To the Graduate Council:

I am submitting herewith a thesis written by Bradley James McKeage entitled "Limited Flight Test Development and Evaluation of a Prototype G-LOC Detection System". 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 Engineering.

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LIMITED FLIGHT TEST DEVELOPMENT AND EVALUATION OF A PROTOTYPE G-LOC DETECTION SYSTEM

A Thesis Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Bradley James McKeage

August 1997

ACKNOWLEDGEMENTS

I gratefully acknowledge the love and dedicated support always provided by my family. I particularly thank my wife, Cheri, and sons, Kevin and Mitchell, who give me the strength and motivation to achieve. A special thanks must go to the entire test team responsible for completing this research effort. In particular I acknowledge the test pilots, Captain Chris Bogdan and Captain C.D. Moore, and the test navigators, Captain Craig Olson and Lieutenant (Navy) Steven Gebert who were key members of the test team which designed and carried out the testing.

I must also pay tribute to the entire UTSI staff, who's support and guidance have been instrumental in my post graduate successes. I am especially thankful to Dr. Collins, my advisor for the support he sincerely extended. The special efforts contributed by Dr. Lewis and Dr. Kimberlin as committee members for my thesis are also greatly appreciated.

"Per Ardua Ad Astra"

DISCLAIMER

The information presented in this thesis is based on flight test data collected in support of a student project during the author's attendance at the USAF Test Pilot School. All comments concerning this development model system are the sole opinion of the author and in no way represent the official position of the Canadian Armed Forces, the USAF Test Pilot School or any branch of the Department of the United States Air Force. Similarly, the conclusions and recommendations presented by the author are for the sole purpose of fulfilling the requirements of this thesis and are not attributed to any of the aforementioned authorities.

ABSTRACT

This thesis presents the results of a developmental test of a prototype G-Induced Loss of Consciousness (G-LOC) Detection System installed on a T-38A aircraft. The purpose of the test was to develop a functioning G-LOC Detection System that was properly integrated into the airborne environment. The test was carried out at the Air Force Flight Test Center, Edwards AFB, California from February through May 1991. Eight test sorties were flown for a cumulative total of 6.7 flight test hours. The program was requested by NASA-Ames-Dryden, and Eidetics International, Incorporated was the manufacturer of the G-LOC Detection System.

The G-LOC phenomenon and the physiological requirements and constraints associated with successful implementation of a non-obtrusive detection system are expored. A careful review of the state-of-the-art technologies in GLOC detection is also conducted.

The G-LOC Detection System evaluated was a simple aircraft sensor-based system designed to detect G-LOC using T-38A Data Acquisition System (DAS) inputs. The G-LOC system continuously calculated an instantaneous probability of pilot G-LOC based on the aircraft load factor time history. The system then monitored various DAS inputs including stick movement and force, throttle and rudder pedal movement, stick grip, and a cockpit activity button to determine if there was in fact cockpit activity. If there was no cockpit activity for 3 seconds and the probability of pilot G-LOC was greater than 50 percent, the system would detect a G-LOC condition which would be reflected with a G-LOC detection light indication in the T-38A rear cockpit.

The overall objective of this program was to develop the prototype detection system so that it accurately recognized whether or not simulated G-LOC had occurred during operationally representative maneuvering in a fighter type aircraft. After five sorties this objective was accomplished, and the G-LOC Detection System was able to recognize when G-LOC was and was not simulated.

The G-LOC Detection System met its basic design objective. The system operated precisely as designed on all test maneuvers following the first 5 developmental sorties. The implementation of this type of G-LOC Detection System is therefore considered feasible.

Consequently, a system designed to unobtrusively detect G-LOC using aircraft data shows promise. Although the system functioned exactly as designed, it contained logic flaws which made it inadequate for military use. The logic flaws included the modeling of pilot stick grip which caused detection failures; the modeling of conscious pilot actions such as afterburner selection/de-selection and switch activations which caused false alarms; and an inaccurate G-LOC probability build-up function. These findings were based on test team experience and were supported with Air Force accepted physiological data.

Finally, improvement proposals (algorithm logic and sensor inputs) are made to better implement this type of detection system in more advanced fighter aircraft where substantially more aircraft and pilot status information is readily available for processing.

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LIST OF ABBREVIATIONS

AB	Afterburner
AFB	Air Force Base
AFM	Air Force Manual
AFSC	Air Force Systems Command
DAS	Data Acquisition System
DBFM	Defensive Basic Fighter Maneuvers
ECM	Electronic Countermeasures
FM	Frequency Modulated
G-LOC	Gravity Induced Loss of Consciousness
IFDAPS	In Flight Data Acquisition and Processing System
IRMD	Infrared Missile Defense
KIAS	Knots Indicates Air Speed
lbs	Pounds
lbs/hr	Pounds per Hour
LED	Light Emitting Diode
LOC	Loss of Consciousness

NASA	National Aeronautics and Space Administration
N_z	Normal Acceleration (G's)
OBFM	Offensive Basic Fighter Maneuvers
OI	Operational Instruction
PC	Personal Computer
PCM	Pulse Code Modulation
RCP	Rear Cockpit
RPM	Revolutions per Minute
S/N	Serial Number
USAF	United States Air Force
USAFTPS	United States Air Force Test Pilot School
YAPS	Yaw, Angle of Attack, Pitot Static System

Chapter 1

INTRODUCTION

Gravity or G-Induced Loss of Consciousness or G-LOC results when an individual is exposed to a specific G onset rate and level for a period of time that exceeds that particular individual's unique neurologic tolerance to such stresses. The dynamic and demanding flight environment associated with high performance fighter aircraft operations provide the greatest routine exposure to this potential phenomenon. Sustained positive G forces result in the downward displacement of blood away from the head and brain. If this condition persists for a long enough period, the normal conscious functioning of the central nervous system (CNS) can be adversely altered. G-LOC has been defined as "a state of altered perception wherein (one's) awareness of reality is absent as a result of sudden, critical reduction of central nervous system circulation caused by increased G force" [1]. Typically G-LOC results in absolute incapacitation of the pilot for periods of time on the average of 12 seconds which are immediately followed by an additional 12 seconds of relative incapacitation or state of confusion during the recovery phase. Effectively, the pilot is not in actual control of the aircraft on average for a net 24 second period which all too often can be catastrophic in the high performance fighter aircraft environment. The need for accurate and timely G-LOC recognition and subsequent transition to an aircraft autorecovery flight mode is unquestionable and should help avoid future G-LOC attributable accidents.

There are essentially two approaches to assessing the conscious state of a pilot. The first involves obtrusive measurement of cardiovascular, cardiopulmonary or encephalographic physiological variables of the pilot. Typically these methods require arterial and venous in-dwelling catheterization with the use of pressure transducers to provide real-time cardiovascular information. Electro-encephalography can also provide very accurate real-time indications of loss of consciousness. The acquisition and utility of this sort of

physiological data in the dynamic airborne environment has proven to be cumbersome and impractical. Aircrew acceptance of such a system would also pose serious opposition to such a system. The other alternative is to unobtrusively monitor physiological metrics in combination with the evaluation of the past and present status of the aircraft. The system under development and test was in fact a very simple, unobtrusive system of this second type.

This research effort was limited to an in-flight developmental test and evaluation of a prototype G-LOC detection system, and more specifically the detection logic. The system was developed by Eidetics International Inc. and funded by NASA-Ames-Dryden as a small business innovation research project. The G-LOC Detection system was a relatively simple aircraft sensor based system designed to detect G-LOC using a combination of physical sensors (stick grip and force), aircraft normal load factor time history to determine G-LOC probability, and cockpit activity indications (stick movement, throttle movement, rudder pedal movement, and a generic cockpit activity button to simulate other pilot actions). The system was tested by several students from the USAF Test Pilot School (TPS) Class 90B as part of the TPS curriculum using a modified T-38A test aircraft platform. The overall purpose of the test was to determine if the prototype G-LOC Detection System when integrated in the aircraft environment accurately recognizes whether or not simulated G-LOC has occurred during operationally representative maneuvering. Initial flights demonstrated the requirement to develop the algorithm logic in order to obtain a functioning system. After a presentation of the background information associated with this research in Chapter 2, the developmental test and system evaluation methods and results are presented in Chapter 3. Finally, conclusions and recommendations are presented in Chapter 4.

Chapter 2

BACKGROUND AND THEORETICAL CONSIDERATIONS

Literature Review and Background Considerations

General

G-LOC is not a new problem and the aircrew community was been aware of its potentially catastrophic results for nearly 80 years. With the emergence of present day, high performance fighter aircraft such as the F-15, F-16, F18 and now the F-22, which are designed to generate and sustain positive G-loads and onset rates well in excess of tolerance limits of human operators employing preventive measure systems, G-LOC will continue to be a significant problem. Since 1982, the number of US aircraft G-LOC incidents resulting in aircraft and aircrew loss is substantial as is depicted in Figure 2-1. The USAF air force alone has acknowledged at least 14 Class A accidents where pilot loss of consciousness due to high G loads was designated as the primary cause.

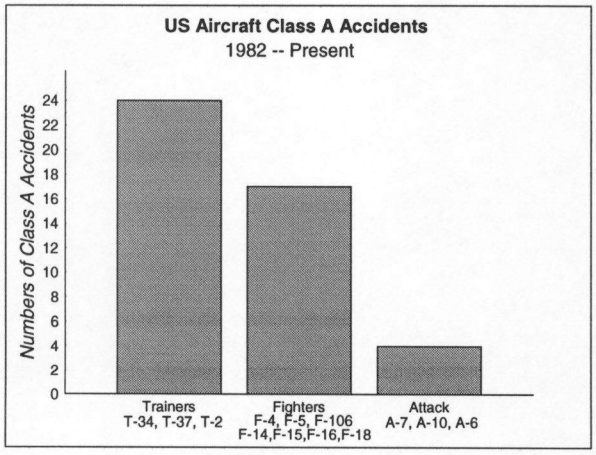


Figure 2-1. Numbers of Class A accidents in U.S. Military Aircraft since 1982 Attributed to G-LOC [2]

Figure 2-1 provides only an indication of the frequency of G-LOC attributable Class accidents for U.S. tactical aircraft and is most likely a very conservative estimate. Certainly these results clearly demonstrate the significance of this killer threat. In fact, G-LOC has become the U.S. Tactical Air Force's second most serious human factors problem, just behind spatial disorientation [2]. Presently there is not a G-LOC monitoring system employed by any fighter aircraft. Present and future aircraft will continue to operate in a pilot limiting high G environment placing both the pilot and aircraft at risk. A much needed operational requirement exists for a system that will protect the pilot and aircraft when preventative measures, offered by anti-G suits and pilot straining maneuvers, have failed and loss of consciousness has occurred. A system to unobtrusively detect the G-LOC condition in real-time, warn other appropriate crewmembers, and automatically safely control the aircraft until the pilot regains complete consciousness will ultimately meet this urgent requirement. The prototype G-LOC detection system installed and evaluated in the T-38 was the first step towards this goal. The prototype was designed as a "proof of concept" system to determine the feasibility of such a detection system and to serve as a baseline design for near-term G-LOC detection systems.

Related Efforts

Many research efforts have been directed toward better understanding the GLOC syndrome leading to the development of physiological sensors to accurately detect G-LOC through the monitoring and analysis in real time of pilot biological data. Physiological metrics which may be obtained unobtrusively in-flight and remain transparent to the pilot (without sticking into or onto the pilot [3]) are summarized in Table 2-1. The specific types of physiological activities which can be monitored in flight for evidence of pilot G-LOC behavior are categorized in Table 2-1 by body part group. Although assessing brain activity has proven to be an extremely accurate means of ascertaining G-LOC occurrence, implementation of a pilot accepted, unobtrusive monitoring system has not yet been successfully developed. More physical human actions such as eye blink rate, head position and muscle activity can be much more readily and accurately detected.

Table 2-1. Physiological Sources for G-LOC Detection

System	Parameter	Technique
Brain	Electrical Activity	EEG, VER
	Blood Flow	Doppler, Impedance
	Oxygen Supply	Oximetry, NIMS
	Blood Volume	NIMS
Eye	Blink Rate	IR Detector, Radar
Head	Position	Helmet Sensor
Muscles	Tension - Hand Grip	Stick Force/Displacement
	- Jaw Clench	EMG
Lungs	Respiration	Flow G-suit Pressure
Voice	Anti-G Straining Maneuver	Pattern Recognition

EEG - Electro-encephalogram; VER - visually evoked response; NIMS - Near infrared multiwave spectrophotometry; EOG - Electro-oculogram; EMG - Electromyogram.

As already mentioned, there is a second and equally important collateral component required in the successful detection of G-LOC. The G time history environment must be continually monitored and an appropriate model which reflects human tolerance to G-LOC must be used along with the monitoring of pilot physiological metrics. The G-time tolerance curve shown below in Figure 2-2 was obtained from Reference 4. It shows susceptibility to G-LOC based on load factor, onset rate and exposure to load factor. This Air Force accepted G-LOC susceptibility curve was used by the contractor to model the G-LOC probability function used in the detection system. This is a very simplistic G susceptibility model that does not account for such important phenomena as the "push-pull" effect or individual/gender susceptibility differences. The "push-pull" effect has demanded more attention recently in studies which have clearly demonstrated a decreased positive G tolerance when preceded by 0 G or negative G loading. A study in 1995 by *Banks, Grissett, Saunders and Mateczun* [5] concluded that "positive G tolerance is reduced by pre-exposure to negative G, where the degree of positive G tolerance reduction depends on the magnitude and time of the preceding negative G exposure." Additional research in this area was recommended.

The Aerospace Engineering Test Establishment of the Canadian Armed Forces will be conducting flight testing in the summer of 1997 of this "push-pull effect" using unprotected (no G suit) aircrew who will be fully instrumented by flight medicine researchers to gather actual physiological and biological data associated with exposure to the phenomenon.

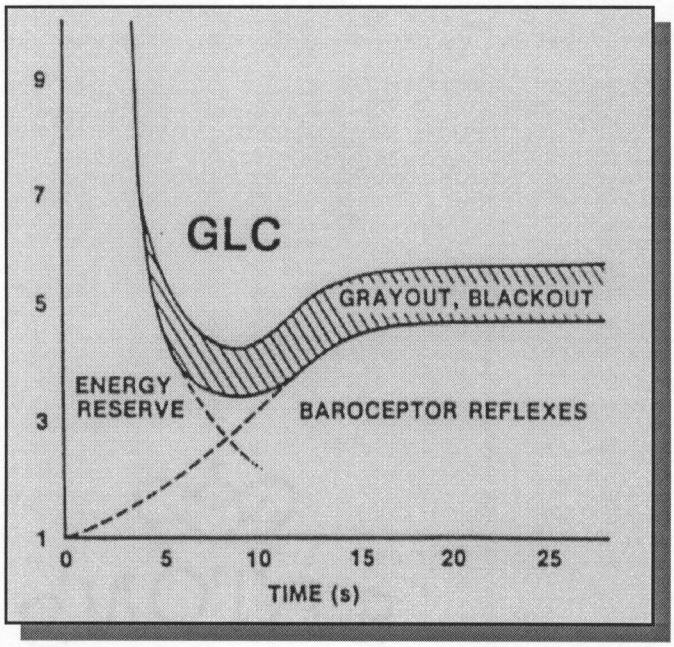


Figure 2-2. G-time Tolerance Curve

Relatively little flight test work has been conducted since the early 90's to develop an advanced G-LOC detection system. I can only speculate that a recent emphasis on anti-G protection device improvements (full body suits with positive pressure breathing) combined with aircrew acceptance concerns toward an automatic and independent aircraft recovery system (implied with G-LOC detection) are responsible for this relative stagnation in G-LOC detection system development.

The G-LOC Physiological Phenomenon

In order to successfully evaluate the system's performance in detecting G-LOC, the flight test techniques had to accurately simulate pilot symptoms associated with G-LOC to provide the system with proper pilot activity cues. Pilot response during a G-LOC

episode has been thoroughly monitored and investigated in centrifuge testing. In the average human being in the relaxed state, the heart provides the head with a blood pressure on the order of 78 millimeters of mercury (mm Hg). With each additional one G increase in load factor, the head blood pressure is reduced by 22 mm Hg. At approximately 4.5 G's, the head level blood pressure is reduced to zero mm Hg at which time pilot unconsciousness will occur. Anti-G protection suits and properly performed pilot straining maneuvers can increase the pilot's G tolerance by an additional 3 to 4 G's by increasing the blood pressure in the brain. G onset rate and duration also play significant factors in a pilot's G tolerance.

Documented cases of G-LOC in the centrifuge have shown that the typical pilot will "go limp" as unconsciousness sets in. Sometimes the unconscious pilot will continue to grip the control stick and at other times he will release it but in all cases he will not be able to maintain aft stick pressure to sustain the aircraft G loading. As a result the aircraft will unload to a lower G around the aircraft trimmed condition when the pilot is incapacitated. At times, a G-LOC episode results in involuntary muscular twitching by the unconscious pilot. This pilot response is more commonly referred to "the funky chicken". This sporadic response is not easily modeled nor simulated and as such was not included in the G-LOC simulation used during this preliminary developmental test. The G-LOC technique used by the test team involved going limp at the time of the simulated G-LOC occurrence and not inputting any pilot activity information. This was accomplished by either completely releasing the control stick and throttle (no stick grip) or by releasing back stick pressure while maintaining a stick grip (depressing the trigger).

Related Developmental Tests of Prototype System

Prior to this in-flight "proof of concept" evaluation, the prototype system under flight evaluation had successfully completed a two-phase, ground based laboratory testing program. During the initial ground simulation, a host IBM personal computer was used to simulate typical T-38 Data Acquisition System (DAS) outputs, transferred these outputs to the test G-LOC system , and then collected the G-LOC results for post test analysis. Boundary condition testing was conducted to verify that input anomalies would not cause a software failure. This was accomplished by inputting unrealistic aircraft inputs to the G-

LOC system and monitoring the system response. During the second phase of ground testing, the system was subjected to an integrated dynamic test which involved running the G-LOC algorithm with the host computer using a representative T-38 flight test profile. The host computer was also subjected to an out-of-tolerance voltage that caused hardware failure. The proper functioning of the system software reset and recovery capability were then successfully verified after this deliberate failure. More detailed information concerning the background of these tests, related studies, as well as results of the ground-based testing are provided in the *Eidetics Test Pilot Users Manual for G-LOC Evaluation* [6].

Chapter 3

DEVELOPMENTAL AND EVALUATION TESTS

Experimental Objectives

The original primary objective of this flight test evaluation was to determine if the prototype G-LOC detection system accurately recognized whether or not simulated G-LOC had occurred during operationally representative maneuvering. More specifically, the objectives were to:

1. Determine the rates at which the prototype system:
   a. Correctly detected G-LOC when G-LOC was simulated (successes);
   b. Failed to detect G-LOC when G-LOC was simulated (failures);
   c. Falsely detected G-LOC when G-LOC was not simulated (false alarms); and
   d. Correctly monitored when G-LOC was not simulated.

Table 3-1 summarizes these four possible G-LOC detection conditions to be evaluated.

Table 3-1. Summary of Possible G-LOC Detection Conditions

G-LOC SIMULATED	G-LOC NOT SIMULATED
G-LOC Detection (OK)	G-LOC Detection (False Alarm)
No G-LOC Detection (Failure)	No G-LOC Detection (OK)

2. Evaluated the logic in the G-LOC detection software and make recommendations to improve the system in future developments.

The test was initially conceived with these objectives in mind to serve as a suitable evaluation of the operability of the G-LOC Detection System when exposed to the actual

flight environment. Early in the program, however, it became clearly evident that developmental work on both the aircraft/G-LOC detection system interface and the system software logic was required to obtain a properly functioning G-LOC Detection System suitable for flight evaluation. Consequently, the thrust of this test program shifted from a functional evaluation to a developmental evaluation. Accordingly, another test objective was introduced as a precursor to those objectives stated previously. The primary objective became to:

3. Develop the prototype G-LOC Detection System to recognize whether or not simulated G-LOC had occurred during operationally representative maneuvering.

As an early proof-of-concept system, the revised primary goal of this evaluation became to develop a functioning G-LOC Detection System that was properly integrated into the dynamic airborne environment, was quite suitable.

Experimental Set-up

Test Aircraft Description

The G-LOC detection system was installed in T-38A S/N 63-8135. The T-38A was a tandem seat, supersonic jet trainer made by Northrop Corporation and powered by two General Electric J85-GE-5 after-burning turbojet engines. The test aircraft had the following instrumentation modifications:

1. Teac Metraplex Data Acquisition System (DAS).
2. Flight test yaw, angle-of-attack, pitot-static nose boom.
3. Sensitive airspeed and Mach indicators and calibrated altimeter.
4. FM telemetry transmitter.

Special cockpit instrumentation in the T-38A included a calibrated altimeter, sensitive airspeed, Mach and G meters, and a G-LOC Indicator Light in the rear cockpit. The onboard Teac DAS recorded the parameters listed in Table 3-2 at a sampling rate of 32 samples per second.

Table 3-2 DAS Recorded Parameters

Parameter	Units
Time	Seconds
Event Marker (Cockpit Activity Indication)	1=no Ckpt Activity 0=Ckpt Activity
Stick Trigger (Stick Grip Indication)	
Normal Acceleration (N_z)	G's
Longitudinal Stick Position	Inches (in)
Longitudinal Stick Force	Pounds Force (lb_f)
Lateral Stick Position	Inches (in)
Lateral Stick Force	Pounds Force (lb_f)
Rudder Pedal Position	inches
Stabilator Position	inches
L/H Engine RPM	Percentage
R/H Engine RPM	Percentage
L/H Afterburner Fuel Flow	Pounds per hour (lbs/hr)
R/H Afterburner Fuel Flow	Pounds per hour (lbs/hr)
G-LOC Detection	Light On
G-LOC Probability	Percentage

The general arrangement diagram of the T-38A test aircraft is provided in Figure 3-1. A more detailed description of the T-38A aircraft is contained in the *T-38A Flight Manual* [7].

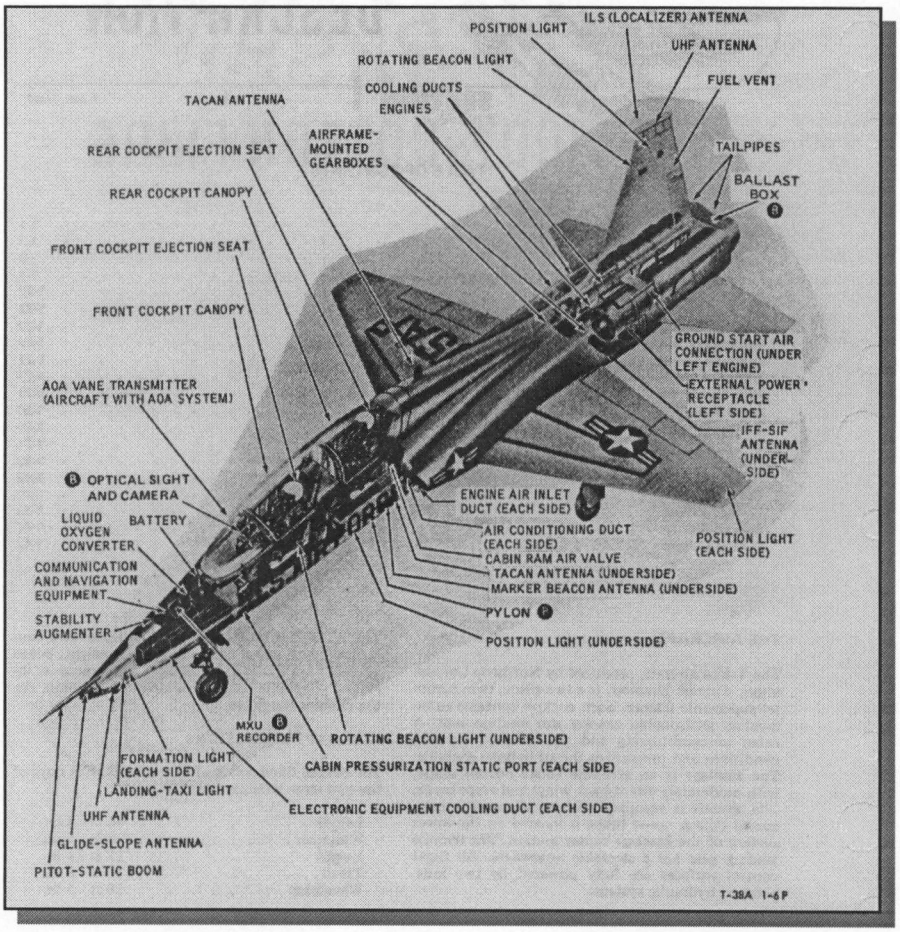


Figure 3-1. General Arrangement Diagram of the T-38A Test Aircraft [7]

Prototype G-LOC Detection System.

The original (baseline) Eidetics G-LOC Detection System was designed to be an aircraft sensor based system capable of detecting G-LOC using aircraft load factor time history (G-LOC probability), and cockpit activity (stick/throttle/rudder pedal movement, cockpit activity button and stick grip). The total system consisted of a Micro Linear Controls MLC-XT computer with serial and parallel ports. The MLC-XT was a simple IBM PC-compatible design with increased ruggedness for industrial applications. The system's software algorithm was designed to receive aircraft data inputs from the T-38A's Metraplex DAS, compute the probability of G-LOC, determine if cockpit activity exists by monitoring

pilot inputs, and then activate a rear cockpit (RCP) mounted LED if G-LOC detection occurred. The complete system block diagram is shown in Figure 3-2.

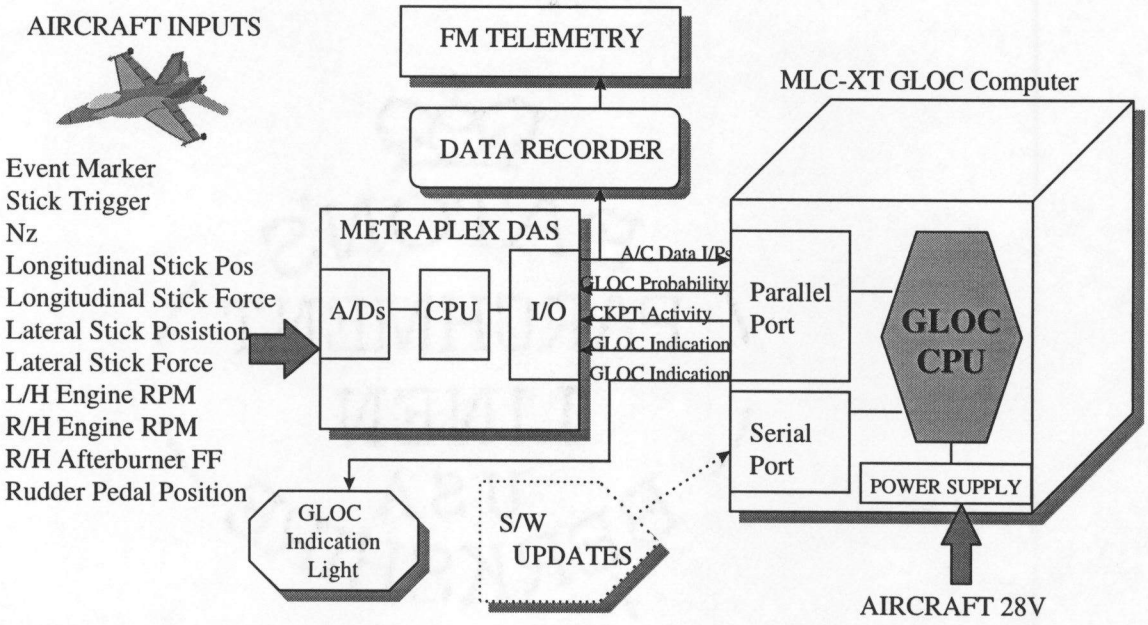


Figure 3-2. G-LOC System Block Diagram

The onboard Teac Metraplex Data Acquisition System (DAS) served as the input source to the G-LOC detection system of the various aircraft data (stick force, position etc.) used to detect pilot activity and determine G-LOC occurrence. Processed output data from the G-LOC box were returned through the DAS for in-flight recording of critical parameters and real-time telemetry to the ground control room. The baseline G-LOC algorithm consisted of two components:

a. G-LOC probability computation; and
b. G-LOC detection.

The probability portion was designed to calculate a cumulative G-LOC probability continually during loaded maneuvering. This probability was a function of G level, G onset

rate, and the length of time the G level was sustained and was expressed as a percentage (0% to 100%). A simplified flow diagram of the G-LOC Probability portion of the algorithm is provided in Figure 3-3.

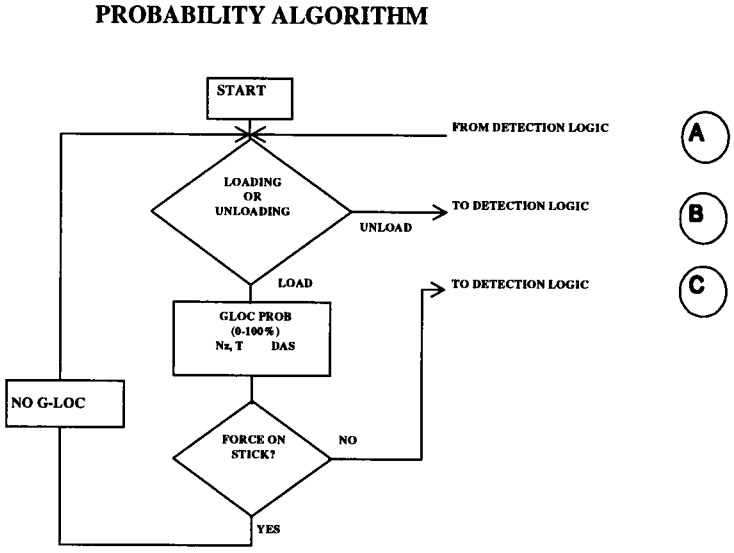


Figure 3-3. Simplified G-LOC Probability Component of Algorithm

The G-LOC probability algorithm used a constant decay rate during aircraft unloading below a 2 G threshold to reduce the G-LOC probability during straight and level flight.

The detection portion of the algorithm was performed only after the aircraft was unloaded to below 2.0 G or the longitudinal stick force was less than 1.5 pounds force (lbf) pull when the aircraft was above 2.0 G's. The rationale was that an incapacitated pilot would not maintain aft stick back pressure and this physiological pilot response was supported by medical research in the centrifuge. This would result in an unloaded aircraft flight condition below 2 G's or small longitudinal stick forces during the unloading from higher G. The assessment of G-LOC occurrence was only required under these conditions. After the unload, the detection logic continually checked for cockpit activity (stick/throttle/rudder pedal movement, stick grip, activation of switches, etc.). The T-38A instrumentation was primarily designed for aircraft performance and handling qualities testing and as such did not

monitor nor record many of the cockpit activities a conscious pilot would conduct during maneuvering flight. Accordingly, several of these cockpit activity indications had to be simulated. Stick grip, for example, was simulated by holding the stick trigger to the half or full detent position. Depressing the event marker button, associated with the DAS, simulated all other cockpit activities not related to stick, throttle, and rudder pedal movement. These included such pilot physical actions as weapon selection changes, master arm/de-arm and radio calls as specific examples. If any cockpit activity was observed, the G-LOC detection portion of the algorithm was completely bypassed. If no activity was observed for a sustained period of 3.0 seconds (time delay designed to avoid flagging G-LOC condition prematurely) and the calculated probability of G-LOC exceeded 50 percent, then a G-LOC condition was flagged. This was indicated to the test aircrew by the activation of a red Light Emitting Diode (LED) lamp in the rear cockpit (RCP). A simplified schematic showing the detection algorithm logic is illustrated in Figure 3-4.

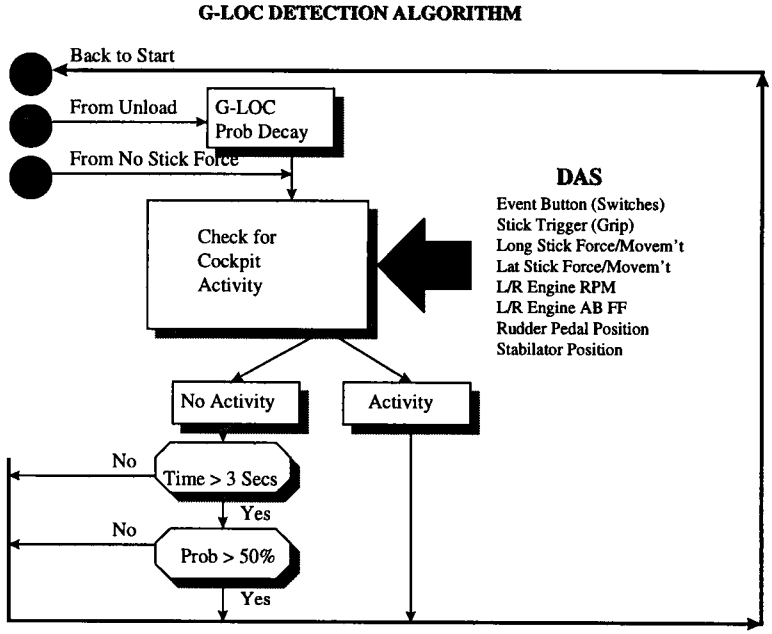


Figure 3-4. Simplified G-LOC Detection Algorithm (Baseline)

During the testing (between test points), the G-LOC probability value and all logic parameters were reset to zero by rapidly depressing the stick trigger switch 3 to 6 times. A

good reset was confirmed by the rear cockpit LED flashing 3 times. Figure A-1 in Appendix A outlines the baseline algorithm flow chart in detail. A more detailed description of the baseline G-LOC detection system is contained in the *Test Pilot Users Manual for G-LOC Evaluation* [6].

G-LOC System Integration into Test Aircraft

The G-LOC Detection System was contained in a small strengthened aluminum box (6.4"x4.2"x2.3") weighing approximately two pounds shown in Figure 3-4 and was mounted in the left nose bay of T-38A aircraft S/N 63-8135. The box housing the system was installed in an area which had previously been occupied by counterweights. The system was wired to the aircraft 28 volt power supply (powered by the Instrumentation Master Power Switch), the Metraplex DAS, and a rear cockpit LED lamp for in-flight detection confirmation.

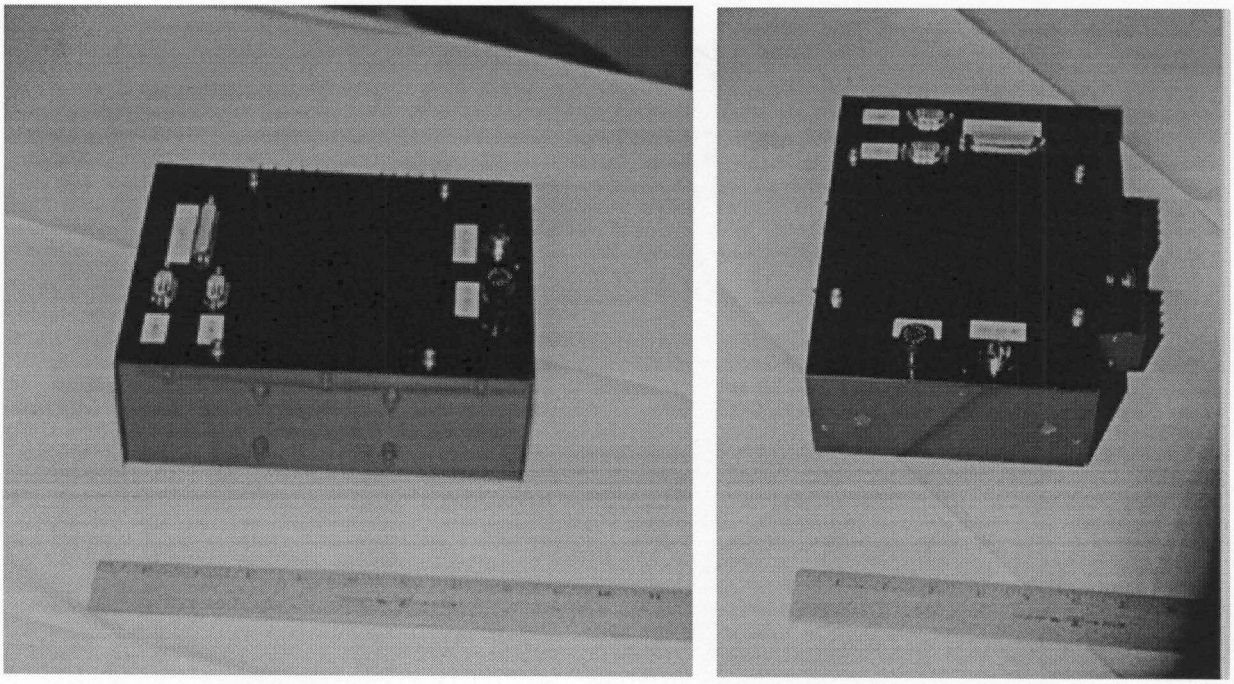


Figure 3-5. G-LOC Detection Box

These installation modifications are depicted in Figure 3-6.

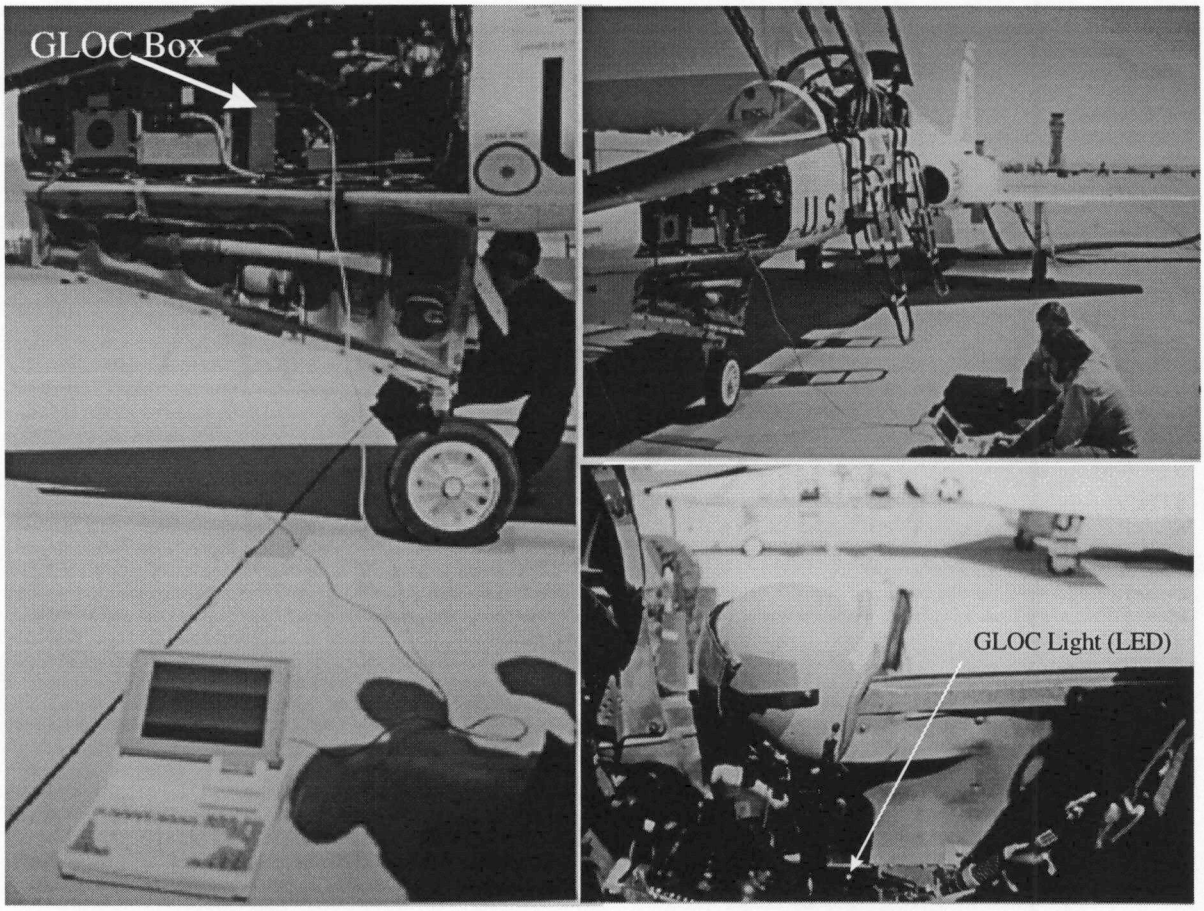


Figure 3-6. G-LOC Detection System Installation in T-38A Test Aircraft (Top Right - T38 aircraft, Bottom Right - Rear Cockpit GLOC Light, Left - Nose Installation)

The T-38A cockpit layout is shown in Figure 3-7 to provide the reader with a better idea of the general cockpit arrangement and more specifically the throttle, rudder pedals, control stick and various switches layout of the T-38A.

The test aircraft had certain limitations that prevented the G-LOC Detection System from being integrated to the maximum extent which had been conceived. Most notably the

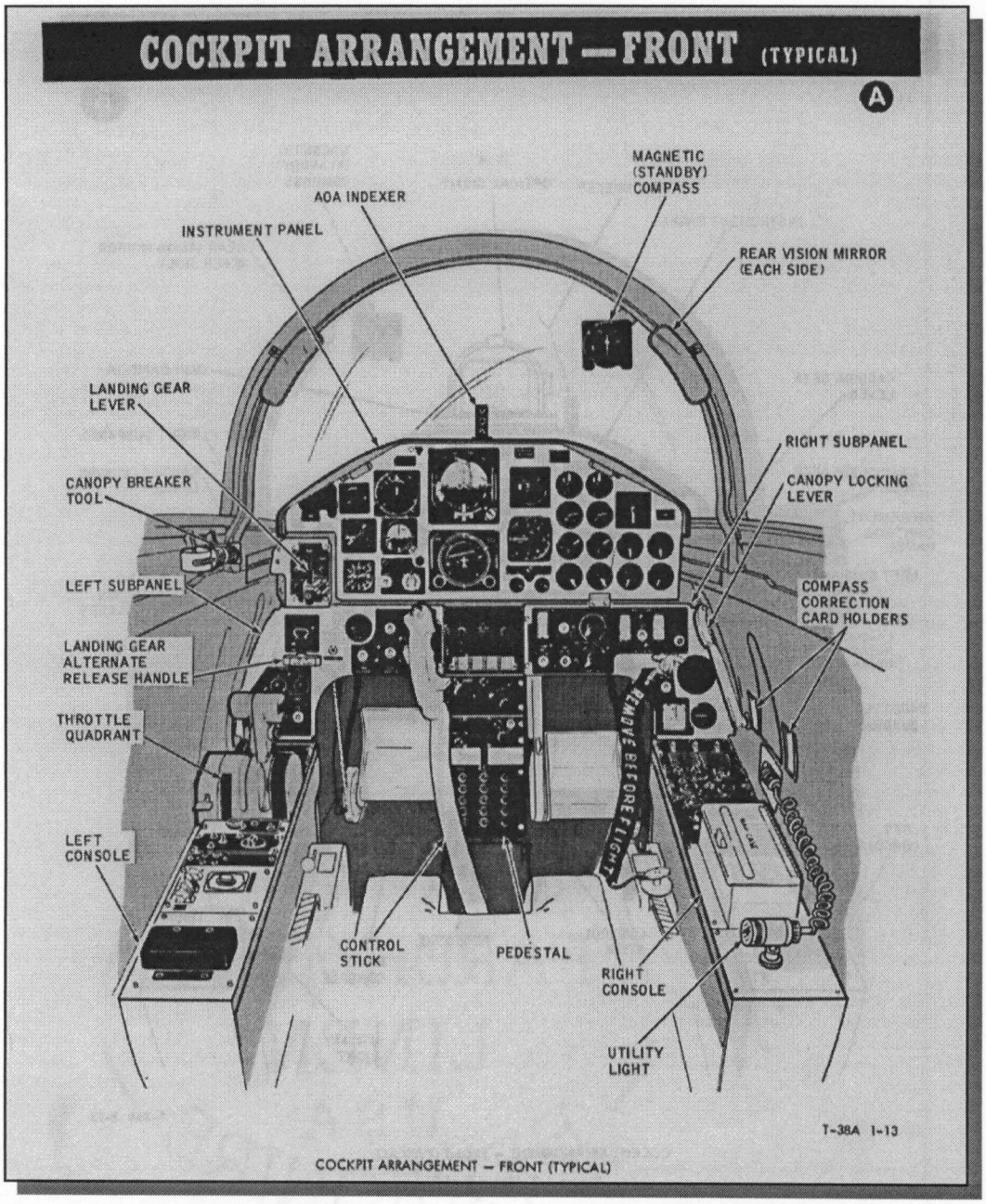


Figure 3-7. General Arrangement T-38A Front Cockpit [7]

aircraft lacked a 1553 data bus from which all desired aircraft parameters, controls and systems could be easily monitored. As already mentioned, several cockpit activity indications were simulated. These inputs, with the exception of normal acceleration (N_z), were designed to indicate cockpit activity when the sensitivity threshold for that input was exceeded. For

example, if stick displacement from trim condition exceeded ±0.5 inches, then the system would flag cockpit activity. This 0.5 displacement threshold was purposely made greater than the stick free-play values of approximately 0.2 inches of travel to avoid false indications of pilot stickactivity. The thresholds for all inputs are shown in Table 3-3.

Table 3-3. Cockpit Activity Thresholds

INPUT	THRESHOLD FOR COCKPIT ACTIVITY
Lateral/Longitudinal Stick Force	Force [3] ±2.0 lbs
Lateral/Longitudinal Stick Displacement	Displacement Change [3] ±0.5 in
Rudder Displacement	Displacement Change [3] ±0.5 in
Left/Right Engine RPM	RPM Change [3] 2.5%
Left/Right Afterburner (AB) Flow	Fuel Flow Change [3] ±2.5% (1 gallon/min)

The only inputs which were not based on a change from trimmed condition were lateral and longitudinal stick force. If either of these values exceeded ±2 lbf, then cockpit activity was flagged. Again this threshold was purposely set higher than the stick breakout forces of approximately 1 lbf. In addition to providing inputs, the DAS also recorded G-LOC parameter outputs from the computer. These were highlighted in Figure 3-2.

A test limit of a maximum of 6 G's was imposed for safety reasons (to avoid an actual inadvertent GLOC episode during testing) and aircraft performance capability limitations. Because of this 6 G test limit, the G-LOC probability algorithm had to be modified. In the 0 to 3.5 G region, the algorithm G input mirrored the actual aircraft G. However, from 3.5 to 5.5 G's (actual), the algorithm input was linearly scaled so that the

maximum planned aircraft load factor (5.5 G's) was input into the algorithm as 9.0 G's. Figure 3-8 illustrates the G-scaling of the algorithm input.

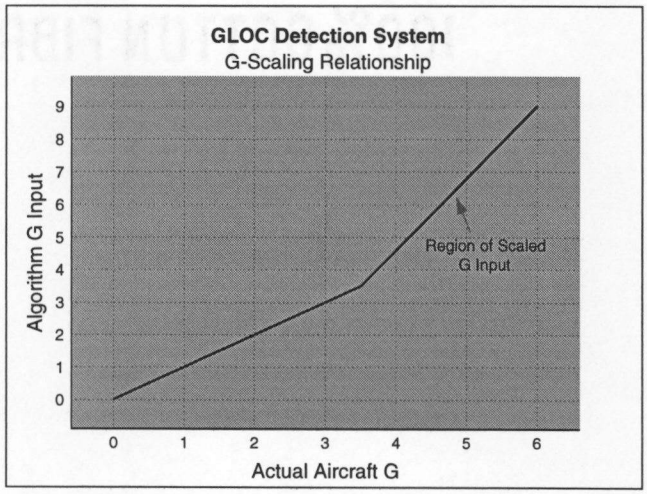


Figure 3-8. G-LOC Detection Algorithm G-Input Scale

Telemetry

In addition to the airborne DAS, the TPS In-Flight Data Acquisition and Processing System (IFDAPS) was used during each test sortie to provide real time feedback to the test aircrew monitoring the flights on the ground regarding aircraft data inputs (i.e. n_z, stick position, etc.) and G-LOC parameters (probability, cockpit activity, and G-LOC indication) as shown in Figure 3-2. The flight test parameters listed in Table 3-2 were relayed for real-time monitoring on the 16 channel strip chart recorders. Use of the IFDAPS facility contributed significantly in collecting consistent data and ensuring test maneuvers were properly performed.

Data Reduction

All DAS recorded parameters were reduced on the TPS PDP 11/84 main frame computer. All of the aircraft data were calibrated in accordance with standard TPS software used for Flying Qualities and Performance Phase data reductions [8]. These data, along with

G-LOC data, were transported to Dell personal computers via the TPS network system. The G-LOC data were then decoded using a specially written software program which transformed the 10 bit binary code output into four unique G-LOC outputs:

a) G-LOC Probability;
b) G-LOC Detection;
c) Cockpit Activity; and
d) Stick Grip.

The G-LOC probability was presented as a percentage while G-LOC detection, cockpit activity and stick grip were presented in binary code (1 = present, 0 = not present). Additional required aircraft data parameters were plotted as a function of time for the test maneuvers flown.

Test Procedures

General

G-LOC testing involved both ground and flight testing. The test program was developed such that the system could be tested using operationally representative maneuvers under moderate G loads with the system scaling actual aircraft G loads to simulate higher G loadings. The pre-planned, repeatable maneuvers were developed to satisfy certain conditions. First they needed to be operationally representative with respect to both aircraft motions and pilot actions. Secondly, each maneuver needed to isolate one element of the software logic (e.g. longitudinal stick force or activation of the event marker, etc.) so that the effects of the isolated parameter could be independently investigated. These maneuvers provided the foundation of the software development by enabling the test team to evaluate each logic element in a realistic, dynamic airborne scenario.

Test Crew Training

Aircrew training prior to the first test sortie involved three general training areas: hands-on training of the Eidetic's G-LOC system hardware; aerospace physiological refresher training dealing with special breathing and G-LOC prevention straining maneuvers; and a thorough review of all applicable TPS Operating Instructions involving G-Induced Loss of Consciousness Policy.

The hands-on system training covered cockpit switchology including system activation (on/off), DAS event button activation, resetting the system using the trigger switch, and using and interpreting the rear cockpit G-LOC light indicator. This training was conducted in conjunction with the system ground testing prior to the first flight.

Although the test program had been set up for test maneuvers for a maximum aircraft load factor of 5.5 G's, the importance of properly performing the L-1 straining maneuver to reduce aircrew fatigue due to repeated moderate G maneuvers could not be overlooked. Accordingly each test team crewmember received one hour refresher training from an aerospace physiology specialist covering proper breathing techniques and other means for reducing G-induced loss of consciousness.

Ground Test Methods.

Ground testing was performed prior to the first sortie to verify the DAS/G-LOC system interface. It included a 30 minute evaluation with engines running in which all G-LOC system inputs were checked (except normal acceleration and afterburner fuel flow) to ensure that they properly indicated cockpit activity. Table 3-4 shows the inputs which were checked during the ground evaluation. Each aircraft input was tested independently with the system being reset between each test. For example, after resetting the system and starting from the neutral stick position, the longitudinal stick position and force inputs were verified by slowly pulling aft on the stick. Real time aircraft telemetry was monitored to ensure that cockpit activity was being flagged when stick forces and deflections were greater than 2 lbs and 0.5 inches, respectively. Similar checks were performed for all system inputs during ground testing to ensure proper indications of cockpit activity. DAS data, recorded during the ground check, were reduced and analyzed to ensure consistency with the real-time

telemetry indications. This also afforded the test team the opportunity to evaluate the data reduction procedures specifically developed for the G-LOC project.

Table 3-4. G-LOC Ground Check

Cockpit Activity Parameter	Cockpit Task*
Event Marker	Press control stick button
Control Stick Trigger	Squeeze and Release Trigger
Longitudinal Stick	Full Aft and Full Forward
Lateral Stick	Full Left and Right
Rudder Pedals	Full Left and Right
Engine RPM (Left/Right)	Idle to Idle plus 10%

*Reset G-LOC detection system between inputs.

Flight Test Methods

Generic Test Maneuvers.

The test maneuvers were broken down into three basic or generic maneuvers shown in Table 3-5.

Table 3-5. Generic Test Maneuvers

Generic Maneuver	Operational Maneuver
1. Windup Turn	OBFM/DBFM Sustained G Turn
2. Vertical Pull-up	Air-to-Ground Pull Off Target Aerobatic Maneuvering
3. Abrupt Turn	Defensive Break Turn Hard Turns Offensive Weapons Pointing

Windup Turn.

The windup turn maneuver represented typical offensive and defensive basic fighter maneuvering and high sustained G turning which occurs in operational flying using a low to moderate G onset rate. The technique involved establishing level flight at 400 KIAS and an altitude that allowed for a descending 360 degree turn at the target G. The pilot then conducted a coordinated turn using a G buildup rate of 2 G's per second to obtain the target G. Power adjustments were permitted depending on the specific operational maneuver being represented. Altitude loss was permitted in order to maintain the target G through the 360 degree turn. After completing 360 degrees of turn, the aircraft was recovered to 1 G, level flight unless otherwise specified (simulating G-LOC). A typical generic Wind Up Turn is shown in Figure 3-9.

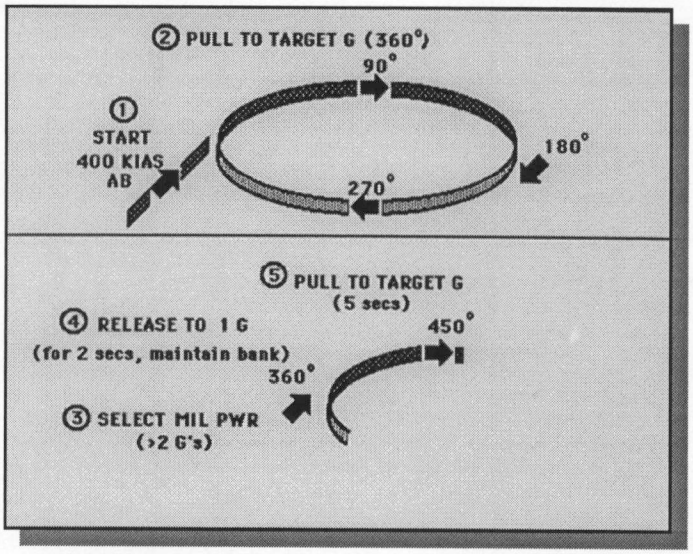


Figure 3-9. Sample Wind Up Turn Test Maneuver

Vertical Pull-up.

The vertical pull-up maneuver represented various operational maneuvers which used a moderate to high G onset rate. The maneuver consisted of attaining a 30 degree dive at 450 KIAS at a power setting below military power. Once stabilized in the dive, the pilot smoothly pulled to the target G within 1 second (moderate onset rate). The throttles remained fixed during the maneuver unless otherwise specified. The aircraft was recovered

to a 1 G, wings level flight condition after attaining a 20 degree nose high attitude. A typical generic Vertical Pull-up is shown in Figure 3-10 where GLOC is simulated.

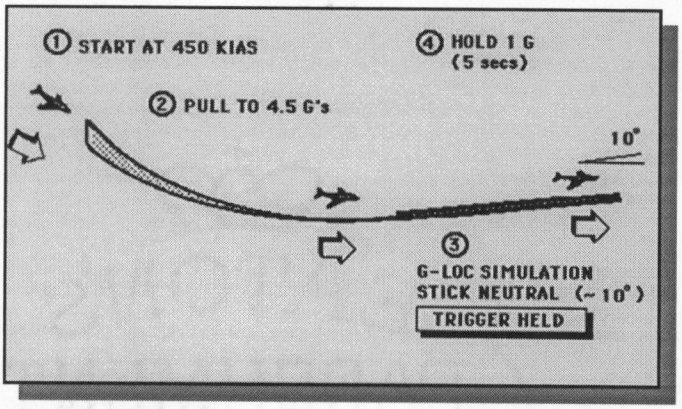


Figure 3-10. Sample Vertical Pull-up Test Maneuver

Abrupt Turn.

The abrupt turn maneuver represented operational maneuvers which employ a high G onset rate. The test maneuver was conducted from a level flight attitude at 400 KIAS. The aircraft was then rolled to 80° of bank followed with a smooth application of aft stick to achieve the target G within 1 second. Power adjustments were made depending on the specific maneuver being simulated. The target G was sustained through 180 degrees of heading change at which time recovery to a 1 G wings level flight attitude was made unless otherwise stated. A typical generic Abrupt Turn is shown in Figure 3-11.

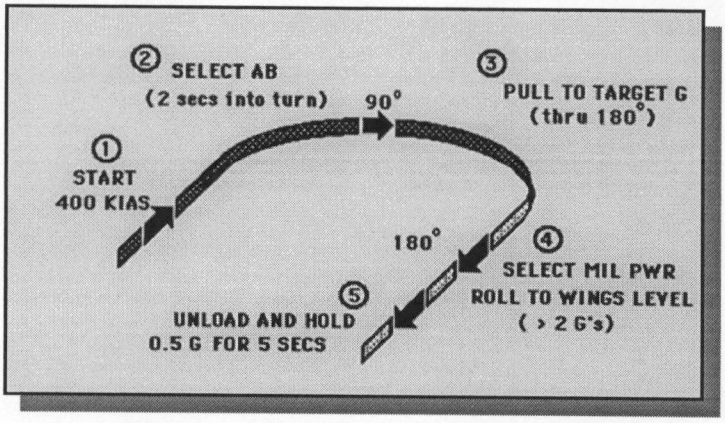


Figure 3-11. Sample Abrupt Turn Test Maneuver

Specific Test Maneuvers

By adding various recovery techniques and cockpit activities to the generic maneuvers, specific test maneuvers were created. These specific maneuvers were designed to simulate combat maneuvers in terms of both aircraft performance and cockpit activity. The heart of the G-LOC flight testing centered around the 14 specific test maneuvers described in Table B-1 and depicted in Figures B-1 through B-3 of Appendix B. These maneuvers represented areas of a higher than normal potential for causing G-LOC. This was based on the test team's operational experience and was supported by physiological data. Each maneuver, in addition to being operationally realistic, was designed to isolate and test each individual system input. Table 3-6 indicates the specific system input being tested by the 14 specific maneuvers.

Table 3-6. Logic Parameters Tested with Maneuvers

MANEUVER	RPM	AB (FUEL FLOW)	LAT STICK	LONG STICK	COCKPIT ACTIVITY	STICK GRIP	TIME DELAY
1A B				X			X
1C D			X				
1E F						X (RELEASED)	X
1G H						X (HELD)	X
2A					X		
2B	X						
2C							X
3A				X			
3B		X					X
3C							X

Fluid Maneuver Testing

Two "fluid" maneuver sequences were developed to simulate the dynamic, longer term flight profiles representative of typical operational ground-to-ground and air-to-air

maneuvering. These groups of maneuvers were to be flown consecutively without resetting the G-LOC Detection System between maneuvers. These tests would evaluate the system's robustness to the dynamic flight environment and verify G-LOC probability build-up and decay in a changing flight environment. Figures 3-12 and 3-13 graphically illustrate the air-to-ground and air-to-air maneuver sequences which were planned.

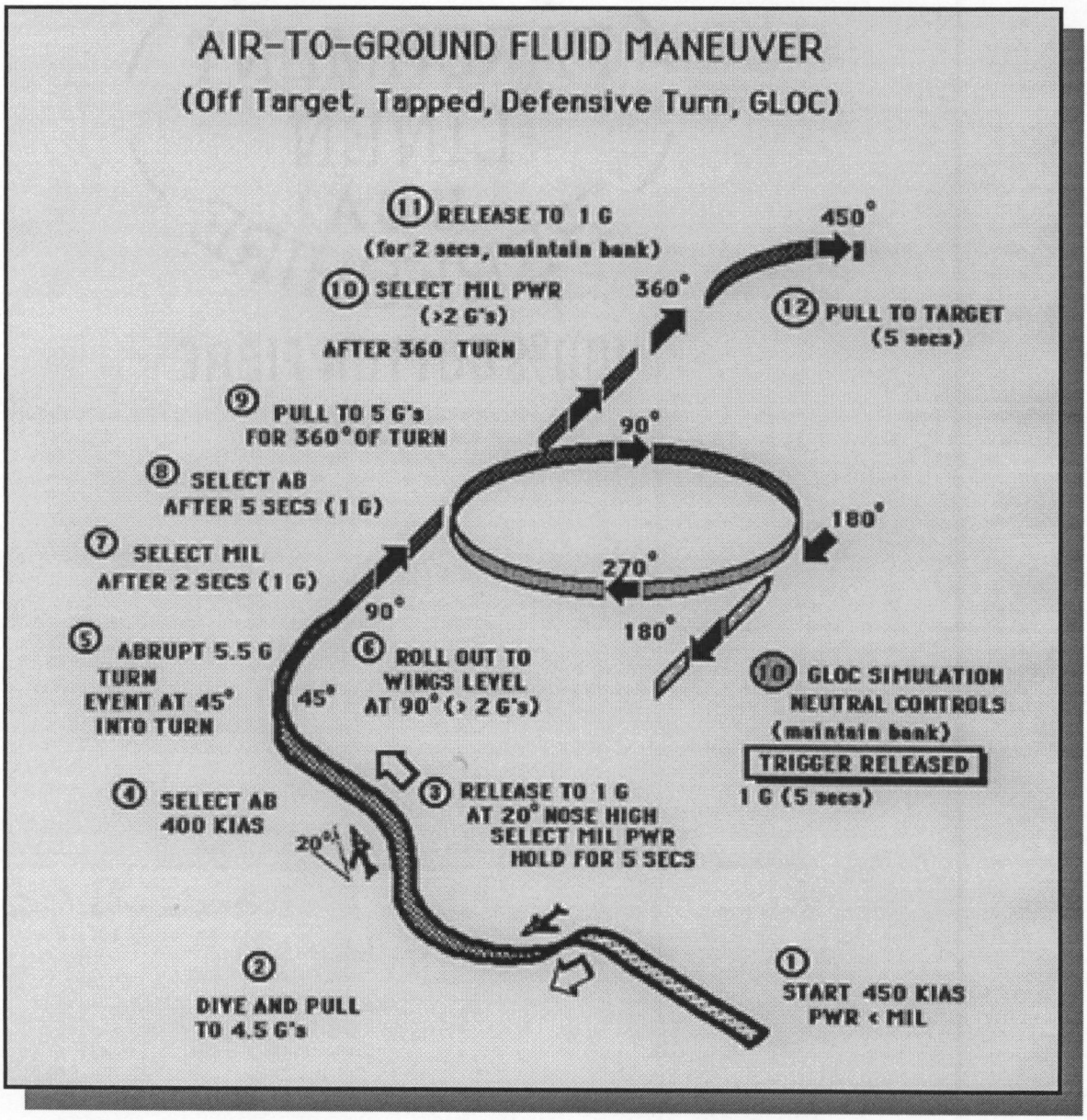


Figure 3-12. Air-to-Ground Fluid Maneuver Sequence

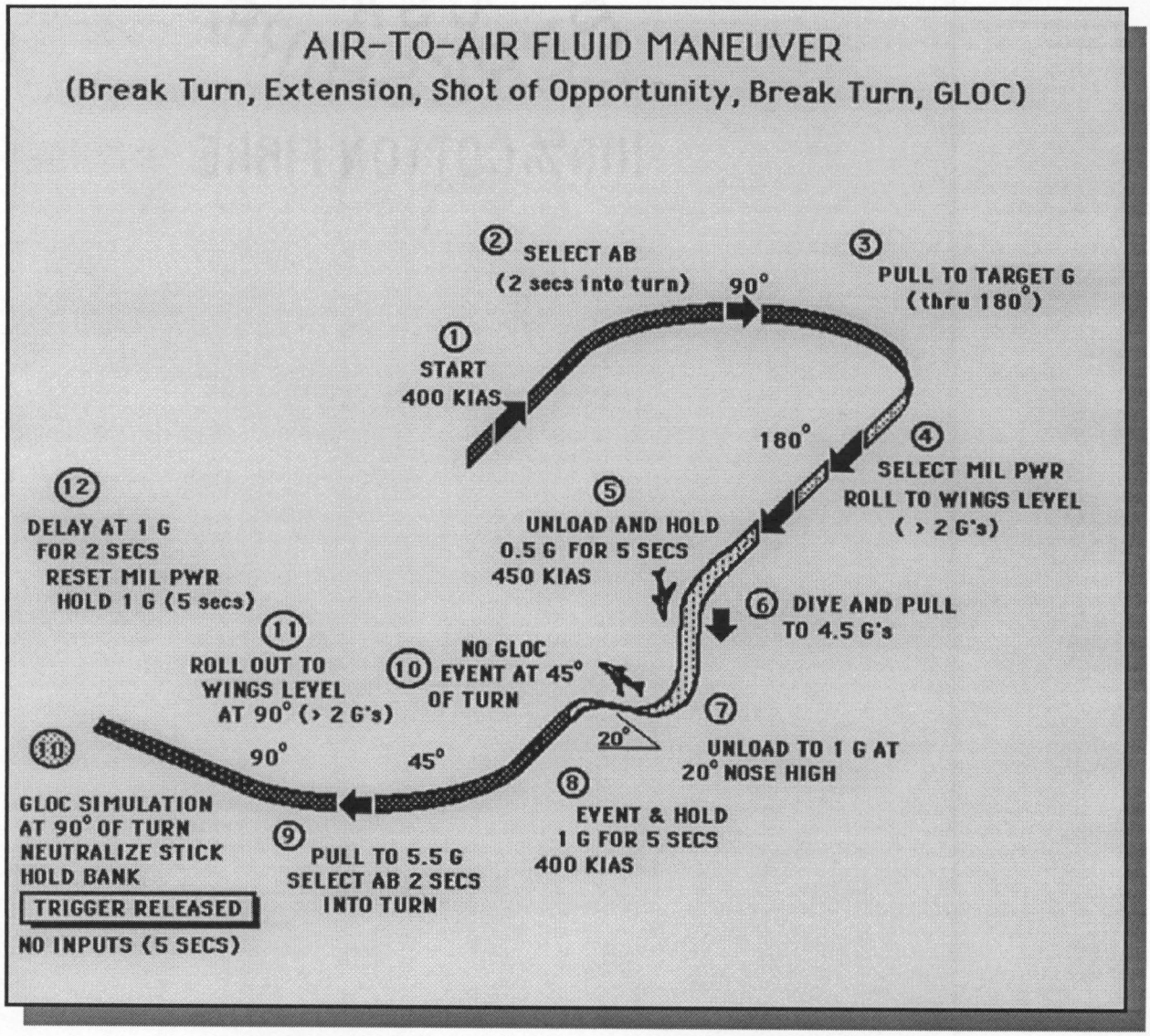


Figure 3-13. Air-to-Air Fluid Maneuver Sequence

G Envelope Coverage

Figure 3-14 indicates how the maneuvers were designed to cover the full range of system G loads. By isolating individual system inputs and covering the full range of system G loads, these 14 operationally realistic maneuvers were used to analyze and develop the overall system.

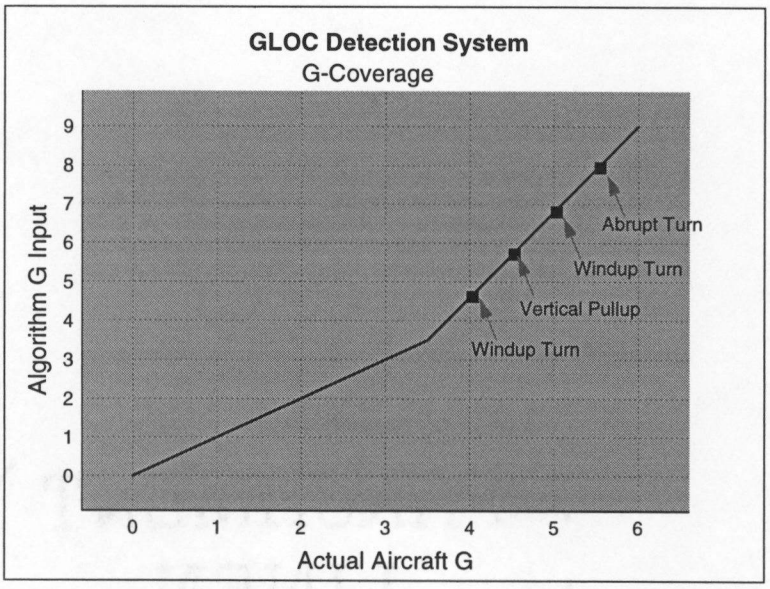


Figure 3-14. Test Maneuver G Coverage

Maneuvers in which G-LOC was simulated were performed by initially releasing the stick and allowing it to return to the trimmed position. No cockpit activities (i.e. throttle movements, rudder pedal movements, stick movements, or switch actuation's) took place until either the G-LOC system detected G-LOC or recovery of the aircraft was necessary to remain within the test envelope. These actions did not include any simulation of pilot flailing or jerking movements.

A minimum of 10 specific test maneuvers were planned for each test sortie except for the first two sorties which were designated as familiarization sorties. The "fam" sorties consisted of 4.0 G maneuvers (1A, 1C, 1E, 1G) and unusual attitude recovery practice, G onset practice, and G awareness maneuvers in accordance with the test plan (Reference 4). Prior to initiating test maneuvers, an Airborne Input Data System (AIDS) check was performed on each test sortie. The AIDS test independently checked each cockpit activity indication with the system being reset between each activation. The AIDS check is shown in Table 3-7.

Table 3-7. Airborne Input Data System Check

Cockpit Activity Parameter	Cockpit Task*
Event Marker	Press control stick button
Control Stick Trigger	Squeeze and Release Trigger
Longitudinal Stick	Singlet-Both Directions
Lateral Stick	Aileron Roll - 1/2 deflection
Rudder Pedal	Singlet-Both Directions
Engine RPM (Left)	80% to Mil Power to 80%
Engine RPM (Right)	80% to Mil Power to 80%
AB Fuel Flow (Left)	80% to AB Power to 80%
AB Fuel Flow (Right)	80% to AB Power to 80%
Normal Acceleration	4 G Level Turn

*Reset G-LOC detection system between inputs.

After completing the AIDS check, the first test maneuver was initiated from a stabilized, 1G, level flight attitude at the appropriate maneuver entry conditions (airspeed and altitude). After each maneuver was completed, the entry conditions for the next test point were established, and the G-LOC system was reset. Table B-2 summarizes the specific test maneuvers that were performed on each of the eight project sorties.

Flight Test Envelope.

All test maneuvers were successfully performed within the test envelope shown in Figure 3-15. This envelope was used primarily to avoid known areas of engine flameout and

compressor stall susceptibility. This heart of the T-38 flight envelope was completely adequate for the scaled G loadings required for the flight test program.

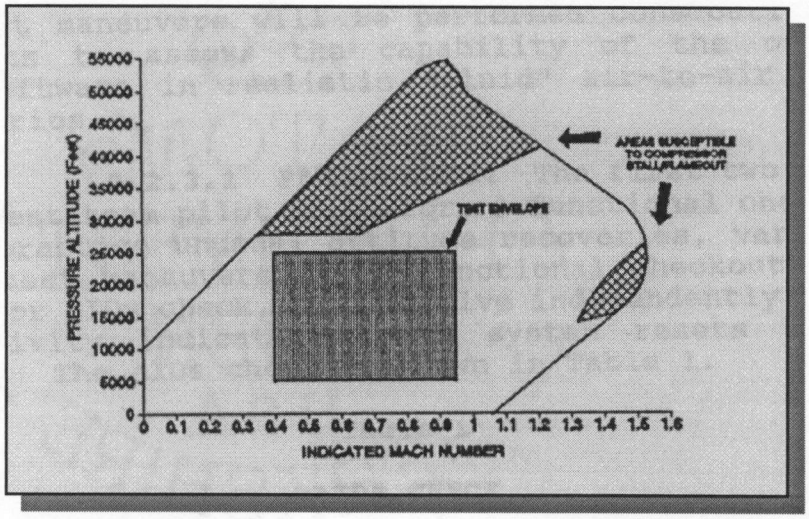


Figure 3-15. Flight Test Envelope

Test Results and Analysis

Software Development

Development of the G-LOC Detection System from the baseline configuration to the final, functional system required five dedicated test sorties and substantial additional ground simulation testing. The initial phase included ground testing and the two familiarization sorties. Software changes as a result of this initial testing are summarized below:

1. Left AB fuel flow was no longer used as an input due to sensor malfunctions (noise).
2. G-LOC probability spikes were eliminated with a simple software change.
3. Lateral stick force indicating cockpit activity was increased from 1 lbf to 2 lbf.

The noisy left AB fuel flow input which was creating false cockpit activity inputs is shown in Figure 3-16. The solution was to disconnect the left AB fuel flow input to the DAS.

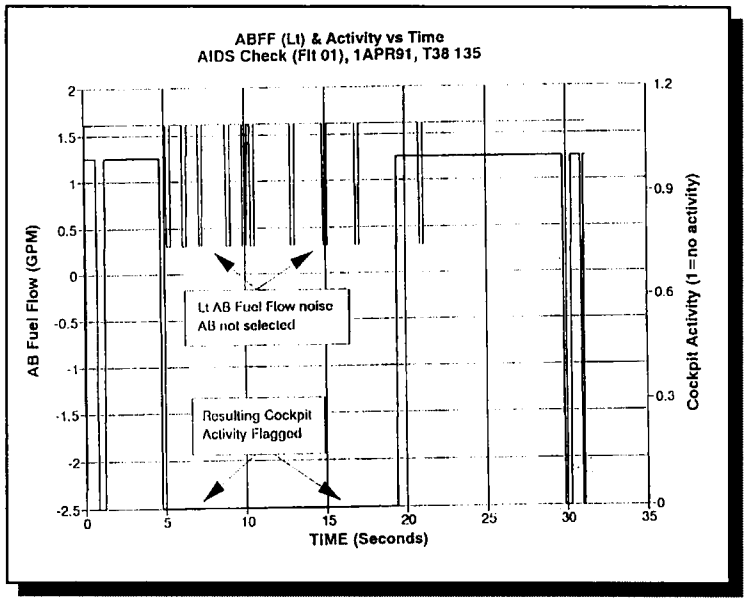


Figure 3-16. Noisy Left AB Fuel Flow Input

Figure 3-17 shows a time history trace of typical aileron forces required during straight and level flight. This clearly shows that the original $\pm$ 1 lateral pound force threshold was in fact much to sensitive. The lateral force threshold was increased to $\pm$ 2 lbf.

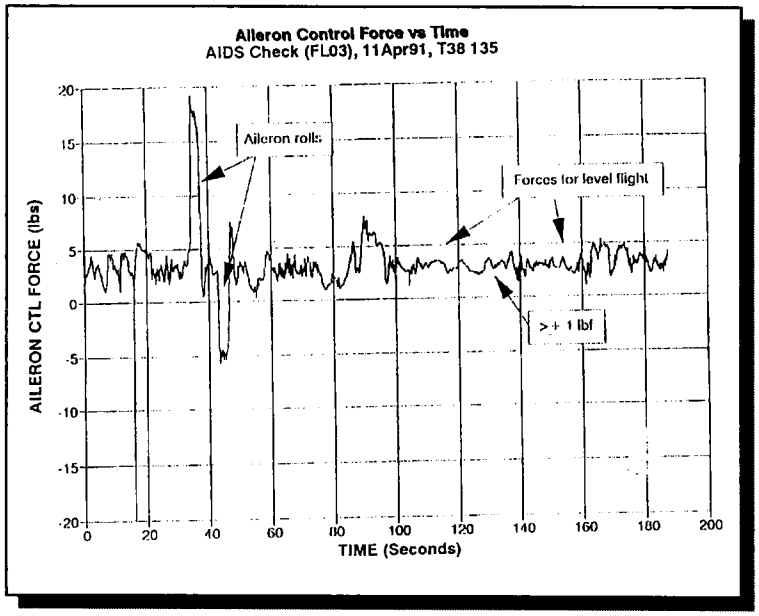


Figure 3-17. Lateral Stick Forces for Level Flight

These changes were implemented and the revised system was re-evaluated on sorties #3 and #4. The 33 maneuvers flown during these sorties can be found in Table B-2. Of the 33 maneuvers, 12 simulated G-LOC. The system did not detect any of the simulated G-LOC conditions. Post flight data analysis revealed that all DAS/G-LOC interfaces were working properly and cockpit activity was being flagged at the appropriate times during the maneuvers. The G-LOC probability was also building up appropriately. However, a significant logic problem was discovered concerning the decay of the G-LOC probability being used for G-LOC detection.

Figure 3-18 shows the time history plot of the GLOC probability build up superimposed over the G load time history. This test maneuver involved a vertical pull up with a fairly rapid G onset rate to just over 7 G which was held for approximately 10 seconds. GLOC was then simulated by releasing aft stick pressure and the aircraft was subsequently unloaded back to around 1 G. The GLOC probability buildup is shown once the loaded condition was achieved. The probability quickly built up to a maximum of 57% and then started to decay as a result of the aircraft unloading. The system correctly delayed three seconds and then searched for any indications of cockpit activity. None had been simulated and as a result the algorithm then checked the GLOC probability value. Instead, however, of using the 57% value, the decayed value of 37% which corresponded with the GLOC probability 3 seconds after the detection algorithm initiation. The algorithm was incorrectly using the real-time GLOC probability rather than the value at the start of the detection cycle. As a result, in practically all cases the probability had decayed below the 50% detection threshold because of the linear decay rate and a GLOC detection could not occur.

This software logic flaw was corrected so that the maximum probability value at the start of the detection cycle was used to determine whether or not GLOC had occurred.

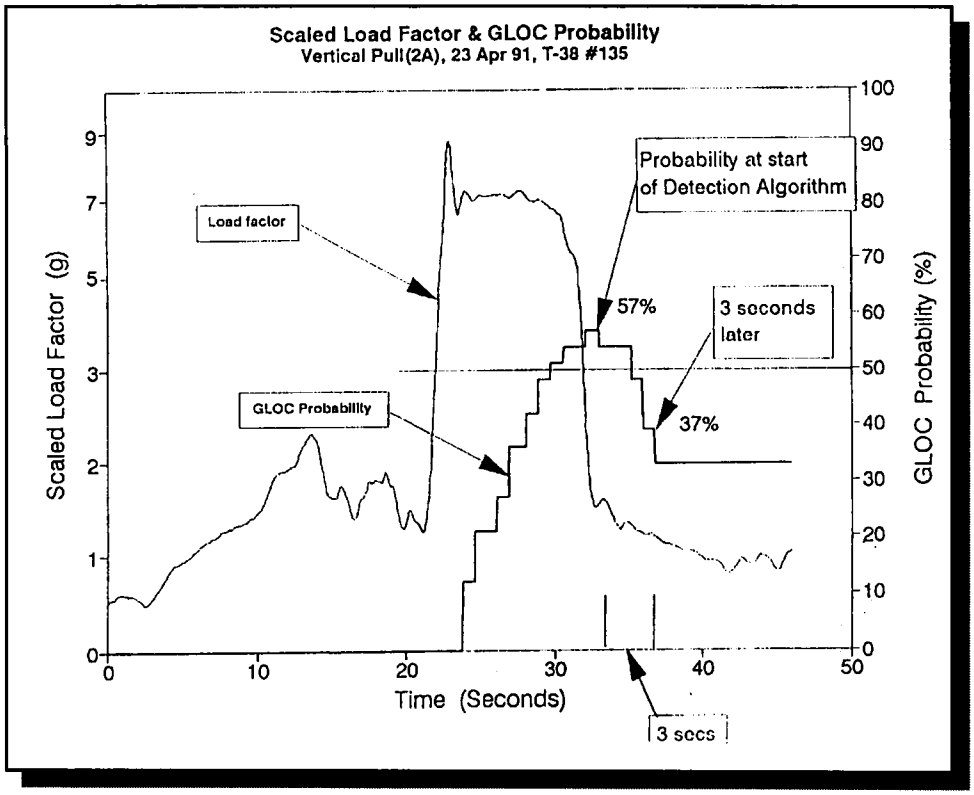


Figure 3-18. Incorrect GLOC Probability Value used for Detection

The system was reevaluated on sortie #5. The maneuvers flown during this sortie can be found in Table B-2. Post flight data analysis revealed that the previous change was ineffective. The G-LOC Detection System still did not detect simulated G-LOC although the DAS system interfaces were functioning correctly. A second logic flaw was discovered and corrected. However, checking each software change with a test sortie was costly and time consuming. Instead, a ground simulation procedure was created to investigate the detection software with actual flight data from sortie #5. In this way, flight test data could be run through the detection system logic and specific algorithm parameters could be monitored frame by frame. This process proved to be invaluable in analyzing and correcting software faults. The software changes implemented after sortie #5 were successfully ground checked using this procedure. The ground simulation process is described in Annex C.

Flight Test Results

The revised software was flown on sorties #6, #7, and #8. Figure A-2 shows the final algorithm flow chart in detail. A total of 41 maneuvers were flown on these three sorties as summarized in Table B-2. During all three sorties the G-LOC Detection System functioned as designed. Figure 3-19 shows maneuver 3C test results in which a successful G-LOC detection occurred.

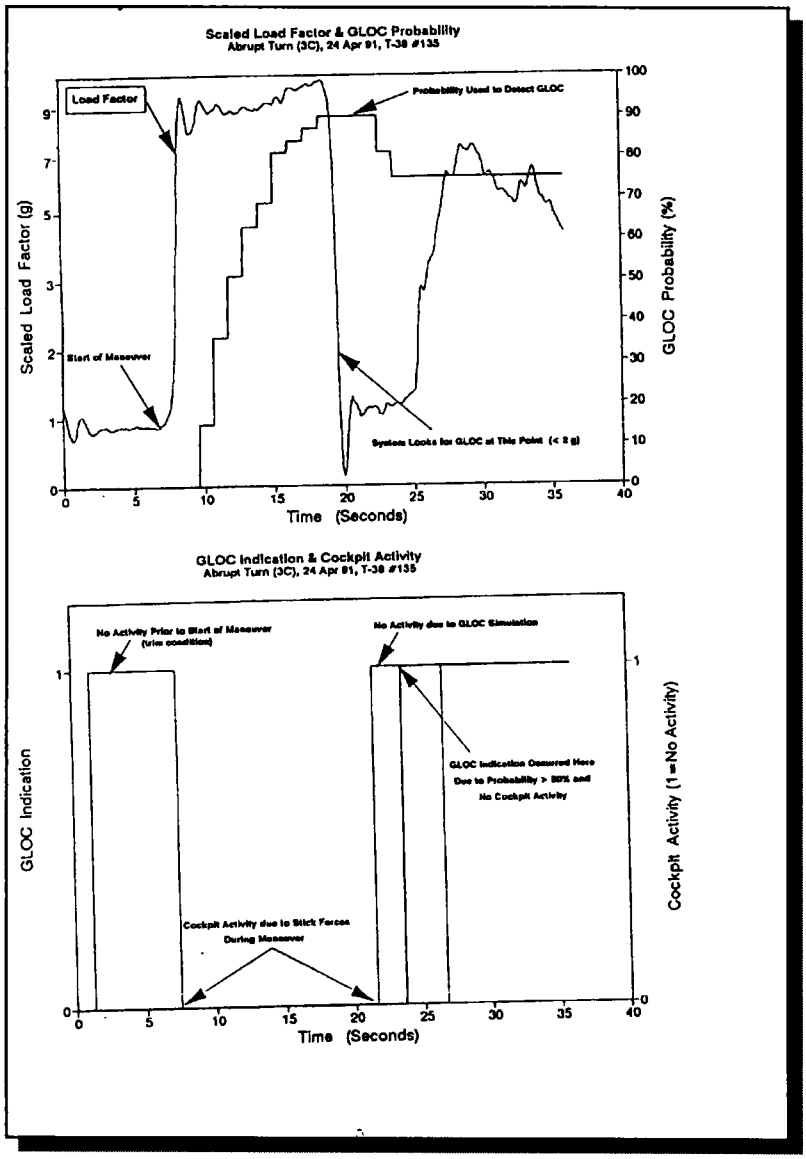


Figure 3-19. Maneuver 3C Test Results

This maneuver consisted of a scaled 9G abrupt turn followed by G-LOC simulation and G-LOC detection. The top plot shows how G-LOC probability built to a maximum of 90 percent as the load factor increased and was sustained during the maneuver (8 to 19 seconds). This was the G-LOC probability used when the system detected G-LOC. The bottom plot shows the corresponding cockpit activity and G-LOC indication throughout the maneuver. Prior to the start of the maneuver, there was no cockpit activity (1 to 7 seconds), as the aircraft was stabilized in 1G flight. Cockpit activity was indicated between 7 and 21 seconds due to the aft stick forces which were required to sustain the loaded condition (greater than two pounds). From 19 to 20 seconds, G-LOC was simulated by releasing the control stick and making no further control inputs. This is illustrated by the sharp decrease in load factor beginning at 19 seconds. At 21 seconds the system detected no cockpit activity as seen in the bottom plot. At 24 seconds, 3 seconds after no cockpit activity was detected, the system correctly identified a G-LOC condition.

These results indicated that the DAS/G-LOC interface worked properly. Cockpit activity was flagged at the appropriate times and the probability buildup and detection functions operated as designed. Results were consistent on all 41 maneuvers flown during sorties #6, #7, and #8--the system operated precisely as designed. Implementation of this type of G-LOC detection system was therefore considered feasible. Consequently, a system designed to unobtrusively detect G-LOC, using aircraft data, shows promise.

Logic Flaws

Although the system logic functioned exactly as it was designed, the test team concluded that this logic was flawed in certain areas. This was based on the test team's combined operational experience and accepted physiological data. Consequently, in its present form, the system would be inadequate for military use and would require additional development and future validation flight test.

Stick Grip Logic.

During sorties #6, #7 and #8, G-LOC was simulated on 17 of the 41 maneuvers. Of the 17 simulations, the system detected G-LOC 15 times and failed to detect G-LOC

twice for a detection rate of 88 percent. During the two failures to detect, the system functioned exactly as designed. This indicates that there was a problem with the logic and not the implementation of that logic. The two test points where the system failed to detect G-LOC were both maneuver 1H. This maneuver was a scaled 8G windup turn where G-LOC was simulated with the pilot still depressing the stick trigger (indicating that he was still gripping the stick). Based on documented results of operational pilot G-LOC training at Brookes Medical Research Facility collected over the years, where a similar stick trigger was used, this is an entirely possible scenario. In reality, sometimes the pilot held the trigger, and at other times he released it during G-LOC conditions [12] in the centrifuge. As the data in Figure 3-20 indicate, a G-LOC condition was not detected because the stick trigger, when depressed, continuously flagged cockpit activity. Consequently the system considered the pilot conscious and detection was impossible.

It was concluded that the stick grip logic, as currently implemented in the detection system, is inadequate because it prevents G-LOC detection with the pilot holding or gripping the stick.

Cockpit Activity Logic.

G-LOC was not simulated during 24 of the 41 maneuvers flown on sorties #6, #7 and #8. Of these 24 maneuvers, there were five G-LOC detections (false alarms) for a false alarm rate of 20.8 percent. Again, the system functioned exactly as designed. As in the detection failures, the false alarms were a result of faulty logic and not the implementation of that logic. Three of the five false alarms were due to AB fuel flow logic. The remaining two false alarms were due to cockpit activity logic simulated by the event button.

Figure 3-21 shows maneuver 3B, a scaled 9G abrupt turn, which isolated the AB fuel flow logic. As the data indicate, there was cockpit activity between 8 and 25 seconds due to stick forces during maneuvering that were greater than two pounds. During this loading, the G-LOC probability reached a maximum of 75 percent at 20 seconds. At 25 seconds, the aircraft was unloaded and the only cockpit activity performed was deselecting AB at 27 seconds. At 28 seconds, cockpit activity was flagged due to this AB de-selection. However, at 29 seconds, no cockpit activity was once again detected indicating that AB de-selection was

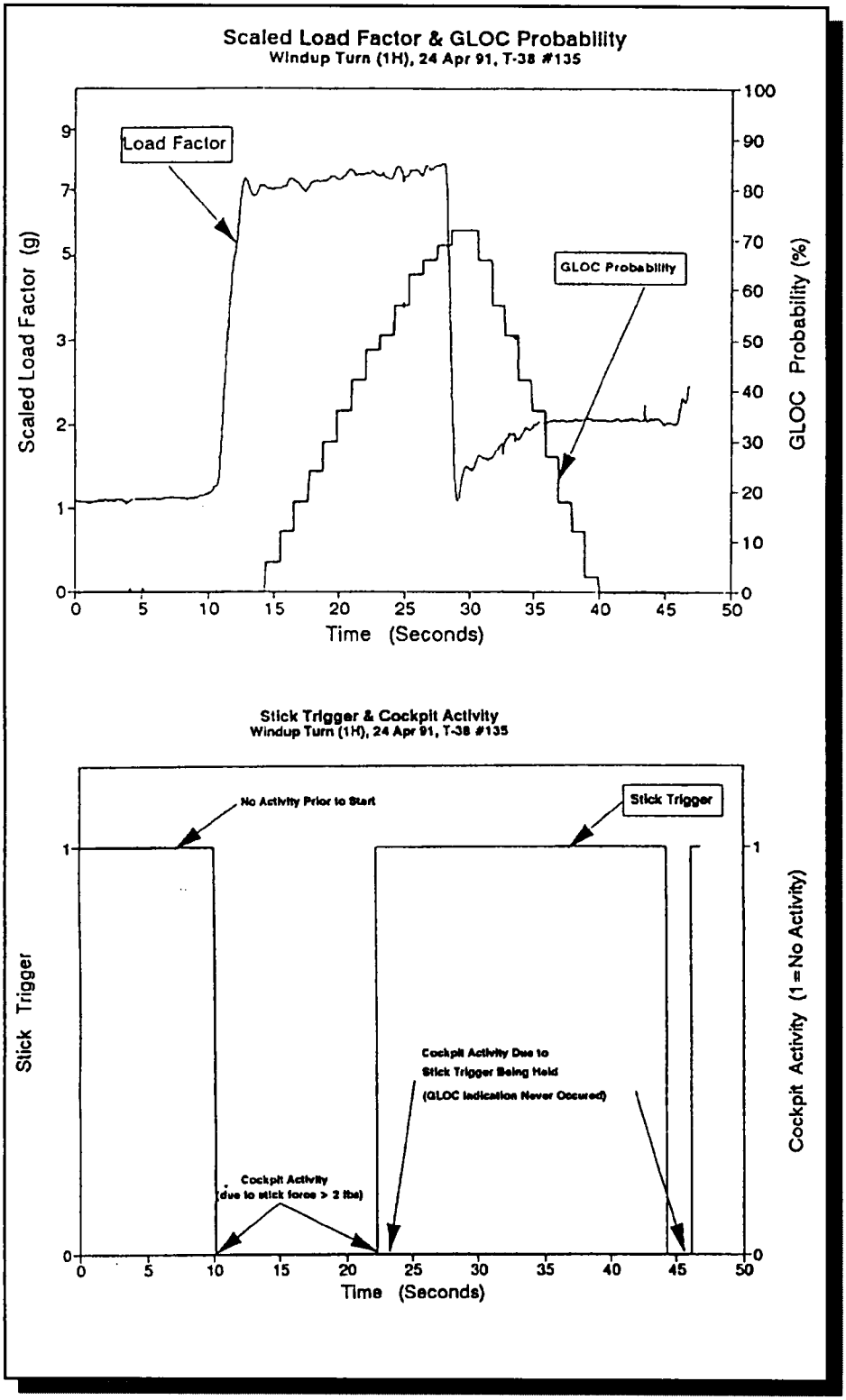


Figure 3-20. Maneuver 1H (Detection Failure from Stick Trigger)

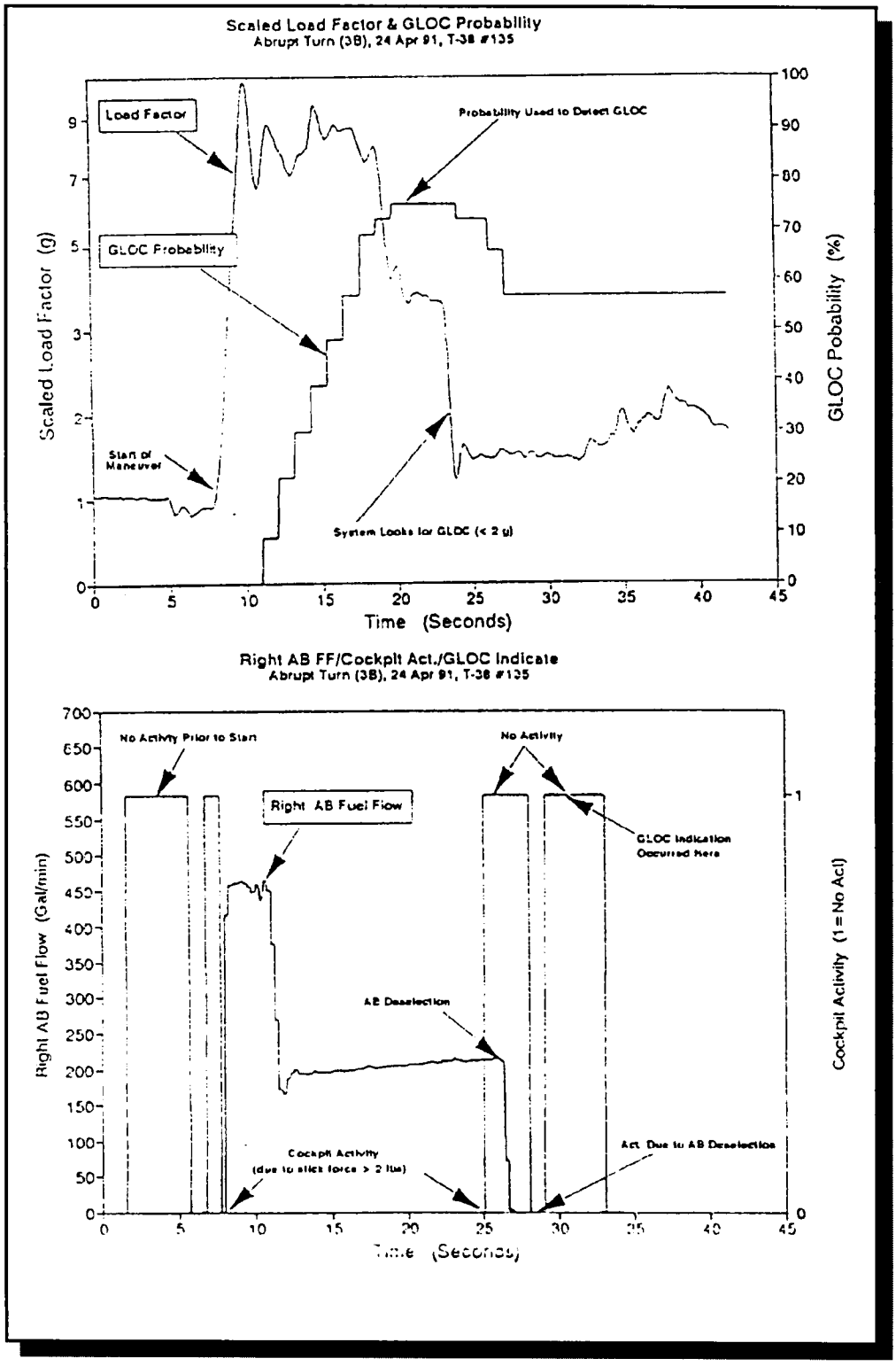


Figure 3-21. Maneuver 3B (False Alarm Following AB Fuel Flow De-selection)

only a momentary indicator of cockpit activity. Shortly thereafter, the system falsely detected G-LOC.

Figure 3-22 shows maneuver 2A, a scaled 6.5G vertical pull-up, where activation of the event button was isolated. The event button simulated all pilot actuated switch changes (e.g. radar mode changes, safing weapons, radio calls etc.).

The maneuver begins at 21 seconds and cockpit activity was indicated between 21 and 31 seconds due to stick forces greater than 2 pounds during the pull-up. The G-LOC probability reached a maximum of 58 percent during the pull-up at 32 seconds. At this time, all cockpit activity ceased. At 33 seconds, the event marker was depressed simulating a pilot actuated switch change. At 34 seconds, cockpit activity was indicated due to the event button actuation. At 35 seconds, there was no cockpit activity, indicating that the event button, like AB de-selection, only momentarily flagged cockpit activity. Three seconds later, a false G-LOC detection occurred.

One of the characteristics of the G-LOC phenomena is involuntary jerking and flailing movements during the episode [11]. However, conscious actions such as selection/de-selection of AB and activation of cockpit switches would be virtually impossible when experiencing G-LOC [10]. These specific actions are a strong indication that the pilot is not experiencing G-LOC. For this reason, such conscious actions should prevent G-LOC detection. When modeled in the G-LOC Detection System, conscious actions such as selecting/deselecting afterburner and actuating cockpit switches should prevent G-LOC detection until the next loaded condition or system reset.

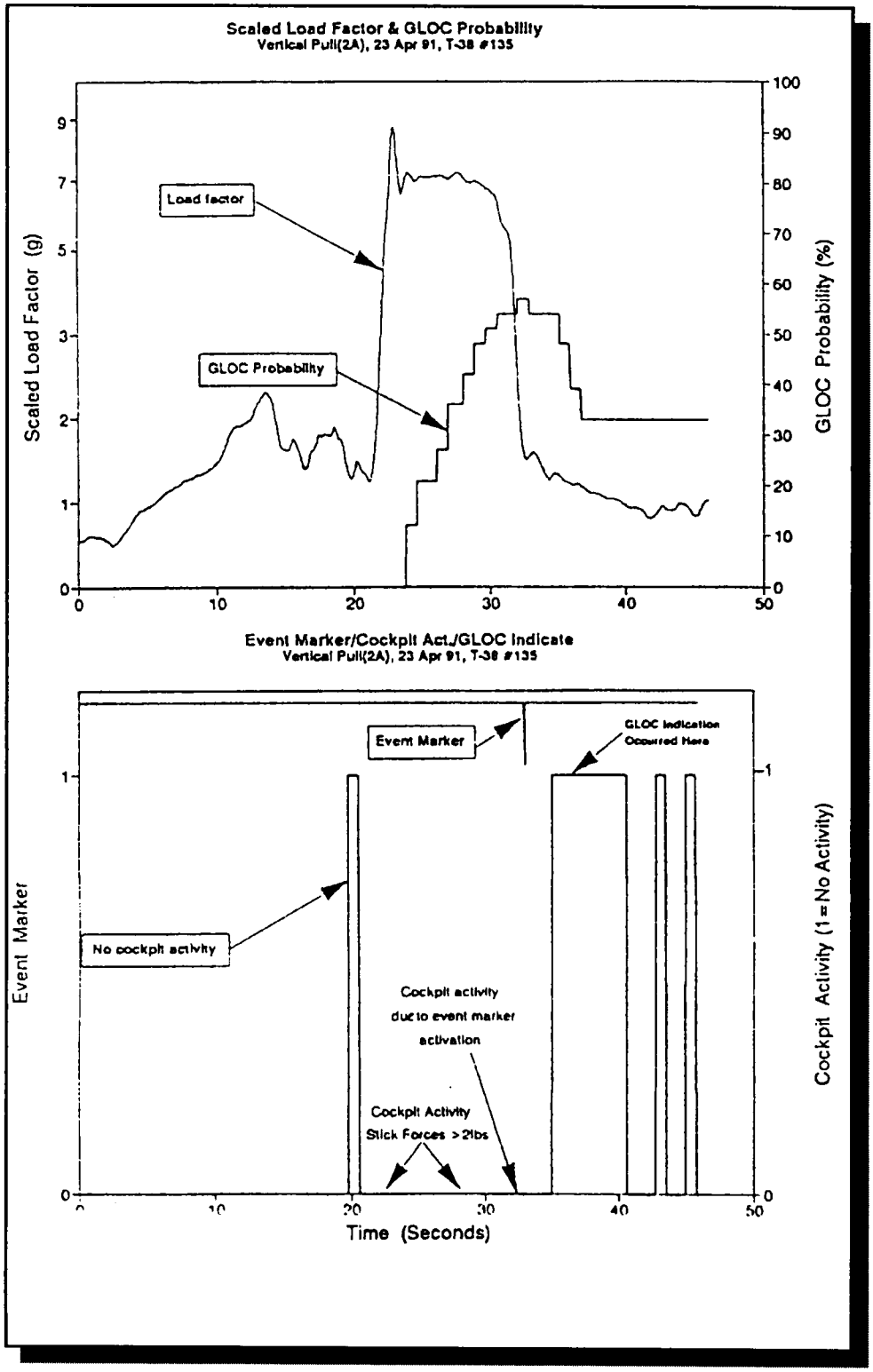


Figure 3-22. Maneuver 2A (False Alarm following Event Button)

G-LOC Probability The final item of concern dealt with the buildup of the G-LOC probability during scaled 4.8 G windup turns. Figure 3-23 shows scaled load factor and G-LOC probability for maneuver 1C, a scaled 4.8 G windup turn.

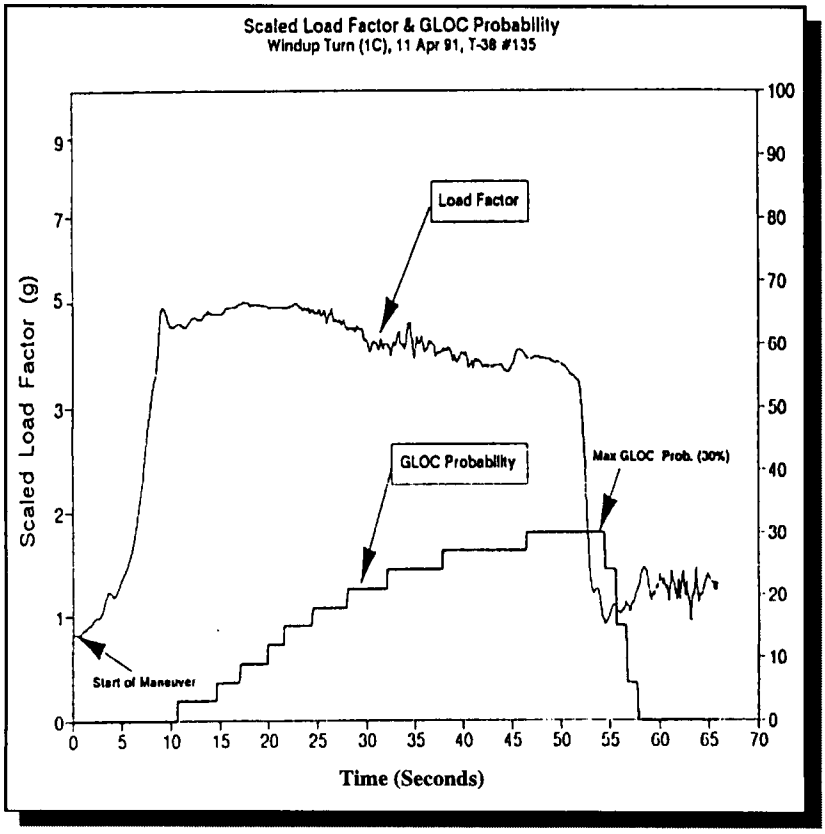


Figure 3-23. Maneuver 1C G-LOC Probability

As the data indicate, the load factor was sustained for approximately 40 seconds and resulted in a maximum probability buildup of 30 percent. Of all the scaled 4.8 G windup turns (1A, 1C, 1E, 1G) performed during this evaluation, 30 percent was the highest G-LOC probability attained.

The G-time tolerance curve shown below in Figure 3-24 was obtained from Reference 6. It shows susceptibility to G-LOC based on load factor, onset rate and exposure to load factor and in particular considers the lower G (4-5 G) windup turn area of the flight envelope.

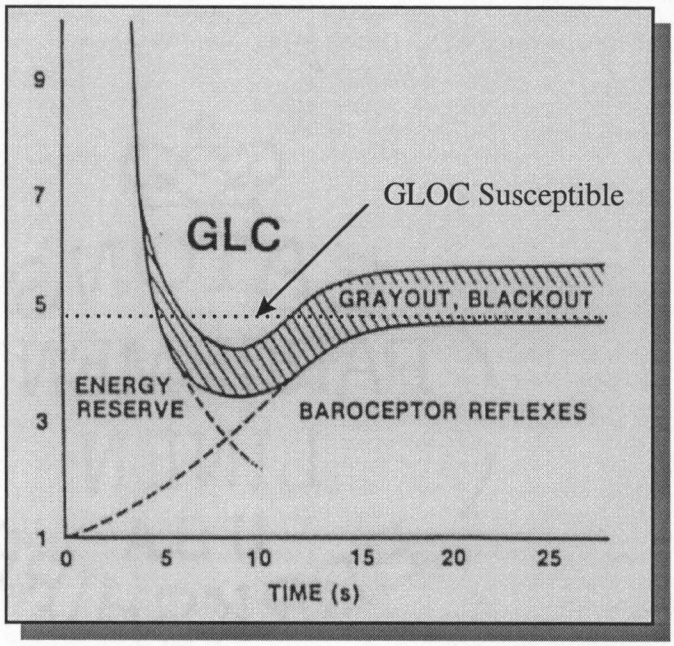


Figure 3-24. G-time Tolerance Curve 4.8 G Susceptibility

This G time tolerance curve indicates that during a 4.8 G maneuver held for at least five seconds (as was performed in maneuver 1C), there is potential for grayout, blackout, or G-LOC. These data were supported by pilot observations made during maneuver 1C, windup turn. The pilots felt that there was at least some potential for grayout or blackout if the proper straining maneuver was not correctly performed. The data presented in Figure 3-23 indicate that the maximum probability of G-LOC was 30 percent for the scaled 4.8 G windup turn. This probability was too low to ever flag a G-LOC condition because it always remained below the 50 percent probability threshold. This indicates that the probability buildup function does not accurately reflect the physiological data upon which it was based. The G-LOC probability function should be corrected to accurately reflect accepted physiological data.

The fluid maneuver test portion of this development and evaluation program was not completed due to a serious near-catastrophic failure of the horizontal stabilizer torque tube in the test aircraft. Testing was halted prematurely prior to any fluid maneuvers testing.

As a result, the long term robustness of the G-LOC system software was not adequately developed nor evaluated. Future testing should address this performance area.

Improvements to the GLOC Detection System

The most beneficial improvements to this "proof of concept" system would be the installation on a more advanced aircraft type (such as the F-16 or F-18) and interfacing with a MIL-STD-1553 data bus. Careful and thorough monitoring and analysis of the myriad of aircraft and pilot activity data accessible through the 1553 data bus would enhance cockpit activity detection. Head slump position has been considered a very reliable indication of G-LOC and accordingly development of a consistent and accurate head position monitoring system and incorporation into this unobtrusive system would likely dramatically reduce false alarm rates and improve detection capabilities. Pilot breathing patterns and anti-G straining audio signals may also prove to be reliable measures of the pilots conscious state and should be further investigated. Development of a more realistic and more complex G-LOC susceptibility model which includes "pilot unique" compensation is also recommended. Certainly the "push-pull phenomenon" area needs to be addressed in a new model. The effects of cumulative G-cycling experienced during a flight resulting in pilot fatigue should also be considered in the susceptibility model. The relatively simplistic model evaluated herein assumed a constant G-LOC probability decay rate which is likely not realistic given the many possible G onset rate/G level and time history scenarios which are encountered in the actual combat flight environment. A more realistic decay algorithm, better modeling actual human recovery rates (based on centrifuge data) should be developed for inclusion in the G-LOC detection system algorithm.

Chapter 4

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this program was to develop the prototype G-LOC Detection System so that it recognized whether or not simulated G-LOC had occurred during operationally representative maneuvering. This objective was met. The first five sorties of the program were required to develop a functioning G-LOC Detection System. Results from all 41 maneuvers flown during sorties #6, #7 and #8 were consistent - the system operated precisely as designed. Implementation of this type of G-LOC Detection System is therefore considered feasible. Consequently, a system designed to unobtrusively detect G-LOC, using aircraft data, shows promise.

Although the system functioned exactly as designed, it contained logic flaws which presently make it inadequate for military use. The detection system modeled the pilot's grip on the stick as an absolute indication of consciousness. Whenever the stick trigger (used to simulate stick grip) was depressed, G-LOC could never be detected. Physiological data indicate that a pilot may hold the stick trigger depressed during a G-LOC episode. Consequently, the stick trigger logic, as currently implemented in the detection system, is inadequate because it prevents detection of a G-LOC condition with the pilot holding the stick trigger--a case known to be possible. The stick grip logic should be amended to address this possible G-LOC scenario.

Flight test results showed that conscious actions such as selecting/deselecting afterburner and depressing the event button (simulating pilot actuated switch changes) did not prevent the system from detecting G-LOC. This resulted in a 20.8 percent false alarm rate. Such pilot actions are strong indications of pilot consciousness and should prevent G-LOC detection as it would be virtually impossible for the pilot to accomplish these tasks during a G-LOC episode. When modeled in the G-LOC Detection System, conscious actions such as selecting/deselecting afterburner and actuating cockpit switches should prevent G-LOC detection until the next loaded condition or system reset. The detection algorithm should be amended to reflect this.

The buildup of G-LOC probability during wind-up turns did not accurately reflect the physiological data upon which it was based. These data, along with pilot observations during this test project, indicate that there was a potential for gray-out, blackout, or G-LOC during these wind-up turns. The buildup function did not accurately reflect this potential because the G-LOC probability always remained below the 50 percent threshold, and G-LOC detection was impossible if the probability was less than 50 percent. The G-LOC probability function should be corrected to accurately reflect accepted physiological data.

The most beneficial immediate improvement to this "proof of concept" system would be the installation on a more advanced aircraft type (such as the F-16 or F-18) and interfacing with a MIL-STD-1553 data bus. Careful and thorough monitoring and analysis of the myriad of aircraft and pilot activity data accessible through the 1553 data bus would enhance cockpit activity detection.

Head slump position has been considered a very reliable indication of G-LOC and accordingly development of a reliable and accurate head position monitoring system and incorporation into this unobtrusive system would likely dramatically reduce false alarm rates and improve detection capabilities. Pilot breathing patterns and anti-G straining audio signals may also prove to be reliable measures of the pilots conscious state and should also be further investigated and developed for monitoring.

Development of a more realistic and more complex G-LOC susceptibility model which includes "pilot unique" capabilities and compensation is also recommended. Certainly the "push-pull phenomenon" area needs to be addressed in a new susceptibility model. The effects of cumulative G-cycling experienced during a flight resulting in pilot fatigue and reduced tolerance should also be considered in the susceptibility model. The relatively simplistic model evaluated herein assumed a constant G-LOC probability decay rate which is likely not realistic given the many possible G onset rate/G level and time history scenarios which are encountered in the actual combat flight environment. A more realistic decay algorithm, better modeling actual human recovery rates (based on centrifuge data) should be developed for inclusion in the G-LOC detection system algorithm.

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APPENDICES

APPENDIX A

GLOC DETECTION SYSTEM ALGORITHM DESCRIPTION

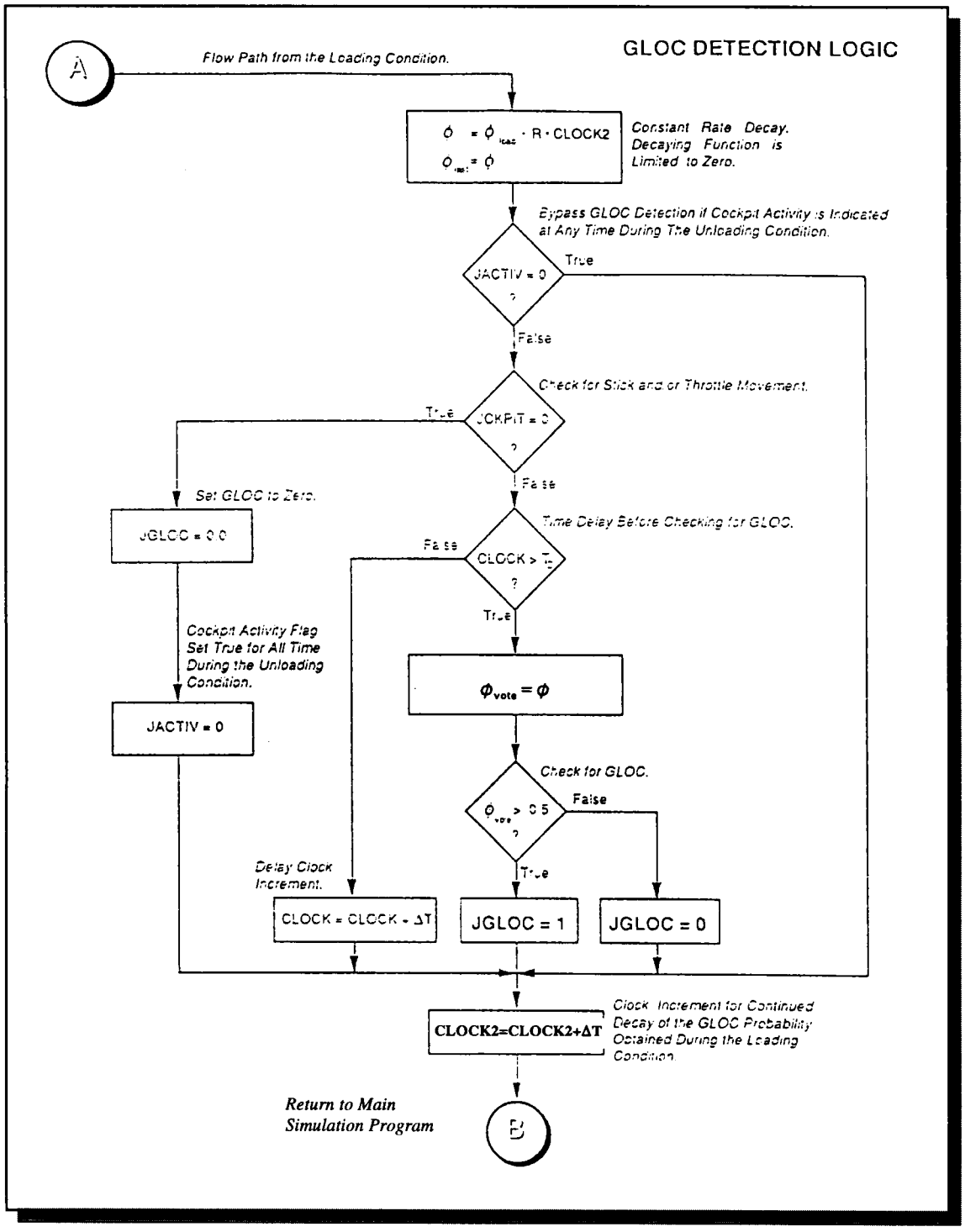


Figure A-1a. Baseline GLOC Detection System Algorithm

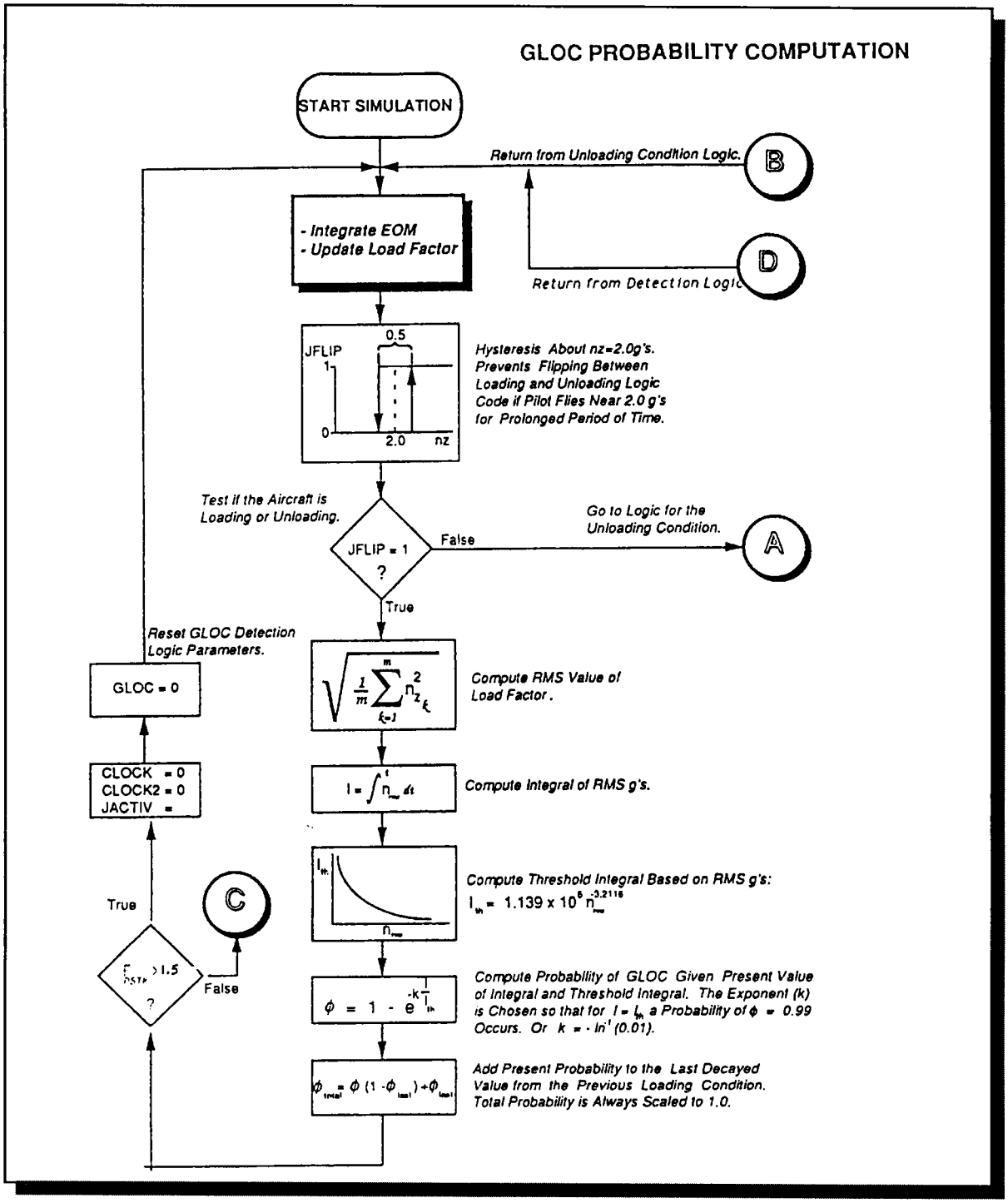


Figure A-1b. Probability Calculation Component of GLOC Algorithm (Baseline)

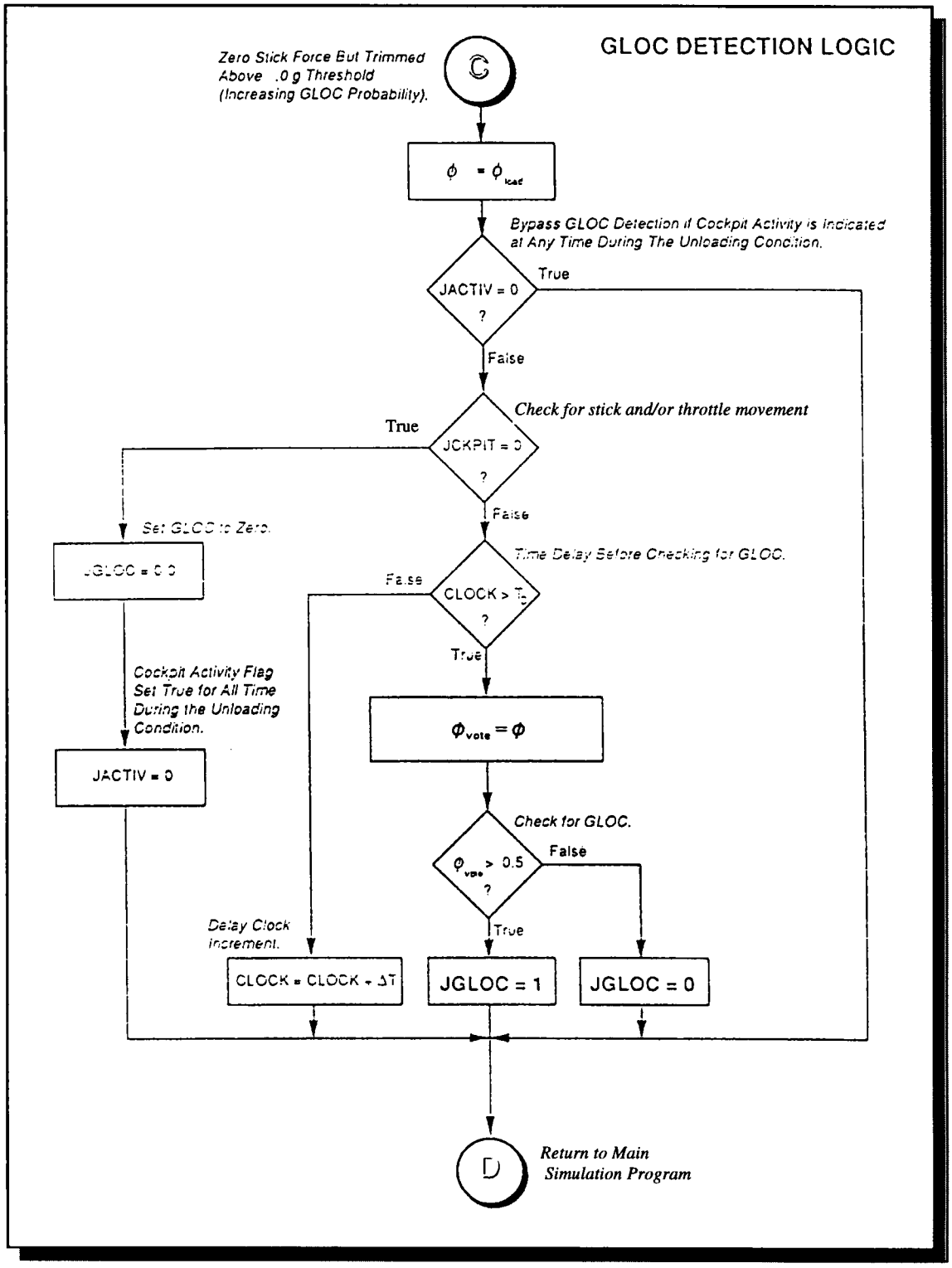


Figure A-1c. Detection Logic Component of GLOC Algorithm (Baseline)

GLOC Detection System Algorithm Description (Final)

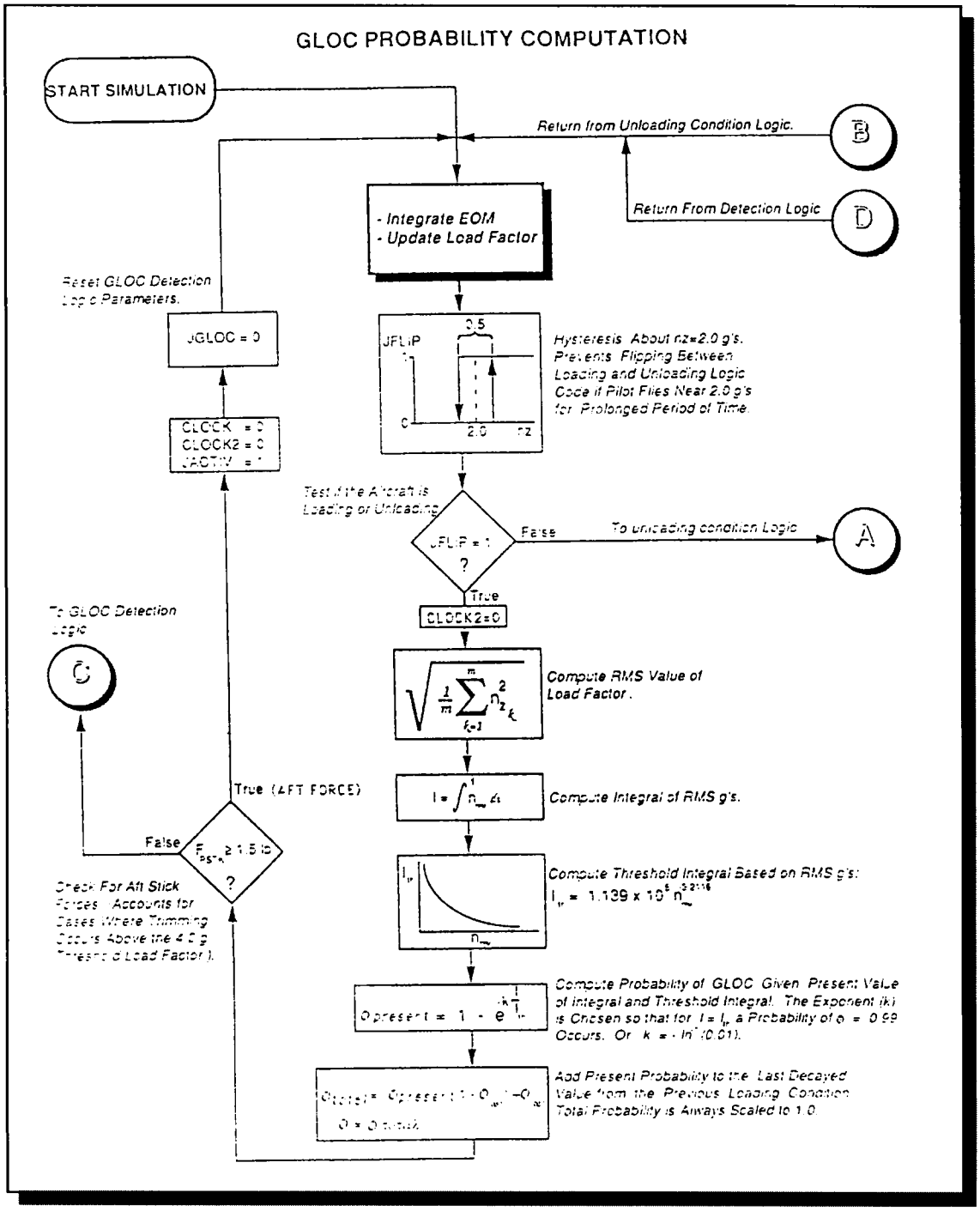


Figure A-2a. Final GLOC Detection System Algorithm

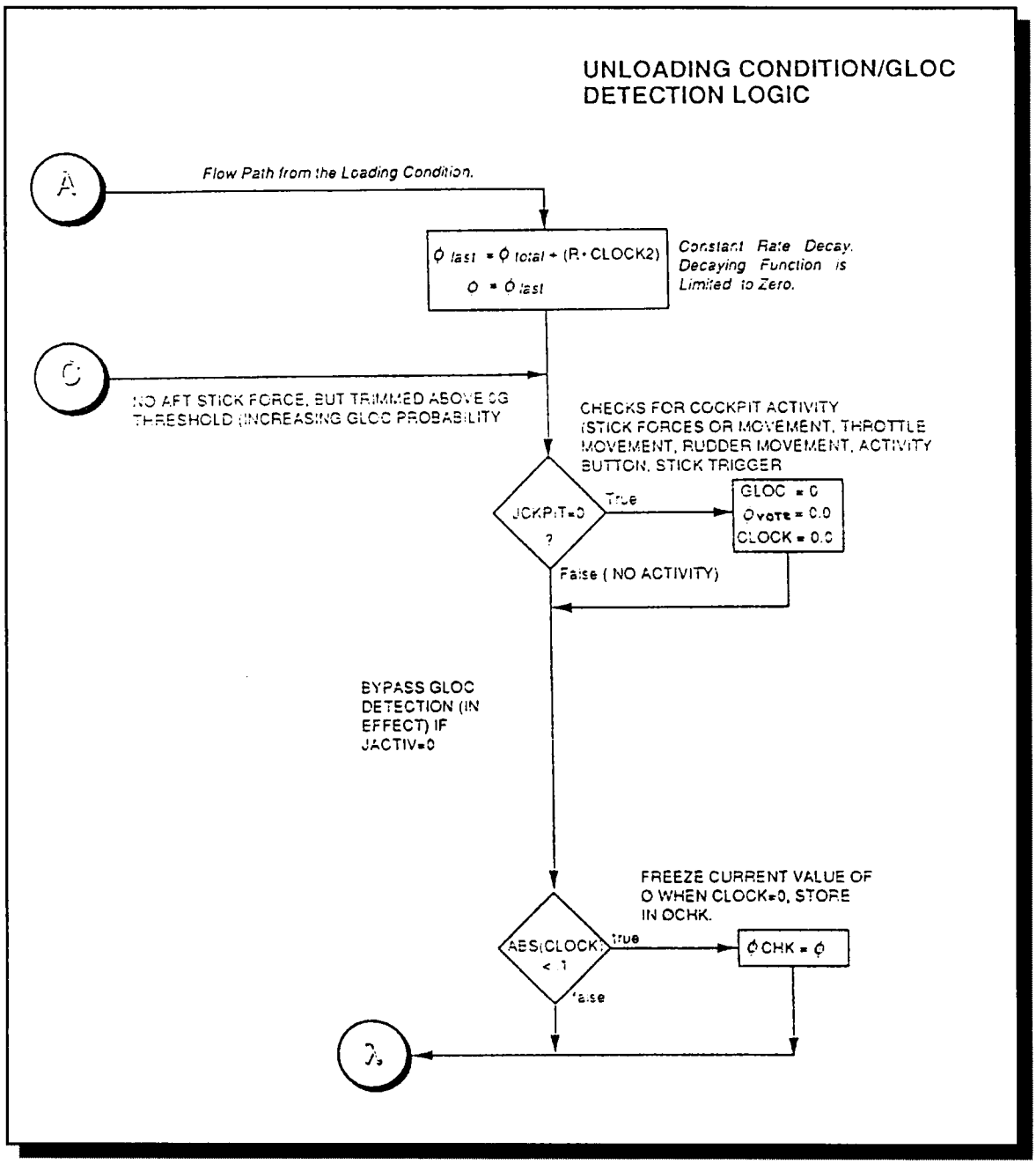


Figure A-2b. Probability Calculation Component of GLOC Algorithm (Final)

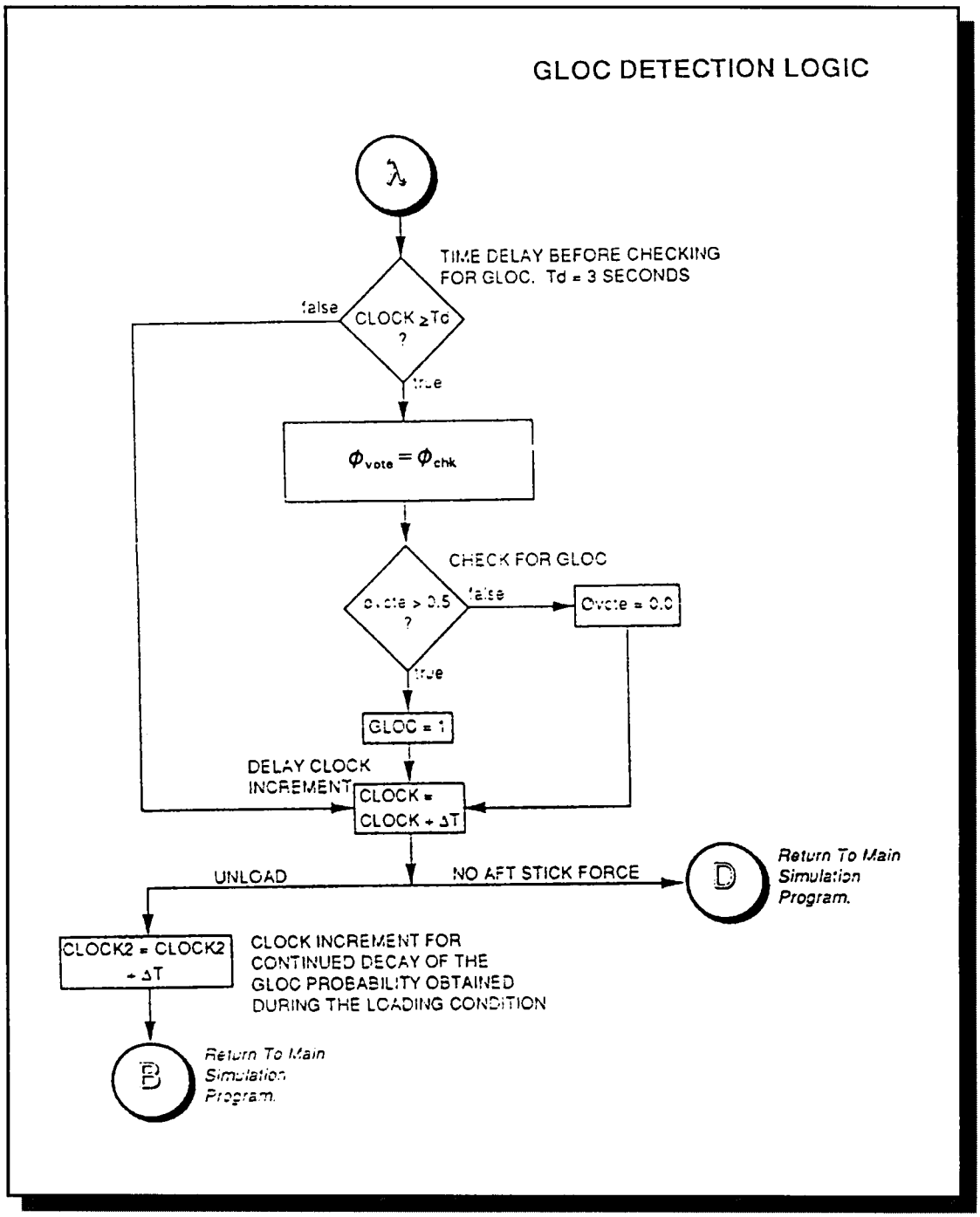


Figure A-2c. Detection Logic Component of GLOC Algorithm (Final)

APPENDIX B

GLOC TEST POINT DESCRIPTIONS AND SORTIE PROFILES

Table B-1. Specific Test Maneuvers

Test Point #	Generic Maneuver	Target Load Factor (G)	Cockpit Activity and Recovery*	Simulated Operational Task
1A B	Windup Turn	4.0 5.0	Throttles to Mil (4.0 G)/AB (5.0 G) power commencing turn and held for 360° of turn; select Mil (5.0 G) while > 2 G's; unload to 1 G while maintaining bank; after 2 seconds, reestablish target G for 5 sec.	DBFM IRMD Extension
1C D		4.0 5.0	Throttles to AB power commencing turn; event button at 180° point; select Mil power after 360° of turn (while > 2 G's); unload to 1 G, roll to wings level and maintain for 5 seconds	OBFM Weapons Setup Closure Control Separation
1E F G H		4.0 5.0 4.0 5.0	Throttles to Mil power commencing turn; after 180° of turn, smoothly neutralize controls while maintaining bank (hold stick lightly); no control inputs for 5 seconds Same as E/F but with trigger held	Defensive Spiral *(G-LOC)*
2A	Vertical Pullup	4.5	After passing horizon (~20° nose high), unload to 1 G and maintain for 5 seconds; depress event button 1 second after unloading	Safe Weapons Change Modes
2B		4.5	After passing horizon (~20° nose high), unload to 1 G and maintain for 5 seconds; select Mil power 1 second after unloading	Complete Aerobatic Maneuver
2C		4.5	Smoothly neutralize controls after passing horizon (~10° nose high) (hold stick lightly); no control inputs for 5 seconds	Pull off Target *(G-LOC)*
3A	Abrupt Turn	5.5	Throttle from Mil to AB 2 sec into turn; after 180° of turn, select Mil power and roll to wings level (while > 2 G's); unload to 1/2 G and hold for 5 sec; no cockpit activations	Defensive Break Turn IRMD Separation
3B		5.5	Throttle to AB power commencing turn; depress event button at 45° point; roll to wings level (while > 2 G's) at 90° point; unload to 1 G flight and hold 2 seconds; select Mil power and maintain 1 G for 5 Seconds	Hard Turn ECM Activation Weapons Employment Visual search
3C		5.5	Throttles in Mil power; after 90° of turn, smoothly neutralize controls while maintaining bank (hold stick lightly); no other inputs for 5 seconds	Defensive Break Turn *(G-LOC)*

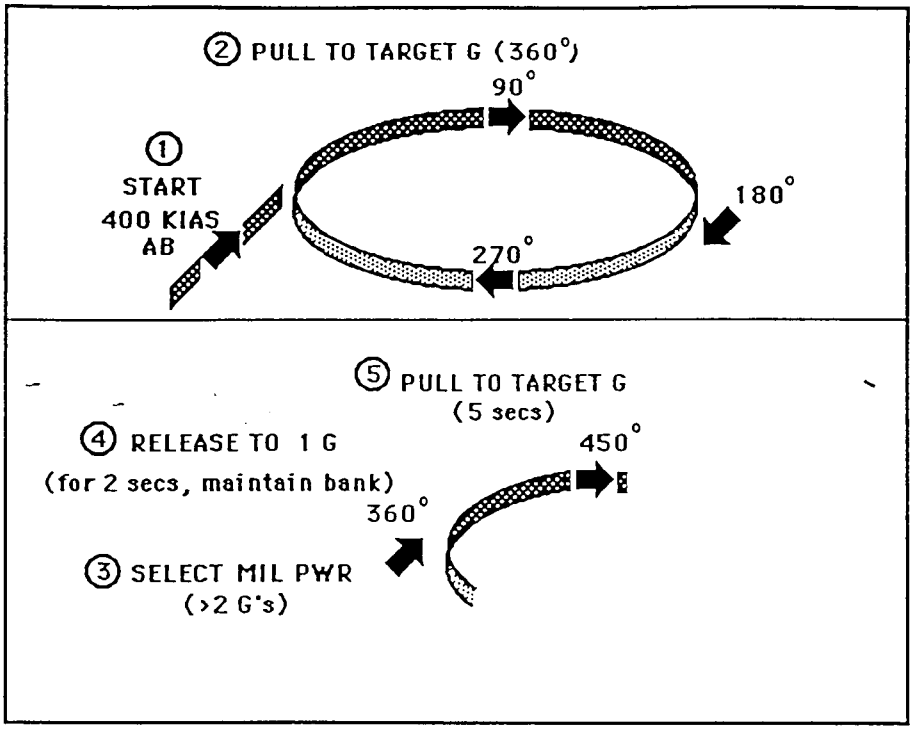
*Unless otherwise noted the trigger switch will be released throughout the maneuver.

Table B-2. Sortie Summary

SORTIE #	CREW	DATE	SORTIE TIME	MANEUVERS FLOWN													
				1A	1B	1C	1D	1E	1F	1G	1H	2A	2B	2C	3A	3B	3C
1	Bogdan/McKeage	1 Apr 91	0.8	1		1		1		1							
2	Moore/Gebert	5 Apr 91	0.5	No Maneuvers (inflight emergency)													
3	Bogdan/McKeage	11 Apr 91	1.0	1		1		2		1		2	1	1	1	2	5
4	Bogdan/Olson	16 Apr 91	0.9	1	1	1	1	1	1	1		2	2	1	1	1	3
5	Bogdan/Gebert	18 Apr 91	0.8	1	1	1	1	1	1	1		1	1	1	1	1	3
6	Bogdan/Olson	23 Apr 91	0.9	1	1	1	1	1	1	1	1	3	1	2	1	1	1
7	Moore/McKeage	23 Apr 91	0.9	1		1		1		1		1	1	1	1	1	1
8	Moore/Gebert	24 Apr 91	0.9		1		1		1		1	2	2	2	1	1	2
Totals			**6.7**	**6**	**4**	**6**	**4**	**7**	**4**	**6**	**2**	**11**	**8**	**8**	**6**	**7**	**17**

WIND UP TURN (4 & 5 G's)

1A
1B



1C
1D

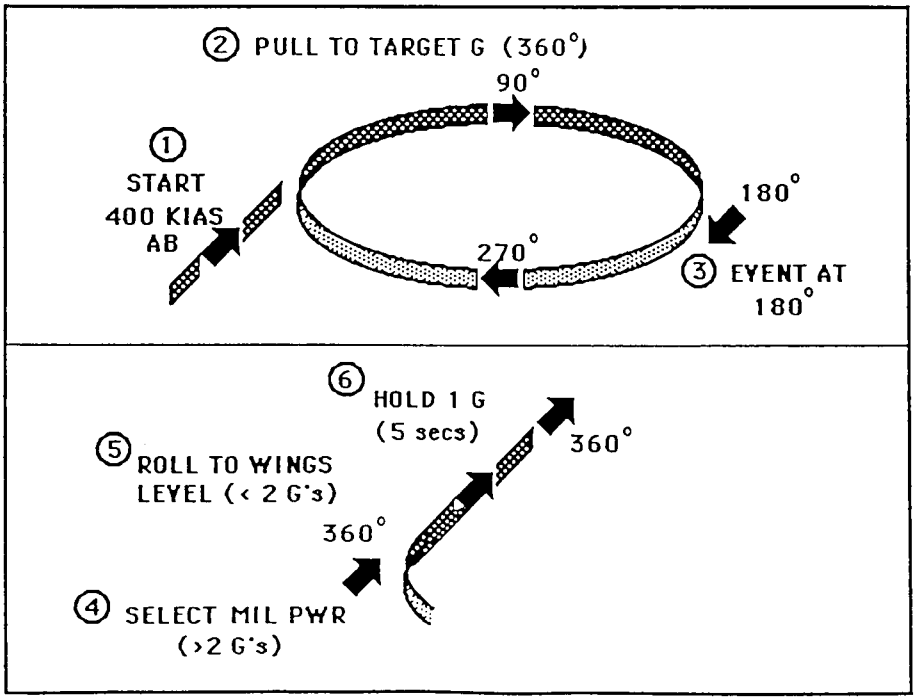
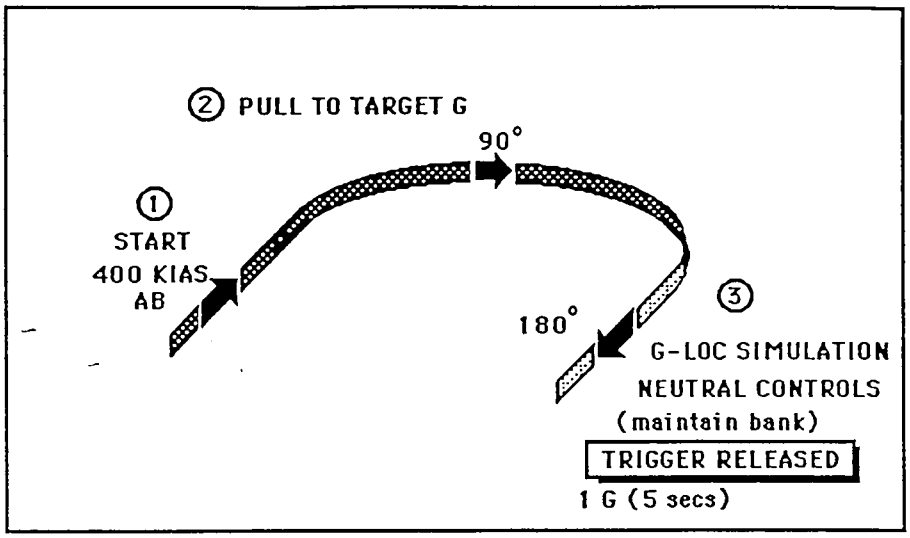


Figure B-1a. Wind Up Turns

WIND UP TURN (4 & 5 G's) CON'T

1 E
1 F



1 G
1 H

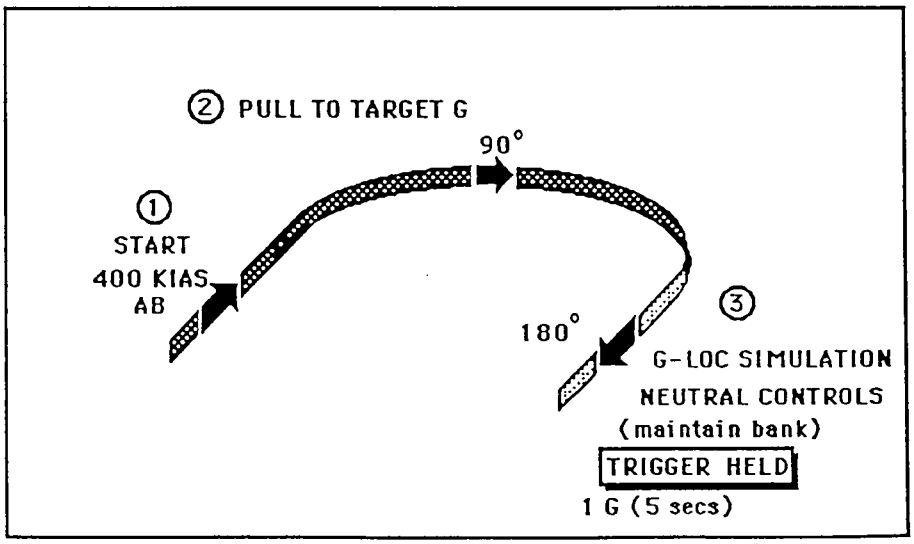


Figure B-1b. Wind Up Turns (Continued)

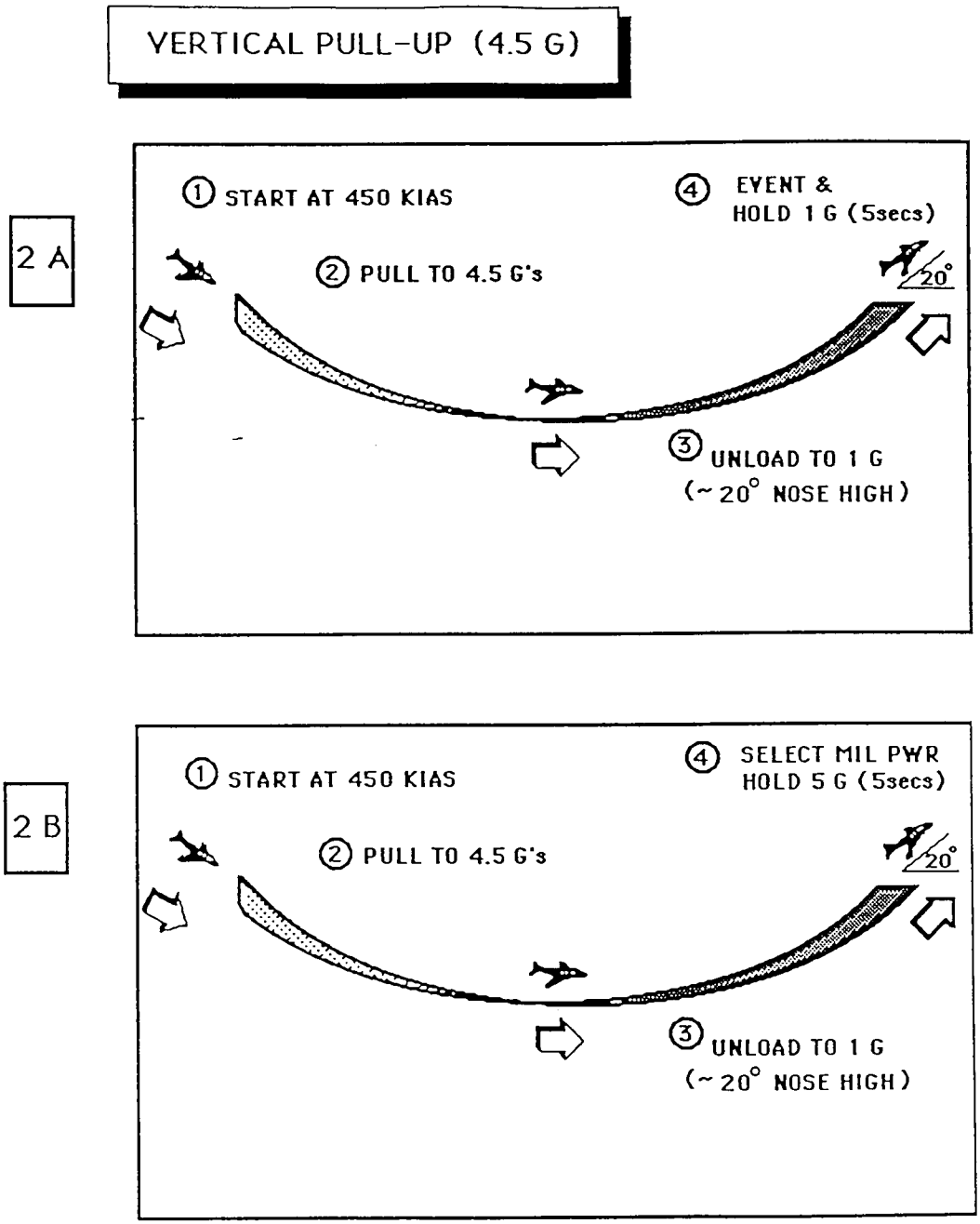


Figure B-2a. Vertical Pull-Ups

VERTICAL PULL-UP (4.5 G) CONT'D

2 C

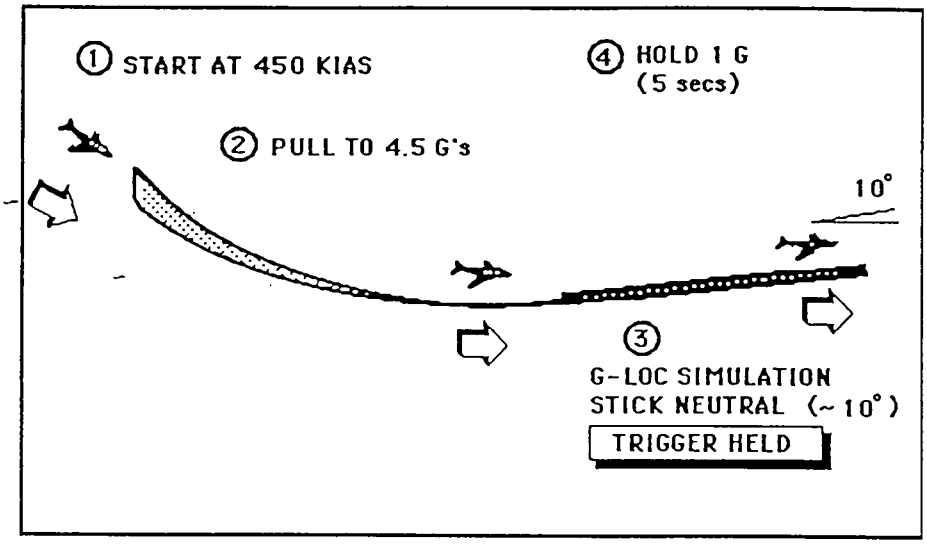
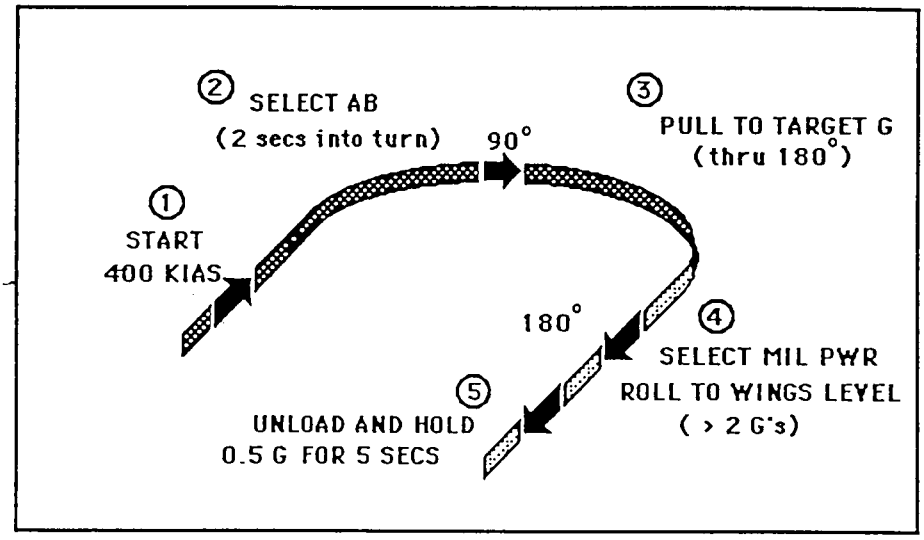


Figure B-2b. Vertical Pull-Ups (Continued)

ABRUPT TURN (5.5 G)

3 A



3 B

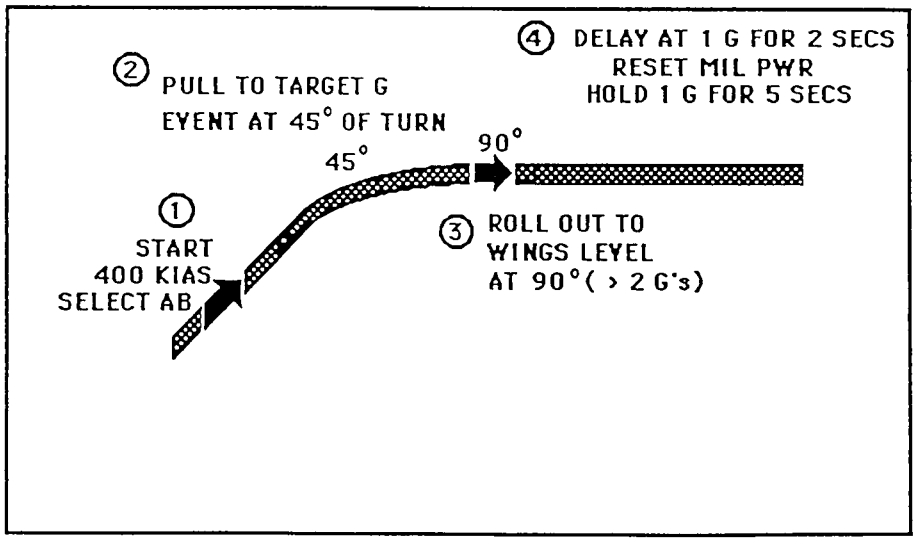
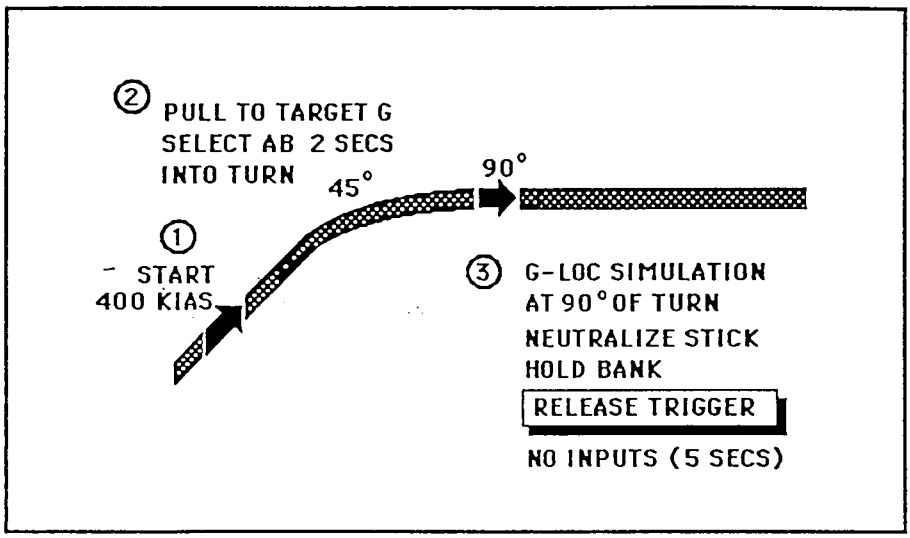


Figure B-3a. Abrupt Turns

ABRUPT TURN (5.5 G)

3 C



3 D

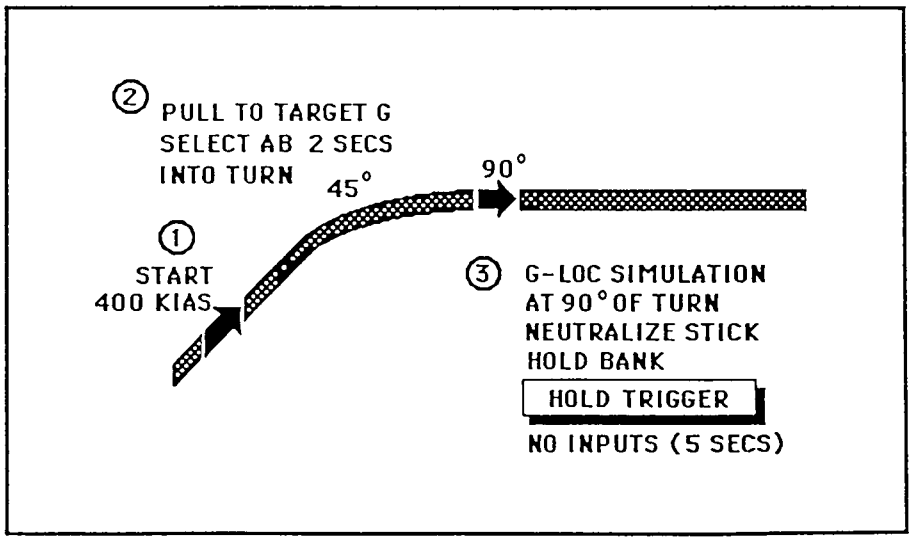


Figure B-3b. Abrupt Turns (Continued)

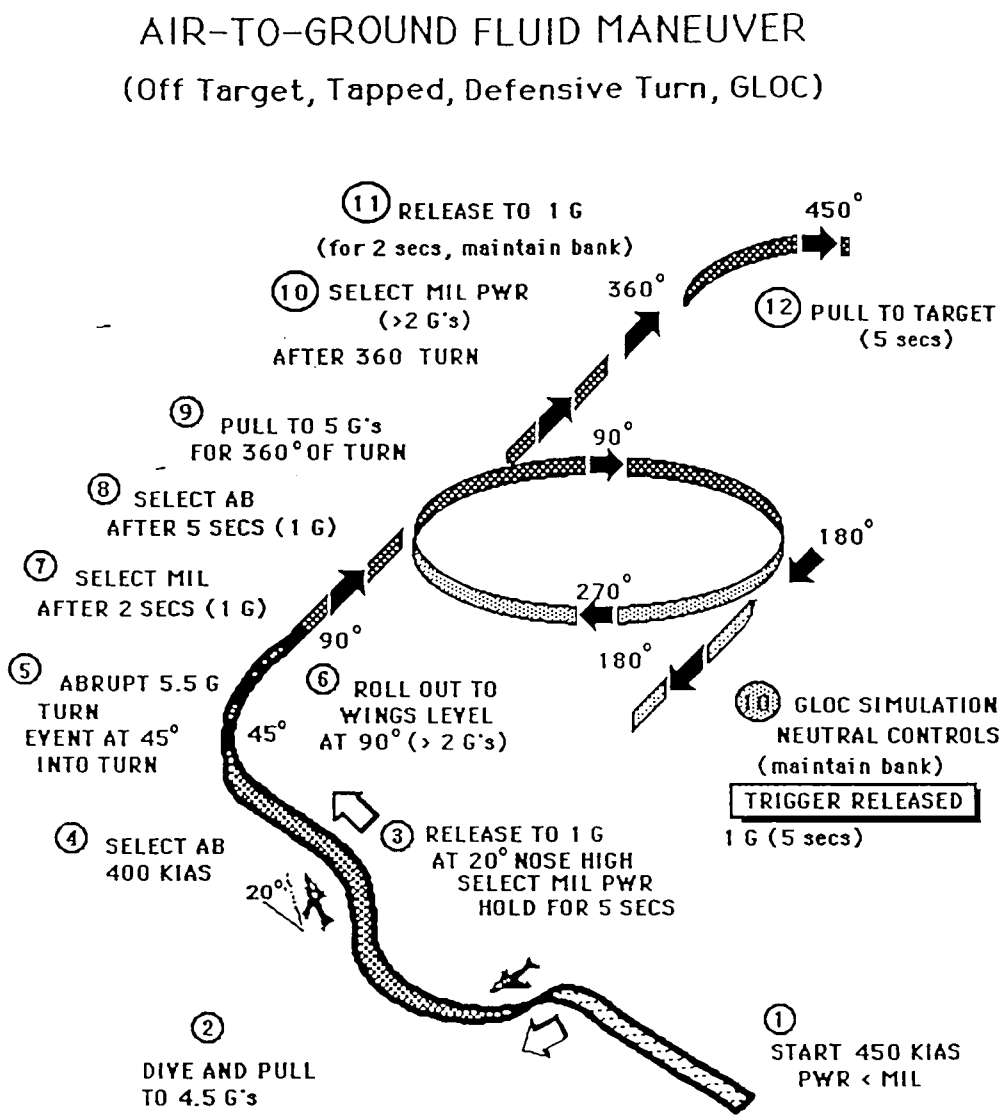


Figure B-4. Air-to-Ground Fluid Maneuver Sequence

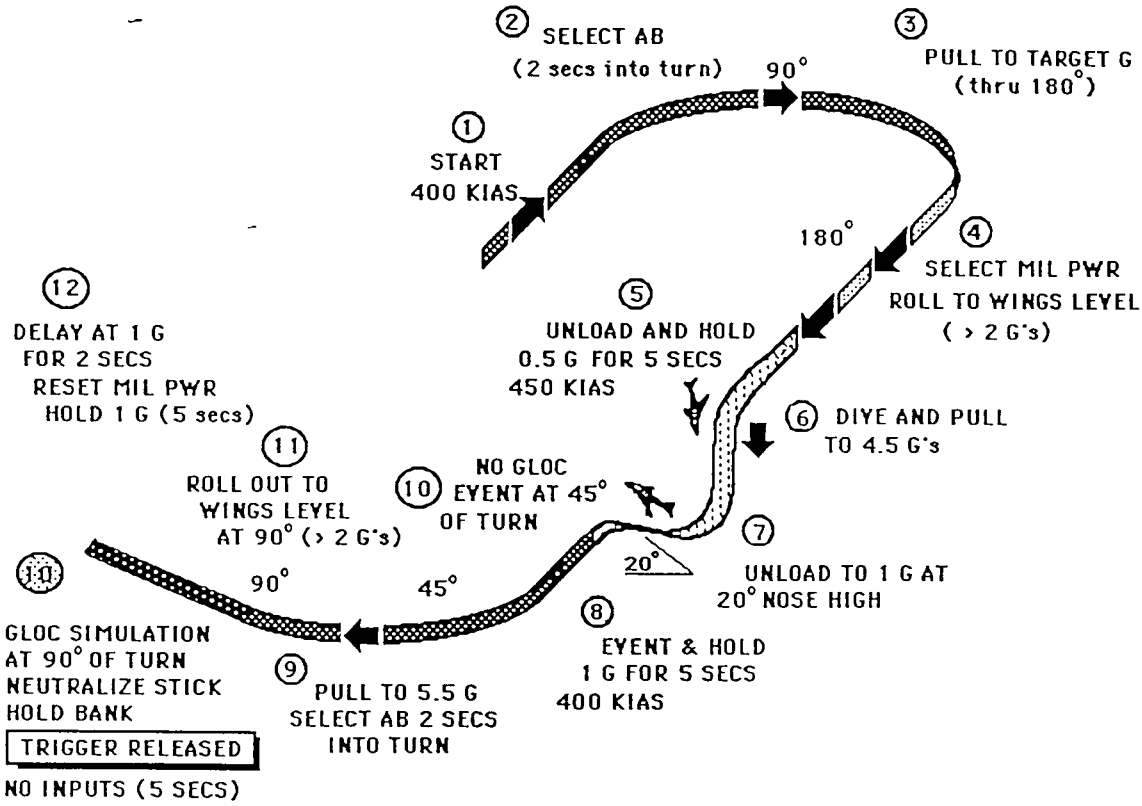


Figure B-5. Air-to-Air Fluid Maneuver Sequence

APPENDIX C

GLOC DETECTION GROUND SIMULATION PROCEDURE

G-LOC DETECTION GROUND SIMULATION PROCEDURE

A logic flaw discovered after sortie #5 required monitoring actual logic parameters such as JACTIV and JGLOC as the system iterated through the algorithm. This became an absolute necessity in order to develop a functioning G-LOC detection system. The solid state disk could have provided this monitoring, but this would have required flying an additional sortie to obtain the data. This option would have been costly as well as time consuming. Instead. an innovative ground simulation procedure was created to check the detection software with actual flight data from sortie #5. A TEAC V-2500-FN VCR used in conjunction with a Merlin ME-990 Decoder provided the basis of this ground simulation as shown in Figure C-1 below.

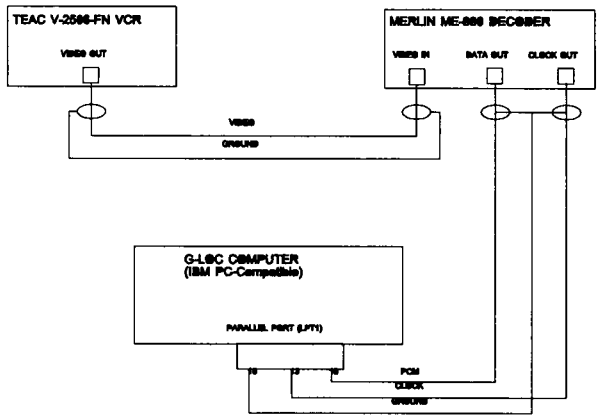


Figure C-1. G-LOC Ground Simulation Block Diagram

The Merlin decoder was then tied into an IBM PC-compatible laptop computer which acted as the host computer for the G-LOC detection software. This setup used the actual inflight data from sortie #5 recorded on a TEAC cassette tape. The data was regenerated (synchronous PCM stream) and then routed to the G-LOC host computer and run through the G-LOC detection software. A simple software edition to save and print the true G-LOC parameters iteration by iteration allowed for monitoring of system logic as it responded to actual recorded flight data. Table C-1 shows the results of the ground simulation for maneuver 3C performed during sortie #5.

Table C-1. Configuration II Ground Simulation Results

Time	Nz	JGLOC	JHist	JCkpt	JHead	PGLOC	Clock2	Jflip	Pcheck	δT	JActiv	Clock	AGLOC
3501	1.1	0	1	0	1	.0	1.0	0	.0	1.0	1	0.0	0.0
3502	1.5	0	1	0	1	.0	1.0	0	.0	1.0	1	0.0	0.0
3503	1.6	0	1	0	1	.0	1.0	1		1.0			
4504	2.6	0	1	0	1	.0	.0	1		1.0			
3505	10.5	0	1	0	1	.1	.0	1		1.0			
3506	9.7	0	1	0	1	.4	.0	1		1.0			
3507	9.7	0	1	0	1	.6	.0	1		1.0			
3508	8.6	0	1	0	1	.7	.0	1		1.0			
3509	8.4	0	1	0	1	.8	.0	1		1.0			
3510	8.0	0	1	0	1	.8	.0	1		1.0			
3511	7.4	0	1	0	1	.9	.0	1		1.0			
3512	5.0	0	1	0	1	.9	.0	0	.9	1.0	1	0.0	0.0
3513	1.5	0	1	0	1	.9	1.0	0	.9	1.0	1	1.0	0.0
3514	.8	0	1	1	1	.8	2.0	0	.9	1.0	1	2.0	0.0
3515	.7	0	1	1	1	.7	3.0	0	.9	1.0	1	3.0	0.0
3516	.7	1	1	1	1	.6				1.0			
3517	.8	1	1	1	1	.6				1.0			

By examining this line by line output of the G-LOC parameters, a more complete understanding of the system logic was obtained. This resulted in software changes (Configuration III) that ultimately lead to a functioning G-LOC detection system.

VITA

Bradley James McKeage was born on 10 March, 1962, in Ottawa, Ontario, Canada. As a military dependent, he attended numerous public schools in various geographic locations including Baden-Baden, West Germany, Cold Lake, Alberta, St. Albert Alberta and Ottawa, Ontario. In June 1980, he graduated from Cairine Wilson High School in Orleans, Ontario and then immediately joined the Canadian Armed Forces which had selected him for fully sponsored undergraduate training at the Royal Military College (RMC) of Canada in Kingston Ontario. In May 1984, 2nd Lieutenant McKeage graduated from RMC with a Bachelor's Degree in Mechanical Engineering. After the completion of occupational training as an Aerospace Engineering Officer, Lieutenant McKeage completed a tour as the Project Manager for various Anti-Submarine Warfare Research and Development Projects. Captain McKeage then completed an Operational posting as a Squadron Maintenance Officer with 412 VIP Squadron in Ottawa Ontario. He was then selected to undergo Flight Test Engineering (FTE) training at the USAF Test Pilot School (TPS)at Edwards AFB. In June 1991, he graduated as a Qualified Flight Test Engineer and proceeded to Canada's Aerospace Engineering Test Establishment in Cold Lake, Alberta where he was employed in the Fighter Evaluation Section. He was subsequently selected by the Canadian Armed Forces for post graduate training at UTSI where he completed a Masters of Science degree in Aerospace Engineering in May 1997 and a Masters of Science degree in Aviation Systems in August 1997.