

“Aircrew Endurance and Effectiveness”

NACES Endurance Improvement

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Abstract

With changing operational environments for tactical aircraft new demands are being placed on aircrew, which are pushing the limits of physical endurance. In particular, mission durations have increased to the point that previous issues with ejection seat comfort have become more pronounced and have begun to affect aircrew performance.

In the past, short duration missions have been the norm and the effect of ejection seat comfort was not well documented. However, changed mission profiles requiring extended seated durations have highlighted the effect of discomfort on aircrew performance.

As part of the Navy Aircrew Common Ejection Seat (NACES) Stability Improvement Programme (SIP) Martin-Baker have been working alongside the US Navy to assess and develop comfort improvements suitable for the SJU-17A seat used in F-18's and T-45's. Various cushion designs were first assessed for anthropometric compatibility and thus comfort, and then environmental testing was undertaken on a reduced number of the chosen cushioning designs. The 3 most promising designs were finally tower and ejection tested in support of a flight clearance. Three F-18 squadrons, who complete regular evaluation questionnaires, are currently flying these three ejection seat designs. The initial results of this trial are demonstrating a need for improved lumbar support and the introduction of non-foam cushion inserts, rather than the highly compressible urethane and slow response cushions that are currently used.

It is acknowledged that comfort affects the state of mental and physical well being of the aircrew, and their performance in the cockpit. Therefore understanding their endurance requirements and providing solutions to resolve these issues are imperative for the future of high performance fast jet aircrew.

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Introduction

When designing ejection seat profiles, two main problems occur, the first is how sufficient comfort can be offered to a pilot so that backache, reduced blood flow and muscle damage leading to fatigue and reduced lethality can be prevented. Secondly, is how such a comfortable sitting posture can meet the requirements for a safe and optimal ejection from the aircraft.

It is considered that historically comfort has been neglected, and in the past with short sorties this may have been acceptable, but the emergence of this problem is all the more apparent since the introduction of mid-air refuelling and increased mission durations. This has led to pilots sitting in excess of 7 hours with minimal movement.

Previous seat evaluations by Fernandez and Poonawala (1998) have been able to show that the comfort of a sitting platform can be assessed without the need for equal duration comfort trials when using the 11-point general comfort rating scale (GCR) (Figure 1) devised by Shackel *et al.* (1969). It can be concluded that at the end of the third hour, the results obtained are not significantly different from those obtained at longer seated durations.

Rating	Description
1	I feel completely relaxed
2	I feel perfectly comfortable
3	I feel quite comfortable
4	I feel barely comfortable
5	I feel uncomfortable
6	I feel restless and fidgety
7	I feel cramped
8	I feel stiff
9	I feel numb (or pins and needles)
10	I feel sore and tender
11	I feel unbearable pain

Figure 1 11-point general comfort rating scale devised by Shackel *et al.* (1969)

The introduction of pressure mapping techniques like the Tekscan System have increased the science behind comfort, moving it away from a purely subjective definition, to a quantifiable, graphical image, when used with reference to a controlled baseline.

This comfort evaluation methodology when used in conjunction with a subjective questionnaire has been the chosen method for the stability improvement program (SIP) being undertaken on the NACES F-18 ejection seats.

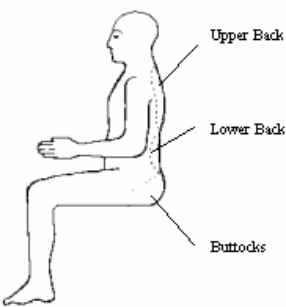
Down Selection Process

To develop comfort improvements suitable for NACES, the initial task was to undertake a trade study on existing market products and materials. 12 suitable cushion products were initially tested for comfort. These included slow response, memory foams, honeycombs, air-filled and gel-filled cushions, vibrating and massage cushions and spacer fabrics.

Two human anthropometric extremes volunteered to undertake comfort trials on various new cushioning materials and sitting profiles to determine the ability of each material to remain comfortable over 3 hours of seated duration. Wearing summer Aircrew Equipment Assembly (AEA) and a PCU-56/P torso harness each subject was required to sit in an unarmed mock-up NACES equipped cockpit for three hours being monitored at 5-minute intervals by the Tekscan system, whilst completing a comfort questionnaire every hour (Figure 2) produced from combining the 11-point general comfort rating scale (GCR) and the work of Lusted *et al.* (1994) who devised the body area chart discomfort checklist for monitoring the discomfort of any particular body part.

DOES YOUR BODY HURT NOW?

	How bad is it? (Mark scale to indicate intensity)		GCR Scale Rating	What kind of sensation? (Indicate one or more)	
	No Pain or Discomfort	Agony			
			1 to 11		
Head or Neck				<input type="checkbox"/> Ache <input type="checkbox"/> Sharp pain <input type="checkbox"/> Burning <input type="checkbox"/> Numb <input type="checkbox"/> Tingling <input type="checkbox"/> Other	
Shoulder				<input type="checkbox"/> Ache <input type="checkbox"/> Sharp pain <input type="checkbox"/> Burning <input type="checkbox"/> Numb <input type="checkbox"/> Tingling <input type="checkbox"/> Other	
Upper Back				<input type="checkbox"/> Ache <input type="checkbox"/> Sharp pain <input type="checkbox"/> Burning <input type="checkbox"/> Numb <input type="checkbox"/> Tingling <input type="checkbox"/> Other	
Arms & Hands				<input type="checkbox"/> Ache <input type="checkbox"/> Sharp pain <input type="checkbox"/> Burning <input type="checkbox"/> Numb <input type="checkbox"/> Tingling <input type="checkbox"/> Other	
Lower Back				<input type="checkbox"/> Ache <input type="checkbox"/> Sharp pain <input type="checkbox"/> Burning <input type="checkbox"/> Numb <input type="checkbox"/> Tingling <input type="checkbox"/> Other	
Buttocks				<input type="checkbox"/> Ache <input type="checkbox"/> Sharp pain <input type="checkbox"/> Burning <input type="checkbox"/> Numb <input type="checkbox"/> Tingling <input type="checkbox"/> Other	
Thighs				<input type="checkbox"/> Ache <input type="checkbox"/> Sharp pain <input type="checkbox"/> Burning <input type="checkbox"/> Numb <input type="checkbox"/> Tingling <input type="checkbox"/> Other	
Knees				<input type="checkbox"/> Ache <input type="checkbox"/> Sharp pain <input type="checkbox"/> Burning <input type="checkbox"/> Numb <input type="checkbox"/> Tingling <input type="checkbox"/> Other	
Lower Legs/ Calves				<input type="checkbox"/> Ache <input type="checkbox"/> Sharp pain <input type="checkbox"/> Burning <input type="checkbox"/> Numb <input type="checkbox"/> Tingling <input type="checkbox"/> Other	
Ankles and Feet				<input type="checkbox"/> Ache <input type="checkbox"/> Sharp pain <input type="checkbox"/> Burning <input type="checkbox"/> Numb <input type="checkbox"/> Tingling <input type="checkbox"/> Other	



Total Sector Length

Hours Elapsed

Date

Subject

Signature

Figure 2 Comfort Questionnaire used for ‘In-House’ Evaluation

At this stage materials were only de-selected based on comfort, therefore 7 of the 12 materials continued through to the environmental testing. This testing included fire resistance, altitude, decompression and behaviour over the temperature range of -65F to 165F. At this stage a further down select was undertaken leaving only 3 material candidates. A Vicair insert comprising of individual air bags, a Supracor insert comprising of a honeycomb structure and a Spacer Fabric insert consisting of layers of fabric resembling netting.

Tower testing was then undertaken on these 3 insert materials and the existing NACES cushion to determine the dynamic response index (DRI) and insure that it did not exceed a value of 18, which would lead to possible spinal injuries. All three of the cushions recorded DRI values of below 14, and were within the scatter of the current NACES baseline cushion.

Flight Trials

With 3 cushion inserts providing equally good evaluation results a decision was taken with the US Navy to flight trial all 3 and let to aircrew down select to the final candidate solution.

Three F-18 squadrons were chosen to trial these cushions based on their availability and typical sortie duration, and to increase the knowledge gained from this assessment external materials for the covers were also discussed. Each Squadron was given one set of 10 cushions all in leather, sheepskin or the existing black honeycomb fabric, so that within a squadron each cushion looked the same. However, internally a variety of the 3 insert materials were provided for evaluation, only to be identified by a numerical label or by the aircraft that they were installed in. After each sortie, aircrew were requested to complete a single questionnaire, (Figure 3) which provides Martin-Baker and the US Navy with comfort data for analysis to assist with the future down select.

COMFORT EVALUATION QUESTIONNAIRE

	How bad is it? (Mark scale with a X to indicate intensity)		GCR Scale Rating (Indicate one or more if any apply)	What kind of sensation? (Indicate one or more if any apply)
	No Pain or Discomfort	Agony		
Head or Neck	X		1	<input type="checkbox"/> Ache <input type="checkbox"/> Sharp pain <input type="checkbox"/> Burning <input type="checkbox"/> Numb <input type="checkbox"/> Tingling <input type="checkbox"/> Other
Shoulder	X		1	<input type="checkbox"/> Ache <input type="checkbox"/> Sharp pain <input type="checkbox"/> Burning <input type="checkbox"/> Numb <input type="checkbox"/> Tingling <input type="checkbox"/> Other
Upper Back	X		2	<input type="checkbox"/> Ache <input type="checkbox"/> Sharp pain <input type="checkbox"/> Burning <input type="checkbox"/> Numb <input type="checkbox"/> Tingling <input type="checkbox"/> Other
Arms & Hands	X		1	<input type="checkbox"/> Ache <input type="checkbox"/> Sharp pain <input type="checkbox"/> Burning <input type="checkbox"/> Numb <input type="checkbox"/> Tingling <input type="checkbox"/> Other
Lower Back	X		2	<input type="checkbox"/> Ache <input type="checkbox"/> Sharp pain <input type="checkbox"/> Burning <input type="checkbox"/> Numb <input type="checkbox"/> Tingling <input type="checkbox"/> Other
Buttocks	X		2	<input type="checkbox"/> Ache <input type="checkbox"/> Sharp pain <input type="checkbox"/> Burning <input type="checkbox"/> Numb <input type="checkbox"/> Tingling <input type="checkbox"/> Other
Thighs	X		1	<input type="checkbox"/> Ache <input type="checkbox"/> Sharp pain <input type="checkbox"/> Burning <input type="checkbox"/> Numb <input type="checkbox"/> Tingling <input type="checkbox"/> Other
Knees	X		1	<input type="checkbox"/> Ache <input type="checkbox"/> Sharp pain <input type="checkbox"/> Burning <input type="checkbox"/> Numb <input type="checkbox"/> Tingling <input type="checkbox"/> Other
Lower Legs/Calves	X		1	<input type="checkbox"/> Ache <input type="checkbox"/> Sharp pain <input type="checkbox"/> Burning <input type="checkbox"/> Numb <input type="checkbox"/> Tingling <input type="checkbox"/> Other
Ankles and Feet	X		1	<input type="checkbox"/> Ache <input type="checkbox"/> Sharp pain <input type="checkbox"/> Burning <input type="checkbox"/> Numb <input type="checkbox"/> Tingling <input type="checkbox"/> Other

Rating	Description
1	I feel completely relaxed
2	I feel perfectly comfortable
3	I feel quiet comfortable
4	I feel barely comfortable
5	I feel uncomfortable
6	I feel restless and fidgety
7	I feel cramped
8	I feel stiff
9	I feel numb (or pins and needles)
10	I feel sore and tender
11	I feel unbearable pain


Cushion Ref	X23232
Total Flight Duration	4 Hours
Date	2/2/05
Name	J. Jones
Squadron	208
Type of Mission	Transit Flight
Height	5' 10"
Weight	194 lbs
Signature	

Figure 3 Example of the Comfort Questionnaire completed after each Sortie

The flight trial began in March 2005 and has so far provided over 640 flight hours of data from 69 different aircrew, including 124 hours on the existing NACES cushion to use as a comparative baseline.

As the regularity of each cushion insert to be flown depends on the aircraft availability, there will not be the same number of flight surveys for each, therefore the results shown in Figure 4 have been normalised against the maximum score that they could have received for the number of surveys. This number is shown within brackets in the dialogue box of Figure 4.

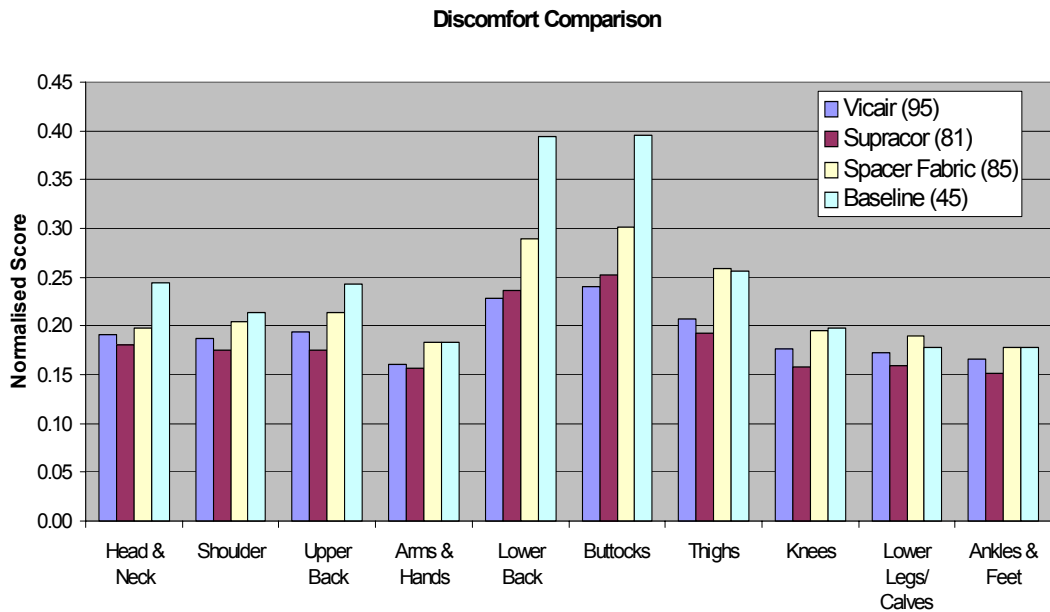


Figure 4 Displays a comparison between the 4 cushions being flown. The higher the score the greater the discomfort.

The duration of each sortie will affect the results therefore Figure 5, displays the spread of durations, clearly showing that the majority (79%) have occurred at 2 hours or below.

Spread of Flight Durations

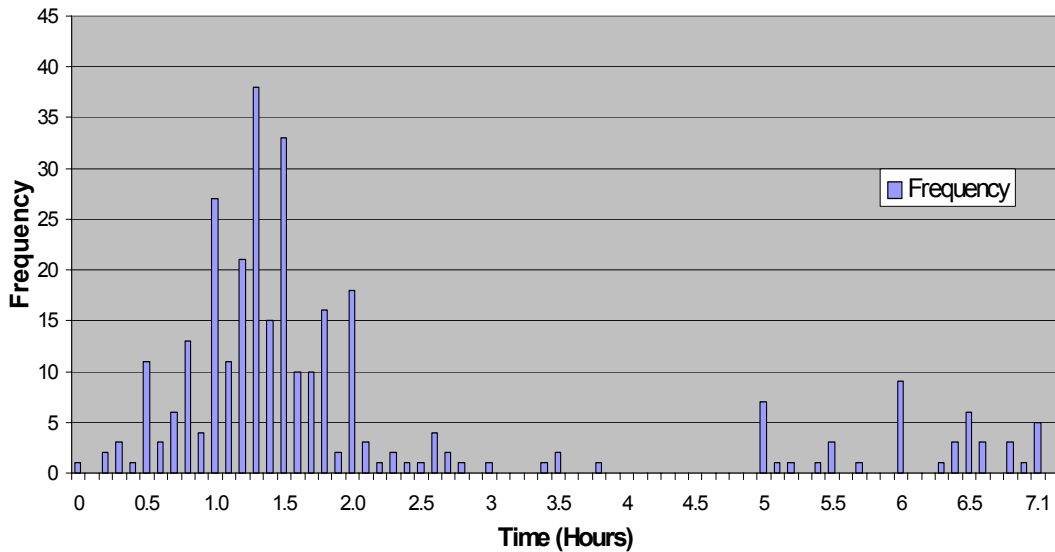


Figure 5 Displays the variation in Sortie duration

When the results for the comfort questionnaires are separated into above and below 2-hour sortie durations the results show that the Vicair out performs the others for short duration missions and the Supracor performs best for longer duration missions. In both cases the existing NACES cushion has the highest level of discomfort with the Spacer Fabric a close second.

Future Work

A second round of flight trials are set to begin before the end of 2005, with three further squadrons with only two cushions for evaluation. The Spacer Fabric has been de-selected based on comfort performance and the leather external cover has also been removed from the evaluation as it was seen to be too hot and costly without showing any benefit.

Slight modifications will be made to the contours of the cushion based of fleet comments, and the flight trials are expected to be only 4 months in duration, leading to a final comfort improvement solution being reached by the middle of 2006.

Conclusion

From the research and development that has been undertaken within the SIP programme it can be shown that although many cushions display instantaneous comfort, over time they can collapse or 'bottoms out' or experiences a temperature rise due to there inability to breathe. By starting the down selection process with 'in-house' comfort evaluations, using the Tekscan System, comfort was given the greatest importance. Ensuring that all the remaining cushions from each down selection processes will be comfortable.

The test results showed that most cushions only begin to become uncomfortable after 1 or 2 hours, therefore previous short duration studies (less than 1 hour seated) would not effectively assess the duration comfort of a cushion. Therefore showing that for aircrew instantaneous comfort is not the solution, rather it is an unchanging cushion solution that will remain comfortable and acceptable for the entire flight duration. Leaving the pilot unaware of their sitting surface and free to concentrate without fatigue on their mission.

With this information the final three solutions were provided for flight trial and were expected to be better than the cushion currently being flown on NACES by the F-18 aircrew. Figure 4 confirms the use of pressure mapping techniques in the design of comfort improvements, as all three are an improvement.

The devised comfort questionnaire is straightforward, quick and easy to use, and because of this has improved the quality of the subject's evaluation data being received. Limiting the variables and removing the need for comments by introducing crosses and the GCR number scale, has meant that very few surveys have been completed incorrectly.