The Iraqi Journal For Mechanical And Material Engineering, Vol.12, No.2, 2012

NUMERICAL INVESTIGATION OF FREE VIBRATION ON NEW STEPPED WING MODEL

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Abstract:

Free vibration study represents one of the most important studies for complex structure such as wing structure. In this search, a new model for wing structure was created including changing in the airfoil shape. The wing of airfoil Naca 2414 of aluminum 2024 alloy was used to construct the wing. Four case studies were accomplished for different airfoil shape so that the location of the airfoil is change from location to other at the chord. Free vibration analysis for five modes was performed to obtain the vibration characteristics such as natural frequency and mode shapes. From the results, it was found that, in general **the change in the airfoil leads to (keeping same weight so the thickness and wing length remain constant)** increase the vibration characteristics. A numerical program include the analysis was achieved and added to ANSYS milieu as a new motivation.

الخلاصة:

دراسة الاهتزاز الحر يمثل واحد من أهم الدراسات للهياكل المركبة والمتمثلة بهيكل الجناح . في هذا البحث، تم دراسة نموذج جديد لهيكل الجناح وذلك بتغيير شكل مقطع الجناح. مقطع الجناح هو من طراز 2414 القياسي المصنوع من سبائك الالمنيوم 2024 .وقد درست اربع حالات لمقاطع اجنحة مختلفة بحيث يتغير موقع العتبة على طول الباع. للتحقق من النماذج المقترحه، تم اجراء تحليل الاهتزاز الحر لخمسة انماط للحصول على التردد الطبيعي ونمط الاشكال . من خلال النتائج وجد بان تغير شكل او هيئة مقطع الجناح (بالحفاظ على نفس الوزن بحيث يبقى السمك وطول الجناح ثابت) بصور عامة ادى الى تحسين خصائص الاهتزاز الحر). وكذلك كان لتغير موقع العتبة الاثر الكبير في تصرف استجابة الجناح. تم انجاز موديل رياضي اضيف الى بيئة الانسز كدراسة كاملة عن هذا البحث.

1.1 Introduction:

In 1999, Joseph W Clement* and Diann Breit[1] create an active rotor blade flap system to reduce the vibrations in rotorcraft. In his search, he used added flaps to the wing to change the aerodynamic characteristics which in turn lead to increase the frequency of the wing. **It was appeared that the researcher add a new masses to the structure so that the total weight was increased.**In 2001, William (Wei) Cai and Pragasen Pillay [2] obtain the resonant frequencies and mode shapes of the SRM stator to decrease the acoustic noise. He solved the differential equation using finite element method and elasticity theory .they concluded that resonant frequency of the stator stack was decreased roughly linearly with increased of the yoke radius when the yoke thickness is kept unchanged. Furthermore, the existence of the stator poles were reduced the frequencies of the first few order modes and increased the higher order natural frequencies so that the geometry of the poles effects on the resonant frequencies of the SRM.

In 2009, Meng-chun Yu and Chyanbin Hwu [3] studied the free vibration on the tapered composite wings employing the Hamilton’s principle and finite element formulation. They observed that the divergence dynamic pressure was increased and the fundamental natural frequency was decreased when the taper ratio was increased. In August 2009(Xavier Mauclère) [4] founded a new airfoil design based on direct numerical optimization of a B-spline representation of airfoil shape ,which allowed to reproduced different airfoils with various geometries with maximal geometry difference less than 0.5% . That means existed different mass with the same thickness of the new airfoil design. In February 2011, B. Sobhani Aragh · M. H. Yas[5] investigated three-dimensional free vibration analysis of four-parameter continuous grading fiber reinforced (CGFR) cylindrical panels resting on Pasternak foundations using generalized power-law distribution. From This research they concluded that the non-dimensional natural frequency decreases with increasing the R/L ratio .that means decreased in length to diameter ratio for the cylinder to increasing natural frequency and reduced vibration.

1.2 Closing Remark:

1-Joseph W Clement **,**was used an active rotor blade flap system(C-block actuators) which means adding a new mass to the wing to reduce vibration, but in this research no mass was added to reduce vibration.

2- William (Wei) Cai, proved that the existence of the stator poles were reduced the frequencies of the first few order modes and increased the higher order natural frequencies ,that means (increasing length with the same thickness) were reduced vibration by increasing natural frequency ,but in this research (same length and same thickness) was used.

3- Meng-chun Yu,considerd proved that the increasing in taper ratio which including increasing in wing length affect on natural frequency ,but in this research the length of wing still constant with change in geometry of wing and that was lead to increased natural frequency.

4-(Xavier Mauclère) founded new airfoil design but with small difference in the length about 0.5%, but in this research (same length and same thickness) was used.

5-B. Sobhani Aragh, founded that decreased in diameter to length ratio of cylinder reduced vibration, which means different length, but with compared by this research no different length ratio needed to reduced vibration.

2.1 Finite Element Discrimination:

In recent years, finite element is present as progressive mean to analyze the structure. The finite element method is the most powerful numerical technique, which offers an approximate solution to most realistic types of structures [6]. The use of the computational tools has become common in design, and the need for explicit design formulas have therefore decreased. More direct and accurate calculations may be performed in order to achieve safe and optimal design. (**ANSYS 5.4**) is used to analyze a stepped wing. In the present study, an 8–node structural shell is used for discrimination of the stepped wing as a shell 3-D analysis.

2.2 Element Parameters:

The geometry, node locations and coordinate system for this element are shown in **Fig.(1)** .the element is defined by eight nodes , four thickness and the orthotropic material properties. Mid side nodes may not be removed from this element. The element is particularly well suited to model curved shells. The element has six degrees of freedom at each node: translation in the nodal x, y, and z directions and rotations about the nodal x, y, z axes. The deformation shapes are quadratic in both in –plane deflection. The element has plasticity, stress stiffing, large deflection and large Strain capabilities [7].

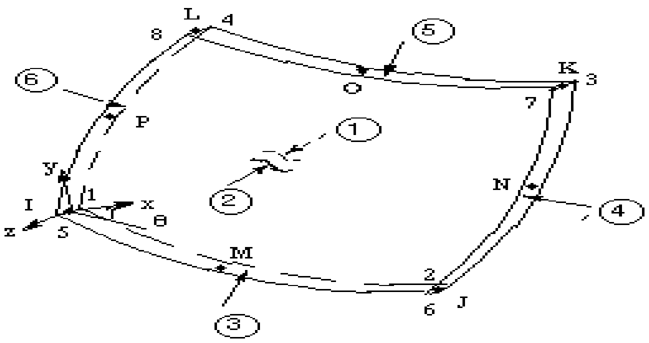


Fig.(1) Representation of shell 93 element

2.3 Mesh Generation and Boundary Conditions:

One of the most important steps in finite element analysis is how the model or structure is divided into sub domain called elements. The processes called mesh generation. Number of elements has a significant effect in accuracy and time of processes. Therefore, some convergence studies should be induced to obtain the required numbers of element for covering the mesh processes. After these studies, it was noted that there are 25 to 30 elements for plate length and width, respectively. The wing area is divided into 4 area (a,b) areas represent airfoil 2414 which are symmetric areas and they have private mesh with high accuracy because of sharp curved lines and because that they are small areas .(c,d) areas represents the upper and lower surface of the wing which is divided into many triangular segments to equivalent with the sharp segments of (a,b) areas. **Fig (2)** shows the proposed finite element model (no stepped wing). ANSYS finite element package is used as a mathematical tool in the analysis of this model.

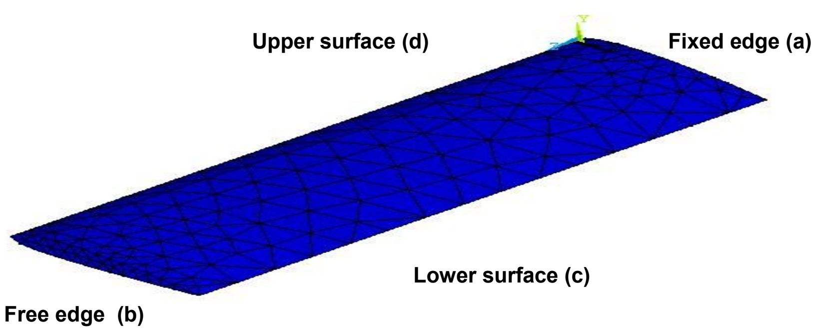
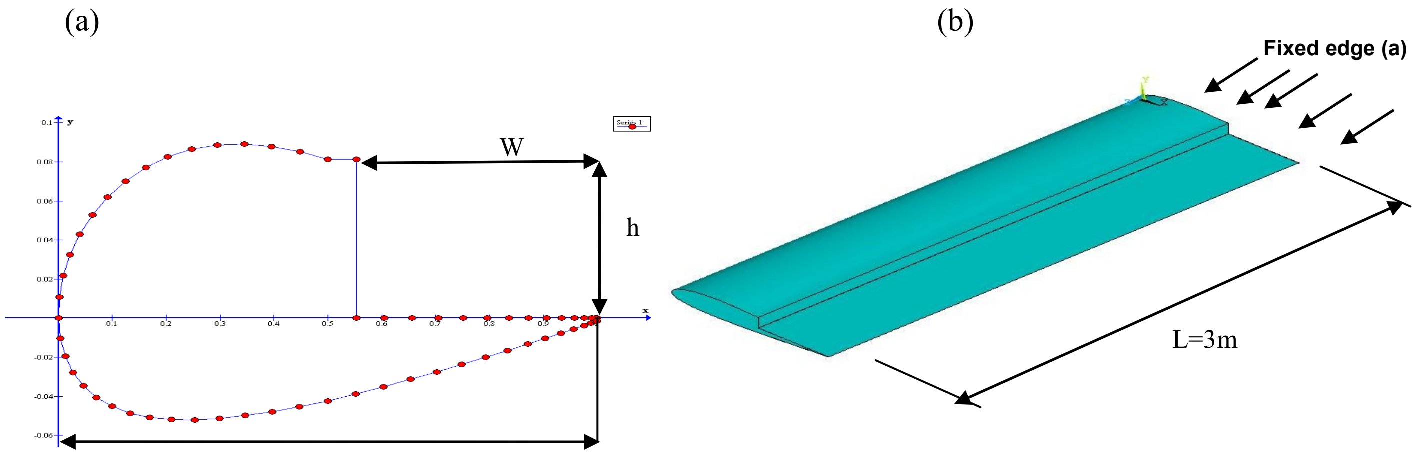


Fig.(2): Finite elements modeling and boundary conditions .

As showed obviously that each node of elements has sex degrees of freedom, then the boundary condition are related to them. The boundary conditions at each edge of the wing were also showed in **Fig (2).** The edges of the plate are assumed to be free to move in plane, but fixed from the other side.

3. Mathematical analysis:

In this investigation, a free vibration problem has been solved for stepped wing geometry. The stepped wing geometry and stepped airfoil are shown in **Fig. 3(a-b).** It consists of a stepped airfoil 50% chord



W

Fig.3 schematic diagram of the stepped wing with fixed end area symmetrically at the sided area

The fundamentals of vibration analysis can be understood by studying the mathematics used to describe its behavior is identical to other simple harmonic oscillators free vibration without damping, where the force applied to the mass by the spring is proportional to the amount of spring displacement "x" in (m) units (we will assume the spring is already compressed due to the weight of the mass) and the proportionality constant, k, which is the stiffness of the spring and has units of force/distance (N/m).

The sum of the forces on the mass then generates this ordinary differential equation as follows :

$$m\ddot{x} + kx = 0. \qquad (1)$$

If we assume that we start the system to vibrate by stretching the spring by the distance of A and letting go, the solution to the above equation that describes the motion of mass is:

$$x(t) = A\cos(2\pi f_n t). \tag{2}$$

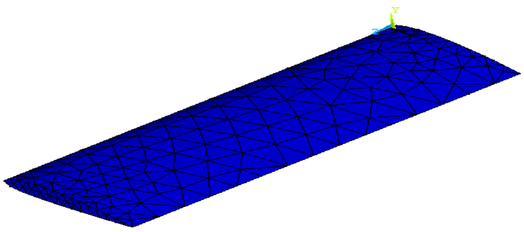
This solution explain that the wing will oscillate with simple harmonic motion that has an amplitude of A and a frequency of f_n. The number f_n is one of the most important quantities in vibration analysis and is called the undamped natural frequency. For the simple mass–spring system, f_n is defined as:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}. \tag{3}$$

Note: Angular frequency ω ($\omega = 2\pi f$) with the units of radians per second is often used in equations because it simplifies the equations, but is normally converted to “standard” frequency (units of Hz or equivalently cycles per second) when stating the frequency of a system [8]

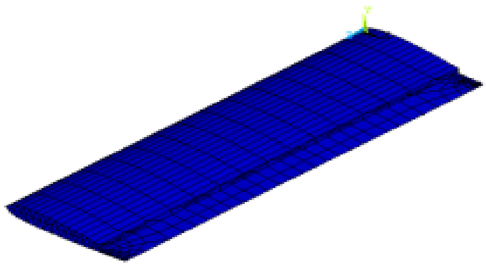
4. Geometrical Modeling

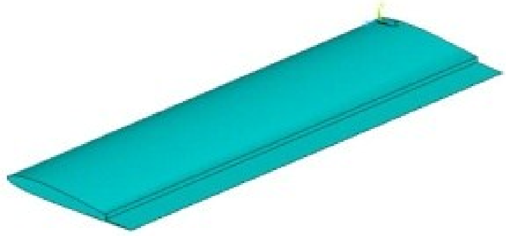
In general, the model is stepped wing with three location of step with respect to the chord of airfoil and fully airfoil 2414 as shown in **Fig.(4).** Each one of them is 3m in length and fixed from one end. The airfoil dimensions are 1000mm chord length, and (1.47*2) mm in thickness. The idea is to construct three types of stepped airfoil with respect to their location from chord. They are: stepped 33% c, stepped50% c, and stepped 66% c, respectively depending on the location of step. It's important to refer that the lower surface is remain without change and the step is in the upper surface of the airfoil only.



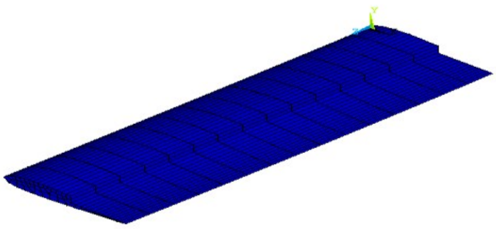
a- fully no stepped wing

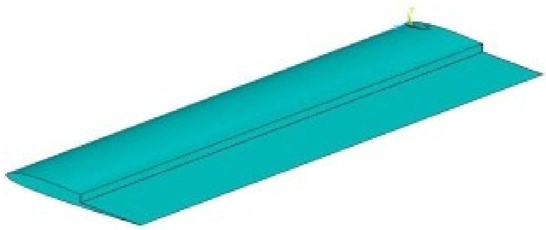
a^-





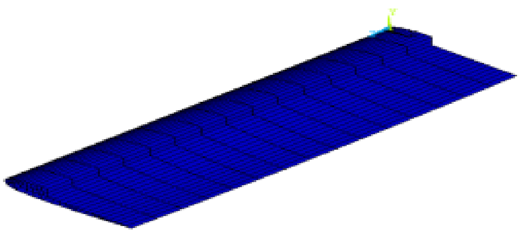
b- 33% chord stepped wing

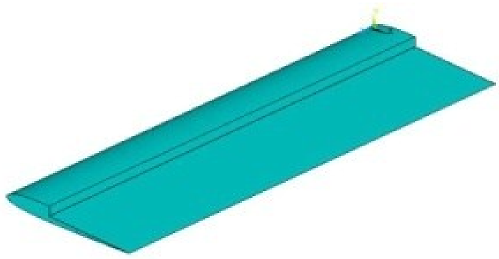




c^-

C- 50% chord stepped wing





d- 66% chord stepped wing d^-

Fig. (4) fully and stepped wing models with and without mesh generation.

5-Results and Discussion:

In this research three cases of different stepped airfoil where studied; they are 33%, 50% and 66% stepped chord airfoil wing. The most important results of free vibration of the free vibration analysis are frequency and mode shapes. Due to the large numbers of results which excluded for the analysis the concentration will be on the displacement (Uy) in Y-direction.
So it has direct relationship to the first, second modes (most the worst modes) and third mode.

Table (1) presents natural frequency for three modes .Generally, it was noted that the changing in airfoil geometry has a great noticed effect on the natural frequency and behavior or responses of the wing. In the other hand, the location of these change also play an important role in the direction of increasing or decreasing the stiffness of the wing.

The natural frequency is increased with increased with increasing the mode number for the first three modes, it was noted that the maximum natural frequency was occurred at stepped 66% chord for all modes and decreased at 50%, 33% and no stepped wing respectively.

The change in the airfoil to develop part of the wing skin to a straight or normal part connect with the other parts of surface skin may be represent a special case for the spar (which connect the upper and lower skin to each others, so the change in airfoil increase the amount of inertia of area or in other definition increase the flexural stiffness (EI), the increasing in the stiffness lead to increase the natural frequency for each model.

The change in the location of the airfoil shape give different height of stepped and then different flexural stiffness, this is why the difference in natural frequency for chord 66%, 50%and 33%.And this reason is also explain why the difference in natural frequency between the 3rd and 1st mode for 66% chord stepped wing is maximum and it decreased at 50%, 33% and no stepped wing, respectively.

It was noted from literature research [9]that the maximum stress occur at the region of maximum chord thickness and decreased respectively with decreasing in the chord height, This mean that this region suffers from stress constriction. So for 66% stepped chord the stress will be reduce due to increasing the stiffness under same boundary conditions comparing with 33% stepped chord which represents the smallest thickness of the stepped wing types and were subjected to minimum stresses.
It also can be noticed from results that for no stepped (fully airfoil) the third mode shape is the torsional mode at (10.7 Hz) natural frequency while the third mode is the simple bending for 66% and 50% and bending for 33% stepped chord .This mean that the change in wing shape leads also to increase the resistance of the wing for twisting or torsional modes .this change of the third mode at (no stepped) airfoil from torsion to bending and simple bending called (mode transform) as shown in figures at appendix- A.

Table (1): presents Natural Frequency (ω_n) for stepped and no stepped airfoil 2414 for five mode shapes.

Model index	Natural Frequency (ω_n) (rad/sec.)			
	1^{st} mode	2^{nd} mode	3^{rd} mode	
Stepped 66% chord	4.06 (simple bending)	11.45 (simple bending)	14.68 (simple bending)	
Stepped 50% chord	2.71 (simple bending)	8.72 (simple bending)	13.31 (bending)	
Stepped 33% chord	2.62 (simple bending)	8.41 (simple bending)	12.13 (bending)	
Fully(no stepped)	2.5 (bending)	7.99 (simple bending)	10.7 (torsion)	

6. Conclusions:

1- The changing in the airfoil shape has large affect at the vibrational characteristics of the wing.
2- Location of the step (w) on the airfoil upper surface plays an important role to increase or decrease the stiffness of the wing.
3- The changing in the airfoil shape was also affect on the mode shapes and it may change the wing mode at higher frequency (mode transformation).
4- Natural frequency increased with increasing of the height of the step (h) at the airfoil upper surface.

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Nomenclature:

AOA = angle of attack

C = chord length of airfoils

Ux= displacement in x-direction

Uy= displacement in y-direction

Uz= displacement in z-direction

ROT X= Rotational displacement in x-direction

ROT Y= Rotational displacement in y-direction

ROT Z= Rotational displacement in z-direction

Clmax= maximum lift coefficient

R/L = ratio of radius to length of cylinder

h= stepped airfoil height

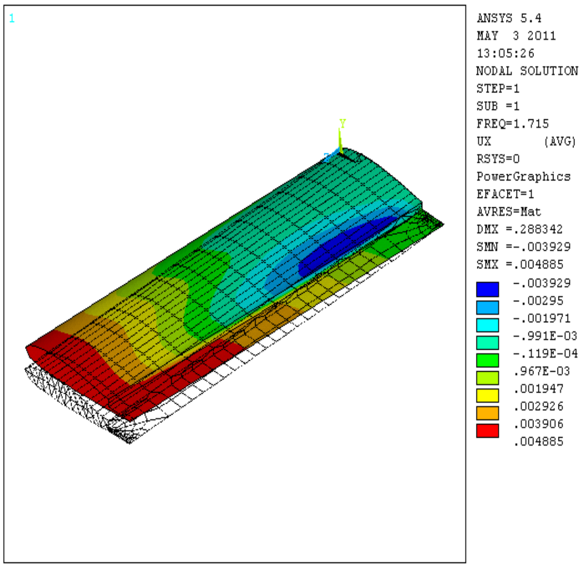
w= stepped airfoil width

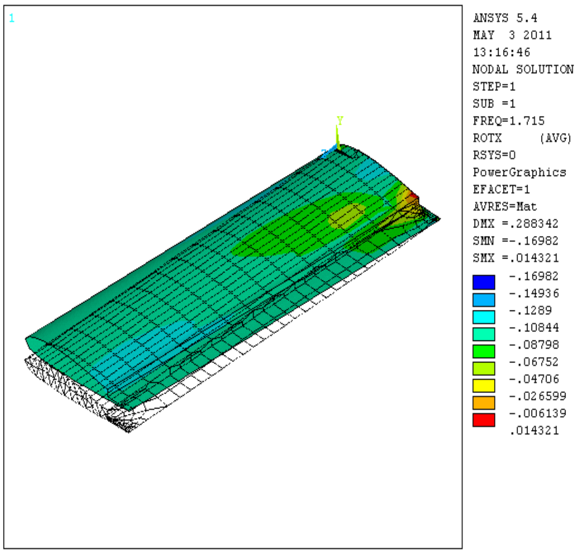
r_t = the taper ratio

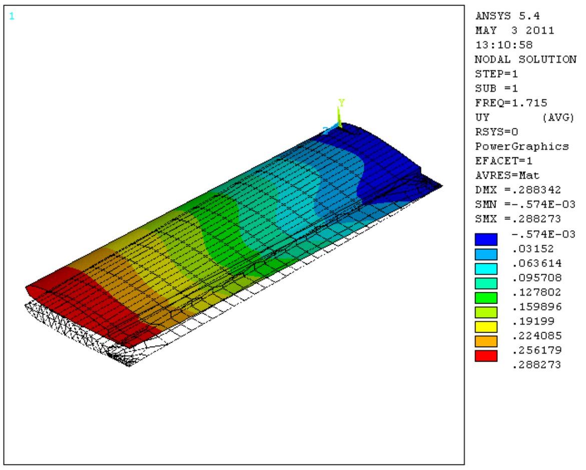
SRM = switched reluctance motors

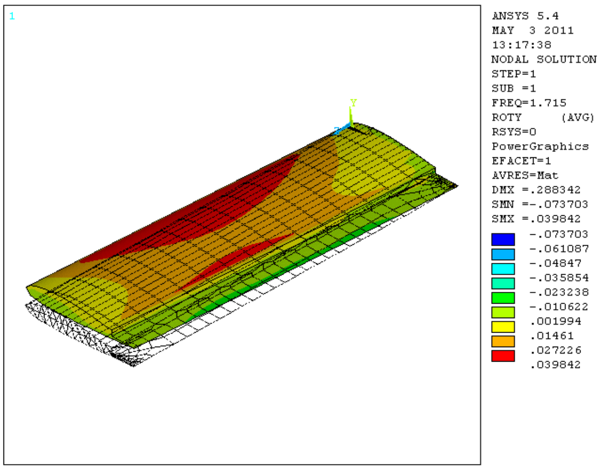
Appendix (A):

Appendix (A) gives some details about the nodal solutions of the no stepped and stepped wings for deformed and undeformed first, second and third mode shapes represents displacements in (x,y,z) directions and also rotational displacement in (x,y,z) direction .









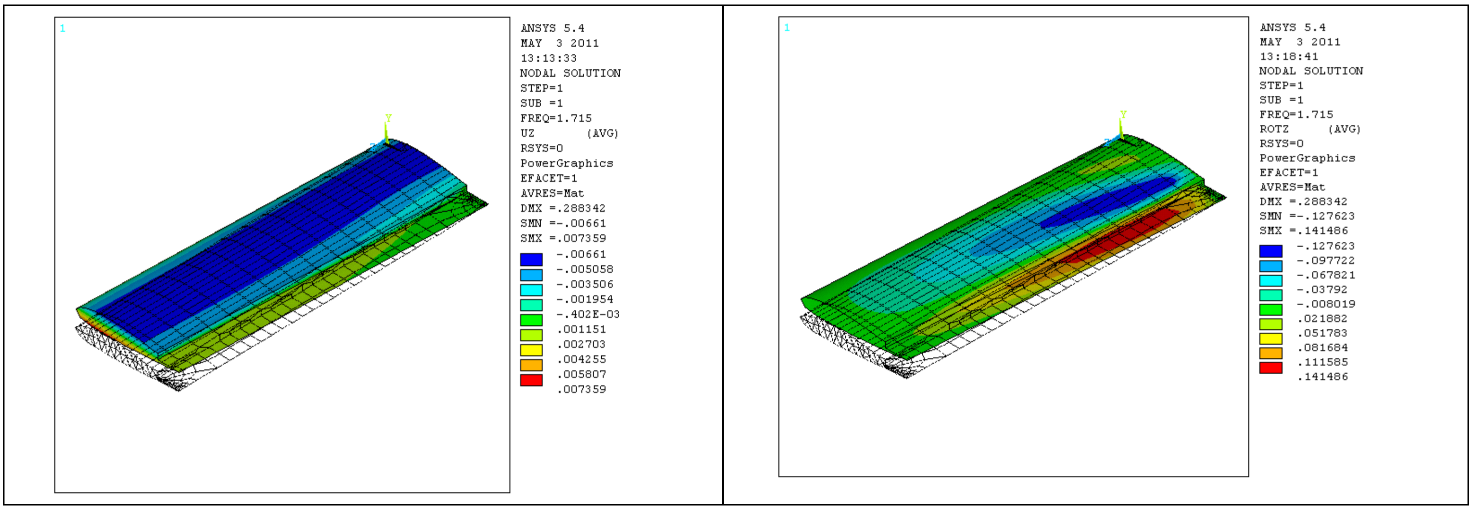


Fig.(5) first mode shape for 33% stepped wing deformed
(colored regions) and undeformed (black lines)

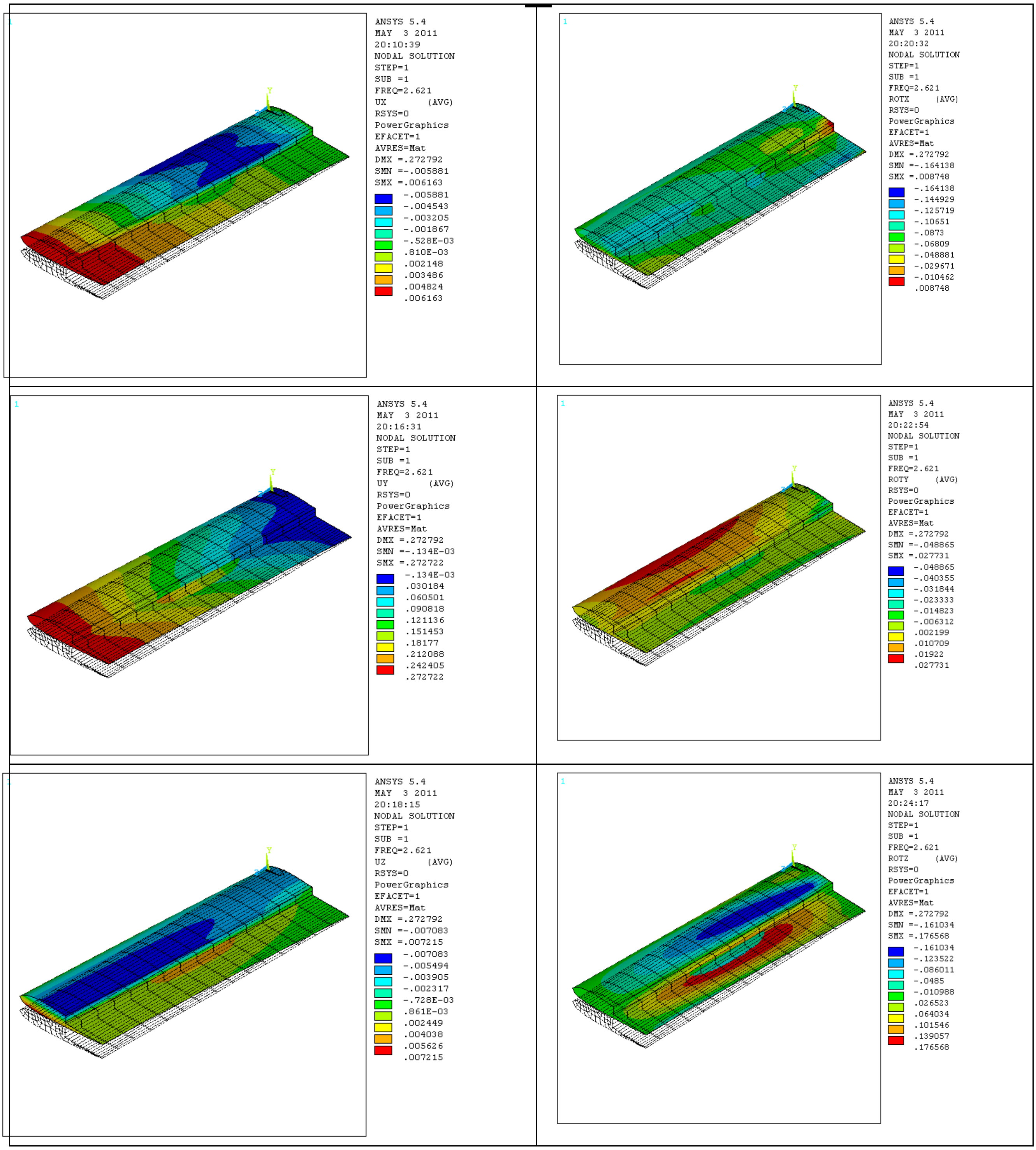


Fig.(6) first mode shape for 50% stepped wing deformed (colored regions) and undeformed (black lines)

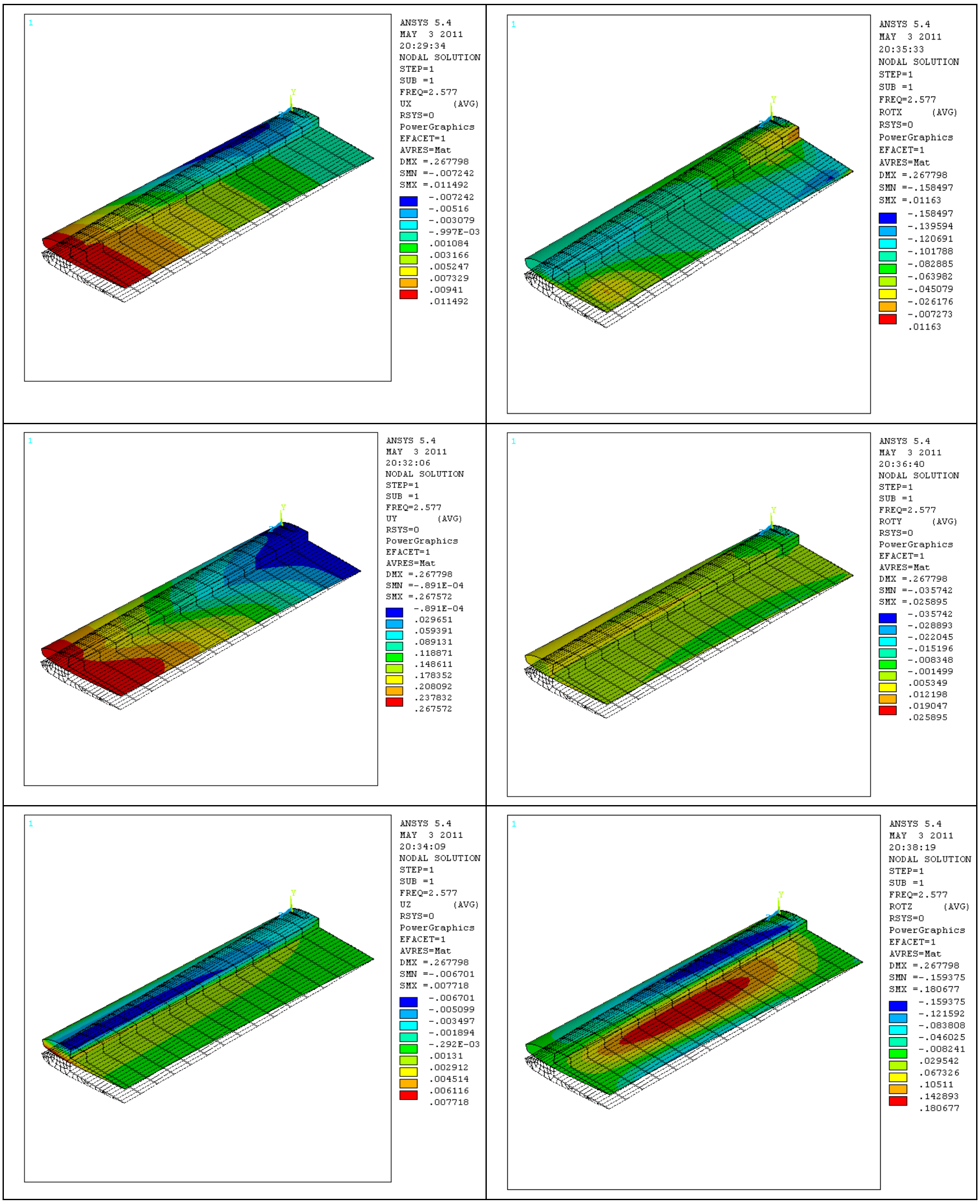


Fig.(7) first mode shape for 66% stepped wing deformed
(colored regions) and undeformed (black lines)

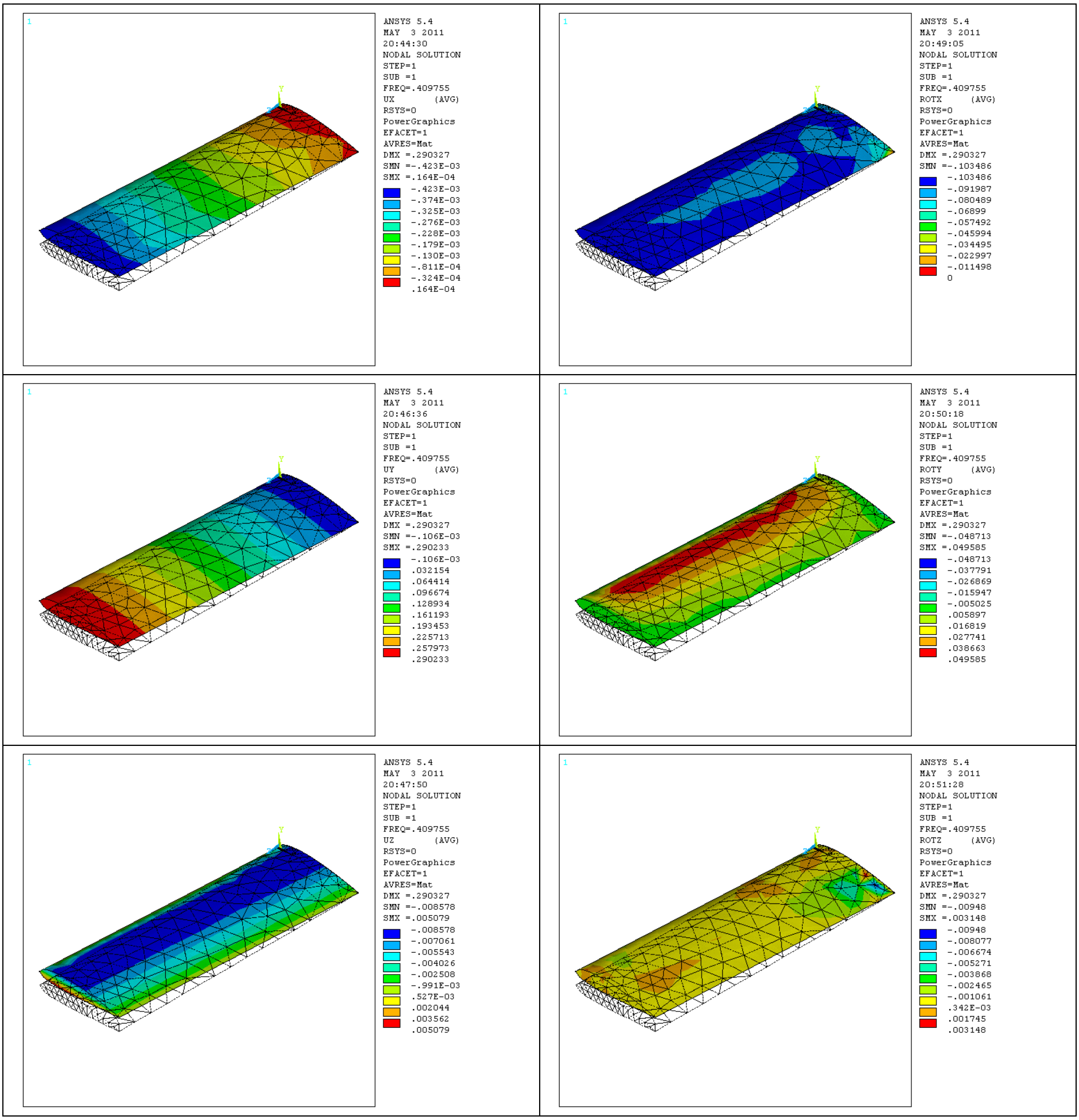


Fig.(8) first mode shape for fully (no stepped) wing deformed (colored regions) and undeformed (black lines)

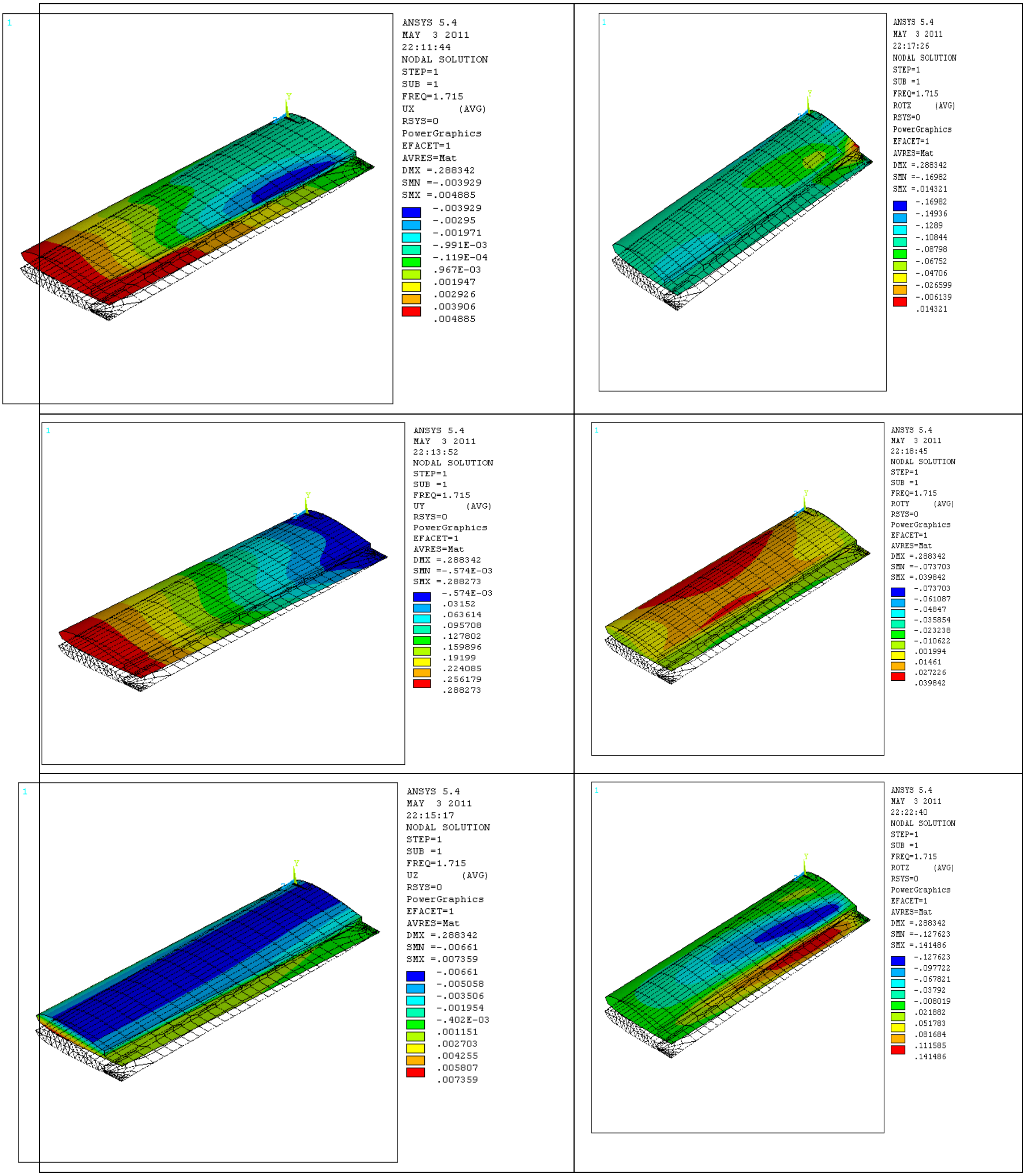


Fig.(9) second mode shape for 33% stepped wing deformed (colored regions) and undeformed (black lines)

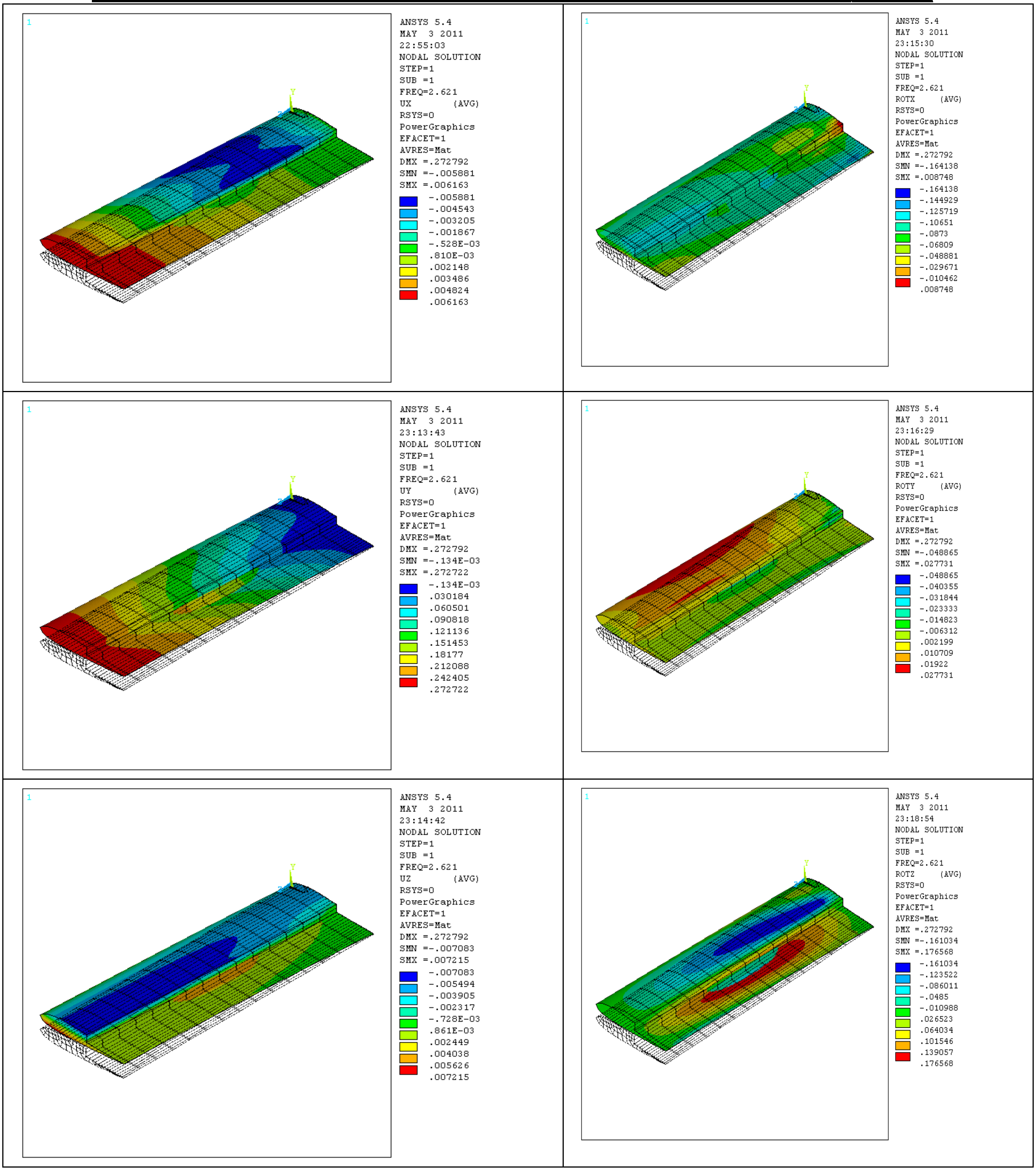


Fig.(10) second mode shape for 50% stepped wing deformed (colored regions) and undeformed (black lines)

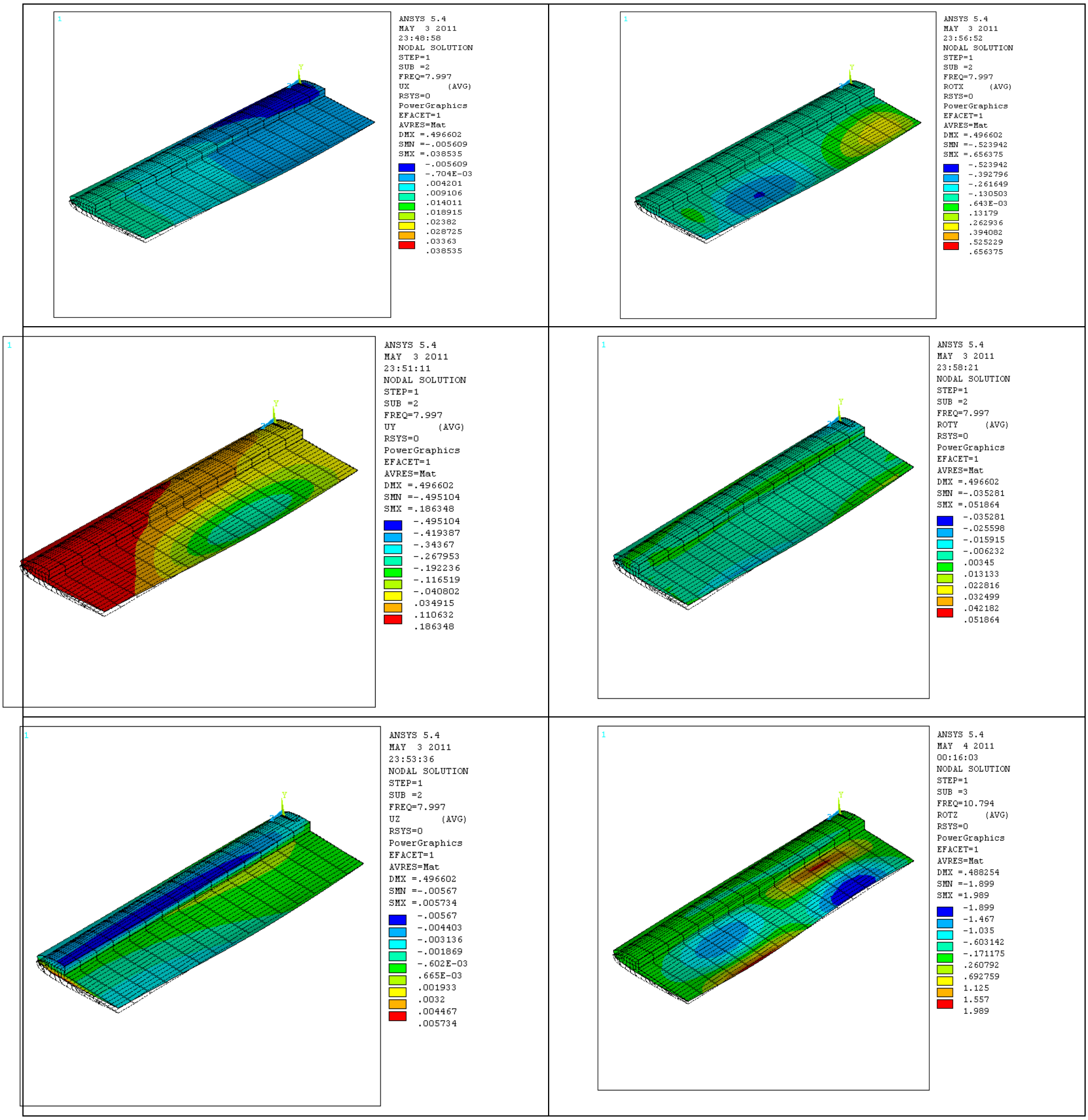


Fig.(11) second mode shape for 66% stepped wing deformed (colored regions) and undeformed (black lines)

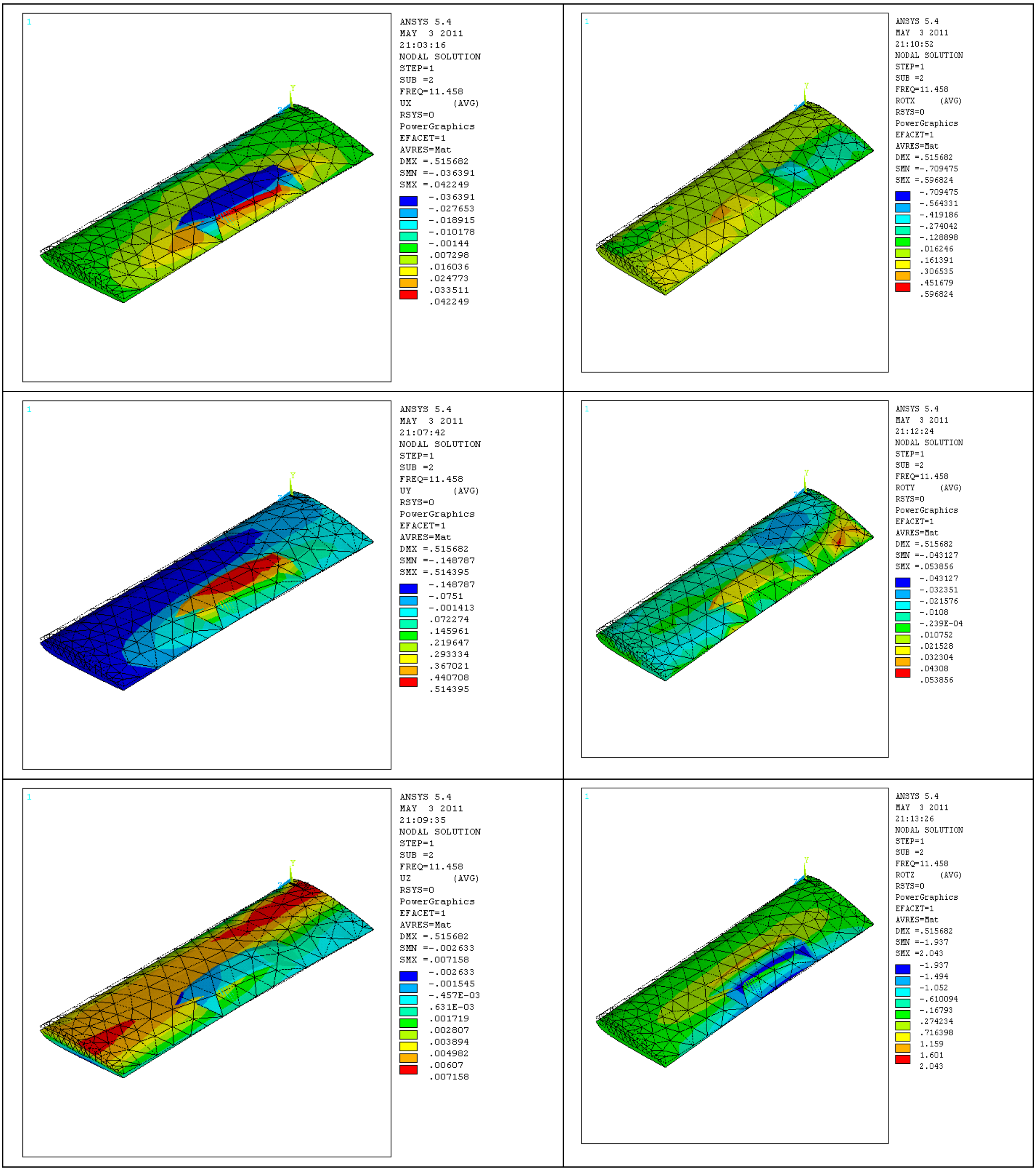


Fig.(12) second mode shape for fully no stepped wing deformed (colored regions) and undeformed (black lines)

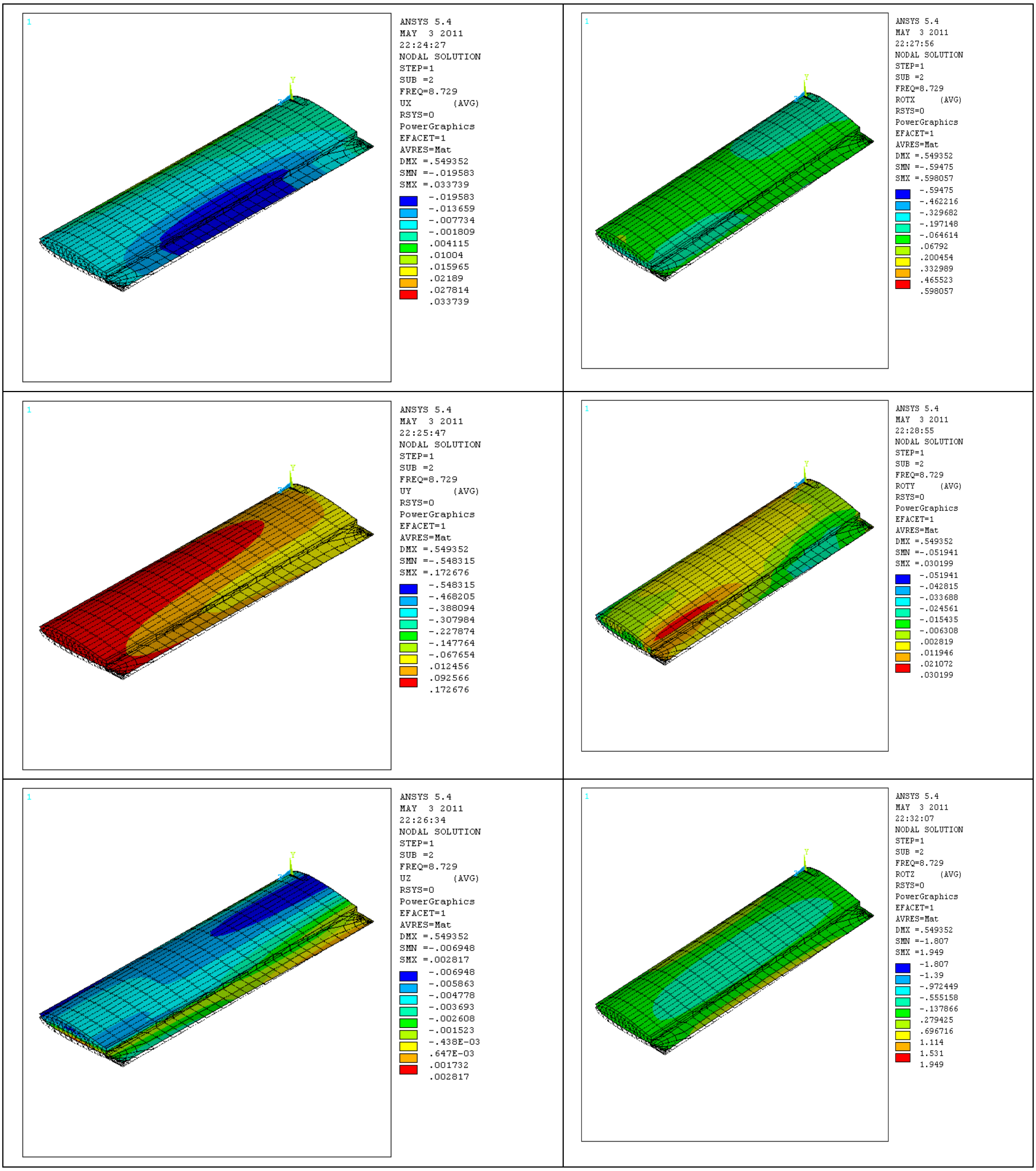


Fig.(13) third mode shape for 33% stepped wing deformed
(colored regions) and undeformed (black lines)

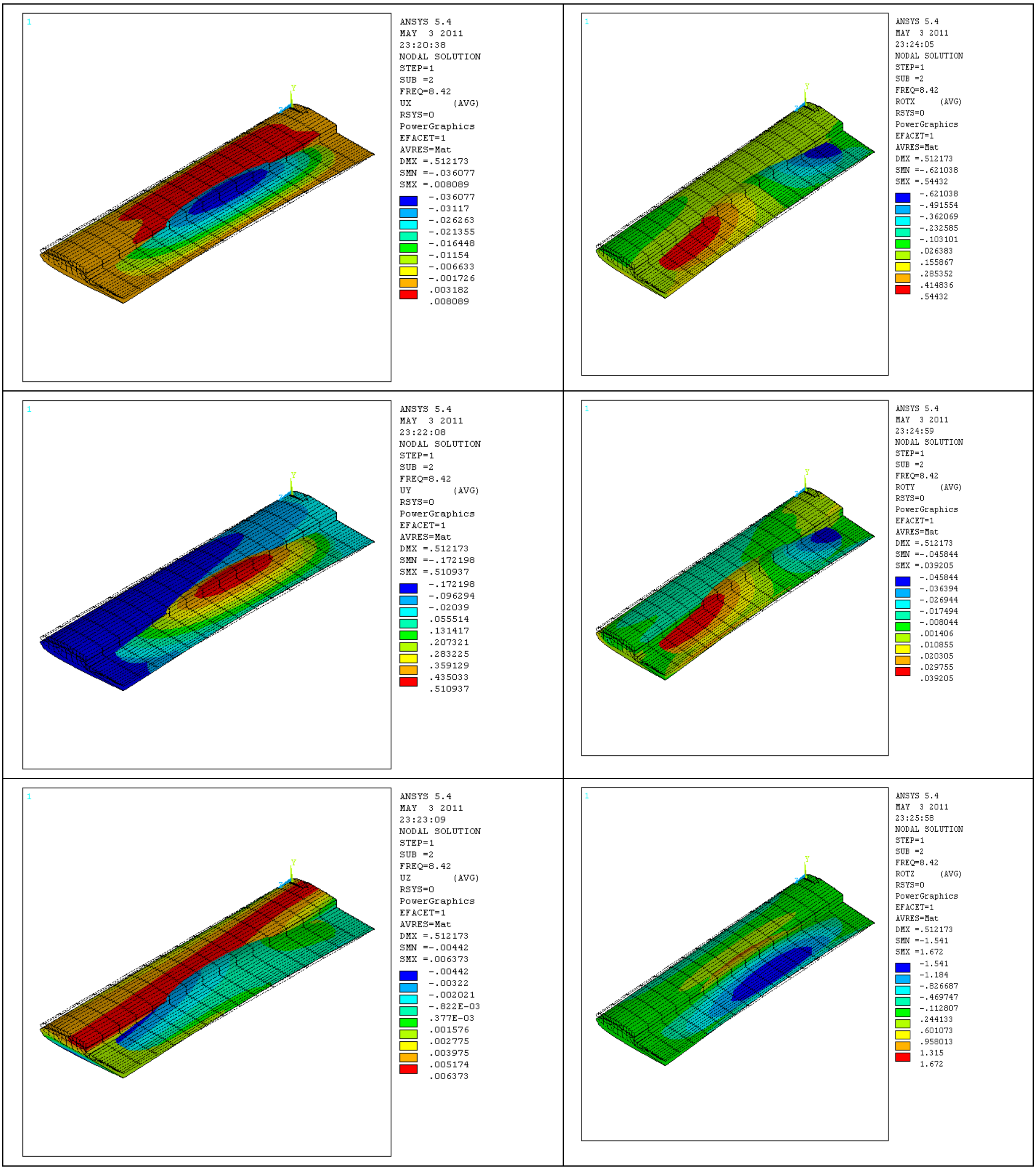


Fig.(14) third mode shape for 50% stepped wing deformed (colored regions) and undeformed (black lines)

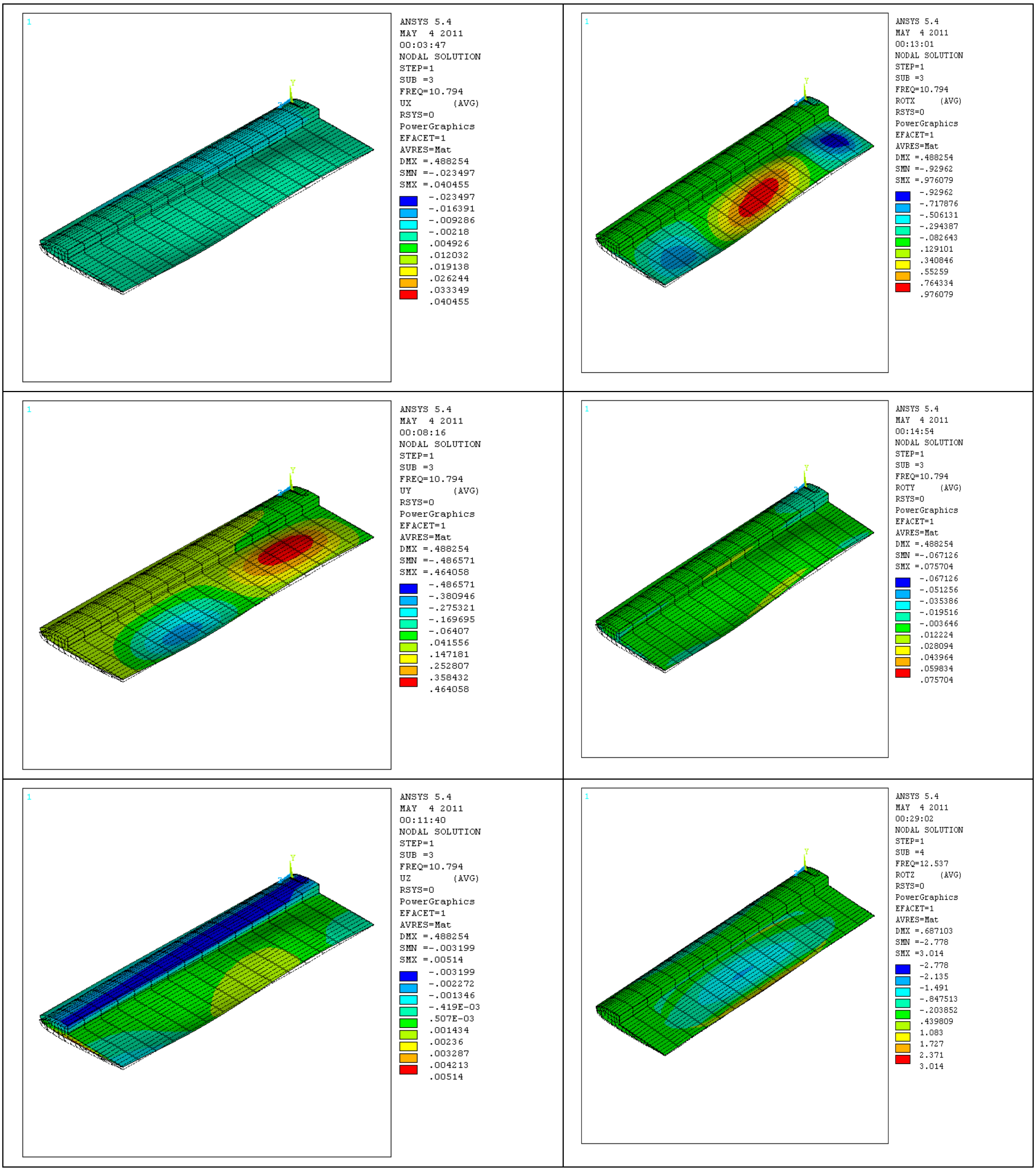


Fig.(15) third mode shape for 66% stepped wing deformed (colored regions) and undeformed (black lines)

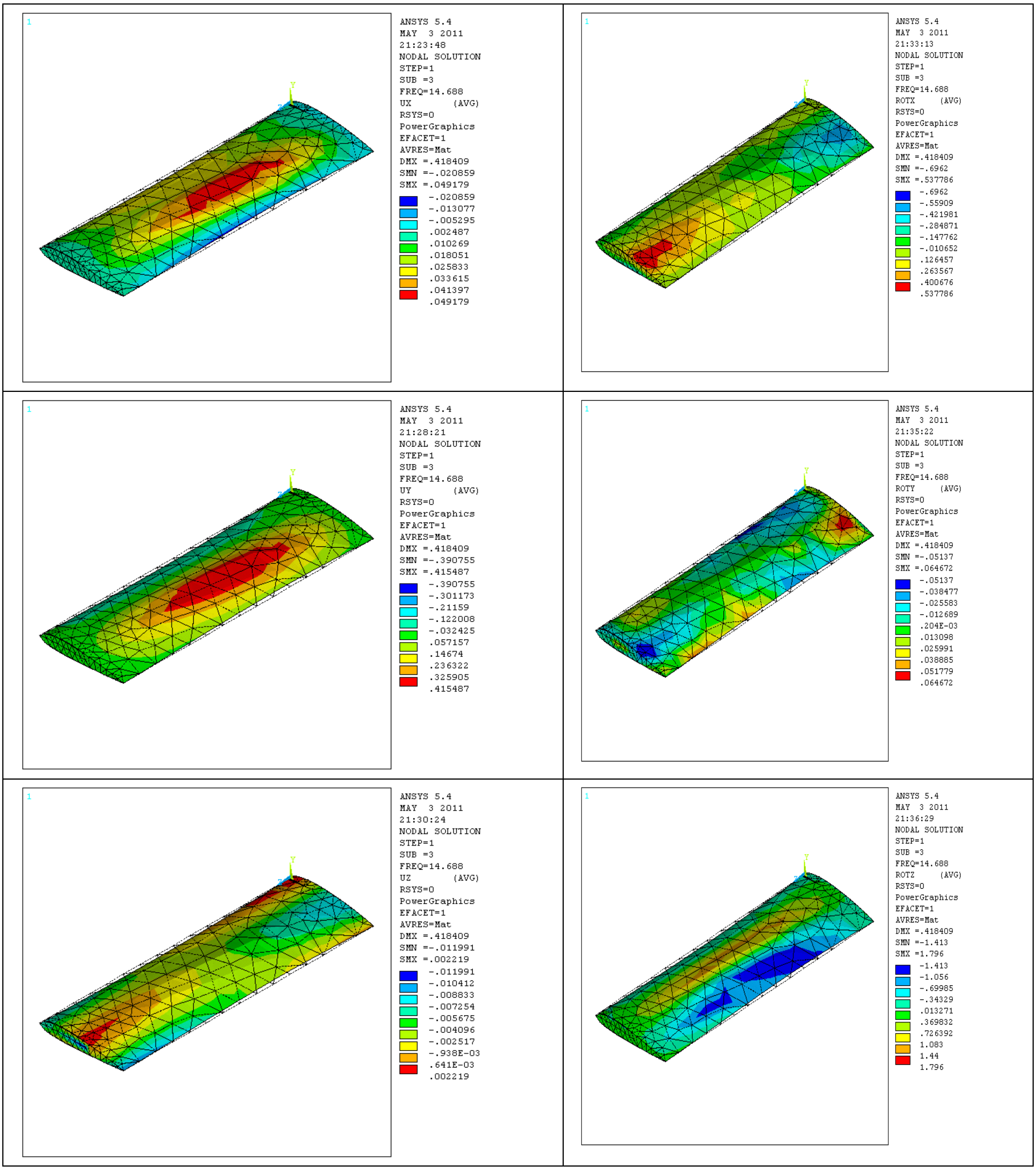


Fig.(16) third mode shape for fully no stepped wing deformed (colored regions) and unreformed (black lines).