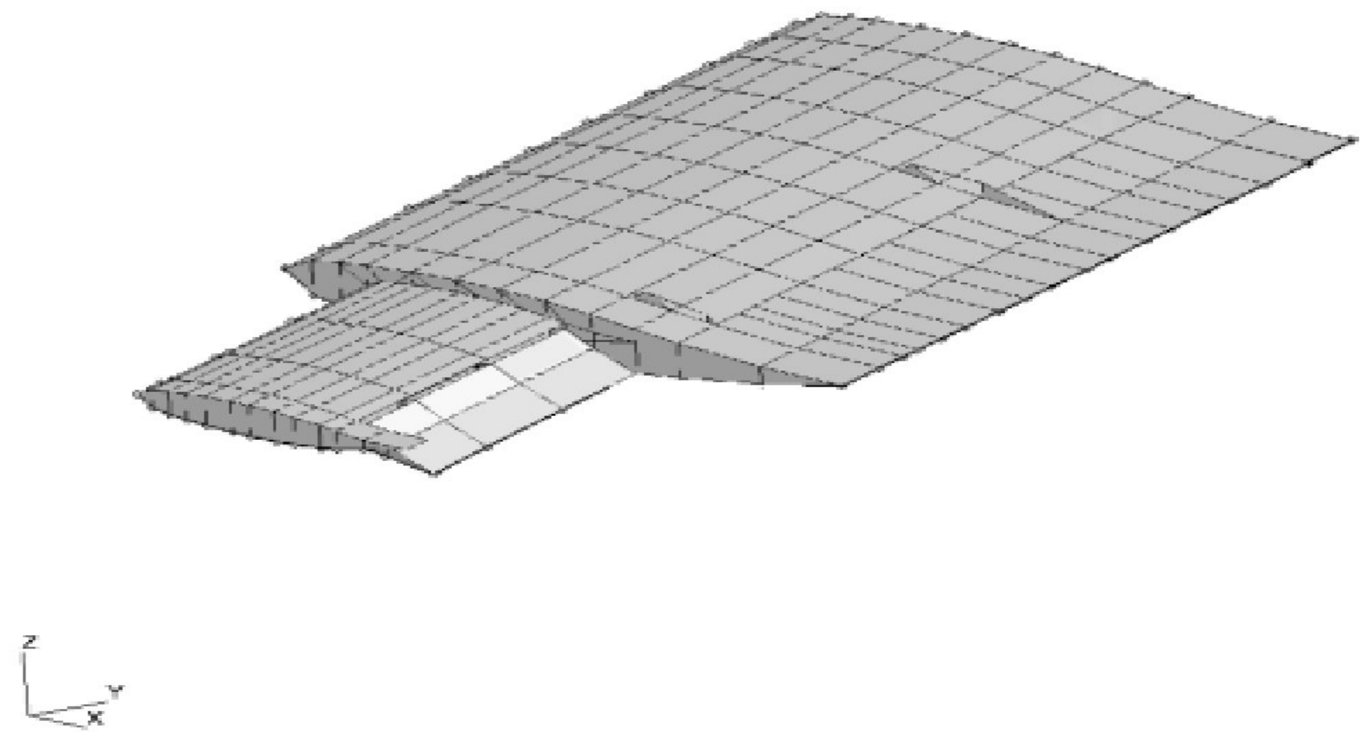
Design, Flutter and Buckling Analyses of an Adaptive Telescope Wing Configuration

HAMID RABIA, SÖREN NILSSON



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Report title

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Abstract

The objective of the presented work is to determine a feasible design concept for a telescope wing and to investigate its aeroelastic properties. As input to an overall performance estimate the added weight and the reduction in available fuel-volume is also estimated. The telescopic outer wing will be used at high altitude to increase operating range and also for start and landing. During high-speed low-level dash the outer wing will be retracted to reduce transonic drag.

This work is a part of the Adaptive Structures project at FOI.

The wing was made 20% shorter in the spanwise direction and to that the extended telescopic outer wing was added, giving the wing a 20% larger span than for the original wing. The chord of the outer wing is chosen to be 50% of the inner wing chord to fit between the wing beams when retracted.

A design concept is presented and fundamental structural strength-calculations have been performed. The aeroelastic model for analyses with the programme MSC/NASTRAN is presented. The configuration denoted Nuk-14-telescope within the project is found to have good flutter-characteristics. The buckling-characteristics of the telescopic wing is determined and compared to that of the original wing.

The telescopic wing is estimated to cause a 5% increase in structural-weight of the wing after weight optimisation. The reduction in fuel-capacity is $95kg$ per wing if the telescopic outer wing is left empty. A design containing a control-surface in the outer wing has also been analysed. The aeroelastic properties remain satisfying but the structural weight as compared to the original wing is estimated to be 10% higher.

Keywords

Aerodynamic, Elasticity, Aeroelasticity, Stability, MSC/NASTRAN, FEM, Shell Elements, beam elements

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Rapportens titel
Konstruktion, fladder och bucklings-undersökning av en adaptiv teleskop-vinge konfiguration

Sammanfattning

Målsättningen med det beskrivna arbetet är att ta fram en realisbar strukturmekanisk design och undersöka de dynamiska aeroelastiska egenskaperna för en modiferad vinge. Arbetet är en del av projektet Adaptiva Strukturer inom FOI.
Originalvingen har gjorts kortare, med i övrigt bibehållen yttre geometri. En teleskopisk ytter-vinge har föreslagits som kan fällas ut vid start och landning samt vid flygning på hög höjd.
En konstruktion för att möjliggöra att teleskopvingen skjuts in och ut har föreslagits. Ingenjörsmässiga hållfasthetsberäkningar har även genomförts.
Den analyserade vingkonfigurationen, vilken benämns nuk14-teleskop inom projektet, konstateras ha bra fladderegenskaper.
I rapporten beskrivs den aeroelastiska modell som används vid analyser med programmet MSC/NASTRAN. Modellen består av en strukturmodell beskriven med finita element av skal- och balk-typ samt en aerodynamisk panel-modell av vingar och roderytor.
Vingen har även analyserats med FEM avseende bucklingsegenskaper.
Teleskopvingen bedöms efter en tänkt viktsminimering medförren ökad strukturvikt för vingen med cirka 5% relativt originalvingen.

Nyckelord
förstudie, aeroelasticitet, fladder, roderverkan, adaptiv struktur, projektarbete

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Contents

1 Introduction

The Structural design and flutter analysis of the Nuk14 wing configuration modified with an adaptive telescope outer wing reported herein represents a part of a project at FOI denoted Adaptive Structures. The initiative to start the project was taken by the Swedish Defence Material Administration (FMV). The objective is to increase the capability at FOI to incorporate the available expertise in aeronautical disciplines in projects where multidisciplinary analysis and design are required.

We are concerned with search for a feasible structural design including determination of the classical flutter properties of the wing.

Aeroelasticity refers to the phenomena of mutual interaction of aerodynamic and structural forces. Aeroelastic analysis is the prediction of the phenomena and it's influence on the design of a wing. Flutter and divergence are examples of such phenomena. We are also concerned with buckling phenomena.

Initially different design concepts for a telescope wing were discussed, paying special attention to obtain a minimum of extra weight. Preliminary design type stress analyses where also performed to give input for the aeroelastic and buckling analyses.

The report contains a design concepts of the telescope wing. Secondly a general description of the aerodynamic model and the structural model, of the wings used for the aeroelastic analyses, and the interconnection of the structural and the aerodynamic models. Thirdly analysis of flutter, aeroelastic static divergence and buckling are performed and the results obtained are evaluated.

2 Design of the telescope wing

The original NUK 14 wing was of a traditional aluminium design with spars, stringers and webs. The structural weight of the original wing was 220 kg and the wing tank contained a maximum of $410kg$ fuel. The wing is swept backwards 30^o and has a constant aerodynamic profile.

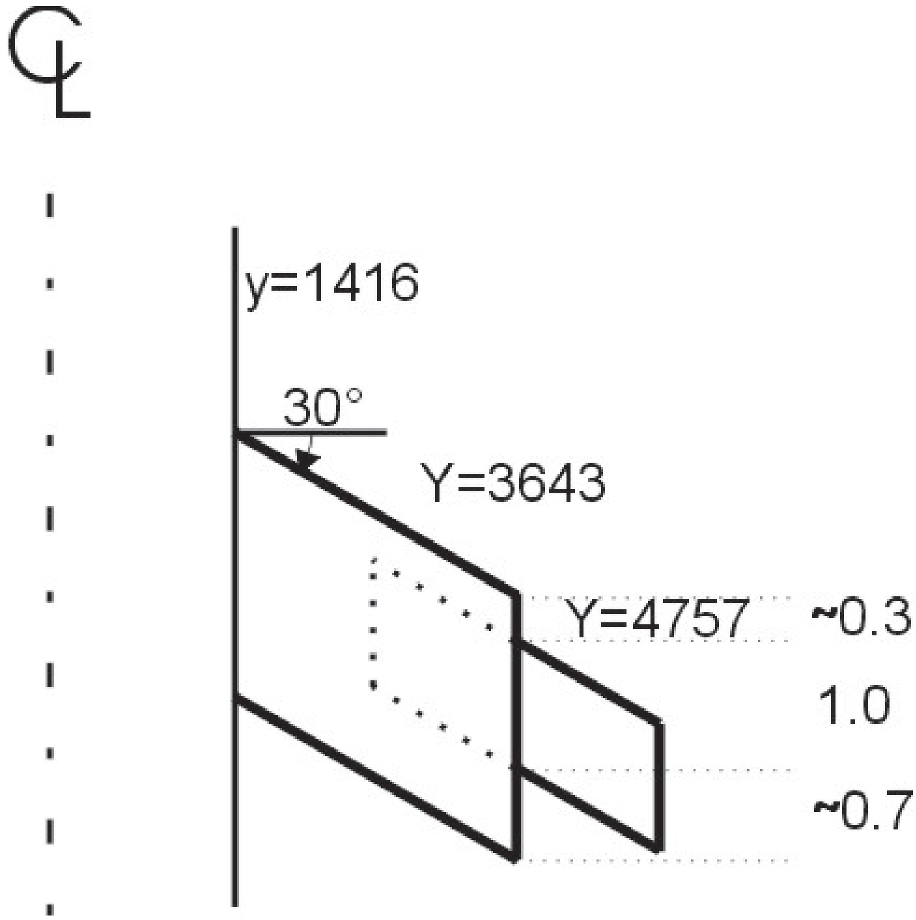
In order to study the possibility to increase the performance of the aircraft it was suggested that the wing should be redesigned as an adaptive structure. The original wing was shortened with 20 %, and supplied with a telescope outer wing with a length of 1.11 m which should be used during take of and landing and also during cruise at high altitudes. Therefore the telescope wing was designed for a failure load factor of only $n_z = 4$ compared to the original wing that is designed for a failure load of $n_z = 9$. The design is outlined in Fig. 2.1 below.

The telescope wing was given the same profile and basic design as the original wing but with a chord length of $1m$ so that the telescope wing should fit between the spars of the original wing.

To make it possible to move the telescope wing into the shortened main wing it is necessary to remove a number of ribs in the original wing. This redesign resulted in aeroelastic and buckling problems and the stiffeners and skins had to be strengthened in the main wing. The fuel tank also had to be reduced. However there is a possibility to have wing tanks above and below the telescope wing, hence the loss of fuel tanks can be reduced to approximately $95kg$ per wing.

The fundamental requirement on the design of the telescope wing was that a minimum of extra weight was introduced by the mechanism that would facilitate the telescope wing to move in or out of the main wing. Different ideas to design such a telescope wing were initially discussed. It was quickly decided

Figure 2.1: Outline of the telescope wing



that a system based on hydraulic or pneumatic jacks would be too heavy as the stroke of such jacks must be 1.11 m. To facilitate a weight estimation of the mechanism some existing products were to be used in as high degree as possible. Another important requirement was that the mechanism would be as small as possible to minimize the loss of space for fuel tanks.

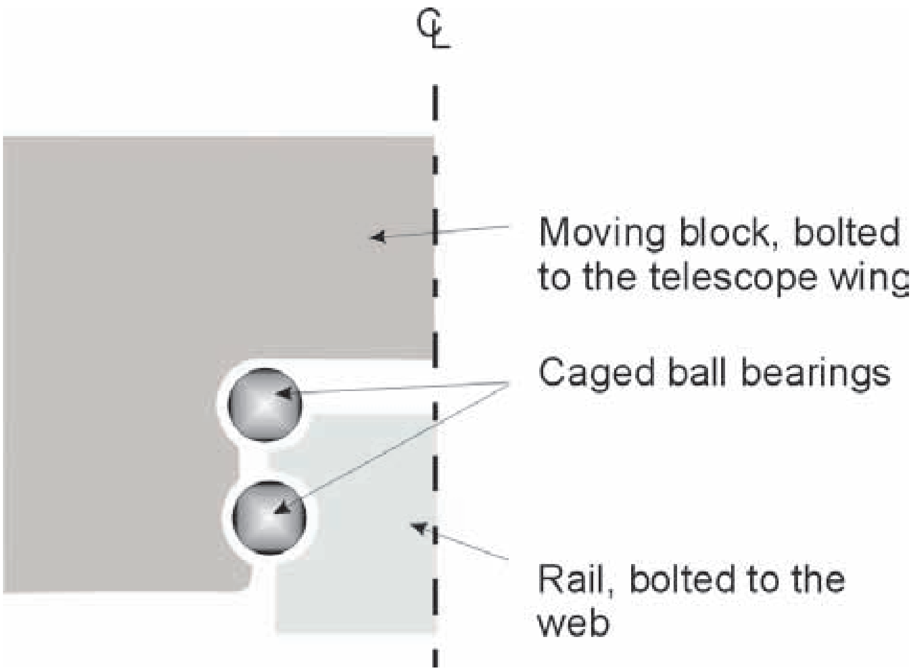
Another requisite was that the design should preferably be such that the loads are directly transferred into the spars, and not be transferred by the wing skins into the spars, as it was assumed that such a design would be most weight effective and also less sensitive to fatigue loads. Further requirement on the design was that the play should be a minimum; otherwise the design would be critical to aeroelasticity phenomena.

2.1 Proposed Mechanism for the Telescope

As milling machines are used to manufacture products with high accuracy, the requirements on such linear motion systems are high. The clearance play has to be extremely smallas well as the deformations to achieve the desired accuracy of product beeing produced in the milling machine. For economic reasons parts of a milling machine also have to withstand a large number of fatigue loads. Therefore it was desided to apply such an existing system for the telescope mechanism in this preliminary design.

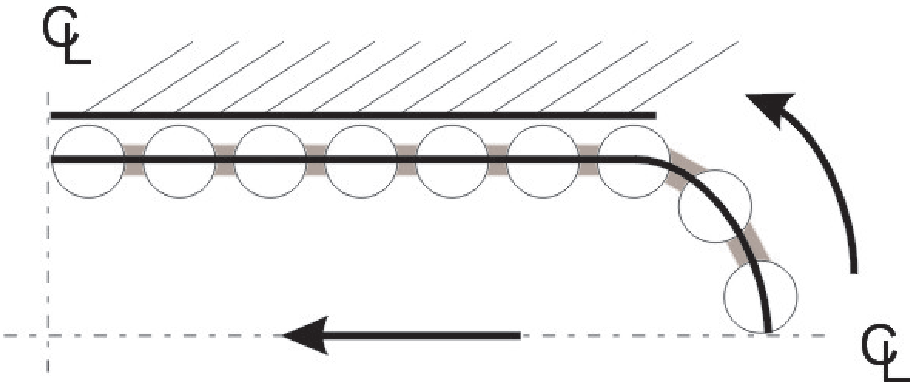
Such linear motion systems are based on a moving block with one or more cages that can slide on the rail. Different types of bearings are used, dependent on the requirements on load bearing capacity, to minimize friction between the cage and the rail. (Such systems could be seen on for example *www.thk.co.uk* or *www.aratron.se*). In Figs 2.2 and 2.3 the basic principle for such linear motion systems are depicted.

Figure 2.2: Basic principle of the linear motion system



To position the telescope wing in the desired position, an electric servomotor could be used as the required force to move the telescope wing should be very small.

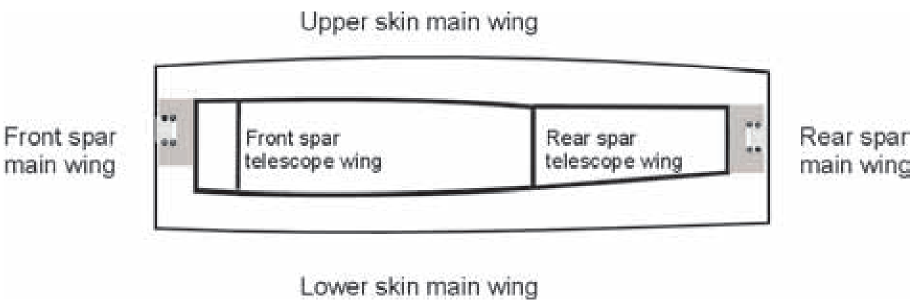
Figure 2.3: Caged ball bearings in the moving block



The basic design of the telescope wing was chosen to be the same as for the original wing, only with reduced dimensions. However, to be able to transfer the loads from the telescope wing to the webs in the main wing, the telescope wing has to extend some extra 200 mm in to the original wing. This extension has to be somewhat modified geometrically to facilitate the linear motion system to be mounted.

The design of the fixture for the linear motion system is depicted in Fig 2.4. The spars and the upper and lower skins between the spars of the telescope wing are extended into a box on which the linear motion blocks are mounted. The linear motion rail is mounted directly on the spars of the main wing.

Figure 2.4: Linear motion system mounted on the box and the spars of the main wing



2.2 Stress Analyses

A simplified stress analysis was performed in order to estimate dimensions of the telescope wing and to be able to estimate the calculated weight of the structure.

Input for the basic stress analyses were aerodynamic loads. The loads are given as normal forces at 11 (spar stations) different y-coordinates for the main wing and at 8 different y-coordinates for the telescope wing.

As the telescope wing only will be used during take of and landing and during cruise at high altitudes, and not during the attack phase, it was decided that the telescope wing should be designed only to a maximum $n_z = 4g$ limit load loading and a failure load of $n_z = 6g$.

Normal loads, and centre of pressure are given for spanvise stations for the wing and the telescope wing, for $C_{N_{tot}} = 0.29$, $Mach = 0.8$, Altitude $11km$.

$Mach = 0.8$

$S_{REF} = 17.5$

$SPAN = 8.4$

The wing is optimised for minimum drag over lift ratio at $C_N = 0.29$. Configuration angle of attack is $\alpha = 0.0443$ *Radians*

Short span wing + long tip results are calculated in the span-stations table 2.1

Table 2.1: Calculated aerodynamic data for the main wing and the telescope wing

Wing								
No	Y	2*Y/Span	XLE	XTE	CHORD	CN	C.P.X	C.P.Y
1	1.5172	0.3612	6.0314	8.1144	2.0830	0.00617	6.92233	1.51723
2	1.7197	0.4094	6.1482	8.2312	2.0830	0.00613	7.05310	1.71968
3	1.9221	0.4577	6.2650	8.3480	2.0830	0.00605	7.14827	1.92214
4	2.1246	0.5059	6.3819	8.4649	2.0830	0.00594	7.24630	2.12459
5	2.3270	0.5541	6.4987	8.5817	2.0830	0.00581	7.34898	2.32705
6	2.5295	0.6023	6.6155	8.6985	2.0830	0.00567	7.45590	2.52950
7	2.7320	0.6505	6.7323	8.8153	2.0830	0.00550	7.56658	2.73195
8	2.9344	0.6987	6.8491	8.9321	2.0830	0.00532	7.68046	2.93441
9	3.1369	0.7469	6.9660	9.0490	2.0830	0.00512	7.79686	3.13686
10	3.3393	0.7951	7.0828	9.1658	2.0830	0.00487	7.91527	3.33932
11	3.5418	0.8433	7.1996	9.2826	2.0830	0.00456	8.03822	3.54177
T Wing								
12	3.7126	0.8840	7.5982	8.5982	1.0000	0.00281	8.18715	3.71263
13	3.8519	0.9171	7.6786	8.6786	1.0000	0.00271	8.20826	3.85188
14	3.9911	0.9503	7.7589	8.7589	1.0000	0.00254	8.26866	3.99112
15	4.1304	0.9834	7.8393	8.8393	1.0000	0.00233	8.33763	4.13037
16	4.2696	1.0166	7.9197	8.9197	1.0000	0.00210	8.40940	4.26963
17	4.4089	1.0497	8.0001	9.0001	1.0000	0.00182	8.48166	4.40887
18	4.5481	1.0829	8.0804	9.0804	1.0000	0.00147	8.55296	4.54813
19	4.6874	1.1160	8.1608	9.1608	1.0000	0.00099	8.62200	4.68737

$Remarks:$

$XLE = X \;\; Leading\ edge$

$XTE = X \;\; Trailing\ edge$

$C_N = \frac{Normalforce}{S_{REF}\, Q}$

$Q = 0.5\, \rho\, U^2 = 0.5\, \rho\, (M\, a)^2;\ (Mach = 0.8,\ H = 11km)$

$Q = 0.5 \times 0.3648\, (0.8 \times 295.2)^2 = 10172.7$

$CPX = Moment\ centre$

$Normalforce = C_N\, S_{REF}\, Q = C_N \times 17.5 \times 10172.7 = C_N \times 178022.8\, N$

Aluminium is used also in the telescope wing with material properties

$E = 71\ 000$ MPa and with allowable stresse is set to be $\sigma_{max} = 250MPa$ with respect to fatigue loads. The density of the material is set to 2.7 kg/dm^3

Out of Table 2.1 the normal forces and the bending moments can be calculated and used in the stress analysis. The aerodynamic forces results in a normal force of $2985N$ and a bending moment of $1398Nm$ at the root of the telescope wing at the load factor $n_z = 1$. With a required failure load factor of $n_z = 6$ the required dimensions of the structure can be estimated.

With the proposed structure of the telescope wing as shown in Fig 4.4 we obtain a moment of inertia

$I_x = \int Z^2 dA = 2.1 \times 10^6 mm^4$

And consequently the maximum stress due to the bending moment will be

$\sigma = \frac{M\, \Delta z}{I_x} = 159MPa$

Shear stresses in the spars can be estimated to

$T = \frac{P}{A} = 26MPa$

where P is the normal force and A is the area of the spars.

And consequently the margin for stress concentrations is good.

With the proposed design we end up with a mass of the structure of the telescope wing of approximately $10kg$ excluding the guiding system and the box to transfer the loads into the spars of the main wing. However, in this weight is not the control surface that later was introduced in the aeroelastic and buckling analyses performed with the FE technique.

In the analyses the dimensions of the spars and the stringers have been given a constant thickness. There is a possibility to reduce the weight of the structure by tapering both the spars and the stringers, but this will as maximum reduce the weight of the telescope wing in the order of $1.5Kg$, which is much less than 1% of the total mass of the complete wing structure.

Instability of the stringers in the proposed design where also estimated. Aluminium profiles can be ordered in any desired shape and consequently we are not limited to standard profiles. If we for simplicity assume that the stringers are produced of a U-profile with dimension $h = 22mm$, $b = 10mm$ and thickness of flanges of $1.5mm$ and the thickness of the web of $1mm$, we obtain a moment of inertia of the spars of $I_x = 13079\ mm^4$. If we for simplicity assume that the spars are simply supported at both ends we obtain a the instability load

$P_k = \frac{\pi^2 EI}{l^2} = 67480N$

and with a maximum stress of $159MPa$ we have a load of only 7791 N whereas the margin for instability of the spars is very good. Other instability forms of the spars, like buckling of the flanges, where also investigated [5] and the margins for instability problems were found to be good and are therefore not further presented here

However the box that the telescope wing is attached to from which the loads from the telescope wing are transferred via the guiding system into the main wing will have to be further studied.

The box that will be added consists of material with thickness varying from 1 to 3 mm and consequently there will be some extra masses added to the above mentioned mass. A good estimate of the mass of the box is in the order of $5kg$, and with the mass of the guiding system we end up with a total mass of the telescope wing of approximately $20kg$. However the mass later increased when the control surface was introduced.

The total mass of the main wing and the telescope wing also increased significantly as the aeroelastic and buckling FE-analyses showed that the main wing had to be strengthened due to the fact that when removing the webs in the main wing to make room for the telescope wing inside the main wing, the boundary conditions of the panels altered and problems arose in the form of buckling of the wing panels between the spars. Actually, buckling of the leading edge of the main wing was also a result of this action as is described later in chapter 8 Linear buckling analysis.

The buckling and the aeroelastic problems of the leading edge could of course be solved by a supporting low-density core material instead of increasing thicknesses of skins and stringers. Such a core material would significantly save weight, and should not affect the capacity of fuel tanks.

The design of the main wing has been changed, by removing several webs to make room for the telescope wing. Therefore it is quite realistic to assume that an optimization of the structure will save a significant amount of weight. Such an optimization would result in a structure that is of the order 5 to 10% heavier than the original wing, without and with a control surface in outer wing respectively.

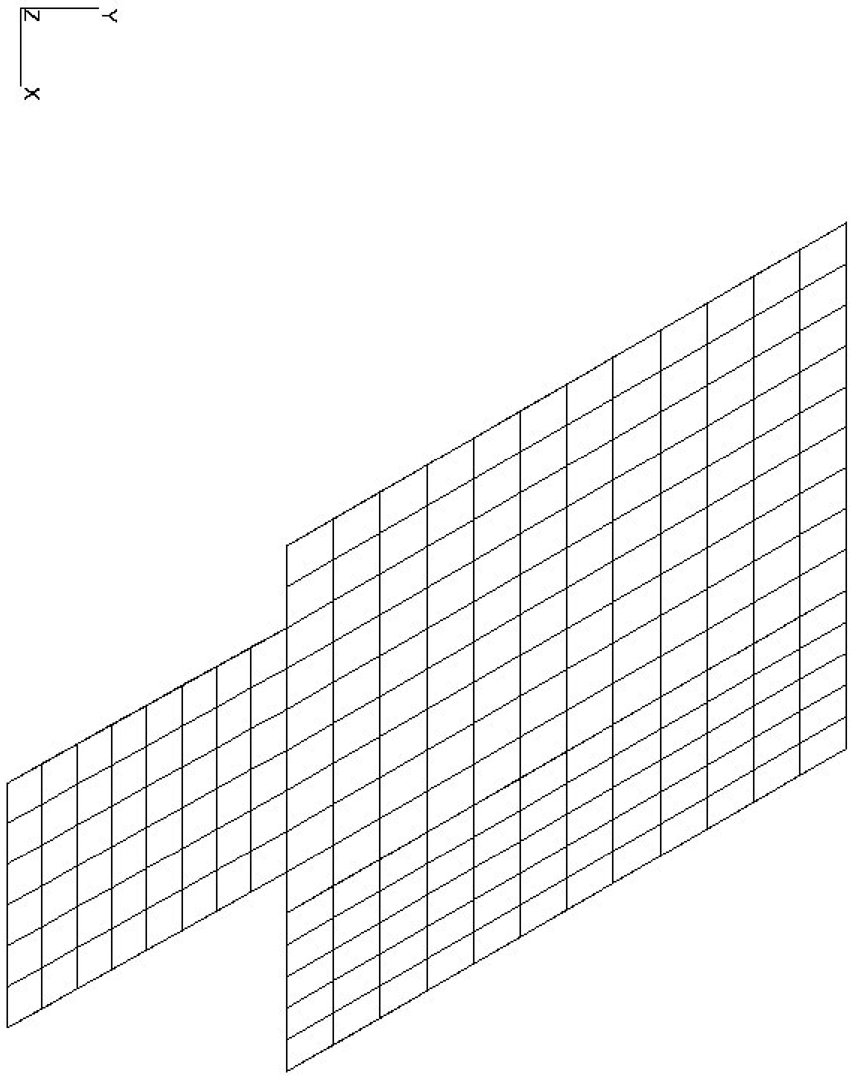
3 The MSC/NASTRAN Aerodynamic Model

The Panel method used for the aerodynamic analysis is based on linearized potential flow [1]. One property of the method is that the surface can be represented by segments of planes for the purpose of calculating lift distributions. The surface is divided into small trapezoidal panels in a manner such that the panels are arranged in columns parallel to the free-stream.

The Nuk14 wing aerodynamic model used here has 118 panels, and 178 panels for the model with telescope wing see 3.1. A total of 178 panels represents the wing and 40, 20 and 48 panels represent the elevons, inboard, outboard and the telescope wing control surface respectively.

The wings are considered to be flat plates, without twist, or camber and no incidence. The interconnection of the aerodynamic model and the structural model is made by a surface spline method [1]. The position and motion of the aerodynamic panels are tied to the corresponding nodes of the structural model.

Figure 3.1: Wing aerodynamic model with a telescope wing



4 The MSC/NASTRAN Structural Model

The structural finite element model of the Nuk14 wing configuration used in this analysis was provided by SAAB Military Aircraft AB. Whereas the modified Nuk14-telescope wing was built up at FOI. This modified wing model has the same structural concept as the Nuk14 (dimensions of the cross sections of beam elements as well as the thickness distribution of the shell elements and the mass properties are modified).

The configuration denoted nuk14 had a total wing mass of $247kg$. The mass consist of concentrated masses and distributed masses. The exterior design of the new wing; Nuk14-telescope is the same as the original nuk14. The chord length of $2m$ is kept, but the half span is reduced by 20%. An additional telescope wing having a chord length of $1m$ and span length of $1.11m$ is incorporated at the tip of the main wing. A third configuration has a control surface on the telescope wing, denoted nuk14-telescope-k. The total mass of the Nuk14-telescope-k is $293kg$.

The structural discretization is fairly simple, only 4-noded structural shell elements (type: CQUAD4) and beam elements (type: CBAR) are used. The global finite element mesh description of the wings, the boundary conditions and the telescope wing is given in the Fig 4.1, 4.2 and 4.3. The material for the wings is assumed to be aluminium. A concentrated mass representing the guiding system of the telescope wing are added on the leading and the trailing beams of the head wing, 2 X $3.3kg$.

The different dimensions of the beam cross sections in the frame and the skin thicknesses, t_{skin}, forming the telescope wing are given in table 4.1, with notations corresponding to those in the Fig 4.4.

A generalized spring and damper structural finite elements type are used for the interconnection between the control surfaces and the wing.

Figure 4.1: Nuk14 wing finite element model

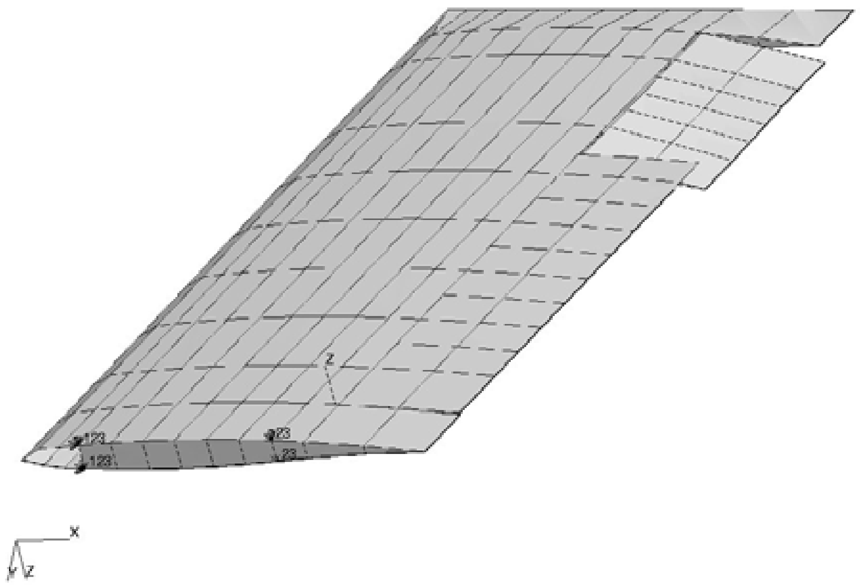


Figure 4.2: Nuk14 wing and the telescope wing finite element model (model: nuk14-telescope-k)

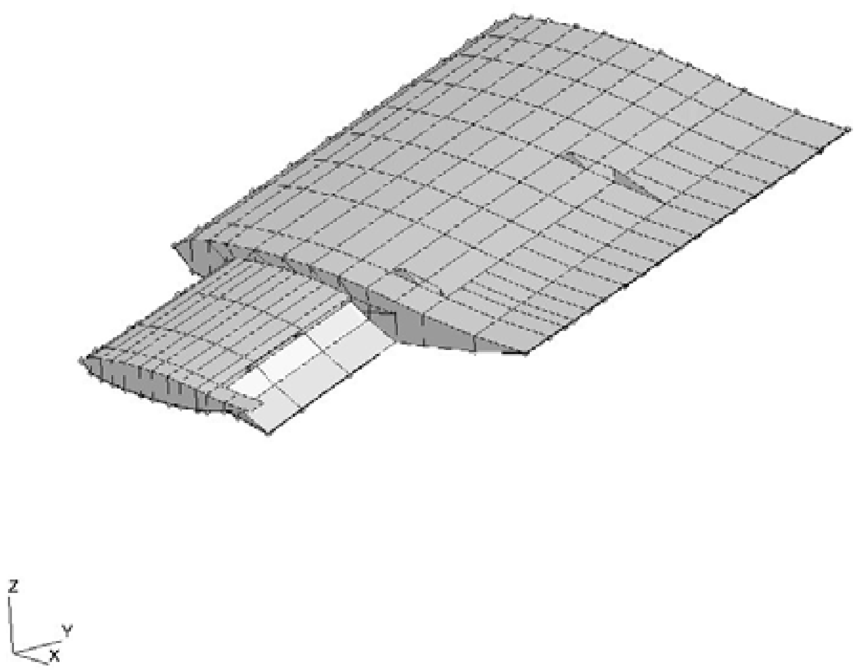


Figure 4.3: Wing beam and concentrated mass model of the wing

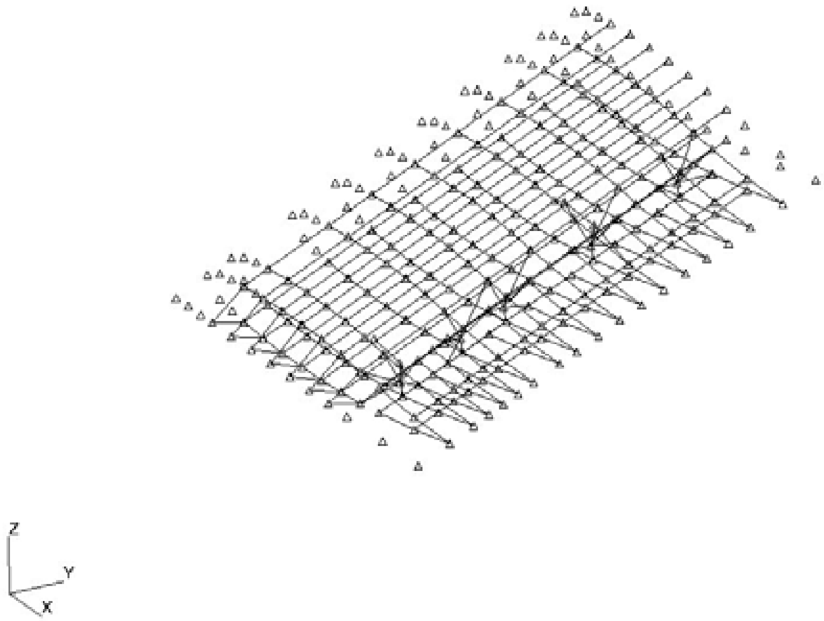
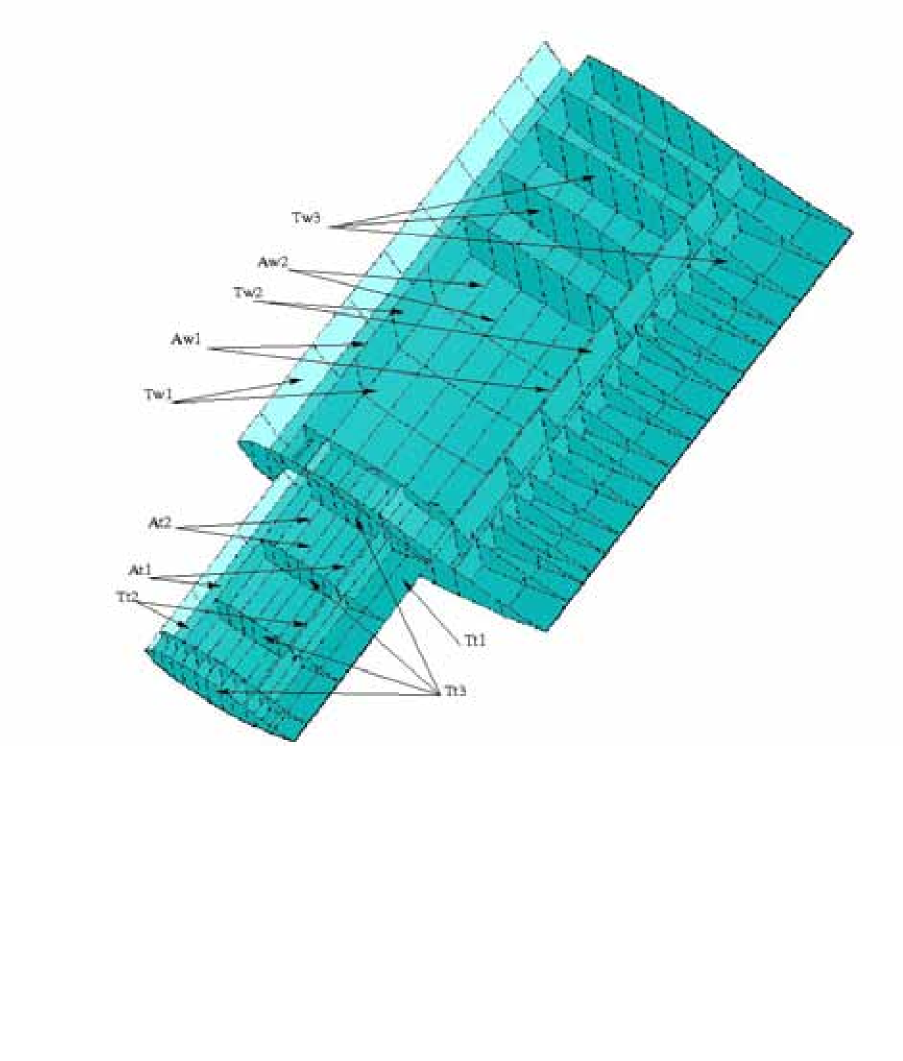


Table 4.1: structural model cross sections and skin dimensions

Thickness	$t_{skin} mm$	$t_{skin} mm$ Nuk14 orig
Tt1	0.7	
Tt2	2.0	
Tt3	0.7	
Tw1	1.0 - 3.0	2.0 2.3
Tw2	3.0	0.9 - 3.0
Tw3	1.3 - 1.5	1.3
Area	$A = bXbmm^2$	$A = bXbmm^2$
At1	49.0	
At2	49.0	
Aw1	150.0 - 560.0	190.0 - 560.0
Aw2	150.0 - 220.0	200.0 - 220.0

Figure 4.4: Nuk14 wing and telescope wing structure geometries



5 Vibration Analysis: Natural Frequencies and modes

The vibration modes method is used to reduce the number of degrees of freedom in preparation for the flutter stability analysis. A sufficient number of modes must be used to obtain the required accuracy. An aspect of the modal method is the transformation of the aerodynamic influence coefficients into modal coordinates.

20 eigenmodes are chosen in the vibration analysis, thus the vibration analysis is reduced to the first 20 modes and later on, the flutter analysis is based on these 20 modes.

The first 6 vibration eigenmodes are shown in Figs 5.1 - 5.6, 5.7 - 5.12, and 5.13 - 5.18, for nuk14, nuk14-telescope and the nuk14-telescope-k models respectivelly.

Concerning the Nuk14 wing configuration, the first vibration mode is typically vertical bending mode, the second and the third modes are the wing control surfaces deflection modes. The torsion mode of the wing is the corresponding leading and trailing beam torsion modes which are respectivelly the fourth and the seventh modes, Table 5.1.

The configurations with a telescope wing have beside the wing bending modes the bending mode of the telescope wing and the telescope rudder deflection modes. A combination mode between the telescope rudder deflection and the wing, inboard/outbord wing rudder occur, see Tables 5.2 and 5.3

Table 5.1: Natural frequencies and description of the mode, Nuk14 model

Mode	Freq Hz	Mode description
1	12.77	vertical wing bending
2	27.74	inboard rudder deflection
3	32.88	outboard rudder deflection
4	48.80	leading edge beam torsion
5	53.50	horizontal wing bending
6	62.81	second order wing bending
7	67.87	trailing edge beam torsion
8	71.90	inboard rudder torsion
9	75.54	leading edge skine bending
10	80.08	trailing edge skine bending

Figure 5.1: Nuk14 model, first mode, F=12.77 Hz

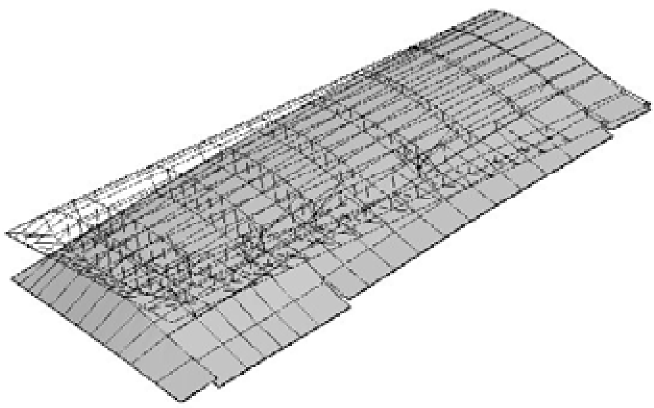


Figure 5.2: Nuk14 model, second mode, F=27.74 Hz

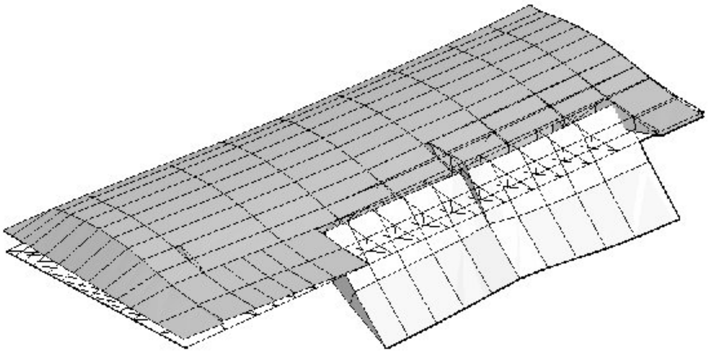


Figure 5.3: Nuk14 model, third mode, F=32.88 Hz

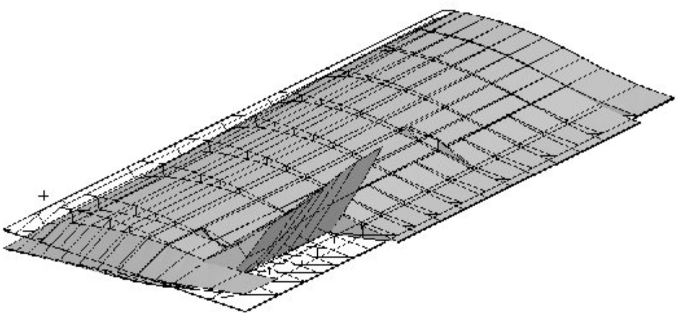


Figure 5.4: Nuk14 model, fourth mode, F=48.80 Hz

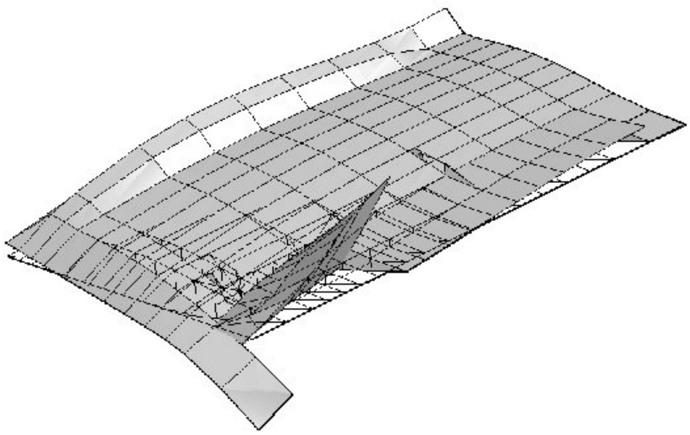


Figure 5.5: Nuk14 model, fifth mode, F=53.50 Hz

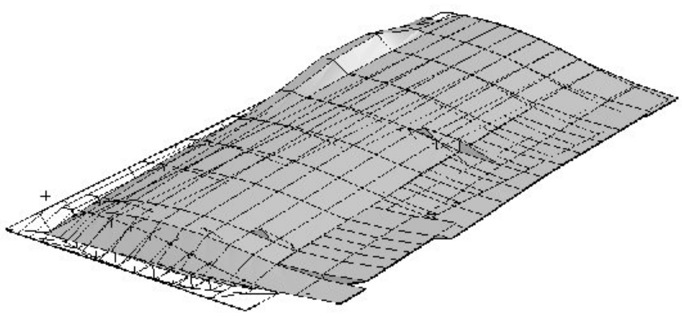


Figure 5.6: Nuk14 model, sixth mode, F=62.81 Hz

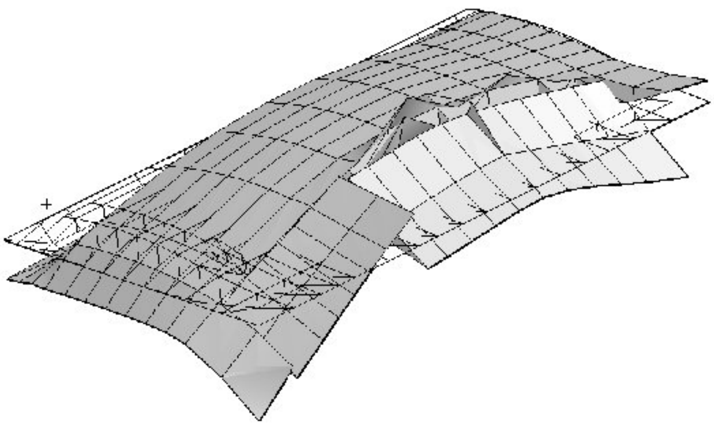


Table 5.2: Natural frequencies and description of the modes, nuk14-telescope model

Mode	Freq Hz	Description
1	11.35	vertical wing bending
2	29.18	inboard rudder deflection + telescope wing bending
3	33.53	outbord rudder deflection + telescope wing bending
4	37.69	inboard + outboard rudder deflection + telescope wing bending
5	56.21	wing torsion
6	58.06	horizontal wing bending
7	66.93	second order vertical vertical wing bending

Figure 5.7: Nuk14-telescope model, first mode, F=11.35 Hz

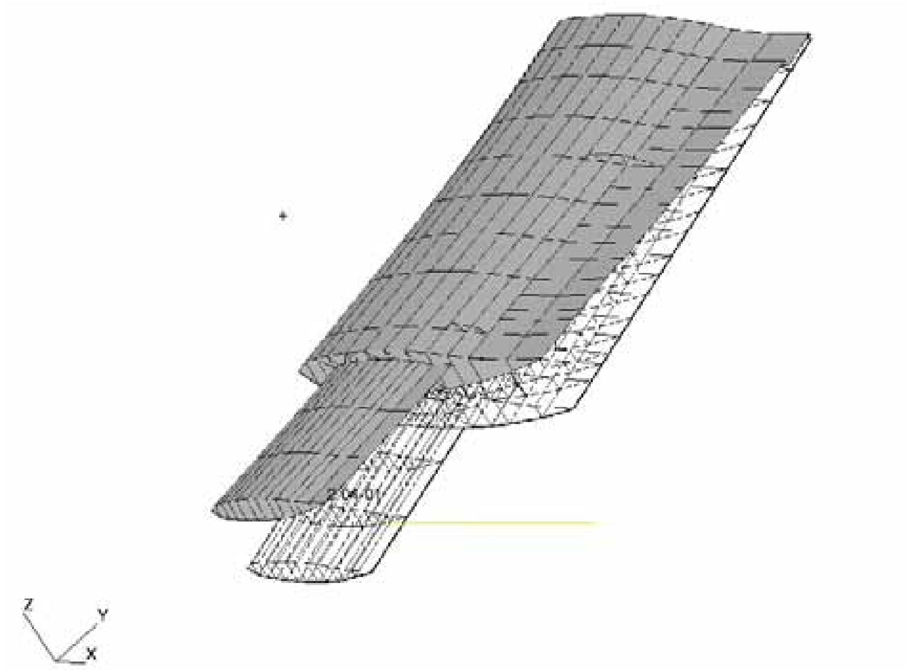


Figure 5.8: Nuk14-telescope model, second mode, F=29.18 Hz

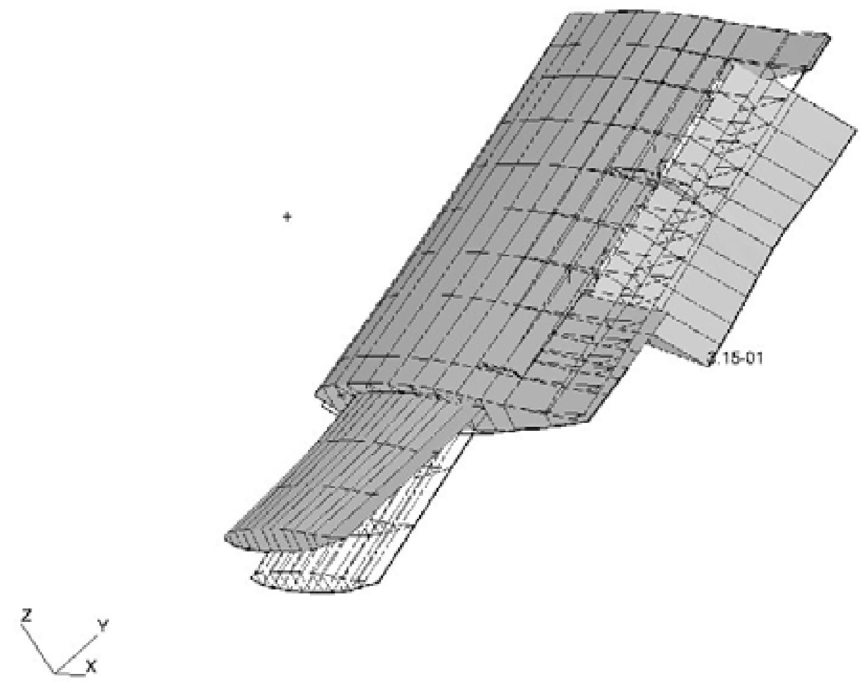


Figure 5.9: Nuk14-telescope model, third mode, F=33.53 Hz

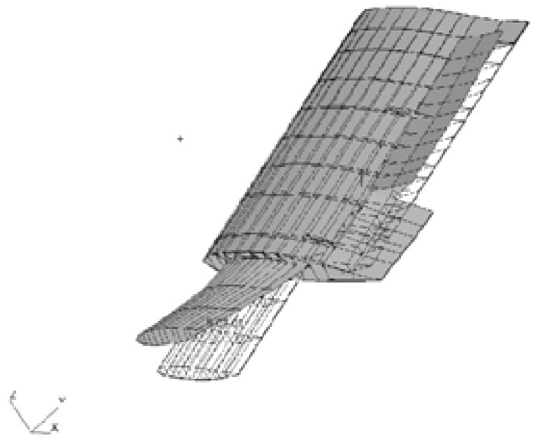


Figure 5.10: Nuk14-telescope model, fourth mode, F=37.69 Hz

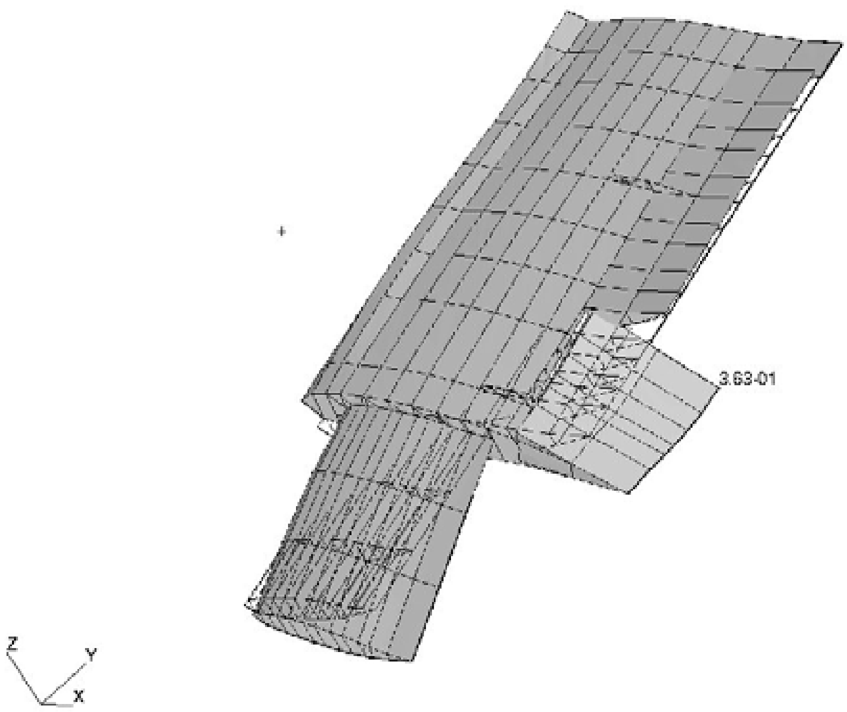


Figure 5.11: Nuk14-telescope model, fifth mode, F=56.21 Hz

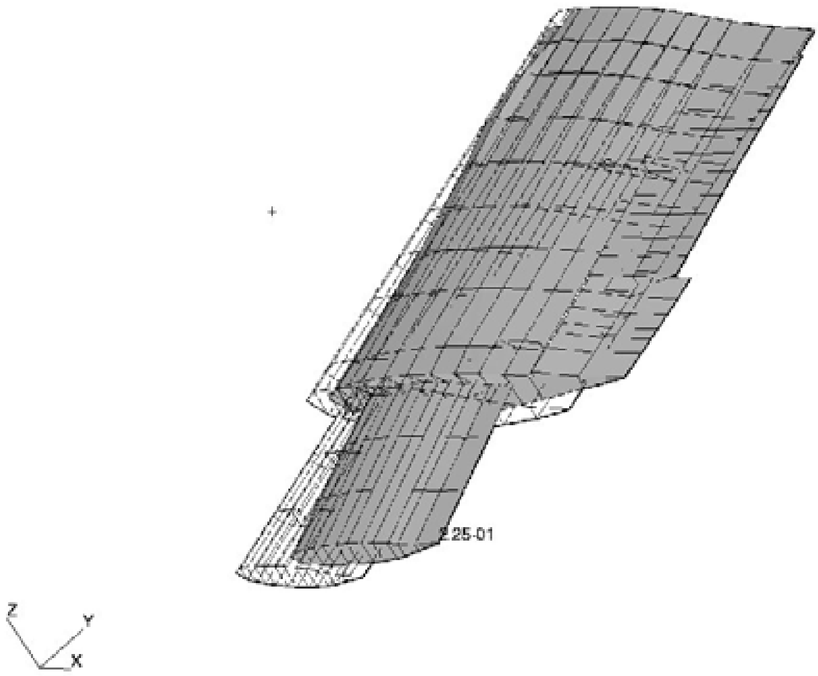


Figure 5.12: Nuk14-telescope model, sixth mode, F=58.06 Hz

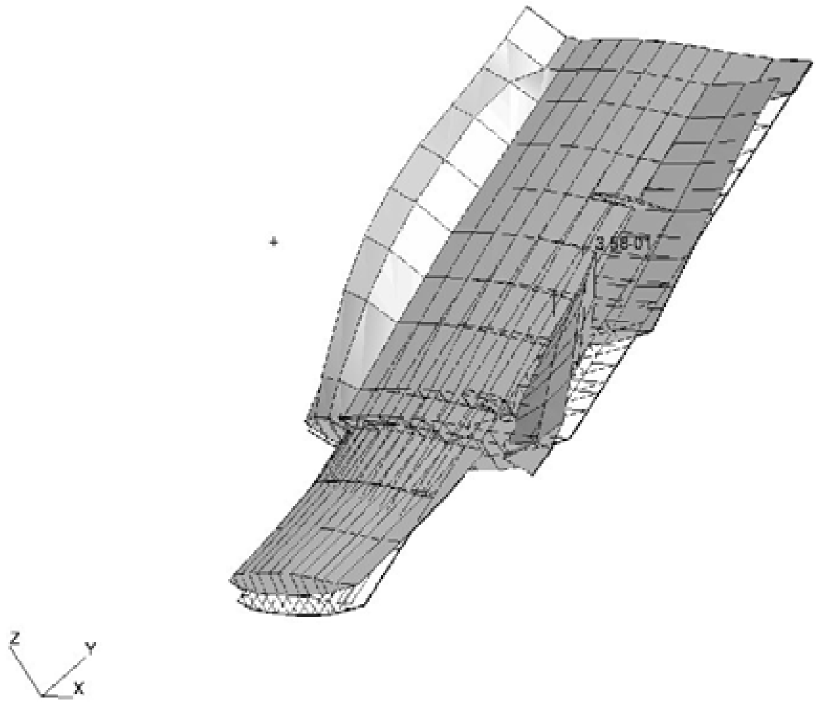


Table 5.3: Natural frequencies and description of the modes, nuk14-telescope-k model

Mode	Freq Hz	Description
1	7.29	vertical wing bending
2	24.87	wing and telescope rudder deflection
3	27.34	telescope rudder deflection
4	31.96	wing inboard rudder deflection
5	33.58	wing outboard rudder deflection
6	34.57	horizontal wing bending
7	54.57	second order vertical wing bending

Figure 5.13: Nuk14-telescope-k model, first mode, F=7.29 Hz

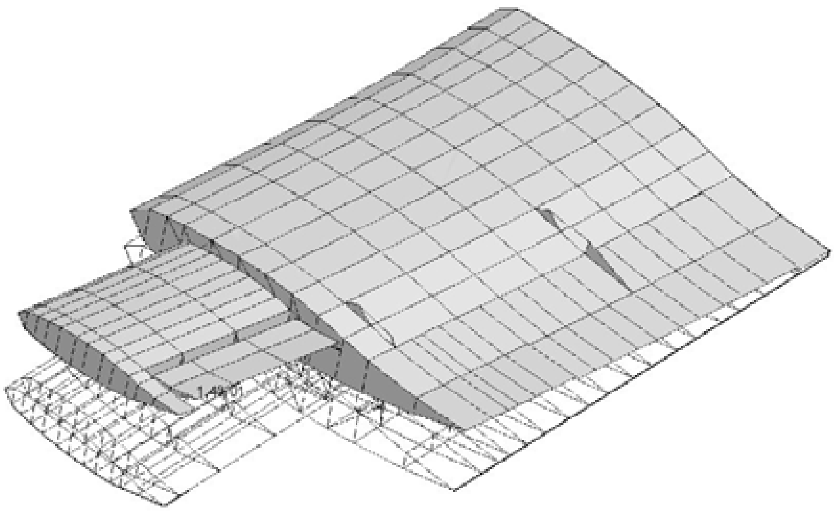


Figure 5.14: Nuk14-telescope-k model, second mode, F=24.87 Hz

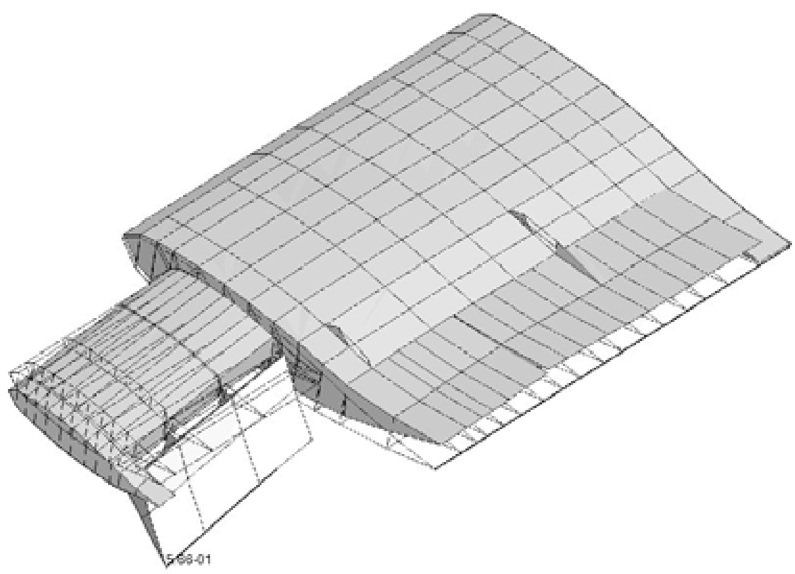


Figure 5.15: Nuk14-telescope-k model, third mode, F=27.34 Hz

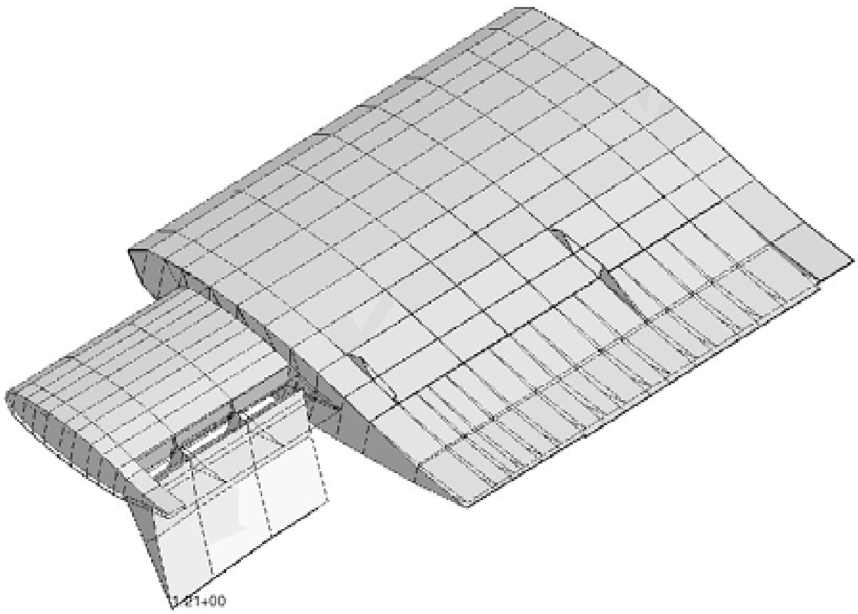


Figure 5.16: Nuk14-telescope-k model, fourth mode, F=31.96 Hz

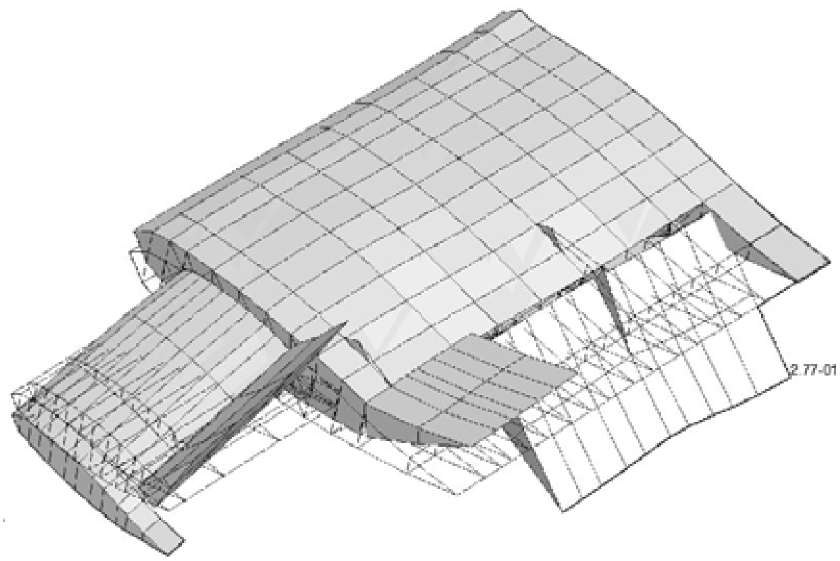


Figure 5.17: Nuk14-telescope-k model, fifth mode, F=33.58 Hz

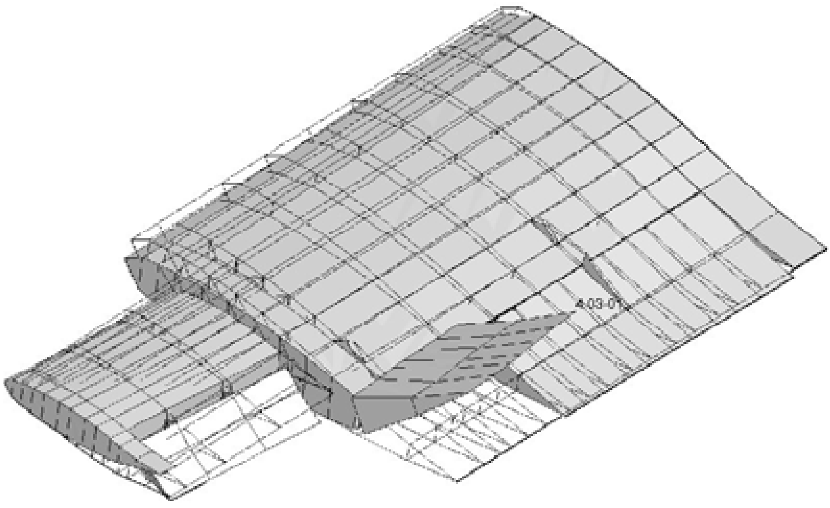
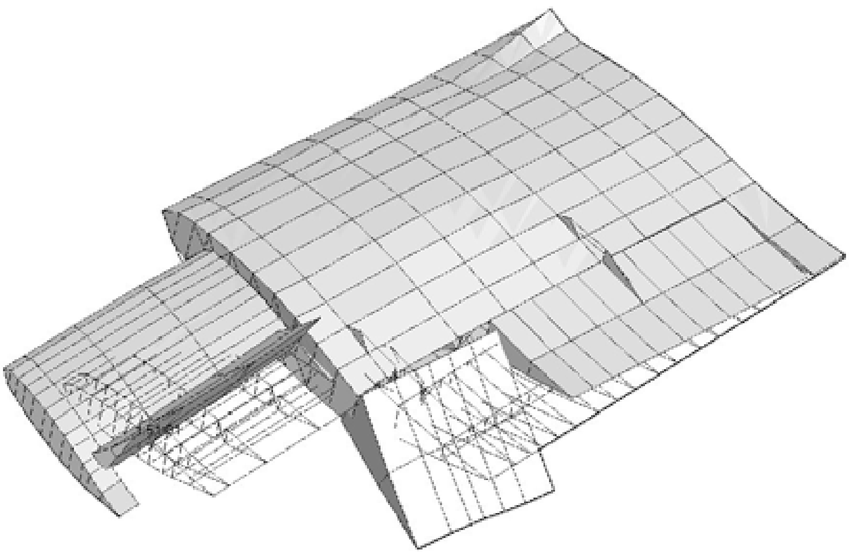


Figure 5.18: Nuk14-telescope-k model, sixth mode, F=34.57 Hz



6 Flutter Analysis

The objective of the flutter analysis is to predict under which flight conditions, like altitudes (air density) and air-speeds, flutter occurs.

Flutter is a self-excited dynamic instability caused by the interaction of aerodynamic, elastic, and inertial forces. If flutter is present in an aero-structure system, then energy begins to be added to the system. Any perturbation of the structure will cause an increasing structural oscillation which will grow until limited by nonlinear effects or until the structure fails.

The flutter prediction technique used for the study presented herein, involves a series of eigenvalue solutions. The eigenvalue problems to be solved depend on the way in which the aerodynamic loads are included in the equations of motion, or whether certain damping terms are included.

In this analysis the critical flutter speed variables are determined using the P-K flutter method, assuming cruise at different altitudes, $H = -3$ to $10km$, with a corresponding air density of $\rho = 1.6$ to $0.413kg/m^3$.

The flutter velocities and frequencies are summarized in the table 6.1, 6.2, and 6.3.

The predicted flutter velocities are increasing with altitudes from $V_f = 490.0m/s$ to $695.0m/s$, while the flutter frequency is almost constant at $F_f = 25.0Hz$ for the nuk14 wing configuration. Whereas the flutter velocities for the configurations with telescope increases from $V_f = 410.0m/s$ to $710.0m/s$ and $V_f = 370.0m/s$ to $475.0m/s$ at frequencies 26.0 to $29.0Hz$ for the telescope configurations without and with rudder.

The lowest and possibly the most important critical flutter velocity is $V_f = 490.0m/s$, $410.0m/s$ and $390.0m/s$ at altitude $H = -3km$ for the Nuk14, Nuk14-telescope and Nuk14-telescope-k respectively. The common critical flutter deformation mode is namely dominated by the inboard rudder deflection se Fig 5.3, 5.8 and 5.16,

Hence the wing has a good safety margin regarding flutter.

Table 6.1: Flutter velocity and frequency wing Nuk14

Altitude $H[Km$	Velocity $V_f m/s$	Freq $F_f Hz$	Mode Nbr
-3.	490.0	25.40	2
0.	555.0	25.25	2
6.	695.0	25.16	2
10.	–	–	–

Table 6.2: Flutter velocity and frequency wing Nuk14 with telescope wing

Altitude HKm	Velocity $V_f m/s$	Freq $F_f Hz$	Mode Nbr
-3.	410.0	26.40	2
0.	580.0	26.17	2
6.	710.0	26.00	2
10.	-	-	-

Table 6.3: Flutter velocity and frequency wing Nuk14 with telescope and rudder

Altitude HKm	Velocity $V_f m/s$	Freq $F_f Hz$	Mode Nbr
-3.	390.0	29.71	4
0.	425.0	29.67	4
6.	500.0	29.63	4
10.	-	-	-

Figs 6.1 and 6.2 shows the variation of the flutter velocity V_f and flutter frequency F_f versus the altitude.

The nuk14 configuration and the configuration with the telescope wing have a good flutter behavior, the flutter speeds are outside the required flight envelope.

Figure 6.1: Flutter velocity

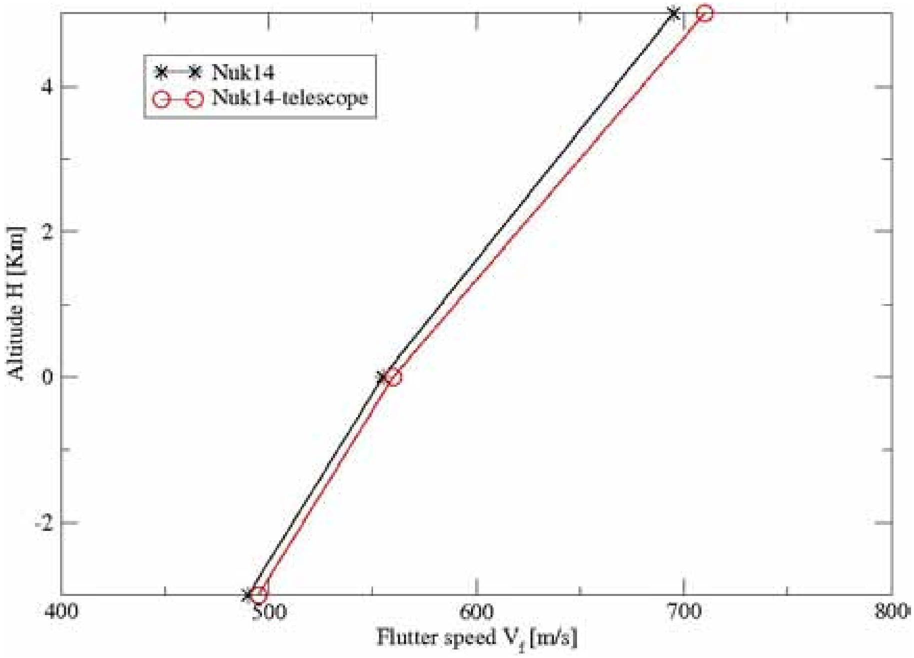
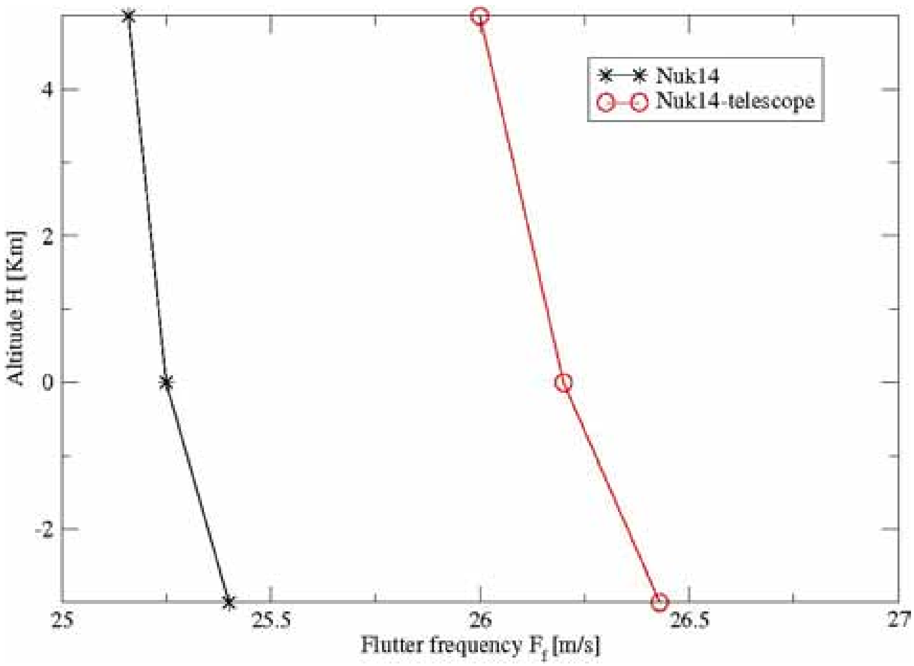


Figure 6.2: Flutter frequency



7 Static Aeroelastic Divergence Analysis

The objective of this analysis is to extract the critical divergence dynamic pressure, typicaly the lowest one is of the interest.

The divergence analysis is carried out using a complex eigenvalue method for solving the equation linking the structural stiffness matrice [K] and the aerodynamic influence matrix [Q]:

$[k - \lambda Q]U = 0.$

Where the eigenvalues of this system of equations, $\lambda = q_d$ are the divergence dynamic pressure. Only the positive values of q_d have a physical significance and the lowest value of q_d is the critical dynamic pressure, since the second and the higher divergence pressure are not of pratical intrest. The calculated divergence dynamic pressure and the corresponding divergence modes are summarized in the table 7.1

The Nuk14 telescope configuration have a good margin for aeroelastic divergence, since the the minimum critical divergence dynamic pressure is $q_d = 2.40e + 05Pa$, at sea level the corresponding speed is $V_d = 443m/s$.

Table 7.1: Divergence dynamic pressure

Model	Dynamic pressure $q_d Pa$	Mode Nbr
Nuk14	2.51e+05	1
Nuk14-telescope	2.83e+05	2
Nuk14-telescope-k	2.40e+05	1

8 Linear Buckling Analysis

The classical linear buckling eigenvalue method is used for this analysis. The objective is to provide an estimate of the principal buckling load and the associated buckling mode. The structural model is subjected to a gravitation load only, as crude estimate of true loading. With the proportionality factor λ. The idea is to compare the buckling strenght of the telescope design with the original Nuk14 designs strenght.

The calcuted critical buckling load factors λ and corresponding modes for the different configuration are summarized in the table 8.1 and Fig 8.1, 8.2 and 8.3.

Table 8.1: buckling load

Model	load factor λ	Mode Nbr
Nuk14	67.8	1
Nuk14-telescope	53.90	1
Nuk14-telescope-k	32.68	1

The configuration nuk14 and the nuk14-telescope are structurally stable for the loading amplitudes up to 32 times the weight of the wing. The model show a sign of local buckling for a load factor $\lambda = 32.68$ for the telescope configuration with rudder nuk14-telescope-k. This local bucling is localized at the leading edge of the main wing.

The local buckling behavior at this part of the wing could be improved by using spars, etc.

The finite element model used for this analysis is intended to estimate load carring capacity of the wing. More, advanced buckling analysis (using the non-linear buckling method) for a better prediction of instabilities, require more detailed structural model as well as a specified load distribution.

Figure 8.1: Nuk14 model, first buckling mode, λ = 67.80

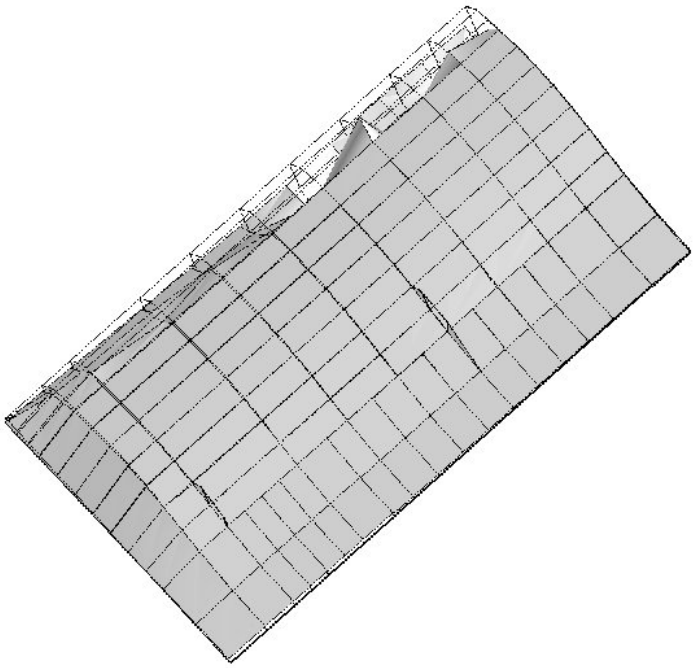


Figure 8.2: Nuk14-tlescope model, first buckling mode, λ = 53.90

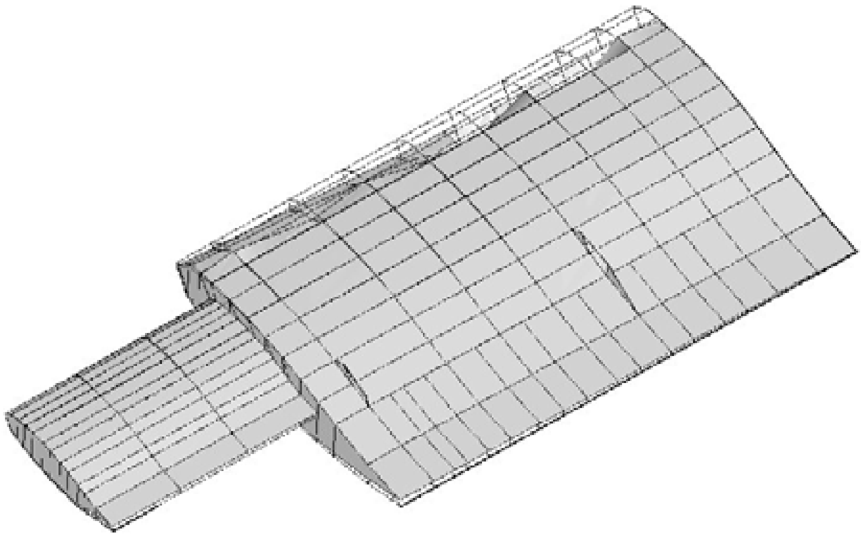
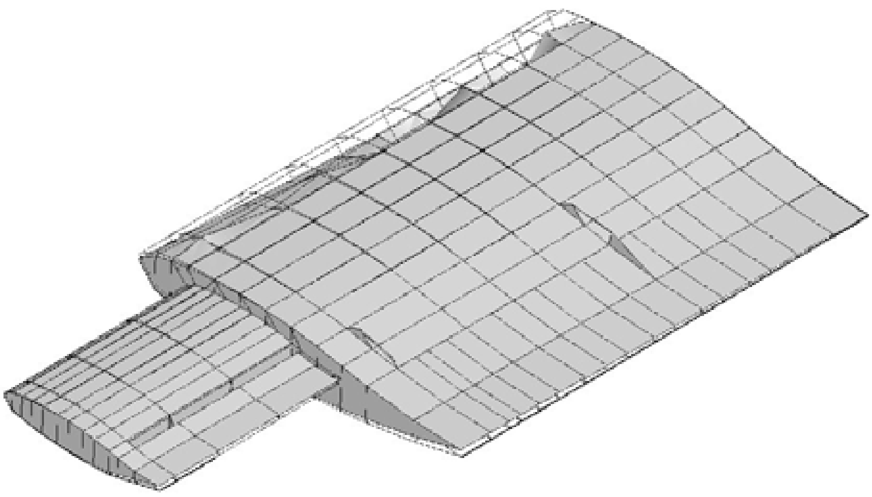


Figure 8.3: Nuk14-tlescope-k model, first buckling mode, λ = 32.68



9 Concluding remarks

A design concept has been proposed for a telescope wing that could telescope into the main wing. The telescope wing is to be used during take of and landing and during cruise at high altitudes.

Preliminary design stress analyses where performed including instablility analysis of the structure. The proposed design of the telescope wing resulted in a weight of this structure of approximately $20kg$. However, to make a room for the telescope wing, to be totaly telescoped into the main wing, a number of webs had to be removed. And consequently aeroelastic and buckling problems of the main wing where observed during the following FE-analyses. These problems where handled by increasing thicknesses of the material of the main wing, and the total weight of the new wing configuration was approximately 18% heavier than the original wing. However, by optimization the structure a significant weight saving is possible, and by the use of stringers instead of increased thicknesses. It is resonable to assume that the increased weight would be of order 5 to 10% without and with a control surface in the outer wing respectively. Howerver, due to the telescope wing, the wing tanks will hold $95kg$ less fuel per wing. There is of course a possibility to introduce fuel tanks in the fuselage. To do so would of course require that the center of gravity is not moved outside the limits.

A dynamic (flutter) analysis of a configuration of the nuk14 and the modified nuk14 wing having a telescope wing in the Adaptive Structures project has been made. The work presented is carried out using a linear Panels method for the aerodynamics and the Finite Element Method for the structures.

Concerning flutter, the wings sems to be properly designed from an aeroelastic point of view for the given mass and mass distribution and for the intended speed range $M < 0.8$, $U = 270m/s$.

At sea level $H = 0km$, the flutter critical air velocities are $V_f = 555m/s$, $V_f = 580m/s$ and $V_f = 425m/s$ for the Nuk14, Nuk14-telescope and Nuk14-telescope-k configurations respectively.

The results of this study show reduction of flutter velocities by 20% for the telescope configuration with a control surface. This reduction could be compensated by increasing the damping and the stiffness of the telescope control surface.

The different configurations have a good margin for aeroelastic divergence, since the lowest critical dynamic pressure is $q_d = 2.4bar$ (at sea level the divergence speed is $V_d = 443.5m/s$).

The tentative buckling analysis showed a stability of the different configurations regarding the global buckling behavior. This analysis is carried out by using load distribution proportional to the gravitation load. Up to 67.8, 53.9 and 32.6 times the weight of the wing configurations respectively the nuk14, nuk14-telescope and nuk14-telescope-k models are stable.

Acknowledgement

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