ABSTRACT

The deformation of the flexible structure under aerodynamic loads at subsonic high speeds due to the aeroelasticity phenomenon was not considered in aircraft design until recently. Further studies showed that the deformation might lead to structure instability and unsafe operation.

In this study, an aircraft already in operation, from the subsonic high speed group, was investigated for the effect of these aeroelasticity phenomena. The design specification data of the study Aircraft was used through reverse engineering to analytically calculate the aerodynamic loads & review the effects of the aeroelasticity on the Aircraft wing at ten speeds within the n-V diagram limits.

The aerodynamic loads were investigated for the effect of trim. It was found that the Lift along the wing span increased under the trim condition. This subsequently increased the wing forces and moments

The computed divergence and flutter speeds when compared with the design speeds agreed within 97% to 95% respectively.

The wing structure stability analysis showed a stable structure within the n-V limits, but the skin near the wing tip has a safety margin of 30 % only. The skin safety margin decreased to 12% when the maximum limit speed was increased by 5%. It is believed that the Aircraft skin is a problem and might lead to unsafe situation.

It is recommended to address this problem at current operation and future a/c. At the current operation level to make the pilots more aware of the situation through and notices to avoid operation near the maximum limit speed. The notices can be through placards or retrofit of an oral warning system. At the redesign level to include the outcome of the researches in progress and use of the smart material.

ملخص البحث

مؤخراً كنتيجة لظاهرة للمرونة الهوائية اضحت تشوهات الهياكل المرنة بسبب القوى الايروديناميكية عند السرعات العالية دون الصوتية تؤخذ بالاعتبار عند تصميم الطائرات. اوضحت الدراسات ان تلك التشوهات من الممكن ان تؤدى الى مشاكل تشغيلية او حوادث .

فى هذا الدراسة , تم التحقيق عن تأثيرات ظاهرة المرونة الهوايئة تحليلياً على جناح طائرة ركاب مدنية دون الصوتية موجودة فى الخدمة. استخدمت خصائص الطائرة عن طريق التصميم الهندسى العكسى للتحليل الحسابى للقوى الايروديناميكية ومعرفة تاثيرات الرفرفة والتباعد على جناح الطائرة عتد عشر سرعات مختلفة داخل المخطط الحملى.

ايضاً تم التحقيق عن تأثير الاتزان الطولى على ظاهرة المرونة الهوائية. ووجد ان الاستقرارية الطولية تتسبب بزيادة الرفع على طول الجناح وهذه الزيادة تتسبب فى زيادة القوى والعزوم على الجناح.

عند مقارنة سرعة الانفراج والرفرفة المحسوبة مع السرعات التصميمية وجدت متوافقة بنسبة 97 % و 95% على التوالى .

تحليل استقرارية الهيكلية لاجزاء الجناح توضح ان الهيكل مستقر داخل المخطط الحملى. الا ان معامل الامان على بطانة الجناح عند الطرف 30 % فقط . دراسة اثر زيادة السرعة بنسبة 5% من السرعة القصوى يوضح نقصان معامل الامان الى 12%. وذلك يعنى ان البطانة قد تسبب مشاكل تشغيلية او حوادث للطائرة.

نوصى بان يتم التعامل مع هذه المشكلة فى مستويين . المستوى الاول للطائرات الموجودة فى الخدمة , توضع تنبيهات لقائد الطائرة لكى يكون حذراً من القيادة قرب هذه الحالة و عدم الطيران بالسرعة القصوى . هذه التنبيهات يمكن ان تكون صوتية أو نظام انزار مرئ . المستوى الثانى مرحلة اعادة التصميم حيث يمكن استخدام الابحاث التى تمت واستخدام المواد الذكية

Dedication

This research is dedicated to my mother **Futheya Ahmed**. Without her love and support I would not be the person I am today, Also to my wife, for her love, support and great expectation.

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Contents

LIST OF FIGURES

Nomenclature

A_θ	Excitation force
$A_{\dot{y}}$	Damping force
A_F	Area of flange
A_{1S}	Area of Cell 1
A_{2S}	Area of Cell 2
F	The force acting on the spar flange
L	Lift force
M	Mach number
M_0	Bending moment
M_K	Torsional moments
P_{res}	Resilient force
S	Wing area
P_{in}	Inertia force
T_{YO}	Shear force
Re	Reynolds Number
W	Maximum Weight of the aircraft
GJ_k	Wing rigidity
EJ_k	Wing Stiffness
a	Lift curve slope
q	Shear flow
q_{KS}	Web shear flow
q_{K1}	Cell 1 Shear flow

q_{K2}	Cell 2 Shear flow
t	Thickness of the web
n	Load factor
h_e	Height of the web
C_L	Lift coefficient
$C_{L\max}$	Maximum lift coefficient
CC_{la}	The additional lift distribution
CC_{lb}	The basic lift distribution
C_{M0}	Zero bending moment coefficient
C_M	Bending moment coefficient
C_d	Drag coefficient
ΔC_L	The increments of lift coefficient
$\Delta C_{M_{EA}}$	The increments moment coefficient
V	Air speed
V_1	Cockpit instrument reading
V_{IAS}	Indicated Air speed
V_{CAS}	Calibrated Air speed
V_{EAS}	Equivalent Air speed
V_{TAS}	True Air speed
ΔV_c	Compressibility correction
ΔV_P	Air speed sensor position error correction
ΔV_1	Instrument error correction
$v_{\max}$	Maximum speed
V_{DIV}	Divergence speed
V_F	Critical flutter speed
K_S	Factor depending on the way of fixing the web

C_e	Effective airfoil chord
C	Airfoil chord
$\overline{C}$	Mean geometric chord
α	Angle of attack
α_{ZL}	Zero-lift Angle of attack
Λ	Sweepback angle
σ_{pt}	Ultimate stress
θ	Twisting angle
υ_1	Torsion angle per unit length of cell (1)
υ_2	Torsion angle per unit length of cell (2)
ε_1	Geometric twist angle
ε_0	Section twist angle referred to the zero lift line of airfoil section of the plane of symmetry.
τ	Shear stress
σ	Normal stress
$\tau_{\overline{CR}}$	Critical shear stress
φ_t	Reduction coefficient of skin stresses
φ_{ST}	Reduction coefficient of longitudinal stringers stress
σ_{PANEL}	Panel stresses
$\sigma_{allow\,Skin}$	Allowable Skin stresses
σ_{CR_F}	Critical stresses due to the local loss of stability of the compression flange
$\sigma_{CR_{ST}}$	Critical stresses due to the local loss of stability of the longitudinal stringers
σ_{CR_S}	Critical stresses due to the local loss of stability of the skin

σ_{CR_S}	Function of wing deformation along the span
$\varphi(y)$	Standard function
θ_0	Constant amplitude
ω	Angular frequency of the flutter
ρ	Air density
$\bar{e}$	Distance between the aerodynamic axis and the elastic axis
Δz	
a	Lift curve slop
ρ	Density
μ	Dynamic Viscosity of Air
σ	Relative density
q	Dynamic pressure
Δn	The increments of load factor
A/C	Aircraft
AAW	Active aeroelastic wing
3AS	Active aeroelastic aircraft structures
AFW	Active flexible wing
AMVT	All movable vertical tail
CS	Certification specifications - EASA