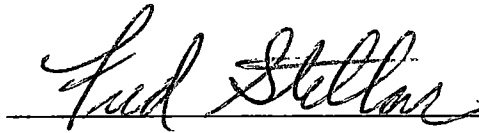


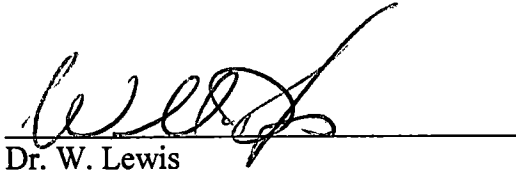
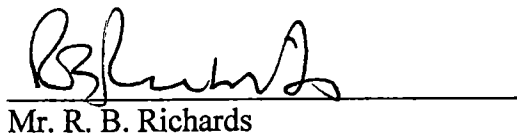
To the Graduate Council:

I am submitting herewith a thesis written by Donald J. Parker entitled "An Investigation of Brake Release on the Catapult—A non-Ergonomic Solution to an Ergonomic Problem in the T-45 Goshawk." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.



Mr. F. Stellar, Major Professor

We have read this thesis and
recommend its acceptance:


Dr. W. Lewis
Mr. R. B. Richards

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Associate Vice Chancellor
and Dean of The Graduate School

**AN INVESTIGATION INTO BRAKE RELEASE ON THE
CATAPULT – A NON-ERGONOMIC SOLUTION TO AN
ERGONOMIC PROBLEM IN THE T-45 GOSHAWK**

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Donald J. Parker

August 2000

DISCLAIMER

The foundation of this research is based on the author's participation in a United States Department of Defense sponsored Naval Air Warfare Center, Aircraft Division project. The analysis and discussion of the data and results, conclusions and recommendations presented are the author's point-of-view and should not be interpreted as an official position of the Department of Defense, or any command within the U.S. Navy.

ABSTRACT

This study investigates a modification to the T-45 Goshawk that releases brake pressure when the aircraft is on the catapult of an aircraft carrier, preventing the pilot's inadvertent brake application in the cockpit from applying the brakes at the wheel. The modification arose from numerous incidents of Student Naval Aviators inadvertently actuating the brakes during catapult shots, ultimately causing the tire(s) to explode. The subsequent landings with blown tires have proven extremely hazardous resulting in at least three catastrophic mishaps in four years of operational training. The modification takes a radical departure from conventional naval aviation wisdom concerning the pilot's control of brakes, because it inhibits hydraulic pressure from actuating the brakes. This system effectively removes the pilot's pedal input to the brake system during a catapult launch, when brake application is undesirable.

The problem of inadvertent braking on the catapult results mainly from cockpit ergonomics in the T-45. Specifically, the fulcrum of the brake pedal sits too close to the floor beneath, preventing the pilot from executing normal catapult procedures conducted in the fleet, where he slides his feet to the deck for the catapult launch. The alternative solutions included a "Toe-bar" and minor adjustments to the brake pedal height and deck plate location within the limits of the aircraft's major structure. The "Toe-bar" was a reference point at the mid-point of the brake pedal, under which the pilot placed the toe of his boot. It effectively placed the pilot in a position that prevented him from applying sufficient moment to actuate the brakes. The "Toe-bar" was implemented in fleet T-45 aircraft, and produced moderate success at preventing blown tires on the catapult. It has ergonomic issues of its own however, since it places the pilot in an extremely uncomfortable position that is potentially hazardous in an ejection scenario. The other modifications were found unsuitable, particularly for larger pilots during early cockpit mock-up testing.

This study provides an analysis of the causes of blown tires on the catapult, the human factors involved with alternative ergonomic solutions, the method of testing the brake release solution, and a psychological discussion of the transfer of training concerns

regarding students transitioning to fleet aircraft after flying the T-45 with brake release incorporated.

The author concluded that the brake release system will successfully prevent pilot brake application from resulting in blown tires on the catapult, but discovered one correctable ground handling deficiency with the prototype system as it was installed in the T-45.

The author made three recommendations:

- The Navy should incorporate the brake release system in the T-45 after correcting the ground handling deficiency.
- The Navy should incorporate the brake release system in future fleet aircraft
- The Navy should research whether the blown tire problem exists in fleet aircraft, and pending the results modify existing fleet aircraft with the brake release system.

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Chapter 1

Introduction

Background

Research Motivation

In August, 1998 a US Marine Corps First Lieutenant, Student Naval Aviator (SNA) accepted his second, catapult launch in a T-45A "Goshawk" from a US naval aircraft carrier. During the catapult stroke the right wheel locked causing the tire to skid, and ultimately explode. Once airborne, the aircraft flew normally, but the difficult task of landing the aircraft with a blown tire lay ahead. The ensuing landing was to be the SNA's second arrestment aboard an aircraft carrier. Landing an aircraft aboard an aircraft carrier requires extremely precise control of the aircraft's flight-path with little tolerance for error. The student entered the aircraft carrier landing pattern and executed a normal approach to the ship. The student flew the aircraft to touchdown on the deck of the aircraft carrier, but missed the last arresting wire resulting in the aircraft rolling along the deck toward the end of the landing area. As the aircraft rolled along the deck, the increased drag from the blown tire yawed the aircraft to the right. The student lost control of the aircraft and impacted the port side of the ship as the aircraft departed the landing area approximately four seconds after initial touchdown. This mishap resulted in one fatality and loss of the aircraft (Training Squadron-22, Message 232030Z Oct 98)

The US Naval Air Training Command had experienced numerous incidents of blown tires on the catapult since the T-45 entered operational service in 1994, most of which resulted in uneventful shore based landings. This mishap however, was the second that resulted in the destruction of a valuable training asset and the first that resulted in a fatality in the aircraft's relatively short operational service. The apparent cause of the blown tires had been students inadvertently applying one or both brakes during the catapult stroke, resulting in a locked wheel and ultimately a blown tire. The training

command knew of the inadvertent brake application problem and attempted to prevent it by training students to avoid applying the brakes during the catapult stroke. The attempt to alleviate the problem through training however was ineffective since T-45 students continued to experience blown tires, as demonstrated in the August 1998 mishap. The aircraft needed an engineering solution to prevent future blown tire occurrences.

The SHEL Model

Systems are composed of three major resources: Hardware, Software and Liveware. Hardware is the components and materials used to make up the physical portion of the system. Software is the procedures, rules, practices and habits that govern the system's operation. Liveware is the human beings within the system, often the system operator. In any system each of the above exists in a surrounding environment, over which the system designer has no control. These four elements make up a construct known as the SHEL model Figure 1.

While each of the components is critical in the system, equally critical are the interfaces between each of the components. It is at the interfaces where system failures most frequently occur (Wiener & Nagel, 1988). In the case of the T-45 on the catapult of an aircraft carrier, the Student Naval Aviator (Liveware), is in an unfamiliar *environment* where the procedures (Software) are new as well. The student is therefore under considerable stress and error prone (chapter 4). An inappropriate mismatch at the Liveware-Hardware interface in a system that is intolerant of error, can easily result in disaster. The critical node of Liveware-Hardware interface in this case is that of the T-45 rudder/brake pedal, and the pilot's lower body, mainly his feet.

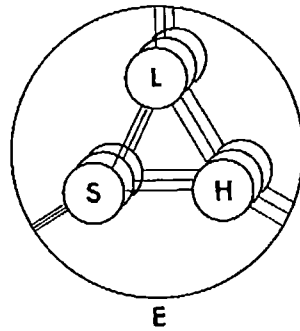


Figure 1 SHEL Model

Source: Weiner, Earl L., Nagel, David C., Human Factors in Aviation. San Diego:
- Academic Press, 1988

Systems engineering process

The systems engineering process is a disciplined approach to problem-solving that breaks down the components of the system into identifiable pieces that can be managed at a subsystem level. The process is designed to optimize the system's components, attributes, and relationships to maximize the efficiency of the entire system, vice optimizing the system's individual elements, which may sacrifice overall system efficiency. In the case of the T-45 on the catapult, the system consists of the catapult on the aircraft carrier, the personnel on the flight deck, the T-45 aircraft and its student operator. The system shortcoming however, lies mainly in the relationship between the T-45 aircraft and its student operator, the L-H interface in the SHEL model.

The author applied the concepts of the SHEL model and used a seven-step process to develop a solution to the problem. The process consisted of the following steps: problem definition, alternatives generation, alternatives and constraints analysis, system selection, and system testing, and identification of the solution's impact on other portions of the global system (flight training).

Problem definition

Clearly defining the problem is first step of the approach to obtaining an engineering solution. It is crucial that the scope of the problem be sufficiently narrowed such that solutions can be generated with the appropriate level of specificity to be effective.

In the case of the T-45 the author began with the mishap statistics. Three Class-A mishaps (30% of all T-45 Class-A mishaps) occurred during landing attempts with blown tires. Landing the T-45 with blown tires however, involves the issues surrounding the basic ground handling characteristics of the aircraft complicated by one or more blown tires. Solving the innate ground handling problems in the T-45 will require considerable effort and funding since the problems stem from numerous contributors. Reducing the incidents of blown tires however, may be a more rapid and simpler solution.

Narrowing the scope further, exposes the fact that two of the three blown tire landings occurred as a result of blown tires that happened during catapult launches when a student inadvertently applied the brake(s). Despite training attempts to prevent it students were routinely applying the brakes on the catapult resulting in at least 16 blown tire landings. All, except the two aircraft involved in mishaps, were safely recovered ashore, but the blown tire phenomenon placed the aircraft, the pilot and ground personnel in extremis since likelihood of a mishap was high. The single largest cause of blown tires was inadvertent braking on the catapult. If the inadvertent braking problem could be eliminated, it had the potential to significantly reduce the risk associated with SNA's participating in carrier qualification. The problem of interest in this thesis, therefore is inadvertent brake application on the catapult.

Alternatives generation and constraints analysis is the phase when potential solutions to the problem are conceptually developed. A free-thinking approach is used throwing none of the potential solutions out, until the system constraints are applied. The system constraints eliminate the impractical alternatives and reduce the scope of those alternatives that remain practical but need a reduction in scope to fit within the

constraints of the system. The system constraints may be any of a wide variety from economic to physical structures preventing progress in a particular direction. The specific alternative solutions to the inadvertent brake problem, and the system constraints are discussed in chapter 5.

The system selection phase further narrows the range of choices by selecting the solutions that offer the most promise to be effective, then preparing them for testing. In the T-45 the chosen system is the brake release system, the design of which is discussed in chapter 6.

System testing is conducted to ensure the solution(s) operate within the constraints of the system and accomplish their assigned mission. Testing may be conducted by simple analysis, mock-ups, and in the latter stages, flight test. The brake release method of testing and results are discussed in chapter 7.

Solutions to problems in a system may impact other parts of the system or other systems altogether. When solving one problem it is imperative that the designer identify the potential side effects of incorporating the solution and determine if the solution warrants implementation. The potential side effect of the brake release system is its impact on transfer of training as the student transfers habit patterns learned in the T-45 to future aircraft. This is discussed in chapter 8.

Research Objective

The objective of the research is to apply the systems engineering approach discussed above to the problem of inadvertent brake application on the catapult in the T-45. This is conducted in an effort to obtain a long term solution to last through the life expectancy of the aircraft.

Chapter 2

Description of the T-45 “Goshawk”

Overview

The T-45 Goshawk is a subsonic, single-engine, tandem-seat, jet trainer (Figure 2 and Figure 3). The aircraft is used by the US Navy to train student naval aviators who are destined to fly naval aircraft aboard aircraft carriers in the fleet. It is an adaptation of the land-based, British Aerospace Hawk aircraft, but it has been modified to operate aboard US naval aircraft carriers. The T-45 acquisition program originally intended the aircraft to be an inexpensive, Commercial Off The Shelf (COTS) purchase of an existing, proven airframe, minimally modified to perform the mission of training student naval aviators. The result however, was a significantly modified aircraft that did not conform to many of the US Military Standards (MIL-STD) for aircraft design. The following paragraphs provide an abbreviated overview of the aircraft’s critical systems involved with ground handling and the blown tire phenomenon.

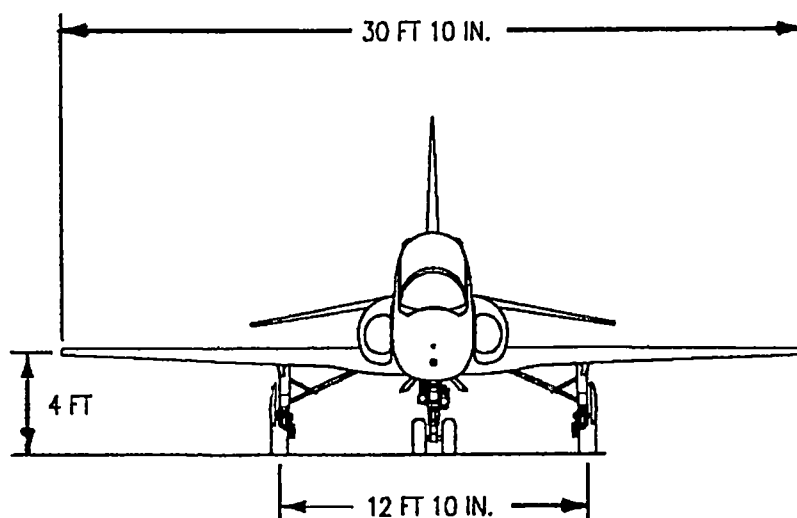


Figure 2 Front View of a T-45

Source: T-45 NATOPS Flight Manual

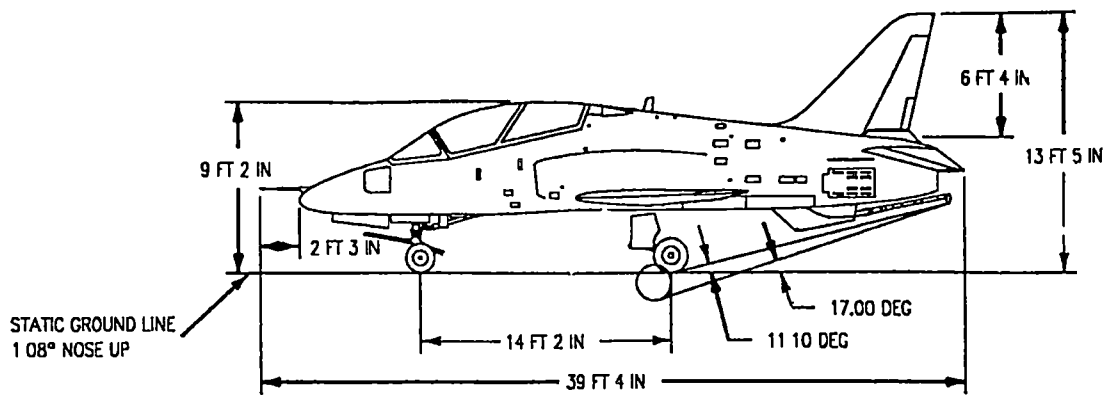


Figure 3 Side View of a T-45

Source: T-45 NATOPS Flight Manual

Landing Gear

The T-45 incorporates a retractable, tricycle-type landing gear system. The nose gear has dual wheels and a launch bar, designed for use on catapults of aircraft carriers. This is one of the significant changes from the Hawk, which has only a single nose gear tire, common for land-based aircraft. The T-45 main gear are wing mounted and have trailing arm suspension, similar to the F/A-18 Hornet. The landing gear are mounted such that the main gear tires are 12 feet, 10 inches apart and 14 feet, 2 inches aft of the nose gear when the aircraft is on the deck. A conventional landing gear handle in each cockpit controls retraction and extension of the landing gear, which are hydraulically actuated. The nose gear retracts forward and the main gear retract inboard toward the fuselage.

Nose Wheel Steering System

A full time nose wheel steering system provides the primary means of directional control when the aircraft is on deck. It is electrically controlled and hydraulically actuated through the landing gear hydraulic system. The hydraulic system also provides rotational shimmy damping, limiting the likelihood that the nose wheel truck assembly

will oscillate directionally during high-speed operations on deck. The nose wheel steering system is dual gain during normal land operations. The low gain provides $\pm 12^\circ$ of nose wheel rotation and is the default gain. The high gain is for low speed taxi only, providing $\pm 65^\circ$ of nose wheel rotation either direction, and must be selected and held by the pilot to remain engaged. Placing the aircraft's launch bar down automatically disengages the nose wheel steering. The pilot may reengage nose wheel steering to a medium gain that provides $\pm 20^\circ$ of nose wheel rotation only when the launch bar is down. This is typically accomplished only when preparing for a catapult launch from an aircraft carrier.

The pilot controls the nose wheel steering system via two electrical switches on the stick and through displacement of the rudder pedals. The pilot can disengage nose wheel steering by momentarily depressing the Paddle Switch (Figure 4). During normal taxi operations with the launch bar UP, the pilot may engage nose wheel steering to low gain by momentarily depressing the nose wheel steering button (Figure 4).

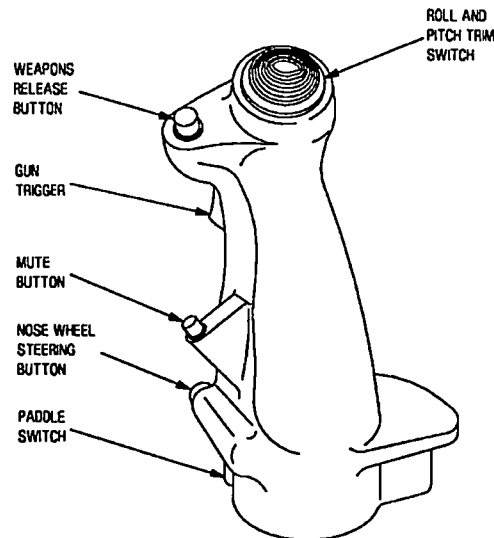


Figure 4 T-45 Stick Grip and Controls

Source: T-45 NATOPS Flight Manual

To obtain high gain, the pilot need only depress and hold the same button for as long as he desires high gain nose wheel steering. With the launch bar down, a condition normally encountered when preparing for a catapult launch aboard an aircraft carrier, the nose wheel steering is automatically disengaged, but the pilot selects medium gain by depressing and holding the nose wheel steering button. The pilot controls the azimuth of the nose wheel relative to the fuselage through rudder pedal displacement. Pushing the left pedal forward to its limit for example, will cause the nose wheel to rotate 12° left in low gain, 20° left in medium gain, and 65° left in high gain.

The nose wheel steering system has two lights to advise the pilot of its operational status. It has a green NOSE WHL STR advisory light, located on the Advisory light panel (Figure 5), and an amber NOSE WHL STR caution light located on the

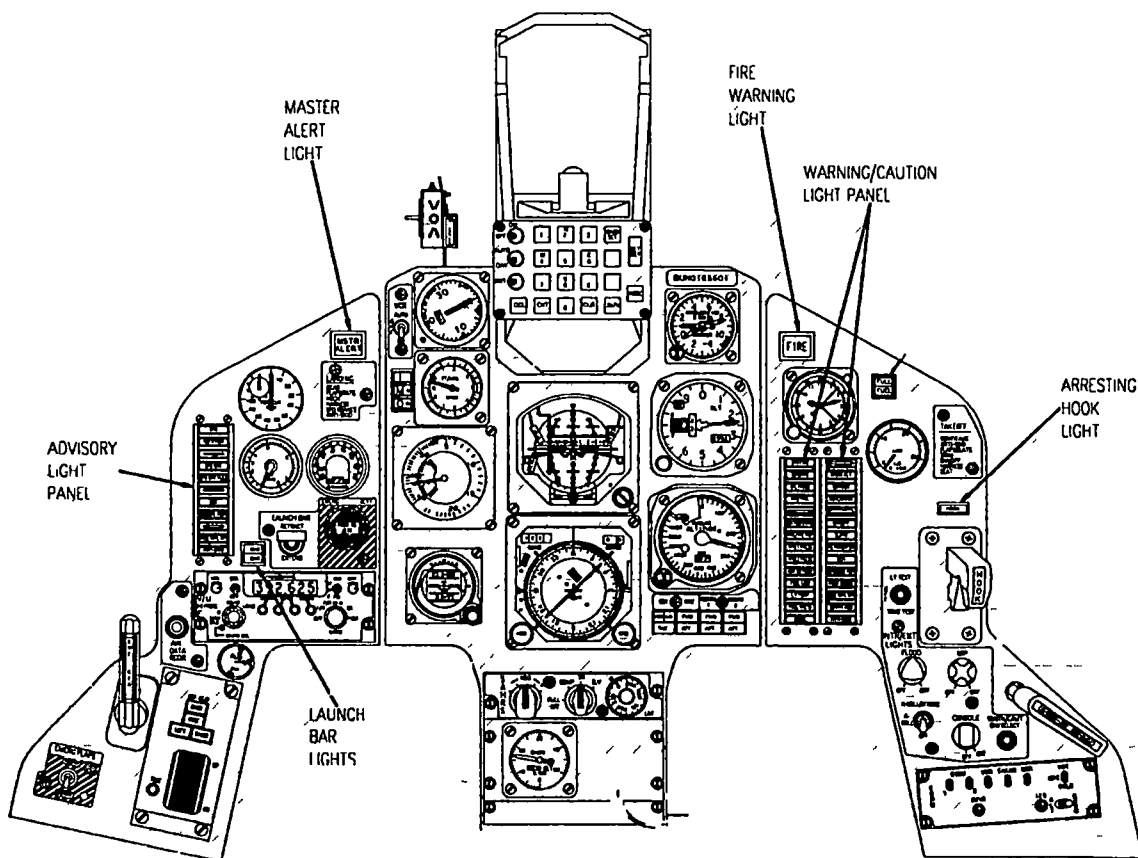


Figure 5 T-45A Forward Cockpit Instrument Panel

Source: T-45 NATOPS Flight Manual

Warning/Caution light panel. The green advisory light illuminates only when high gain steering is selected. The amber caution light illuminates when the nose wheel steering system is disengaged or when the system self detects a fault. In either case the nose wheel steering system will be inoperative with the caution light illuminated.

Launch Bar System

Carrier-based aircraft require a large propulsive force, much greater than that provided by their internal engines, to attain flying speed in the short distance available on the deck of an aircraft carrier. A steam-powered catapult, located beneath the flight deck provides the necessary energy by accelerating the aircraft forward at roughly three times the force of gravity. All current carrier-based naval aircraft, including the T-45, interface

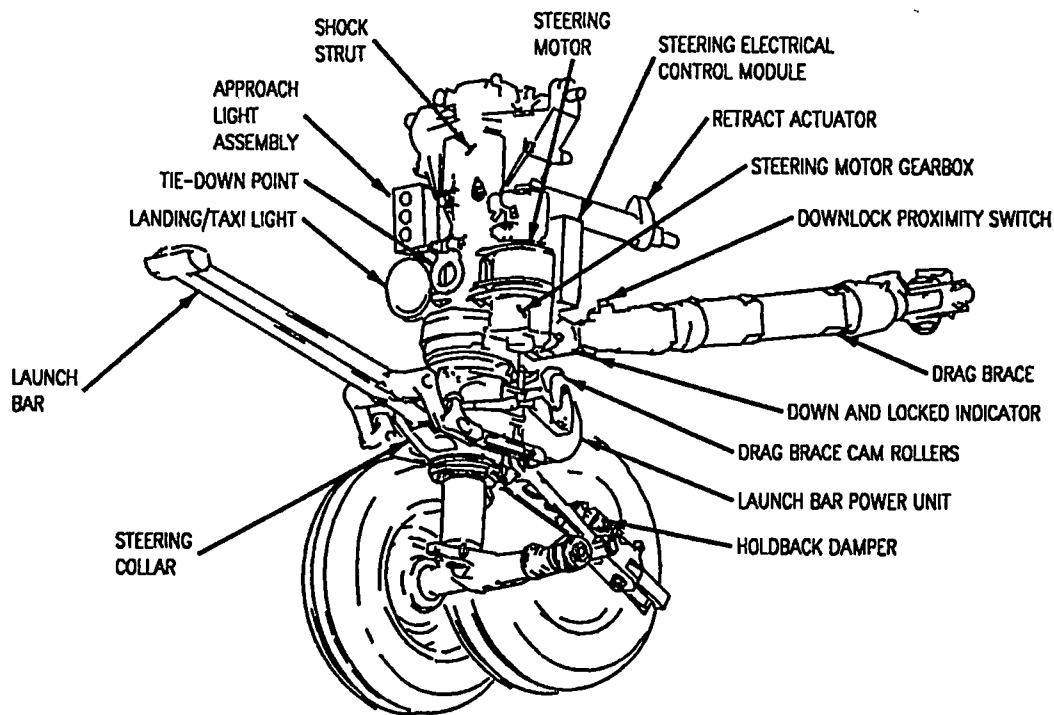


Figure 6 T-45 Nose Gear Assembly

Source: T-45 NATOPS Flight Manual

with the ship's catapult using a launch bar located on the nose gear strut. (Figure 6). The figure pictures the launch bar in the RETRACT position, which prevents interference with the ground objects during normal ground operations. Figure 7 provides a side view of the launch bar in the extended position with the end of the launch bar set in the catapult shuttle, as if preparing for a catapult launch.

The launch bar is electrically controlled and hydraulically operated. The pilot controls the position of the launch bar through a two-position switch located on the front cockpit instrument panel (Figure 7). The two positions are labeled "LAUNCH BAR RETRACT" and "EXTEND" (Figure 7). The switch is spring loaded to the RETRACT position but magnetically held in the EXTEND position once placed there by the pilot, when the aircraft is on deck. When the aircraft's weight is off of its wheels, the electromagnet in the switch disengages, allowing the switch to return to the RETRACT position.

A green L BAR advisory light and a red L BAR warning light located on the instrument panel in both cockpits display the condition of the launch bar to the pilot (Figure 7). When the launch bar switch is placed to EXTEND and the launch bar is in the EXTEND position, the green light illuminates indicating the launch bar is down when the aircraft is on deck. The red L BAR warning light illuminates after the aircraft has been airborne at least ten seconds and the launch bar has not retracted. This warns the

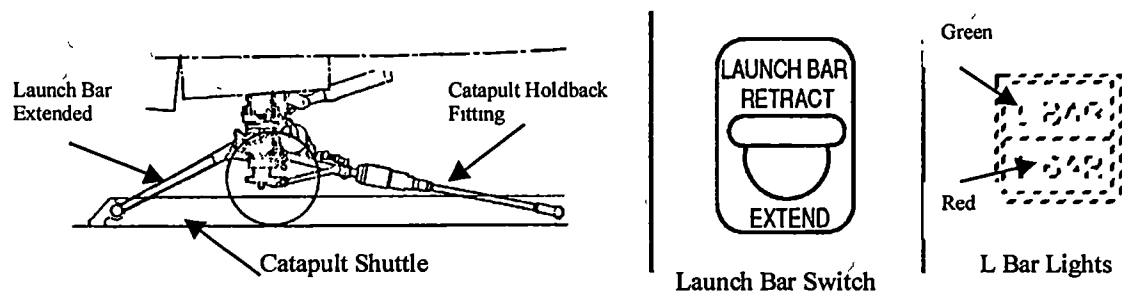


Figure 7 Nose Gear Strut with Launch Bar Extended. Launch Bar Switch and Indicator Lights from Forward Cockpit Instrument Panel

Source: T-45 NATOPS Flight Manual

pilot of an extremely dangerous landing condition due to the likelihood that the launch bar will catch a cross-deck pendant after touchdown.

Brake and anti-skid systems

The T-45 uses conventional disc brakes on the main landing gear to provide deceleration power for the aircraft. The brakes are powered through an engine driven hydraulic system and have a backup hydraulic accumulator to provide hydraulic pressure in the event of a hydraulic system failure. The pilot actuates the brakes by pressing the top portion of the rudder pedals, which modulate the brakes in proportion to the displacement of the pedals. The right brake pedal controls the brake on the right main wheel and the left pedal controls the brake on the left main wheel. A J-shaped parking brake handle is located on the right vertical instrument panel in the front cockpit. Pulling and rotating the handle clockwise sets the parking brake, immediately applying maximum hydraulic pressure to both brake assemblies. The parking brake system includes a PARK BRAKE caution light, located on the warning/caution light panel, which illuminates when the parking brake is set, and the throttle is advanced beyond an intermediate position.

Unlike automobiles, high performance jet aircraft provide no appreciable feedback to the pilot if he applies too much brake resulting in a skid. In most circumstances a pilot will not know that his tire(s) are skidding until one explodes, resulting in a hazardous ground handling situation. Reliably obtaining the maximum braking capability of the aircraft for a given set of gross weight, runway, landing speed, crosswind and other variable parameters, is impossible for the pilot with a non-augmented brake system. The T-45 brake system, therefore, includes an electrically controlled anti-skid mechanism designed to minimize tire skid and decrease stopping distance. The anti-skid system incorporates a two-position ANTI-SKID switch in both cockpits, a wheel speed sensor on both main wheels, an electrical anti-skid control unit, and an anti-skid control valve as its main components. When the anti-skid system is engaged, the pilot actuates the brakes through the brake pedals, and the brake system modulates hydraulic pressure to the brakes in proportion to the brake actuation

commanded by the pilot. If the commanded brake pressure exceeds either tire's skid threshold, the wheel speed sensor senses a rapid wheel deceleration, and opens the anti-skid control valve, releasing brake pressure to both brakes until the wheel speed recovers. It then reapplies brake pressure to a threshold slightly lower than that when it sensed the skid. The anti-skid system is inoperative until the aircraft has reached a speed of 30 knots during accelerations such as takeoff, and below 13 knots during decelerations, such as landing. Below these speeds, the pilot has normal braking available, unassisted by the anti-skid system. During carrier and field arrestments, the aircraft's deceleration is so rapid that the anti-skid system senses a skid and releases brake pressure, causing the brakes to be temporarily inoperative. For this reason and the fact that taxi speeds are well below 11-13 knots, anti-skid is selected OFF for operations at the aircraft carrier.

The pilot controls the anti-skid through independent anti-skid switches; one in each cockpit. With both switches selected ON, the anti-skid system operates except when automatically disengaged during low speed taxi. With the anti-skid selected OFF in either cockpit, the pilot has normal braking without anti-skid protection.

The anti-skid system incorporates a green ANTI-SKID advisory light on the advisory light panel and an amber ANTI-SKID caution light on the warning/caution light panel to display the condition of the system to the pilot (Figure 5). The advisory light illuminates with both anti-skid switches ON and the landing gear DOWN. The amber caution light illuminates when the anti-skid built in test detects a fault in the system indicating that the system is inoperative.

Flight controls & hydraulic systems

The T-45 has conventional primary and secondary flight controls. The primary flight controls include hydraulically powered ailerons and stabilator, and a mechanically powered rudder. The ailerons and stabilator are irreversible, and have tandem hydraulic actuators that use hydraulic power from both independent hydraulic systems. The rudder control mechanism is a reversible system actuated wholly by the force the pilot imparts to the rudder pedals. The reversible rudder system feeds back aerodynamic forces on the

rudder to the pilot through the rudder pedals. The pilot interfaces with the primary flight controls through a conventional control stick and rudder pedals.

Two engine-driven hydraulic systems (HYD 1 and HYD 2), provide power for primary and secondary flight controls, and utility services. The HYD 1 system powers the flight controls including ailerons and stabilator, and utility services including flaps, slats, speed brakes, landing gear, nose wheel steering, wheel brakes, arresting hook and launch bar. The HYD 2 system provides hydraulic power only to the ailerons and stabilator.

Rudder & Brake pedals, the human interface

The pilot operates the directional control and wheel-brake systems through the rudder and brake pedals actuated by the pilots feet. The aircraft incorporates a conventional pedal system where a single pedal for each of the pilot's feet actuates the directional control and brake systems independently. This is accomplished by actuating the two systems in two planes of operation. The directional control operates through longitudinal pedal displacement, while the brake system operates through forward pedal rotation about a fulcrum aligned with lateral axis(Figure 8). The entire mechanism is longitudinally adjustable at nine equally spaced positions through a range of approximately 18.2 cm (7.2 inches), to accommodate pilots of varying sizes.

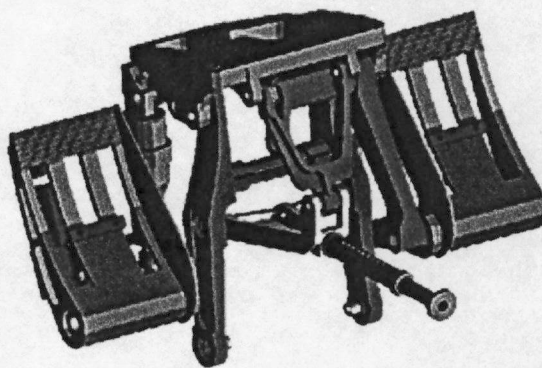


Figure 8 T-45 Brake Pedal Assembly

Source: Legal, Robert, et al. "Design Change Considerations to Prevent Inadvertent Brake Applications." First brief to US Navy T-45 Review Board. Boeing Patuxent River Md. 6 May, 1999

The pilot commands rudder, and corresponding nose wheel steering when the aircraft is on deck, through longitudinal pedal displacement. When one pedal is displaced forward, the opposite pedal is equally displaced aft. The amount of available displacement changes slightly as a function of the adjustment position of the entire pedal mechanism, but is nominally 12.5cm (4.9 inches) from full left to full right (Figure 9). The angle formed between the pedal and the waterline of the aircraft changes as a function of both the adjustment position of the rudder pedal mechanism, and directional control pedal displacement. As the pedal mechanism is adjusted forward the angle increases, to accommodate the pilot's natural resting foot position. Likewise, as one rudder pedal is displaced forward for directional control, its angle increases, while the opposite pedal's angle decreases. The pedal angle changes from approximately 57° at the forward-most adjustment point, to approximately 40° at the aft-most adjustment point. The pedal angle varies from full left to full right pedal displacement, less than 1° at the forward-most adjustment point to nearly 6° at the aft-most adjustment point.

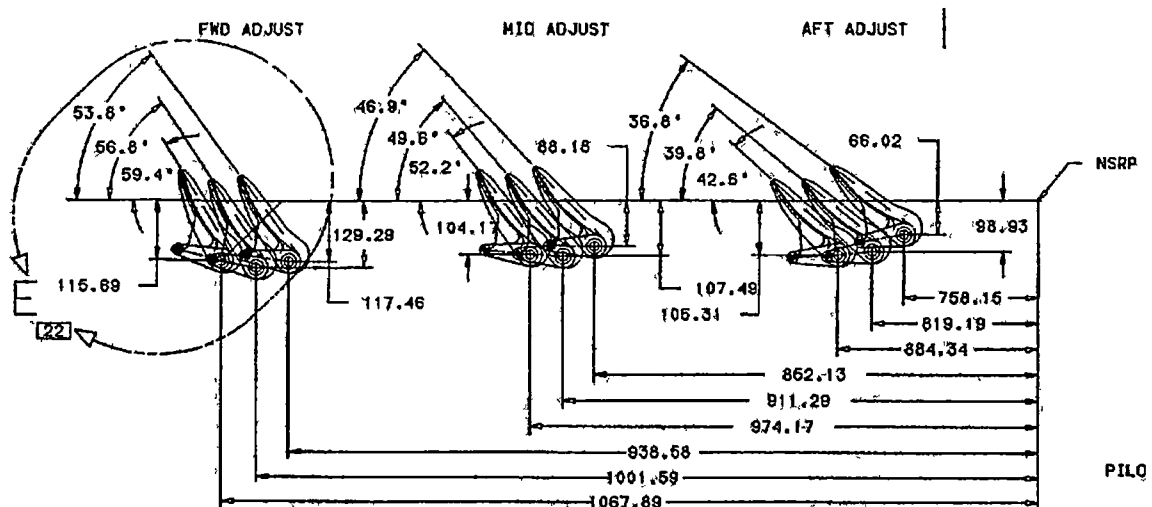
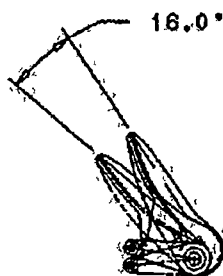


Figure 9 T-45 Rudder Pedal Adjustment and Displacement Geometry with respect to the Neutral Seat Reference Point (measurements in mm)

Source: Douglas Aircraft Company. "T-45A Crewstation Geometry." Scale drawing number DA00SA0051. 28 July 1993

The main landing gear brakes are actuated independently through the left and right brake pedals. The brake pedal is designed to rotate forward through an angle of approximately 16° to command full brake pressure at the brake assembly (Figure 10). The pilot applies a toe-forward force to the top of the rudder pedal resulting in a rotation about its fulcrum. The brake pressure and pedal angle that correspond to the applied force are plotted in Figure 11. Brake pressure is a linear function of pedal force over its entire range, with approximately 16 lb of breakout force required to move the pedal off the aft stop. The pedal angle is also a linear function of pedal force over most of the useful range, but the gradient shallows at approximately 15° of travel, requiring nearly



FULL BRAKE APPLIED (TYP)

Figure 10 Brake Pedal Travel

Source: Source: Douglas Aircraft Company. "T-45A Crewstation Geometry." Scale drawing number DA00SA0051. 28 July 1993

double the pedal force to move the last $\frac{1}{2}$ degree of brake pedal travel. The sharp change in gradient is designed to prevent the pilot from easily applying high pressures at the brake assembly that will result in a tire skid.

The longitudinal braking force achieved at the tire is proportional to the brake pressure applied at the brake assembly when anti-skid is disengaged. When anti-skid is engaged the system operates the same until the tire begins to skid, then the anti-skid system meters brake pressure to stop the skid. Many external variables contribute to tire braking force including tire pressure, weight on the main landing gear and flight deck or

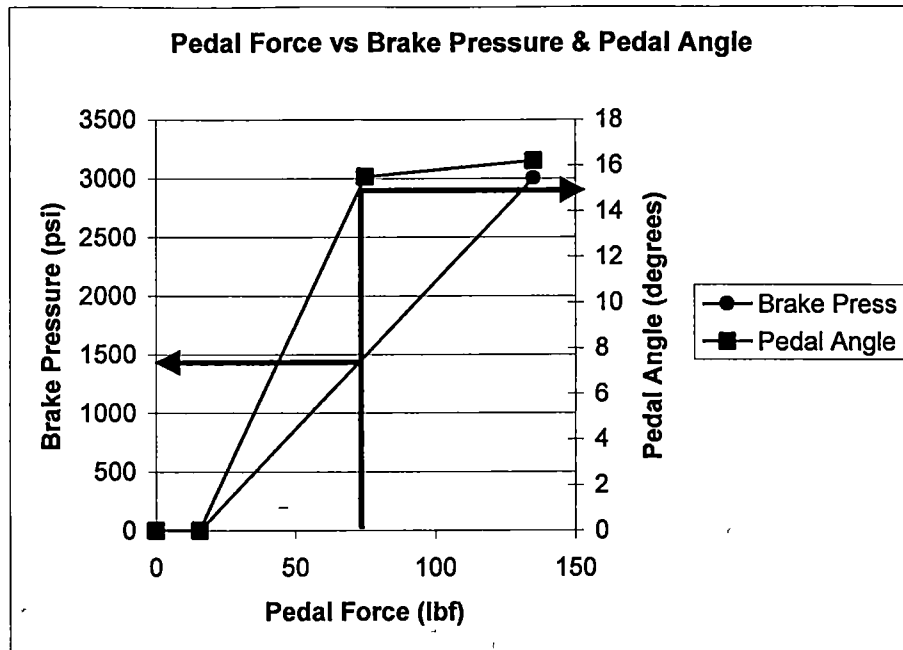


Figure 11 Correlation between T-45 Brake Pedal Force, Pedal Angle and Corresponding Hydraulic Brake Pressure.

runway condition, making it difficult to associate a particular brake pressure with maximum tire braking efficiency. Therefore, the anti-skid system is engaged during land-based operations to permit the pilot carefree brake operation.

T-45 Anthropometry

The specification detailing the design requirements for the T-45 states "...the cockpit shall be completely compatible with pilot(s) dimensions (lower limit three percentile man, upper limit 98 percentile and equivalent females, as specified in U.S. Navy Report NAEC ACCEL-533, Anthropometry of Naval Aviators-1964 with personal flight gear...)" (T-45 Detail Specification, SD-570).

Accommodation requirements focus on the aircrew being able to conduct the mission of the aircraft and egress safely. The requirements do not consider mission performance degradation due to abnormal, but safe sitting positions, or the discomfort

and fatigue encountered from long periods in those positions. In aircraft equipped with an ejection seat, the most restrictive cockpit design and human anthropometric considerations revolve around providing the aircrew member with a safe ejection envelope. This is largely due to the violent acceleration and harsh environment of an ejection. While the T-45 may provide a safe ejection envelope over the population range dictated in the specification, its anthropometric accommodation places many pilots, particularly larger subjects, in uncomfortable and ergonomically unsuitable positions that affect pilot performance.

Cockpit ergonomics

Ejection seat

The Neutral Seat Reference Point (NSRP) is an arbitrary datum roughly midway between the upper and lower seat adjustment limits at the back of the ejection seat. It is a convenient datum from which to design the cockpit since it coincides with the pilot's tailbone, a point on the human that moves very little when sitting. Most of the cockpit measurements are taken from the NSRP. The T-45 ejection seat has a total vertical adjustment capability of 12.7 cm (5 inches). The lowest and highest adjustment limits of the seat set 5.7 cm (2.2) inches below and 7.0 cm (2.8 inches) above the NSRP, respectively (Figure 12). The seat has canopy breakers, which are pointed metal objects designed to penetrate and shatter the canopy in an ejection. The canopy breakers sit atop the head box at the highest point on the seat 97.3 cm (38.3 inches) above the NSRP.

In a normal ejection the pilot pulls the ejection handle between his legs at the leading edge of the seat pan, which initiates a rapid sequence of events to remove the seat and pilot from the aircraft. Among the earliest events in the ejection is initiation of an explosion of the Mild Detonation Cord (MDC) on the canopy above the pilot's head. This shatters the canopy into small particles and allows the pilot to be propelled upward without impacting the canopy. If the MDC system fails and the canopy remains intact, the ejection sequence continues, but the canopy breakers atop the ejection seat pierce the canopy, shattering it sufficiently to provide the pilot an unobstructed passage as he travels

upward with the seat. If the pilot's helmet rests above the canopy breakers, his helmet will impact the canopy before the canopy breakers, potentially resulting in pilot injury. This occurred in one T-45 ejection where the MDC system failed and the pilot was ejected through the canopy. The pilot sustained significant neck and head injuries due in part to his seat adjustment position that placed the top of his helmet above the canopy breakers (Training Squadron-22, 191900Z Feb 97).

Design Eye Position

Much of an aircraft's cockpit is designed with respect to the Design Eye Position (DEP) because a pilot obtains the vast majority of his flight information visually. In the T-45 the DEP sets 76.7 cm (30.2 inches) above the NSRP (Figure 12). With the pilot's eye at the DEP in the T-45, the external field of view is relatively limited. (Appendix A, Figure 24), but he is capable of seeing through the Head Up Display (HUD) field view

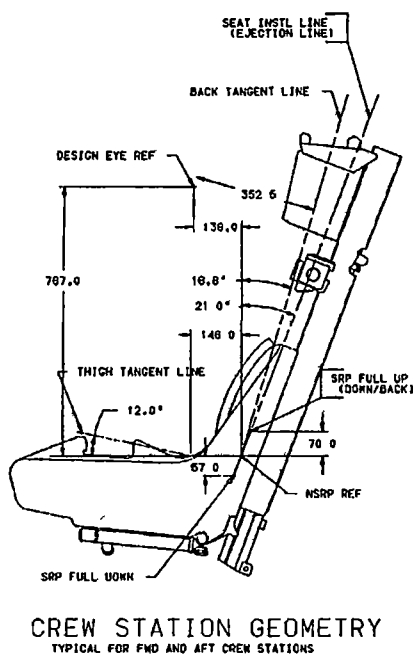


Figure 12 T-45 Ejection Seat

Source: Douglas Aircraft Company. "T-45A Crewstation Geometry." Scale drawing number DA00SA0051. 28 July 1993

Note: Measurements in millimeters

and viewing the instruments on the instrument panel. Many pilots therefore, desire to sit elevated above the DEP to enhance their external field of view, enabling them to see further downward. The Pilot's desire for improved external field of view however, is moderated by two concerns: The pilot sacrifices the capability of viewing the instruments on the instrument panel because the glare shield over the top of the instrument panel obscures them as the pilots eye elevation above DEP increases; and the pilot faces the consequences of a back-up ejection scenario where he is ejected through the canopy. Therefore, many pilots sit at an elevation such that their eyes are somewhat above the DEP, and their helmets are even with or slightly below the canopy breakers. This position permits improved downward external field of view while mitigating the possibility of head and neck injuries from an ejection, since a small amount of spinal compression would hopefully bring the pilot's helmet below the canopy breakers. For pilots with a large sitting height, the cockpit restrictions force them to adjust the seat to the lowest setting.

Rudder/brake pedal adjustment

The rudder/brake pedals can be adjusted fore and aft over a range of 18.3 cm (7.1 inch) range with the forward-most adjustment position 100.2 cm (39.4 inches) forward of the NSRP as seen in Figure 9. As the pedals are moved forward or aft, the vertical position and pedal angle also changes through a very complex mechanism. The forward-most adjustment position is very restrictive for larger pilots and results in a significant gap between the pilot's thigh and the ejection seat. For comparison, the F/A-18 rudder/brake pedals are adjustable longitudinally over a range nearly 1 ½ times larger than that of the T-45, 25.4 cm (10.0 inches), with the forward-most position 114.3 cm (45 inches) forward of the NSRP (Figure 13).

Rudder pedal to floor distance and Mil Std-1333B compliance

The distance between the fulcrum of the brake pedal and the floor of the cockpit is approximately 7.1 cm (2.8 inches). The military design standard governing cockpit

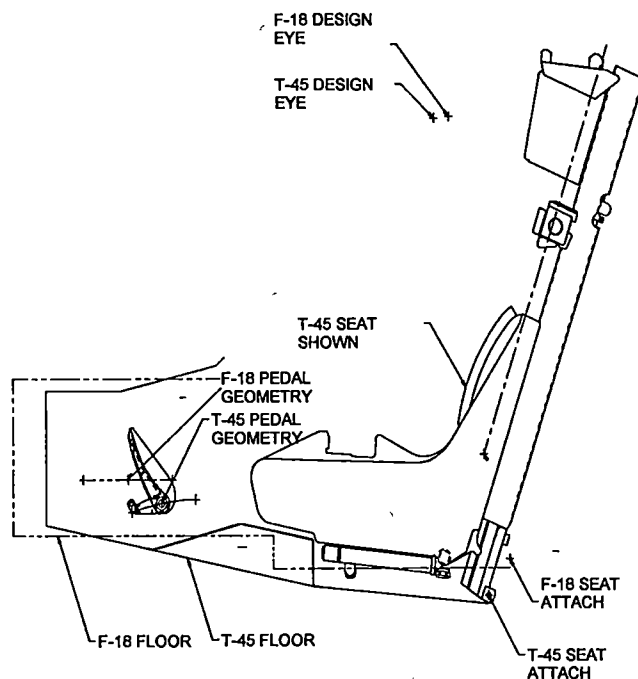


Figure 13 T-45 to F/A-18 Cockpit Geometry Comparison

Source: Legal, Robert, et al. "Design Change Considerations to Prevent Inadvertent Brake Applications." First brief to US Navy T-45 Review Board. Boeing Patuxent River Md. 6 May, 1999.

design parameters, Mil Std-1333B, states "Throughout the range of yaw control adjustment and travel, the distance from the brake fulcrum to the nearest point on the crewstation floor shall be a minimum of 4.75 inches" (12.1cm) (Figure 14). The additional distance dictated by Mil Std-1333B is intended to permit the pilot to actuate the brake and rudder pedals during normal taxi, then lower his heels to the floor to actuate the rudder pedals only, when brake application is not desired, such as during catapult launches. The T-45 geometry however, contributes to inadvertent brake pedal actuation because longitudinal leg force on the rudder pedals tends to couple into moment about the fulcrum of the brake pedal. Additionally, the elevated position in which the pilot rests his foot on the pedals reduces the muscular force required to actuate the brake, furthermore contributing to inadvertent brake application.

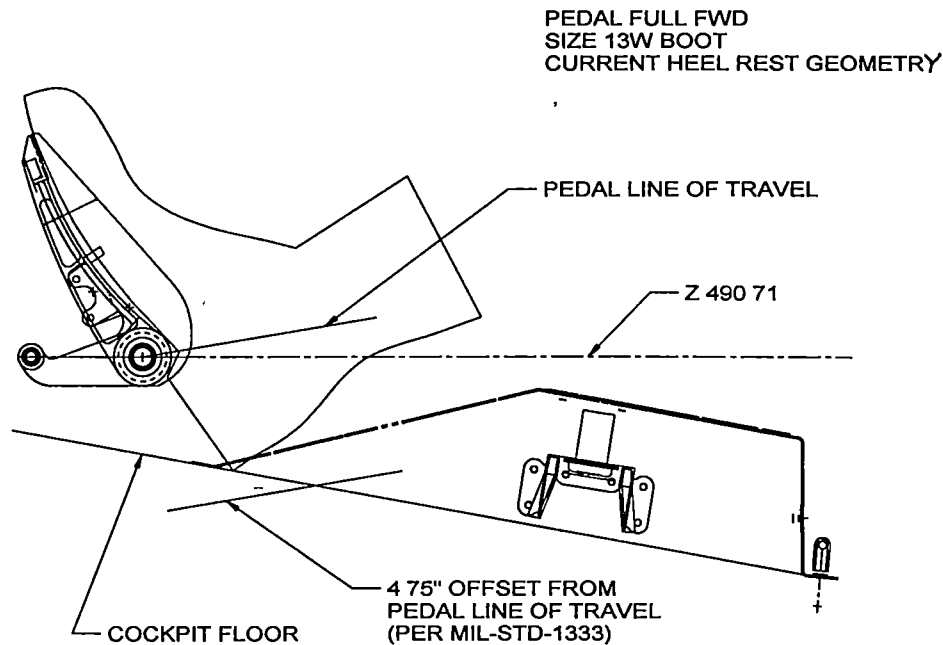


Figure 14 T-45 Rudder Pedal and Cockpit Floor Geometry

Source: Legal, Robert, et al. "Design Change Considerations to Prevent Inadvertent Brake Applications." First brief to US Navy T-45 Review Board. Boeing Patuxent River Md. 6 May, 1999

Large pilot accommodation

Complaints about anthropometric accommodation in the T-45 come mainly from relatively large pilots. The following provides a brief analysis of a 90th percentile male from the 1964 Anthropometric Survey of Naval Aviators (Gifford et al, 1965). The 90th percentile male was picked because he represents a relatively large male whose dimensions fit well within the cockpit design specification requirements. The adjustment ranges of the seat and rudder pedals therefore, should permit him to function comfortably within the T-45 cockpit. The pertinent measurements of concern are overall stature 185.5 cm (73 inches), sitting height 96.2 cm (37.9 inches), and sitting eye height 84.1 cm (33.1 inches)(Appendix C).

The following is a simple analysis of the seat height required to place the pilot's eyes at the desired elevation. The two corresponding cockpit benchmarks about which the pilot is concerned are the elevations of the DEP and canopy breakers. The DEP is 76.7 cm (30.2 inches) above the NSRP and the pilot's sitting eye height is 84.1 cm (33.1 inches). If the pilot desires to sit with his eyes at the DEP, he will have to adjust the seat to its lowest position, setting the seat pan 82.4 cm (32.4 inches) below the DEP. The pilot will still have to slump down in the seat 1.7 cm (0.7 inch) to place his eye at the DEP with the seat pan at the lowest setting.

Using the same linear analysis technique for a pilot desiring to sit at the highest safe position, (top of the helmet level with the canopy breakers) the analysis must include approximately 5.1 cm (2.0 inches) added to the pilot's sitting height for helmet thickness. In this case, the pilot can move the seat vertically only 1.7 cm (0.6 inch) above the lowest setting, a relatively small range of adjustment.

The second anthropometric consideration is the rudder pedal adjustment position as compared to the pilot's functional leg length. Functional leg length is the distance measured from the buttock to the sole of the foot with the leg fully extended. The 1964 survey did not measure functional leg length, but a more comprehensive 1988 survey of US Army aviators shows a 90th percentile male's functional leg length is 108.8 cm (42.8 Inches). Adding approximately 2 ½ cm (1 inch) for the sole of the pilot's boot, brings his overall leg length to approximately 111 cm (43 ¾ inches). The rudder pedals adjusted to their full forward position sit 100.2 cm (39.4 inches) forward and 12.9 cm (5.1 inches) below the NSRP. Unfortunately simple trigonometry of the knee angle does not provide an adequate prediction of the pilot's lower body position due to numerous other variables including buttock-to-knee length, sitting knee height, popliteal length, thigh circumference and seat pan angle to the waterline of the aircraft. There is, nevertheless, clearly 11 cm (4.3 inches) of extra leg length to be accommodated by a knee bend angle. During measurements of one 90th percentile male subject, with the seat adjusted to place the top of his helmet level with the canopy breakers (highest safe elevation) and rudder pedals full forward, the subject had a 8 ¾ cm (3 ½ inch) thigh gap. Although

uncomfortable because of the large thigh gap described below, this position was the optimum position for the pilot because it elevated the pilot's head to the highest safe position, maximizing external field of view, while minimizing thigh gap. The position however, resulted in an uncomfortable body position that caused rapid buttock fatigue, discomfort at the pilot's heels and forced the pilot to slump to see through the HUD field of view.

Thigh gap

In an ejection the aircraft seat imparts an extremely high upward acceleration to the pilot. Many people associated with tactical aviation have voiced concerns that a significant gap between a pilot's thigh and the seat may result in serious femoral injuries and possibly fracture, due to the impact of the seat with the pilot's thigh, called seat slap. When the T-45 was introduced, the Escape Systems branch of the Naval Air Development Center conducted a thigh gap study measuring the thigh gap in various aircraft, and researching Naval Safety Center ejection statistics to determine the results of thigh gap during ejections. While the Safety Center data showed little evidence of seat slap injuries, the data was insufficient to make reasonable conclusions since it was impossible to determine each pilot's thigh gap at the time of the ejection. The measurements however, showed that large pilots have a larger thigh gap in the T-45 than in any of the other naval aircraft in which personnel were measured. Personnel with 99th percentile buttock-to-knee and sitting-knee-height measurements experienced a 19.8cm (7.8 inch) thigh gap with the seat adjusted to place the subject's eyes at the DEP (Appendix B, Figure 25). Correlation between thigh gap and femoral injuries has still not been established, but the Navy is conducting a study of thigh gap and the risks it poses in ejection scenarios at the time of this publication.

The thigh gap pilots experience in the T-45 results partly from the limited forward adjustment for the rudder pedals. Figure 13 shows a comparison of the T-45 to the F/A-18 seat-to-rudder pedal position. Note that the full forward adjustment position of the T-45 corresponds approximately to the mid adjustment position of the F/A-18, the Navy's primary strike-fighter. The resulting thigh gap in the T-45 causes the pilot's upper body

weight to be supported by his tailbone and much of the weight of his legs to be supported by heel of his boot or his feet on the rudder pedals. While the ejection considerations of thigh gap remain in question, thigh gap does contribute to inadvertent brake application due the resulting position of the pilot's lower body. Pilots with large buttock-knee measurements, and correspondingly large functional leg lengths have their knees further forward than pilots with smaller measurements. This reduces the shin-to-toe angle and may place some pilots in a position such that their resting ankle position applies a force against the top of the brake pedal; effectively a pre-loaded brake application force.

Anthropometric restriction

In 1998 the Human Systems Division of the Naval Air Warfare Center conducted a study on the Navy's trainer aircraft to develop new anthropometric restrictions for crewmembers. Anthropometric accommodation was defined as "permitting an aviator from a single seat position to see, reach, and operate all controls and displays that must be seen and operated in immediate action emergency conditions under harness locked conditions and have an unimpeded emergency escape path." (Kennedy, Tucker and Crawford, 1998) The evaluation did not address the effects of flying aggressive flight profiles, limitations based on individual aircrew strength, or mission effectiveness due to fatigue and discomfort. The resulting codes restricted from the T-45 and TA-4 are shown in Table 1. The Exclude column restricts personnel with the listed code from operating the aircraft. The Fit Check column requires personnel with the listed codes to don the appropriate flight gear, sit in the crew station and have an aviation physiologist observe whether that person's dimensions are suitable for the cockpit while the subject performs various cockpit tasks. The dimensions corresponding to each anthropometric code are included in Table 2. Note that the TA-4, the T-45's predecessor, had no restrictions for aviators with large dimensions in sitting height, buttock knee, or functional leg length.

All of the Excluded and Fit Check codes lie outside the 3rd to 98th percentile range dictated by the T-45 design specification. The code 7 sitting height, buttock-knee length and functional leg length are all extremely close, however to the 98th percentile aviator. Pilots with measurements near the 98th percentile are therefore very close to the limits of

a safe ejection scenario and are certainly placed in an uncomfortable body position. While the allowable codes theoretically provide the pilot with a safe ejection envelope and the capability to operate all of the aircraft equipment, they fail to consider fatigue, comfort and psychological stresses on the aviator that may affect his performance. If these considerations could be quantified, they would likely result in further restrictions to the anthropometric accommodation in the T-45.

Table 1 T-45 and TA-4 Anthropometric Restriction Codes

Adapted from: Kennedy, Greg. Tucker, Heather. Crawford, Jennifer. "Navy Aircrew Accommodation Expansion Program Revised USN Trainer Aircraft and H-60 Helicopters Anthropometric Restriction Codes" Report # NAWCADPAX--98-154-TR. Naval Air Warfare Center-Aircraft Division, Patuxent River Md. 6 August 1998.

Aircraft/ Crew Station	Revised ARC's							
	Sitting Height		Functional Reach		Buttock Knee Length		Functional Leg Length	
	Exclude	Fit Check	Exclude	Fit Check	Exclude	Fit Check	Exclude	Fit Check
T-45A/Fwd	0 8 9	1 2 3 7		9	8 9	7	9	7 8
T-45A/Aft	0 1 8 9	2 7		9	8 9	7	9	7 8
TA-4/Fwd		0 1	8 9	5 6 7				
TA-4/Aft		0 1	8 9	5 6 7				

Table 2 Anthropometric Restriction Codes and their Corresponding Measurements
(in inches)

Adapted from: Kennedy, Greg. Tucker, Heather. Crawford, Jennifer. "Navy Aircrew Accommodation Expansion Program Revised USN Trainer Aircraft and H-60 Helicopters Anthropometric Restriction Codes" Report # NAWCADPAX--98-154-TR. Naval Air Warfare Center-Aircraft Division, Patuxent River Md. 6 August 1998.

ARC	Sitting Height (in.)	Functional Reach (in.)	Buttock Knee Length (in.)	Functional Leg Length (in.)
9	40.0-41.0	< or = 27.9	> 28.0	49.0-50.0
8	39.5-39.9	28.0-28.4	27.0-28.0	48.0-48.9
7	39.0-39.4	28.5-28.9	26.5-26.9	47.0-47.9
6	38.5-38.9	29.0-29.4	26.0-26.4	46.0-46.9
5	38.0-38.4	29.5-30.4	25.5-25.9	45.0-45.9
4	35.0-37.9	30.5-30.9	25.0-25.4	43.0-44.9
3	34.0-34.9	31.0-31.4	24.0-24.9	40.0-42.9
2	33.0-33.9	31.5-32.4	23.0-23.9	39.0-39.9
1	32.5-32.9	32.5-33.9	22.0-22.9	38.0-38.9
0	32.0-32.4	= or > 34.0	< or = 21.9	36.0-37.9

Note: Shaded areas depict exclusions or fit-check requirement in the T-45.

Chapter 3

T-45 Ground handling

Although not the problem on which the author focuses, T-45 ground handling characteristics are included for two main reasons. The first is to provide the reader a sense of the urgency experienced in recovering a T-45 with a blown tire. The second is to demonstrate the common ergonomic connection between ground handling and blown tires on the catapult to ensure that a solution to one problem doesn't adversely impact the other.

Historical perspective

Since the first few months of the T-45 test program in 1988, poor ground handling has plagued the aircraft. The first two prototype aircraft had a castored nose wheel steered by differential braking and rudder. Test pilots observed Pilot Induced Oscillations (PIO) during landing rollout in the 70 to 100 knot regime and identified it as a serious safety of flight deficiency in November 1989 (SATD Yellow Sheet SA-4A, 1989). A full time, hydraulically powered nose wheel steering system was added to prevent the PIO, but pilots continued to have problems in both low and high-speed ranges.

During ship suitability testing, test pilots identified further problems however, in February 1992 with the nose wheel steering system, stating that it lagged the commanded rudder pedal position((SATD Yellow Sheet SA-147, 1992). While taxiing on the aircraft carrier flight deck where small radius turns and rapid directional changes were required. The nose wheel steering system rotation rate of approximately 20° per second was too slow, requiring 3 seconds to reach neutral from a fully deflected position resulting in overshoots of the aircraft's desired heading.

In May 1993, the Navy noted a deficiency clarifying some of the directional control problems, stating that the directional control during landing rollout was overly sensitive (SATD Yellow Sheet SA-162, 1993). Directional inputs at speeds above 50

knots frequently resulted in uncomfortable directional deviations from centerline that initiated directional pilot induced oscillations. During landing rollout, the pilot had to carefully match the brake input on both sides to prevent differential braking from steering the aircraft. The brake pedal force to displacement gradient however, was very shallow and combined with poor cockpit ergonomics making it difficult for pilots to accurately match braking input between the two main wheels. Test pilots therefore, experienced unintentional asymmetric braking and inadvertent nose wheel steering inputs during landing rollouts that resulted in PIO.

In June 1994 the T-45 program formed a joint Navy-MDA team commissioned to identify potential causes of, and solutions to the PIO problems on the ground. Among the many contributors to PIO, the team identified brakes, crew station ergonomics, flight control mechanical characteristics, landing gear structure, mass properties, nose wheel steering and tires as some of the largest contributors. None of the contributors however, stood out as the central source of the problem, on which to focus a specific solution. Although the team tested a configuration that fed yaw rate data to the rudder on the ground, it was ineffective and not incorporated into the aircraft.

Ground handling Class A mishaps

The T-45 program has experienced ten Class A mishaps where an aircraft was destroyed. Out of those ten mishaps, five were related to ground handling problems, and three were the result of one or two blown main landing gear tires. In addition to the above mishaps, the T-45 program has experienced one Class C mishap and at least 13 runway departures where ground handling was a contributing factor (Wester, Jan. 2000). The August 1998 mishap that occurred on board an aircraft carrier was the most recent, and caused the first ground handling fatality

General ground handling characteristics

While all of the ground mishaps had other contributing factors, there are numerous problems with the basic ground handling characteristics of the T-45. The factors that resulted in the ground handling mishaps, particularly blown tires, have

become known as serious emergencies in the T-45. Identical circumstances in other naval aircraft constitute an emergency, but are not elevated to the level of alarm that they are in the T-45 since their basic ground handling characteristics are more docile.

Poor ground handling characteristics in the T-45 cause the most problems during landing rollouts, which are complicated considerably by crosswinds. When a pilot makes a directional correction, the aircraft yaws in the direction of the pilot's input, after some phase lag, but the aircraft's direction of travel responds very slowly to that input. Additionally, during crosswind landings, the aircraft requires a relatively large crab angle to maintain the direction of travel aligned with the runway, after touchdown. The crab required is a function of aircraft speed and dissipates at an unpredictable rate as the aircraft decelerates. This presupposes a skid angle on the main landing gear during the landing rollout that manifests itself into a sideforce felt by the pilot. The aircraft has a pitot tube extending from the nose of the aircraft that provides the pilot with a precise visual presentation of the direction the aircraft is pointing, but the pilot must estimate the aircraft's direction of travel from other, less precise visual cues.

The aircraft has a considerable roll-opposite-yaw characteristic that frequently results in 5° roll angles during routine landing rollouts. During ground handling tasks, pilots consider roll angles larger than 2° extremely uncomfortable (Reinsberg et al, 1995). The roll associated with directional activity accentuates the relatively high lateral forces felt by the pilot; as much as 0.4g, and complicates his visual picture while tracking the runway centerline. In crosswinds the roll characteristic further complicates the pilot's task, in that the upwind wing rises, creating a bank angle about which the oscillations take place. The amount the wing rises is a function of the crosswind and the fuel weight of the aircraft. If the aircraft is relatively light at touchdown the upwind wing will rise a greater amount than if the aircraft is heavy, and remain elevated during most of the landing rollout unless the pilot places nearly full lateral control into the wind immediately at touchdown. If the pilot pauses until the upwind wing has already risen, then the belated lateral input into the crosswind will not be effective in reducing the bank angle during the rollout. The lateral characteristics then, are a function of the innate aircraft

configuration, crosswind strength, aircraft gross weight, and pilot technique, which combine to make an unpredictable lateral response to pilot inputs.

The ergonomics of the lower portion of the aircraft's cockpit contribute to a to unintentional brake inputs. The limited distance between the pedals and the cockpit floor combined with the thigh gap in large pilots results in a forward rotational force being applied to the brake pedals for some pilots while the pilot's lower extremities are resting on the pedals. When a pilot applies a longitudinal force to the rudder pedal for directional control, it tends to couple into a rotational moment about the fulcrum of the brake pedal. Undulations in the rolling surface complicate this unintended brake application since they cause minor dynamic vertical accelerations that vary the pilot's brake application. When the pilot commands left rudder, for example, the longitudinal force along his left leg will tend to couple into a toe-forward brake pedal application dependent upon numerous anthropometric factors, including pilot's shoe size. In this scenario, the right leg moves aft during a left rudder pedal application, and the pilot's right thigh gap increases, reducing the angle between his toe and shin. This causes a propensity for inadvertent brake application on the right side as well. These ergonomic factors interface with the nose wheel steering, which has approximately 2° of rotational freeplay. Asymmetric braking is a powerful directional controller in the T-45 and causes the nose wheel steering to deflect to the limits of the freeplay as the pilot inadvertently applies differential brakes.

Aircraft design contributions to static stability

While ground handling characteristics have been discussed, to gain a more complete understanding of the T-45 ground handling characteristics, one must look to the basic aircraft design. It is convenient to compare the aircraft design to that of an aircraft with ground handling qualities generally considered satisfactory. The T-45 is often compared to the F/A-18 in many ways, because the F/A-18 is generally accepted as having adequate ergonomic accommodation, flying qualities, performance and ground handling qualities. Additionally, roughly 80% of the students completing training in the T-45 will go on to fly the F/A-18 as their follow-on fleet aircraft (Manning, June 1999).

Basic static directional stability

Referring to Figure 16, the T-45 main landing gear are relatively close longitudinally, to the center of gravity (CG) (measurement "A"). This reduces the static directional stability of the aircraft on the ground because the largest restoring moment for directional deviations from the ground track comes from the side force provided by the main landing gear about the CG. This moment is relatively small in the case of the T-45 due to the short moment arm from the main gear to the CG. In the extreme sense, if the CG were moved aft in line with the main gear axles, the aircraft would have no restoring moment from main gear sideforces, a neutrally stable condition. Aerodynamic effects are stabilizing, but the effects become smaller as the aircraft decelerates from its touchdown speed.

Longitudinal braking reduces static directional stability, for two main reasons. The maximum friction that the tire can develop is a vector quantity approximately independent of direction (Figure 15). As longitudinal braking is applied ($F_{\text{longitudinal}}$), the tire friction increases until it reaches its maximum value leaving no additional friction available for the stabilizing sideforce ($F_{\text{directional}}$). Secondly, the effect of braking causes a nose down moment about the main landing gear. This results in a transfer of weight to the nose gear, which is destabilizing.

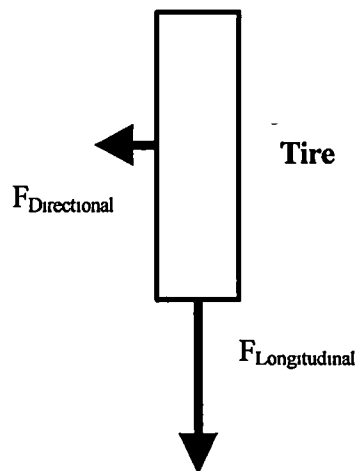


Figure 15 Tire-to-Surface Force Depiction

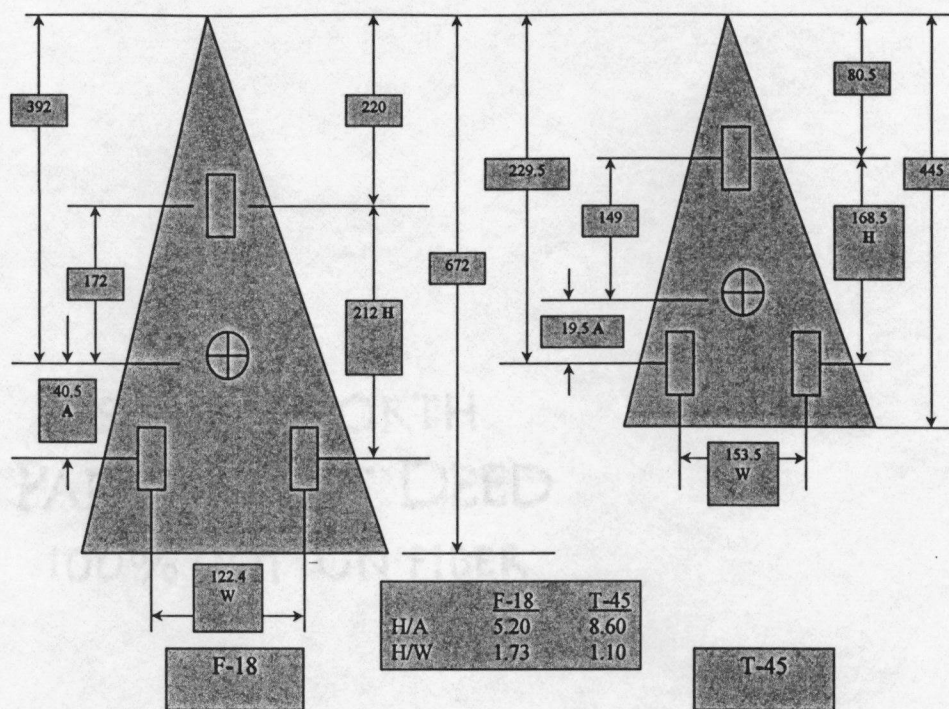


Figure 16 F/A-18 and T-45 Landing Gear and Center of Gravity Configuration

Source: Reinsberg, James G., Kuhlmann, J. R., Venker, R.A., "T-45A Aircraft Investigation of Active Rudder Yaw Damping to Reduce PIO Tendencies During Landing Rollout." 2 Volumes, Mc Donnell Douglas Aerospace report # MDA97T0007. 24 April 1995

Main gear stance

The T-45 main landing gear stance (measurement "W") is relatively wide. The problem this creates is that minor differences in drag or differential braking between the right and left sides causes a relatively large yawing moment. It is complicated by the roll-opposite-yaw characteristic where the aircraft transfers a significant amount of its weight from one main landing gear to the other, changing the yawing moment. With a constant and evenly divided level of brake application between the left and right sides, the roll characteristic causes an unexpected yawing moment for which the pilot must compensate. The ergonomic factors in the cockpit that lead to inadvertent braking and

rudder pedal inputs, further complicate the ground handling characteristics in a complex and dynamic directional control problem the pilot must solve during landing rollout.

Wheel-base scaling

The wheel-base (measurement "H") is the major scaling factor for comparison between the two aircraft. In the T-45 it is relatively short when compared with the wide stance and short distance from the main landing gear to the CG. While the wheel-base of the T-45 measures about 80% of the F/A-18's, the stance is approximately 125% over that of the F/A-18. This makes the main landing gear asymmetric longitudinal force (braking or blown tire) a relatively powerful directional controller in the T-45. This is undesirable in most circumstances because pilots desire directional aircraft responses through conventional directional controllers, such as rudder and nose wheel steering.

Dynamic stability

Systems Technology Incorporated in conjunction with Boeing and Navy test pilots performed hundreds of ground handling tasks in Boeing's Modular Six-Degree-of-Freedom (MODSDF) simulation to provide an independent assessment of the T-45 ground handling characteristics and propose potential solutions to the existing problems. MODSDF has been used since the early stages of the T-45 program and is validated through extensive flight test data. Two lower order equivalent models, commonly used for automobiles, were developed to complement the MODSDF simulation. The lower order systems were developed to assist in gaining an understanding of the dominant dynamics at the simplest level leaving the second order effects for more complex models. The simplest model was a two degree-of-freedom yaw-sideslip model referred to as the "Bicycle". The model essentially places the main landing gear at the lateral center of the aircraft, obscuring the second order effects of roll. A three degree-of-freedom model, which adds numerous details to the bicycle model, including the effects of roll, was also used to complement MODSDF. The philosophy of reduced order simulation was to capture the dominant characteristics in the simplest possible model and validate it against MODSDF and available flight test data.

Understeer gradient and stability factor

Vehicle stability is routinely expressed in terms of stability factor, K , or understeer gradient, UG , which are closely related and used almost interchangeably.

They arise from a yaw rate to steering command gain $G_{\delta_w}^r(0)$

$$\text{Equation 1} \quad K = \frac{m(bY_{\alpha_2} - aY_{\alpha_1})}{2(a+b)^2 Y_{\alpha_2} Y_{\alpha_1}} \quad (\text{sec}^2/\text{ft})$$

$$\text{Equation 2} \quad UG = 57.3g(a+b)K \quad (\text{deg/g})$$

$$\text{Equation 3} \quad \bar{G}_{\delta_w}^r(0) = \frac{U_0}{(a+b)(1 + KU_0^2)} \quad (\text{sec}^{-1})$$

$$\text{Equation 4} \quad U_c = 1/\sqrt{-K}$$

Where:

- U_0 = vehicle speed;
- m = vehicle total mass;
- a, b = front and rear longitudinal distances between the tire axles and the cg;
- g = the acceleration of gravity
- and
- $Y_{\alpha_1}, Y_{\alpha_2}$ = front and rear (dimensional) tire cornering stiffness.

As shown in Figure 17 a vehicle is termed neutral steer, and yaw rate gain increases in proportion to speed, when $K = 0$. When $K > 0$ the vehicle is understeer, and yaw rate gain is more constant with speed. Finally, when $K < 0$ the vehicle is oversteer. Above the critical speed, U_c , the oversteer vehicle becomes directionally unstable. Understeer vehicles are generally considered more desirable for passenger cars and typical drivers. Some racecars are intentionally made to be oversteer to provide the appropriate response to aggressive driver inputs. In the case of aircraft an oversteer characteristic is

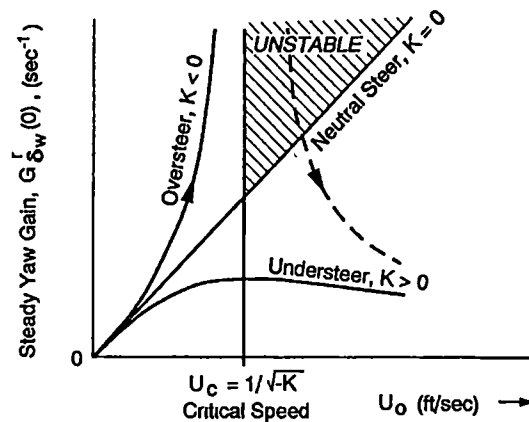


Figure 17 Oversteer/Understeer as a Function of Speed

Source: Klyde, David H. et al. "Identification of the Dominant Ground Handling Characteristics of a Navy Jet Trainer" DRAFT COPY AIAA Atmospheric Flight Mechanics Conference. 14-17 August 2000

undesirable since a pilot, particularly a student, needs docile handling characteristics under all runway conditions during the relatively short period the aircraft is landing or taking off. Aircraft generally do not gain mission effectiveness by the capability to maneuver aggressively on the takeoff or landing roll so stability is desirable over controllability.

The fundamental difference between aircraft and automobiles is that aircraft intentionally develop large aerodynamic forces, while automobile designs generally attempt to minimize most aerodynamic forces. While automobile aerodynamic effects are roughly constant over a wide speed range, aircraft aerodynamic forces change dramatically with aircraft speed and greatly effect the understeer gradient. For the discussion of directional control, these forces can be lumped into two general categories, direct and indirect. Direct aerodynamic forces are those that affect the directional stability, provided mainly by the vertical stabilizer. Indirect aerodynamics are those that affect the tire normal forces, primarily lift, pitching and rolling moments. Both direct and indirect aerodynamics provide a powerful stabilizing force in the T-45, but both dissipate rapidly as the aircraft decelerates from its touchdown speed during a landing rollout.

Figure 18 shows the primarily oversteer characteristic of T-45 as a function of speed. Note the stabilizing effects of aerodynamics. The aircraft touches down on a landing rollout nominally between 115 and 120 knots where it appears to have an understeer characteristic. The understeer gradient decreases rapidly and the aircraft becomes oversteer below approximately 110 knots. Between approximately 70 and 40 knots the aircraft's directional characteristics come very near the boundary, between positive and negative stability. The T-45 is closest to its critical speed between 50 and 60 knots. Below 50 knots the directional handling characteristics migrate further above the stability boundary and the aircraft gradually becomes a better ground-handling vehicle as it decelerates.

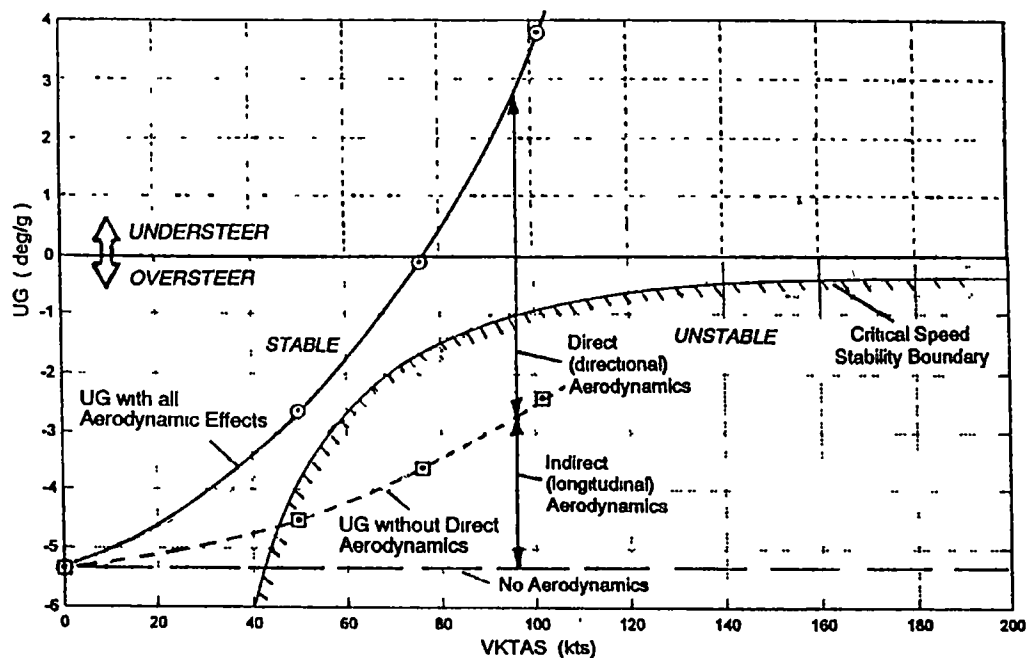


Figure 18 Understeer Gradient as a Function of Speed

Source: Reinsberg, James G. "Boeing Final Report: Analysis of T45 Ground Handling Characteristics Performed by Systems Technology, INC (STI)." Boeing Report # Boeing-STL 00T0002. 17 March 2000.

Blown tire simulation

Following the August 1998 mishap, test pilots took part in simulations to reassess the ground handling problems with blown tires. The simulation results provided data that supported two main conclusions. First, the T-45 was controllable to a full stop with a single blown main landing gear tire. Second, the aircraft was uncontrollable below approximately 70 knots with two blown main tires.

With a single blown tire the pilot must input nearly full rudder and nose wheel steering opposite the blown tire within one half second of the aircraft touchdown, then reduce the pedal throw to approximately $\frac{3}{4}$ to maintain directional control during the remainder of the landing rollout (NATOPS Flight Manual, 1999). Since the T-45 directional control system is not boosted, the initial full pedal input required up to 180 lbs. pedal force from the pilot, which is a greater force than some pilots can apply with a single leg. After the initial full pedal input, $\frac{3}{4}$ rudder displacement was an average position to trim the drag from the blown tire, but the aircraft heading oscillated requiring rapid directional inputs from the pilot to prevent directional divergence. Coordinated opposite brake was also required, particularly between 40 and 70 knots where the handling characteristics near the stability boundary. The task was extremely difficult, although controllable, for an experienced pilot, and beyond the capabilities of a student pilot.

Summary

The T-45 has experienced a disproportionately large number of mishaps and incidents caused by inherently poor ground handling characteristics. Numerous factors contribute to the aircraft's ground handling, including cockpit ergonomics, which is the primary connection to the problem of blown tires on the catapult. With a single blown main landing gear tire the aircraft is controllable, but gives experienced pilots an extremely difficult ground handling task. With two blown tires, the aircraft is uncontrollable below approximately 70 knots regardless of the pilot's level of experience. An arrestment is the only existing method of safely recovering an aircraft with one or

more blown tires, but a successful arrestment requires ground equipment, personnel and considerable pilot skill (chapter 4).

When evaluating a potential solution to the problem of blown tires on the catapult, one must ensure that it doesn't adversely affect the already deficient ground handling characteristics.

Chapter 4

Problem—Blown Tires on the Catapult

Description of the Blown Tire Problem

A blown tire on the catapult causes significant problems for the T-45 in the landing phase of flight. It may cause two independent emergency conditions, each of which has significant hazards, but combined, synergistically lay the groundwork for disaster.

Blown tire

A blown tire on the catapult is not only hazardous to the aircraft, but also to nearby personnel on the aircraft carrier, because air pressure in the tires for carrier operations is very high. Tire pressure is increased from 125 psi for shore-based operations to 350 psi for carrier operations in the T-45 as part of a process to “carrierize” the aircraft before it commences operations at an aircraft carrier (T-45 NATOPS flight manual, 1999). This increase in pressure is intended to prevent the tire carcass from being pinched between the wheel and an arresting cable, should the aircraft land directly on a cable during a carrier arrestment. When the carcass of a tire with such high pressure is breached, it releases a large amount of energy, propelling tire particles in a manner similar to shrapnel from an exploded bomb. After the tire blows, the tire carcass continues to roll with the tire, but may be destroyed as the rim of the metal wheel pinches the tire between itself and the deck. As the aircraft accelerates through speeds exceeding 100 knots the rotating wheel may throw large pieces of tire in its plane of rotation. This can result in flying object damage to the aircraft and injury to flight deck personnel. It also leaves particles on the flight deck that may be ingested into the engine

intake of the victim aircraft, or other jet engines, possibly resulting in catastrophic engine failure.

Once the aircraft is airborne, the blown tire is not a problem by itself, because it does not affect the flying qualities of the aircraft. It does, however cause significant consternation to the pilot who, in the case of the T-45, is an inexperienced student, and to the local command structure that is responsible for helping the student to safely land the aircraft. The real problem arises when the aircraft must be landed since the normally deficient ground handling qualities of the T-45 are even further degraded. It is possible, although extremely difficult to maintain directional control of the aircraft on a conventional landing rollout with a single blown tire, but an aircraft with dual blown tires becomes directionally uncontrollable below approximately 70 knots (NATOPS Flight Manual, 1999). In either situation the aircraft will likely depart the prepared runway surface pointed in a direction other than its direction of travel. This greatly increases the likelihood that the aircraft will roll over. To reduce the risk of a conventional landing with blown tires the first priority for recovery is for the aircraft to engage a field arresting cable. This decelerates the aircraft rapidly, while providing static directional stability from the arresting cable pulling aft on the aircraft's arresting hook. Successfully engaging a cable at the field, however, is a task highly dependent on pilot technique during the approach and on the ground, Landing Signal Officer (LSO) assistance, and a properly serviced arresting hook system.

HYD 1 system hydraulic failure

The wheel well and landing gear contain numerous high-pressure HYD 1 system hydraulic lines that provide hydraulic power to the landing gear actuators and the wheel brakes. The hydraulic lines are vulnerable to flying tire particles when a tire has blown at high speed since they may burst from the impact of a tire particle. A ruptured HYD 1 hydraulic line quickly depletes the hydraulic system fluid, leaving the aircraft with only its HYD 2 system flight controls, and emergency operation of the flaps and wheel brakes. This provides the flaps with a single actuation, and the wheel brakes with approximately ten cycles before the emergency fluid is depleted. When using the emergency

accumulator for flap extension, the flaps are held extended by hydraulic pressure alone. Therefore, the flaps will remain extended for only a limited time, the length of which is dependent on the integrity of the already ruptured hydraulic system. If the flaps retract before the aircraft lands, the aircraft must fly faster, potentially above the maximum engagement speed of the arresting gear. This forces the pilot to land well before the gear to decelerate on deck, while attempting to remain on the runway.

While the approach flying qualities are minimally affected by a HYD 1 failure, the handling qualities on the ground are considerably degraded. With a HYD 1 failure the nose wheel steering is inoperative, making the rudder and differential braking the primary means of directional control. Rudder effectiveness is completely lost below approximately 70 knots leaving differential braking, with a very limited number of applications, as the sole means of directional control to a full stop. For these reasons a short field arrestment is the first priority for landing the aircraft with a HYD 1 failure.

Short field arrestment

A field arrestment involves engaging a cable rigged across the runway with the arresting hook on the tail of the aircraft. The cable is connected to any one of a variety of mechanisms designed to rapidly dissipate the kinetic energy of a rolling aircraft. A short field arrestment specifically identifies the use of a cable rigged normally within 1500 to 2000 feet of the approach end of the runway. At most airfields, the Optical Landing System (OLS) is displaced a considerable distance toward the approach end of the runway. For emergencies when directional control is not in question, this permits the pilot to fly the commanded glideslope to touchdown then comfortably roll approximately 500 to 1000 feet before engaging the arresting gear. When the aircraft has an emergency such as a blown tire, where directional control is questionable immediately upon touchdown however, the aircraft must land as close as possible to the arresting gear without flying past it. This requires the assistance of an LSO located at the side of the runway, adjacent to the arresting gear to talk the pilot onto the appropriate glideslope that results in aircraft touchdown within 50 feet of the cable. Arresting gear also have very limited off-center engagement capability, requiring the pilot to precisely control his

lateral position on the runway during the approach and touchdown. Once on deck, engaging the cable requires carefully coordinated pilot technique and a properly serviced arresting hook. The pilot must first maintain directional control with full rudder opposite the side of the blown tire to counter the impending yaw at touchdown, while simultaneously applying military thrust and longitudinal control to rotate the aircraft to a 5° to 10° nose-up attitude. This places the aircraft in a proper arrestment attitude and prepares it for immediate takeoff in the event the arresting hook fails to engage the cable. If the pilot fails to accurately control the aircraft's yaw, pitch attitude, or thrust, the hook will likely miss the arresting gear since wheel brake or blown tire drag tends to lift the tail causing the hook to bounce on the deck. This level of coordination is challenging for experienced pilots and possibly exceeds the neophyte's level of competency.

Blown tire incidents

In four years of operational training the T-45 experienced 16 incidents of blown tires during catapult launches. Statistically, blown tires were occurred in at least once every 12,500 flight hours. All of the incidents occurred during one of the first three catapults a student received, and all but one occurred during one of the first two (Wester, October 1998).

Blown tire mishaps

As part of the 16 blown tire incidents on the catapult, the training command experienced two T-45 Class A mishaps when students attempted landings. A third blown tire Class A mishap was caused when a student landed with good tires, but applied too much brake with the anti-skid OFF, blowing a tire during the landing rollout and departed the runway surface. Of the ten T-45 Class A mishaps to date, two (20%) were the result of one or more blown tires on the catapult.

The T-2C Buckeye and the TA-4J Skyhawk, are the recent predecessors of the T-45. Naval Safety Center statistics for those aircraft note only one Class A mishap and three incidents of blown tires on landing resulting in runway departures in the TA-4J over an eighteen year period. Neither airframe however, had any reports of mishaps or

incidents resulting from inadvertent blown tires on the catapult over the same period. Since the training program for student carrier qualification has changed very little, these statistics pointed strongly to a problem unique to the T-45.

Cockpit ergonomics contribution to the problem

In the T-45 students inadvertently actuating one or both brakes causes the problem of blown tires on the catapult. This phenomenon is largely due to a cockpit that is ergonomically unsuitable for the task of training naval aviators, but it also has a psychological human factors origin that explains why seasoned aviators have not encountered the problem.

Catapult procedures in naval aircraft

Most of the procedures for launching a fixed-wing naval aircraft from an aircraft carrier are similar between the different types of planes. As the aircraft approaches the catapult track, the pilot ensures he has completed the takeoff checklist and taxis slowly forward, following the direction of the taxi director on the flight deck. The ground crew installs a hold back fitting (Figure 7) and the pilot continues to taxi forward very slowly until the launch bar is forward of the catapult shuttle. The catapult officer directs the pilot to lower the launch bar into the shuttle, then directs the catapult operators to take tension. Taking tension places a forward force on the launch bar that is not strong enough to break the hold back, but sufficient to remove any backlash in the aircraft-catapult system. The pilot selects military thrust, scans his engine and warning indications, exercises the flight controls, *drops his heels to the floor beneath the rudder pedals* and salutes the catapult officer to signal that he is prepared for the launch. Pilots generally brace for the catapult shot to ensure their back and head are firmly against the seatback. This prevents being slammed against the seatback when the catapult acceleration begins.

Specific ergonomic factors

Three major ergonomic factors described in chapter 2 are the dominant contributors to inadvertent brake application. The vertical distance between the brake pedal fulcrum and the cockpit floor is too small. In other naval aircraft the pilot has room to move his heels to the deck when he is ready to launch, thereby moving his ankle below the fulcrum of the brake pedal, making it difficult to apply brake pressure. In the T-45, however, pilots with relatively large feet have the forward edge of the heel of their boots resting on the fulcrum of the brake pedal while the back of the heel rests on the deck. This places the ankle vertically above the fulcrum of the brake pedal such that longitudinal leg force against the rudder pedal couples into a toe-forward moment actuating the brake (Figure 14). Additional muscular tension in the calves, which is natural for a high stress situation, exacerbates the inadvertent brake problem.

The second factor is the limited forward adjustment capability of the rudder pedals, which contributes to the third factor, thigh gap. Many T-45 pilots fly with the rudder pedals at the full forward position. That position fails to comfortably accommodate the pilots with large lower body and sitting height dimensions however, as noted in chapter 2. Those pilots are placed in a position where they have a considerable gap between the seat pan and their thigh, and for those with large buttock-knee dimensions, the angle between their toe and shin is reduced to the limit that the flight boot will allow. These factors all result in the pilot applying a brake-application moment to the brake pedal when he is relaxed. Longitudinal force inputs to the rudder pedals increases the toe-forward moment, worsening the effect of inadvertent brake application (Parker, March 1999).

Student human factors and psychology

While the largest contributor to the blown tire problem is cockpit ergonomics, the psychological stress of the unfamiliar environment is also a significant contributor. These factors offer an explanation why seasoned aviators accustomed to the aircraft carrier environment have not experienced blown tires on the catapult due to inadvertent brake application.

Human factors for the student aviator during Carrier Qualification

When the student enters the Carrier Qualification (CQ) phase of his training, he has flown approximately 160 hours in the T-45 and 230 hours total flight time in naval aircraft (CNATRAINST 1542.120A, 1995). CQ is one of the final phases of training before the student becomes certified as a Naval Aviator. He is relatively comfortable in the T-45 and knows its limitations well, but all of his flight experience up to this point has been land-based. In a land-based scenario, simple procedures such as taxiing the aircraft are far less complex and much more forgiving of any errors, than aboard the ship. Although the student receives some CQ simulator training, when he goes to the ship he enters a completely foreign environment. During CQ in the T-45 the student experiences many facets of shipboard operations for the first time. The following are just a few:

- The extremely tight control a taxi director exhibits over an aircraft. (Aircraft are taxied within inches of structures, other aircraft and the edge of the flight deck, requiring the student to follow taxi directors with a level of attention they have never before exercised for taxi operations.)
- Radio communications procedures, standard phrases and controlling agencies different from those with whom he is accustomed.
- Hot crew-switch and hot refueling (changing aircrew in an aircraft and refueling while the engine is running). These are methods of rapidly replenishing an aircraft with new aircrew and fuel, but permit the new aircrew minimum time in the cockpit to prepare for his upcoming launch.
- Takeoff and landing checklists change to meet the needs of shipboard operations.

These and many other environmental factors differ significantly from any operations the student has experienced thus far in his training. The most significant however, are the shipboard arrestments and the catapult shots for which the CQ instructors spend considerable time instilling a healthy respect. Not only are they the most critical phases of flight ashore, but they are fraught with their own unique hazards at the ship.

During the catapult shot, the student experiences a longitudinal acceleration approximately 3 times the acceleration of gravity for about 2 ½ seconds. Until his first catapult launch, he has never felt longitudinal acceleration near that magnitude. Before the student accepts the launch, he spends anywhere from 2 to 25 minutes waiting in line, refueling or taxiing to the catapult, generally consumed by other tasks requiring high levels of attention. While taxiing, he is handed off from one taxi director to another as he traverses the ship in what appears to be a maze of confusion to the novice. Once at the catapult, he is directed to taxi with an inch-by-inch precision he has never before experienced. Meanwhile, he must complete a takeoff checklist that differs slightly from his land-based habit pattern, ensure all of his systems are operating normally, and follow directions from outside the aircraft from personnel with whom he is not familiar. Finally, the catapult will be ready to go, "in tension," and a few personnel will rush out from under the aircraft. The student must select maximum power, exercise the flight controls, check that all onboard systems are functioning normally, and signal to accept or suspend the catapult shot via visual signals to the catapult officer on the deck of the ship. Once the student commits to the catapult shot, he must determine by feel and vestibular sensations whether the launch will produce sufficient speed to support the aircraft in flight. At the end of the stroke he must instantaneously decide whether to fly or eject based upon a rapid scan of his instruments despite potential neural confusion brought about by his inner ear. All of these procedures differ significantly from the land-based procedures for takeoff. Additionally, the pilot has no abort option once he accepts the catapult launch. While the student prepares for the carnival ride of his life, he is unable to draw upon the habit patterns that he has developed during land-based training to conduct the elementary and routine operations preparing him to fly. When the acceleration of the catapult commences, the student naturally braces himself against the rudder pedals to ensure that his body is firmly against the seat back. When combined with an ergonomically unsuitable cockpit for carrier operations, the natural reaction to brace for the shot on the rudder pedals couples into a rotational moment about the fulcrum of the pedal resulting in brake application. In short, the student is under an

extremely high stress situation where the routine matters of going flying consume his cognitive capabilities. This renders him incapable of attending to the peripheral details of the launch, such as avoiding the natural ergonomic reaction of depressing the brakes.

Span of attention

Aircraft mishap reports have common phrases meaningful to aircrew used to describe the aircrew failures such as “lack of flight discipline”, “loss of situational awareness”, or “poor crew coordination”. All relate to one of the following attention anomalies also commonly cited in mishap reports, but are more meaningful to the aviation psychologist: channelized attention, distraction, cognitive task saturation, inattention, habituation, negative transfer, and fascination (Santilli, 1982). The student on the catapult is most vulnerable to distraction and cognitive task saturation. Distraction is the interruption of the required conscious attention to a task by non-task related stimulus, which implies that the individual’s span of attention is sufficient to attend to the task. In most cases the T-45 CQ student has a sufficient span of attention to accomplish the task of his first catapult shot without applying the brakes, but once every 12,500 flight hours, a student demonstrates otherwise. In the cases of the T-45 blown tires, the student may be distracted from the *whole* task of launching the aircraft. That task is multifaceted in the T-45, in that it includes a conscious effort on the part of the aircrew to avoid placing pressure on the brake pedals, while naturally bracing for the acceleration in an ergonomically unsuitable cockpit. Other fleet aircraft do not require that level of effort, because the rudder pedal system permits the pilot to drop his heels to the deck, placing the fulcrum of rotation on the pedal above that of the pilot’s ankle.

Cognitive task saturation

Even more likely than distraction is the student’s vulnerability to cognitive task saturation where the student receives a multiple stimuli that decrease his margin of attention to zero. “Historically, good judgement comes from experience...”(Santilli, 1982) Experienced naval aviators can differentiate between the cues requiring immediate action and those that are merely informational. The student, however, must mentally

process even the insignificant cues on an equal priority level, because of his lack of familiarity with the environment. The irrelevant cue of maintenance personnel stepping out from under the aircraft as the pilot selects maximum thrust for example, probably occupies a larger portion of the student's span of attention, if he sees them, than that of the experienced aviator. Since the student has never seen that cue before, he must focus a greater portion of his attention span on that cue than an experienced aviator in an effort to process the information. The student's attention span is insufficient to process all of the new stimuli by which he is being bombarded. Therefore, he will simply overlook the peripheral portions of the task, such as keeping his feet off of the brakes, while he attempts to process the visual and proprioceptive cues of his environment through a dynamic and disorienting catapult launch.

Arousal

The student's level of arousal during carrier qualification is at the highest point he has experienced in flight training, and possibly in his life. This is largely due to the threatening environment perceived by the student. The student feels threatened not only through fear for his life, but through fear of unsatisfactory performance, possibly resulting in removal from flight training. Training command instructors sometimes state, tongue in cheek, that the student's fear of a Down (unsatisfactory flight) far outweighs his fear for his life. The smaller margin for error during carrier qualification and increase in hazards to the student's life both combine to raise the level of arousal to new heights. The Yerkes-Dodson law is an inverted U-shaped function relating the level of arousal to performance in an individual for a particular task (Figure 19). The law implies that for both complex and simple tasks there is an optimum level of arousal where an individual's performance is maximized. In a classic experiment soldiers taking part in a field exercise were very realistically misled to believe that their lives, or the lives of someone for whom they felt responsible, were in danger. In each of the cases the soldiers had procedural tasks to perform while under the high state of arousal. Task performance in all cases suffered, but the more experienced soldiers had far less degradation in

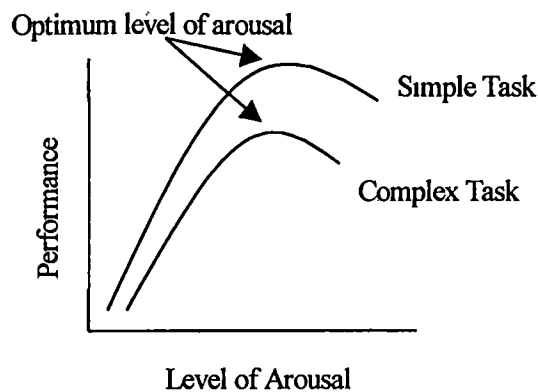


Figure 19 Yerkes-Dodson law relating arousal to performance

Source: Wickens, Christopher D. Engineering Psychology and Human Performance second edition. New York: Harper Collins, 1992.

performance (Wickens, 1992). When applied to the case of the T-45 on the catapult, the student, who has no experience in the aircraft carrier environment, is at the greatest risk of making an error in the task of launching the aircraft. This is due to the facts that the student's level of arousal is extremely high, and he is inexperienced in the carrier environment.

Unfortunately, the Yerkes-Dodson law is not helpful in predicting the optimum level of arousal for a particular individual, since the optimum level differs for each person. Additionally, the multiple stressors complicate the picture in that their combined effects are neither additive nor multiplicative. In fact, some combinations of stressors will offset the effects of one another because they are influencing the level of arousal from opposite ends of the continuum. The point is that predicting the student psychologically most likely to make a mistake on any particular day is extremely difficult. The most promising solution to an environment known to be error prone for the student is to design an error tolerant system.

Chapter 5

Alternative solutions to solve the blown tire problem

Ground handling interference considerations

When analyzing engineering solutions to the problem of inadvertent braking on the catapult, one must observe the constraint that the proposed solutions must not degrade the already deficient ground handling characteristics of the aircraft. While this is possibly intuitive, it places considerable limits on ergonomic solutions that physically move or alter the range of travel of the directional control system.

Feet on the floor

The simplest ergonomic solution is a procedural change, rather than an airframe modification. The proposal is that the student should place his feet flat on the floor of the cockpit during the catapult launch, since some pilots practice this in other tactical fleet aircraft to ensure they avoid brake application. The slope of the heel rest and limited space provided by the rudder pedals in the T-45 however, result in an undesirable body position. The thigh gap becomes excessive, potentially rotating the pelvis out of alignment for safe ejection and the pilot's knees naturally migrate to a position outside the aircraft's safe ejection envelope (O'hara & Dykhoff, 10 Sep 1998). Note the difference in the cockpit floor between the T-45 and F/A-18 (Figure 13).

Rudder pedal toe-bar guides

Another proposal is a compromise between the pilot's normal foot position (Figure 14), and placing his feet flat on the floor. It requires the pilot to place the toe of his boot at the vertical mid-point of the rudder pedal. While causing a very large thigh gap (appendix C, Table 4), and minor interference with maximum lateral stick displacement, it met the basic ergonomic requirements for ejection. The position is nevertheless awkward and requires a reference point under which the pilot can orient his

foot to make the position repeatable. A horizontal Toe-Bar provides the necessary tactile and visual reference point (Figure 20). The resulting foot position for the catapult launch is pictured in (Figure 21)

This foot position tends to inhibit brake actuation in three ways. First, it reduces the pilot's lever about the fulcrum of rotation on the brake pedal, increasing the force required by the pilot to actuate the brake. Second, it removes the ball of the pilot's foot from the pedal, substitutes it with his toe, placing him in an ergonomically incompatible position to apply significant force to the brake. Finally, it moves the pilot's heel aft, decreasing the pilot's knee angle to approximately 90°, further inhibiting the pilot from applying significant force through his quadriceps when he braces for the launch.

The Toe-Bar modification was tested and ultimately implemented as a permanent modification to the T-45. It was successful at reducing the incidents of blown tires on the catapult, but failed to eliminate them. The toe-bar modification requires that the pilot

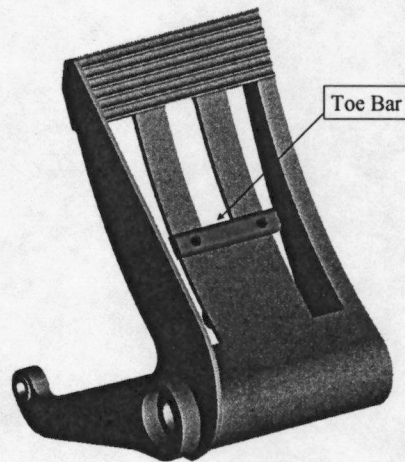


Figure 20 Toe-Bar Modification to the T-45 Rudder Pedals

Source: Legal, Robert, et al. "Design Change Considerations to Prevent Inadvertent Brake Applications." First brief to US Navy T-45 Review Board. Boeing Patuxent River Md. 6 May, 1999

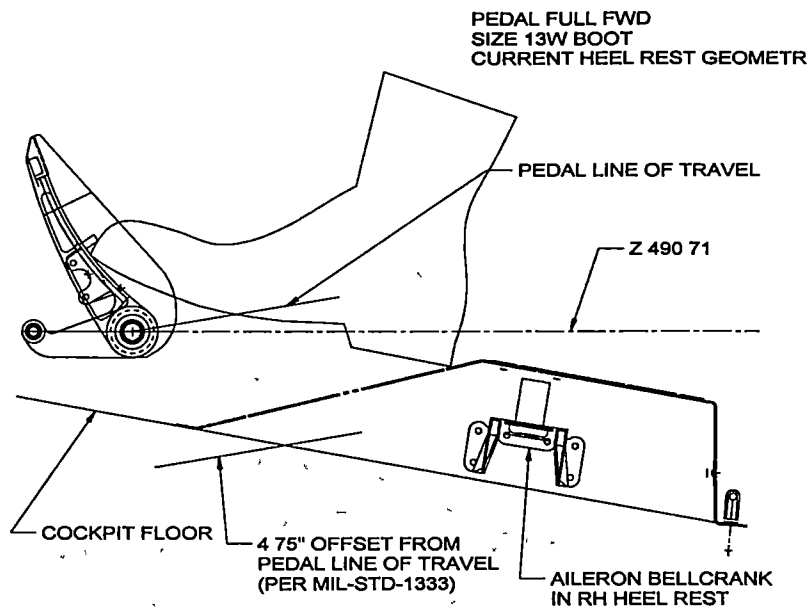


Figure 21 Foot Position for Catapult Launches with Toe-Bar Modification Installed.

Source: Legal, Robert, et al. "Design Change Considerations to Prevent Inadvertent Brake Applications." First brief to US Navy T-45 Review Board. Boeing Patuxent River Md. 6 May, 1999

firmly wedge the toe of his boot beneath the toe-bar to prevent his foot from becoming dislodged during the catapult launch. One student failed to do this causing his foot to slip out from under the toe-bar. He recognized his incorrect body position and attempted to reset his foot during acceleration of the catapult launch. He placed his foot in the normal position on the brake pedals and inadvertently actuated the brake, causing the blown tire (Training Squadron-23, Message 122200Z APR 99). This phenomenon was later termed Dynamic Leg Flail. On this occasion, the aircraft was recovered ashore without further damage, but it was clear that another solution was needed.

Deck plate and rudder pedal height adjustment

The most desirable solution to the ergonomic problem is an ergonomic airframe adjustments that permit the pilot to move his heels to the floor of the cockpit and the

rudder pedals further forward. These changes would require significant alterations such as moving the forward pressure bulkhead, adding length to the forward portion of the fuselage, changing the floor configuration, and redesigning the rudder pedal and directional control mechanisms. Each of these changes would impact major structural members in the airframe, effect flying and ground handling qualities, raise fatigue life concerns, and require a enormous monetary expenditures, well beyond the fiscal constraints of the program.

The compromise is to incrementally improve the ergonomics of the cockpit by altering those portions of the cockpit that would not effect major structural members in the airframe, thereby bringing the cockpit closer to the requirements of Mil-Std-1333. This approach is limited to increasing the distance between the fulcrum of the brake pedals and the floor. The rudder pedals would be raised one inch and the sloped portion of the heel rest moved aft Figure 22.

The modifications were installed in a mock cockpit for evaluation by five relatively large T-45 pilots (Appendix C, Table 4). All of the pilots fell within the allowable anthropometric sizes for the T-45. The toe-bar modification was installed in the mock cockpit and pilots evaluated rudder pedal and heel rest modification proposals with their feet in the normal position, and with their toes under the toe bars, as they would be for a catapult launch. All but one of the pilots found an increase in comfort with their feet in both positions and commented that the task of placing the toe of their boot under the toe bar was easier with the modifications. All but two of the pilots flew with the pedals at the full forward limit of adjustment. The pilots who flew with the pedals at a mid-range adjustment found the greatest improvement from the heel rest adjustment since the pilot's heel is directly over the heel rest only at pedal adjustment positions aft of the full forward position. The pilot with the largest foot size found an decrease in comfort and greater interference to rudder pedal throw with his foot in the

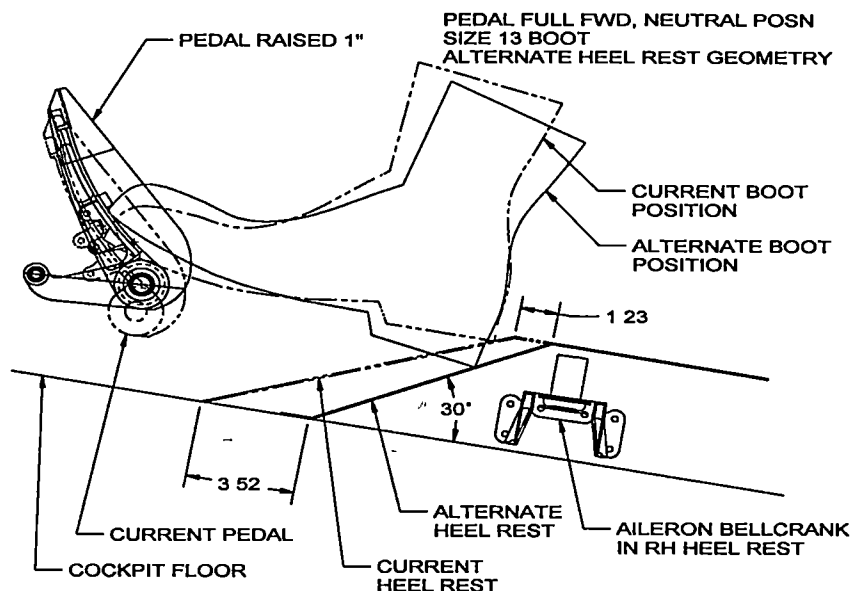


Figure 22 Proposed Rudder Pedal and Heel Rest Modifications to the T-45 Cockpit.

Source: Legal, Robert, et al. "Design Change Considerations to Prevent Inadvertent Brake Applications." First brief to US Navy T-45 Review Board. Boeing Patuxent River Md. 6 May, 1999

catapult position because the heel of his boot lie at the aft edge of the of the heel rest where the adjustment tapered to zero. The original heel rest was parallel to the rudder pedal's line of travel (Figure 14), permitting the pilot to deflect the rudder pedals without interference from the heel rest. The modified heel rest however, restricted aft movement of the rudder pedal as the pilot's heel became wedged between the pedal and the heel rest. The results of the evaluation indicated that the smaller pilots obtained a marginal improvement, but larger pilots, particularly those with large feet, found the modifications to be detrimental to crew comfort and would restrict directional pedal movement.

From a systems analysis perspective, the rudder pedal and heel rest modifications, while not affecting major structural members, did effect the relatively complex directional control system and a metal deck plate. Implementation of the modifications

would require a redesign effort for the rudder pedal assembly, and new parts that would affect the logistical costs. The resulting changes provided only marginal benefit for pilot comfort and there was no way to quantify whether they aided in preventing inadvertent brake application.

Brake release system

The confining geometric limitations imposed on ergonomic solutions makes all but the toe-bars impractical from a systems and fiscal standpoint. Since inadvertent brake application is the root cause of the blown tire problem, the next natural step is to look into the brake system for a solution. Since the aircraft's existing anti-skid system releases brake pressure to prevent a skid, its logic inputs could possibly be altered to release brake pressure under conditions encountered only on the catapult. If those conditions could be identified and isolated, the system may be effective without adversely impacting other aircraft characteristics or systems.

Chapter 6

Brake Release solution

Catapult procedures in the T-45

Before discussing the technical characteristics of the brake release system, one must first have basic understanding of the key operational procedures used on the catapult that relate to the system. When the aircraft is on the flight deck preparing to launch, the pilot taxis the aircraft forward toward the catapult. Once the aircraft is properly aligned and at the appropriate position, personnel on the flight deck install a holdback fitting on the aft side of the nose gear strut. The pilot continues to taxi very slowly forward again; pulling the holdback through its track, until the aircraft nose gear arrives at the catapult shuttle. The pilot lowers the launch bar to the EXTEND position via the launch bar switch on the forward cockpit instrument panel, and taxi slowly forward until the launch bar falls into the catapult shuttle (Figure 7). The flight deck personnel place the aircraft in tension, causing the shuttle to place a forward force on the launch bar, which removes any backlash from the catapult-aircraft-holdback system. The forward force combined with engine maximum thrust is not sufficient, however, to break the holdback. When the aircraft is in tension the pilot selects maximum thrust, ensures the systems in the aircraft are operating normally, places the launch bar switch to RETRACT, and signals the catapult officer that he is ready to accept the catapult launch. The shuttle holds the launch bar down until the aircraft has been launched. The key portions of the above procedure that isolate them from any other activity in the aircraft are:

1. Launch bar position
2. Launch bar switch position (forward cockpit instrument panel)
3. Throttle position

System overview

The brake release system is a relatively simple design that uses the aircraft's existing anti-skid control valve to prevent hydraulic pressure from reaching the brake assembly regardless of the pilot's brake application when the following conditions are satisfied:

1. Left main landing gear down & locked
2. Launch bar not in the RETRACT position (EXTENDED or in transition)
3. Throttle position greater than approximately 95% engine RPM
4. Launch bar switch in the RETRACT position

Each of the above conditions has an electrical switch associated with it that produces a discreet electrical signal when the condition is met. When the above conditions are met, the anti-skid control valve ports hydraulic fluid to the brake return line, preventing the brake assembly from applying pressure to the wheel brakes, regardless of pilot input on the brake pedals. The system senses the above conditions through proximity switches already used for other functions in the aircraft.

The brake release system adds one additional caution light to the warning/caution lights panel (Figure 5) to notify the pilot of a system failure or abnormal condition, specifically that brake pressure may be available on the catapult. The portion of the brake release system associated with the caution light uses a separate circuit and proximity switches to prevent switch and relay failures from causing a brake release system failure without annunciation.

Circuitry

The brake release modification amounts to little more than one external proximity switch, a few relay switches a caution light and some wiring added to the existing production aircraft. From the top-level standpoint of the operator, the circuit can be simplistically divided into two portions: the brake release control, and caution light control (Appendix E).

Brake release control

Control of the brake release circuit is accomplished through four proximity or relay switches in placed series. If any of the switches is not in the appropriate position, then brake release will not occur. The switches are:

1. The Throttle position 95% proximity switch, (senses throttle position above or below a point corresponding to 95% engine RPM)
2. Launch Bar switch (pilot switch located in the cockpit),
3. Launch Bar Position #1 proximity switch (located on the nose gear to sense launch bar position)
4. Left Main Landing Gear Down proximity switch.

Once all of the switches are closed, they energize two Anti-Skid valve mode select relays (two for redundancy), which open the anti-skid control valve, releasing hydraulic pressure at the brake assembly until one or more of the switch conditions changes (Appendix E).

One switch, the Launch Bar Position #1 proximity switch, has a two second delay built in. When the catapult shuttle reaches the end of its travel it stops and the aircraft launch bar retracts as the aircraft continues to roll the remaining short distance to the bow. With the brake release system installed, brake pressure would be available once the launch bar retracted during the last approximately few feet of roll to the end of the ship. For this reason the Launch Bar Position #1 proximity switch has a two-second delay to ensure the aircraft is airborne before allowing hydraulic pressure to be applied at the brake assembly.

Caution indication control

The caution light portion of the system uses separate relay and proximity switches to prevent a single switch from controlling both the brake release and the caution annunciation. The caution light circuit receives power from the anti-skid valve mode select relay after the Brake Release control switches are closed (Appendix E).

Parking brake control

The parking brake handle contains a relay, which disables the entire brake release electrical circuit when the parking brake is set. The parking brake also performs its intended function of setting the parking brake, resulting in maximum brake pressure being applied to the brake assembly.

System safety risk analysis

Incorporating a system that intentionally fails the pilot's lifeline of stopping power on the deck naturally sparks negative emotional reactions from pilots who want an immediate, positive response to their control inputs, particularly the brakes. To a far greater extent than land-based aircraft, a loss of brakes on the deck of the carrier causes a condition of extremis for the aircraft, aircrew, flight deck personnel and other aircraft on the flight deck. A brake loss on the flight deck can easily end in tragedy if the aircrew and flight deck personnel fail to act immediately to stop the aircraft before it hits another aircraft or structure, or rolls over the side of the ship. The second concern is a brake release system failure during a catapult launch. If the student inadvertently applies the brake, with a system failure, then the original problem of blown tire(s) will result.

A fault tree is a safety analysis of a system, primarily used to uncover single point failure modes and establish the probability of a specific event occurring. The fault tree of interest that dealt with catapult operations identifies "Blown tire due to brake pressure in the catapult" as its top event (Appendix G, Figure 28). It assumes the pilot follows catapult procedures, placing the launch bar switch to retract while the aircraft is in tension. The pilot will be directed by the catapult officer to do so. For the pilot to blow a tire on the cat after he has completed the appropriate procedures; he must have his feet on the brakes, the brake release system must not energize, and the caution light must be inoperative since he would abort the launch for any caution light. That situation is statistically calculated to occur $5.96 \text{ E} -10$ per flight hour, or approximately once every 1.7 billion flight hours. The fault tree concerned with failure of brakes during ground operations identified "Loss of Brake pressure during ground operations" as its top event. For this to occur, the aircraft must be on the ground, and the system must fail, energizing

the brake release system. That situation is statistically calculated to occur $1.99 \text{ E } -08$ per flight hour, or approximately once every 50 million flight hours (Appendix G, Figure 27). The T-45 fleet is forecast to operate approximately 3.5 million flight hours through its life expectancy in 2035 (Wester, May 1999). The probability of a non-annunciated failure in the brake release system is extremely remote, far less likely than the probability of far more serious emergencies occurring.

Chapter 7

Ground and flight test

Background

A prototype version of the brake release modification was installed in a flight test aircraft for the purpose of evaluating the mechanization and operation of the brake release system. The test aircraft was uniquely suited to the task of testing the brake release system since it was extensively instrumented for carrier suitability testing.

Method

The method of testing a system such as the brake release must differ from that of the ergonomic alternative solutions. While the investigation of the earlier cockpit modifications was subjective based upon individual pilot opinions, the brake release system is designed to remove the ergonomic concerns from the cockpit. The brake release system was tested using a systems approach, breaking the entire system down into its individual components to verify that they operated as designed.

The test matrix (Appendix F) is divided into four general categories that provide a build-up in technical risk level and developed test team familiarity with the system:

- System Verification and Failure Simulation,
- System Verification Static Checks,
- Catapult Launches and Arrested Landings.

System Verification and Failure Simulation tests are the basis of the test matrix, essentially providing a circuit analysis ensuring that the brake release system logic operates as intended. It is an exhaustive matrix testing each of the discrete electrical signals from the individual system components.

The System Verification Static tests continue the previous test, but more closely mimic operational conditions, stopping short of an actual catapult launch. These tests

include the engine running and the aircraft placed in tension at a shore-based catapult to analyze the impact of external environmental and procedural factors on the brake release system. These tests specifically address only the controls and displays directly observed by the pilot during catapult operations, integrating normal and abnormal catapult procedures into the test. This is also the first opportunity to test the system with all aircraft system components operational, allowing a verification that the brake release system is electromagnetically compatible with the aircraft.

The Operational checks are the final phase of testing, consisting of land-based catapult launches and land-based arrestments that simulated conditions on an aircraft carrier. Since the previous test points are conducted up to the point of launch, the launches and arrestments are essentially a sneak circuit analysis checking that the brake release system is not affected by the stresses and accelerations or carrier operations. These tests expose the aircraft and aircrew to the greatest risk and continue to use a building-block approach within this phase of testing. The testing begins with a nominal catapult launch and ends with the test pilot actuating both brakes during the catapult stroke to ensure satisfactory system operation. Arrested landings at the field are included to ensure unforeseen system anomalies do not effect the aircraft's braking capability during operationally representative conditions on the aircraft carrier.

Results

During the test program the Brake Release system operated as designed, by preventing pilot brake inputs from reaching the brake assembly during catapult launches. The system exhibited excellent potential as a means to alleviate blown tires on the catapult, traditionally caused by inadvertent braking.

Flight test programs inevitably discover unexpected anomalies in the systems they test, and the Brake Release test program was no exception. One advantage of flight test is the opportunity to place the system being tested into near operational conditions, many of which are unrelated to the test itself. During the brake release testing the test team discovered two anomalies, one of which was serious deficiency, unacceptable for incorporation into fleet aircraft.

While taxiing and making sharp left turns, the brake release system disengaged the nose gear steering, illuminated the brake release caution light and sounded the aural caution tone when the nose gear rotation angle exceeded approximately 45° to the left. The pilot was able to re-engaged the nose wheel steering system, but lost directional control momentarily. When onboard an aircraft carrier, very tight turns are commonplace and normally conducted within inches of other aircraft or structures. Losing control of the nose wheel steering on the carrier deck would eventually result in the aircraft impacting another aircraft or object on the deck of the carrier. The problem was caused by a second proximity switch that was added for the launch bar on the backside of the nose gear. When the nose gear rotated beyond approximately 45° left the new proximity switch sensed a launch bar down condition, disengaging the nose wheel steering. This was considered an unacceptable deficiency that must be corrected prior to incorporation into fleet aircraft.

During normal preflight checks, the pilot exercises the various external hydraulically operated components on the aircraft to ensure they work as designed, including the launch bar. The launch bar was lowered, then raised as a normal part of the ground checks, and requires approximately two seconds to transition both directions. During the launch bar's transition from the EXTENDED position to the RETRACTED position, the Brake Release caution system senses the following logic:

1. Left main landing gear down & locked (normal catapult condition)
2. Launch bar not in the RETRACT position (normal catapult condition)
3. Throttle position *less than* approximately 95% engine RPM (*abnormal catapult condition*)
4. Launch bar switch in the RETRACT position (normal catapult condition only after the throttle is set above 95%).

The one a logic condition out of place for the catapult is the low throttle setting, which the Brake Release system assumes to be a failure of the throttle proximity switch, resulting in the annunciation. In this case the caution ceases after approximately 2 seconds when the launch bar arrives in the RETRACT position. While this could be

viewed as a nuisance alert, it also provides assurance that the brake release logic and the caution system operate correctly. This test occurred during ground checks when the pilot normally performs other routine tests to ensure that all of the aircraft's systems operate normally. Hence, the new annunciation was deemed acceptable as an additional item the pilot should check for as a part of the existing preflight checks, requiring no changes to existing procedures.

Conclusions

The test team found the brake release system to be a positive contribution to alleviating the problem of blown tires on the catapult. When the pilot executed normal catapult procedures, the system prevented his brake application from resulting in brake pressure at the brake assembly. With one exception, the brake release system did not interfere with other aircraft systems and allowed the use of normal catapult procedures.

The test team found one major deficiency regarding the nose wheel steering control, for which they recommended the vendor provide a solution for further ground testing. The remaining issues found during testing were less notable and could be included into the T-45 operator's manual upon installation of the brake release system.

Chapter 8

Transfer of training

Training transfer concerns

The chief concern surrounding the Brake Release modification is that it may cause students to take the habit of applying brakes on the catapult stroke with them to their fleet aircraft with undesirable results. Although the modification will permit the pilot to apply the brakes during the catapult shot without fear of a blown tire, it is unlikely the training command policy will allow the carrier qualification phase to intentionally train the students to apply the brakes on the catapult. The brake release system was intentionally designed to permit the training command to continue using existing procedures without changes. In a similar sense, the aircraft's brake system also contains "spin-up" protection that doesn't allow brake pressure to be applied until the wheels have spun-up to a specified rotation rate following a landing touchdown. Despite the fact that this mechanism aids in preventing blown tires on landing, the training command doesn't teach the students to land the aircraft with the brakes applied at touchdown, because of the potentially devastating results in the event of a system failure. The system is taught as a back up to good pilot technique. The behavior of depressing the brakes on the catapult, therefore, should not become a highly learned response to the stimulus of a catapult shot, but only a byproduct of a poorly designed ergonomic cockpit and student anxiety. The anxiety will most likely be overcome by experience after the first few catapult shots, since this has already been observed in the data, showing that inadvertent brake applications have occurred only during students first three catapult launches and all but one have occurred during their first two. System designers and flight testers may have a limited influence on operational doctrine through the operators manual and reports of test results, but do not have direct control over the training techniques. One must consider the possibility therefore, albeit unlikely, the worst case situation that

the student learns to apply the brakes on the catapult as a matter of routine operations in the T-45.

External stimuli and response

Transfer of a learned behavior from one aircraft to another is a function of the stimuli in the environment and the response to those stimuli that the operator is trained to command. If a pilot is trained to perform a particular action in response to a given stimulus in a training aircraft, and that same action is appropriate to similar stimulus in his follow-on aircraft, then there is a positive transfer of training. For example, when the pilot flies a retractable landing gear trainer and learns to lower the gear before landing, then transitions to another retractable gear aircraft and carries over the same behavior, then a positive transfer of training will occur. Conversely, if a pilot observes similar stimuli in two different aircraft, but is supposed to take a different action in response to those stimuli, then a possibility for negative transfer exists.

Training transfer, positive or negative

A highly learned behavior in one aircraft becomes the pilot's response to similar stimuli in the other aircraft, but if the behavior is undesirable in the second aircraft the transfer is considered negative. Stated another way, the major source of negative transfer is actually a positive transfer of responses that are inappropriate in the new aircraft. The transfer matrix in Table 3 shows the combinations of stimuli and responses that influence the degree of transfer from one aircraft to another. If the environmental stimulus is the same between two aircraft for example, while the desired response from the pilot is different, then the transfer is "highly negative." This implies that the pilot will execute the incorrect procedure in one of the aircraft due to a highly learned behavior from the other aircraft. Conversely, if the stimulus is different and the desired response is different, then no transfer occurs. The extreme example of differences in both stimuli and desired responses might be a fixed-wing pilot transitioning to a helicopter, and attempting to perform a vertical takeoff task. Much of the environmental stimulus is different from the fixed wing scenario and most of the desired responses are different.

Table 3 Transfer Matrix

Source: Boyd, Stephen P. Patrick M. Harper. "Flight Deck Improvement versus Commonality – Human Factors Implications for Mixed Fleet Operations." 9th International Symposium on Aviation Psychology Proceedings. (1997): 831-836

STIMULUS	RESPONSE	
	SAME	DIFFERENT
SAME	HIGH POSITIVE	HIGH NEGATIVE
DIFFERENT	LOW POSITIVE	NONE

Therefore, there is no effective transfer of training making the highly learned skills of fixed wing flying nearly useless in the helicopter for the specific task of a vertical takeoff.

Conditions for training transfer

Four factors most heavily influence the transfer of training between aircraft (Boyd & Harper, 1997):

- The amount of experience the pilot has in one variant vs. the other variant.
- How frequently the pilot switches between the two variants.
- How often the specific behavior is exercised.
- Whether the behavior is called up by memory or by written procedure.

Responding to the above issues individually for the case of the T-45, the student will complete his training in the T-45 with approximately 175 hours in the aircraft, but only ten catapults and arrestments at the aircraft carrier. He will then be trained in his fleet aircraft at a Fleet Replacement Squadron (FRS), but he may experience a lengthy period, sometimes as much as a year, before he begins training in his fleet aircraft. Most importantly, he won't experience flight in the aircraft carrier environment again until he has established a minimum of 50 hours, generally more, in his new aircraft. While his experience level in his fleet aircraft may be less than in the T-45 when he begins the

carrier qualification phase, his overall flight experience and decision making capabilities will have grown considerably. During the carrier qualification phase in his fleet aircraft, he will have extensive preparation for the carrier environment, emphasizing the operational procedures of that particular aircraft. The recent procedural training in his fleet aircraft and the long period of time since T-45 flight training, will both aide in reducing the likelihood the student depressing the brakes on the catapult in his fleet aircraft.

Once the student completes training in the T-45, earning his wings as a Naval Aviator, he will not likely fly the aircraft again. Therefore, he will not switch between aircraft on a regular basis, unlike the commercial pilots in the mixed fleet operations. Applying the brakes during a catapult shot will therefore not be reinforced following completion of the T-45 syllabus. Additionally the student will be trained to respond procedurally to the ergonomic stimulus of his fleet aircraft that readily permits him to move his heels to the deck as he braces for the catapult launch. This will aide in preventing inadvertent brake application.

Compared to other procedural and skill-based tasks in flight training, the frequency that the catapult behavior will be exercised is relatively low for both the T-45 and follow-on fleet aircraft. As previously mentioned, the student will receive approximately ten catapult launches in the T-45, statistically averaging around eleven considering the students who fail at their first attempt at carrier qualification, then repeat that phase of training. When the aviator gets to the carrier qualification phase of training in the FRS, he will most likely receive 16 catapult launches, possibly 20 if he is to be transferred directly to a deployed fleet squadron. When compared to the hundreds of field landings that the student practices prior to carrier qualification, the frequency is extremely low. It is not clear how many times a task must be performed to become a highly learned habit, but practicing beyond the first or second error-free trial causes the student to begin overlearning the skill, making it reside in memory longer (Wickens, 1992). In the case of landings practiced during hundreds of events, students clearly overlearn the skill-based stick and throttle responses and transfer those to their fleet

aircraft. In the case of catapult launches, the relatively small number of events minimizes any degree of overlearning the task.

Skill-based and procedure-based task

The task of keeping one's feet off the brakes during a catapult shot has both skill-based and procedural characteristics, but the dominant is procedural. While there are external cues providing the aviator some direction to which he responds as he goes to the catapult (skill-based), he must remember to execute the procedure appropriate to his aircraft for avoiding brake application (procedural). Even if a student overlearns a procedure, recall attenuates quickly for procedures with multiple parts or steps, making the length of time between rehearsals a powerful determiner of the level of recall. Supervising one's feet is only one part of a much larger procedure for a catapult launch. The skill-based memory used during catapult shot, however, will decline in the same fashion as procedural memory in Figure 23, albeit at a much slower rate. In most cases T-45 students finishing carrier qualification will not experience a catapult shot in his fleet aircraft for over one year. While a student is likely to recognize and respond to signals from flight deck personnel, it is unlikely he will resort to a barely learned procedure/skill last performed a year prior.

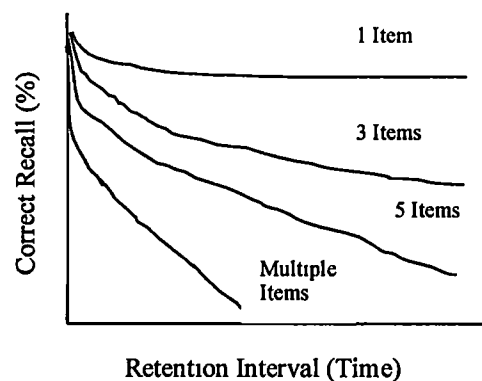


Figure 23 Effect of Retention Interval on Recall from Working Memory with Rehearsal Prevented.

Adapted from: Wickens, Christopher D. Engineering Psychology and Human Performance second edition. New York: Harper Collins, 1992

Memorized vs. written procedure

In both the T-45 and fleet aircraft, the procedures for appropriately positioning one's feet are called up by memory, rather than written procedure. This generally increases the likelihood of a negative transfer occurring. The ergonomic differences in the fleet cockpit however, will provide differences in environmental stimuli. In some aircraft the naval aviator is placed in a less comfortable position, having to physically lift the weight of his legs in front of him to be able to apply the brakes. Simply relaxing in these cases will naturally cause the aviator's heels to fall to the deck. The ergonomic differences between the fleet cockpit and that of the T-45 will provide significantly different stimuli to which the student is expected to respond differently. Referring to Table 3, one observes that a different stimulus and response leads to no transfer of training.

The preceding transfer of training discussion assumed that the student would be taught to actuate the brakes during catapult launches, as though it was a required procedure in the T-45. This scenario is unlikely, but presents a worst case consideration for transferring an undesirable habit pattern to fleet aircraft. Predicting the outcome of the learned behavior in the T-45 as it relates to fleet aircraft is extremely difficult since there is not an analytic tool to quantitatively measure the effect each stimulus will have on the pilot. It is clear however, that T-45 cockpit ergonomics play an important role in the inadvertent braking phenomenon and that a student's fleet aircraft will provide significantly different stimuli to mitigate the probability of the same occurring in the student's fleet aircraft. Applying the general guidelines regarding habit transfer to the case of the T-45, persuaded the author toward the belief that a learned brake application habit will not be transferred to fleet aircraft.

Chapter 9

Conclusion

Blown tire problem

The T-45 has poor baseline ground handling characteristics that challenge even experienced pilots during routine landing rollouts. One or more blown main landing gear tires exacerbates the ground handling problems making the aircraft marginally controllable in the case of a single blown tire, and uncontrollable in the case of dual blown tires. Thirty percent of the T-45's lost to Class A mishaps have occurred as a result of one or more blown tires, making blown tire landings one of the most critical emergencies the pilot faces in the T-45.

Blown tires have been caused largely by students inadvertently applying the brakes on one of their first three catapult launches from an aircraft carrier. While the training command has made efforts to instruct students to avoid brake application on the catapult, training alone has not been successful at alleviating the problem. This is largely due to the ergonomics of the T-45 cockpit.

Ergonomics

Inadvertent brake application on the catapult in the T-45 is caused mainly by cockpit ergonomics that are unsuitable to the mission of training tactical Student Naval Aviators. The rudder pedal mechanism has very limited forward adjustment capability, causing many pilots to sit in an uncomfortable position with a significant gap between their thighs and the seat pan. Not only is the resulting body position fatiguing, but it promotes inadvertent brake application during ground operations including catapult launches, and routine landings. The thigh gap problem is made worse for pilots with a tall sitting height because they must adjust the seat to a position near the lowest adjustment point for ejection safety considerations. The rudder pedal mechanism also

sets too close to the floor of the cockpit, placing the fulcrum of the rudder pedal below the elevation of the pilot's ankle. This causes the pilot's longitudinal leg force to couple into an inadvertent brake application.

Solution(s)

Both blown tires and ground handling issues can be partially attributed to the ergonomics of the T-45 cockpit. A combination of ergonomic adjustments to the cockpit to bring the design up to the Mil Std requirements would be a desirable solution but is restricted by existing structural components. Solving the problems ergonomically will likely require a cockpit redesign that moves major structural members and possibly extends the forward portion of the fuselage. Within the scope of this thesis, the program technical and financial constraints disallow such large-scope airframe changes.

The toe-bar modification has been at least partially responsible for reducing the statistical likelihood of a blown tire on the catapult, but it has not eliminated the problem. Its apparent success however, may not be entirely due to the engineering change, but also due to a heightened awareness of the blown tire phenomenon since it was implemented within a short period of the death of a Student Naval Aviator. The success of the toe-bar modification depends heavily on the pilot carefully placing his foot in an awkward position that results in an uncomfortable, and possibly hazardous lower body posture. While the toe-bar solution was simple and somewhat effective, it represents an interim measure to mitigate the risk of inadvertent brake application on the catapult. The aircraft continues to need a long-term solution that will alleviate the blown tire problem for the remainder of its operational life.

Brake release

The brake release solution is a relatively simple system that represents a radical departure from conventional wisdom about operations on the deck of an aircraft carrier. Its technical and program risks are low however, and its cost is significantly less than the major airframe modifications required to bring the aircraft's cockpit up to the military standard. The system inhibits pilot brake inputs from being transformed into brake

application under the conditions present only on the catapult, and requires no modifications to current flight deck procedures. Since pilots will not be trained to specifically apply the brakes during a catapult launch with the system installed, the concern that they will transfer an inappropriate habit pattern to fleet aircraft is unsubstantiated.

Despite one major deficiency, the brake release system ground and flight test demonstrated successful system operation, preventing pilot brake pedal application from resulting in brake actuation. Furthermore, because of the system's simplicity, there are a few avenues available to correct the deficiency through hardware or software alterations.

The carrier qualification phase of the Student Naval Aviator's training has been statistically the most hazardous, largely due to blown tires on the catapult. The brake release system is a non-ergonomic solution to the blown tire problem that is largely caused by cockpit ergonomics in the T-45. The brake release system will eliminate blown tires due to inadvertent brake application on the catapult, significantly diminishing the hazards of qualifying Student Naval Aviators in aircraft carrier operations.

Chapter 10

Recommendations

While one detail of the brake release system remains unacceptable for incorporation as a permanent modification into the T-45, the overall design concept is mature. The directional control problem associated with a large, left nose gear steering angle should be corrected through a minor change to nose landing gear hardware. The brake release system should subsequently be incorporated as a modification to existing T-45 aircraft, and included as part of current production line T-45 aircraft.

The brake release system represents a significant change in operational mindset, by removing control of a critical system from the pilot. The pilot relinquishes control of the brakes, however, during a phase of flight when brake application is undesirable regardless of the type of aircraft on the catapult. The brake release system is a solution to a problem that is mainly ergonomic in the T-45. Inadvertent brake application on the catapult however, has psychological origins as well, which exist regardless of the airframe in which the pilot sits. Future carrier aircraft will likely continue to become more complex, incorporating systems for status analysis. These systems should include a brake release system that prevents inadvertent pilot braking from actuating the brakes during a catapult launch.

The US Navy should additionally support research to establish whether there is a similar inadvertent braking problem in current fleet aircraft, particularly in the Fleet Replacement Squadrons where Naval Aviators receive their first experience in their fleet aircraft. If the results of such research indicate a problem with blown tires on the catapult, the Navy should investigate the applicability of the brake release system as a potential solution to the problem.

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Appendices

Appendix A

T-45A External Field of View From Design Eye Position in the Forward Cockpit

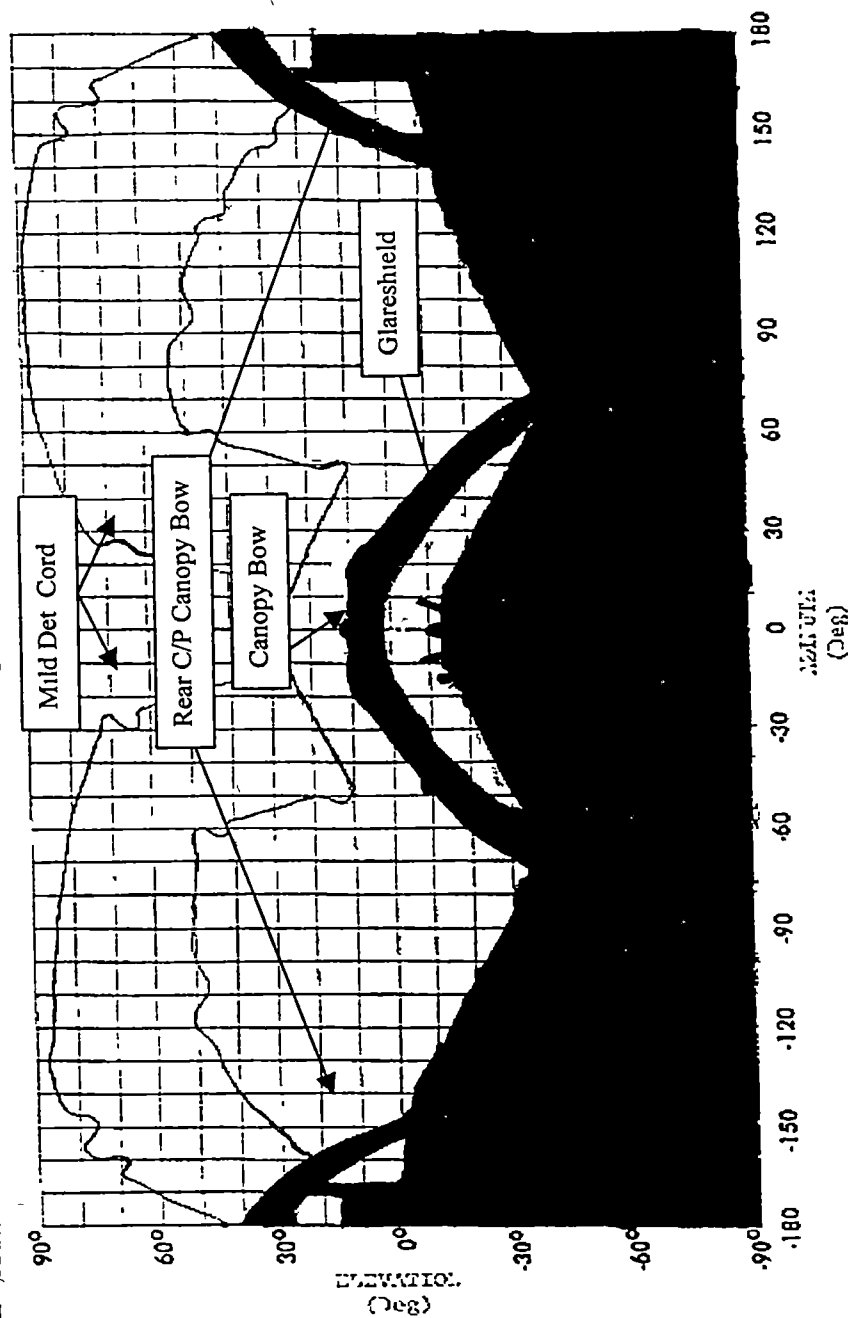


Figure 24 Rectilinear Plot of a T-45A forward cockpit field of view.

Source: (Parker) Cockpit Evaluation of the T-45A for the Advanced Trainer Mission

Figure 24 is a hand-drawn rectilinear plot of the field of view from Design Eye Position in the forward cockpit of a T-45A. The 0° azimuth is aligned with the longitudinal axis of the aircraft. The 0° elevation corresponds to the pilot's view of the horizon with the aircraft sitting on the ground and normal tire and strut servicing. Data to develop the plot was collected by hand using a protractor and string to estimate the relative positions of the obstructions to external field of view. Data were collected at key points, mainly where significant angles were formed by two obstructions, then curves faired by hand to fit the points.

While the field of view may appear relatively unobstructed, the pilot's primary concern lies immediately ahead of the aircraft, primarily between $\pm 60^\circ$ azimuth and $\pm 30^\circ$ elevation. The canopy bow and the glareshield obstruct much of that area, greatly limiting the forward field of view.

Appendix B

Thigh gap comparison

COCKPIT THIGH GAP COMPARISON

Front Cockpit
seat adjusted for DEP

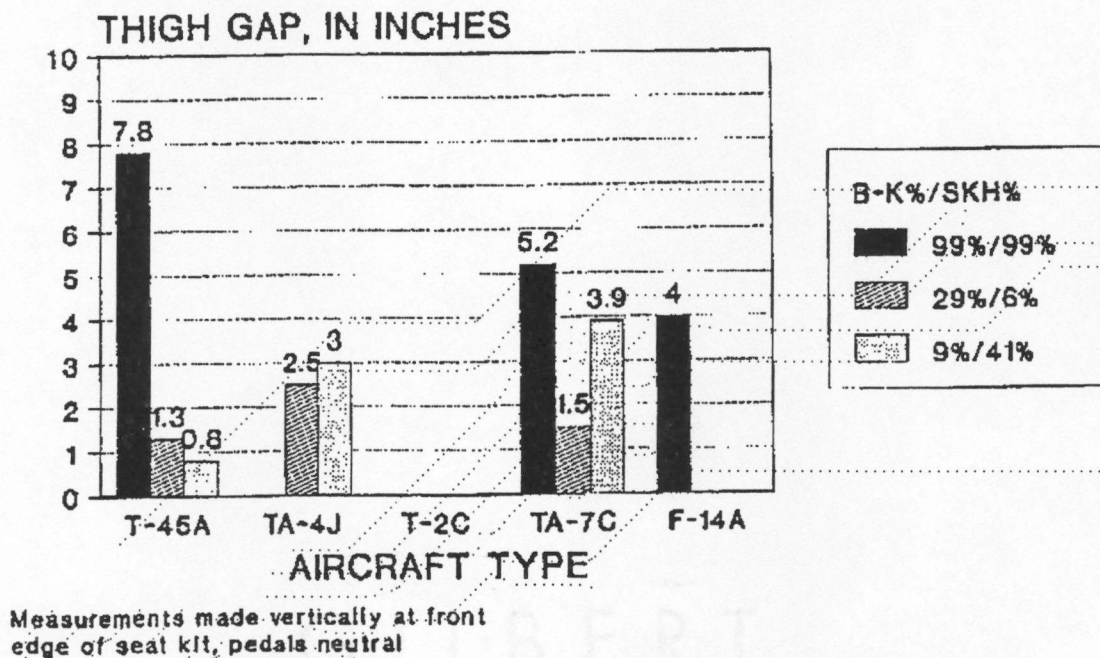


Figure 25 Plot of thigh gap in inches with the seat adjusted to place the occupants eye at DEP

Source: (Whitman, 1989) T-45 Thigh Gap Study

Figure 25 shows the vertical distance from the leading edge of the seat pan to the bottom of the pilot's thigh (thigh gap) for the listed aircraft, when the seat was adjusted to place the pilot's eye at the Design Eye Position. Each colored bar on the chart represents a test subject with the measurements listed in the legend. The measurements listed in the legend are B-K (Buttock-Knee) and SKH (Sitting Knee Height) and their associated percentiles with respect to the 1964 Anthropometric survey of Naval Aviators.

Note that the T-45 accommodates the smaller subjects with a relatively small thigh gap. The large subject however, is restricted by the forward travel limit of the rudder pedals, creating a larger thigh gap than in other tactical naval aircraft. While the T-45 was not designed to accommodate the 99th percentile aviator, it was designed to accommodate the 98th percentile aviator, whose Buttock-Knee and Sitting Knee Height measurements are smaller by only 0.28 inch(0.71 cm) and 0.25 inch (0.64 cm) respectively, appendix C. The T-45 clearly accommodates the large aviator poorly, placing him in an uncomfortable lower body position that induces fatigue and exacerbates inadvertent brake application.

The T-45 program manager commissioned the Naval Air Development Center to study thigh gap and its impact on ejection injuries, largely because of the known ergonomic problems with the T-45. The study looked at 1940 ejections from naval aircraft by sorting through Naval Safety Center data, looking for evidence of seat slap injuries. The results ranged from none in the TA-7 to over 9% of the total number of ejections in the TA-4 displaying signs of seat slap injury. When investigating further for signs of *disabling* seat slap injuries, most aircraft had none, while the A-4 had 1.2%, the TA-4 had 1.8% and the F-14A had 0.6% of the ejections showing signs of disabling injuries due to seat slap. The data obtained from this study is valuable, but provides anecdotal information that is subjective, leaving numerous ejection variables unknown. Nevertheless, it provided the program manager with sufficient information to continue the T-45 program and terminate further investigation into the thigh gap.

With advances in anthropometry, and computer modeling, the T-45 program has once again commissioned a study that will model the conditions of an ejection and its impact on the various sizes of personnel that can be accommodated by the T-45. It will also perform actual ejection seat tests with instrumented anthropometric dummies to specifically isolate thigh gap as a variable during an ejection. The data obtained from this study is expected to provide more detailed information about the impact that the ergonomics of the T-45 has in an ejection (Lackner, 2000).

Appendix C

T-45 Cockpit Mock-up Subjects, 1964 Naval Aviator, and 1988 Army Survey Anthropometrics

Table 4 Measurement summary of pilots participating in 3 March 1999 T-45 Cockpit Mock-up

Source: (Kennedy) Spreadsheet of Anthropometric Measurements of Pilots in 3 March 1999 T-45 Cockpit Mock-up.

Subject #	1		2		3		4		5	
	cm	in	cm	in	cm	in	cm	in	cm	in
Boot size (US size)	12.5	12 5	9.5	9.5	10	10	9	9	13	13
Stature	174 5	69 5	173 4	69 0	187 5	74 6	175.6	69 9	184 3	73 3
Sitting height	91.9	36.2	91.2	35 9	95 7	37 7	93.1	36 7	96 9	38 1
Sitting eye height	78 7	31 0	80 0	31 5	82 6	32 5	81 8	32 2	84 4	33 2
Seat adjust at DEP	2.0	2.0	2.5	2 5	2 0	2.0	2.5	2 5	2.0	2 0
Sitting shoulder height	61 0	24.0	60 8	23 9	64.6	25 4	62.7	24.7	64 7	25 5
Buttock knee	63 2	24 9	62 6	24 6	67.6	26.6	61 8	24.3	64 8	25 5
Sitting knee	57 3	22.6	54 0	21.3	59 4	23 4	55 0	21 7	58 6	23 1
Popliteal length	50.5	19 9	51 3	20 2	54 7	21 5	51.9	20 4	51 5	20 3
Toe Bar thigh gap	9.9	3 9	13.2	5.2	17.5	6.9	9.7	3 8	13 7	5 4
Toe Bar knee angle	106 0	106.0	110 0	110 0	98 0	98.0	108.0	108.0	99 0	99 0
Functional leg length	113 4	44.6	112.3	44 2	121.5	47 8	111.5	43.9	115 4	45 4
Thumb tip reach	31 3	31.3	29 8	29 8	33 8	33 8	29.5	29 5	33 5	33 5
Thigh circumference 2 inches from knee	17 3	17.3	16.0	16 0	14.3	14 3	17 0	17 0	17.5	17 5
Thigh circumference 5 inches from knee	21 0	21 0	19 0	19 0	16.5	16.5	19 8	19.8	20 8	20 8
Shoulder breadth	52 0	20.5	51.6	20 3	48.9	19 3	50.0	19.7	51.0	20 1

Table 4 represents anthropometric and cockpit fit measurements taken of T-45 male pilots during a cockpit mock-up evaluation for various proposed changes to the T-45 cockpit.

Table 5 Functional Leg Length of Army Aviators.

Source: (Donelson) 1988 Anthropometric Survey of US Army Personnel: Pilot Summary Statistics.

Functional Leg Length		
Mean	Standard Deviation	Range
42.81 (0.21)	1.85 (0.06)	38.62 – 48.23 IN
108.73 (0.15)	4.71 (0.15)	98.10 – 122.50 CM
Coefficient of variation: 9.7%		
Inches	Percentiles	Centimeters
39.96	1 ST	98.97
39.28	2 ND	99.77
39.51	3 RD	100.35
39.84	5 TH	101.19
40.40	10 TH	102.62
40.82	15 TH	103.67
41.16	20 TH	104.54
41.46	25 TH	105.32
41.75	30 TH	106.03
42.01	35 TH	106.70
42.26	40 TH	107.35
42.51	45 TH	107.98
42.76	50 TH	108.61
43.01	55 TH	109.25
43.27	60 TH	109.90
43.53	65 TH	110.57
43.81	70 TH	111.27
44.11	75 TH	112.04
44.44	80 TH	112.89
44.83	85 TH	113.86
45.30	90 TH	115.06
45.97	95 TH	116.77
46.39	97 TH	117.82
46.67	98 TH	118.55
47.10	99 TH	119.62

Table 5 represents functional leg length statistics of male army aviators from the 1988 anthropometric survey of 486 subjects. This group was chosen as a surrogate to the 1964 Naval Aviator study since the 1964 study did not measure functional leg length.

Table 6 Buttock-Knee Length of Naval Aviators

Source: (Gifford) Anthropometry of Naval Aviators- 1964

Buttock – Knee Length		
Mean	Standard Deviation	Range
24.09 (0.03)	1.00 (0 02)	20 73 – 27 81 IN
61 20 (0 06)	2 54 (0 05)	52 65 – 70.55 CM
Coefficient of variation 4.15%		
Inches	Percentiles	Centimeters
21 78	1 ST	55 32
22.08	2 ND	56 06
22 26	3 RD	56 55
22.50	5 TH	57 15
22.85	10 TH	58 03
23 08	15 TH	58.61
23 26	20 TH	59 07
23.41	25 TH	59 47
23.55	30 TH	59.82
23.68	35 TH	60 16
23 81	40 TH	60 48
23.93	45 TH	60.79
24.06	50 TH	61 10
24.18	55 TH	61 42
24.31	60 TH	61 75
24 44	65 TH	62 09
24 59	70 TH	62 45
24 75	75 TH	62 85
24 92	80 TH	63 31
25.13	85 TH	63 84
25.40	90 TH	64 52
25.80	95 TH	65 53
26 06	97 TH	66.18
26 24	98 TH	66.65
26.52	99 TH	67.37

Table 7 Functional Reach of Naval Aviators

Source: (Gifford) Anthropometry of Naval Aviators- 1964

Functional Reach		
Mean	Standard Deviation	Range
31.51 (0.04)	1.42 (0.03)	27.26 – 36.31 IN
80.03 (0.09)	3.61 (0.06)	69.26 – 92.15 CM
Coefficient of variation 4.51%		
Inches	Percentiles	Centimeters
28.56	1 ST	72.54
28.87	2 ND	73.34
29.07	3 RD	73.84
29.33	5 TH	74.51
29.75	10 TH	75.55
30.03	15 TH	76.29
30.27	20 TH	76.89
30.48	25 TH	77.43
30.68	30 TH	77.92
30.86	35 TH	78.69
31.04	40 TH	78.85
31.22	45 TH	79.3
31.40	50 TH	79.76
31.59	55 TH	80.23
31.78	60 TH	80.72
31.98	65 TH	81.23
32.20	70 TH	81.78
32.44	75 TH	82.39
32.71	80 TH	83.08
33.03	85 TH	83.89
33.44	90 TH	84.93
34.04	95 TH	86.46
34.42	97 TH	87.44
34.70	98 TH	88.13
35.11	99 TH	89.17

Table 8 Overall Height of Naval Aviators

Source: (Gifford) Anthropometry of Naval Aviators- 1964

Height (Stature)		
Mean	Standard Deviation	Range
69.94 (0.06)	2.33 (0.04)	63.48 – 77.25 IN
177.64 (0.15)	5.91 (0.11)	161.25 – 196.15 CM
Coefficient of variation 3.33%		
Inches	Percentiles	Centimeters
65.09	1 ST	165.32
65.5	2 ND	166.38
65.79	3 RD	167.12
66.22	5 TH	168.19
66.92	10 TH	169.99
67.44	15 TH	171.3
67.87	20 TH	172.39
68.25	25 TH	173.35
68.6	30 TH	174.24
68.93	35 TH	175.08
69.25	40 TH	175.89
69.56	45 TH	176.68
69.87	50 TH	177.47
70.28	55 TH	178.26
70.50	60 TH	179.07
70.83	65 TH	179.91
71.18	70 TH	180.8
71.56	75 TH	181.76
71.98	80 TH	182.83
72.46	85 TH	184.05
73.06	90 TH	185.57
73.91	95 TH	187.72
74.42	97 TH	189.03
74.78	98 TH	189.94
75.3	99 TH	191.26

Table 9 Sitting Eye Height of Naval Aviators

Source: (Gifford) Anthropometry of Naval Aviators- 1964

Sitting Eye Height		
Mean	Standard Deviation	Range
31 57 (0 03)	1 18 (0 02)	28 05 – 35 72 IN
80 18 (0 08)	3 01 (0 05)	71.25 – 90.65 CM
Coefficient of variation 3 75%		
Inches	Percentiles	Centimeters
28 81	1 ST	73 18
29 19	2 ND	74 14
29 41	3 RD	74 70
29.70	5 TH	75 43
30 11	10 TH	76 48
30 38	15 TH	77 17
30 59	20 TH	77 70
30.77	25 TH	78.16
30.94	30 TH	78.58
31 09	35 TH	78.96
31 23	40 TH	79.34
31.38	45 TH	79 70
31 52	50 TH	80.07
31 67	55 TH	80.44
31 82	60 TH	80.82
31.98	65 TH	81 22
32 15	70 TH	81 65
32.33	75 TH	82.13
32.55	80 TH	82.67
32 8	85 TH	83 31
33 12	90 TH	84 14
33 61	95 TH	85.38
33 93	97 TH	86 19
34.16	98 TH	86.78
34 52	99 TH	87.68

Table 10 Overall Sitting Height of Naval Aviators
Source: (Gifford) Anthropometry of Naval Aviators- 1964

Sitting Height		
Mean	Standard Deviation	Range
36.28 (0.03)	1.25 (0.02)	32.19 – 41.62 IN
92.14 (0.08)	3.16 (0.06)	81.75 – 105.65 CM
Coefficient of variation 3.43%		
Inches	Percentiles	Centimeters
33.46	1 ST	85.00
33.76	2 ND	85.75
33.96	3 RD	86.26
34.24	5 TH	86.96
34.68	10 TH	88.09
34.98	15 TH	88.86
35.23	20 TH	89.47
35.43	25 TH	90.00
35.62	30 TH	90.48
35.79	35 TH	90.92
35.96	40 TH	91.33
36.11	45 TH	91.73
36.27	50 TH	92.13
36.43	55 TH	92.52
36.58	60 TH	92.92
36.75	65 TH	93.33
36.92	70 TH	93.77
37.10	75 TH	94.24
37.31	80 TH	94.77
37.56	85 TH	95.39
37.87	90 TH	96.19
38.36	95 TH	97.43
38.69	97 TH	98.27
38.95	98 TH	98.92
39.37	99 TH	100.00

Table 11 Sitting Knee Height of Naval Aviators

Source: (Gifford) Anthropometry of Naval Aviators- 1964

Sitting Knee Height		
Mean	Standard Deviation	Range
21 84 (0 02)	0 98 (0 02)	19 00 – 25 13 IN
55 48 (0.06)	2 48 (0.05)	48.25 – 63 75 CM
Coefficient of variation 4 47%		
Inches	Percentiles	Centimeters
19 71	1 ST	50.06
19 93	2 ND	50 61
20 07	3 RD	50.97
20.27	5 TH	51 48
20 59	10 TH	52 29
20 81	15 TH	52 86
20 99	20 TH	53.33
21 15	25 TH	53 73
21 30	30 TH	54.10
21 44	35 TH	54 45
21 57	40 TH	54.78
21 69	45 TH	55.10
21 82	50 TH	55 42
21.95	55 TH	55.75
22 08	60 TH	56 07
22.21	65 TH	56 42
22 35	70 TH	56 78
22 51	75 TH	57.17
22 68	80 TH	57.61
22 88	85 TH	58 12
23 14	90 TH	58 76
23 50	95 TH	59 70
23 74	97 TH	60.29
23 91	98 TH	60.72
24.16	99 TH	61 37

Appendix D

Acronyms and Definitions

Acronyms

CG	Center of Gravity
CQ	Carrier Qualification
FRS	Fleet Replacement Squadron
HUD	Head Up Display
HYD-1	Hydraulic system number one
ITTV	Instrumented Tire Test Vehicle
LSO	Landing Signal Officer
MDC	Mild Detonation Cord
Mil-Std	Military Standard
MODSDF	Modular Six Degree of Freedom
NSRP	Neutral Seat Reference Point
OLS	Optical Landing System
PIO	Pilot Induced Oscillations
PSI	Pounds-force per Square Inch
RAT	Ram Air Turbine
SNA	Student Naval Aviator

Definitions

Accumulator – A component commonly used in hydraulic systems that stores hydraulic fluid under pressure to prevent system pressure loss during periods of high demand.

Angle deck – That portion of the aircraft carrier flight deck that runs approximately 10° left of the longitudinal axis of the ship. It permits aircraft to land without directly impacting aircraft or operations taking place on the bow of the ship.

Backlash – Play or lost motion between mechanical links in a system.

Buttock knee length – An anthropometric measurement taken while the human subject is sitting erect against a vertical wall with the thigh level. The measurement extends from the wall to the leading edge of the subject's knee.

Carrierize – A maintenance process conducted on naval aircraft preparing them for operations aboard an aircraft carrier. It includes, amongst other procedures, increasing tire pressure to that specified for carrier operations.

Catapult officer – The officer responsible for directing the launch process for aircraft on an aircraft carrier.

Catapult shuttle – The portion of the catapult on the flight deck, into which the aircraft's launch bar mates.

Class A, mishap – A naval aircraft accident resulting in \$1 million damage, a fatality, or destruction/loss of the airframe.

Class B mishap - A naval aircraft accident resulting in between \$200,000 and \$ 1 million in damage or permanent partial disability of government personnel

Class C mishap - A naval aircraft accident resulting in \$10,000 to \$200,000 in damage.

Crab Angle – An angle formed between the longitudinal axis of the aircraft and its direction of travel. It is used to compensate for crosswinds.

Cross-deck pendant – The cable across the landing area that is engaged by an aircraft's arresting hook. The cable is connected to a mechanical device that rapidly dissipates the aircraft's kinetic energy.

Down – An unsatisfactory grade for a ground or flight event in the Naval Aviation Training Command.

Drag – A force opposite the direction of travel of an aircraft.

Field Arrestment – Short, Long or Mid field arrestment refers to a maneuver where the aircraft uses its tail hook to engage a cable across the runway to quickly decelerate. Short field refers to arresting gear nearest the approach end of the runway.

Freeplay – Lost motion in a control system.

Functional Leg Length – The straight line distance between the plane of the bottom of the foot with the leg extended, and the back of the subject's buttock.

Glideslope – The vertical path flown by an aircraft on an approach to touchdown.

Hazard report – A naval aviation safety system message reporting a hazardous condition to other aircraft users and to the Naval Safety Center for statistical tracking purposes.

Hold-back fitting – A fitting that attaches to the aft side of the nose gear strut of a carrier aircraft. It prevents the aircraft from moving forward when the pilot selects maximum thrust and the catapult is placed into tension.

Knot(s) – A rate of speed equivalent to one nautical mile per hour.

Landing Signal Officer -- An LSO is responsible for the safe recovery of aircraft aboard ship. He controls the landing pattern, talks to pilots to help them land, waves off unsafe approaches, and grades and comments on each landing.

Launch bar – The component on the nose landing gear of a carrier aircraft that can be lowered into the catapult shuttle on the deck of the aircraft carrier.

Margin of attention - Margin of attention is an individual's excess cognitive capability when focused on a particular task.

Military thrust – The maximum amount of thrust a non-afterburning jet engine can develop.

MK-7 arresting gear – Arresting gear used on board aircraft carriers. It differs from conventional field arresting gear in that the available run out is less so it dissipates aircraft energy more rapidly.

Overlearning – Practicing a task beyond the first error-free trial, reducing the cognitive thought process required to repeat the task.

Pitot – A hollow tube that senses the dynamic pressure from travel through the air.

Popliteal length – A measurement taken with a subject sitting erect with thigh parallel to the deck and shin vertical. The measurement is from the deck to the back of the knee.

Port – The left side of a ship as the observer faces the bow.

Proximity switch – An electromagnetic switch that senses when a metal target is near to open or close an electrical circuit. The switch does not use physical contact

Reversible – A term describing a type of control system where the control forces are fed back to the pilot.

Shuttle – That portion of the catapult mechanism which rides above the flight deck and mates with an aircraft launch bar.

Sitting knee height – An anthropometric measurement taken as the subject sits erect with shin vertical and thigh parallel to the deck. The measurement is from the deck to the top of the knee.

Span of attention - Span of attention is both the duration and capacity that an individual is capable of devoting to a task. It varies with age, motivation, training and experience.

Tension – The process where the catapult shuttle applies a forward force (approximately 4500 lbs) to the launch bar in preparation to launch the aircraft. The force is insufficient to break the holdback when combined with maximum thrust from the aircraft.

Wing aircraft – The aircraft which is not the lead aircraft in a flight of two.

Appendix E

The diagram illustrates the electrical architecture of an anti-skid system. It features several interconnected components and control logic:

- Anti-Skid Voltage Detect Relay:** Receives input from the "ANTI-SKID VOLTAGE DETECT RELAY" and provides output to the "ANTI-SKID SYSTEM".
- Anti-Skid Control Box:** A central unit with multiple terminals (A, B, C, D, E, F, G, H) and internal wiring. It receives signals from the "ANTI-SKID SYSTEM" and the "DUAL ANTI-SKID VALVE". It also controls the "ANTI-SKID VALVE MODE SELECT RELAY" and the "ANTI-SKID VALVE MODE SELECT RELAY".
- Dual Anti-Skid Valve:** A solenoid valve with two coils, "SERVO COIL" and "HYD RETURN SOL", controlled by the "ANTI-SKID SYSTEM".
- Launch Bar Position Switches:** Two switches, "LAUNCH BAR POSITION (PROX SW 1)" and "LAUNCH BAR POSITION (PROX SW 2)", provide input to the "ANTI-SKID SYSTEM".
- Brake Release Control Circuit:** Includes a "BRAKE RELEASE" switch and a "BRAKE RELEASE" indicator lamp. It also features a "BRAKE RELEASE CONTROL CIRCUIT" with a "BRAKE RELEASE" switch and a "BRAKE RELEASE" indicator lamp.
- Caution Indication Circuit:** A circuit that provides a "CAUTION" signal to the "ANTI-SKID SYSTEM".
- Anti-Skid System:** The main control unit, which receives inputs from the "ANTI-SKID VOLTAGE DETECT RELAY", "ANTI-SKID CONTROL BOX", "LAUNCH BAR POSITION (PROX SW 1)", "LAUNCH BAR POSITION (PROX SW 2)", and "BRAKE RELEASE". It controls the "ANTI-SKID VALVE MODE SELECT RELAY", "ANTI-SKID VALVE MODE SELECT RELAY", and "ANTI-SKID VALVE MODE SELECT RELAY".

The diagram uses standard electrical symbols for switches, relays, solenoids, and lamps. Wires are labeled with letters (A, B, C, D, E, F, G, H) and numbers (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100). The diagram is a technical drawing of an electrical system, showing the connections between various components and the flow of electrical signals.

Source: (Kiernan) T-45 Brake Pressure Dump on Catapult Launches. Naval Air Warfare Center Test Plan

Figure 26 illustrates the electrical circuit of the brake release system. The portion of the circuit nearest the bottom of the figure includes the four switches in series that control the brake release system that can be thought of the **Brake Release Control**. It includes:

1. Throttle Position 95% proximity switch
2. Cockpit Launch bar switch
3. Launch bar position proximity switch #1 (located on the nose gear)
4. Left main landing gear down & locked relay

When those four switches are closed, they energize the two Anti-skid valve mode select relays (redundant relays in lower right portion of the figure). The Anti-skid valve mode select relays then close the four switches connected by the vertical dashed line. The top three of those switches opens the anti-skid control valve, releasing hydraulic brake pressure at the brake assembly, while the bottom switch energizes the caution indication portion of the circuit.

The **Caution Indication** portion of the circuit consists of three switches in series that include:

1. Right main landing gear down & locked relay
2. Launch bar position proximity switch #2 (located on the nose gear)
3. Launch bar switch *relay*

When the three switches above are closed, they energize the “Brakes” caution light located in the “CWSEU” (Caution and Warning System Electronic Unit) box at the upper left of the diagram. The caution light will only illuminate if the system logic senses an abnormality in the circuit, which may represent a failure in the system, potentially permitting brake application on the catapult.

The Parking Brake proximity switch, seen at the lower right corner of the figure grounds the entire system. If the pilot pulls the Parking Brake handle, closing that switch, it disables the brake release system.

Appendix F

Ground and Flight Test

Tables 12-14 represent the ground and flight test effort conducted to ensure that each of the components of the Brake Release system operated as designed. The test method was essentially a system verification and sneak circuit analysis that used build up in risk over the course of the test, finally achieving operational catapult launches. The System Verification/Failure Simulation Ground Test, shown in Table 12, was the first phase of testing conducted in the hangar with external electrical and hydraulic power applied to the aircraft. The ground test was an exhaustive assessment of the various relay and proximity switches in the brake release system. The switches and relays were tested to ensure that the system released/restored brake pressure, and provided the appropriate caution lights and tones for abnormalities in the system logic.

System Verification Static Checks at TC-7 was the second phase of testing, and a natural build up following the System Verification/Failure simulation. Table 13 shows the specific actions taken with the engine running and the aircraft stationed at the land-based TC-7 catapult. The catapult was inactive, but had hydraulic power to place the aircraft in tension. This made the catapult incapable of inadvertently launching the aircraft. The aircraft was connected/disconnected to/from the catapult shuttle utilizing various procedures, some differing from normal procedures. This was done to ensure that the brake release system released and restored brake pressure then provided the necessary caution lights and tones in near operational conditions.

The final phase of the test consisted of Operational Catapults at the TC-7 catapult site and Arrestments at the MK-7 arresting gear Table 14. The TC-7 catapult and MK-7 arresting gear are the same equipment as those on an aircraft carrier, but are located at NAS Patuxent River for the express purpose of testing new aircraft and their components to ensure that they are suitable for the aircraft carrier environment. The operational catapult launches consisted of a build up beginning with a nominal launch and progressed

to launches with the pilot intentionally applying both brakes during the catapult stroke. The arrestments were conducted to ensure that no unexpected brake anomalies would occur as a result of the rapid deceleration during an arrestment.

TABLE 12

SYSTEM VERIFICATION/FAILURE SIMULATION GROUND TEST

TEST POINT	L/H MLG POSN UP/DOWN/ REMOVE POWER	R/H MLG POSN UP/DOWN/ REMOVE POWER	ANTI-SKID OFF/ON	OVERRIDE (PARKING BRAKE) OFF/ON	LAUNCH BAR POSN #1 UP/DOWN/ TARGET	LAUNCH BAR POSN #2 UP/DOWN/ TARGET	LAUNCH BAR SWITCH UP/DOWN	LAUNCH BAR SWITCH RELAY UP/DOWN	9% THROTTLE POSN	"BRAKE" CAUTION LIGHT OFF/ON	ANTI-SKID CAUTION LIGHT OFF-ON	BRAKE PRESSURE RELEASE/ RESTORE	OTHER CAUTION LIGHTS COMMENTS / NOTES
1	DOWN	DOWN	OFF	ON	DOWN	DOWN	UP	UP	MIL	ON	OFF	RESTORE	
2	DOWN	DOWN	OFF	OFF	DOWN	DOWN	UP	UP	MIL	OFF	OFF	RELEASE	
3	DOWN	DOWN	OFF	OFF	DOWN	DOWN	DOWN	DOWN	MIL	OFF	OFF	RESTORE	Launch Bar Advisory
4	DOWN	DOWN	OFF	OFF	DOWN	DOWN	UP	UP	MIL	OFF	OFF	RELEASE	
5	DOWN	DOWN	OFF	OFF	DOWN	DOWN	UP	UP	IDLE	ON	OFF	RESTORE	
6	DOWN	DOWN	OFF	OFF	DOWN	DOWN	UP	UP	MIL	OFF	OFF	RELEASE	
7	DOWN	DOWN	OFF	OFF	TARGET	DOWN	UP	UP	MIL	ON	OFF	RESTORE	Place target between launch bar down prox Switch #1
8	DOWN	DOWN	OFF	OFF	DOWN	DOWN	UP	UP	MIL	OFF	OFF	RELEASE	Remove target from launch bar down prox Switch #1
9	DOWN	DOWN	OFF	OFF	DOWN	TARGET	UP	UP	MIL	OFF	OFF	RELEASE	Place target between launch bar down prox Switch #2 (NO Indication)
10	DOWN	DOWN	OFF	OFF	DOWN	DOWN	UP	UP	MIL	OFF	OFF	RELEASE	Remove target from launch bar down prox Switch #2
11	REMOVE POWER	DOWN	OFF	OFF	DOWN	DOWN	UP	UP	MIL	ON	OFF	RESTORE	Remove power from L/H landing gear down prox switch
12	DOWN	DOWN	OFF	OFF	DOWN	DOWN	UP	UP	MIL	OFF	OFF	RELEASE	Restore power to L/H landing gear down prox switch
13	DOWN	REMOVE POWER	OFF	OFF	DOWN	DOWN	UP	UP	MIL	ON	OFF	RELEASE	Remove power from R/H landing gear down prox switch
14	DOWN	DOWN	OFF	OFF	DOWN	DOWN	UP	UP	MIL	OFF	OFF	RELEASE	Restore power to R/H landing gear down prox switch

Notes: 1. When removing/restoring power from/to MLG proximity switches, external power shall be removed and battery switches shall be turned off. Power shall be removed from MLG proximity switches by disconnecting electrical plugs.

TABLE 12

SYSTEM VERIFICATION/FAILURE SIMULATION GROUND TEST

TEST POINT	LH MLG POSN UP/DOWN/REMOVE POWER	RH MLG POSN UP/DOWN/REMOVE POWER	ANTI-SKID OFF/ON	OVERRIDE (PARKING BRAKE) OFF/ON	LAUNCH BAR POSN #1 UP/DOWN/TARGET	LAUNCH BAR POSN #2 UP/DOWN/TARGET	LAUNCH BAR SWITCH UP/DOWN	LAUNCH BAR SWITCH RELAY UP/DOWN	95% THROTTLE POSN	"BRAKE" CAUTION LIGHT OFF/ON	ANTISKID CAUTION LIGHT OFF/ON	BRAKE PRESSURE RELEASE/RESTORE	OTHER CAUTION LIGHTS COMMENTS / NOTES
15	DOWN	DOWN	OFF	ON	DOWN	DOWN	UP	UP	MIL	ON	OFF	RESTORE	Launch Bar Advisory
16	DOWN	DOWN	OFF	ON	DOWN	DOWN	DOWN	DOWN	MIL	OFF	OFF	RESTORE	
17	DOWN	DOWN	OFF	ON	DOWN	DOWN	UP	UP	MIL	ON	OFF	RESTORE	
18	DOWN	DOWN	OFF	ON	DOWN	DOWN	UP	UP	IDLE	ON	OFF	RESTORE	
19	DOWN	DOWN	OFF	ON	DOWN	DOWN	UP	UP	MIL	ON	OFF	RESTORE	Place target between launch bar down prox Switch #1
20	DOWN	DOWN	OFF	ON	TARGET	DOWN	UP	UP	MIL	ON	OFF	RESTORE	Remove target from launch bar down prox Switch #1
21	DOWN	DOWN	OFF	ON	DOWN	DOWN	UP	UP	MIL	ON	OFF	RESTORE	Place target between launch bar down prox Switch #2
22	DOWN	DOWN	OFF	ON	DOWN	TARGET	UP	UP	MIL	OFF	OFF	RESTORE	Remove target from launch bar down prox Switch #2
23	DOWN	DOWN	OFF	ON	DOWN	DOWN	UP	UP	MIL	ON	OFF	RESTORE	Remove power from LH landing gear down prox switch
24	REMOVE POWER	DOWN	OFF	ON	DOWN	DOWN	UP	UP	MIL	ON	OFF	RESTORE	Restore power to LH landing gear down prox switch
25	DOWN	DOWN	OFF	ON	DOWN	DOWN	UP	UP	MIL	ON	OFF	RESTORE	Remove power from RH landing gear down prox switch
26	DOWN	REMOVE POWER	OFF	ON	DOWN	DOWN	UP	UP	MIL	OFF	OFF	RESTORE	Restore power to RH landing gear down prox switch
27	DOWN	DOWN	OFF	ON	DOWN	DOWN	UP	UP	MIL	ON	OFF	RESTORE	Remove power from landing gear down prox switch
28	DOWN	DOWN	OFF	OFF	DOWN	DOWN	UP	UP	MIL	OFF	OFF	RELEASE	

Notes: 1. When removing/restoring power from/to MLG proximity switches, external power shall be removed and battery switches shall be turned off. Power shall be removed from MLG proximity switches by disconnecting electrical plugs.

TABLE 12
SYSTEM VERIFICATION/FAILURE SIMULATION GROUND TEST

TEST POINT	L/H MLG POSN UP/DOWN/ REMOVE POWER	R/H MLG POSN UP/DOWN/ REMOVE POWER	ANTI-SKID OFF/ON	OVERRIDE (PARKING BRAKE) OFF/ON	LAUNCH BAR POSN #1 UP/DOWN/ TARGET	LAUNCH BAR POSN #2 UP/DOWN/ TARGET	LAUNCH BAR SWITCH UP/DOWN	LAUNCH BAR SWITCH RELAY UP/DOWN	95% THROTTLE POSN	"BRAKE" CAUTION LIGHT OFF/ON	ANTISKID CAUTION LIGHT OFF-ON	BRAKE PRESSURE RELEASE/ RESTORE	OTHER CAUTION LIGHTS COMMENTS / NOTES
29	DOWN	DOWN	ON	ON	DOWN	DOWN	UP	UP	MIL	ON	OFF	RESTORE	
30	DOWN	DOWN	ON	OFF	DOWN	DOWN	UP	UP	MIL	OFF	ON	REI EASE	Launch Bar Advisory
31	DOWN	DOWN	ON	OFF	DOWN	DOWN	DOWN	DOWN	MIL	OFF	OFF	RESTORE	
32	DOWN	DOWN	ON	OFF	DOWN	DOWN	UP	UP	MIL	OFF	ON	RELEASE	
33	DOWN	DOWN	ON	OFF	DOWN	DOWN	UP	UP	IDLE	ON	OFF	RESTORE	
34	DOWN	DOWN	ON	OFF	DOWN	DOWN	UP	UP	MIL	OFF	ON	RELEASE	
35	DOWN	DOWN	ON	OFF	TARGET	DOWN	UP	UP	MIL	ON	OFF	RESTORE	Place target between launch bar down prox Switch #1
36	DOWN	DOWN	ON	OFF	DOWN	DOWN	UP	UP	MIL	OFF	ON	REI EASE	Remove target from launch bar down prox Switch #1
37	DOWN	DOWN	ON	OFF	DOWN	TARGET	UP	UP	MIL	OFF	ON	REI EASE	Place target between launch bar down prox Switch #2
38	DOWN	DOWN	ON	OFF	DOWN	DOWN	UP	UP	MIL	OFF	ON	RELEASE	Remove target from launch bar down prox Switch #2
39	REMOVE POWER	DOWN	ON	OFF	DOWN	DOWN	UP	UP	MIL	ON	OFF	RESTORE	Remove power from L/H landing gear down prox switch
40	DOWN	DOWN	ON	OFF	DOWN	DOWN	UP	UP	MIL	OFF	ON	REI EASE	Restore power to L/H landing gear down prox switch
41	DOWN	REMOVE POWER	ON	OFF	DOWN	DOWN	UP	UP	MIL	ON	ON	RELEASE	Remove power from R/H landing gear down prox switch
42	DOWN	DOWN	ON	OFF	DOWN	DOWN	UP	UP	MIL	OFF	ON	RELEASE	Restore power to R/H landing gear down prox switch

Notes: 1. When removing/restoring power from/to MLG proximity switches, external power shall be removed and battery switches shall be turned off. Power shall be removed from MLG proximity switches by disconnecting electrical plugs.

TABLE 12
SYSTEM VERIFICATION/FAILURE SIMULATION GROUND TEST

TEST POINT	LH/MLG POSN UP/DOWN/ REMOVE POWER	RH/MLG POSN UP/DOWN/ REMOVE POWER	ANTI-SKID OFF/ON	OVERRIDE (PARKING BRAKE) OFF/ON	LAUNCH BAR POSN #1 UP/DOWN/ TARGET	LAUNCH BAR POSN #2 UP/DOWN/ TARGET	LAUNCH BAR SWITCH UP/DOWN	LAUNCH BAR SWITCH RELAY UP/DOWN	95% THROTTLE POSN	"BRAKE" CAUTION LIGHT OFF/ON	ANTISKID CAUTION LIGHT OFF-ON	BRAKE PRESSURE RELEASE/ RESTORE	OTHER CAUTION LIGHTS COMMENTS/NOTES
43	DOWN	DOWN	ON	ON	DOWN	DOWN	UP	UP	MIL	ON	OFF	RESTORE	
44	DOWN	DOWN	ON	ON	DOWN	DOWN	DOWN	DOWN	MIL	OFF	OFF	RESTORE	Launch Bar Advisory
45	DOWN	DOWN	ON	ON	DOWN	DOWN	UP	UP	MIL	ON	OFF	RESTORE	
46	DOWN	DOWN	ON	ON	DOWN	DOWN	UP	UP	IDLE	ON	OFF	RESTORE	
47	DOWN	DOWN	ON	ON	DOWN	DOWN	UP	UP	MIL	ON	OFF	RESTORE	
48	DOWN	DOWN	ON	ON	TARGET	DOWN	UP	UP	MIL	ON	OFF	RESTORE	Place target between launch bar down prox Switch #1
49	DOWN	DOWN	ON	ON	DOWN	DOWN	UP	UP	MIL	ON	OFF	RESTORE	Remove target from launch bar down prox Switch #1
50	DOWN	DOWN	ON	ON	DOWN	TARGET	UP	UP	MIL	OFF	OFF	RESTORE	Place target between launch bar down prox Switch #2
51	DOWN	DOWN	ON	ON	DOWN	DOWN	UP	UP	MIL	ON	OFF	RESTORE	Remove target from launch bar down prox Switch #2
52	REMOVE POWER	DOWN	ON	ON	DOWN	DOWN	UP	UP	MIL	ON	OFF	RESTORE	Remove power from LH landing gear down prox switch
53	DOWN	DOWN	ON	ON	DOWN	DOWN	UP	UP	MIL	ON	OFF	RESTORE	Restore power to LH landing gear down prox switch
54	DOWN	REMOVE POWER	ON	ON	DOWN	DOWN	UP	UP	MIL	OFF	OFF	RESTORE	Remove power from RH landing gear down prox switch
55	DOWN	DOWN	ON	ON	DOWN	DOWN	UP	UP	MIL	ON	OFF	RESTORE	Restore power to RH landing gear down prox switch
56	DOWN	DOWN	ON	OFF	DOWN	DOWN	UP	UP	MIL	OFF	ON	RELEASE	

Notes: 1. When removing/restoring power from/to MLG proximity switches, external power shall be removed and battery switches shall be turned off. Power shall be removed from MLG proximity switches by disconnecting electrical plugs.

TABLE 13
SYSTEM VERIFICATION STATIC CHECKS AT TC-7

TEST POINT	L/H MLO POSN UP/DOWN/TARGET	R/H MLO POSN UP/DOWN/TARGET	ANTI-SKID OFF/ON	OVERRIDE (PARKING BRAKE) OFF/ON	LAUNCH POSN #1 UP/DOWN/TARGET	LAUNCH POSN #2 UP/DOWN/TARGET	LAUNCH SWITCH UP/DOWN	LAUNCH BAR SWITCH RELAY UP/DOWN	93% THROTTLE POSN	"BRAKE" CAUTION LIGHT OFF/ON	ANTISKID CAUTION LIGHT OFF-ON	BRAKE PRESSURE RELEASE/RESTORE	OTHER CAUTION LIGHTS COMMENTS/NOTES
57	DOWN	DOWN	OFF	OFF	UP	UP	UP	UP	IDLE-MIL	OFF	OFF	RESTORE	Holdback installed, brakes applied, increase RPM slowly to MIL. Brake pressure should hold. Checks launch bar logic.
58	DOWN	DOWN	OFF	OFF	DOWN	DOWN	DOWN	DOWN	IDLE-MIL	OFF	OFF	RESTORE	Holdback installed, take tension, brakes applied, increase RPM slowly to MIL. Brake pressure should hold. Checks launch bar switch logic.
							UP	UP	MIL	OFF	OFF	RELEASE	Launch Bar Advisory Move launch bar switch up. Brake pressure should release.

TABLE 13
SYSTEM VERIFICATION STATIC CHECKS AT TC-7

TEST POINT	L/H MLG POSN UP/DOWN/TARGET	R/H MLG POSN UP/DOWN/TARGET	ANTI-SKID OFF/ON	OVERRIDE (PARKING BRAKE) OFF/ON	LAUNCH BAR POSN #1 UP/DOWN/TARGET	LAUNCH BAR POSN #2 UP/DOWN/TARGET	LAUNCH SWITCH UP/DOWN	LAUNCH BAR SWITCH RELAY UP/DOWN	95% THROTTLE POSN	"BRAKE" CAUTION LIGHT OFF/ON	ANTISKID CAUTION LIGHT OFF-ON	BRAKE PRESSURE RELEASE/RESTORE	OTHER CAUTION LIGHTS COMMENTS/NOTES
59	DOWN	DOWN	OFF	OFF	DOWN	DOWN	UP	UP	IDLE-MIL	ON-OFF	OFF	RESTORE-RELEASE	Holdback installed, take tension, brakes applied, increase RPM slowly to MIL. Brake pressure should release at approximately the 95% switch position. Checks PLA logic. Reduce RPM slowly. Brake pressure should restore when throttle position is less than approximately 95%.
60	DOWN	DOWN	OFF	OFF	DOWN-UP	DOWN-UP	UP	UP	MIL-IDLE	ON-OFF	OFF	RESTORE-RELEASE	Holdback installed, take tension, brakes applied, increase RPM slowly to MIL. Initiate suspend. Brake pressure should restore when launch bar retracts. Checks launch bar position logic and time delay.

TABLE 13
SYSTEM VERIFICATION STATIC CHECKS AT TC-7

TEST POINT	L/R MLG POSN UP/DOWN/TARGET	R/H MLG POSN UP/DOWN/TARGET	ANTI-SKID OFF/ON	OVERRIDE (PARKING BRAKE) OFF/ON	LAUNCH BAR POSN #1 UP/DOWN/TARGET	LAUNCH BAR POSN #2 UP/DOWN/TARGET	LAUNCH SWITCH UP/DOWN	LAUNCH BAR SWITCH UP/DOWN	95% THROTTLE POSN	"BRAKE" CAUTION LIGHT OFF/ON	ANTISKID CAUTION LIGHT OFF-ON	BRAKE PRESSURE RELEASE/RESTORE	OTHER CAUTION LIGHTS COMMENTS/NOTES
61	DOWN	DOWN	ON	OFF	UP	UP	UP	UP	IDLE-MIL	OFF	OFF	RESTORE	Holdback installed, brakes applied, increase RPM slowly to MIL. Brake pressure should hold. Checks launch bar logic.
62	DOWN	DOWN	ON	OFF	DOWN	DOWN	DOWN	DOWN	IDLE-MIL	OFF	OFF	RESTORE	Holdback installed, take tension, brakes applied, increase RPM slowly to MIL. Brake pressure should hold. Checks launch bar switch logic.
							UP	UP	MIL	OFF	ON	REL EASE	Move launch bar switch up. Brake pressure should release. Launch Bar Advisory.

TABLE 13
SYSTEM VERIFICATION STATIC CHECKS AT TC-7

TEST POINT	LH MILG POSN UP/DOWN/TARGET	R/H MILG POSN UP/DOWN/TARGET	ANTI-SKID OFF/ON	OVERRIDE (PARKING BRAKE) OFF/ON	LAUNCH POSN #1 UP/DOWN/TARGET	LAUNCH POSN #2 UP/DOWN/TARGET	LAUNCH BAR SWITCH UP/DOWN	LAUNCH BAR SWITCH UP/DOWN	95% THROTTLE POSN	"BRAKE" CAUTION LIGHT OFF/ON	ANTI-SKID LIGHT OFF/ON	BRAKE PRESSURE RELEASE/RESTORE	OTHER CAUTION LIGHTS OFF/ON	COMMENTS / NOTES
63	DOWN	DOWN	ON	OFF	DOWN	DOWN	UP	UP	IDLE-MIL	ON-OFF	ON WHEN RELEASED	RESTORE-RELEASE		Holdback installed, take tension, brakes applied, increase RPM slowly to MIL. Brake pressure should release at approximately the 95% switch position. Checks PLA logic
									MIL-IDLE	OFF-ON	OFF WHEN RESTORED	RELEASE-RESTORE		Reduce RPM slowly. Brake pressure should restore when throttle position is less than approximately 95%
64	DOWN	DOWN	ON	OFF	DOWN-UP	DOWN-UP	UP	UP	IDLE-MIL	ON-OFF (OFF AFTER 2 SECOND DELAY)	OFF-ON-OFF	RESTORE-RELEASE-RESTORE		Holdback installed, take tension, brakes applied, increase RPM slowly to MIL. Initiate suspend. Brake pressure should restore when launch bar retracts. Checks launch bar position logic and time delay

TABLE 14
OPERATIONAL CHECKS
CATAPULTS AND ARRESTMENTS

TEST POINT	MANEUVER	STORE CONG	AIRCRAF T CONF	ANTI-SKID ON/OFF	OVERRIDE (PARKING BRAKE) ON/OFF	LH MLD POSN	RH MLD POSN	LAUNCH BAR POSN	LAUNCH BAR SWITCH UP/DOWN	POWER SETTING	"BRAKE" CAUTION LIGHT OFF/ON	ANTISKID CAUTION LIGHT OFF/ON	BRAKE PRESSURE	BRAKE PEDAL POSN	COMMENTS/NOTES
65	NOMINAL CATAPULT	CLEAN	CARRIER TAKEOFF	OFF	OFF	DOWN	DOWN	DOWN	UP	MIL	OFF	OFF	RELEASE	OFF	
66	NOMINAL CATAPULT	CLEAN	CARRIER TAKEOFF	ON	OFF	DOWN	DOWN	DOWN	UP	MIL	OFF	OFF	RELEASE	OFF	
69	NOMINAL CATAPULT	CLEAN	CARRIER TAKEOFF	OFF	OFF	DOWN	DOWN	DOWN	UP	MIL	OFF	OFF	RELEASE	ON	TM CONFIRMATION OF NO BRAKE PRESSURE REQUIRED PRIOR TO CATAPULT LAUNCH SEE NOTE 1
70	NOMINAL ARRESTMENT	CLEAN	POWER APPROCH	OFF	OFF	DOWN	DOWN	UP	UP	MIL	OFF	OFF	RESTORE	OFF	
71	NOMINAL ARRESTMENT	CLEAN	POWER APPROCH	ON	OFF	DOWN	DOWN	UP	UP	MIL	OFF	OFF	RESTORE	OFF	NOTE 2

NOTES:

1. TM confirmation of no brake pressure required prior to catapult launch Brake application shall be terminated following weight off wheels. If a soft catapult is experienced, brake application shall be terminated (brake application with tires in contact with the surface for more than 2 second following launch bar release will cause tires to skid and and possibly blow). If a blown tire(s) occurs follow NATOPS blown tire procedure.
2. With anti-skid ON, the skid control system detects the rapid wheel deceleration as a sustained skid Skid control will release brake pressure during the deceleration and brakes will not be available momentarily during roll back from the arresting wire. Careful brake application required to prevent aircraft from wheeling and tailcone contacting surface.

Appendix G

Brake Release Fault Tree Analysis

The following briefly discusses the fault tree analysis (Boudreau, 1998) performed to analyze the probability of failure for the Brake Release system. It details the assumptions that were made to arrive at the final results, and includes two of the 14 fault trees performed to analyze the system's safety. The two fault trees provide an analysis of the likelihood of the system failing to an non-annunciated condition of brake pressure on the catapult and a non-annunciated condition of loss of brake pressure on the ground, when the pilot desires brake availability.

The safety engineer assumed that the existing brake and anti-skid system had acceptable level of safety such that they would not be covered in the fault tree analysis for the brake release system. This means that the probability for internal brake failure, anti-skid dump valve, electrical failures and other existing hazards were not considered since their level of contribution to the top level hazard did not change as a result of the brake release system.

Safety events are normalized to the number of flight hours flown by the fleet of aircraft. While events associated with failures of a brake system or blown tires on the catapult do not lend themselves well to a flight hour correlation, the safety analysis must be compared with systems on the rest of the aircraft and other aircraft. This requires that the event probabilities be normalized to the number of flight hours. The probabilities of most basic importance are the probability that the aircraft is on the catapult, the probability that the aircraft is in ground operations (taxi, takeoff, landing etc.), and the probability that the pilot has his feet on the brakes during the catapult shot. Based on the number of carrier operations over the operational life of the aircraft, number of catapult launches, estimated time in the catapult, number of blown tires on the catapult, and estimated time for field ground operations, the analyst established the following three probabilities:

$$P_{a/c \text{ in cat}} = 4.83 \text{ E-3}$$

$$P_{a/c \text{ in gnd ops}} = 2.08 \text{ E-1}$$

$$P_{\text{feet on brakes}} = 8.10 \text{ E-5}$$

The brake release system is a simple system, primarily comprised of electrical relay switches and proximity switches. Actual failure rates, based on maintenance actions, were used to establish the probability of failure of the individual switches. The failure mode, could not normally be determined, so the analysis included here assumed a worst case where the switch failed to the hazardous condition 100% of the time.

Figure 27 presents the fault tree detailing the probability for loss of brakes during ground operations. Two main events must occur: the aircraft must be in ground operations, and one or more component failures in the brake release system must energize the brake release relay.

Figure 28 presents the fault tree detailing the probability that a student will experience blown tire(s) due to brake pressure availability on a catapult launch. Figure 29 through Figure 33 provide fault trees that support the sub-events in Figure 28. This particular fault tree assumes that the student executed the catapult checklist correctly and raised the launch bar switch prior to accepting the launch. The primary concern is with potential for system failure, vice human error, which is not likely to change as a result of the installation of the brake release system. In order to blow a tire, the student must apply the brakes, the brake pressure relay must fail to energize, and the brake dump caution light/aural tone must be ineffective.

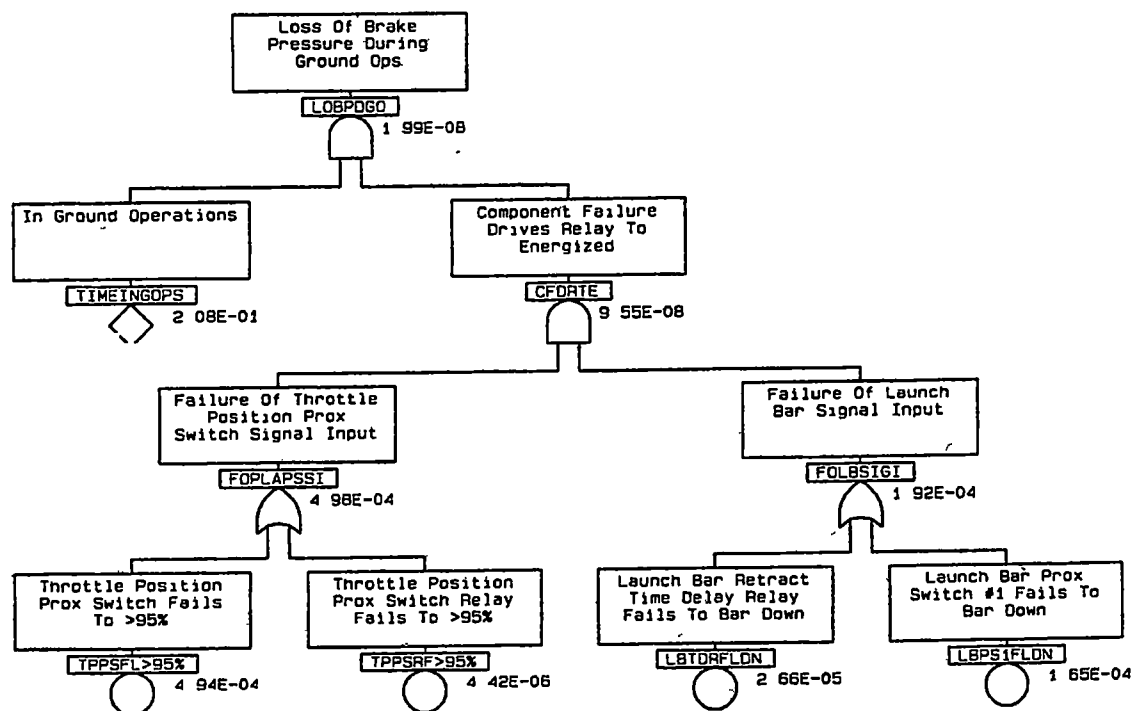


Figure 27 Fault Tree detailing the probability of losing brakes on the ground due to the Brake Release system.

Source: (Boudreau) Safety Considerations for Proposed Removal of Brake Pressure Prior to a Catapult Launch. 3 September 1998.

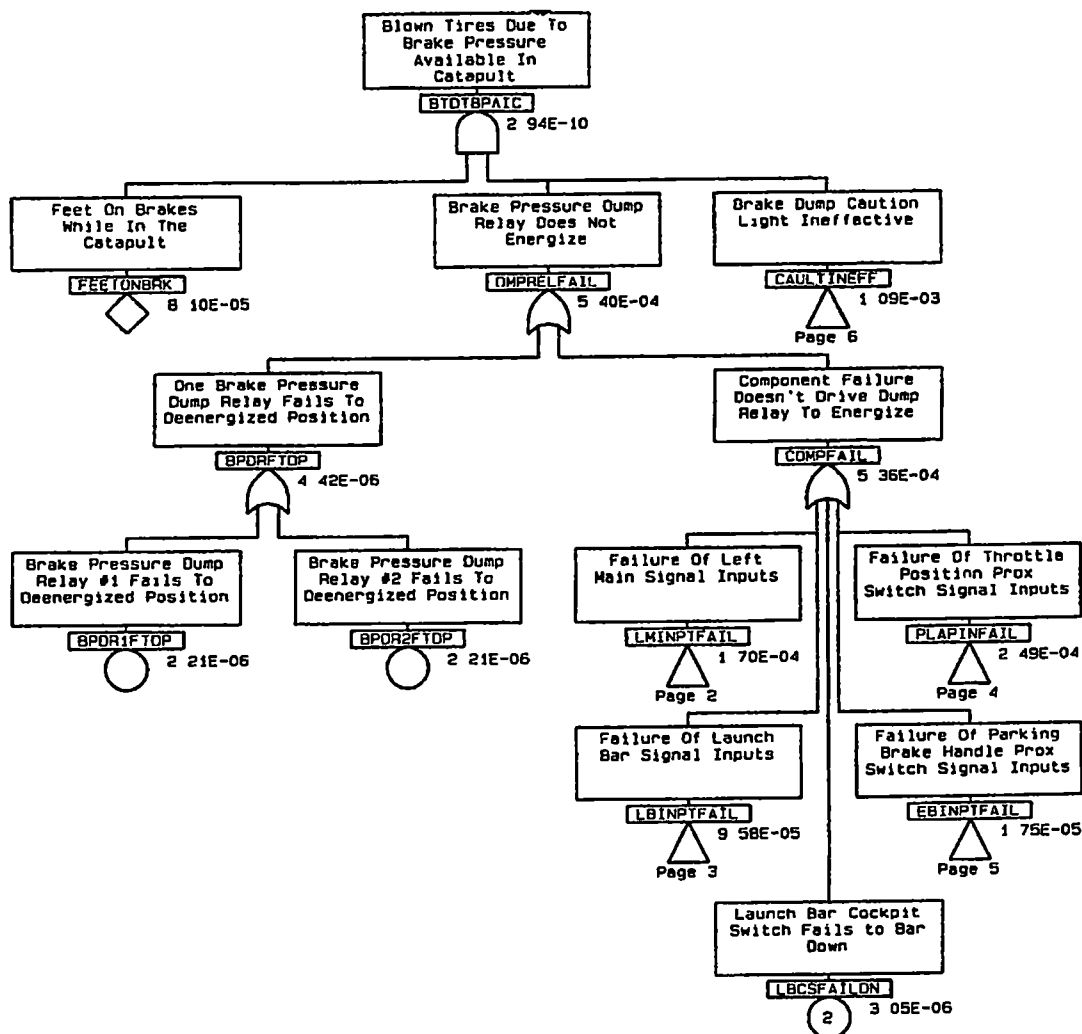


Figure 28 Fault Tree detailing the probability of blowing a tire on the catapult.

Source: (Boudreau) Safety Considerations for Proposed Removal of Brake Pressure Prior to a Catapult Launch. 3 September 1998. .

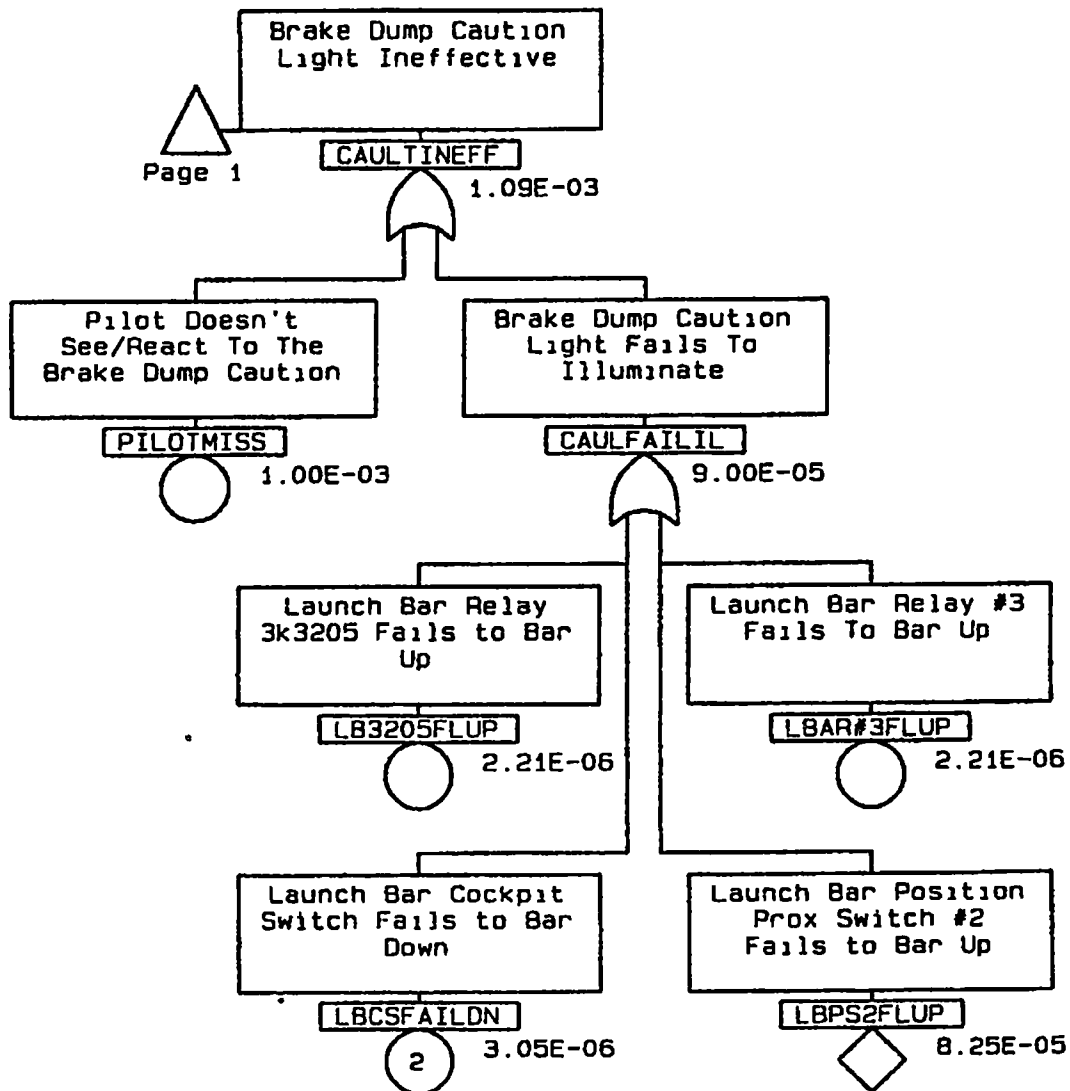


Figure 29 Fault Tree detailing probability that the Brake Release Caution light will not function.

Note Continues in Figure 2 under "Brake dump caution light ineffective"

Source: (Boudreau) Safety Considerations for Proposed Removal of Brake Pressure Prior to a Catapult Launch. 3 September 1998.

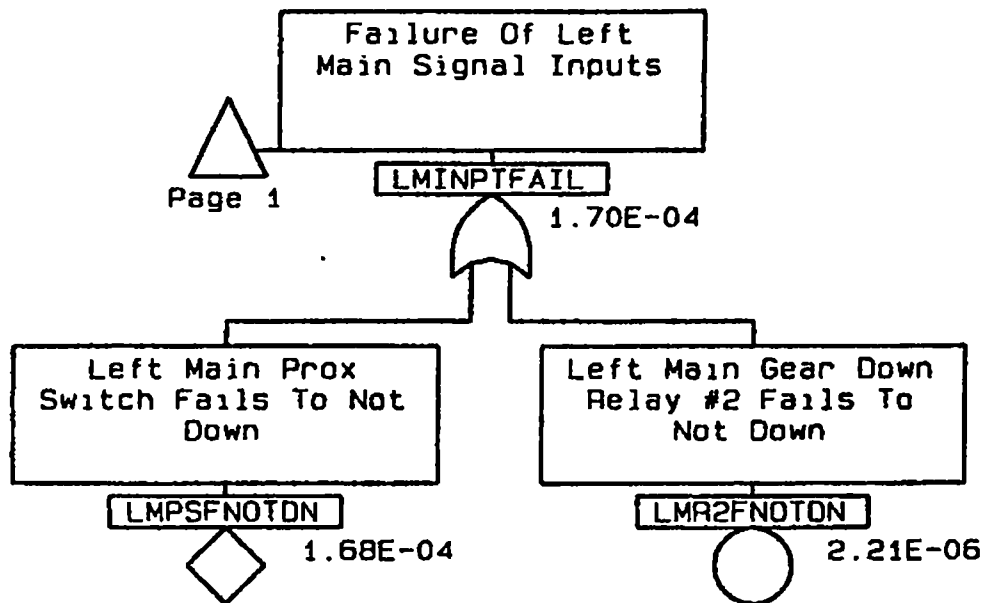


Figure 30 Fault Tree detailing probability that the inputs from the left main landing gear will fail

Note: Continues in Figure 2 under "Failure of left main signal inputs."

Source: (Boudreau) Safety Considerations for Proposed Removal of Brake Pressure Prior to a Catapult Launch. 3 September 1998.

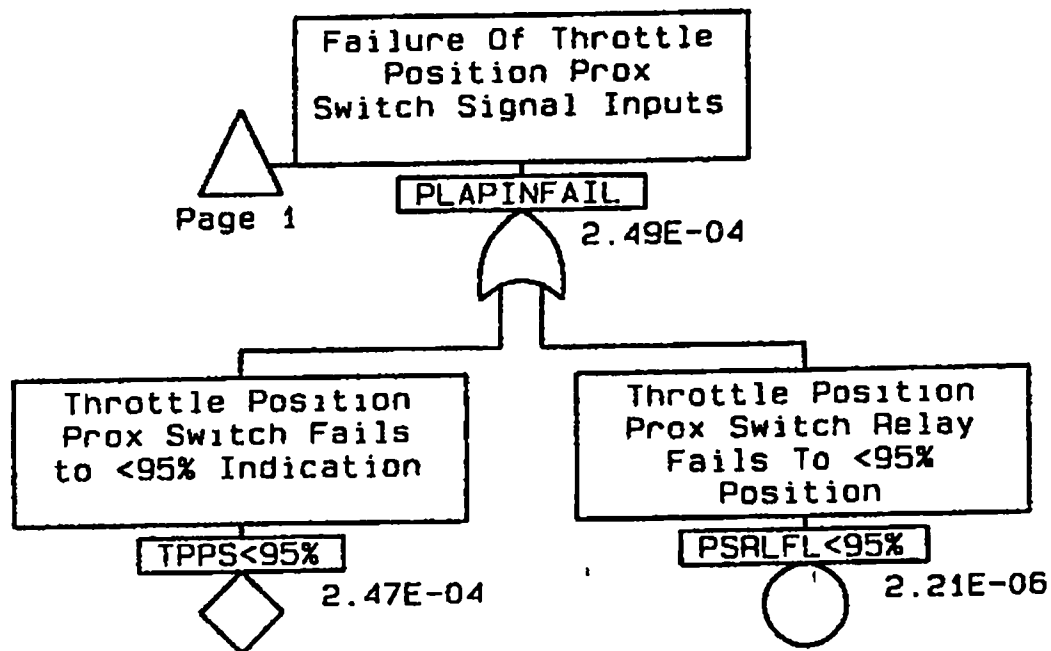


Figure 31 Fault Tree detailing probability that the Throttle Proximity switch signal will fail.

Note Continues in Figure 2 under "Failure of throttle position prox switch signal inputs "

Source: (Boudreau) Safety Considerations for Proposed Removal of Brake Pressure Prior to a Catapult Launch. 3 September 1998.

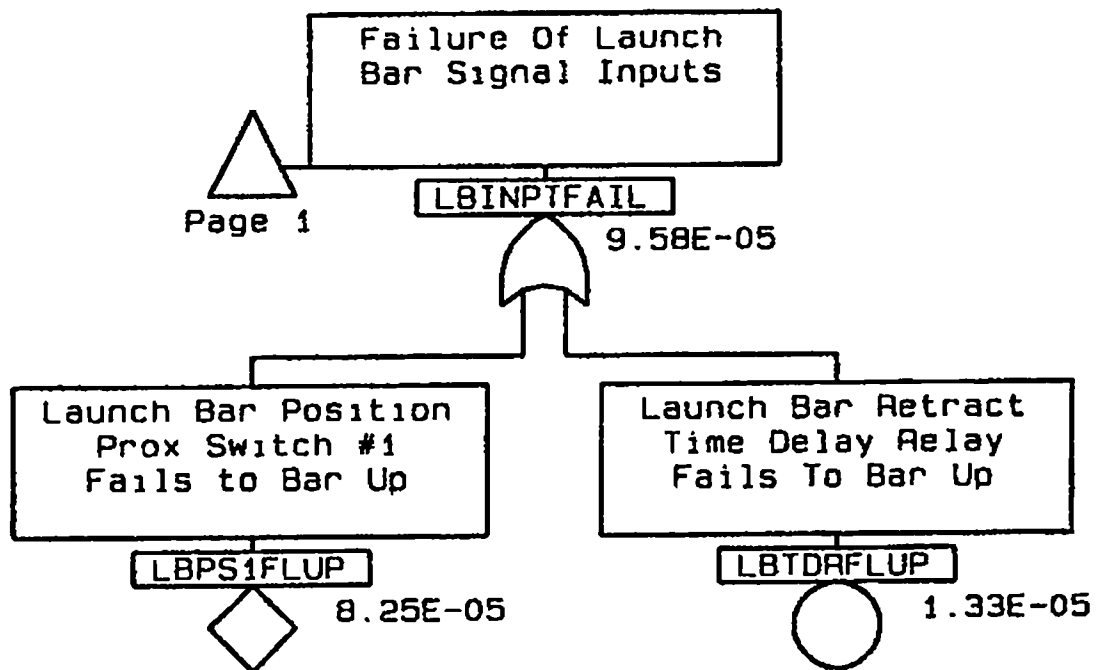


Figure 32 Fault Tree detailing probability that the Launch Bar signal will fail.

Note Continues in Figure 2 under "Failure of launch bar signal inputs."

Source: (Boudreau) Safety Considerations for Proposed Removal of Brake Pressure Prior to a Catapult Launch. 3 September 1998.

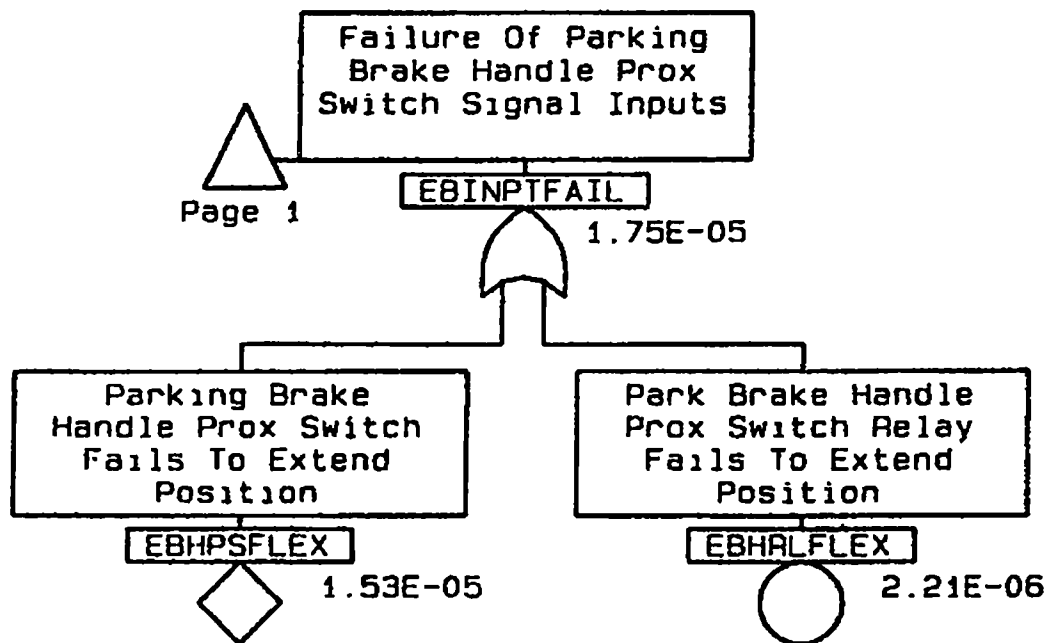


Figure 33 Fault Tree detailing probability that the Parking Brake signal will fail.

Note Continues in Figure 2 under "Failure of parking brake handle prox switch signal inputs "

Source: (Boudreau) Safety Considerations for Proposed Removal of Brake Pressure Prior to a Catapult Launch. 3 September 1998.

Vita

Donald Parker was born in Spokane, Washington on 6 December, 1966. He attended local public schools and graduated from Shadle Park High School in 1985. He enrolled the following school year at the University of Washington in Seattle, where he received a Bachelor of Science degree in Aeronautical and Astronautical engineering in August 1989. During his years at the University of Washington, he was enrolled in the Naval Reserve Officer Training Corps and was commissioned as a Naval Officer upon graduation. He entered flight school in the Fall of 1989 at Pensacola, Florida and was designated a Naval Aviator in December, 1991 in Meridian Mississippi. He completed operational deployments flying A-6E Intruders in the Western Pacific and Arabian Gulf theaters through 1995, then returned to shore duty flying QF-4 Phantoms in Point Mugu, California until June 1997. He left Point Mugu to attend the US Naval Test Pilot School at Patuxent River, Maryland, where he graduated in June 1998. He transferred to the Naval Strike Aircraft Test Squadron where he managed the T-45 flight test program and flew T-45 and F/A-18 Hornet flight test projects. During this period he entered the University of Tennessee's Aviation Systems Master of Science program, receiving his degree in May 2000.