Old Time of New Time

The Art and Physics of Contrails:

Project 5: Clouds #2

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Origins

Old Time of New Time is the result of the fifth project, called Clouds #2, for the Flow Visualization class at the University of Colorado at Boulder. The goal of the image is to demonstrate the beauty that can exist in a man-made cloud. Capturing a wide, clear (undisipated) contrail allows for a very forward presentation in a final image, and having light layering of clouds in the rest of the sky allows for a wider overall pallet. The post processing for the original photograph resulting in a brown scale black and white similar to old time photos which have aged, and a near painted effect on the overall image. The goal of these changes was to help draw attention to the image and focus the eye on the contrail as opposed to a brilliant blue sky. The image title is meant to simply play on the fact that the final image is of a relatively recently occurring and understood phenomenon, but the color pallet and style hint to an earlier time in human history.

Photograph Circumstances

The original photograph was taken from the top of the parking structure adjacent to the Engineering Center at the University of Colorado in Boulder. Seeing the cloud formations occurring at the edge of the approaching front, a fellow Flow Visualization student and I ran to the top of the parking structure and began taking several photos. On a few occasions over an hour time frame contrails were formed overhead allowing for opportunities to capture this curiosity of flight. The photo was taken facing practically directly upward. The photo was taken on March 11, 2013 at 1543 MST.

Cloud Discussion and Cloud Physics

The clouds in the background of the photograph are most likely altostratus clouds, and contribute to the diagonal shading effect present in the background of the final image. These are definitely of the stratus family due to the long, flat, sheet like appearance and probably of the alto designation due to their less dense appearance and higher altitude, but their lack of wispy appearance and presence of some weight keeps them from being a cirrostratus. The atmosphere was quite possibly unstable in the lower regions and more stable in the upper regions, which would explain the formation of these altostratus clouds as well as the low level cumulous and stratocumulus which were present elsewhere in the sky. This can be seen only slightly in the skew-T diagram for that evening, Figure 1, but this is likely due to the arrival of a front during the time frame in which the photograph was taken. Since the front came from the direction of Denver, where the measurements are taken, it is likely that this diagram is only a ghost of what the atmosphere was like in Boulder at the time.

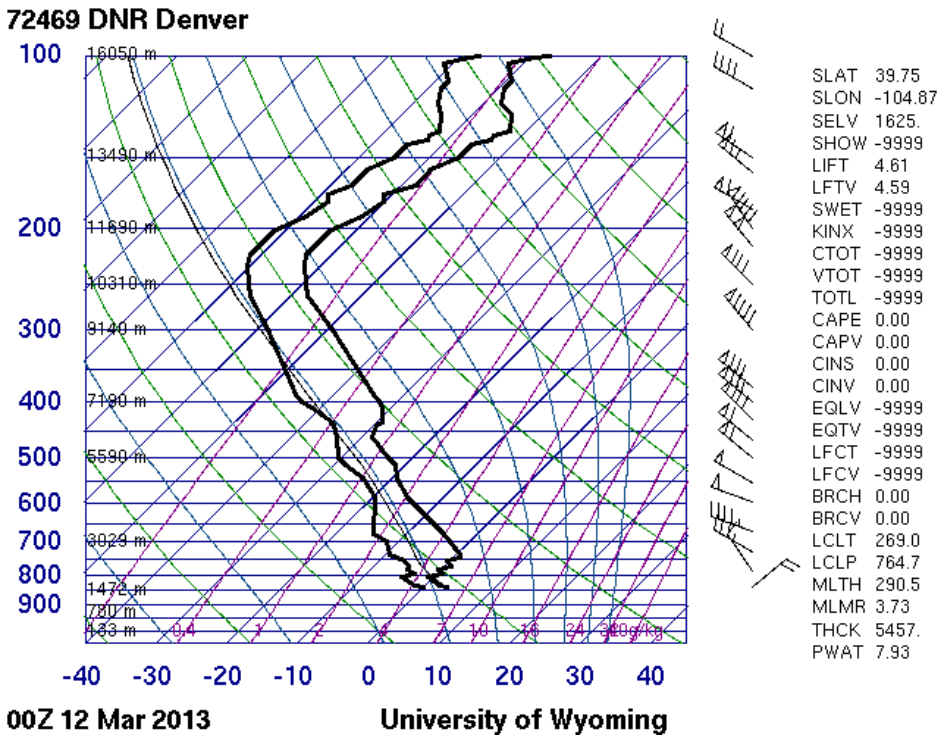

Figure 1: Skew-T diagram for Denver from within a couple hours of photographs being taken. [72469]

The main focus of the image however is the contrail. These man-made clouds can only form at altitudes where the ambient temperature is below 40° C. As the skew-T diagram in Figure 1 shows, this occurs around an elevation of 8000 m, which is considered normal. There are primarily three types of contrails: short-lived, persistent, and persistent spreading. Short lived contrails only exist for a short distance following the aircraft causing its creation before sublimating away. Persistent (non-spreading) contrails can last for a period of time after their creator has moved on, but only linger for a longer period of time and do not grow in size. Persistent spreading contrails however do grow and have the potential to last for even longer. Persistent spreading contrails can even develop into full grown, natural looking cirrus clouds. The contrail captured here is of this third type, persistent spreading. The easiest way to gauge this in a short period of time is to compare the width to a finger width held at arm's length, and if the contrail is wider then it is likely spreading. In the case of this contrail, I was also around for long enough to watch it grow in size over the course of about half an hour.

Contrails are very curios byproducts of the jet age. First discovered in the 1919 with the start of high-altitude flying, contrails remained just that, a curiosity. It was not until World War II that they became something worth serious study. It was noted that bombers could be spotted miles away due to their contrails, and large contrail formations had a tendency to mess with navigation and target spotting. There were even a few midair collisions due to these massive contrail formations. It was several years before the physics behind contrail formation was completely understood, but in 1953 an American scientist, H. Appleman, published a chart which successfully predicted when contrails would form. This chart has formed the basis of contrail-forecasting methods used by the U.S. Air Force until just recently [Contrail Science].

The formation of contrails is the culmination of several phenomena from combustion to water condensation. The burning of jet fuel produces several by products; in fact there are more byproducts by mass than there is initial jet fuel due to the inclusion of atmospheric oxygen during the combustion process. Aside from CO_2, the greatest constituent is water vapor followed by several aerosols. The water vapor and aerosols act as nucleation sites for moisture present in the air, often super-cooled water vapor, to begin condensing and freezing into the tiny water droplets and ice crystals which makeup clouds. This means that it is not the exhaust itself that comprises the majority of the contrail, but instead the moisture from the surrounding atmosphere, which allows for contrails to vary in size, length, and even grow into giant cirrus clouds depending on the conditions of the surrounding air. Figure 2 below begins to demonstrate how the atmospheric conditions determine if contrail formation takes place and what type of contrail is formed.

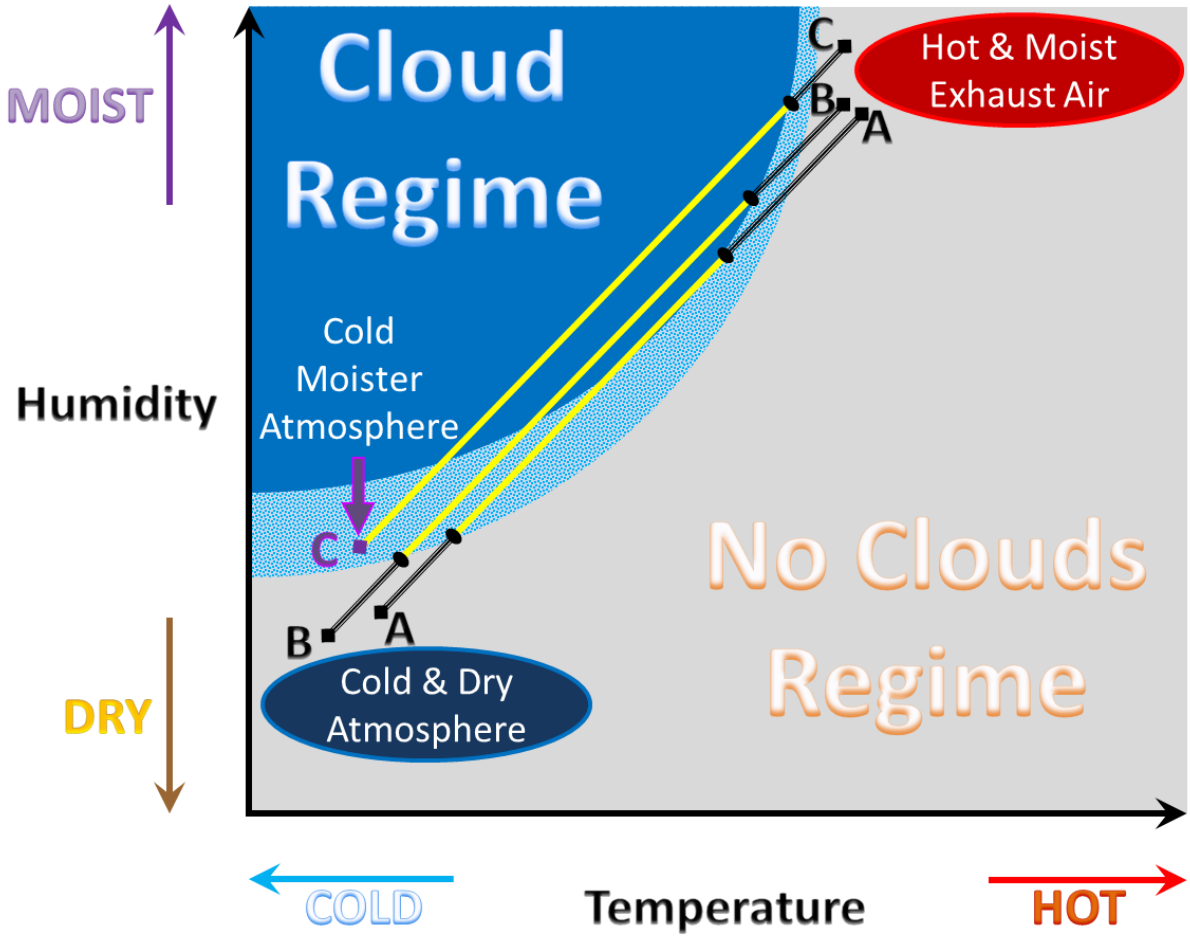

Figure 2: Lines A, B, and C connect the thermodynamic state of the exhaust to that of the surrounding atmosphere (both marked with squares). There exists a thermodynamic region where clouds form and a buffer zone where they can exist prior to disappearing. The ovals mark when formation occurs and then when a contrail should dissipate. Line A represents a short lived contrail, line B represents a persistent contrail, and line C represents a persistent spreading contrail.

In Figure 2, the three plotted lines connect the thermodynamic state of the engine exhaust to that of the surrounding atmosphere. The region in which water will condense into droplets and eventually freeze into tiny ice crystals is marked by the 'Cloud Regime.' There exists a buffer region between this regime and that in which clouds cannot exist. It is here that water droplets evaporate and ice crystals remain. Note that leaving this regime results in sublimation of the ice directly into water vapor, however the reverse process cannot happen in the atmosphere. If a line plotted on such a thermodynamic graph barely kisses the Cloud Regime, such as line A, then a short lived contrail will be formed by the exhaust producing aircraft. If a line passes further into the Cloud Regime, but still exits the buffer zone on the other side like line B, then a persistent (non-spreading) contrail will be formed. Finally, should the atmosphere be moist enough that such a line can pass into the Cloud Regime and terminate before exiting the buffer zone then a persistent spreading contrail will be formed [Contrail Identification]. This means that the atmosphere around the contrail in the image must have been relatively moist, which is entirely possible since it formed near the edge of an approaching cold front.

Because contrails are essentially clouds, despite being man-made, they behave in the same way that other clouds do. They can, and do, move with the air flow in their vicinity. This can result in very significant movement from their formation location since most contrails are formed at high enough elevations to see extremely high wind speeds. This also means that they interact with light and other EM radiation in the same way as natural clouds, which amounts to both reflecting solar radiation back into the exosphere as well as trapping the geothermal radiation and reflected radiation from the earth's surface. This aspect of contrails, particularly persistent spreading contrails, concerns environmental scientists because it has the potential to alter the difference between daytime and nighttime temperatures, making the days cooler and the nights warmer. In fact a study done during the three days following the 9/11 disaster, when planes were grounded nationwide, noted a greater day-night temperature difference of close to two degrees Fahrenheit. Other concerns include potentially contributing to long term climate change due to these effects on the day-night temperature shift, as well as due to the alterations in the water vapor levels in the upper atmosphere resulting from the forced cloud formation [Tyson].

Photographic Technique

The camera used was a Canon Power Shot SX 500 IS. A high shutter speed was necessary due to the fact that it fairly bright out and the clouds were moving fairly quickly. For this reason a shutter speed of $1/500$ sec was used. In order to achieve the desired depth of field and help control the light levels, an f-stop of 8.0 was used. Since plenty of light was not a concern, an ISO of 100 was able to be used, producing the best possible clarity. A list of all pertinent photo information, including settings and image sizes is found in the appendix.

Photoshop was used to manipulate the photo in order to produce the desired color scale and old timey feel. The only adjustment made was a single curves application to partially invert the colors into the desired color set. The curve used is shown in Figure 3 below. Aside from this, there were no other adjustments made to the original image, not even cropping.

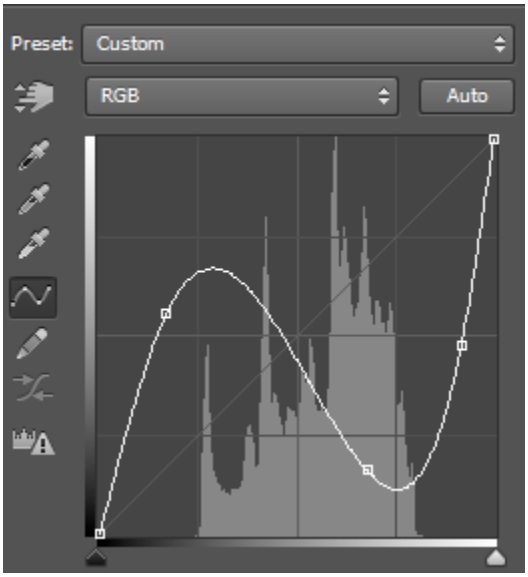

Figure 3: Curves diagram for the color alteration resulting in the final image.

Discussion

To me the image reveals the beauty and complexity of the everyday contrail. The color modification helps to bring out detail that is otherwise lost or washed out which helps to make the contrail even more impressive. The image makes me want to lie out and watch contrails form at an airport all day. And learning more about contrails has made me more curious about their formation and growth processes. And so even though my initial intent was fulfilled, I would like to attempt a series of photos capturing the growth of one of these persistent spreading contrails and possibly even a time lapse. I think that much more could be done with these curious byproducts of the jet era and much more could be and is yet to be revealed.

References

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Appendix

Photographic Information

Photograph Date and Time	**11 March, 2013 at 15:43**
Camera Type	**Canon PowerShot SX500 IS**
Shutter Speed	**1/500 sec**
Aperture	**f/8.0**
ISO Setting	**100**
Lens Focal Length	**39.0 mm**
Distance from Lens to Contrail	**~8,000 m**
Field of View	**Approximately: 4,000 m x 2,250 m**
Original Image Size	**4608 x 2592 pixels**
Final Image Size	**4608 x 2592 pixels**

Original Image