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REVIEW OF THE OPERATIONAL EFFICACY OF USAF FLIGHT HELMETS IN CRASH AND ESCAPE ENVIRONMENTS

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A review of available statistics from aircraft ejections and crashes was conducted to evaluate the efficacy of USAF flight helmets. The review was presented to the fifteenth meeting of Working Party 61 of the Air Standardization Coordinating Committee held in Auckland, New Zealand. The report concentrates on the analysis of data obtained from reports of accidents that occurred during the period of 1 January 1968 to 31 December 1972. Helmet loss rates are compared to the type of helmet, helmet suspension system, use of visor, use of chin or nape strap, airspeed, and aircraft type.

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A REVIEW OF THE OPERATIONAL EFFICACY OF USAF FLIGHT

HELMETS IN CRASH AND ESCAPE ENVIRONMENTS

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Available statistics on the efficacy of USAF flight helmets in operational aircraft crash and emergency escape system environments have been reported in references 1, 2 and 3. The purpose of this paper is to summarize the information that is available from operational statistics, and to comment on the significance of the statistics in terms of the usefulness of specific design features of flight helmets in providing crew protection.

Table I is a summary of the USAF aircraft crash statistics contained within reference 1. The aircraft categories that were studied included fighter, cargo/transport, jet trainer, reciprocating engine trainer, helicopters, and others (bomber, FAC, etc.). Of the categories where the number of the accidents exceeded 100, jet fighter accidents were the least survivable (65.5%) and helicopter accidents were the most survivable (93.4%). The percentages of fatal head injuries were highest in helicopters (6.1%) while the occurrence of major head injuries was highest in the fighter aircraft category (13.6%). Fatalities occurred in 25.9% of the crewmen who were exposed to aircraft crash. Twenty-one of the crewmen received fatal head injuries (2.6% of the fatalities) while 38 crewmen received

TABLE I. HEAD INJURY IN USAF AIRCRAFT CRASHES (Adapted from ref 1)
1 Jan 1963 - 31 Dec 1967

1,303	Ground-impact accidents
951	Accidents were survivable (72.9%)
3,052	Crewmen were exposed
790	Fatalities (25.9%)
234	Major injuries (7.7%)
21	Fatal head injuries (2.6% of fatalities)
38	Major head injuries (16.2% of major injuries)

major head injuries (16.2% of the major injuries). A crewman's chances of receiving a fatal or major head injury was 1.9%.

Of the 38 major head injuries reported in reference 1, 23 were the result of hitting objects in the cockpit and 15 were due to burns. No major head injuries occurred if the crewman was restrained by both a shoulder harness and lap belt. Furthermore, no fatal head injuries occurred if any body restraint was used.

Helmets were available to and used by 1,299 of the 3,052 individuals involved in ground impact accidents. Major and fatal head injuries occurred in 2.4% of the individuals who wore the helmets. If helmets were not worn head injuries (fatal and major) occurred in 2.8% of the individuals. Thus, one must conclude that a crewman's chances of receiving a head injury are the same in a ground impact accident regardless of whether a helmet is worn. However, an analysis of the major head injuries, where the helmet was used, revealed that less serious injuries such as facial fractures, lacerations, and burns comprise 86% of the injuries. Conversely, serious head injuries such as skull fracture or concussion accounted for 14% of the injuries. In individuals wearing no head protection, serious head injury accounted for 35% of the injuries and less serious facial injuries accounted for 65%. Moreover, the same analysis revealed that three of the serious injuries, which occurred with helmet usage, would have been fatal had helmets not been worn. If only fatal head injuries are considered, 11 of the 21 total occurred in survivable accidents. Nine were in cargo/transport aircraft and two occurred in helicopters. None of these individuals were wearing a helmet at the time of the crash. Analysis of this group indicates that some, if not all, might have been saved if helmets had been worn. In all 11 cases, the head injury was the only fatal injury in the accident. Nine of these individuals were crew and load masters whose duties prevented them from being restrained in their seats.

Table II provides the number and percentage of head and neck injuries which resulted from aircraft ejections where the flight helmet was retained intact versus those cases where the helmet structurally failed. The information was adapted from reference 2 which covers the period of 1 January 1968 through 31 December 1972. These data show that structural failure of the flight helmet was not a frequent problem. The cases where the helmet did structurally fail represent only 2.9% of incidence where the flight helmet was retained. Fourteen out of the 20 cases of structural failure resulted from unchecked falls.

Table III provides an overview of the remaining six helmet failures. The four broken helmet shells in this table were the result of two mid-air collisions (which were survived) and two seat/man impacts. The broken oxygen mask connector resulted in loss of the helmet.

TABLE II. HEAD AND NECK INJURY RATES WHERE THE HELMET WAS INTACT VS. FAILED (Adapted from ref 2)

Helmet Status	Number Involved	Injured (Number)	Injured (Percent)
Helmet intact	539	48	9.0
Structurally failed	20	9	45.0
TOTAL	559	57	10.2

TABLE III. SIGNIFICANT HELMET FAILURES (Adapted from ref 2)

Broken Shells	4
Sprung Shell	1
Broken Mask Connector	1
TOTAL	6

Table IV subdivides the helmets which were involved in the ejections that were studied in reference 2 into the various types which are used by the USAF and provides statistics on their respective loss and structural failure rates. Note that the differences between the HGU-2/P, HGU-2A/P and the HGU-26/P are relatively minor. The HGU-2A/P flight helmet was an improvement of the HGU-2/P which incorporated better fitting head pads, an adjustable nape strap, a reduction of helmet weight, and a new visor assembly. The statistics of Table IV show that there is a significant difference in the loss rates between these two helmets. However, the number of cases reported where the HGU-2/P was used are small. Earlier

TABLE IV. HELMET TYPE VS. HELMET LOSS AND STRUCTURAL FAILURE
(Adapted from ref 2)
1 Jan 1968 - 31 Dec 1972

Helmet Type	Number Involved	Lost (Number)	Lost (Percent)	Failed (Number)	Failed (Percent)
HGU-2/P	58	6	10.3	2	3.5
HGU-2A/P	524	92	17.6	16	3.1
HGU-26/P	32	4	12.5	1	3.1
Lombard/Custom Fit	18	2	11.1	1	5.6
Ballistic	5	0	0	0	0
Misc/Other/ Unknown	44	9	20.5	0	0
TOTAL	681	113	16.6	20	2.9

studies with a larger number of cases reported show the HGU-2/P had a loss rate of approximately 18% (reference 3). The HGU-26/P incorporates the dual visor assembly but is otherwise unchanged from the HGU-2A/P. The number of cases where the Lombard or HGU custom fit helmets were used is small and no conclusions can be reached about the effectiveness of the custom fit, foamed-in-place liners used in these helmets.

Table V compares the helmet loss rate numbers and percentages arranged according to the configuration of the flight helmet worn during ejection. The one important statistic that stands out in this information is that the helmet loss rate is 2 1/2 times higher if the visor is left up at the time of ejection. It is disconcerting to note that the loose chin strap or nape strap appear to have no effect on the helmet loss rate.

TABLE V. HELMET LOSS RATE FOR CONFIGURATION WORN
(Adapted from ref 2)
1 Jan 1968 - 31 Dec 1972

Helmet Configuration	Number Involved	Helmets Lost (Number)	Helmets Lost (Percent)
Optimum	323	38	11.8
Visor Down (Chin or Nape strap loose)	92	10	10.9
Visor up (Chin or nape unspecified)	177	54	30.5
Unspecified	81	10	12.3
Other/Unknown	8	1	12.5
TOTAL	681	113	

Table VI shows the head and neck injury locations related to the number and percentages of cases where the helmet was retained intact compared to the number and percentage of cases where the helmet was lost or structurally failed. Forty-eignt individuals received head or neck injuries in spite of the fact that they were wearing intact flight helmets. Of the 52 separate injuries which occurred in these cases the face was the most frequently injured. Damage to the skull and muscles or vertebrae of the cerebral area accounted for 23.1% and 21.2% respectively. The 34 individuals who were injured subsequent to loss or damage of their helmets experienced 41 injuries. Injuries to the neck were significantly fewer while injuries to the skull and the brain were slightly higher. The absence of the additional mass of the helmet probably explains the lower injury rate in the cervical area.

The effect of the type of aircraft from which the individual ejected was studied by dividing the aircraft types into three groups shown in Table VII.

TABLE VI. HEAD AND NECK INJURY LOCATION DISTRIBUTIONS
(Adapted from ref 2)
1 Jan 1968 - 31 Dec 1972

Injury Location	Helmet Intact (Number)	Helmet Intact (Percent)	Helmet Lost/Failed (Number)	Helmet Lost/Failed (Percent)
Skull	12	23.1	11	26.8
Brain	2	3.8	3	7.3
Face	22	42.3	17	41.5
Eyes	2	3.8	2	4.9
Ears	3	5.8	2	4.9
Cervical Area	11	21.2	6	14.6
	52		41	
	N = 48		N = 34	

NOTE: Two injuries with helmet status unknown

TABLE VII. HELMET LOSS RATE FOR AIRCRAFT TYPES (Adapted from ref 2)
1 Jan 1968 - 31 Dec 1972

Aircraft Type	Ejections (Number)	Helmets Lost (Number)	Helmets Lost (Percent)
Fighter	475	87	18.3
Bomber	74	8	10.8
Trainer/Attack/Observation	132	18	13.6

As one would expect helmet loss rate with fighter aircraft was much higher than experienced with the slower bomber and trainer/attack/observation aircraft categories. This comparison naturally leads a more detailed consideration of helmet loss statistics as a function of air speed.

Table VIII shows the helmet loss rates at specific air speed increments. Figure 1 is a histogram constructed from these data. The histogram shows that the loss rate tends to increase exponentially with air speed. This is as it should be since the aerodynamic loads acting to remove the helmet increase as the square of the velocity of ejection. One may also speculate that there is a component of the total loss rate that is independent of air speed. This component would consist of losses due to failure of helmet retention devices, removal of the helmet by impact with the parachute risers, etc. This component probably accounts for 10-15% of the losses across the whole spectrum of air speeds. Some of the conclusions that can be drawn from the information that has been presented are as follows:

1. The most important factor in prevention of head injuries in USAF aircraft crashes is the use of a shoulder harness with the lap belt restraint.
2. The major head injury and fatality rates in crashes were the same regardless whether a flight helmet was worn or not but the use of helmets reduces the severity of head injuries. However, under emergency escape conditions the head injury rate was twice as high if the helmet was lost.
3. Structural failure of the USAF flight helmet is not a significant operational problem.
4. The visor is a significant factor in retaining the helmet during ejection.

5. Facial injurie are the most common head injuries in both crash and ejection environments.

6. The loss rate of the USAF flight helmet increases with airspeed and appears to be directly related to the aerodynamic pressure.

TABLE VIII. HELMET LOSS AS A FUNCTION OF AIR SPEED
(Adapted from ref 2)
1 Jan 1968 - 31 Dec 1972

Air Speed (Knots)		Number Involved	Lost (Number)	Lost (Percent)
0 - 99		44	5	11.4
100 - 249		348	42	12.1
250 - 439		118	27	22.9
350 - 449		56	18	32.1
450 - 549		20	9	45.0
Over 550		2	1	50.0
Unknown		86	11	0.0
Unknown		7	Unknown	0.0
	TOTAL	681	113	

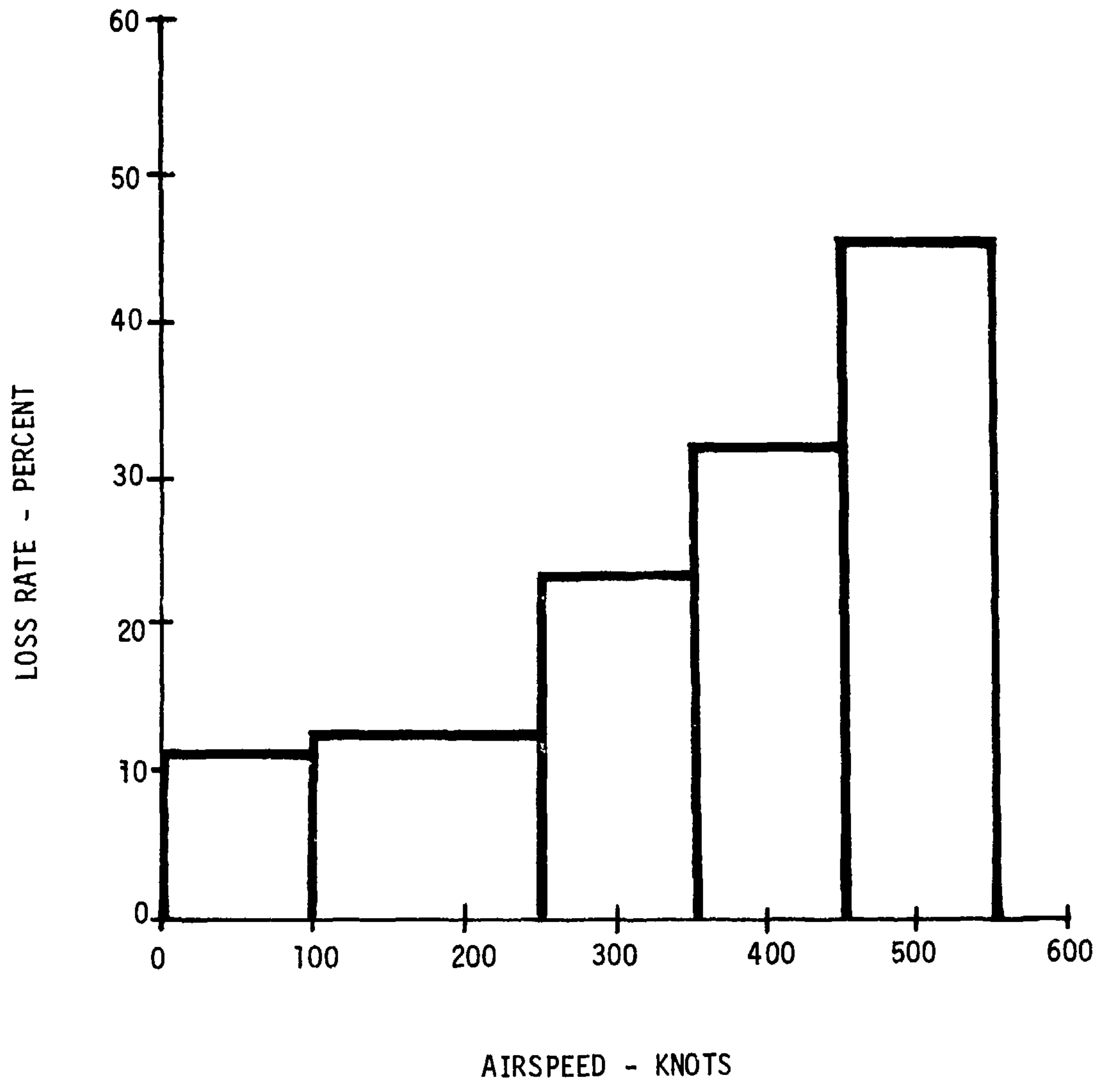

FIGURE 1. HELMET LOSS RATE VERSUS AIRSPEED (Adapted from ref 2)

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