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ON THE PILOT'S BEHAVIOR OF DETECTING A SYSTEM PARAMETER CHANGE

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16. Abstract

This paper deals with the detection characteristics of a human pilot, who is engaged in a compensatory control, to a sudden change in the controlled element's characteristics. Taking the case where the change manifests itself as a variance change of the monitored signal, it is shown that the detection time, defined to be the time elapsed until the pilot detects the change, is related to the monitord signal and its derivative. Then, the detection behavior is modeled by an optimal controller, an optimal estimator, and a variance-ratio test mechanism that is performed for the monitored signal and its derivative. Results of a digital simulation show that the pilot's detection behavior can be well represented by the model proposed here.

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1. INTRODUCTION

An additional task of the human pilot of aircraft besides the primary task of being the controller of the aircraft is the monitoring task to promptly cope with troubles and sudden changes in the automated devices and the measurement instruments. It is quite important to become thoroughly familiar with the human function which detects such troubles and changes in the characteristics of the system and to express it using mathematical models. This is important for the designing of aircraft as well as other human - machine system.

Research activities in the area of formation of models of human function in human - machine system are many. In these research activities, human is considered as servo mechanism. 1-4) At the same time, research activities of human compensatory control that is seen at the time of sudden changes in the characteristics of the system are also carried out. 5) Yet, these research activities are not related to the formation of models of abnormal detection system of human being. Instead, they are thought to be the consideration of the model formation related to the control of the closed-loop system.

Past research activities concerning human being from the standpoint of the detection of the system abnormality include

reports on experimental examination of human detection function. 6, 7) On the subject of the model formation concerning the function of human detection, some of them express the human detection model of the monitoring task by the detection of gradual probability ratio applied to Carman * filter and integral calculus of the remaining difference of the filter. 8) The above model appears to be suitable in the case where abnormality appears as the bias change in the output. Yet, it (the model) seems to require further discussion if it is to be applied to the situation where the target system shows sudden changes or where sudden changes are made in the controlled element as human is carrying out the control within a closed-loop system.

Authors conducted an experiment aimed at the secondary system on the subject of detection by human of parameter changes of dynamic system involving irregular noises as excitation input. 9) Based upon the result of the above experiment, authors have reported that the detection motion in the case where human is simply functioning as a monitor can be expressed using the most suitable assumption and the variance-ratio test. 10)

In this research which deals with the detection motion at the time when the pilot control is in effect, above mentioned motion as the monitor is also included as the special case. In the same manner as the case of the monitor, the detection

time by the experiment (time between the change in the parameter and the time when the change is detected) can be connected to the signal being watched and dispersion of the time differentiated figure. The mathematical model in this case consists of the control of the closed-loop system and the detection of abnormality. Model formation of the former is done by the optimal controller through the Weiner's method. Model formation of the latter is done according to the same method as that of the monitoring tasks. For the purpose of discussing the adequacy of the above model, a digital simulation of abnormality detection is conducted through the use of a model in order to compare the result with the result of the experiment by human.

2. THE OBJECT SYSTEM

Fig. 1 shows the control task used here. The following secondary system are used as the controlled element G(s):

$$G(s) = \frac{K\omega_n^2}{s^2 + 2\zeta_n\omega_n s + \omega_n^2} \qquad (1)$$

s：ラプラス変換のパラメータ
ζ_n：減衰比
ω_n：固有周波数
K：ゲイン定数
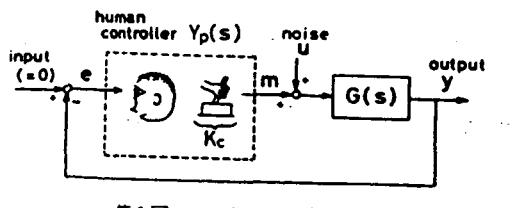
S : parameter of rapuras ✻ exchange

ζ_n : damped ratio

ω_n : specific frequency

K : Gain coefficient

Fig. 1 Control task

第1図　コントロールタスク

The way the abnormality appears caused by mechanical trouble and others tends to vary. Some are drastic. Examples of the above are rapid change in the number of the system or polarity. Others are less drastic. Examples are bias change in output, rapid change in the parameter K, ζ_n, or ω_n, and change in characteristics of the excitation input u. In this study, the question of detecting as soon as possible only the parameter ζ_n of the controlled element G(s) or only ω_n or the rapid changes which take place concurrently is handled as a human conducts compensatory control so as to make the error e zero under the influence of irregular noise u. Such sudden change is thought to be equivalent of a mechanical trouble developed in the safety devices of aircraft. Human transmission coefficient Yp(s) is explained in chapter 4.1.

3. EXPERIMENT

In conducting the experiment, controlled element G(s) was realized on an analogue computer. Tested personnel was provided with the error signal e as visual information. This

was shown on an oscilloscope as a horizontal line which moves toward up and down directions. The tested personnel was directed to maintain the horizontal line at the position as close to the standard line as possible. The operating device with a joy stick is structured to generate output voltage in proportion to the rotation angle of the joy stick. The figure of the control gain Kc was set at 0.1 volt/ deg or twice this figure. (The test result shown in this essay describes only the case of 0.1 volt/ deg.) Furthermore, the tested personnel was directed to press a push switch when he (she) made a judgment that some changes have occurred in the parameter through the observation of the error signal. Under the normal condition (shown in the letter n), ζ_n = 0.7 and ω_n = 4 rad/ sec at all times. Under this condition, only the parameter   , only the parameter   or the two parameters were changed. The excitation input u is the output of the noise generator. Its spectrum density is fixed up to 500 Hz. It is Gaussian signal whose figure is 7.24 x 10^{-3} V^2/Hz. In all experiments, the gain K of the controlled element is set at 1.

The experiment was conducted on two subjects (two graduate students: O is 23 years of age, and H is 26 years of age.). Eight series of tests as shown in Tab. 1 were conducted on each subject. The experiment lasted approximately an hour and a half a day. The eight series of tests were completed within two days. In conducting each

series of tests, the order of the test was from the ones with greater parameter changes to the ones with less parameter changes. The time when changes in the parameter occur is the optional time between 10 to 25 seconds after the commencement of each test. Data collection was initiated after the tested personnel became adequately accustomed to the parameter changes. Measured data are in the form of time (detection time td) between the parameter change in the controlled element and the time when the subject of the test presses the push switch. At each test point, approximately ten trial tests were conducted. If the push switch was not pressed within fifteen seconds of the parameter change, then such data were considered as "miss". If the push switch was pressed before the parameter change, then such data were classified as "false" and removed from the measurement data. The result of the experiment shown later is the average figure of the data collected according to the above method. Among the detected time, the longest and the shortest ones were removed before such data were averaged.

Tab. 1 Form of changes in parameters

第1表 パラメータの変化形態
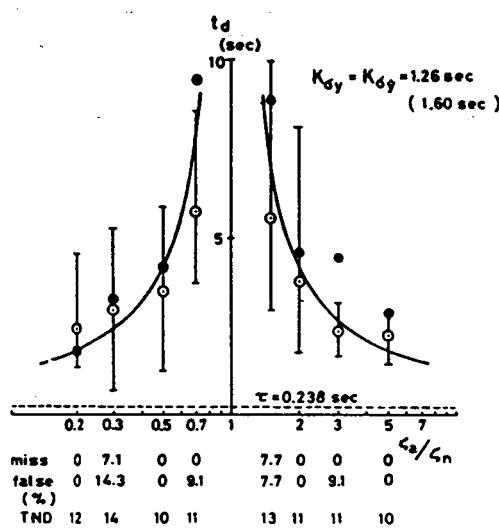
1. 変 化 形 態						シリーズ2.
$\zeta_n \rightarrow \zeta_a$	ζ_a/ζ_n	1.5 0.7	2 0.5	3 0.3	5 0.2	1) 2)
$\omega_n \rightarrow \omega_a$	ω_a^2/ω_n^2	1.5 0.7	2 0.5	3 0.3	5 0.2	3) 4)

|						
	ζ_a/ζ_n	1.5	2	3	5	5)
	ω_a^2/ω_n^2	1.5	2	3	5	
(ζ_a, ω_n)	ζ_a/ζ_n	0.7	0.5	0.3	0.2	6)
$\downarrow$	ω_a^2/ω_n^2	1.5	2	3	5	
(ζ_a, ω_a)	ζ_a/ζ_n	1.5	2	3	5	7)
	ω_a^2/ω_n^2	0.7	0.5	0.3	0.2	
	ζ_a/ζ_n	0.7	0.5	0.3	0.2	8)
	ω_a^2/ω_n^2	0.7	0.5	0.3	0.2	
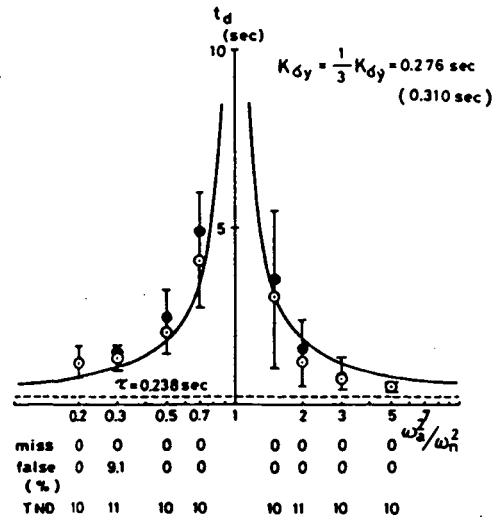
1. form of changes   2. series

Fig. 2   Time of detection (changes in only   )

第2図　検知時間（ζ_aのみの変化）

Fig. 3   Time of detection (changes in only   )

第3図　検知時間（ω_nのみの変化）

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Fig. 2 and Fig. 3 show the test result in which ζ_n and ω_n make changes alone independently. Fig. 2 shows the measurement data of the detection time in which only ζ_n changed (series 1), 2)). Fig. 3 shows the measurement data of the detection time in which only ω_n changed (series 3), 4)). Circles with a dot show the test result, while blackened circles indicate the average detection time in the case of monitoring tasks. They show a little longer time than the average detection time in the control tasks. The mark τ indicates the detection time as the horizontal line on the oscilloscope was made to jump by 1.5 cm. It is considered as being equivalent of the reaction time of the test subjects. The total sum of the data used (including the "miss" and "false" data) is shown in TND. In the same figure, the solid line curves indicate the relation of the ratio of the detection time td and the average of the output y before and after the parameter change and square average figures of $\dot{y}$ using the following formulas (2) and (3).
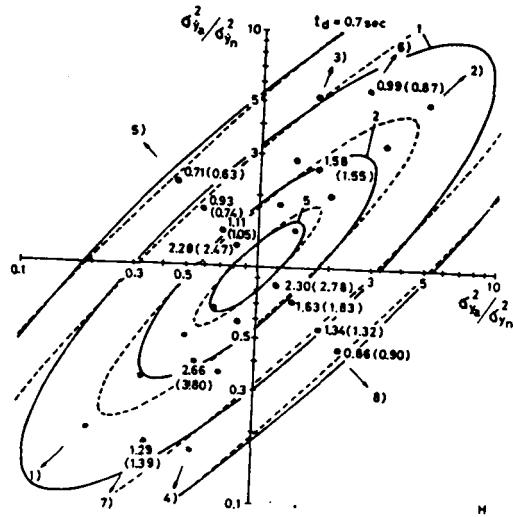
$$t_d = K_{\sigma y} / \left| \log_{10} \frac{\sigma_{yn}^2}{\sigma_{y_n}^2} \right| \qquad (2)$$

$$t_d = K_{\sigma \dot{y}} / \left| \log_{10} \frac{\sigma_{\dot{y}n}^2}{\sigma_{\dot{y}_n}^2} \right| \qquad (3)$$

In the above formulas, σy^2 and $\sigma \dot{y}^2$ indicate the square average figures of y and $\dot{y}$. The letter alpha indicates the figure

after the parameter change. The figures of $K\delta y$ and $K\delta \dot{y}$ can be obtained through the minimum square method from the test data. They are shown in the figure. (The ones within parentheses indicate the ones in reference to the monitoring tasks.) The curves in the figure shown in the formulas (2) or (3) are in reference to the controlled tasks. Yet, they are all in agreement with the test data, which indicates that the detection time by human can be well related with the ratio of δy^2 and $\delta \dot{y}^2$ before and after the parameter change.

Fig. 4   Detection time curve

第4図 検知時間曲線
──コントローラ，……モニター．・は実験点，
数値は検知時間(秒)，カッコ内はモニターの場合

Solid lines indicate the controller. Dotted lines indicate the monitor. Dots indicate the test points. Figures indicate the detection time (sec). Figures in parentheses show the case of the monitor.

Fig. 4 shows the result of the series 5) - 8) in which ζ_n and ω_n are simultaneously changed. The horizontal axis indicates the ratio of δy^2 before and after changes; vertical axis indicates the ratio of $\delta \dot{y}^2$. The dot marks indicate the test points. Test points of the series 1) - 4) are also shown here. The numbers attached to the test point of the series 5) - 8) indicate the average detection time. (Figures in parentheses indicate the case of monitoring tasks.) The curves in the same figure indicate the average detection time using the following formula (4).

$$\frac{1}{t_d^2} = \frac{1}{K_1^2}\left[\log_{10}\frac{\sigma_{y_a}^2}{\sigma_{y_n}^2} + \log_{10}\frac{\sigma_{\dot{y}_a}^2}{\sigma_{\dot{y}_n}^2}\right]^2 + \frac{1}{K_2^2}\left[\log_{10}\frac{\sigma_{y_a}^2}{\sigma_{y_n}^2} - \log_{10}\frac{\sigma_{\dot{y}_a}^2}{\sigma_{\dot{y}_n}^2}\right]^2 \qquad (4)$$

K1 2 and K2 2 were determined through the minimum square method using the entire test data. The solid lines indicate the case of the control tasks, while the dotted lines indicate the case of the monitoring tasks. The direction toward which $\delta y_a^2/\delta y_n^2$ and $\delta \dot{y}_a^2/\delta \dot{y}_n^2$ become smaller and larger together, particularly the direction of the changes of the series 1) and 2) tests, compared with other directions is considered as the direction with longer detection time, in other words, the direction that is difficult to detect in spite of the fact that the change ratio of δy_n^2 and $\delta \dot{y}_n^2$ is great. On the contrary, the direction of the series 5) and 8) is the direction with short detection

time in spite of the small change ratio. In other words, it is considered as the direction that is easy to detect. As the monitoring tasks and the control tasks are compared, the detection time is shorter in the case of the controller rather than the observer in the direction that is considered difficult to detect. In the direction that is thought to be easier to detect, no significant changes are recognizable in the detection time.

Fig. 2 - 4 are in reference to the tested personnel H. Similar result has been obtained in the case of the tested personnel O. For further detailed experimental data, refer to the reference literature 9).

4. HUMAN DETECTION MODEL

From the result of the experiment described in the previous chapter, it became apparent that human detection time was related to the ratio of the square average figure of y and $\dot{y}$ (equal to $-e$ and $-\dot{e}$ here) before and after the parameter change. Accordingly, human is thought to utilize the monitor volume as well as its differential figure at the time of structuring human detection model. The most suitable estimate is presumably provided for the purpose of obtaining the signal e and $\dot{e}$ which are used at the time of detecting the parameter change. At that time, human is thought to utilize his own output (operational volume m for the control) as known

(established) signal. In the case of the monitoring, m

becomes equal to zero.

It is necessary to consider human control characteristics

in the closed-loop system in order to calculate the output m.

Human is assumed to conduct the control of the controlled

element prior to the parameter change until he notices the

change even if sudden changes occur in the controlled element.

The above assumption is necessary in order to prepare the

model of the control characteristics. As for said model, the

optimal controller model through Weiner's * method is adopted.

It is considered in the bibliography 4).

As human detection model, the model as shown in Fig. 5 is

proposed. The part of the most suitable assumption is modeled

by Carman * filter, and the parameter change detection part is

modeled through the use of the variance-ratio test. These

parts, other than the influence of the human output m, are

considered the same as the model formation 10) of the motion

as the monitor.

4.1 Optimal controller (within Fig. 5)

In this section, human transmission coefficient

Yp(s) which would minimize a certain evaluation standard as

the controlled element G(s) is provided is obtained. The

problem in the bibliography 4) is solved as follows. The

wasted time and the delay time of the nerve - muscle system

that is expressed by 1/ (TNS + 1) among the things which show
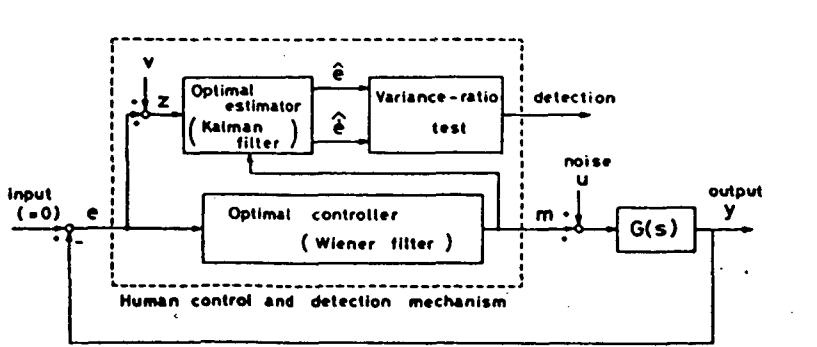
human basic control motion is considered as the same in human who are matured up to a certain degree. This is not something that can be changed intentionally. In this section, wasted time as well as the delay between the nerve and muscle system are expressed by e^{-rs} together and left within the human transmission coefficient. Next, human control motion that is often called the proportional motion, the differential motion and the integral motion is the part which shows adaptability to the characteristics of the controlled element or the external disturbance. In other words, these are the parts that human can intentionally change. These parts are determined through the optimal controller theory using the following evaluation standard.

$$J_m = \overline{e^2} + k_m{}^2 \overline{m^2} \qquad\qquad (5)$$

In the above formula, the lines on top of letters e and m indicate the average figure. The second section on the right shows human labour. In general, m is considered as the item to show human labour. Yet, it is assumed that no additional labour is needed in order to maintain it at a fixed level after completing a fixed operation in the case where instruments without recovery power are used.

Fig. 5 Human detection model

第5図　人間の検知モデル

It is more proper to use $\overline{m^2}$ which is equivalent of the average kinetic energy as the one to indicate human labour. Adequacy of the evaluation standard shown in the formula (5) is discussed after comparing it with the test result obtained by the National Aerospace Laboratory.

According to the method described above, optimal human transmission coefficient Yp(s) is given according to the following formulas.

$$Y_p(s) = \frac{1}{G(s)} \frac{F(s)}{1 - e^{-\tau s} F(s)} \qquad (6)$$

ここで

$$F(s) = \frac{1}{Z(s)} \left[\frac{e^{\tau s} G(s) G(-s)}{Z(-s)} \right]_+ \qquad (7)$$

$$G(s)G(-s) - k_n^2 s^2 = Z(s)Z(-s) \qquad (8)$$

Z(s) is a function structured by a pole of the left side half of the surface (L. H. P.) of the complex surface and the zero point. [·] + indicates the section which has a pole only at L. H. P.

Fig. 6 shows human transmission function Yp(s) obtained through the above described method in the form of board line chart when the controlled element G(s) is given by the formula (1). The result is equal to the result in reference to G(s) prior to the change in the parameter. As

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the figure of km^2, kinetic movement in the vicinity of the
roll axle by movable simulator is simulated in the test. This
is a little different from the one described here. As an
experimental attempt, km^2 = 0.05 sec^2 that is compared with
the test result in the bibliography 4) was adopted. As the
figure of Γ, the instance of 0.15 - 0.3 sec is shown here.
Yet, based upon the following reason #1 and #2, Γ = 0.25 sec
has been estimated in the digital simulation that follows.
[Reason #1] The figure of Γ that is gained as the result of
the experiment is 0.238 sec in the case of the test subject H
and 0.306 sec in the case of the test subject O. [Reason #2]
The estimated figure of Γ in the bibliography 4) is almost
0.25 sec. Incidentally, the indentation in the vicinity of
the frequency 4 rad/ sec shown in the Gain's characteristics
means the reduction in the pilot's gain in the vicinity of the
specific frequency of G(s).
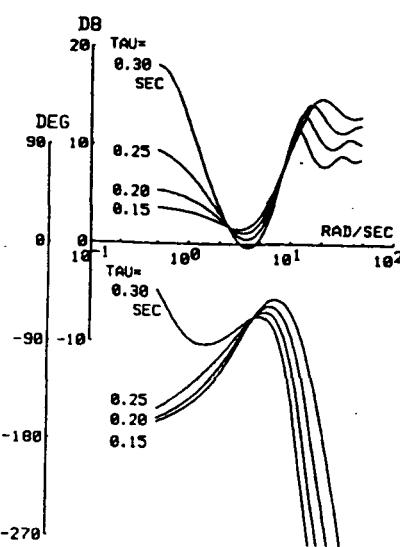
4.2 Optimal estimator (in Fig. 5)

Human internal observation noise v is determined as
the Gaussian white noise. The excitation input u into the
system uses the Gaussian signal. Also, it is assumed that
human are adequately used to the signal prior to the parameter
change and are well aware of these statistical
characteristics. Considering tne fact that the opposing
system is linear, the part of the optimal estimator of the
detection model will become the Carman * filter assuming that

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human are conducting the optimal estimation in the sense of minimizing the average square errors. The formulas for the optimal estimator by the Carman ☆ filter are reported in various literature. Therefore, they are omitted here.

Fig. 6 A board line figure of human transmission function

第6図　人間の伝達関数のボード線図

4.3 Variance-ratio test (in Fig. 5)

When the average figure of a base group N1 and N2 (which are different from each other) is unknown, variance-ratio test to determine whether some variance exist between δ_1^2 and δ_2^2 is considered here. The size of the sample that is extracted from each base group is determined at n1 and n2. At this time, equitable estimate value u1 and u2 in reference to δ_1 and δ_2 are used to calculate the formula (9) shown below.

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$$L=\frac{u_1^2}{u_2^2} \qquad\qquad (9)$$

Then, L follows the F distribution of F (n1 - 1, n2 - 1) under
the hypothesis of $\sigma_1^2 = \sigma_2^2$. (n1 - 1 and n2 - 1 indicate the
degree of freedom.) F(alpha : m, n) is defined as the figure λ_α
for the probability variable Z following the F (m, n)
distribution to satisfy $P(Z \geq \lambda_\alpha)$ = alpha. Then, if either one
of the formulas (10) or (11) shown below is materialized, then
the hypothesis $\sigma_1^2 = \sigma_2^2$ is discarded. If none of the two
formulas is materialized, then the hypothesis is not
discarded. This is the variance-ratio test in mathematical
statistics. Alpha becomes the danger ratio to discard the
hypothesis at the time when the hypothesis is correct.

Fig. 7 shows the method to apply the above method to time
series signal. The two parts among said signal that will
become the target of the variance-ratio test are N1 and N2.
In other words, it is estimated that human conduct
variance-ratio test by extracting n1 and n2 each samples from
N1 and N2 part. In order to detect the parameter change,
human observes this signal. The actual point of the
observation is at the right edge of N2. Considering the fact
that human are quite familiar with the statistical
characteristics under the normal condition, it may be all
right to think that N1 is positioned at the beginning of the
signal. It was thought that only the part of N2 was moved to

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the right along with the passage of time. **R**.

$$L \geq F(\alpha/2 : n_1-1, \; n_2-1) \triangleq F_{crit} \quad (10)$$

$$1/L \geq F(\alpha/2 : n_2-1, \; n_1-1) \triangleq F_{crit} \quad (11)$$

5. DIGITAL SIMULATION BY DETECTION MODEL

Digital simulation was conducted using human model proposed in the chapter 4. The condition of the set up was made identical to that of the experiment. The sampling period was set up at 0.05 second. It was so decided considering the fact that the reading accuracy at the time of the measurement of the detection time during the experiment was 0.05 second and that $\omega_n = 4$ rad/ set (accordingly, the specific period is 1.57 sec). As for the human internal observation noise, it was determined so that the ratio of the variance of $e(\sigma_e^2)$ and the variance of $v(\sigma_v^2)$ was equal to $\sigma_e^2/\sigma_v^2 = 36.$ 8) The length of the signal extracted from the part of N1 can be anything as long as it is long enough to determine the statistical characteristics. Considering $\omega_n = 4$ rad/ sec, it was determined as follows: N1 = 10 seconds. As for the moving N2 part, it can also be determined according to the same manner as N1. Yet, if this part is too long, then the detection becomes somewhat delayed. If it is too short, then it could cause some error because of its inability to fully grasp the statistical characteristics. Here, N2 is made equal to 4.5 seconds. The time when the parameter becomes changed is 12.5 seconds after the beginning of the test.

Fig. 8 to Fig. 13 show the result of the simulation of

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the detection time through the use of models. Fig. 8 and 9

show the change of solely ζ_n , while Fig. 10 and 11 show the

change of solely ω_n . Fig. 12 and 13 show the result in which

both ζ_n and ω_n change simultaneously (series 6), 7)).   In

these figures, detection time obtained by the experiment using

human is also shown using ▲ mark. Fig. 8, 10 and 12 show the

detection time obtained from the variance-ratio of the optimal

estimate figure $\hat{e}$ of e. Fig. 9, 11 and 13 show the detection

time obtained from the variance-ratio of the optimal estimate

figure $\hat{\dot{e}}$ of $\dot{e}$. The sample numbers n1 and n2 to be extracted

from the part of N1 and N2 only need to be sufficient to know

the statistical characteristics of the signal. It should be

determined based upon the frequency band of the signal. The

number of the sample usually affect the threshold figure (for

detection) as well as detection time or generation of "false".

Here, the result in the case of (n1, n2) = (200, 90), (100,

45), (66, 30) is shown. It is the result obtained when alpha

= 0.01. The threshold figure F crit for the detection at that

time is shown in Fig. 2. Each result is the average of the

result of 100 separate simulations which are correctly judged.

Comparing the above result with the result of the experiment

marked with▲, it is obvious that they tend to snow decent

agreement. In the case of the change of ω_n^2 alone, the

detection time in the case where ω_n^2 changes toward the higher

(larger) direction is shorter than the detection time in the

case where the same changes toward the lower (smaller)

direction. This is explained according to the following

manner. In the domain where ω_n^2 is high (large), as it has been

reported previously that a pilot will begin the control after

noticing $\omega_n^2 3$), ω_n^2 can be more easily detected. This tendency

also appears in the detection time obtained from $\hat{e}$ (Fig. 11).

It is safe to assume that human is paying more attention to $\dot{e}$.

In the case of the series 5) and 8), it was difficult to

make the detection through the simulation according to this

model. This is the case in which both   and   became larger

or smaller. Human easily detected the change in the parameter

in this case in spite of the fact that the change ratio of the

variance of e and $\dot{e}$ was rather small. The above fact

indicates the possibility that human commonly use the key

information other than the variance-ratio in order to detect

the changes in parameter. However, as far as other direction

is concerned, human perception is directed only toward the

change ratio of the variance. Thus, fine result is obtained

as shown here.

The influence of the control is not significant as the

result of the simulation is compared with the result of the

monitoring tasks in the bibliography 10). It is particularly

so when all the parameters are regarded as being the same

(equal). Assuming that the number of samples, n1 and n2, from

the N1 and N2 parts is greater in the case of the controlled

tasks than in the case of the monitoring tasks (for example, monitor (n1, n2) = (100, 45) and the controller = (200, 90)), approximately the same degree of difference as the difference of the experimental figure of the detection time in the both cases will appear. This can be interpreted that human tend to be more attentive in the case of being a controller rather than being a monitor. In this study, the data length of N2 part is calculated as being fixed. It is assumed that the detection characteristics may be changed by changing it. In this essay, no discussion has been made concerning the method on how to select these parameters. Consideration of the above discussion may be brought out in the future.

6. CONCLUSION

In this study, an experimental investigation of detection actions of airplane pilots was conducted in the case where the system abnormality can be detected as the variance changes of the output. Based on the above study, a detection model was proposed. It became clear that the pilot's detection time obtained through experiments could be connected with the variance-ratio of the signal being watched and its time differential figure. Based upon the result of the experiments, the pilot's detection model is expressed in the form of the two parts - the optimal control for the closed-loop system control and the detection of the parameter

changes by Carman ∗ filter and the variance-ratio test. Through the comparison of the result of the digital simulation by models and the test result, it is safe to state that the model being proposed here adequately and qualitatively expresses pilot's detection motions as a controller or a monitor with the exception of the special case such as the series 5) and 8).

The questions yet to be solved may include the mutual relation between e and e which are utilized by pilots who are attempting to detect changes. In other words, the future consideration must include the question on which one must be used, or how much of it should be used, or how it should be used...etc. etc. In addition to that, selection method of the parameters in the use of the models must be discussed through further tests and experiments including the research activities on the subject of the difference between the case of the monitoring tasks and the control tasks. It seems that consideration of the control standard other than the variance-ratio is also important.

[Translator's note]

Words marked with ∗ indicate phonetically translated Japanese words.

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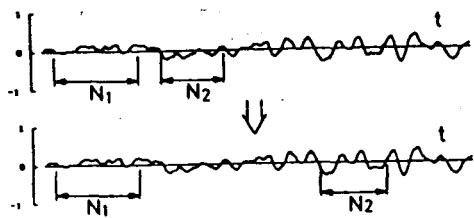
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Tab. 2
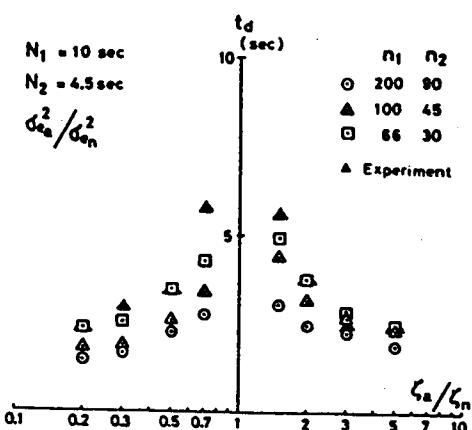
第2表 検知のためのしきい値

$F_{crit}: \alpha = 0.01$

m	n	F_{crit}
199	89	1.621
99	44	2.002
65	29	2.432
89	199	1.564
44	99	1.882
29	65	2.165

Fig. 7
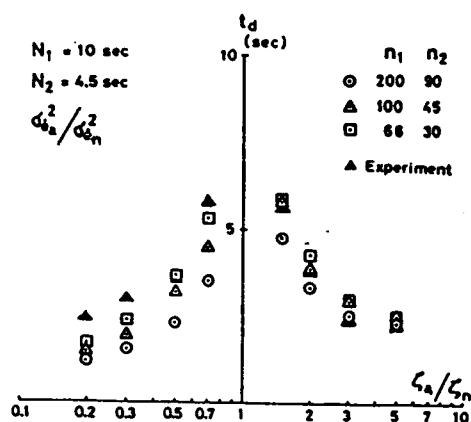
第7図　時系列信号への分散比検定の適用
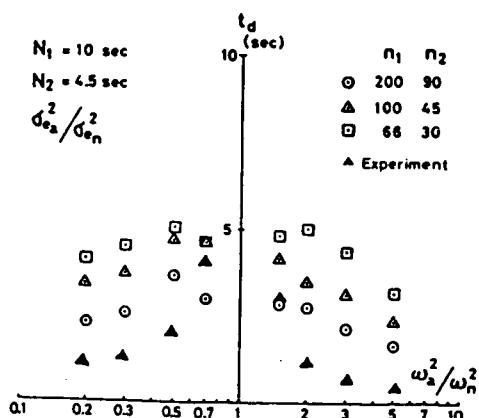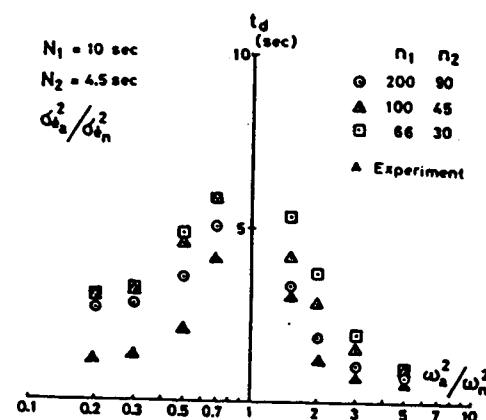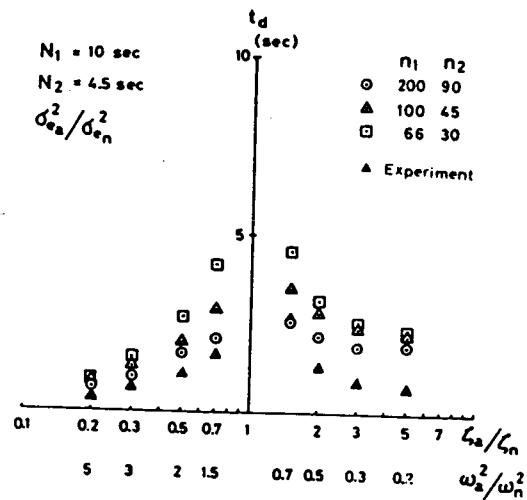
第8図　モデルによる検知時間（$\hat{e}$, ζ_nのみの変化）
Fig.8

第11図　モデルによる検知時間（$\hat{e}$, ω_nのみの変化）
Fig.11

第9図　モデルによる検知時間（$\hat{e}$, ζ_nのみの変化）
Fig.9

第12図　モデルによる検知時間（$\hat{e}$, シリーズ6), 7)）
Fig12

第10図　モデルによる検知時間（$\hat{e}$, ω_nのみの変化）
Fis 10

第13図　モデルによる検知時間（$\hat{e}$, シリーズ6), 7)）
Fig13