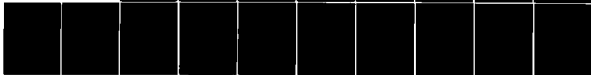


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REPORT NO. NADC-81066-60



AD A102803

**PROCEDURAL HANDBOOK
FOR
ESCAPE SYSTEM/ACCIDENT INVESTIGATION
HELMET USAGE ASPECTS, INCLUDING FAILURE ANALYSIS**

Robert Snyder
Aircraft and Crew Systems Technology Directorate
NAVAL AIR DEVELOPMENT CENTER
Warminster, Pennsylvania 18974

20 May 1981

FINAL REPORT
AIRTASK NO. 512-000002
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NAVAL AIR SYSTEMS COMMAND
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Washington, D. C. 20361

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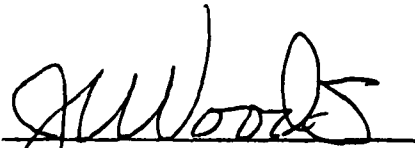
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19. ABSTRACT (Continue on reverse side if necessary and identify by block number) Aircrew protective helmets are currently developed to reduce the severity of head impact injuries. Many helmets involved in ejections and land and water crashes may provide clues concerning the sequence of events immediately prior to and/or during the accident. Helmet design may have been a factor in the serious and sometimes fatal injuries sustained during these accidents. This handbook will describe a systematic analysis of aircrewman's helmets involved in accidents or ejections. This analysis may identify and recognize design weaknesses and result in the initiation of appropriate effective remedial action.		

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INTRODUCTION

Aircrew protective helmets as traditionally and currently conceived and developed are designed to prevent/reduce the incidence rate and severity of aircrewman head impact injuries. In addition, helmets have been and currently are employed to mount many varied equipments, ranging from protective types such as oxygen mask and eye protection to weapons systems elements such as target sighting systems.

There exists a body of in-service information suggesting that while the need for classical head impact injury prevention type protective designs has declined, helmet involvement in and influence upon new forms of head and neck injuries is increasing. Further, the evidence suggests that such injuries are increasing both in frequency of occurrence and in severity. This evidence also suggests that some of this change in head and neck injury patterns may be due to physical interactions between the helmet (and/or helmet mounted equipments) and elements of the escape system.

Individually, and statistically as a group, many helmets involved in ejections and land and water crashes may provide clues concerning the sequence of events immediately prior to and/or during the accident, and they also may provide definition of the injury causal mechanisms. There is strong evidence at this point in time that helmet design has been a contributing factor in serious, sometimes fatal, injuries sustained during ejection. To assure (1) identification and recognition of such design roles, and (2) correct definition of the problem and initiation of appropriate, effective remedial action, it is necessary to introduce a systematic analysis of helmets employed during accidents and ejections regardless of whether (1) the wearer sustained injuries or not, (2) injuries sustained were head injuries, neck injuries or others and/or (3) whether or not the helmet sustained readily apparent damage. There is a need for a continuing critical reappraisal based in part upon in-service experience concerning the nature and significance of the specific threat(s) for which the helmet provides a wearer a measure of protection and, in addition, the nature and significance of injury patterns suggesting the helmet as either a causal or a contributory factor.

The specific nature of individual damage patterns and the statistical characteristics of these damage patterns taken as a group often may point to peculiar and/or to normal helmet equipment-escape system interactions capable of endangering ejectees, either directly (injury) or indirectly (damage to protective or survival equipments capable of degrading ejectee survival in the surface environment). The inspection processes herein established have been selected and/or developed to produce the following necessary data (1) to discern the statistical patterns, (2) to ascertain likely causal factors and undesirable interactions, (3) to identify specific causal factors for specific individual damage patterns, and (4) to cause input of these data to the head protective escape system and other appropriate design processes to enable designers to reduce frequency and severity of ejectee injury and/or damage to ejectee equipments.

To assure complete understanding of the helmet usage environments and their affect(s) upon (1) wearer safety, (2) helmet integrity and (3) helmet protective

capability, it is planned that all helmets used/involved in escape and/or crash will be subjected to a Phase I Nondestructive Inspection. In the event that the Phase I inspection unveils indications of peculiar and/or anomalous helmet behavior, a Phase II In-depth Nondestructive Inspection will be conducted. If this appears warranted, a Phase III Destructive Test Program will be implemented to replicate damage pattern(s) and/or to ascertain other information concerning the helmet.

This handbook presents detailed Phases I and II, including worksheets to be completed for each helmet received, and information to guide the investigators in developing Phase III investigations tailored to the specific needs of each case in which destructive testing is considered necessary. The information obtained during these investigative efforts will be:

- (1) combined with all prior data acquired and analyzed for patterns,
- (2) provided to the appropriate medical officer and aircraft accident/incident board, and
- (3) employed to update design and quality assurance requirements for helmets, helmet-mounted equipments and aircrew automated escape systems as appropriate.

The approaches found herein and implemented by the enclosed OPNAVINST (Chief of Naval Operations Instructions) and OPNAV Instruction amendments have been established to assure the systematic acquisition and analysis of the in-service data in an attempt to reduce the potential for head and neck injuries during escape system operation and during crash. Failure to institute systematic in-service data acquisition and analysis assures that only partial, piecemeal information enters the design and quality assurance requirements and may result in introducing bias that can degrade the helmets protective capability and the wearer's safety.

Issuance of this Handbook is being accompanied by the enclosed OPNAVINST (Enclosure #2) requiring that helmets employed in ejections or crashes be subjected to the systematic thorough analysis herein defined to:

- (1) identify and document conditions attendant to the helmet's use,
- (2) identify and catalog all damage to the helmet (and where possible to the helmet mounted equipments involved),
- (3) ascertain and document the nature of all head and neck injuries sustained by the ejectee (or crashed crewman) wearing the helmet,
- (4) determine the efficacy of the helmet in preventing impact injuries to the head and in avoiding escape system-helmet interaction injuries to the ejectee's head and neck,
- (5) compare damage patterns to previously established damage patterns, and

- (6) compare injury patterns to previously established injury patterns, to injury patterns for comparable helmet damage, to injury patterns for similar conditions, and to injury patterns for comparable damage and similar conditions. The OPNAVINST also sets forth the conditions which will require performance of non-destructive (Phase II) and destructive tests (Phase III) upon the helmet used and/or upon identical sample helmets for obtaining additional information for evaluating the performance of the helmet and/or possible causal factors.

In order to assure that the helmets are delivered for analysis and to avoid the introduction of changes from their critical, "as used/as recovered" condition, the OPNAVINST instructs the Fleet concerning the procedures to be observed in the recovery and subsequent handling, documentation, protection, packaging, and shipping of such helmets.

A form letter will be generated by NAVAIRDEVCE (Naval Air Development Center):

1. Acknowledging receipt of the damaged helmet
2. Indicating when a response will be provided
3. Indicating what investigative procedures will be followed.

H A N D B O O K (M A N U A L)

Phase I - Preliminary Nondestructive Inspection

Phase II - In-depth Nondestructive Inspection

A. Data recorded for Case No. _____

(1) Date received _____

(2) Shipping activity _____

(3) Accident date _____

(4) Type aircraft _____ Bu. No. _____

(5) Aircrew station of helmet wearer _____

(6) Type event in which helmet was used:

a. Ejection Yes _____ No _____

1. Type ejection seat _____

b. Crash Yes _____ No _____

1. Water ☐ Land ☐

2. Type seat _____ Where located _____

3. Type aircraft _____

4. Fully restrained Yes _____ No _____

(7) Enumeration of reported (MOR - Medical Officer's Report) injuries to head:

(8) Enumeration of reported (MOR) injuries to neck:

(9) If cervical fracture and/or other vertebral fractures reported (MOR):

(10) Helmet wearer data:

- a. Age _____
- b. Weight _____
- c. Stature _____
- d. Seated height _____

(11) Helmet data:

- a. Make _____ Model _____
- b. Manufacturer _____
- c. Serial No. _____
- d. Date of Manufacture _____
- e. Form Fit ☐ Pads ☐
- f. Number of fitting pads _____
 - 1. Locations _____
 - 2. Thickness _____

B. Helmet Condition Documentation:

(1) Helmet configuration description

- a. Describe any helmet modifications from standard model, list all helmet mounted equipments and/or provisions for mounting equipments on helmet.

(2) Complete figures 1 through 9 on Standard Helmet Damage Chart, indicating, through symbols and keys, how damage became apparent.

STANDARD HELMET DAMAGE CHART

- Figure 1. Front View
- Figure 2. Right side, exterior
- Figure 3. Left side, exterior
- Figure 4. Back, exterior
- Figure 5. Top, exterior
- Figure 6. Bottom view
- Figure 7. Back, interior
- Figure 8. Right side, interior
- Figure 9. Left side, interior

Notes:

1. Place following information on each figure:
 - a. Case No. _____
 - b. Type/Model Helmet _____
 - c. Ser. No./Lot No. _____
 - d. Examination Date _____
 - e. Examiner/Recorder _____
2. On interior view, number and identify each helmet pad
- (3) Photographs
 - a. Normally black and white 8"x10" glossy prints of all equipments received with helmet and of helmet.
 - b. Color photographs to be employed only where necessary for clarity.
 - c. Photographs in nine standard positions matching damage charts.
- (4) Coherent Light Inspection
(Photograph any damage which was not noticeable under standard lighting)
 - a. Light wavelength _____
 - b. Light intensity _____
 - c. Lens size _____
 - d. Distance from lens to helmet _____
- (5) Infra-red Inspection
(Photograph inside and out in all standard positions whether additional damage apparent or not)
 - a. Light wavelength _____
 - b. Light intensity _____
 - c. Lens size _____
 - d. Distance from lens to helmet _____

(6) Spectral Analysis

- a. Reflective spectral analyses
- b. Refractive spectral analyses
(Examine each damage area and its immediate surroundings
and record spectral lines and spectral line interpretations.)

(7) Dye Penetrant Inspection

- a. Type penetrant _____
- b. Type light _____
- c. Type intensity _____
- d. Distance from light source to helmet _____
- e. Dye penetrant procedure used _____
(Enclosure #3 to handbook)
(Treat and examine each damage area and its immediate sur-
roundings in accordance with procedure used _____
Photograph each damage area keying photographs to Helmet
Damage Chart.)

(8) Pathological Inspection

- a. Analyze obvious head trauma and its relationship to the
helmet
- b. Test for blood and blood types

Phase III - Destructive Analyses

Simulation/duplication of observed damage/degradation of the sub-
mitted helmet using an identical substitute helmet. This testing
will be done only in those cases in which it would appear that the
helmet failed to perform a critical function within the survivable
range of conditions.

A. Impact Test

Determining impact energy for helmet damage analysis

- (1) A special helmet impact test fixture will be constructed which
will allow duplication of damage and determination of impact
energy. An anthropomorphic head and neck will be used to approx-
imate actual head/neck response essential to the accurate deter-
mination of impact energy. Similar helmets will be impacted with
impactors of various sizes and shapes at various velocities, in
progressive steps, until helmet damage has been closely reproduced.

B. Windblast Test

Determination of windblast loading of helmet retention system

- (1) This test will evaluate head loading from the dynamic pressure of windblast on similar helmets. Of concern are those forces acting on the head through the helmets retention system; that is, the chin and nape straps. In addition, investigations will be made of the possible forces exerted on the neck by the helmet edge which may be a causative factor in recent occurrences of cervical fracture. The intent is to simulate ejection conditions through windblast and to record the above head loading data for two cases of windblast exposure.

C. Chin Strap Failure Tests

The objective of this test will be to determine the ultimate chin strap failure levels and mode of failure for similar helmets.

- (1) Helmet chin strap failure loading and damage analysis will be accomplished by two methods.
 - a. Static loading - using standard chin strap test fixtures.
 - b. Dynamic loading - using a specially designed load application device which will load the chin strap in essentially the same manner as experienced in ejection windblast conditions.

D. Controlled Parachute Drop Tests

A possible damage causing mechanism could be related to parachute canopy fittings striking the helmet during the parachute opening phase of ejection.

- (1) The acceleration profile of the canopy fitting during the parachute opening will be determined for the ejection condition.
- (2) This computer analysis will use the 6 degree-of-freedom trajectory simulation which is in operation at NAVAIRDEVCON. This task will include gathering and preparing input data, reviewing qualification test films, to run, compile and verify simulation for the particular Navy escape system.
- (3) Determination of worst case condition (max. parachute loading).
- (4) Output of riser acceleration and riser load vs. time for all parachute configurations.
- (5) Conduct simulated parachute drop test with input conditions (output of computer program) in order to determine the range of acceleration vs. time profiles of parachute canopy fittings.

E. Material Test of Submitted Helmet

- (1) Microscopic tests, tensile/compressive tests of sections of material.
- (2) Extent of delamination.
- (3) If required, determine percentage of moisture absorbed in fiberglass shell.
- (4) Make similar sections of undamaged similar helmets (from the same manufacturer) for baseline purposes. These sections will represent those sections of damaged helmets in which a pattern may have been set.

F. Familial Analysis

There will be a familial (statistical, trend, etc.) analysis of observations both gross as well as detailed observations obtained through the non-destructive examination.

G. Archival Section

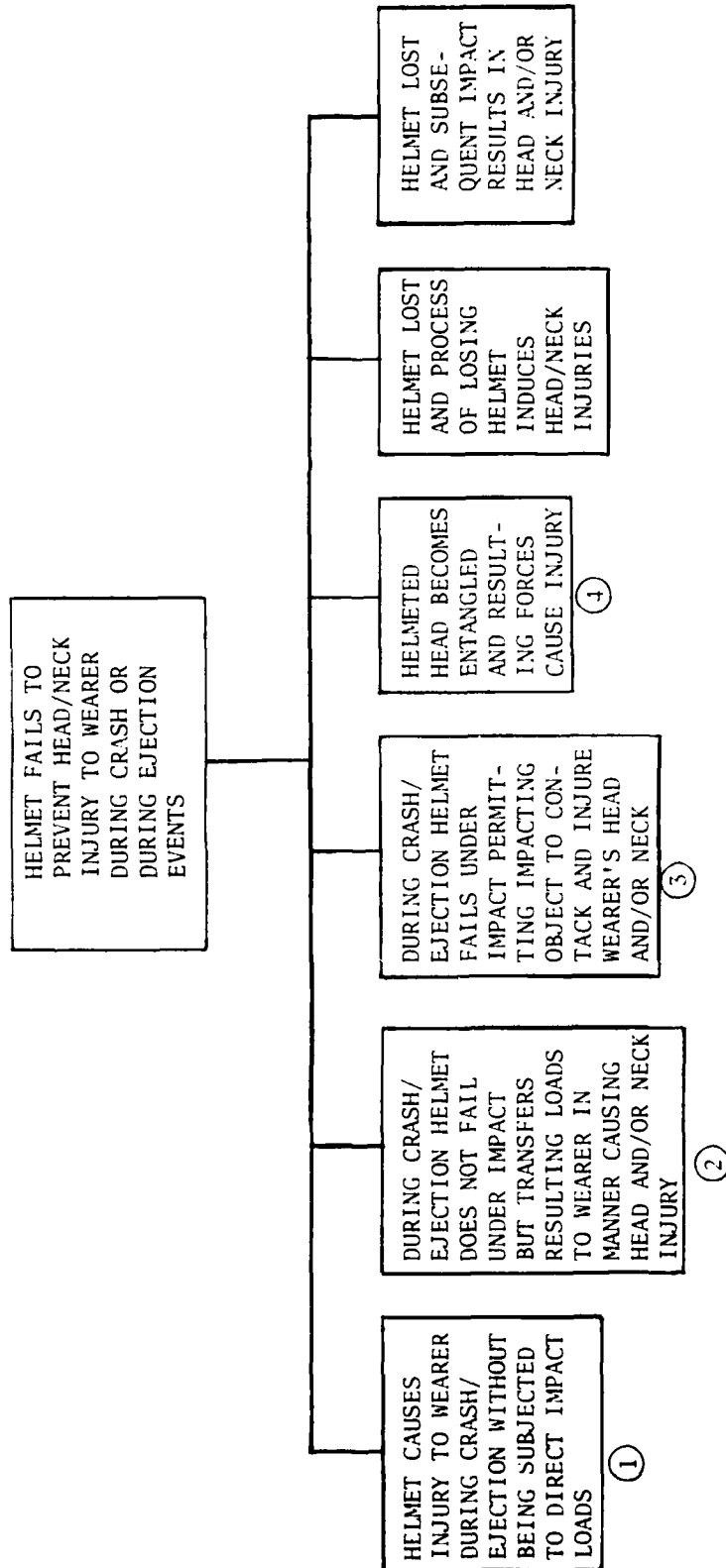
- (1) Statistical and visual documentation (photographs or actual submitted helmets) will be maintained for future reference.
- (2) Establish a reference for all items in aircraft which could come in contact with the helmet-head rest, koch fitting, parachute harness, ejection seat, airplane canopy, etc. Identify what their materials are and expose them to a spectral analysis to give a library of lines against which these lines can be compared with the spectral lines of the damaged helmet.
- (3) A similar library will be established for all nondestructive testing of sample undamaged helmets (from the same manufacturer) to establish baselines.

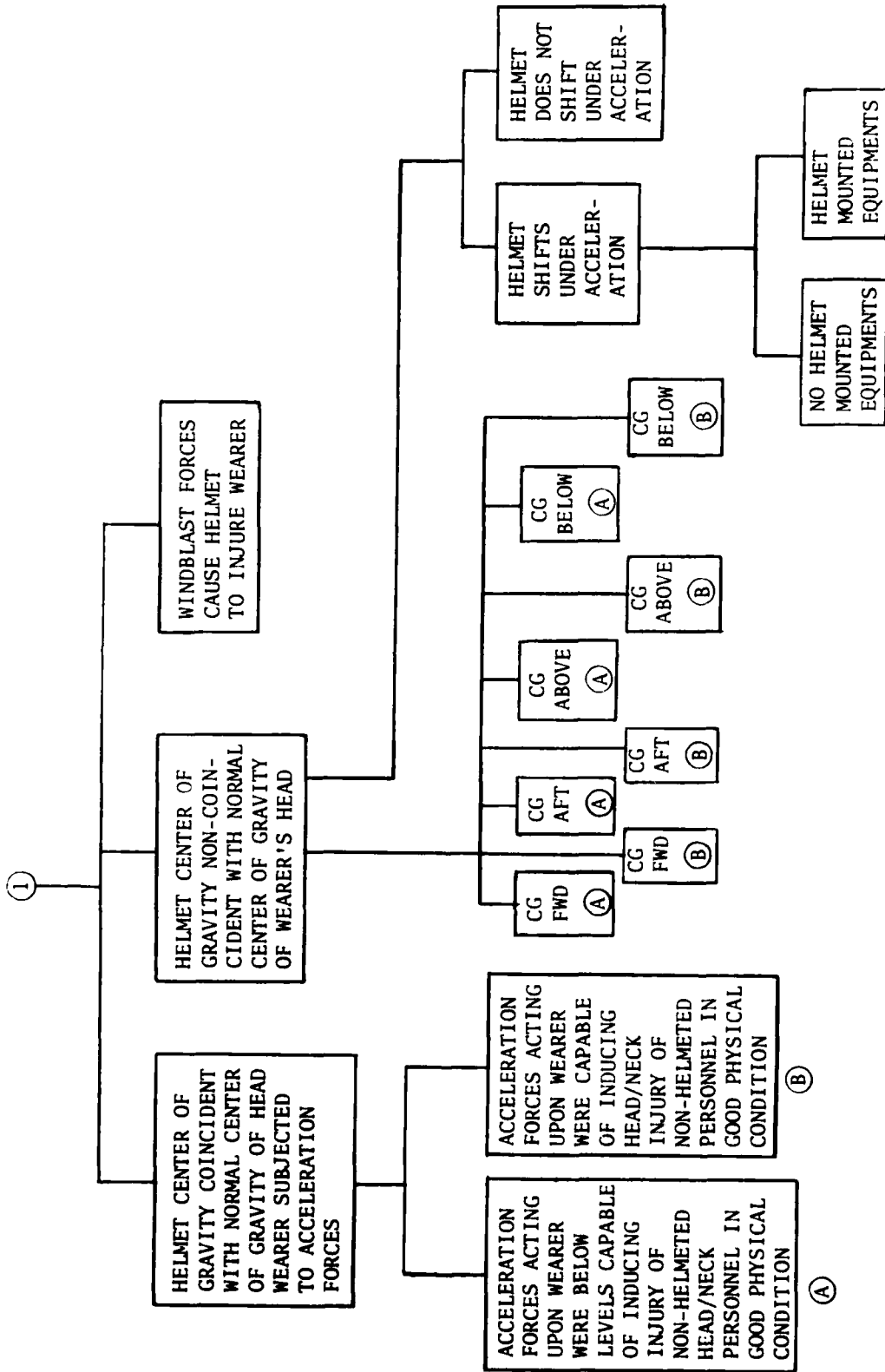
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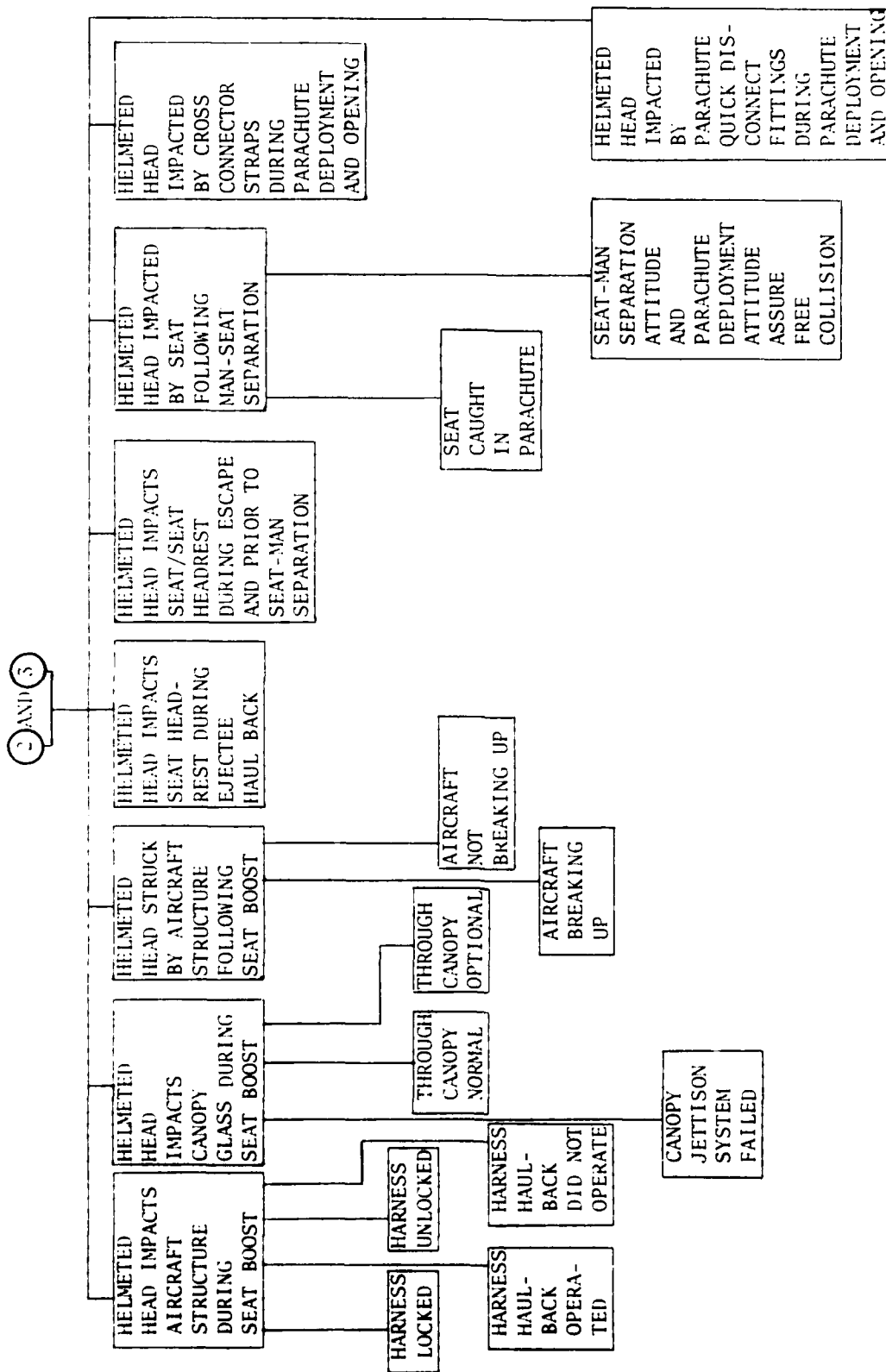
ENCLOSURE NO. 1 - FAULT TREE ANALYSIS

A fault tree type analysis depicts ways in which a helmet could fail to protect the wearer from head and/or neck injuries. Note, however, that failure to protect the wearer need not necessarily be the result of defective helmet design requirements, design execution, manufacture, and/or quality. It may be the result of improper design requirements, design execution, manufacture, and/or quality of other elements of the wearer's total life support system. Note also that in many instances the helmet may be the only recoverable evidence for ascertaining what sequence of events most likely led to a specific injury.

FAULT TREE ANALYSIS







ENCLOSURE NO. 2 - OPNAV INSTRUCTIONS FOR HELMETS INVOLVED
IN EJECTIONS AND/OR CRASHES

OPNAVINST 3750.6L
27 OCT 1978

Information addressees will include: CNO, NAVSAFECEN, COMNAVAIRSYSCOM, Commandant of applicable Naval District, CINCUSNAVEUR (for European and Middle East area), CINCPACFLT (for Pacific), COMSEVENTHFLT (for Far East), CINCLANTFLT (for Atlantic).

405 d. Aviation Life Support Systems (ALSS) (R)

(1) All parachutes, parachute harnesses and associated equipment (R) utilized in bailouts or ejections will be shipped to Commander, NAVAIRDEVCON, Warminster, Pennsylvania 18974. The equipment will be clearly marked "For Evaluation and Testing." After preliminary investigations, and nondestructive testing, the complete parachute system will be forwarded to Commanding Officer, NATPARACHUTETESTRAN, El Centro, California, for further test and evaluation in accordance with NAVAIR 13-1-6.2.

(2) All helmets involved in an aircraft accident, as described (A) by subparagraph 105a, will be shipped to NAVAIRDEVCON if any of the following criteria is met:

- (a) Damage to the helmet. (A)
- (b) Failure of the visor. (A)
- (c) Damaged oxygen mask pulling loose from helmet. (A)
- (d) Helmet lost on ejection but recovered. (A)
- (e) Neck injuries to include sprains, fractures, abrasions, (A) contusions, or lacerations thought to be directly related to the helmet.
- (f) Facial injuries. (A)
- (g) Skull fractures. (A)
- (h) Unconsciousness. (A)
- (i) Fatal head injuries. (A)
- (j) Fatal injuries in which helmet and attachments were (A) recovered.
- (k) Accidents of high interest (new aircraft, air shows, (A) property damage, etc.).

(3) Ejection seats which were activated as a result of a mishap will (A) be shipped to the appropriate CFA and clearly marked "For Evaluation and Testing."

OPNAVINST 3750.6L

27 OCT 1978

Any item of aircrew personal survival equipment that malfunctions, or was suspected to malfunction, will be shipped to NAVAIRDEVCON. This will include but not be limited to damaged flight boots, burned flight suits, improperly functioning mask, flotation garments, seat survival kits, g suits, or survival vests. The equipment will be shipped as complete as possible and not damaged or dismantled beyond that absolutely necessary for the accident investigation. High cost items such as rigid seat survival kits and radios will be returned to the parent activity after all the tests are completed, providing the unit is RFI.

e. Assistance in Wreckage Recovery. In order to facilitate recovery of aircraft wreckage for investigative purposes, accident investigative boards of the military services may request assistance of the nearest military base. For information regarding the availability of requisite equipment, the board may contact the cognizant Naval or Coast Guard District Commandant, Air Force Headquarters, or Army Area Headquarters, as appropriate.

406 SPECIAL MEDICAL REQUIREMENTS

a. The senior member of the aircraft mishap board will ensure that all members of the board participate in the discussion of the medical/human factors involved in the mishap. The significant findings in the AAR and the MOR must
R) be complimentary and coordinated.

b. For specific requirements, see Chapter VII.

ENCLOSURE NO. 3 - DYE PENETRANT PROCEDURES

DIRECTIONS

CLEANER

Use on dirty parts to preclean before test. Apply wet film to part, allow solvent time, wipe clean with rag. Repeat if still dirty. Allow time to dry before using Penetrant.

PENETRANT

Spray Zyglo Fluorescent penetrant on suspected area to wet surface wall, preferably at 60°F. or above. Allow one to thirty minutes before wiping, depending on crack contamination.

REMOVE PENETRANT

Apply CLEANER to wall and dissolve surface penetrant, and wipe clean with cloth. Be sure to remove all penetrant from surface - you can check with black light.

DEVELOPER

IMPORTANT: Shake thoroughly until agitators rattle. Spray thin coat over area being inspected, enough to wet surface over-all and dry to thin layer. Use portable high intensity black light to inspect for fluorescent indications of cracks, pores, etc.

HOW TO OPERATE SPRAY CAN

60°F. or above. Press trigger on top of can, with nozzle 6" to 8" from area to be sprayed, while moving gun in line to lay wet bath across desired area.

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ENCLOSURE NO. 4 - SAMPLE NADC LETTER ACKNOWLEDGING
RECEIPT OF DAMAGED HELMET.

From: Commander, Naval Air Development Center
To:

Subj: Helmet(s) involved in Escape System/Accident Investigation; receipt of

Ref: (a) Procedural Handbook For Escape System/Accident Investigation Helmet
Usage Aspects Including Failure Analysis

1. In accordance with reference (a), receipt of damaged helmet(s) is acknowledged.
2. An investigation of helmet usage aspects including a failure analysis will be made wherever pertinent in accordance with reference (a).
3. A response will be forwarded, when required, as soon as the investigation and analysis is completed.

A C K N O W L E D G M E N T

The author gratefully wishes to acknowledge the assistance of Fred Guill (NAVAIRSYSCOM, AIR-531C) in preparing this handbook.

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