Hawk T Mk2 - Arrestor Barrier (BAN MK2) Engagement Analysis

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Abstract

As the UK Ministry of Defence (MoD) Design Authority for Aircraft Arrestor Barrier Nets, AmSafe products are used to stop aircraft from over-running the end of the runway. The British Arrestor Net (BAN) Mk2 is suspended across the runway over-run area by two electrically driven stanchions and raised or lowered by remote control from the Air Traffic Control tower. Energy Absorption Units (EAU's), located on either side of a runway over-run, assist in the retardation of the aircraft. The system can be operated by local control for maintenance or, in the event of a power failure, raised and lowered manually from the runway site.

The Hawk T Mk2 was selected as the new Advanced Jet Trainer (AJT) for the UK Armed Forces in July 2003. Used by both RAF and RN pilots for fast-jet aircrew training it will replace the existing aircraft of No's 19 and 208 (Reserve) Squadrons at RAF Valley. It will train aircrew for Harrier, Tornado, Typhoon and the future Joint Combat Aircraft.

The Hawk T Mk2 has an extended nose for additional avionics and will feature a number of major changes under the skin, making it a virtually new aircraft. Amongst the additions are two new Smart Probes mounted on the nose of the aircraft and a radio antenna on the vertical tail fin.

This paper describes the process and results of a FE analysis of the engagement of the Hawk T Mk2 aircraft into a Type A Barrier (BAN Mk2). The analysis was performed using RADIOSS, an advanced non-linear explicit Finite Element solver.

Keywords: RADIOSS, HyperMesh

1.0 Introduction

The British Arresting Net (BAN) Mk 2 is a nylon webbing, multi-element net comprising eight major and eight minor net elements superimposed on each other forming a single barrier. The barrier is supported by steel suspension cables, the centre portion specifically by the Centre Suspension Cable.

The design of the barrier is such that an engaging aircraft can catch one element from the Suspension Cable Assembly while leaving the remaining net elements and the Centre Suspension Cable intact. Each of the remaining net elements will be torn away from the suspension cables until the system cannot support itself any longer when it will collapse releasing the Centre Suspension Cable. By delaying the collapse of the suspension system, this feature prevents the cables contacting the aircrafts Windscreen or Canopy removing the potential hazard to the aircrew. The barrier design is such that when this final failure occurs, the aircraft has passed beneath and the cockpit is well clear of the falling Centre Cable.

The current in-service advanced jet trainer, the Hawk T1/1A, is cleared for engagement into the RAF Type A Barrier and during a normal arrest, the aircraft will pass through the vertical webbing members unopposed, only meeting resistance when the intakes or main planes make contact with the net. By this time the cockpit area has passed beneath the steel Suspension Cables.

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2.0 Background to Project

The addition of the two Smart Probes has led to a concern that they will prevent the nose of the aircraft passing unopposed through the vertical webbing of the net and could potentially cause the horizontal webbing at the top of the net to be dragged downward into contact with the windscreen/canopy of the aircraft. In a worst-case scenario the steel Central Suspension Cable could also be dragged downward into contact with the windscreen/canopy, posing a serious risk of injury to the aircrew.

The objective of this study is to apply advanced Finite Element modelling techniques in order to make an assessment of the following issues arising from the highlighted risks:

- Does the net webbing make contact with the canopy/windscreen and if so what level of loads may be expected during initial net engagement and during the 'braking' phase?
- Is there a possibility that the steel central support cable will be dragged down onto the canopy before it can be released from the rest of the net support system?
- What levels of loads are generated at the smart probes when net elements are caught on them during engagement and braking?

Altair's advanced non-linear explicit solver, RADIOSS, has been selected as the solver for this study. Amongst the key strengths that make it ideally suited for this type of application are the following:

- Extensive use in the field of safety-related vehicle crash and impact studies.
- Ability to model dynamic behaviour over wide range of impact velocities -from low-speed automotive crash to high-velocity ballistic impact.
- Extensive material and property libraries

3.0 Modelling Conduct

3.1 Modelling Tools

- 3D Modeller Catia V5 R14.
- HyperWorks Version 9.0
- HyperCrash Version 9.0
- HyperMesh Version 9.0
- Explicit non-linear solver Altair Radioss (Version 44)
- Hyperview Version 9.0

3.2 FE Model of the Hawk T Mk2 Aircraft

The geometry of the Hawk T Mk2 aircraft was supplied as a Catia CAD file. This was imported into Altair Hypermesh and a 2D surface mesh of the airframe was generated using shell elements. The density of the mesh was chosen to keep the element count for the aircraft down to a sensible limit in terms of impact on analysis solution time whilst maintaining a sufficiently accurate physical representation of the significant features of the airframe such as the Smart Probes and the Pitot tube mounted on the nose.

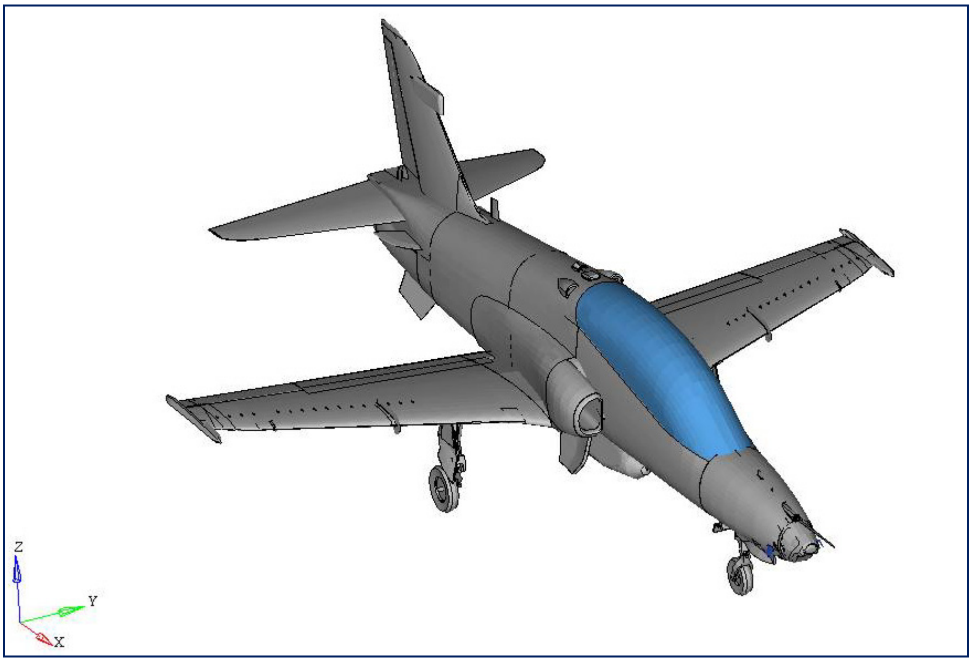


Figure 1: RADIOSS FE Model of Hawk T Mk2 Aircraft

As this analysis is not specifically concerned with deformation or damage to the airframe itself a rigid body was applied to the aircraft. This ensures that the elements of the aircraft cannot deform under impact and affect the overall timestep of the model, which would lead to an unacceptable increase in the overall simulation time.

A generic elastic material was applied to the shell elements of the aircraft. By modifying the density of this material using a scale factor, the correct AUM of the aircraft could be represented.

In addition to representing the AUM of the aircraft, values of translational and rotational inertia were calculated and applied to the rigid body attached to the airframe to further improve the FE representation of the aircraft's dynamic behaviour during engagement with the barrier.

The Smart Probes themselves have been modelled as separate 2D shell components. These were then attached to the nose of the airframe using zero-length Type 8 Spring elements to represent the attachment bolts. This allows axial and shear loads at the attachment points to be monitored and output for post-processing with other results from the model.

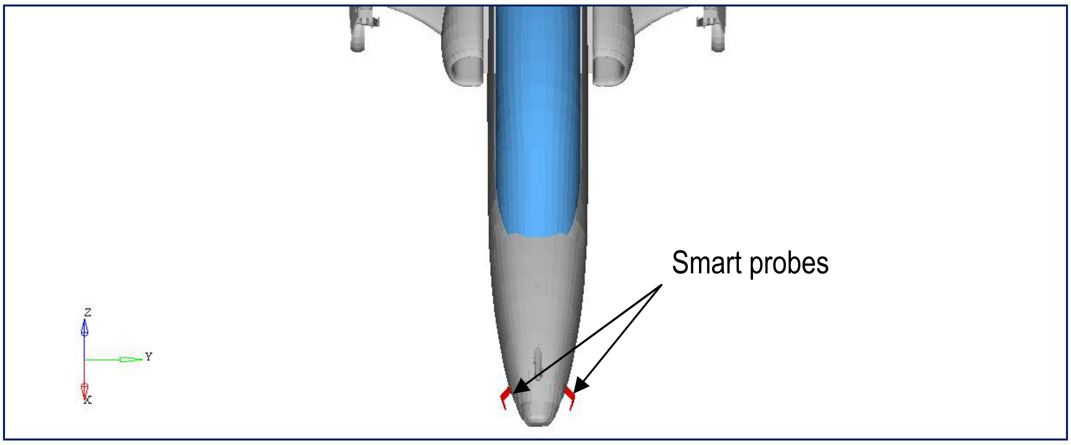


Figure 2: Location of Smart Probes on Nose of Aircraft

3.3 FE model of the BAN Mk2 Barrier Net

The FE model of the barrier net and associated suspension system and Energy Absorbing Units was generated using Hypermesh as an assembly of components modelled using 1d spring and truss elements. The general layout of the barrier net model is illustrated below:

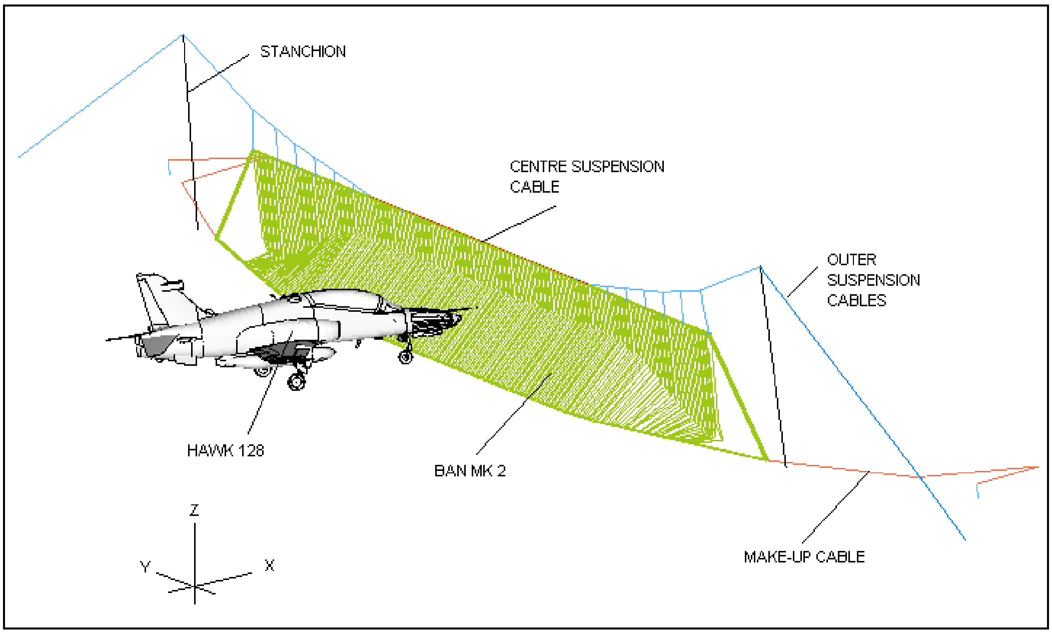


Figure 3: Layout of Barrier Net Model

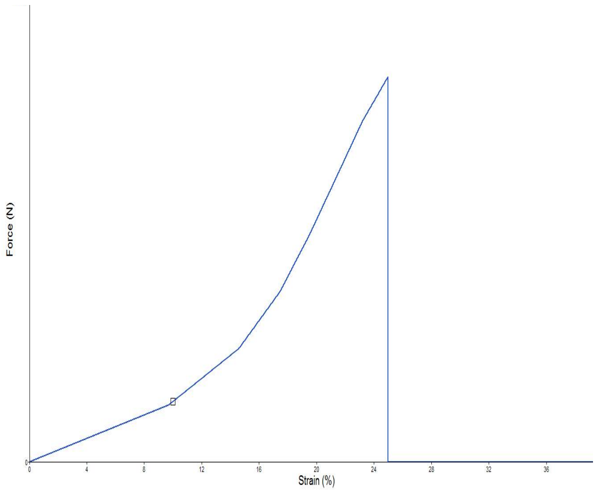
The Barrier Net model consists of the following components:

- Multi-element net made from flat woven polymer-fibre webbing. This consists of a series of individual net elements which are made up from an upper and lower horizontal webbing strip with vertical webbing elements.

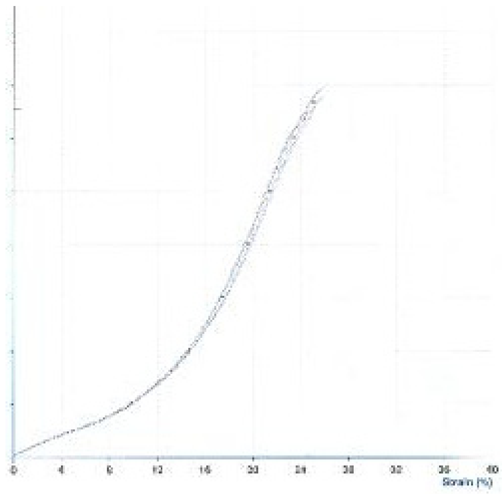
- Suspension system comprising the support stanchions, outer and centre suspension cables.
- The make-up cables and brake lines which are connected to the ends of the horizontal net webbing strips, and the Energy Absorbing Units which absorb the kinetic energy of the aircraft whilst slowing it down to standstill after the aircraft has engaged with the barrier.
- Various strengths of cable ties used to fasten components together such as the net assembly to the suspension cables and the ground anchors.

In order to be able to represent the correct force/extension and failure load characteristics of the various components of the barrier model a simple single-element test model was generated. By using the test model the behaviour of each component of the barrier model could be tuned to match manufacturer's test data (where available) more rapidly than trying to do so using the full FE model of the barrier.

An example of the correlation of the force/extension behaviour and the failure load value for the main net webbing is illustrated below:



FE model



Manufacturer tensile test data

Figure 4: Correlation of Force/Extension behaviour for Main Net Webbing

It can be seen that the force/extension and failure load behaviour of the FE model closely mimics that of the physical data for the webbing obtained from tensile testing of material samples.

A further example of the use of the test model to tune the behaviour of a component of the FE model to match physical behaviour is the Energy Absorption Units (EAUs).

The EAUs are anchored to ground on each side of the barrier and connected to the ends of the net via steel cables mounted on friction-braked drums. As the aircraft engages with the net, the cables on the EAUs are paid-out under load, according to the rating of the braking units and the mass/speed of the aircraft engaging the net.

The EAU's used with this particular barrier system are designed to maintain a constant braking load on the cables from the point of activation of the units to when the aircraft has been brought to a standstill.

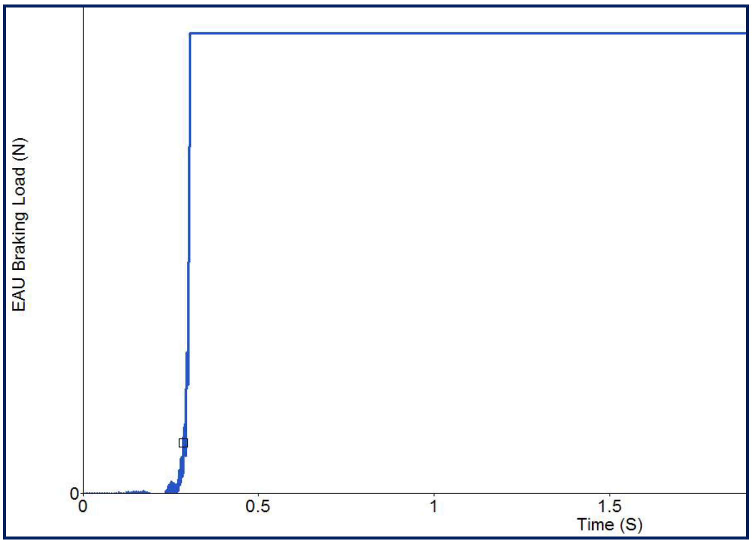


Figure 5: Braking load curve for FE model of EAU

It can be seen from the braking load curve above that the specified braking load is maintained from the point of activation of the units at approximately 0.25secs until the aircraft would be brought to rest.

3.4 Ground Plane (Runway)

The runway was constructed of 2D shells forming a non-deformable ground plane.

3.5 Contact Modelling

In order to capture the interaction between the structure of the aircraft and the various components of the barrier system during the engagement and subsequent retardation phases two main types of contact interface were defined in the set-up of the RADIOSS model.

A Type 7 General contact interface was used to model the interaction between the following aspects of the RADIOSS model:

- Contact between the aircraft's tyres and the ground plane.
- Contact between the components of the barrier system and the ground plane - as the aircraft engages the barrier the net and brake lines will be dragged across the ground and once the central support cable is released the support stanchions will be free to drop sideways onto the ground.
- Contact between the airframe and the components of the barrier system.
- Contact between the aircraft canopy and the components of the barrier system. It should be noted that contact between the aircraft canopy and the net has been separated from that of the airframe. This has been done in order to simplify and reduce the amount of data recorded whilst monitoring any loads generated by contact between the canopy and the net/suspension assembly.

The type 7 interface provides for surface-to-surface contact and node-to-surface contact, however it does not provide the ability to capture edge-to-edge contact between surface contact segments nor can it model contact between 1D elements such as beams, trusses or springs, or between 1D elements and surface segments.

The Type 11 Edge-to-Edge contact was used to model the interaction between the various 1D components of the barrier system, and between the barrier system and the aircraft/canopy as follows:

- Upper net webbing strips and the cable ties connecting them to the suspension cables
- Cable ties connecting the centre suspension cable to the outer suspension cables.
- Lower net webbing strips to the ground anchor cable ties
- Contact between the airframe surface segments and the 1D elements of the barrier system
- Contact between the aircraft canopy surface segments and the 1D elements of the barrier system

3.6 Technical Challenges

Several technical challenges had to be overcome during the course of the project in order to produce a suite of FE models which ran in a stable and consistent manner and gave results which were representative of the expected behaviour of the barrier system during an aircraft arrest event. Amongst the more significant challenges were the following:

- Correct timing of the release of individual net elements from the suspension cable assembly and the ground anchors and the subsequent separation of the Centre Support Cable from the rest of the system.
- Stable behaviour of contact interfaces where objects of relatively high mass/stiffness are in high speed contact with objects of comparatively low mass/stiffness; for example, the rigid-body Hawk model in contact with the stationary net model.
- Control of the time step of the global model to ensure a stable solution in the minimum possible time without adversely influencing the physics of the problem.

3.7 Loadcases

There are a number of physical variables which may have an effect on the behaviour of the aircraft during engagement with the barrier system - both during the initial engagement with the net assembly and during the subsequent retardation phase when the EAU's absorb the kinetic energy of the moving aircraft in order to slow it to standstill. These variables are summarised as follows:

3.8 All Up Mass, (AUM) of the Aircraft

The higher the AUM of the aircraft is, the greater the amount of kinetic energy that is required to be absorbed by the EAUs to slow the aircraft down and the higher any potential contact forces generated between the net and the airframe/canopy are likely to be as the EAUs are brought into operation.

The maximum AUM rated for the aircraft engaging into this model of barrier was selected as this would give the highest kinetic energy and potential contact loads.

3.9 Initial Engagement Velocity

Three engagement velocities were analysed, these were selected to be at the lower, mid-point and upper extremes of the entry speed range at the designated AUM of the aircraft. The upper velocity chosen in combination with the AUM dictates the kinetic energy to be absorbed and the maximum run-out required to slow the aircraft down. Peak contact loads generated are also predicted to occur at maximum engagement velocity.

At the lower extreme of the speed range there is the potential for the aircraft to not have passed sufficiently far through the net for the canopy to be completely clear of the centre suspension cable in the event that the cable is dragged downwards during the engagement phase.

3.10 Relative Heights of Barrier and Aircraft Canopy

The relative heights of the barrier and the aircraft at the moment of engagement could influence whether the steel central suspension could be dragged down onto the canopy. The greatest risk is predicted to occur when the aircraft is at its maximum height with the undercarriage oleos fully extended and the centre of the steel suspension cable is set at the minimum permissible installed height.

3.11 Yaw Angle of Aircraft and Offset from Net Centreline

The position of the aircraft in relation to the centre of the net and also the angle of approach to the net could affect the behaviour of the aircraft as it engages the net and slows down. It is intended that pilots approach the barrier square on to the runway and on the centreline of the net - however experience has shown that in an emergency landing situation this is not always achievable.

Strong crosswinds on landing can also affect the degree of yaw in the aircrafts approach attitude even when perfectly lined up with the runway and barrier.

In total eighteen combinations of approach velocity, aircraft AUM, aircraft approach/yaw angle and engagement position in relation to centreline of barrier were analysed during the course of this study.

Each of the loadcases applied to the aircraft consisted of an initial velocity applied to the aircraft at time=0. In each case the aircraft was positioned close to the barrier at the start of the simulation in order to keep the time taken to engage with the net to a minimum and hence keep the overall solution time down to an acceptable level. Figure 6 below shows the position of the aircraft relative to the net at the start of each simulation.

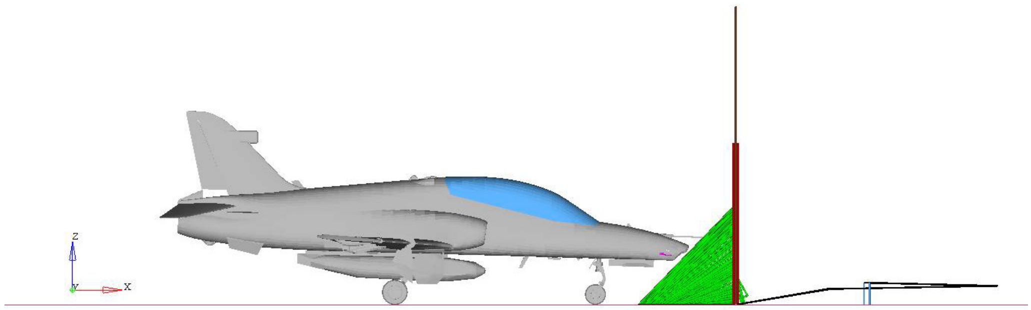


Figure 6: Position of Hawk at time T=0

4.0 Data Monitoring

4.1 Phase 1

The analysis was divided into two separate phases; phase 1 covers the aircrafts engagement from the initial barrier contact to the moment just prior to the operation of the Energy Absorption Unit, (EAU), see Figure 7. The geometric distance to the EAU initiation from the barrier base line was calculated and used as the forward limit of phase 1.

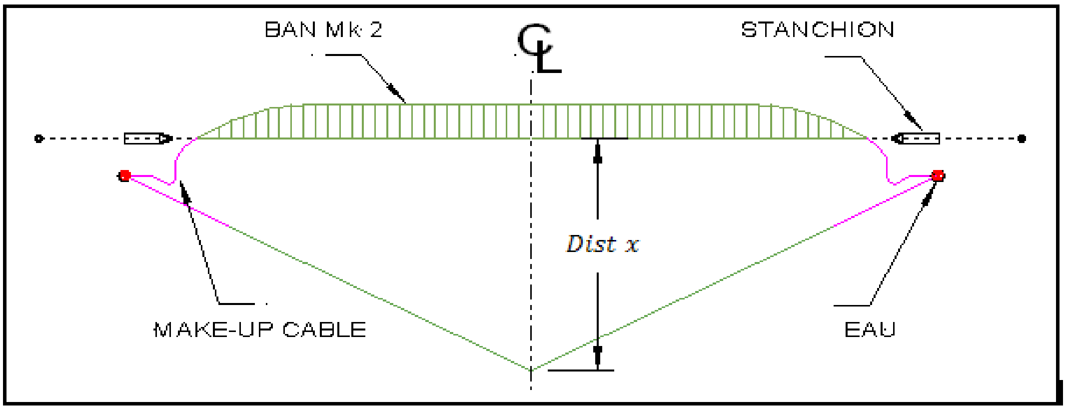


Figure 7: Phase 1 – Limit

To capture the data and provide useful information about the effect of the aircraft entering the barrier net, the following monitoring was carried out:

- The maximum impact loads on the windscreen/canopy were recorded.
- The maximum loads on the port and starboard Smart Probe mountings were recorded.
- Visual assessment of the behaviour of the aircraft and barrier during the engagement with the net - in particular with respect to the potential for net elements to be snagged on the Smart Probes causing the steel Centre Suspension Cable to be brought into contact with the canopy of the aircraft

4.2 Phase 2

Phase 2 considers the behaviour of the aircraft from the point where it has fully engaged with the net and begun to load the brake cables attached to the EAUs to the point where the aircraft has been brought to a standstill.

During this Phase, the EAU's will apply a constant retardation force to the A/C following an initial ramping of the pressure applied to the EAU brake stacks. The maximum loads to the Smart Probes and the aircraft canopy due to contact with elements of the net will occur immediately following the pressure ramp where the aircrafts velocity is still at a maximum.

- The loads on the Smart Probes, Windscreen/Canopy were monitored throughout the EAU initiation.
- Visual assessment of the behaviour of the aircraft and barrier during the braking phase - in particular with respect to the behaviour of the steel Central Suspension Cable as it is released from the rest of the suspension system and the potential for it to impact with the airframe.

5.0 Results

5.1 Engagement with Barrier

As anticipated, the Smart Probes did collect a number of vertical webbing elements as the nose of the aircraft passed through the barrier during the engagement phase. **Figure 8** below shows the vertical net elements (in green) caught around the Smart Probes and the horizontal webbing strips (in red) becoming detached from the steel Centre Support Cable and being dragged downwards onto the front of the canopy.

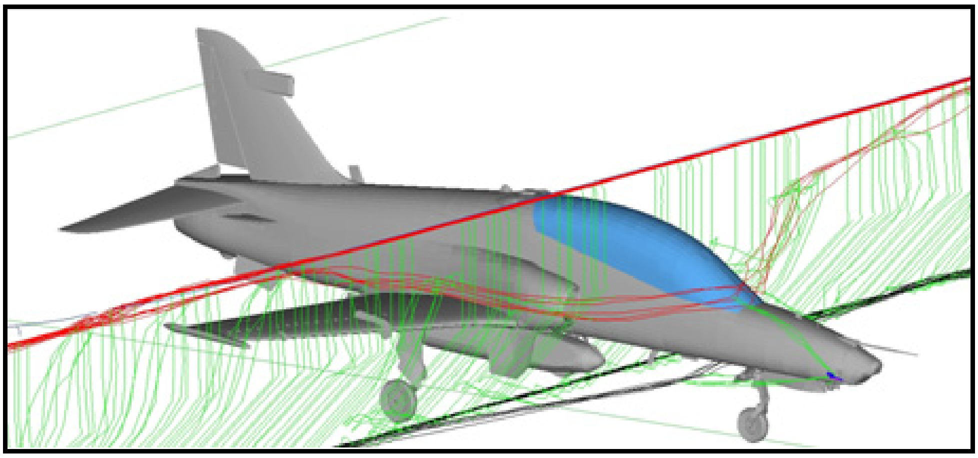


Figure 8: Net elements Being Caught on Smart Probes

The remaining net elements stay attached to the Centre Suspension Cable until they engage with the mainplanes, jet intakes and the main landing gear at which point they too become detached from the Centre Suspension Cable. **Figure 9** below illustrates the separation of the remaining barrier nets from the Central Support Cable.

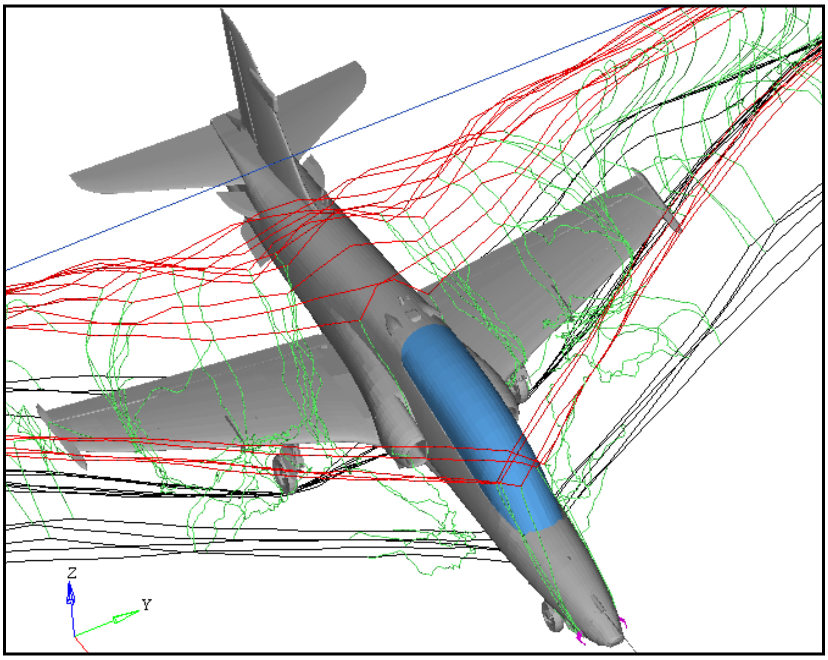


Figure 9: Separation of Barrier Nets from Central Support Cable

Examination of the engagement phase of all eighteen simulations performed did not indicate that the steel Centre Suspension Cable was brought into contact with the canopy of the aircraft - in each case the canopy was well clear of the cable by the time the cable was released from the rest of the suspension system. **Figure 10** below illustrates a typical example of the position of the canopy of the aircraft at the moment the cable is released from the rest of the barrier suspension system (cable highlighted in blue).

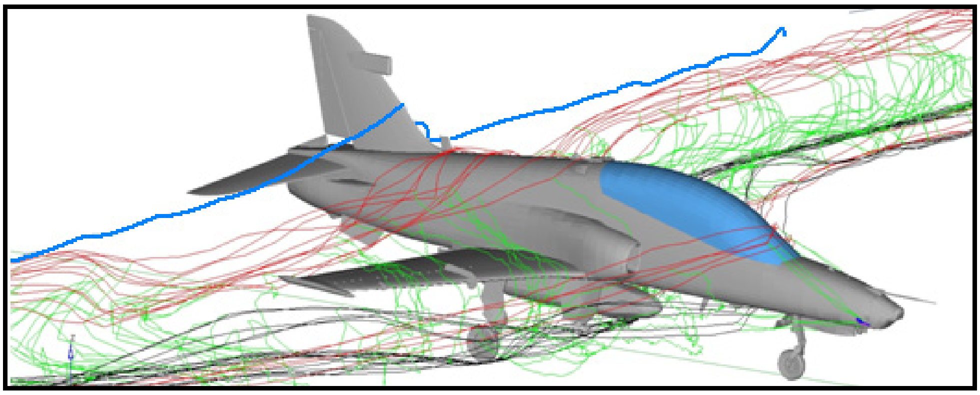


Figure 10: Centre Cable Releasing from Suspension System

Although in all the loadcases there is no apparent hazard from direct contact between the Centre Cable and the canopy, there does remain some concern over the centre cable's behaviour after being released from the suspension system.

During the examination of the results of the barrier engagement phase it was noted that the Centre Suspension Cable became snagged on the RWR radio antenna mounted on the vertical tail fin, causing it to wrap round the tail fin at high speed.

The concern is that the two flailing ends of the Centre Cable could make contact with the cockpit area with the associated potential hazard to the aircrew. It should be noted, however that all the models have been studied and in no instance do the cable ends make contact with the cockpit area.

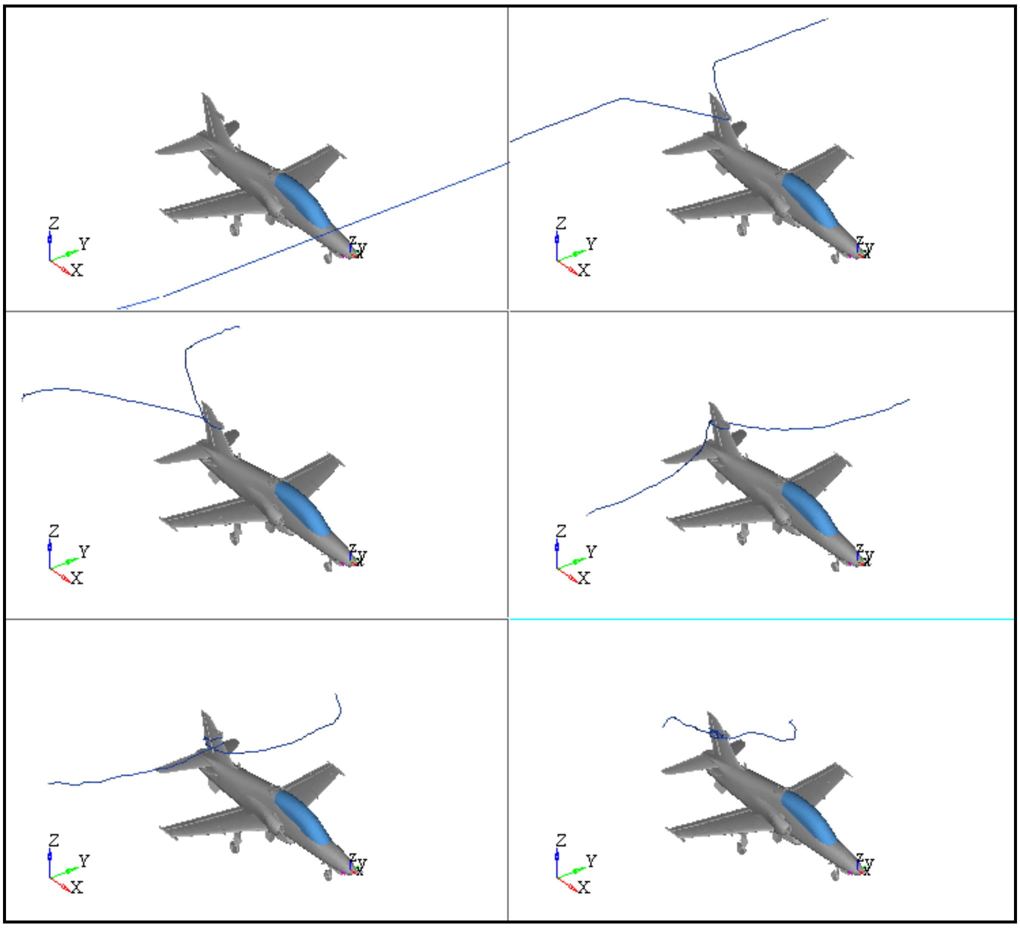


Figure 11: Example of Centre Suspension Cable Behaviour

6.0 Conclusion

In conclusion this study has demonstrated the successful application of advanced finite element modelling techniques to the simulation of a high-speed impact event between an aircraft and a runway barrier net.

A total of eighteen combinations of approach velocity, aircraft AUM, aircraft approach/yaw angle and engagement position in relation to centreline of barrier were analysed during the course of this study.

After analysis of the results of those simulations the following points can be made:

- The addition of the two Smart Probes to the nose of the Hawk T Mk2 does lead to them snagging on the vertical webbing elements of the net as the aircraft engages with the barrier.
- This leads to some of the upper horizontal webbing strips being pulled down in to contact with the canopy however the peak contact loads generated did not reach excessive levels nor were they present for such a period of time to give cause for concern.
- Examination of the engagement phase of all eighteen simulations performed did not indicate that the steel Centre Suspension Cable was brought into contact with the canopy of the aircraft - in each case the canopy was well clear of the cable by the time the cable was released from the rest of the suspension system.
- It was noted that after its release from the suspension system, the centre suspension cable become snagged on the RWR on the vertical tail fin, causing it to wrap around the fin. There may be some risk of damage to the airframe or injury to the aircrew from the flailing ends of the cable however no contact was observed during this study.

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7.0 References

[1] **HyperWorks,** Altair Engineering, 2009