

Preventing Foreign Object Damage of Jet Engines with a New Engine Intake

Elizabeth Godfrey

I was looking for a new area of research as I finished up 9th grade. Like everyone's freshman year, it was challenging, but in my case it was also fortunately marked by my success with my science fair project. That year I conducted a music physics study on how the climate conditions to which musical instruments are exposed impact the sound they produce. I knew my teachers were expecting another year of research from me, and I was pretty hooked on the learning and the competition that are part of the science fair world, but I wanted to investigate something very different. I knew I had to find a new area of research.

My inspiration came at breakfast one day, when CNN switched to a story about the Icelandic volcanic eruption that had grounded air traffic across Europe (due to the abrasive, potentially explosion-causing action that debris has in engines). My immediate thought was, "Someone should fix that."

It took me only a moment to decide that I was going to be that person—that I should invent a device to prevent foreign object damage of jets. It made sense that I be the one, because my background and skills—my exposure to math, my childhood as a daughter of the airline industry, and my love of science—were in alignment to spawn such a project. To begin with, I have always loved math—the side effect of being raised by a math teacher mother. I remember being given napkins in the car that had triangles drawn on them, with only one angle written in degrees and the others in variables. My road-trip entertainment/assignment was to solve for the other angles.

My appreciation of aircraft and interest in air safety were also more bred-in than cultivated. My father has flown planes my entire life, first in the military as a B-52 pilot and

later commercially for American Eagle, and brought home stories about his experiences with aircraft and the industry. He has tangled with birds in the engine, walked runways to check for foreign objects, and watched jets inhale snow and ice on cold mornings on the runway.

Finally, I have always enjoyed science, because I'm endlessly curious and science is the way to get answers. My inclination to solve problems using physics was something that I developed myself. It started in earnest during a childhood visit to Kennedy Space Center, in the gift shop of which I bought a "Space Science" textbook. I settled in to read it, preparing to skip over the propulsion section, full as it was with equations and physics laws. But then I read the first page on propulsion. Then I read the second. Before I knew it, I was hunched over equations, decoding variables and trying to explain how Newton's laws worked. That was my inauguration into the hard sciences, and it launched a life of reading physics books about airfoils, thrust and lift, and fluid dynamics.

So when I asked myself, "How do I create something to protect an aircraft engine?" I had a few tools in the toolbox. I knew it had to be simple and stationary; my father's stories and experiences in the airline industry taught me that anything on an airplane that can move can break, either becoming a hazard or an extra maintenance cost. I knew I wanted it to prevent at least 70% of objects from entering an engine—a random number, but no studies have clearly delineated how much debris is too much for an airplane to take. Finally, I knew from my rudimentary knowledge of fluid mechanics that my goal could be accomplished fairly simply, by creating a kind of obstacle course of fluid flow that solid material couldn't navigate.

However, there were still things I had to learn to accomplish this goal. When I say "rudimentary" to describe my fluid mechanics knowledge, I mean exactly that. I knew very little of the actual math involved, and I had a grasp of the principles without being quite sure

how they could be applied. Instead of trying to learn the basic math and then apply it, I approached my study from the other side. I studied application first, by researching devices that are used to separate contaminants from natural gas and oil, to purify water, and, in vacuum cleaners, to leave dirt in one place while allowing air to bypass it. Then I reviewed in simple basic texts how airspeed differentially affects materials of different density, since my goal was to remove denser materials like debris. I also had to study about how research is done on flying vehicles to test for air flow, and how wind tunnels are built—and then I had to figure out how to do these things in real life.

While I hope to gain something material one day out of my inventiveness, I am most proud of the learning that it has already earned me and the perseverance and creativity it taught me. In terms of learning, I know wind tunnels inside and out; my experience building them taught me a huge amount about tinkering and perseverance in science, so now I recall my study every time I see a wind tunnel—or vacuum cleaner, or anything that moves air quickly. I think about the principles of fluid dynamics and how aircraft engines work every time I see a news story on engine failures and foreign object damage. It has made these principles in science real; they are part of my everyday life, and they always will be. More practical lessons include rewiring parts of my wind tunnel; designing particulate debris delivery methods to test the prototypes; somehow measuring whether the prototypes were removing debris and how much; and doing it all in a household setting and budget.

While one important lesson I would share with aspiring scientists is that they should choose fields of inquiry that are close to their interests and skills, it's not the most important. Anyone who embarks on this kind of study—or any other—should be prepared to put in long hours, sometimes doing a lot of thinking, but a lot of times just doing grunt work like building,

rebuilding, and repairing equipment. Science isn't just about magicians in an ivory tower; it is also about mechanics or tinkerers, the people who stay up all night to do a job, and often they are the same people, or otherwise experiments would never be completed. The most valuable lesson I have found for aspiring scientists to learn is that the only way they can succeed is to roll up their sleeves and get their hands dirty.

Now the topic must turn to the study that I performed over two years, from 2010 to 2012.

Problem

The problem of study and the goals have already been introduced—I wanted to create a device to prevent debris ingestion by jet engines, and I had certain criteria for the device's success, including a 70% debris removal rate, a stationary design, and adequate air flow.

Background

I always am asked whether foreign object damage, FOD, is really that major a problem, because most people have seen a few news reports on jets crash-landing after bird strikes or other major accidents, but they don't know that thousands of these incidents, albeit more minor, happen yearly. Not only by number, but by cost, it clearly *is* a major problem in aviation. Boeing estimates a minimum yearly cost, barring any disasters like the 1.7 billion dollar Icelandic volcanic eruption, of at least 4 billion dollars a year from FOD.

Before embarking on my study, I had to be sure that there were no completely commercially viable solutions already in existence. This problem has been addressed by a handful of patented designs, but all have some problem that prevents their useful application to commercial aircraft. The military sometimes uses filters to protect engines in high-risk environments, but this method requires frequent cleaning and maintenance of the filter or

clogging will result; other methods use an active method, like moving cuffs (Sankrithi 1,2) or nets to capture incoming birds (Chambers 1), both of which require maintenance on the device itself and have limited utility. One of the most significant FOD prevention methods is a two-channeled inlet for helicopters, one of which carries away particulate-heavy air and the other of which carries “clean air” to the engine, but this is not completely effective, and engines utilizing this method require extensive and frequent overhauling to repair FOD (Hartman 5). It was thus determined that there is still significant room for improvement in this field.

Procedures and Results

Phase One

The first phase of the study, after preliminary research, involved designing a basic intake shape to obstruct movement of solid debris, but not air, and testing to verify the intakes’ performance. Cylindrical intakes were designed; they were chosen because of the general conceptual idea that the end device would match the front of a jet engine. These intakes were designed with differing inserts and internal structures intended to create streams of slow- and fast-moving air, which would differentially direct the debris to the slow stream because denser debris cannot move as quickly. Then the prototypes were constructed of household materials—cardboard tubes and disposable dishware, bonded by hot glue, or modeling clay and aluminum foil.

Testing of each phase one model was achieved by placing a utility vacuum nozzle in the exit vent of the intake and turning it on. Qualitative observations of where the air entered the intake were taken, and then thirty grams of flour (as a sample particulate) was directed into the front of the intake to determine if any separation occurred. If some of the flour was not immediately sucked into the vacuum hose, a cloth was laid out underneath the intake prototype and 30 grams of three types of particulate (flour, canning salt, and dragees—basically sugar

ball-bearings—to test a range of particulate sizes) was directed through the model. After each particulate type was directed through the model, the vacuum was turned off and the cloth weighed to determine how much particulate was ejected. The components of testing were cleaned and the cloth weighed again to check for any residual presence of particulate. Ten tests were carried out in this fashion for each model and particulate type.

The first design plan was to use centrifugal inertial separation to force denser debris outward from the faster central air stream. Intake A had a side particulate vent and contained a center post around which three fins twist. Intake B had two rows of longitudinal vents and contained an aluminum foil helix to cause air to spin. The intake interiors from the previous models were also swapped between the two to create two more functional prototypes. None of these designs showed any promise, because air was ingested from the wrong directions and all the particulate was sucked up by the vacuum.

Several intermediary designs were tested on a small scale, and all failed. This took several weeks, and I became concerned that I would not find a design that accomplished anything. But then an idea occurred to me—if I could force air through something like a maze, perhaps it could turn corners that debris could not. The next method aimed to force incoming air through multiple sharp turns that would be allow debris instead to exit the intake.

Intake C was a cardboard tube with transverse cross-sectional plates, or baffles, running down the length of the tube. The baffles left room for exit vents, so that when air was forced to change direction in quick succession, the particulate could be thrown out. The first particulate type, flour, was tested, and 90% of flour was removed. At first I thought the design was working, but then I realized no air was moving through the device, because it was clogged. I stopped testing and immediately looked for a solution.

Intake D used the same concept but had diagonal (slanted) baffling instead of horizontal, to make it easier for the particulate to escape rather than clog the device. I noted less clogging than with Intake C, but after testing, I wanted to add include enlarged, curved vents to promote the exit of the particulate. A mean total flour removal of 14 grams was observed, or about 48%. With salt, the average particulate removal was 29 grams or 97%. Results for large particulate (dragees) were the same.

To improve further upon D, Intake E was constructed in a similar fashion, but the baffles slits were scoop-shaped to facilitate drainage of particulate from the tube. The mean flour removal was 20 grams, or 67% of introduced particulate. With salt, the average removal was 28 grams or 99%. Results for dragees were the same. These results were obviously very promising, and almost fulfill the goals originally set; however, another obstacle appeared at this point—the intakes' dimensions.

The intakes were unreasonably long per their width, all at roughly 25 centimeters in length and 5 centimeters in width. A fifty-foot long intake could never be placed on an actual jet engine! The next goal of design was to decrease the length of the intakes. Based on this goal, Intake F was constructed of a tube that was proportionally shorter, and more shallow baffles were used that each filled in a third of the airstream, each offset by a 120 degree arc.

At the same time, Intake G was constructed using the same design as F, with the same diameter as intakes A through E. Use of a tube with diameter similar to the other tests served as a control, to determine if it was the tube diameter or design that changed filtration potential and to ensure that the trials were more controlled.

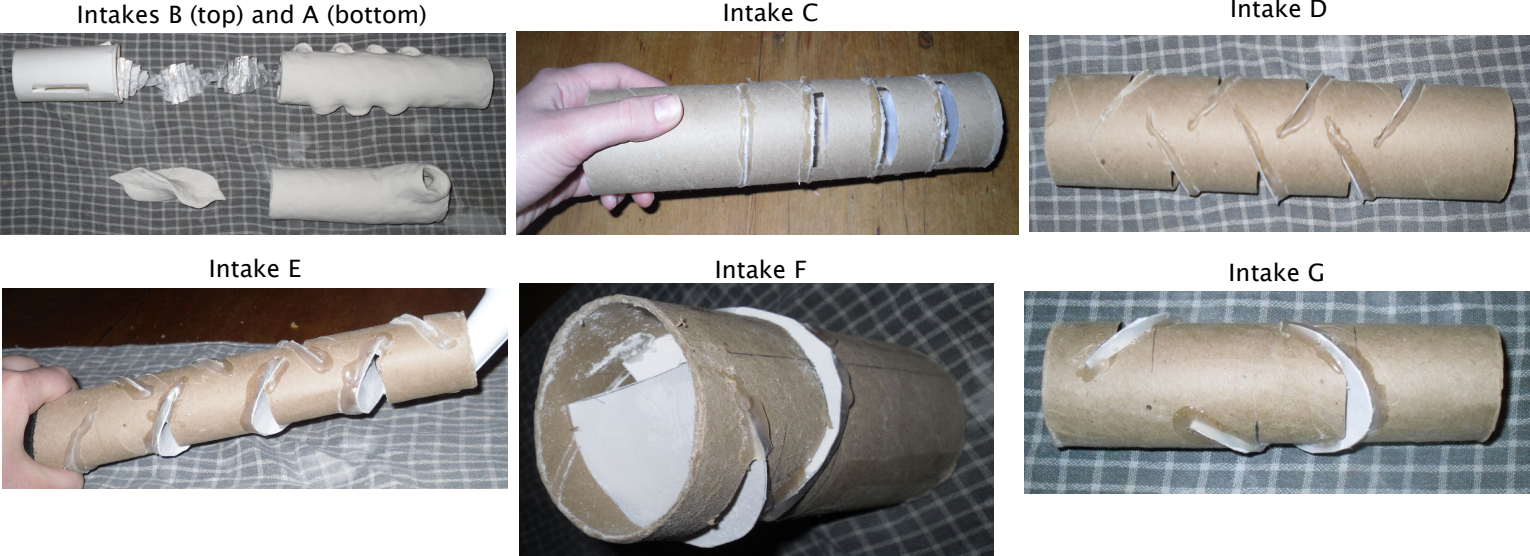
Intake F seemed to exhibit better air flow, judging subjectively. But it did not prevent particulate ingestoin. There was only an average particulate removal of 11 grams, or 37% of

total particulate present. Salt was much better, with a removal of 50% of total particulate. In the dragees trial, there was 67% removal. G was not better; its total flour removal was a mean 8 grams, or 27% of the total flour present. Salt and dragees showed a removal percentage of 67%.

This concluded phase one of testing. I could draw several important conclusions. First, a centrifugal spinner design was shown ineffective, either because of faulty fabrication or because this design only works in moving configurations or at lower speeds for the scale. Also ineffective was a transverse-baffle design of intake C, probably because the open space through which air is pulled had turns too sharp for even air to move easily, so particulate clumped and blocked the air stream. Phase one also ruled out three baffles in a spiraling pattern in Intakes F and G. The reason that little flour was filtered out of this design is that the baffles produced an open space for air to flow that had turns too smooth to force out particulate.

However, in Intake D, the slant of the baffles allowed flour to exit without forming a blockage. Intake E was even more effective; scooping the baffles provided a larger exit vent for the flour without bringing the opening of the vent closer to the top of the baffle, which would have allowed air to curve around the baffle and be pulled through the exit vent to the

Figure 1: Phase One Intake Prototypes



vacuum. The final intake design that went to phase two was cylindrical with diagonal, slanted, scoop-shaped baffles that were on opposite sides.

Phase Two

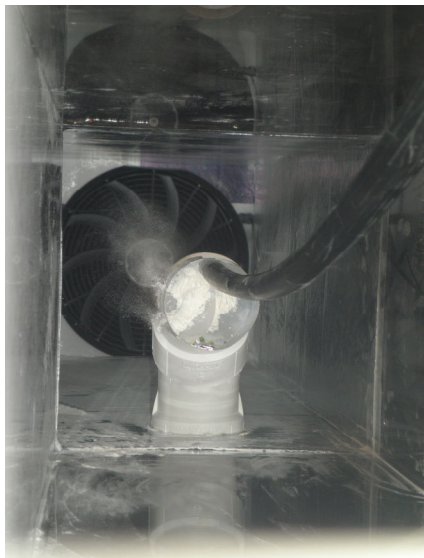
In phase two of testing, I took this final specialized design and did more refined testing. I wanted to check the air flow interruption my prototypes created, because any device that kept air from going through an engine would be completely useless. The prototypes in phase two had differing identifying characteristics like baffle angles (20, 40, and 60 degrees from the horizontal plane of the cylinder in testing) and intake body proportion (4-to-1, 3-to-1, 2-to-1, 3-to-2, and 4-to-3 length to diameter ratio). They were constructed of metal and plastic bonded with silicone adhesive.

I then built a wind tunnel to test the particulate removal and air flow interruption of the prototypes in a realistic environment. It was constructed from basic designs and measurements given by plans on Science Buddies, but modified to fit the experiment, especially by making an easy-access testing section with a door and changing all materials and drive components—a high-powered fan was used to provide the air flow. An apparatus to hold the intakes in place and substitute as a jet engine was constructed out of 3 PVC piping with joints, which joined with the bottom of the drive (back) section and then turned ninety degrees so that the pipe opening faced the front of the wind tunnel. The utility vacuum from phase one was sealed into this apparatus using metallic electrical tape through two adapters to the apparatus to pull air through the intake for testing as a substitute jet engine. (All of this was built in my garage, where it was observed by the neighbors with glee and fascination.)

Figure 2 from left: 4-to-1, 3-to-1, 2-to-1, 3-to-2, 4-to-3, 20°, 40°, and 60°



Figure 3: Particulate being introduced in phase two



For testing of particulate removal, each model was seated in the PVC apparatus with as little of the intake body inserted as possible that could still hold it in place. A coffee filter was kept in the joint of the PVC apparatus to catch ingested “particulate” for it to be measured. Then the wind tunnel fan and the vacuum were turned on

and a black rubber irrigation tube was used to deliver particulate to the model. Twenty grams of flour, the smallest particulate in phase one and the hardest to remove, was used for this test. Once complete, the vacuum was turned off, the filter removed and weighed again, the weight before and after the particulate introduction recorded, and the intake cleaned. This process was repeated for all intakes for twenty trials.

For testing of air flow efficiency (air speed as a percentage of the air speed produced without an intake present), a handheld anemometer was sealed into the PVC apparatus at the second joint of its joining to the vacuum tube when the fan and vacuum were operating. I took readings of wind speed without any intakes. Then each intake model was seated inside the PVC apparatus as in the particulate removal tests and the vacuum and fan were turned on; the resultant air speed was recorded for twenty trials for each intake.

Percent removal was determined simply by calculating how much particulate was removed in each test, averaging for all trials, and then dividing by the input amount. The first intake tested was the 4-to-1 proportion intake. Overall, 89.5% of particulate was removed by this intake. The next intake was the one with a proportion of 3-to-1. Particulate removal averaged 93.5%. The 2-to-1 proportion intake exhibited an average particulate removal of 91.3%. The intake with a 3-to-2 proportion had a particulate removal rating at 88.5%. The 4-to-3 proportion intake exhibited a particulate removal of 89.3%. Of the angled baffle tests, the 20 degree intake exhibited a mean removal percentage of 85.8%. The 40 degree intake removed more particulate; it showed 88.8% particulate removal. Finally, the 60 degree intake averaged a removal rate of 91.0%.

All of these results were very exciting, because they showed even better particulate removal than in the first stage of testing. Removal rates in the 90s were much higher than I ever expected to obtain; despite the tedium of the tests and data analysis, this success helped encourage me to continue.

To assess intake particulate removal consistency, I looked at standard deviation for each set of trials. (I discuss how I calculated that towards the conclusion.) The standard deviation in proportion tests was just over one for the 4-to-1 ratio, decreased to the 2-to-1 ratio, and then proceeded to increase again. The 2-to-1 ratio had a standard deviation of .44, while the 3-to-1 had a standard deviation of .57. All of these standard deviation measures show

relatively low variability in the data. The baffle angle tests began with greater than one standard deviation at the shallow angle and then decreased.

The next phase of data collection was the air speed experimentation. The mean air speed in the intake port without an intake present was 20.83 knots. The 4-to-1 intake exhibited a mean air speed of 19.89 knots, or 95.49% of the original air speed. The 3-to-1 intake exhibited an air speed mean of 17.51 knots, 84.04% of the original air speed. The 2-to-1 intake’s air speed average was 19.43 knots, or 93.25% of the original air speed. The 3-to-2 intake’s mean air speed was 18.91 knots, or 90.78% of the original air speed. Finally, the 4-to-3 intake exhibited a mean air speed of 18.04 knots. This is 86.58% of the air speed without an intake.

The baffle-angle tests followed, and they were done in much the same fashion. The 20 degree test showed an average air speed was 20.09 knots, or 96.42% of the speed without any intake. The 40 degree test showed a mean of 20.00 knots, or 96.02% of the original air speed. The 60 degree test showed a mean air speed of 18.90 knots. This corresponds to 90.71% of the original air speed.

In summation, the 3-to-1 and 2-to-1 proportion intakes had roughly comparable particulate removal potential; the 3-to-1 had a slight edge in removal, but the 2-to-1 removal data showed a lower standard deviation and thus it was a somewhat more consistent intake. The steeper the angle of the baffles in angled tests, the greater the particulate removal. In air speed comparison, the 3-to-1 proportion intake showed greatly reduced air speed compared to the most similar intakes, but the general trend showed that the greater the ratio of length to diameter, the higher the air speed obtained. Air speed decreased only very slightly in this test up to 40 degrees, but was markedly lower in the 60 degree test.

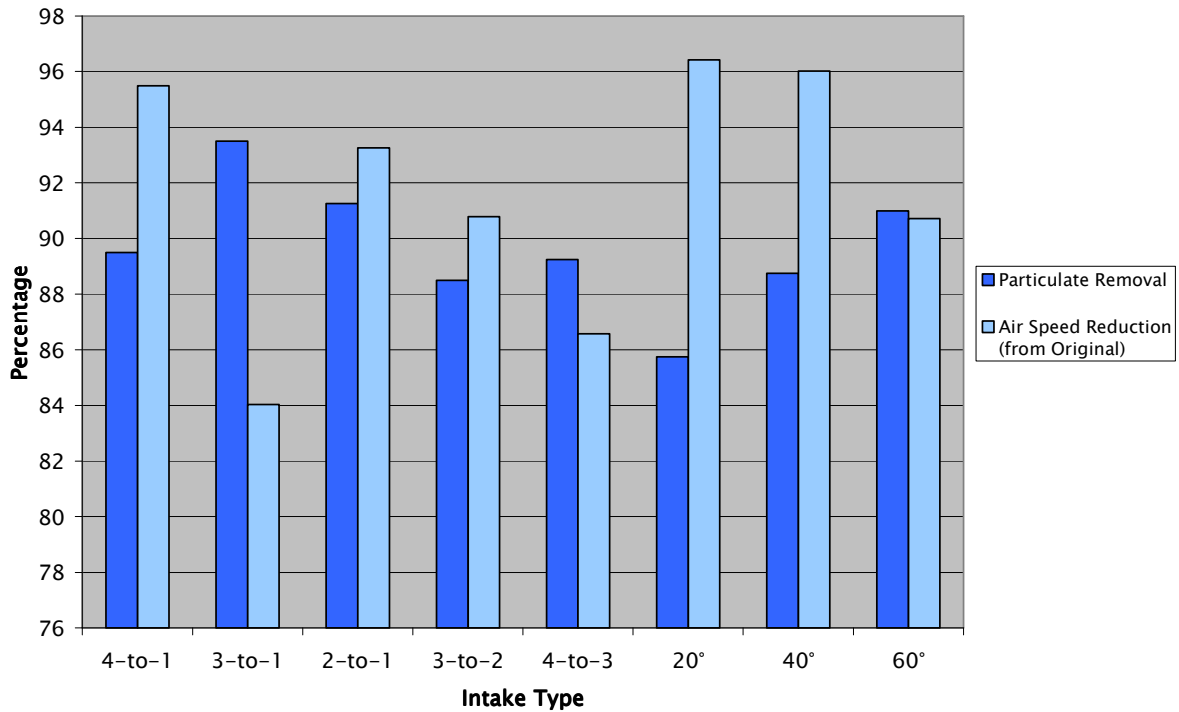
Figure 4: Phase Two Particulate Removal

Intake	Mean Particulate Removal Percentage	Standard Deviation
4-to-1	89.5%	1.07
3-to-1	93.5%	0.57
2-to-1	91.3%	0.44
3-to-2	88.5%	0.47
4-to-3	89.3%	0.59
20°	85.8%	1.14
40°	88.8%	0.85
60°	91.0%	0.62

Figure 5: Phase Two Air Flow Efficiency

Intake	Air Flow Efficiency	Standard Deviation
4-to-1	95.49%	0.58
3-to-1	84.04%	0.16
2-to-1	93.25%	0.17
3-to-2	90.78%	0.13
4-to-3	86.58%	0.21
20°	96.42%	0.18
40°	96.02%	0.24
60°	90.71%	0.16

Figure 6: Phase Two Intake Performance



Since testing consistently returned impressive results of 91.3% to 93.5% particulate removal, the intake design has been demonstrated to be functional and act as intended. Moreover, phase two showed air flow efficiency ratings up to the 96% range, which demonstrates that the design could be applicable to use on aircraft. I had expected appreciably reduced air speed, and was surprised that it did not seem to be highly affected.

Discussion

After phase one produced functional designs, phase two revealed some patterns among intake characteristics. Of all the proportion intake experiments, the 3-to-1 intake was the most effective at removing particulate and the 2-to-1 intake was second most effective, with the latter intake exhibiting a smaller range of ingestion quantities but a higher overall ingestion rate. It appeared that particulate removal was best in mid-range proportions and degraded towards extreme proportions. Data suggest that as baffle angles increase from 20 degrees, so does the particulate removal of the intake.

Though the highest particulate removal percentage is ideal, it is not the only important characteristic of the intake. The consistency of the particulate removal is important; an intake that ingests mostly very little particulate but sometimes all of it is not a very good safety device

for an aircraft, because there would be no way to predict whether it will protect the engines or not on a given day.

I used standard deviation as a loose measure of consistency, because it reflects the variability between trials. The pattern between proportion and consistency appeared to be quadratic; the smallest standard deviation was at the middle proportion test (2-to-1) and increased to either extreme. The 3-to-1 proportion exhibited the highest particulate removal potential, but its dispersion of data was wider than the 2-to-1 intake and it may be thus a less viable intake for an aircraft engine. In the baffle angle tests, the standard deviation decreased as the angle increased, so steeper baffles remove more particulate in a more consistent fashion.

Of the proportion tests, the 4-to-1 intake exhibited the highest air speed efficiency. The air speed efficiency dropped drastically in the 3-to-1 intake, then increased again and continued to steadily drop throughout the remaining intake proportions. Viewing the data except for the 3-to-1 intake very clearly shows that air speed is reduced more (the air speed efficiency decreases) as the intakes become more compact. In comparison of baffle angles, the air speed efficiency decreased minimally between 20 and 40 degrees but then dropped sharply to 60 degrees. Air speed is reduced the least at 20 degrees, where the intake allows air to pass at 96.42% of the original speed, but is so similar to 40 degrees as to be called a negligible difference.

As with particulate removal, the consistency of the intakes is also significant. However, with air speed efficiency, there were no evident patterns between the characteristics of the intakes and the standard deviation of the data. The control standard deviation—the deviation of testing without an intake on the sting to determine normal airflow variation—was actually higher than that of all the varying intake trials. This might indicate that the control had some form of experimental error or that the intakes have a normalizing effect.

Conclusion

To conclude, the engineering goal of simple design was reached with Intakes D and E. The prototypes were very simple, and each consisted of identical baffle shapes in a simple tube. The average particulate removal goal of 70% was reached by far in phase two, which revealed removal rates in the 90s range in small particulate, which is the most difficult to separate. Also in phase two, the final goal of ensuring air speed is not appreciably reduced was achieved.

The second stage of testing also revealed more about the designs and their effectiveness. The air speeds and particulate removal of the successful intakes with differing specifications of length-to-diameter ratio and angle of air flow deflectors (baffles) were evaluated quantitatively and trends evaluated. The main purpose of phase two was to determine whether the design was effective in a wind tunnel that appropriately simulates aircraft use. This purpose was carried out and results show that the design is viable in a wind tunnel, and, by extension, probably at scale at high speeds atmospherically.

Future Expansion

This current model does not seem to promise easy installation or incorporation into an aircraft, so the concept should be reconfigured into a shape more compatible with aircraft use. Also, at conferences presenting this concept, audiences suggested that the debris separation action of the device already is usable for such purposes as protecting compressors in canning plants, and other industrial machinery. Those avenues need to be investigated as well for efficiency and potential areas of improvement.

I also suspect that air speed may not be the best measure of air flow; I was unable to find a scale barometer to use at the time of experimentation, but air pressure needs to be tested for a more reliable picture of air flow impact.

Math in this Study

I used mostly simple mathematics, like means and ranges; the most complex mathematical operations used as presented here were calculations of standard deviation. To calculate standard deviation, the mean for a data set (i.e., the average particulate removal percentage across all trials for an intake) was determined, then for each trial, the difference between the actual value returned in that trial and the mean was squared. This number was then averaged for all trials and finally the square root was taken. The standard deviation tells how far from the mean the values range in a normally distributed data set; this is a valuable number because it shows how tight the data is—how typically self-consistent the data set is. This in turn can be used to extrapolate how valid the data is, although in this case data was so overwhelmingly consistent within each data set and so distinct between intakes and from the control that determining p-values was deemed unnecessary.

There are some mathematically complex procedures that still need to be performed as the study goes forward. Ruark numbers (numbers assessing flow drop through, say, an

obstruction) and Reynolds numbers (they characterize flow as laminar or turbulent) are numbers used in the field of fluid dynamics to characterize air flow; they need to be calculated to characterize the intakes. The devices should also be modeled in computer modeling interfaces to study their performance and test modifications, a math-intensive operation.

References

Bachtel, Brad. "Foreign Object Debris and Damage Prevention." *Aero Magazine. Boeing*. Web. Feb. 18, '12. <http://www.boeing.com/commercial/aeromagazine/aero_01/textonly/s01txt.html>

Ed. Benson, Tom. "Turbojet Engine." National Aeronautics and Space Administration. *FirstGov*. 13 September 2010. Web. 4 October 2010. <<http://www.grc.nasa.gov/WWW/K-12/airplane/aturbj.html>>

Binder, Raymond Charles. *Fluid Mechanics*. 5 ed. Alexandria, VA: Prentice Hall, 1973. Print.

"Filtration Facts." Lakos Separators and Filtration Systems. *Claude Laval Corporation*. 2010. Web. 21 December 2010. <<http://blog.lakos.com/?Tag=centrifugal%20separators>>

"How to Build and Use a Subsonic Wind Tunnel." Science Buddies. *Science Buddies*. 2002. Web. June—September 2011. <<http://www.sciencebuddies.org/science-fair-projects/wind-tunnel-toc.shtml>>.

NPR Staff and Wires. "Europe's Skies Start to Fill with Planes, not Ash." NPR. *NPR*. 21 April 2010. Web. 2 Mar 2011.

"Peerless Centrifugal Separators." Peerless Europe. *Peerless Europe Limited*. 2010. Web. 21 December 2010. <<http://www.peerlesseurope.com/Centrifugal%20Separator%20Tech-Spec.pdf>>

Chambers, David S., et al. "Apparatuses and methods for preventing foreign object damage to aircraft engines." U.S. Patent and Trademark Office. *U.S. Department of Commerce*. 25 January 2005. Web. 23 September 2012.

Groom, Alec R., et al. "Intake duct." U.S. Patent and Trademark Office. *U.S. Department of Commerce*. 21 December 2010. Web. 23 September 2012.

Hartman, Peter A., et al. "Engine Inlet Air Particle Separator with Active Flow Control." U.S. Patent and Trademark Office. *U.S. Department of Commerce*. 20 November 2007. Web. 23 September 2012.

Klujber, Frank. "Foreign matter diverter systems for turbofan engines." U.S. Patent and Trademark Office. *U.S. Department of Commerce*. 11 July 1995. Web. 23 September 2012.

Sankrithi, Mithra, and Paul E. Nelson. "Rotatable scarf inlet for an aircraft engine and method of using the same." U.S. Patent and Trademark Office. *U.S. Department of Commerce*. 20 July 2004. Web. 23 September 2012.