TEST AND EVALUATION CREW RESOURCE MANAGEMENT

A New Perspective in combating Human Performance Errors during Flight Test Operations

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A prime goal of the Society of Experimental Test Pilots as expressed in the SETP Aims and Objectives is: ". . .exchange of information for mutual development of improved test techniques." This paper has precisely the same goal: the presentation of new methods and operational philosophies which the authors believe have substantial potential for improving test techniques by substantially increasing the margins of safety in flight test operations.

The key to understanding the central point of this paper is an initial acceptance of a singular reality: flight test operations are seldom, if ever, a solo enterprise. Whether conducted in the civilian arena with a single pilot linked by a single radio channel to a single monitor on the ground, or whether a major military test program bringing hundreds of professionals together to wring out a new weapons system, modern flight test activities involve disparate groups of people from varied disciplines working together to achieve the same goal. Such groups are, for want of a better definition, "teams." And despite the best intentions and the best training, human teams are capable of making errors. Two specific flight test case studies described in this paper bring to mind, with sobering reality, that flight test operations, even in the most controlled environment, are subject to the same human performance errors that exist in the airline industry.

INTRODUCTION

Professional flight test teams are composed of highly-trained humans who have virtually no desire to make mistakes. Yet mistakes do happen, even during the most carefully planned flight test sequences, and such human mistakes *can* cause - and have caused - terrible accidents and chillingly close calls. In fact, in several recent instances, an accident or incident could arguably have been prevented if the test pilots had merely been told what the test engineers on the ground were seeing on their monitors.

Traditionally, aviation has dealt with serious human error by first deciding who to blame, then ordering that such errors not be made in the future. (Alternately, we've attempted to minimize human error by designing the human out of the loop as much as possible in favor of automation). But in the absence of purposeful acts or gross negligence, placing blame on an embarrassed professional merely sets up the exquisite irony of punishing a human being for being human, a wholly ineffective response which does nothing to prevent the same type of mistake in the future.

But if traditional methods don't work in minimizing human mistakes, which ones do?

By the late seventies, with human error becoming the dominant cause of aviation accidents, the necessity of answering that question became critical. In the commercial airline industry in particular, the realization that human error accidents could not be prevented with traditional training and standardization techniques spurred a painful search for new preventative methods.

That quest, in turn, has sparked a revolution.

CONTROLLING HUMAN FAILURE

We have traditionally refused to apply standard engineering principles to the most critical component in the aerospace equation: the human being. While we go to great lengths to engineer computers into our aircraft and we spare no expense in working to graph and document virtually all measurable parameters in a weapons system under development, when it comes to understanding what makes humans function - and what makes us fail - aviation has always tended to conclude that human failure is too mysterious to predict, and too complicated to control.

The concept, for instance, that human communications can be blocked and garbled by unrecognized human vulnerabilities such as attitude, fatigue, and excessive professional courtesy, seemed rather heretical at first. Yet we now know that such human weakness' can be *as* effective in causing major breakdowns in team performance as a lack of technical training or a major equipment failure. In flight test operations, whether the control room intercoms fail, the test director's radio links with the test pilot go down, or the members of a test team fail to pass vital information to each other for very human reasons, the result - blocked communications - is exactly the same.

To effectively certify a new airplane, the entire performance and aerodynamic envelope of that design must be explored and discovered. To effectively engineer a new piece of electronic equipment into an aircraft or a test control room, the failure modes and failure probabilities of that component must be fully understood and dealt with. In both cases, the knowledge of how to minimize failure modes and the ability to safely absorb those failures that can't be totally eliminated, are critical elements. Since the human being is no less a critical component of the aviation equation, the same need exists when engineering people - carbon-based units - into an environment as technologically complex as a flight test team. To the extent that humans are used as part of such an operating technological entity, their functioning reliability becomes as important as that of the machinery which surrounds them. It is an indisputable truth that unconnected computers can't exchange information, and neither can humans if their ability, or willingness to communicate, has been impaired.

In the aviation world in general, common wisdom traditionally held that humans could not be trained to exercise better judgment, nor effectively trained to improve communications and team formation skills. In fact, the subjects of interfering behavioral styles and personality traits were always considered immaterial when it came to doing the job right in a highly technical environment. But the essence of the human performance revolution is the understanding that even human fallibility can be minimized if the right tools - and the right training - are used. While human caused accidents are common to all corners of aviation, flight test included, it was the commercial airline industry that led the way to a solution. As is so often the case, that leadership was born of tragedy and necessity.

THE AIRLINE INDUSTRY AND COCKPIT RESOURCE MANAGEMENT

On March 27, 1977, two Boeing 747's slammed together on the ground at Tenerife in the Canary Islands killing 583 people. While the world reeled from the news and the horrid pictures of burning wreckage, the aviation community reeled from the chilling realization that there had been virtually nothing wrong with either airplane. Instead of a crash caused by malfunctioning mechanical or electronic units, the Tenerife disaster had been caused by the failure of carbon-based units - human beings. While there had been other crashes in previous years in which perfectly good airplanes were flown into the ground or otherwise destroyed by human mistake, the magnitude of Tenerife meant that the human failures involved could not be ignored. Here a highly trained and experienced aircrew led by KLM's director of training himself (50-year old Captain Jacob Louis Veldhuyzen van Zanten) had made the horrific mistake of *assuming* that a Pan Am 747 was clear of the fog-shrouded runway he was about to use for takeoff. But even worse was the fact that the decision and determination to start the takeoff roll *immediately* had been solely the captain's. Despite the weakly-expressed misgivings of his flight engineer and copilot over whether the Pan Am jumbo had really left the runway, the dangers of angering their captain by challenging his belief was apparently too great. Captain van Zanten, then, was left in effect logging solo time in a multi-place aircraft as his two crewmembers - the last ones who could have prevented the tragedy - retreated into silence believing that no captain so experienced and mighty could possibly make such a mistake. (Complicating the issue were misunderstood radio calls, language barriers, and botched procedures all relating to the difficulties inherent in human communication).

KLM quickly realized that nothing in their training had ever addressed the problems caused by what would later be called the "halo effect" - the tendency of a subordinate to assume his leader couldn't make a mistake. Captains at KLM had never been trained to invite challenges from their subordinate crew members. KLM, like most airlines to that date, was a captain-oriented airline in which the man in the left seat was expected to know more, see more, and be right more often than anyone under his command. To challenge such a leader without specific invitation was simply not done.

Immediately, KLM began a pioneering a new training course aimed at teaching captains how to invite warnings and other information from their crewmembers, and how to listen. For Dutch captains, it was an affront. But with the grand old airline's pride still tattered from the disaster at Tenerife, they buckled under and listened to their company's new approach, and slowly the cockpit culture began to change.

In the United States the lesson had been noted, but nothing had spurred any of the major carriers into action - until the night of December 28, 1978, when two subordinate United Airlines pilots allowed their captain to run a DC-8 completely out of fuel while circling Portland, Oregon with a relatively minor landing gear problem. (Nine people died, and twenty-one were gravely injured). The galvanizing lesson of the United Portland crash was the same as that of Tenerife: strong-willed captains not trained to listen paired with more junior pilots not trained to be assertive are essentially flying solo, and solo pilots are capable of making fatal mistakes. In such cases, the inherent safety margins provided by having more than one pilot are effectively invalidated when the additional pilots can't - or won't - speak up. After a second United accident involving similar human communication problems, United's training department began a revolutionary new training course ultimately called Cockpit Leadership Resource Management (CLRM). This course began changing the culture of United's captain-oriented cockpits. Within eight years, that decision would be validated in two spectacular accidents.

Meanwhile, the lessons continued for commercial aviation. In January of 1982, an Air Florida Boeing 737 augured into the air from Washington's National Airport at an incredibly high angle of attack, its engines producing only 75% power and its leading edges contaminated with ice because of a multiplicity of human errors made by the inexperienced captain and his copilot. Four times the Air Force-trained copilot had verbally expressed his concern to the captain that something was very wrong, but Captain Larry Wheaton had not listened. Both pilots and all but four of their passengers and one of their crew died when the 737 slammed into the 14th Street Bridge.

On October 11, 1983, over Illinois, a young commuter captain with a financial stake in the rapidly-expanding carrier and a reputation for always bringing maintenance problems back to home station for more economical repair refused to turn back when he lost both generators of his Hawker-Siddeley 748 twin engine turboprop just after takeoff from Springfield. Facing a fifty minute flight into thunderstorms with a battery rated at only thirty minutes, the captain continued on battery power alone - effectively unchallenged by the first officer. Thirty minutes later over Pinckneyville, Illinois, the battery died - and so did they. The two man aircrew, blind and lost, slammed into a pastoral hillside and exploded into shards.

Once again the refusal to be assertive and the failure to pass information had resulted in disaster, and once again a commercial airliner had been reduced to a solo pilot operation.

Slowly and painfully the NTSB began to understand that many of the accident-causing human failures they were recognizing had been happening for decades, but had too often been marked off as unfathomable pilot-error. Pressures on pilots to press limits and bend rules in the interest of more economical operations were documented, as were the effects of peer pressure, fatigue, distraction, and personal problems. These were pressures which could be traced directly to increased human failures - pilot errors - which in turn led too often to accidents. And these were pressures which were impervious to chief pilot memos and other directives not to let such things interfere with "professional performance." By 1985, airline managers began to realize two important truths: First, there were new courses widely referred to as CRM (Cockpit Resource Management) that showed promise in improving the safe performance abilities of their flight crews, and second, with more and more airlines starting such courses, those airlines which refused to use CRM training were running the risk of legal liability for not having it. By the time a United Airlines 747 lifted off from Honolulu bound for Auckland, New Zealand on the night of February 24, 1989, CRM was becoming if not a fully accepted airline training program industry-wide, then at least a tolerated one.

Cockpit Resource Management in many ways is misnamed, as some airlines have demonstrated by changing the name of their CRM-style training to Crew Resource Management, or even Crew Integrated Experience (Alaska Airlines). The object of the training is simply the enhancement of timely and effective communications among aircrew members, and that is best accomplished by examining past human failure accidents and spotlighting the normal human tendency to let anger, distraction, fatigue, and various emotions block cooperation and communication in a high stress environment. Additionally, such courses spotlight the effect of various types of stress on professional performance. When most effective, CRM-type courses steer clear of deep psychological discussions and focus clearly and directly on the job to be performed in the cockpit and what human vulnerabilities can get in the way. To the extent that professional pilots were never licensed to even acknowledge such weaknesses before, the ability to admit to being an imperfect human is in itself a significant step in being able to minimize human error.

By 1989 at United Airlines, CRM (in their case CLRM) had already become an ingrained and familiar change in their cockpit culture, and for the previous eight years the company had made it clear that United captains *would* be receptive, and subordinate flight officers *would* be respectfully assertive. There was to be no more solo flying of United jetliners.

After takeoff from Honolulu, in the early hours of February 24, 1989, United Flight 811 - a 747-200 full of fuel and passengers - suffered a catastrophic explosive decompression when the forward cargo door ripped off at 22,000 feet, catapulting nine passengers to their deaths (and one of them into and through number three engine). Instantly United 811's crew was faced with a decompressed, bucking, howling beast of an airplane with two engines out on the right side and a gigantic structural hole in the right fuselage. Descending to ten thousand feet and turning back to Honolulu some sixty miles distant, the crew began functioning verbally and non-verbally like three computers wired together in parallel. What the captain didn't accomplish, the first and second officers did, and while the captain's overall authority was never diminished, his decision to use nearly 85% of his consciousness to physically fly the aircraft left a void which his copilot and engineer filled with seamless cooperative skill. As the crippled 747 sank toward the Pacific too heavy to stay level on two engines, it was the second officer who began dumping fuel on his own authority when it was obvious the captain and copilot were too preoccupied to consider that critical weight-reducing step. In similar fashion, when the captain's struggle with the airplane's mushy flight characteristics blinded him to simple navigational chores, the first officer stepped in without hesitation to give him the appropriate course and heading along with admonitions about airspeed and altitude and other vital flight performance items a more intimidated, non-CRM trained copilot might have avoided mentioning. Indeed, when even the copilot and captain had reached a turning point and were on the verge of deciding to ditch, it was the second officer who raised his voice regarding their true condition (close enough to the airport, arresting the descent, and within view of Honolulu) to turn the decision around. Traditionally, a second officer would never have dared to be so assertive, but due to his intervention, United 811 ended up sitting safely on the concrete apron at Honolulu International some twenty minutes later, rather than breaking up on water impact.

In the aftermath, even if the Captain and crew had not stated flatly that United's CLRM training had made all the difference in enabling them to work so smoothly together, the cockpit voice transcript told the story.

On July 17, 1989, the invaluable effects of CRM-type training were demonstrated again when the number two engine of a United DC-10 bound for Chicago blew apart over Iowa, taking with it all three hydraulic systems and all means of operating the aircraft's flight controls. The subsequent involvement of Denver training Captain Dennis Fitch (who had been aboard as a passenger) in helping Captain Al Haines, First Officer Bill Records, and Second Officer Dudley Divorak find a way to guide the mortally crippled jumbo to a runway in Sioux City has become the stuff of aviation legend, but the bottom line as stated repeatedly by Captain Haines, is extremely simple: teaching aircrew members better ways of communicating and cooperating so as to utilize the maximum collective intellect available was the one factor which enabled more than half the passengers to survive the subsequent crash landing. The message has been repeated eloquently and forcefully by Captain Haines ever since: CRM (or CLRM or any other derivative) not only works, it is a necessity in commercial aviation.

APPLICABILITY OF CRM TO OTHER ELEMENTS OF AVIATION

While the Air Force's Military Airlift Command initiated CRM-style training in 1986 and 1987, most of the U.S. military regarded such training as a civilian-only enterprise until the point was driven home by continuous human-failure accidents that nothing else seems to work in reducing such accidents. Even when the pre-Desert Storm period saw slow incorporation of such training into many multi-place transport, tanker, and bomber wings, the single-seat fighter community in particular rejected CRM-style courses as wholly inapplicable to them. In that resistance - and its ultimate collapse in the face of the fact that CRM is extremely valuable for the fighter community as well - there is a substantial lesson for the flight test world. Fighter pilot resistance to CRM was based on the belief that single seat flight does not require cooperation or communicative interaction with others, and thus training better techniques of communication and cooperation has no operational impact. The reality, however, is that the day of the lone eagle fighter pilot is long gone. Most fighters fly at least in pairs, and almost always in the shadow of tankers, AWACS controllers, air traffic controllers, and other cooperative aircrew members who operate together as a strike team (or in the current parlance, "package"). In such an environment, the idea that fighter pilots need not talk to or cooperate with anyone is a myth. Even at its most restrictive, the definition of modern fighter operations includes a wingman, and that wingman is effectively a copilot when it comes to monitoring the progress of the flight. There too, the day of the blindly-following wingman has to give way to the reality that such deaf and dumb obedience leads to disasters which an alert and involved and assertive wingman might help avoid.

With the collapse of fighter resistance to Crew Resource Management has come a new wave of training which expands the definition of the word "crew" to include the entire fighter operational environment on the ground and in the air. Similarly, that expanded definition has to be applied to all other forms of aviation, and in the case of the flight test community, the flight test team fits the expanded definition of "crew" with startling perfection.

THE TEST TEAM

The evolution of experimental test flying forced the development of new ways to provide test pilots with real-time information, and ultimately spawned today's concept of the "test team". Formerly, the gathering of flight test data was almost exclusively dependent on the flight crew alone. Today's flight test team, however, includes not only the flight crew and the chase crew, but all the members of the electronically-sophisticated flight test control room as well . Staffed by highly trained humans predominantly from the engineering community, the control room has matured into far more than a communications and data-gathering complex melding people from diverse professional disciplines, it has become an integral part of the test team itself.

There is a limiting dynamic reality in the contemporary flight test environment: human flight test aircrews can only use and absorb so much information at any given time. Nevertheless, the growth of highly sophisticated ground-based flight test control rooms has created an almost exponential increase in availability of real-time data during each mission, and the role of filtering such a cascade of information routinely falls to a ground-based test director, an individual whose duties include not only coordinating the test points with the pilot, but coordinating as well the tidal wave of technical information being monitored by his people in the control room. It is the Test Director who must decide what information needs to be passed to the test aircrew. This role plus the proliferation of information combined with the variety of humans involved in today's test team have created a culture which is heir to many of the same human problems which block and garble communications among pilots in multi-place commercial cockpits.

The concept of CRM is the management of crew resources in such a way that each individual part of the crew is utilized to provide synergism to the operation. The key is to first define the crew, and then ensure that the crew is working in harmony with respect to duties, responsibilities, and human performance factors. Unfortunately, simply placing professional people together and expecting them to merely follow standard procedures or instructions has not worked to a satisfactory level in the past. Many test operations, while having been called a *team* have, unknowingly, been plagued by such things as communication blockages, unwarranted assumptions, the halo effect, and other human maladies that prevent the timely passage of critical information from ground to air, and probably vice versa. Therefore, what's needed is a redefinition of what a *team* is in this environment, and at the same time, the infusion of CRM principles to make the team fully cooperative and functional.

CASE STUDIES

Although the flight test community has, in general, a more focused flying environment, it has not escaped the same type of human-caused accidents and incidents which have long plagued airline operations, a point proven with sobering certainty by several recent flight test mishaps. Yet even after the classic example of the B-1 loss-of-control mishap at Edwards AFB in 1984, an accident largely due to breakdown in crew coordination and communication, similar problems continue to plague us.

There are many examples of good crew operations in flight test, and many more untold stories of "saves" because of the proper application of CRM principles. However, in the flight test environment, where expensive resources are at stake and entire acquisition programs are dependent on flight test operations, being close is not good enough. Two recent incidents, in fact, have brought to light the need for T&E CRM. In the first, a B-1B lost a gear door during a production Functional Check Flight (FCF) causing extensive damage to the aircraft. In the second incident, a significant "close call" was experienced during developmental testing of the C-17A when the aircraft significantly exceeded the test angle-of-attack limit for almost two minutes without the knowledge of the entire test team. In both instances, potential answers existed within the confines of the control room, but for various reasons, the information was not passed. Each of these incidents bear great similarity to a host of well-documented airline accidents involving failed information transfer, and both graphically illustrate the potential disastrous consequences of even a single real-time failure in the process of passing critical information among test team members.

B-1B MISHAP

Synopsis. On 21 May 1992, A USAF B-1B flying a Functional Check Flight (FCF), sustained approximately $1.1M worth of damage as a result of the right main gear door coming off inflight during a low level run. A major contributing cause of this mishap was a misunderstanding of troubleshooting information between the aircrew and the ground crew.

Test Team Composition

The test team for this FCF consisted of the following:

Aircraft

Left seat - Aircraft Commander, Senior engineering company test pilot, Instructor pilot qualified.

Right seat - Copilot, Captain, USAF. Instructor pilot qualified.

Right rear seat - Mission Navigator, Lt. Col., USAF.

Left rear seat - Mission engineer, experienced company Flight Test Engineer (FTE).

Ground Crew

The ground crew consisted of one company ground controller in a radio tower, one engineer in a control room communicating with the ground controller through an intercom system, and support engineers located throughout the complex. Only the ground controller was allowed to communicate with the aircrew on a dedicated frequency. During troubleshooting, the ground controller talks mainly to the aircraft Mission Engineer.

History of Flight

Flight E7244 (Viper 05) departed Palmdale Plant 42 on an FCF which included a profile of medium and high altitude checks followed by low altitude, terrain following checks. The aircrew reported for duty with adequate crew rest and completed preflight mission briefings and inspections. The takeoff was nominal and the aircrew initiated the standard FCF procedures. After performing the FCF checklist to evaluate the alternate gear extension system, the aircrew received indications of a red light in the gear handle and the Central Integrated Test System (CITS) issued a CITS Maintenance Code (CMC) indicating the right main landing gear door may not be closed and locked. The aircrew and the Rockwell International Aircraft maintenance Facility (RIAMF) ground crew communicated the appropriate aircraft CITS Parameter Monitor Codes (PMCs) to assess the status of the right main landing gear door lock and hydraulic systems. A determination was made that the problem was isolated to a faulty proximity switch. The aircrew then continued with the previously briefed low altitude terrain following checks. During this portion of the mission, the right main landing gear door departed the aircraft causing damage to the number three engine nacelle and engine, and exterior surface dents to several areas along the underside of the aircraft fuselage. The aircrew then returned to RIAMF and completed an uneventful emergency landing.

Landing Gear Sequence

At the point where the FCF mission profile called for an alternate gear extension, the ALTER GR switch was placed in the ON position. The gear extended with no problems noted. During the reset, which brings the landing gear system back to the normal mode and both gear doors move to the closed position, the FTE noted a "MLG Door Prox" CITS indication. At this point, the FTE relayed this information to the Ground Controller, who had the engineering staff begin their research into the problem. The ground crew then asked to input into the CITS a series of Parameter Monitor Codes (PMCs) (When a PMC is input into the CITS, it returns the status of that particular parameter of interest, such as weight on wheels or landing gear warning light. The status can then be observed on CITS as it changes over time). Due to the complicated nature of the parameter display, interpretation of the PMC results was left to the RIAMF ground engineering staff. One of those returns indicated that the right main landing gear door was not locked. It is not clear whether this result was communicated to the aircrew by the ground controller. The gear was then retracted, the retraction was normal except that the red light in the gear handle remained ON. Another series of PMCs were requested by the ground crew. Another gear extension was performed, in coordination with ground control, to further troubleshoot system status. The gear extended normally with no light in the gear handle. The gear was then retracted one more time; retraction was again normal except for the red light in the gear handle. After the above-mentioned troubleshooting activity, the aircrew believed that the red light in the handle,, and the corresponding CMCs, were isolated to a faulty proximity switch. They reported their intent to "continue" to the ground crew. The word "continue" meant, to the aircrew, the intent to fly the low level portion of the profile at high speed. To the ground crew, the word "continue" meant to return to the RIAMF for landing. Ground control "rogered" the call, and approximately 15 minutes into the low level, the gear door separated.

Analysis

According to the Aircraft Commander (AC), he couldn't tell exactly what the ground crew was looking for, the aircrew reported what they saw as far as cockpit light indications and CITS readouts, they would get codes relayed to them to put in and they read back the status without necessarily going into detail or discussion of what they were looking at. After all the troubleshooting, his understanding was that the door was closed, that they had a switch reporting problem, that the switch, itself, was assumed to be bad by the results of the codes that they had transmitted back and forth. At the point when the troubleshooting ended, there was no specific direction given to them. The aircrew felt like "there should be some kind of period at the end of the sentence".

The Copilot (CP) reported that when they lowered the gear to continue troubleshooting, the ground crew received additional codes, and they reported that they "saw what they expected". When they raised the landing gear the last time, and the red light stayed on, the ground crew again reported that was "as expected". As the ground crew continued to pass more codes back and forth, he remembers codes described as hydro-codes; he then checked the aircraft hydraulic systems and the essential electrical loads. He remembers the broadcast from the ground as being that there was a proximity switch that was not statusing; that they saw what they expected, that the doors were in fact closed and would be held closed (by hydraulic pressure). He then transmitted something like: "then we're cleared to proceed with the profile" (in the form of a question according to the Mission Navigator), at which point ground control "rogered" the call.

The ground controller reported that, after all the troubleshooting, they could not verify that the right main gear door was up and locked but were able to verify that the actuators would hold the doors closed hydraulically. In addition, when the aircrew reported that they were going to continue, they thought that meant to continue on and not exceed the gear limit speed.

Conclusions

This mishap involved highly experienced crews performing their individual tasks with professionalism. Not a single individual can be singled out as being causal in this event. However, the test team as a whole failed to be fully integrated during the resolution of the troubleshooting. The airplane did not damage itself, there was no imminent danger that required immediate action that could not be evaluated. A decision was made to proceed with the profile based on assumptions and a misinterpretation of the word "continue".

The assumption on the part of the aircrew was that the problem had been isolated to a bad proximity switch and that the door was actually locked. In their mind, they thought they understood what had been concluded and, therefore, knew the operational impact. The actual condition, according to the ground crew, was that the gear door locking status could not be verified. The ground crew also assumed that the aircrew would not exceed the gear limits with a red light in the gear handle and, therefore, felt no need to reiterate that fact.

A breakdown in communications occurred on the use of the word "continue". When the aircrew queried that they were continuing with the profile, the ground crew acknowledged, each one thinking of a different scenario. To the aircrew, the word continue meant continue with the complete profile. To the ground crew it meant continue with only the portions that are below gear-limiting speed. There was also an empty feeling on the part of the aircrew at the end of the troubleshooting. They expected a summary of findings and some kind of recommendation from the ground crew as to how to proceed. The ground crew lacked assertiveness in reporting their findings and recommendations.

A lack of situation awareness was also present in the aircrew. During the troubleshooting, they only heard portions of the conversation between the Mission Engineer and the ground crew. That incomplete picture led them to conclude that the problem was only with a proximity switch. Information that the gear door lock status could not be verified was interpreted differently between air and ground crews.

C-17 INCIDENT

Synopsis. During flight testing of the C-17 at the Air Force Flight test center, Edwards AFB, on 29 march 1993, the test aircrew inadvertently entered a stalled condition at approximately 8,000 feet above ground level (AGL), while slowing and configuring the aircraft in preparation for a programmed test point. As the aircraft's right wing dropped and entered a high-rate of descent, the pilot incorrectly thought he was experiencing a flight control failure, and began troubleshooting. In the meantime, one member of the control room recognized what he thought was a stalled condition, but this information was not relayed to the pilot by the test director. The aircraft was recovered at 1700 ft AGL after the aircrew extended the slats in an effort to regain control of the aircraft, never having recognized the condition as a stall.

Flight Control System

The C-17 uses conventional control surfaces for flight path and attitude control. Four elevators, two on each side of the horizontal stabilizer, provide longitudinal control. The movable horizontal stabilizer provides pitch trim. One aileron and four spoilers on each wing provide lateral control. Two double hinged rudders provide directional control. Four leading edge slats and two trailing edge flaps on each wing are used for high lift augmentation. All four hydraulic systems are used to power the flight controls to give maximum redundancy. The aircraft uses an Electronic Flight Control System (EFCS) which is a full time fly-by-wire control system using stick position and force sensors in the pitch and roll axes, and pedal force sensors in the yaw axis. Each axis of the EFCS can be de-selected independently to revert to mechanical control.

Background

The test card deck included mixed low,medium, and hazardous risk test points supporting the first Initial Squadron Operation (ISO) capability for first delivery to Charleston AFB. Specific test points included various configurations of flaps/slats in addition to some hydraulics-off flying qualities tests. The incident test point was considered low risk, and consisted of a demonstration of hydraulics-off (one system) flying qualities with slats retracted and 30 degrees of flap extended (30/ret). The test aircraft was being safety chased by an F-16.

Although the test point was considered low risk, normal desired buildup requirements were not accomplished in the interest of time. Therefore, for that configuration, the stall speed, and minimum speed, were not previously determined. Instead, a minimum speed of 1.2 times the estimated stall speed (1.2 Vs) was established as a safety margin. The predicted Angle-of-Attack (AOA) for the particular test point was well below the predicted stall AOA (3 Vs 12 degrees). In addition, the stall warning system was disabled because actual stalls had been accomplished earlier on the flight profile and the system had not been fully tested and therefore was not reliable.

Aircrew

The aircrew consisted of an Aircraft Commander (AC), a Copilot (CP), a Flight Test Engineer (FTE) occupying the jump seat, and a loadmaster. The AC was the chief company test pilot for the C-17, the CP was a military test pilot on his first high AOA test sortie in the C-17, the FTE was an experienced company employee (FTE on C-17 first flight), the loadmaster was also a company employee.

Control Room

The mission was being controlled from the Riddley Mission Control Center at Edwards AFB. The control room (figure 1) consisted of a total of eight engineers including a Test Director (TD), a Test Conductor (TC), a flight controls engineer, three flying qualities engineers, and two aero-performance engineers. Control room displays consisted of a combination of Cathode Ray Tube (CRT) and strip charts. The TD had overall responsibility for the control room; the TC's responsibilities were to coordinate monitoring activities of the "discipline" engineers, and communicate with the aircrew. All control room personnel communicated internally via an intercom system. Communication between control room and aircrew was via UHF radio only, there was no "hot mike" telemetry capability, therefore, control room personnel were dependent on the pilots to tell them what they were doing. Unless the aircraft was "on conditions" and ready to do a test point, control room personnel could only guess from their displays what was going on with the test aircraft if the pilots did not give them a running description.

Sequence

The specific test point consisted of a demonstration of hydraulics-off (system 2) flying qualities with slats retracted and 30 degrees of flaps extended (30/ret). Trim conditions called for 8000 ft MSL and 172 Knots Calibrated Airspeed (KCAS) which corresponded to 1.2 Vs + 10 knots. Predicted conditions were 3 degree AOA with a pitch attitude (deck angle) of - 0.2 degrees at a flight path angle (FPA) of - 3 degrees. To set up for the test, the aircraft was slowed below the test condition airspeed in order to lower the landing gear. This was an interim, work-around procedure for flight test due to a design deficiency in the landing gear system. The system-two hydraulics were never disconnected due to the roll anomaly perceived right after gear extension..

Figures 2 through 14 describe the aircraft parameters as it descended in the stall condition. These figures were obtained from hard copies of CRT displays in the control room during playback of the data tape. The figures show data at approximately ten second intervals during the sequence from a radar altitude (RALT) of approximately 8,000 ft, to the minimum altitude of 1700 ft. The sequence begins at time 19:39:11 with the slats up, flaps at 30 deg, the landing gear still up, and a deck angle of 5.8 degrees which is six degrees higher than predicted (Figure 2).

During the configuration change, the pilot got distracted by a right roll tendency immediately after lowering the gear. In the meantime, the AOA increased unnoticed by both aircrew and control room personnel as the sink rate increased. The control room was in a relaxed mode having just finished the previous test point, and were waiting for the pilot to call "on conditions"; however, they did notice the higher pitch attitude and were "scratching their heads". At 19:39:41 (Figure 4), the pilot has just lowered the landing gear and the AOA has increased to 11.2 deg. At 19:40:08 (Figure 7) the aircraft is in a right bank which is being countered by the pilot with opposite aileron/spoilers; in addition, the pilot has de-selected the EFCS, and has raised the landing gear. The pilot became convinced that the problem was a flight control failure causing an asymmetry, and consequently proceeded to reverse the configuration sequence. One flying qualities engineer noticed some lateral stick oscillations and asked what was going on; in addition, an areo-performance engineer thought he recognized signs that the aircraft was in a stall and reported to the TD " I think this looks like a stall". The TD discounted this report because he thought the pilot knew what a stall in the C-17 looked like and that the pilot would say something if he was in a stall. Back in the cockpit, the pilot was reluctant to add power during this sequence because he thought the powered lift design of the airplane would aggravate his perceived lateral asymmetry. Finally, as the slats were extended during the reconfiguration, the airplane began to recover. At 19:40:29 (Figure 9) the flaps are fully retracted, the slats are extended, and the aircraft has reached a sink rate in excess of 6,000 feet per minute, and a maximum AOA of 22.9 degrees. In this configuration, the airspeed begins to increase and the AOA also decreases. The sink rate is finally arrested at a radar altitude of 1700 feet with the aircraft in full control.

Nobody in the entire test team noticed the AOA during this sequence until after they played back the data tape. The cockpit was equipped with a sensitive AOA gauge located on top of the glare shield

Conclusions

This incident was fortunate in the sense that the aircraft was not lost or damaged and it only resulted in a slight delay in the program. However, the most fortunate part was to serve as a living example of the reasons why the flight test community needs to focus on CRM concepts. Once again, highly experienced professionals, working in a team environment, did not take advantage of the potential of each member of the team. Most of the classic principles covered in CRM courses were present here: Situation Awareness, Assertiveness, and Communication. A simple conclusion could be made that it was the pilot who was at fault for not "flying" the aircraft. But this conclusion would be wrong; this is precisely the point in CRM. It is not one individual who is responsible for the conduct of the mission, it is the test team's responsibility: it is each individual member of the test team working in harmony, each member knowing the capabilities and limitations of the other members as well as understanding the human interactions involved; and it is applying the principle of synergism where the whole is greater than the sum of its parts. It would be a grave mistake for a pilot to say "I screwed up" and simply leave it at that and continue with a test team that is not fully integrated. This attitude would not prevent a future incident which might easily have more unfortunate results. And this attitude is what drove the airline industry to look at human performance principles in order to avoid the "iron captain" syndrome where the captain is the ultimate authority with no one daring to question that authority, even knowing in some cases that they were going to crash.

SUMMARY

Crew coordination and teamwork has been, to varying degrees, institutionalized in both military and airline training. The concept of Crew Resource Management has been at least acknowledged if not incorporated in aviation training programs; CRM is, therefore, not a new concept anymore. What is new, and still evolving, is the projection of CRM principles outside of what has been considered the core of aviation crews, the cockpit crew. It has not been until recently that the focus has shifted to include a *team* concept. In fact, the acronym CRM has changed from Cockpit Resource Management to Crew Resource Management in order to incorporate a larger part of the humans involved in flight operations; the carbon-based units. The airline industry, although not initially in favor of CRM training, has begun to realize the benefits of such training. Several examples can be cited today where CRM training has been identified as a main reason for saves in airline "close calls" or reducing the effects of mishaps. Nevertheless, statistics show, even today, that approximately 67 percent of aviation mishaps are caused by human performance errors (military and civilian). The flight test community has not escaped these statistics. The case studies presented in this paper are graphic examples of the potential for human performance errors in flight test operations. The common thread that prevails in these and other cases is that it is not enough to put highly trained and experienced crews together in a test team and expect them to perform flawlessly 100 percent of the time. There needs to be some kind of human interaction training in addition to the required technical training to perform safe and efficient flight test operations. The idea of a tailored training program we call Test and Evaluation Crew Resource Management (T&E CRM) is offered here as a first step to target the potential for human error. This idea has already taken fruit in the U.S. Air Force Materiel Command (AFMC). A T&E CRM course which includes classroom and hands-on simulations is being implemented in AFMC using Edwards AFB as a starting point. A similar effort must be undertaken by the rest of the flight test community. This can be done by either developing CRM courses or attending existing courses tailored for flight test operations. The CRM concept has, in the authors' opinion, a great potential for improving flight test operations in both efficiency and safety.

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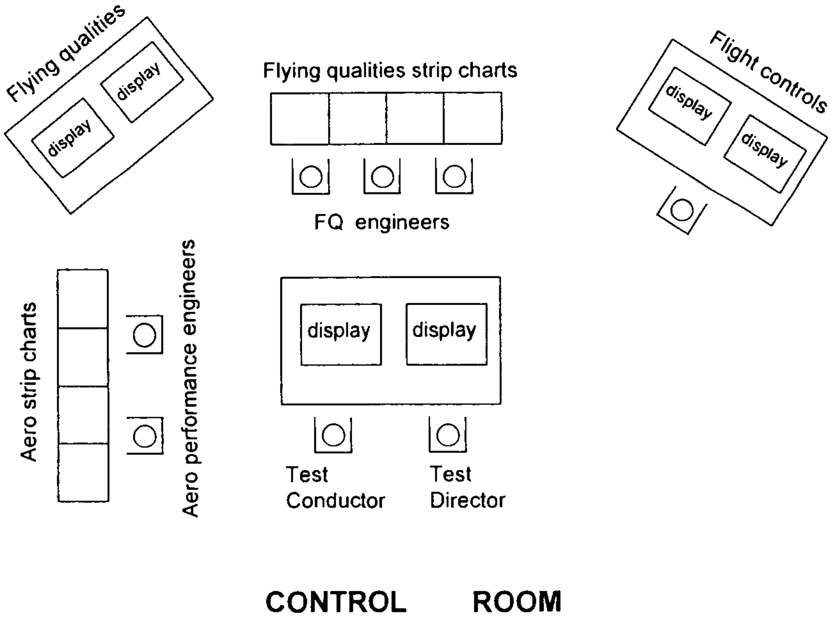
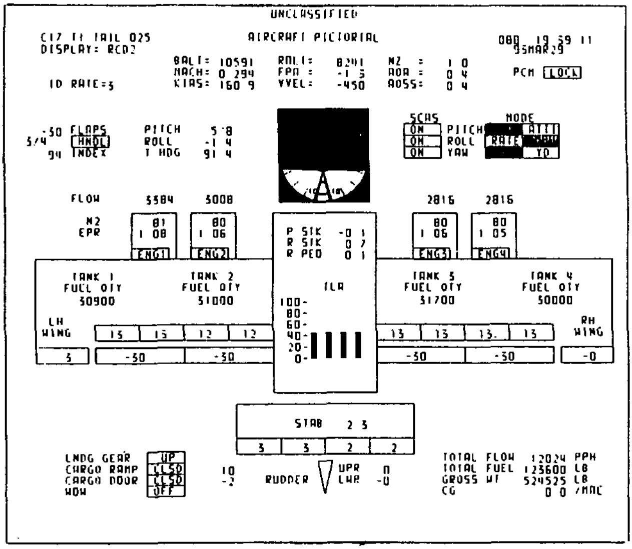

Flying qualities
display
display
Flying qualities strip charts
FQ engineers
Flight controls
display
display
Aero strip charts
Aero performance engineers
display
display
Test Conductor
Test Director
CONTROL ROOM

Figure 1



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                              UNCLASSIFIED

  C17 T1 TAIL 025               AIRCRAFT PICTORIAL                 088  19 59 11
  DISPLAY: RCD2                                                     93MAR29
                      BALT: 10591   RALT:  8241   NZ  :  1 0
                      MACH: 0 294   FPA :  -1 3   AOA :  0 4          PCM [LOCK]
   ID RATE=5          KIAS: 160 9   VVEL:  -450   AOSS:  0 4

                                                      SCAS           MODE
   -30 FLAPS     PITCH    5 8                        [ON] PITCH          [ATTI]
 3/4  [HNDL]     ROLL    -1 4                        [ON] ROLL   [RATE]
   94 INDEX      T HDG   91 4                        [ON] YAW            [ YD ]

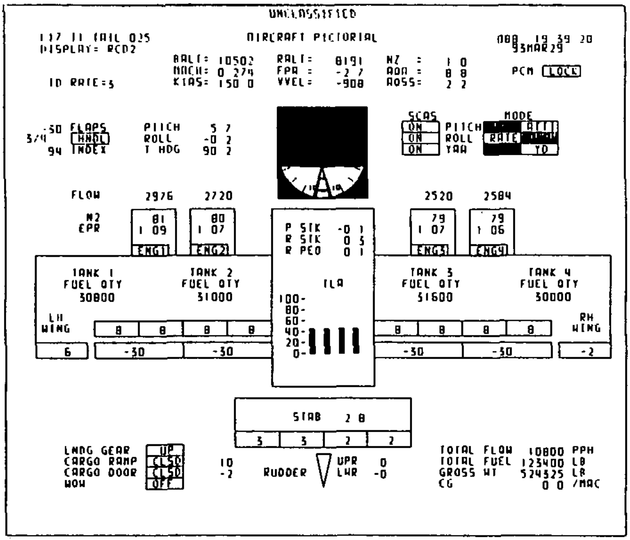
     FLOW        3384    3008                         2816    2816

      N2        [  81 ] [  80 ]                      [  80 ] [  80 ]
     EPR        [1 08 ] [1 06 ]   P SIK  -0 1        [1 06 ] [1 05 ]
                [ENG1 ] [ENG2 ]   R SIK   0 7        [ENG3 ] [ENG4 ]
                                  R PED   0 1
     TANK 1         TANK 2                           TANK 3        TANK 4
    FUEL QTY       FUEL QTY           TLA           FUEL QTY      FUEL QTY
     30900          31000                            31700         30000
                                   100-
  LH                               80-                                     RH
  WING  [ 13 | 13 | 12 | 12 ]      60-          [ 13 | 13 | 13. | 13 ]   WING
                                   40-
                                   20-
  [ 3 ] [  -30  |  -30  ]           0-          [  -30  |  -30  ]      [ -0 ]

                             STAB    2 3
                          [ 3 | 3 | 2 | 2 ]

  LNDG GEAR   [ UP ]                                   TOTAL FLOW   12024 PPH
  CARGO RAMP  [CLSD]    10              UPR   0        TOTAL FUEL  123600 LB
  CARGO DOOR  [CLSD]    -2     RUDDER   LWR  -0        GROSS WT    524525 LB
  WOW         [OFF ]                                   CG             0 0 /MAC
```

Figure 2



```
                              UNCLASSIFIED

  C17 T1 TAIL 025               AIRCRAFT PICTORIAL                 088  19 39 20
  DISPLAY: RCD2                                                     93MAR29
                      BALT: 10502   RALT:  8191   NZ  :  1 0
                      MACH: 0 274   FPA :  -2 7   AOA :  8 8          PCM [LOCK]
   ID RATE=5          KIAS: 150 0   VVEL:  -908   AOSS:  2 2

                                                      SCAS           MODE
   -30 FLAPS     PITCH    5 7                        [ON] PITCH          [ATTI]
 3/4  [HNDL]     ROLL    -0 2                        [ON] ROLL   [RATE]
   94 INDEX      T HDG   90 2                        [ON] YAW            [ YD ]

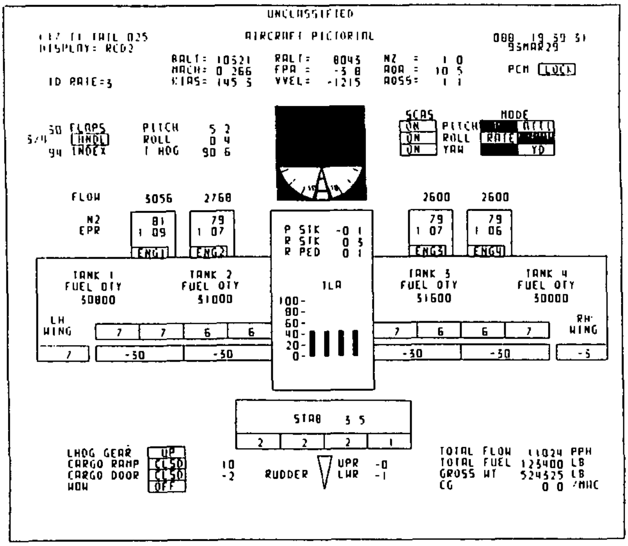
     FLOW        2976    2720                         2520    2584

      N2        [  81 ] [  80 ]                      [  79 ] [  79 ]
     EPR        [1 09 ] [1 07 ]   P SIK  -0 1        [1 07 ] [1 06 ]
                [ENG1 ] [ENG2 ]   R SIK   0 5        [ENG3 ] [ENG4 ]
                                  R PED   0 1
     TANK 1         TANK 2                           TANK 3        TANK 4
    FUEL QTY       FUEL QTY           TLA           FUEL QTY      FUEL QTY
     30800          31000                            31600         30000
                                   100-
  LH                               80-                                     RH
  WING  [ 8 | 8 | 8 | 8 ]          60-          [ 8 | 8 | 8 | 8 ]        WING
                                   40-
                                   20-
  [ 6 ] [  -30  |  -30  ]           0-          [  -30  |  -30  ]      [ -2 ]

                             STAB    2 8
                          [ 3 | 3 | 2 | 2 ]

  LNDG GEAR   [ UP ]                                   TOTAL FLOW   10800 PPH
  CARGO RAMP  [CLSD]    10              UPR   0        TOTAL FUEL  123400 LB
  CARGO DOOR  [CLSD]    -2     RUDDER   LWR  -0        GROSS WT    524525 LB
  WOW         [OFF ]                                   CG             0 0 /MAC
```

Figure 3



UNCLASSIFIED

C17 T1 TAIL 025
DISPLAY= RCD2

AIRCRAFT PICTORIAL

008 19 59 51
95MAR29

BALT= 10521
MACH= 0 266
KIAS= 145 5

RALT= 8045
FPA = -3 8
VVEL= -1215

NZ = 1 0
AOA = 10 5
AOSS= 1 1

PCM LOCK

ID RATE=3

50 FLAPS
5/4 HNDL
94 INDEX

PITCH 5 2
ROLL 0 4
T HDG 90 6

SCAS
ON PITCH
ON ROLL
ON YAW

MODE
ATTI
RATE
YD

FLOW 5056 2768 2600 2600

N2 81 79 79 79
EPR 1 09 1 07 1 07 1 06

ENG1 ENG2 ENG3 ENG4

P STK -0 1
R STK 0 5
R PED 0 1

TLA

TANK 1 FUEL QTY 50800
TANK 2 FUEL QTY 51000
TANK 3 FUEL QTY 51600
TANK 4 FUEL QTY 50000

LH WING 7 7 6 6 7 6 6 7 RH WING
7 -50 -50 -50 -50 -5

STAB 5 5
2 2 2 1

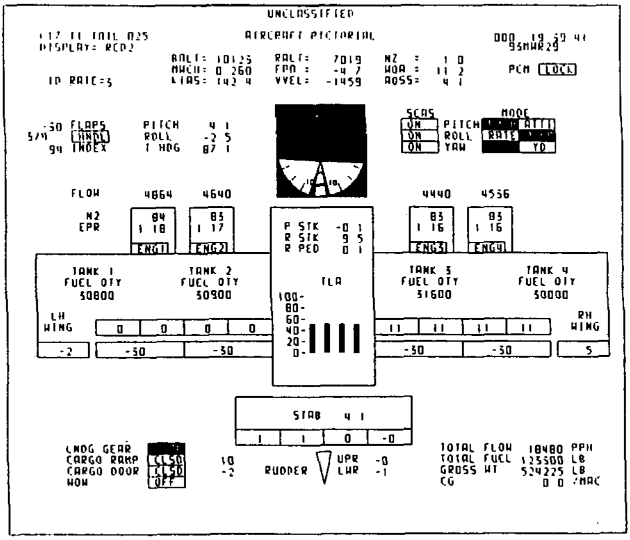
LNDG GEAR UP
CARGO RAMP CLSD
CARGO DOOR CLSD
WOW OFF

10
-2

RUDDER
UPR -0
LWR -1

TOTAL FLOW 11024 PPH
TOTAL FUEL 125400 LB
GROSS WT 524525 LB
CG 0 0 %MAC

Figure 4



UNCLASSIFIED

C17 T1 TAIL 025
DISPLAY= RCD2

AIRCRAFT PICTORIAL

008 19 59 41
95MAR29

BALT= 10125
MACH= 0 260
KIAS= 142 4

RALT= 7019
FPA = -4 7
VVEL= -1459

NZ = 1 0
AOA = 11 2
AOSS= 4 1

PCM LOCK

ID RATE=3

-50 FLAPS
5/4 HNDL
94 INDEX

PITCH 4 1
ROLL -2 5
T HDG 87 1

SCAS
ON PITCH
ON ROLL
ON YAW

MODE
ATTI
RATE
YD

FLOW 4864 4640 4440 4556

N2 84 85 85 85
EPR 1 18 1 17 1 16 1 16

ENG1 ENG2 ENG3 ENG4

P STK -0 1
R STK 9 5
R PED 0 1

TLA

TANK 1 FUEL QTY 30800
TANK 2 FUEL QTY 30900
TANK 3 FUEL QTY 31600
TANK 4 FUEL QTY 30000

LH WING 0 0 0 0 11 11 11 11 RH WING
-2 -50 -50 -50 -50 5

STAB 4 1
1 1 0 -0

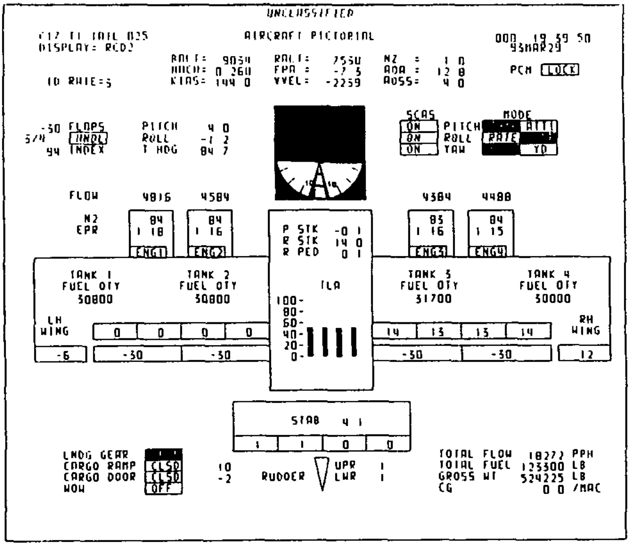
LNDG GEAR
CARGO RAMP CLSD
CARGO DOOR CLSD
WOW OFF

10
-2

RUDDER
UPR -0
LWR -1

TOTAL FLOW 18480 PPH
TOTAL FUEL 125500 LB
GROSS WT 524225 LB
CG 0 0 %MAC

Figure 5



UNCLASSIFIED

C17 T1 TAIL 025
DISPLAY= RCD2

AIRCRAFT PICTORIAL

000 19 59 50
93MAR29

BALT= 9034
MACH= 0 260
KIAS= 144 0

RALT= 7554
FPA = -7 5
VVEL= -2259

NZ = 1 0
AOA = 12 8
AOSS= 4 0

ID RATE=5

PCM LOCK

-30 FLAPS
5/4 HNDL
94 INDEX

PITCH 4 0
ROLL -1 2
T HDG 84 7

SCAS MODE
ON PITCH ATTI
ON ROLL RATE
ON YAW YD

FLOW 4816 4584 4384 4488

N2 84 84 83 84
EPR 1 18 1 16 1 16 1 15
ENG1 ENG2 ENG3 ENG4

P STK -0 1
R STK 14 0
R PED 0 1

TANK 1 FUEL QTY 30800
TANK 2 FUEL QTY 30800
TANK 3 FUEL QTY 31700
TANK 4 FUEL QTY 30000

TLA
100-
80-
60-
40-
20-
0-

LH WING 0 0 0 0
-6 -30 -30

RH WING 14 13 13 14
-30 -30 12

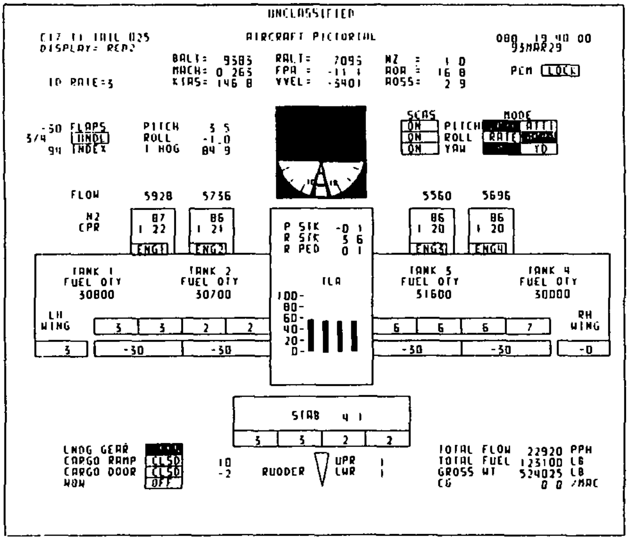
STAB 4 1
1 1 0 0

LNDG GEAR
CARGO RAMP CLSD
CARGO DOOR CLSD
WOW OFF

10
-2
RUDDER UPR 1
LWR 1

TOTAL FLOW 18272 PPH
TOTAL FUEL 123300 LB
GROSS WT 524225 LB
CG 0 0 /MAC

Figure 6



UNCLASSIFIED

C17 T1 TAIL 025
DISPLAY= RCD2

AIRCRAFT PICTORIAL

088 19 40 00
93MAR29

BALT= 9385
MACH= 0 265
KIAS= 146 8

RALT= 7095
FPA = -11 1
VVEL= -5401

NZ = 1 0
AOA = 16 8
AOSS= 2 9

ID RATE=5

PCM LOCK

-30 FLAPS
5/4 HNDL
94 INDEX

PITCH 3 5
ROLL -1.0
T HDG 84 9

SCAS MODE
ON PITCH ATTI
ON ROLL RATE
ON YAW YD

FLOW 5928 5736 5560 5696

N2 87 86 86 86
EPR 1 22 1 21 1 20 1 20
ENG1 ENG2 ENG3 ENG4

P STK -0 1
R STK 5 6
R PED 0 1

TANK 1 FUEL QTY 30800
TANK 2 FUEL QTY 30700
TANK 3 FUEL QTY 31600
TANK 4 FUEL QTY 30000

TLA
100-
80-
60-
40-
20-
0-

LH WING 3 3 2 2
3 -30 -30

RH WING 6 6 6 7
-30 -30 -0

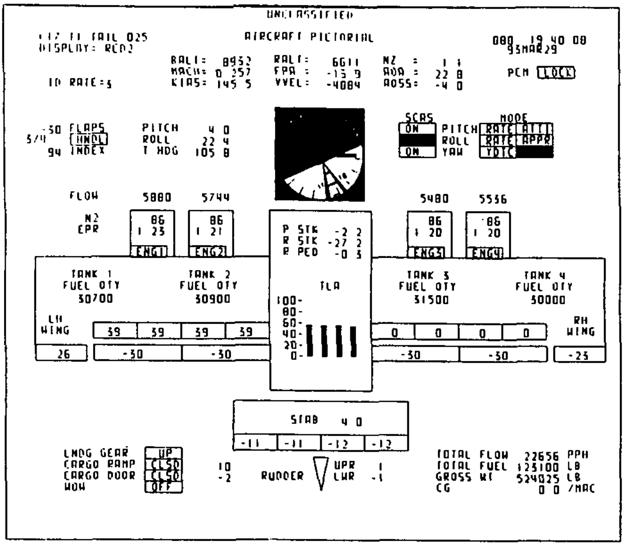
STAB 4 1
3 3 2 2

LNDG GEAR
CARGO RAMP CLSD
CARGO DOOR CLSD
WOW OFF

10
-2
RUDDER UPR 1
LWR 1

TOTAL FLOW 22920 PPH
TOTAL FUEL 123100 LB
GROSS WT 524025 LB
CG 0 0 /MAC

Figure 7



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                                UNCLASSIFIED
C17 T1 TAIL 025                AIRCRAFT PICTORIAL                088  19 40 08
DISPLAY= RCD2                                                      93MAR29
                    BALT=  8952     RALT=   6611    NZ   =   1 1
                    MACH= 0 257     FPA  =  -13 9   AOA  =  22 8     PCM [LOCK]
  ID RATE=5         KIAS= 145 5     VVEL=  -4084    AOSS=   -4 0

      -30 FLAPS      PITCH    4 0                 SCAS          MODE
  5/4    [HNDL]      ROLL    22 4                 [ON ]  PITCH [RATE][ATTI]
      94 INDEX       T HDG  105 8                 [   ]  ROLL  [RATE][APPR]
                                                  [ON ]  YAW   [YDTC][    ]

      FLOW        5880      5744                         5480      5556
        N2        [ 86 ]    [ 86 ]   P STK  -2 2         [ 86 ]    [ 86 ]
       EPR        [1 23]    [1 21]   R STK -27 2         [1 20]    [1 20]
                  [ENG1]    [ENG2]   R PED  -0 3         [ENG3]    [ENG4]
       TANK 1            TANK 2                      TANK 3            TANK 4
      FUEL QTY          FUEL QTY          TLA       FUEL QTY          FUEL QTY
       30700             30900                       31500             30000
                                     100-
  LH                                  80-                                     RH
 WING  [ 39 | 39 | 39 | 39 ]          60-   [ 0 | 0 | 0 | 0 ]                WING
                                      40-
 [ 26 ] [  -30   |  -30   ]           20-   [  -30   |  -30   ]            [ -23 ]
                                       0-

                                  STAB    4 0
                            [ -11 | -11 | -12 | -12 ]

  LNDG GEAR   [UP  ]                                     TOTAL FLOW    22656 PPH
  CARGO RAMP  [CLSD]      10               UPR    1      TOTAL FUEL   125100 LB
  CARGO DOOR  [CLSD]      -2     RUDDER    LWR   -1      GROSS WT     524025 LB
  WOW         [OFF ]                                     CG              0 0 /MAC
```
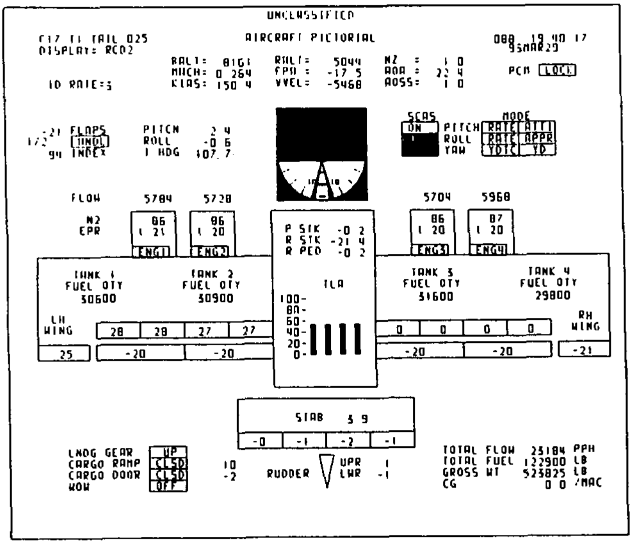

Figure 8



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                                UNCLASSIFIED
C17 T1 TAIL 025                AIRCRAFT PICTORIAL                088  19 40 17
DISPLAY= RCD2                                                      93MAR29
                    BALT=  8161     RALT=   5044    NZ   =   1 0
                    MACH= 0 264     FPA  =  -17 5   AOA  =  22 4     PCM [LOCK]
  ID RATE=5         KIAS= 150 4     VVEL=  -5468    AOSS=    1 0

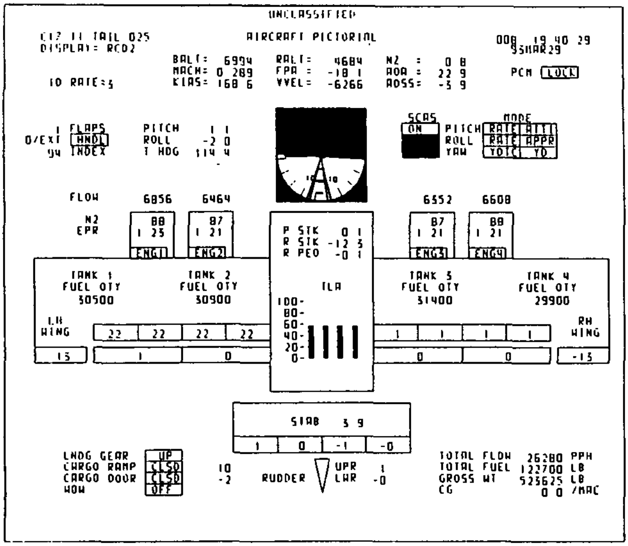
      -21 FLAPS      PITCH    2 4                 SCAS          MODE
  1/2    [HNDL]      ROLL    -0 6                 [ON ]  PITCH [RATE][ATTI]
      94 INDEX       T HDG  107 7                 [   ]  ROLL  [RATE][APPR]
                                                  [   ]  YAW   [YDTC][ YD ]

      FLOW        5784      5728                         5704      5968
        N2        [ 86 ]    [ 86 ]   P STK  -0 2         [ 86 ]    [ 87 ]
       EPR        [1 21]    [1 20]   R STK -21 4         [1 20]    [1 20]
                  [ENG1]    [ENG2]   R PED  -0 2         [ENG3]    [ENG4]
       TANK 1            TANK 2                      TANK 3            TANK 4
      FUEL QTY          FUEL QTY          TLA       FUEL QTY          FUEL QTY
       30600             30900                       31600             29800
                                     100-
  LH                                  80-                                     RH
 WING  [ 28 | 28 | 27 | 27 ]          60-   [ 0 | 0 | 0 | 0 ]                WING
                                      40-
 [ 25 ] [  -20   |  -20   ]           20-   [  -20   |  -20   ]            [ -21 ]
                                       0-

                                  STAB    3 9
                            [ -0 | -1 | -2 | -1 ]

  LNDG GEAR   [UP  ]                                     TOTAL FLOW    23184 PPH
  CARGO RAMP  [CLSD]      10               UPR    1      TOTAL FUEL   122900 LB
  CARGO DOOR  [CLSD]      -2     RUDDER    LWR   -1      GROSS WT     523825 LB
  WOW         [OFF ]                                     CG              0 0 /MAC
```

Figure 9



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UNCLASSIFIED
C17 T1 TAIL 025               AIRCRAFT PICTORIAL              008  19 40 29
DISPLAY= RC02                                                  93MAR29
                 BALT=  6994   RALT=  4684   NZ   :  0 8
                 MACH= 0 289   FPA  = -18 1  AOA  : 22 9       PCM LOCK
  IO RATE=5      KIAS= 168 6   VVEL= -6266   AOSS= -3 9

   1 FLAPS        PITCH    1 1                SCAS        MODE
O/EXT HNDL        ROLL    -2 0                ON   PITCH RATE ATTI
  94 INDEX        T HDG  114 4                     ROLL  RATE APPR
                                                   YAW   YDTC  YD

FLOW      6856    6464                     6552    6608
N2          88      87                       87      88
EPR       1 25    1 21    P STK   0 1      1 21    1 21
          ENG1    ENG2    R STK -12 3      ENG3    ENG4
                          R PED  -0 1
   TANK 1        TANK 2                   TANK 3        TANK 4
  FUEL QTY      FUEL QTY        TLA      FUEL QTY      FUEL QTY
   30500         30900                    31400         29900
LH                              100-                            RH
WING   22   22   22   22        80-      1    1    1    1       WING
                                60-
 13      1          0           40-          0          0        -13
                                20-
                                0-

                          STAB   3 9
                      1    0    -1   -0

LNDG GEAR   UP                                   TOTAL FLOW    26280 PPH
CARGO RAMP  CLSD    10            UPR   1        TOTAL FUEL   122700 LB
CARGO DOOR  CLSD    -2   RUDDER   LWR  -0        GROSS WT     523625 LB
WOW         OFF                                  CG              0 0 /MAC
```
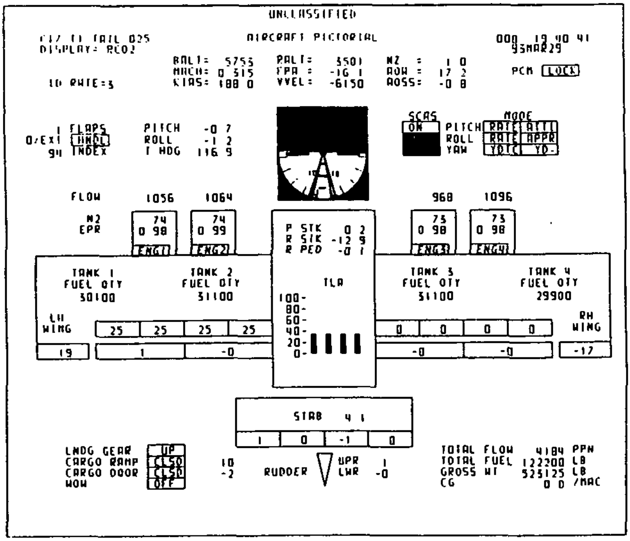
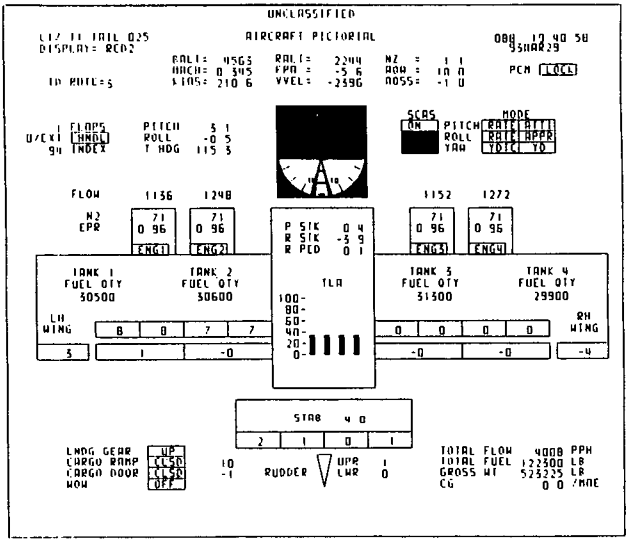

Figure 10



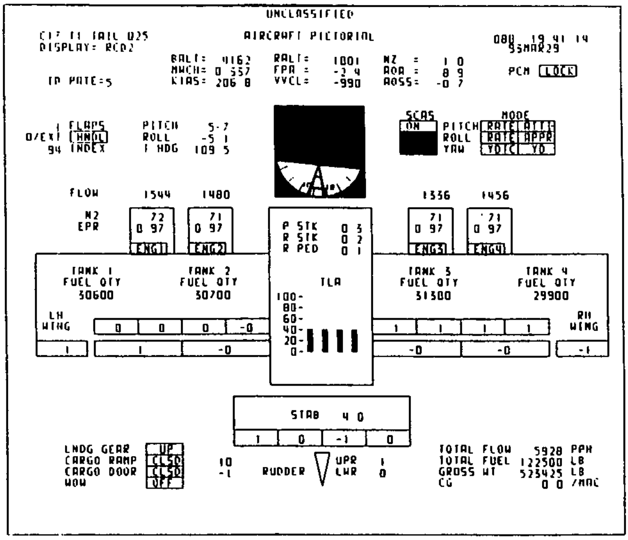
```
UNCLASSIFIED
C17 T1 TAIL 025               AIRCRAFT PICTORIAL              008  19 40 41
DISPLAY= RC02                                                  93MAR29
                 BALT=  5753   RALT=  3501   NZ   :  1 0
                 MACH= 0 315   FPA  = -16 1  AOA  : 17 2       PCM LOCK
  IO RATE=5      KIAS= 188 0   VVEL= -6150   AOSS= -0 8

   1 FLAPS        PITCH   -0 7                SCAS        MODE
O/EXT HNDL        ROLL    -1 2                ON   PITCH RATE ATTI
  94 INDEX        T HDG  116 9                     ROLL  RATE APPR
                                                   YAW   YDTC  YD-

FLOW      1056    1064                      968    1096
N2          74      74                       73      73
EPR       0 98    0 99    P STK   0 2      0 98    0 98
          ENG1    ENG2    R STK -12 9      ENG3    ENG4
                          R PED  -0 1
   TANK 1        TANK 2                   TANK 3        TANK 4
  FUEL QTY      FUEL QTY        TLA      FUEL QTY      FUEL QTY
   30100         31100                    31100         29900
LH                              100-                            RH
WING   25   25   25   25        80-      0    0    0    0       WING
                                60-
 19      1         -0           40-         -0         -0        -17
                                20-
                                0-

                          STAB   4 1
                      1    0    -1    0

LNDG GEAR   UP                                   TOTAL FLOW     4184 PPH
CARGO RAMP  CLSD    10            UPR   1        TOTAL FUEL   122200 LB
CARGO DOOR  CLSD    -2   RUDDER   LWR  -0        GROSS WT     523125 LB
WOW         OFF                                  CG              0 0 /MAC
```

Figure 11



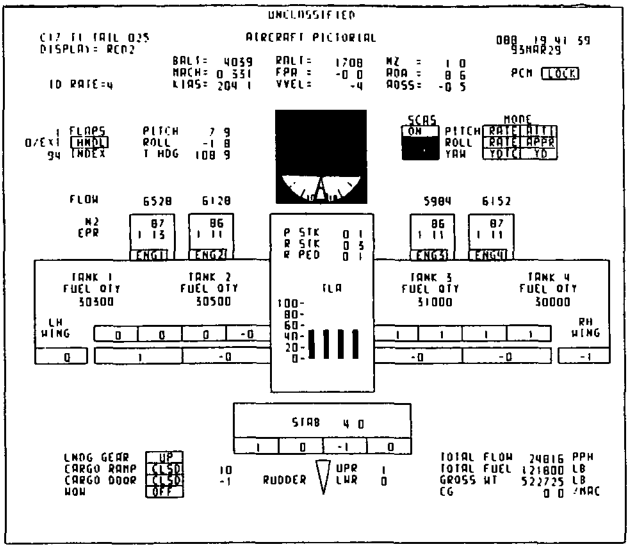
```
                              UNCLASSIFIED
C17 T1 TAIL 025                AIRCRAFT PICTORIAL              088 19 40 58
DISPLAY= RCD2                                                     95MAR29
                      BALT=  4563   RALT=  2244   NZ  =  1 1
                      MACH= 0 345   FPA =  -5 6   AOA = 10 0      PCM LOCK
  ID RATE=5           KIAS= 210 6   VVEL= -2396   AOSS= -1 0

     1  FLAPS     PITCH     5 1                  SCAS        MODE
U/EXT   HNDL      ROLL     -0 5                  ON   PITCH RATE ATTI
    94  INDEX     T HDG   115 3                       ROLL  RATE APPR
                                                      YAW   YDTC  YD

   FLOW         1136    1248                     1152    1272
     N2           71      71                       71      71
    EPR         0 96    0 96    P STK  0 4       0 96    0 96
                ENG1    ENG2    R STK -3 9       ENG3    ENG4
                                R PED  0 1
     TANK 1        TANK 2                        TANK 3        TANK 4
    FUEL QTY      FUEL QTY           TLA        FUEL QTY      FUEL QTY
     30500         30600                         31300         29900
 LH                             100-                                    RH
 WING  | 8 | 0 | 7 | 7 |         80-         | 0 | 0 | 0 | 0 |        WING
                                 60-
                                 40-
| 3 |  |   1   |  -0   |         20-         |  -0   |  -0   |        | -4 |
                                  0-

                            STAB   4 0
                       | 2 | 1 | 0 | 1 |
 LNDG GEAR   UP                                         TOTAL FLOW    4008 PPH
 CARGO RAMP  CLSD    10            UPR   1              TOTAL FUEL  122300 LB
 CARGO DOOR  CLSD    -1    RUDDER  LWR   0              GROSS WT    523225 LB
 WOW         OFF                                        CG             0 0 /MAC
```

Figure 12



```
                              UNCLASSIFIED
C17 T1 TAIL 025                AIRCRAFT PICTORIAL              088 19 41 14
DISPLAY= RCD2                                                     95MAR29
                      BALT=  4162   RALT=  1001   NZ  =  1 0
                      MACH= 0 557   FPA =  -2 4   AOA =  8 9      PCM LOCK
  ID RATE=5           KIAS= 206 8   VVEL=  -990   AOSS= -0 7

     1  FLAPS     PITCH     5 7                  SCAS        MODE
U/EXT   HNDL      ROLL     -5 1                  ON   PITCH RATE ATTI
    94  INDEX     T HDG   109 5                       ROLL  RATE APPR
                                                      YAW   YDTC  YD

   FLOW         1544    1480                     1336    1456
     N2           72      71                       71      71
    EPR         0 97    0 97    P STK  0 3       0 97    0 97
                ENG1    ENG2    R STK  0 2       ENG3    ENG4
                                R PED  0 1
     TANK 1        TANK 2                        TANK 3        TANK 4
    FUEL QTY      FUEL QTY           TLA        FUEL QTY      FUEL QTY
     30600         30700                         31300         29900
 LH                             100-                                    RH
 WING  | 0 | 0 | 0 | -0 |        80-         | 1 | 1 | 1 | 1 |        WING
                                 60-
                                 40-
| 1 |  |   1   |  -0   |         20-         |  -0   |  -0   |        | -1 |
                                  0-

                            STAB   4 0
                       | 1 | 0 | -1 | 0 |
 LNDG GEAR   UP                                         TOTAL FLOW    5928 PPH
 CARGO RAMP  CLSD    10            UPR   1              TOTAL FUEL  122500 LB
 CARGO DOOR  CLSD    -1    RUDDER  LWR   0              GROSS WT    523425 LB
 WOW         OFF                                        CG             0 0 /MAC
```

Figure 13



C17 T1 TAIL 025
DISPLAY= RCD2
ID RATE=4
BALT= 4039
MACH= 0 331
KIAS= 204 1
RALT= 1708
FPA = -0 0
VVEL= -4
NZ = 1 0
AOA = 8 6
AOSS= -0 5
088 19 41 59
93MAR29
PCM LOCK

1 FLAPS
0/EXT HNDL
94 INDEX
PITCH 7 9
ROLL -1 8
T HDG 108 9

SCAS ON
MODE
PITCH RATE ATTI
ROLL RATE APPR
YAW YDTC YD

FLOW 6528 6128 5984 6152
N2 87 86 86 87
EPR 1 13 1 11 1 11 1 11

P STK 0 1
R STK 0 5
R PED 0 1

TANK 1 FUEL QTY 30300
TANK 2 FUEL QTY 30500
TANK 3 FUEL QTY 31000
TANK 4 FUEL QTY 30000

0 0 0 -0
0 1 -0
1 1 1 1
-0 -0 -1

STAB 4 0
1 0 -1 0

LNDG GEAR UP
CARGO RAMP CLSD
CARGO DOOR CLSD
WOW OFF

10
-1
RUDDER UPR 1
LWR 0

TOTAL FLOW 24816 PPH
TOTAL FUEL 121800 LB
GROSS WT 522725 LB
CG 0 0 %MAC

Figure 14