SOME DYNAMIC PROBLEMS IN DESIGN OF AIRCRAFT LANDING GEAR

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Abstract

This paper deals with the influence of initial pressure in the air-oil shock absorber of landing gear on the lateral inertial load of main structure due to the dynamic response to the roughness of runway in both vertical and lateral directions, aiming at to clarify some specious concepts, such as the advantage of so-called "soft filling" to the fatigue load spectrum, or the superior effect of shortening the struct to reduce the lateral bending moment of struct.

This paper also deals the influence of dynamic properties of the wheel with pneumatic tyre, i. e. the rolling relaxation length of the tyre, the longitudinal stiffness of the tyre, the inertial moment of the wheels etc. on the load history during the landing impact. It is concluded that these factors may have significant influence on the relation between the maximum horizontal load point and the maximum vertical load point, but little influence on the magnitude of the load peak; on the other hand , the different mechanical models have significant influence on the maximum load point in the lower part of struct, but rather little influence on the load history in the upper part of struct.

This conclusion is important for specifying the fatigue load spectrum in landing gear design. Some numerical results are shown to make a brief comfirmation.

1. Introduction

Landing gear is one of the main sources of troubles or accidents during the flight test in development of an aircraft or during its service. Sufficient consideration of the influence of various structural factors or others on dynamic response in landing gear design, and reasonable selection of design parameters, are very important to improve the takeoff or landing performance of an aircraft in order to reduce the impact load and fatigue load, therefore to lighten the structural weight or to increase the reliability of landing gear system.

This paper summarizes a part of the author's experience about the dynamic design of landing gear. The following two points are emphasised.

1. The influence of the initial internal pressure and the damping coefficient of the air-oil shock absorber on the lateral inertial load due to dynamic response to the roughness of run way in both vertical and lateral directions is discussed , aiming at to clarify some specious concepts of some technicians, such as the advantage of so-called " soft filling" (i. e. to reduce the initial internal pressure in air-oil chamber) to the fatigue load spectrum, or the superior effect of shortening struct to reduce the lateral bending moment. The results, based both on the dynamic analysis and from the records of measurement in flight test, have shown the so-called " soft filling" will increase not only the vertical dynamic load but also the lateral dynamic load, because the disadvantageous effect of increasing stiffness of the struct is superior to the advantageous effect of shortening the struct. It should be noticed that in order to balance the same aircraft weight , to reduce the initial pressure will increase the stiffness of shock absorber but not soften it, that is adverse to the case for tyre. On the other hand , to shorten the struct will also increase the lateral stiffness of struct, and to increase the stiffness will worsen the dynamic response.

2. The influence of dynamic preperties of the wheel with pneumatic tyre, i. e. the rolling relaxation length of the tyre, the longitudinal stiffness of the tyre, the inertial moment of the wheels, the forward velocity of the aircraft etc. on the load history during the landing impact. It is concluded that these parameters may have significant influence on the relation between the maximum horizontal load point and the maximum vertical load point, but little influence on the magnitude of the load peak; on the other hand, the different mechanical models adopted in the analysis have significant influence on the maximum load point in the lower part of struct, but rather little influence on the load history in the upper part of struct. It should be emphasised that in the analysis of rolling-up wheel and spring-back struct the local deformation of tyre and its derivatives and

their corresponding forces should be considered.

The author has introduced a numerical procedure to calculate the dynamic response, emphasising the above-mentioned consideration. The procedure can cover various structural types of landing gear. The results are shown to make a brief confirmation of the argumentation.

The conclusions obtained are important for specifying the fatigue load spectrum in landing gear design. It should be pointed out that some prescriptions in relative items in existing requirements or regulations are not satisfactory, where the ratio between the maximum vertical load and the proposed simulateneous maximum horizontal load is taken roughly as a fixed value or estimated within a given range.

2. The Discussion of "Soft-filling"

The dynamic equation of a running airplane is

$$[M]\{\ddot{q}\}+[C]\{\dot{q}-\dot{q}_a\}+[K]\{q-q_a\}=0 \tag{1}$$

where the boundary conditions are displacements but not forces. The author has compiled a versatile computational program, in which the degrees of freedom can be taken arbitrarily. However, here what we are concerned to is only a conventional dynamic problem, so we will not go into every detail of this procedure. What we will put emphasis on are only the influences of " soft filling" on the dynamic response, aiming to clarify which tendency is superior, the advantageous one or the disadvantageous one. The former is caused by shortening the struct, and the latter is caused by stiffening the shock absorber, both due to the "soft filling". For simplicity in explanation of the problem, we ignore the elastic deformation of the airframe, that is reasonable for small or moderate aircraft, and does not change the essential conclusion for general case. Furthermore we discuss only the antisymmetrical movement, i. e. the lateral displacement and the rolling rotation, because the answer of the effect of "soft filling " on symmetrical vertical movement is apparent , as is well known.

In this case the concerned parameters in equation (1) are:

$q_1 = z$ —— the lateral direction
$q_2 = r_x$ —— the rolling retation
q_a —— prescribed movement boundary condition
$M_{12} = MH_G$ —— the moment of mass
$H_G = H_0 - DH$ —— the height of C. G. (for vertical struct)
DH ——the precompression of shock absorber (due to the weight)
C_{12} , C_{22}—— probably varies with DH
K_{11} , K_{22} —— varies with DH, the formulas are deduced as below.

The static force due to the compression of air in shock damper is

$$P=\frac{p_0A}{\left(1-\frac{AS}{V_0}\right)^n}=\frac{p_0A}{\left(1-\frac{S}{L_0}\right)^n} \tag{2}$$

and then

$$S_0=\left[1-\left(\frac{p_0A}{P_0}\right)^{\frac{1}{n}}\right]L_0$$

where

p_0 —— initial air pressure
A —— the cross-sectional area of air-oil chamber
V_0 —— the initial volume of air
S —— piston travel
S_0 —— the precompression travel
P_0 —— static load due to the weight of aircraft
L_0 —— the initial length of air chamber
$n = 1.2 - 1.4$ —— the delivery exponent of air

so that

$$K_s=\frac{dP}{dS}=\frac{np_0A}{\left(1-\frac{S_0}{L_0}\right)^{n+1}L_0} \tag{3}$$

$$\frac{K_{s1}}{K_{s2}}=\frac{p_{01}}{p_{02}}\frac{\left(1-\frac{S_{02}}{L_0}\right)^{n+1}}{\left(1-\frac{S_{01}}{L_0}\right)^{n+1}}$$

$$=\left(\frac{p_{02}}{p_{01}}\right)^{\frac{1}{n}}$$

For a vertical struct,

$P_0 = W/2$
$K_y = 1/(1/K_s + 1/n_wK_{tr})$
$K_{22} = K_yB^2/2$

where

W —— the weight of aircraft
n_W —— the number of wheels of one main struct
K_{tr}—— the radial stiffness of tyre
B —— the interval between two main structs

The oil damping force on the piston is

$$P_h=\frac{\dot{S}}{|\dot{S}|}\left(\frac{1}{2}\rho\frac{A^3}{C_d^2A_h^2}\right)\dot{S}^2$$

where

ρ —— the density of oil
C_d —— the discharge coefficient
A_h ——the area of oil hole , probably changable with S.

The damping force is a nonlinear item. It is usally linearized by some equivalent condition. The range of dimensionless damping coefficient is taken from 0. 5 to 2. 0 in our numerical examples.

The forces can be obtained after solving equation (1):

$$\{F\} = -[C]\{\dot{q}-\dot{q}_a\} - [K]\{q-q_a\}$$

Using the concerned data of a civil airplane, we have obtained the numerical results by the program, as shown in figure 1 to figure 8. Where the parameters are shown in dimensionless;

(1) The abscissa R_f denotes the ratio of exciting frequency to one representative inherent frequency;

(2) The ordinates DX, DY denote the relative dynamic magnifying factors corresponding to lateral movement and rolling movement respectively, and the latter is caused by antisymmetrical vertical movement boundary condition of two main landing gears;

(3) The parameter R_p denotes the ratio of *initial* pressure, *which reflects the amount of* precompression, but adversely in direction.

It can be concluded from the figures that to reduce the initial pressure results in increasing the dynamic load both for lateral excitation and antisymmetrical vertical (or rolling) excitation, just like in the case of symmetrical vertical excitation. That shows the disadvantageous effect of increasing stiffness of the struct is superior to the advantageous effect of shortening the struct. Therefore it is impossible to improve the fatigue life by reducing the initial pressure in shock absorber for an existing aircraft. Only the lateral load of landing gear will be reduced by "soft filling" when the aircraft turns at a low running speed, but it is not the important item in fatigue load spectrum, and anyhow the turning speed can be controlled artificially by the pilot.

3. The Influence of Relaxation Property of Tyre

The dynamic equation of a landing gear during its impact on ground is

$$M\ddot{X} + \frac{\partial M}{\partial X}\dot{X}^2 + C\dot{X} + KX = F \qquad (4)$$

which is a nonlinear one and can only be solved by numerical method. As usual we use the Runge-Kutta Method. In our program considered are not only the deformation of the landing gear structure and airframe, but also the local deformation of the rolling tyre. The emphasis is put on the comparison of different models discribing the relation between the resistant force on the ground and the relative sliding velocity of the tyre.

We discuss two different models in the following.

(1) The relation usually adopted in literatures is

$$F_x = dF_y$$

where

F_x —— rolling friction force
F_y —— vertical force
d —— rolling friction coefficient

The friction coefficient is decided by an empiric formula, for example:

$$d = 5.62V_s \qquad (-0.13 < V_s < 0.13)$$
$$d = 0.77 - 0.32V_s \qquad (0.13 < V_s < 1.0)$$

where

V_s —— ratio of sliding velocity, denoting

$$V_s = (V_w - r_e w)/V_w$$

and

V_w —— forward velocity of wheel
w —— rotative velocity of wheel
r_e —— effective radius of deformed tyre

The forward velocity of wheel consists of the running velocity of aircraft and the deformation velocity of structure.

(2) Considering the local deformation and balance of the wheel with pneumatic tyre, The equations in addition to equation (4) are

$$m_{wt}\ddot{x}_w + m_t\ddot{x}_t + c_t\dot{x}_t + k_t x_t = F_x \qquad (V_s = 0)$$
$$c_t r_e \dot{x}_t + k_t r_e x_t - (d_r r_e - x_t)F_y = J_w \dot{w}$$
$$V_s = V_w - r_e w - \dot{x}_t - V_w x_t / L_t$$
$$V_s > 0 \qquad (F_x = d_0 F_y)$$
$$V_s = 0 \qquad (ABS(F_x) < d_0 F_y)$$
$$V_s < 0 \qquad (F_x = -d_0 F_y)$$

where

subscript w —— wheel
subscript t —— tyre
d_r —— *rolling resistant coefficient*
d_0 —— static friction coefficient
L_t —— the longitudinal relaxation length of tyre

For simplicity we may take

$$m_{wt} = m_t \ll m_w$$
$$r_e = r_0$$
$$c_t = 0$$

The calculation has been done for a civil airplane by use of both models. Figures 9, 10 show the results from model (1), (2) respectively, and figures 11, 12 show the comparison of the load in lower part and upper part of the struct respectively.

The symbols in the figures are

SN —— vertical load applied to tyre (Fy)
SP —— horizontal load applied to tyre (F_x)
PH —— bending load in upper part of struct

It can be concluded from these figures that the different models have significant influence on the maximum load point in the lower part of struct, but rather little influence on the load history in the upper part of struct and fuselage. So that whether a certain model is suitable depends on which part of structure is in question.

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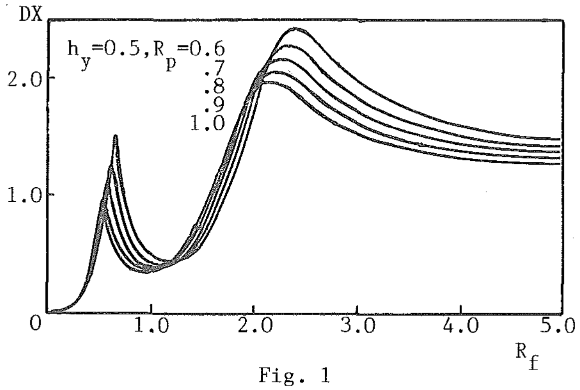
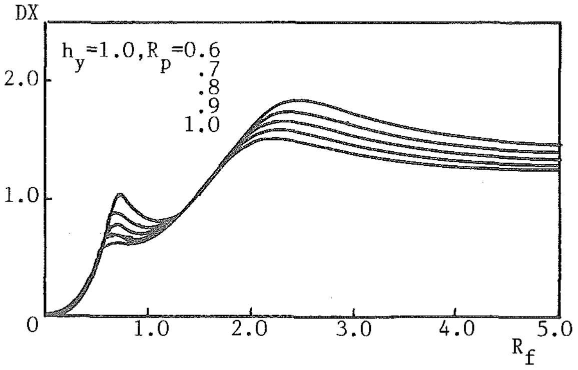


Fig. 1



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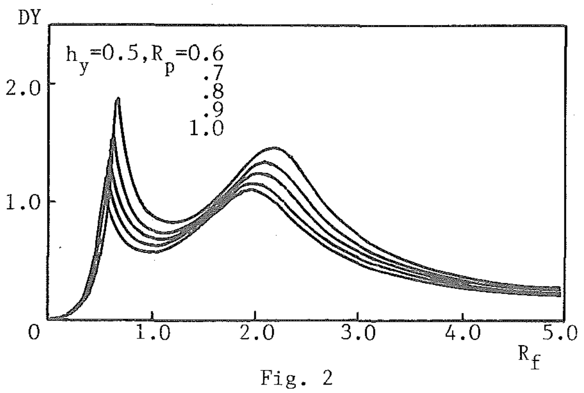

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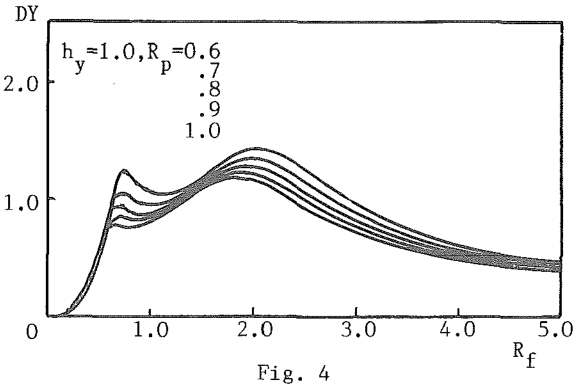

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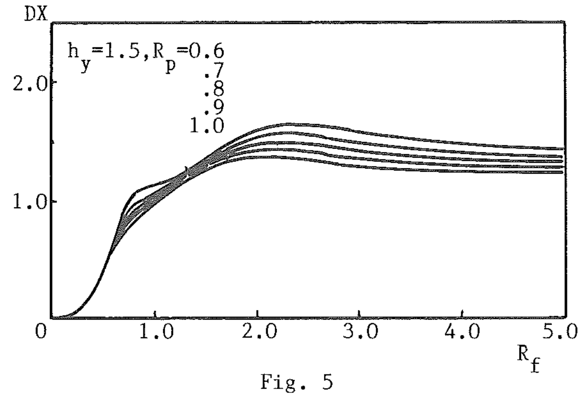

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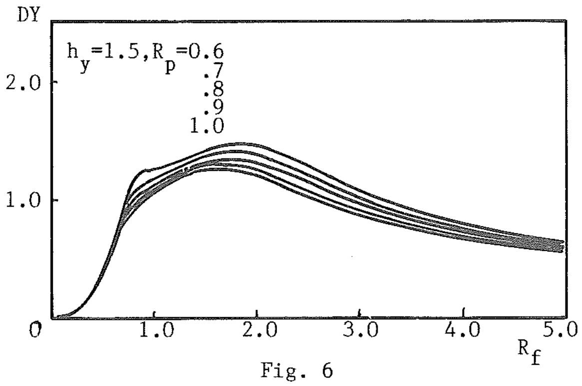

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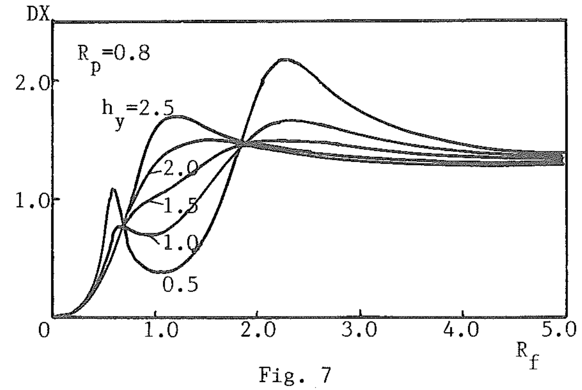


Fig. 7

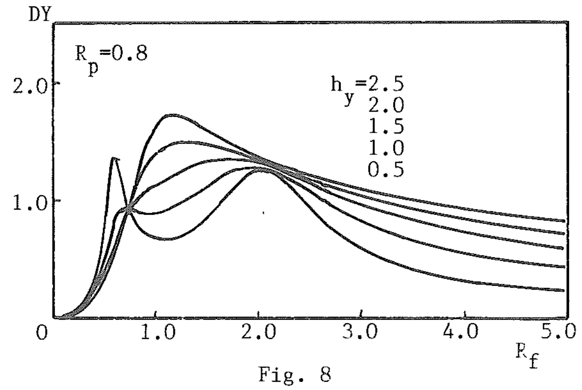


Fig. 8

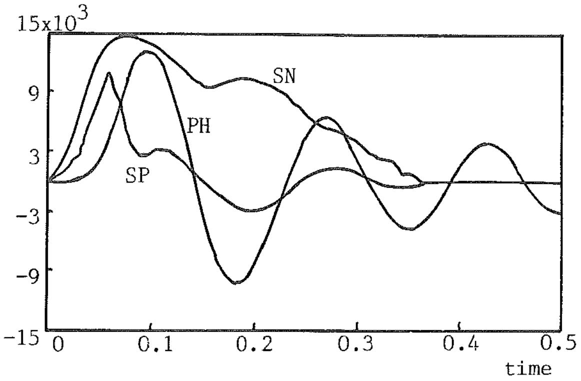


Fig. 9

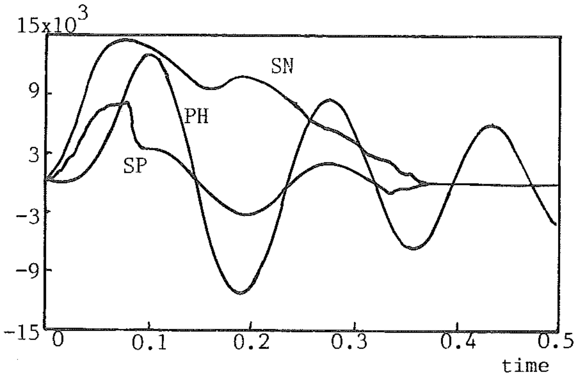
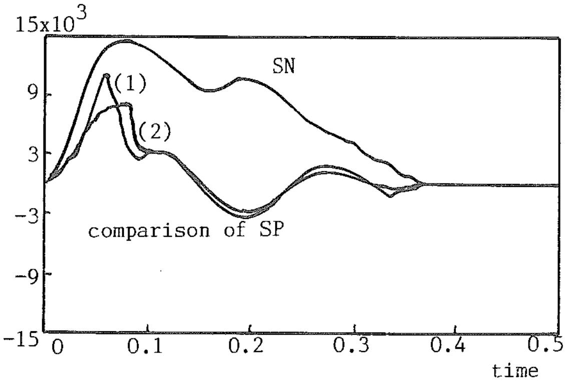


Fig. 10



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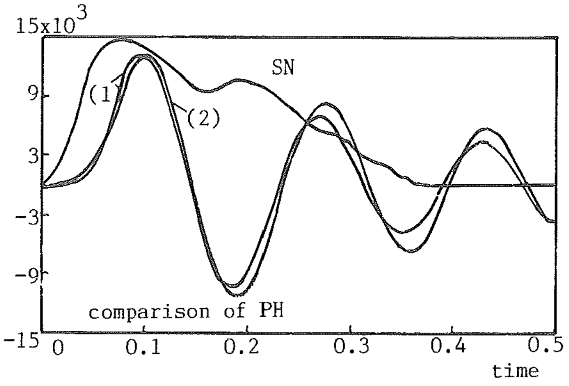

Fig. 12