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Evaluation of the Selection and Training of Fighter Pilots

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Analysis of historical combat data indicates that the fraction of fighter pilots killed (pilot hazard rate) decreases as the number of decisive air-to-air combats increases. This could be a result of two groups of pilots being present; a superior group represented by those who learn from experience and an inferior group represented by those with no learning. A proposed plan for pilot selection and training, based on this hypothesis, is presented. The purpose of the plan is to lower the hazard rate that pilots would experience in real combat by first subjecting these pilots to a selection and training process based on successive simulated combats. Using a mathematical model, based on renewal theory, the paper shows how such a program can have significant payoff in terms of improved force effectiveness and reduced pilot losses.

Introduction

HERBERT Weiss[1] has written a paper which includes some statistics and analysis on pilot survival in air-to-air combat. In his paper, Weiss states that in past wars involving extensive air-to-air combat, a small number of pilots—the aces—were responsible for most of the kills. He therefore hypothesizes that fighter force capability depends on the performance of a few top pilots rather than on the collective skills of all oilots.

A "decisive combat" is defined by Weiss as one in which a pilot is either killed or adds one to his score. Mathematically, the hazard rate h_i on decisive combat i, is

$$h_i = K_{i-1}/(S_i + K_{i-1}) \qquad (1)$$

where K_i = number of pilots downed by enemy aircraft with score i; S_i = total number of pilots (living or dead) with at least score i.

Of particular interest in the Weiss paper is data giving the probability of being killed as a function of the decisive combat number for the German squadron Jagdgeschwader JG26 in World War II. These data show a decrease in the probability of being killed as the number of encounters increases. This probability, being a conditional probability, is defined as the hazard rate as given by Eq. (1).

The question arises whether the initial decline in hazard rate with score represents learning, or the elimination of the least skilled pilots. One interesting hypothesis concerning the JG26 data can be made by reference to Fig. 1 which gives the hazard rate for the JG26 plotted on a semilog scale. One hypothesis is that two straight-line segments are prominent on this chart. The first line segment represents a composite of two dominant groups of individuals; one group is represented by a constant learning slope and an initial hazard rate of roughly 0.2; the other group, exhibits a higher initial hazard rate and essentially zero learning. This latter group quickly dies out of the population and is almost completely gone by the 5th decisive combat if no replacement takes place. This is shown by the progression of circles at the bottom of the chart. The size of the circles represent the reduction in total population, there being about a 50% reduction in total population with the first decisive combat.

Two points of consequence emerge from this hypothesis. First, we have both survival of the fittest and learning going on in the process; the learning seems to be largely restricted to the superior group of pilots; second, the loss of almost half of the pilots in their first decisive combat is a situation we could do much to improve.

Thus, our task is twofold: to identify potential aces early and to allow the learning process to proceed sufficiently so that a maturing effect is already in existence by the time combat takes place. The use of training simulators can do this for us. The effect in improving force effectiveness and pilot replacement rate can be dramatic, as will now be illustrated.

Payoff of the Program

A training program for fighter pilots should include both initial screening of candidates and retention of selected candidates throughout the program for progressive development. These two aspects depend on the degree of innate vs acquired skills which pilots display in actual (or simulated) air-to-air encounters. Controlled experimentation through flight tests and training simulators is necessary to isolate and identify those factors which account for these effects on sequential air-to-air encounters.

We now examine the impact of using a proper scheme of selection and training of pilots. The effects we will examine are in terms of replacement rates demanded of a training program (pilots lost in combat) and the fighter force effectiveness in terms of exchange ratio (ratio of expected enemy losses to expected friendly losses).

To demonstrate these effects, we will present a model and analysis based on the theory of renewals, or recurrent events.[2] Before doing this, however, let us first examine a

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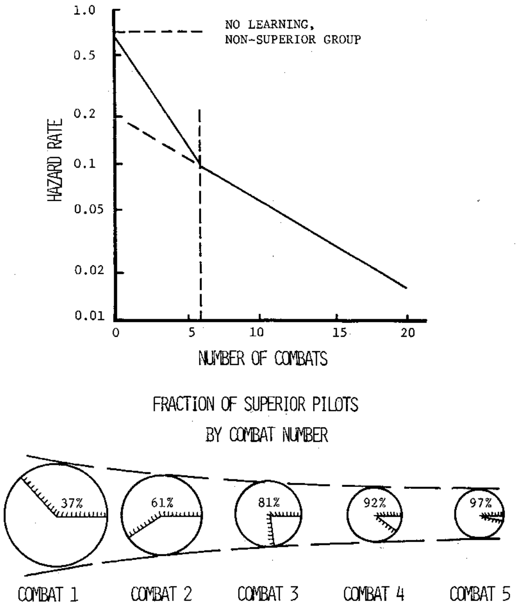

Fig. 1 Hazard rate JG26.

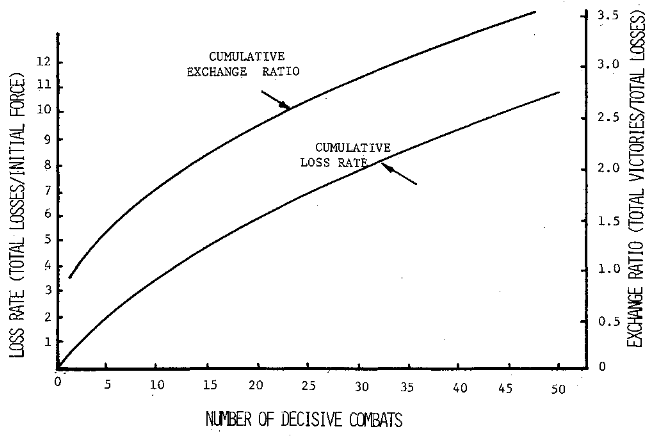

Fig. 2 Cumulative exchange ratio and loss rate calculated from JG26 data.

method for computing the hazard rate as a function of elapsed combats based on the hypothesis that only two classes of pilots comprise the population—those who start with a lower initial hazard rate and learn from experience, and those who have a higher initial hazard rate and do not learn from experience (by learning we mean that the hazard rate for a class of individuals decreases as a function of elapsed combats). With this as our assumption, the hazard rate can be determined by the set of simultaneous equations, Eqs. (2) and (3).

$$H(n) = \alpha(n-1)H_\alpha(n) + \beta(n-1)H_\beta(n) \tag{2}$$

$$\alpha(n-1) = \frac{\alpha(0)\prod_{i=0}^{n-1}[1-H_\alpha(n-i)]}{\alpha(0)\prod_{i=0}^{n-1}[1-H_\alpha(n-i)] + \beta(0)\prod_{i=0}^{n-1}[1-H_\beta(n-i)]}$$

$$n \geq 1 \tag{3}$$

where

$H(n)$ $\doteq$ hazard rate for combat n
$H_\alpha(n)$ $\doteq$ hazard rate for superior pilots
$H_\beta(n)$ $\doteq$ hazard rate for inferior pilots
$\alpha(n-1)$ $\doteq$ fraction of superior pilots at beginning of combat n;
$\beta(n-1)$ $\doteq$ fraction of inferior pilots at beginning of combat n
$\alpha(0)$ $\doteq$ initial fraction of superior pilots
$\beta(0)$ $\doteq$ initial fraction of inferior pilots

Now under our hypothesis, we say that the superior pilots have an improved (lower) hazard rate with elapsed combats (i.e., they learn from experience) whereas the inferior pilots have a constant hazard rate. Thus, we can write

$$H_\alpha(n) = (\gamma)^{n-1}[H_\alpha(1)]; \quad n \geq 1 \tag{4}$$
$$H_\beta(n) = \text{const}; \quad n \geq 1$$

When one refers back to the Weiss hazard curve, using the semilog plot described earlier in this paper, one can establish the following values:

$$\alpha(0) = 0.37,\ \beta(0) = 0.63,\ H_\alpha(1) = 0.2$$
$$H_\beta(1) = H_\beta(n) = 0.7,\ \gamma = 0.88$$

We make one further stipulation, i.e., that the computed values for the hazard rate $H(n)$ have a lower bound. For our model, the minimum value of $H(n)$ is chosen as equal to 0.02. This value is in general agreement with the JG26 data shown earlier.

Before proceeding further with our analysis, it should be noted that Eqs. (2) and (3) demonstrate that a decreasing hazard rate with successive combats can be due to a variety of conditions of learning, survival of the fittest, or combinations thereof. Only through controlled experimentation can we determine the relative degrees of each effect; we have to keep the subjects alive on succeeding combats.

We now develop our model for pilot replacements. From renewal theory, the number of replacements (deaths) on decisive combat n will be

$$u(n) = \sum_{i=1}^{n} f(i)u(n-i); \quad n \geq 1 \tag{5}$$

$u(o) = 1$
$u(n)$ = replacements due to pilots being downed on combat n
$f(i)$ = frequency of replacements on combat i; $i \leq n$

also

$$f(n) = H(n)\prod_{j=1}^{n}[1-H(n-j)]; \quad n \geq 1 \tag{6}$$
$$f(o) = H(o) = 0$$
$$\sum_{n=1}^{\infty} f(n) = 1$$

The number of pilot replacements required through battle n can be computed as

$$L(n) = \sum_{i=1}^{n} u(i)N; \quad n \geq 1 \tag{7}$$

where N is the desired force level of pilots. The exchange ratio through battle n is

$$ER(n) = [\sum_{i=1}^{n} 1 - u(i)] / \sum_{i=1}^{n} u(i); \quad n \geq 1 \tag{8}$$

Now if we fight an extremely large number of decisive combats, i.e., if n goes to a very large number, then it can be shown that the loss rate $LR(n)$ and the exchange ratio

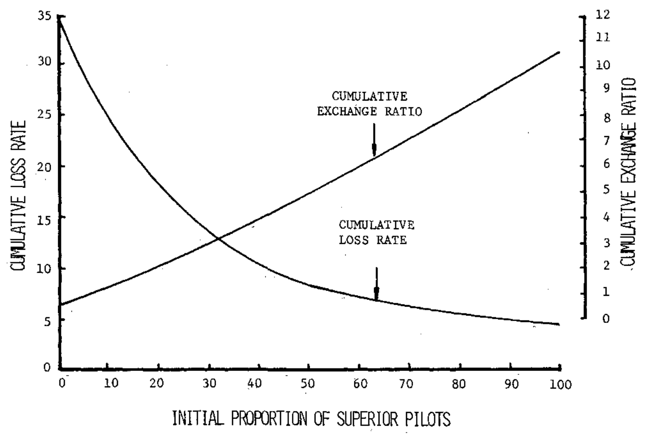

Fig. 3 Cumulative loss rate and exchange ratio after 50 decisive combats—hypothesized from JG26 data.

ER(n) is

$$LR(n) \rightarrow 1/\sum_{n=1}^{\infty} f(n)n \tag{9}$$

$$ER(n) \rightarrow \sum_{n=1}^{\infty} f(n)(n-1) \tag{10}$$

Thus, in the long run, the loss rate of pilots and the effectiveness of the force will stabilize. However, this may take an extremely large number of combats which may never be achieved. What is of primary interest is transient behavior of replacements; in other words, the loss rate and exchange ratio cumulated through a given number of combats. Reference is made to Fig. 2 which gives these values through the first fifty battles using the JG26 data.

We now ask ourselves, what would have been the effect had we lowered our hazard rates, either through a process of selecting superior pilots in the beginning, or inducing learning in the group as a whole, or a combination of the two. First let us see what the effect would have been had the JG26 souadron started off with an enriched population of superior pilots.

It will be recalled that we hypothesized earlier that 37% of this squadron were superior pilots who exhibited learning and 63% who exhibited no learning. Thus in our model our values for $\alpha(0)$ and $\beta(0)$ in Eq. (3) were 0.37 and 0.63, respectively. To change the proportion of superior to in-

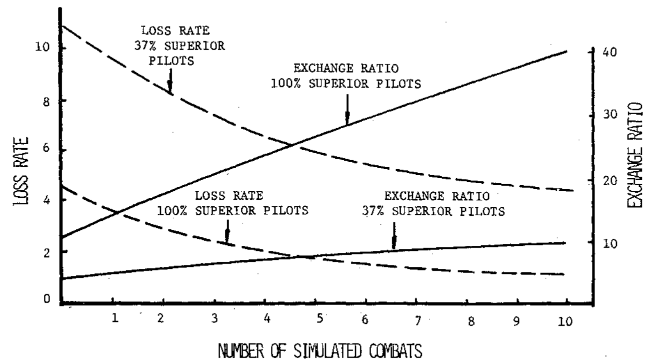

Fig. 4 Effect of induced learning on loss rate and exchange ratio after 50 decisive combats—hypothesized from JG26 data.

ferior pilots, we parameterize the values of $\alpha(0)$ and $\beta(0)$. Figure 3 shows the effect of changing these proportions on the loss rate and exchange rate at the fiftieth combat. combat.

When we combine a selection process with induced learning we have a further improvement. Figure 4 shows the effect of induced learning, using one through ten simulated combats to substitute for the otherwise initial real combats. Mathematically, induced learning is accounted for in Eq. (4) by properly indexing the exponent.

Conclusions

A training program which addresses itself to a selection process for identifying and retaining superior pilots, combined with induced learning, can have significant payoff in terms of improved force effectiveness (exchange ratio) and reduced pilot losses. Both effects can be translated into direct cost savings, both in terms of aircraft investment costs and total costs of pilot training. Training a pilot with a program as described in this paper could result in more cost expenditure per graduating pilot, but the replacement requirements for pilots will be reduced, resulting in an over-all savings in training program costs.

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