AFRL-RH-WP-TR-2009-0056

Multi-Variant/Capability Next Generation Troop Seat (M-V/C NGTS)

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January 2009

Final Report for April 2008 to January 2009

Air Force Research Laboratory
711th Human Performance Wing
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NOTICE AND SIGNATURE PAGE

AFRL-RH-WP-TR-2009-0056 HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION IN ACCORDANCE WITH ASSIGNED DISTRIBUTION STATEMENT.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
January 2009

2. REPORT TYPE
Final Technical Report

3. DATES COVERED *(From - To)*
April 2008-January 2009

4. TITLE AND SUBTITLE
Multi-Variant/Capability Next Generation Troop Seat (M-V/C NGTS)

5a. CONTRACT NUMBER
FA8650-08-M-6876

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
65502F

6. AUTHOR(S)
J.D. Glatz, J. Eyth, K.L. Miller, M.A. Lilly

5d. PROJECT NUMBER
3005

5e. TASK NUMBER
HP

5f. WORK UNIT NUMBER
3005HPBB

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Glatz Aeronautical Corporation
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Newtown PA 18940

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Materiel Command
Air Force Research Laboratory
711th Human Performance Wing
Human Effectiveness Directorate
Biosciences and Protection Division
Biomechanics Branch
Wright-Patterson AFB OH 45433-7947

10. SPONSOR/MONITOR'S ACRONYM(S)
711 HPW/RHPA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-RH-WP-TR-2009-0056

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
88ABW/PA cleared 19Jun09, 88ABW-09-2754.
This research was conducted under the Small Business Innovation Research (SBIR) Phase I contract.

14. ABSTRACT
This Final Report documents the SBIR Phase I efforts that established concept feasibility of the Multi-Variant/Capability Next Generation Troop Seat (M-V/C NGTS). The M-V/C NGTS comprised three variants. Each of these variants specifically addressed, at the lightest weight possible, the three established performance criterions. The recent implementation of crashworthy troop seats over the last decade has identified that weight is the critical issue in their employment. By providing three variants the implementer will be able to choose the best solution for their application and not be limited by the weight constraint of a single solution. These SBIR Phase I efforts developed and fabricated three new variants of the NGTS that were significantly lighter and cheaper than the existing state-of-the-art.

15. SUBJECT TERMS
crashworthy, energy attenuation, Dynamic Structural Beam (DSB), Next Generation Troop Seat (NGTS)

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					John A. Plaga
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
U	U	U	SAR	20	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18

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PREFACE

This Final Report documents the Glatz Aeronautical Corporation's (GAC's) Phase I efforts relative to the US Air Force SBIR topic number AF081-003, *Innovative Research for Crashworthy Stowable Troop Seating for Helicopters*. The objective of this topic was the development "of innovative technology concepts for a crashworthy, lightweight, and rapidly stowable/removable helicopter troop seat with crash protection equivalent to the flight crew." The approach to topic solution was to fabricate prototypes and evaluate them relative to topic requirements. It was believed that fabricating prototypes would provide a greater degree of confidence than the typical Phase I paper study.

These prototypes were based on previous and proven GAC designs and proprietary technology. Known as the Next Generation Troop Seat (NGTS), three variants were fabricated to address the US Military's three performance requirements. They were also developed as generic hybrids to allow "cross platform" application.

The NGTS variants fabricated during this effort met or exceeded all Phase I program goals. Most importantly, the seat designed to replace the existing state-of-the-art weighed less than 10 pounds and was half that of existing systems. Based on the pre-production drawings, the cost was also about half that of existing systems. This represented a significant improvement.

The primary focus of the Phase I effort was the fabrication of prototypes and their evaluation relative to seat weight, seat cost, seat strength and seat performance. In addition, the Phase I effort also included minimal secondary evaluations. These were conducted to obtain additional confidence in the technology. The result of all evaluations was that no information was uncovered that would preclude further development.

The summation of the Phase I effort was that the NGTS represents a viable technology to achieve topic solution.

1.0 INTRODUCTION

United States military helicopter/rotary-wing crashworthy troop seating has had an unusual evolution. Initially, an extensive analysis of the helicopter mishap environment was used to establish a design guide, and design specifications from which seats termed Full Capability (***FC***) were developed and implemented. While the capabilities of these ***FC*** seats were exemplary, they were too heavy to find widespread cross-platform application. Subsequently, a second generation of seats termed Reduced Capability (***RC***) was developed wherein seat strength was reduced in order to reduce seat weight. The ***RC*** seats, and the generic specifications from which they were developed, are now becoming the accepted norm. These first generation ***RC*** seats have two flaws. They are still too heavy to be employed in the most weight critical applications; and, it has been determined that the performance degradation is more severe than originally thought. Recently, the performance degradation of either using an ***RC*** seat or a non-crashworthy seat has been better documented. There are the studies of US Air Force Colonel Pete Mapes, which are understood to be the basis for initiating this SBIR topic. Additionally, there is the white-paper by this effort's Principal Investigator, J.D. Glatz, titled, "Military Crashworthy Troop Seating: An analysis of the primary variables affecting implementation." Last, a closer look at the data and conclusions of a 1988 US Navy report, "The Naval Aircraft Crash Environment: Aircrew Survivability and Aircraft Structural Response" further emphasized the need to utilize crashworthy troop seats; and especially, ***FC*** seats. It should also be noted that the US Navy data yielded comparable results to that obtained during a previous US Army analysis of their own database.

The US Navy data involved aircraft with non-crashworthy seats. As such, it provides a baseline wherein the performance of various levels of crashworthiness can be evaluated. The energy (velocity) associated with the 95th percentile survivable accident was originally established as the threshold for protection. And, this yielded the ***FC*** requirement and resultant seats. Normalizing the data relative to the 95th percentile survivable accident yields the following table. (See Table 1)

Table 1: Navy Injury Summary		
	Injury type (%)	
Seat type	**none/minor**	**major/fatal**
Non-crashworthy	55	45
Reduced Capability (***RC***)	78	22
Full Capability (***FC***)	100	0

This table clearly shows the impact of the ***RC*** compromise as well as the impact of non-crashworthy seats. In terms of cost, the US Navy data was updated to current year dollars. The ***RC*** compromise resulted in a cost of $4.5M per every 100 occupants involved in a mishap. As can be deduced, the use of a non-crashworthy seat was even worse: $9M per every 100 occupants involved in a mishap.

A quote from the report provides a clear summation:

> *Analysis of the distribution of injuries and injury costs in helicopter accidents indicates that a disproportionate share occur near the survivable limit in the referenced fleet of aircraft. Almost 40 percent of the injury costs occur within 15 feet per second of the 95th percentile survivable accident velocity.*

The point 15 feet per second less than the 95th percentile survivable accident roughly approximates the design point established by the ***RC*** requirements.

Studies of Aviation Week & Space Technologies' "Year in Review" issue ("World Military Aircraft Inventory." Aviation Week & Space Technology, 13 January 2003, pp. 257 – 276) identified that approximately a third of US Military rotary-wing aircraft troop seat locations utilize an ***FC*** seat; about half utilize a non-crashworthy seat; and, the remainder use an ***RC*** seat. It should be noted that while half use a non-crashworthy troop seat only about a third of the total fleet could be considered a weight critical application. In contrast, all rotary-wing cockpit stations have crew seats that provide protection up to the 95th percentile survivable mishap.

A discussion of a hypothetical scenario involving the US Navy's S-3 Viking may better place this current situation in to more visual terms and help emphasize the critical need to develop and implement lightweight crashworthy troop seats. The S-3 is a jet aircraft whose primary mission is sub-hunting. The crew stations are equipped with ejection seats. There were also variants with the capability to ferry passengers. The passenger seats are not ejection seats.

A rhetorical question would be: How would it look if in an emergency an S-3 pilot and copilot ejected leaving the passengers to "ride it in"? But, this is precisely what the US Military is doing in approximately two-thirds of the mishaps with rotary-wing aircraft. The analogy is that the ***FC*** seat is comparable to an ejection seat; and, an ***RC*** seat or non-crashworthy seat is comparable to not having an ejection seat.

It should be noted that as a matter of policy, the S-3's ejection seats were "pinned" such that they were not functional when ferrying passengers. This was also the case for early V-22 flight test aircraft which had ejection seats in the cockpit. These too were "pinned" when additional personnel were in the cabin during flights.

In the context of the S-3 and flight test V-22s, the reasons for "pinning" the seats are obvious. Or, more importantly, the difference in protection is better understood and comprehended. In the rotary-wing community, one seat looks as good as another and decision makers have not been educated to the point of making the connection to the importance of ***FC*** seating and the negative impact of continuing to employ either ***RC*** seats or non-crashworthy seats.

Even beyond this failure to implement our nation's philosophy of "exchanging treasure for blood," there is an equally important reason to develop ***FC*** seats that are applicable in even the most weight critical applications. Conflicts today are, for the most part, "come as you are" wars. While the length of the present conflict has tempered that to a point, it is still highly applicable at the battlefield engagement level. The commander on the ground will be in a much better situation if his troop assets are able to survive an unforeseen mishap while entering the engagement.

As can be seen, the solution to this SBIR topic is extremely important. It will reinforce our nation's attitudes towards its soldiers by protecting their well being, and it will ensure that our commanders have the resources they need when they need them.

An evaluation of the current state-of-the-art relative to troop seats yields:

- current ***FC*** seats weigh approximately 19 ½ pounds
- current ***RC*** seats weigh approximately 15 ½ pounds
- non-crashworthy troop seats weigh approximately 6 ½ pounds per occupant location

Based on research of past and current seats and discussions with US Navy personnel responsible for future seats, a viable lightweight crashworthy troop seat should weigh no more than:

- 10 pounds in non weight critical applications
- 8 pounds in weight critical applications

These thresholds became the goals of the GAC Phase I efforts.

2.0 METHODS, ASSUMPTIONS, AND PROCEDURES

The method for approaching the solution of this topic is a continuation of the iterative process GAC has implemented to develop the Next Generation Troop Seat (NGTS). This consists of using the previous seat variant as a foundation, evaluating its viability, and incrementally improving it. Ultimately, as long as no insurmountable obstacles occur, the NGTS will become a qualified system in the US Military inventory.

The primary technology underlying the NGTS and its predecessors is the patented Dynamic Structural Beam (DSB) [patent no. 6,122,885]. It is exclusively licensed to the Glatz Aeronautical Corporation. This device is the foundation through which all of the advanced capabilities of these seats and the variants developed during the Phase I effort are derived.

The DSB is a unique and novel structural element. All previous structural elements behave similarly whether they are in a static or a dynamic environment. That is, if their failure point is a specific force, they will fail at this force regardless of whether it is applied at 0 g's (static), 10 g's or some other dynamic level. As such, conventional structural elements used in a dynamic environment need to be designed for the maximum associated loading. The DSB's uniqueness and novelty is that its load carrying capability is proportional to the dynamic level of the applied load. This allows it to be more efficient then current structural elements. As a result it can be designed to provide comparable dynamic load carrying capability at a lighter weight than conventional seat components. In application the DSB is extended in width to become a structural "plate" that comprises the seat pan of the proposed seat.

The DSB also provides the majority of the seat's energy attenuation in an extremely robust subsystem. During the DSB's transition from the static to the dynamic environment, the beam's "neutral axis" shifts upward to more efficiently react to the increased dynamic loads. In the physical realm, the neutral axis doesn't actually move - it is the beam that moves downward as the neutral axis normalizes around the new dynamic state. As the beam moves down, so does the occupant; this provides the theoretical displacement and energy attenuation. In actuality further deflection occurs due to the inefficiency of the transfer of loading as the beam transitions from the static to the dynamic event. These in combination provide the total energy attenuating displacement.

The first DSB based seat developed was known as the All Fabric Troop Seat (AFTS). This proof-of-concept variant is shown in Figure 1. It is a semi-rigid foam and fabric seat that attaches to the wall/bulkhead of the aircraft through the use of six snap hooks.

Figure 1: All Fabric Troop Seat (AFTS)

The AFTS project was a simple "build / test" proof-of-concept effort. The test component focused on the key specification requirement: dynamic testing, which is the primary determinant of a seat's "crashworthiness."

Dynamic tests were conducted on the AFTS using the US Navy's Horizontal Accelerator Facility located at Warminster, Pennsylvania. The tests were consistent with specification requirements and subjected the seat to two types of aircraft vertical orientation impacts at the maximum mishap severity, and one type of aircraft horizontal orientation impact. The vertical orientation impacts were conducted with a range of manikin weights (5^{th} percentile female, 50^{th} percentile male and 95^{th} percentile fully equipped male) with the aircraft impacting at an attitude of "pure" vertical and an attitude of 30 degree nose down pitch and 10 degree roll. The purpose of the first scenario was to evaluate the seat's energy management subsystem at the system level under relatively benign conditions. The purpose of the second scenario was to evaluate the entire seat system (and also the energy management subsystem) while the seat is subjected to asymmetric loading. These are the most severe tests. In addition the test with the maximum weight manikin is the ultimate evaluation of a seat's strength. The horizontal orientation impact was conducted with the maximum weight manikin with the aircraft impacting at a 15 degree yaw. Its purpose was primarily to evaluate the restraint system.

Data acquired during testing consisted of electronic, photographic, and visual examinations. The electronic data comprised various accelerations and forces in the manikin. Important in evaluating occupant injury potential is the seat pan vertical acceleration and manikin vertical lumbar force. Due to the structure of the AFTS and the inability to mount an accelerometer on the seat, pelvis vertical acceleration was used in place of the seat pan acceleration. During analysis it was determined that the pelvis data, based on past testing of crashworthy seating systems, provided a harsher analysis than the seat pan data. This created significant uncertainty in the data analysis conclusions. The photographic and visual examinations were used to evaluate occupant motion during the tests and the seat's ability to withstand the applied loading during the testing.

Key results of the AFTS fabrication and evaluation were:

- Designed to meet MIL-S-85510 requirements.
- Wall/Bulkhead mounting.
- Weight of 7 pounds 4 ounces.
- Easily and quickly removable (snap hooks).
- Easily stowable (see 6x20x20 inch bag holding seat in Figure 1).
- Dynamically tested to US Navy's ***RC*** requirements which were used to qualify and field crashworthy troop seats for the H-53A/D, H-53E and UH-1Y.
- Individual seats structurally sound after multiple tests with 330 pound weight manikin.
- Projected to be capable of passing ***FC*** dynamic tests.

The results of the AFTS evaluations were phenomenal when compared with the existing state-of-the-art. This minimal effort provided proof-of-concept and valuable information for the next incremental improvement. There were three primary areas that would be addressed in subsequent iterations: restraint subsystem, environmental capabilities, and injury protection.

The AFTS utilized the V-22 troop seat's 3-point restraint. The V-22 restraint was qualified with a much lighter maximum weight occupant: approximately 265 pounds. The AFTS dynamic tests uncovered deficiencies in the use of the restraint with heavier weight occupants. The resolution consisted of implementing the 4-point restraint utilized on the H-60 Black Hawk crashworthy troop seat. This restraint is qualified up to the ***FC*** requirements. The impact of this design change would be an increase in seat system weight.

The AFTS was designed, to the maximum extent practical, to utilize off-the-shelf components qualified for use in the US Military environment. The notable exception to this was the fabric used in the majority of the seat. This fabric is known as Spectra; and, is extremely strong and lightweight. Unfortunately, it is unable to pass the military flammability requirements. Once again, the solution came from the H-60 Black Hawk crashworthy troop seat and consisted of using its seat pan fabric. Again, the impact of this design change would be an increase in seat system weight.

The AFTS dynamic tests yielded some uncertainty in the ability of the system to protect the occupant. Analysis of the data identified results that ranged from acceptable to inconclusive. Part of the problem was the use of the pelvis acceleration data in place of the seat pan acceleration data. Another major problem was caused by the test facility and the method of conducting the tests. Due to the use of a Horizontal Accelerator to conduct the tests, those tests with a predominantly vertical crash vector were conducted in a horizontal orientation. It was determined that while this was not much of a problem on previous testing with rigid crew seats, it was a problem with less rigid troop seats like the AFTS. The lack of a 1g preload into the seat pan caused a dynamic uncoupling that resulted in the AFTS being subjected to a harsher test that did not necessarily represent the specification or real world environment. Part of the solution is relatively straightforward and consists of assuring that vertical orientation tests be conducted on a drop tower. The second part of the solution is the planned identification of, and evaluation of, modifications to the seat that will improve its occupant protection capabilities.

The Next Generation Troop Seat (NGTS) Mrk1 was the next variant fabricated. This seat incorporated the previously identified 4-point restraint and the use of the qualified fabric. In addition, it was point designed for use in the H-60 Black Hawk. It can be seen in Figure 2 with the current seat in the background. Key results of its development were:

- Designed to meet MIL-S-85510 requirements.
- Ceiling/Floor mounting specifically for H-60 Black Hawk series aircraft.
- Weight of 9 pounds 1 ounce.
- Easily removable (using snap hooks for the upper attachment and the existing attachments for the floor).
- Easily stowable (using same stowage bag as the AFTS).
- Projected production cost of $1,800.00 USD per unit.
- Ad hoc field evaluations, during a successful aircraft fit check (shown), resulted in extremely positive feedback from users.

Figure 2: Next Generation Troop Seat

The fabrication of the NGTS Mrk1 yielded several important results. It demonstrated that:

- the NGTS could be mounted in both of the attachment configurations utilized in US Military rotary-wing aircraft
- the NGTS could be point designed for a specific application without requiring modifications to the aircraft platform
- the incremental improvements could be implemented without exceeding weight and cost thresholds

In addition system configuration and manufacturing improvements were also identified.

The Phase I program had several assumptions which were derived from the prior efforts and perceived US Air Force requirements for this development effort. These were:

1. The AFTS dynamic test results would provide the foundation for assuring that the Phase I NGTS variants would be capable of structurally passing future tests. That is, as long as the NGTS variants were stronger than the AFTS, it could be expected that the new variants would be able to pass dynamic testing.

2. The AFTS dynamic test results were insufficient to quantify injury protection. This would be addressed in two ways. First, future testing would be conducted to preclude the impact of the previously identified testing anomalies using only horizontal input vectors. Second, design modifications would be identified that could enhance injury protection. Due to the need to quantify the effectiveness of the design changes through dynamic testing, something beyond the scope of a Phase I effort, these were deferred and planned to be evaluated during subsequent development efforts.

3. As the US Air Force hasn't identified a platform of application, it would be necessary to make the NGTS generic such that it could attach in either the wall/bulkhead or ceiling/floor orientation.

Three NGTS variants were developed to address each of the three performance requirements. These performance requirements consisted of the previously mentioned ***RC*** and ***FC***; as well as, a newer requirement for troop seats that matched the cockpit requirements and became known as Cockpit Capability or ***CC***.

The ***CC*** requirement and ***FC*** requirement are similar in that they both provide performance at the 95th percentile survivable accident level. The difference is that the ***CC*** requirement has a higher peak deceleration than the ***FC*** requirement. This difference is due to cockpit having less "crush depth" than the cabin; and as a result, the cockpit being subjected to higher decelerations. Table 2 shows the differences in the requirements for the most severe dynamic qualification test. This test was described earlier as the asymmetric test; and, is also known as the Combined Vertical (CV) test.

Table 2: Summary Requirement Parameters		
	Test Parameter	
Requirement	Deceleration (g's)	Energy (fps^2)
RC	30	35
FC	32	50
CC	46	50

The ***CC*** variant provides a solution that allows the NGTS to be used as an auxiliary crew / jump seat in the cockpit. Due to the added structural requirements this variant had a 12 pound weight threshold.

The procedures for achieving topic solution derived from the aforementioned assumptions. This basically consisted of combining the AFTS and NGTS Mrk1 systems in to a singular design that incorporated all of the lessons learned to date.

3.0 RESULTS AND DISCUSSION

3.1 NGTS Mrk2 [FC variant]

Figure 3: NGTS Mrk2/*FC* variant

The NGTS Mrk2 was the first variant developed and fabricated during the Phase I effort. It was designed to meet the ***FC*** requirements and is shown in Figure 3.

The NGTS Mrk2/***FC*** variant was weighed using an American Weigh Scales, Inc. H-22 scale. This scale can weigh objects up to 22 pounds with a resolution of 0.01 pounds (0.16 ounces). The NGTS Mrk2/***FC*** variant weighed 9 pounds 11 ounces. This satisfied the Phase I goal in that it weighed less than the 10 pound threshold. In addition, as can be seen in Figure 3, the seat included all attachments to mount in either a ceiling/floor, wall/bulkhead or some hybrid mounting orientation. It is expected that in application, only 6 of the 10 attachments will be utilized. This will further reduce the weight of the NGTS Mrk2/***FC*** variant by approximately 9 ounces. Also, manufacturing improvements were identified that will further reduce the weight by about 3 ounces. It is expected that the NGTS Mrk2/***FC*** variant will weigh approximately 8 pounds 15 ounces when tailored for a specific application. The existing state-of-the-art ***FC*** seat weighs approximately 19 ½ pounds. As can be seen, the NGTS Mrk2/***FC*** variant represents a significant improvement. This is also significantly less than the existing state-of-the-art ***RC*** seat which weighs approximately 15 ½ pounds.

The importance of weight in achieving the solution of this topic cannot be over emphasized. With this, as well as all similar engineering endeavors, the cost to achieve the results is also extremely important. These Phase I efforts had an informal cost threshold of $2,000.00 per seat unit. The variants were manufactured from draft production drawings, and an analysis was conducted to establish the variant cost. The basic premise of the cost evaluation was the delivery of 3000 units over 3 years. The result was that the NGTS Mrk2/***FC*** variant is expected to cost approximately $1,500.00. Royalty costs and the recovery of development costs are expected to add approximately $500 to the acquisition cost. Research was conducted to determine the cost of the existing state-of-the-art ***FC*** crashworthy troop seat. The best information available established a cost of not less than $3,000.00. The NGTS Mrk2/***FC*** variant represents a significant cost savings.

The next area of evaluation is *Performance*. Relative to crashworthy seating, it has been found that this variable is better applied if separated into two new metrics: *Seat Strength* and *Seat Performance*. *Seat Strength* quantifies the ability of the seat to structurally survive a given mishap severity. It can be directly related to seat weight as well as, mishap severity. As such, *Seat Strength* directly corresponds to the seat's capability: ***FC***, ***CC*** or ***RC***. *Seat Performance* quantifies the ability of the seat's energy management system (energy attenuators) to protect the occupant and limit injuries to minor or none.

For this Phase I effort, the *Seat Strength* evaluation is better considered in the terms of it being a design constraint. Successful dynamic testing of the AFTS demonstrated that it was capable of meeting the ***FC*** requirement for *Seat Strength* with significant design margin. The NGTS Mrk2/***FC*** variant was designed such that all areas of the seat had a strength comparable or superior to similar locations on the AFTS. As such, it is expected that the NGTS Mrk2/***FC*** variant will be capable of passing dynamic testing. In addition, if for some reason it became necessary, sufficient weight margin is available to allow the implementation of modifications as a result of dynamic testing.

Of these primary evaluations, *Seat Performance* is the most difficult to quantify. The AFTS data demonstrated performance that ranged from acceptable to inconclusive (based on the test anomalies). The NGTS variants incorporate a design change that should improve the *Seat Performance*. And, a future part of development will be to identify, test and implement improvements.

The analyses that resulted in the separation of *Performance* in to *Seat Strength* and *Seat Performance* also quantified the relative importance of these two new metrics. The impact of *Seat Strength* is reflected in Table 1. The ***RC*** requirement results in a seat with less strength than an ***FC*** requirement seat, and the table shows that this resulted in 22 major/fatal injuries. Compromises to *Seat Performance* on the other hand merely result in a transition along the injury scale. That is, an ***FC*** seat with a reduced *Seat Performance* capability will result in some "none" injuries becoming "minor" injuries and some "minor" injuries becoming "major" injuries. These conclusions are consistent with what is physically happening. In the case of *Seat Strength*, the ***RC*** requirement represents a clear demarcation between the seat remaining structurally sound and catastrophic failure. In the case of *Seat Performance*, reductions in capability merely represent an incremental decrease and are reflected by the resultant incremental change in injury type.

3.2 NGTS Mrk3 [*CC* variant]

The NGTS Mrk3/***CC*** variant was the second variant developed and fabricated during the Phase I effort. It was designed to meet the ***CC*** requirements and, is shown in Figure 4. This variant was a stronger version of the Mrk2 such that it could meet the ***CC*** *Seat Strength* requirements. This primarily consisted of adding multiple layers of fabric in the key side-bottom-side area of the seat. It also included the minor manufacturing improvements identified in the previous section. The seat was originally designed with both Velcro and snap hooks as the method of enclosing the foam in the seat. After manufacturing the Mrk2, it was determined that only the Velcro was necessary.

The NGTS Mrk3/***CC*** variant was weighed in a manner similar to the Mrk2 and weighed 9 pounds 13 ounces. This satisfied the Phase I goal in that it weighed less than the 12 pound threshold. In addition, as can be seen in Figure 4, the seat included all attachments to mount in either a ceiling/floor, wall/bulkhead or some hybrid mounting orientation. Accounting for the probable mounting configuration, the NGTS Mrk3/***CC*** variant is expected to weigh approximately 9 pounds 4 ounces when tailored for a specific application. As there is no existing state-of-the-art ***CC*** troop seat, there is nothing to compare with. However, the weight is significantly less than either the operational state-of-the-art ***FC*** or ***RC*** seat.

Figure 4: NGTS Mrk3/*CC* variant

The cost to manufacture the NGTS Mrk3/***CC*** was calculated in a manner similar to the other variants using the draft production drawings and based on 3,000 units over 3 years which resulted in an estimate of $1,600.00. This is slightly more than the NGTS Mrk2/***FC*** and primarily due to the additional reinforcement of the seat necessary to achieve the ***CC*** capability. The NGTS Mrk3/***CC*** is the first troop seat fabricated to this requirement, so there was nothing to compare cost to except to identify it is cheaper than the operational ***FC*** and ***RC*** seats.

The *Seat Strength* evaluation of the NGTS Mrk3/***CC*** had added difficulty. As shown in Table 2, the ***CC*** requirement is considerably more severe than the ***RC*** dynamic testing conducted on the AFTS. The necessary seat capabilities were obtained by scaling the AFTS seat strength relative to the difference between the ***CC*** requirements and the AFTS dynamic tests. The considerable design margin the AFTS demonstrated during its dynamic tests further augmented the confidence in this solution. Therefore, it is believed that the NGTS Mrk3/***CC*** variant will be capable of passing dynamic testing per this requirement. Once again, sufficient weight margin is available to allow the implementation of modifications as a result of dynamic testing.

Seat Performance for the NGTS Mrk3/***CC*** variant also had added complexity. *Seat Performance* is basically an evaluation of the seat's energy management system (usually discrete energy attenuators). These systems, while limiting injuries to minor and none, are dependent on the amount of controllable displacement that they can provide. In systems with dedicated energy attenuators, this is approximately 12 inches and results from the dynamics of performance of current energy attenuators when subjected to the ***CC*** mishap parameters. The ***FC*** and ***RC*** requirements have a reduced need for controllable displacement. The NGTS design contains an "inherent" energy management system that comprises the DSB and other parts of the total seat system. This has benefits and drawbacks. The benefits are that there is sufficient "displacement" to meet the ***FC*** and ***RC*** requirements and that the NGTS energy management system is logistically better than the discrete systems on existing state-of-the-art seats. The downside of the NGTS energy management system is that it is unlikely to provide sufficient displacement to meet the ***CC*** requirement. In all likelihood this will result in an incremental increase in injury potential. As with the Mrk2/***FC*** variant, this will be a focus of future development.

3.3 NGTS Mrk4 [*RC* variant]

The NGTS Mrk4/***RC*** variant was the last variant developed and fabricated during the Phase I effort. It was designed to meet the ***RC*** requirements and is shown in Figure 5.

The NGTS Mrk4/***RC*** variant is an especially unique response to this topic's problem. The goal of the introduction to this report was to clearly identify the detrimental impact of the ***RC*** compromise. The answer is that the underlying problem is still weight, and the current systems fielded to this requirement are too heavy and not being used to replace non-crashworthy troop seats in the weight critical applications. The solution offered by the NGTS Mrk4/***RC*** variant is a crashworthy troop seat system light enough to be implemented in lieu of the continued application of non-crashworthy troop seats. The benefit is shown in Table 1; the seat will result in 23 fewer major/fatal injuries for every 100 occupants involved in a mishap.

Figure 5: NGTS Mrk4/*RC* variant

Initially, the goal was for this variant to be similar to the Mrk2 and Mrk3, but after initial design efforts, it was determined that this was not possible within the weight constraints. As a result, several design compromises were implemented. The major design compromise consisted of removing the head rest portion of the basic NGTS design, such that the Mrk4 was more of a "jump seat." This also eliminated the upper attachments resulting in the elimination of the ceiling/floor attachment orientation. As all the weight critical applications utilize a wall/bulkhead attachment orientation, it was determined that this compromise was acceptable. In addition, the floor attachments at the back of the seat were also eliminated as their purpose is to stabilize the seat in the ceiling/floor attachment orientation. Finally, to get the seat under the 8 pound threshold, the foam configuration in the seat pan area was changed from using a 2.2 pound density foam in the base to using a 1.7 pound density foam in the base. The NGTS Mrk4/***RC*** variant is the least refined of the variants designed during this SBIR Phase I effort.

The NGTS Mrk4/***RC*** variant was weighed in a manner similar to that of the Mrk2 and Mrk3 and weighed 7 pounds 15 ounces. This satisfied the Phase I goal in that it weighed less than the 8 pound threshold. This variant represented the most challenges and has very little weight margin to accommodate future design "growth." The existing state-of-the-art ***RC*** seat weighs approximately 15 ½ pounds, and, the NGTS Mrk4/***RC*** variant represents a significant improvement. Relative to a comparison with non-crashworthy seats, it is still heavier, and only future involvement with the platform acquisition community will determine if this is an acceptable weight.

The cost to manufacture the NGTS Mrk4/***RC*** was calculated in a manner similar to the other variants using the draft production drawings and based on 3,000 units over 3 years which resulted in an estimate of $1,400.00. Research was conducted to determine the cost of the existing state-of-the-art ***RC*** crashworthy troop seat. The best information available established a cost of not less than $3,500.00. The NGTS Mrk4/***RC*** variant represents a significant cost savings.

The *Seat Strength* evaluation of the NGTS Mrk4/***RC*** was relatively straightforward and has resulted in an extremely overdesigned system. The AFTS demonstrated that it could meet the ***FC*** requirement, and while it was possible to "scale" the results to design the Mrk3 to the ***CC*** requirements, it was not possible to "scale" the results in the opposite direction to design the Mrk4. This is due to the difference between the three requirements (***FC***, ***CC*** and ***RC***) and a unique result of the AFTS dynamic testing.

The AFTS demonstrated something that had never been seen in a crashworthy troop seat: the dynamic test results demonstrated that the seat, its structural subsystems, and components were always in the elastic range of their stress/strain curves. This meant that for the maximum forces applied, the AFTS could withstand the continual application of energy. A review of the ***RC*** and ***FC*** requirements will show that they are very similar in maximum applied force with the only difference being the maximum applied energy. This was the reason why the AFTS, which was tested to the ***RC*** requirement, is projected to be capable of passing the ***FC*** testing. These results represent a significant design "margin" but also the reason that "scaling" couldn't be used to design the NGTS Mrk4/***RC*** variant. The Mrk4/***RC*** variant, for the most part, is designed to the ***FC*** requirements, albeit, as a "jump seat" configuration. It is expected that refining the design through testing will optimize the seat for the ***RC*** requirement and reduce seat weight.

The evaluation of *Seat Performance* was also was simplified since the ***RC*** requirement is the least severe. As identified, the AFTS data demonstrated performance that ranged from acceptable to inconclusive (based on the test anomalies).

3.4 Secondary Evaluations

3.4.1 Introduction

This section discusses several secondary metrics of importance within crashworthy troop seat systems. For the most part, these discussions are short engineering judgment analyses. And, it is expected that those that require more investigation will be quantified in subsequent program phases.

3.4.2 Manufacturability (Time Feasibility)

In addition to having a seat that demonstrates *Concept Feasibility* in the technical realm, the solution must be able to be produced in quantity efficiently. If not the concept is not truly *Feasible*. The NGTS variants fabricated for this Phase I effort were completed using draft production drawing packages. And, they were fabricated by C.R. Daniels, Inc., an established manufacturer with a long history of fabricating crashworthy troop seats. As a result this development effort verifies the manufacturability of the NGTS and demonstrates the best possible *Time Feasibility*. That is, of the prototypes fabricated, we can produce them in quantity.

3.4.3 Removability

Typically, crashworthy troop seats have a mechanism for disconnecting the seat at each of the aircraft attachments. The NGTS is similar. And it would be expected, that with all things being equal, the NGTS will have removal times comparable to existing operational systems. However, the NGTS has an advantage: existing operational systems are rigid, causing some binding in the attachment itself which impacts the time it takes to remove the system. This degrades further as the systems are in operational use. The NGTS with its flexible design does not have this detriment, and it is expected in the real world operational environment that the NGTS will have better removability than existing operational systems.

3.4.4 Stowability

Existing operational crashworthy troop seats are actually extremely delicate systems. This is due to their energy attenuating subsystems and minimal structure in an attempt to reduce weight. These systems are extremely sensitive to the way they are handled in the operational environment. Casual review of how these systems are handled in the fleet is completely different from how they are handled (“delicately”) in the lab. When out of the aircraft, individual seats are bulky and multiple seats are routinely tied together using their restraints. This rough handling jeopardizes the system and its ability to function when needed. The NGTS reduces the risk to the energy attenuating subsystem by employing a robust subsystem integrated in to the seat. In addition, the flexible seat can be stored in a convenient 6” x 18” x 20” volume. It is also envisioned due to the light weight that multiple seats could be stored in a single package. As such, it is expected that the NGTS will have better stowability characteristics than existing operational seats.

3.4.5 Logistics (Reliability / Maintainability)

Existing operational crashworthy troop seats are a relative complex system with many moving parts. Their energy attenuating subsystem is extremely sensitive to handling in the operational environment. Anecdotal information also suggests these systems are not handled in a manner similar to when they were qualified in the lab. The NGTS is a simple foam and fabric system with inherent energy attenuation capabilities. The NGTS projects to be more reliable and maintainable than existing systems due to its fewer parts and more robust design.

3.4.6 Comfort

Feedback from users has suggested that existing operational crashworthy troop seats are not as comfortable as they can be. One limitation is that all have some form of crossbar at the front of the seat. This hard-point is at a location that impacts user comfort. The NGTS is an almost completely soft foam and fabric seat. There are no hard-points. In addition the use of rate-sensitive foams has been shown to enhance comfort. Preliminary user evaluations of the All Fabric Troop Seat (AFTS) and NGTS are extremely positive in its superior comfort compared to existing operational systems.

3.4.7 Gx restraint

Generally, when the term "restraint" or "restraint system" is used, people think of the lap belt and/or shoulder harness. In actuality, the entire seat system is a restraint which holds the occupant in a specified location in the aircraft. In general the seat reacts + Gz and – Gx and the restraint reacts – Gz and + Gx. Both the seat and restraint share reacting $\pm$ Gy. Crashworthy troop seats can be mounted in one of four orientations: forward facing; aft facing; and, side facing on either side of the aircraft. Within any specific aircraft platform, the layout typically has either forward and aft facing or side facing on either side. In any specific mishap, there will be seats where the loading vector is pulling the occupant out of the seat and where the loading vector is pushing the occupant into the seat. Typically, dynamic qualification testing has focused on the loading vector that is pulling the occupant out of the seat.

Until recently this was not thought to be a problem. However, crashworthy troop seats typically contain a backpack flap to adjust the seat between occupants with and without a backpack. This backpack flap is typically attached in a manner that is neither crashworthy nor structurally sufficient to react to the crash loads that would be applied from an occupant being pushed in to the seat. In essence, it is another problem with existing seats that has not been identified or quantified.

The NGTS addresses this concern by not having a back pack flap. The seat has been sized and designed based on anthropometry to still accommodate from the 5th percentile female to the 95th percentile male with or without a backpack. In addition the seat with its side panels and back panel has been designed to react the loading when the occupant is pushed in to the seat and provide a safe shell to react the loading. No current operational crashworthy troop seat provides this capability. As such, the NGTS provides superior, and more important, - Gx restraint.

3.4.8 Anthropometry

Crashworthy troop seats are required to accommodate the 5th percentile female through the 95th percentile male occupant with or without a backpack. Review of this anthropometry identifies that it matches the requirement for a minimum seat width of 20 inches: as identified in MIL-S-85510. Some recent development efforts have resulted in seat widths around 18 inches. This reduced width reduces overall loading within the seat system and results in a lighter seat. It also reduces the overall population that can utilize the seat. Effectively limiting its use to the 25th percentile male occupant based on seated shoulder width. This is a significant concern that cannot be overstated. In single seat laboratory tests, the manikin can be placed in the ideal test position and obtain the best results; however, in the real world, occupants will be forced to be out of position and suffer the consequences of this reduced human tolerance capability. The NGTS is designed with a 20 inch width to meet the specification requirements.

4.0 CONCLUSIONS

The development and implementation of lightweight crashworthy troop seating will greatly benefit the US Military. For every 100 occupants involved in a 95th percentile survivable mishap:

- 22 major/fatal injuries will be reduced to none/minor injuries when a lightweight, less than 10 pound, ***FC*** crashworthy troop seat is used in lieu of an ***RC*** crashworthy troop seat;
- 45 major/fatal injuries will be reduced to none/minor injuries when a lightweight, less than 10 pound, ***FC*** crashworthy troop seat is used in lieu of a non-crashworthy troop seat; and,
- 23 major/fatal injuries will be reduced to none/minor injuries when a lightweight, less than 8 pound, ***RC*** crashworthy troop seat is used in lieu of a non-crashworthy troop seat.

The fabrication of prototypes during this effort provided a greater confidence in the results than the typical Phase I paper effort. Their fabrication from draft production drawings by a major crashworthy seat manufacturer demonstrated confidence that the seat can be fabricated in a production environment.

The NGTS Mrk2/***FC*** variant represents a viable alternative to existing state-of-the-art ***FC*** and ***RC*** seats:

- at a projected implementation weight of 8 pounds 15 ounces and cost of $1,500.00, the NGTS Mrk2/***FC*** variant represents a significant improvement over existing, state-of-the-art ***FC*** seats which weigh approximately 19 ½ pounds and cost approximately $3,000.00; and,
- at a projected implementation weight of 8 pounds 15 ounces and cost of $1,500.00, the NGTS Mrk2/***FC*** variant represents a significant improvement over existing state-of-the-art ***RC*** seats which weigh approximately 15 ½ pounds and cost approximately $3,500.00.

The NGTS Mrk4/***RC*** variant represents a viable alternative to existing state-of-the-art ***RC*** seats and potential alternative to non-crashworthy troop seats:

- at a projected implementation weight of 7 pounds 15 ounces and cost of $1,400.00, the NGTS Mrk4/***RC*** variant represents a significant improvement over existing state-of-the-art ***RC*** seats which weigh approximately 15 ½ pounds and cost approximately $3,500.00; and,
- at a projected implementation weight of 7 pounds 15 ounces and cost of $1,400.00, the NGTS Mrk4/***RC*** variant represents a potential alternative to non-crashworthy troop seats which weigh approximately 6 ½ pounds.

The NGTS Mrk3/***CC*** variant represents a potential new type of lightweight auxiliary seat for use in rotary-wing aircraft cockpits.

The *Seat Strength* of each variant was designed to meet its associated requirement. Preliminary review of the NGTS Mrk2/***FC*** variant and NGTS Mrk3/***CC*** variant suggests that this includes additional design “margin”; as well as, sufficient weight margin to implement additional structural capability. Preliminary review of the NGTS Mrk4/***RC*** variant suggests the inclusion of design margin to the point of being “over-designed.” This design philosophy appears sufficient to meet the Phase I requirements.

The *Seat Performance* of each variant appears sufficient based on prior development efforts.

During this effort no information was uncovered that would preclude future development.

5.0 RECOMMENDATIONS

Continue the development of the NGTS Mrk2/***FC*** variant as an alternative to existing state-of-the-art ***FC*** and ***RC*** crashworthy troop seats.

Continue the development of the NGTS Mrk4/***RC*** variant as an alternative to existing state-of-the-art ***RC*** and non-crashworthy troop seats.