THE COCKPIT: A BRIEF HISTORY "History will not tell us what to do, but . . . what we ought to avoid."--Jose Ortega y Gasset.
Aviation has been captured by an irony--a very great irony. Men and women who expected to participate in a great adventure of individualism and personal control are memorizing tedious procedures manuals. Spirited people who hoped for a career of spontaneous action are forced to program computers. It is an irony. It is a great irony called . . . automation.

Rather suddenly, the profession of aviation--that vocation of leather jackets and exciting experiences--has become a career of computer monitoring and equipment management. You once thought you would dance on silver wings, and now you are merely tapping on a keypad. It is a great irony.

Further, it is futile to think that the irony will go away. Automation is a permanent fixture in the cockpit and will grow in its scope and authority. Count on it. Cockpit automation is a tide that will not be confined. And since we cannot hold back the tide, we had better learn to swim.

Actually, automation has always been controversial. Men and women who spend a great deal of time developing professional skills are frustrated and even insulted by the thought that a mere machine could perform those tasks. Furthermore, they are frightened by the prospects of career changes and even career elimination. It is a very old controversy.

In 1801, Joseph Marie Jacquard developed an automated loom that was operated by punched paper cards similar to those used in offices until 20 years ago. Working men who had developed great skills as weavers and knitters were suddenly confronted with an entire new technology that could do the same work with greater precision and speed. By 1811, the fear and frustration from this automation was so great that there were riots around Nottingham and Lancashire, England. The riots led to violence and destruction of mills and machinery. These protesters called themselves "Luddites," for reasons that are now obscured.

Eventually the riots provoked the British government to intervene, and the Luddites were crushed. In 1813, 14 of them were hanged, but the term "Luddite" is still used to describe one who cannot or will not accommodate technological change.

That reaction has been repeated for nearly 200 years as cotton gins and combines, automobiles and railroads, computers and robots have changed the workplace forever. Now it is happening in the cockpit in ways that no one predicted even a few short years ago.

Automation can be defined as the use of any device that replaces human activity, either physical or mental. It is a very broad classification that can include major computerized operations as well as everyday conveniences. One simple form of automation can be illustrated with your home heating system. The furnace alone only produces heat. It must be turned on and off as needed. While you could install a manual switch, a thermostat would automate the process. When you tell the thermostat to turn the furnace on and off to maintain a given temperature, it assumes that responsibility and takes over control of the furnace. It is a happy relationship until the thermostat malfunctions or a human gives it the wrong instructions.

In aviation, automation generally began with systems that stabilize an aircraft's attitude through mechanical manipulation of the flight control surfaces--what we now call autopilots. It has now progressed through an incalculable number of steps to the automated cockpit in which the pilot is primarily an operator and monitor of automated systems. In state-of-the-art aircraft, dancing on silver wings can only be accomplished if you know all the right computer entries.

In general, that automation has arrived in four clearly identifiable giant steps, each made up of many smaller elements. A basic airplane is flown by a pilot who manually manipulates the flight controls to direct the airplane. The pilot is directly involved in all of the processes, and because of that direct involvement receives immediate feedback through his five senses. This basic
configuration can be outlined like this:

-- Pilot;

-- Primary aircraft controls;

-- Aircraft response.

Cockpit automation begins with an autopilot to manipulate the flight controls. The pilot assigns specific tasks to the autopilot, such as heading and altitude, and the autopilot performs those tasks. It is the first step in separating the pilot from direct control and authority over the airplane, and it masks the most basic feedback cues, such as control feel and airplane response time. It also is the first piece of equipment with sufficient authority to fly the airplane into harm's way. This first level of automation introduces an additional level:

-- Pilot;

-- Autopilot;

-- Primary aircraft controls;

-- Aircraft response.

Autopilots are wonderful and beneficial systems, but they have their own unique impact on safety.

Cruising at 31,000 feet, a Boeing 707 was under the control of its autopilot. Without being commanded to do so, the autopilot rolled the airplane to the right, eventually reaching bank angles of over 90 degrees. The airplane descended more than 10,000 feet and achieved speeds near 1.0 Mach. The crew assumed manual control to recover the airplane, which experienced over 3g's during the pullout. The right wing was damaged, as were the left and right flaps and the right horizontal stabilizer. Happily, this airplane was landed safely.

The second level of automation could be the "controllers" that feed information to the autopilot. These controllers may use navigation information or altitude information or rate-of-descent commands (or others), which transmit instructions to the autopilot such as "turn to and maintain this heading" or "fly along this course" or "maintain this rate of descent." In this configuration, the pilot now has two layers of automation separating him from direct control of the aircraft. He must program and monitor the "controllers" to make sure they are sending the correct commands to the autopilot, and he must monitor the autopilot for proper operation. At this level of automation, any one of those controllers, or the autopilot itself, has sufficient authority to place the airplane in jeopardy. This second level of automation looks like this:

-- Pilot;

-- Controllers;

-- Autopilot;

-- Primary aircraft controls;

-- Aircraft response.

Various types of controllers can greatly reduce the workload in certain maneuvers and can provide an accuracy that is difficult for humans to duplicate. They also can introduce their own problems.

The Boeing 747 approached Runway 27 at London's Heathrow Airport. The airplane was low on fuel due to headwinds on a long flight, and the approach was hurried. The autopilot was operating in "approach mode."

Because the approach was hurried, the radio beams were captured late, the "controllers" had limited authority, and the autopilot was unable to stabilize the airplane. At DH, the runway was not in sight and the airplane sank to 75 feet before gaining altitude. A subsequent investigation revealed that the airplane was far to the right of course and had overflown a hotel by a scant few feet. The flightcrew was suspended and the captain later charged with endangering passengers and persons on the ground.

The third level of automation is the flight management computer (FMC). Now, the pilot must program the computer . . . to instruct the controllers . . . to transmit instructions to the autopilot . . .
to fly the airplane. And the pilot is now removed from direct control of the airplane by three layers of automation. It looks like this:

-- Pilot;
-- Flight management computer;
-- Controllers;
-- Autopilot;
-- Primary aircraft controls;
-- Aircraft response.

Most pilots who have flown with an FMC do not wish to return to older, analog cockpits. FMCs provide a reservoir of information and assistance that is unprecedented, but they also have great authority over the aircraft's performance.

The Boeing 757 approached Cali, Colombia through a narrow valley. The airplane was being flown by autopilot . . . which received several "controller" inputs for navigational guidance . . . which were selected and programmed by a flight management computer . . . when the flightcrew had entered the correct instructions.

At a point approximately 40 nm from the airport, the air traffic controller changed the flight's clearance to a straight-in approach using the "Rozo One Arrival." The captain attempted to program "Rozo" NDB into the FMC, but used the wrong identifier. The FMC accepted the identifier typed in by the captain and dutifully commenced an approximately 90-degree turn toward that (wrong) NDB. The airplane struck a mountain ridge at 8,900 feet.

A fourth level of automation integrates the FMC with airplane systems such as fuel and environmental control. In one representative airplane, the cockpit humidifier is turned on by a signal from the FMC when the airplane reaches cruising altitude, and is turned off by the FMC two hours prior to the descent point. Considering that FMCs track fuel consumption, flight time, vertical path, course, speed, throttle position and countless other bits of data, it takes little imagination to see the potential for FMCs to effectively control the airplane in virtually all respects. When systems control is included in FMC functions, the diagram becomes:

-- Pilot;
-- Flight management computer;
-- Controllers;
-- Autopilot/aircraft systems;
-- Primary aircraft controls;
-- Aircraft response.

At this level of automation, the FMC, controllers, autopilot and automated systems have so much authority that pilots must be extremely knowledgeable and vigilant. The potential for unwanted actions and maneuvers is nearly infinite.

An Airbus A-300 approached Runway 34 at Nagoya, Japan. The copilot was flying, and at some point during the approach he inadvertently triggered the automatic go-around feature (TOGA) of the autoflight system. The fully integrated system added power and commanded a pitch up to conduct the unintentionally commanded go-around. The copilot attempted to manually fly the airplane down the glideslope while the autopilot countered those attempts with nose-up trim. Eventually, the elevator trim exceeded the copilot's authority and the airplane pitched nose up, reaching an attitude greater that 50 degrees. The airplane stalled and slid backward to the ground.

Someday soon, there will be a fifth level of automation that allows air traffic controllers on the ground to enter or at least suggest entries into the FMC on board the airplane. That level will look like this:

-- Air traffic controller/pilot;
-- Flight management computer;
Despite these and other accidents and incidents, cockpit automation works well to provide
greater navigational accuracy, better efficiency, vastly expanded information and critical
assistance for life-threatening crises. Further, while there is extensive literature on the failures and
problems with automated cockpits, there is little compensating documentation on the accidents
and incidents that have been averted by various levels of automation in the cockpit. But mark this:
Automated transport aircraft have, in fact, a far better safety record than previous jet transports.
To maintain otherwise is, well, Luddism.

The profession of flying has changed forever, and cockpit automation will grow in scope and in
depth at an accelerating pace. Pilots will find that virtually every element of their work environment
will be automated, digitized and computerized in a few short years. Based on this first decade of
experience with serious cockpit automation, it is clear that the technology is not perfect. Experts
generally debate the limitations and appropriate fixes, but our short list is limited to some core
issues:

Flight training must be modified to include automation and its proper role in cockpit discipline in
the earliest stages. Pilots will always have to aviate, navigate and communicate as their baseline
responsibilities, but they also must learn to manage the various resources available to automate
and simplify those responsibilities.

Automation training must allow pilots to freely explore the possibilities offered by automated
equipment in the same way that ab initio pilots are free to explore the envelopes of their aircraft.
Trainees should be able to conduct exercises, interrupt those exercises, repeat those exercises
and modify those exercises in ways that are fully compatible with operational flying. Automation
trainers are now as critical as flight simulators to aviation safety.

Automation training should include comprehensive reviews of automation accidents and incidents
as well as practice for automation failures and anomalies. Accidents and incidents that are wholly
or partially caused by automation frequently fall into identifiable categories.

Mode confusion has emerged as perhaps the single-most dangerous mistake for pilots of
automated cockpits. It is imperative to know what the equipment is doing and how it intends to
accomplish that task. Is the descent predicated on rate or angle? Is the autopilot tracking a course
or holding a heading? Is the indicated airspeed being controlled by this display or that one? Mode
confusion is a constant threat and one that requires careful cockpit management. Training has
always emphasized that pilots "keep ahead of the airplane," but now they must also "keep
ahead of the modes."

CRM is crucial to the automated cockpit. It becomes a three-way challenge between the pilot
flying (PF), the pilot not flying (PNF) and the automation. Pilots of automated airplanes must have
a deep commitment to the principles and practices of CRM, but automation needs its own CRM
built in.

Automation CRM--to coin a phrase--would allow the equipment to clearly explain what it is doing,
and how it is doing it, through effective annunciation. Well-designed automation will include
messages and warnings that make what is going on very clear to the pilots. It also will permit
interventions and "soft" instructions that allow the pilots to become a part of the process--without
interrupting the process--when necessary.

The issue here, as with all CRM, is the free flow of information in all directions in the cockpit.
Automation in the cockpit has become so pervasive that it becomes a virtual person. And that
virtual person must practice the same CRM skills as any other person. Vertical track information
must be displayed as clearly as that for horizontal track. Current equipment presents clear map
displays of the navigation track, but leaves vertical profiles largely to the pilot's imagination; and
this at a time in the flight profile when the pilot is often preoccupied with the expanding demands
of a safe departure or arrival. Safety demands better.

Safety professionals need to develop specific categories of automation failure for accident and
incident reporting. Mode confusion, annunciation confusion, database errors, programming errors,
software problems, hardware failure and other automation-specific malfunctions ought to be
identified and tracked as designated categories.
The irony of automation has captured the cockpit. Along with the irony come hazards, challenges, anxieties and opportunities. To cross an ocean as the FMC tracks the route and calculates optimum speeds and altitudes, to communicate with distant air traffic controllers using digital FANS procedures, to watch a descent fully programmed for crossing restrictions, to follow a Category IIIIB approach from initial setup to the end of the landing roll—without ever having to see the runway itself as a criteria for landing—is to look at the future of aviation, and the challenges to aviation safety. Welcome to the irony.

Part II of B/CA's special series on automation will appear in the July issue.