DESIGN AND STRUCTURAL ANALYSIS OF TRANSPORT AIRCRAFT WING

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Abstract: This project deals with the structural analysis of transport aircraft wing. The aim of this project work is to design and analyse the wing of a transport aircraft, and to obtain the Stress and displacement due to the applied loads. For this we did a comparative study on particular transport aircraft.

The optimum design parameters for a transport aircraft are suitably selected based on the classical method of calculations and then a 3-Dimensional model of the wing structure will be designed using the CATIA-V5 software, which is developed by Dassault systems and is very famous for its 3D modeling capabilities.

The Major loads acting on the aircrafts wing are determined and the bending moments, shear force etc., are also determined. The wing structure was also explained and functions of each component and their arrangement are also studied. The methodology of finite element method and the detailed description about various FEM tools have been studied and implemented in this work. The linear static analysis carried out using MSC Nastran and Patran, patran is used for carrying out operations like importing the geometry, Finite element modelling , defining material properties , Loads and cross sectional properties of the structure , whereas Nastran is used for as a solver. When carrying out a linear static analysis, in the finite element method the stress of a wing structure is determined.

Key words: Transport Aircraft Wing, CATIAV5, Finite Element Modelling, MSC PATRAN &NASTRAN, linear static analysis, Compressive stress, Torsion, shear force bending moment variation.

1) INTRODUCTION

1.1 WING:

The wing is a framework made up of spars and ribs and covered with metal. Wings develop the major portion of the lift of a heavier-than-air aircraft. Wing structures carry some of the heavier loads found in the aircraft structure. The particular design of a wing depends on many factors, such as the size, weight, speed, rate of climb, and use of the aircraft. The wing must be constructed so that it holds its aerodynamics shape under the extreme stresses of combat maneuvers or wing loading.

Wing is mainly used as a lift producing component in an aircraft.

1.2) COMPONENTS OF WING:

The internal wing structure, consisting of spars, ribs and stringers, and the external wing, which is the skin.The wing skin serves as a smooth covering over the wing support structure providing the proper lift required for powered flight The skin combined with the ribs, stringers, and spars maintain the proper airfoil shape for the entire wingspan

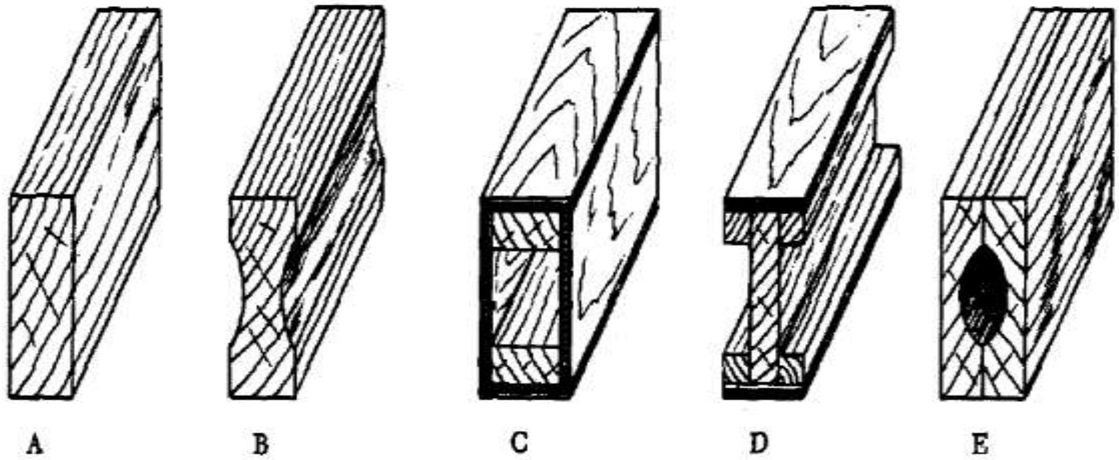
1.2.1 Spar:

Spars are the main structural members of the wing., running spanwise at right angles (or thereabouts depending onwing sweep to the fuselage. The spar carries flight loads and the weight of the wings whilst on the ground. Other structural and forming members such as ribs may be attached to the spar or spars, with stressed skin construction also sharing the loads where it is used. They extend from the fuselage to the tip of the wing. All the load carried by the wing is taken up by the spars. The spars are designed to have great bending strength.

The front spar of the wing serves as a primary load path for the bending moments imposed by the lift of the wing.
The ribs also need to be supported, which is done by the spars. These are simple beams that usually have a cross-section similar to an I-beam. The spars are the most heavily loaded parts of an aircraft. They carry much more force at its root, than at the tip. Since wings will bend upwards, spars usuall carry shear forces and bending moments. Aerodynamic forces not only bend the wing, they also twist it. To prevent this, the introduction of a second spar seems logical. Torsion now induces bending of the two spars, which is termed differential bending. Modern commercial aircrafts often use two-spar wings where the spars are joined by a strengthened section of skin, forming the so-called torsion-box structure. The skin in the torsion-box structure serves both as a spar-cap (to resist bending), as part of the torsion box (to resist torsion) and to transmit aerodynamic forces.
Some of the forces acting on a wing spar are

- Upward bending loads resulting from the wing lift force that supports the fuselage in flight. These forces are often offset by carrying fuel in the wings or employing wing-tip -mounted fuel tanks.
- Downward bending loads whilst stationary on the ground due to the weight of the structure, fuel carried in the wings, and wing-mounted engines if used.
- Drag loads dependent on airspeed and inertia.
- Rolling inertia loads.

- Chordwise twisting loads due to aerodynamic effects at high airspeeds often associated with washout, and the use of ailerons resulting in control reversal



1.2.2 Rib:

Ribs give the shape to the wing section, support the skin (prevent buckling) and act to prevent the fuel surging around as the aircraft manoeuvres. They serve as attachment points for the control surfaces, flaps, undercarriage and engines. The ribs need to support the wing-panels, achieve the desired aerodynamic shape and keep it, provide points for conducting large forces, add strength, prevent buckling, and separate the individual fuel tanks within the wing.

There are many kinds of ribs. Form ribs consist of a sheet of metal, bent into shape. Plate-type ribs consist of sheet-metal, which has upturned edges and weight-saving holes cut out into it. These ribs are used in conditions of light to medium loading. Truss ribs consist of profiles that are joined together. These ribs may be suitable for a wide range of load-types. Closed ribs are constructed from profiles and sheet-metal, and are suitable for closing off sections of the wing. This rib is also suitable for a variety of loading conditions. Forged ribs are manufactured using heavy press-machinery, and are used for sections where very high loads apply. Milled ribs are solid structures, manufactured by milling away excess material from a solid block of metal, and are also used where very high loads apply.

1.2.3 Stringers:

The stringers on the skin panels run in the length of the wing, and so usually need to bridge the ribs. There are several methods for dealing with this problem. The stringers and ribs can both be uninterrupted. The stringers now run over the rib, leaving a gap between rib and skin. Rib and skin are indirectly connected, resulting in a bad shear load transfer between rib and skin. The stringers can be interrupted at the rib. Interrupting the stringer in this way certainly weakens the structure, and therefore extra strengthening material, called a doubler, is usually added. Naturally, the stringers can also interrupt the rib. The stringers now run through holes cut into the rib, which also causes inevitable weakening of the structure.

2) LITERATURE SURVEY

Comparing the data of some of the existing trainer aircrafts that approximately matches our ideas and we get the required values for wing design:

Name Of Aircrafts	**EURO FIGHTER TYPHOON**	**DESSAULT RAFALE**	**CHENGDU J10**	**SAAB 39 GRIPEN**	**IAI KFIR C2**	**Average**
Wing span (m)	10.98	10.8	9.75	8.4	8.22	9.63
Length (m)	15.96	15.27	15.49	14.8	15.65	15.434
Height (m)	5.28	5.34	5.45	4.5	4.55	5.024
Wing Area (m^2)	51.2	45.7	33.1	30	34.8	38.96
Service Ceiling (m)	16765	15235	18000	18500	17680	17236
Rate Of Climb (m/s)	315	304.8	285	254	233	278.36
Stall Speed (m/s^2)	72.589	76.459	75.392	70.754	78.358	74.7104
Range (Km)	2900	3700	1850	3938	1300	2737.6
Max Speed (m/s)	590.09	531.08	649.1	590.09	590.09	590.09
Aspect Ratio	2.354695313	2.552297593	2.871978852	2.352	1.94162069	2.41451849

Max Weight (Kg)	23500	24500	19277	14250	16200	19545.4
Wing Loading	312	306	381	283	254.8	307.36
Empty Weight (Kg)	11000	10196	9750	6800	7285	9006.2
Sweep Angle	53					Average

3) STRUCTURAL DESIGN OF WING

By comparing the data of various jet trainer and averaging the values, we come to a conclusion of finalized values of wing area, wing span and weight of the aircraft.

Wing area $S = 38.96\ m^2$,

Wing span $b = 9.63$ m,

Weight, $W = 19545.4$ Kg

Geometry and performance Calculations:

Lift Coefficient - $C_{Lmax} = 2\times W/\ \rho\times(V_{STALL})^2 \times S$

$W = 19545.4 \times 9.81 = 191740.374$ N

$\rho_0 = 1.225$ kg/m^3

$V_{STALL} = 74.7104$ m/s

S= 38.96 m^2

Parameter	**Values**	**Unit**
Clmax	1.439548846	No unit
Talt	216.5	K
ρ	0.1948	kg/m^3
V0	590.09	m/s
T0	288	K

Table 3.1 Values used

The optimum design parameters for a transport aircraft are suitably selected based on the classical method of calculations and then a 3-Dimensional model of the wing structure will be designed using the CATIA-V5 software, which is developed by Dassault systems and is very famous for its 3D modeling capabilities.

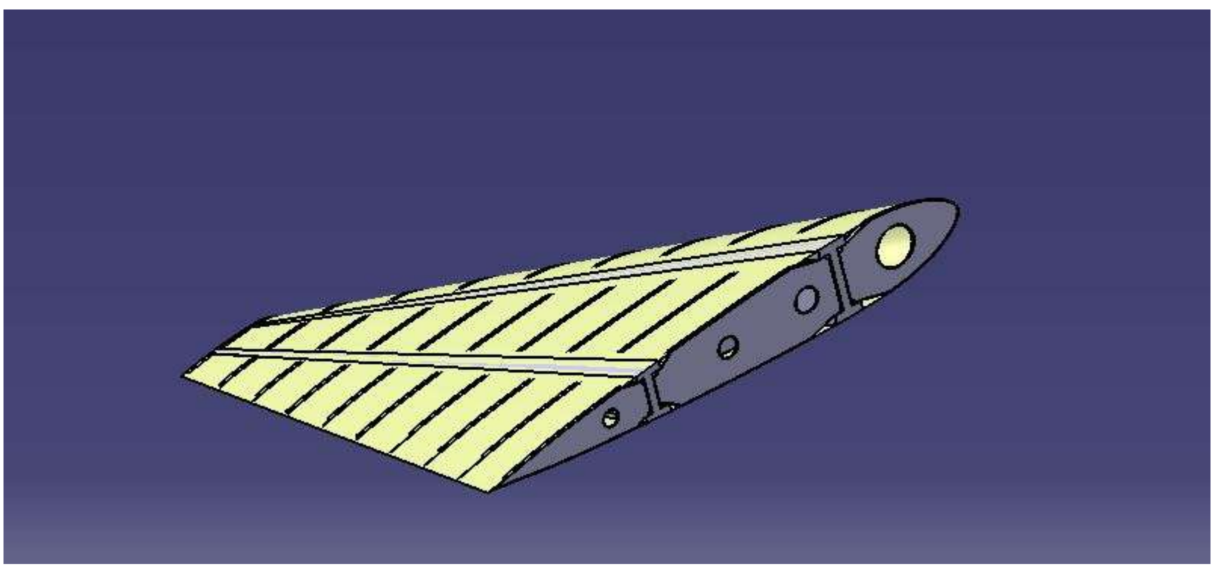


Fig 3.1 : Design of a wing

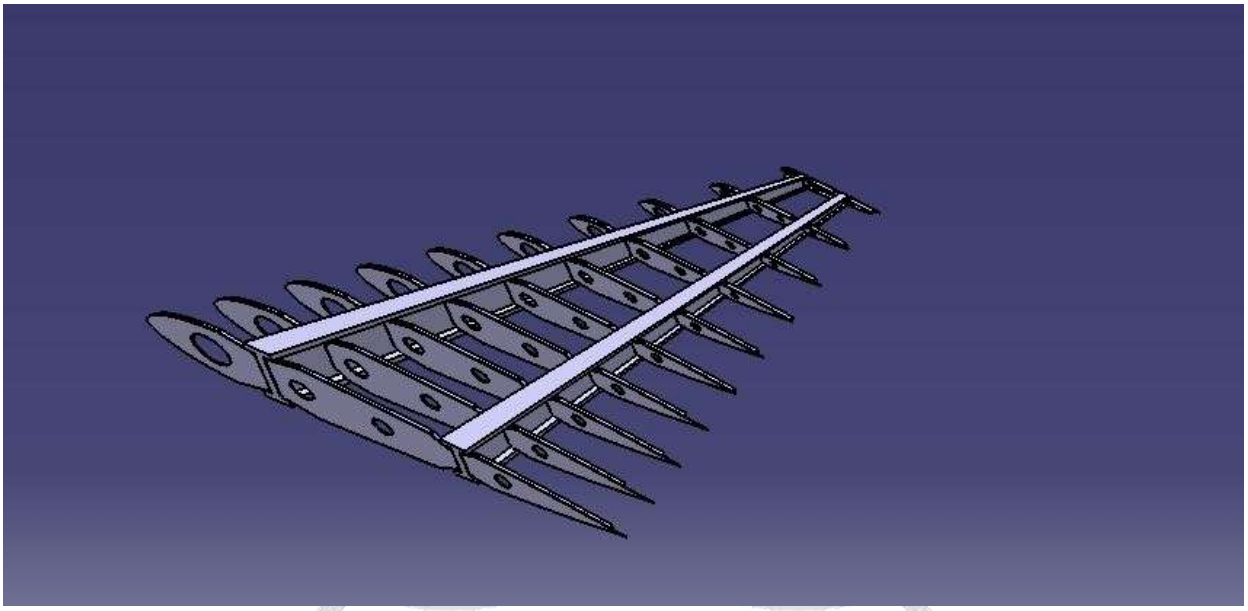


Fig 3.2 : Structural components of wing

4 ANALYSIS USING NASTAN PATRAN SOFTWARE

4.1 MESHING:

Meshing is process of breaking the model into small pieces (finite elements). The network of nodes and elements is called a mesh. The types of elements extensively used in meshing the are Quad and Tria. To prevent failure, parameters should be verified periodically. Duplicates, the boundaries, connectivity have to be verified for each element. Skew and aspect for a Tria element need to be verified. For quad element Aspect, warp, taper and skew to be verified.

4.1.1 Element details

Sketsh section			**Element number**
Skin	Upper skin		1:450
	Lower skin		451:900
Spars	Front spar	web	901:960
		flange	1202:1231,1232:1261
	Rear spar	web	961:1020
		flange	1262:1291,1292:1321
Ribs			1172:1201 1021:1164 1166:1171

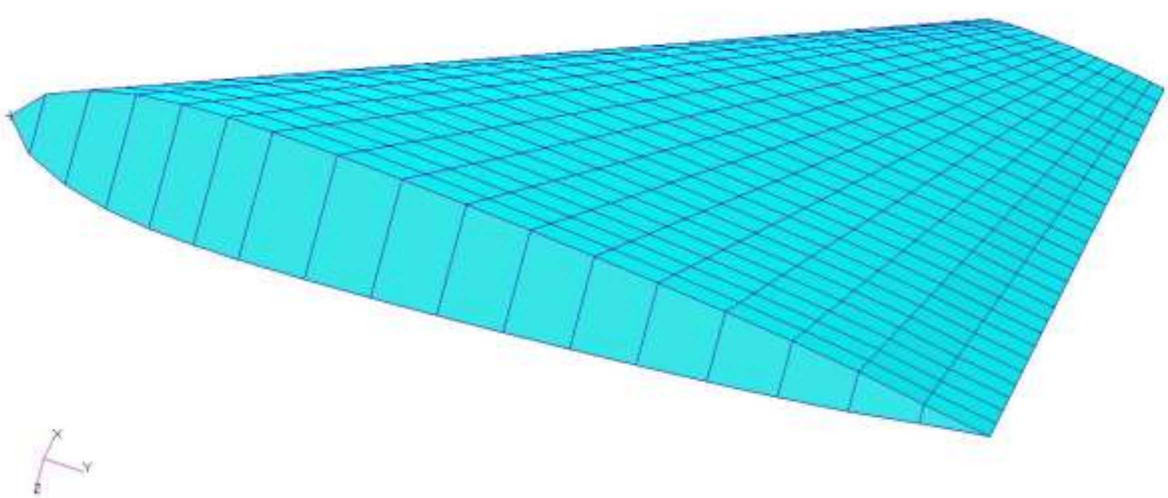


Fig 4.1 Meshed wing structure _ shade mode

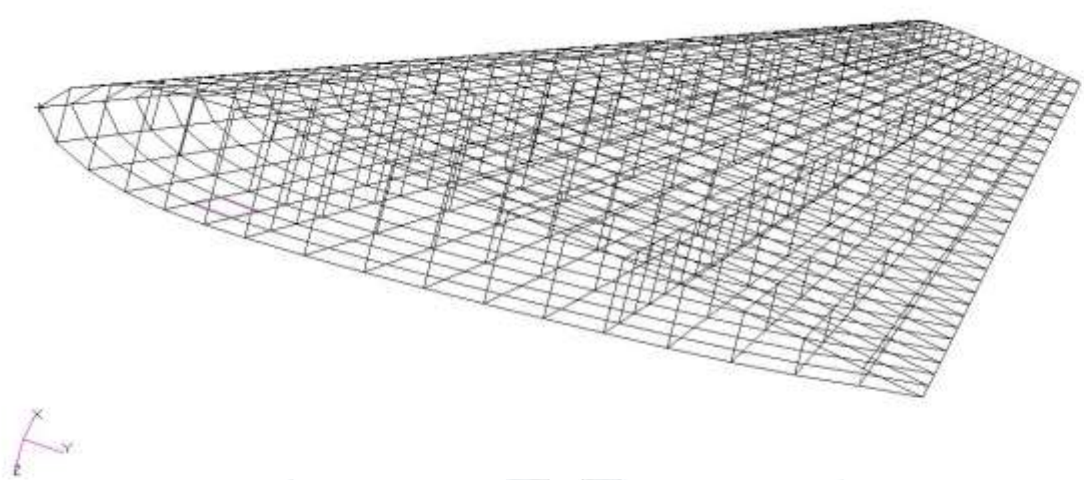


Fig 4.2 : Meshed wing structure_Wire frame mode

5) RESULTS

5.1 PROPERTIES AND MATERIALS:

For the skin section, both upper and lower skin, the properties of membrane is given by providing thickness. And for other sections such as ribs and web portion of the spars, the property of shell is given by providing a thickness. For the flange portion of the spar, the property of rod is given with area of the flange.

S.No	Material	Young's Modulus (GPa)	Poison Ratio	Density (g/cc^3)	Yield Strength (MPa)	UTS (MPa)
1	Titanium Alloy	115	0.3	4.48	710	830

Table 5.1 Material used

5.2 LOADS AND BOUNDARY CONDITION

Loads

Lift Load = 9G
Factor of Safety = 1.5
Exposed wing area = 38.96m/s^2
Chord length = 1.94m

The structure of an aircraft is required to support two distinct classes of load: the first, termed ground loads, includes all loads encountered by the aircraft during movement or transportation on the ground such as taxiing and landing loads, towing and hoisting loads; while the second, air loads, comprises loads imposed on the structure during flight by maneuvers and gusts. In addition, aircraft designed for a particular role encounter loads peculiar to their sphere of operation. Carrier born aircraft, for instance, are subjected to catapult take- off and arrested landing loads: most large civil and practically all military aircraft have pressurized cabins for high altitude flying.

The two classes of loads may be further divided into surface forces which act upon the surface of the structure, e.g. aerodynamic and hydrostatic pressure, and body forces which act over the volume of the structure and are produced by gravitational and inertial effects. calculation of the distribution of aerodynamic pressure over the various surface of an aircraft's structure is presented in numerous texts on aerodynamics and will therefore not be attempted here. Load type applied on the horizontal wing to measure the displacement at the nodal point on the object and it is been applied at frequent intervals of the ribs.

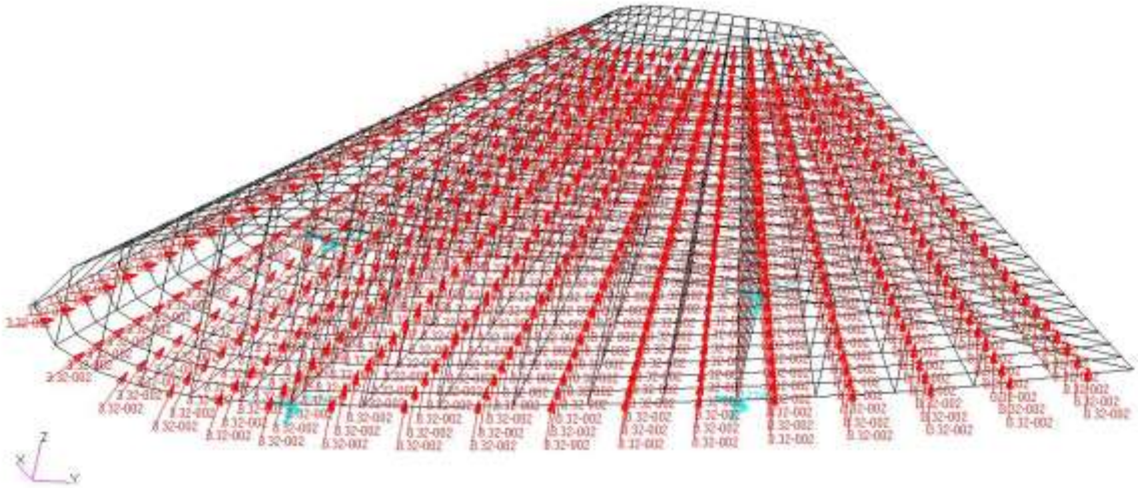


Fig 5.1 – Load applied at the nodal point

Boundary condition

Front spar and the rear spar in horizontal wing are attached to after end of the fuselage. So the displacement is arrested at the leading edge spar and trailing edge spar.

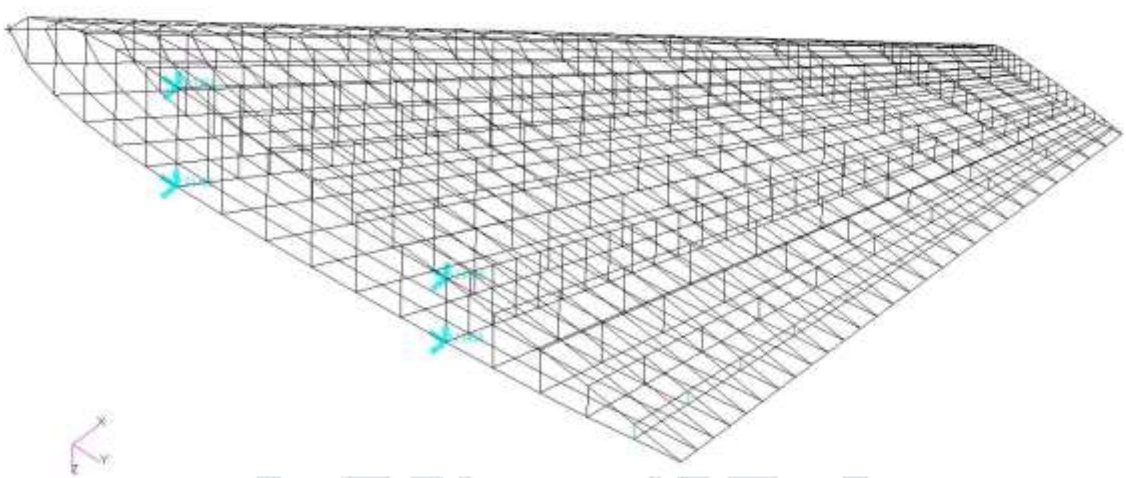


Fig 5.2 – Spars in horizontal wing

6) CONCLUSION

S.No	Material	Allowable Stress (MPa)	Acting Stress (MPa)
1	Titanium	710	585

- Stress analysis of the titanium wing is carried out and maximum stress is identified.
- FEM approach is followed for the stress analysis of the wing. Maximum tensile stress of 585 MN/m^2 is observed.
- Several iterations are carried out to obtain a mesh independent value for the maximum stress.

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