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**INCORPORATING THE SJU-17A NAVAL AIRCREW COMMON
EJECTION SEAT IN THE EA-6B AIRCRAFT**

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Daniel D. Moore
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DEDICATION

This thesis is dedicated to my
wife, Elspeth Jane Moore, for her
patience, encouragement, love,
and support.

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I would like to thank the men and women with whom I have worked over the past 10 years of naval service whose dedication and professionalism have been a never-ending source of inspiration.

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ABSTRACT

This research investigated the feasibility of incorporating the Martin Baker Aircraft Company (MBA) SJU-17A Naval Aircrew Common Ejection Seat (NACES) and an electronic command eject sequencing system in the Northrop-Grumman EA-6B Prowler aircraft. The EA-6B is a four seat tactical aircraft derived from the A-6 Intruder airframe and flown solely by the U. S. Navy and Marine Corps. The mission of the EA-6B is electronic warfare (EW), providing suppression of enemy air defenses (SEAD) by the use of electronic noise jamming and the employment of the AGM-88 High Speed Anti-Radiation Missile (HARM). The current ejection system in the EA-6B uses the MBA GRUEA-7 ejection seat combined with a gas sequencing command ejection system, and has a 1.2 second delay before the pilot's ejection sequence begins. This time is excessive in a crashing aircraft and the loss of 3 pilot lives can be attributed to this delay. Out-of-envelope ejections have led to the loss of 8 additional ECMO lives. These two factors have caused the EA-6B ejection system to make the top-ten list of required change priorities of the Operational Advisory Group (OAG) of EA-6B community. The EA-6B will be the only aircraft in the U. S. Navy still using the GRU-7 series of ejection seats when the F-14A/B model Tomcats are retired by 2008, placing a strain on the maintenance and logistics systems to keep the seats in safe working condition.

A discussion of the GRUEA-7 ejection seat requirements compared to the SJU-17A NACES was used to determine feasibility of incorporating this new ejection seat in the EA-6B. The basis of the research was the review of ejection seat publications, EA-6B aircraft literature, interviews conducted with the enlisted personnel that maintain

the ejection seats, and the experience of the author as a Naval Flight Officer (NFO) in both the EA-6B and the FA-18F. This thesis concluded that the SJU-17A NACES is more capable than the GRUEA-7 ejection seat and feasibly adaptable to the EA-6B airframe as both a stand-alone seat and part of an electronic command ejection system.

The recommendations of this thesis were:

1. Replace the MBA GRUEA-7 ejection seat with the MBA SJU-17A NACES in the EA-6B aircraft.
2. Replace the gas sequencing ejection system with an electronic command ejection sequencing system in the EA-6B aircraft, and investigate the possibility of ejecting more than 1 aircrew at a time after performing a structural analysis of the floorboards and airframe to make sure the added reaction forces will be supported.
3. Replace the 21 foot diameter main parachute in the SJU-17A NACES with a 28 foot diameter main parachute for incorporation into the EA-6B aircraft after investigating the additional opening shock imparted to the occupant by the larger parachute throughout the expected EA-6B flight regime and the impact on the five SJU-17A NACES modes of operation.

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LIST OF ABBREVIATIONS

AME	Aviation Structural Mechanic – Safety Equipment
CNO	Chief of Naval Operations
DOD	Department of Defense
ECMO	Electronic Counter Measures Officer
EMC	Electromagnetic Consideration
EMI	Electromagnetic Interference
EW	Electronic Warfare
EXCAP	Expanded Capability
GPS	Global Positioning System
HARM	High Speed Anti-Radiation Missile
IADS	Integrated Air Defense System
ICAP	Improved Capability
INS	Inertial Navigation System
JSF	Joint Strike Fighter
MBA	Martin-Baker Aircraft Company
MSL	Mean Sea Level
NACES	Naval Aircraft Common Ejection Seat
NATOPS	Naval Air Training and Operating Procedures Standardization
NFO	Naval Flight Officer

OAG	Operational Advisory Group
SEAD	Suppression of Enemy Air Defenses
SEAWARS	Seawater Activated Release System
SHEL	Software, Hardware, Environment, and Liveware
SOP	Standard Operating Procedure
WSO	Weapon Systems Operator

CHAPTER 1: INTRODUCTION

THE EA-6B PROWLER

The EA-6B Prowler is a four-seat, all weather, twin turbojet engine, tactical aircraft manufactured by Northrop-Grumman based on the airframe of the retired A-6 Intruder. The EA-6B is operated by the U. S. Navy and Marine Corps from paved runways ashore and aircraft carrier flight decks at sea. The EA-6B mission is electronic warfare (EW), in which a pilot and three Electronic Counter Measures Officers (ECMOs), Naval Flight Officers (NFO) trained specifically for the EA-6B, use the ALQ-99 Weapon System on board the EA-6B to deny, degrade, and destroy the capability of opposition Integrated Air Defense Systems (IADS) to track and engage friendly strike and fighter aircraft with surface and air radar using a combination of electronic noise jamming and the AGM-88 High Speed Anti-Radiation Missile (HARM). Figure 1 depicts a three view drawing of the EA-6B Prowler.

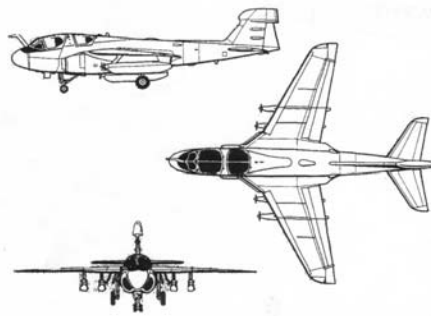


Figure 1. The EA-6B Prowler.

Source: *EA-6B Prowler History*, Global Security, Feb 2003

The need for a tactical, carrier based aircraft to specialize in the EW mission became apparent during the Vietnam War, when aircraft losses to surface-to-air missiles (SAMs) were very high. The Navy first received the EA-6B in January 1971, and quickly sent the aircraft to its first combat deployment in Vietnam during 1972.¹ The EA-6B has undergone several upgrades over the airframe lifetime, improving airframe, engine, and weapon system performance. The first major upgrade occurred in 1973 when the extended capability (EXCAP) EA-6B increased the frequency spectrum covered by the ALQ-99 receiver and jammer system.² The next upgrade to the EA-6B happened in 1976 with the introduction of the improved capability (ICAP) aircraft. The next major upgrade would not occur until 1985, where the ICAP II EA-6B was first deployed with improved displays, mission planning support, navigation systems, and expanded frequency spectrum coverage. The Block 89A aircraft debuted in the year 2000 and featured an improved navigation system featuring a ring laser gyro inertial navigation system (INS) integrated with a Global Positioning System (GPS) receiver that was tied into the weapon system for improved navigation and weapon employment. The last planned major upgrade to the EA-6B, known as ICAP III and planned to enter the fleet in 2005, is currently in test and evaluation. The ICAP III merges the Block 89A navigation system with the ALQ-218 receiver set, new color displays, and improved computer processing capabilities.

The EA-6B in its many versions has a distinguished combat history including service in Vietnam, Operations Desert Shield and Desert Storm, Operations Provide Comfort and Provide Hope, Operations Northern Watch and Southern Watch, Operation

Allied Force, and Operations Enduring Freedom and Iraqi Freedom. The EA-6B is expected to remain in service until 2015 when the Navy plans to replace the aging aircraft with an EW version of the two-seat FA-18F Super Hornet and the Marine Corp plans to transition to an EW version of the single-seat Joint Strike Fighter (JSF). In 1998 the U. S. Air Force retired the EF-111 Raven, which was the only tactical Air Force EW platform.³ This placed a further burden on the Navy and Marine Corps EA-6B aircraft as the only remaining airborne platform in the United States inventory capable of providing tactical EW support. The last EA-6B produced rolled off the Northrop-Grumman assembly line in 1989. The high tempo of operations supporting the various theaters around the globe have required the majority of the EA-6B aircraft to remain deployed, and with the addition of the requirement to support the Air Force, the aging EA-6B airframes are being placed under constant stress. The ejection seat, the only single piece of gear in the aircraft that must work the first time, every time, allows aircrew to escape from situations that would otherwise end in their demise.

The ejection seat used in the EA-6B, the Martin-Baker Aircraft Company (MBA) GRUEA-7 has performed well to date, but is aging along with the airframe. With the retirement of the A-6 Intruder and the ongoing retirement of the F-14A and B model Tomcats, the EA-6B remains the only aircraft using the GRU-7 series of ejection seats, providing a strain on the training commands and the naval logistic system to maintain and support the GRUEA-7 ejection seat since the remainder of the tactical fleet aircraft, such as the FA-18A-D series Hornet, FA-18E/F Super Hornet, T-45 Goshawk, and F-14D Tomcat use MBA SKU-17 Naval Aircraft Common Ejection Seat (NACES). Many

different models of ejection seats are available from manufacturers world-wide, and although many of these seats may be compatible with the EA-6B, or a new seat designed solely for the EA-6B might provide the best capability, the increasing pressure on the U. S. Navy to save money and to emphasize parts commonality between aircraft, combined with the current widespread use of the SJU-17A makes the SJU-17A NACES the most favorable option. The EA-6B Prowler is scheduled to be replaced by a version of the FA-18F Super Hornet, designated the EA-18G starting in 2008. As the EA-18G will utilize the SJU-17A NACES, replacing the GRUEA-7 ejection seat with the SJU-17A NACES will make the transition more seamless from the standpoint of aircrew, maintenance, and logistics support.

MISHAPS INVOLVING THE EA-6B PROWLER

There have been 30 EA-6B major mishaps with the MBA GRUEA-7 ejection seat installed since 1 January 1980.⁴ There have been 88 EA-6B aircrew lives saved with no more than major injuries by successful ejections in the MBA GRUEA-7 ejection seat. There have been 18 EA-6B aircrew fatalities involved with 7 of the lost aircraft. Table 1 lists the details for each flight involving a fatality in the EA-6B aircraft equipped with the MBA GRUEA-7 ejection seat. The 1.2 second delay for pilot ejection from the aircraft can be considered a factor in the loss of the pilot in 3 ejection attempts. Out-of-envelope ejections can be considered a factor in the loss of 11 aircrew total. These deaths caused the EA-6B ejection system to make the top-ten list of required change priorities of the Operational Advisory Group (OAG) of EA-6B community, a committee made up of EA-6B squadron commanding officers and executive officers that officially prioritize and

Table 1. EA-6B Fatalities with the MBA GRUEA-7 Ejection Seat.

Event #	Number on Board	Ejections Initiated	Fatalities	Details of Event
1	3	3	1	Out of control flight. Pilot ejected but lost at sea.
2	3	3	3	Lost control in landing pattern. 3 unsuccessful out-of-envelope ejection attempts
3	4	4	1	Dual engine failure on takeoff. Pilot ejection initiated but did not clear cockpit.
4	3	3	3	Lost control on takeoff. All ejection attempts out-of-envelope.
5	4	4	2	Out-of-control flight. ECMO 1 survived ejection but killed on personnel parachute opening when left harness quick-release fitting impacted helmet. Pilot ejection initiated but did not clear cockpit prior to impact.
6	4	2	4	Controlled flight into terrain. 2 ejection attempts, cleared cockpit but did not survive.
7	4	0	4	Collided with another aircraft while landing on aircraft carrier. No ejection attempts.
Total	25	19	18	

Source: *Aviation Database: EA-6B Ejection Database for the GRUEA-7 Ejection seat 1 January 1980 – 21 January 2003*, Naval Safety Center, January 2003

recommend funding for the addition of newly available capabilities or correction of deficiencies to the Chief of Naval Operations (CNO) in 2000 and 2001.⁵

CHAPTER 2: THE MBA GRUEA-7 EJECTION SEAT

HISTORY

The MBA Mark VII series of ejection seats resulted from the addition of a rocket motor during the 1960s to the MBA Mark V series of ejection seats.⁶ A distinguishing feature of the MBA Mark VII ejection seats was the separation of the catapult and rocket charges into separate guns. Moving away from the combined gun approach allowed for a more vertical ejection trajectory, which increased occupant survivability during ejections at low altitudes and in out-of-envelope ejections. The U. S. Navy purchased the MBA Mark VII series of ejection seats and modified them for use in three separate aircraft. The MBA GRU-7 ejection seat was developed for the A-6 Intruder, the MBA GRU-7A ejection seat was developed for the F-14 Tomcat, and the GRUEA-7 ejection seat was developed for the EA-6B Prowler.

DESCRIPTION

The MBA GRUEA-7 is a telescopic catapult/rocket assisted ejection seat, providing each aircrew an emergency means of escape from the aircraft while on deck or airborne. The four individual seats are labeled according to crew station, starting at the pilot and proceeding clockwise around the cockpit. Figure 2 shows the labels for each seat. Each ejection seat can safely initiate ejection at zero airspeed and zero altitude, which is known as a “zero-zero” capability.⁷

Each seat is composed of a main beam assembly, which consists of two vertical beams and three horizontal beams. Figure A-1 shows the right side of the MBA

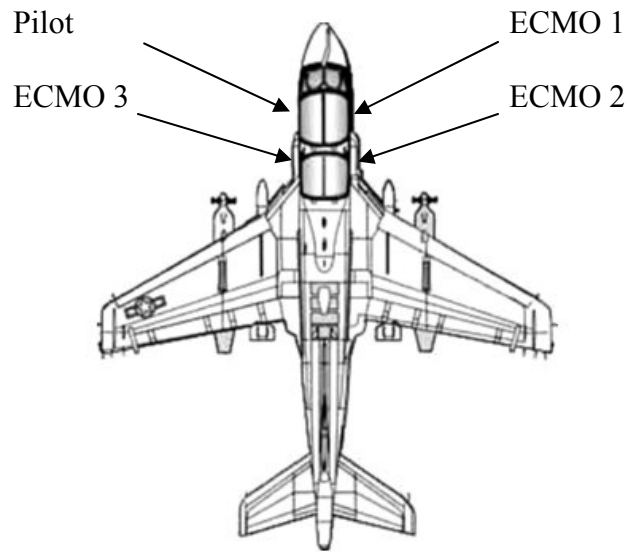


Figure 2. EA-6B Ejection Seat Labels.

Source: *EA-6B NATOPS Flight Manual*, April 2002

GRUEA-7 ejection seat. Figure A-2 shows the left side. All figures labeled as “A-X” are found in the appendix. The occupant is attached to the ejection seat at six points. The occupant wears a torso harness that attaches to two lap belts and two shoulder harness quick-release connectors, called Koch fittings. The shoulder harnesses connect the operator to the parachute risers and fasten the occupant to the seat back. The lap belts fasten the occupant to the seat pan. The occupant also wears a leg garter on each leg that attaches to the leg restraint cords using quick-release clips. These leg restraint cords are withdrawn when ejection is initiated to prevent leg flail injuries.

There are several key components integrated into each MBA GRUEA-7 ejection seat. The first component is the seat-stabilizer drogue parachute, which provides initial

deceleration and stabilization of the ejection seat and occupant immediately after ejection. The seat-stabilizer drogue parachute is located in the headrest of each seat.

A 28 foot personnel parachute is provided in a personnel parachute container that is located in each ejection seat back. The occupant's torso harness attaches to the personnel parachute risers via the shoulder harness Koch fittings.

The face curtain handle provides the upper ejection activation method. When the face curtain handle is pulled at least 7 inches by the seat occupant, the primary firing mechanism is mechanically withdrawn, which then fires the primary cartridge initiating ejection, and initiates the harness retraction unit. The face curtain also provides protection to the occupant's face and protection from arm flail injuries if the occupant holds on to the face curtain handle with both hands during ejection. An operator-activated safety handle can be positioned to lock the face curtain handle in place preventing the initiation of ejection.

The lower ejection handle provides a second means of initiating the ejection. The lower ejection handle mechanically withdraws the primary firing mechanism which then fires the primary cartridge initiating ejection, and initiates the harness retraction unit when the lower ejection handle is pulled at least 2 inches by the seat occupant. Actuation of the lower ejection handle requires at least 75 pounds of pulling force. An operator-activated safety handle can be positioned to lock the lower ejection handle in place preventing the initiation of ejection, but this safety mechanism can be overridden by the seat occupant if 120 pounds of force are applied.

The personnel services disconnect is located on the left back side of each seat and

provides connections for supply lines from the aircraft to the occupant for oxygen, communications, anti-“g” suit bleed air, and ventilation systems. A “g” is the measure of the normal load factor of the aircraft, which is equal to aircraft’s normal acceleration divided by the acceleration of gravity. During some aircraft maneuvers, the lift increases but the weight remains constant, which causes acceleration in the direction of lift. This acceleration causes the aircraft and occupant to experience an apparent increase in gravity causing increased stress on the airframe and human body, commonly referred to as an increase in “g’s”. Bleed air is provided to inflate air bladders in the anti-“g” suit worn around the occupants legs and stomach to prevent blood from pooling in the lower extremities under high load factors, which helps prevent the pilot from losing consciousness due to loss of blood in the brain. Quick-disconnect fittings connect the supply lines to the occupant service lines. A quick-release pin holds the personnel services disconnect to the aircraft supply lines. When an ejection is initiated, a lanyard pulls the quick-release pin that secures the personnel services disconnect to the seat which releases the disconnect and causes the supply lines to be disconnected at their quick-release fittings.

The RSSK-7 and SKU-2/A survival kits contain a 15 minute emergency oxygen supply and survival gear. Figure A-3 shows both versions of the seat pan. The emergency oxygen system is automatically actuated during an ejection by a cable that connects the emergency oxygen supply to the aircraft floorboard. When the ejection seat leaves the aircraft, the cable pulls the survival kit oxygen release allowing oxygen to flow through the occupant’s personnel oxygen regulator to the oxygen mask. The emergency

oxygen system can be actuated by pulling a green ring located on the inside left thigh of the seat pan. There is no way to stop the flow of oxygen from the emergency oxygen supply once it has been initiated. The survival kit is contained inside a two-piece container which is stowed in the seat bucket under the ventilated seat pad. The survival kit consists of the following items:

- An LR-1 one-person life raft with inflation cylinder and valve rations.
- 50 feet of nylon cord.
- A desalter kit.
- A water storage bag.
- A bailing sponge.
- Sunburn ointment.
- One AN/URT-33 survival beacon.
- One MK-13 MOD 0 day/night distress signal.
- Two packs of dye markers.
- One signal mirror.
- One ground/air emergency code card.

The harness retraction unit is fired when ejection is initiated by mechanical extraction of the seat. The harness retraction unit burn time is set to position the occupant in an upright position prior to seat movement to prevent back and neck injuries. The harness retraction straps are connected to both of the upper torso harness fittings, which connect to the parachute risers.

The upper torso harness connects to the occupant's torso harness through shoulder

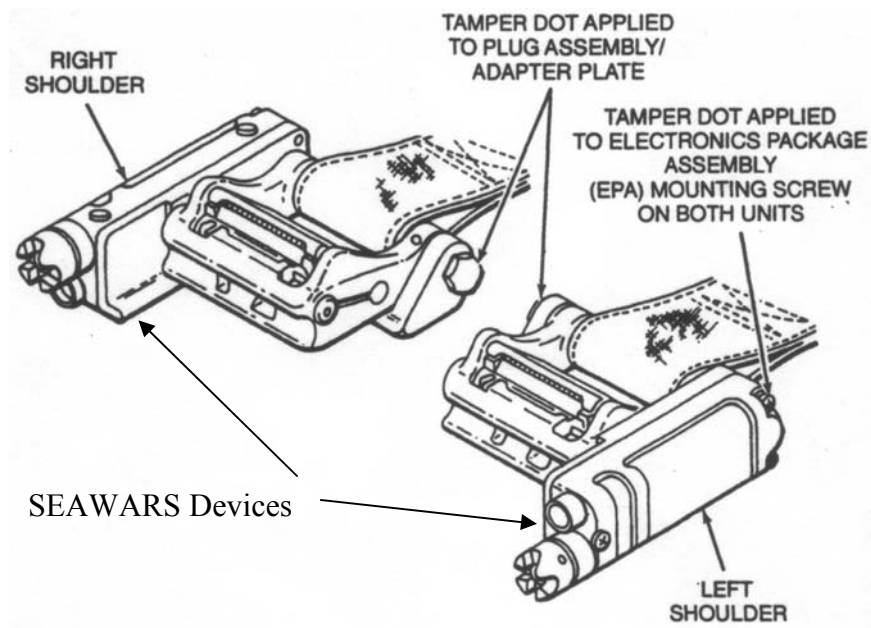


Figure 3. Upper Torso Harness Quick-Release Fittings with SEAWARS.

Source: *EA-6B NATOPS Flight Manual*, April 2002

harness Koch fittings. These Koch fittings have a parachute harness sensing-release unit called the Seawater Activated Release System (SEAWARS). The SEAWARS provides automatic separation of the occupant's upper torso harness and the personnel parachute risers to prevent the occupant from being dragged underwater if the occupant is unconscious or injured. Figure 3 shows the upper torso harness Koch fittings and the SEAWARS parachute harness sensing-release units.

An emergency restraint release handle is provided on the forward right side of each seat bucket. When the emergency restraint release handle is in the normal forward and locked position, the occupant remains attached to the ejection seat. When the emergency restraint release handle is pulled up and back by the occupant, the occupant is

released from the ejection seat by means of the initiation of the parachute withdrawal line guillotine which severs the personnel parachute from the ejection seat and the drogue parachute, while simultaneously releasing the lap-belt harness locks, personnel parachute container, survival kit attachment lugs and sticker clips, harness retraction unit straps, and the dual leg-restraint cords. If the occupant actuates the emergency restraint release handle before ejection, the face curtain and lower ejection handles will be locked, providing an expeditious means to egress the aircraft during an emergency while on the ground. The seat will still eject if command ejection is initiated.

A time release mechanism is located on the right side of the ejection seat. An altitude sensing barostat is integrated into the time release mechanism to prevent premature deployment of the parachute at high altitudes that would cause an opening shock to the occupant sufficient to cause injuries. As the ejection seat falls through approximately 11,500 to 14,500 feet of altitude above mean sea level (MSL), the time release mechanism is unlocked and after a two second time delay releases the drogue parachute from the scissors shackle, which then pulls the personnel parachute withdrawal line from the guillotine and deploys the personnel parachute. The shoulder harness restraints, lap belt, leg restraints, parachute container, survival kit, and face curtain are simultaneously unlocked. When the ejection is initiated below 11,500 feet MSL, the two second time delay begins immediately after ejection initiation.

Ventilated parachute back pads and ventilated seat cushions provide conditioned twelfth stage bleed air circulation through the cushions for occupant comfort.

A seat-bucket height adjustment actuator provides the pilot with seat height and tilt adjustment and the other three seats with height-only adjustment to provide for occupants of differing personal heights. All seats may be adjusted vertically by up to five inches of travel, and the pilot's seat may be adjusted by up to seven degrees of tilt.

SINGLE SEAT EJECTION SEQUENCE

The ejection sequence of the MBA GRUEA-7 ejection seats in the EA-6B aircraft operates independently of the canopy operation. Either the back canopy or both the forward and back canopies together may be jettisoned by independent aircrew initiation of the canopy jettison system, but canopy jettison is not required for ejection. The primary means of ejection in an emergency is through the closed canopy. Figure A-4 depicts the entire airborne ejection sequence of a single GRUEA-7 ejection seat from the EA-6B aircraft.

When an individual seat ejection sequence has been initiated by pulling the upper face curtain at least seven inches from its stowed position or by pulling the lower ejection handle upward at least two inches, the catapult seat and harness retraction unit seat are withdrawn, and the sequence gas generator seat is withdrawn at the pilot's seat and at ECMO 1's seat if the command eject lever is set to the ECMO 1 position. The command ejection sequence will be discussed after the single seat ejection sequence. The harness retraction unit will pull the occupant against the seat to prevent back and neck injuries at the initial onset of force. The catapult gun then fires and the expanding gases propel the catapult tubes upward, ejecting the seat with the occupant attached through the canopy and out of the aircraft. The catapult gun uses water-tight seals to allow underwater

ejection. As the seat rises out of the aircraft, the following events happen almost simultaneously:

- The leg restraint cords are pulled tight drawing the occupant's legs close against the lower leg pads to prevent leg flail injuries.
- The emergency oxygen supply is activated.
- The drogue gun trip rod is pulled.
- The time-release mechanism trip rod is pulled.
- The rocket motor gas generator lanyard is pulled.
- The personnel services quick-release pin lanyard is pulled.
- The survival kit AN/URT-33 survival beacon is activated, providing an intermittent tone on the international distress frequency 243.0 MHz.
- The transponder will begin broadcasting the emergency code of 7700 if the transponder master switch is not "OFF".
- A programmed chaff sequence is fired from the ALE-39 Expendables Dispensing System if chaff is installed, and if the ALE-39 selector switch is in any position other than "OFF".
- The radio, transponder, and GPS key codes are zeroized if aircraft essential power is available.

While the seat is rising out of the aircraft, the tension built up on the leg restraint cords sheers the rivets that secure the cords to the cockpit floor, which frees the cords from the aircraft. The occupant's legs will remain secured to the seat until seat separation. The rocket motor will fire when the rocket motor gas generator lanyard

reaches its limit, propelling the seat and occupant away from the aircraft. The drogue gun will fire one half second after ejection, and the drogue piston will withdraw the controller drogue parachute. The controller drogue parachute will then deploy and withdraw the stabilizer drogue parachute. The stabilizer drogue parachute decelerates and stabilizes the seat and occupant. The time release mechanism is denied activation above 14,500 MSL by the barostat, keeping the drogue parachute retention shackle locked to the seat by the restrain scissor. Once below 14,500 feet MSL, the barostat will free the time release mechanism, which releases the drogue gun shackle restraint scissor and allows the continued pull of the drogue parachute on the link lines to release the face curtain restraint and the main personnel parachute. The occupant's shoulder harness restraints and leg restraints, and the parachute container and survival kit are all released at this time as well. The occupant will remain attached to the seat by sticker clip retention of the lower restraint harness on the seat bucket until the line stretch of the personnel parachute pulls the occupant, survival kit, and lower restraint harness free of the sticker clips. The seat will then fall free and the occupant returns to Earth by means of the personnel parachute.

If the occupant believes the time release mechanism has failed to actuate at 14,500 feet MSL or high terrain projects into the 11,500 to 14,500 feet MSL window of automatic seat separation, the seat separation can be manually initiated by pulling up and back on the emergency restraint release handle on the right side of the seat pan. This will release the occupant from the ejection seat by means of the initiation of the parachute withdrawal line guillotine which severs the personnel parachute from the ejection seat

Table 2. Ejection Seat Trajectory Divergence from Vertical.

Aircrew Position	5 Percentile Divergence from Vertical (Degrees)	95 Percentile Divergence from Vertical (Degrees)
ECMO 3	14 Left	10 Left
ECMO 2	0	0
ECMO 1	14 Right	10 Right
Pilot	14 Left	10 Left

Source: *EA-6B NATOPS Flight Manual*, April 2002

and the drogue parachute, while simultaneously releasing lap-belt harness locks, personnel parachute container, survival kit attachment lugs and sticker clips, harness retraction unit straps, and the dual leg-restraint cords. Manual activation of the emergency restraint release handle disables the automatic deployment of the personnel parachute, so the D-ring handle on the left shoulder harness strap must be pulled to deploy the personnel parachute.

In the event of an ejection while on the ground, the GRUEA-7 ejection seat will perform the same as at higher altitudes, with the exception that the time release mechanism will actuate the personnel parachute deployment and seat separation with no delay after the drogue parachute inflates. Figure A-5 shows an example of a ground ejection from the EA-6B aircraft with a speed of 80 knots.

Individual seat separation is provided by using oversized inboard rocket motor nozzles on the pilot, ECMO 1, and ECMO 3 seats. All rocket motor nozzles on the ECMO 2 seat are the same size. Table 2 shows the degrees divergence from vertical for each ejection seat. Permissible occupant weight range is given as a percentile range

based on nude weights from 140 pounds to 204 pounds based on the GRUEA-7 ejection seat development and testing, assuming a male anthropometric model. (EA-6B NATOPS Flight Manual, April 2002) The lightest occupant nude weights specific to the GRUEA-7 ejection seat are considered to be in the 5 percentile range and the heaviest occupant nude weights are considered to be in the 95 percentile. (EA-6B NATOPS Flight Manual, April 2002) On the other hand, the minimum and maximum allowed aviator nude body weights are 100 pounds to 235 pounds, so a gap exists both above and below the rated nude body weights approved for the GRUEA-7 ejection seat.⁸

The GRUEA-7 ejection seats use a total of seven pins to provide a backup means of preventing inadvertent ejection. The pilot and ECMO 1 seats each have an eighth pin that prevents the command ejection gas sequencer from discharging. A pinned seat will not be ejected even during a command ejection. Seats that will not have an occupant during a flight are left pinned to prevent the seat from ejecting during a command ejection to prevent collision with other seats.

COMMAND EJECTION SEQUENCE IN THE EA-6B PROWLER

The command ejection capability permits one aircrew to initiate ejection for all four ejection seats. The pilot seat will always initiate a command ejection. A command ejection selection handle is provided on the console between the pilot and ECMO 1 in the front cockpit to allow the selection of “NORM” to allow only the pilot to initiate command ejection, and “ECMO” which allows either the pilot or ECMO 1 to initiate a command ejection. ECMO 2 and ECMO 3 can only initiate an ejection for their own crew station. Each ejection seat has a preset automatic timing device that causes an

Table 3. EA-6B Command Ejection Sequence Preset Delays.

Aircrew Position	Color Coding of Ejection Time Delay Unit	Delay for Ejection After Command Eject Initiation (Seconds)
ECMO 3	White	0.0
ECMO 2	Orange	0.4
ECMO 1	Purple	0.8
Pilot	Brown	1.2

Source: *EA-6B NATOPS Flight Manual*, April 2002

ejection delay which creates a separation between the individual ejection seats so that there are no collisions or tangling of personnel parachutes. A color code provides external identification of the delay associated with the automatic timing device of each ejection seat. Table 3 presents the color coding and preset delay for each ejection seat. The delay will be present even if a seat is individually ejected.

When a command ejection is initiated by the pilot, the pilot's command gas actuated piston fires the pilot's command sequence gas generator which simultaneously initiates ejection of all four seats according to their individual preset delays. When "ECMO" is selected with the command ejection selection handle and ECMO 1 initiates and ejection, ECMO 1's command sequenced gas generator operates the pilot's command gas actuated piston which then fires the pilot's command sequenced gas generator and initiates ejection of all four seats according to their individual preset delays. If ECMO 1 initiates an ejection with the command ejection selection handle in "NORM" then ECMO 1's command sequenced gas generator on the ejection gun vents into the cockpit and only ECMO 1's ejection seat will exit the aircraft.

The timing for a command ejection is critical to allow proper seat and personnel parachute deployment so no collisions of ejecting seats or occupants occur. In the EA-6B it is not recommended to initiate a command ejection at airspeeds below 80 knots due to inadequate escape system sled testing. The nude weight of the occupants is of concern for slow speed command ejections, especially when the front seat occupants are very light and the back occupants are very heavy. The highest likelihood of collision from a slow, stable aircraft is when the pilot is a 5 percentile nude body weight and ECMO 3 is a 95 percentile nude body weight. ECMO 3 may not proceed far enough from the aircraft to prevent the lighter pilot from catching up to and colliding with ECMO 3. Figure A-6 shows a command ejection at an airspeed of 80 knots at ground level when all four occupants are 5 percentile nude body weights. In this case there is little chance of ejection seat collision or personnel parachute entanglement. Figure A-7 shows a command ejection at an airspeed of 80 knots at ground level when all four occupants are 95 percentile nude body weights. Although the ejection seats do not project to as high an altitude as the 5 percentile nude body weight occupants and do not spend as long in the air prior to landing, there is still little chance of ejection seat collision or personnel parachute entanglement. Figure A-8 shows a command ejection at an airspeed of 80 knots at ground level when the pilot and ECMO 1 are 5 percentile nude body weights and ECMO 2 and ECMO 3 are 95 percentile nude body weights. In this case, depending on winds and aircraft orientation, there is a significantly higher chance that the ejection seats will cross paths and collide or the personnel parachutes will become entangled.

CHAPTER 3: THE MBA SJU-17A NACES

HISTORY

The U. S. Navy awarded the NACES contract to the Martin-Baker Aircraft Company in May of 1985.⁹ As the name implies, the NACES was designed as a common ejection seat for all U. S. Navy aircraft. The NACES was developed based on the MBA Mark 10 ejection seat used in the earlier models of the FA-18 A-D model Hornets. The NACES was first flown operationally in the F-14D Tomcat, and then was incorporated in the FA-18A-D model Hornets and the T-45 Goshawk. The NACES was scheduled to replace the GRU-7 ejection seat in the A-6 Intruder, but that program was cancelled. The SJU-17/A NACES added an electronic sequencing system and was incorporated in the FA-18E/F Super Hornet.

DESCRIPTION

The MBA SJU-17A NACES is a telescopic catapult/rocket assisted ejection seat, providing each aircrew an emergency means of escape from the aircraft in any flight condition ranging from zero knots to 600 knots of airspeed, and from ground level to 50,000 feet MSL, giving the MBA SJU-17A NACES a “zero – zero” capability¹⁰. The SJU-17A NACES is qualified for use by aviators with nude body weights ranging from 136 to 245 pounds, which leaves a gap between the minimum allowed aviator nude body weights of 100 pounds and the rated nude body weight approved. The SJU-17A NACES is composed of two vertical beams in the back of the seat, with all of the NACES subassemblies attached to the two vertical beams. Figure A-9 shows the right side of the

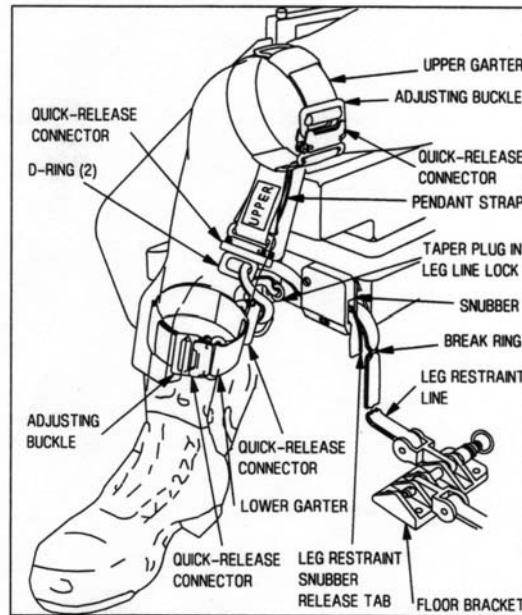


Figure 4. SJU-17A NACES Leg Restraint System.

Source: *EA-6B NATOPS Flight Manual*, April 2002

SJU-17A NACES. Figure A-10 shows the left side of the SJU-17A NACES. The occupant is attached to the ejection seat at eight points. The occupant wears the same torso harness with the same fittings at the GRUEA-7 occupants. The shoulder harness fittings are the same SEAWARS equipped quick-release fittings used on the GRUEA-7 ejection seat. The lap belts fasten to the lower fittings of the occupant's torso harness to the seat pan using the same quick-release fittings as the GRUEA-7 ejection seat. Each of the SJU-17A NACES leg restraint garters are attached to the ejection seat by a single quick-release connector, and are then connected to the aircraft floor at the floor bracket. The leg restraint garters attach to the occupant with two adjustable buckles on each leg; one wraps above each ankle, and one wraps above each knee. Figure 4 shows the

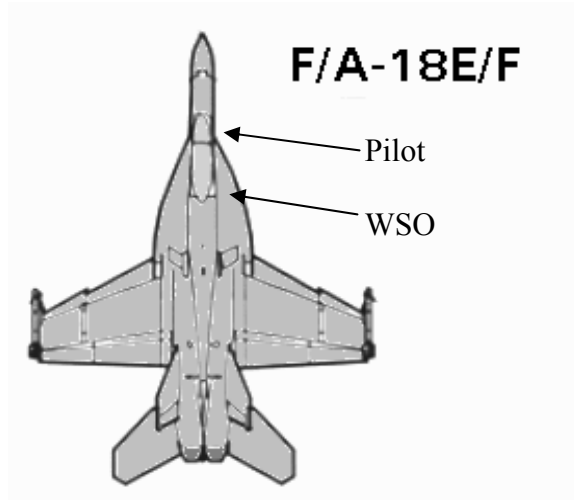


Figure 5. FA-18F Super Hornet Seat Labels.

Source: *FA-18 NATOPS Flight Manual*, March 2001

SJU-17A NACES Leg Restraint System and how the leg garters are worn and attach to the ejection seat. These leg restraint cords are withdrawn when an ejection is initiated to prevent leg flail injuries.

The single seat Super Hornet, the FA-18E, is equipped with one SJU-17A NACES. The dual seat Super Hornet, the FA18F, is equipped with two SJU-17A NACES, and is labeled according to the crew position; the front seat occupant is the pilot and the back seat occupant is the Weapon Systems Operator (WSO), the NFO trained specifically for the FA-18F. Figure 5 shows the labels for each seat. Discussion will focus on the FA-18F to compare seat performance and command ejection capabilities between the SJU-17A NACES and the GRUEA-7 ejection seat in multi-seat aircraft.

There are several key components integrated into each SJU-17A NACES, and some of them are identical to those found in the GRUEA-7 ejection seat. The identical

components are the upper and lower torso harness Koch fittings, as well as the SEAWARS parachute harness sensing-release units, and the personnel services disconnect, allowing an occupant to use the same torso harness and oxygen mask equipment in either ejection seat. The anti-“g” suit connection fitting is the same as on the GRUEA-7 seat, except in the FA-18E/F Super Hornet the anti-“g” suit bleed air connector is located on the left console panel instead of on the ejection seat.

A seat-stabilizer drogue parachute provides initial deceleration and stabilization of the ejection seat immediately after ejection. The drogue parachute is contained in a canister mounted on top of each ejection seat. The drogue parachute attaches to the back of each ejection seat at three points by a stabilizing bridle, which causes the seat and occupant to face into the relative wind providing increased stabilization. The drogue parachute is jettisoned prior to the main parachute deployment.

A 21 foot main parachute is provided in a separate container on top of the drogue deployment catapult. The main parachute is deployed by means of a parachute deployment rocket. The main parachute has water deflation pockets to aid in dumping air from the canopy after a water landing.

The SJU-17A NACES only has one ejection control handle located on the front of the seat pan between the legs of the occupant. This is the only method an ejection can be initiated other than by command ejection. Actuation of the ejection control handle requires a pull of 20 pounds to 40 pounds of force to remove the handle from the ejection control handle housing, and a continued pull of 30 pounds to 60 pounds of force to withdraw the dual seat initiator sears. Operation of only one of the dual seat initiators is

required to initiate an ejection. The ejection handle remains connected to the seat after ejection.

The ejection seat safe/armed handle is located on the right forward side of the seat pan. When the ejection seat safe/armed handle is rotated up and forward, a pin is inserted into the ejection firing mechanism preventing withdrawal of the dual seat initiator sears in order to prevent an inadvertent ejection. When the ejection seat safe/armed handle is rotated down and back, the pin is removed, allowing the ejection command handle to initiate an ejection if it is pulled up with sufficient force.

The personnel services disconnect is located on the left back side of each seat pan and provides the connections for supply lines from the aircraft to the occupant for oxygen and communications. When an ejection is initiated, the personnel services disconnect is freed by a quick-release fitting that connects the seat pan to the aircraft.

The SKU-10/A seat survival kit is composed of the seat pan, emergency oxygen cylinder, and fabric survival rucksack. Figure A-11 shows top and bottom views of the SKU-10/A seat survival kit. The emergency oxygen cylinder provides approximately 15 minutes of emergency oxygen to the occupant. The emergency oxygen cylinder is automatically activated during an ejection by a lanyard that connects both the emergency oxygen cylinder and the AN/URT-33 survival beacon to the aircraft floor. As the seat leaves the aircraft, the lanyard is pulled until both systems are activated, providing emergency oxygen to flow through the occupant's personnel oxygen regulator to the oxygen mask and providing a homing beacon to assist in occupant rescue. The emergency oxygen cylinder can also be manually activated at any time by the operator by

using a green looped handle located on the left front of the seat pan. The emergency oxygen handle can be reset allowing the operator to stop the flow of emergency oxygen. The survival equipment present is the same that is used in the GRUEA-7 ejection seat pan; however the survival equipment in the SJU-17A NACES pan is contained in a fabric rucksack that can be easily detached from the underside of the seat pan by releasing five fabric straps and a double cone and release system.

The shoulder harness inertial reel is mounted in the seat just below the main parachute container. The shoulder harness connects to the occupant's torso harness using Koch fittings with the SEAWARS units attached. When an ejection is initiated, a pyrotechnic cartridge is fired retracting the shoulder harness to pull the occupant into an upright position to prevent neck and back injuries.

A manual override handle, equivalent to the emergency restraint release handle on the GRUEA-7 ejection seat, is provided on the right side of the seat pan, just behind the ejection seat safe/armed handle. When the manual override handle is in its normal down and locked position, the occupant remains attached to the ejection seat. The manual override handle is activated by pressing down on the thumb button on the forward part of the handle and rotating the handle up and back. When activated before an ejection, the manual override handle simultaneously releases the occupant's leg restraint cords and survival kit attachment lugs, unlocks the upper harness inertial reel lock, and automatically rotates the ejection seat safe/armed handle up and forward to the "SAFE" position, providing an expeditious means to egress the aircraft during an emergency while on the ground.

An electronic sequencer uses altitude, acceleration, and airspeed to control the timing of all events after the rocket motor initiation including control drogue deployment, main parachute deployment, and seat/occupant separation. When an ejection is initiated, thermal batteries are fired that power up the electronic sequencer. The electronic sequencer then uses a built-in software lookup table to determine the optimum ejection profile out of five possible modes of operation based on the altitude, acceleration, and airspeed. Figure 6 shows the five modes of operation of the SJU-17A NACES as a plot of airspeed versus altitude.

The high altitude mode of the electronic sequencer allows the seat to fall slowed only by the drogue parachute until the seat and occupant reach 18,000 feet MSL when the main parachute is deployed and seat/occupant separation occurs. The medium altitude mode, between 8,000 and 18,000 feet MSL, and the three low altitude modes allow main parachute deployment and seat/occupant separation after a delay of between 0.45 and 2.90 seconds, depending on the altitude and airspeed, to allow for seat stabilization and initial deceleration by the drogue parachute.

A 4-second mechanical delay is provided in case of a partial or total failure of the electronic sequencer. The 4-second mechanical delay initiates the barostatic release unit which frees the occupant from the ejection seat and deploys the main parachute between 14,000 and 16,000 feet MSL if the ejection occurred above that altitude range, or immediately after the 4-second delay if the ejection occurred below 14,000 feet MSL.

A seat bucket position switch on the left forward side of the seat pan allows the seat to be positioned vertically in a 6.1 inch range. A back pad adjustment mechanism

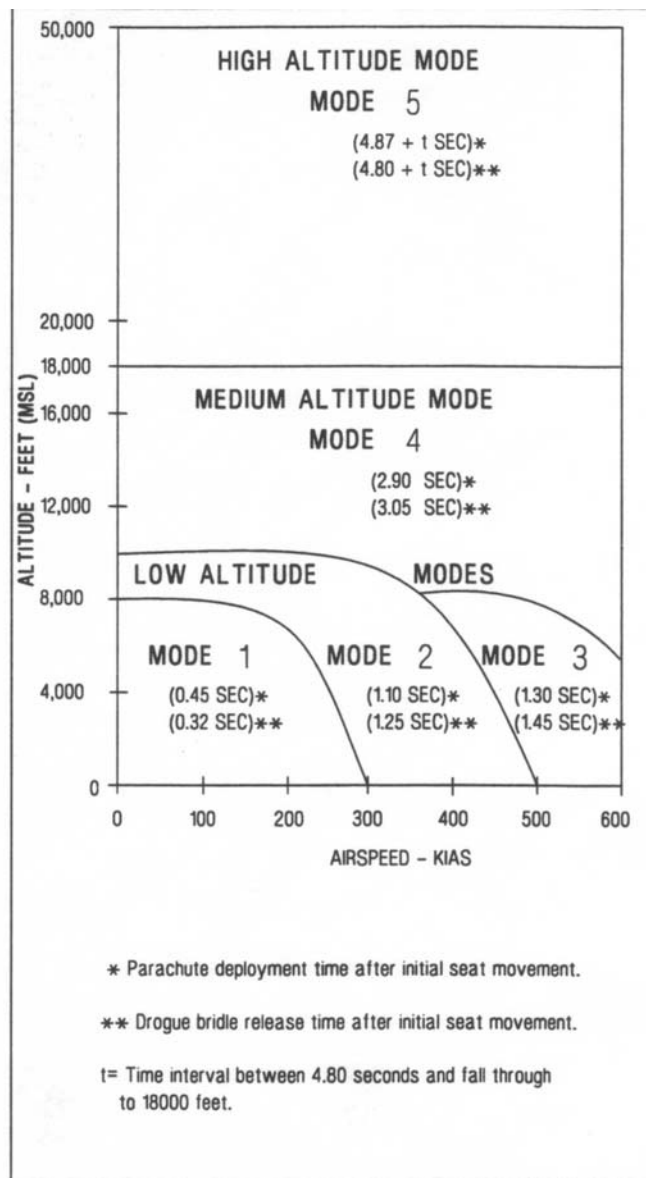


Figure 6. SJU-17A NACES Ejection Modes.

Source: *FA-18 NATOPS Flight Manual*, March 2001

handle is located on the seat bucket next to the top left side of the back pad and is connected to the back pad by a linkage that allows the selection of three positions, full-forward, middle, and full-back, giving a total adjustment potential of 1.6 inches of horizontal travel.

The SJU 17A NACES has only one ground safety pin, the ejection handle safety pin, which pins the ejection control handle as a secondary safety measure to prevent inadvertent ejection in case the ejection seat safe/armed handle is positioned incorrectly or does not function properly.

SINGLE SEAT EJECTION SEQUENCE

The ejection sequence of the SJU-17A NACES in the FA-18E/F Super Hornet is sequenced with the jettison of the canopy, although canopy jettison is not required for ejection. Figure A-12 shows the entire ejection sequence for the SJU-17A NACES from an FA-18E/F Super Hornet.

When an individual seat ejection sequence has been initiated by pulling the ejection control handle up, the dual seat initiator sears are withdrawn and immediately the automatic canopy jettison initiates, the transponder squawks the emergency code of 7700, and the pyrotechnic cartridge is fired retracting the shoulder harness to pull the occupant into an upright position. Pyrotechnics then pressurize the telescopic catapult ejecting the SJU-17A NACES out of the aircraft. As the seat travels upward the occupant's legs are withdrawn against the lower ejection seat pan by the leg restraint cords and the emergency oxygen supply and emergency locator beacon are activated by their combined lanyard. The leg restraint cords are released from the cockpit floor by tension as the seat

exits the aircraft. When the ejection seat passes the end of the catapult the rocket motor ignites further accelerating the ejection seat and occupant away from the aircraft, and the drogue catapult is fired deploying the drogue parachute to stabilize and decelerate the seat.

The electronic sequencer is activated and determines which of the five modes to utilize for drogue parachute release and main parachute deployment based on altitude, airspeed, and acceleration. If the electronic sequencer fails in part or in whole, then the 4-second mechanical delay initiates the barostatic release unit which frees the occupant from the ejection seat and deploys the main parachute between 14,000 and 16,000 feet MSL if the ejection occurred above that altitude range, or immediately after the 4-second delay if the ejection occurred below 14,000 feet MSL.

At the moment directed by either the electronic sequencer or the 4-second mechanical delay, the drogue parachute is released, the main parachute rocket fires to extract and deploy the main parachute, and the harness and leg restraints cords are released. The opening shock of the parachute separates the occupant from the ejection seat.

If the occupant believes the electronic sequencer and the 4-second mechanical delay have failed or that high terrain projects above 14,000 to 16,000 feet MSL, then the occupant can pull the manual override handle. After ejection, pulling up and back on the manual override handle will release all restraints and fire the operator override initiator cartridge activating the parachute deployment rocket motor. The main parachute will deploy and the opening shock will separate the occupant from the seat.

In the event of ejection while on the ground, the ejection sequence will remain the same as an airborne ejection and the electronic sequencer will use the appropriate mode based on altitude, airspeed, and acceleration.

COMMAND EJECTION SEQUENCE IN THE FA-18F SUPER HORNET

A command ejection sequencing system is provided to allow dual ejection initiated from either seat. A command ejection mode handle is provided in the back cockpit to determine if an ejection initiated from the back cockpit is a command ejection by the “AFT INITIATE” position or an individual ejection of the back seat by the “NORM” position. The front seat ejection always initiates a command ejection unless the “SOLO” position is selected by the mode selector handle. The “SOLO” position can only be selected by using a special mode selector handle pin to prevent inadvertent selection which would prevent the back seat occupant from ejecting. The “SOLO” position is to be used only when the back seat is empty to prevent seat collision on ejection.

Preset delays are programmed into the command ejection sequence to prevent collision between the canopy and either ejection seat. Table 4 lists the preset delays for the FA-18F command ejection sequence jettison and ejection events.

Table 4. FA-18F Command Ejection Sequence Preset Delays.

Event	Delay After Command Eject Initiation (Seconds)
Canopy Jettison	0.0
WSO Ejection	0.4
Pilot Ejection	0.8

Source: *FA-18 NATOPS Flight Manual*, March 2001

CHAPTER 4: INTEGRATION

REQUIREMENTS

The SJU-17A NACES must meet several requirements as determined by the author in order to provide a viable replacement for the GRUEA-7 ejection seat in the EA-6B aircraft. These requirements are based on interviews with the enlisted personnel that maintain both types of ejection seats, information provided by the researched references, and the experience of the author as a NFO in both the EA-6B and the FA-18F. The requirements are:

1. The ejection of all four aircrew must take less than or equal to 1.2 seconds.
2. The SJU-17A NACES must provide increased safety and reliability.
3. The operator human factors conditions must be satisfactory.
4. The EA-6B gross weight and center of gravity changes must be small.
5. The front and back canopies must remain unchanged.
6. The airframe must require only minor changes for SJU-17A NACES fit.
7. The SJU-17A NACES must require minimal training for aircrew and maintainers.
8. The SJU-17A NACES must be logistically supportable.
9. The transition cost must be as small as possible based on the total costs of all listed requirements, and must not make replacing the GRUEA-7 ejection seat cost prohibitive. Expected costs will be individually discussed in each requirement.
10. The SJU-17A NACES must contain the standard naval aircrew survival equipment.

COMMAND EJECTION

The electronic sequencer on each SJU-17A NACES unit provides a very precise ejection sequence for each ejection seat. Combining this precision with five possible modes of ejection allows each seat to follow a precise timeline for ejection that can be programmed to maximize each occupant's survival. This precise timeline can be utilized by an electronic command ejection sequencer to reduce the probability of seats colliding or becoming entangled after an ejection. The electronic command ejection sequencer can also have a parameter lookup table to use airspeed, altitude, acceleration, and which ejection seats are armed for ejection to determine which command ejection mode of a series of modes would be most appropriate to ensure the survival of the occupants. The electronic command ejection sequencer could also reference ejections seats that are pinned and therefore not occupied, bypass that crew station, and allow other ejection seats to eject earlier in the sequence.

The ejection sequence time could be reduced by allowing ECMO 2 and ECMO 3 to simultaneously eject, and then after a short delay allow the pilot and ECMO 1 to simultaneously eject. Additional structural analysis would have to be performed to determine if the current floorboard and airframe in the EA-6B could handle the additional reaction forces of two seats ejecting vice one seat ejecting. Any additional reinforcement of the floorboards or airframe will increase the cost of incorporation of the NACES in the EA-6B aircraft.

Directional separation remains important with the NACES in the EA-6B to prevent collision between the ejected seats or parachute entanglement, whether the seats

ejected simultaneously or not, and would have to be provided on the NACES by diverging catapult rails, additional outboard weights, or oversized inboard rocket motor nozzles. Re-designing the NACES will require additional modeling and simulation, rocket sled testing, maintenance training, and documentation changes which will increase the cost of the incorporation of the NACES in the EA-6B aircraft.

The command ejection could be further enhanced by allowing the electronic sequencer in each NACES to determine the individual delay for drogue parachute and main parachute deployment to maximize seat separation during a command ejection at low altitudes when the time for the pilot to exit the aircraft is critical. By allowing the main parachute of ECMO 2 and ECMO 3 to open earlier, initial separation after ejection will be increased.

By using the precise timing of the electronic command ejection sequencer, combined with the electronically sequenced NACES and the improvements listed previously, the ejection time for the pilot after command ejection initiation could be reduced to as little as 0.8 to 1.0 seconds. This 0.2 to 0.4 second margin may have saved the lives of the 3 pilots who have died due to late ejections.

The existing command ejection selection handle in the EA-6B can be used to input the handle position to the electronic command ejection sequencer so that no airframe modifications or training are required.

EJECTION ENVELOPE

The SJU-17A NACES has 5 separate modes of operation while the GRUEA-7 ejection seat only has 1 mode of operation. The 4 extra modes of the SJU-17A NACES

focus on the low and medium altitudes where the aircrew that ejected in the GRUEA-7 ejection seats have been lost. The SJU-17A NACES takes airspeed, altitude, and acceleration into account, while the GRUEA-7 ejection seat only operates in one mode without reference to these parameters. The SJU-17A NACES would increase the survivability of the aircrew throughout all phases of flight, and provide a more reliable alternative to the GRUEA-7 due to fewer moving parts, the addition of an electronic sequencer, and fewer maintenance requirements. The SJU-17A NACES would increase the safe ejection envelope of the EA-6B aircraft.

HUMAN FACTORS

The human factors Software, Hardware, Environment, and Liveware (SHEL) model must be examined to ensure the proper interrelationships exist between the three types of resources and the environment. Figure A-13 shows the three resources of software (S), hardware (H), and liveware (L) of the SHEL model and how they interact with and are surrounded by the environment (E).¹¹ The software resource consists of regulations, standard operating procedures (SOPs), policies, manuals, checklists, performance charts, and maps. The hardware resource consists of the aircraft and its systems, including the ejection seats. The liveware resource consists of the aircrew and every person that the aircrew interacts with on the ground and in the air. The environment is the actual physical environment that the aircraft and aircrew operate in such as weather or the battlefield. The primary concerns of integrating the SJU-17A NACES in the EA-6B aircraft are the liveware-hardware interface; the interaction between the aircrew and the aircraft controls and systems and how the ejection seat

affects this interaction, and the hardware-hardware interface; the interaction between the different systems onboard the E-6B aircraft.

The SJU-17A NACES must meet the requirements for vision, reach, and ejection clearance for all aviators from the 5 percentile to the 95 percentile¹². Figure A-14 shows the standard arm reach requirements and how the ejection seat may affect the arm requirements. Figure A-15 shows the bended knee reach and vision requirements and how the ejection seat may affect the bended knee reach and vision requirements. Figure A-16 shows the ejection clearance requirements. The SJU-17A NACES must meet the requirements for electromagnetic interference (EMI) and electromagnetic consideration (EMC), especially considering the primary mission of the EA-6B Prowler is EW through the use of electro-magnetic radiation.¹³

The addition of another inch of vertical seat adjustment and 1.6 inches of horizontal seat adjustment by the SJU-17A NACES will provide greater flexibility for all permitted occupant body types and will increase the ability of the occupant to adjust the ejection seat into a position allowing the maximum reach potential. This will allow the occupant to more comfortably see and manipulate controls and displays and increase the mission effectiveness of the occupant. The additional inch of seat travel will not place the SJU-17A NACES in violation of the ejection clearance requirements, and will not affect the design of the forward or aft canopies.

The SJU-17A NACES was designed to be used in a saturated EMI/EMC environment caused by powerful air-to-air radar and other systems that utilize the electromagnetic spectrum. The electronic sequencer and other systems associated with

the SJU-17A NACES have shown no susceptibility to EMI, and should be fully compatible with the EA-6B aircraft's EW mission.

AIRFRAME MODIFICATIONS

The integration of the SJU-17A NACES in the EA-6B aircraft must require only minor airframe changes to mitigate the expense and to preclude additional structural analysis and aerodynamic testing. The front and back canopies must remain unaltered, the pilot's control stick must remain unaltered, the ECMO 1 radar pedestal must remain unaltered, the ECMO 2 and ECMO 3 digital display indicator control (DDIC) pedestals must remain unaltered, and all controls and displays in the front and back cockpits must remain unaltered. The gross weight and center of gravity of the aircraft must not change significantly.

The weights and dimensions of both the GRUEA-7 ejection seat and the SJU-17A NACES are approximately the same, with the NACES weighing about 50 pounds less per seat, so few if any airframe modifications would be required, and the controls and displays of all four crew stations can remain unaltered. The aircraft's gross weight and center of gravity will also not change significantly, and no additional reinforcement of the aircraft floorboards will be required, unless simultaneous ejection of two ejection seats requires additional strengthening. The ejection seats are approximately the same height, so the front and aft canopies will remain unaltered.

The SJU-17A NACES would require that the new telescopic catapult rail be installed. This could directly replace the previous telescopic catapult rail with little airframe modification. An anti-"g" suit quick release fitting would have to be added to

the SJU-17A NACES personnel services disconnect or installed in the aircraft at the four crew stations. The leg restraint cord connectors for the GRUEA-7 ejection seat would have to be removed and the SJU-17A leg restraint floor bracket would have to be installed. All of these changes are minor, but would require the aircraft to be placed in a non-flying status for a period of time, which could be offset by performing the modifications while the aircraft was not flying due to other modifications, such as night vision devices or aircraft re-winging.

TRAINING, MAINTENANCE, AND LOGISTICS

All pilots trained by the U. S. Navy fly the SJU-17 equipped T-45 Goshawk, and all naval NFO's will soon be taught the final phase of training in the T-45 as the T-2 Buckeye and TA-4 Skyhawk are retired from service. The difference between the SJU-17 and the SJU-17A is the electronic sequencer and is transparent to the aircrew for training and operation. Since the aviators are already qualified in the use of the NACES before they arrive for EA-6B specific training, time and money would be saved by not having to teach the aircrew the new GRUEA-7 ejection seat. Some EA-6B aircrew would require initial NACES training, but this training is minimal and the cost will be small.

Initial maintainer training would require some added cost for current EA-6B assigned enlisted personnel in the Aviation Structural Mechanic - Safety Equipment (AME) profession, but once complete the AME personnel would then be qualified to work on any NACES seat in the Navy. When an air wing, the naval unit comprised of the individual squadrons, deploys on an aircraft carrier with all versions of the FA-18, the

F-14D, and the EA-6B, then any AME personnel will be able to help the other squadrons. The SJU-17A NACES requires far less maintenance than the GRUEA-7 due to fewer parts and the addition of the electronic sequencer.¹⁴ The decreased maintenance time per ejection seat would allow AME personnel to concentrate on other facets of their job and learn more aviation related maintenance skills making them more valuable to the Navy. The AME personnel would then be more versatile for transfer to other aviation commands, to include the aviation training commands, requiring less training for all personnel in the long term.

The incorporation of the SJU-17A NACES in the EA-6B aircraft would place less strain on the logistics support system over time. With the EA-6B becoming the only remaining aircraft to use the GRU-7 series of ejection seats, there will be less spare parts available, requiring more time, effort, and expense to find and send the parts to the required locations. With fewer GRU-7 series ejection seats in aircraft on the airfields and aircraft carriers, there will be less spare parts to immediately have access to, which may cause lost flights when ejection seats are broken and awaiting parts. Incorporating the SJU-17A NACES in the EA-6B will increase the spare parts carried on board the airfields and aircraft carriers increasing the readiness of all the attached naval tactical aviation squadrons. Initially, purchasing four NACES units for the 123 EA-6B aircraft in the U. S. inventory, along with the initial parts to support these additional seats, will incur a significant cost. (Global Security, 2003) These costs will be offset over time by the reduction of cost due to the retirement of the GRUEA-7 ejection seat and the required

spare parts, the increased availability of NACES parts to all tactical naval aircraft, and the interchangeability of parts between tactical naval aircraft.

The incorporation of the SJU-17A NACES in the EA-6B will remove the necessity to maintain the training and documentation programs for the GRUEA-7 ejection seat, which will save time, effort, and money for the naval logistics, training, and publications programs. The initial cost of implementing new training for EA-6B aircrew and maintainers and the documentation for the NACES modified specifically for the EA-6B, will increase the initial start-up cost of incorporation of the NACES. The potential savings over time caused by all naval aircrew and maintainers training to a single ejection seat, combined with single source training and maintenance documentation can be large enough to offset the initial costs.

The SJU-17A NACES carries the same survival equipment required of the GRUEA-7 ejection seat which will have no impact on the training of aircrew and maintainers or the logistics support system.

CHAPTER 5: CONCLUSIONS

The EA-6B Prowler will continue to be an important tactical and strategic asset to the defense interests of the United States. As the airframe continues to age, the importance of the ejection seat and ejection system to save aircrew lives will only increase with time. The GRU-7 series of ejection seats, although reliable to date, use 30 year old technology, providing limited ejection capability in low altitude ejections, especially when a command ejection is used. The expense of operating, maintaining, and supporting the GRUEA-7 ejection seat will only increase as more aircraft that use the GRU-7 series of ejection seats are retired from service.

The SJU-17A NACES provides a low cost, low risk solution to replace the GRUEA-7 ejection seat in the EA-6B aircraft. The operating, maintenance, and support systems are already in place, and the widespread use of this common ejection seat is only growing with time. Table 5 lists a side-by-side capabilities comparison of the GRUEA-7 ejection seat and the SJU-17A NACES. The only degradation of capabilities are the reduction of main parachute diameter, which would cause less drag during parachute fall and increase the speed and the chance of occupant injury, and the lack of a seat tilt function for the pilot. The main parachute used in the SJU-17A can be replaced with the 28 foot diameter parachute, although this will require a slight modification to the SJU-17A NACES main parachute container which will affect the size and weight of the seat and possibly change the installation requirements due to airframe modifications. Additional analysis will have to be performed to evaluate the differences of opening shocks between the two parachute sizes, and the difference that the opening shock of a

Table 5. Comparison of GRUEA-7 and SJU-17A NACES.

Parameter	GRUEA-7	SJU-17A NACES	Comparison
Modes of Operation	1	5	Improvement
Electronic Sequencer	No	Yes	Improvement
Seat/Occupant Automatic Separation	11,500 to 14,500 feet MSL	14,000 to 16,000 feet MSL	Improvement
Automatic Personnel Parachute Deployment after manual Seat/Occupant Separation	No	Yes	Improvement
Personnel/Main Parachute Diameter	28 feet	21 feet	Degradation
Nude Body Weight Range	140 to 204 pounds	136 to 245 pounds	Improvement
Emergency Oxygen Flow Control by Occupant	No	Yes	Improvement
Leg Restraint System	Yes	Yes	No Change
Canopy Breakers on top of Seat	Yes	Yes	No Change
Back Pad Adjustment	No	1.6 inches	Improvement
Seat Height Adjustment	5 inches	6.1 inches	Improvement
Pilot Seat Tilt Adjustment	7 degrees, pilot only	No	Degradation
Safety Pins	8 front/7 back	1	Improvement

Sources: *EA-6B NATOPS Flight Manual*, April 2002, and *FA-18 NATOPS Flight Manual*, March 2001

larger parachute will have on the 5 modes of the NACES. This additional analysis will increase the cost of the NACES incorporation into the EA-6B aircraft.

The SJU-17A has a one inch increase in vertical travel and the capability to adjust the back pad in a 1.6 inch range, compensating for the loss of the seat tilt and gaining a capability at the ECMO stations.

The SJU-17A NACES has been concluded by the author to be a more capable seat and feasibly adaptable to the EA-6B airframe for the following reasons:

1. The ejection of all four aircrew from the EA-6B aircraft can be reduced to less than 1.2 seconds using a combination of the SJU-17A NACES and an electronic command ejection sequencer with multiple modes of operation based on airspeed, altitude, acceleration, and number of occupied ejection seats. Further investigation to refine the modes of operation of the NACES and the electronic command ejection sequencer to provide for four ejection seats will be required.
2. The SJU-17A NACES will provide a safer and more reliable option due to the electronic sequencer and its five modes of operation, and the simpler design and maintainability.
3. The SJU-17A NACES will be more compatible with the wide range of operator sizes and shapes due to an increased nude body weight capability and range of adjustment for all operators.
4. Incorporation of the SJU-17A NACES will require only a few minor airframe changes, the aircraft gross weight and center of gravity will not significantly change,

and the front and aft canopies will remain unchanged. Further structural analysis will be required to provide for multiple seat simultaneous ejection.

5. The SJU-17A NACES will require initial training for aircrew and maintainers, but as the U. S. Navy continues to transition to this ejection seat as the standard, the training for aircrew and maintainers will actually decrease since the GRUEA-7 ejection seat training will no longer be required.
6. The SJU-17A NACES is already fully logistically supported by the naval logistic system, and the GRUEA-7 is placing a strain on the naval logistic system, so incorporating the SJU-17A NACES into the EA-6B aircraft will reduce the burden on the naval logistic system and save time, effort, and money while increasing readiness.
7. The transition cost to the SJU-17A NACES in the EA-6B aircraft will be small as compared to designing a new ejection seat or incorporating an ejection seat that is unproven in naval aircraft based on the minor airframe modifications required, current widespread use throughout the U. S. Navy leading to future cost savings, and the ease of maintenance. As the airframe and GRUEA-7 ejection seat age, the cost of maintaining the GRUEA-7 will exceed the initial investment required to incorporate the SJU-17A NACES.
8. The SJU-17A NACES contains the standard naval survival gear required for occupant survival.

CHAPTER 6: RECOMMENDATIONS

Based on the research performed by the author while writing this thesis, the following recommendations are made:

1. Replace the MBA GRUEA-7 ejection seat with the MBA SJU-17A NACES in the EA-6B aircraft.
2. Replace the gas sequencing ejection system with an electronic command ejection sequencing system in the EA-6B aircraft, and investigate the possibility of ejecting more than 1 aircrew at a time after performing a structural analysis of the floorboards and airframe to make sure the added reaction forces will be supported.
3. Replace the 21 foot diameter main parachute in the SJU-17A NACES with a 28 foot diameter main parachute for incorporation into the EA-6B aircraft after investigating the additional opening shock imparted to the occupant by the larger parachute throughout the expected EA-6B flight regime and the impact on the five SJU-17A NACES modes of operation.

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- ⁴ Naval Safety Center. "Aviation Database: EA-6B Ejection Database for the GRUEA-7 Ejection Seat 1 January 1980 – 21 January 2003." Letter from the Naval Safety Center. 21 January 2003. (Used with permission).
- ⁵ VAQ-141 Commanding Officer's Brief to Squadron Aircrew. February 2000.
- ⁶ Carey, Christopher T. "Achtung! Schleuder-Sitzaparat! A Brief History of the Development of Western Aircraft Ejection Seat Systems." AeolusAero Online. 10 January 2003. <http://www.lanset.com/aeolusaero/Articles/seat_history.htm>
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- ⁹ Martin-Baker Aircraft Company. "Navy Aircrew Common Ejection Seat (NACES)." Martin-Baker.com. 25 July 2002. <http://www.martin-baker.com/eject_naces.html>
- ¹⁰ FA-18E/F NATOPS Flight Manual. NAVAIR A1-F18EA-NFM-000. 1 March 2001.

¹¹ Collins, F. G. "Aviation Systems 501: Introduction to Aviation Systems Class Notes". 11 September 2002.

¹² MIL-STD-1333B. "Military Standard Aircrew Station Geometry for Military Aircraft." 9 January 1987.

¹³ MIL-STD-18471G (AS). "Military Specification; System, Aircrew Automated Escape, Ejection Seat Type: General Specification For." 8 June 1983.

¹⁴ Interview conducted with Petty Officer Second Class R. Finey, AME day-shift shop supervisor. 7 February 2003.

APPENDIX

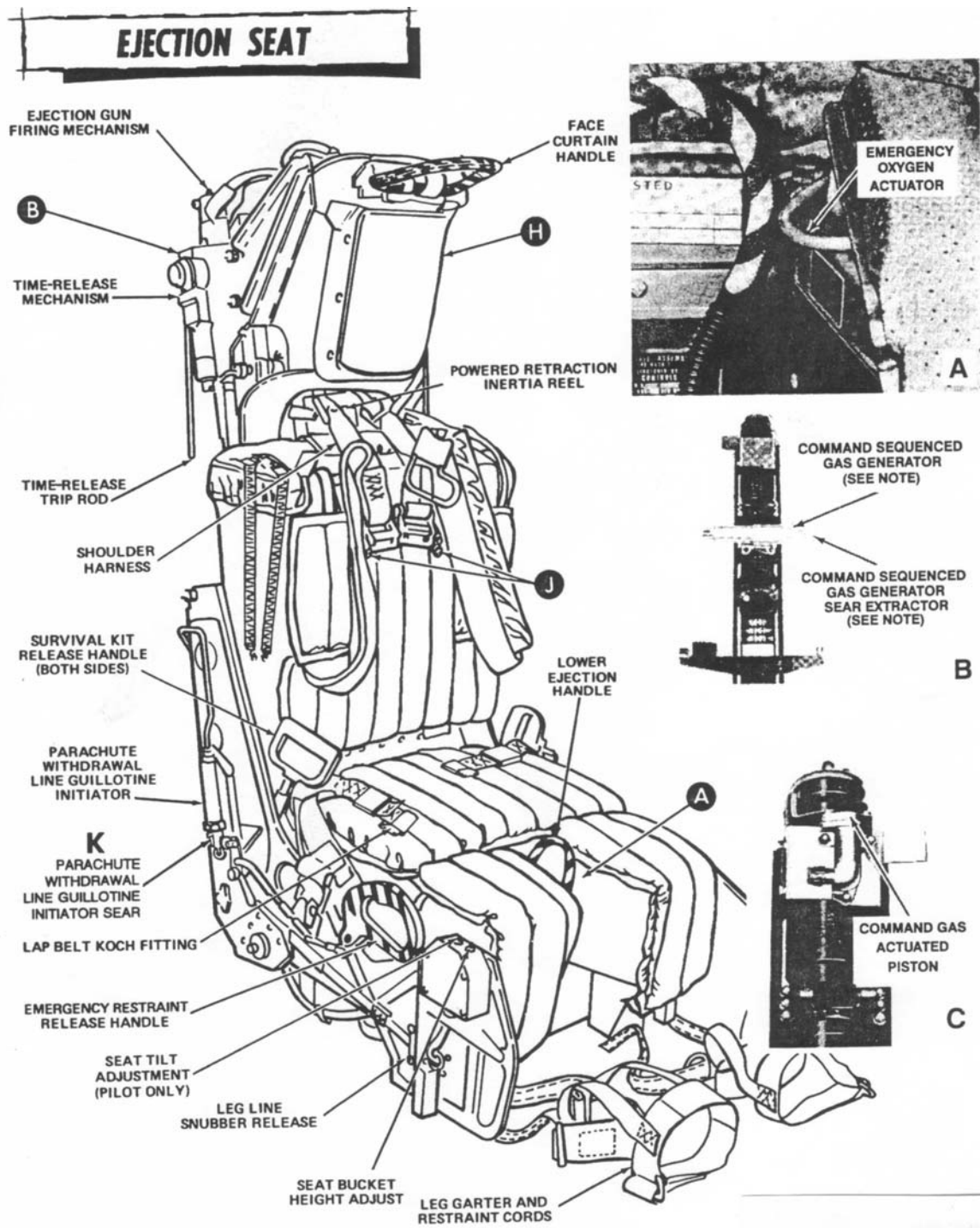


Figure A-1. GRUEA-7 Ejection Seat Right Side.

Source: *EA-6B NATOPS Flight Manual*, April 2002

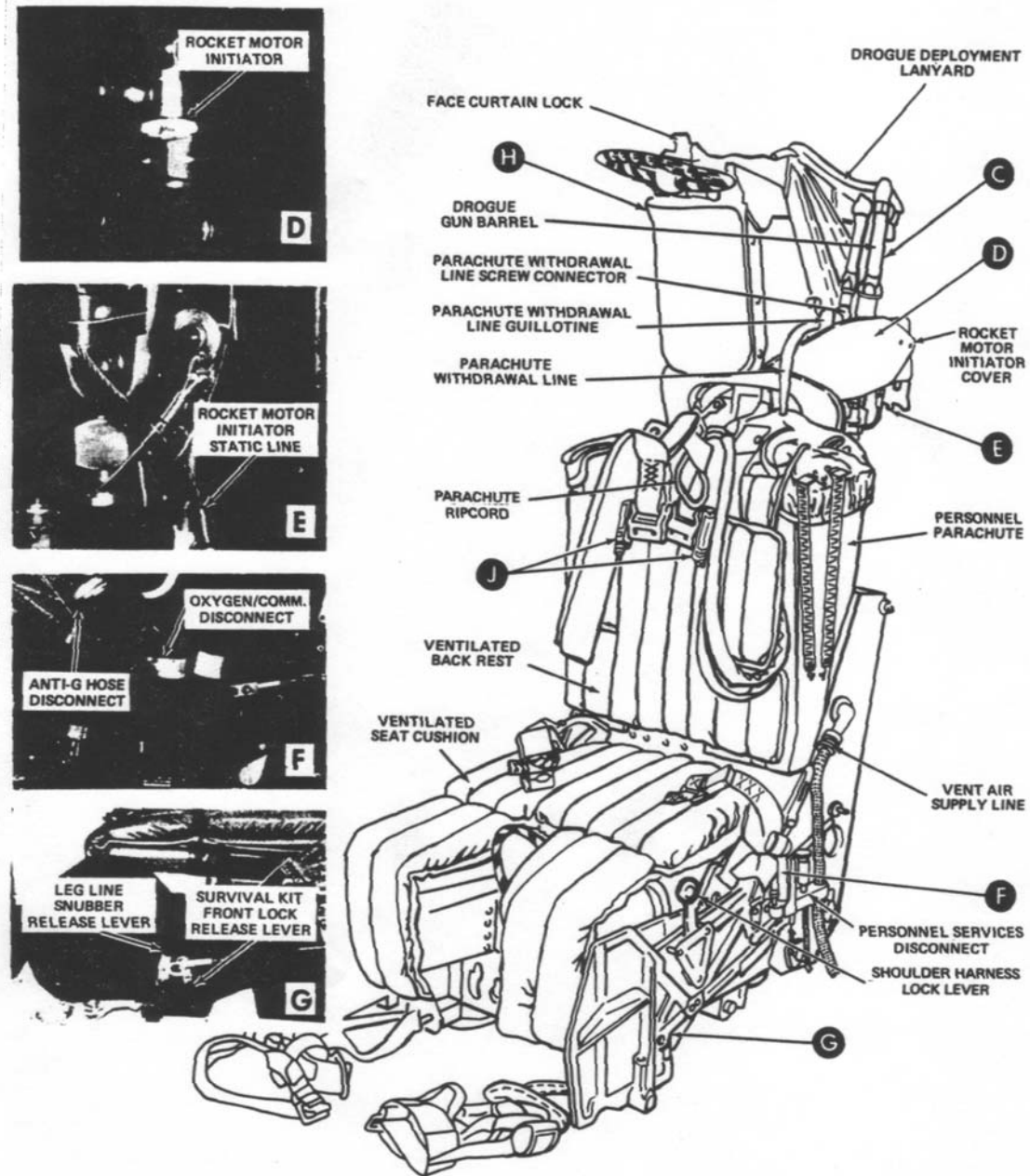


Figure A-2. GRUEA-7 Ejection Seat Left Side.

Source: *EA-6B NATOPS Flight Manual*, April 2002

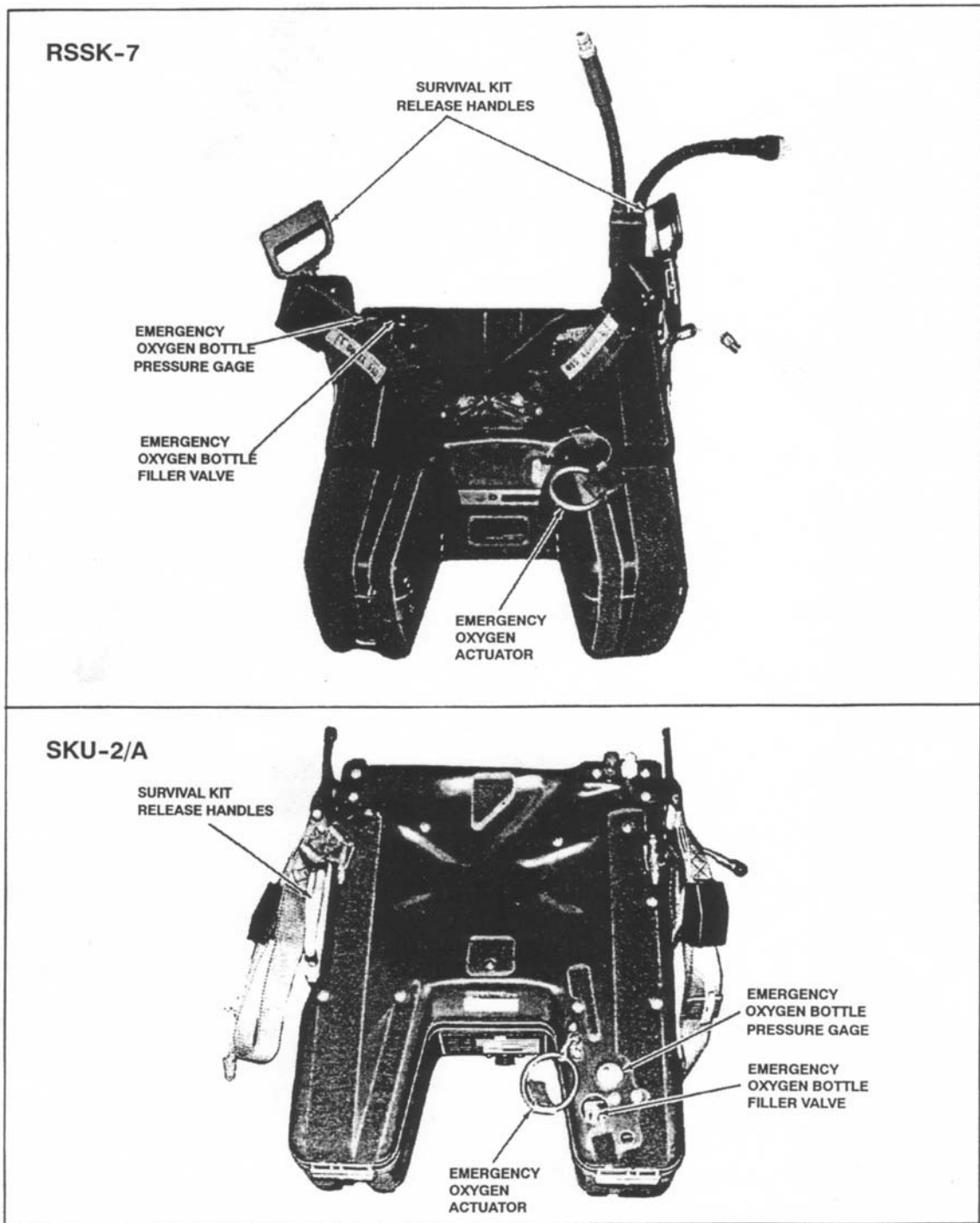


Figure A-3. GRUEA-7 Ejection Seat Pan Models RSSK-7 and SKU-2/A.

Source: *EA-6B NATOPS Flight Manual*, April 2002

EJECTION SEQUENCE

GRUEA-7

- 1 INITIAL EJECTION: EMERGENCY OXYGEN RELEASED, IFF ACTUATED TO EMERGENCY, CHAFF FIRED IF INSTALLED, URT-33 SURVIVAL RADIO IN SEAT ACTUATED, SHOULDER HARNESS RETRACTED AND LOCKED, LEG RESTRAINTS WITHDRAWN AND LOCKED AND TIME RELEASE AND DROGUE GUN MECHANISMS ARE TRIPPED AND PERSONNEL SERVICES AND ROCKET MOTOR LANYARDS ARE PULLED AS SEAT LIFTS OUT OF COCKPIT.
- 2 ROCKET MOTOR INITIATOR SEAR WITHDRAWN BY EXTENDED LANYARD, GAS DRIVES ROCKET MOTOR FIRING MECHANISM, IGNITING MOTOR.
- 3 DROGUE GUN FIRES ONE HALF SECOND AFTER EJECTION; DROGUE PISTON WITHDRAWS CONTROLLER DROGUE PARACHUTE.
- 4 CONTROLLER DROGUE DEPLOYS AND WITHDRAWS STABILIZER DROGUE.
- 5 STABILIZER DROGUE DEPLOYS, STABILIZING AND DECELERATING SEAT AND OCCUPANT.
- 6 ABOVE 14,500 FEET: BAROSTAT SECURES TIME RELEASE MECHANISM UNTIL COMPLETION OF DESCENT.
- 7 TO LOWER ALTITUDE, DROGUE PARACHUTE RETENTION SHACKLE REMAINS LOCKED TO SEAT BY RESTRAINT SCISSOR AND SEAT AND OCCUPANT DESCEND THROUGH HIGHER ALTITUDES ON DROGUE PARACHUTES ONLY.
- 7 BETWEEN 14,500 AND 11,500 FEET: BAROSTAT FREES TIME RELEASE ESCAPEMENT MECHANISM. TIME RELEASE MECHANISM SUBSEQUENTLY RELEASES DROGUE GUN SHACKLE RESTRAINT SCISSOR, OCCUPANT'S SHOULDER HARNESS RESTRAINTS, LAP BELT LEG RESTRAINTS PARACHUTE CONTAINER AND SURVIVAL KIT. RELEASE OF SHACKLE PERMITS CONTINUED PULL OF DROGUE PARACHUTES ON LINK LINES TO RELEASE FACE CURTAIN RESTRAINT, AND MAIN PERSONNEL PARACHUTE. OCCUPANT REMAINS ATTACHED TO SEAT BY STICKER CLIP RETENTION OF LOWER RESTRAINT HARNESS ON SEAT BUCKET.
- 8 LINE STRETCH OF MAIN PARACHUTE PULLS OCCUPANT, SURVIVAL KIT AND LOWER RESTRAINT HARNESS FREE OF STICKER CLIPS. SEAT FALLS FREE. OCCUPANT DISCARDS FACE CURTAIN AND CONTINUES NORMAL PARACHUTE DESCENT.

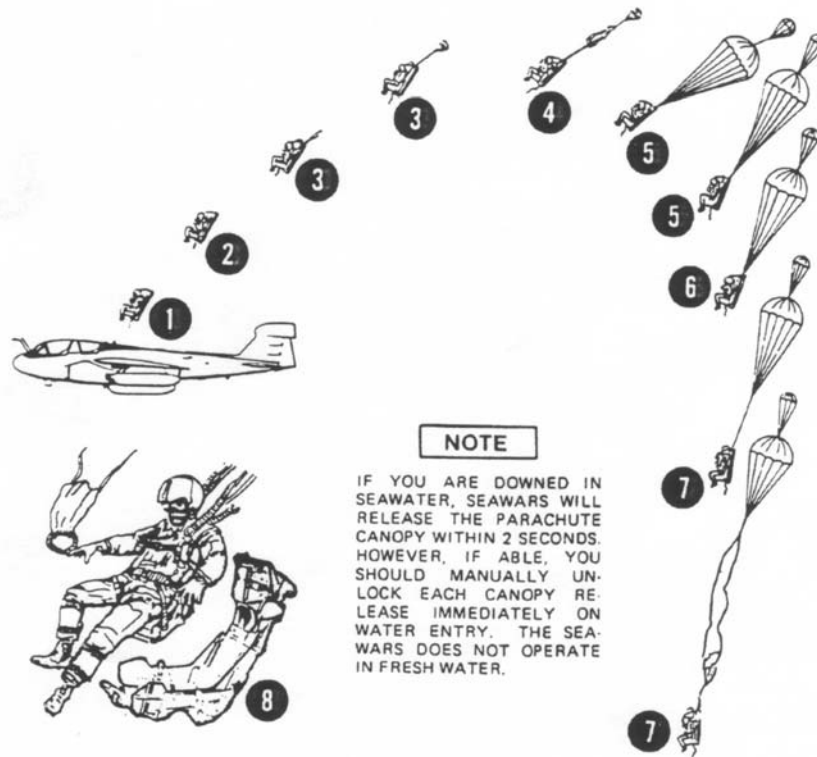


Figure A-4. GRUEA-7 Airborne Ejection Sequence from the EA-6B.

Source: *EA-6B NATOPS Flight Manual*, April 2002

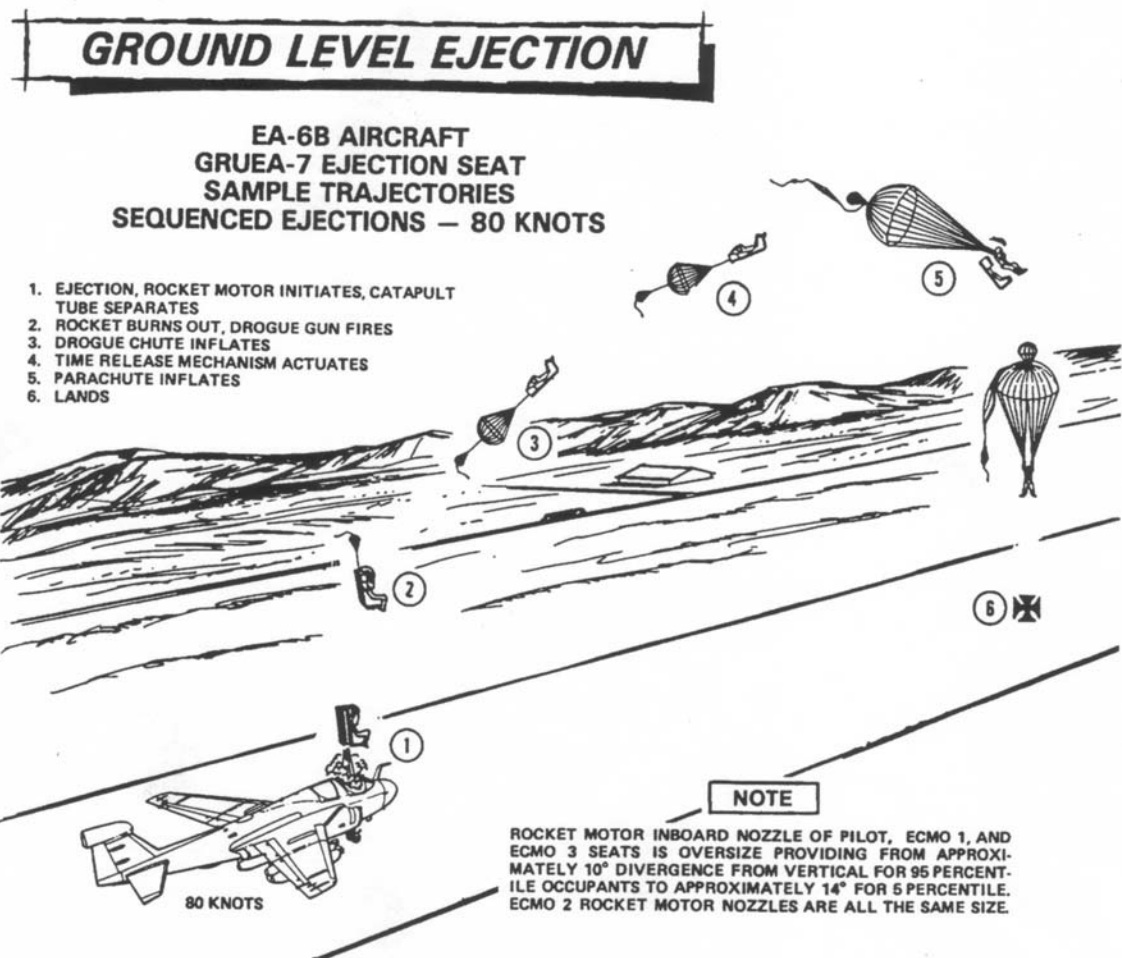


Figure A-5. GRUEA-7 Ground Ejection Sequence from the EA-6B.

Source: *EA-6B NATOPS Flight Manual*, April 2002

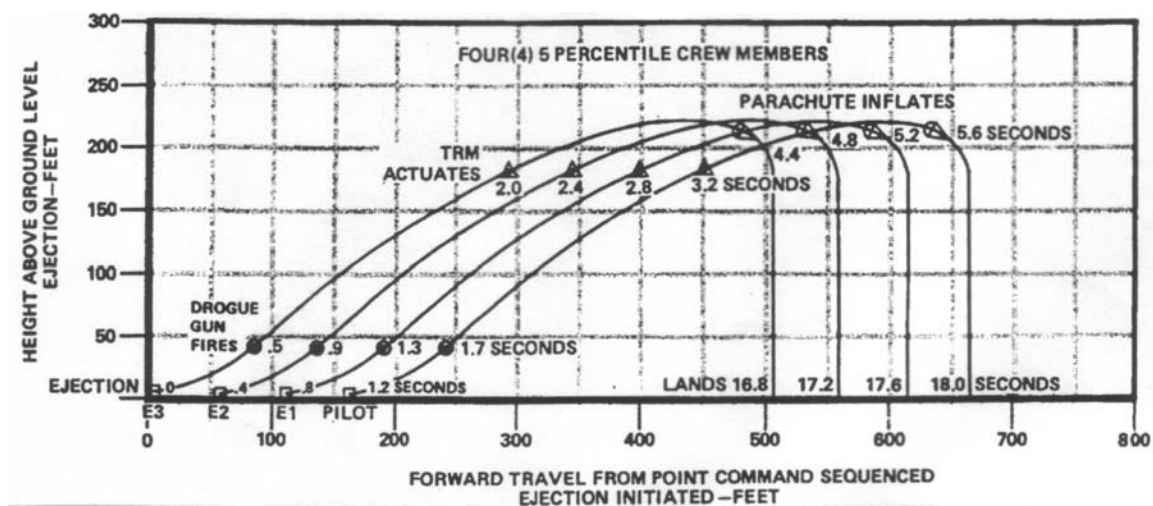


Figure A-6. EA-6B Command Ejection at 80 Knots with four 5 Percentile Aircrew.

Source: *EA-6B NATOPS Flight Manual*, April 2002

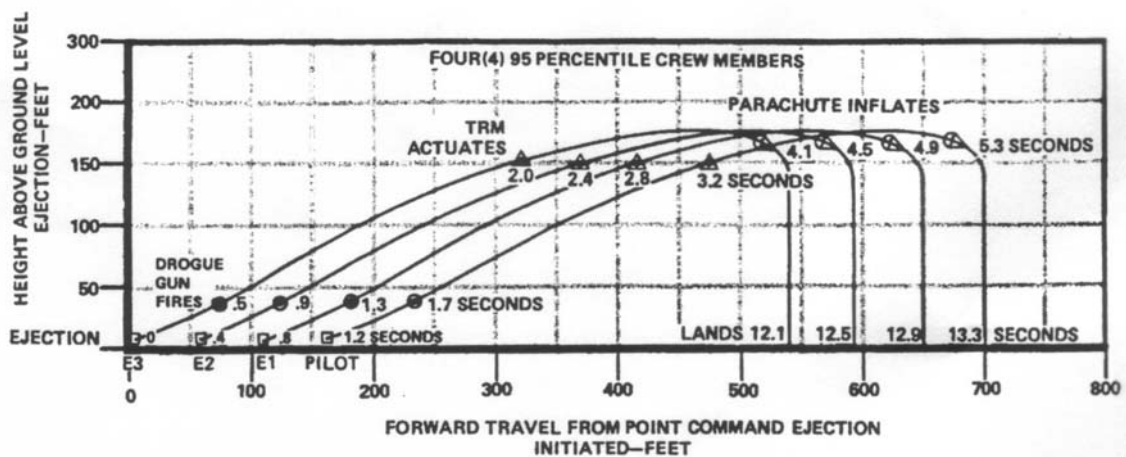


Figure A-7. EA-6B Command Ejection at 80 Knots with four 95 Percentile Aircrew.

Source: *EA-6B NATOPS Flight Manual*, April 2002

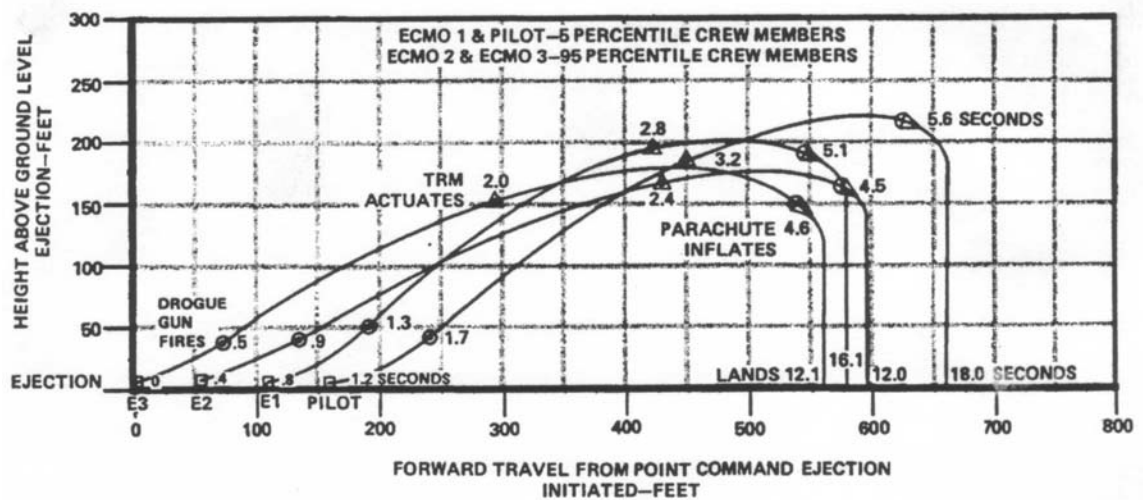


Figure A-8. EA-6B Command Ejection at 80 Knots with 5 Percentile ECMO 1 and Pilot and 95 Percentile ECMO 2 and ECMO 3.

Source: *EA-6B NATOPS Flight Manual*, April 2002

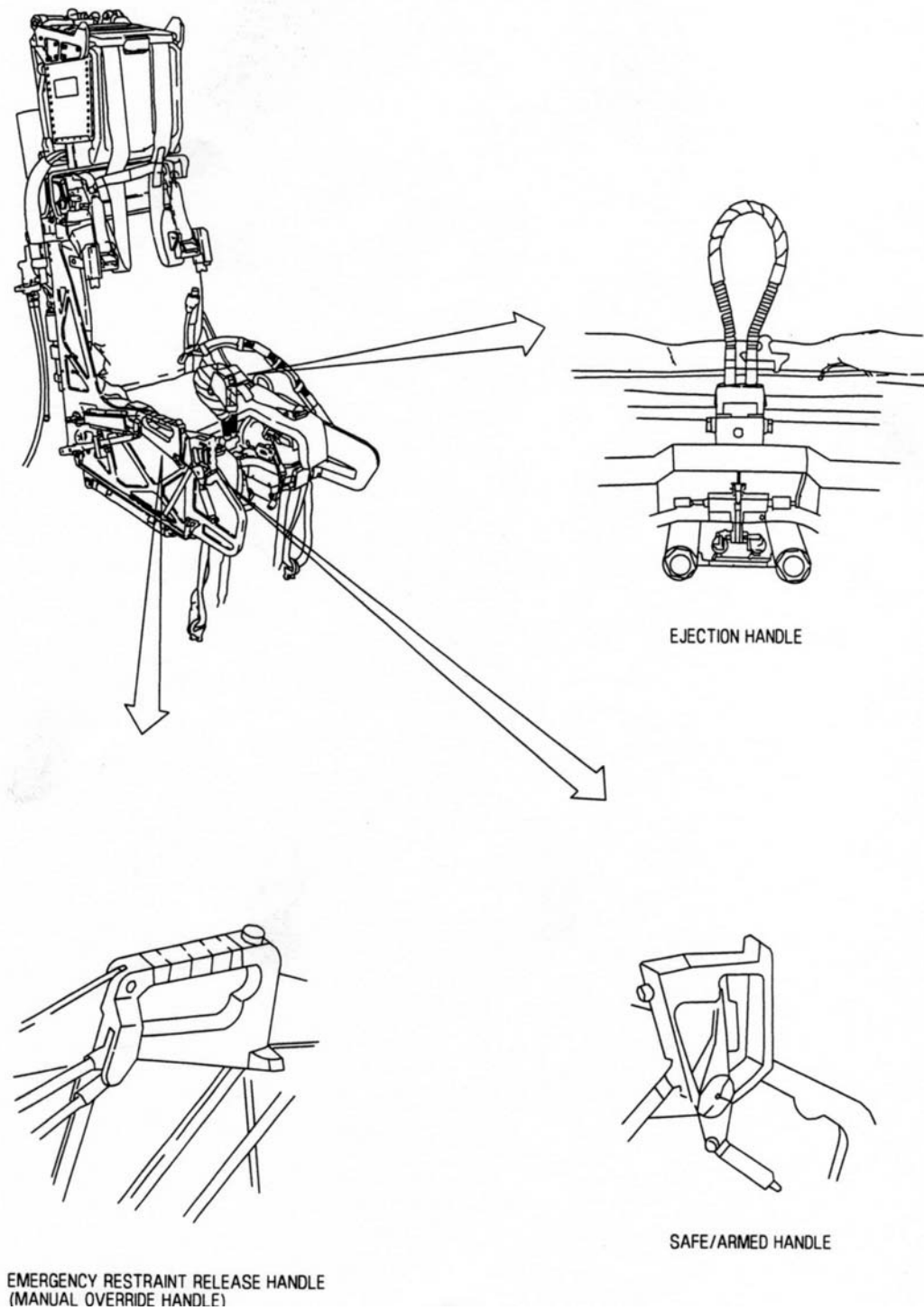


Figure A-9. SJU-17A NACES Right Side.

Source: *FA-18 NATOPS Flight Manual*, March 2001

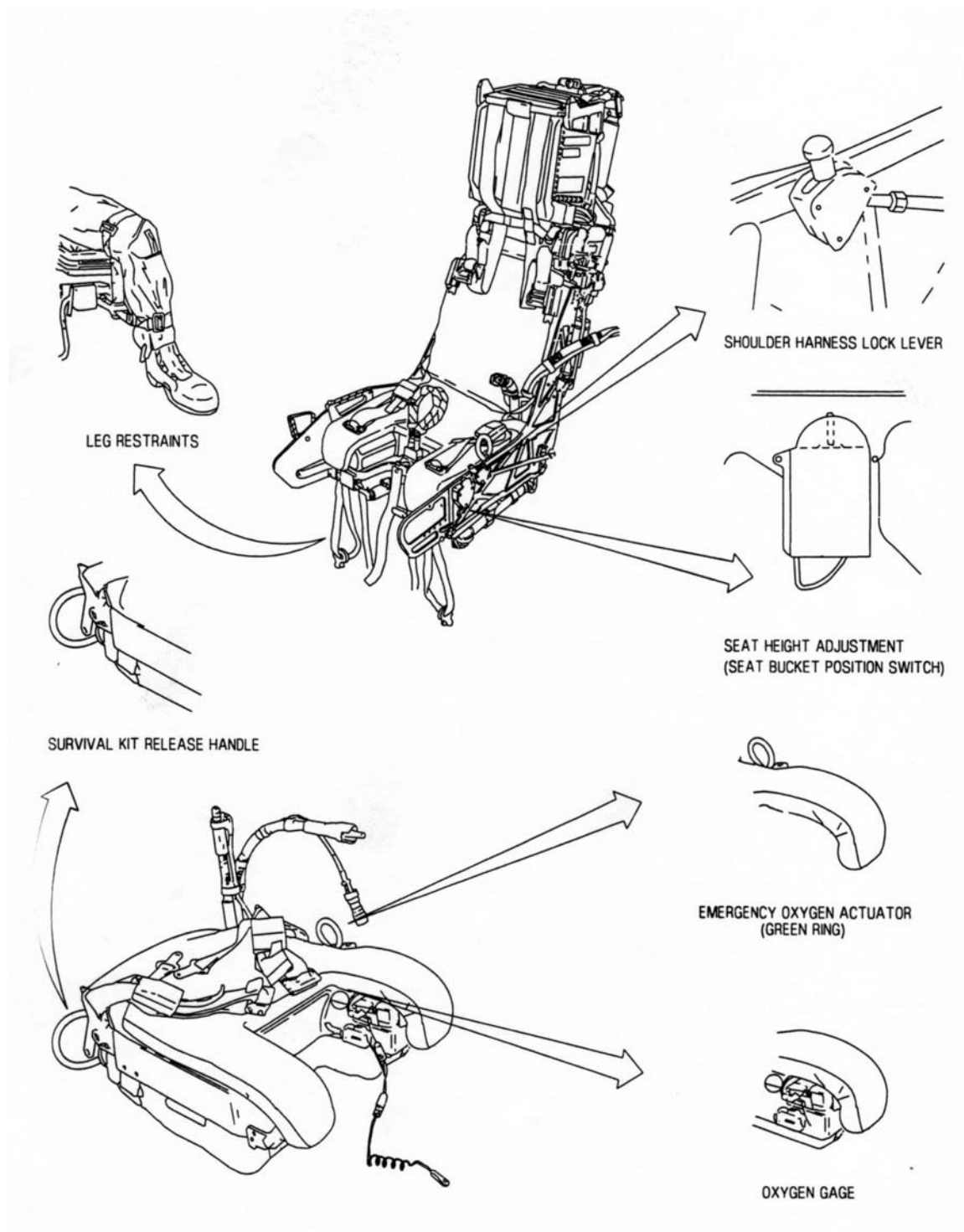


Figure A-10. SJU-17A NACES Left Side.

Source: *FA-18 NATOPS Flight Manual*, March 2001

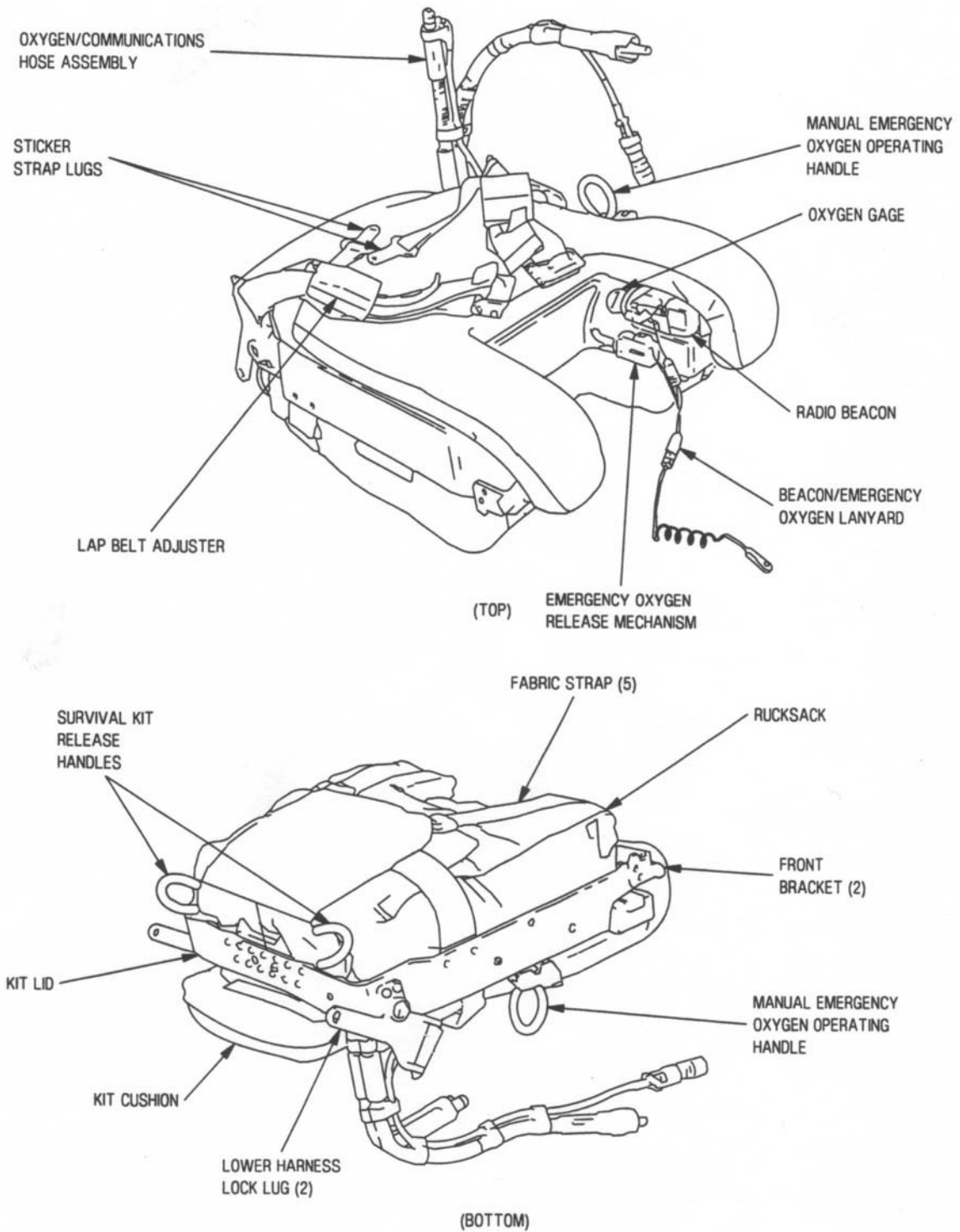


Figure A-11. SJU-17A NACES Survival Kit Model SKU-10/A.

Source: *FA-18 NATOPS Flight Manual*, March 2001

**SJU-17 SEAT SYSTEMS (CONTINUED)
AUTOMATIC SEAT/MAN SEPARATION**

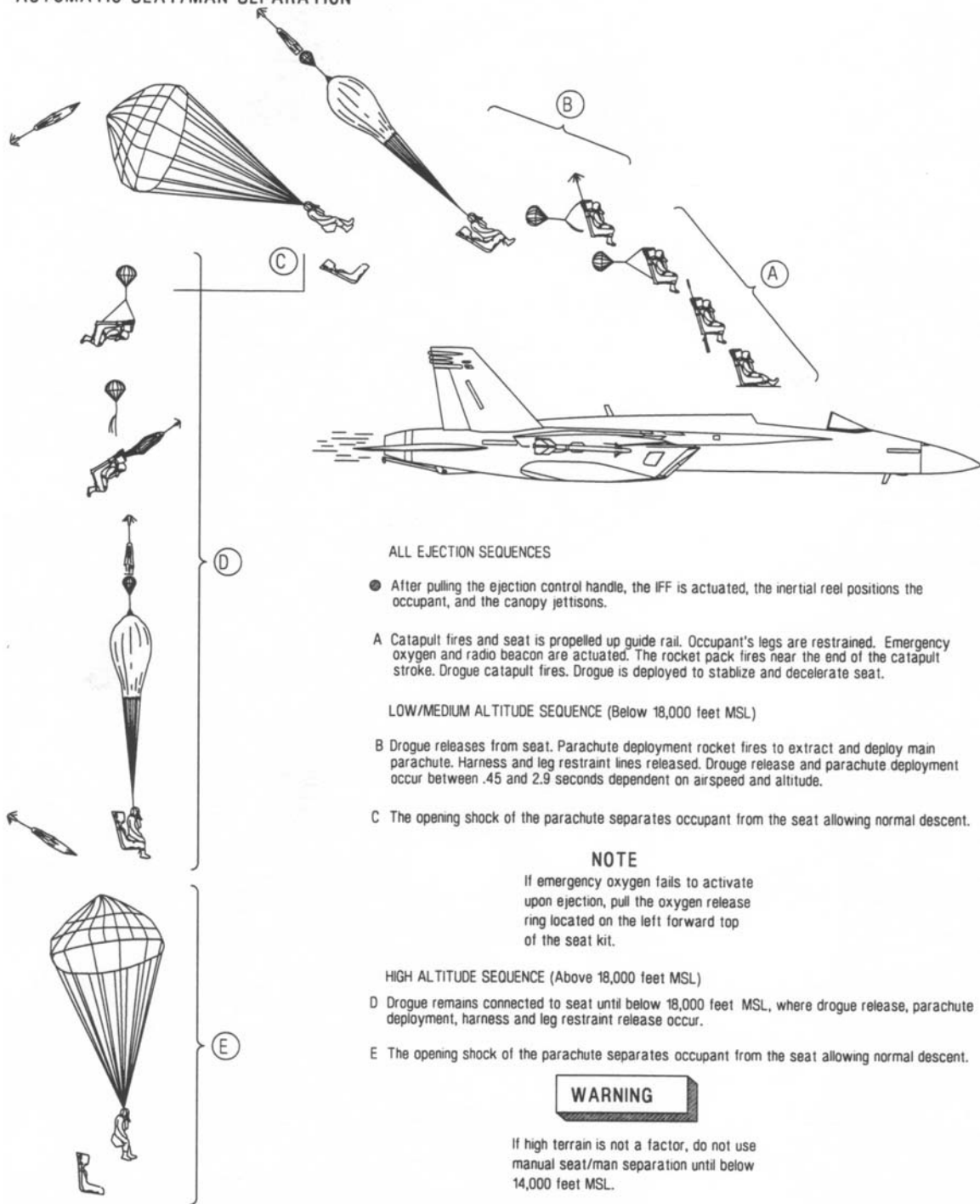


Figure A-12. SJU-17A NACES Ejection Sequence from the FA-18E/F.

Source: *FA-18 NATOPS Flight Manual*, March 2001

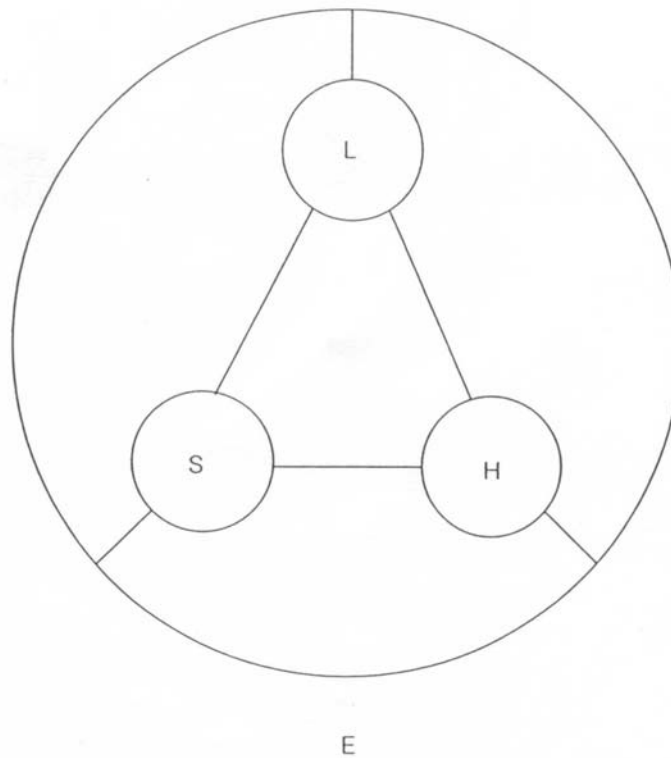


Figure A-13. The SHEL Model.

Source: *Aviation Systems 501: Introduction to Aviation Systems Class Notes*,
Collins, F. G., September 2002

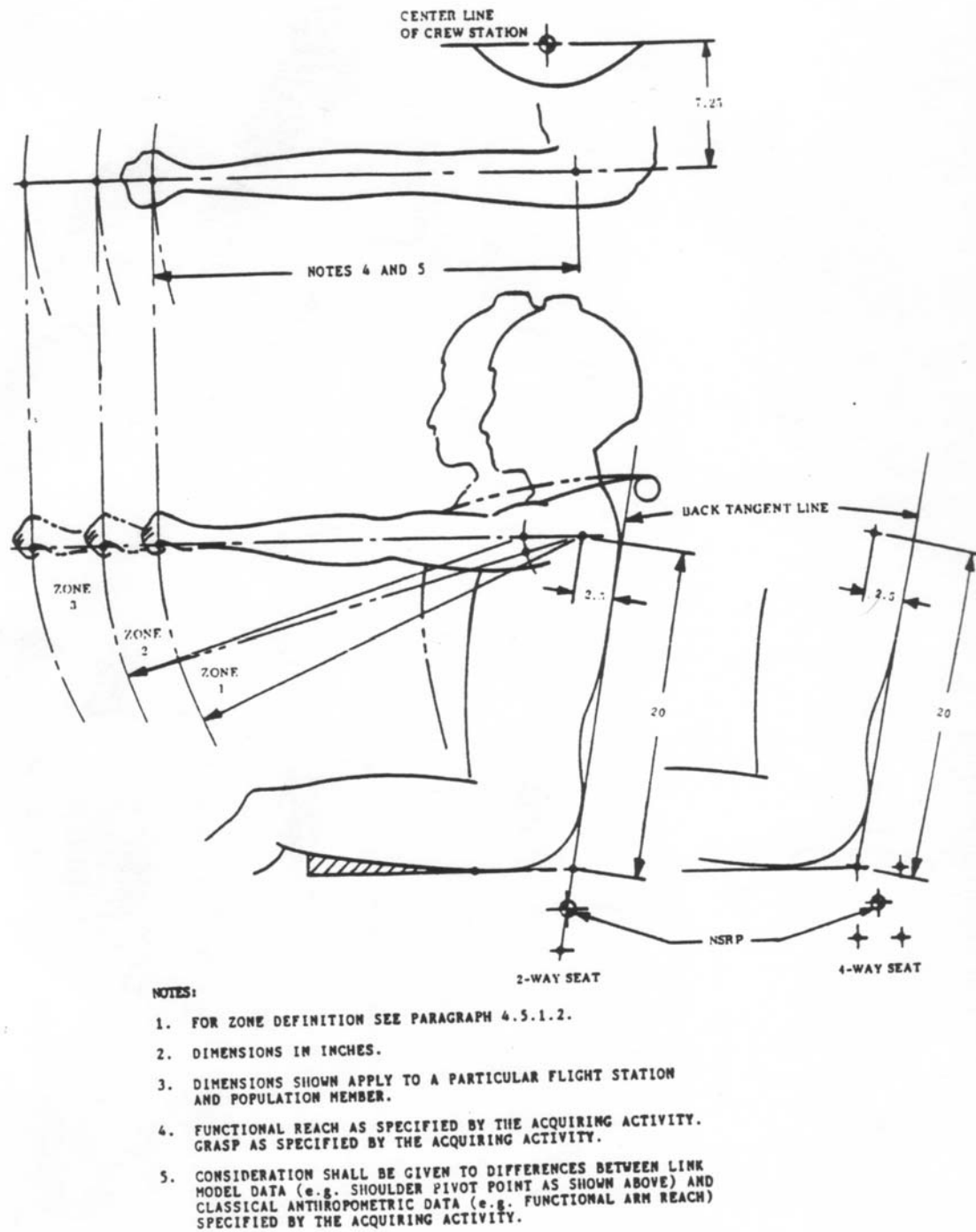


Figure A-14. Arm Reach Requirements.

Source: MIL-STD-1553B: *Military Standard Aircrew Station Geometry for Military Aircraft*, January 1987

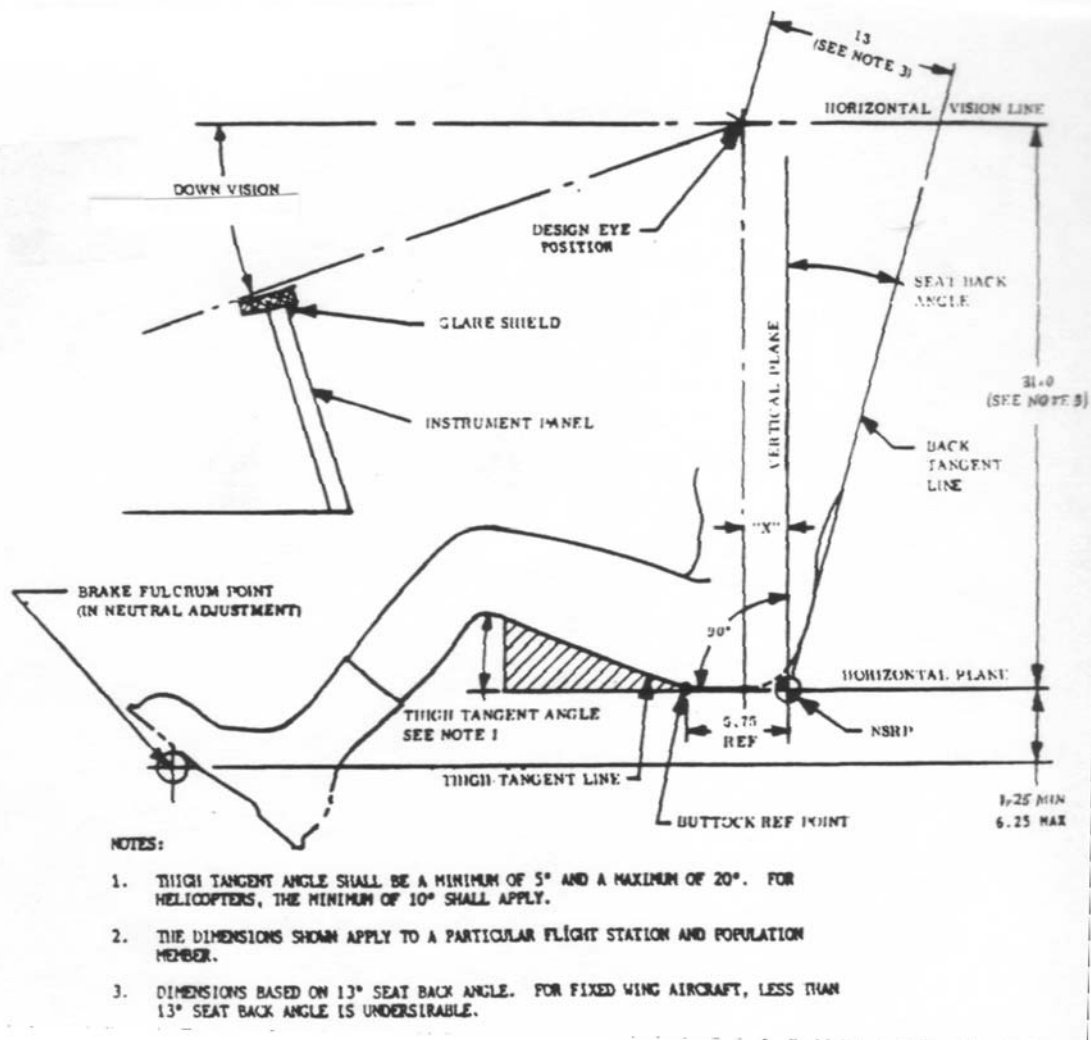


Figure A-15. Leg Angle Reach and Vision Requirements.

Source: *MIL-STD-1553B: Military Standard Aircrew Station Geometry for Military Aircraft*, January 1987

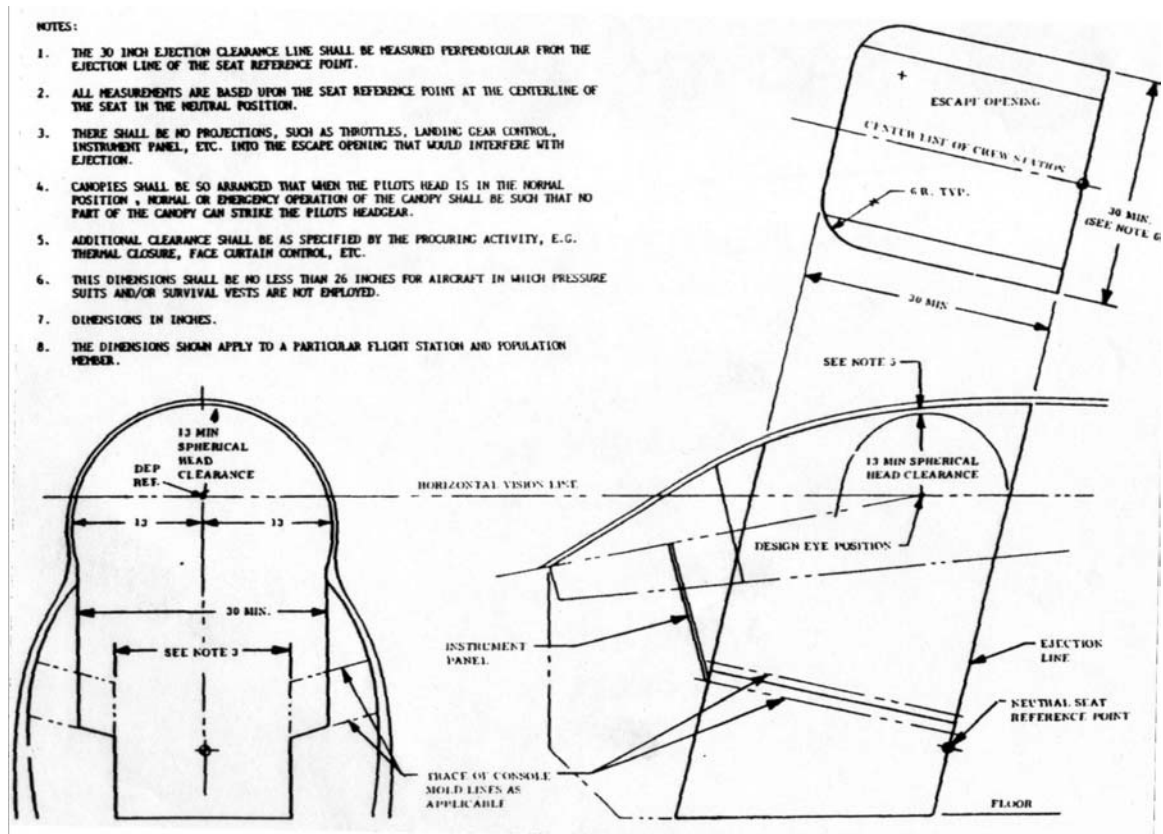


Figure A-16. Ejection Clearance Requirements.

Source: MIL-STD-1553B: Military Standard Aircrew Station Geometry for Military Aircraft, January 1987

VITA

Lieutenant Daniel David Moore was born in Muncie, Indiana on the first of June, 1970. He moved to Richmond, Indiana a few months later where he spent the next 13 years. He then moved to Columbus, Indiana where he graduated from Columbus East High School in 1988. He continued his education at Purdue University, where he graduated in 1992 with a Bachelor of Science in Aeronautical and Astronautical Engineering. Following his graduation from college, he enlisted in the United States Navy and completed the Naval Nuclear Power program in Orlando, Florida and Charleston, South Carolina. After qualifying as a nuclear mechanical operator, LT Moore was transferred to Officer Candidate School in Pensacola, Florida. Upon completion of Officer Candidate School in 1995 he was commissioned as an Ensign and immediately began flight training as a Student Naval Flight Officer. After earning his wings and then completing initial qualification as an EA-6B Prowler Electronic Counter Measures Officer in Whidbey Island, Washington, he served in an operational EA-6B squadron, where he deployed the Mediterranean Sea and Persian Gulf on board the USS THEODORE ROOSEVELT (CVN-71).

Lieutenant Moore is married to the former Elspeth Jane Shook and currently resides in China Lake, California where he serves as an EA-6B operational test director with Air Test and Evaluation Squadron Nine.