The Challenges of Characterizing a Wind & Temperature Spectrometer for Space Weather Measurements

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Predictive models and their development for the low earth orbit drag environment is a field gathering more and more attention recently as space junk and decommissioned satellites are becoming more present in the news media. Models that exist are generally established off of empirical data from the monitoring of different satellites as their orbits decay, but there is certainly a need for satellites dedicated to making measurements of the atmosphere not just to be monitored as a drag target. The Drag & Atmosperic Neutral Density Explorer (DANDE) fulfills the goals of this niche by making in-situ measurements of accelerations and atmospheric composition in low earth orbit. DANDE is being built at the University of Colorado Boulder Colorado Space Grant and Aerospace Engineering Sciences Department. The satellite itself was part of the Univesity Nanosatellite Competition and announced as the competition winner in January 2009. This satellite is slated for launch in late 2012 which is foruitious timing since the next predicted maxium for solar activity is anticipated in the middle of 2013.

The DANDE satellite is comprised of two novel experimental science instruments. One being an accelerometer suite designed for sensitivity at the µg level and the other is for directly sampling the atmosphere entitled the Wind and Temperature Spectrometer (WTS). The WTS shares development history with the Goddard Space Flight Center (GSFC) Wind-Ions-Neutral Composition Suite (WINCS) which has variants flown on the Atmospheric Neutral Density Experiment (ANDE) from Naval Research Labs (NRL). These types of instruments are extremely powerful in the data they can provide since they are relatively inexpensive to produce and have the resolution necessary to decern the number densities of constituent particles in the neutral thermosphere. Identifying the sources of uncertainty from this ion optics setup is a key challenge in defining the performance metrics supporting infrastructure of electronics and mechanics. Previous simulations of the chief source of error, the energy selector, have been conducted by GSFC and the University of Colorado as well as empirical testing of the instrument itself. However, given advances in the understanding of the ion optics it is prudent to develop an analytical model that studies the instrument in a three dimensional space to identify key senesitivities of the sampled ion stream. Here a discussion on model validation will be discussed starting from the initial developments by GSFC and transition to the testing knowledge the DANDE system has from instrument characterization to produce a 3D model of the WTS instrument.

I) Introduction

The Drag & Atmospheric Neutral Density Explorer (DANDE) is a student built satellite at the University of Colorado. DANDE is a unique platform to study the atmosphere in Low Earth Orbit (LEO) and how perturbations affect satellite orbits. Perturbations under investigation include tidal variability as well as energy transfer from outside sources, such as a Coronal Mass Ejection (CME) from the Sun. What is of particular interest is how these changes will manifest themselves as changes in spacecraft orbits. Ultimately the mechanics observed with these phenomena are like that of a hot air balloon, where the burner is the energy transfer mechanism. When energy is added the air trapped inside expands and becomes less dense providing a buoyancy force. In the Earth system the energy transfer excites the atmosphere, but without the bound of the balloon structure the atmosphere is free to expand. In the reference frame of satellites this is observed with an increase collisions with particles from the atmosphere, the number density of these collisions is what fluctuates. The collisions are what are the key to orbit changes, these are occurring at the molecular level as the satellite flys through the atmosphere there is a small

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energy exchange between the satellite and molecule. Much akin to to the thought exercises in high school physics classes where an object is ejected from a stationary body that is unconstrained on a low friction surface. The movement of the object along its velocity vector will result in an energy balance with the initial stationary body which will have some translational kinetic energy in the opposite direction, or Newton's Third Law.

DANDE attempts to study this interaction via a dual instrument single spacecraft setup. The satellite is not three-axis stabilized which presents a challenge of projecting a known cross-sectional area to the velocity vector since variation will result in a greater or weaker force acting on the satellite. To combat this DANDE is a spherical shape that is spin stabilized around orbit normal, shown in Figure 1, N represents the orbit normal vector. R is the radial vector from the the Earth and T is the vector tangent to the direction of flight along the orbit path. Scientific measurements are then made in the TR plane to find acceleration and couple that with a concept of composition and density during measurement. Using a novel accelerometer suite that conveniently uses the spacecraft rotation with six navigation grade accelerometers to sample bulk accelerations of the spacecraft in the velocity vector, this setup is capable of achieving sub-μg resolution via an active set of filtering and amplication electronics. The signal to noise ratio (SNR) is further boosted by the fact that six measurements are being taken and could be coupled together to help remove random noise associated with the electronics and sensor heads. The predicted output of the accelerometer instrument is shown in Figure 2. A red least squares fit line has been fitted to the observed data to show the intrinsic sinusoidal shape and a method for reducing the data product by determining the fundamental constituents of a sinewave, amplitude, frequency, phase, and bias.

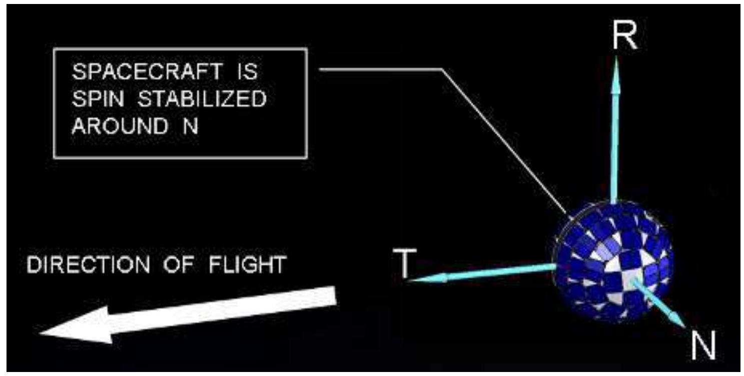


Figure 1 DANDE Operational Attitude

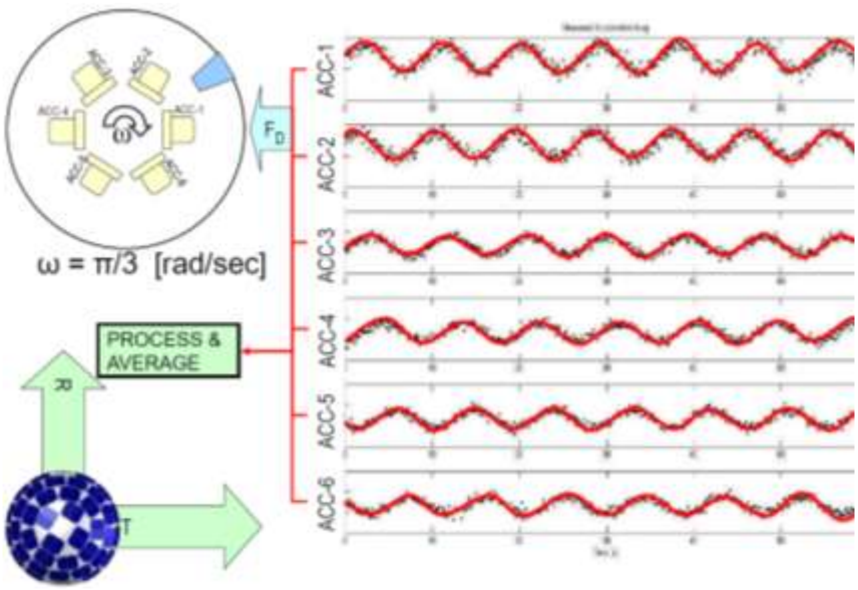


Figure 2 DANDE Accelerometer System Measurements

Accelerations on the spacecraft provide insight to the full scene of what is affecting satellites on orbit, however to fully understand the dynamics in play making measurements of the atmosphere is a crucial component. The Wind and Temperature Spectrometer (WTS) on board DANDE makes measurements of the energy spectra and their angular distribution, these additional pieces of information then allow the DANDE spacecraft to have full insight to the drag equation, this is illustrated by Figure 3. The method by which the DANDE WTS makes these measurements is similar in design principle to the Goddard Space Flight Center (GSFC) Wind-Ions-Neutral Composition Suite (WINCS). It takes advantage of the spacecraft and wind velocities to measure the energy of the neutral constituents of the atmosphere. A full energy spectra is achieved through a Small Deflection Energy Analyzer (SDEA). This component in effect is two parallel plates one at ground and the other capable of being driven through a ramp, this ramping will change the strength of the electric field the neutral species are flying through perturbing their flight through the instrument as a function of their energy. Lower energy particles then require a weaker electric field to deflect their path than higher ones effectively selecting the desired energy to be view at any given instance in time. Once selected the quantity of specimens at that energy are effectively counted by an electric current produced by a mico-channel plate with each impact. With the full data set being identified DANDE data could then be fed back in to predictive models of the atmosphere to be used as a calibration target.

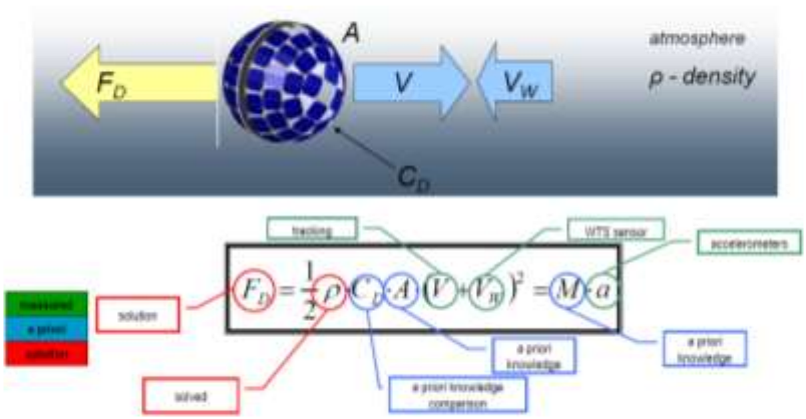
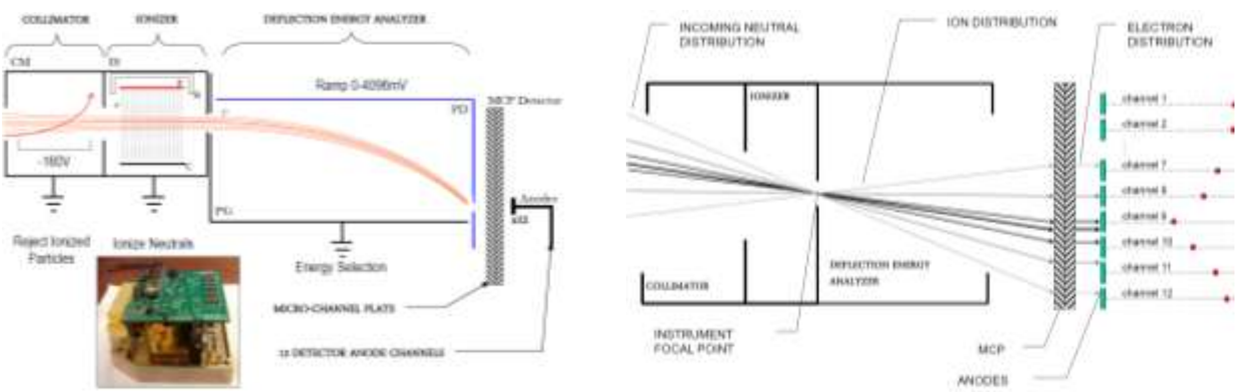


Figure 3 DANDE Scientific Measurement Techniques

Design & Makeup of the WTS Instrument

The WTS is designed to observe the lower energy particles in the atmosphere, specifically the energy range from 1-14eV. Further it is designed to only sample the neutral particles in the atmosphere due to practical limitations of measuring the naturally occurring ions at LEO. The limiting factor is that naturally ionized particles whether they be O^+, N_2^+, H^+, etc. their charge with respect to the DANDE satellite cannot be easily measured nor controlled. As DANDE moves through the ionized atmosphere it is likely to build charge over time and there is no means built into the spacecraft to dissipate this charge. All of this charging takes place in reference to the Earth system, what is nice about the neutral particles is the WTS can charge them internally and then sample them in reference to the DANDE system effectively controlling their energy. This then leads to how the WTS rejects the ions, since they cannot be effectively screened before entering the instrument aperture, ionizes the desired specimens and selects them for observation.

The make up of the ion optics can be broken down into four fundamental parts. First the collimator and ion deflector, the deflector applies an electric field inside the instrument entrance aperture perpendicular to the sample velocity vector. Ionized particles are perturbed from their direction of travel by this field while the neutrals do no respond since they have yet to get a charge. The collimator part of this is a series of knife edges the trim the entering



Vertical Cross-Section **Horizontal Cross-Section**

Figure 4 Cross Sectional Views of the WTS

sample to a field of view that is 30° along the spacecraft cross track and 2° along the satellite radial axes. Then neutral species move into an ionizing chamber which has a beam of electrons to singly ionize the neutrals with respect to the overall DANDE structural ground. Once charged neutrals continue on their initial flight path and enter an energy selector that acts as a parallel plate capacitor where one side is held at ground and the other can be ramped from 0-4V perturbing the path of the now ionized neutrals as a function of their energy. Once the energy is selected neutrals exit and strike a charged Micro-Channel Plate which produces an signal that can be processed as an impact and factored into an overall number density calculation. This flight of ionized and neutral particles through the instrument is shown graphically by Figure 4. On the left is a vertical cutaway of the instrument, and on the right is a horizontal view. Both are important because as previously mentioned this instrument also provides the angular distribution or wind vector of the atmosphere to the spacecraft reference frame. The vertical cross-section shows how a desired energy species can be sampled with the top (blue) plate of the SDEA can ramp from 0-4096mV and bending the ionized neutral beam to the SDEA exit. When Ions exit they will strike the MCP which is biased to -2.5kV to achieve first a sufficient gain for the detector electronics to register the impact, but also to produce a large electric field at the exit of the SDEA that essentially will remove any additional vertical component to their movement capturing the selected SDEA energy. Horizontally the atmosphere is free to enter at up to a 15° angle to the spacecraft velocity vector, some distribution to the atmosphere will be observed and is shown by the varying weighting of the ion paths into the instrument. The darker lines represent a higher number of neutrals so the ouput channels will observe a higher number of impacts where the distribution is centered. The width of this distribution across energy levels and aside from its location in the 12 channel array detector then speaks to the temperature of the sample which is further information to the drag equation. All of this information from the instrument results in Figure 5. The major constituents of the atmosphere that DANDE is trying to observe would then be the relative ratio of atomic oxgen to molecular nitrogen which occure at roughly in the middle of the energy spectrum that can be selected by the SDEA. This is important because the estimated composition of the atmosphere in LEO is 99.8%[2] by mass O and N_2. The energy of the molecules observed is a result of the spacecraft and atmosphere velocities at the entrance to WTS and since the species are at the molecular level their velocity and mass become interrelated as kinetic energy. With the spacecraft traveling at 8km/s this becomes the dominant term for finding the energy which can be shown as eq 1. For testing purposes the assumption that kinetic energy then dominates is a good approximation.

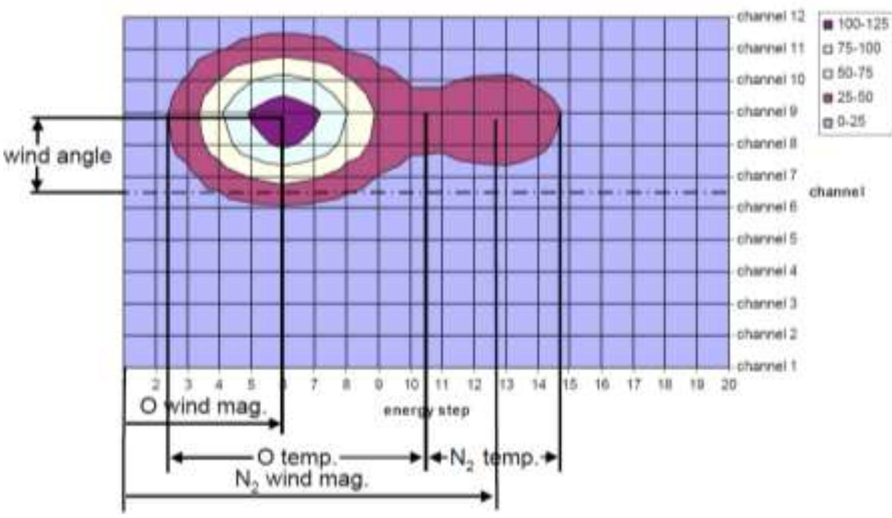


Figure 5 WTS Data Product

$$K = 1/2 m_i V_T^2 \qquad (1)$$

It is important to consider though that the standard method for considering K as shown above yields an answer of Joules [J] and must be converted to electron Volts [eV] by a factor of 1.6022e-19 $^J/_{eV}$.

With a better understanding now of what the WTS instrument can provide as a data product the chief concern becomes how to characterize and test the instrument on the ground. Resolution knowledge of the energy selection and the and characterizing the electrostatic forces affecting the desired energy selection can be done by injecting samples into the instrument at varying energies and sampling the counts at the output. Studying the sensitivity to wind angle becomes less of a concern since it is a function of the geometry of the instrument versus the electrostatics, although the edge effects of the electric fields should be analyzed at extreme wind angles.

Current Analytical Model Validation

At present three studies have been conducted or are underway to predict the performance of the SDEA. GSFC and pervious students at the University of Colorado have used simulation tools to map the trajectories through the SDEA at varying electric fields. As a baseline to draw conclusions from any current work these past analyses can be used as a baseline since they both showed agreement for plate factor, which describes the electric field on the SDEA and the selected ion energy at the exit, and pass band for ions exiting the SDEA chamber. Further when tested the actual DANDE WTS instrument has data for the energy selection plate factor and bandpass data. The benefit to further refining models after this empirical data set has been gathered is so that future revisions can be adapted to different platforms with the knowledge that evidence of accurate performance metrics is rooted in empirical data. All show plate factors for the SDEA of 3.4$^{eV}/_V$ and a triangular pass band as a function of the selected energy.

[2] Pilinski, M. D. "DANDE CDR Section V: Analysis." UN-5 CDR: Univ. Colorado DANDE Satellite. Lecture.

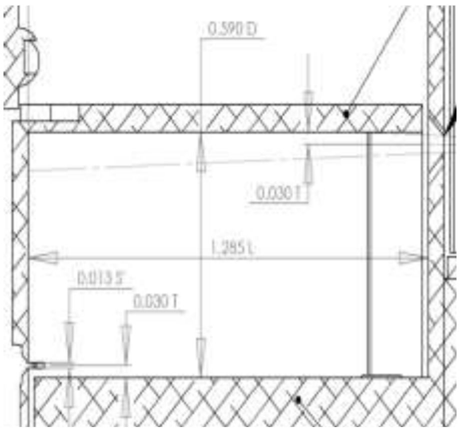
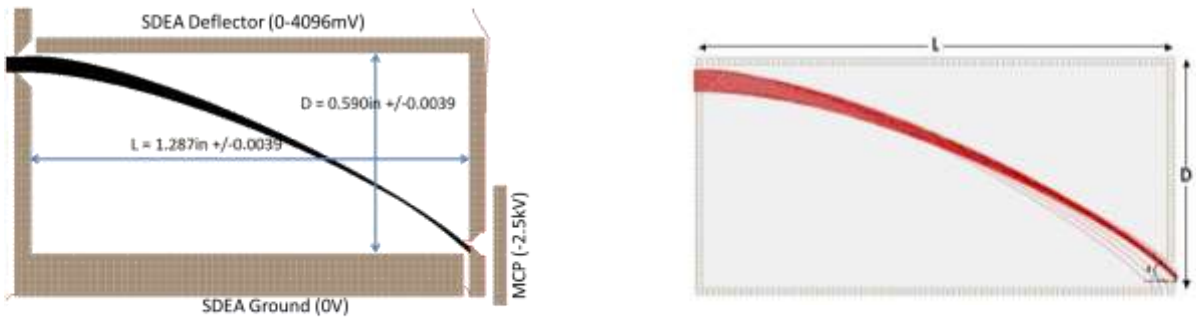


Figure 6 SDEA Internal Geometry Reference

The SDEA geometry can effectively be normalized down to a ratio of its length to height, L and D respectively. The entrance aperture and exit aperture positions can then be related by these critical parameters. By maintaining this ratio scaling of the SDEA chamber should have little effect on the resulting performance, the reference geometry is shown in Figure 6 where the SDEA entrance is on the right and exit on the left. The gemotetry as shown has a L/D ratio of 2.18 and this is the current setup inside of the DANDE instrument. Simulations run at GSFC used a geometry of 2.12[3] and yielded the same plate factor as the tested DANDE WTS which has the potential to show there is little sensitivity to the changes in SDEA chamber geometry[3].

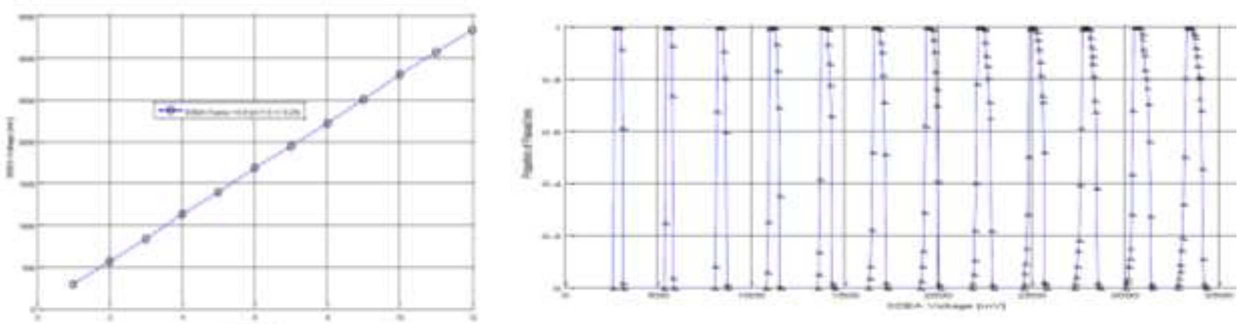
Then using these data sets as a validation source for current modeling efforts then is the first step to producing a full three dimensional model of the DANDE WTS instrument. In the efforts covered in this paper the software package SIMION 8.1 was used with a spatial resolution of 0.1mm. In a two dimensional setup the desired performance metrics would be those matching the previous GSFC scenario and testing configuration used during DANDE WTS testing in 2008-2009. In order to simulate the ion optics of the SDEA and discern a plate factor and



Current SIMION Simulation (L/D = 2.18) GSFC SDEA Simulation (L/D = 2.12)

Figure 7 Simulation Illustrative Comparison

pass band geometry a set of 1000 ions are flown of uniform energy and velocity vector through the SDEA while varying the SDEA deflector voltage with subsequent tests with a 5mV resolution. The end results would be at each energy from 1-12eV of simulated ions up to 30 simulations would be run collecting the total number of ions that are passed through the SDEA for that independent simulation. In order to better replicate the electrostatic fields occurring inside of the SDEA a mock up of the Micro-Channel Plate (MCP) is placed 0.065” from the SDEA exit



SDEA Factor Results Pass Band of Each Ion Energy (1eV Left to 12eV Right)

Figure 8 Simulated SDEA Performance Results

aperture at a potential of -2.5kV to replicate the potential drop at the exit, Figure 7 shows the effective geometry used for these simulations on the left, and the previous GSFC simulations on the right that are the validation source.

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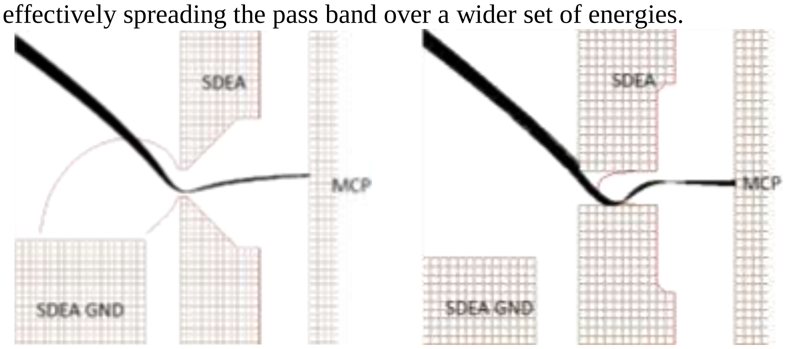
[3] Herrero, Fred. "Miniaturized Charge Particle Spectrometer Development at Goddard." Detector Systems Branch. NASA Goddard Space Flight Center, Greenbelt, MD. Speech.

The observed plate factor for this round of modeling yielded a SDEA factor of $3.58^{eV}/_{V}$ and a pass band geometry that is rectangular in nature versus triangular as seen with the GSFC results, these two observations as shown in Figure 8. It is concerning that the two disagree on the fundamental performance metrics which would indicated one of the two is not properly replicating the physical phenomena being observed. Note again though how in Figure 7 the geometry of the SDEA presented here utilizes knife edges at the entrance and exit apertures (ultimately mimicking the designed components) whereas GSFC simulates these with a single thin wall of electrodes. This actually has a profound effect on the ions and how their are effected inside of the SDEA chamber. The red line in the current SDEA simulations is the 0V equipotential line with the SDEA voltage just after selecting 12eV ions. That 0V potential extends into the SDEA chamber when in principle the dominant field is supposed to be that of the deflector plate. When ions cross the 0V equipotential then the dominant field becomes the MCP which effectively begins pulling the positively charged ions to the exit and causing an ambiguity in the selected ions effectively spreading the pass band over a wider set of energies.



LEFT Knife Edge As Built Geometry, RIGHT Solid Thin Wall GSFC Simulation Both with 4eV Ions

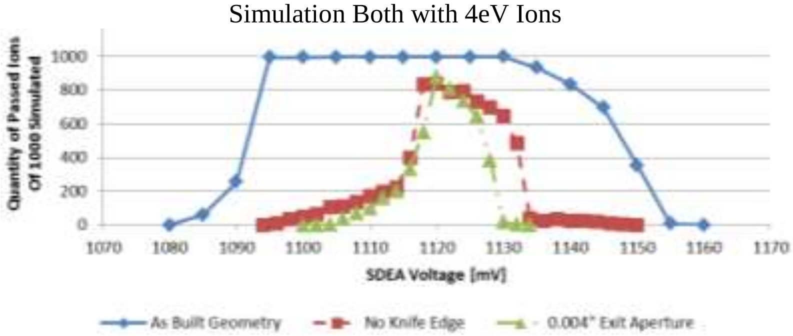


Figure 9 Knife Edge Effects On Pass Band Geometry

This presents an interesting opportunity to study the effects of geometry inconsistencies between the two modeling techniques. GSFC advocates for a triangular pass band geometry and would observe that result with a SDEA physical geometry as shown in Figure 9 where the exit aperture is not modeled with a knife edge. At the same energy levelof 4eV and a knife edge being used the 0V equipotential line actually couples with the SDEA ground plate and passes all of the ions. The lower graph shows how the as built geometry responds with what is almost a rectanglular band pass, supporting the theory that they MCP is influencing the SDEA chamber. The dashed red line shows the resulting quanity of ions passed without the knife edge where there is only one peak efficiency which is the key characteristic of the triangular pass band. Finally a quick study of a knife edge in the smallest case that could be resolved with the 0.1mm grid unit spacing shows how using the knife edges and the actual aperture size could affect the band pass and shape the resulting SDEA parameters such that the half max peak was significantly narrower than the current geometry. A 0.1mm exit aperture would effectively be one third of the current exit size, and it is possible through careful machining that this exit aperture could be made even smaller, possibly as low as 0.002”. The crux to this narrowing of the pass band is the max of the passed ions does not achieve a full 100% efficiency even in the 0.004” case presented above which must be considered in the final design.

Another interesting take away from Figure 9 is that even though the modeled entrance and exit differ in geometry from the GSFC to the results presented here the effect on the SDEA factor does not change as observed right now the plate factor is still $3.58^{eV}/_{V}$ as presented in Figure 8. The no knife edge case is a recreation of the thin wall theory used in the GSFC simulations which did have an L/D ratio of 2.12 versus the DANDE WTS L/D of 2.18. This indicates further study of the L/D ratio is required to confirm the results of the previous GSFC testing and simulations. Since the current simulations are built off of the geometry that is used inside of the DANDE WTS the disagreement between test data for the plate factor at $3.4^{eV}/_{V}$ and the simulation here is puzzling, but up until now the simulation has been as close to tolerance as allowable by the 0.1mm resolution in SIMION, the question can be raised then what would the effects of mechanical tolerances do to the performance metrics of the SDEA. This sets up key areas that can be further developed to determine the validity of the SIMION simulations used here compared to previous testing.

Sensitivity Study on the Energy Selector

Starting with the baseline knowledge of the SDEA simulations having significant result in plate factor and pass band as compared to the empirical testing results further study of the design space around the as built geometry needs to be conducted to understand if the results are within the bounds of acceptability. This narrow trade space testing the different sensitivities will also present itself as further opportunities to refine the WTS design as a greater foundation of the critical variables in play are understood and characterized.

A. Mechanical Tolerances

With the as built system on the DANDE spacecraft and not in a position to see any significant changes to its physical design understanding how the mechanical tolerances stack up is beneficial since the model of the SDEA and the test results observed from the instrument do not agree in their energy selection. From the simulation a reasonable ion energy of 4eV (approx. Atomic Oxygen) would be selected at 1111mV, whereas the tested results of WTS are at 1175mV for the peak passage of ions. Roughly speaking this then entails an ambiguity of a quarter electron volt, recall the key constituents of the atmosphere desired to be sampled are atomic oxygen and molecular nitrogen with have peaks that are far enough apart at 4 and 9eV respectively to not fall into this ambiguity. However the temperature of these speciemens is a function of the half peak width of the energy which may be as tight as 4eV, this ambiguity represents a more sizeable percentage error then for the temperature data product versus the absolute energy definition. If the ambiguity in plate factor can be resolved from mechanical tolerances then the largets component affecting temperature resolution is reduced to the pass band size which as previously noted relates to the geometry of the exit knife edge.

In the WTS instrument the datum reference is the instrument chassis which is a single piece of aluminum. The SDEA ground plate is directly bolted to the chassis while the SDEA deflector is floating off of the chassis with an Ultem insulating pad that has a tolerance of 0.002". The other factors that play into the changes in geometry of the SDEA chamber are the ground and deflector respectively. The ground plate has a universal tolerance 0.005" and a 0.002" in locating the SDEA entrance. This in essence means that the SDEA chamber critical dimension D which represents the height of the chamber could from the ground plate alone be 0.005" larger than previsouly estimated. The deflector has similar tolerance stack up, however it was considered the part requiring higher precision at the time of manufacture and the base to what would be the ceiling of the SDEA chamber is within a tolerance of 0.0005". Ultimately this means that they chamber could change in height alone by 0.0075". Suppose then for a moment that the only parameter in play is the height and the length stays constant at 1.285" as specified in Figure 6.

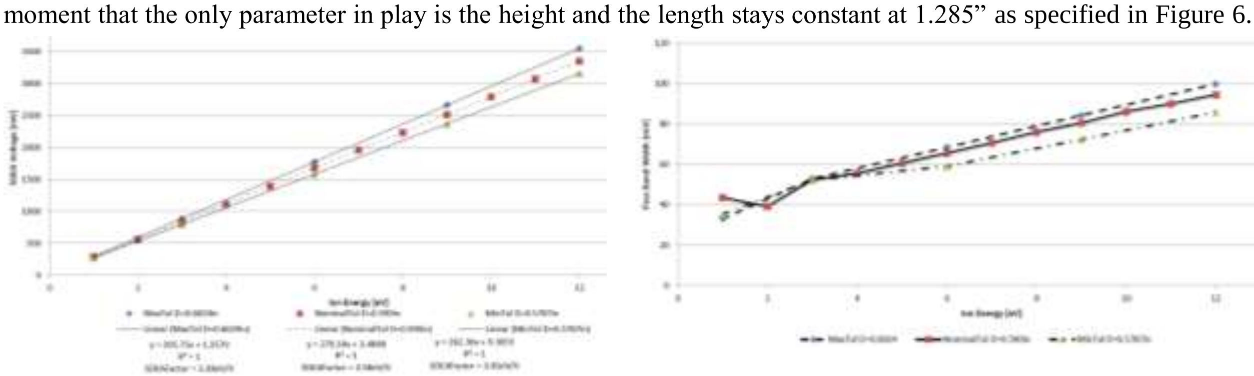


Figure 10 LEFT SDEA Plate Factor Perturbations due to Tolerances, RIGHT Pass Band v. Ion Energy

In this scenario the critical dimension D grows to 0.5975" changing the L/D ratio from 2.18 down to 2.15, this places the SDEA in the realm of the GSFC simulations where the plate factor is slightly lower. Due to the resolution of the SIMION grid units the height of the SDEA under test was selected as 0.6024" which further drops the L/D under test to 2.13. Figure 10 shows the effects of the maximum and minimum SDEA internal chamber height and how they effect the SDEA plate factor compared to the as specified geometry. At the maximum internal geometry the SDEA factor does drop down to $3.38^{eV}/_{V}$, recall that this configuration is an L/D = 2.13 and the GSFC simulations with L/D = 2.12 had a plate factor of $3.4\,^{eV}/_{V}$. This mechanical sensitivity then plays a large roll in the overall SDEA plate factor and should be further explored. Interestingly though the effect on the pass band geometry and change across SDEA chamber geometries is largely unaffected as noted in the right hand side of the graph in Figure 10. The pass band is defined as the point at half peak width and related in millivolts to the SDEA deflector plate. To convert this to the ambiguity in energy of ions the observed SDEA factor can be multiplied in as a rough estimate.

B. L/D Ratio

Leveraging from the discovery of the sensitivity to mechanical tolerance changes variation in the L/D ratio from the nominal DANDE WTS configuration should yield an interesting set of results. The nominal L/D = 2.18, and with the maximum chamber height tolerance stack up the L/D = 2.13, on the other side of the coin the minimum height from tolerance stack up produces and L/D = 2.22. The SDEA plate factor then is sensitive to the change in height, but to what end, is there a point at which the effects of geometry changes approach diminishing returns. For now consider a scenario where the SDEA chamber height is altered by ~0.030" or roughly 4 times the tolerance stackup effects. For the sake of argument suppose this 0.030" is considered for increasing the the SDEA height since in the current definition of the geometry if the ceiling is lowered much beyond the current tolerance stack-up it will affect the flow of ions from the entrance slit and the geometry of the entrance and exit aperture with respect to each other has not been investigated at this point in time. This would raise the SDEA height to 0.620" and the L/D factor would become 2.07. Based on the trend previsouly investigated the SDEA plate factor would become very nearly $3.0^{eV}/_{V}$, Figure 11 shows the mapped results of this investigation where the critical dimensions of chamber length (L) and height (D) are varied independently of eachother. When the L/D is dropped to the lower bound of four times off of the specified tolerance height the SDEA factor does in fact nearly drop to the much lower $3.0^{eV}/_{V}$, and with previous results this too shows little effect on the pass band geometry and width at each energy level of flown.

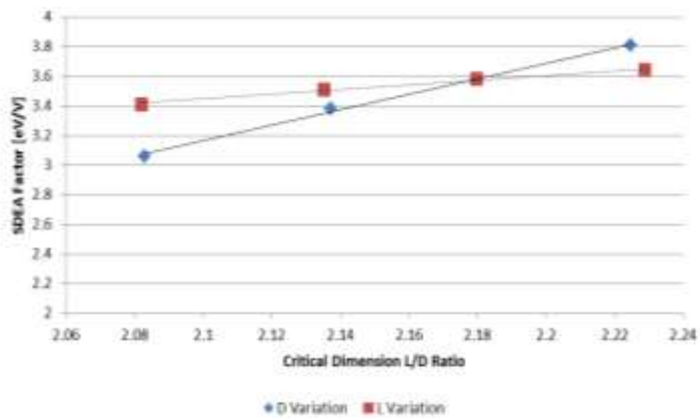


Figure 11 Independent Critical Dimension Variation

Up until this point the discussion has largely centered around variations in height, consider now the variation in length of the chamber. By tolerances from the as built SDEA the geometry is has a play of 0.005" to maintain inspect manufacture. Using the L/D ratio as a tool to compare the sensitivities of the instrument to different perturbations in geometry now lengths that are shorter or longer while holding D constant at the specified 0.590" to match the L/D ratios from perturbations in D. These results are now plotted on Figure 11 and surprisingly have the same trend in the SDEA plate factor, but not the same magnitude. It seems then the WTS instrument is much more tolerance to changes in the length of the energy selector than the changes in height. The tabulated results for both L variation and the previsou D variation are show in Table 1.

Table 1 L/D Independent Variation Results

L [in]	D [in]	L/D	SF [eV/V]
1.2874	0.5904	2.18	3.58
1.2874	0.6024	2.14	3.38
1.2874	0.5787	2.22	3.81
1.2874	0.6181	2.08	3.06
1.2598	*0.5904*	2.14	3.51
1.3150	*0.5904*	2.23	3.64
1.2284	*0.5904*	2.08	3.41

This is a key sensitivity that will have to be analyzed at any juncture when scaling the instrument to different sizes to ensure that the effect on L/D is understood at a different physical size. Further investigation to the instrument as a whole may show that it is desireable to have a SDEA factor that is lower so that electronics supporting the energy selection voltage ramp are not required to have as fine of a resolution. At the same time packaging constraints on future platforms may advocate for a longer shallower SDEA. This will become one of the first junctures in the investigation of how the ion optics and supporting electronic hardware meet to effect the fidelity of the instrument.

Future Analyses for WTS Characterization

The geometry of this instrument has now become a key concern for understanding how the ion optics chain is affecting the fidelity of measurement. In the near future it may prove fruitful to have an understanding of how the system can change in the trade space for the benefit of supporting electronics or increased sensitivity, or even smaller form factors on differnet platforms other than DANDE. Three major items remain that should be studied for their effects on energy election and resolution of the instrument in the energy spectrum. The chamber outer geometry from floor to ceiling and wall to wall has been discussed, but the relation of the entrance and exit apertures is the next major parameter that should be analyzed. For the more distant future planning understanding in two dimensions how the system can scale provides insight into how small or large the package can become before the effect of diminishing returns on investment becomes a major player. The draw backs then to all of these discussions is it excludes the geometry of the system in three dimensions. The internal SDEA equipotential lines will have some non-symmetric change due to the shape of the SDEA which not only may play into the plate factor and resolution but also the angular distribution in the cross-track spacecraft axis that cannot be captured by a two dimensional setup.

A. Entrance & Exit Aperture Sizes and Placements

During the study of the tolerance stack-up and independent variation of the SDEA critical dimensions the entrance aperture and exit aperture were varied uniformly with the SDEA ground and deflector respectively. What then would be the effect to the instrument selectivity if the apertures were only varied with repsect to eachother holding the SDEA chamber in a constant geometry. The tolerance stack-up analysis actually has an interesting effect in this since as the SDEA chamber becomes taller from manufacturing errors in the ultem isolating pad, ground, and deflector the entrance and exit apertures actually become closer together along the vertical axis. When the effect is only 0.0075” off the nominal state the system appears to largly respond due to the floor and ceiling proximity, but surely the SDEA factor would have to increase as the entrance and exit are made to be closer together in height. Further the proximity to the florr and ceiling is discussed as a key parameter to the pass band geometry by GSFC[3]. Relating the proximity fo either aperture to the height (D) and ensuring that they are not within 0.1D of either the floor for the SDEA exit and ceiling for the entrance is said to greatly affect the observed pass band geometry shifting from a rectangular shape to a more desiarable triangular profile. Interestingly the DANDE WTS instrument has this critical dimension at roughly 0.030” which would be ~0.05D and in the band where a rectangular shape is to be expected.

Discussed briefly and illustrated by Figure 9 the size of the aperture will also come into play to affect the pass band geometry, this has the added challenge of decreasing the efficiency of passed ions, however the effect is small since the observed result with a 0.004” aperture at the SDEA exit was over 90% at the peak SDEA voltage. The benefit to shrinking the exit aperture is simple in nature the pass band can be tailored to a desired result independent of the SDEA factor. This is likely not the case with the constraint on the aperture center to the SDEA floor or ceiling since it likely will move the apertures closer together in height which is similar to reducing the overall chamber size and causing the SDEA factor to rise. The ramifications of decreasing the exit aperture size are not purely benefits though, the flux of the atmosphere into the instrument as a whole must be considered for the sampling system, and the integration time to get a clear picture. A longer integration time on DANDE would mean that measurements become more coupled with the satellite spin and could skew data. These insights will show how future revisions and the desired for speed over resolution will impact not only the science generated but also the stability of the platform and the accuracy of the entire attitude system.

B. Scalability

The ultimate desire for the WTS concept is to fit it onto smaller platforms and potentially generate global coverage for a more swarm-like network. This can be achieved through the use of cubesats which have a low cost, but also a small profile. The WTS on DANDE is essentially the size of a 1U cubesat and actually weighs in heavier than the CalPoly specification of 1kg. How then could a payload like this be made to fit onto a platform smaller than the current iteration, the answer is to make the ion optics smaller ultimately reducing the size of the chassis and therefore reducing size and footprint. This may prove to be ill advised if the ion optics reach a tipping point where the fringe effects of the electric fields start to interact with the specimens that are being sampled. The worst case scenario is that the angular distribution is altered and the system has an astigmatism which will render much of the cross track wind data unhelpful. At this point the concept of these detrimental effects is conjecture, but a useful discussion point for future iterations of testing.

C. Three Dimensional Energy SDEA Model

Simply saying that a three dimensional model needs to be generated is a bit of an understatement because the effects of the geometry around the whole system must be modeled and sensitivities confirmed again. There may be coorelation to the two dimensional cases however the least understood and most likely to be effected edge cases are the interesting parameters to capture. For instance the three dimensional geometry may give rise to a SDEA factor that is a function of geometry. Moving to a more representative model will also provide the added benefit of analytically verifying the field of fiew for both the cross-track and radial solid angles. This is difficult to do in an experimental setup since the system would require the instrument and ion source for testing to be independently mounted and adjustable. This type of model will not be devoid of a validation source since resolution and performance parameters are available from experimental results at GSFC in 2008-2009.

Conclusions

This analysis of the DANDE WTS instrument shows that the software package SIMION and understanding the geometries of the key elements in the energy selection of the desired species can be modeled and to such a degree that agreement between previously accepted results and more importantly empirical test data. Here the resolution of the SDEA has been presented in a form that traces the largest source of error to the ambiguity observed in the pass band of the selected ions. Since the simulated SDEA scenario was of a single ion energy as a collimated beam into the chamber, but across a wide band of SDEA voltages the ions would be passed that width can be translated into a energy band. At present in the region of 4eV that band is 0.3eV wide before the simulated energy is effectively attenuated. Consistent with testing at GSFC of the actual instrument the cutoff of the pass band is sharp which means that the proximity of resolved energies can be made at fractional energy steps. This also presents the first area that warrents more investigation of how to most effectively control the pass band either through geometric changes in the SDEA chamber related the the position of the apertures, or tailor the exit aperture to be more narrow in design reducing the area where ions can be selected.

In terms of forward looking progress of the instrument design and the modeling involved the key performance metric know as the SDEA plate factor has been shown to effectively and accurately modeled with the simplified two dimensional model, this parameter has been shown to be controllable by tailoring the the SDEA physical geometry. Packaging the instrument in the future will likely have profound effects on the geometry of the SDEA and ultimately its selectivity of ions passing through. Understanding that the length and heigh effect the observed SDEA factor independently now will identify this as a key to future iterations and simulation prior to vacuum chamber testing. The plate factor has a profound effect on the resolution of the supporting electronics since a higher value will require a higher resolution ramp to make fractional energy measurements. The higher the resolution of the SDEA deflector ramp, or the total number of steps taken in the cycle from 0 to 4096mV, will ultimately produce more data which may not be desirable or even possible for a given system bus infrastructure. Looking forward these concepts of how different physical scenarios effect the resolution of the instrument must be integrated with the next steps in characterizing the instrument from a simulation level. This will help predict the output of the instrument once on orbit with the DANDE spacecraft and the data products of future instruments coming to fruition.

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