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THE RESPONSE OF HELICOPTER TO DISPERED GUST

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ABSTRACT

The response of helicopter to dispersed gust is investigated in this paper. The processes of which helicopter penetrates gust, steepes gust and withdraws from gust are considered. According to the demand of specification, sine-squared gust model is selected, sine-gust model is also selected in order to investigate the influences of different gust models on response. An articulated rotor with a blade hinge offset from the shaft and with an elastic restrain about the flap hinge is used as the rotary wing dynamic model. The non-uniform distribution of induced velocity on the rotor disk which derived from generalized vortex theory is taken into account. The linear partial differential small perturbation equation is not used.

A samped calculation of a typical helicopter has been made. A detail calculation is given of response which helicopter penetrates gust, steeps gust and withdraws from gust.

1. Introduction

In general, continuous turbulence, dispersed gust, mean wind and wind shears are included in the phenomena of the atmosphere. The study of the atmospheric turbulence response plays an important role in modern design of helicopter. Because the flight altitude of helicopter is always in the range of low or mean position, the atmospheric turbulence are serious in these region not only the probability of the production but also the intension of atmospheric turbulence. Therefore comparing with the fix-wing aircraft, besides the conventional demand of the flight quality, the helicopter must have the better quality of resisting turbulence.

There are many investigations in continuous turbulence response. But a great deal of the random atmospheric turbulence are described in the continuous turbulence, if the helicopter is upseted or moved voilently due to a gust, this case can't be described using the continuous turbulence response. Therefore, the response of helicopter to continuous turbulence and dispersed gust can't replace each other, the relationships of them are complementary each other.

As we know, there are three processes of helicopter penetrating gust, steeping gust and withdrawing from gust which belong to a total process when the helicopter passes through the turbulence. There are no literatures about the response of helicopter to gust considering the total process, Ref. [1], [2] analysed the rotor response to gust, in which gust was assumed to act on the rotor, Ref. [3] considered the penetrating gust but only for rotor and no processes of other two cases.

Ref.(4) also considered the case of helicopter flight vertically through the gust.

For the purpose of describing the real motion of helicopter passed through the gust, the total process included the penetrating gust, steeping gust and withdrawing from gust must be analysed in detail. The response of helicopter to gust considering the total process will be given in this paper.

The characters of this paper is as following:

(1) The total process of helicopter penetrating gust, steeping gust and withdrawing from gust were considered.

(2) The gust model was selected according to the demand of specification(5). Therefore the study has the common sense and the more ability of description.

(3) The responses of helicopter to the gust are calculated when the distribution of induced velocity over rotor disk is uniform and non-uniform.

(4) The motion equations of helicopter are a set of nonlinear differential equations. The linearization is not used in the calculation of the response. So that the results of study will really reflect the characters of the motion of the helicopter.

(5) In this paper, trim state was selected as initial state, the frequencies of helicopter motion act as the frequency of the gust. The calculation of trim, stability and gust response are connected so that the method given in this paper has the common and pratical sense.

2. Establishment of the model

(1) Dynamic model of rotor

The dynamic model of rotor is equivalent to an articulated rotor with a flapping hinge offset from the shaft and an elastic restraint about the flapping hinge. The condition of equivalent is the equal of first natural property in flapping. Otherwise, the inclination of rotor shaft and precone angle of blade are considered.

(2) Aerodynamic model of rotor

The compression and stall are not considered. Aerodynamic load acted on the rotor are calculated using the quasi-steady theory when helicopter passes through the gust. The distribution of induced velocity on the rotor disk is used from generalized vortex theory(6). The influence of gust on vortex is not considered.

(3) Gust model

It is assumed that the dispersed gust is non-anisotropic, the intensity of gust is equal in any direction and it has nothing to do with the selection of coordinate system. The gust field is taken to be "frozen" i.e. it does not change with time.

There are four typical gust models: step, ramp, sine and sine-squared. All of them can be used to evaluate the response feature of helicopter to gust. In this paper, the demand of specification, sine-squared model is selected, which expression is shown as follows:

$$W_g = \begin{cases} 0 & d < d_1 \\ C \, \mathrm{Sin}^2 \pi/2Hg \cdot (d - d_1) & \text{when } d_1 \leq d < d_1 + 2Hg \\ 0 & d > d_1 + 2Hg \end{cases} \quad (1)$$

where: d = distance from the origion to the considered point
d_1 = distance from the origion to the fore-edge of the gust
Hg = ramp length or distance over which the velocity of gust increase
C = constant of the controlled amplitude of gust

In order to investigeste the influence of gust model on response, the response of helicopter to sine gust model is also discussed. The expression of sin gust model is follows:

$$W'_g = \begin{cases} 0 & d < d_1 \\ e \, \mathrm{Sin} \, \pi/2Hg \cdot (d - d_1) & \text{when } d_1 \leq d < d_1 + 2Hg \\ 0 & d > d_1 + 2Hg \end{cases} \quad (2)$$

where e = constant of the controlled amplitude of gust.
There frequency of gust is determined by the demand of specification. In this paper, the frequencies of longitudinal, short period, up-down and Holland roll motion are used as the frequency of the gust respectively. Otherwise, the coupling of longitudinal motion and lateral motion is considered.

3. Analysis of the total processes included penetrating gust, steeping gust and withdrawing from gust for helicopter

(1) Analysis of the total processes included penetrating gust. steeping gust and withdrawing from gust for rotor.

The analysis of the penetrating gust, steeping gust and withdrawing from gust for rotor is the key of this study. The expression of sine-squared gust model can be also written as

$$(Wg)_i = \tfrac{1}{2}(W_{go})_i \left[1 - \cos \pi/(Hg)_i \quad (d-d_1) \right] , \quad (i = 1,2,3) \qquad (3)$$

where the subscript $i = 1,2,3$ is referred to longitudinal short period motion, up-down motion and Holland roll motion respectively, and

$$(W_{go})_i = (V_{yg})_i = \left(\frac{V_{yg}}{\sigma_y}\right)_i \sigma_y \qquad (4)$$

indicate the magnitude of gust in a certain frequency respectively, V_{yg} is the magnitude of the vertical gust, σ_y is the Dryden intensity in itself direction.

(2) Analysis of the total processes included penetrating gust, steeping gust and withdrawing from gust for fuselage.

Because the velocity of gust has an effect on motion equations of helicopter only by aerodynamic item. The influence of the aerodynamics item on the fuselage is the attack angle and slipping angle when the fuselage passes through the gust considered the total process.

The variations of fuselage attack and slipping angle can be described as follows:

$$\Delta\alpha_g = -tg^{-1} W_g/V_x$$

$$\Delta\beta_g = 0 \quad \text{(Because of the only vertical gust considered)} \tag{5}$$

(3) Analysis of the total processes included penetrating gust, steeping gust and withdrawing from gust for tailrotor.

Comparing the gust with the head-on velocity of blade section, the primary effect of the gust on the tailrotor is the head-on velocity of the section of the blade. The component of gust is so small that the influence of gust on the tailrotor can be neglected.

4. Calculation of the response of helicopter to the gust

The trim equations are a set of nonlinear equations in this paper and can be solved used the optimal method. Using the small-disturbance theory, the dynamic motion equations of helicopter may be linearization. By linear transformation of coefficient and treating the reducing matrix rank, the following expression can be obtained as follows:

$$(DE - A_s)x = B_g \tag{6}$$

where $x = \left[\Delta V_x,\ \Delta V_y,\ \Delta V_z, \Delta\omega_x, \Delta\omega_y, \Delta\omega_z, \Delta\gamma_x, \Delta\psi_y, \Delta\vartheta_z\right]^T$

E is the unit matrix by 9×9

A_s, B_s are coefficient of the matrix, when $B_s = 0$, the roots of stability can be obtained. The distribution of induced velocity over rotor disk are uniform and nonuniform considered respectively.

The dynamic response of helicopter penetrating gust, steeping gust and withdrawing from gust are determined by the dynamic motion equations of helicopter. There are nice variables in these equations. In order to solve these equations, another three kinematic equations must be completed, i.e. :

$$\frac{d\gamma_x}{dt},\ \frac{d\psi_y}{dt},\ \frac{d\vartheta_z}{dt}$$

Solving the above two sets of equations simultaneously, the response can be obtained. Because the sourse of lift is primary from rotor. The dynamic response of rotor has an effect on helicopter dynamic response. In return, the response of helicopter has an effect on flapping of rotor. So that it's necessary to solve the simultaneous equations of helicopter motion and rotor flapping.

5. Results and conclusions of calculation

A sample calculation for a typical helicopter is given. The dynamic response of helicopter to penetrating gust, steeping gust and withdrawing from gust are given at forward speed $\mu = 0.2$. The sine square gust model is selected. The frequencies of longitudinal short period, up-down motion and Holland roll motion are act as the frequency of the gust. In order to investigate the influence of gust model on the response, the sine gust model is also selected.

(1) The dynamic stability roots considering the coupling of longitudinal and lateral are calculated. Comparing with the flight specification MIL-83300, it is found that the roots are according with the demands of specification. The distribution of induced velocity over the rotor doesn't change the stability of helicopter.

(2) Calculated results and analysis of penetrating gust, steeping gust and withdrawing from gust for helicopter.

Fig.1 - 6,7 - 12, 13 - 18 show the time histories of helicopter response to gust when gust frequency is the frequencies of Holland roll motion, longitudinal short period and up-down motion respectively.

According to the practical hypothesis of the engineering, the nonlinear system can be considered as weak nonlinear system. So it's feasible that longitudinal short period, up-down and Holland roll motion frequency is acted as the frequency of gust to analysis the response of helicopter to gust respectively.

From table (1) we can know that longitudinal short period motion model and Holland roll motion model are stable and up-down motion model is unstable. Therefore the response of the unstable model is divergence when the helicopter withdraws from the gust. Because of weak nonlinear system which changes the feature of linear system in a some degree, all the motions are divergent in three cases when helicopter withdraws from gust. For up-down motion model the divergent is biggest and for the longitudinal short period motion model the divergent is weakest because the damping of the Holland motion model is larger than the longitudinal short period motion model.

(3) Conclusion of helicopter response to sine model gust

The calculation of helicopter response to sine model gust is also made. It's found that the different gust models have the different responses. If the frequency of the gust is far away from the frequency of the motion model though the magnitude of gust is greater than sine-squared model. Therefore, it is important that the frequency of the motion model must be taken as the frequency of gust.

(4) Influence of distribution of induced velocity over disk on response

For sine and sine-squared gust models the calculation of helicopter response are made when distribution of induced velocity over disk are uniform and nonuniform. From the results of calculation it's found that the distribution of induced velocity have an effect on helicopter response to gust.

(5) Conclusions

5-1. It is feasible that the responses of helicopter to the gust is calculated by the quasi-steady theory when the frequency of gust is greatly smaller than angular velocity of rotor.

5-2. The total process of helicopter penetrating gust, steeping gust and withdrawing from gust must be considered in calculation of helicopter response to gust.

5-3. The coupling of the longitudinal motion and lateral motion must be considered when the total process of helicopter penetrating gust, steeping gust and withdrawing from gust are studied.

5-4. The responses of helicopter to gust is different when the different gust model is selected respectively.

5-5. Calculating the response of helicopter to the gust, only the frequencies of longitudinal short period motion, up-down motion and Holland roll motion is acted as the frequency of gust respectively.

5-6. The results given by this paper not only agree with physical concepts but also agree with the dammand of specification in nature and agree with reference [5] [6] simplified according to same conditions in quantity.

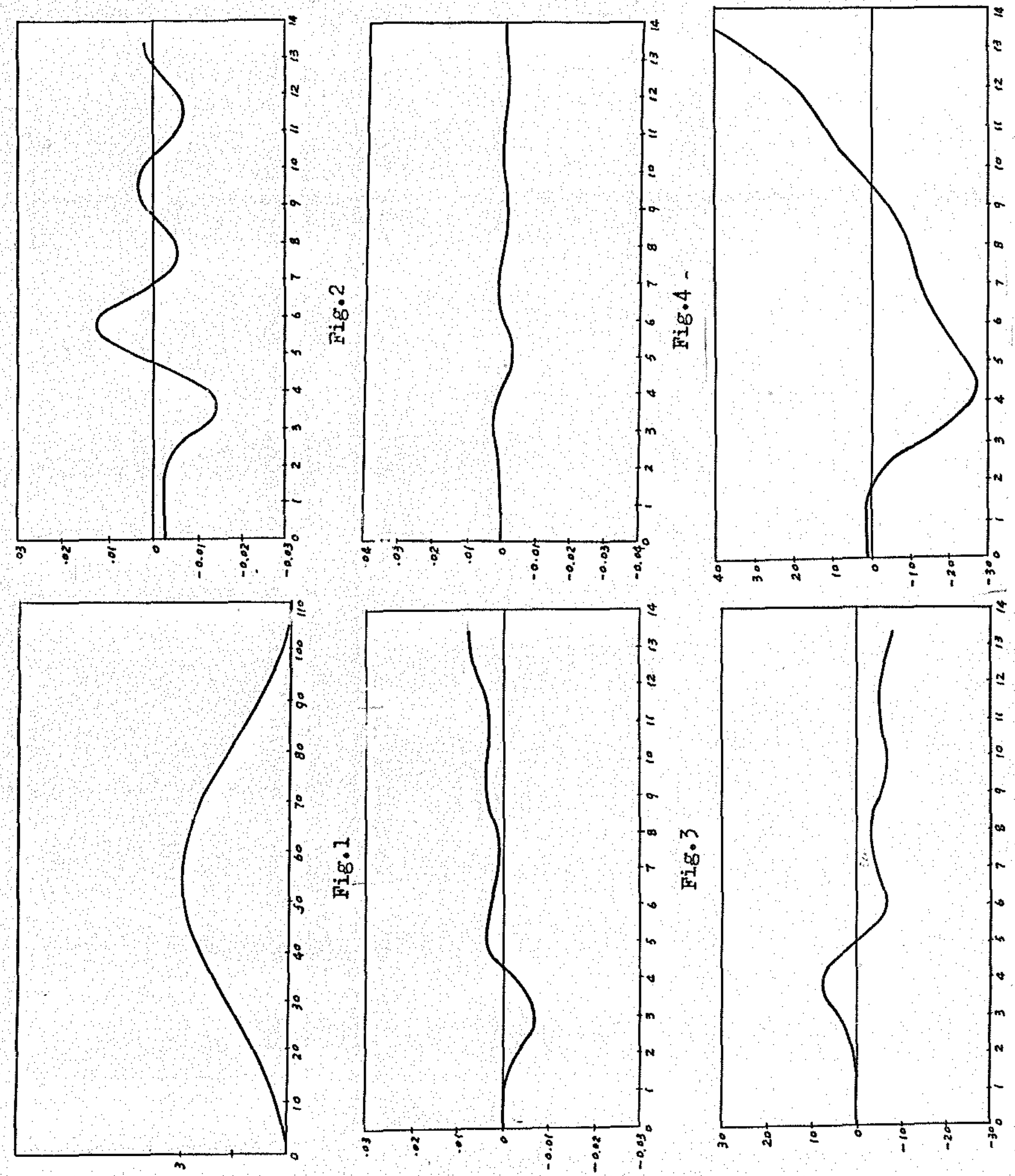


Fig.1 Gust range
2 The response of vertical velocity
3 The response of roll angular velcity
4 The response of pitch angular velocity
5 The response of roll angle
6 The response of pitch angle

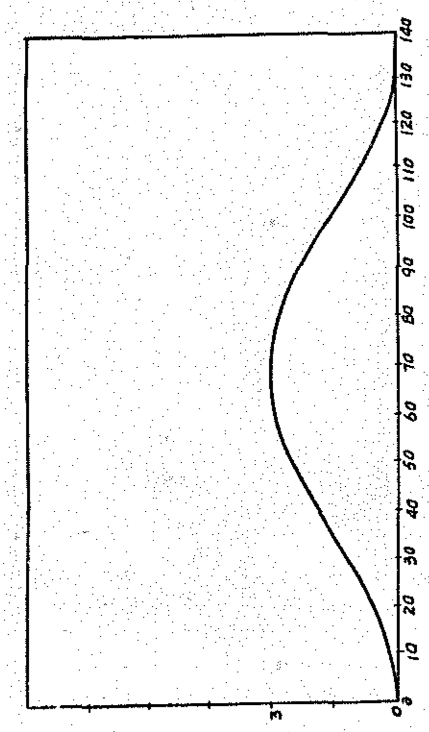
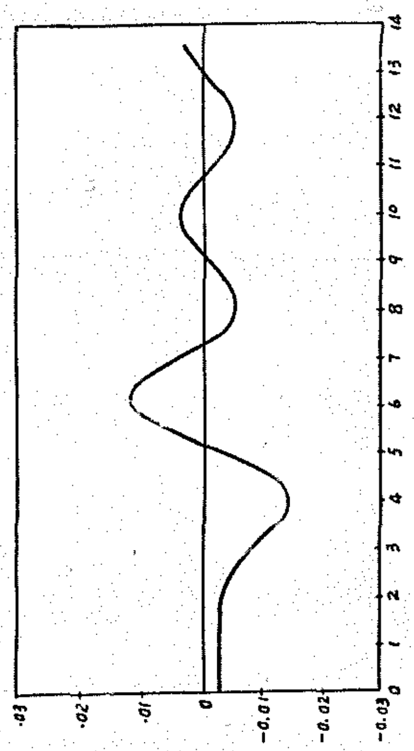


Fig.7



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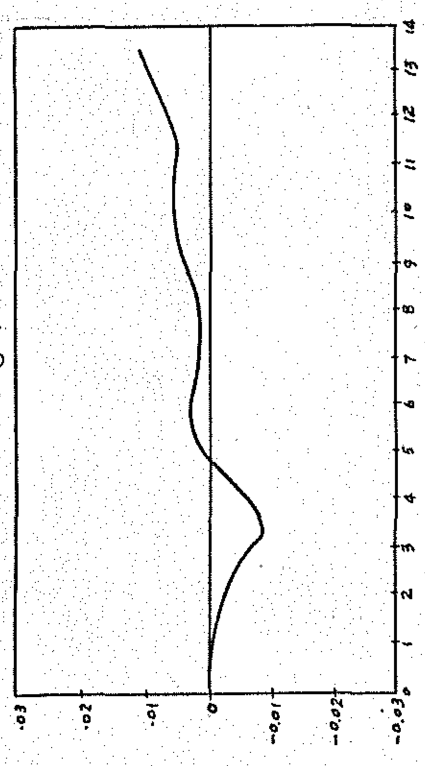

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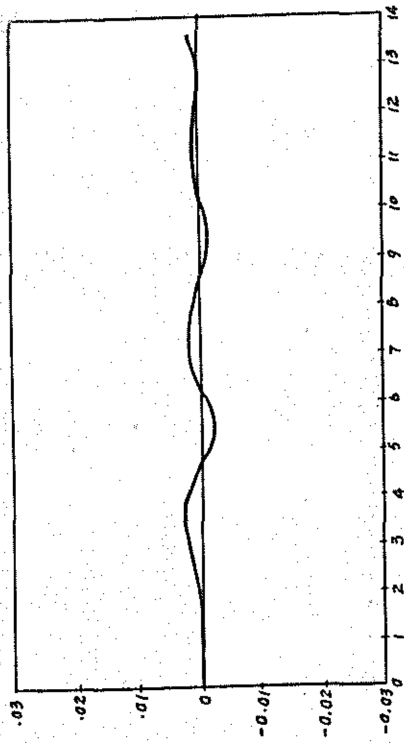

Fig.10

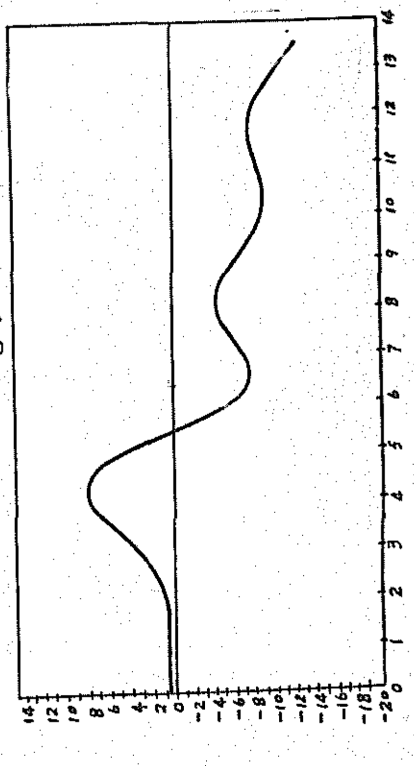

Fig.11

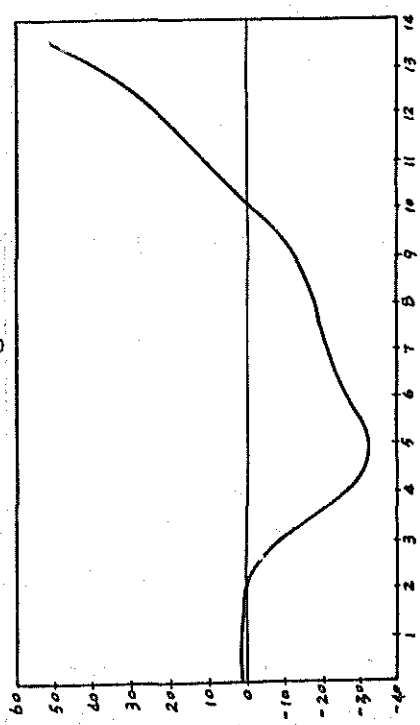

Fig.12

Fig.7 Gust range
8 The response of vertical velocity
9 The response of roll angular velocity
10 The response of pitch angular velocity
11 The response of roll angle
12 The response of pitch angle

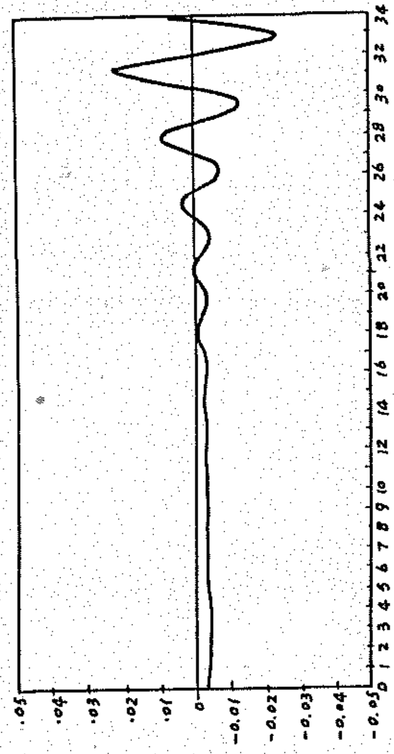

Fig.14

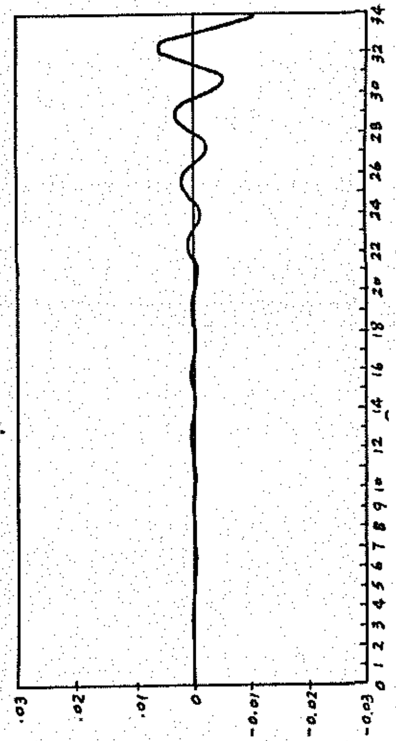

Fig.16

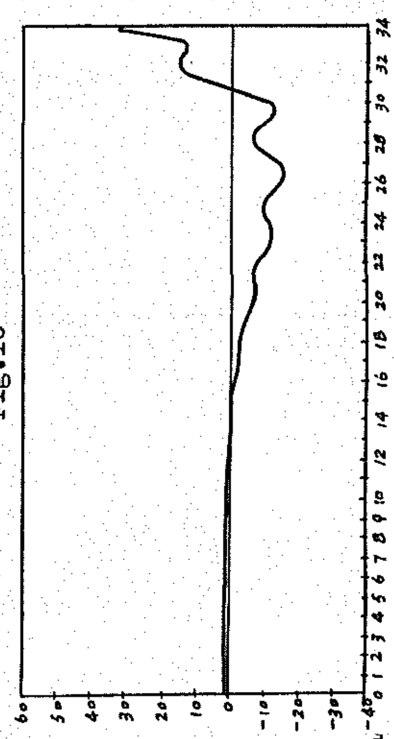

Fig.18

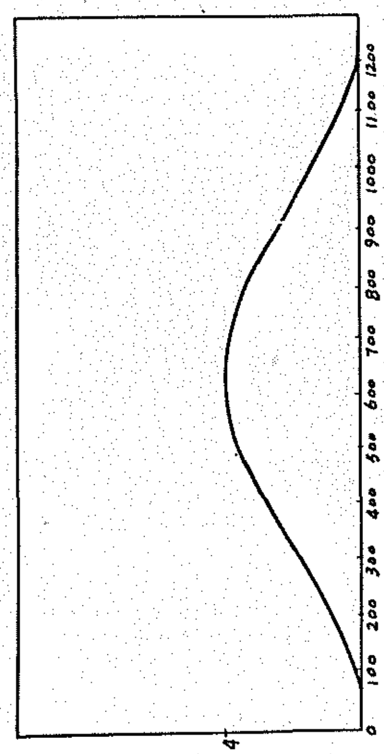

Fig.13

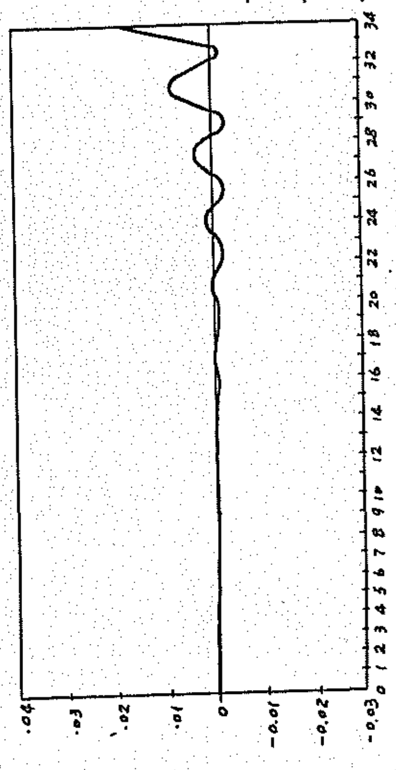

Fig.15

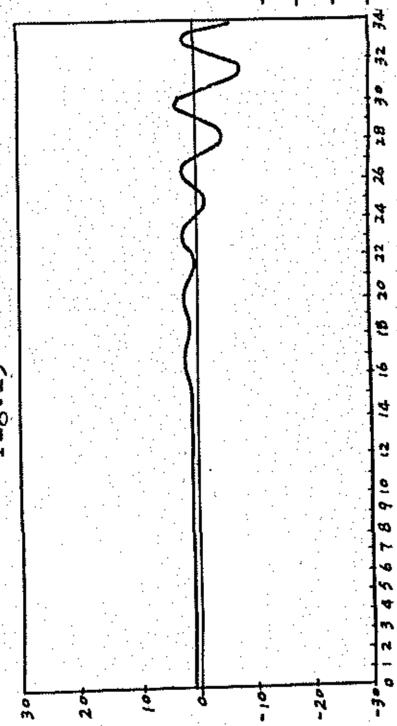

Fig.17

Fig.13 Gust range
14 The response of vertical velocity
15 The response of roll angular velocity
16 The response of pitch angular velocity
17 The response of roll angle
18 The response of pitch angle

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