THE COBRA HELMET MOUNTED DISPLAY SYSTEM FOR GRIPEN

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Abstract

Selected to meet the stringent requirements of the Gripen swing-role combat aircraft, the Cobra Helmet Mounted Display System, has been integrated as a key component to the Gripen weapon delivery system.

Saab Aerosystems has since 2003 together with BAE System been developing the Cobra HMD and in parallel integrating the system in Gripen for South Africa and Sweden.

This paper will highlight some technical challenges and experiences with integrating a HMDS in a small cockpit environment as in Gripen and present an overview of the Cobra HMD design and installation. Furthermore the paper will discuss prediction of neck injuries during emergency escape for pilots using HMD.

1 Introduction

Saab Aerosystems have since 1997 in different research and development projects studied integration of a HMD system in Gripen. During 1998 to 2001 one Pilkington Guardian HMD system was integrated in a test aircraft as part of the air to air missile IRIS-T development integration in Gripen. In total 20 HMD flight trials were performed and resulted in an extensive HMD system experience which has been used as important input to further development. In parallel to the Guardian integration an extensive work was done in simulators to develop a Gripen specific HMD symbology set with focus on the air to air mode. The development work continued in the ACE project [1] which used a Saab SK60 twin seat jet trainer as a HMD technology test platform. The developed Gripen HMD symbology was first flight tested within the ACE project in 2002.

Saab Aerosystems have in close cooperation with BAE Systems Rochester UK and partners including Carl Zeiss Optronics of South Africa been developing the Cobra HMD system into the Gripen swing role combat aircraft. The Cobra HMD System is developed as an option for Gripen Export version and is integrated into the Gripen single seat and front seat of the two-seat aircraft. The project started in 2003 and is now in the final stage for delivery to the first customer at the end of this year [3].

2 Challenges

One of the major challenges of integrating the Cobra HMD system has been to integrate it in to a small cockpit environment without jeopardizing pilot safety. One area that has been a key requirement thru the development is ejection safety with regards to helmet weight and helmet Centre of Gravity. This paper will highlight some development and integration work performed with regards to the Cobra HMD Day Camera separation and clearance for safe ejection.

3 The Cobra HMD System

The Cobra helmet display system builds on the technology for the Eurofighter Typhoon "Striker" HMD System. The helmet is a two-shell design: the outer shell is the platform for the display and optical parts and has a pair of fully overlapped CRTs giving a 40° field-of-view and can display both raster- or vector-generated graphics. The outer helmet also includes infra-red light-emitting diodes (LEDs) for tracking, while the inner shell, custom fitted by laser-scan to the pilots' head contains communication equipment and a specifically developed oxygen mask and mounting points to ensure a perfect fit.

The helmet's position is tracked using a Carl Zeiss Optronics electro-optical tracking system comprising three CMOS tracking sensors. The Gripen HMD also includes a pilot's line-of-sight camera with superimposed symbology for recording in the Mission Support System for training and evaluation purposes. The Daycamera is integrated as a clip-on camera and will separate from the helmet prior to ejection in the same way as provisional Night Vision Devices through the helmet camera release unit.

The Cobra HMD System has been fully integrated into the Gripen avionics system and operates through Mil-Std 1553B digital bus to the different weapon and sensor system.

The Cobra HMD System compromises the following parts:

- Helmet Assembly:
  - Outer helmet including binocular CRT fully overlapped 40˚ Field of View
  - Inner helmet including Custom Fit Protective Liner
  - Dual visor (blast/display and glare visor)
  - Oxygen mask
- HMD Electronic Unit (HMDEU), size 3MCU , Forced air-cooling
- Helmet Camera Release Unit (HCRU)
- Helmet Tracker System Sensor (HTSS)
- Daycamera
- Helmet Vehicle Interface (HVI)

The Cobra HMD design solution for the separation between pilot and a/c in case of an ejection includes a new developed quick release connector integrated in the aircraft together with a short umbilical HVI to interface to the cockpit bulkhead. The Cobra QRC design is based on a friction force release mechanism with the helmet/man mounted part clipped on to the flight jacket in order to take the force in case of an ejection or emergency egress.

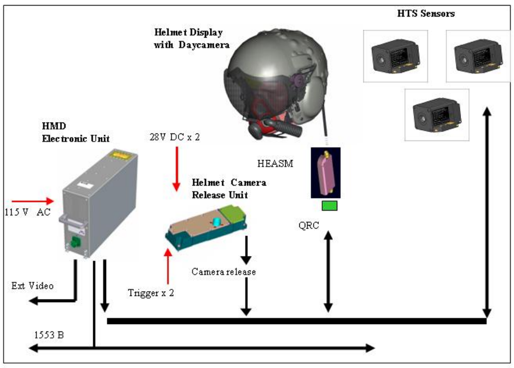

Fig 1. Overview of the Cobra HMD System.

Fig 2. The Cobra HMD integration on Flight Jacket

4 Daycamera & QRC separation

The Cobra HMD also provides an integration of new developed daycamera to record the outside world in the pilot's line-of-sight together with superimposed symbology. The camera field of view is 50˚ x 40˚and provides a 525 lines video image. The recorded video can be replayed in the Mission Support System for training and evaluation purposes. Based on experiences from earlier HMD integrations a daycamera has been seen as a key requirement for the Cobra HMD system. The design solution for the daycamera has been to integrate it on the left hand side to a outer housing with the same electric interface and auto detach mechanism as the Eurofighter HMD Night Vision Camera [2]. The camera is repeatable replaceable with a high line of sight accuracy. In order to minimize the neck load during ejection the camera will auto detach prior to ejection which is triggered from the Helmet Camera Release Unit. The Helmet Camera Release Unit uses a complete redundant system with both independent trigger circuits as independent current outputs to the camera release mechanism.

The requirement for the camera to separate before the ejection put extreme time critical requirements on when to receive the trigger signals as it needs to be released before the seat starts to move and accelerate. Another key requirement is also for reliability reasons not to include any electronic equipment onto the ejection seat. The Gripen design has been to use one trigger signal from an ejection seat pressure switch and one from the existing canopy fracturing system. Both these switches are mechanical operated and triggered from the pressure built up in the ejection seat firing system.

The daycamera release mechanism and QRC separation have been qualified at Saab Aerosystems Tower Track Test Facilities in Linköping by a series of tests, see Figure 3. The tower is 36 meter with an angle of 30 degree from vertical and can provide ejections up to 20 G acceleration. The test set up included both fully dressed maximum and minimum manikins as well an instrumented Hybrid III 50th percentile dummy for head and neck load measurements. First the tests showed that the QRC separation with the HEASM attached to the flight suit releases as designed and with all separation forces taken through the jacket and secondly the daycamera separations.

For a safe daycamera separation the two critical times identified are first after the seat have

Fig 3. Qualification test with Daycamera and QRC separation.

moved 25 cm [t_3] which is when the helmet will start to be exposed to windblast and secondly approximate after 35 cm [t_4] which is when the QRC will separate and no contact to the camera exist.
A summary of the timing figures from the worst case tests are seen in table 1 and shows that both trigger signals will release the camera before the seat starts to move and that the margin between the camera separation and two most critical times t4 and t3 are around 100 ms.

Table 1. Daycamera separation timings

Ejection 5th percent.	t_1	t_2	t_3	t_4
Speed (m/s)	0	0	6.4	8.4
Acceleration (m/s^2)	0	0	99	110
Distance (m)	0	0	0.25	0.33
Time from t_0 (ms)	12	20	110	135

t_0 = Ejection handle

t_1 = Camera release, trigger circuit A (seat switch)

t_2 = Camera release, trigger circuit B (CFS switch)

t_3 = Seat moved 25 cm

t_4 = QRC separation

5 FE modeling for Safe Ejection

As part of the Cobra HMD integration into the Gripen a/c a study was performed in to order to get more detailed information of how the neck injury depends on the Flight Helmet mass and centre of gravity. The study included computer simulations with the different Flight Helmet HMD and both finite element models of the helmets, the seat and the parachute harness was developed. The simulations were performed by using two different models, 1st with a FE-model of the 50th percentile male Hybrid III dummy [12] and 2nd with a model from the Royal institute of Technology in Stockholm (KTH) in this paper called the KTH neck model [7].

The Hybrid III model, Fig. 4, has been validated for the same load cases as the experimental Hybrid III. The output from this model comes from accelerometers in the head and chest. The upper and lower neck parts have beam elements that give force and moment data representative of the joints between the occipital condyles and atlas vertebra called C1, and between C7 and the fist thoracic vertebra (T1) [12].

Fig. 4 Hybrid III

The KTH neck model, Fig. 5, is a unique, detailed model of the cervicial vertebral column from the skull down to the first thoracic vertebra (T1). The model has previously been used in studies with vertical loading and is validated for compression loading and injury prediction during compression- flexion motions [7].

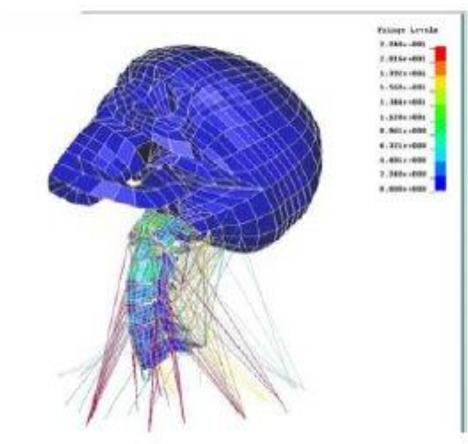

Fig 5 KTH neck model.

5.1 Flight Helmet HMD- Hybrid III

This simulation with the Flight Helmet HMD on the Hybrid III dummy started with that the centre of gravity and the moment of inertia of the Flight Helmet HMD were defined. The helmet was positioned on the Hybrid III head in relation to the design eye and merged with the head in order to follow all movements of the Hybrid III. Refer to Fig. 6 for the picture of the test set up.

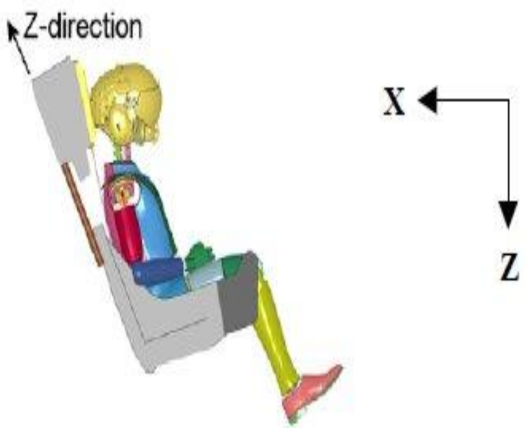

Fig 6. Illustration of the direction of motion along the z-axis for the seat.

The ejection seat motion was defined and applied in the positive z-direction. The relative static pressure due to the windblast was derived from Computer Fluid Dynamics (CFD) simulations; the data was converted to pressure curves as a function of time. The pressure was applied on free surfaces of the dummy and the helmet excluding the legs and the feet.

10 simulations were performed. This report covers the results from simulation ID 4-7, ID 9 and 0 which are simulations of a realistic ejection situation with varying aircraft velocity refer to table 2. The other simulations were omitted or performed in order to validate the model.

Table 2 Performed simulations, Flight Helmet HMD-Hybrid III

ID	$V_{a/c}$ [kts]	β [deg]	p [rad/s]	Note
4	200	0	0	Validation 3 Head rot 45° Only windblast
5	450	0	0	
6	600	0	0	
7	450	0	3	A constant rotation of 3 rad/s was applied to the seat.
9	600	0	3	A constant rotation of 3 rad/s was applied to the seat.
0	0	0	0	

5.1.1 Injury Criteria

The injury criteria according to Table 3 were used to predict injury.

Table 3 Injury Criteria for Hybrid III 50 percentile male.

Criteria	Injury Prediction	Ref
HIC36	1000	[4]
HIC15	700	[5]
NIC	10 (0% injury risk), 15 (18% injury risk)	[6]
Flexion bending moment (Nm)	190	[4]
Extension bending moment (Nm)	57	[4]
Axial tension (N)	1100 (45 ms), 2900 (35 ms), 3300 (0 ms) 4170 peak limit	[4] [5]
Axial compression (N)	1100 (30 ms), 4000 (0 ms) 4000 peak limit	[4] [5]
Shear force	(along X –axis) (N) 1100 (45ms), 1500 (25-35ms), 3100 (0ms)	[4]
Nij	1.0 for 15% injury risk	[4]
Chest deflection	63 mm	[5]

5.1.2 Results

The result of the simulation with ejection with increasing degree of windblast is summarized below. The results from ID0 and ID4-9 performed with the Flight Helmet HMD and the Hybrid III. The simulations except ID 0 had the same seat ejection pulse but increasing wind velocity. A higher wind velocity resulted in a quicker head flexion motion, refer to Fig. 7.

Fig. 7 Flight Helmet HMD- Hybrid III Head motion ID 0, ID4, ID5 and ID6

5.1.3 Conclusion

Head injury is not predicted during phase 1, but can not be evaluated during head rest contact due to modeling simplifications. Head impact severity is instead evaluated with the head velocity at impact, which ranged between 19 – 27 m/s for ID 6 to 9.

Pure tension injury is predicted for simulations ID 5, 6, 7, and 9. However, in the validation of the model it was noticed that the upper neck had a high peak that was not representative for the test. Hence, the upper neck z-forces for ID5-9 may not be entirely representative of the actual event.

Neck injuries due to tension-extension loading are predicted with the Nij criterion for ID 6 and ID 9 during the rebound of the head, right before head rest impact.

Soft tissue injuries according to the NIC criterion are predicted only for simulations ID 6 and ID 9. Hence, soft tissue injuries are only predicted for those cases where vertebral injuries were predicted according to other criteria. However, the Hybrid III is not well suited to analyze these minor soft tissue injuries.

Neck injuries are predicted with the Hybrid III using automotive injury assessment levels for wind blast speeds of 450 knots and 600 knots. No injuries are predicted for wind blast speeds of 200 knots or lower.

5.1.4 Discussion

During the study the following limitations regarding the simulations with the Hybrid III were discussed.

- The method to simulate windblast in the simulations did not simulate the change of windblast loading caused by flexion in the neck. It is not known how much this affects the results.
- It is not possible to verify that the CFD data mapped on the Hybrid III 50% is correct.
- There are no irregularities or unexpected properties in the CFD data sets used. [2].
- The Hybrid III 50% dummy is not developed or validated for load conditions with a major vertical component.
- Correlation of the injury assessment in the dummy and the human responses is not known.
- The FE Hybrid III 50% is not fully validated with the response of the experimental Hybrid III 50% for load conditions with a major vertical component and high CFD loading.

5.2 Flight Helmet HMD- KTH neck model

The simulation made with the Flight Helmet HMD on the KTH neck model started with that the KTH neck model was positioned in - 18º around the y- axis to fit the Saab Gripen seat, refer to Fig. 8. The centre of gravity of the Flight Helmet HMD was defined and the helmet was attached to the head.

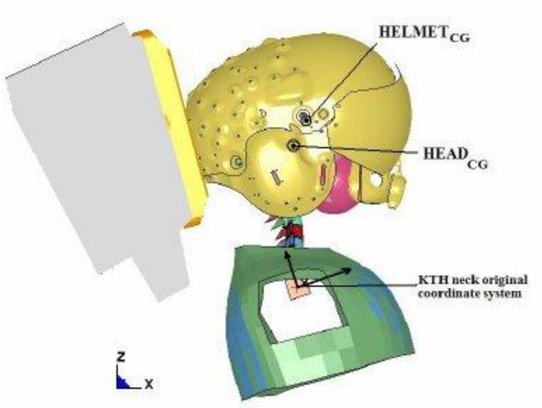

Fig. 8 The KTH neck model with the Flight Helmet HMD and the Saab Gripen neck support.

The KTH neck model is only a neck model and therefore the simulations do not include the lower part of the body or seat. The loadings on the head and the neck were derived from the simulations with the Hybrid III and applied on the first thoracic vertebrae (T1). The aero dynamical loads were calculated from CFD for a static head in initial position. Different degrees of muscle activation was simulated, full activation, 50% activation and no activation and 0.1 seconds delayed activation, refer to Fig. 9. The unprepared aircrew was assumed to reach full activation 100ms after the external load starts.

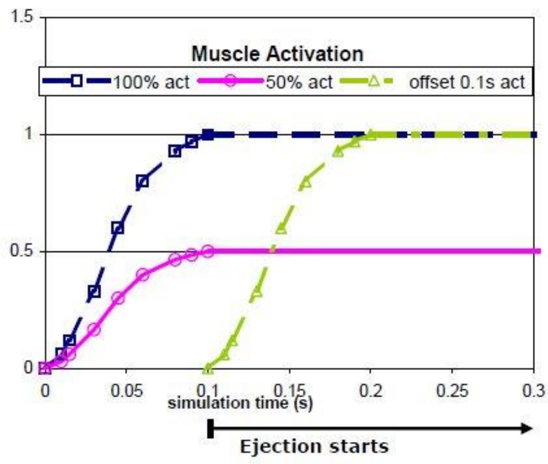

Fig. 9 Activation curve for 100%, 50% and offset 0.1 seconds.

Seven simulations were performed. This report covers the results from simulation ID4-6 and 0 which are simulations of a realistic ejection situation with varying aircraft velocity refer to table 4. The other simulations were omitted or performed in order to validate the model.

Table 4 KTH neck model performed simulations

ID	Va/c [kts]	β [deg]	p [rad/s]	Head position	Note
4	200	0	0	Head against neck support	
5	450	0	0	Head against neck support	
6	600	0	0	Head against neck support	
0	0	0	0	Head against neck support	No wind-blast.

5.2.1 Injury Criteria

The following three injury criteria were used to predict injury. The beam criteria according to Table 5, the Local Tissue Criteria, thresholds for stresses and strains according to Table 6 and the Injury threshold for ligaments according to Ref [10] and [11].

Table 5 Intercept values for Beam Criterion

	Fz tension*	Fz compr.*	My flexion*	Ref.
Beam Criteria	5660 N	5430 N	141Nm	[8]

*Forces and moments were computed from the C7-T1 joint of the KTH- model.

Table 6 Intercept values for Local Bone Tissue injury criteria

Local Tissue Injury Criteria	Tension (MPa)	Compr. (MPa)	Ref.
Compact Bone	125	200	[9]
Trabecular Bone	10	10	[9]

5.2.2 Results

The result of the simulation with ejection with increasing degree of windblast using the Flight Helmet HMD and the KTH Neck Model is summarized below. The results from ID 4-6 simulations had the same seat ejection pulse but increasing wind velocity. A higher wind velocity resulted in a faster head flexion motion; refer to Fig. 10 and 11.

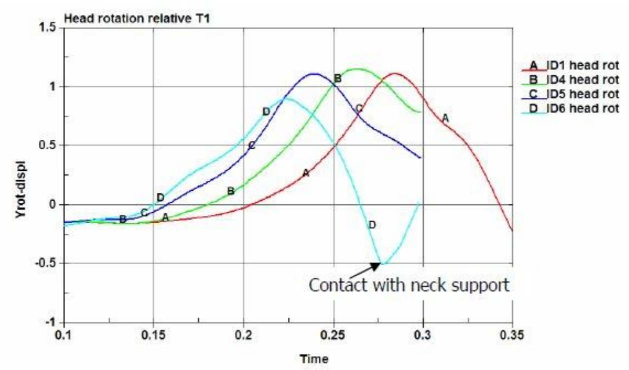

Fig. 10 Head rotation (radians) relative T1 starting at t=0.1 as the ejection initiates [2].

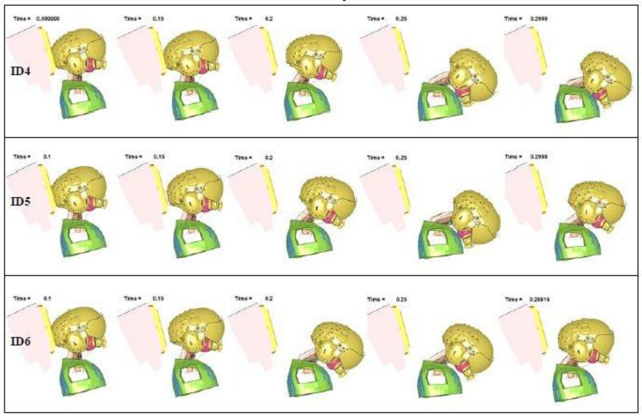

Fig. 11 Animation series for ID4, ID5 and ID6.

5.2.3 Conclusion

Vertical acceleration pulses applied to the T1 vertebrae results in high loads in the cervical spine. Ejection of a fully prepared pilot wearing a Flight Helmet HMD was injurious for some of the posterior cervical ligaments. For airspeeds of 200kts or 600kts the vertebral stresses or beam criteria did not predict injury, while for 450kts the vertebral stresses in the compact bone exceeded the failure threshold.

For ID4 with the lower air speed of 200kts and a fully prepared pilot, the global lower neck criteria is just below risk of injury (0.96) and the vertebral stresses are well beneath injurious values. However, some of the ligaments predict failure, especially the lower neck show high critical values.

For ID5 the critical value is the vertebral stresses, which have a peak above the threshold value just at the end of the simulation as the vertebral column is compressed by the vertical forces. The beam criterion is slightly lower than for ID4 and the ligament failures are similar to ID4 with higher failure values in the lower neck ISL and LF C6-C7.

In ID6 it seems like the windblast load lifts the head up and counteracts the compressive ejection forces resulting in lower vertebral stresses than for ID5. The beam criterion and ligament failures are similar to the other ID's though the strain is distributed a bit differently.

The muscle activation parameter study shows that for the combined ejection- windblast loads of ID4 - ID6 full activation protects the spine whereas for the pure ejection pulse of ID1 the activation adds to the vertical forces and is more harmful than protective. Muscle activation offset (an unprepared pilot) affects especially the beam criteria by passing the threshold for injury. The vertebrae and ligaments show some increase but no additional injury is predicted. The load applied on the T1 vertebrae is essential for the prediction of ligament injuries.

The computed stresses and strains in the neck model are above the reported injury criteria. The highest vertebral stresses and ligament strains was seen when the head was pushed back to the neck support.

However, there has not been reported any injuries in the cervicial spine from real life ejections with the Gripen aircraft. The model predicts injury for cases that should be risk free.

5.2.4 Discussion

During the study the following limitations regarding the simulations with the Hybrid III were discussed. The study must be seen as a pre- study aimed to develop an evaluation method for ejection injuries in the human neck since only a few simulations has been performed.

The KTH neck model of the cervical spine does not predict the same kinematics as the experimental Hybrid III dummy. This is because there is a large difference between the Hybrid III neck and the human neck. The Hybrid III dummy is not developed for compression loading.

The simulations included a vertical acceleration pulse compared with different grades of windblast. The windblast load was calculated for a static head in initial position leaning on the neck support. This affects the direction of the load. The head movement during ejection results in different load directions and aero dynamical profile.

The computed stresses and strains in the neck model are above the reported injury criteria. However, there has not been reported any injuries in the cervicial spine from real life ejections with the Gripen aircraft. The model predicts injury for cases that should be risk free. The following reasons for this have been further discussed:

- The strains and stresses computed could be too high. High values of the posterior ligaments in the region of C6/C7 can be a consequence of the rotation in T1. For these simulations the displacement and rotations are taken from the Hybrid III dummy that is stiffer than the KTH neck model, the y-rotation is therefore underestimated.
- Simulations show that allowing the T1 vertebrae to rotate in this direction reduces the strains in the ligaments significantly. Another possible reason for high computed values is that the T1-pulse is unrealistic or too “sharp”, as it is taken from the chair or the Hybrid III dummy.
- Some of the high values occur when the chin of the pilot hits the torso. The models in the simulations did not wear a flight jacket. The life vest collar on the flight jackets could have limited the flexion motion.
- Some of the material parameters in the KTH neck model have been taken from experiments performed with an older population. The aircrew is probably younger and better trained. Also the injury criterias used in the study are derived from experiments on an older population and is probably to low.
- A comparative simulation without windblast was performed with the Flight Helmet HMD. The helmet weight was decreased to 0.93 kg. This helmet reduced the ligament strains but still predicted injury in the lower interspinous ligaments. This observation seems to indicate that the predicted values in the posterior lower neck are too high.
- However the simulations show that the loadings on the cervical spine depend on how the head is positioned and if the aircrew is aware of the ejection. Muscle activation protects the cervical spine in

the combined ejection- windblast simulations. In the simulations without windblast it is seen that the muscle activation loads adds the vertical forces and are more harmful than protective. The 100% activation in the simulations is defined for a normally trained male.

6 Summary

With an integration of such complex system as a HMD a lot of key requirement has to be designed early in the project which will have a major impact on the cost and time if they turn out to be wrong. The pilot's safety with regards to a/c ejections with HMD has been a key factor in the development of integrating the Cobra HMD system into the Gripen a/c. The different performed simulations and FE-models of the helmet and neck shows the difficulties in predict injuries. The Hybrid III dummy has been developed and optimized for the forces present in car crashes not aircraft ejection with high Fz forces. Therefore it is not suitable for use in pass/fail ejection simulations with regard to injury criteria. New FE-models and dummies should be developed with the forces present at aircraft ejection in mind. However the existing FE-models and Hybrid III dummies may be used for parameter studies of different helmet design and comparative test cases to some extent.

The ejection test results shows that the Cobra HMD integration passes the requirement for safe ejections and that the capability of the Cobra HMD further enhances Gripen's combat edge performance and will be taken into service in the end of this year

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