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POSTSTALL FLIGHT IN CLOSE COMBAT

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Abstract

Due to modern aircraft technology it might be possible to fly at high angle of attack, far beyond the stall limit (poststall). This gives a new control quality of speed braking and opens for a new turning concept. During the last 3-4 years this feature has been discussed to be used in close aerial combat. This paper will focus on a particular simulation analysis in order to find out the advantages of using poststall in close combat. A hybrid computer set up gives the opportunity to scan through many cases and obtain an almost optimal solution in each case. With somewhat simplified models of the poststall as well as the conventional aircraft and with the goal to point at each other as soon as possible 75 different one-on-one combat engagements has been run through. The results are condensed in statistics, which show that the poststall feature gives significant advantages. However, there are still questions to be answered e.g. if the new concept can be used to its full extent in practice as it gives a very low speed and difficulties in maneuvering the aircraft, etc.

I. Introduction

In a close combat a new important combat quality of an aircraft will be the improved ability to point at the hostile aircraft. This means that such an aircraft must be able to change the direction of its velocity vector rapidly and nevertheless have the capability to stay inside the hostile aircraft's turning area, which also makes it hard for the hostile aircraft to point back. A certain maneuver using a high angle of attack far beyound the stall limit (poststall) can be used in order to reach such a close combat quality.

A new concept and new tactics must be evaluated carefully. The poststall (PST) feature has been analysed in a manned aircombat simulator as well as by using theoretically optimal trajectory methods[1]. The latter approach gives precise numerical outputs but can be used in a limited number of cases due to its difficulty in using an optimization program. From these studies a typical flight using the PST facility can look like in Fig 1. In order to evaluate the benefit of a PST aircraft a large number of situations, i.e. various initital ranges and headings, must be tested. By systematical simulations, using maneuver pieces from the optimal investigation, it is possible to scan through the bulk of situations. The controls and model used, can be coarse due to the fact that the large number of examples statistically fade out the effects of the errors.

The purpose of this paper is to introduce a simulation technique, which makes it possible to scan through many cases easily. The object of this work is to evaluate the advantages of a PST aircraft in an one-on-one aerial combat. In the game situation we do not take into account disadvantages of the PST that for example the very low speed can be.

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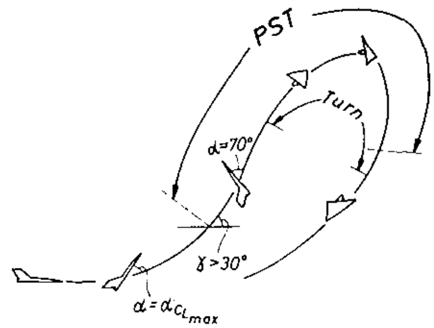

Figure 1. A typical PST maneuver.

II. Modelling the PST feature

A three-dimensional spatial motion of a point-mass aircraft is described by the differential equations

$$\dot{x} = v \cos\gamma \cos\chi \tag{1}$$

$$\dot{y} = v \cos\gamma \sin\chi \tag{2}$$

$$\dot{h} = v \sin\gamma \tag{3}$$

$$\dot{\gamma} = g\ (T \sin\alpha /m + L) \cos\mu - \cos\gamma\ )/v \tag{4}$$

$$\dot{\chi} = g\ (T \sin\alpha /m + L) \sin\mu\ /(v \cos\gamma) \tag{5}$$

$$\dot{v} = g\ (T \cos\alpha /m - D - g \sin\gamma) \tag{6}$$

where x and y are the horizontal coordinates, h is the altitude, γ is the climb angle , χ is the course angle, v is the velocity, g is the acceleration due to gravity, μ is the bank angle, α is the angle of attack, T is the thrust, and m is the mass assumed constant. The drag and lift factors can be written as

$$D = Sq\ (C_N(\alpha) \sin\alpha + C_T(\alpha) \cos\alpha)/(mg) \tag{7}$$

$$L = Sq\ (C_N(\alpha) \cos\alpha - C_T(\alpha) \sin\alpha)/(mg) \tag{8}$$

where S is the reference wingarea and q is the dynamic pressure. As aerodynamic coefficients we will use the normal- and axial- coefficients C_N and C_T respectively. At low speed these coefficients depend on α as shown in Fig 2.

At velocities below the corner velocity , v_c, the load factor can not exceed the maximum limit. Then it is possible to use an angle of attack above the $\alpha_{C_{L_{max}}}$ (the stall limit) i.e. the aircraft can perform a post stall flight. Due to the fact that C_N is rather constant and C_T is comparatively small (see fig 2), we may approximate Eqs(7, 8) by

$$D = 7\left(\frac{v}{v_c}\right)^2 \sin\alpha \tag{9}$$

$$L = 7\left(\frac{v}{v_c}\right)^2 \cos\alpha \tag{10}$$

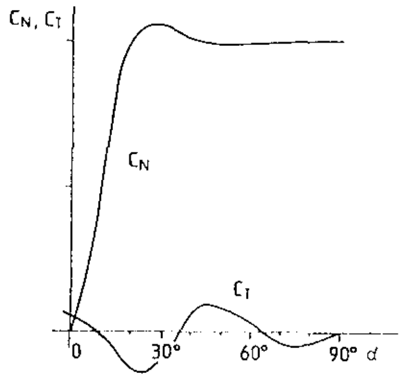

Figure 2. C_N and C_T vs angle of attack.

where we have assumed the maximum load factor to be 7. Introduce

$$k_1 = g\ T/m \qquad (11)$$

$$k_2 = g\ 7/v_c^2 \qquad (12)$$

The numerical values in this paper will be $T/m = .75$ and $v_c = 140$ m/s.

Rewrite Eqs (4-6) using Eqs (9-12) gives

$$\dot{\gamma} = (k_1 \sin\alpha/v + k_2\ v \cos\alpha) \cos\mu - g \cos\gamma/v \quad (13)$$

$$\dot{X} = (k_1 \sin\alpha/v + k_2\ v \cos\alpha) \sin\mu/\cos\gamma \qquad (14)$$

$$\dot{v} = k_1 \cos\alpha - k_2\ v^2 \sin\alpha - g \sin\gamma \qquad (15)$$

In order to illustrate the turn capability the instantaneous accessible turnrate, Eq (14) with $\mu = \pi\ \frac{1}{2}$, is plotted in Fig 3 for various velocities. Two plots are for $\gamma = 0$ and $\alpha = 30^\circ$ or 70° respectively. One plot is for $\alpha = 70^\circ$ and with γ set to the associated value due to a climb in accordance with a flight like Fig 1. Obviously at low velocities a very high turn rate can be obtained. It also gives a very short turn radius. This is due to the thrust term in Eq (14).

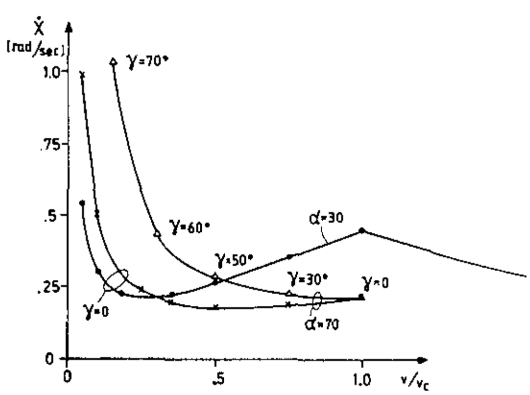

Figure 3. Accessible turn rate vs velocity.

The flight shall be performed in the following way. First, achieve a hard pull-up with $\alpha = 30^\circ$ in order to gain a steep climb, the $\dot{\gamma}$ has a related plot to Fig 3. Then the poststall shall be performed with a large α, around 70° to obtain a high value of the second term in Eq (15), until the speed has broken down to a low value. Then the very high turn rate can be utilized i.e. a high pointing capability.

III. Simulation set up

The purpose of this paper is to, by simulations, make a statistical analysis of an one-on-one close combat engagement between a PST aircraft and a conventional aircraft with good turning capability.

The PST aircraft shall be used in accordance with Fig 1, and the discussion above from where we can split up the flight in several phases. The different phases are modelled as in section II and the length of the phases and the turn direction will be input parameters to the simulations. This gives that by a few parameter settings it is possible to model a realistic combat.

The simulations are performed on an analog computer "Applied Dynamic AD/4" (32 integrators, 24 multipliers, 2 trigonometric generators) interfaced to a PDP-15 by a 200 kHz 12 bit A/D converter. The differential equations Eq(1-3, 13-15) are solved very rapidly by the analog computer. The beneficial idea is to repeatedly generate solutions on a cathode ray tube (CRT) fast enough to make steady curves for the eyes. By turning a potentiometer the influence of a certain parameter can be visualized direct on the CRT. This gives a very good feeling for how to tune the few knobs, and an almost optimal solution is very easily and rapidly reached. The digital computer administrates the runs, e.g. checks the stop condition, generates new initial condition, collects output data, etc. The stop-condition will be when one of the combatants gets the other one within an error of .1 radians in boresight angle.

The PST flight is controlled by five potentiometer settings and one sign switch, whereas the hostile, conventional, aircraft is controlled by one potentiometer setting and one sign switch. The time axis is split in subintervals controlled by the potentiometers as in Fig 4. The sign of the turnrates ω_1 and ω_2 is also tested during the simulations. As for the PST aircraft ω_1 is in accordance with Eq (14). The conventional aircraft is assumed to be able to make a sustained turn at corner speed, which is set equal to the corner speed of the PST aircraft (140 m/s). This gives a very good turning rate $\omega_2 = .49$ rad/s (28 °/s).

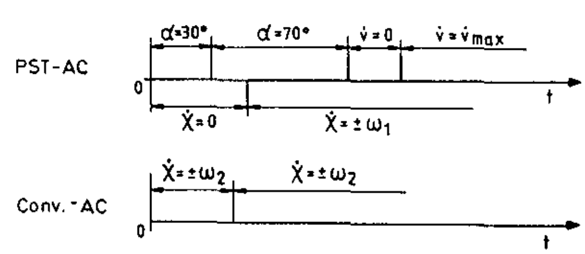

Figure 4. Division of the time interval.

IV. Results

By turning the knobs, the best outcome for the PST aircraft as well as for the conventional aircraft is found in 75 cases with the initial situations as in Fig 5. The units on the axes are 49 % of the constant turning radius for the conventional aircraft (285 meters). The arrows show the direction the conventional aircraft starts with. The letters V means that the position is favourable for the PST aircraft, F means favourable to the conventional aircraft and M gives an even outcome. The horizontal projection of one solution with an F + M outcome is given in Fig 6. In this example the conventional aircraft has a very favourable initial position as it can point at the PST aircraft in the beginning. Nevertheless the PST-aircraft is able to obtain a mutual pointing at the end of the game. The study, in this paper, will be focused to the horizontal plane due to the fact that the important turn around and pointing capability is most critical and also best visualized here.

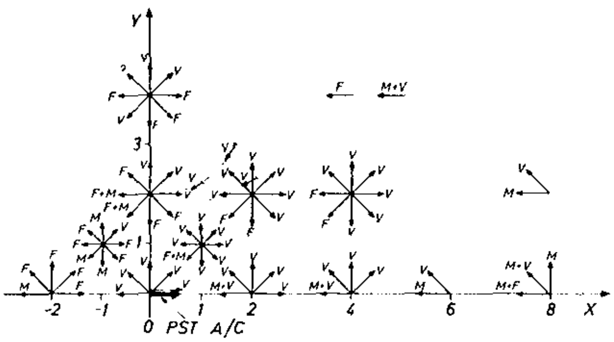

Figure 5. Initial positions, fixed altitude.

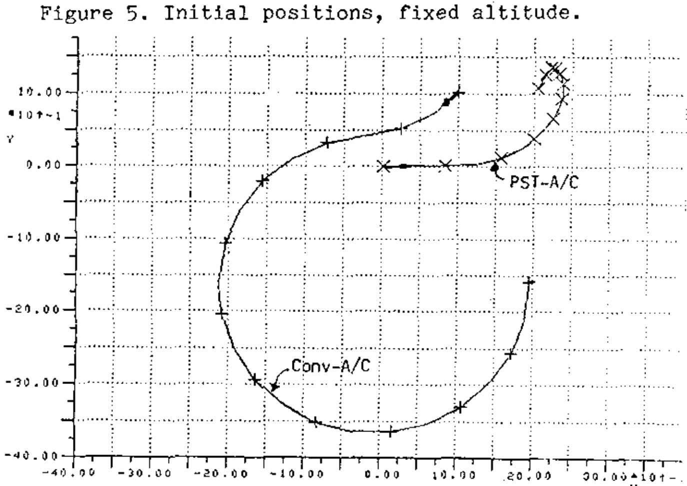

Figure 6. Best trajectories in the horizontal plane.

The most relevant statistics are shown in Figs 8-17. Winnings are defined when the off-bore sight angle (Θ in Fig 7) is below .1 radians. The mean value and deviation are given for each diagram. In 15 cases head-on encounters were obtained. These cases are not included in the statistics.

From Figs 8,9 it is clear that the PST aircraft is superior 41 to 19. In the winning cases the distance to the opponent is given in Figs 10,11. For the PST aircraft the mean distance is 3.48x140 = 485 meters and for the conventional aircraft it is 2.05x140 =285 meters, both within gun range. By Fig 12 we notice a rather high aspect angle (φ in Fig 7). It might be a disadvantage to use a gun due to the difficulty to aim at the target. In adition, by the high aspect angle it seems possible that the conventional aircraft will be able to point back shortly after the PST aircraft has obtained pointing position. This might be true in a few cases, but mostly the PST aircraft is inside the turning circle of the conventional aircraft which by further turning cannot obtain pointing back position. Also note that the conventional aircraft used here, has a very short turn radius. With a larger turn radius the threat from the conventional aircraft will be diminished. The very low speed (Fig 13) is a disadvantage concerning escape capability and maneuvering performance.

Figure 7. Defining off-bore sight angle, Θ , and aspect angle, φ .

The Figs 8-13 are based on cases where some might not give justice to the conventional aircraft. They are motivated if we assume that the PST aircraft is able to plan for the combat before entering in close combat. In order to choose strictly neutral cases the following initial positions are picked out for Figs 14-17, (-2,0), (0,0), (2,0), -1,1), (1,1) and (0,2). Now the advantage with PST is reduced to 18 to 11 but it is still convincing.

V. Summary

By an organized simulation set up it has been possible to work through many cases systematically for a small effort. From the optimal trajectories in Ref 1, and related works, it is possible to select important optimal pieces, which have been combined in the simulation and almost optimal trajectories have easily been realized.

The conclusion of the investigated object is that a PST quality is feasible in close combat. Particularly when performing a pure aggressive aerial combat, even though the hostile aircraft has a very good turn capability including a very short turn radius. From a defensive point of view the PST flight can be crucial as the speed usually is very low. However, in some cases the PST aircraft is inside the turning domain of the hostile aircraft. Then the latter aircraft cannot be a threat for the PST aircraft. The low speed can however be a crucial drawback in a scenario where there are other opponents around.

Reference

1. Well, K.H., Faber, B. and Berger, E., "Optimization of Tactical Aircraft Maneuvers Utilizing High Angles of Attack", AIAA Guidance and Control, Vol. 5, No. 2, March-April 1982.

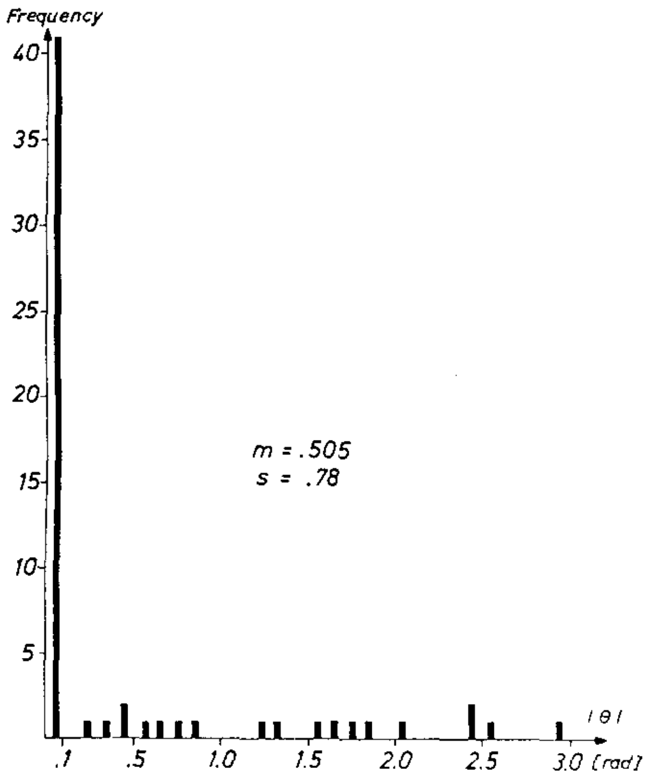

Figure 8. Off-bore sight angle of the PST-A/C.

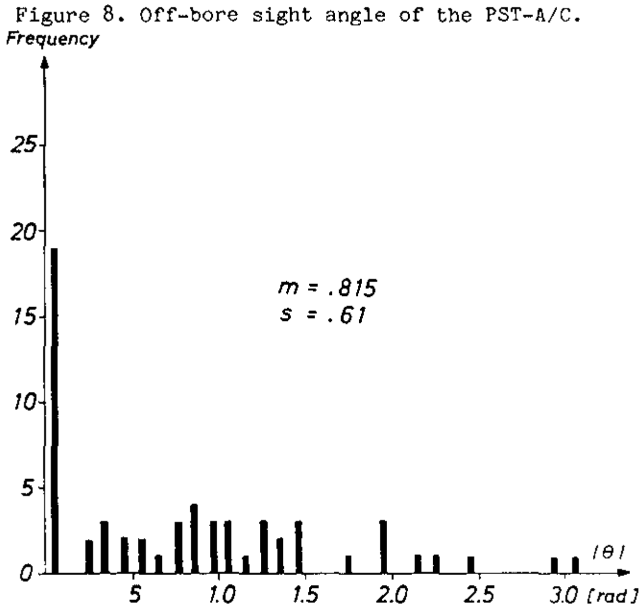

Figure 9. Off-bore sight angle of the conv. A/C.

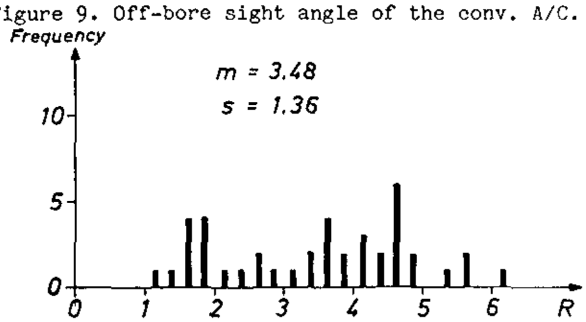

Figure 10. Range in the winning cases of the PST-A/C.

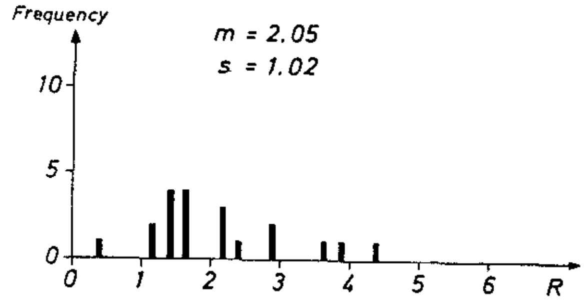

Figure 11. Range in the winning cases of the conv. A/C.

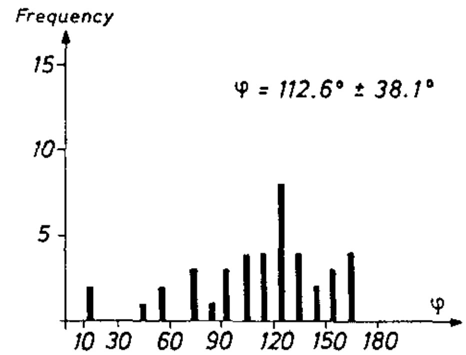

Figure 12. Aspect angle of the PST-A/C, in all winning cases.

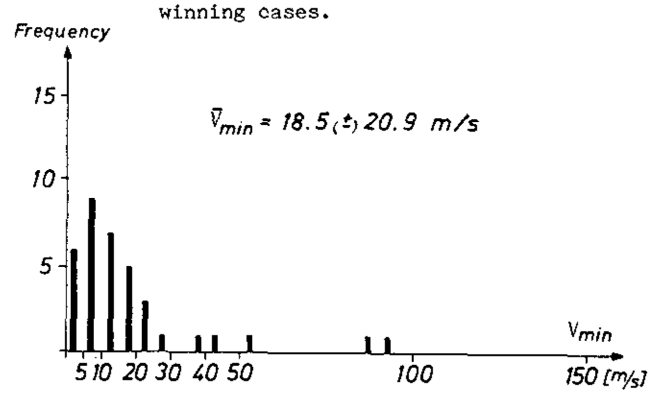

Figure 13. The minimum speed of the PST-A/C, in all winning cases.

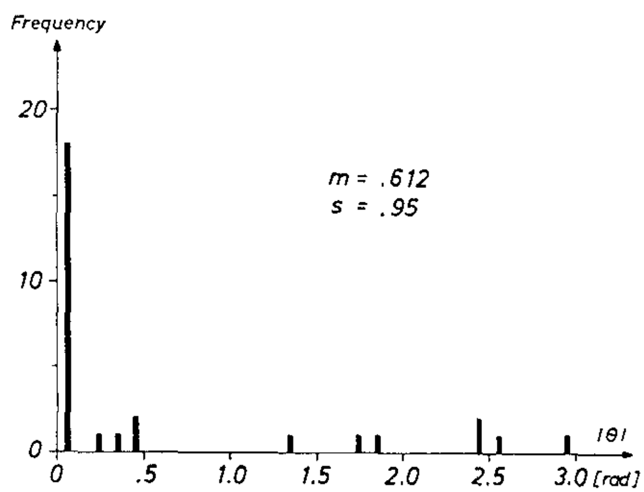

Figure 14. Off-bore sight angle of the PST-A/C. neutral cases.

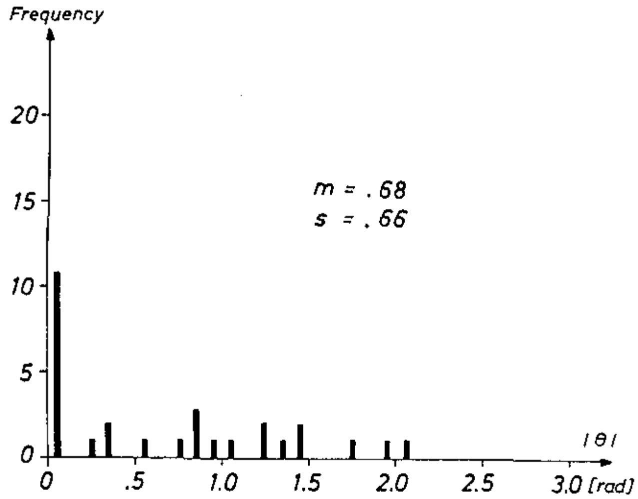

Figure 15. Off-bore sight angle of the conv. A/C, neutral cases.

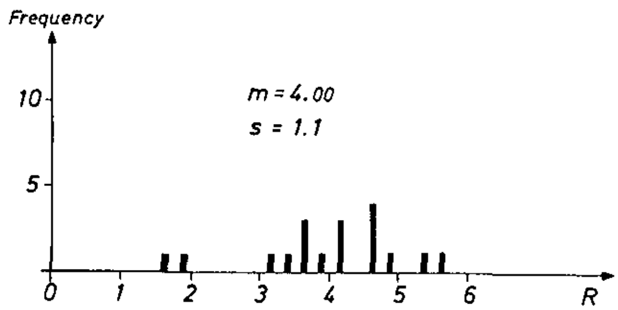

Figure 16. Range in the winning neutral cases of the PST-A/C.

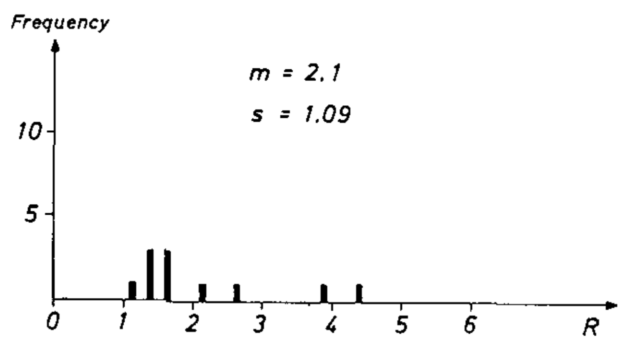

Figure 17. Range in the winning neutral cases of the conv. A/C.