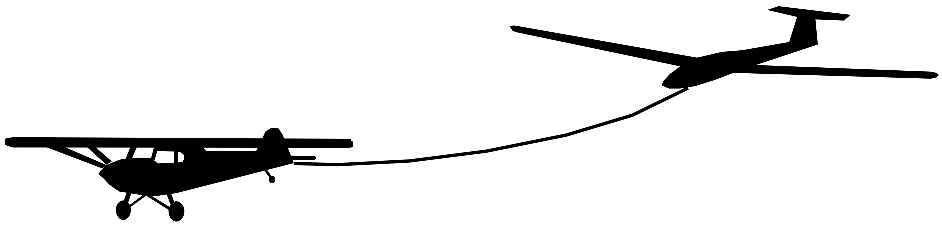
# SAILPLANE/TOWPLANE AEROTOW AND GLIDE PERFORMANCE EVALUATION

USAFA/DFAN

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**June 1994**


**PRELIMINARY REPORT OF RESULTS**




**DEPARTMENT OF AERONAUTICS**
**USAF ACADEMY**
**UNITED STATES AIR FORCE**

This Preliminary Report of Results (Sailplane/Towplane Aerotow and Glide Performance Evaluation) was submitted by the Department of Aeronautics, United States Air Force Academy, Colorado, 80840-6222.

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## Introduction

Purpose

- 10,000 feet Density Altitude Restriction
- 200 feet AGL 1 nm Past Departure End of Runway
- Determine Validity, Recommend Operational Changes

Scope

- 20 May to 24 June 1994
- 7 Towplane Only Flights
- 9 2-33 Aerotow/Glide Flights
- 251 2-33 Takeoffs, 10 ASK-21 Takeoffs, 1 1-26 Takeoffs Observed

Test Aircraft

- Towplane:  N5043N
- Sailplane:  N5579S
- Production Representative
- Load Cell, OAT Gauge, Manifold Pressure Gauge

Test Operations

- 12,000 feet Pressure Altitude Maximum
- Sailplane 8000 feet Pressure Altitude Minimum
- Day VFR
- Smooth Air
- All Flight Manual Limits and Local Operating Limits Observed
- Takeoff Observations of Normal AM-251 and AM-461 Operations

## Introduction

The 94th Airmanship Training Squadron (94th ATS) has an operational restriction to halt flight operations if the airfield density altitude exceeded 10,000 feet (54th Operations Group (OPG) OI 55-2 Vol IV 15 Dec 1993 ¶ 1.4.2.6). Additionally, "...all tow operations will cease when a minimum altitude of 200 feet AGL (6700' MSL) cannot be achieved by one nautical mile from the departure end of the runway" (54th OPG OI 55-2 Vol IV 15 Dec 1993 ¶ 3.5.6.9). The 94th ATS requested this flight test program to determine the validity of these restrictions and to provide guidance concerning actual aircraft performance pertaining to aerotow operations.

The flight test program was conducted from 20 May 1994 to 24 June 1994 at the 94th Airmanship Training Squadron, USAF Academy airfield. It consisted of sixteen flights over this period, seven in the Bellanca Scout towplane alone, and nine in an aerotow combination of the Bellanca Scout and the Schweizer 2-33. In addition, 262 aerotow takeoffs were observed with the Bellanca Scout towing the Schweizer 2-33, Schleicher ASK-21, and the Schweizer 1-26 at varying density altitude, wind, and weight conditions.

The Bellanca Scout towplane used for all flight testing was N5043N and the Schweizer 2-33 sailplane used was N5579S. These aircraft were considered production representative. The towplane was fitted with a Lycoming 0-360-C2E engine and a MacCauley 8041 fixed pitch propeller. Data were taken from production cockpit instrumentation. The airspeed indicator and altimeter in the towplane and the sailplane were calibrated. A manifold pressure gauge was added in the towplane for brake horsepower determination. For some flights, a tow rope load cell was added to the tow hook of the towplane. Load cell data was recorded by a meter and laptop computer in the rear seat of the aircraft. The load cell was connected to a 200 foot polypropylene rope which was used to tow the sailplane. A temporary outside air temperature gauge was installed in both the towplane and the sailplane during flight tests.

Testing in both aircraft was limited to a pressure altitude of 12,000 feet MSL by operations guidelines at the 94th ATS. Sailplane alone testing was terminated at 8000 feet MSL to ensure safe recovery. All flights were limited to day VFR conditions. All flights were made very early in the morning to ensure smooth, stable air to aid in maintaining airspeeds and headings, as well as to avoid any lift or sink conditions. All flight manual limitations were observed for both aircraft. The sailplane was flown no slower than slow flight speeds and no faster than redline. The towplane was flown no slower than 50 mph and no faster than redline speed. All takeoff observation data were below 10,000 feet density altitude because of the current operations restriction. All takeoff observations were of normal AM-251 and AM-461 operations during summer days.

## Objectives

- Determine Conditions For Safe Operations on High Density Altitude Days

- Develop Performance Data For Aerotow and Glide

# Objectives

The primary objective of this project was to determine under what conditions operations could be safely conducted at the 94th ATS during high density altitude days. The current limitation of 10,000 feet density altitude has no known supporting data. This project was done to consider this limitation's validity and suggest any possible modifications. The requirements to continue operations in a high density altitude environment are to ensure aerotow takeoff within the limitations of the runway and to ensure a climb of 200 feet AGL by one nautical mile from the departure end of the runway.

In addition to the main objective, the project also developed actual drag polars for both the towplane and sailplane as well as an aerotow climb performance chart at varying density altitudes and airspeeds.

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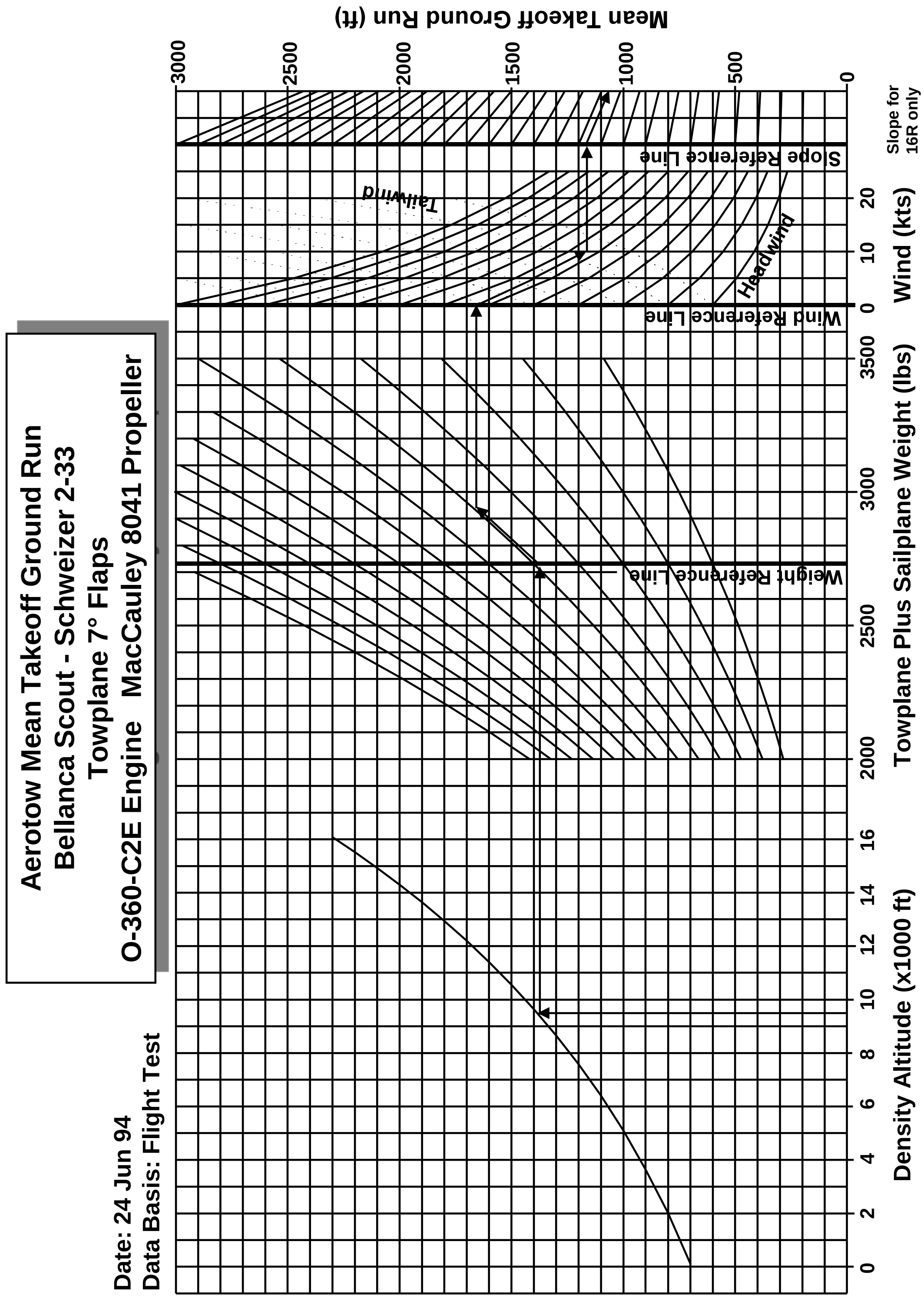

## Takeoff Mean Ground Run Performance

The Aerotow Takeoff Ground Run chart shows the mean takeoff distance for the Bellanca Scout towing a Schweizer 2-33 sailplane for varying density altitudes, weights, winds, and runway slope. Seven degrees of flaps (first notch) are used on the towplane. The towplane is equipped with a Lycoming O-360-C2E engine and a MacCauley 8041 propeller.

Standard weight for the towplane-sailplane combination is 2732 lbs. This was determined using the following weights:

| Item | Weight |
|---|---|
| Towplane Empty Weight | 1350 lbs |
| Tow Pilot Weight | 180 lbs |
| 27 gallons fuel (3/4 tanks) | 162 lbs |
| Towplane Total Weight | 1692 lbs |
| Sailplane Gross Weight | 1040 lbs |
| Total Weight | 2732 lbs |

The weight range shown on the chart is sufficient to cover the lightest takeoff weight (Schweizer 1-26 plus no towplane fuel) to the heaviest takeoff weight (ASK-21 at maximum gross, full towplane fuel, plus towplane rear seat observer). While the chart is built for the Scout plus 2-33 configuration, it will provide conservative estimates of takeoff ground run with the ASK-21 or the 1-26 sailplanes. If the proper weight for the towplane-sailplane combination is used, the aerodynamic drag of the ASK-21 or 1-26 is less than the 2-33, and thus the takeoff ground roll will be shorter. While collecting takeoff data, 10 ASK-21 and 1 1-26 takeoffs were observed. After correction for weight differences, the takeoff performance was not significantly different from the 2-33 performance.

Winds shown are limited to 25 knots, the maximum wind allowable for 2-33 operations. The runway slope correction is to be used for runway 16R operations only. Runway 34L has zero slope and does not require a correction.

Chart Example:

Given:
9500 feet Density Altitude
2950 lbs Combined Gross Weight
10 knot headwind component
Runway 16R

Procedure:

Find density altitude on density altitude scale. Move vertically to density altitude curve. Move horizontally to the weight reference line. Follow guidelines up or down as appropriate to total weight of towplane and sailplane. Move horizontally to the wind reference line. Follow the guidelines (down for headwind, up for tailwind) to the appropriate wind component. Move horizontally to the slope reference line. For 34L operations, continue horizontally to read the mean takeoff ground run. For 16R operations, follow the guidelines down to the mean takeoff ground run.

Example numbers yield a mean takeoff ground run of 1075 feet.

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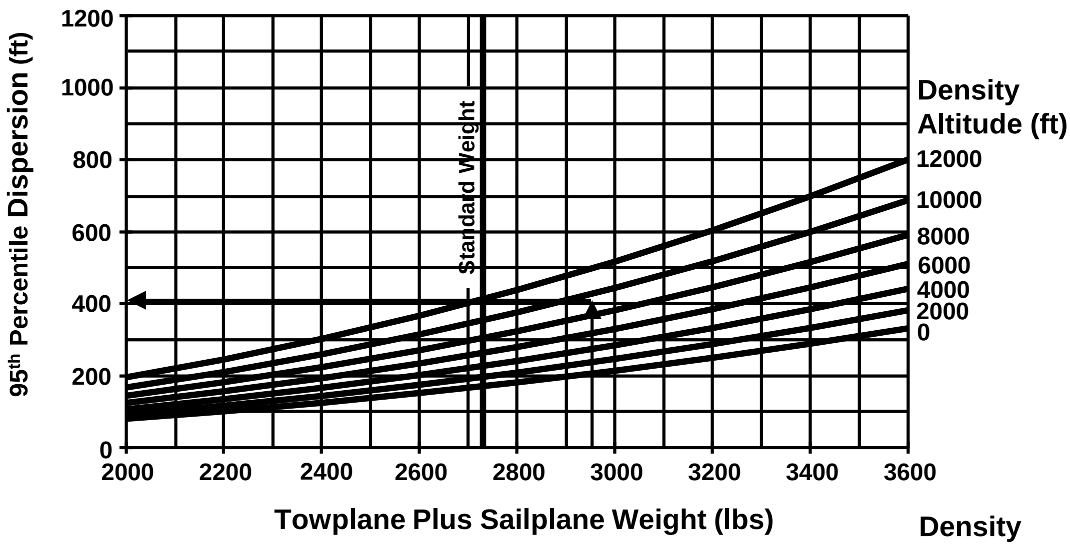
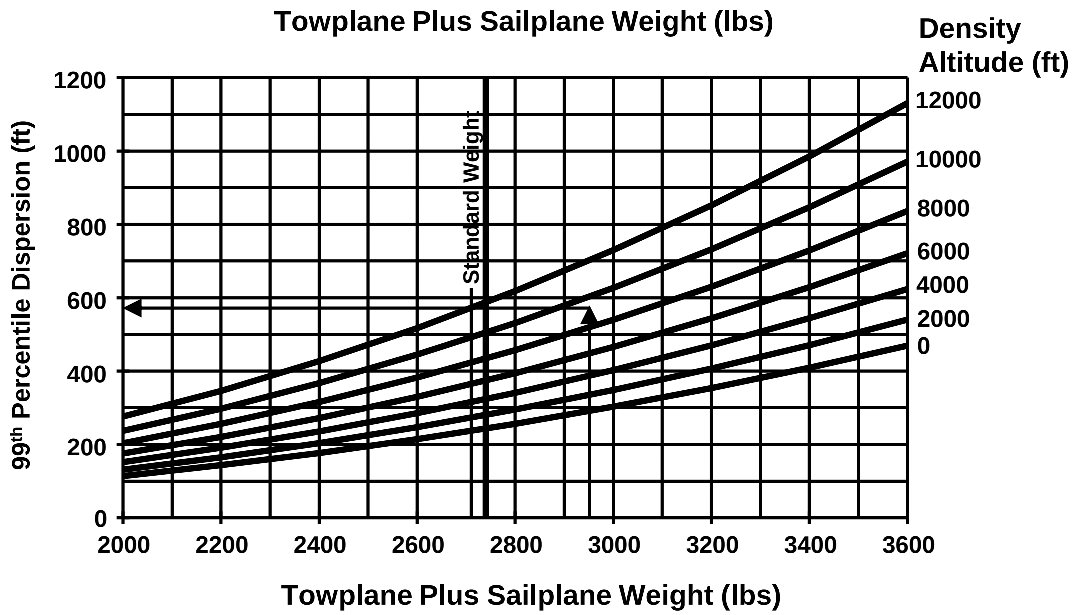
**Aerotow Takeoff Ground Run Dispersion**
**Bellanca Scout - Schweizer 2-33**
**Towplane 7° Flaps**
**O-360-C2E Engine   MacCauley 8041 Propeller**

Date: 24 Jun 94
Data Basis: Flight Test



# Takeoff Ground Run Dispersion

The takeoff ground run dispersion charts show the additional distance to be added to the mean takeoff ground run to determine if operations can be conducted safely without departing the end of the runway. This extra distance accounts for variations in takeoff technique, differences in tow pilot weight, and differences in towplane performance. During data collection, it was noted that towplane N5043N had a consistently shorter mean takeoff distance, and towplane N240SS had a consistently longer mean takeoff distance than the other four towplanes. Since shorter takeoffs are not a safety concern, dispersion is only reported for extending takeoff distance. The dispersion numbers reported account for these differences in takeoff performance.

To determine if operations can be conducted safely, add the 95th percentile dispersion to the mean takeoff ground roll. If the result is less than the available runway length, safe operations are possible. This ensures that each takeoff has a 95% chance of being completed in the available runway. As each takeoff is independent, *this does NOT mean that one in twenty takeoffs will depart the runway.*

As an additional check, the 99th percentile dispersion should be added to the mean takeoff ground roll. This result should be less than the available runway length plus the overrun available.

These charts show that for 10,000 feet density altitude, standard weight, zero headwind, and 34R operations, the mean takeoff ground run is 1430 feet. The 95th percentile dispersion is 350 feet, for a total ground run of 1780 feet. The available runway is 2250 feet from midfield. The 99th percentile dispersion is 500 feet, for a total ground run of 1930 feet.

Normal operations are not limited by runway length. For standard weight, takeoff ground run plus 95th percentile dispersion equals runway available at approximately 14,000 feet density altitude. As will be seen later, climb performance becomes the limiting factor.

Chart Example:

Given:
9500 feet Density Altitude
2950 lbs Combined Gross Weight

Procedure:

Find combined weight on the combined weight scale. Move vertically to the appropriate density altitude curve. Move horizontally to the left to read dispersion distance.

Example numbers yield a 95th percentile dispersion of 410 feet, and a 99th percentile dispersion of 575 feet.

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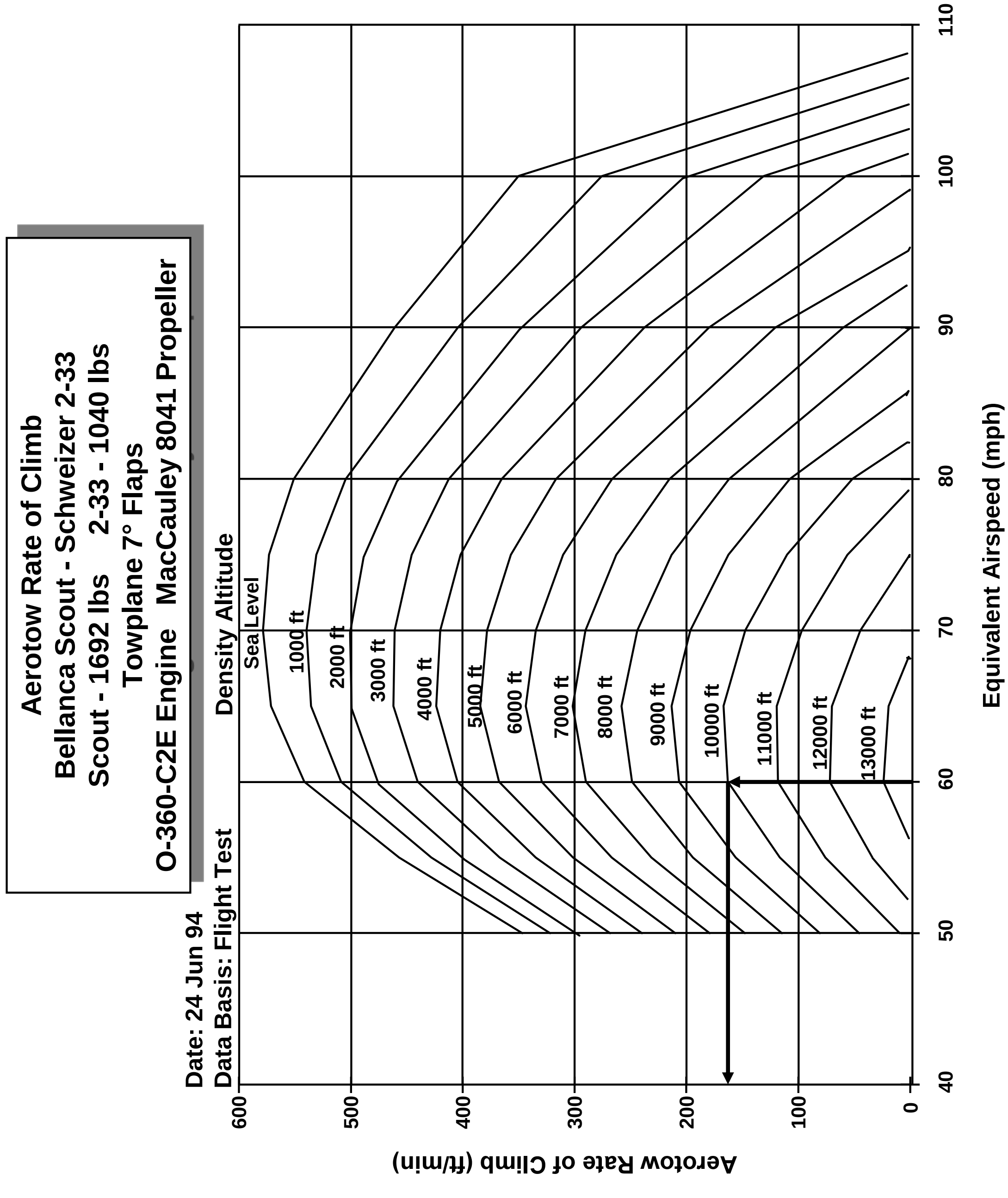

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## Aerotow Rate of Climb

The Aerotow Rate of Climb chart shows the rate of climb available at different density altitudes and different airspeeds. This chart was developed from the towplane alone rate of climb tests and the towplane and sailplane drag polars developed during this program. Comparison of predicted data to actual aerotow climb data at 60 mph revealed that an additional drag on the sailplane was required to match the flight test data. This additional drag (tow rope tension) was verified from towline load cell data. The additional drag was modeled as an additional induced drag factor, and is suspected to arise from interference effects between the towplane downwash and the sailplane. Additional wind tunnel research should be done regarding the interference effects between the towplane downwash and the sailplane.

The Aerotow Rate of Climb chart shows that between 6000 and 13,000 feet density altitude, the airspeed for maximum rate of climb changes from 65 mph to 60 mph. At 6000 feet density altitude, the additional rate of climb available by flying at 65 mph instead of 60 mph is less than 20 feet per minute. The maximum angle of climb is achieved at 60 mph. To meet the 200 feet climb requirement, initial climb should be flown at best angle of climb airspeed. Therefore, current airspeeds for aerotow should not be changed.

The chart also shows that above 13,000 feet density altitude, climb is not possible without thermal or wave lift. This density altitude can be seen on summer days attempting to climb to 12,000 feet MSL. Thus, maximum possible aerotow altitude will be performance limited on high density altitude days.

Chart Example:

Given:
10,000 feet Density Altitude
60 mph Equivalent Airspeed

Procedure:

Find equivalent airspeed on the equivalent airspeed scale. Move vertically to the appropriate density altitude curve. Move horizontally to the left to rate of climb.

Example numbers yield a rate of climb of 170 feet per minute.

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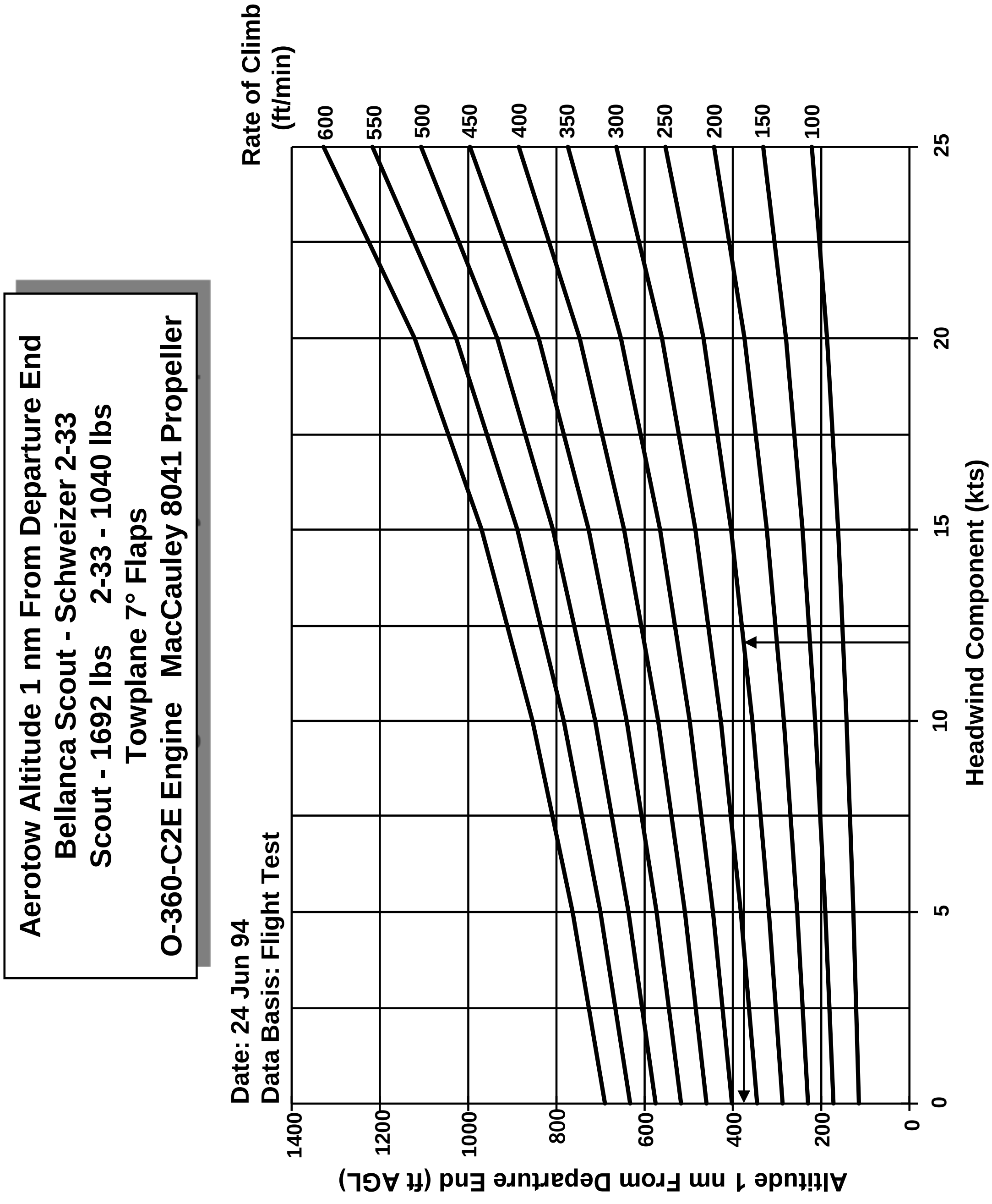

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# Takeoff Climb Performance

The takeoff climb performance chart shows the altitude gain at a point 1 nm ground distance from the departure end of the runway at standard weight as a function of headwind and rate of climb. Rate of climb is determined from the Aerotow Rate of Climb chart.

Takeoff climb performance data is reported at standard weight. For conditions when takeoff climb performance is marginal, actual weight will generally be below the standard weight, since some fuel will have been burned off and the sailplane is not necessarily at gross weight. Lower weights will improve climb performance.

For the current operating limitation of 10,000 feet density altitude, the Aerotow Rate of Climb chart shows a rate of climb of 170 feet per minute at 60 mph and standard weight. The takeoff climb performance chart then shows that the 200 feet climb criteria is just met at zero headwind.

The next chart combines this information into a format from which a go-no go decision can be easily made.

Chart Example:

Given:
12 knot headwind component
250 feet per minute rate of climb

Procedure:

Find headwind component on the headwind component scale. Move vertically to the appropriate rate of climb curve. Move horizontally to the left to altitude 1 nm from departure end.

Example numbers yield an altitude of 380 feet AGL.

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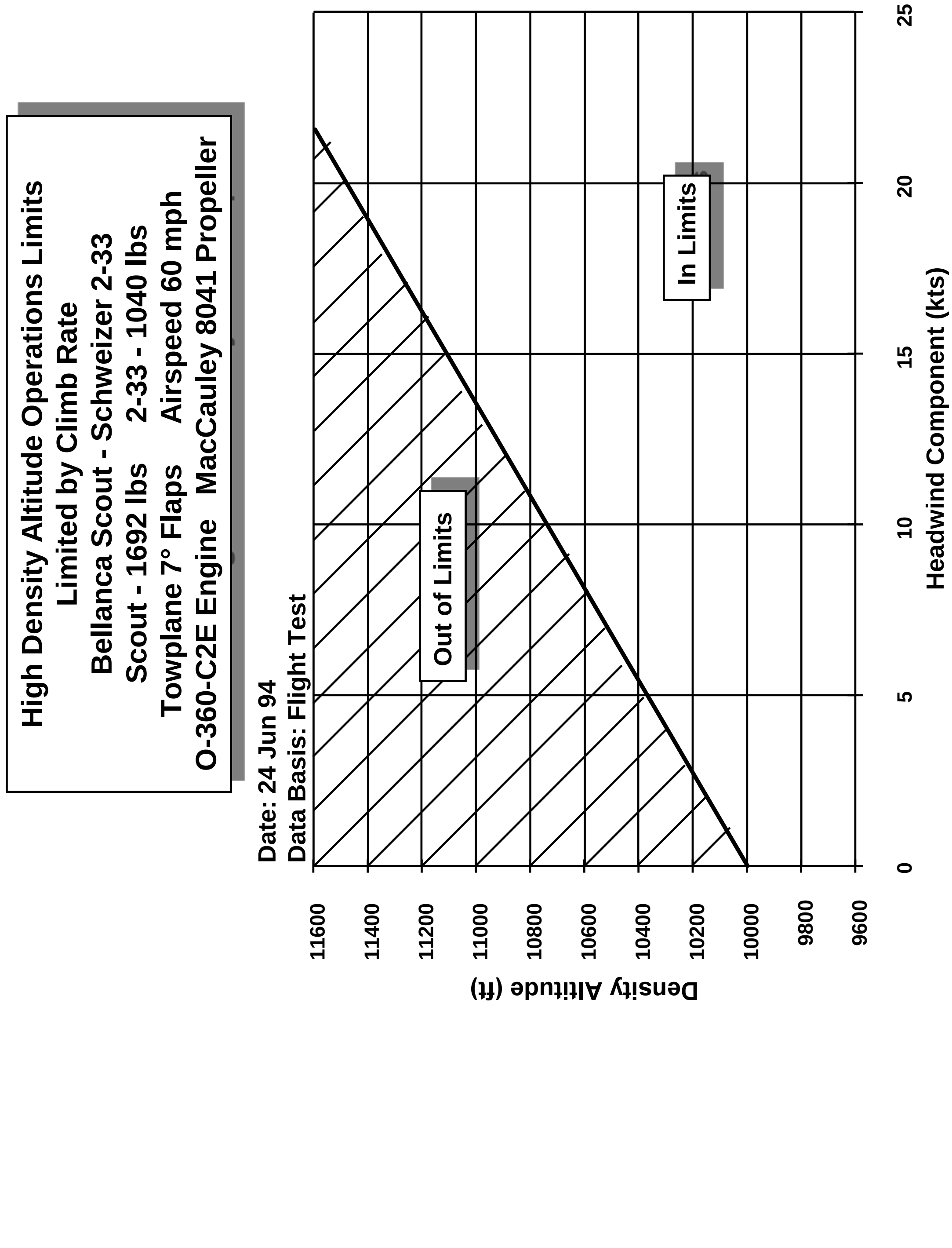

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## High Density Altitude Operations Limits

The High Density Altitude Operations Limits chart provides the decision maker with a convenient tool for making a go-no go decision based on density altitude and headwind component. These data are based on a standard weight of 2732 lbs for the towplane and sailplane combined. Lighter weight combinations will have better climb performance. The heaviest weight expected for summer operations (heaviest known tow pilot, 3/4 tanks, 2-33 at full gross weight [56 lbs over standard weight]) does not change aerotow rate of climb sufficiently to invalidate use of this chart.

Enter the chart with density altitude and headwind component. If this point falls inside the “In Limits” area of the chart, then safe operations are possible.

At a pressure altitude of 6500 feet, 10,000 feet density altitude occurs at a temperature of 93° F. Assuming a 10 knot headwind component, operations can be safely continued to 10,750 feet density altitude. This density altitude corresponds to a pressure altitude of 6500 feet and a temperature of 106° F.

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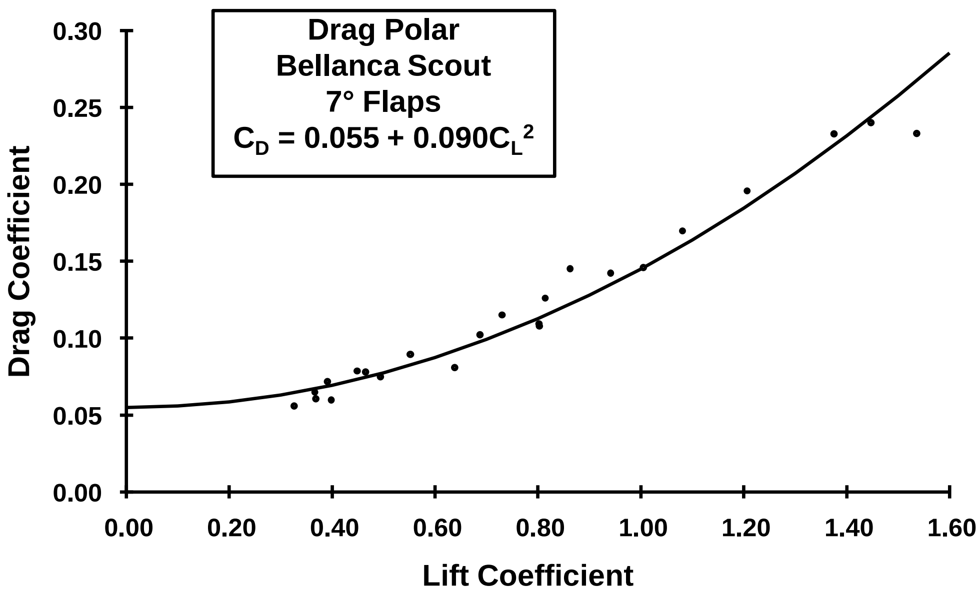
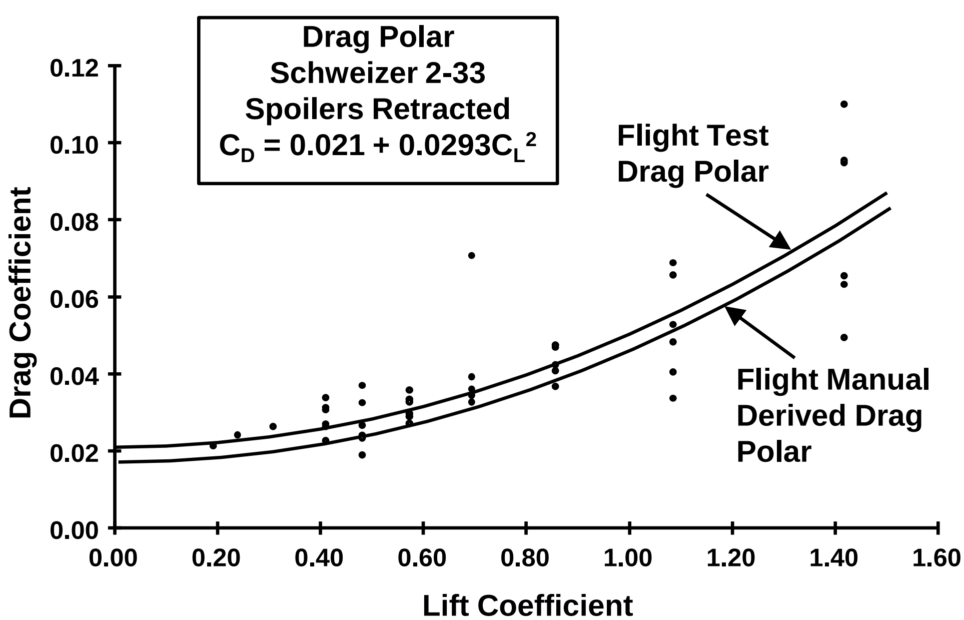
**Date: 24 Jun 94**
**Data Basis: Flight Test**



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## Drag Polars

The drag polar charts show the flight test derived drag polars for the Scout towplane and the Schweizer 2-33 sailplane. The towplane drag polar was developed from speed-power tests, measuring engine manifold pressure, RPM, and airspeed in level flight for different power settings. Flaps were set at 7° (normal aerotow position) for these tests. The resulting drag polar was $C_D = 0.055 + 0.090C_L^2$. This drag polar shows good agreement with the data points.

The sailplane drag polar chart shows the flight test derived drag polar and the flight manual derived drag polar. The flight manual drag polar was derived from the best glide speed and the aircraft weight and dimensions. The best glide speed for dual was assumed to be for maximum gross weight. The flight manual derived drag polar was $C_D = 0.01612 + 0.02932C_L^2$. The flight test derived drag polar was determined from constant speed stabilized glides at differing airspeeds. The flight test derived drag polar was $C_D = 0.021 + 0.0293C_L^2$. The induced drag coefficient showed no change from the flight manual derived drag polar. The parasite drag coefficient increased, which is normal for an old airplane suffering from hangar rash and bug specks.

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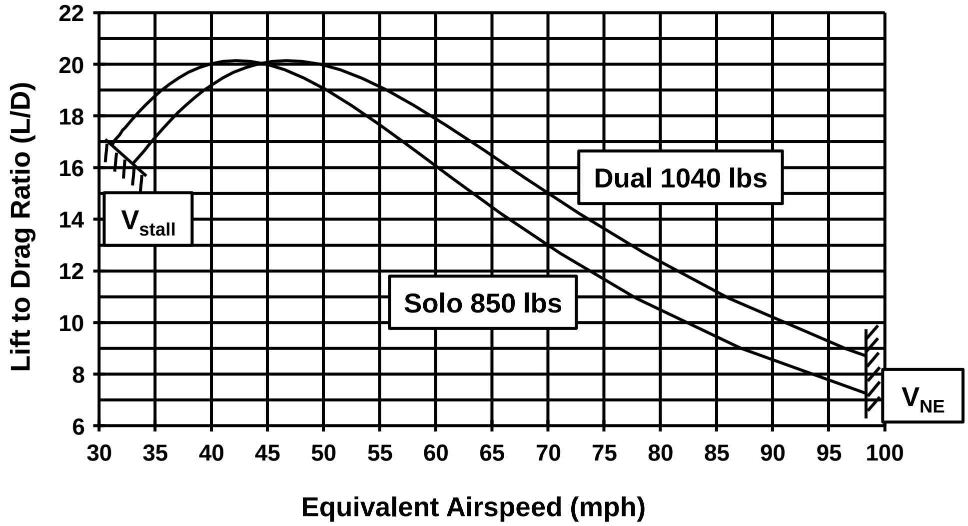
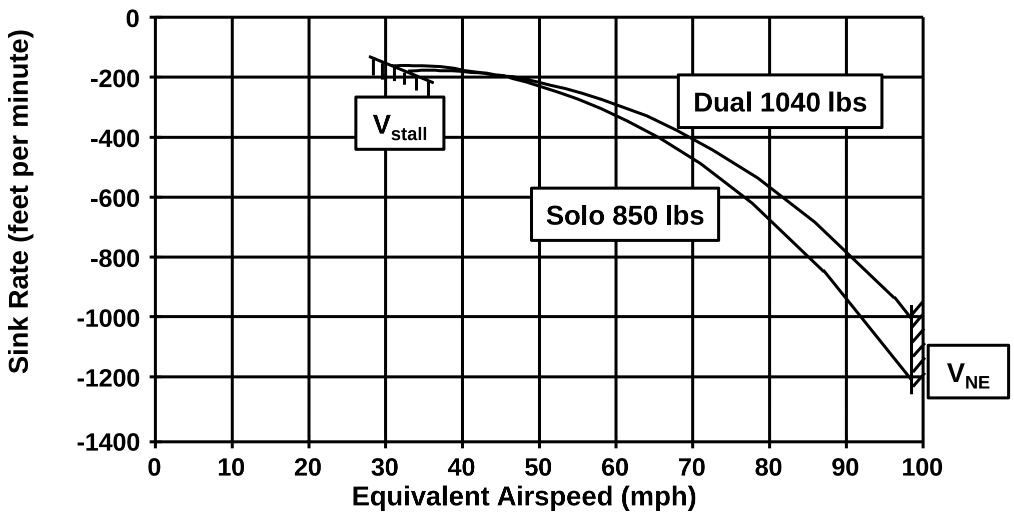
## Schweizer 2-33 Glide Performance
## Spoilers Retracted

**Date: 24 Jun 94**
**Data Basis: Flight Test**

### Penetration




### Polar



## Schweizer 2-33 Glide Performance

The Schweizer 2-33 penetration chart is shown for the dual and solo configurations. These results were for flight with spoilers retracted. The best L/D achievable was 20.2, significantly lower than the manufacturer's quoted L/D of 23. This was consistent with the higher parasite drag previously discussed. The airspeed to obtain this L/D was 47 mph dual and 42 mph solo, compared to the manufacturer’s quoted airspeeds of 50 mph and 45 mph respectively.

The Schweizer 2-33 polar chart also shows a decrease in performance from the manufacturer’s data. The two lines on the chart represent dual and solo configurations. The minimum sink airspeeds were 35 mph dual and 32 mph solo compared to manufacturer’s quoted airspeeds of 42 mph and 38 mph respectively. The minimum sink rate was 180 feet per minute dual and 160 feet per minute solo, both slightly higher than what the flight manual derived drag polar would produce. Again, this was consistent with an older sailplane.

## Conclusions And Recommendations

- Operations Can Be Safely Continued Above 10,000 Feet Density Altitude Under Certain Conditions

- Go-No Go Chart Provided

- Continue Aerotow At 60 mph

- Wind Tunnel Research On Towplane/Sailplane Interference

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## Conclusions And Recommendations

The overall conclusion from this project was that operations above 10,000 feet density altitude can continue under certain wind and weight conditions. Operations can also be aided by the downward slope when using runway 16R. A go-no go chart is included for determining the possibility of safe operations for a known density altitude and wind. Aerotow airspeed should remain at 60 mph to give the best opportunity to reach 200 feet AGL one nautical mile from the departure end of the runway.

Additional wind tunnel research should be done to determine the interference effects between the towplane downwash and the sailplane.

## Future Testing and Reporting

- Fall Semester ASK-21 And 1-26 Flights
- Full Flight Test Report To Follow
- *Soaring* Magazine Article
- AIAA Student Paper Competition
- SFTE Symposium Paper

## Future Testing and Reporting

In the fall semester, flight tests will be continued with the ASK-21 and 1-26 to determine aerotow and glide performance for these sailplanes. Data obtained during operations at lower density altitudes will also be used to confirm performance extrapolations.

After the completion of flight testing, a full report will be provided containing a complete analysis of all data and documentation of flight test and data reduction procedures. We also plan a possible article to be published in *Soaring* magazine reporting our aerotow results. Other papers are planned for the American Institute of Aeronautics and Astronautics Student Paper Competition and the Society of Flight Test Engineers Symposium.


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