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Shock Mitigation Seats Test

Final Report

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Contract Number: W7707-125536
Contract Scientific Authority: Liam Gannon, 902-426-3100 x130

Defence R&D Canada – Atlantic

Contract Report
DRDC Atlantic CR 2012-252
November 2013

Canada

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Abstract

High Speed Craft (HSC) passengers and crew can be exposed to high levels of repeated shock loading as a result of routine operation in elevated seas. Considerable attention is currently focused on mitigating the potentially adverse effects through the use of suspension seat technology. To support research into the behaviour and performance of HSC seating, a project to develop a single impact drop test device was initiated by DRDC Atlantic. As part of this project, the Carleton University Applied Dynamics Laboratory has investigated alternative drop test rig arrangements and has designed, built, and demonstrated a custom-designed drop tower for the purpose of HSC seat testing.

This report presents the work undertaken as part of the project. A literature review examined contemporary drop test equipment with an emphasis on devices appropriate for testing shock mitigation seats as used in small, high speed marine craft. A dynamic model of drop testing was developed such that it could be used to guide the detailed design of a single-impact drop test device. Based on this, an appropriate drop tower was designed, constructed, instrumented, and evaluated. To ensure that the Carleton Drop Tower met its design requirements, a sample drop test was successfully performed. The results of this drop test are also presented and discussed in the report.

The resulting test apparatus provides a facility to support investigation of the dynamics of suspension seating when exposed to large, stochastic shocks by simulating the high-g environment experienced by the seat under normal operating conditions. It is expected that the Carleton University Drop Tower should be able to support research aimed at developing more effective seat testing methodologies, to improve dynamic modelling and simulation of the human-seat interaction under various operational conditions, and provide relevant data to assist with seat design and injury mitigation.

Résumé

L'équipage et les passagers d'un engin à grande vitesse (EGV) peuvent subir un grand nombre de chocs lors d'une opération de routine dans une mer agitée. À l'heure actuelle, beaucoup d'efforts sont déployés pour atténuer les effets potentiellement néfastes de ces chocs en utilisant des sièges suspendus. Pour appuyer la recherche portant sur le comportement et le rendement des sièges d'EGV, un projet visant à développer un dispositif d'essai de largage à collision unique a été lancé par RDDC Atlantique. Dans le cadre de ce projet, l'Applied Dynamics Laboratory de l'université Carleton a étudié des montages d'essai de largage alternatifs et a conçu, construit et présenté une tour de largage personnalisée pour tester les sièges des EGV.

Le présent rapport présente les travaux entrepris dans le cadre du projet. Une analyse de la documentation a permis d'examiner l'équipement d'essai de largage contemporain en mettant l’emphase sur les dispositifs convenant à l’essai des sièges d’atténuation des chocs utilisés à bord des petites embarcations à grande vitesse. Un modèle dynamique des essais de largage a été développé de façon à pouvoir être utilisé pour guider la conception détaillée d’un dispositif d’essai de largage à collision unique. En se basant sur ce modèle, une tour de largage appropriée a été conçue, construite, instrumentée et évaluée. Pour s’assurer que la tour de largage de l’université Carleton respectait les exigences de conception, un essai de largage d’échantillon a été effectué avec succès. Les résultats de cet essai de largage sont aussi présentés et analysés dans le rapport. L’appareil d’essai obtenu aide à étudier la dynamique des sièges suspendus soumis à de gros chocs stochastiques en simulant l’environnement à accélération (g) élevée du siège dans des conditions d’utilisation normales. On s’attend à ce que la tour de largage de l’université Carleton soit capable d’appuyer la recherche qui vise à développer des méthodes d’essai de siège plus efficaces, d’améliorer la simulation et la modélisation de type dynamique de l’interaction humain-siège dans diverses conditions d’utilisation, et de fournir des données pertinentes pour aider à concevoir de tels sièges et à atténuer les blessures.

Executive summary

Shock Mitigation Seats Test

Rob Langlois, Zuneid Alam, Anne Wice, Fred Afagh; DRDC Atlantic CR 2012-252; Defence Research and Development Canada – Atlantic; November 2013.

Background: High Speed Craft (HSC) passengers and crew can be exposed to high levels of repeated shock loading as a result of routine operation in elevated seas. Considerable attention is currently focused on mitigating the potentially adverse effects through the use of suspension seat technology. To support research into the behaviour and performance of HSC seating, a project to develop a single impact drop test device was initiated by DRDC Atlantic. As part of this project, the Carleton University Applied Dynamics Laboratory has investigated alternative drop test rig arrangements and has designed, built, and demonstrated a custom-designed drop tower for the purpose of HSC seat testing.

Principal results: The developed drop test apparatus was demonstrated to provide a relatively compact inexpensive design for testing shock mitigation seats under the influence of single high-g impact loading. Preliminary tests achieved vertical accelerations at the seat support of up to 20 g with the drop height set to approximately half of the highest designed drop height. Preliminary testing also confirmed that the impact pulse shape and duration can be influenced by the compliance of the contacting materials such that some tuning of the impact profile is possible.

Significance of results: The resulting test apparatus provides a facility to support investigation of the dynamics of suspension seating when exposed to large, stochastic shocks by simulating the high-g environment experienced by the seat under normal operating conditions. It is expected that the Carleton University Drop Tower will be able to support research aimed at developing more effective seat testing methodologies, to improve dynamic modelling and simulation of the human-seat interaction under various operational conditions, and provide relevant data to assist with seat design and injury mitigation.

Future work: Follow-on work is aimed at determining suitable drop test methodology and analysis procedures to extract suspension seat component properties, assess seat and passenger accelerations and inertial loading as a result of high-g impacts, and record validation data for guiding and evaluating the design of mathematical models of HSC suspension seating.

Sommaire

Shock Mitigation Seats Test

Rob Langlois, Zuneid Alam, Anne Wice, Fred Afagh ; DRDC Atlantic CR 2012-252 ; Recherche et développement pour la défense Canada – Atlantique ; novembre 2013.

Introduction : L'équipage et les passagers d'un engin à grande vitesse (EGV) peuvent subir un grand nombre de chocs lors d'une opération de routine dans une mer agitée. À l'heure actuelle, beaucoup d'efforts sont déployés pour atténuer les effets potentiellement néfastes de ces chocs en utilisant des sièges suspendus. Pour appuyer la recherche portant sur le comportement et le rendement des sièges d'EGV, un projet visant à développer un dispositif d'essai de largage à collision unique a été lancé par RDDC Atlantique. Dans le cadre de ce projet, l'Applied Dynamics Laboratory de l'université Carleton a étudié des montages d'essai de largage alternatifs et a conçu, construit et présenté une tour de largage personnalisée pour tester les sièges des EGV.

Résultats : L'appareil d'essai de largage développé s'est avéré peu coûteux et relativement compact. Il permet de tester les sièges d'atténuation des chocs sous l'influence de chocs à accélération (g) élevée uniques. Les essais préliminaires ont permis d'obtenir des accélérations verticales au support du siège pouvant atteindre 20 g avec la hauteur de largage réglée à environ la moitié de la hauteur de largage la plus haute prévue. Les essais préliminaires ont aussi confirmé que la durée et la forme des impulsions des collisions peuvent être influencées par la conformité des matériaux de contact de façon à ce qu'un certain réglage du profil de collision soit possible.

Portée : L'appareil d'essai obtenu aide à étudier la dynamique des sièges suspendus soumis à de gros chocs stochastiques en simulant l'environnement à accélération (g) élevée du siège dans des conditions d'utilisation normales. On s'attend à ce que la tour de largage de l'université Carleton soit capable d'appuyer la recherche qui vise à développer des méthodes d'essai de siège plus efficaces, d'améliorer la simulation et la modélisation de type dynamique de l'interaction humain-siège dans diverses conditions d'utilisation, et de fournir des données pertinentes pour aider à concevoir de tels sièges et à atténuer les blessures.

Recherches futures : Les travaux à venir visent à déterminer des procédures d'analyse et une méthode d'essai de largage adéquates pour extraire les propriétés des composantes des sièges suspendus, évaluer les charges initiales et les accélérations des passagers et des sièges découlant de collisions à accélération (g) élevée, et pour consigner les données de

validation permettant de guider et d’évaluer la conception de modèles mathématiques de sièges suspendus d’EGV.

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Table of contents

List of figures

List of tables

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1 Introduction

High Speed Craft (HSC) passengers and crew can be exposed to high levels of repeated shock loading as a result of routine operation in elevated seas. Considerable attention is currently focused on mitigating the potentially adverse effects through the use of suspension seat technology. To support research into the behaviour and performance of HSC seating, a project to develop a single impact drop test device was initiated by DRDC Atlantic. As part of this project, the Carleton University Applied Dynamics Laboratory has investigated alternative drop test rig arrangements and has designed, built, and demonstrated a custom-designed drop tower for the purpose of HSC seat testing.

This report presents the work undertaken as part of this project. Specifically, a literature review, presented in Section 2, identified, examined, and reported on contemporary drop test devices, with an emphasis on devices appropriate for testing shock mitigation seats as used in small, high speed marine craft. Subsequently, the single-impact drop test device was designed, constructed, and evaluated. A dynamic model of the drop itself is presented in Section 3 and the detailed design of the apparatus is described in Section 4. In order to ensure that the Carleton Drop Tower can meet its requirements, a sample drop test was performed. The results of this drop test are presented and discussed in Section 5.

The resulting test apparatus provides a facility to support investigation of the dynamics of suspension seating when exposed to large, stochastic shocks by simulating the high-g environment experienced by the seat under normal operating conditions. It is expected that the Carleton University Drop Tower should be able to support research aimed at developing more effective seat testing methodologies, to improve dynamic modelling and simulation of the human-seat interaction under various operational conditions, and provide relevant data to assist with design support and injury mitigation.

2 Literature Review

A brief literature review identifying and assessing existing drop test devices, with a focus on those which would be suitable for testing shock mitigation seats as used in small high speed marine craft, is outlined below. This literature review confirmed that the conceptual design developed during the Summer of 2011, with minor modification, is the best alternative for the Carleton University Drop Tower, considering practical constraints.

2.1 Existing Drop Test Devices

Conventional methods of testing HSC seating are: (1) At-sea testing, and (2) Laboratory testing. At-sea testing provides accurate results, at the expense of time, personnel, linearity, and the requirement for elaborate equipment. Laboratory evaluation is a good alternative for simulating the required environment by using singular testing events, while also mitigating the challenges faced during at-sea testing.

Research work related to seat testing has been carried out in the fields of high speed marine craft, mine-proof vehicles, and the aerospace industry. Most of the testing methodologies used in these industries could be applied to HSC seating as the fundamental principals are similar. The studies undertaken in the marine industry are presented first, followed by similar seat-testing work carried out in other industries.

A study on the Analysis and Mitigation of Mechanical Shocks on High Speed Planing Boats at M.I.T. involved a drop testing approach similar to that used for the Carleton University Drop Tower [1]. A primary objective of the study was the development of testing methodologies for HSC shock mitigation seats through the design and validation of an inexpensive drop tower. The first specimen was a STIDD800v5 seat used on US Navy boats. The M.I.T. Drop Tower consisted of a reinforced steel frame drop table, linearly guided by means of steel posts and sleeves. The table section was raised using a 1 ton chain-fall hoist. A quick-release hook similar to those used for dropping life-boats was used to drop the table, leading to impact. A wide range of shock pulse-shapes could be obtained by varying the characteristics of the impact tile material. Drops were performed using lumped mass weights varying from 180 lbs to 205 lbs to represent the seat occupant. The drop heights used to generate acceleration impulses in the range of 5 g to 8 g varied between 6 inches and 8 inches. However, the shock absorber's action during impact was not evaluated owing to the nature of study. Instrumentation consisted of a SigLab system, Dell laptop, PCB signal conditioners, ICP piezo-accelerometers, and an FFT box. SigLabVersion 2.3 was used to record and process accelerometer data from the impacts. The sensors were interfaced to a MATLAB application for post-processing. The test-runs showed high repeatability of the drop table as is evident from the graph shown in Figure 1.

Work of a similar nature was carried out at Virginia Polytechnic, which involved the con-

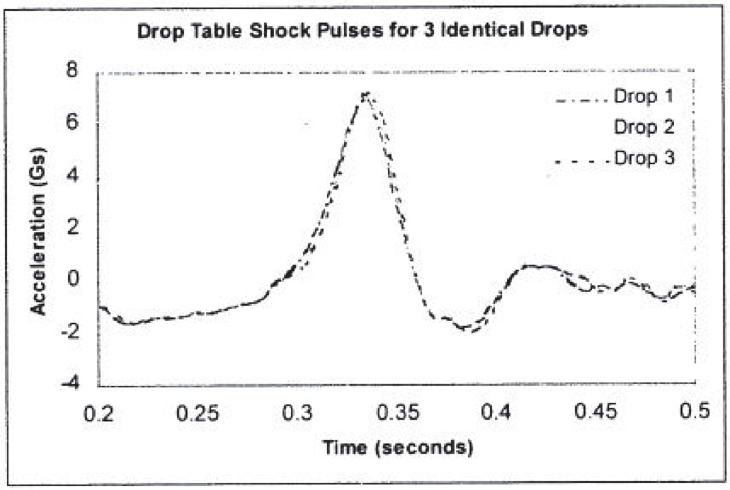


Figure 1: Repeatability of responses obtained from drop tests [1].

struction of a seat testing apparatus to evaluate the dynamics of shock mitigation seats in a controlled environment [2]. The apparatus simulated seat motion along its vertical axis. The outer frame support structure of the apparatus was made of aluminum. Rigidity of the structure was improved by addition of diagonal and horizontal supporting braces secured to the four vertical uprights on the corners. An inner carriage with rollers made of 80/20 preformed aluminum was implemented to allow vertical motion of the carriage. The outer frame was secured to the floor by bolts. A STIDD 800v5 shock mitigation seat was mounted onto a solid steel plate of 1 inch thickness. This steel plate was bolted to the inner mobile carriage. A hydraulic actuation system, MTS model 242.09, was employed to simulate high vertical acceleration. The system was able to simulate both single waveforms and multiple frequency waveforms. The actuator had a stroke of ±2 inches and a force capacity of ±2200 lbf. It had a built-in load cell and Linear Variable Differential Transformer (LVDT) for accurate measurement of force and displacement. The actuator was equipped with a digital MTS 407 servo controller, providing displacement and force control through a single channel to the actuator. An MTS 505.20 SilentFlo hydraulic power unit, capable of a flow rate of 20 gal/min, was employed to provide pressurized fluid to the actuation system. Instrumentation on the system comprised three accelerometers, an LVDT, a string potentiometer, a dSPACE digital signal processor, and a laptop. Interfacing for each of the sensor's signals was implemented using Simulink in MATLAB and the dSPACE Control Desk. The accelerometers were positioned on the seat floor, seat-pan, and external weights. To ensure a strong hold, a vibration resistant super-glue was used to glue the PCB MEMS 3741D4HB10G uniaxial accelerometer to the seat floor which was a steel plate to which the seat was fastened. A PCB 352C65 shear piezoelectric uniaxial accelerometer was used to measure the acceleration of the mass on top of the seat cushion. Industrial grade wax was used to attach the accelerometer to this mass. A string potentiometer was used to measure the position and velocity of the shock mitigation system. It was mounted to the bottom of the seat-pan with the string attached to the steel base floor of the apparatus. The LVDT provided real-time position values of the actuator on a feedback loop. Signals from these sensors were routed to the dSPACE Autobox via a DS2201ADC analog to digital converter. The Autobox provided digital signal processing.

Other work, conducted at the University of Nevada, included the design and construction of two drop towers to characterize the behavior of shock mitigation seats used in combat vehicles during mine-blast threats [3]. One of the drop towers stood 12 ft high on a steel platform, which weighed in excess of 300 lbs. This had two robust bearing shafts located on either side, which functioned as linear guides for the vertical drop of the seat-pan. The second drop tower was lighter in construction as it used a four-point guided aluminum seat-pan, with four bearing shafts located at each of the corners of the platform. This was done in order to reduce input signal noise and a more controlled descent of the platform as compared to the former drop tower. For signal capture and instrumentation, an SAE seat-pad accelerometer was mounted at the seat-butt interface of the cushion. A 2mV/g Dytran shock accelerometer, capable of measurement up to 2500 g, was mounted onto the impact plate because of its noise-reduction and high sensitivity characteristics. A combination of a 1 inch thick rubber base on a 6 inch by 6 inch impact base along with a thin gel elastomer on the striking plate's bottom surface was used to smooth the acceleration profiles. A 1-D passive anthropomorphic dummy developed at the University of Southampton was used to mimic the damping features of a human body with a natural frequency near that of a human body, at about 5 Hz. The dummy was strapped onto the seat's lumbar support to prevent any transverse motion.

A study which involved the drop testing of helicopter suspension seats was conducted jointly between the Beijing University of Aeronautics and Astronautics and the China Helicopter Research and Development Institute [4]. This study aimed to evaluate the energy-absorption capacity of a new type of helicopter crash-worthy seat, and the resulting human response during impact. The drop tower consisted of two vertical rails used to guide the seat carriage vertically. The seat carriage was guided to a cylindrical pool of water upon impact. The cylinder was equipped with holes of variable diameter to achieve a controlled signal profile. An Anthropomorphic Test Device (ATD) was secured to the seat for drop-testing. The instrumentation was elaborate due to the inclusion of the ATD for testing. Accelerometers were attached at the head and chest positions to measure the accelerations experienced by the occupant in these locations. One accelerometer was mounted to the seat pan to measure its acceleration. To measure the input pulse, an accelerometer was fixed on the bottom of the carriage. A pelvic load cell was used to measure lumbar compressive force. A displacement transducer was mounted between the seat pan and the carriage to measure the relative motion. Two dynamic strain gauges were fixed on the frame to record the dynamic strain response. An LMS DIFAIII system was used for data acquisition of output signals at 1024 Hz. A high-speed camera was employed to monitor the impact at 500 fps. System TEMA was used for the post-processing of data.

From the reviewed literature it is concluded that the design of the Carleton University Drop Tower, presented subsequently, is consistent with general principles of seat drop testing. The incorporation of angular variation of the seat plate in the Carleton design provides additional capability for the evaluation of lateral and longitudinal forces experienced by the occupant during impact, providing the potential for additional insight into load coupling that may be beneficial for mathematical modelling of seats as well as understanding human-seat interaction experienced at sea.

3 Theoretical Basis for Modelling of Impact

The impact experienced by the carriage-seat system during testing using an apparatus of the same type as the Carleton University Drop Tower (shown in Figure 2) can be modelled using classical Newtonian mechanics by considering either the kinematics or the kinetics of the motion. Both approaches are presented in this section.

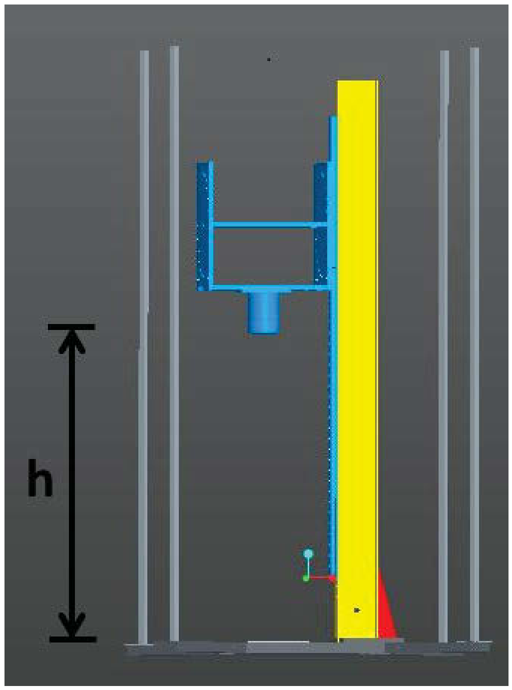


Figure 2: Carleton University Drop Tower ProE model.

In both approaches, it is assumed that if the carriage drops from a height h, its velocity just before impact, V_1, will be:

$$V_1 = \sqrt{2gh} \tag{1}$$

where g is the acceleration due to gravity.

Due to the polyurethane impact surface and the high mass of the carriage-seat system, the impact following initial contact is assumed to be inelastic, i.e.:

$$V_2 = 0 \tag{2}$$

3.1 Kinematic Approach

From simple kinematics, the acceleration upon impact is the time rate of change of velocity. As such, the acceleration due to impact is:

$$a = \frac{dV}{dt} = \frac{V_1}{\Delta t} = \frac{\sqrt{2gh}}{\Delta t} \tag{3}$$

where Δt is the duration of the impact.

3.2 Kinetic Approach

Since accelerometers are used to capture the impact response on the carriage as it contacts the impacting surface, it is often more suitable to model the impact process by assuming a half-sine wave acceleration profile during impact. A half-sine wave closely approximates the velocity and acceleration pulse shapes observed during impact. Such pulse shapes are illustrated in Figures 3 and 4, where T is the pulse duration of the impact.

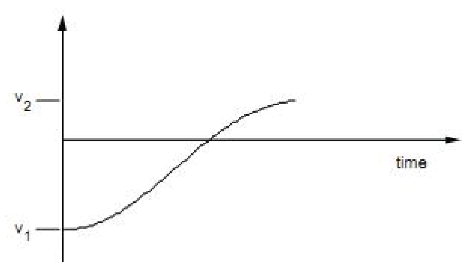


Figure 3: Expected velocity pulse during impact.

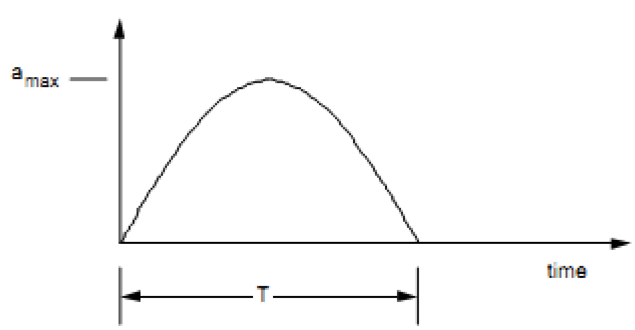


Figure 4: Expected acceleration pulse during impact.

From the velocity-time profile of Figure 3, the equation for the velocity can be written as:

$$V = \left(\frac{V_1 - V_2}{2}\right)\cos\frac{\pi t}{T} \tag{4}$$

where $\left(\frac{V_1 - V_2}{2}\right)$ is the velocity amplitude.

To obtain an equation which defines the acceleration profile of Figure 4, the velocity expression is differentiated with respect to time:

$$a = -\frac{dV}{dt} = -\left(\frac{V_1 - V_2}{2}\right)\left(\frac{\pi}{T}\right)\sin\frac{\pi t}{T} \tag{5}$$

The peak value of the acceleration profile is obtained from the amplitude of Equation 5 as

$$a_{max} = -\frac{dV}{dt} = -\left(\frac{V_1 - V_2}{2}\right)\left(\frac{\pi}{T}\right) \tag{6}$$

From the assumption of inelastic impact, V_2 is zero. Hence, the final expression of the peak acceleration upon impact is:

$$a_{max} = -\frac{V_1}{2}\left(\frac{\pi}{T}\right) = -\frac{\sqrt{2gh}}{2}\left(\frac{\pi}{T}\right) = -12.59\frac{\sqrt{h}}{T} \tag{7}$$

where h and T are expressed in basic Imperial units (feet and seconds, respectively).

Maximum impact energy is obtained for the seat-carriage-occupant mass system under ideal conditions, i.e., assuming no friction, as:

$$E = mgh \tag{8}$$

where m is the mass, g is the acceleration due to gravity, and h is the height.

As an example, using Equations 6 and 8, and assuming a pulse duration of 30 ms, the peak acceleration and impact energy for a mass of 730 lb is given as a function of drop height in Table 1.

Table 1: Acceleration and impact energy values as a function of drop height corresponding to a 30 ms impact duration.

Drop Height [ft]	**Acceleration [g]**	**Impact Energy [ft-lbf]**
5.6	29.5	131527.3
4.6	26.7	108040.3
3.6	23.6	84553.3
2.6	20.1	61066.3
2.0	17.7	46974.0
1.6	15.8	37579.2
0.6	9.6	14092.2

4 Design and Manufacturing

The Carleton University Drop Tower, shown in Figure 5 consists of a seat attached to a horizontal platform, that is in turn attached to a vertical guide rail by a sliding mechanism that allows free movement in the vertical direction, but prevents horizontal movement. The platform with the specimen seat attached is raised up the vertical guide rail, and then released, so that it falls under the acceleration of gravity and impacts against a “terminal impact” base plate, at the bottom of the vertical guide rail. The attachment method for securing the seat to the horizontal platform allows the seat to be mounted at a fixed angle relative to the horizontal, varying from zero degrees, i.e., horizontal, to approximately 45 degrees. This angular variation allows the measuring of the lateral or longitudinal forces between the seat’s slider-rail system depending upon the installed orientation of the seat. The drop test device is capable of supporting a single, large or “coxswain style” shock mitigation seat, as well as additional weight representative of a seated human occupant and equipment, to a total weight of approximately 440 lb. A complete set of manufacturing drawings is provided in Appendix A.

The Carleton University Drop Tower was manufactured in-house in the Mechanical and Aerospace Engineering Machine Shop at Carleton University, with the exception of the carriage-plate’s indexing holes. A S200 X 27 steel I-beam constitutes the main structural support on which the slider rail is mounted. This assembly is secured onto an upper base by welding and the slider-I-beam-upper-base assembly is then bolted to a 2 inch thick base plate. Gusset plates are welded to the back of the I-beam to provide full cantilever support for the I-beam assembly at the base plate support. Four diagonally-extended steel legs at each corner of the base plate provide additional stability for the complete assembly. Vertical steel posts are mounted at the ends of these diagonal legs. These posts are used as supports for the meshed safety net that will enclose the tower during testing to restrain any element of the apparatus or the test specimens that might become airborne during impact. An electric clutch-type winch having 1200 lb capacity is mounted at the top of the I-beam to provide for safe lifting of the carriage-seat-occupant weight. The facing plates of the carriage have a circular pattern of holes on opposite quadrants to enable easy swiveling of the seat-plate. The carriage was mounted to the I-beam with the help of two sliders rated to the expected dynamic loads. The combined slider-rail ensures that the carriage drops almost as if it were in free fall. A mechanical Release-Matic quick release hook is attached to the winch’s hook, which functions as the trigger for free fall of the carriage. A polyurethane bumper is mounted to the underside of the carriage. This impacts on a softer polyurethane sheet secured on the 2 inch base plate to deliver a pulse upon impact. Materials of various durometers and compliances can be used in order to obtain desired and smooth signals for the acceleration pulse.

The instrumentation of the Carleton University Drop Tower consists of seven uniaxial MEAS Model 4000A 3rd generation silicon MEMS accelerometers, one Penny-Giles linear potentiometer, a voltage supply unit, a DAQ system, and a computer terminal, as illustrated in Figure 6. Three accelerometers were orthogonally mounted to faces of a cuboid in order to measure the accelerations along the vertical, lateral, and longitudinal axes as shown in Figure 6a. This assembly was securely mounted with screws to the underside of the seat pan. A similar assembly will be mounted on the occupant mass to measure its accelerations in three orthogonal directions. An accelerometer was also mounted to the bottom side of the carriage to measure its vertical acceleration (Figure 6b). The Penny-Giles linear potentiometer was mounted to the air-spring shock absorber using collar brackets on the tubes. The DAQ system used was a National Instruments NI USB-6289 M Series board. Interfacing was done through LabView-2010 and the signals were acquired at a sampling rate of 2 kHz. The PC used for interfacing was an Intel Dual-Core system running the Windows-7 operating system.

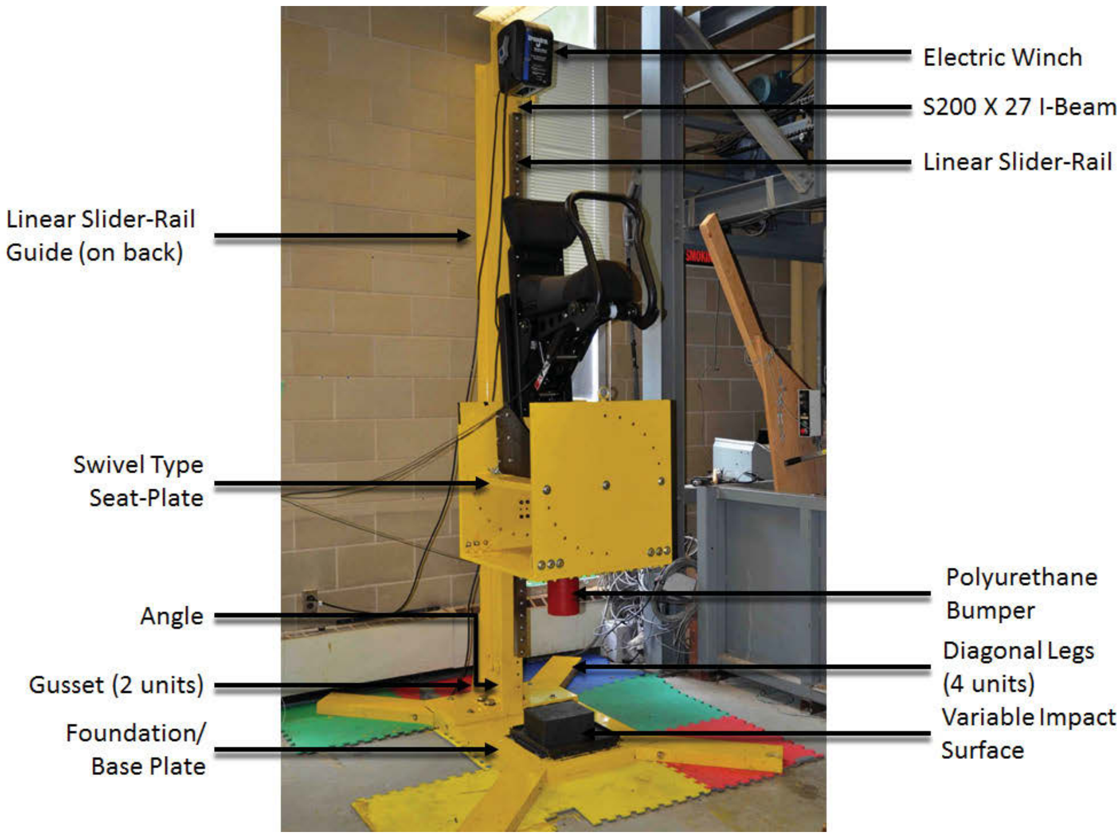
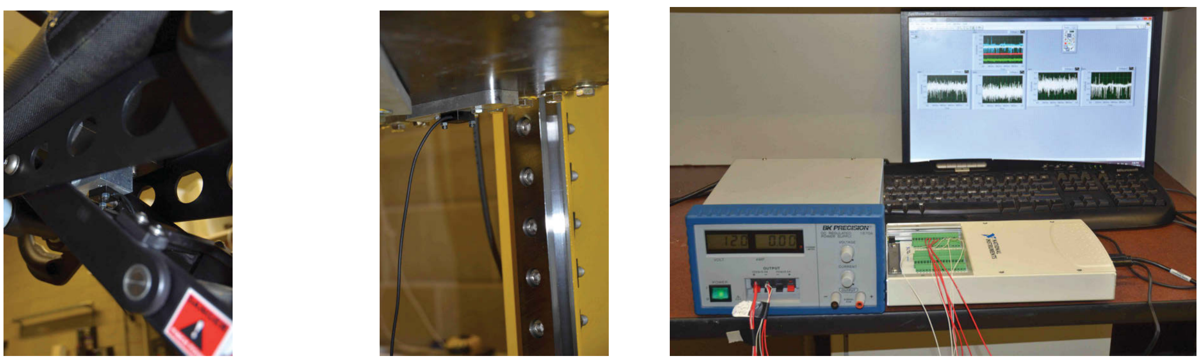


Figure 5: Carleton University Drop Tower.



(a) Seat accelerometers. (b) Carriage accelerometer. (c) DAQ and interfacing.

Figure 6: Carleton University Drop Tower instrumentation.

5 Sample Drop Data

A sample drop test was performed on a typical shock mitigation seat using the developed drop tower and a drop height of 2 ft. Signals from the sensors were recorded by LabView and logged into MS Excel using the TDMS data logger function for post-processing signal analysis. The acceleration profiles recorded during impact for the seat and carriage are shown in Figures 7 and 8, respectively. The expected peak acceleration of the carriage was 18 g. The observed peak acceleration was approximately 17 g, as can be seen in Figure 8. In both plots, the acceleration profile is initially smooth as it rises immediately following impact. However, as the acceleration decreases, high frequency vibrations are observed. These vibrations are the result of structural vibrations of the seat and carriage after impact resulting from their respective flexibility. Also contributing to the vibration is the fact that the carriage is fixed at a single point, effectively acting as a cantilever. The observed structural vibration is expected and does not affect the desired acceleration data for use in dynamic modelling and analysis of the tested systems. The observed acceleration profile can be approximated as a half-sine wave with a pulse width of 50 ms. Pulse shaping, as previously described, is likely possible to obtain different pulse profiles and durations.

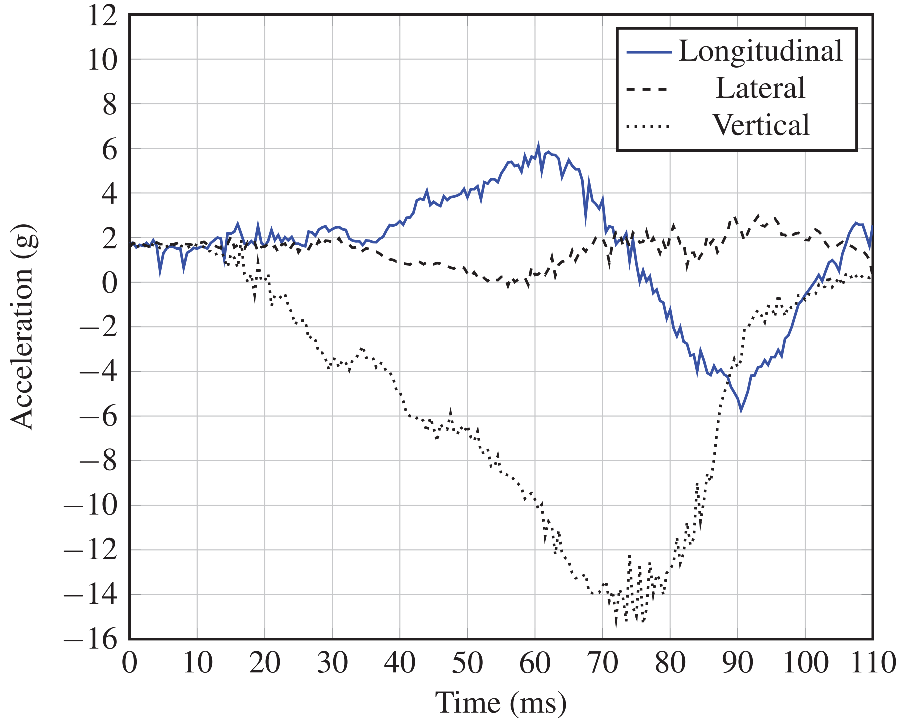


Figure 7: Measured triaxial acceleration of typical jockey seat.

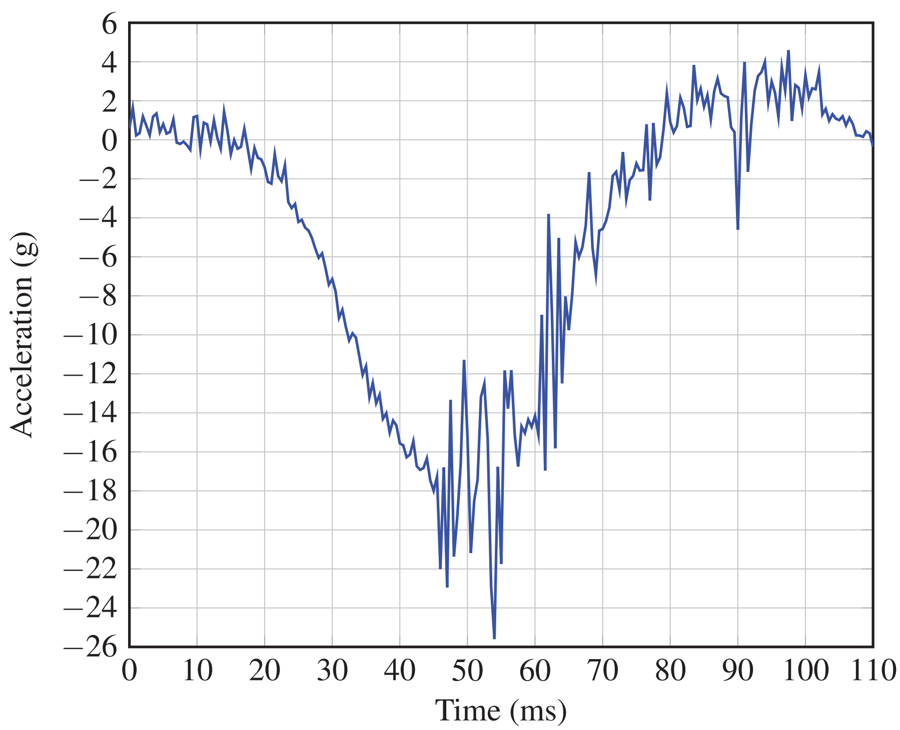


Figure 8: Vertical acceleration of seat carriage.

6 Conclusion

The developed Carleton University Drop Tower satisfies the requirement for a single-impact drop test device for shock mitigation seat testing. Its design is consistent with existing drop test devices as found in the literature. Initial results indicate that the tests can produce and measure accelerations within 5% of the desired theoretical values by choosing a material with a proper stiffness as the impact surface. The acceleration profiles of the seat and carriage measured during the impact were also observed to closely follow the assumed half-sine wave. During sample drop tests conducted to date, the Carleton University Drop Tower performed well. By monitoring the accelerations of the mass, seat, and carriage, the performance of the drop tower can be monitored as well as providing insight into the interactions of these elements of the system during a high-g impact. The ability of the Carleton University Drop Tower to drop the seat at several different inclinations to the horizontal allows it to more truly simulate the stochastic nature of high-g slam impacts experienced by occupants of high-speed marine craft where horizontal and vertical loading often occur together. As such, it is concluded that the Carleton University Drop Tower is suitable for further experimental testing of shock mitigation seating.

References

[1] Kearns, S. (2001), Analysis and Mitigation of Mechanical Shock Effects on High Speed Planing Boats, Master's thesis, Massachusetts Institute of Technology.

[2] Christopher Liam, M. A., Testing and Modelling of Shock Mitigation Seats for High Speed Craft, In *FAST:2001*, Honolulu, Hawaii.

[3] Ladkany, G. (2009), Design and Characterization of a Shock and Vibration Mitigation Seat System, Master's thesis, University of Nevada.

[4] D.Y. Hu, J.L. Yang, M. H. (2009), Full-Scale Vertical Drop Test and Numerical Simulation of a Crashworthy Helicopter Seat/Occupant System, *International Journal of Crashworthiness*, 14(6), 565–583.

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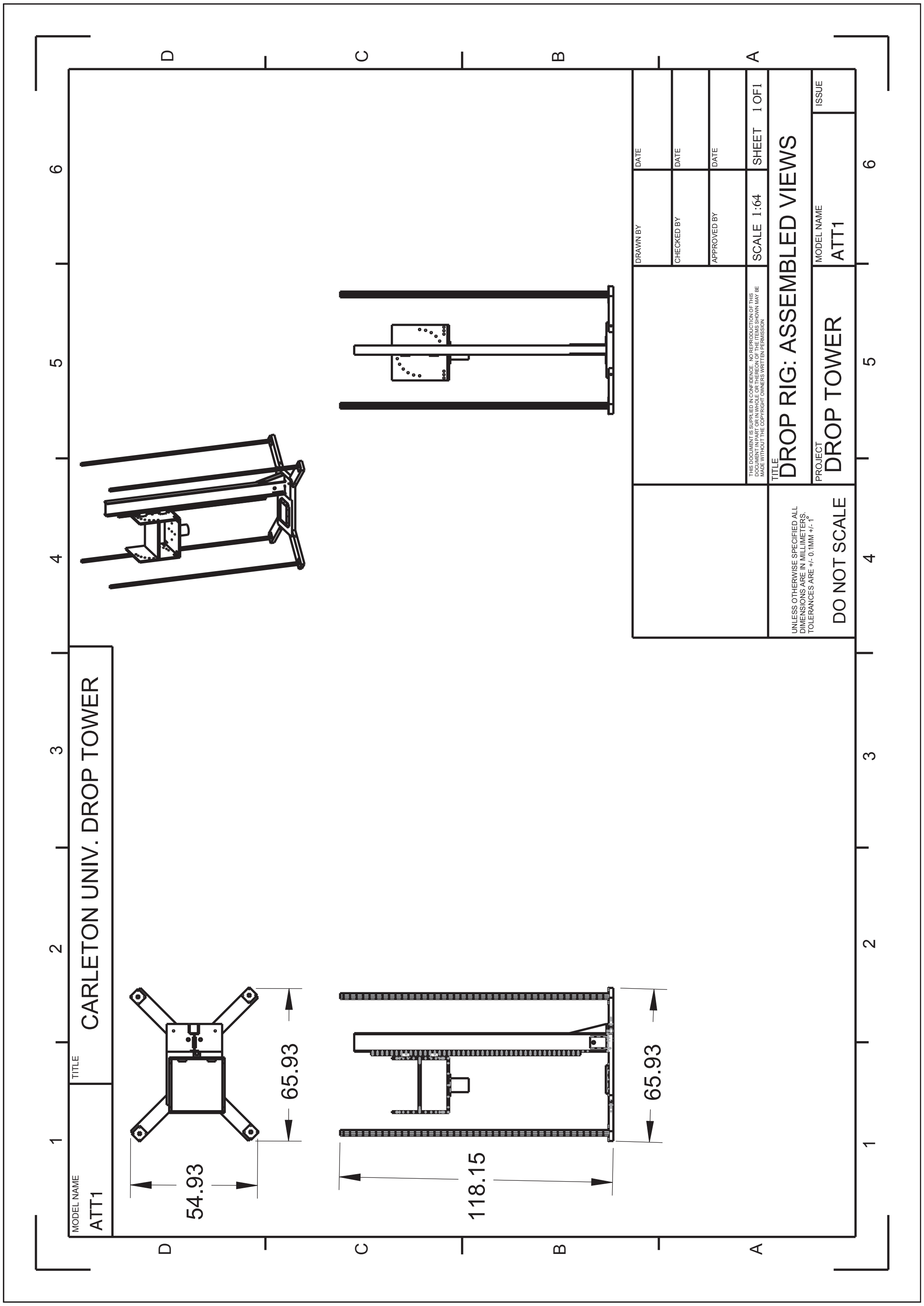
Annex A: Drawing Package

List of drawings


CARLETON UNIV. DROP TOWER
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ATT1
TITLE
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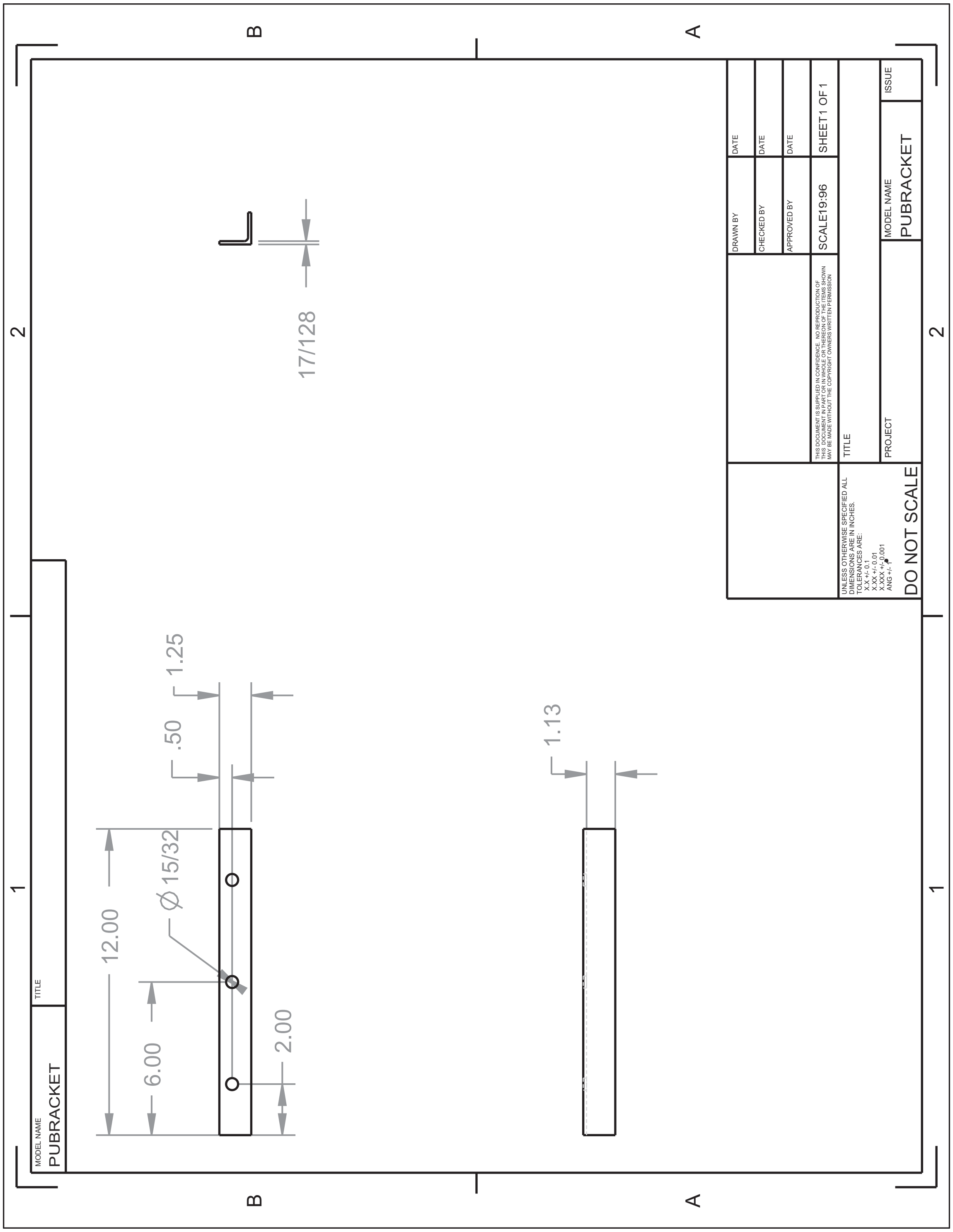
65.93
118.15
65.93
DRAWN BY
CHECKED BY
APPROVED BY
DATE
SCALE 1:64
SHEET 1 OF1
TITLE
DROP RIG: ASSEMBLED VIEWS
PROJECT
DROP TOWER
MODEL NAME
ATT1
ISSUE
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN MILLIMETERS. TOLERANCES ARE +/- 0.1MM +/- 1°
DO NOT SCALE

Figure A.1



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6.00
2.00
⌀15/32
.50
1.25
1.13
17/128
DRAWN BY
DATE
CHECKED BY
DATE
APPROVED BY
DATE
SCALE19:96
SHEET1 OF 1
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES.
TOLERANCES ARE:
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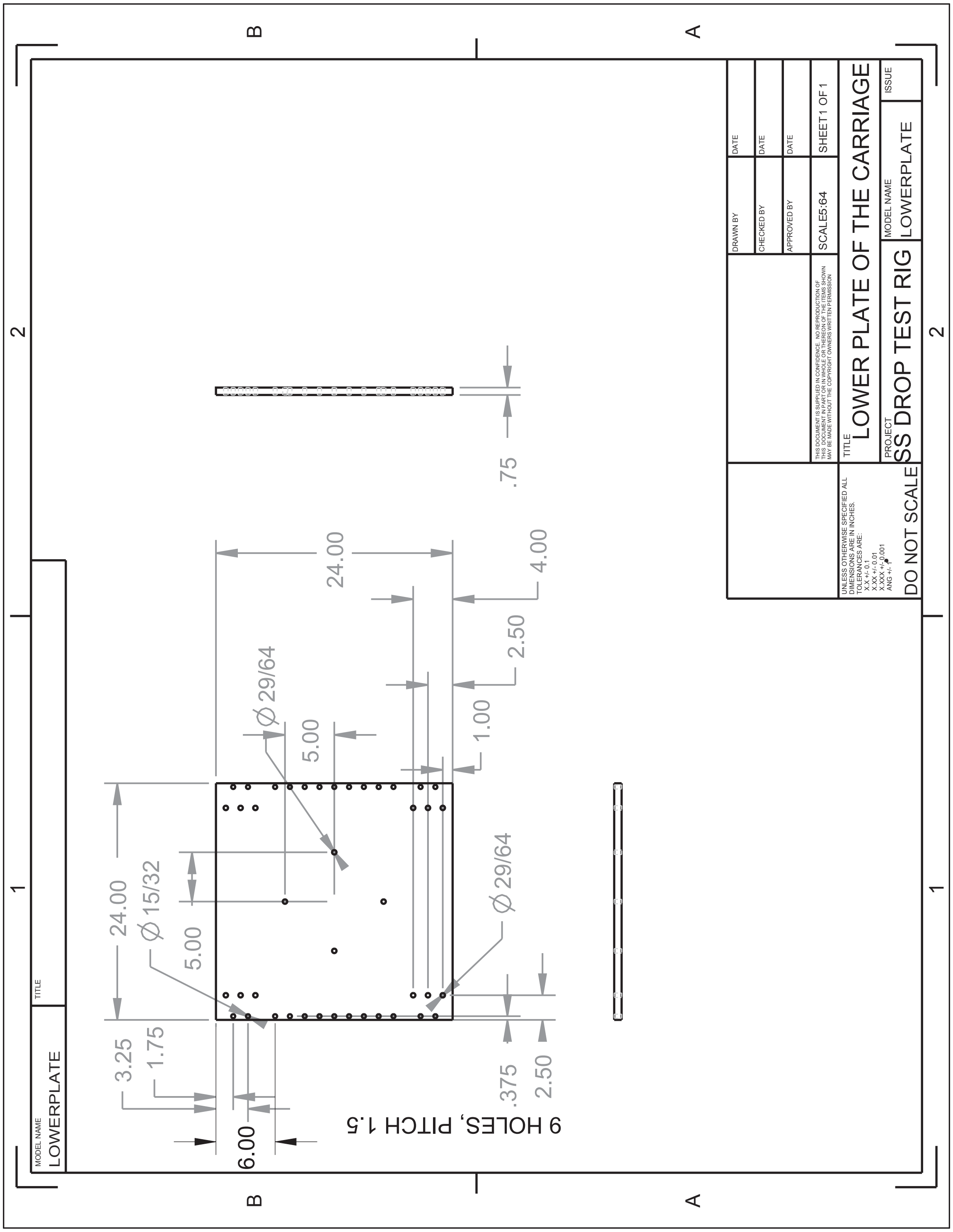
X.XX +/- 0.01
X.XXX +/- 0.001
TITLE
DO NOT SCALE
PROJECT
MODEL NAME
PUBRACKET
ISSUE

Figure A.2



LOWER PLATE OF THE CARRIAGE
SS DROP TEST RIG
MODEL NAME
LOWERPLATE
SCALE5:64
SHEET1 OF 1
DRAWN BY
CHECKED BY
APPROVED BY
DATE
ISSUE
TITLE
PROJECT
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES.
DO NOT SCALE
9 HOLES, PITCH 1.5
24.00
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6.00
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.375
2.50
1.00
4.00
.75
Ø15/32
Ø29/64

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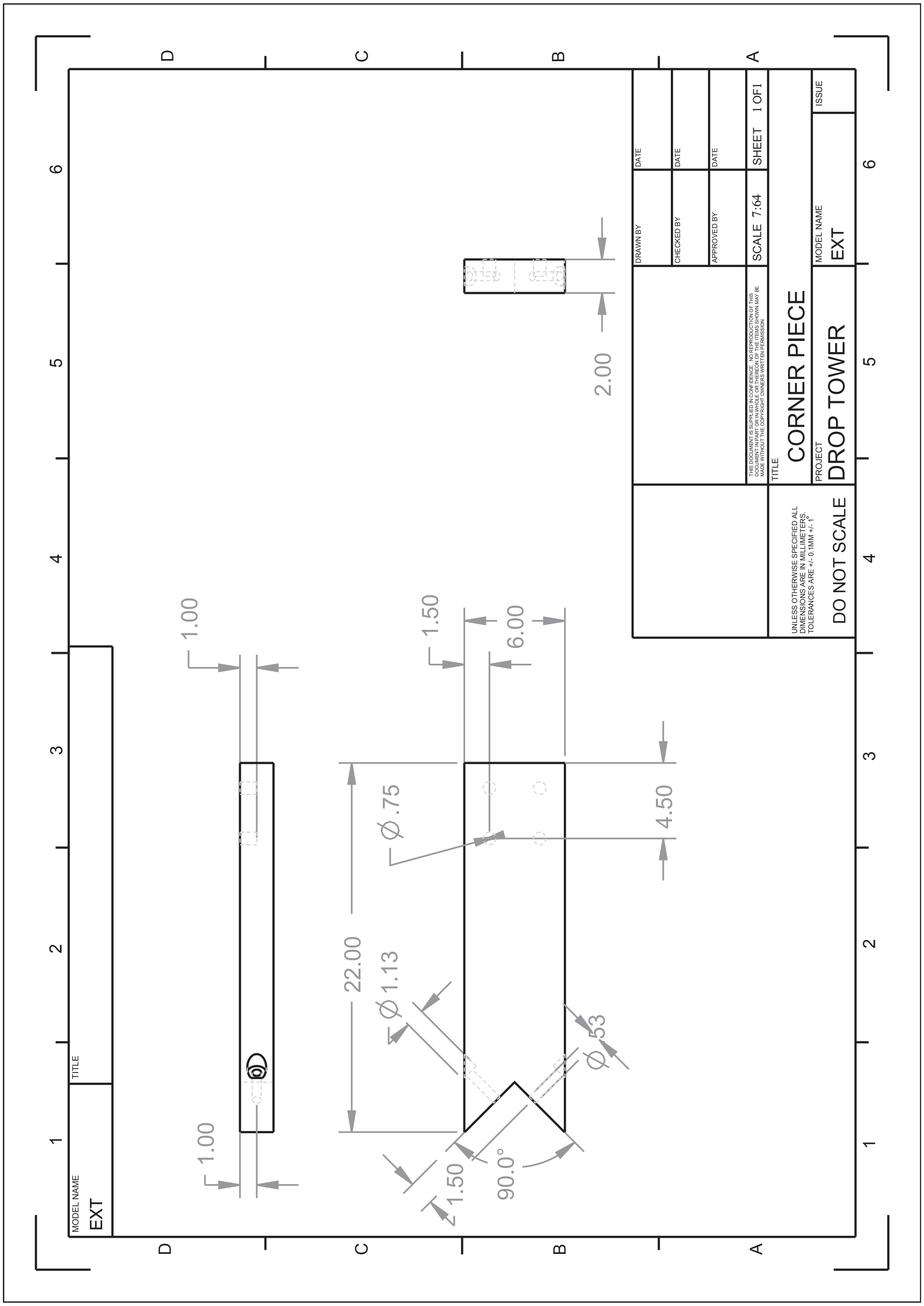
CORNER PIECE
DROP TOWER
DO NOT SCALE
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN MILLIMETERS.
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SHEET 1 OF1
MODEL NAME
EXT
TITLE
PROJECT
ISSUE
DRAWN BY
CHECKED BY
APPROVED BY
DATE
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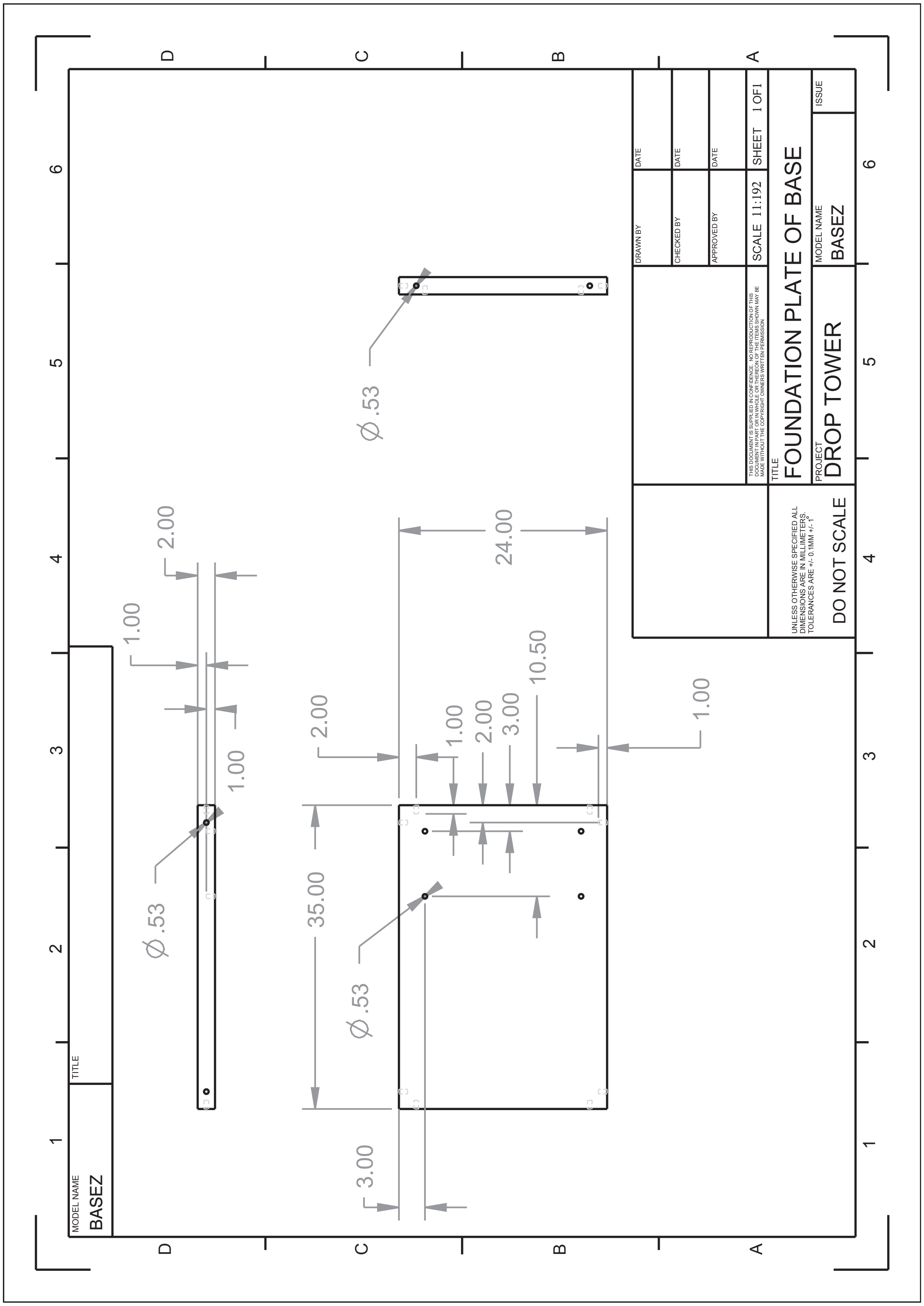
∅1.13
∅.53
90.0°

Figure A.4



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TITLE
DRAWN BY
DATE
CHECKED BY
DATE
APPROVED BY
DATE
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SHEET 1 OF1
TITLE
FOUNDATION PLATE OF BASE
PROJECT
DROP TOWER
MODEL NAME
BASEZ
ISSUE
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN MILLIMETERS. TOLERANCES ARE +/- 0.1MM +/- 1°
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Ø .53
Ø .53
2.00
1.00
1.00
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10.50
2.00
1.00
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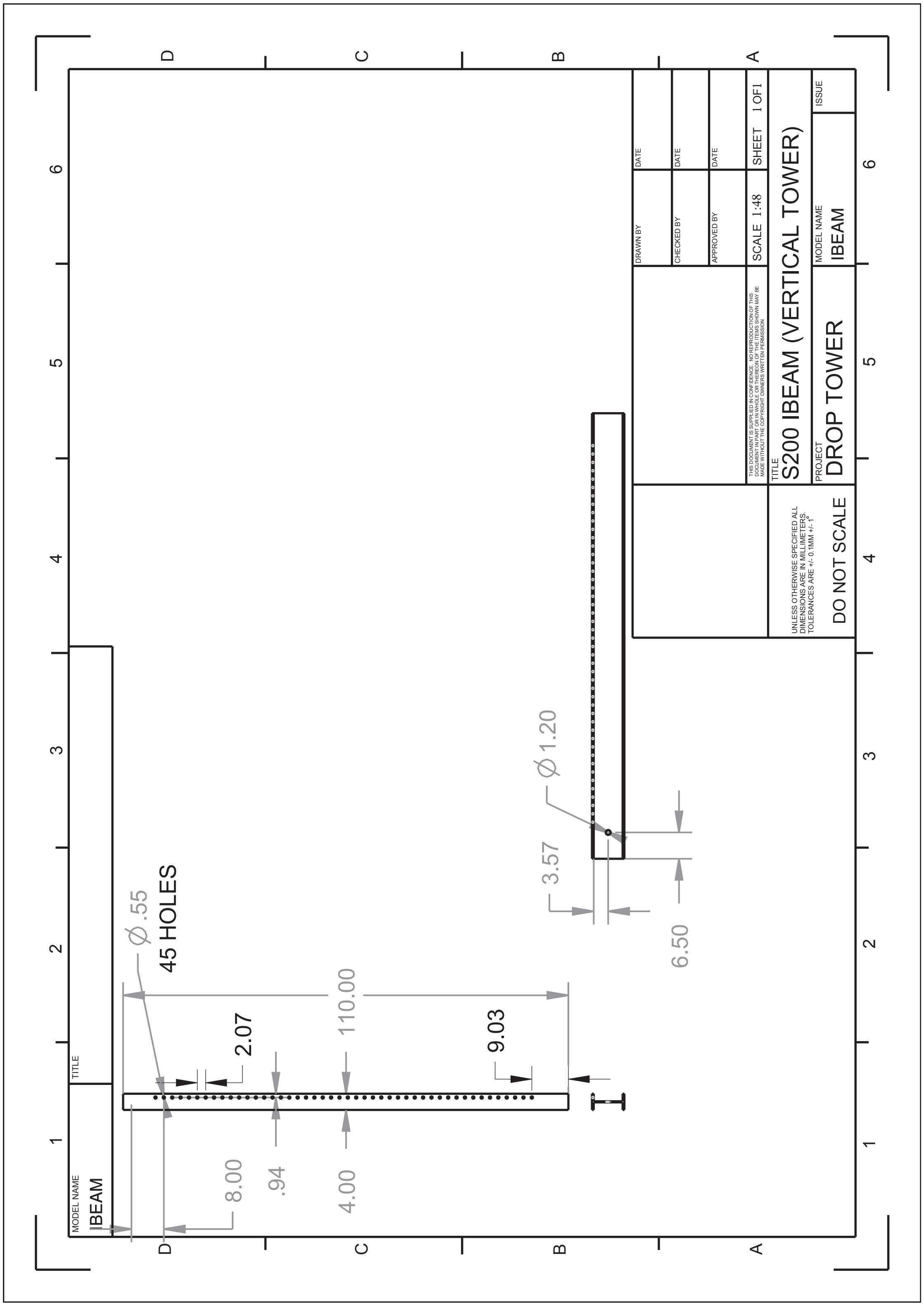
3.00
1.00
35.00
3.00

Figure A.5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2.07
9.03
8.00
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4.00
3.57
Ø 1.20
6.50
MODEL NAME
IBEAM
TITLE
DRAWN BY
DATE
CHECKED BY
DATE
APPROVED BY
DATE
SCALE 1:48
SHEET 1 OF1
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN MILLIMETERS. TOLERANCES ARE +/- 0.1MM +/- 1°
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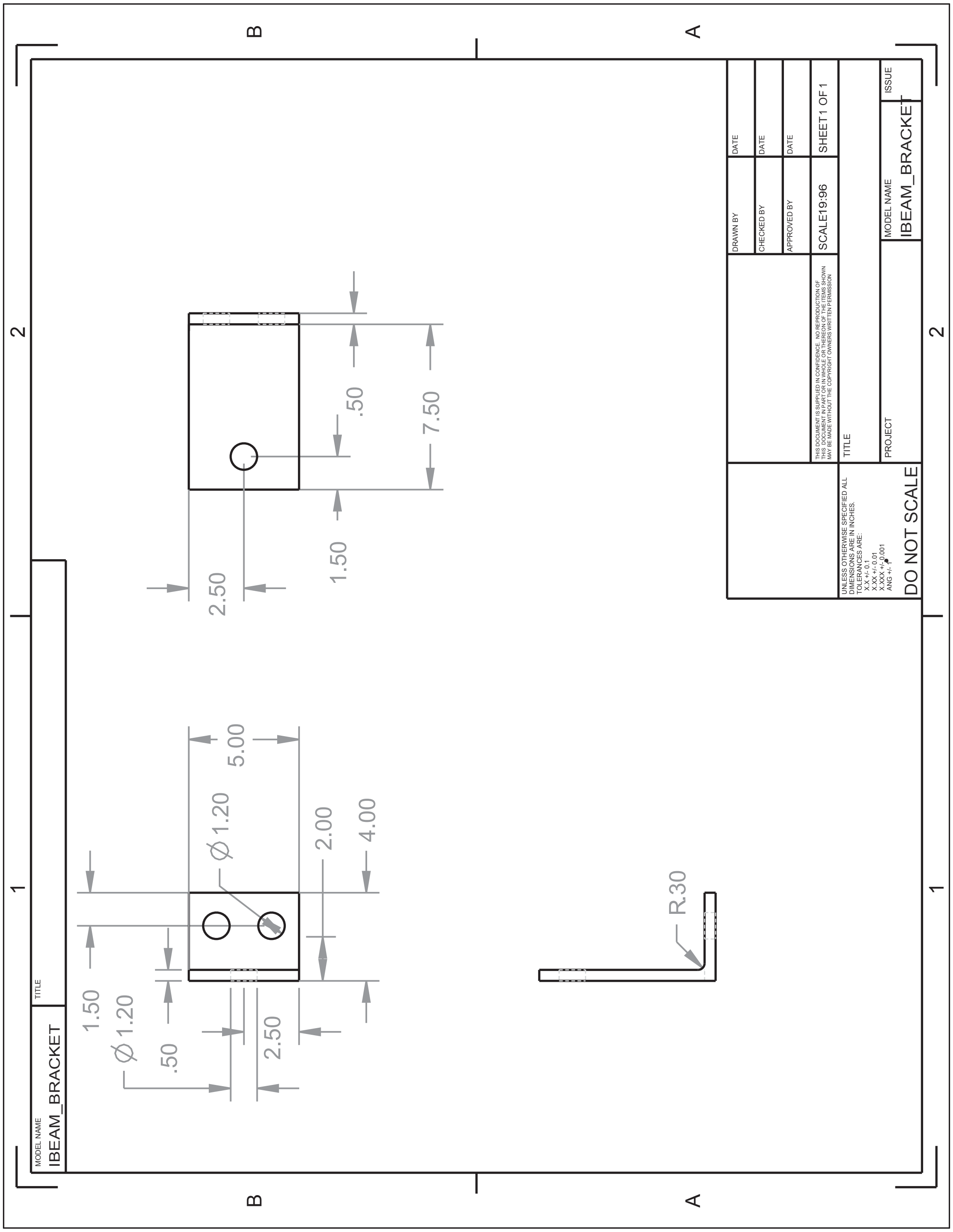
S200 IBEAM (VERTICAL TOWER)
PROJECT
DROP TOWER
MODEL NAME
IBEAM
ISSUE

Figure A.6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2.00
4.00
R.30
2.50
1.50
.50
7.50
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES. TOLERANCES ARE:
DO NOT SCALE
TITLE
PROJECT
DRAWN BY
CHECKED BY
APPROVED BY
DATE
SCALE19:96
SHEET1 OF 1
MODEL NAME
IBEAM_BRACKET
ISSUE

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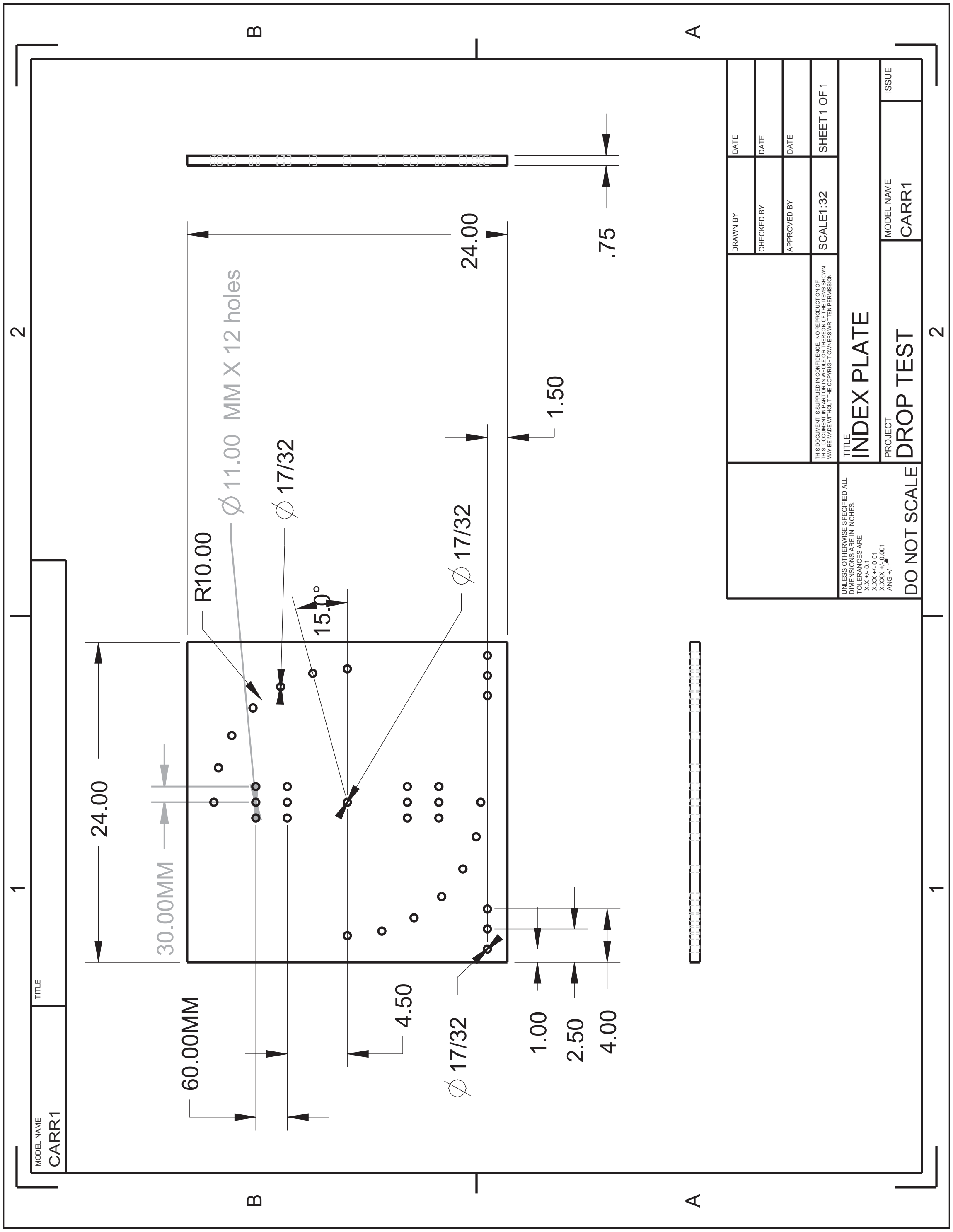
INDEX PLATE
DROP TEST
CARR1
SCALE1:32
SHEET1 OF 1
DO NOT SCALE
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24.00
.75
1.50
R10.00
Ø11.00 MM X 12 holes
Ø17/32
15.0°
30.00MM
60.00MM
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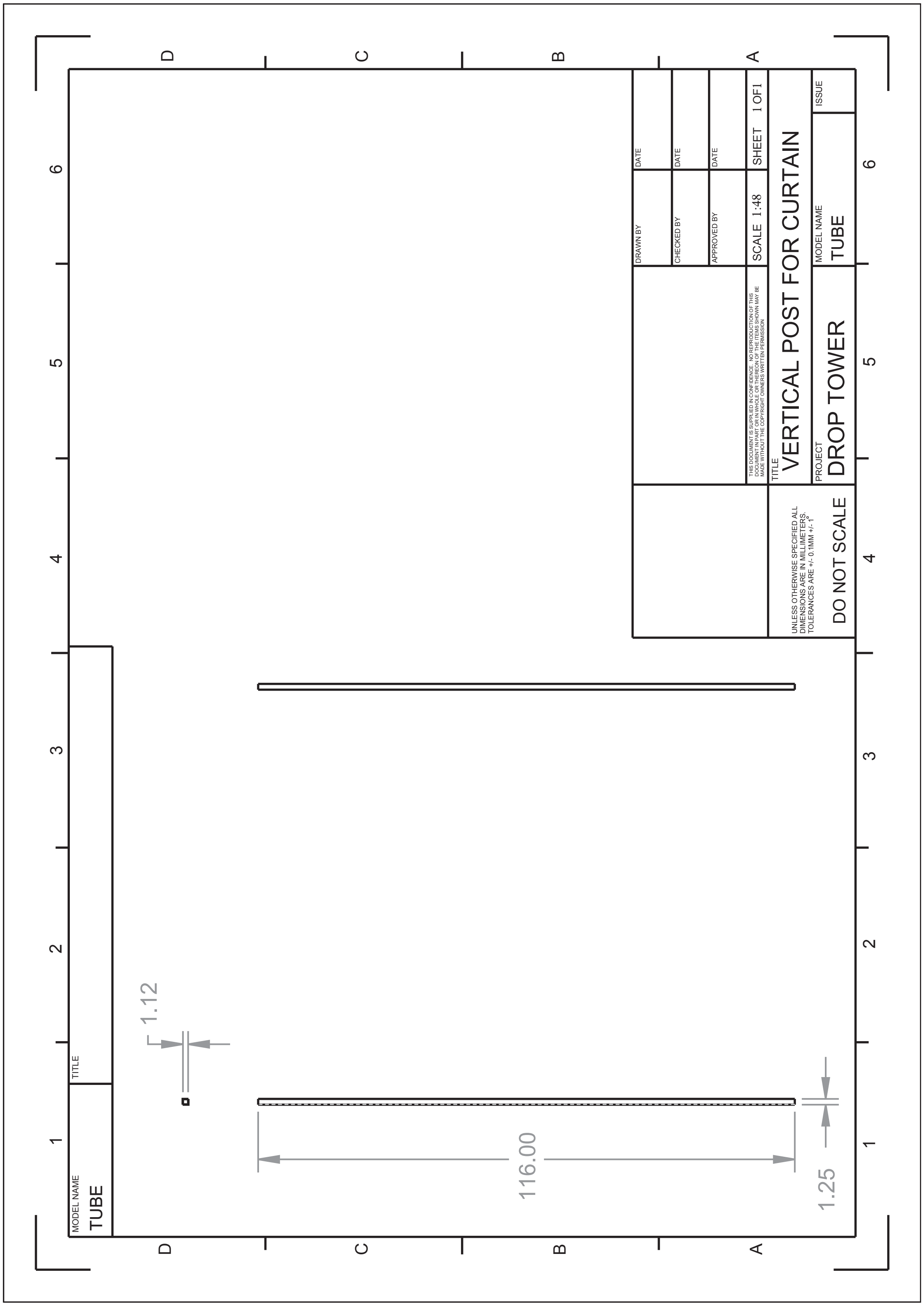
2.50
4.00

Figure A.8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1.25
DRAWN BY
CHECKED BY
APPROVED BY
DATE
SCALE 1:48
SHEET 1 OF1
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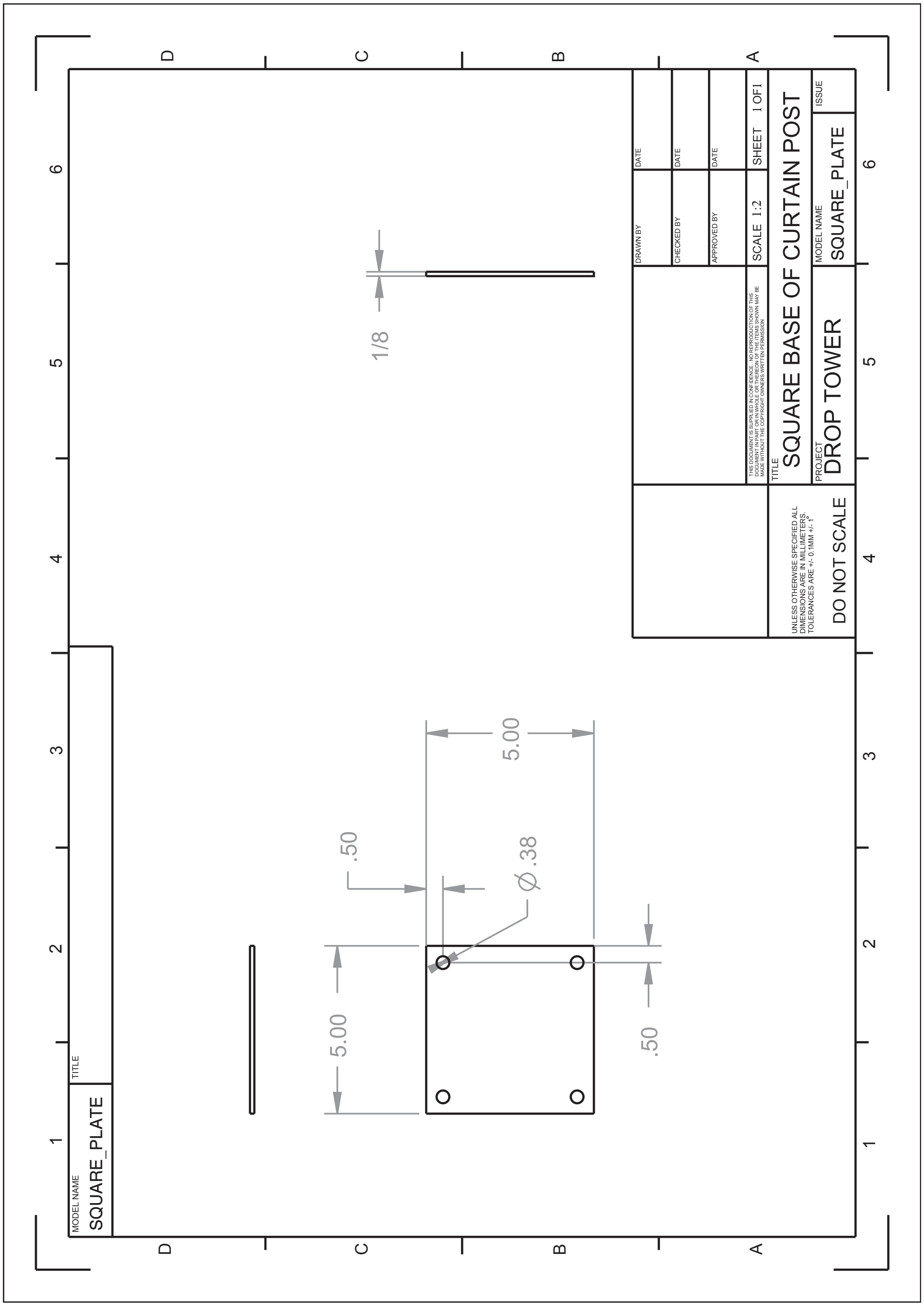
TITLE
VERTICAL POST FOR CURTAIN
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN MILLIMETERS. TOLERANCES ARE +/- 0.1MM +/- 1°
DO NOT SCALE
PROJECT
DROP TOWER
MODEL NAME
TUBE
ISSUE

Figure A.9



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DATE
CHECKED BY
DATE
APPROVED BY
DATE
SCALE 1:2
SHEET 1 OF1
TITLE
SQUARE BASE OF CURTAIN POST
PROJECT
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MODEL NAME
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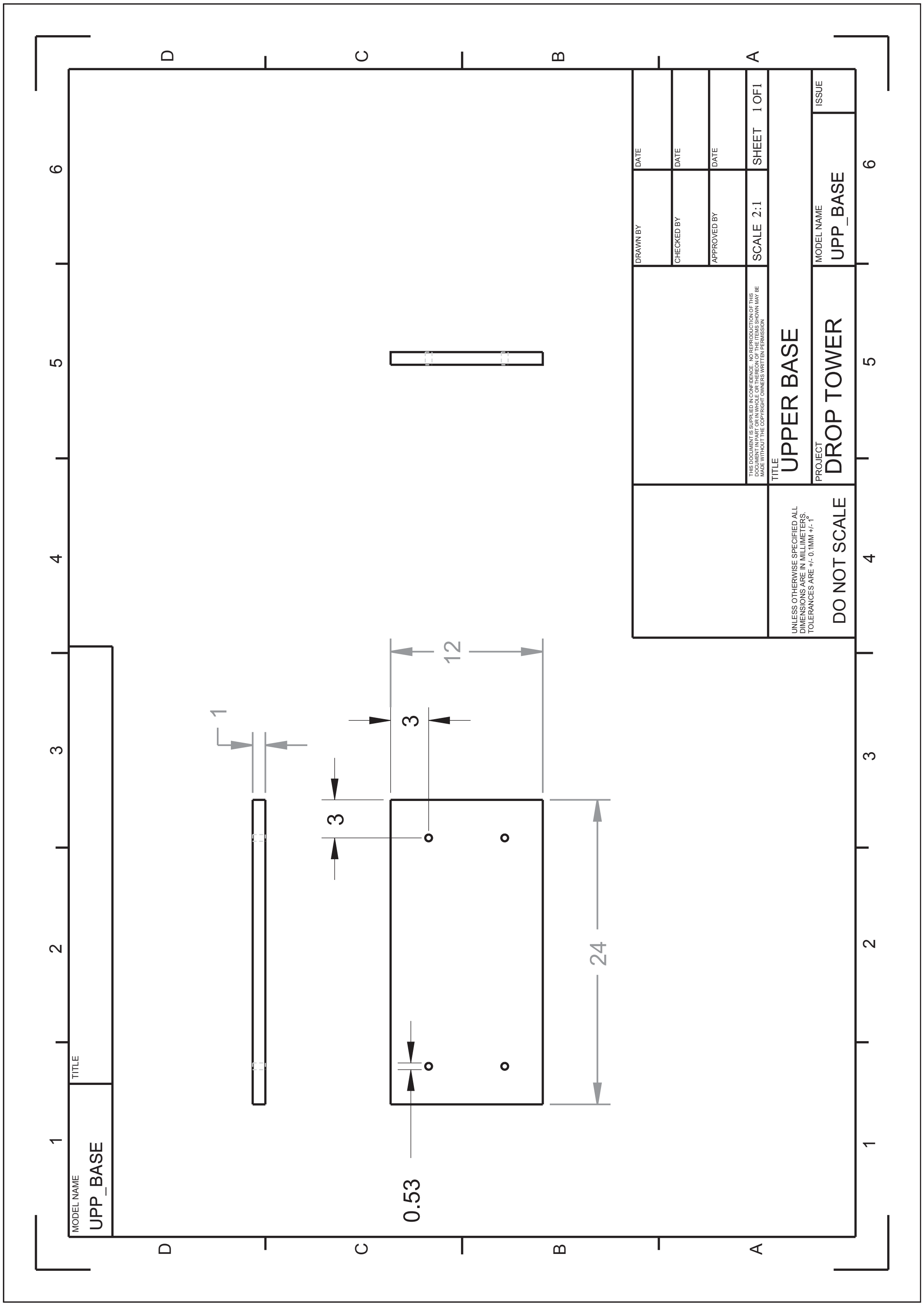
DO NOT SCALE

Figure A.10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DROP TOWER
MODEL NAME
UPP_BASE
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SHEET 1 OF1
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UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN MILLIMETERS.
TOLERANCES ARE +/- 0.1MM +/- 1°
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CHECKED BY
APPROVED BY
DATE
ISSUE
TITLE
PROJECT
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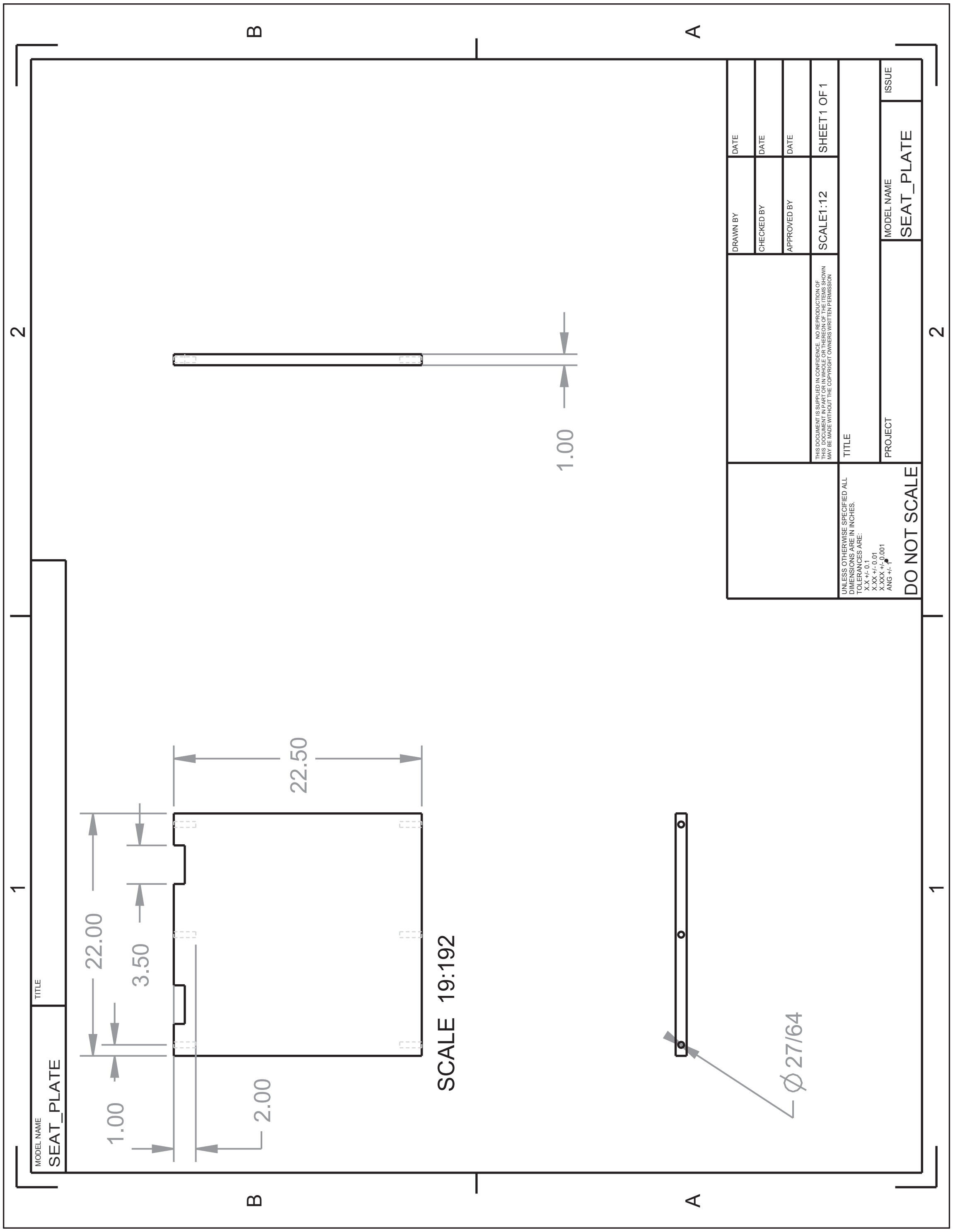
3
1
24
0.53

Figure A.11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Ø 27/64
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DATE
CHECKED BY
DATE
APPROVED BY
DATE
SCALE1:12
SHEET1 OF 1
TITLE
PROJECT
MODEL NAME
SEAT_PLATE
ISSUE
UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES.
DO NOT SCALE

Figure A.12

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High Speed Craft (HSC) passengers and crew can be exposed to high levels of repeated shock loading as a result of routine operation in elevated seas. Considerable attention is currently focused on mitigating the potentially adverse effects through the use of suspension seat technology. To support research into the behaviour and performance of HSC seating, a project to develop a single impact drop test device was initiated by DRDC Atlantic. As part of this project, the Carleton University Applied Dynamics Laboratory has investigated alternative drop test rig arrangements and has designed, built, and demonstrated a custom-designed drop tower for the purpose of HSC seat testing.

This report presents the work undertaken as part of the project. A literature review examined contemporary drop test equipment with an emphasis on devices appropriate for testing shock mitigation seats as used in small, high speed marine craft. A dynamic model of drop testing was developed such that it could be used to guide the detailed design of a single-impact drop test device. Based on this, an appropriate drop tower was designed, constructed, instrumented, and evaluated. To ensure that the Carleton Drop Tower met its design requirements, a sample drop test was successfully performed. The results of this drop test are also presented and discussed in the report.

The resulting test apparatus provides a facility to support investigation of the dynamics of suspension seating when exposed to large, stochastic shocks by simulating the high-g environment experienced by the seat under normal operating conditions. It is expected that the Carleton University Drop Tower should be able to support research aimed at developing more effective seat testing methodologies, to improve dynamic modelling and simulation of the human-seat interaction under various operational conditions, and provide relevant data to assist with seat design and injury mitigation.

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drop tower, shock mitigating seat

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