element Analysis System) and digital assembly using EPIC (Electronic Preassembly Integration on CATIA). The CAD systems allowed Boeing engineers to simulate the geometry of an airplane design on the computer without the costly and time-consuming investment of using physical mock-ups. More than 3 million parts were represented in an integrated database. A complete 3D virtual mock-up of the airplane was created. This allowed the designers to investigate part interferences, assembly interfaces and maintainability using spatial visualizations of the aircraft components. The consequences were dramatic. In comparison with the earlier aircraft design and manufacturing processes, Boeing eliminated more than 3000 assembly interfaces without any physical prototyping, and achieved 90 percent reduction in engineering change requests, 50 percent reduction in cycle time for engineering change request, 90 percent reduction in material rework, and 50 times improvement in assembly tolerances for fuselage. Overall, CAD/CAM systems and digital pre-assembly greatly improve the quality of airplane designs and reduce the time required to introduce new airplanes into the marketplace. The application of CAD in the design of the Boeing 777 is illustrated in figure 7.12.

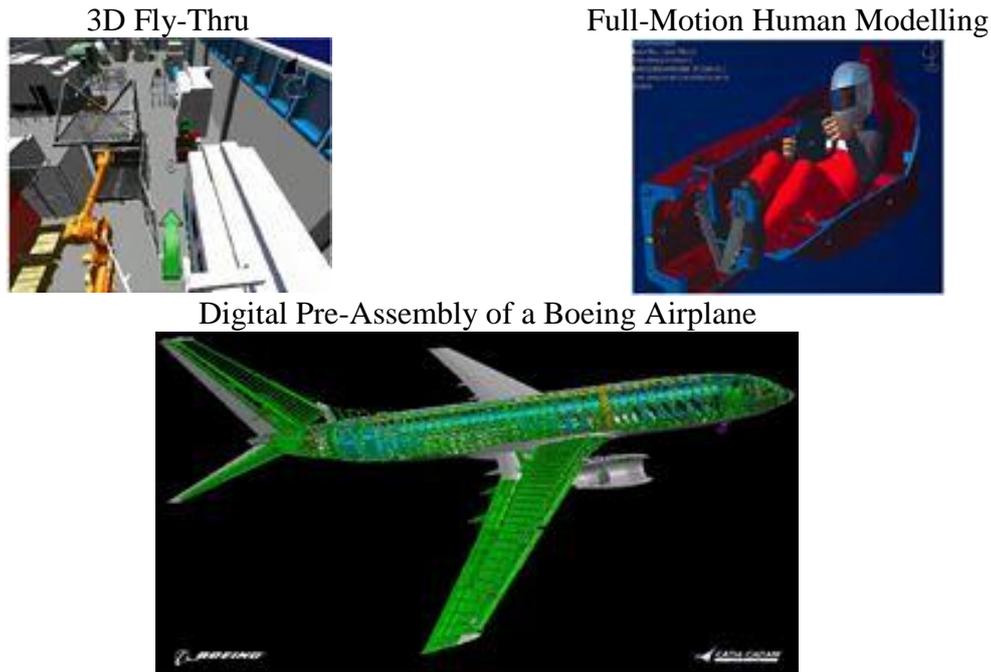


Figure 7.12 CAD applications in aircraft design and manufacturing (Courtesy of CATIA, Computer Aided Three-dimensional Interactive Application).

7.3 Fly-By-Wire and other on-board systems

Early high performance computers were far too bulky and heavy to be carried on-board an aircraft, and consequently the role of computers was limited to functions that could be performed on the ground, such as design and manufacturing. The advent of the modern microprocessor has completely changed the situation. A processor such as an Intel Core i7 with 4 cores clocked at 2.7 GHz is just as powerful as the supercomputers of the 80s. Hence, it is now possible to computerize critical on-board functions such as control, guidance, navigation, and collision avoidance. In particular, the development of digital FBW (Fly-By-Wire) systems has revolutionized the operation of both military and commercial aircraft. The General Dynamics F16 was the first Fighter military aircraft with a full digital FBW control system. Led by Ziegler, a former fighter pilot, Airbus was the first company to use Fly-By-Wire for civil aircraft, the Airbus A320. Soon after FBW control systems were adopted for the Airbus 330 and 340, and the Boeing 777. The FBW control system has been credited with a key role in the successful descent of an Airbus 320 on the Hudson River with both engines out after a bird strike.

In a FBW system digital controls replace the conventional mechanically operated flight controls. The elimination of mechanical components in the new digital system is clearly illustrated in figure 7.13. The pilot no longer physically moves the control surfaces through mechanical linkages. Instead the pilot's commands, or the orders from the autopilot computers (when in autopilot mode) are transmitted digitally to a group of flight computers which instantly interpret and analyse the control inputs and evaluate the aircraft's speed, weight, atmospheric conditions, and other variables to arrive at the optimum control deflections. The flight control surfaces are then moved by actuators which are controlled by the electrical signals. The replacement of the conventional mechanical components with electrically transmitted signals along wires leads to the name FBW. Realization of the FBW system is not possible without the development of digital flight computers and microprocessors that enable a fail-safe flight control system to be implemented economically, safely, and reliably.

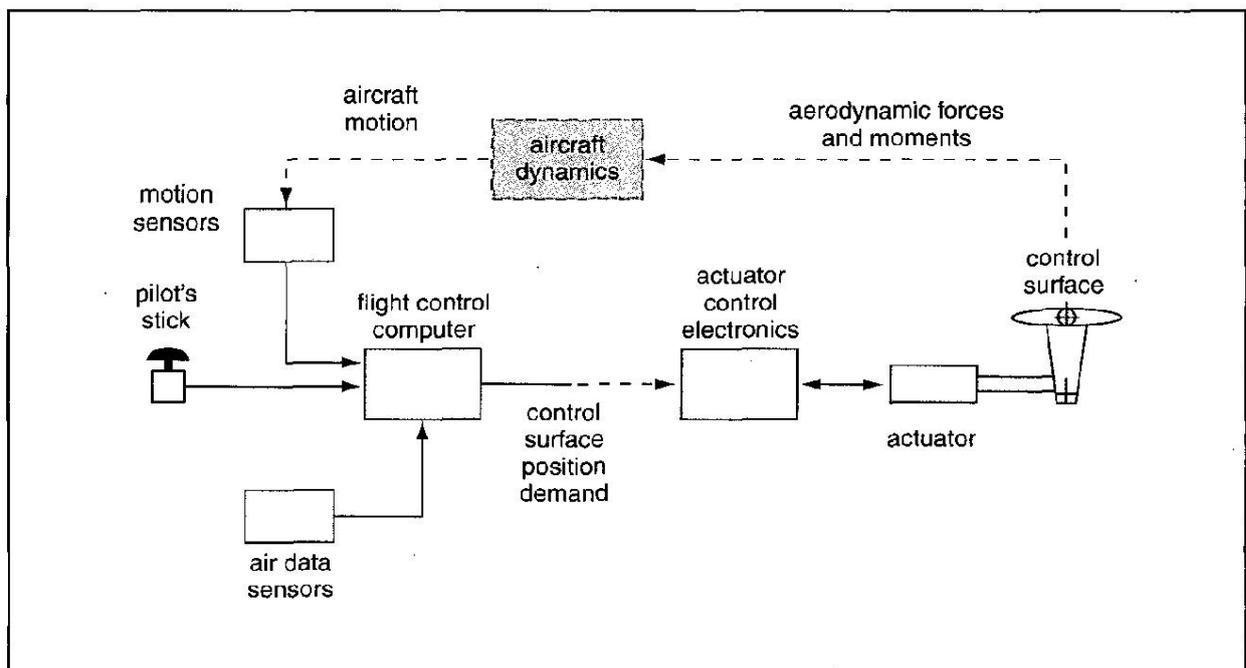


Figure 7.13 Schematic of a digital FBW system.³⁰

The flight computers take in all the information including pilot's order, the aircraft's current state and its external environment, and move the control surfaces to follow the desired flight path while at the same time achieve good handling quality and make sure the airplane is not over-stressed beyond its flight envelope. There are multiple computers for redundancy. Sophisticated voting and consolidation algorithms help to detect and isolate failures in the event of faults occurring in any of the actuators. Another advantage of digital FBW actuation is the faster control surface position feedback that significantly increases actuation response speed. Fast FBW system response is crucial for keeping aerodynamically unstable airplane from divergence. An extreme example is the Lockheed F117 stealth fighter, which could fly for about 1/10 second if it were not for its FBW system. In commercial aircraft, FBW systems allow the use of smaller tail surfaces with a consequent reduction in both weight and drag.

7.4 Airborne software

While Fly-By-Wire systems are one of the most visible uses of on-board digital system, airborne software is now used to control almost every function of both military and commercial aircraft. The Block 3 software for the Lockheed F35 fighter is planned to have 8.6 million lines of code written in C and C++.^{31,32} This will be used to provide a complete fusion of the flight control systems with the battlefield awareness systems. The first use of

³⁰ R.P.G. Collinson, *Introduction to Avionics Systems*, 2nd Edition, Kluwer Academic Publishers, 2003

³¹ C++ is a programming language that is general purpose, developed by Bjarne Stroustrup starting in 1979 at Bell Laboratories (formerly known as American Telephone & Telegraph, AT&T, Bell Laboratories). It was originally named C with Classes, adding object oriented features, such as other enhancements to the general-purpose programming language C programming language developed by Dennis Ritchie between 1969 and 1973 at AT&T Bell Laboratories.

³² G. Warwick, *Flight Tests Of Next F-35 Block Underway*, Aviation Week and Space Technology, 2010

airborne software in a commercial aircraft was the Litton LTN-51³³ Inertial Navigation System on the Boeing 707 in 1968.³⁴ Since then, it has been growing rapidly with each new generation of commercial aircraft, as microprocessors with ever increasing power have become available. Two and a half million lines of code were newly developed for the Boeing 777 in the ADA language.^{35,36} Including commercial-off-the-shelf software, the B777 has more than 4 million lines of airborne software. The FAA (Federal Aviation Administration) has developed standards for the certification of airborne software. Modern commercial aircraft feature loadable systems that can easily be replaced or upgraded. On the Boeing 777, these include systems such as the EEC (Electronic Engine Control), the ADM (Air Data Monitor), the CSDS (Cargo Smoke Detector System), the PFC (Primary Flight Computer), the GPSSU (Global Positioning System Sensor Unit) and the SATCOM (Satellite communications) system.

Airborne collision avoidance systems are a particularly important example of airborne software. The current standard is the TCAS (Traffic Alert and Collision Avoidance System). However, the Lincoln Laboratory at the MIT (Massachusetts Institute of Technology) has been developing advanced algorithms during the last few years which have been incorporated in the new ACAS X (Airborne Collision Avoidance System X),³⁷ and the FAA is undertaking trials with the aim of making this the new standard.

7.5 Ground based computer systems

Ground based computers of very large capacity are now used to control every aspect of commercial aviation. The ATC (Air Traffic Control) system is heavily dependent on computers. There are around 7,000 aircraft in the air over the United States at times of peak traffic, as illustrated in figure 7.14b. Computers are needed for safety, efficiency and to enable increased capacity.

Computer systems are equally crucial to airline management and operations. As passengers, we have all experienced electronic reservation systems. The first such system, named 'SABRE' (Semi-Automated Business Research Environment), was a joint development of American Airlines and IBM. After its introduction in 1964, other airlines soon followed suit. Today, each airline's computer reservation system interfaces with one of several GDS (Global Distribution System). The major GDS providers are Amadeus,³⁸ Travelport,³⁹ and Sabre.⁴⁰ Computer systems are also used for online flight tracking. In addition, the airlines use yield management systems which adjust ticket prices from minute to minute, taking account of factors such as the number of unsold seats and the time to departure, with the aim of maximizing the revenue yield of each flight.

³³ Litton LTN-51 **was** an inertial navigation system developed by Litton Industries now part of Northrup Grumman Corporation: www.northropgrumman.com.

³⁴ J.P. Potocki de Montalk, *Computer software in civil aircraft*, Microprocessors and Microsystems, Volume 17, Issue 1, p. 17, 1993

³⁵ ADA is a structured and object-oriented high-level computer programming language originally designed by a team led by Jean Ichbiah of CII Honeywell Bull (now Bull: www.bull.com) under contract to the US DoD (Department of Defense) from 1977 to 1983. It was named after Ada Lovelace (1815–1852), who is credited as being the first computer programmer.

³⁶ R.J. Pehrson, *Software development for the Boeing 777*, The Boeing Company, Technical Report, 1996

³⁷ M.J. Kochenderfer et al., *Next-Generation Airborne Collision Avoidance System*, Lincoln Laboratory Journal, Volume 19, N. 1, p. 17, 2012

³⁸ www.amadeus.com

³⁹ www.travelport.com

⁴⁰ www.sabre.com

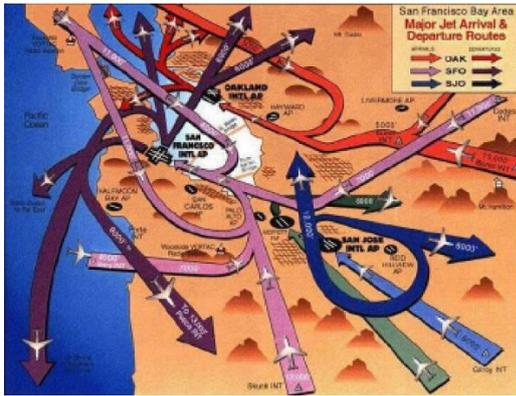


Figure 7.14a Air traffic control chart.

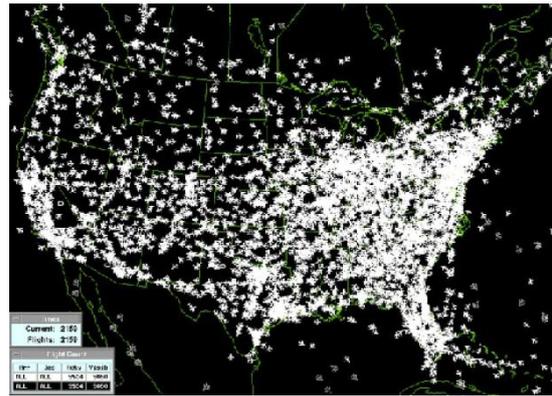


Figure 7.14b Aircraft movement at peak traffic.

(Courtesy of FAA, Federal Aviation Administration)

7.6 Conclusion

The external appearance of long range commercial aircraft has not changed much during the last 50 years, since the introduction of the first jet transports around 1960, reflecting the qualitative understanding of swept wing design that had been achieved by aerospace engineers. The design process, however, has been completely revolutionized during the same period by the systematic use of computational simulation. Moreover the role of information technology now extends well beyond the design and manufacturing process to the actual flight operations and management, through technologies such as digital FBW. Looking to the future, these trends will inevitably continue. According to the forecasts of Boeing and Airbus, air traffic is likely to continue growing at close to 5 percent per year for the next 20 years to more than double its current levels, with about twice as many aircraft in service. This will lead to increasingly severe environmental impacts in both emissions and community noise. Consequently, the European Union has announced an Aeronautics 2020 Vision which calls for

- 50 percent cut in CO₂ emission per passenger kilometre.
- 80 percent cut in nitrogen oxide emission.
- 50 percent cut in airplane drag.
- 50 percent cut in perceived noise.

These targets are not likely to be realized without the pervasive use of advanced computational simulations. A major challenge is in aero-acoustics, paced by the demand to reduce the noise signature of both take-off and landing operations. The prediction of airframe noise due to high lift systems and landing gear remains intractable with current computational methods, and will probably require a combination of high order numerical algorithms with massively parallel computation at the exascale.

On the operational side, there is tremendous interest in unmanned air vehicles (UAVs) for both military and civil applications. To date, the majority of UAVs, such as the Predator drone, are remotely piloted by human operators based in ground stations. In the future, we will see increasing use of autonomous UAVs, able to fly completely pre-programmed missions without human intervention. Autonomous UAVs can greatly reduce the cost of surveillance and remote sensing operations, and actually enable them in inhospitable environments such as thunderstorms. While it is not clear how soon passengers may be willing to fly in aircraft without pilots on board, the technology already exists for autonomous unmanned cargo operations, if the issues of the integration of UAVs into the air traffic control system can be satisfactorily resolved. In fact, unmanned operations may actually prove to be safer, given that pilot errors are one of the main causes of airplane

crashes. The use of autonomous UAVs for customer deliveries is already being envisaged by companies such as Amazon.

Overall, we can anticipate that the future will see an increasing penetration of autonomous UAVs into all aspects of aviation, including novel surveillance and transportation systems. The emergence of autonomous UAVs represents the ultimate fusion of the technologies of computing and flight. Such machines may ultimately be able to match the capabilities already achieved in nature by insects and birds.