Engineering Notes

ENGINEERING NOTES are short manuscripts describing new developments or important results of a preliminary nature. These Notes cannot exceed 6 manuscript pages and 3 figures; a page of text may be substituted for a figure and vice versa. After informal review by the editors, they may be published within a few months of the date of receipt. Style requirements are the same as for regular contributions (see inside back cover).

Comparison of Linear and Nonlinear Dampers for Landing Gears

C. Venkatesan*
Indian Institute of Science, Bangalore, India

Nomenclature

A_a = pneumatic area
A_h = hydraulic area
C_L, C_{NL} = damping constants for linear and nonlinear dampers, respectively
F_a = pneumatic force
F_d = damping force
K_T = tire stiffness
$K_{z\,max.}$ = peak ground load
M_1 = upper mass (aircraft)
M_2 = lower mass (wheel unit)
n = polytropic constant
P_{a0} = air pressure in the upper chamber for fully extended strut
s = shock absorber stroke
$\dot{s}$ = stroke velocity
$s_{max.}$ = maximum shock absorber stroke
V_0 = air volume for the fully extended strut
V_d = design descent velocity
$\zeta_{max.}$ = maximum shock absorber stroke allowable

Introduction

In a study on the use of linear dampers in aircraft landing gears, Hall[1] has concluded that for struts having the same maximum stroke and for identical conditions of touchdown, the linear damper can give a 10% reduction in the peak ground load as compared with a conventional nonlinear orifice damper. In his computations, Hall compared the landing gear with a nonlinear orifice damper considered by Milwitsky and Cook[2] with an equivalent landing gear having a linear damper. It is felt that a better estimate of the relative merits of the two dampers will be obtained if their performances are compared under optimum conditions. For a given weight of aircraft and descent velocity, the parameters preload and linear or nonlinear damping, governing the performance of the landing gear, are optimized so as to obtain the minimum peak ground load with a constraint on the maximum stroke. It is shown that if the maximum strokes are kept identical, the peak ground loads are nearly the same for both of the landing gears. However, if the landing gears are optimized for a given velocity of descent and then used at lower or higher velocities of descent, the nonlinear orifice damper shows a better performance, since the peak ground loads obtained are lower than those obtained with a linear damper. It is noted from the literature[3,4] that the maximum number of landings occur at 2-3 fps descent velocity. From the fatigue damage point of view also, the nonlinear damper gives a better performance.

Received Nov. 28, 1977; revision received April 18, 1978.
Index categories: Landing Dynamics; Subsystem Design.
*Research Student, School of Automation.

Mathematical Model

Figure 1 shows the models of the landing gears used in the present study. The nonlinear air spring is governed by the relation

$$F_a = P_{a0} A_a \left(\frac{V_0}{V_0 - A_a s} \right)^n \tag{1}$$

The force-velocity relation of the damper can be expressed as

$$F_d = C_{NL} \dot{s} \, |\dot{s}| \qquad \text{(Nonlinear)} \tag{2}$$

or

$$F_d = C_L \dot{s} \qquad \text{(Linear)} \tag{3}$$

The mathematical model for the calculation of ground load is based on the analysis of Yff.[5] Optimization, by Powell's direct search technique,[6] is performed by varying the preload and damping to minimize the peak ground load, with constraint on shock absorber stroke. For the investigation, values considered for M_1, M_2, and K_T are, respectively, 2411 lb, 131 lb, and 18,500 lb/ft. The assumptions made are 1) the velocity of descent is uniform, 2) the forward velocity of the aircraft is zero, and 3) the force-deflection characteristic of the tire is linear. Behavior of the system is studied at three different velocities of descent, namely, 3, 8.86, and 11 fps.

Results

Table 1 shows a comparison of the results obtained in the present study with those of Hall[1] for both the linear and nonlinear dampers. For each velocity of descent, the table shows values of the landing gear parameters, the peak ground load and the maximum stroke for three cases: 1) the results obtained by Hall,[1] 2) the optimum values obtained in the present study with no restrictions on the maximum stroke, and 3) the optimum values obtained by constraining the maximum stroke to be nearly the same as that obtained by Hall.

A study of this table shows that by optimizing the configurations, the following performance gains (compared with the basic design used by Hall[1]) are obtainable.

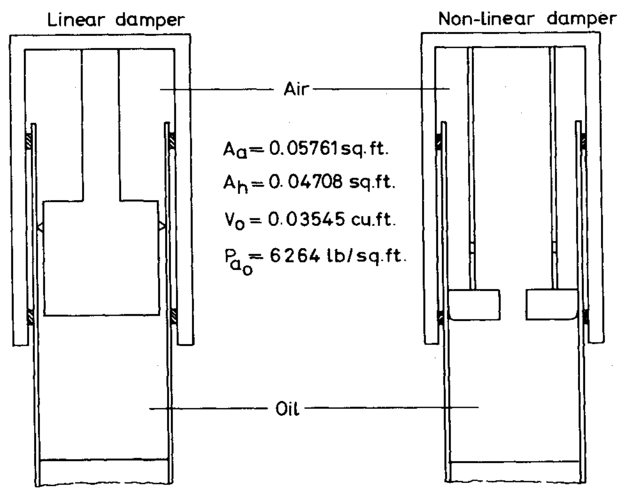

Fig. 1 Shock absorbers.

Table 1 Comparison of dampers under optimum conditions

Velocity of descent	Quantity	Linear damper a	Linear damper b	Linear damper c	Nonlinear damper a	Nonlinear damper b	Nonlinear damper c
				$\zeta_{max} \leq 0.547$			$\zeta_{max} \leq 0.547$
11 fps	C_L or C_{NL}[d]	1095	912	915	346.5	177	180
	P_{a0} (lb)	360.8	360.8	400	360.8	360.8	460
	K_{zmax} (lb)	7755	7228	7246	8668	7454	7516
	s_{max} (ft)	0.548	0.551	0.546	0.547	0.559	0.546
				$\zeta_{max} \leq 0.51$			$\zeta_{max} \leq 0.51$
8.86 fps	C_L or C_{NL}	1095	702	695	346.5	147	150
	P_{a0}	360.8	360.8	510	360.8	360.8	550
	K_{zmax}	6275	5185	5299	6682	5313	5498
	s_{max}	0.51	0.532	0.51	0.51	0.538	0.51
				$\zeta_{max} \leq 0.19$			$\zeta_{max} \leq 0.19$
3 fps	C_L or C_{NL}	1095	125	90	346.5	40	30
	P_{a0}	360.8	360.8	1060	360.8	360.8	1100
	K_{zmax}	2255	1286	1919	1802	1237	1926
	s_{max}	0.181	0.358	0.189	0.248	0.368	0.187

a = Hall's values and results.
b = optimum damping : no restriction on the stroke but preload held constant.
c = optimum damping and preload : restriction on the maximum stroke.
[d] C_L, C_{NL} = damping constants corresponding to linear and nonlinear cases : C_L in lb/(ft/s), C_{NL} in lb/(ft/s)^2.

Table 2 Performance of dampers

	Linear damper				Nonlinear damper			
Velocity of descent, fps	C_L, lb/(ft/s)	P_{a0}, lb	$K_{z\,max}$, lb	s_{max}, ft	C_{NL}, lb/(ft/s)^2	P_{a0}, lb	$K_{z\,max}$, lb	s_{max}, ft
11.0[a]	915	400	7246	0.546	180	460	7516	0.546
8.86			5863	0.516			5722	0.521
5.0			3407	0.338			2807	0.398
3.0			2142	0.192			1565	0.261
2.0			1510	0.115			1092	0.166
8.86[a]	695	510	5299	0.51	150	550	5498	0.51
11.0			8004	0.538			7888	0.537
5.0			3131	0.351			2719	0.388
3.0			2018	0.199			1575	0.249
2.0			1463	0.116			1155	0.152

[a] Damping and preload optimized at that descent velocity.

1) By varying the damping only and keeping the preload constant, the peak ground load can be reduced by values ranging from approximately 43% ($V_d = 3$ fps) to 7% ($V_d = 11$ fps) in the case of the linear damper, when there is no restriction on the maximum stroke, which however increases between 98% ($V_d = 3$ fps) to 0.5% ($V_d = 11$ fps). For the nonlinear damper, reductions in the peak ground load vary from 31.4% (at $V_d = 3$ fps) to 14% (at $V_d = 11$ fps), while the maximum stroke shows increases between 48.4% (at $V_d = 3$ fps) and 2% (at $V_d = 11$ fps).

2) However, if we restrict the maximum stroke to be the same as that obtained by Hall, it is still possible to obtain reductions in the peak ground load. Columns (c) of Table 1 show that, it is possible to obtain reductions in the peak ground load varying from 15% (at $V_d = 3$ fps) to 6.7% (at $V_d = 11$ fps) for the linear damper. For the nonlinear damper, the changes range from a 6.9% increment (at $V_d = 3$ fps) to a 13% reduction (at $V_d = 11$ fps).

In his comparison of the (nonoptimized) linear and nonlinear dampers, Hall[1] found that the linear damper has a better performance compared with the nonlinear damper since the former results in a reduced peak ground load at higher descent velocities, there being a reduction of 10.5% for 11 fps and 6.1% for 8.86 fps, while the peak ground load increases by 25% at 3 fps.

The present study also shows a similar trend. For the gears optimized by restricting the maximum stroke to be the same as that obtained by Hall, the linear damper shows a better performance compared with the nonlinear damper. In this case, however, the differences are smaller than in the case of the nonoptimized gears, the linear damper showing a reduction of 3.6% at 11 fps and 3.9% at 8.86 fps.

Table 2 shows a comparison of the peak ground loads obtained by using the linear and nonlinear landing gears which have been designed to give optimum performance at two different descent velocities, viz: 11 fps and 8.86 fps. For landing gears optimized at 11 fps, having identical strokes, but used at lower descent velocities, the shock absorber employing a linear damper gives a larger peak ground load as compared with that using the nonlinear damper at all velocities except at the optimized velocity of descent (V_d). The difference in the peak load expressed as a percentage of the peak load for the linear type increases as the descent velocity decreases.

Similarly, the gears optimized at 8.86 fps, but used at higher or lower descent velocities, offer a reduction in the peak ground load for the nonlinear case. The percentage reduction is more when the descent velocity is far different from the design descent velocity.

Conclusion

A comparison of the performances of landing gears using linear and nonlinear dampers is effective on optimizing preload and damping for minimum peak ground load. However, when the gears have been optimized for a relatively high velocity of descent (as is usual in practice) and then used at lower descent velocities, the penalty involved in the linear damper is much higher. Since statistically it is known that most of the landings occur at low descent velocities, the use of a nonlinear orifice damper in the shock absorber is preferred from the fatigue damage point of view. Viewing this in a global way, the conventional nonlinear orifice damper seems to be better than a linear damper. As the linear damper design given by Hall needs special fabrication, it appears that an optimized nonlinear orifice damper offers simplicity in design and better performance.

Acknowledgment

The author thanks A.K. Rao and R. Krishnan of the Indian Institute of Science, Bangalore, and R. Sankaranarayanan and V.T. Nagaraj of Hindustan Aeronautics Limited, Bangalore, for their encouragement and guidance in doing this work.

References

[1] Hall, H., "Some Theoretical Studies Concerning Oleo Damping Characteristics," Ministry of Technology, British Aeronautical Research Council, Current Papers, C.P. No. 951, 1967.

[2] Milwitzky, B. and Cook, F.E., "Analysis of Landing Gear Behavior," NACA TR 1154 (TN 2755), 1953.

[3] Andrews, W., Carter, A.L., Horsefall, W., and Troke, R.W., "Fatigue Test and Analysis of the F-100 Landing Gear," North American Rockwell Corporation, NA-69-535, Aug. 1969.

[4] "Airplane Strength and Rigidity: Reliability Requirements," MIL-A-8866 (ASG), May 1960.

[5] Yff, J., "Analysis of Dynamic Aircraft Landing Loads and a Proposal for Rational Design Landing Load Requirements," Ph.D. Thesis, Technische Hogeschool, Delft, June 1972.

[6] Himmelblau, D.M., *Applied Non-linear Programming,* McGraw-Hill, New York, 1972.

Computation of Two-Dimensional Potential Flow Using Elementary Vortex Distributions

Pradeep Raj* and Robin B. Gray†
Georgia Institute of Technology, Atlanta, Ga.

Nomenclature

A_{ij} = induced velocity influence coefficient
c = chord
C_p = pressure coefficient
N = number of elements on the surface
$\boldsymbol{n}$ = unit vector normal to the surface
V_∞ = freestream speed
x = chordwise coordinate
z = vertical coordinate (normal to x)
α = angle of attack
γ = intensity of elementary vortex distribution

Introduction

THE integral equation formulation using surface singularity distributions as suggested by Lamb[1] is a commonly used procedure for inviscid, incompressible flow computation on arbitrarily shaped bodies. Giesing,[2] Hess and Smith,[3] and Hess[4] utilized the source as a surface singularity; the vorticity distribution is superimposed to provide the circulation for lifting bodies. Martensen[5] and Jacob and Riegels[6] developed a procedure based on the streamfunction and used only surface-vorticity distributions. The boundary condition that the tangential velocity be zero on the inside of the profile curve leads to a Fredholm integral equation of the second kind similar to the one resulting from source distributions. Mavriplis[7] extended the same approach to single- and multielement airfoils and indicated that the surface-vorticity method may be more accurate than the surface-source method.[8] In the opinion of the authors, an important additional advantage of using vorticity is that the velocity distribution is obtained *directly* as the solution of the integral equation. Stevens et al.[9] and Woodward[10] employ vorticity as the surface singularity and implement normal-velocity boundary conditions. The profile curve of the body is approximated by an inscribed polygon composed of straight-line elements over each of which the vorticity is assumed to vary linearly. Hess[11,12] shows that this is a mathematically inconsistent higher-order implementation. His analysis indicates that the polynomial expressing the element shape should be one degree higher than that defining the surface singularity density, namely: straight-line element, constant density; parabolic element, linear distribution.

In the present investigation velocity and pressure distributions are computed on the surface of a circular cylinder and NACA basic thickness form airfoils. A second-order equation defines the profile curve of the cylinder, and the bounding surface of the airfoil is analytically represented by a higher-order expression given in Ref. 13. Surface-vorticity method coupled with zero-normal-velocity boundary condition gives a Fredholm integral equation of the first kind. An elementary vortex distribution technique which utilizes a linear distribution on each element is employed to approximate the integral equation by a set of linear algebraic equations. The resulting coefficient matrix has diagonal entries larger than other entries which is a crucial factor in numerical solution. The results presented in this note provide the detailed input vorticity distribution required by an iterative method to determine the three-dimensional flow on thick wing tips.[14]

Mathematical Model

The bounding surface is divided into a finite number of small elements each containing an unknown vorticity distribution. A simple model for the latter consists of a continuous, piecewise linear distribution with respect to the chord. All linear elementary distributions are equivalent to a set of overlapping triangular distributions. Each triangle spanning two successive surface elements is called a regular elementary vortex distribution (EVD).[15] Only one unknown, namely the vortex intensity value, γ_j, at the apex of the triangle is required for each EVD. The unknown strengths are determined by solving the system of equations

$$\sum_{j=1}^{N} A_{ij}\gamma_j = \boldsymbol{V}_\infty \cdot \boldsymbol{n} \qquad (i=1,2,\ldots,N)$$

where A_{ij}, the induced velocity influence coefficient, is the normal component of induced velocity at the ith control point due to the jth EVD of unit strength. For the uniqueness of the solutions, an auxiliary condition of the total circulation around the body is specified or determined by the Kutta condition which requires zero circulation around a body for nonlifting flows. Use of symmetry about a diametric plane for the circular cylinder and the chordwise symmetry for the airfoil implicitly imposes zero circulation for nonlifting flows while simultaneously reducing the order of the coefficient matrix A. However, this also results in one more control point than the EVD stations on the surface. This problem is remedied by replacing the vorticity distribution of the surface element next to the forward stagnation point by one

Received May 25, 1978.

Index categories: Aerodynamics; Computational Methods.

*Graduate Research Assistant; presently Assistant Professor, Dept. of Aerospace Engineering, Iowa State University, Ames, Iowa. Member AIAA.

†Regents' Professor and Associate Director, School of Aerospace Engineering. Member AIAA.