International Journal of Advanced Scientific Research and Management, Vol. 1 Issue 2, February 2016.
www.ijasrm.com

Design And Development Of Energy Absorption Fixtures For Safe Belly Landing On Land For a Typical Aircraft Configuration

Charles.G.Martin[1] and Dr. A. Arokkiaswamy[1],
[1] Department of Aeronautical Engg, DSCE, Shavige Malleshwara hills,
Bangalore-560078,India

Abstract

Crash landing is one of the most dangerous types of landings, as the impact and deceleration forces experienced in landing are normally enormous. The present concept is to design and develop fixtures which prevent crash energy being diverted to structure and crew during belly landing(Emergency landing).The ski fixture is assembled with the crash tube beneath the fuselage, between the under carriage and fuselage frame. The ski and crash fixtures are replaceable units which may fail during a crash but ensuring high reliability and safety of the aircraft during emergency belly landing on land. The earlier approaches were to divert the crash energy to be absorbed completely by collapse of structures which results in total loss of structure or high repair cost. The present technique deals with design of a ski that can glide and absorb the crash impact energy during a landing gear snag with minimum damage to the aircraft and the passengers. The main objective is to develop an additional fixture beneath the fuselage which prevents the crash energy being transmitted to structure and crew by using energy absorbers. In the present method, thin-walled tubes are considered as the most common type of energy absorber. This is primarily due to their relative simplicity compared with other types of energy absorbers.

Keywords: *Crash Landing, Crash tube, Composite Skis, Belly Landing on Land, Aluminium foam.*

1. Introduction

. This paper deals with the Design and development of safe belly landing fixtures for safe of emergency belly landing condition using collapsible structures- circular crash tubes and skies structure between the entire fuselage floor and lower surface of the fuselage at different sections to isolate the impact loading during the emergency crash landing condition.

Since at instance of crash the impact energy causes higher rate of damage to the structure and rendering it irreparable. Therefore the impact energy has to be absorbed by collapsible structures to reduce the damage caused to the crash landing.

The study concentrates on design and impact validation of tubular collapsible structures to absorb the energy caused during the crash landing into structural deformation, in turn reducing the impact load transferred to the airframe structure. The crash tubes used in the current study are hollow cylindrical structure with additional modifications, in order to increase the efficiency of energy absorption. The material considered for crash tube structure is Al6061 Alloys.

These crash tubes are fixed on to the ski structure, which helps in uniform distribution of the Impact loads. The ski structure is made up of sandwich materials consisting of Titanium metal wrapped with foam and carbon fibre sheets.

The proposed design for safe belly landing-energy absorbing fixtures is shown in Fig 1.

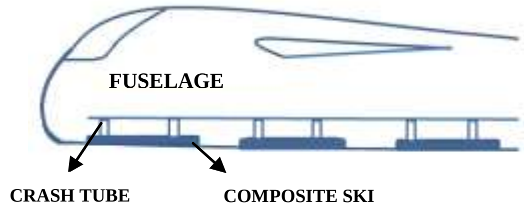


Fig 1. Proposed Energy Absorption Fixture assembly for safe Belly Landing on Land.

2. Review on Different Types of Crash Tube Design.

The main energy absorbing unit considered in the current study is crash tube. The design of the crash tube is derived from pervious literature survey. Application of crash tube is widely used in automotive fields to reduce the direct impact collision in Cars, Trucks and High Speed Trains. In current investigation crash tube design optimization is done according the previous researchers.

S.R. Reid [1], studied about impact energy absorbtion. Development of circular and square metal tube absorption fixtures filled with polyurethane foam. The experiment was conducted for axial crushing condition for specimens square tubes (b=10,6,4 mm) and circular tube (dia =10,6,4 mm) of t= 1.6mm.Material considered for the specimen is steel. The comparative studies as shown in Fig 2 the foam filled square tubes are subjected to axial loading tend to split and buckle at the corners axially.Progressive buckling inversion and splitting are discussed and areas for the future work identified. Thefoam filled circular tubes are more stable and absorb impact.

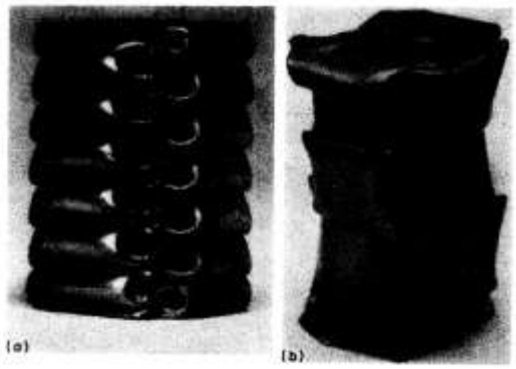


Fig 2. Axially crushed square tubes (a) Compact crushing mode (Aluminium tube c/t = 32.4) and (b) noncompact crushing mode (mild steel tube c/t=100), Ref [1].

Drop-hammer [2], has conducted test on circular Aluminium and Mild steel tube of different sizes. The quasi-static experiment was conducted at speed of 2mm/min using Instron machine, the load compression curves were plotted using Quartz load cell. Progressive collapse took place in concertina and diamond modes of deformation were recorded as shown in the Fig 3.Aluminium deform in diamond mode and deform in concertina mode when annealed.Raw as received strain-hardened steel tubedeforms in concertina mode and after annealing they deform in diamond mode.The t/D ratio for Aluminium from 0.033-.06 and steel tube 0.034-0.096 was tested.The L/D = 2 & 3 tubes deformed in ring mode.t/D=0.04-0.08 also deforms in ring mode(concertina mode) for L/D=3.

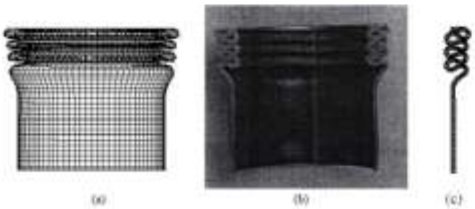
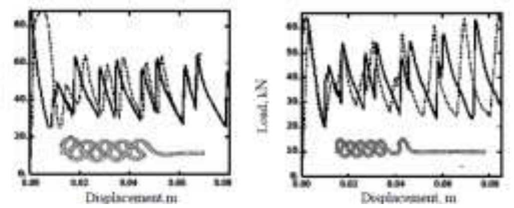


Fig 3 (a) 3-D, (c) 2-D and (b) Experimental deformed tube of diameter 61.5 mm, length of 120 mm and thickness 1.5 mm, compressed at 68.5 mm Ref.[1]

A. A. N. Aljawihas investigated[3], the crash worthiness of circular steel tubes using experimentation and finite element software (ABAQUS) explicit and implicit codes for Quasi-Static and Dynamic loading conditions.2D Model and 3D Model discretized models are modelled consisting of 4 parts – i)Tube ii)Rigid surface for Crushing.iii)Mass element representing hammer strike.vi) A contact link to transfer the energy to tube. Quasi-static case - no mass is considered for the striker to simulate the load transfer.

Fig 4. It shows that both experimental data (E) and finite element analysis prediction (FEA) indicate a maximum load of 88kN.however the energy dissipated due to plastic deformation is represented by area under the load-displacement curve, for the crushing length of 68.5mm are “3309J and 3026 J for E and FEA, respectively. Note that the corresponding experimental and FEA average loads for the crushing length og 68.5 mm are 48.31kN respectively. The 5 to 10% underestimation by FEA predictions as compared to the experimental results may be attributed to initial post-buckling of the load during the experimental studies within the elastic region.



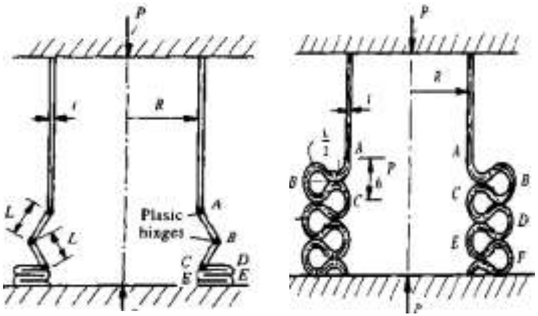
(a) (b)

Fig 4. Experimental (……),and ABAQUS(—),Load displacement results ,ABAQUS final deformed shape at axial displacement of 80.0mm,for quasi-static crushing of steel tubes of (a) Average diameter D=61.5mm,length L=120.0 mm and thickness t=1.5mm (b) average diameter D=45.0 mm. Length L=150.0 mm and thickness t = 1.5*mm*.Ref. [3]

Fig 5.Deformed and Undeformed tube sides. Ref[3]

N.K Gupta and R.Velmurugan[4], conducted experiments for short Aluminium and steel tubes to study the Axi-symmetric folding and the extent by which the tube folds internally. The specimen dia considered is between 25-79 mm. Theexperiment studies about symmetric mode of folds and Axi-Symmetric mode of folds for different model boundary condition. The Aluminium tubes were annealed in an oven for 40 mins at 300^0 and were cooled for 24 hrs and steel tube specimen were tested in 'as received' condition.

Aluminium tubes deforms in diamond mode for as received condition and steel deforms in concertina mode for as received condition but they deform in diamond mode when annealed [2]. The all tube selected in the experiment deforms in concertina mode. Fig 5.Shows thetwo types of concertina modes.



A b

Fig 5. Models to study the Axi-symmetric concertina mode Ref [4]

Aluminium and mild steel round cylindrical tubes which collapse in axisymmetric concertina mode to show that the tubes fold both internally and externallydue to axial compression. The extent of the internal folding is seen to depend on D/t ratio. Both the fold length and the mean collapse load vary with the variation in folding parameter *m*.

S.J Hosseinipour and G.H Daneshi[5], have studied the energy absorption and mean crushing load of thin-walled grooved tubes under axial conditions. For experimental purposes seamless mild steel tubes of 60 mm diameter and 5 mm wall thickness with 3 mm wide and 1 mm deep grooves were used. Alternate annular grooves were cut inside and outside the tube surfaces. Quasi-static axial crushing, using 20 ton AMSLER hydraulic testing machine at crosshead speed of 5 mm/min, initially showed formation of convolutions in concertina mode which changed to diamond mode after the formation of two rings. The Fig 6and Fig 7shows the successive stages of axial crushing. The overall wave amplitude and mean collapse load were reduced by the introduction of grooves providing characteristics of an efficient energy absorption device.

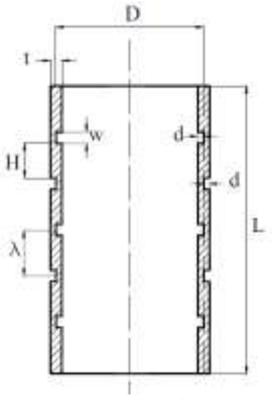
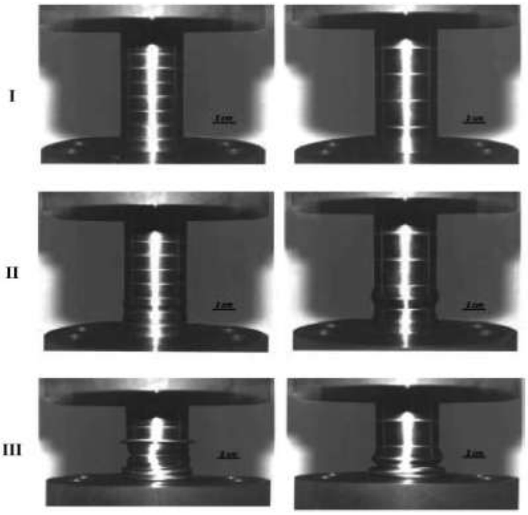


Fig 6 Specimen Design of the Crash tube.



(a) B2 (b)B3

Fig 7 Specimens (a) B2 (b) B3.
(I)Before axial loading.(II)During initial bucking
(III)During Axial Crushing. Ref [5]

M.M.Younes[6], has investigated on Steel Tubes of different cross-section are subjected to axial crushing loads and mode of deformation behavior is studied. The specimen crushing conditions considered are square, circular, ellipse, triangle, pentagon and hexagon. The crushing deformation response is studied and experiment is considered in Quasi-Static condition are studied numerically and using commercial finite element package ABAQUS/Explicit was used for the investigative study. Various initial peak loads and the mean crushing force with the tube side breadth and fold depth were investigated. The empirical formulas, finite element results for the absorbed energy were developed as a function of the side breadth/thickness (b/t) ratio of the tubes. The comparative results were made and the study concludes (i)All the tubes models were crushed in symmetric concertina modes but the highest number of folds were observed in circular cylinder and minimum folds were recorded in triangular tubes. (ii)The triangular tube terminates folding without contact between folds but The cylindrical tubes fold with short depth in a compact fold.(iii)The initial peak load increases with the increasing no of sides in the tube and decreases with the increasing of the side breadth.(iv)The greatest energy absorption capacity was obtained by the circular cylinder while the square tube absorbed minimum energy.

S.A Yousefsani, J. Rezaeepazhand *et. al.*[7], have studied about Metallic and Reinforced Metallic Tubes. The experimental results were recorded for various cross sections (Square, Triangle and Circular tubes) Fig 8. Three different reinforcement are considered for reinforced metallic tubes. The research investigation concludes that the reinforced metallic tube models have better energy absorbing characteristics than Metallictubes. The Circular tubes folds with minimum length/fold ratio when compared to other cross section of tubes.

(a) (b)

Fig.8 Deformation models of (a)Only Metalic tube (b)Reinforced Metalic Tube. Ref. [7]

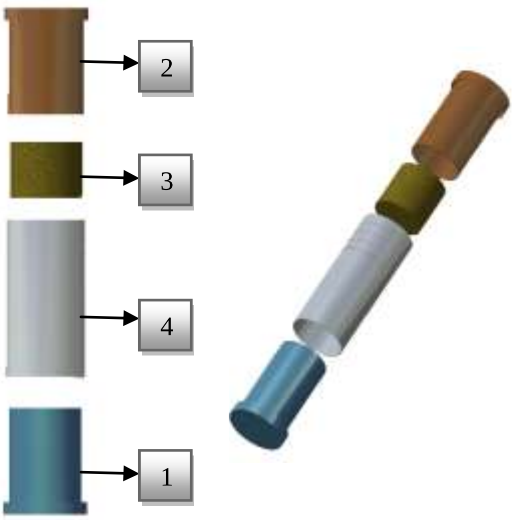
Fig.9 Deformation model of Reinforced Model of Circular Crash Tube. Ref. [7]

3.INNOVATIVE CRASH TUBE DESIGN.

3.1 Selection of Energy Absorbtion Fixtures.

The current investigative study deals with design of energy absorbing fixtures for impact energy absorption during a belly landing condition on land. In the beginning pneumatic and hydraulic shock absorbers were considered for designing the energy absorbtion fixture but both were ruled out. Pneumatic shock absorbers cannot be considered in this type of fixtures, since air shock absorbers have very less reaction time .Due to high frequency response at the time ofimpact; ifblow out plug fails to open, the whole shock absorber unit might exploded followed by destruction of the fuselage structure. Springs cannot be used for landing energy absorbing fixture, as it can multiply intensity of impact damage due its recoiling property. Hydraulic shock absorbers poses high reaction time when compared to air shock absorbers but oil has to be stored in reservoir for their mechanism.Sparks created at the time of impact might initiate ignition of oil, if any oil leakage happens to due failure of the oil shock absorber or due to blow out plugs provide to the oil shock absorber. So the need for a safe energy absorbing shock absorber leads to the ideology of design and develop of anew prototype crash tube fixture.

3.2 *Prototype Design of Crash Tube*



FRONT VIEW **ISO VIEW**

Fig 10 Exploded View of a Crash tube.
[1] Bottom tube [2] Top Tube [3] Foam [4] Crash Tube

The crash tube is designed according to the space available between the fuselage floor and the bottom surface of the fuselage. The research studies from [1]-[7] was considered for design of the crash tube. The typical Aircraft configuration of 13228 kg is considered for the current research study.Table 3 gives the design parameters considered for the Aircraft configuration. The Fig 12 represents the front and isometric sectional view of the crash tube. The crash tube consists of 4 parts (i) Bottom Tube[Fig 11] (ii)Top Tube[Fig 12] (iii) Foam [Fig 13] (iv) Crash tube[Fig 14]. The Axial load impact loads is considered for the crash design.

3.3 Design Optimization of Crash Tube.

The (i) Bottom Tube and (ii) Top Tube are provided with chamfer of [Length=3 mm – Angle= 45^{0}] to initiate the 1st fold during impact [Ref 2].The (iv) crash tube design was optimized as per the Ref [5].The crash tube isgrooved like piston ring slots around the tube to initiate the controlled deformation in terms of folds [Fig 15]. Four grooves are provided on the circular tube at positon 20 mm from the top of the crash tube.

Table 1 : Material selection

Specimen	Material
Tube	Al 6061 Alloy(Annealed), Carbon fiber
Foam	Aluminium Foam, Polyurethane Foam

Table 2 Crash tube design for (Dia 100 mm)

Thickness (mm)	Dia=100mm		Length (mm)
	Di(mm)	Do(mm)	
2	96	100	250

Table 3 Typical Aircraft Design Parameter

Design Parameter	**Metric value**
Aircraft Mass	13228 kg
Fuselage Rolling Inertia	12762.595 kg-m^2
Fuselage Pitching Inertia	14748.4404 kg- m^2
Fuselage Yawing Inertia	26600.1761 kg- m^2
CG Location	10.1 m
Space between the floor and bottom surface of fuselage	0.25 m

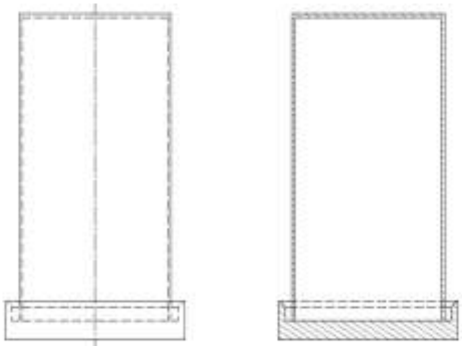

FRONT VIEW SECTION VIEW

Fig 11 Bottom part of Crash Tube

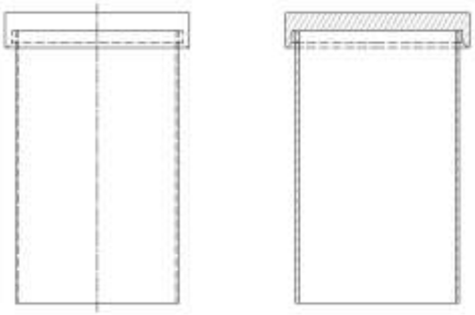
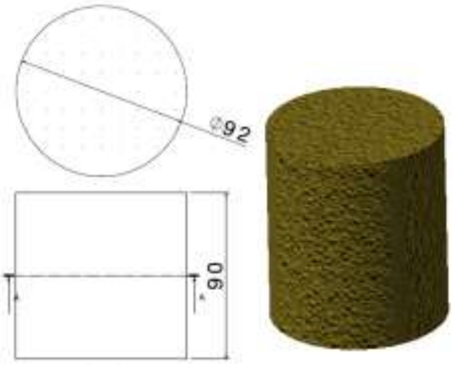

FRONT VIEW SECTION VIEW

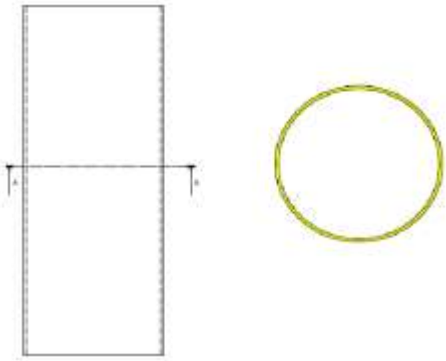
Fig 12Top part of Crash Tube



FRONT VIEW ISO VIEW

Units (mm)

Fig 13 Foam of Crash Tube



FRONT VIEW SECTIONAL VIEW

Fig 14 Crash tube

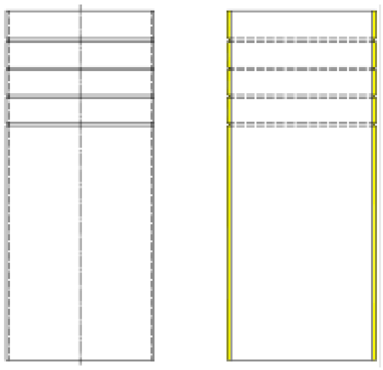

FRONT VIEW SECTIONAL VIEW

Fig 15 Slotted Crash tube

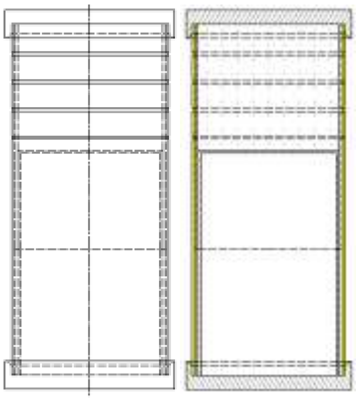
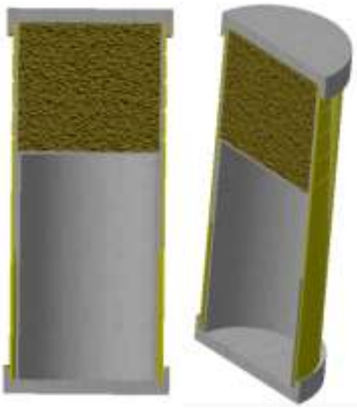

FRONT VIEW SECTIONAL VIEW

Fig 16 Slotted Assembled Crash tube



FRONT VIEW SECTIONAL VIEW

Fig 17 Slotted Assembled Crash tube(3D)

ISO VIEW

Fig 18 Prototype Crash tube and ski Assembly

3.3 Mechanism of Crash Tube prototype.

Usually the pilot lands the aircraft touches the belly at the time as landing and glides on water and on ice landing condition in case of emergency landing due to failure of landing retraction. The axial impact load when applied on the crash tube, it deforms in folds in concertina mode [Fig 3&Fig 5]. The energy is absorbed due to high density foam inside the tubeassembly as shown the Fig 13 and the crash tube in-terms of deformation in controlled concertina mode.

4. CONCLUSION

Following are the observations made from the previous studies and the current innovative crash tube design when combined with skies as shown in Fig 1, Fig 18 and Fig 19 acts as energy absorbtion fixture for safe belly landing on land.

- ☑ Circular slotted crash tubes can easily absorb the energy completely by concertina mode (controlled folding) deformation as shown in Fig 7 & Fig 5.
- ☑ The protype design enables the pilot to confidently go for belly landing on land with minimum damage on the fuselage structure. In-turn reduces the magnitude of the impact energy transfer to the crew and passengers.
- ☑ This type of design can avoid explosion of the airplane due to sudden impact which damages the on the structure and avoid fuel leakages.
- ☑ The current crash tube design will not explode in any condition. Since it is accompanied by foam as a damper.
- ☑ The whole energy is absorbed by 4 crash tubes assembled on the single unit frame with the skis as shown in the Fig 1& Fig 18.

5. FUTURE SCOPE OF THE WORK

- ➢ Finite element Analysis as to be conducted using available commercial software ANSYS WORKBENCH (Explicit Dynamics).

- ➢ Experimentation for the prototype model to be conducted
  - (i) Hammer drop test
  - (ii) Quasi-static Impact test.

REFERENCES

[1] Airoldi A and Janszen G, A design solution for a crashworthy landing gear with a new triggering mechanism for the plastic collapse of metallic tubes. Aerospace Science and Technology, Volume 9, Issue 5: 445-455, (2005).

[2] Aljawi A A N. Numerical Simulation of Axial Crushing of Circular Tubes, JKAU: Eng. Sci., 14 (2):101-115, (2002).

[3] Gupta N K , Some aspects of axial collapse of cylindrical thin-walled tubes. Thin-Walled Structures, 32 :111-126 ,(1999).

[4] Gupta N K and Velmurugan R, Consideration of internal folding and non-symmetric fold formation in axisymmetric axial collapse of round tubes. International Journal of Solids and Structures,34(20):2611-2613,(1998)

[5] Hosseinipour S J and Daneshi G H, Energy absorbtion and mean crushing load of thin-walled grooved tubes under axial compression. Thin-walled structures, vol. 41 (1):31-46 , (2003).

[6] Reid S R, Plastic Deformation Mechanisms In Axially Compressed Metal Tubes Used As Impact Energy Absorbers. Int. J. Mech. Sci., Vol 35: 1035-1052, (1993).

[7] Younes M M , Finite element modelling of Cushing behaviour of thin tubes with various cross-sections. 13th International Conference on Aerospace Sciences and Aviation Technology, Paper: ASAT-13-ST-34,(2009).

[8] Yousefsani S A and Rezaeepazhand J et. al “Axial crushing of metallic and hybrid energy absorbing thin-walled tubes with polygonal cross-section: Numerical analysis”, Department of mechanical Engineering, Fedowsi University of Mashhad, Mashhad ,Iran.