San José State
UNIVERSITY

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The Designated 'roject +ommittee Approves the 'roject Titled

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T1E USE 3F ADD/T/2E A,UFA+TU./,0 TE+1,3-30/ES F3. T1E DES/0, A,D DE2E-3' E,T 3F A +UBESAT

By atthe* +& ,apoli

The +u%eSat standard *as designed to provide quic(5 lo* cost access to space mainly for universities and research institutions& To further reduce the cost and improve the customi6a%ility of +u%eSats5 polymer e7trusion additive manufacturing has %een proposed as a method for %uilding +u%eSat structures& A $D8printed +u%eSat structure *as designed5 %uilt and analy6ed to prove the concept of an e7trusion %ased additive manufacturing for small satellites& 1igh outgassing from $D8printed ABS plastic could affect other launch payloads as *ell as any optics on the +u%eSat %ut other materials can %e su%stituted in its place& This project sho*s that additive manufacturing is a via%le method for +u%eSat production&

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+urrently5 most +u%eSat projects incorporate either speciali6ed (its for their +u%eSat structures or must custom %uild them from metal5 usually aluminum& These options can %e %oth costly and time consuming&

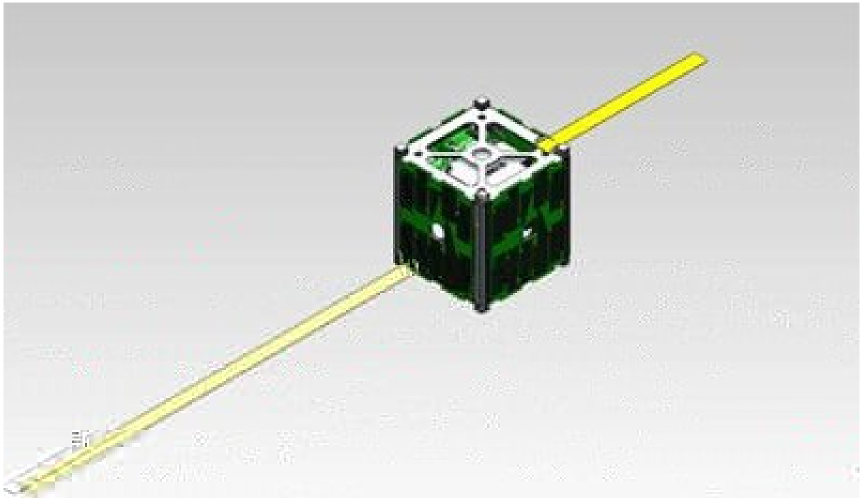

Figure #; TechEd Sat <Source; SJSU=

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The FD printing process uses a spool of plastic *hich is melted and e7truded through a no66le& A %ead of material is deposited on a platform *hile the printer controls the hori6ontal placement& F hen one layer is complete the platform moves do*n and another layer is started& This process is continued *ith each layer adhering to the one %elo* it5 as sho*n in Figure $&

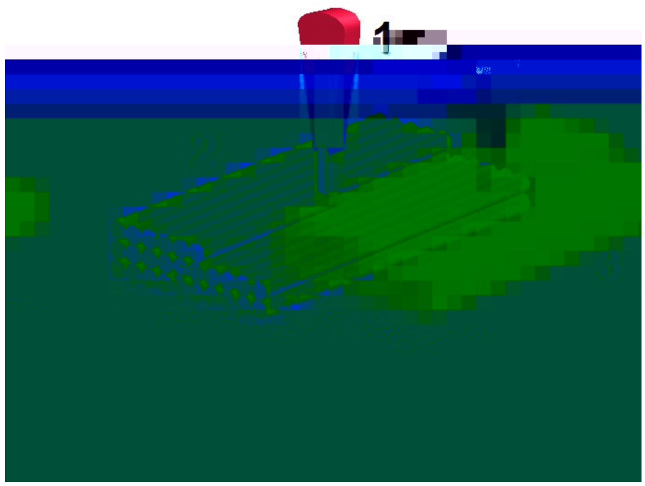

Figure $; FD -ayering ?@A

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Figure B; . A ' A . T +u%eSat at 2arious Design Stages

Figure B5 a%ove5 sho*s various iterations of the . A ' A . T +u%eSatLs structural design& This image displays t*o significant attri%utes of additive manufacturing& First5 multiple iterations of the design *e fully optimi6e the structure& F hile their procedure for material testing can %e utili6ed5 unfortunately the material properties *ill need to %e retested as they vary %y printer model&

Additive manufacturing has %een most often utili6ed as a method for rapid prototyping& /n this sense5 $D printing has %een used in numerous +u%eSat projects& The prototypes can %e used to visuali6e the design5 *or(out system integration issues5 configure the components5 or just %e used as a model for display purposes& After the printed parts are created and the design has %een set the parts can then %e manufactured out of traditional materials& Figure C %elo* sho*s some e7amples of prototyped +u%eSats&

Figure C; $D8'rinted +u%eSat 'rototypes <, ASA=

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A $D8printed +u%eSat *as designed and analy6ed to see if it meets the standard requirements for a +u%eSat& There are several un(no*ns a%out $D printing that needed to %e addressed prior to design& A set of standard material properties of $D8printed ABS has not %een universally accepted& aterial testing *ill %e

performed to determine the strength of printed parts (overprinted: e addressed to its Spaicsep the $D %6J F pp M8(A'S testin7) and accurately *ithout any *arping5 layer separation or dimensional errors& A set of design constraints relevant to +u%eSat models needs to %e created& The approach for developing these design tools is split in t*o studies; material properties of $D8printed ABS plastic and limitations of $D8printed features&

The second phase of the project is the design the $D8printed +u%eSat& A design *ill %e created using the material properties and design features determined during the first phase& The design *ill then %e analy6ed and tested to determine if it *ill meet the requirements for launch and deployment&

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A material standard for $D8printed ABS does not e7ist since it has yet to %e accepted as a conventional method for fa%ricating plastic parts& Furthermore5 industry standards for testing for the material properties of $D8printed parts have not %een pu%lished& The same approach used to determine the material properties of molded plastic *ill %e used for $D8printed ABS& The AST D D$@ tensile testing standard specifies the method for determining the yield strength of a plastic using a Universal Test achine& This process is follo*ed to find the material properties of printed dog%one samples and the results *ill %e used for the design of the $D8printed +u%eSat& The results are compared to pu%lished material properties for other $D8printed materials to verify that the results are valid&

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E7trusion %ased $D printing is not the most accurate nor most versatile additive manufacturing technique in the industry5 particularly *ith lo*er end models that do not have the a%ility to print support structure& Fa%rication testing *as performed to determine the limits of $D8printing& Areas of interest are minimum *all thic(ness and tolerances& Each of these features is printed over a range of si6es to determine the limits for manufacturing& A design envelope can then %e created from the gathered information&

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A #U +u%eSat *ill %e designed using commercially availa%le components and a $D8printed structure& This *ill allo* for a %asic design to prove the concept of a $D8printed +u%eSat& All the systems required for a small satellite including an electrical po*er supply <E ' S=5 transceiver5 flight computer5 solar panels and

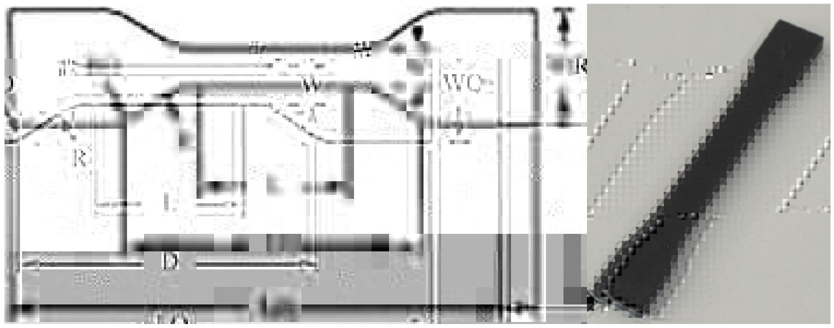


Figure D; AST D D$@ Dog%one Test +oupon ?9A

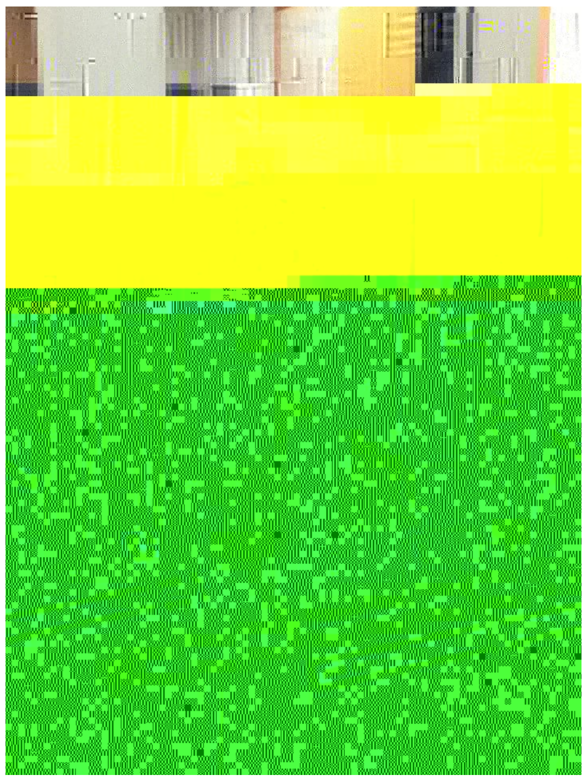
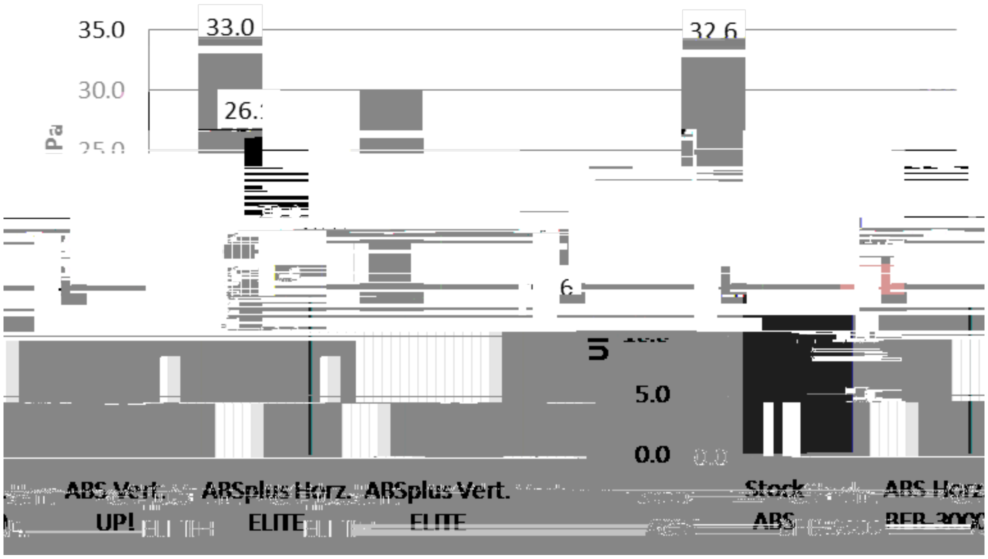


Figure E; /nstron Universal Test achine5 SJSU aterials -a%

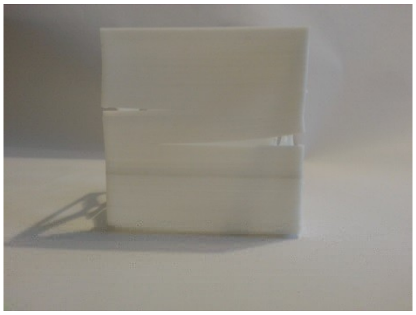
Si7 dog%ones *

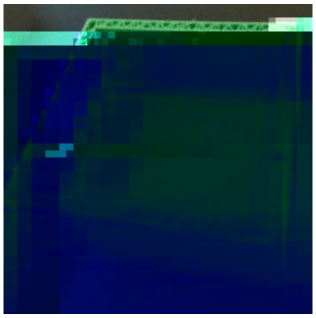
ABS %eing the rating on the ra* feedstoc(material prior to printing& Both the hori6ontal and vertical tests sho* the average of the samples tested&



Fie @;ltite Tensile Strength of $D8'ried 'arts

The ultimate tensile strength for solid injection molded ABS is rated at $$ 'a& Testing sho*ed the strength of the adhesive bond <vertical





The preliminary $D8printed +u%eSat design contains standard lo* cost off the shelf +u%eSat components& The electrical po*er system <E'S=5 flight module5 transceiver5 and solar panels are catalog components from 'ump(in5 /nc& and +lyde Space& The structure is custom designed to %e manufactured using an FD printer&

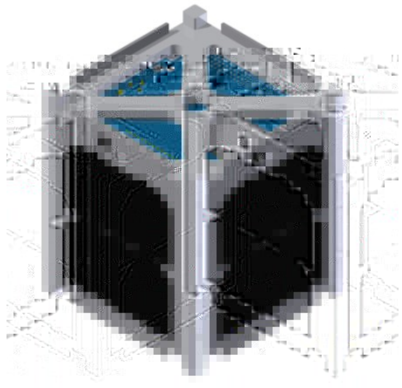


Figure #$; $D8'rinted +u%eSat Design

The 'ump(in F B$" Flight odule is a single %oard computer for harsh environments& The module controls +ommand and Data 1andling <+SD1=5 +ommunications <+3 =5 mass storage and po*er s*itching& The %oard requires a C2 po*er input to po*er its #D8%it microcontroller5 temperature sensors5 cloc(s and $&$2 /N3& The module contains a #"B8pin connector for stac(ing %oards& A model of the F B$" is sho*n in Figure #B&

Figure #B; 'ump(in F B$" Flight odule

The -inear E'S odule from 'ump(in is a rechargea%le electrical po*er system for +u%eSat (its& /t provides a regulated C2 and $&$2 po*er supply using t*o #C""mAh -i8'oly %atteries for a total of ##Fh of po*er& The stac(a%le design5 sho*n in Figure #C5 eliminates the need for additional *iring %et*een %oards& The module also interfaces *ith the Solar Array to recharge the %atteries&

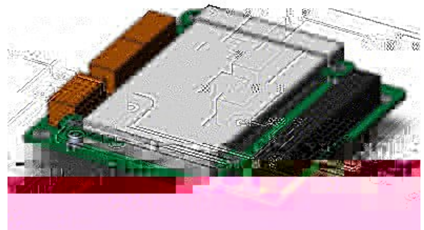


Figure #C; 'ump(in -inear E'S odule

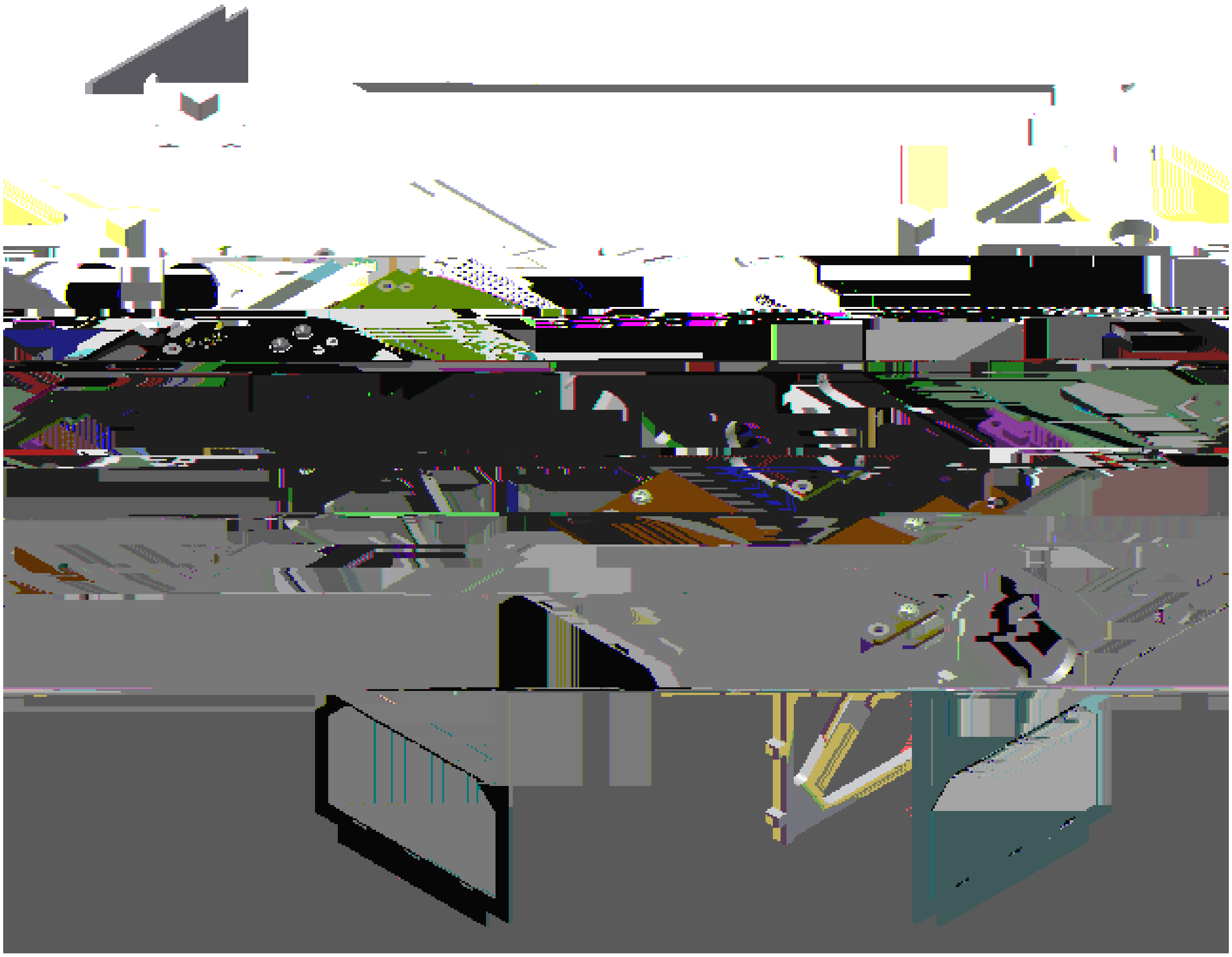


Figure #9; $D8'rinted +u%eSat +AD Design

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Upon completion of the $D8printed +u%eSat design the satellite *as a%le to %e immediately printed& Additionally5 each of the off the shelf components including the E'S5 Flight odule5 odem and B solar panels *ere printed to use as models for fit chec(s and orientation& The professional8grade Stratasys Elite

9.1.2 Dimensions

The +u%eSat Acceptance +hec(list <+A+=5 as sho*n in Appendi7 B5 has a set of dimensional and design requirements that must %e met %y each satellite unless a deviation *aiver is su%mitted& The *idth of the #U +u%eSat must %e *ithin #""Q"&#mm and the height ##$&CQ"&#mm& An inspection of the $D8printed +u%eSat sho*ed the *idth to %e 99&9mm and the height ##$&@mm& F hile the height of the rail is out of tolerance5 that could %e remedied %y reducing the dimensions in the +AD or %y simply cutting off "&$mm from the top of each rail&

The surface finish of ABS is not applica%le as plastic has a much lo*er coefficient of friction and *ould slide more easily than aluminum&

9.1.3 Launch Loads

The launch loads are ta(en from the general launch vehicle loads as defined %y , ASA per SS' C"@$C& This encompassed the *orse cases from all the vehicles that supply the #c', Aye èq

E'S card slot and the model material *as set as steel& The structure and door *ere given custom material properties using the material testing data and a tensile strength of ##&D 'a&

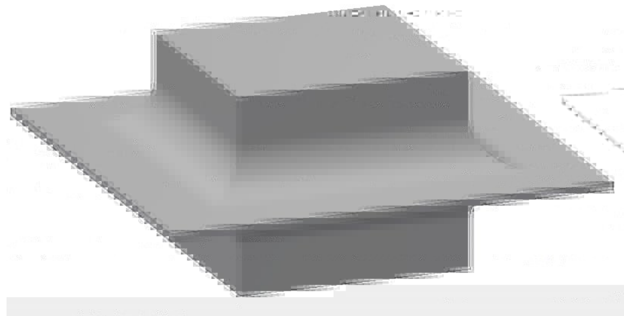

Figure !#; # (g Simulated 'ayload

A polygonal mesh *as created of the +u%eSat structure and the simulated payload5 see Figure !!& The mesh included $9!$9 nodes and !"#ED elements& The model *as fi7ed on the %ottom face of each of the rails and all components *ere %onded together&

Figure !!; $D8'rinted +u%eSat esh

The four cases sho*ed similar results for ma7imum stresses as *ell as displacement5 see Ta%le B& The ma7imum 2on ises stresses *ere %et*een @&! X @&D 'a *hich *ere concentrated at the %ase of each rail near the constrained face5 see Figure !$& 3ther areas of high stress *ere no more than $ 'a5 *hich is %elo* the materials yield strength& a7imum displacement is "&#"C mm and is located at the top of the +u%eSat&

	a7 2on ises Stress	a7 Displacement
+ase #	@&! 'a	&#"B mm
+ase !	@&B 'a	&#"C mm

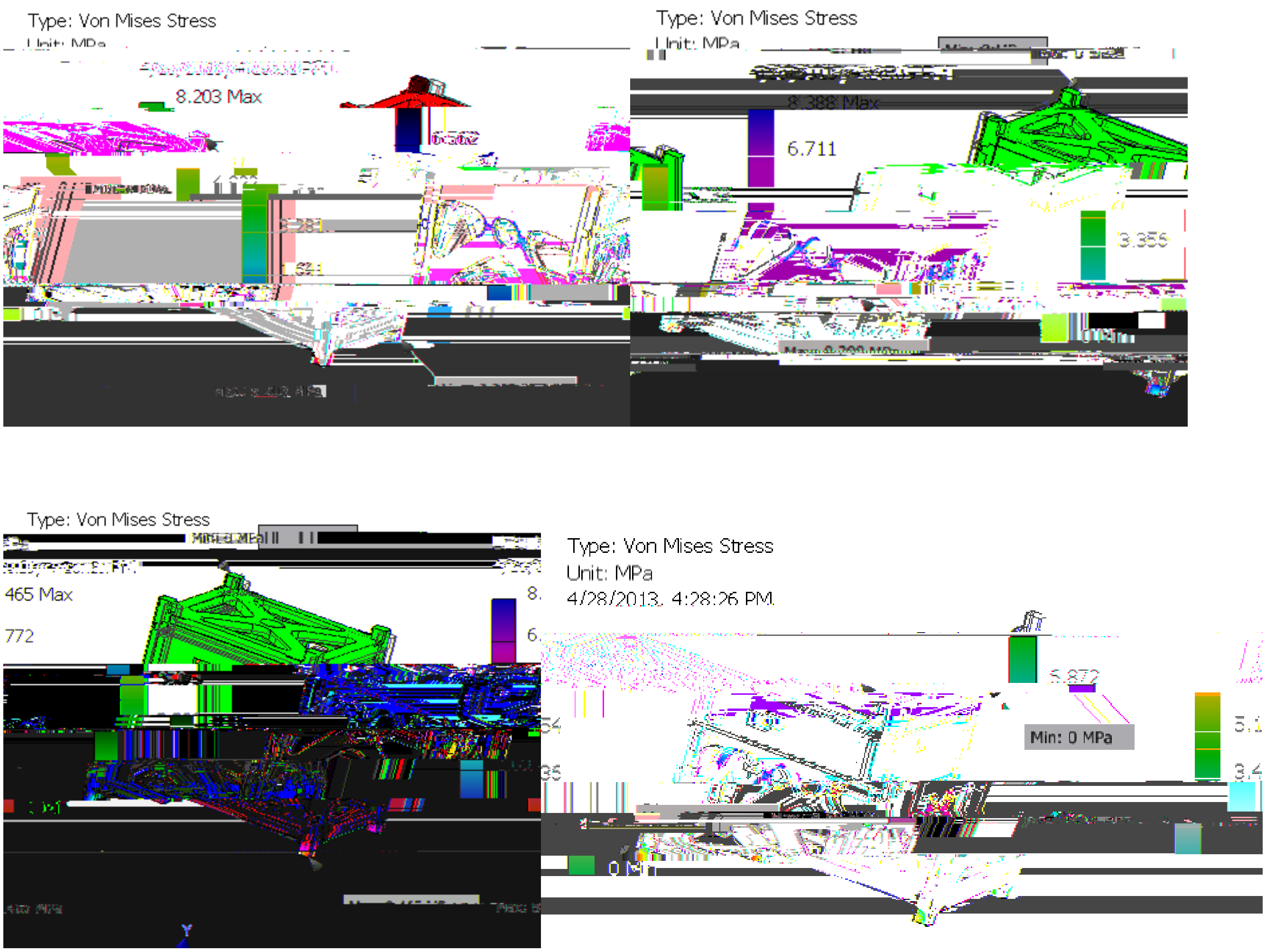

Figure !$; 2on ises Stresses5 Top . o* 8 +ase#5 !5 Bottom . o* 8 +ase $5 B

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The research and sample models printed point to*ards the feasi%ility of a functional $D8printed +u%eSat& F hile the *all thic(ness *ould %e thic(er than a similar aluminum structure5 the a%ility to customi6e at lo* manufacturing cost can offset that design constraint& ABS is a very common5 lo* end material for $D n3ŰØ -ý

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Figure !B; +u%eSat Specification Dra*ing

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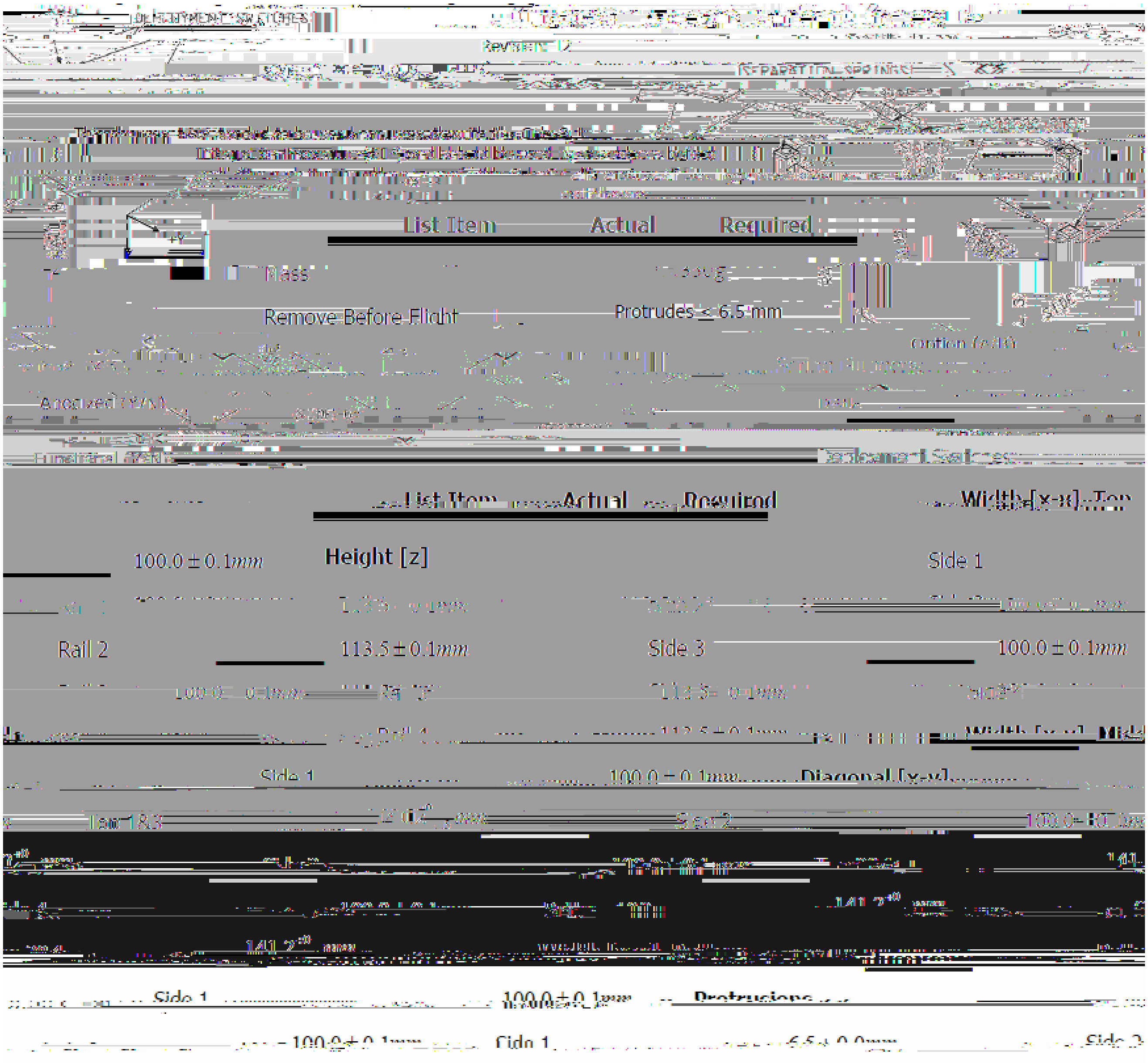

Figure !C; +u%eSat Acceptance +hec(list

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