TP 13480E

Air Velocity Distribution Behind Wing-Mounted Aircraft Engines

Prepared for

Transportation Development Centre
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Civil Aviation

Transport Canada

APS AVIATION INC.

October 1999

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by

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Un sommaire français se trouve avant la table des matières.

PREFACE

At the request of the Transportation Development Centre of Transport Canada, APS Aviation Inc. has undertaken a research program to advance aircraft ground deicing/anti-icing technology. The specific objectives of the APS test program are the following:

- To develop holdover time tables for new anti-icing fluids, and to validate fluid-specific and SAE holdover time tables;
- To gather enough supplemental experimental data to support the development of a deicing-only table as an industry guideline;
- To examine conditions for which contamination due to anti-icing fluid failure in freezing precipitation fails to flow from the wing of a jet transport aircraft when subjected to speeds up to and including rotation;
- To measure the jet-blast wind speeds developed by commercial airliners in order to generate air-velocity distribution profiles (to predict the forces that could be experienced by deicing vehicles), and to develop a method of evaluating the stability of deicing vehicles during live deicing operations;
- To determine the feasibility of examining the surface conditions on wings before takeoff through the use of ice-contamination sensor systems, and to evaluate the sensitivity of one ice-detection sensor system;
- To evaluate the use of warm fuel as an alternative approach to ground deicing of aircraft;
- To evaluate hot water deicing to determine safe and practicable limits for wind and outside ambient temperature;
- To document the appearance of fluid failure, to measure its characteristics at the point of failure, and to compare the failures of various fluids in freezing precipitation;
- To determine the influence of fluid type, precipitation (type and rate), and wind (speed and relative direction) on both the locations and times to fluid failure initiation, with special attention to failure progression on the Bombardier Canadair Regional Jet and on high-wing turboprop commuter aircraft;
- To evaluate snow weather data from previous winters to identify a range of snow-precipitation suitable for the evaluation of holdover time limits;
- To compare the holdover times from natural and artificial snow trials and to evaluate the functionality of the NCAR simulated snowmaking system; and
- To develop a plan for implementing a full-scale wing test facility that would enable the current testing of deicing and anti-icing fluids in natural and artificial freezing precipitation on a real aircraft wing.

The research activities of the program conducted on behalf of Transport Canada during the 1998-99 winter season are documented in twelve reports. The titles of these reports are as follows:

- TP 13477E Aircraft Ground De/Anti-icing Fluid Holdover Time Field Testing Program for the 1998-99 Winter;
- TP 13478E Aircraft Deicing Fluid Freeze Point Buffer Requirements for Deicing Only Conditions;
- TP 13479E Contaminated Aircraft Takeoff Test for the 1998-99 Winter;
- TP 13480E Air Velocity Distribution Behind Wing-Mounted Aircraft Engines;
- TP 13481E Feasibility of Use of Ice Detection Sensors for End-of-Runway Wing Checks;
- TP 13482E Evaluation of Warm Fuel as an Alternative Approach to Deicing;
- TP 13483E Hot Water Deicing of Aircraft;
- TP 13484E Characteristics of Failure of Aircraft Anti-Icing Fluids Subjected to Precipitation;
- TP 13485E Aircraft Full-Scale Test Program for the 1998-99 Winter;
- TP 13486E Evaluation of Snow Weather Data for Aircraft Anti-Icing Holdover Times;
- TP 13487E Development of a Plan to Implement a Full-Scale Test Site; and
- TP 13488E A Snow Generation System – Prototype Testing.

This report, TP 13480E, addresses the following objective:

- To measure the jet-blast wind speeds developed by commercial airliners in order to generate air-velocity distribution profiles (to predict the forces that could be experienced by deicing vehicles), and to develop a method of evaluating the stability of deicing vehicles during live deicing operations.

This objective was met by conducting tests and collecting hard data for the air velocities experienced in the vicinity of wing-mounted aircraft engines during live deicing operations. A safety check method was developed and tested on engines on aircraft.

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This research has been funded by the Civil Aviation Group, Transport Canada, and with support from the Federal Aviation Administration. This program could not have been accomplished without the participation of many organizations. APS would like to thank, therefore, the Transportation Development Centre of Transport Canada, the Federal Aviation Administration, the National Research Council Canada, Atmospheric Environment Services Canada, Transport Canada, and several fluid manufacturers. Special thanks are extended to US Airways Inc., Delta Air Lines, Royal Airlines, Air Canada, the National Research Council Canada, Canadian Airlines International, AéroMag 2000, Aéroport de Montreal, the Greater Toronto Airport Authority, Hudson General Aviation Services Inc., Union Carbide, RVSI, Cox and Company Inc., the Department of National Defence, and Shell Aviation, for provision of personnel and facilities and for their co-operation on the test program. APS would like also to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data.

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Research reports produced on behalf of Transport Canada for testing during previous winters are available from the Transportation Development Centre (TDC). Twelve reports (including this one) were produced as part of this winter's research program (1998-99). Their subject matter is outlined in the preface. This project was co-sponsored by Delta Air Lines, Aeromag 2000 Inc., and Hudson General Aviation Services Inc.

16. Abstract

This study had focussed on two main objectives:

- Acquisition of experimental data on the air velocity distribution experienced in the blast from wing-mounted aircraft engines at idle, during live deicing operations;
- Development and evaluation of a method that could be used as a safety check for deicing truck stability, and incorporated into an SAE standard.

Two supplemental objectives were also addressed:

- Measurement of air velocities in the vicinity of the Boeing 777 auxiliary power unit (APU) exhaust;
- Measurement of the air velocity profiles 100 m behind a Boeing 777 engine at three-quarter throttle.

Nineteen tests were conducted on nine different aircraft at three airports. Air velocity measurements were recorded on all occasions and were considered as a function of aircraft geometry and engine rating. Peak air velocity measurements were recorded for the various aircraft. The Airbus A320 recorded the highest air velocity, 180 km/h.

The overturning moment on a deicing truck subject to the jet blast of a wing-mounted aircraft engine at idle was found to be 7.4 percent of that required to overturn the truck. A viable and repeatable preliminary test method was developed.

Boeing 777 APU tests observed excessively high heat and recorded an air velocity in excess of 200 km/h.

Boeing 777 three-quarter throttle tests recorded an air velocity in excess of 190 km/h, but were discontinued because of equipment damage. The stability of the deicing truck during this test was affected by the overwhelming wave of air created by the aircraft engine and the truck was considered unsafe.

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Les rapports de recherche produits au nom de Transports Canada sur les essais réalisés au cours des hivers antérieurs peuvent être obtenus auprès du Centre de développement des transports (CDT). Le programme de la saison hivernale 1998-1999 a donné lieu à douze rapports (dont celui-ci). On trouvera dans la préface l'objet de ces rapports. Ce projet a été coparrainé par Delta Air Lines, Aeromag 2000 Inc. et Hudson General Aviation Services Inc.

16. Résumé

L'étude poursuivait deux grands objectifs :

- l'acquisition de données expérimentales sur la distribution des vitesses de l'air soufflé par des réacteurs de voilure au régime ralenti, lors d'opérations de dégivrage;
- la mise au point et l'évaluation d'une méthode permettant de vérifier la tenue au renversement des camions de dégivrage, pour incorporation éventuelle à une norme SAE.

Deux autres objectifs étaient également visés :

- la mesure de la vitesse de l'air à proximité de l'échappement du groupe auxiliaire de bord (APU) d'un Boeing 777;
- l'établissement des profils de vitesse caractérisant la zone située à 100 m en aval d'un réacteur de Boeing 777 fonctionnant aux trois quarts de son régime de puissance maximal.

Dix-neuf essais ont été réalisés à l'aide de neuf types d'avions, à trois aéroports. À chaque essai, les données concernant la vitesse de l'air étaient enregistrées et mises en rapport avec la taille de l'avion et la puissance nominale du réacteur. Les vitesses de pointe ont été déterminées dans le cas de chaque appareil. La vitesse maximale (180 km/h) a été enregistrée avec l'Airbus A320.

Le souffle d'un réacteur au régime ralenti produit sur un camion de dégivrage un moment de renversement équivalant à 7,4 p. 100 du moment nécessaire pour renverser le camion en question. L'étude a été l'occasion de mettre au point une méthode d'essai préliminaire viable et reproductible.

Au cours des essais mettant en jeu l'APU d'un Boeing 777, les chercheurs ont observé le dégagement d'une chaleur excessive et des vitesses d'air supérieures à 200 km/h.

Les essais menés avec le réacteur fonctionnant aux trois quarts de son régime de puissance maximal ont produit des vitesses d'air de 190 km/h. Mais des dommages au matériel ont forcé les chercheurs à interrompre ces essais. De plus, la vague d'air en sortie du réacteur était si forte qu'elle faisait vaciller le camion de dégivrage, faisant craindre pour la sécurité du personnel.

17. Mots clés

Distribution des vitesses de l'air, stabilité des camions de dégivrage, dégivrage avec moteurs en marche, réacteur d'aéronef, charges de renversement

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EXECUTIVE SUMMARY

At the request of Transport Canada's Transportation Development Centre and based on an initiative of Delta Air Lines, through the SAE G12 Equipment Subcommittee, APS undertook a research program to further advance live ground de/anti-icing safety.

Safety in live (engines on) ground de/anti-icing operations has always been a critical issue. New concerns have developed as live deicing has been implemented by an increasing number of operators in an effort to reduce deicing service times. Attention has been placed on personnel safety and deicing vehicle safety during these operations. During deicing of the tailplane of large aircraft, decing trucks frequently pass behind the exhaust of wing-mounted engines. Major concerns regarding the stability of these vehicles are the high air velocities and associated forces developed in the vicinity of jet engine exhaust plumes. The focus of the APS research was to obtain working spatial distributions of these air velocities and to better understand their effect on deicing truck stability.

This report contains the results of research conducted by APS Aviation in 1998-99 related to air velocity distribution in the vicinity of aircraft tailplanes behind wing-mounted aircraft engines. The study addresses concerns expressed by the SAE G-12 Equipment Sub-Committee. The areas of study include:

Air Velocity Distribution

The objective was to acquire experimental data on the air velocity distributions experienced in the blast of wing-mounted aircraft engines, at idle, during live de/anti-icing operations, 2.5 m (8 ft.) ahead of the leading edge of the horizontal stabilizer root.

Deicing Truck Overturning Loads

Current SAE standards do not include a safety check to evaluate the stability of deicing trucks subjected to engine blast. The objective was to develop and evaluate a method that could be used as a safety check and could possibly be incorporated into an SAE standard.

Two supplementary topics were also addressed:

Boeing 777 APU Air Velocity Tests

The objective of this test was to obtain nominal measurements of air velocities in the vicinity of the Boeing 777 auxiliary power unit (APU).

Boeing 777 Three-Quarter Throttle Tests

The purposes of these tests were to obtain air velocity profile measurements 100 m (330 ft.) behind a Boeing 777 wing-mounted engine at three-quarter throttle and to evaluate the safety of deicing vehicles under these conditions.

PROCEDURE AND DATA

Air Velocity Distribution

Nineteen tests were conducted on nine different aircraft models during five test sessions at the Montreal (Dorval), Toronto, and Atlanta airports.

Five anemometers positioned at 0.6 m (2 ft.) intervals on a 3 m (10 ft.) pole were used to record air velocity. The pole was vertically mounted on the bucket of a deicing vehicle, which was positioned perpendicular to the wing-mounted engine, 2.5 m (8 ft.) ahead of the leading edge of the horizontal stabilizer root, and the aircraft wing span's length away from the fuselage. The test vehicle advanced in 0.6 m (2 ft.) increments towards the fuselage and air velocity measurements were recorded at each increment.

Deicing Truck Overturning Loads

One test was conducted at the Central Deicing Facility operated by Hudson General Aviation Services Inc., at Toronto's Lester B. Pearson International Airport. An Airbus A310 was provided by Royal Airlines for the test.

A deicing truck was positioned on portable weigh scales and subjected to the jet blast of an Airbus A310 engine at idle. The weight shift caused by the blast was used to calculate the overturning moment of the truck. A second method of moment calculation converted air velocity measurements to forces acting on the deicing truck.

Boeing 777 APU Air Velocity Tests

One test was conducted at Hartsfield Atlanta International Airport on a Boeing 777 provided by Delta Air Lines.

The five pole-mounted anemometers were positioned in the vicinity of the Boeing 777 APU, and air velocity measurements were recorded.

Boeing 777 Three-Quarter Throttle Tests

One test was conducted on a Boeing 777 aircraft on a runway of Hartsfield Airport; the aircraft was provided by Delta Air Lines.

The five pole-mounted anemometers were positioned 100 m (330 ft.) behind the starboard engine, offset 10 m (33 ft.) from the centreline of the engine in a direction away from the fuselage. The engine power was increased to three-quarter throttle and air velocity measurements were recorded.

RESULTS AND CONCLUSION

Nominal values of air velocity were obtained in the vicinity of the aircraft horizontal stabilizers during live deicing. A preliminary method of checking the safety of deicing vehicles during live deicing operations was developed.

Air Velocity Distribution

The sample data collected has provided insight into the magnitude of air velocities experienced during live deicing operations, 2.5 m (8 ft.) ahead of the leading edge of the horizontal stabilizer root. A viable method for conducting further tests has been established. The notion that larger aircraft with more powerful engines produce the highest air velocity is false; air velocity measurements experienced in the vicinity of the horizontal stabilizers are aircraft specific, not a function of aircraft size or engine rating.

Nine aircraft types were tested during 19 tests. The Airbus A320 recorded the highest peak velocity (180 km/h), the SAAB 340 the lowest (60 km/h).

Deicing Truck Overturning Loads

Initial steps towards a viable test method to measure overturning loads on deicing vehicles, during live deicing, were developed. The stability of deicing trucks can be evaluated by using weigh scales or measuring air velocity. The stability and behaviour of deicing trucks is truck specific, not generic. The FMC Corporation deicing truck used in our test session experienced only 7.4 percent of the total moment needed to overturn it. The FMC truck had no deicing fluid in the reservoir tanks but was not in its most vulnerable configuration during the test. Other influences may affect truck stability and should be evaluated.

Boeing 777 APU Air Velocity Tests

Air velocity measurements were obtained 2.1 m (7 ft.) behind the Boeing 777 APU. The peak velocity recorded was 200 km/h. Excessive damage caused by the heat was observed in the vicinity of the exhaust and testing was discontinued. Specific temperatures were not recorded. Caution should be used when deicing this aircraft.

Boeing 777 Three-Quarter Throttle Tests

Approximately two minutes of air velocity measurements were obtained. Equipment was damaged and became inoperable during testing. Emergency escape manoeuvres were implemented to avoid further damage or injury to personnel. A peak velocity of 190 km/h was recorded. The stability of the deicing truck during this test was affected by an overwhelming wave of air created by the aircraft engine, and the truck was considered unsafe.

SOMMAIRE

À la demande du Centre de développement des transports de Transports Canada et pour faire suite à une initiative lancée par Delta Air Lines par la voie du sous-comité G12 de la SAE, APS a entrepris un programme de recherche visant à déterminer le risque associé au dégivrage au sol d'avions.

La sécurité des opérations de dégivrage alors que les réacteurs sont en marche est depuis longtemps un sujet de préoccupation. Le fait que de plus en plus d'exploitants procèdent au dégivrage avec les réacteurs en marche, voulant bénéficier ainsi de toute la durée d'efficacité des liquides antigivrants, a suscité de nouvelles inquiétudes reliées à la sécurité du personnel et à la sûreté du véhicule, pendant ces opérations. La principale crainte concernant le véhicule tient au risque de renversement par le souffle puissant des réacteurs. Le but de la recherche menée par APS était d'obtenir, par l'expérience, la distribution spatiale des vitesses de l'air, afin de mieux comprendre leur effet immédiat sur la stabilité des camions de dégivrage.

Ce rapport donne les résultats des travaux réalisés par APS Aviation en 1998-1999 sur plusieurs sujets reliés à la distribution des vitesses de l'air à proximité des réacteurs de voilure. L'étude répond aux préoccupations exprimées par les membres du sous-comité G12 de la SAE. Voici les différents volets de l'étude :

Distribution des vitesses de l'air

Le but était d'acquérir des données expérimentales sur la distribution des vitesses de l'air soufflé par les réacteurs de voilure au régime ralenti pendant des opérations de dégivrage, à 2,5 m (8 pi) en amont du bord avant de l'emplanture de l'empennage horizontal.

Charges de renversement des camions de dégivrage

Les normes SAE actuelles ne prévoient aucune vérification de sécurité de la stabilité des camions de dégivrage à portée du souffle des réacteurs. L'objectif était de mettre au point et d'évaluer une méthode qui permettrait de vérifier la tenue au renversement des camions de dégivrage, pour incorporation éventuelle à une norme SAE.

Deux autres questions ont aussi été examinées :

Mesure de la vitesse de l'air à proximité de l'APU d'un Boeing 777

Cet essai visait à obtenir des données nominales concernant la vitesse de l'air

dans le voisinage du groupe auxiliaire de bord (APU) d'un Boeing 777.

Essais avec réacteurs de Boeing 777 fonctionnant aux trois quarts de leur régime maximal

Le but de ces essais était d'établir les profils de vitesse de l'air caractérisant la zone située à 100 m (330 pi) en aval d'un réacteur de Boeing 777 dont la manette des gaz était placée aux trois quarts de sa course, et d'évaluer le risque associé à des opérations de dégivrage menées dans ces conditions.

DÉMARCHE EXPÉRIMENTALE

Distribution des vitesses de l'air

Dix-neuf essais cumulatifs ont été réalisés à l'aide de neuf modèles d'avions différents, au cours de cinq séances d'essais tenues aux aéroports de Dorval, de Toronto et d'Atlanta.

La vitesse de l'air était mesurée par cinq anémomètres disposés à des intervalles de 0,6 m (2 pi) sur un poteau de 3 m (10 pi) de longueur. Le poteau était monté à la verticale sur la nacelle d'un véhicule de dégivrage, lequel était stationné perpendiculairement à l'axe du réacteur de voilure, à 2,5 m (8 pi) en amont du bord avant de l'emplanture de l'empennage horizontal, à une distance du fuselage équivalente à l'envergure de l'aile. Le véhicule d'essai avançait de 0,6 m (2 pi) à la fois en direction du fuselage. À chaque étape, les anémomètres enregistraient la vitesse de l'air.

Charges de renversement des camions de dégivrage

Un essai a eu lieu au poste central de dégivrage exploité par Hudson General Aviation Services Inc., à l'aéroport international Lester B. Pearson de Toronto. Un Airbus A310 avait été fourni par Royal Airlines.

Un camion de dégivrage a été disposé sur des bascules de pesage portables et soumis au souffle d'un réacteur d'Airbus A310 au régime ralenti. Le déplacement du poids produit par le souffle a été utilisé pour calculer le moment de renversement du camion. Une deuxième façon de déterminer le moment consistait à convertir les données anémométriques en forces agissant sur le camion.

Mesure de la vitesse de l’air à proximité de l’APU d’un Boeing 777

Un essai a eu lieu à l’aéroport international Hartsfield d’Atlanta, à l’aide d’un Boeing 777 mis à la disposition des chercheurs par Delta Air Lines.

Cinq anémomètres montés sur un poteau disposé à proximité de l’APU du Boeing mesuraient la vitesse de l’air.

Essais avec réacteurs de Boeing 777 fonctionnant aux trois quarts de leur régime maximal

Un essai a été réalisé à l’aide d’un Boeing 777 sur une piste de l’aéroport Hartsfield; l’avion avait été fourni par Delta Air Lines.

Cinq anémomètres montés sur un poteau ont été disposés à 100 m (330 pi) en aval du moteur de droite, à 10 m (33 pi) de l’axe du réacteur, dans la direction opposée au fuselage. Des mesures de la vitesse de l’air ont été prises alors que la manette des gaz du réacteur était aux trois quarts de sa course.

RÉSULTATS ET CONCLUSIONS

Des valeurs nominales ont été obtenues concernant la vitesse de l’air dans la zone de l’empennage horizontal des aéronefs, au cours d’opérations de dégivrage avec réacteurs en marche. Une méthode préliminaire pour vérifier la sûreté des véhicules de dégivrage au cours d’opérations avec réacteurs en marche a été mise au point.

Distribution des vitesses de l’air

L’échantillon de données recueilli a permis de quantifier les vitesses de l’air dans la zone immédiate où sont réalisées les opérations de dégivrage avec réacteurs en marche, soit à 2,5 m (8 pi) en amont du bord avant de l’emplanture de l’empennage horizontal. Une méthode d’essai viable a été établie. L’idée voulant que plus l’avion est gros, plus la vitesse de l’air est grande a été démentie; les mesures anémométriques prises à proximité de l’empennage horizontal sont propres à chaque type d’appareil, et ne dépendent ni de la taille de l’avion ni de la puissance nominale du réacteur.

Neuf modèles d’avions ont participé à 19 essais. La vitesse d’air maximale (180 km/h) a été enregistrée avec l’Airbus A320 et la vitesse minimale (60 km/h), avec le SAAB 340.

Charges de renversement des camions de dégivrage

Les premiers pas ont été faits vers une méthode d'essai viable pouvant servir à déterminer les charges de renversement des véhicules de dégivrage lors d'opérations avec réacteurs en marche. Il est possible d'évaluer la stabilité des camions de dégivrage soit au moyen de bascules de pesage, soit en mesurant la vitesse de l'air. Chaque camion de dégivrage affiche une stabilité et un comportement qui lui sont propres. Dans le cas du camion de la FMC Corporation utilisé aux fins des essais, le souffle a généré un moment de seulement 7,4 p. 100 du moment total nécessaire pour le renverser. Les réservoirs de liquide dégivrant du camion FMC étaient vides au moment des essais, mais cela ne plaçait pas pour autant le véhicule dans sa configuration la plus vulnérable. Il existe d'autres facteurs susceptibles d'influer sur la tenue au renversement des camions, et ceux-ci devraient être étudiés.

Mesure de la vitesse de l'air à proximité de l'APU d'un Boeing 777

Les mesures de la vitesse de l'air ont été prises à 2,1 m (7 pi) en aval de l'APU du Boeing 777. La vitesse maximale enregistrée était de 200 km/h. Une grande chaleur, causant des dommages au matériel, a été observée à proximité de l'échappement et l'essai a été interrompu. On conseille la prudence lors du dégivrage de ce type d'avion.

Essais avec réacteurs de Boeing 777 fonctionnant aux trois quarts de leur régime maximal

Environ deux minutes de données anémométriques ont été obtenues. Le matériel a été endommagé au cours de l'essai, au point de devenir inutilisable. Des mesures d'évacuation d'urgence ont été prises pour prévenir tout autre dommage matériel ou blessure. Une vitesse de pointe de 190 km/h a été enregistrée. La vague d'air en sortie du réacteur était si forte qu'elle faisait vaciller le camion de dégivrage, faisant craindre pour la sécurité du personnel.

CONTENTS

LIST OF APPENDICES

LIST OF FIGURES

LIST OF TABLES

LIST OF PHOTOS

GLOSSARY

APU	Auxilliary Power Unit
APS	APS Aviation Inc.

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1. INTRODUCTION

At the request of Transport Canada's Transportation Development Centre and based on an initiative of Delta Air Lines, through the SAE G-12 Equipment Sub-Committee, APS undertook a research program to further advance live aircraft ground deicing/anti-icing safety.

Safety in live (engines on) ground deicing/anti-icing operations has always been a critical issue. New concerns have developed as live deicing is being implemented by an increasing number of operators in an effort to optimize holdover times by reducing deicing service times. Attention has been placed on personnel safety and deicing vehicle stability during these operations. Major concerns regarding the stability of these vehicles are the high air velocities and associated forces developed in the vicinity of jet engine exhaust plumes. The focus of the research conducted by APS was to obtain working spatial distributions of these air velocities and to better understand their immediate effect on deicing truck stability.

This report contains the results of research conducted by APS Aviation in 1998/99 on several subjects related to air velocity distribution in the vicinity of wing-mounted aircraft engines. This study addresses concerns of the G-12 Equipment Sub-Committee. A desire to evaluate the safety of deicing vehicles and personnel during live deicing was expressed. So was a desire to explore the feasibility of developing a method to check the safety of deicing vehicles and, if appropriate, recommend inclusion in an aerospace standard. The results of the meetings presented the following two main objectives:

- Air velocity distribution
- Deicing truck overturning loads

From the original two objectives, the following supplemental objectives were developed:

- Boeing 777 APU air velocity tests
- Boeing 777 three-quarter throttle tests

1.1 Objectives

This subsection provides an outline of the research on air velocity distribution in live deicing/anti-icing, including overall objectives of the study.

1.1.1 Air Velocity Distribution

The objective of this part of the study was to acquire experimental data on the air velocity distributions experienced in the blast of wing-mounted aircraft engines, at idle, during live deicing/anti-icing operation, 2.5 m (8 ft.) ahead of the leading edge of the horizontal stabilizer root. Nominal values for these air velocities do exist. After initial studies, however, it was concluded that the nominal values quoted in the literature could not be directly applied to the specific area of study. Therefore, hard data was collected.

1.1.2 Deicing Truck Overturning Loads

Current SAE standards do not include a safety check to evaluate the stability of deicing trucks subjected to engine blast. The intent was to develop and evaluate a method that could be used as a safety check and be incorporated into an SAE standard.

1.1.3 Boeing 777 APU Air Velocity Tests

Conversations with various deicing personnel outlined the concern that the jet blast of the B-777's APU (Auxiliary Power Unit) was rather significant when compared to that of other aircraft. Deicing personnel are exposed to the APU during standard deicing of the horizontal and vertical stabilizers. They described conditions of excessive turbulence and general discomfort.

The purpose of this test was to obtain nominal measurements of air velocities in the vicinity of the B 777 APU.

1.1.4 Boeing 777 Three-Quarter Throttle Tests

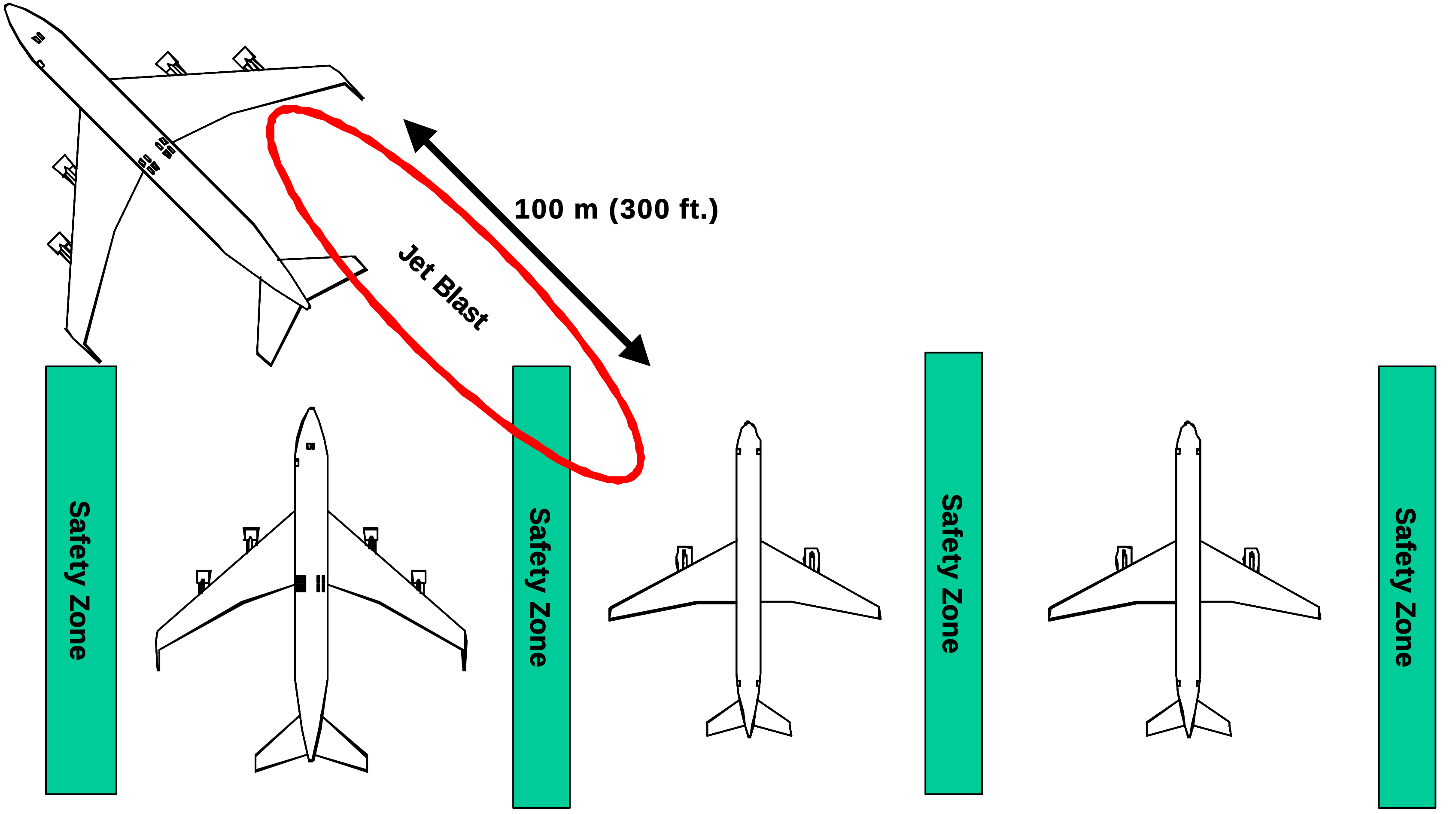
This test was based on an undocumented occurrence that was observed by an airline pilot. The scenario includes the layout of a typical deicing pad holding adjacent deicing bays numbered sequentially (from left to right) from one to three. The incident involves a Boeing 747 in bay number one and an Airbus A320 in bay number two. The Boeing 747, having just been deiced, proceeds to exit the bay by moving forward and then making a left turn. As the aircraft begins to turn, it is forced to stop. (The aircraft has now rotated through the first 30° of the total 90° needed to turn.) As the aircraft begins to move again, the starboard engines are increased to three-quarter throttle in an effort to overcome the stationary inertia. The jet blast causes snow and excess deicing fluid from the ground of the deicing bay onto the A320 aircraft. As a result, it must be deiced again (Figure 1.1).

In second undocumented occurrence a parked deicing truck exposed to the jet blast of a turning Boeing 777 was reported as experiencing very high loads which the truck crew feared might overturn the truck.

The purposes of this test were to obtain measurements of the air velocity profile 100 m (300 ft.) behind a Boeing 777 wing-mounted engine at three-quarter throttle and to evaluate the safety of deicing vehicles under these conditions.

Figure 1.1

Three-Quarter Throttle Jet Blast Area



2. METHODOLOGY

This section details the testing environment, including information about test facilities, equipment, procedures, and personnel.

2.1 Air Velocity Distribution

This subsection describes air velocity tests performed on operational aircraft in live deicing operations.

2.1.1 Test Sites

Air velocity distribution tests on aircraft with wing-mounted engines were conducted at three airports. Tests conducted during live deicing operations took place at the Central Deicing Facility, operated by Aeromag 2000 Inc. (Dorval Airport in Montreal). Other tests were also conducted on operational aircraft at the Central Deicing Facility operated by Hudson General (Pearson Airport in Toronto) and by Delta Air Lines (Hartsfield Airport in Atlanta).

2.1.2 Equipment

Five anemometers positioned at 0.6 m (2 ft.) intervals on a 3 m (10 ft.) vertical pole were used to record the air velocities (Photo 2.1). The 3 m (10 ft.) pole was mounted vertically on the bucket of a deicing vehicle (method of installation varies with the configuration of the deicing bucket (see Photos 2.2 and 2.3). The deicing vehicle used was an out of service Ford FMC model with no deicing fluid in the reservoir tanks. A horizontal clearance of 0.6 m (2 ft.) between the vertical pole and the deicing bucket was maintained to avoid disruption of the airflow. The bottom of the 3 m (10 ft.) pole, corresponding to the bottom of the deicing bucket was used as the datum from which distance above ground was measured. Additional bracing and safety harnesses were included for added stability and security. The five anemometers were connected to a data logger (Photo 2.4) that was connected in turn to a laptop positioned in the truck's cab. This set-up allowed real-time viewing and recording of the anemometer readings. A small generator placed in the deicing bucket provided power. A wind vane was mounted on the 3 m (10 ft.) pole to confirm that the anemometers were recording jet blast and not ambient air velocity.

A laser range finder was installed in the truck's cab (Photos 2.5 and 2.6). The instrument transmits a laser beam to measure linear distance from the instrument to any selected target. It has a maximum range of 100 m (300 ft.) with an accuracy of ± 3 mm.

VHF radio headsets provided communication between APS personnel. Deicing personnel were in communication with the deicing pad tower control. Timepieces were provided and synchronized with the laptop.

2.1.3 Description of Test Procedure

Preliminary tests were conducted to obtain nominal values for air velocities experienced in the vicinity of wing-mounted aircraft engines and to evaluate the need for further testing. These tests used a hand held anemometer at the end of a 3 m (10 ft.) pole. The pole was manoeuvred by a person in the bucket of the deicing vehicle provided by Aeromag 2000 Inc. The test was conducted during live deicing operations. The driver of the deicing vehicle was instructed to approach the jet blast area of the aircraft engine. The person in the bucket was then instructed to probe the area with the anemometer/pole assembly. Measurements were recorded from a hand-held logger in the cab.

After a conclusive series of preliminary tests (Attachment D), it was ascertained that further testing would be required. The objective of these subsequent tests was to develop detailed profiles of the air velocities experienced in the vicinity of wing-mounted aircraft engines. Nineteen tests were conducted. Of these, seventeen were conducted during live deicing operations; two were conducted on operational aircraft during ground time. Test procedures for the two conditions were identical except for the protocols associated with each.

APS monitored weather conditions on an ongoing basis throughout the test season to anticipate conditions that would require aircraft deicing. If these conditions were forecast, the test team was alerted 48 hours prior to the predicted event. Tests were scheduled during low traffic deicing periods so as not to disrupt regular operations.

Test equipment was installed indoors. All instruments were tested for functionality and then calibrated.

Tower control was instructed to announce the arrival of all aircraft with wing-mounted engines and their designated deicing bays. The test vehicle (deicing truck with anemometers) then proceeded to the prescribed safety zone of the deicing bay in anticipation of the aircraft arrival.

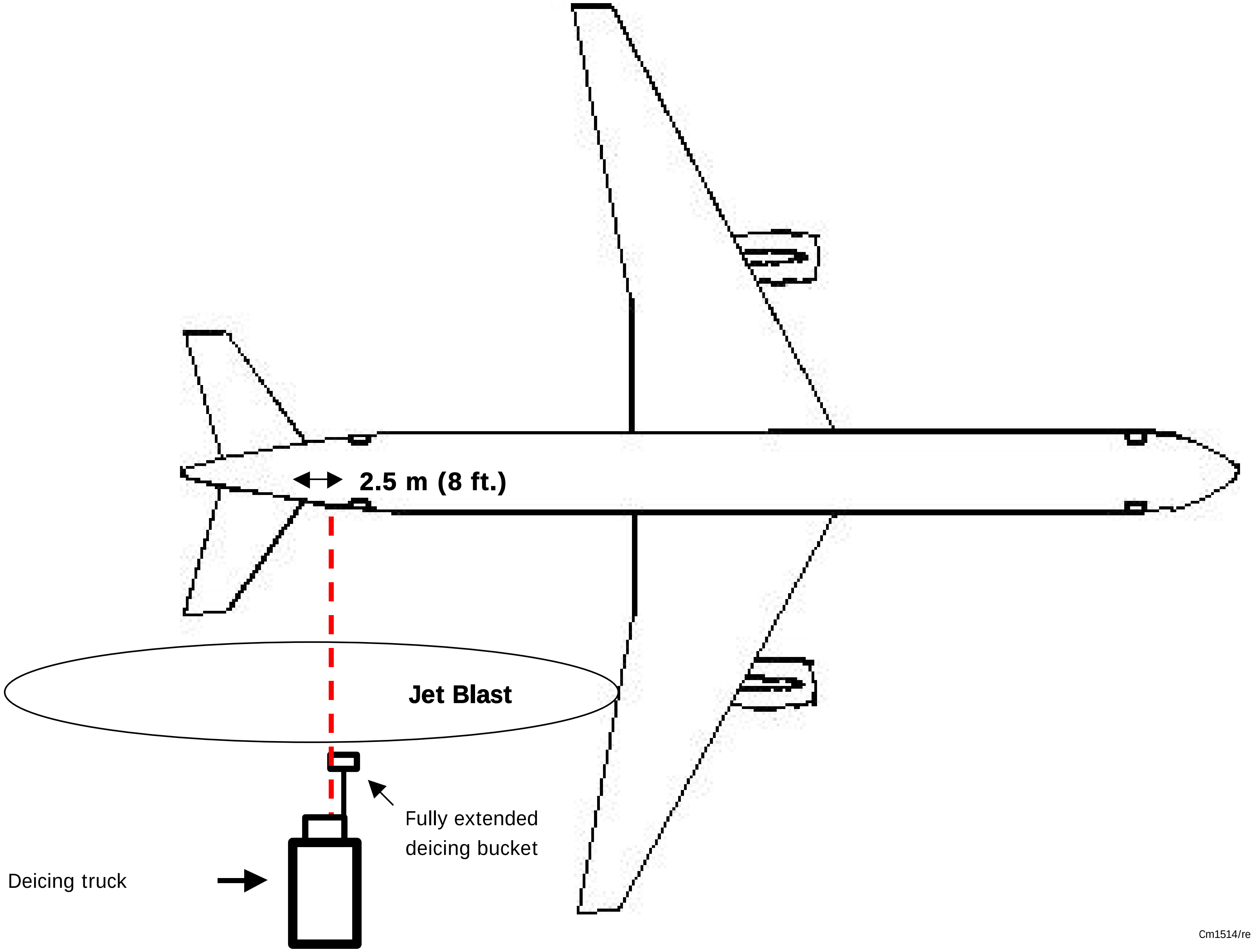
After its arrival and upon receiving clearance from the tower, the test vehicle moved to a position perpendicular to the wing-mounted engine, 2.5 m (8 ft.) ahead of the leading edge of the horizontal stabilizer root, and a distance corresponding to the aircraft wing span, away from the fuselage (Figure 2.1). The 2.5 m (8 ft.) distance represents the typical position of a deicing truck when the horizontal stabilizer of an aircraft is being deiced. The boom of the deicing vehicle was fully extended and the bucket lowered to ground level. Adjustments were made to confirm that the laser range finder was perpendicular and reading linear distance to the fuselage. The driver of the test vehicle was then instructed to advance in 0.6 m (2 ft.) increments toward the fuselage. Air velocity measurements of the aircraft at idle were recorded for a minimum period of one minute at each increment. Linear distance to the fuselage and the time corresponding to each increment position were recorded. The translation continued to a position perpendicular to the centreline of the engine. The deicing bucket was then raised 1.5 m (5 ft.) - the anemometers are mounted on a 3 m (10 ft.) pole, raising the pole assembly 3 m (10 ft.) extends the profile range to 4.6 m (15 ft.) - and the driver asked to retract from the fuselage in the same incremental way. (Photo 2.7). This allowed the air velocity to be recorded spatially over a flux area corresponding to the distance between the engine and the wing tip in a direction perpendicular to the fuselage. Upon completing the incremental retraction, the test vehicle cleared the aircraft and returned to the safety zone.

A second method, including the use of a surveying instrument (Total Workstation) in a remote area to record incremental movements of the test vehicle, was evaluated for feasibility. A reflector was placed atop of the 3 m (10 ft.) pole bearing the anemometers. The test vehicle would proceed to a dimensionally detailed part of the aircraft (e.g. wing tip). The surveying instrument was used to measure the distance to this point and note it as a datum. Consecutive measurements were recorded as the test vehicle proceeded through its incremental translation. The incremental distances, corresponding to distance from the test vehicle to the fuselage, of the aircraft were then derived through simple geometry.

This method was discontinued because of its functional complexity and limitations. Testing was limited to daytime and good visibility conditions. The aircraft often obstructed the necessary direct, clear path between the surveying instrument and the reflector. The complexity of the instrument logistics and parameters, in short, made this method impractical.

Figure 2.1

Top View of Aircraft and Truck Orientation



Cm1514/report/wind_vel/FIGURES.PPT

2.1.4 Data Forms

Two data forms were developed for these tests, one for the test person in the cab of the test vehicle (Figure 2.2) and the other for the test co-ordinator overseeing the test from a remote location (Figure 2.3). The principal information recorded on the “cab” form included:

- Aircraft type
- Airline
- Fin number
- Serial number
- Distance from test vehicle to aircraft engine
- Distance from test vehicle to leading edge of the horizontal stabilizer root
- Horizontal distance from Laser Range Finder to the anemometers
- Incremental distances from test vehicle to fuselage
- Time of incremental measurement recording
- Overview of aircraft layout

The principal information on the co-ordinator form included:

- Aircraft type
- Airline type
- Fin number
- Engine manufacturer
- Engine type
- Start/end test time
- Deicing bay number
- Wing tested (port/starboard)
- Ambient wind speed
- Direction of the aircraft with respect to the ice house

2.1.5 Personnel

A minimum staff requirement of two testers was needed to conduct these tests. Deicing personnel drove the deicing trucks. Co-operation of the deicing facilities and airport authorities was essential and varied with each test occasion.

FIGURE 2.2

WIND MEASUREMENTS ON AIRCRAFT

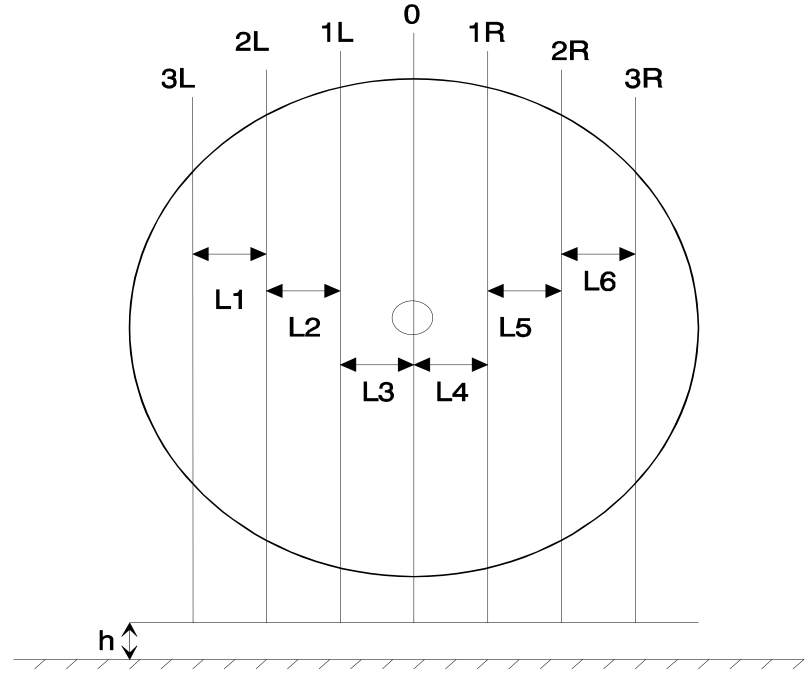
DATE: ____________________ **RUN #:** ____________________

AIRCRAFT TYPE: ____________________

AIRLINE: ____________________

FIN #: ____________________

SERIAL #: ____________________



h = Height from ground (ft)
L = Horizontal distance (ft)

TIME

	3L	2L	1L	0	1R	2R	3R
Time (Inward)							
Time (Outward)							

DISTANCE

	L1	L2	L3	L4	L5	L6	Height (ft)
Distance (Inward)							
Distance (Outward)							

COMMENTS: ____________________

MEASUREMENTS BY: ____________________

cm1514/report/wind_vel/Gform.xls
At: Wind
Printed: 04/07/01, 1:19 PM

FIGURE 2.3

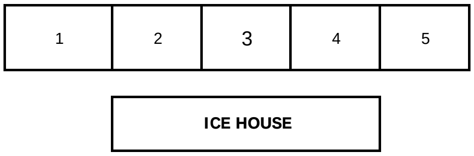
GENERAL FORM (EVERY TEST)

(TO BE FILLED IN BY TEST COORDINATOR)

DATE: ______________________________ **DEICING BAY #:** ________

RUN #: ______________________________ **WING:** PORT (A) STARBOARD (B)

DRAW DIRECTION OF A/C WRT DE-ICING BAY:



AIRCRAFT TYPE: ____________________

AIRLINE: ____________________

FIN #: ____________________

ENGINE MANUFACTURER: ____________________

ENGINE TYPE: ____________________

Start of Test Time: ____________________ (hr:min:ss)

End of Test Time: ____________________ (hr:min:ss)

COMMENTS: ____

____

____

____

____

____

MEASUREMENTS BY: ____

HANDWRITTEN BY: ____

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Printed: 04/07/01, 1:47 PM

2.2 Deicing Truck Overturning Loads

This subsection describes the deicing truck overturning load tests performed on an operational aircraft.

2.2.1 Test Sites

The test was conducted on one occasion at the central deicing facility operated by Hudson General, at Pearson Airport in Toronto.

2.2.2 Equipment

Four weigh scales were leased from a Toronto based company called Canadian Scale. The weigh scale pads had a maximum capacity of 9,000 kg (20,000 lb.) each with a graduation of 5 kg (10 lb.). The four weigh scales were connected to a logger and laptop allowing real-time monitoring and recording from remote locations. The weigh scales could be configured to record individually (as four independent weigh scales) or to record collectively (as a platform scale).

The air velocity distribution equipment outlined in Section 2.1.2 was used to develop an air velocity distribution profile prior to the test.

2.2.3 Description of Test Procedure

APS co-ordinated a joint effort with Hudson General and Royal Airlines. Hudson General provided a deicing truck and access to ice house facilities. Royal Airlines provided an operational Airbus A310 Aircraft. The latter was taxied to the deicing pad. Air velocity distribution profiles were recorded and developed according to the procedure outlined in Section 2.1.3.

After the air velocity distribution measurements were completed, the pilot of the aircraft was instructed to shut down the engines. Set-up for the truck-overturning test was initiated by placing a deicing truck 2.5 m (8 ft.) ahead of the leading edge of the horizontal stabilizer root, with the sides of the fluid reservoir tank centred and perpendicular to the centreline of the wing-mounted engine (Photos 2.8, 2.9, 2.10 and 2.11). The positions of the truck's wheels were noted and the truck was then removed. A single weigh scale was then placed in each of the previously noted wheel positions. The truck was then driven onto the weigh scale.

An "engines off" or "dead weight" measurement was recorded. The logger for the weigh scales was installed in a remote area clear of the engine blast. All personnel were instructed to clear the engine blast area. The pilot was asked to start the engines and run them at idle speed. Each weigh scale was logged for a minimum of two minutes. Video and still cameras were used to record oscillations of the truck subject to the blast. At the end of the test, the aircraft engine was shut down and the equipment dismantled.

2.2.4 Data Form

The air velocity distribution test was documented on a form outlined in Section 2.1.4. The form used for the overturning test included a dimensioned layout of the aircraft, the weigh scales, and the truck (Figure 2.4). Weight measured with the aircraft engine off was also recorded on the same form.

2.2.5 Personnel

A minimum crew of three was necessary. Hudson General supplied its own personnel to operate the deicing truck. Royal Airlines provided the pilot for the aircraft. The weigh scales were operated by a technician from the Canadian Scale Company.

2.3 Boeing 777 APU Air Velocity Tests

This subsection describes the Boeing 777 APU air velocity tests performed on an operational aircraft.

2.3.1 Test Sites

The tests were performed, on a single occasion, at the Delta Air Lines facility of Hartsfield Airport in Atlanta.

2.3.2 Equipment

The equipment detailed in Section 2.1.2 was used.

FIGURE 2.4

WEIGH SCALES GENERAL FORM (EVERY TEST)

DATE: ______________________

RUN #: ______________________

WING: PORT (A) STARBOARD (B)

AIRCRAFT TYPE: ______________________

AIRLINE: ______________________

FIN #: ______________________

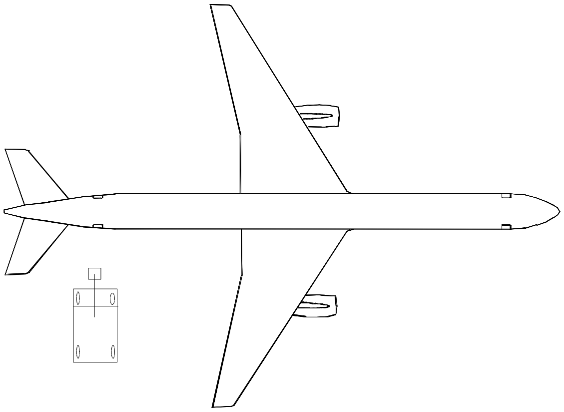
SERIAL #: ______________________

ENGINE MANUFACTURER: ______________________

ENGINE TYPE: ______________________

Start of Test Time: ______________________ (hr:min:ss)

End of Test Time: ______________________ (hr:min:ss)



Draw distances on diagram

Weigh Scales (Start Time)

Scale 1 ______________________ (hr:mm:ss)

Scale 3 ______________________ (hr:mm:ss)

Scale 2 ______________________ (hr:mm:ss)

Scale 4 ______________________ (hr:mm:ss)

Total ______________________ (hr:mm:ss)

Truck Dimension

Height __________ ft

Length __________ ft

Width __________ ft

COMMENTS:

____

____

____

MEASUREMENTS BY: ______________________

HANDWRITTEN BY: ______________________

2.3.3 Description of Test Procedure

APS co-ordinated a joint effort with Delta Air Lines. Delta Air Lines provided a deicing truck, access to the ice house facilities and an operational Boeing 777 Aircraft. Tests were conducted at one of the Delta gates. The pilot was instructed to turn on the aircraft APU. The APS team then approached the APU with the anemometer set-up described in Section 2.1.2. The latter was placed at a perpendicular distance of 2.1 m (7 ft.) from the centreline of the APU exhaust. At least one anemometer was directly aligned and perpendicular to centreline of the APU exhaust. The distance from the anemometers to the APU exhaust was increased in increments of 0.6 m (2 ft.) to a maximum distance of 4 m (13 ft.). Air velocities were monitored and recorded from a remote logger and laptop installation. Measurements were recorded with the aircraft air condition packs “on.” Measurements were recorded for a minimum of two minutes.

2.3.4 Data Forms

The data forms outlined in Section 2.1.4 were used.

2.3.5 Personnel

A minimum APS crew of two was necessary. Delta Air Lines supplied its own personnel to operate the deicing truck and a pilot for the aircraft.

2.4 Boeing 777 Three-Quarter Throttle Tests

This subsection describes the tests performed on an operational Boeing 777 aircraft.

2.4.1 Test Sites

The test was performed on a runway at Hartsfield Airport in Atlanta.

2.4.2 Equipment

The equipment detailed in Section 2.1.2 was used.

2.4.3 Description of Test Procedures

APS co-ordinated a joint effort with Delta Air Lines, who provided a deicing truck, access to the ice house facilities and an operational Boeing 777 Aircraft. Tests were conducted on a runway, to ensure a clear area behind the test set-up, at Hartsfield Airport. A Boeing 777 was taxied out to the runway. The test vehicle described in Section 2.1.2 was positioned 100 m (300 ft.) behind the starboard engine and offset 10 m (30 ft.) from the centreline of the engine in a direction away from the fuselage. The truck was perpendicular to the centreline of the aircraft engine (Figure 2.5). An emergency shutdown signal and escape route were established. Personnel were cleared from the jet blast area. The pilot was instructed to increase throttle to 70%. Air velocity measurements were recorded for approximately one minute.

2.4.4 Data Forms

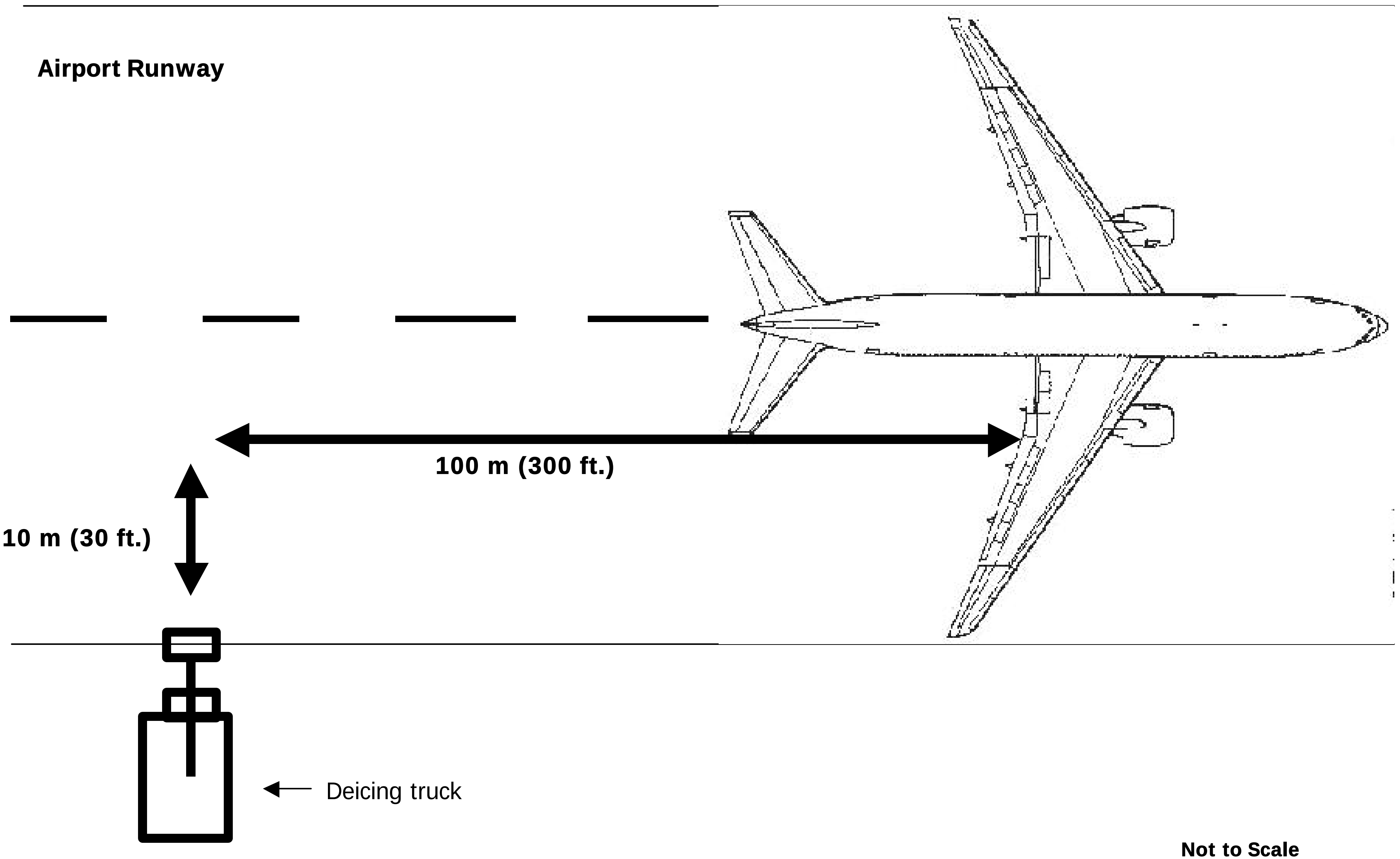
The data forms outlined in Section 2.1.4 were used.

2.4.5 Personnel

A minimum APS crew of two was necessary. Delta Air Lines supplied its own personnel to operate the deicing truck and a pilot for the aircraft.

Figure 2.5

Three-Quarter Throttle Test Layout Boeing 777



Not to Scale

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Photo 2.1
Anemometer Assembly

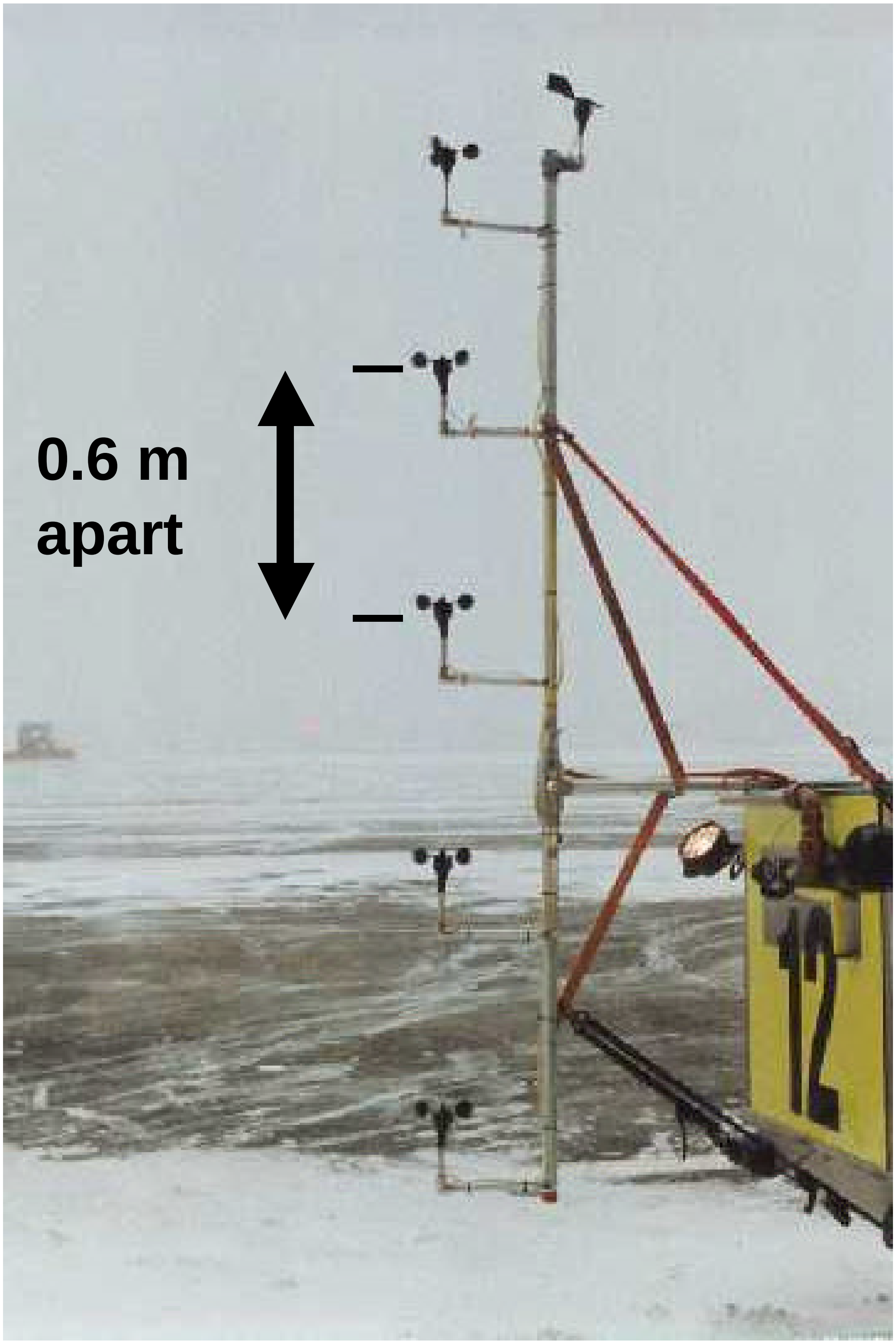


Photo 2.2
Installation on a Trump D-240 Deicing Truck

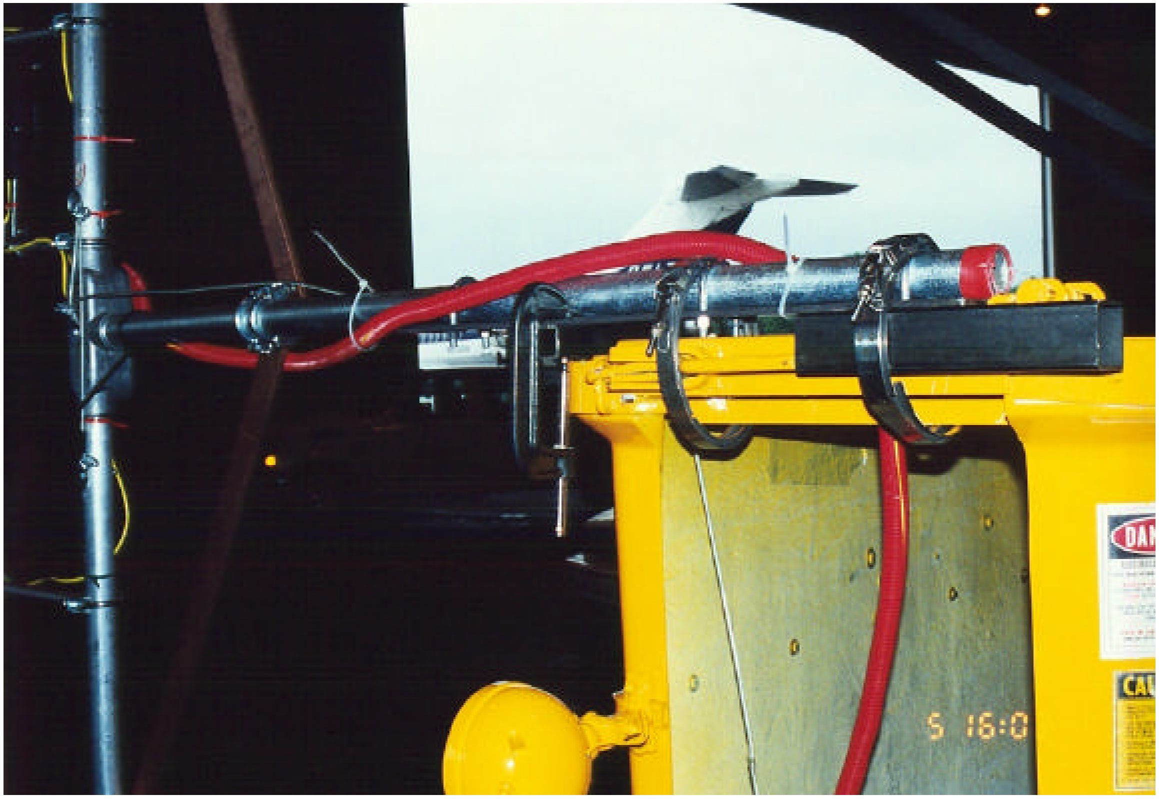


Photo 2.3
Installation on a FMC Deicing Truck

Photo 2.4
Anemometer Data Logger

Photo 2.5
Laser Range Finder Inside Deicing Truck Cabin

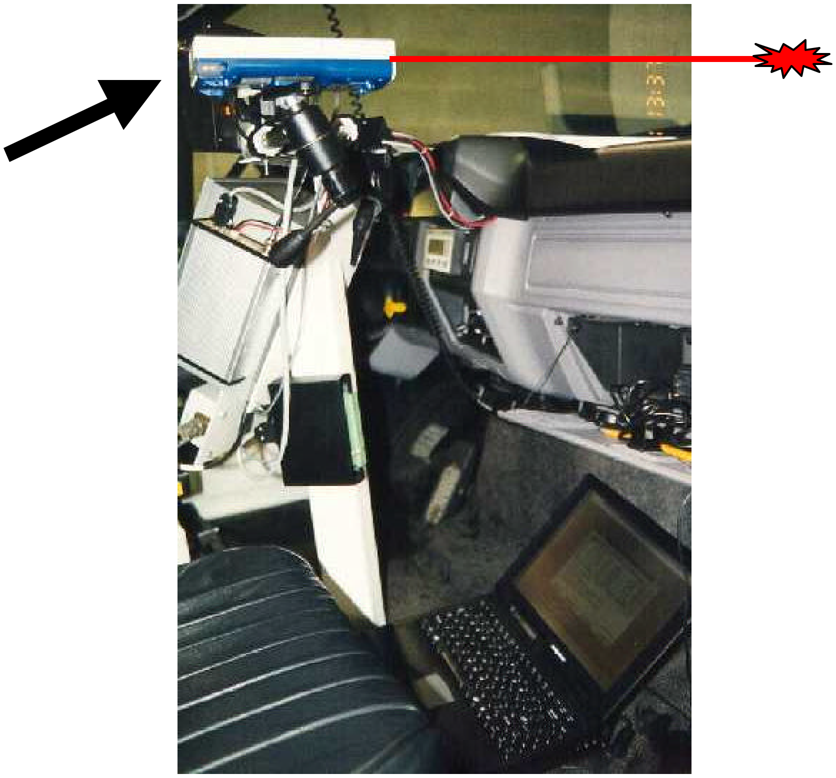


Photo 2.6

Front View of Laser Range Finder Inside Deicing Truck Cab

Photo 2.7

Anemometer Assembly Raised Above Ground

Photo 2.8

Weigh Scale Layout

Photo 2.9

Deicing Truck on Weigh Scale

Photo 2.10

Deicing Truck Position

Photo 2.11

Deicing Truck Position (Front View)

3. DESCRIPTION AND PROCESSING OF DATA

3.1 Air Velocity Distribution

3.1.1 Overview of Test Sessions

Preliminary tests were conducted in November 1998 to obtain nominal values for the air velocities in the vicinity of wing-mounted aircraft engines and evaluate the need for further testing. (Details of the preliminary tests are presented in Appendix D.)

Air velocity distribution tests were conducted between January and May 1999. A log of events was completed detailing the location, the number of tests, and the aircraft on which they were conducted (Table 3.1). (ID numbers associated with each aircraft correspond to the detailed individual air velocity vs time plots presented in Appendix C.) Test sessions were scheduled around peak deicing periods so as not to interfere with regular operations. The limited number of tests is another function of this parameter. Nineteen tests were conducted, seventeen on operational aircraft in live deicing operations during three different test sessions at Dorval Airport and two on operational aircraft during ground time at the Atlanta and Toronto airports.

Tests during live deicing operations generally took place during the early morning. The session in Atlanta took place at night, the one in Toronto during the day.

APS monitored weather conditions on an ongoing basis throughout the test season to anticipate conditions that would require aircraft deicing. If these conditions were forecast, the test team was alerted 48 hours prior to the predicted event.

Data, comments, and visual documentation were collected for each session. In addition, video and photo records were kept.

3.1.2 Discussion of Test Variables

Air velocity was recorded during each session from a location 2.5 m (8 ft.) ahead of the leading edge of the horizontal stabilizer root. Variables affecting the recorded air velocity included:

- Engine rating (the higher the rating, the higher the air velocity);

TABLE 3.1

AIRCRAFT TESTED FOR AIR VELOCITY

ID #	A/C Type	Location	# of Tests
12	A310	YYZ	1
4,5,6	A319	YUL	4
7,8,9, 10,11	A320	YUL	8
1	A340	YUL	1
2	Beechcraft 1900	YUL	1
Appendix D	B 737	YUL	1
Appendix D	B 767	YUL	1
13	B 777	ATL	1
3	SAAB 340	YUL	1
	9 A/C		19 Total

- Distance from the leading edge of the horizontal stabilizer root to the engine (the greater the distance, the lower the air velocity);
- Height of the engine above ground (the height above ground will affect where the highest air velocity is experienced); and
- Direction of the wind (a small crosswind can significantly redirect the direction of the engine thrust).

Table 3.2 shows the relation of these variables for the aircraft tested.

3.1.3 Description of Data Collected

The air velocity recorded for each of the five anemometers during each test was plotted against real-time (Figure 3.1). This shows peak velocities recorded during the test, the times of their occurrence, and their height above ground. (Detailed individual air velocity vs time plots are presented in Appendix C.)

3.2 Deicing Truck Overturning Loads

3.2.1 Overview of Test Sessions

One test was conducted on 23 March, 1999 at the central deicing facility operated by Hudson General, at Pearson Airport in Toronto. The test was scheduled on a day when no deicing operations were anticipated. Air velocity distribution measurements outlined in Section 2.1.3 were conducted as part of the two step operation. Weigh scale installations and verifications of functionality were part of a one-hour set-up process.

The four weigh scales were positioned, and the deicing truck was driven onto the weigh scales (one wheel on each). After the dead weight of the truck was recorded, the aircraft engines were turned on.

The number of sessions was limited by the flight schedule of the Airbus A310 provided by Royal Airlines.

Data, comments, and visual documentation were collected for the test session.

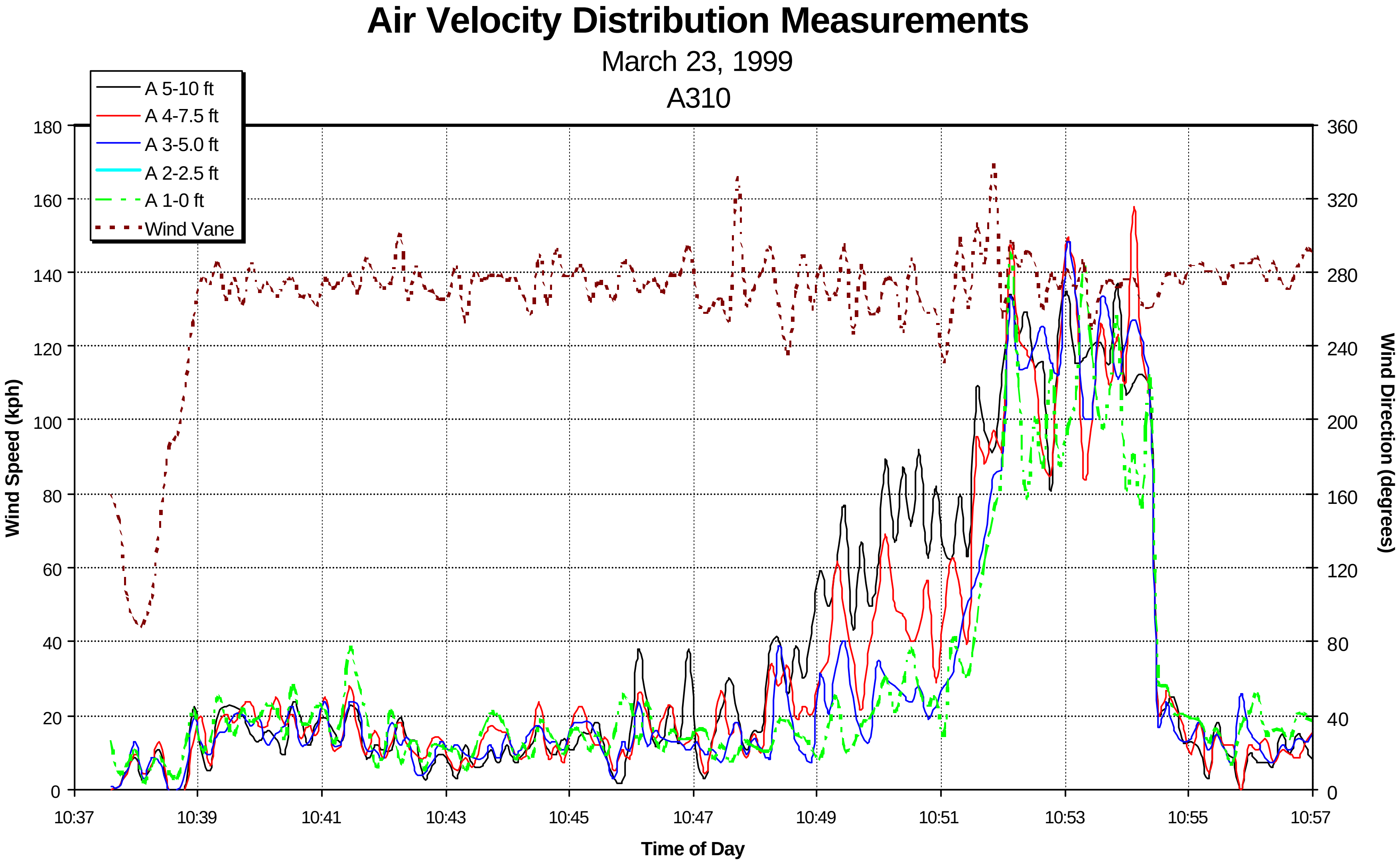
TABLE 3.2

RELATION OF AIRCRAFT VARIABLES

A/C TYPE	# of Tests	# of Engines	Typical Engine Rating	Engine to Stab. Dist.	Height of Engine Above Ground
A310	1	2	59,000 lb st (262 kN)	18 m (58 ft)	0.6 m (2 ft)
A319	4	2	22,000 lb st (98 kN)	12 m (38 ft)	1.1 m (3.6 ft)
A320	8	2	25,000 lb st (111 kN)	16 m (52 ft)	1.1 m (3.6 ft)
A340	1	4	34,000 lb st (151 kN)	19 m (61 m)	2.5 m (8.2 ft)
Beechcraft 1900	1	2	1,100 shp (820 kW)	8 m (28 ft)	0.3 m (0.98 ft)
B 777	1	2	84,000 lb st (375 kN)	28 m (93 ft)	0.8 m (2.6 ft)
SAAB 340	1	2	1,750 shp (1,350 kW)	10 m (34 ft)	0.6 m (2 ft)

Figure 3.1

Sample Test Data



3.2.2 Discussion of Test Variables

Variables affecting the initial air velocity measurements are outlined in Section 3.1.2.

Weight oscillations caused by the impact of the engine blast on the side of the deicing truck were recorded throughout the test. The oscillations are a function of the following variables:

- Geometric profile of deicing truck;
- Suspension design of the deicing truck;
- The amount of deicing fluid in the truck’s reservoir tank;
- The position, extension, and height of the truck’s boom;
- The type of aircraft engine creating the thrust; and
- Active crosswinds.

An out-of-service FMC deicing truck, with no deicing fluid in its reservoir tank, was tested on this particular occasion. The truck was not in its most vulnerable configuration. Royal Airlines provided an A310 aircraft.

3.2.3 Description of Data Collected

Air velocity values recorded for each of the five anemometers during the test were manipulated as described in Section 3.1.3.

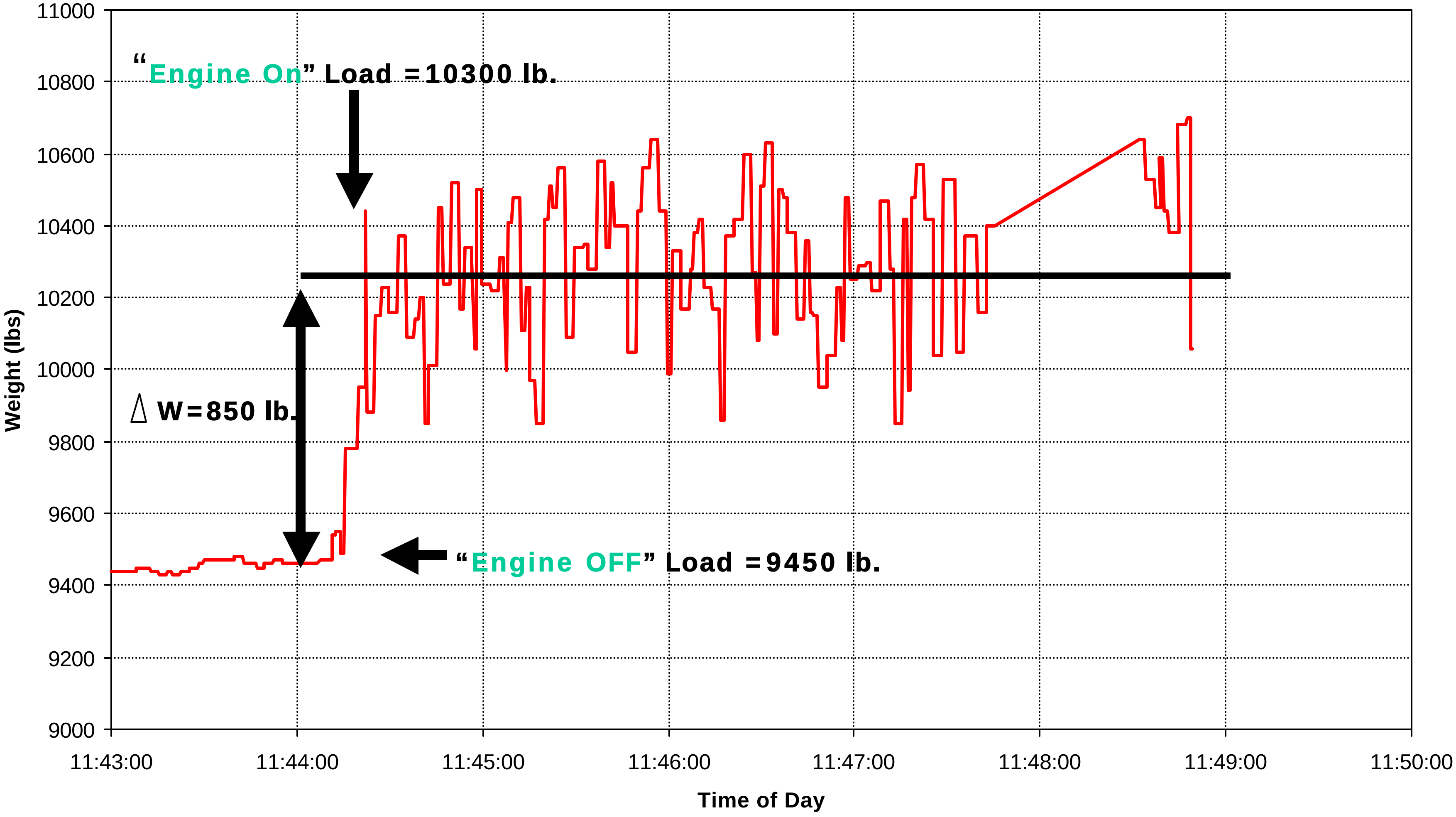
The data recorded from each weigh scale during the “engine on“ period was plotted against real-time. The corresponding dead weight recorded from each weigh scale during the “engine off” period was then superimposed on the plot so that change in weight could be noted (Figure 3.2).

Figure 3.2

Weigh Scale Test Data

WIND VELOCITY - YYZ - WEIGH SCALE #1 (Rear, Leeward)

March 23, 1999



Cm1514/report/wind_vel/FIGURES.PPT

3.3 Boeing 777 APU Air Velocity Tests

3.3.1 Overview of Test Sessions

One test was conducted on 5 May, 1999 at the Delta Air Lines gate of Hartsfield Airport in Atlanta. It was scheduled at night. Equipment outlined in Section 2.1.2 was used. Installation and verifications of functionality were part of a one-hour set-up process. The number of tests was limited by the predetermined list of events scheduled for that particular evening. Excessive heat created by the APU caused reparable damage to the anemometers. Tests were finally discontinued in an effort to avoid permanently damaging equipment.

3.3.2 Discussion of Test Variables

Data, comments and visual documentation was collected for the test session.

Air velocity was recorded during the test session. Variables were predominantly related to the type of APU and the distance from the anemometer to APU exhaust. It is suspected that the electrical loads on the APU (e.g. air conditioning on or off) can cause the exhaust patterns to change.

3.3.3 Description of Data Collected

Air velocity recorded for each of the five anemometers was plotted against real-time. This indicates velocities and the distance to the APU.

3.4 Boeing 777 Three-Quarter Throttle Tests

3.4.1 Overview of Test Session

One test was conducted on 5 May, 1999, on a runway at the Hartsfield Airport in Atlanta. The test was scheduled at night. Equipment outlined in Section 2.1.2 was used. Installation and verifications of functionality were part of a one-hour set-up process. The number of tests was limited by the flight schedule. Tests were discontinued due to permanent equipment damage caused by the first test. The jet blast of the engine at three-quarter throttle overwhelmed the structural integrity of equipment

(Photo 3.1). Predetermined emergency escape manoeuvres were implemented to prevent further damage to the deicing truck and avoid injury to personnel.

Data, comments, and visual documentation were recorded for each session.

3.4.2 Discussion of Test Variables

Due to the limited data collected, only speculative comments can be made regarding the test variables. It is suspected that the dominant variables are the engine rating and the distance between the anemometer and the engine.

3.4.3 Description of Data Collected

Air velocity recorded for each of the five anemometers was plotted against real-time. This plot indicates peak velocities and the distance above ground, where they were measured. Approximately two minutes of data were recorded.

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Photo 3.1
Anemometer Test Equipment and Deicing Bucket Damaged

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4. ANALYSES AND OBSERVATIONS

4.1 Air Velocity Distribution

Air velocity tests on aircraft engines at idle were conducted on a total of nineteen aircraft. Nine types of aircraft were tested during the nineteen test sessions. Of these, seventeen were conducted during live deicing operations; two were conducted on operational aircraft. Table 4.1 details a list of the aircraft tested and the associated peak air velocity measurements recorded. (ID numbers associated with each aircraft correspond to the detailed air velocity vs time plots presented in Appendix C.) The maximum peak velocity recorded during the test sessions was 180 km/h and was consistently associated with the Airbus 320 which has two engines and a thrust rating of 11,250 kg (25,000 lb.) each. Five tests were conducted on this particular type of aircraft. The lowest peak velocity measurement recorded was 60 km/h and corresponds to the SAAB 340 (a turbo propeller aircraft).

Of the aircraft tested, the Boeing 777 had the highest thrust rating, 40,500 kg (90,000 lb.) of thrust per engine. Moreover, the peak air velocity recorded for this aircraft is only 100 km/h (Table 4.1).

The air velocity measurements were consistently recorded 2.5 m (8 ft.) ahead of the leading edge of the horizontal stabilizer root. The geometric configurations of different aircraft will cause the distance between the aforementioned position and the wing-mounted engine to vary. On an Airbus A320, this distance is approximately 17 m (55 ft.). Alternatively, the same distance on a B 777 measures 30 m (100 ft.) (Table 4.1).

The air velocity recorded for each of the five anemometers during each test was plotted against real-time (Figure 3.1). This shows peak velocities recorded during the test, the times of their occurrence, and their height above ground. (Detailed individual air velocity vs time plots are presented in Appendix C.) The velocity versus time plot can then be correlated with times corresponding to linear distance from the anemometers to the fuselage as recorded during the session. Alternatively, the average velocity for each incremental interval can be computed and then related to the corresponding anemometer/fuselage distance. This information creates a two-dimensional plot of the vertical air velocity contours, perpendicular to the centreline of the aircraft engine and at a distance of 2.5 m (8 ft.) ahead of the leading edge of the horizontal stabilizer root (Figure 4.1).

Furthermore, the contour lines can be scaled and superimposed onto a scale drawing of the aircraft (Figure 4.2). The contour lines for the Airbus A310 in Figure 3.3 show air velocities at the height of the horizontal stabilizer to be less than 25 km/h.

TABLE 4.1

RELATION OF AIRCRAFT VARIABLES

A/C TYPE	# of Tests	# of Engines	Typical Engine Rating	Engine to Stab. Dist.	Height of Engine Above Ground	Peak Velocity at 2.5 m from Horz. Stab.
A310	1	2	59,000 lb st (262 kN)	18 m (58 ft)	0.6 m (2 ft)	160 Km/h
A319	4	2	22,000 lb st (98 kN)	12 m (38 ft)	1.1 m (3.6 ft)	140 Km/h
A320	8	2	25,000 lb st (111 kN)	16 m (52 ft)	1.1 m (3.6 ft)	180 Km/h
A340	1	4	34,000 lb st (151 kN)	19 m (61 m)	2.5 m (8.2 ft)	120 Km/h
Beechcraft 1900	1	2	1,100 shp (820 kW)	8 m (28 ft)	0.3 m (0.98 ft)	100 Km/h
B 777	1	2	84,000 lb st (375 kN)	28 m (93 ft)	0.8 m (2.6 ft)	100 Km/h
SAAB 340	1	2	1,750 shp (1,350 kW)	10 m (34 ft)	0.6 m (2 ft)	60 Km/h

Figure 4.1

Air Velocity Distribution - Half Profile (8 ft. Ahead of Horizontal Stabilizer)

AIR VELOCITY VERTICAL CROSS SECTION PROFILE

Toronto Airport, March 23, 1999

A310

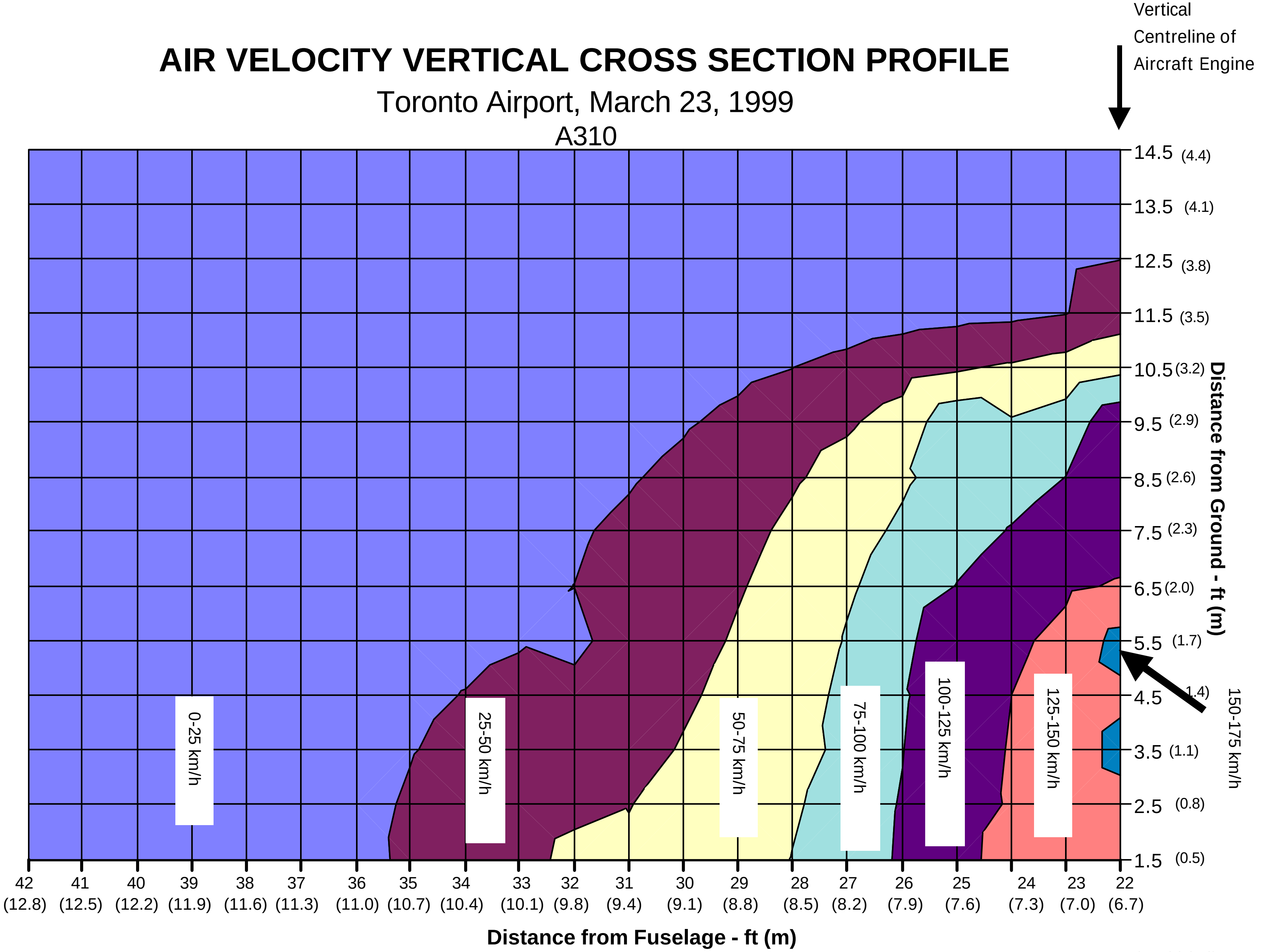

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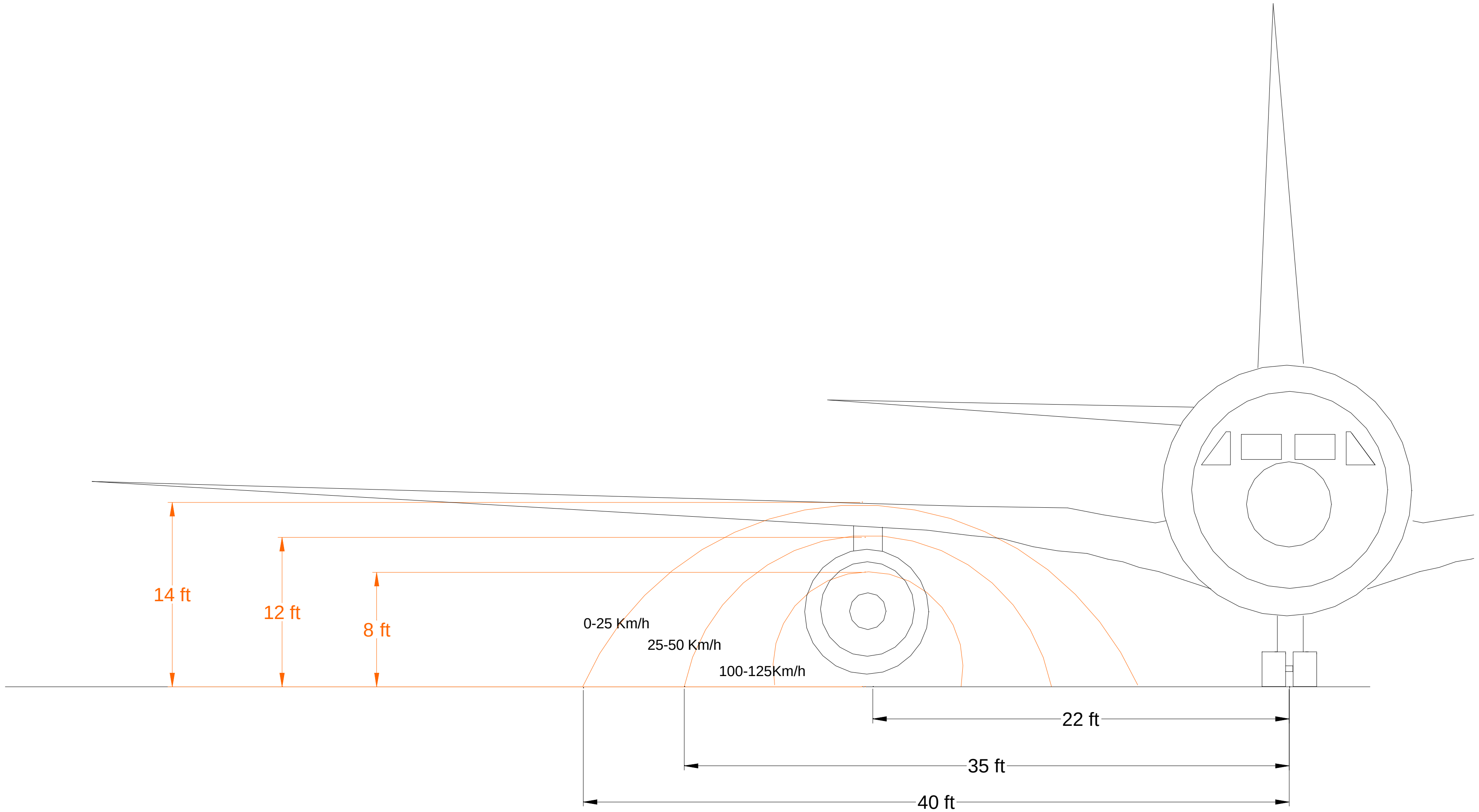
FIGURE 4.2

VERTICAL CROSS SECTION OF VELOCITY CONTOURS 8 FT AHEAD OF HORIZONTAL STABILIZER



cm1514/report/wind_vel/Velocity Contours.xls
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Reproducibility of the measurements collected is illustrated in Figure 4.3, showing data collected on three occasions from three Airbus A320 aircraft. All three cases recorded the same peak velocity.

The height of the aircraft engine affects the vertical distance above ground where the peak velocity will be recorded. The diameter of the engine typically dictates the area of the velocity distribution (Table 4.1).

It was noted on several occasions that a small crosswind was enough to effectively divert the natural path of the engine blast (Figure 4.4). On one occasion, air velocity measurements in areas where the blast was anticipated recorded no velocity. The same occasion provided visual confirmation; the diverted air path was confirmed as it effectively rippled a glycol puddle beneath the fuselage.

The highest air velocities were often experienced near the ground. It is suspected that this is due to ground effect.

4.2 Deicing Truck Overturning Loads

The FMC truck provided for the test had an empty fluid reservoir tank. The net weight of the truck was 12,091 kg (26,870 lb.), this translates to a relative weight of approximately 1,800 kg (4,000 lb.) for each of the front wheels and 4,230 kg (9,400 lb.) for each back wheel.

When the Airbus A310 engine was turned on, the impact force of the jet blast caused a weight transfer from the windward side of the truck to the leeward side. The order of magnitude is approximately 382 kg (850 lb.) for the back wheels and 45 kg (100 lb.) for the front (Figure 4.5). The difference can be attributed to two factors, namely, the truck suspension and the greater surface area of the non-aerodynamic geometry of the reservoir tank. Moreover, the centroid of the tank side area was aligned with the centreline of the aircraft engine.

The weigh scale "weight transfer" data can be used to obtain the overturning moment value. The resisting moment caused by the dead weight (W_d) is calculated about the long leeward axis of the truck and subtracted from the overturning moment created by the weight shift (W_{avf}) caused by the air velocity force (Figure 4.6). The equation is:

$$M = \Delta W * D$$

Figure 4.3

Test Data Reproducibility

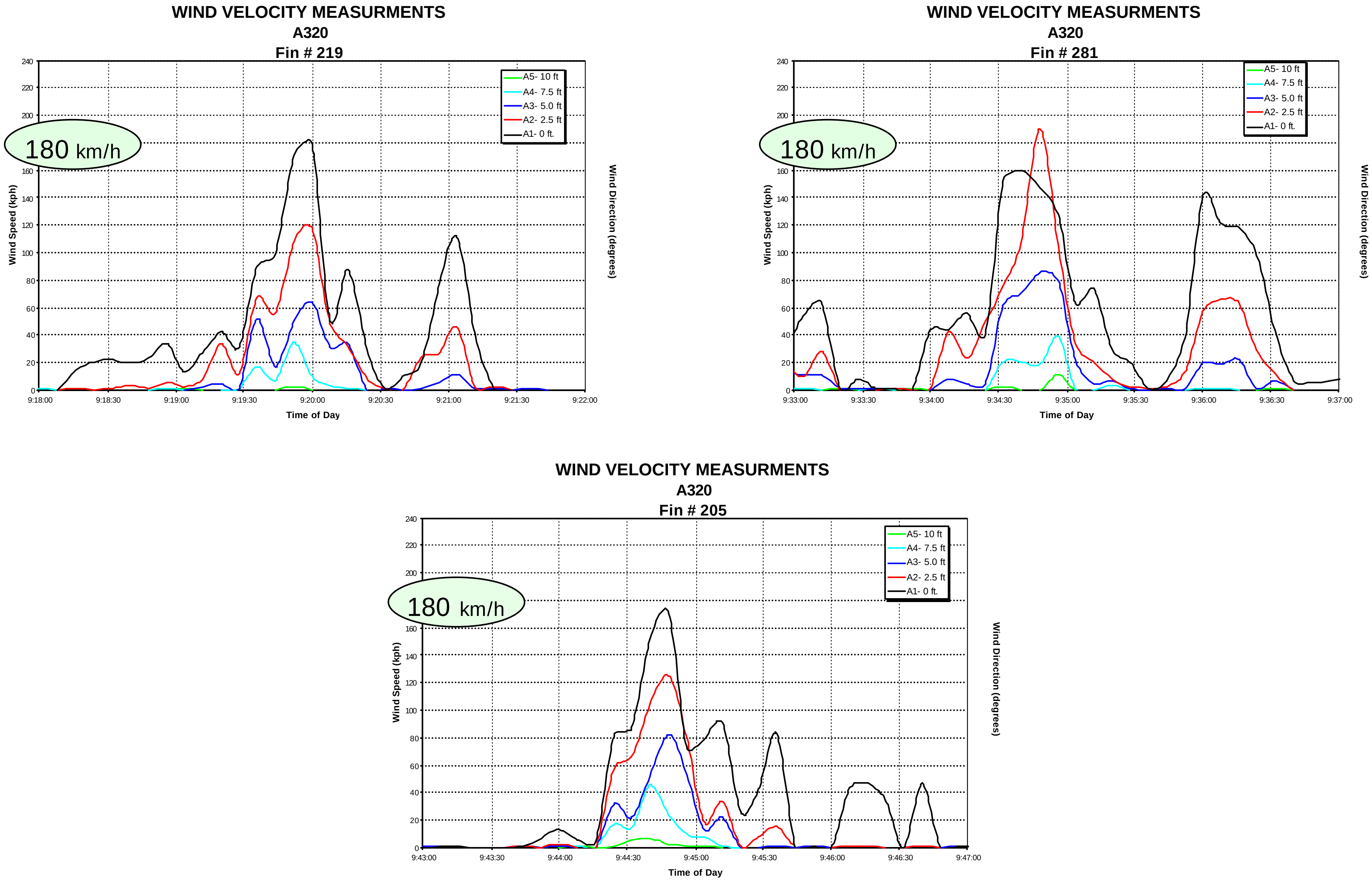


Figure 4.4
Crosswind Effect

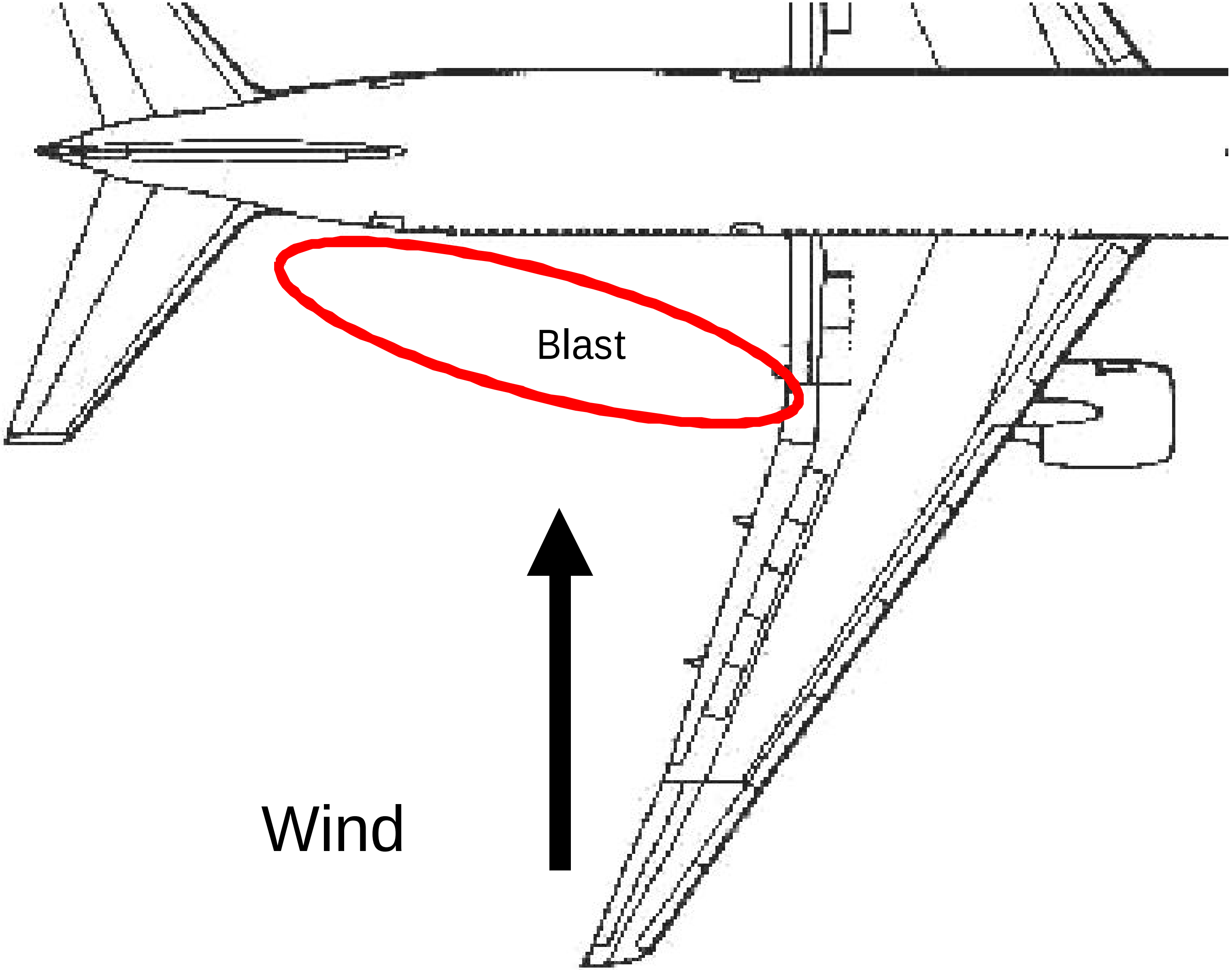
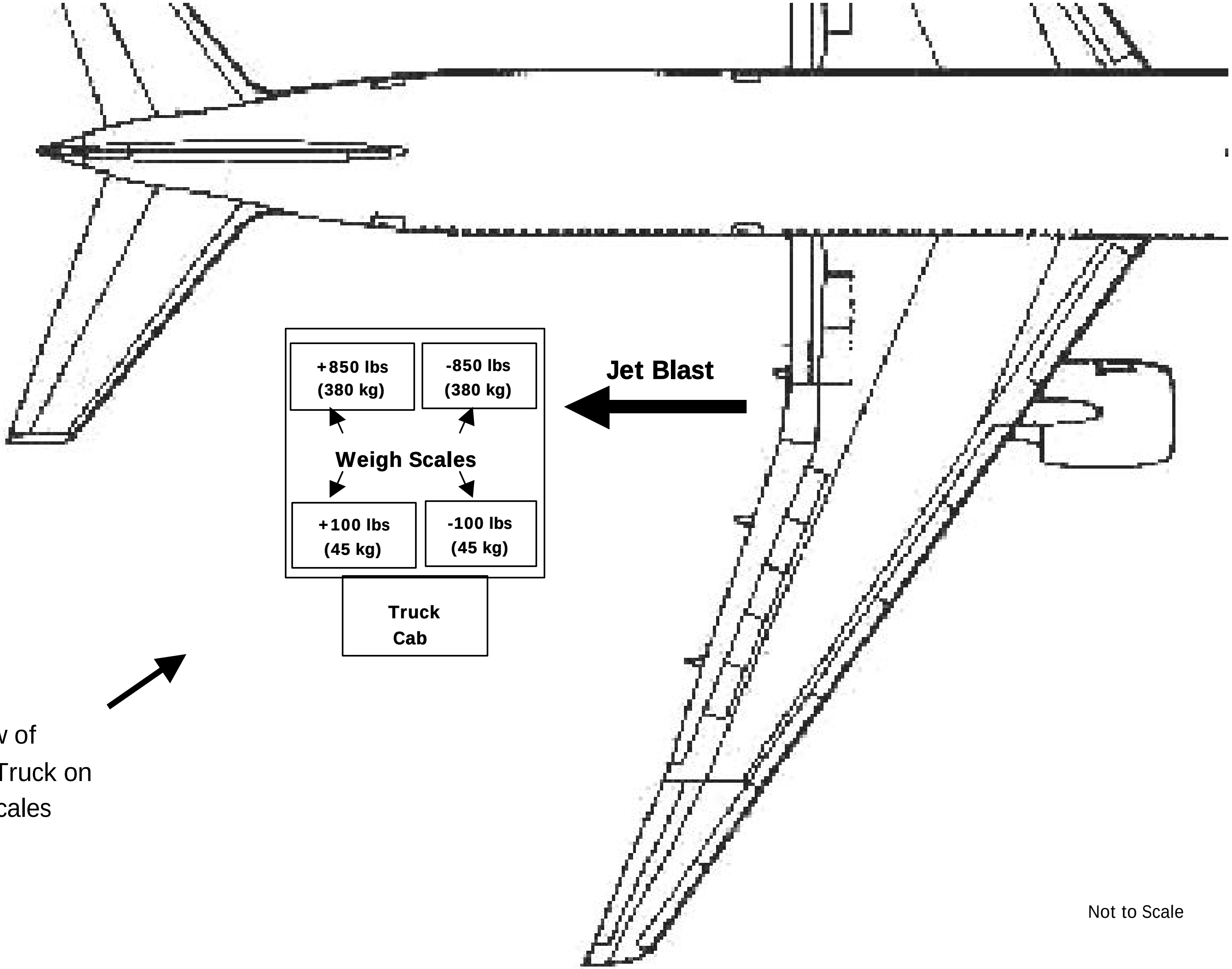


Figure 4.5

Weight Transfer Caused by Jet Blast



Top View of
Deicing Truck on
Weigh Scales

Not to Scale

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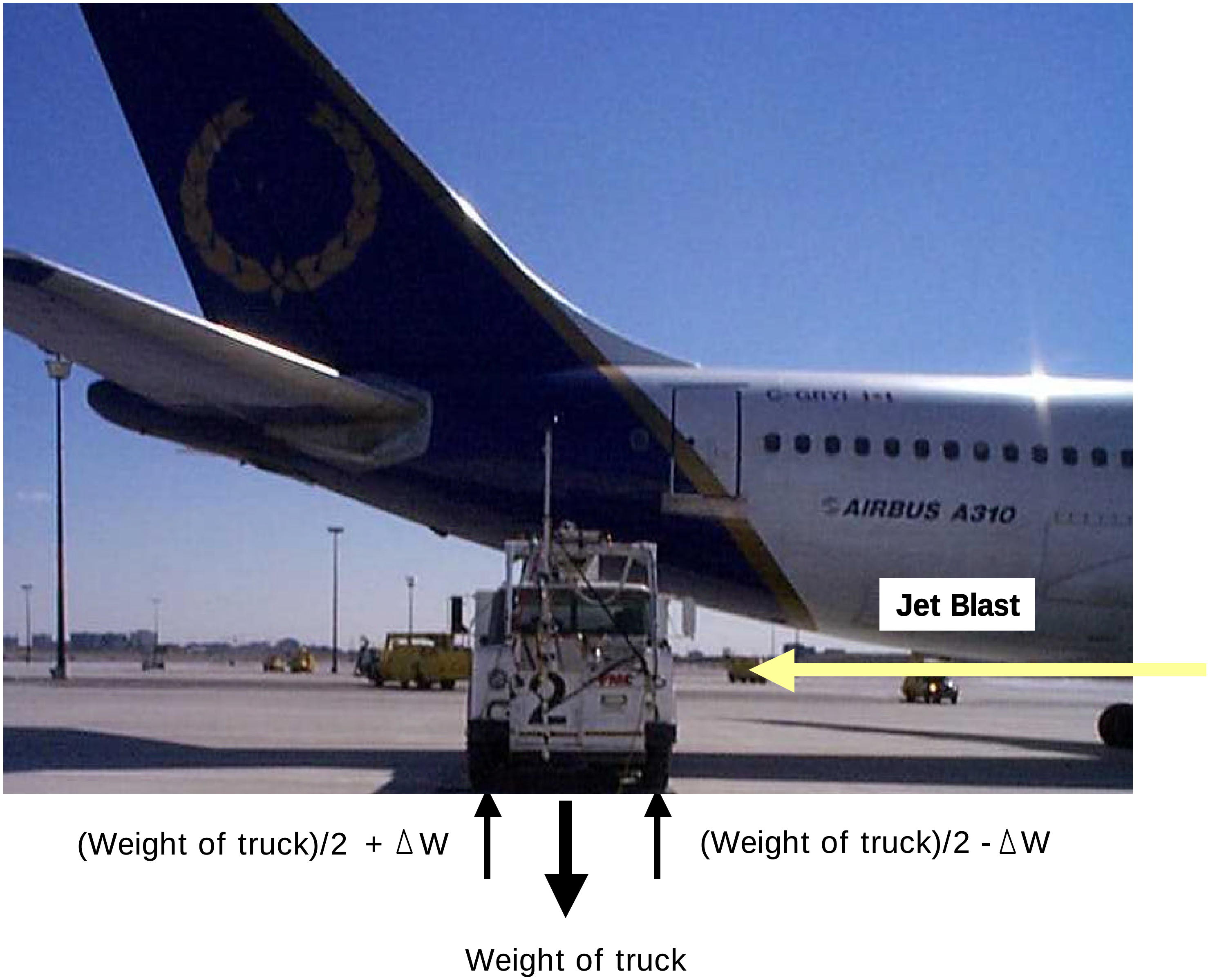
Figure 4.6

Weigh Scale Overturning Moment Calculation



Where $M =$ overturning moment
$\Delta W = (W_d - W_{avf})$
$D =$ (distance between truck wheels)

The overturning moment is calculated to be 10,300 Nm. The total moments about the leeward wheels of the truck, due to the weight, are 145,800 Nm. This moment is approximately 7.1% of the required moments to overturn the truck.

Alternatively, the approximate overturning moment can be calculated using air velocity data. The surface area of the deicing truck is horizontally subdivided into quadrants corresponding to the positions (distance above ground) of the five anemometers initially used to obtain the measure of air velocity. The surface area is then subdivided vertically into lengths corresponding to the incremental movements of the deicing vehicle during the recording sessions (Figure 4.7). The force exerted by the air velocity on each quadrant can be approximated by use of the force equation[1], and assuming an effective drag coefficient of 1.0:

$$F_x = 1/2\ (\rho * A * V^2)$$

Where $F_x =$ force in Newtons (N)
$\rho =$ density of air
$A =$ area of subdivided quadrant
$V =$ air velocity

The Airbus A 310 used for this test recorded a peak air velocity of 160 km/h. The magnitude of the air velocity forces created by the A 310 thrust ranged from the order of 24 N to 2,300 N. These forces can be converted to moments acting on the truck. The overturning moment is calculated by using the forces for each quadrant, and the dead weight centroidal force of the truck, to calculate the moment about the long leeward axis of the truck at ground level. The total overturning moments exerted by the air velocity can then be shown as a percentage of the resisting moment caused by the dead weight centroidal force.

The total moments exerted by the thrust are approximately 10,700 Nm. The total moments about the leeward wheels of the truck, due to the weight, are 145,800 Nm. The moments exerted by the thrust are approximately 7.4% of the required moments to overturn the truck. It should be noted that the moment exerted is proportional to the square of the wind speed. Therefore, doubling the wind speed would quadruple the moment. Moreover, it is

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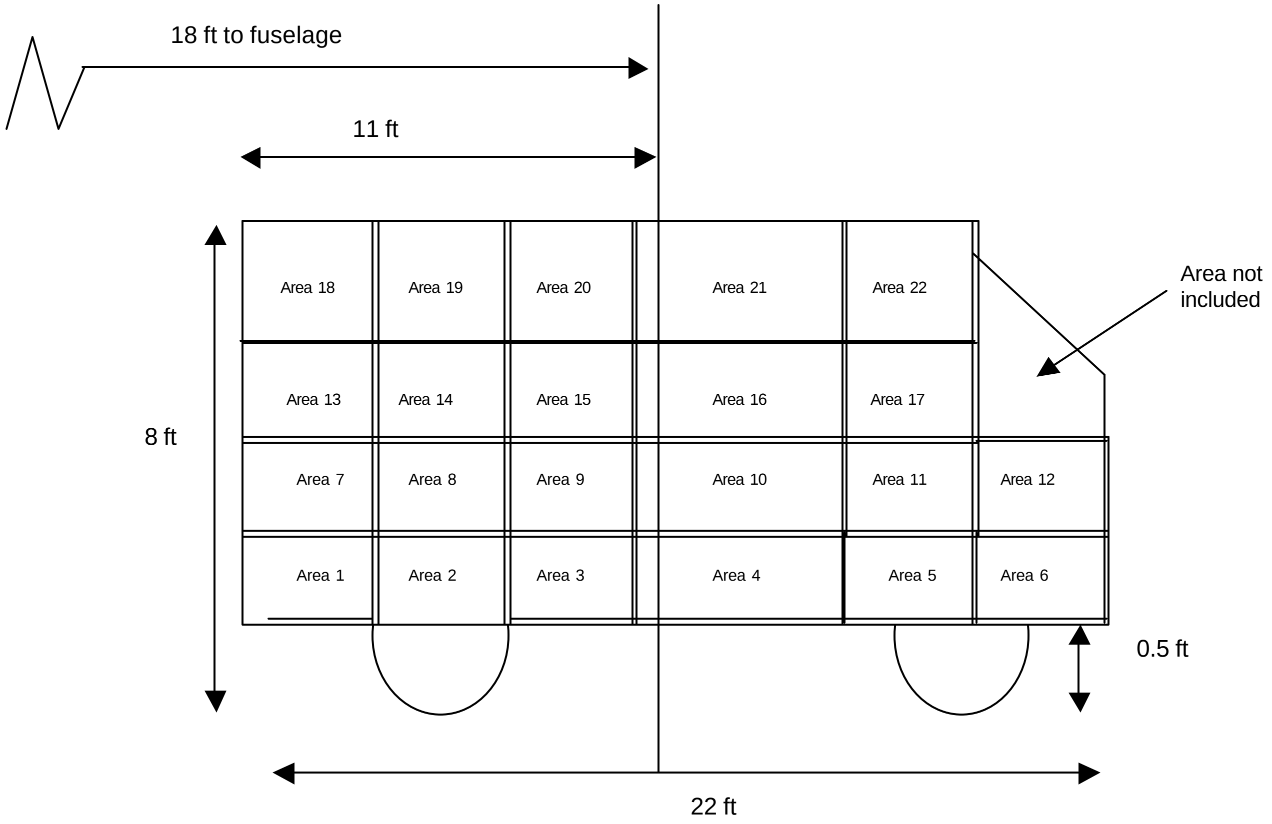
[1] Hutcheon, N. B., and Handegord, G. O. P., *Building science for a cold climate.* Third printing by the Institute for Research in Construction. Ottawa: National Research Council Canada.

Figure 4.7

Tipping Moment Analysis



The direction of the jet blast relative to this diagram would be perpendicular and into the page.

Assumptions:

-No oscillation
-No fluid in truck
-Constant airflow

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suspected that the distance away from the engine and the air velocities measured vary according to an exponential function. It has been stated that air velocities immediately at the exhaust of an aircraft engine are typically supersonic.

The difference between the two methods of calculation for the present case is approximately 4%.

Analysis was based on four main assumptions:

- No truck oscillation
- No fluid in truck
- Constant air flow created by jet blast (not turbulent or pulsating)
- Truck was stationary (not in motion as is often the case in live deicing)

In effect, these assumptions result in an analysis that is non-conservative. It is suspected that if these assumptions were considered active, they would negatively affect the stability of the deicing truck.

Truck oscillations were observed during testing. Turbulent, pulsating airflow created by the engine jet blast contributes to the truck oscillation. In theory, if the frequency of the oscillation matches the frequency of the pulsating airflow, the amplitude of oscillation would increase and negatively affect the stability of the deicing truck.

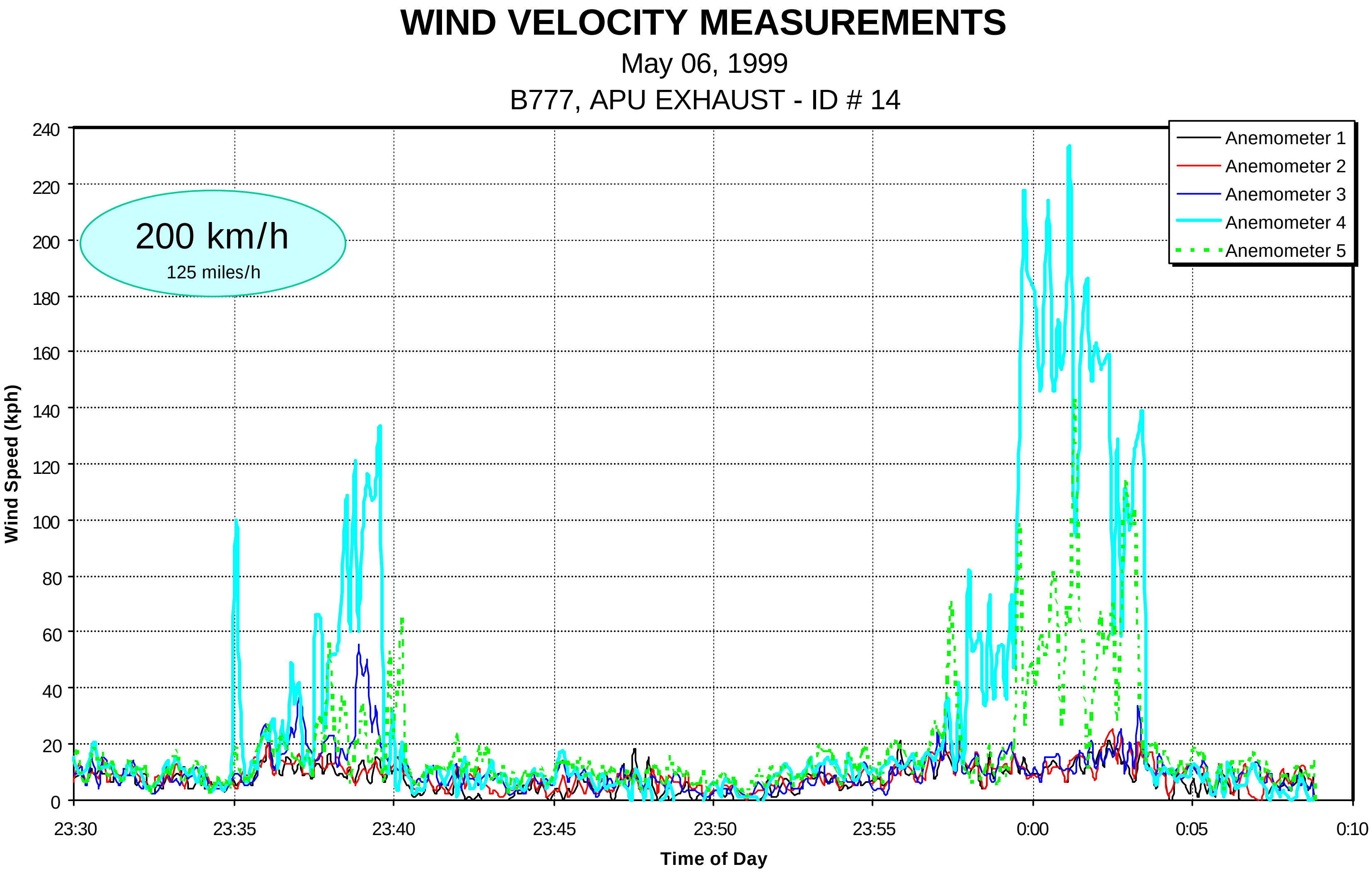
The deicing truck was not in its most vulnerable configuration during the test. A vulnerable position could include having the truck boom fully extended and over to one side, creating a huge lever arm and a center of gravity high above the ground. A vulnerable position would affect the deicing truck stability.

4.3 Boeing 777 APU Air Velocity

Air velocity was recorded at the exhaust of a Boeing 777 APU. The APU exhaust is approximately 0.3 m (1 ft.) in diameter and is located on the port side of the aircraft tailcone. The exhaust plume profile was narrow and was analysed with two anemometers positioned at a vertical distance of 0.6 m (2 ft.) apart. Measurements were recorded at a distance of seven feet behind the exhaust, where a deicing bucket may be placed while deicing the horizontal stabilizers. A peak velocity of 200 km/h (100 mph) was recorded (Figure 4.8). Excessive heat produced by the exhaust of the APU was sufficient to melt the anemometer coupling. The exhaust of the APU heated the 3 m (8 ft.) pole described in Section 2.1.2 to a temperature that

Figure 4.8

APU Velocity Test Data



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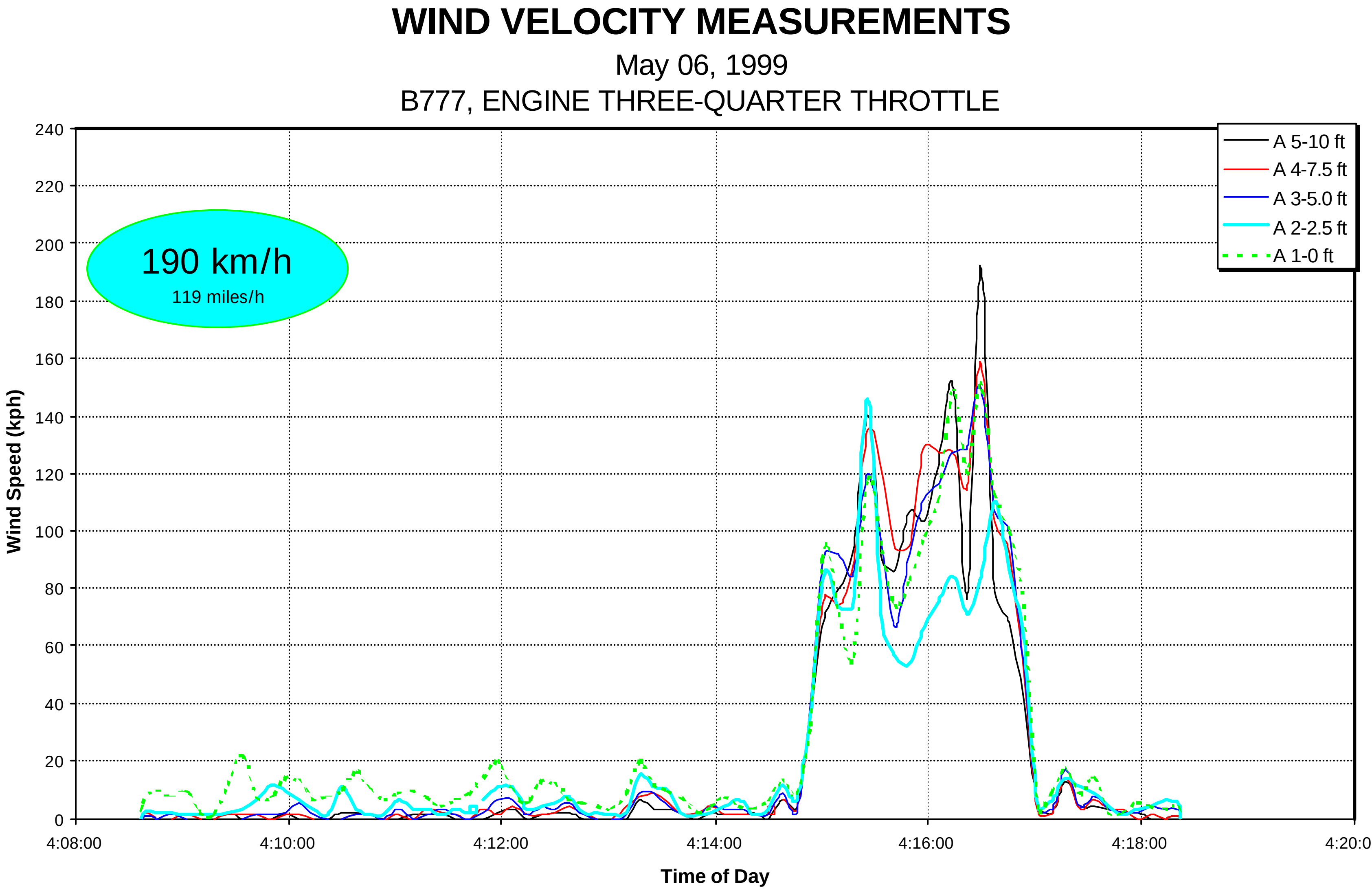
could not be handled with bare hands. Tests were discontinued in an effort to prevent further damage to equipment.

4.4 Boeing 777 Three-Quarter Throttle Test

Air velocity measurements were recorded for approximately two minutes. The peak velocity recorded was 190 km/h (119 mph) (Figure 4.9). The jet blast, described as a “huge wave of air”, was overwhelming in power, and dramatically acknowledged by personnel inside the deicing truck’s cab. The test was discontinued due to equipment damage caused by the blast, the imminent possibility of overturning the truck, and fear of causing personal injury to the crew.

Figure 4.9

Three-Quarter Throttle Test Data



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5. CONCLUSIONS

Nominal values of air velocity were obtained in the vicinity of the aircraft horizontal stabilizers during live deicing. A preliminary method of checking the safety of deicing vehicles during live deicing operations was developed. Supplemental objectives were also addressed.

5.1 Air Velocity Distribution

The sample data collected has provided insight into the magnitude of air velocities experienced during live deicing operations, 2.5 m (8 ft.) ahead of the leading edge of the horizontal stabilizer root. A viable method for conducting further tests has been established. The notion that larger aircraft with more powerful engines produce the highest air velocity is false; air velocity measurements experienced in the vicinity of the horizontal stabilizers are aircraft specific, not a function of aircraft size or engine rating.

Nine aircraft models were tested during 19 tests. The Airbus A320 recorded the highest peak velocity (180 km/h), the SAAB 340 the lowest (60 km/h).

5.2 Deicing Truck Overturning Loads

Initial steps towards a viable test method to measure overturning loads on deicing vehicles, during live deicing, were developed. The stability of deicing trucks can be evaluated by using weigh scales or calculated to a close approximation measuring air velocity distribution. The stability and behaviour of deicing trucks is truck specific not generic. The FMC deicing truck used in the test session experienced only 7.4 percent of the total moment needed to overturn it. The FMC truck had no deicing fluid in the reservoir tanks and was not in its most vulnerable configuration during the test. Other influences, such as truck movement, may affect truck stability and should be evaluated.

5.3 Boeing 777 APU Air Velocity Tests

Air velocity measurements were obtained 2.1 m (7 ft.) behind the Boeing 777 APU. The peak velocity recorded was 200 km/h. Excessive damage-causing heat was observed in the vicinity of the exhaust and testing was discontinued. Caution should be used when deicing this aircraft.

5.4 Boeing 777 Three-Quarter Throttle Tests

Boeing 777 three-quarter throttle tests recorded an air velocity in excess of 190 km/h, but were discontinued because of equipment damage. The stability of the deicing truck during this test was affected by the overwhelming wave of air created by the aircraft engine and the truck was considered unsafe.

6. RECOMMENDATIONS

6.1 Air Velocity Distribution

- Testing should be extended to a selection of aircraft representative of the international transport fleet. It is disconcerting that aircraft size and air velocity can not be directly associated.
- The 2.4 m (8 ft.) distance ahead of the leading edge of the horizontal stabilizer root that was used as a standard throughout the testing should be increased incrementally in future tests. This distance represents an ideal situation and is not necessarily representative of the varied deicing practices. The distance should be increased to establish a safety threshold.
- Current and future data should be complied into a table, published, and made available to all deicing facilities. The table should outline aircraft type, air velocity, and distance to the engine where measurement was taken.
- Future testing should evaluate the high heat created at a location immediately behind the exhaust of wing-mounted engines. (Because of the physical limitations of some deicing trucks, some deicing facilities are forced to have deicing procedures that place the trucks immediately behind the aircraft engine.)

6.2 Deicing Truck Overturning Loads

- Testing should be repeated with the deicing vehicle set in its most vulnerable configuration (e.g. its boom raised at full extension and over to one side of the truck).
- The technology to log four weigh scales simultaneously should be acquired so that truck oscillation effects can be evaluated.
- Testing should be conducted on a representative selection of deicing trucks in representative configurations.
- Testing should be conducted with varying amounts of deicing fluid in the reservoir tank.
- Future testing should attempt to simulate natural (non-ideal) live deicing conditions (e.g. braking suddenly, strong ambient winds).

6.3 Boeing 777 APU Air Velocity Tests

- Operators of deicing facilities should be advised of the high exhaust velocity and the high heat produced in the vicinity of the Boeing 777 APU.

- Further testing should be conducted to confirm that high velocity does not affect the deicing truck's stability.

- Further testing should be conducted to obtain nominal values for the temperatures in the vicinity of the APU and to confirm that the high temperatures do not damage vital truck components.

- Replace anemometers by pitot tubes, which are not affected by heat.

6.4 Boeing 777 Three-Quarter Throttle Tests

- Further research should be conducted to learn the frequency and occurrence of excessive engine power being used on deicing pads. Airline pilots should be questioned.

- A safe, generic, maximum throttle threshold should be established for all aircraft models in service. These values should be compiled into a table and published.

- Deicing facilities should be made aware of this possible occurrence and prompted to take necessary precautions.

- Engine throttle should be increased incrementally if test is repeated, to create a more controlled situation.

- Replace anemometers by sturdy pitot tubes.

APPENDIX A

WORK STATEMENT

AIRCRAFT AND FLUID HOLDOVER TIME TESTS FOR WINTER 98/99

APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE

WORK STATEMENT

AIRCRAFT AND FLUID HOLDOVER TIME TESTS FOR WINTER 98/99

(December 1998)

1. INTRODUCTION

Following the crash of a F-28 at Dryden in 1989 and the subsequent recommendations of the Commission of Inquiry, the Dryden Commission Implementation Project (DCIP) of Transport Canada (TC) was set up. Together with many other regulatory activities an intensive research program of field testing of deicing and anti-icing fluids was initiated with guidance from the international air transport sector through the Society of Automotive Engineering (SAE) G-12 Committee on Aircraft Ground De/Anti-icing. As a result of the work performed to date Transport Canada and the US Federal Aviation Administration (the FAA) have been introducing holdover time regulations and the FAA has requested that the SAE, continue its work on substantiating the existing ISO/AEA/SAE Holdover Time (HOT) tables (TC research representing the bulk of the testing).

The times given in HOT Tables were originally established by the Association of European Airlines based on assumptions of fluid properties, and anecdotal data. The extensive testing conducted initially by the DCIP R&D Task Group and subsequently by its successor Transport Canada, Transportation Development Centre (TDC) Aviation Winter Operations R&D (AWORD) Group has been to determine the performance of fluids on standard flat plates in order to substantiate the times or, if warranted, to recommend changes.

TDC has undertaken most of the field research and much other allied research to improve understanding of the fluid HoldOver Times. Most of the HOT table cells been substantiated, however low temperatures have not been adequately explored and further tests are needed.

The development of ULTRA by Union Carbide stimulated all the fluid manufacturers to produce new long lasting anti-icing fluids defined as Type IV. All the Type IV fluids were upgraded in early 1996 and therefore all table conditions need to be re-evaluated and the table revised if necessary. Certain special conditions for which advance planning is particularly difficult such as low temperatures with precipitation, rain or other precipitation on cold soaked surfaces, and precipitation rates as high as 25 gm/dm^2/hr need to be included in the data set. All lead to the need for further research.

Although the Holdover tables are widely used in the industry as guides to operating aircraft in winter precipitation the significance of the range of time values given in each cell of the table is obscure. There is a clear need to improve the understanding of the limiting weather conditions to which these values relate.

An important effort was made in the 94/95 and 95/96 seasons to verify that the flat plate data were representative of aircraft wings. Airlines cooperated with DCIP by making aircraft and ground support staff available at night to facilitate the correlation testing of flat plates with performance of fluids on aircraft. An extension of this testing was to observe patterns of fluid failure on aircraft in order to provide data to assist pilots with visual determination of fluid failure, and to provide a data to contamination sensor manufacturers. The few aircraft tests made to validate the flat plate tests were inconclusive and more such tests are needed. Additional tests testing with hot water for special deicing conditions were not completed. All these areas are the subjects for the further research that is planned for the 98/99 winter.

The primary objective of 97/98 testing was the performance evaluation of new and previously qualified Type IV fluids over the entire range of conditions encompassed by the holdover time tables. The effect of different variables on the fluid holdover time, in particular the effect of fluid viscosity, was examined and deemed to be significant. As a result, any future Type IV fluid holdover time testing will be conducted using samples representative of the manufacturers lowest recommended on-wing viscosity. Current methods for establishing holdover times in snow involve outdoor testing, which has been the source of industry concern for some time. It is recommended that a snowmaking device in development need to be evaluated for the future conduct of snow holdover time tests in controlled conditions. The study of fluid buffers was also continued in 97/98 and identified several industry concerns which will be addressed in further research. The adherence of contaminated fluid to aircraft wings was also evaluated in a series of simulated takeoff runs without aircraft rotation. Further research in these areas is needed.

2. PROGRAM OBJECTIVE (MCR 16)

Take an active and participatory role to advance aircraft ground de-icing/anti-icing technology. Develop international standards, guidance material for remote and runway-end de-icing facilities, and more reliable methods of predicting de-icing/anti- icing holdover times.

3. PROGRAM SUB-OBJECTIVES

3.1. Develop reliable holdover time (HOT) guideline material based on test information for a wide range of winter weather operating conditions.

3.2. Substantiate the guideline values in the existing holdover time (HOT) tables for fluids that have been qualified as acceptable on the basis of their impact on aircraft take-off performance.

3.3. Perform tests to establish relationships between laboratory testing and real world experience in protecting aircraft surfaces.

3.4. Support development of improved approaches to protecting aircraft surfaces from winter precipitation.

4. PROJECT OBJECTIVES

4.1. Develop holdover time data for all newly qualified de/anti-icing fluids.
4.2. Develop holdover time data for Type IV fluids using lowest qualifying viscosity samples.
4.3. Develop supplementary data for a reduced buffer ‘de-icing only’ Table.
4.4. Determine whether recycled, recovered fluid can be used as a ‘De-icing only’ fluid.
4.5. Determine whether the extreme precipitation rates used for laboratory testing of de/anti-icing fluids are in fact encountered in practice.
4.6. Obtain equipment for laboratory production of artificial snow which most closely reproduces natural snow.
4.7. Assess the limiting conditions of wind, precipitation and temperature under which water can be used as the first step of a two-step de-icing procedure.
4.8. Determine the patterns of frost formation and of fluid failure initiation and progression on the wings of high-wing turbo-prop and jet commuter aircraft.
4.9. Assess the practicality of using vehicle-mounted remote contamination detection sensors for pre-flight (end-of-runway) inspection.
4.10. Provide base data on the capabilities of remote sensors.
4.11. Provide pilots with reference data for the identification of fluid failure. Quantify pilot capabilities to identify fluid failure
4.12. Provide support services for the conduct of tests to determine under what conditions contaminated fluid adheres to aircraft lifting surfaces.
4.13. Assess whether pre-warming fuel at time of re-fuelling will help to eliminate the ‘cold soaked’ wing problem.
4.14. Develop a low-cost test wing which can be used in the laboratory in lieu of field testing full scale aircraft.
4.15. Establish the safe limits for de-icing truck operation when de-icing aircraft with the engines running.
4.16. Provide general support services.
4.17. Disseminate test findings

5. DETAILED STATEMENT OF WORK

5.1. General

5.1.1. Planning and Control

Develop a detailed work plan, activity schedule, cash flow projection, project management control and documentation procedures (as specified in Section 9,"Project Control") within three weeks of effective commencement date, confirming task priorities, suggesting hardware and software suppliers, broadly identifying data needs and defining the roles of subcontractors, and submit to TDC for review and approval.

5.1.2. Safety and Security

Particular consideration will be given to safety in and around aircraft on the airport and deicing sites In the event of conflict between access for data gathering to obtain required test results and safety considerations, safety shall always govern.

5.2. Holdover Time Testing and Evaluation of De/Anti-icing Fluids

5.2.1. Newly Certified Fluids

Conduct flat plate tests under conditions of natural snow and artificial precipitation to record the holdover times, and to develop individual Holdover Time Tables based on samples of newly certified or re-certified fluids supplied by Fluid Manufacturers under as wide a range of temperature, precipitation rate, precipitation type, and wind conditions as can be experienced. Anticipate tests for one new fluid. Snow tests shall be conducted outdoors, and ZD, ZR-, Zfog, and CSW tests will be performed in the laboratory. All testing shall be performed using the methodology developed in the conduct of similar tests for Transport Canada in past years.

5.2.2. Low Viscosity Type IV Anti-icing Fluids

Fluid holdover time testing of Type IV fluids will be conducted using procedures established during past test seasons but using fluid with the lowest operational use viscosity.

5.2.2.1. Flat Plate Tests for New Type IV Fluids

Conduct flat plate tests under conditions of natural snow and artificial precipitation to record the holdover times, and develop individual Holdover Time Tables based on samples of new Type IV fluids supplied by Fluid Manufacturers under as wide a range of temperature, precipitation rate, precipitation type, and wind conditions as can be experienced. Anticipate for four new fluids using samples with one viscosity. Snow tests shall be conducted outdoors, and ZD, ZR-, Zfog, and CSW tests shall be performed in the laboratory using methodology applied in past years.

5.2.2.2.Effect on Holdover Time of Viscosity

Conduct tests aimed at determining the effect of fluid viscosity on holdover time. Tests shall be conducted in light freezing rain and freezing drizzle conditions at various temperatures in the National Research council (NRC) Climatic Environment facility (CEF) using low and high viscosity samples representing production limits of three anti-icing fluids: a propylene, an ethylene and the Fluid X (which will become the benchmark for laboratory based HOT testing).

Anticipate a total of approximately 100 tests to be conducted under ZR- and ZD at -3 and -10 Celsius at low and high rates.

5.2.3. Recycled Fluids as Type I Fluids

5.2.3.1.Holdover Times

A complete set of holdover time tests shall be conducted using two fluid test samples of recovered glycol based freezing point depressant fluid which have been recycled and exhibit nominal conformance to Type I de-icing fluid performance characteristics. The objective of this series of tests is to establish a sound base of data sufficient to establish valid holdover time tables for these fluids.

5.2.3.2.Compatibility with Type IV Fluids

Fluid compatibilty trials shall be conducted using various combinations of the recycled fluids and commercial Type IV fluids. Determine how the Inland fluids perform when used in conjunction with a Type IV fluid overspray.

5.3. Supplementary Data for Deicing Only Table

Evaluate the test conditions used in establishing the deicing only table by undertaking the following test series at sub zero temperatures but with no precipitation.

5.3.1. Establish Quantity of Fluid for Field Tests.

Conduct a series of comparative laboratory tests with 0.5, 0.25 and 0.1 litre per plate. Consider the case of spraying for frost with a fan shape to cover a wide area with a small amount of fluid compared with a stream as used to remove snow or ice. Examine typical fluid quantities representing frost removal spray. Conduct some tests on aircraft piggybacking on other testing if feasible.

5.3.2. Establish Temperature of Fluid for Field Tests

Laboratory tests will be performed with fluids initial temperatures at the spray nozzle of 60ºC, 50ºC, and 40ºC initial temperature.

Field tests on aircraft will be designed to measure the loss of fluid temperature and to measure fluid evaporation and enrichment during the air transport phase between spray nozzle and wing surfaces, for various distances and shapes of spray pattern (3 distances; 2 spray patterns).

5.3.2.1.

Examine the effect on the final freeze point of sprayed fluids on the wing, resulting from variations in the temperature of the fluid (60ºC, 50ºC, and 40ºC).

5.3.2.2.

Examine the effect on wing heat and fluid evaporation of removing contaminant from the wing surface. Various degrees of ice depth shall be deposited using a hand-held rainmaker, including a very light coating to simulate frost. The amount of fluid sprayed shall be controlled by the operator, spraying until a clean surface results**.**

5.3.3. Perform tests at current buffer limit as baseline.

Perform a series of comparative tests using buffers at 3ºC and 10ºC to compare to the new data and the data collected last season with buffers at 0ºC .

5.3.4. Simulate High Wind Conditions

Tests shall be performed using NRC fans producing winds up to 30 kph for comparison with the earlier series of tests with speeds up to 20 kph

5.3.5. High Relative Humidity

Perform a series of plate tests at 90% RH to compare results to those already gathered. Review the condition with weather services to determine typical RH values during deicing only conditions.

5.3.6. Cold Soaked Wings

Perform a series of tests on cold soak boxes to establish whether the natural buffer provided by evaporation would be sufficient to provide protection if the wing were in a cold-soaked condition, with wing temperature several degrees below OAT. These tests can be run in conjunction with high humidity tests when deposition of frost on cold soaked surfaces would normally be expected.

5.3.7. Effect of Snow Removal on Fluid Heat Input

Perform tests to establish whether removal of snow results in extesive amounts of heat being carried away and insufficient heat being transferred to the wing during deicing.

Expose flat plates to snowfall (either natural or as simulated by approved equipment) and protect snow catches of various thicknesses. Tests shall be run in an area protected from further snowfall. Fluid shall be applied with a hand sprayer, until the plate is cleaned, measuring the amount of fluid applied. The final fluid concentration on the plate shall be measured. The heat lost in fluid run off shall be measured. Parallel tests will be conducted on bare surfaces.

A carefully calculated heat balance shall be determined for each experiment based on the temperatures of the applied fluid, the plate and the collected run-off material.

5.3.8. Effect of Composite Surfaces on Evaporation

Evaluate the effects of the use of composite materials in wings on the heat transfer from deicing fluid to the wing. Conduct a series of laboratory comparative tests on a several samples of composite surfaces.

Identify an appropriate aircraft having a wing surface composed of new technology composite material as well as aluminium, determining the thermal pathways connecting the composite surfaces to the main wing structure.

Conduct field tests on a sample aircraft.

5.3.9. Unpowered Flight Control Surfaces

Field trials will be conducted on DC9 aircraft to assess the impact of fluids of various buffers on the freedom of operation of the unpowered elevator control tabs to establish whether the natural buffer provided by evaporation would be sufficient to provide protection if the wing were in a cold-soaked condition, with wing temperature several degrees below OAT

5.3.10.Field Tests on Aircraft

Three overnight test sessions shall be planned for these tests. Tests shall be conducted on aircraft types including the McDonnell Douglas DC-9 and Canadair RJ, with a minimum of one night for each type. Testing on a third aircraft type would be useful to improve confidence and to confirm the universality of the results. Use an ice detector sensor system to provide a separate source of data.

5.3.11.Laboratory Tests

The number of proposed tests shall be controlled by limiting tests to the minimum number of ambient conditions that will support conclusions on the significance of the issues raised while maintaining a good level of confidence. As a minimum, this encompasses about 230 plate tests and would require about 8 days at the NRC CEF Facility or other suitable facility.

5.4. Flow of Contaminated Fluids from Wings during Takeoff

5.4.1. Requirement

Evaluate anti-icing fluids for their influence on adherence, in particular, propylene based Type IV fluids which were observed during fluid failure

A test plan shall be developed jointly with NRC.

Two days of testing at Mirabel Airport shall be planned.

Use an ice contamination sensor to assist in documenting contamination levels to provide valuable assistance in data gathering. A contingency allowance to fund sensor company participation shall be included.

Data collected during these trials shall include:

- type of fluid applied;
- record of contamination level prior to take off runs,;record of level of contamination following takeoff runs;
- observations, photography and video taping, and ice sensor records; and
- specifics on aircraft takeoff runs obtained from NRC personnel.

5.4.2. Conduct of Trials and Assembly of Results

Coordinate all test activities, initiating tests in conjunction with NRC test pilots based on forecast weather. Analyse results and document all findings in a final technical report and in presentation format.

5.5. Aircraft Full-Scale Tests

5.5.1. Purpose of Tests

Conduct full-scale aircraft tests:

- To generate data which can be used to assist pilots with visual identification of fluid failure;
- To generate data to be used to assess a pilot's field of view during adverse conditions of winter precipitation for selected aircraft; (See item 5.11)
- To compare the performance of de/anti-icing fluids on aircraft surfaces with the performance of de/anti-icing fluids on flat plates;
- To examine the pattern of failure using Type IV fluid brands not tested in the past; and
- To further investigate progression of failure on the two wings in crosswind conditions.

5.5.2. Planning and Coordination

Planning and preparation for tests including provision of facilities, personnel selection and training, and test scheduling shall be the same as provided to TDC in previous years

5.5.3. Testing

All tests and dry runs shall be performed using the methodology developed in the conduct of similar tests for Transport Canada in past years.

Test planning will be based on the following aircraft and facilities:

Aircraft	Airline	Test Locn.	Deicing Pad	Deicing Crew
Canadair RJ	Air Canada	Dorval	Central	Aéromag 2000
ATR42	Inter Canadian	Dorval	Central	Aéromag 2000

5.5.4. Test Measurements

Make the following measurements during the conduct of each test:

- Contaminated thickness histories at selected points on the wings. The selection of test points shall be made in cooperation with the Transportation Development Centre,
- Contamination histories at selected points on wings (selected in cooperation with the Transportation Development Centre),
- Location and time of first failure of fluids on the wings,
- Pattern and history of fluid failure progression,
- Time to failure of one third of the wing surface
- Concurrent measurement of time to failure of fluids on flat plates. The plates will be mounted on standard frames and on aircraft wings at agreed locations,
- Wing temperature distributions,
- Amount of fluid applied in each test run and fluid temperature,
- Meteorological conditions, and
- For crosswind tasks, effects of rate of accumulation on each wing.

In the event that there is no precipitation during full-scale tests, the opportunity shall be taken to make measurements of fluid thickness distributions on the wings. These measurements shall be repeated for a number of fluid applications to assess the uniformity of fluid application.

5.5.5. Pilot Observations

Contact airlines and arrange for pilots to be present during the tests to observe fluid failure and failure progression, and to record pilot observations from the cockpit and the cabin for later correlation with aircraft external observations.

5.5.6. Remote Sensor Records

Record the progression of fluid failure on the wing using RVSI and/or Cox remote contamination detection sensors if these sensors are made available.

5.6. Snowmaking Methods and Laboratory Testing for Holdover Times

5.6.1. Evaluation of Winter Weather Data

5.6.1.1. Snow Rates

Collect and evaluate snow weather data (precipitation rate/temperature data) during the winter to ascertain the suitability of the data ranges used to date for evaluation of holdover time limits.

Obtain current data from Environment Canada for three sites in Quebec: Rouyn, Pointe-au-père (Mont-Joli), and Ancienne Lorette (Quebec City), in addition to Dorval (Montreal).

5.6.1.2. Fog Deposition Rates

Devise a procedure and conduct fog deposition measurements outdoors on at least two occasions to determine the range of fog deposition rates which occur in natural conditions.

5.6.1.3. Frost Deposition Rates

Frost deposition rates shall be collected at various temperatures in natural conditions in order to determine a deposition range for this condition. Consideration shall be given to collecting deposition rates in cold temperatures (for example in Thompson, Manitoba). A total of five sessions shall be planned.

5.6.2. Snowmaking Methods

Acquire a version of the new snow generation system recently developed by the National Centre for Atmospheric Research (NCAR).

Evaluate the NCAR system for the future conduct of holdover time testing in simulated snow conditions. Tests shall be conducted in a small climatic chamber at Concordia University, PMG Technologies, or at NRC. Tests shall also be conducted with one Type IV fluid over a range of temperature and snowfall rates to compare the SAE holdover times for this fluid in natural and simulated conditions.

A further series of tests shall be performed with the system in order to assess the holdover time performance of the reference fluid (as described in the proposed SAE test procedures).

A total of 8 days of climatic chamber rental shall be planned for the conduct of the proposed tests.

5.7. Documentation of Appearance of Fluid Failure for Pilots

Current failure documentation deals largely with freezing drizzle and freezing rain conditions

5.7.1. Documentation of Failures

Finalise documentation of failure through limited further research as follows:

5.7.1.1.

provide similar documentation for fluids exposed to snow conditions, taking advantage of the availability of a snow making device for laboratory use;

5.7.1.2.

provide documentation for a propylene based Type IV fluid at typical delivered viscosity, for precipitation conditions tested previously, to determine characteristics at its operational limits and the nature and mechanisms of failure. Conduct selected comparison tests with a second fluid to test commonality of responses. Data from this activity will be cross-analysed with data from proposed research to examine the flow of similar fluids at different levels of contamination from aircraft wings during a simulated takeoff; and

5.7.1.3.

examine and document the appearance and nature of failure of propylene base fluids at cold temperatures (-10 C).

5.7.1.4.

Conduct tests at the National Research Council Climatic Environmental Facility based on last years' procedures, with enhancements as necessary and available. Snow documentation may be conducted in a different laboratory facility. Documentation under outdoor snow conditions will be conducted for comparison purposes to laboratory conditions.

5.7.2. Conduct of trials/assembly of results

Coordinate all test activities, scheduling tests with NRC CEF in conjunction with other test activities. Analyse results and document all findings, recommendations and conclusions in a final technical report and in presentation format. Provide timely updates of schedule revisions to TDC.

5.7.3. Pilot Observations

Contact airlines and arrange for pilots to be present during tests to observe fluid failure and failure progression. Record pilot observations for later correlation with aircraft external observations.

5.8. Feasibility of Performing Wing Inspections at End-of-runway

5.8.1. Requirement

Examine the feasibility of scanning aircraft wings with ice contamination sensors just prior to aircraft entering the departure runway using Dorval airport as an example scenario.

Explore ways of positioning sensors at agreed locations on an airport.

Composition and conduct of tests shall be adapted as information is gained on the practicality of this activity.

5.8.2. Planning

A Project Plan shall be prepared which will include:

a) activities to determine the parameters, operational issues and constraints related to the proposed process, and

b) a test plan for operational trials to examine the capabilities of the contamination sensors to determine the feasibility of their operational use.

The test plan for operational trials (three sessions) shall include:

- establishing test locations with airport authorities,
- establishing operational procedures with airport authorities,
- arranging equipment for scanning; vehicle, sensor installation and radios,
- collecting and coordinating information from the deicing activity at the deicing centre,
- test procedures with detailed responsibilities for all participants,
- control of the confidential data gathered on wing condition, and

- notification to all concerned in the project, including aircraft operators, that scanning activities will take place.

5.8.3. Coordination

Coordination all activites with authorities from Aéroports de Montréal and arrange support from Cox and/or RVSI

5.8.4. Field Trials

Conduct trials to further evaluate the feasibility of integrating such a process within current airport operations management, as well as to gather information on wing condition, just prior to takeoff, during deicing operations. These trials shall be based on the use of mobile equipment currently available. A “truthing” test pannel shall be present at each trial to demonstrate the validity of the wing readings on an ongoing basis

The trials shall be designed to address issues such as:

- equipment positioning versus current runway clearance limitations,
- time delay between inspection and start of take-off
- system capabilityto meet its design objectives in severe weather
- suitability of mobile equipment or fixed facility.
- need for rapid extension and retraction of sensor booms,
- airport support needed, e.g. snow clearance, provision of operating locations,
- accommodating scanner limitations for distance, light, angle of incidence.
- communications needed to support scanning operation,
- recording data from the sensors, and
- communicating results of the scanning to pilots and regulatory authorities.

5.8.5. Test Personnel and Participation

Initiate all tests based on suitable weather conditions. The individual test occasions shall be coordinated with Aéroports de Montréal and Aéromag 2000.

Coordinate the provision of a suitable vehicle and the installation of an ice detection sensor. Monitor the test activity, ensuring the collection and protection of all scanning data, as well as the collection of data related to weather conditions and previous aircraft deicing activities. Ensure that the instrument providers deliver data and an objective measure of wing contamination based on scanner information in a timely and reproducible manner.

5.8.6. Study Results

Results from the feasibility study shall be presented in technical report format which shall include comments pertinent to long term implementation.

Results from the scanner tests shall be provided in technical report format and shall include analysis of wing contamination data cross-referred to the deicing history of individual aircraft scanned.

5.9. Ice Detection Sensor Certification Testing

5.9.1. Minimum Ice Thickness Detectable in Tactile Tests

Prepare procedures and conduct tests to establish human limits in identifying ice through tactile senses. These tests shall use the NRC or equivalent test facilities acceptable to TDC and a test setup equivalent to that planned for sensor certification. Several ice thicknesses and textures shall be tested to establish tactile sensing limiting thickness for smooth ice and for roughened ice.

The experiment shall involve sufficient participants and test conditions such as to provide reliable results usable in approving sensors to replace human tactile testing.

TDC shall assist in the experimental design

Tests shall be conducted with both contractor personnel and a selection of pilots as subjects.

A professional human factors scientist shall be used to establish testing parameters such as:

- what proportion of plates should be bare
- whether subjects should be blindfolded to eliminate visual cues.
- whether the same plate should be judged more than once
- how to ensure that subjects do not compare plates
- what should be the minimum time between plate touching

Results of the tests shall be analysed statistically to establish confidence limits for the findings

5.9.2. Field Tests for Sensor Distance and View Angle Limits

Develop a detailed test plan with a matrix of all test parameters, required coordination of equipment detailing the responsibilities of all participants.

Collect test data, including photo and video records of all tests.

The areas of ice contamination used for sensor evaluation shall be quantified by size, location and thickness. Angles of incidence, sensor heights and distances shall be verified independently. In concert with the sesor manufacturer, data from sensor readings and observer data shall be collated and analysed to reach conclusions on sensor limitations for distance and angle of incidence in various weather conditions.

5.10. Planning a Wing Deicing Test Site

Develop a plan for implementing a deicing test site, centred on an aircraft wing and supported by current fluid and rainmaking sprayers.

The plan shall include the acquisition of a surplus complete wing, from either a scrapped or an accidented moderate sized aircraft or an outboard section of a larger aircraft. The wing section should if possible include ailerons and leading edge slats The design of the test site shall include a test area that could contain and recover sprayed fluids. Installation of the wing should entail a mounting designed to allow the wing to be rotated relative to current winds. The site must be secure yet allow ease of access and ability to install inexpensive solutions to control sprayed fluid.
Costs shall be estimated for the main elements of the development of a wing test bed site including:
wing purchase and delivery,
site lease and development, and
wing mount design and fabrication.

5.11. Evaluation of Hot (and Cold) Water Deicing

Investigate unheated and hot water deicing/defrosting, to determine under what meteorological conditions and temperatures these procedures are safe and practicable.
Unheated water deicing shall be evaluated at air temperatures above 1 degree C(34 degrees F).
Hot water deicing shall be evaluated at air temperatures below 1 degree C and include temperatures below –3 degrees C (27 degrees F).
These experiments shall establish how long it takes for the water to freeze on the surface under these conditions.
This is to be the first step of a two step procedure. From these data, a safe and practical lower limit shall be established considering the three-minute window required for second step anti-icing in the two-step deicing procedure.
Precipitation rates, as utilised in the generation of holdover time tables, shall be considered. Environmental chamber tests shall be correlated with outdoor aircraft tests. All laboratory test procedures and representative test results shall be recorded on videotape, including failure modes where applicable. The video shall depict a recommended full-scale aircraft hot water deicing procedure. A written report shall include the laboratory test results and a recommended aircraft unheated/hot water deicing procedure, including the limitations of precipitation, OAT and wind.

5.12. Evaluation of Warm Refuelling

Conduct a feasibility study of the suitability of refuelling with warm fuel to reduce susceptibility to “cold-soaked wing” icing, and to improve holdover times.
Coordinate activities to support testing the “warm fuel” concept using operational aircraft, including arranging;

- Participation of interested airlines, along with provision of aircraft for test purposes;
- Participation of local refueller;
- Arrangements with the equipment supplier (Polaris) to deliver the equipment to the selected airport along with the required technical support.

Testing will be conducted at Dorval on three occasions, one of which will include snow or freezing precipitation. Test aircraft selected should include a representation of both “wet” and “dry” wings if possible.

Wing surface temperatures of test wings will be monitored at several points over a period of time, to assess the influence thereon of warmed fuel. A reference case based on fuel boarded at the normal local temperature will be conducted.

5.13. Engine Air Velocity Distributions near Deicing Vehicles

Measure air velocity distributions in the vicinity of a de-icing truck when de-icing a large aircraft whose engines are running.

Tests shall be conducted during a period of no precipitation, either frost deicing or following snowfall, on two separate occasions at the Dorval International Airport deicing facility. Aircraft with engines mounted on the wing (e.g. B737) as well as rear engines mounted aircraft (e.g. DC-9 and RJ) will be sampled during live deicing operations, the precise type to be agreed by TDC. The tests shall be coordinated with Aéroport de Montréal and Aéromag 2000.

Wind velocity shall be measured from an Elephant-mu de-icing truck at locations recommended by TDC around the tail of the aircraft at different elevations and distances from the engines depending on the aircraft type, and the de-icing procedure followed by Aéromag 2000.

Photograph and video record the conduct of all tests.

5.14. Provision of Support Services

Provide support services to assist TDC with testing, the reduction of data and presentation of findings in the activites identified below which relate to the content of this work statement, but are not specifically included.

5.14.1. Re-Hydration

Conduct a series of exploratory trials on flat plates at the Dorval site or NRC to observe the behaviour of re-hydrated Type IV fluids and to help determine how re-hydration affects the flow- off characteristics of a Type IV fluid exposed to frost conditions.

5.14.2. Frost Tests on a Regional Jet

Conduct a series of tests to determine the roughness of frost deposition on the wings of a Regional Jet aircraft. Conduct tests on three overnight occasions.

5.14.3. Ice-Phobic Materials Evaluation

Conduct a series of tests on flat plates to determine the effects of ice-phobic materials on the film thickness and on holdover time of de/anti-icing fluids.

5.14.4. Evaluation of Infra-Red Thermometers

Evaluate use of infra-red technology as a method of determining accurate skin and fluid temperatures during operational conditions. Conduct tests in conjunction with full-scale and holdover time testing.

5.14.5. Frost Self-Elimination

Examine the self-elimination of frost on several test surfaces under variable weather conditions. Conduct test in conjunction with frost deposition trials on flat plates.

5.14.6. Environmental Impact Assessment

Assess the environmental issues related to the use of glycol-based products for aircraft de-icing purposes. Examine the waste fluid collection and disposal procedures for several deicing facilities in relation to current and future environmental legislation.

5.14.7. An Approach to Establish Wing Contamination

Document an approach to determining operational limits for levels of contamination on aircraft wings. This approach will include consideration of the location of contamination on the wings and the area contaminated. The levels of contamination on aircraft wings prior to takeoff as determined during the scanning trials prior to takeoff will be factored in.

The approach will discuss how the limits (when defined) could be used in software routines to enable sensor systems to provide Go/No-Go indications to the aircraft pilot and regulatory authorities.

5.14.8. Accident/incident Database Analysis

Provision of database manipulation and support aimed at establishing problem areas and their significance.

5.14.9. Other activities

Other activities, such as the evaluation of forced air technology, the evaluation of alternate (zero glycol) deicing methods, and the evaluation of frost removal equipment at gates, or others may emerge as issues during the course of the winter season.

APPENDIX B

EXPERIMENTAL PROGRAM

ENGINE AIR VELOCITY DISTRIBUTIONS NEAR DEICING VEHICLES

CM1514.001

EXPERIMENTAL PROGRAM
ENGINE AIR VELOCITY DISTRIBUTIONS NEAR DEICING VEHICLES

Winter 1998/99

APS AVIATION INC. APS

November 9, 2001
Version 2.0

EXPERIMENTAL PROGRAM
ENGINE AIR VELOCITY DISTRIBUTIONS NEAR DEICING VEHICLES

Winter 1998/99
Version 2.0

APS will conduct a series of tests to measure air velocity distributions in the vicinity of a de-icing truck when de-icing a large aircraft whose engines are running.

1. OBJECTIVES

Measure wind velocity in the vicinity of a de-icing truck to establish the safe limits for a de-icing truck operation when de-icing aircraft with the engines running. In addition, APS will provide support to Delta Airlines on air quality monitoring inside the de-icing truck.

2. TEST REQUIREMENTS

Preliminary trials will be conducted during live de-icing operations on aircraft with engined mounted on wing (e.g. B737). Wind velocity shall be measured from an Elephant-*m* de-icing truck at different locations around the tail of the aircraft and at different elevations and distances from the engines. A preliminary set of trials (Phase I) will be conducted on or around January 11, 1999. Definition of the second set of trials will be developed based upon the findings of the 1st phase results.

3. EQUIPMENT

Test equipment is listed in Attachment II.

4. PERSONNEL

A team of Five APS personnel is required for these trials.

A description of the responsibilities and duties of each member of the test team is provided in Attachment III.

5. SUMMARY OF PROCEDURE

The trial will be initiated by APS Aviation based on forecast weather conditions, and confirmation of actual aircraft de-icing by Aéromag 2000.

Two APS personnel will be positioned on a de-icing truck and will measure Wind velocity and the distance from the Leading Edge of the tail of the aircraft.

A record will be maintained of all test parameters, including ambient conditions, aircraft serial number and engine manufacturer.

A complete photo and video record will be maintained.

A detailed test procedure is contained in Attachment IV.

6. DATA FORMS

Data forms are listed below:

Figure 2	General Form (Every Test);
Figure 3	Wind Measurements on Aircraft (Every Test);

7. PROPOSED NOTICE PROCEDURE

i) Potential for testing		24 to 48 hours prior to test
ii) Prior to testing	-	Monitoring throughout day
	-	advise 8 to 12 hours prior to test.

Potential participants to be alerted:

- Aéromag 2000;
- Transportation Development Centre;
- Delta Airlines;
- Aéroports de Montréal;

ATTACHMENT I
TEST PLAN FOR AIRCRAFT TRIALS
ENGINE AIR VELOCITY DISTRIBUTIONS NEAR DEICING VEHICLES

PHASE I

AIRCRAFT TYPE	MEASUREMENT LOCATIONS
Aircraft with engines mounted on wing.	8 ft from Leading Edge of Tail section

PHASE 2

AIRCRAFT TYPE	MEASUREMENT LOCATIONS
Aircraft with engines mounted on wing.	**TO BE DEFINED**

ATTACHMENT II
ENGINE AIR VELOCITY DISTRIBUTIONS NEAR DEICING VEHICLES
TEST EQUIPMENT CHECKLIST

TASK
Logistics for Every Test
Call Personnel
Advise Aéromag 2000
Monitor Forecast
Call potential participants
Test Equipment
Test procedures x 7
Data forms
Video Camera x 2 plus tripod + films, batteries and charger
Photo camera 35 mm + films
Anemometer x 2
Watches x 3
Tape recorder
Megaphone x 1
Measuring tape x 2
VHF radio
Walkie-talkie x 4
Plumb bob
Hearing Protectors
Other Equipment
Aircraft
De-icing truck

ATTACHMENT III
ENGINE AIR VELOCITY DISTRIBUTIONS NEAR DEICING VEHICLES
RESPONSIBILITIES/DUTIES OF TEST PERSONNEL

Refer to Figure 1 for position of equipment and personnel relative to the aircraft. Also refer to the test procedure (Attachment IV) for more detailed tester requirements.

Video 1 / Photographer 1(V1/P1)

- Video and photograph general test site;
- Video and photograph setup, including de-icing truck position, aircraft type, serial number and engine brand;
- Video actual wind measurement;
- Knowledge of test procedures.

Wind Tester 1 (WI)

- Responsible for measuring wind velocity; and
- Identify measurement location; and

Wind Tester 2 (W2)

- Assist WI in identifying measurement locations and;
- Measure and record location wrt to aircraft tail; and
- Record wind velocity measured by WI;

Aéromag/APS Coordinator (TC1)

- Coordinate with Iceman/Aéromag crew Coordinator;
- Coordinate with APS staff; and
- Ensure safety of staff.

Test Coordinator (TC2)

- Responsible for area and people;
- Supervise site personnel during the conduct of tests;
- Oversee wind measurements to ensure proper procedure followed;
- Prepare all data forms in advance;
- Complete general data form for each aircraft test;
- Record aircraft position on de-icing bay;
- Assist wing observers as required;
- Coordinate actions of APS team with Aéromag 2000 personnel;
- Ensure proper documentation of tapes, diskettes, cassettes;
- Verify test procedure is correct; and
- Responsible for weather condition observations and forecast, initiate test and calls to tester team.

ATTACHMENT IV
ENGINE AIR VELOCITY DISTRIBUTIONS NEAR DEICING VEHICLES
TEST PROCEDURE

1. PRETEST SET-UP

Monitor weather forecasts seeking precipitation or frost formation.

When suitable weather is out looked, discuss with Aéromag 2000 to decide and prepare for tests.

Advise all involved.

Prior to test, APS team:

i) Assembles and briefs. Prepare and distribute data forms;

ii) Synchronize all timepieces including cameras;

iii) Confirm functioning of camera and video recorder;

iv) Move to deicing centre with equipment;

2. INITIALISATION OF TEST

Record aircraft serial number, airline, engine manufacturer and position at de-icing bay;

3. EXECUTION OF TEST

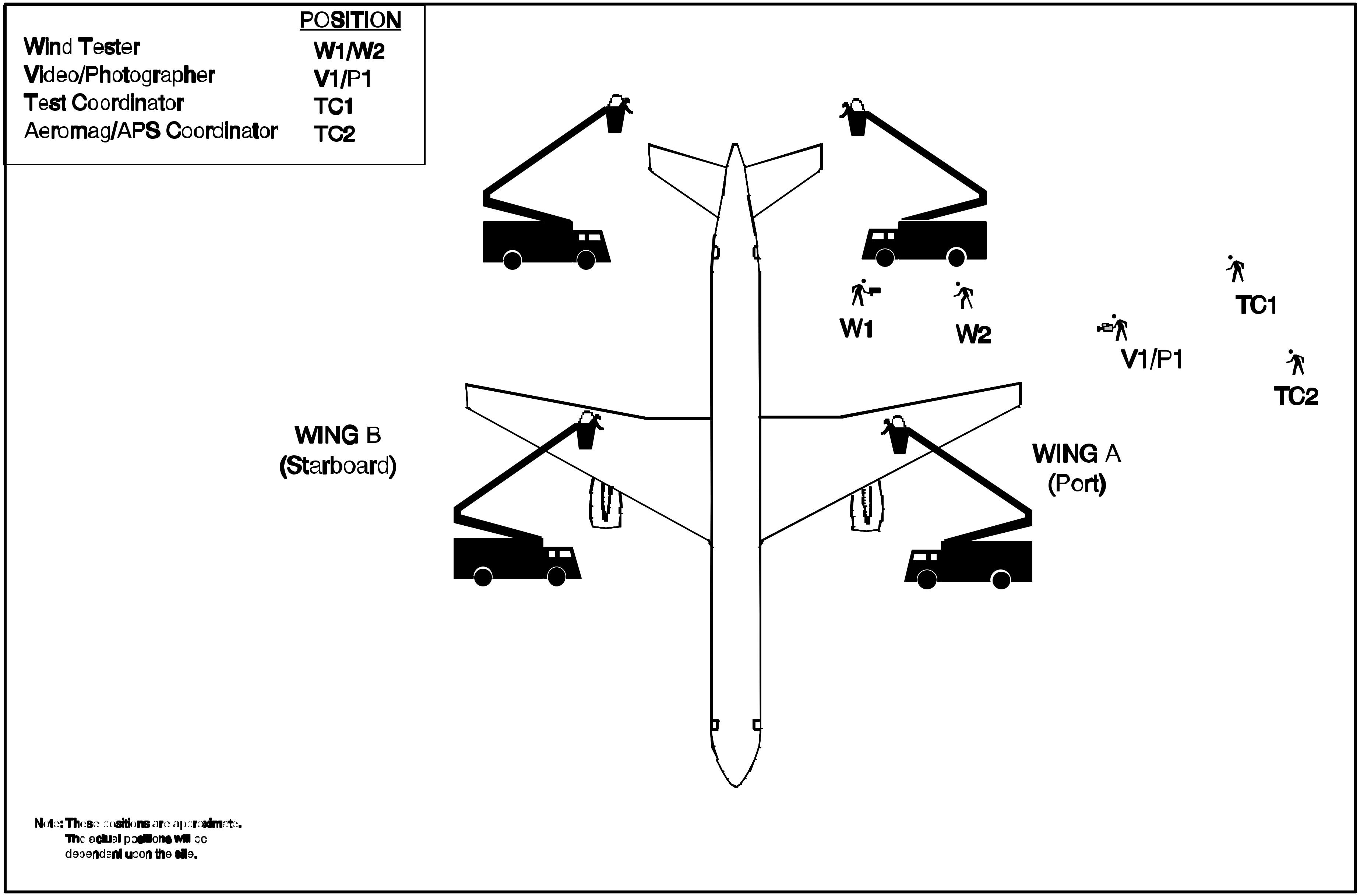
i) Measure position relative to aircraft tail and engine;
ii) Measure wind velocity; and
iii) Acquire complete photo and video record of conduct of test.

4. END OF TEST

Test Coordinator will advise end of test. This will normally occur when sufficient data collected or when de-icing operation ceases.

FIGURE 1

POSITION OF EQUIPMENT AND PERSONNEL



cm151 [illegible]

FIGURE 2

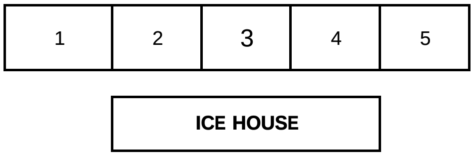
GENERAL FORM (EVERY TEST)

(TO BE FILLED IN BY TEST COORDINATOR)

DATE: ______________________________ **DE-ICING BAY #:** ________

RUN #: ______________________________ **WING:** PORT (A) STARBOARD (B)

DRAW DIRECTION OF A/C WRT DE-ICING BAY:



AIRCRAFT TYPE: ____________________

AIRLINE: ____________________

FIN #: ____________________

ENGINE MANUFACTURER: ____________________

ENGINE TYPE: ____________________

Start of Test Time: ____________________ (hr:min:ss)

End of Test Time: ____________________ (hr:min:ss)

COMMENTS: ____

____

____

____

____

____

MEASUREMENTS BY: ____

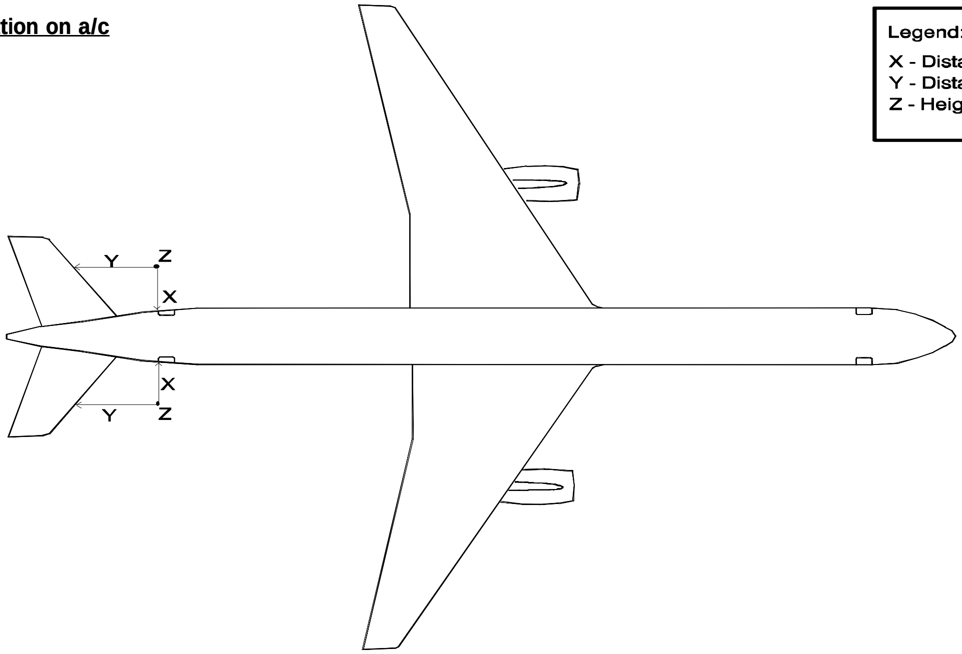
HAND WRITTEN BY: ____

FIGURE 3

WIND MEASUREMENTS ON AIRCRAFT

DATE: ________________________ **RUN #:** ____________

Draw Location on a/c



Legend:
X - Distance from fuselage
Y - Distance from LE of Tail section
Z - Height from ground.

Location	Distance (ft)			Wind Velocity (kph)	Gusts (kph)
	X	Y	Z		
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

Location	Distance (ft)			Wind Velocity (kph)	Gusts (kph)
	X	Y	Z		
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

COMMENTS: ________________________

MEASUREMENTS BY: ____________ **HAND WRITTEN BY:** ____________

ENGINE AIR VELOCITY DISTRIBUTIONS NEAR DEICING VEHICLES
TEST PLAN

Preliminary trial will be conducted on January 11th, 1998, based on forecast weather conditions, and confirmation of actual aircraft de-icing by Aéromag 2000.

Thursday January 07, 1999

- Monitor Forecast; and
- Send test plan to participants;

Friday January 08, 1999

- Monitor Forecast;
- Discuss with Aéromag of potential test on Monday January 11, 1999;
- Advise APS Personnel; and
- Advise Delta Airlines, Transport Canada, and Vestergaard;

Sunday January 10, 1999

- Monitor Forecast;
- Confirm with APS Personnel; and
- Confirm with Delta Airlines, Transport Canada, and Vestergaard;

Monday January 11, 1999

In the occurrence of snowfall: (Plan A)

- APS Personnel to meet at Dorval Test site at 7:00 am;
- Assemble equipment and discussion 7:00 – 8:00 am;
- Proceed to Dorval Airport Terminal 8:00 – 8:30;
- Meet with Delta Airlines, Transport Canada and Vestergaard Personnel at Delta Airlines Ticket Counter at 9:00 am;
- Discussion with all 9:00 – 10:00 am;
- Proceed to Aéromag 10:00 – 10: 30 am;
- Discussion with Aéromag 10:30 – 11:15 am; and
- Proceed to Deicing Bay 11:30.

In the occurrence of Frost: (Plan B)

- APS Personnel to meet at Dorval Test site at 4:30 am;
- Assemble equipment and discussion 4:30 – 5:15 am;
- Proceed to Aéromag 5:15 - 5:30 am;
- Meet with Delta Airlines, Transport Canada and Vestergaard Personnel at Aéromag Deicing Center at 5:30 am;

- Discussion of procedure 5:30 – 6:15 am; and
- Proceed to Deicing Bay 6:30 am.

In the occurrence of no Precipitation: (Plan C)

- Meet with Delta Airlines, Transport Canada and Vestergaard Personnel at Delta Airlines Ticket Counter at 9:00 am;
- Discussion with all 9:00 – 10:30 am;
- Monitor Forecast for potential testing on Monday afternoon; if not:
    - Monitor Forecast for potential testing on Tuesday (Plan A or B);

Test will end when sufficient data collected or when de-icing operation ceases. Debriefing will follow.

APS Personnel:

Video 1 / Photographer 1(V1/P1)	-	Jeff Mayhew
Wind Tester 1 (WI)	-	Elio Ruggi
Wind Tester 2 (W2)	-	Nicolas Blais
Aéromag/APS Coordinator (TC1)	-	John D'Avirro
Test Coordinator (TC2)	-	Medhat Hanna

Other Participants:

- Aéromag 2000.
- Transport Canada
- Delta Airlines.
- Vestergaard.

Contacts:

Medhat Hanna
Project Engineer
Tel: (514) 626-7009 (home)
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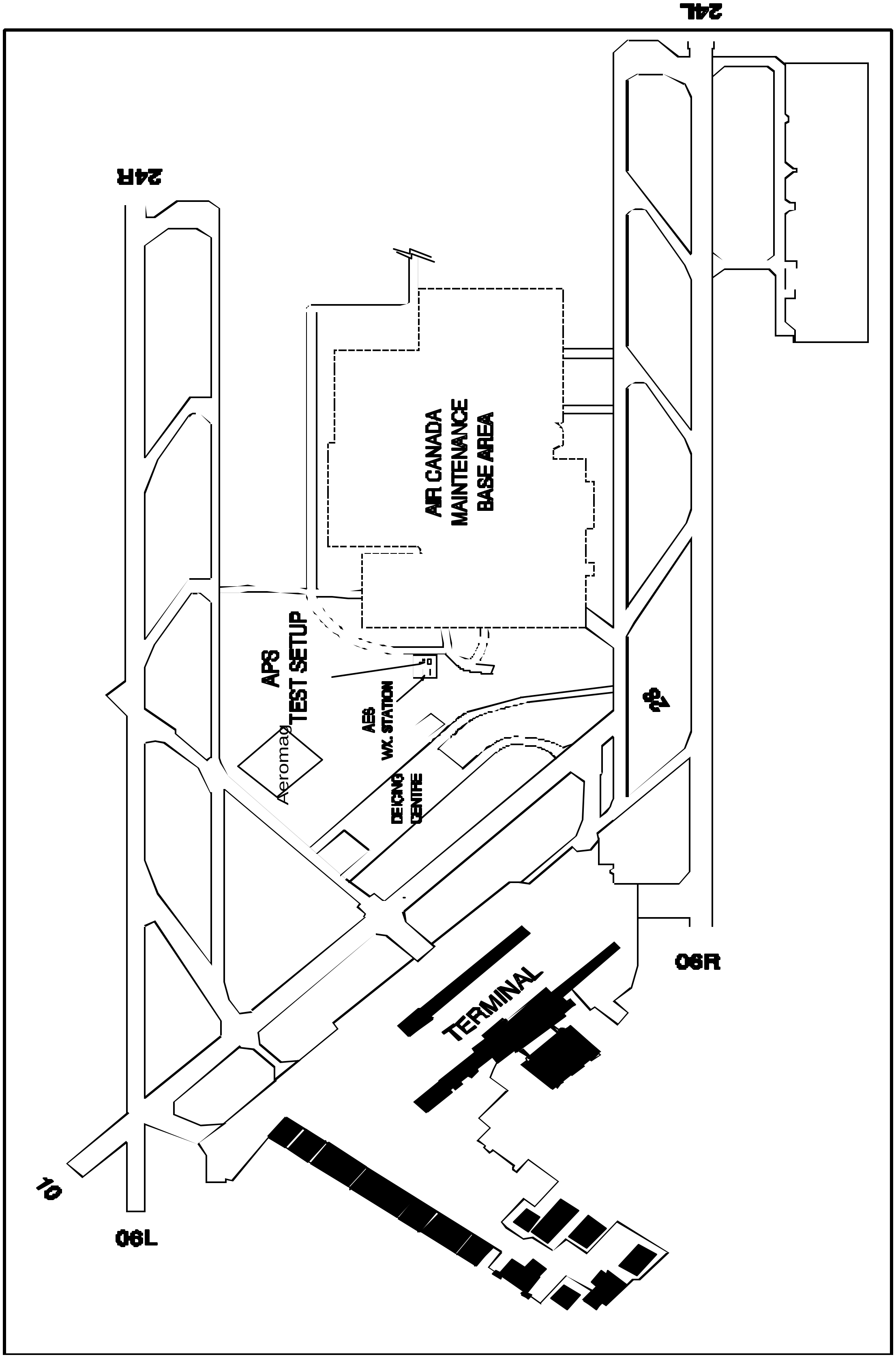
Project Manager
Tel: (514) 428-9313 (home)
Cell: (514) 239-6388
E-Mail: j.davirro@adga.ca

APS Aviation Inc
Tel: (514) 878-4388
Fax: (514) 861-6310

Dorval Test Site
Tel: (514) 633-1435

TEST LOCATION AT DORVAL AIRPORT



ADDENDUM
ENGINE AIR VELOCITY DISTRIBUTIONS NEAR DEICING VEHICLES
PHASE II
Winter 1998/99

1. OBJECTIVES

Measure wind velocity distribution in the vicinity of a de-icing truck to establish the safe limits for a de-icing truck operation when de-icing aircraft with the engines running. Two test sessions are anticipated; one having evening operations and one during morning operations.

2. TEST REQUIREMENTS

Trials will be conducted during live de-icing operations on aircraft with engine mounted on wing (e.g. B737). Wind velocity shall be measured from deicing truck at different locations around the tail of the aircraft and at different elevations and lateral offset distances from the engines.

3. EQUIPMENT

Five annemometres mounted vertically on a 10 feet pole connected to a data logger will be used to record the wind velocity. The pole will be mounted on a structure and will be attached to the bucket of the deicing truck.

4. PROCEDURE

Wind velocity will be measured with the anemometers mounted on the bucket. The measurements will be taken at a distance of 8 feet from the leading edge of the tail section of the aircraft. The anemometers will be positioned in the jet blast and the wind velocity will be recorded. The vertical pole will be positioned at about 6 to 10 lateral stations and held stationary at each station for about 15 seconds. The approximate position of the pole and the exact measured times will be recorded. This process will not require a person stationed in the deicing bucket.

EQUIPMENT LIST

- Laptop computer
- Anemometers with data logger
- Generator
- Range Finder
- Total Station (to measure distance)
- Binoculars
- Camera equipment
- VHF radios
- Walkie-talkies
- Watches x 3
- Pens and pencils
- Measuring tape
- Data Forms

FIGURE 4

GENERAL FORM (EVERY TEST)

(TO BE FILLED IN BY TEST COORDINATOR)

DATE: ______________________ **DE-ICING BAY #:** ________

RUN #: ______________________ **WING:** PORT (A) STARBOARD (B)

DRAW DIRECTION OF A/C WRT DE-ICING BAY:

1	2	3	4	5

ICE HOUSE

AIRCRAFT TYPE: ______________

AIRLINE: ______________

FIN #: ______________

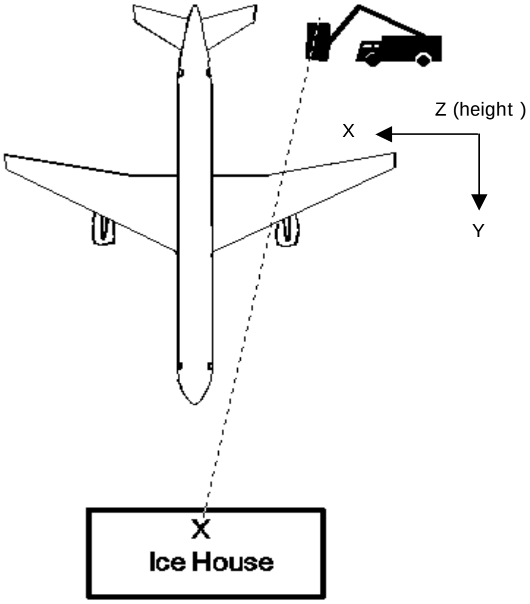
SERIAL #: ______________

ENGINE MANUFACTURER: ______________

ENGINE TYPE: ______________

Start of Test Time: ______________ (hr:min:ss)

End of Test Time: ______________ (hr:min:ss)



Measure distance and angle from Ice House to deicing bucket.

	Ref.	3L	2L	1L	0	1R	2R	3R
X								
Y								
Z								

COMMENTS: ____

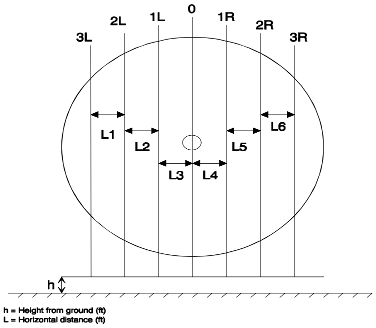
MEASUREMENTS BY: ______________________

HAND WRITTEN BY: ______________________

FIGURE 5

WIND MEASUREMENTS ON AIRCRAFT

DATE: ______________



RUN #: ______________

AIRCRAFT TYPE: ______________

AIRLINE: ______________

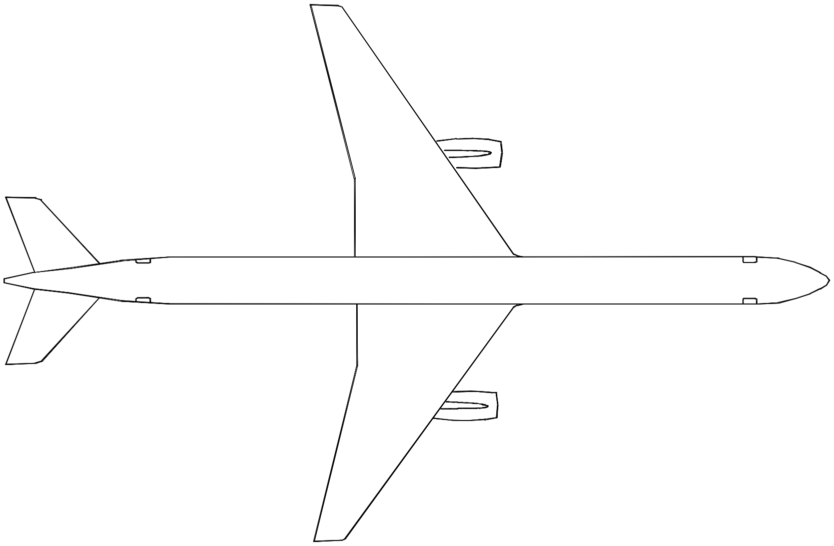
FIN #: ______________

SERIAL #: ______________

Distance to Engine: ______________

Distance to Tail: ______________

Distance from Truck to Anemometers: ______________



Inward	**3L**	**2L**	**1L**	**0**	**1R**	**2R**	**3R**	**Height (ft)**
Time (Inward)								
Distance (Inward)								

Outward	**3L**	**2L**	**1L**	**0**	**1R**	**2R**	**3R**	**Height (ft)**
Time (Inward)								
Distance (Inward)								

COMMENTS: ______________________________

____

MEASUREMENTS BY: ______________________________

ADDENDUM
ENGINE AIR VELOCITY DISTRIBUTIONS NEAR DEICING VEHICLES
PHASE III
Winter 1998/99

1. OBJECTIVES

Measure wind velocity distribution in the vicinity of a de-icing truck to establish the safe limits for a de-icing truck operation when de-icing aircraft with the engines running. In Phase III, determine overturning moments on a sample deicing truck during simulated deicing operations.

2. TEST REQUIREMENTS

Trials will be conducted on aircraft with mounted engines. Deicing truck will be positioned on weigh scales at a distance of eight feet from the leading edge of the tail section of the aircraft

3. EQUIPMENT

One aircraft parked, with engines running, and one open bucket deicing truck will be used for the test. Six anemometers mounted vertically on a 10 feet pole connected to a data logger will be used to record the wind velocity. The pole will be mounted on a structure and will be clamped to the bucket of the de-icing truck. Four weigh scales will be used to determine the de-icing truck wheel loads.

4. PROCEDURE

One de-icing truck will traverse the wind profile in two feet increments across a plane perpendicular to the fuselage axis, eight feet ahead of the tailplane leading edge. Wind velocity will be measured with the anemometers mounted on a vertical pole on the bucket of the de-icing truck. The vertical pole will be positioned at about 6 to 10 lateral stations and held stationary at each station for approximately 60 seconds. The position of the pole and the measured times will be recorded. The aircraft engine will be shut down for weigh scale positioning. In a second run the truck will be positioned, on two weigh scales, in the jet stream at a distance of 8 feet from the leading edge of the tail section of the aircraft. The load on each wheel will be logged from weigh scales under the wheels of the de-icing truck before and after turning the engines on. Truck to be positioned with axis perpendicular to aircraft axis. Location subject to wind velocity observations. Successive test locations subject to findings.

5. EQUIPMENT/LIST OF SERVICES

- Six anemometers mounted on a pole;
- Data Logger;
- Laptop computer;
- Generator;
- Fuel for generator
- One Deicing truck – open buckets (provided by Hudson);
- Five Weigh scales;
- Laser Range Finder;
- Six weigh scales with data logger;
- Data Forms;
- Pens and Pencils; and
- Video and still photo cameras.
- Tape Measure

Services by Hudson
- Obtain security passes for attendees; and
- Make conference room available.

6. SCHEDULE

Dry Run	7:00 AM (Aps/Cdn Scales only)
Presentation	8:45 AM (Elio – Proposed Tests)
Start Tests	9:30 AM
End of Tests	12:00 Noon

7. ATTENDEES

7.1 TEST TEAM

F.W. Eyre	TC/TDC	
John D'Avirro	APS	
Elio Ruggi	APS	
Marc Hunt	APS	
Jeff Weir	Canadian Scales	(416) 259-1111
Dominique Banoun	M.O.V.E. Productions	(416) 936-9752

7.2 VISITORS

Paul Ritchi	GTAA
Joe Fernandini	Delta
Mario Rosa	AeroMag
Robert Kidd	TC Aeroports

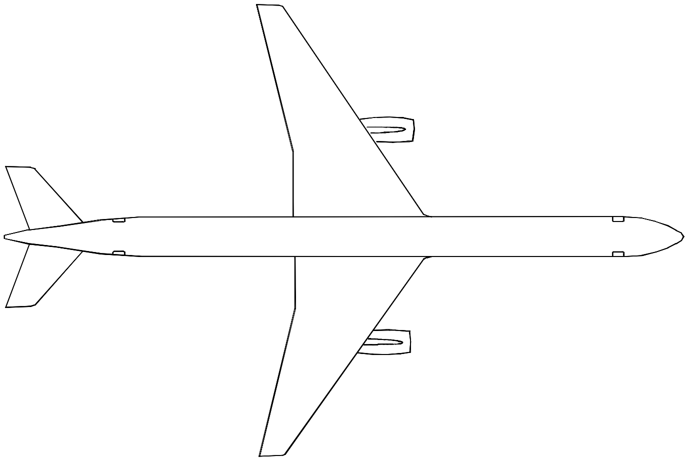
FIGURE 1

GENERAL FORM (EVERY TEST)

(TO BE FILLED IN BY TEST COORDINATOR)

DATE: ______________________________

RUN #: ______________________________



AIRCRAFT TYPE: ____________________

AIRLINE: ____________________

FIN #: ____________________

SERIAL #: ____________________

ENGINE MANUFACTURER: ____________________

ENGINE TYPE: ____________________

Start of Test Time: ____________________ (hr:min:ss)

End of Test Time: ____________________ (hr:min:ss)

POSITION OF TRUCK

Distance from Fuselage:

Distance from Engine:

COMMENTS: ____

____

____

MEASUREMENTS BY: ____

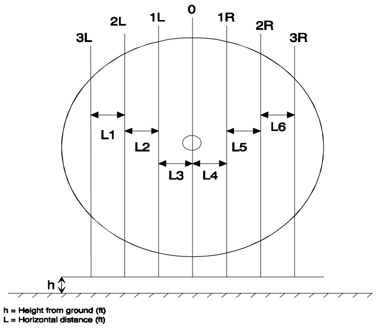
HAND WRITTEN BY: ____

File:g:\cm1514\procedur\wind_vel\:Phase3.xls
At: GFORM (2)
Printed: 09/11/01, 10:00 AM

FIGURE 2

WIND MEASUREMENTS ON AIRCRAFT

DATE: ______________



RUN #: ______________

AIRCRAFT TYPE: ______________

AIRLINE: ______________

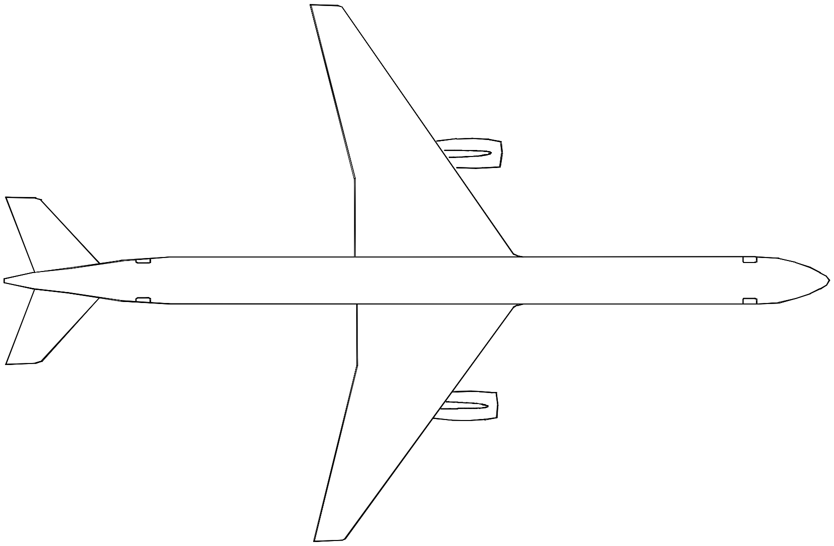
FIN #: ______________

SERIAL #: ______________

Distance to Engine: ______________

Distance to Tail: ______________

Distance from Truck to Anemometers: ______________



Inward	**3L**	**2L**	**1L**	**0**	**1R**	**2R**	**3R**	**Height (ft)**
Time (Inward)								
Distance (Inward)								

Outward	**3L**	**2L**	**1L**	**0**	**1R**	**2R**	**3R**	**Height (ft)**
Time (Inward)								
Distance (Inward)								

COMMENTS: ____

____

MEASUREMENTS BY: ______________________________

APPENDIX C

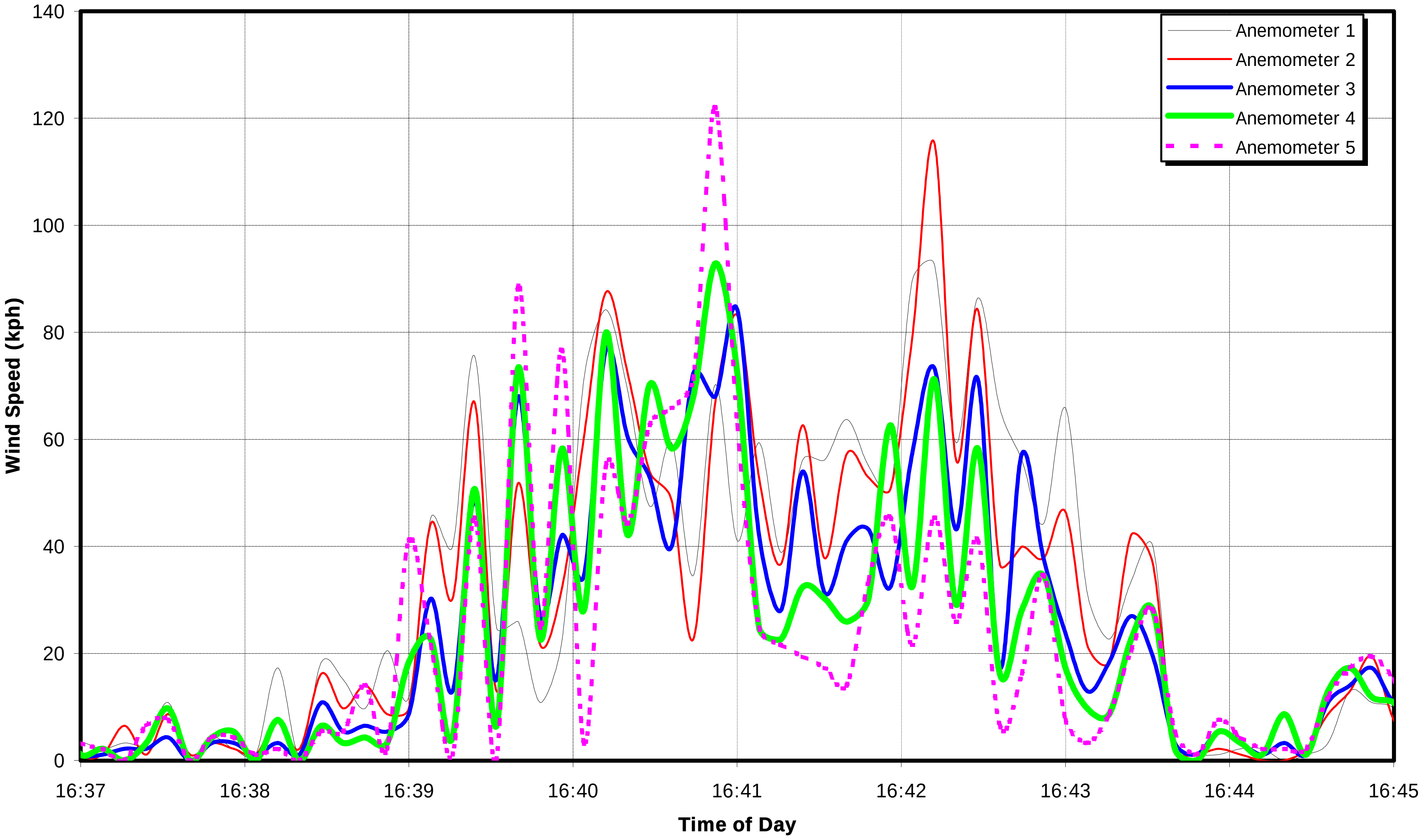
TEST RESULTS

WIND VELOCITY MEASUREMENTS

WIND VELOCITY MEASUREMENT

AIRBUS 340, March 01, 1999

Run 1 - ID # 1

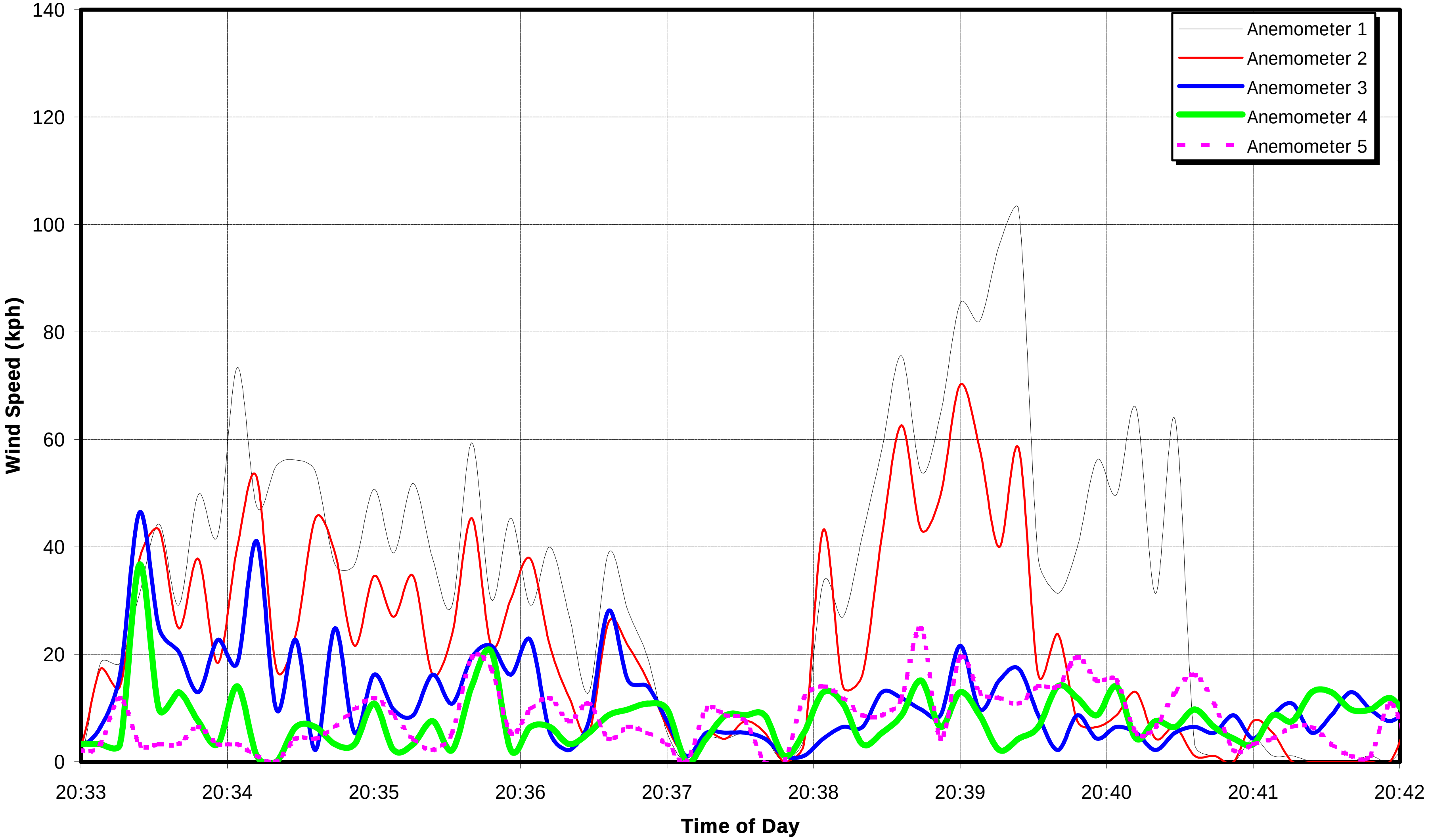


cm1514/analysis/wind_vel/march_01/Wind_mr1.xls
At: Run 1
04/07/01, 3:55 PM

WIND VELOCITY MEASUREMENT

Beechcraft 19, March 01, 1999

Run 2 - ID # 2

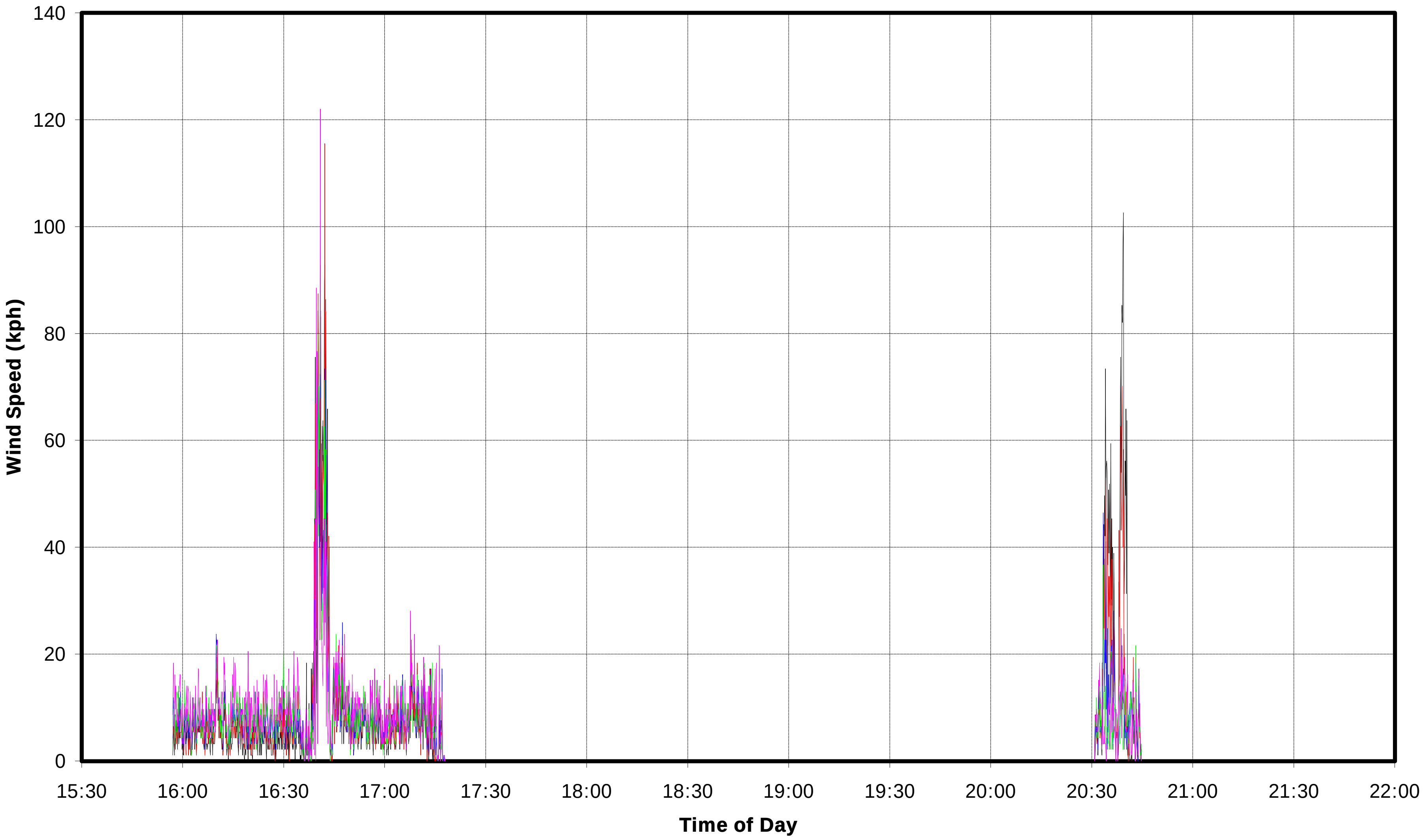


cm1514/analysis/wind_vel/march_01/Wind_mr1.xls
At: Run 2
04/07/01, 3:56 PM

WIND VELOCITY MEASUREMENT

March 01, 1999

Test Session Summary

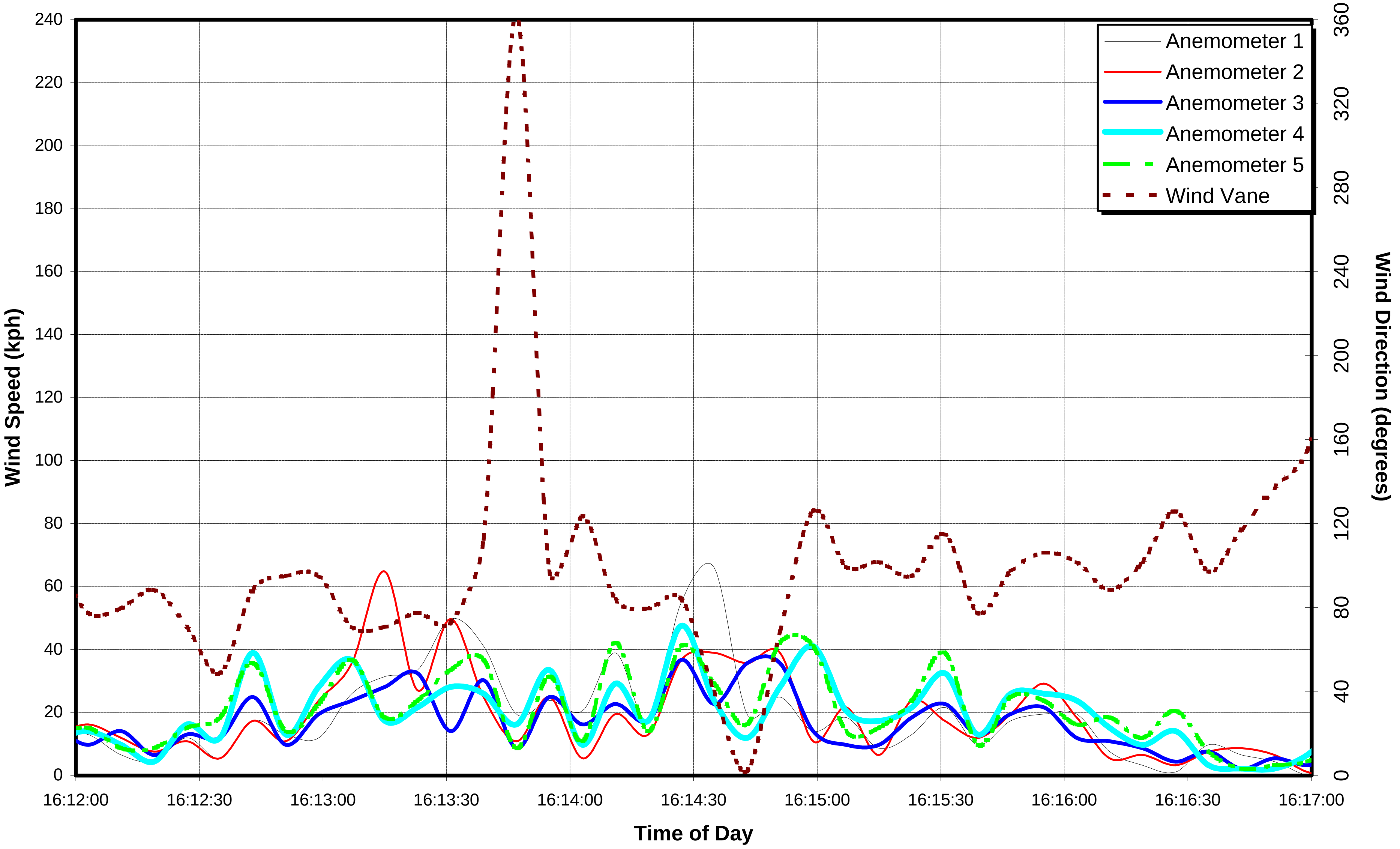


cm1514/analysis/wind_vel/march_01/Wind_mr1.xls
At: Chart1
04/07/01, 4:02 PM

WIND VELOCITY MEASURMENTS

March 06, 1999

Run # 1, SAAB 340 - ID # 3

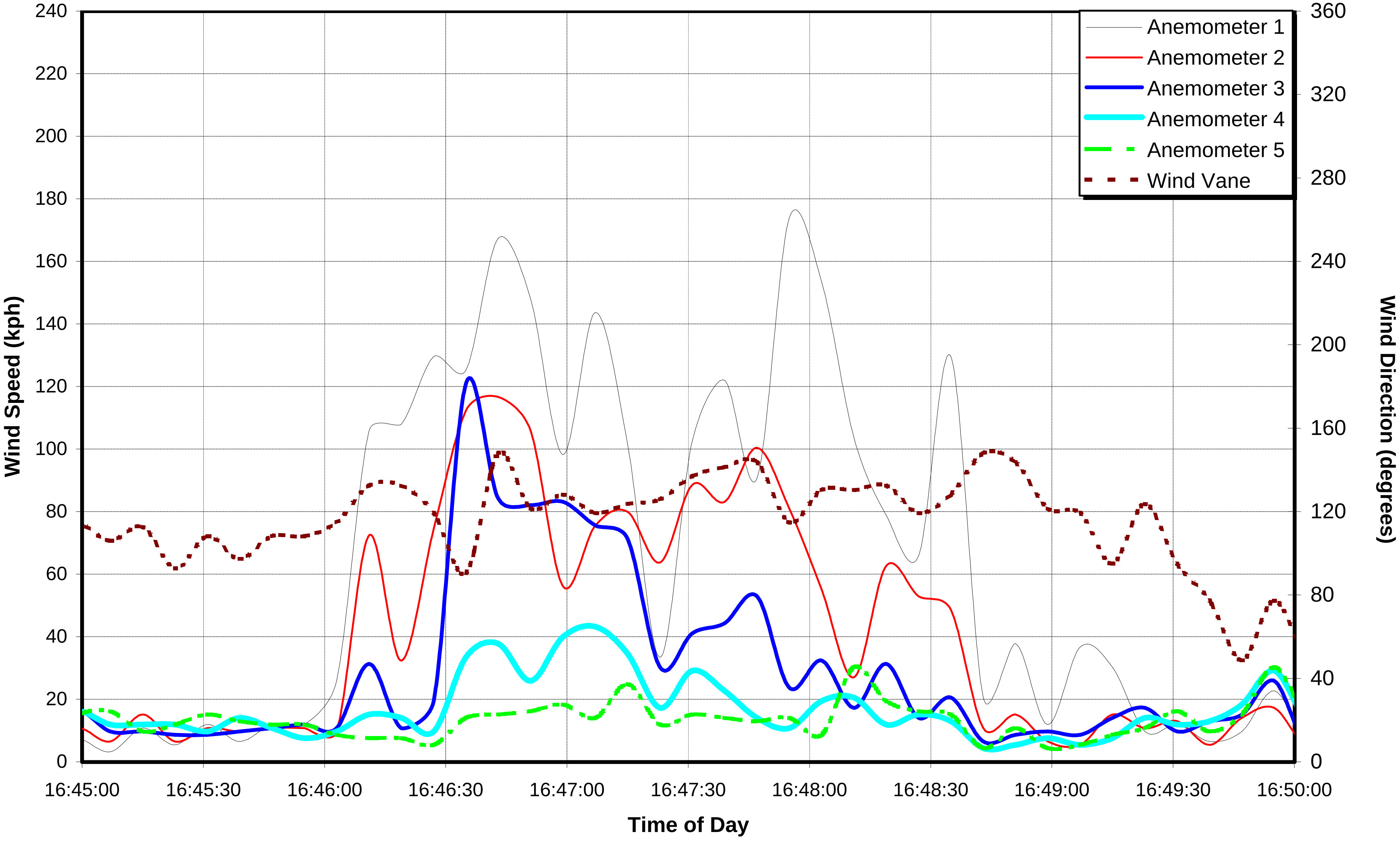


cm1514/analysis/wind_vel/march_06/Wnd_mr06.xls
At: Run1

WIND VELOCITY MEASURMENTS

March 06, 1999

Run # 2, A319 - ID # 4

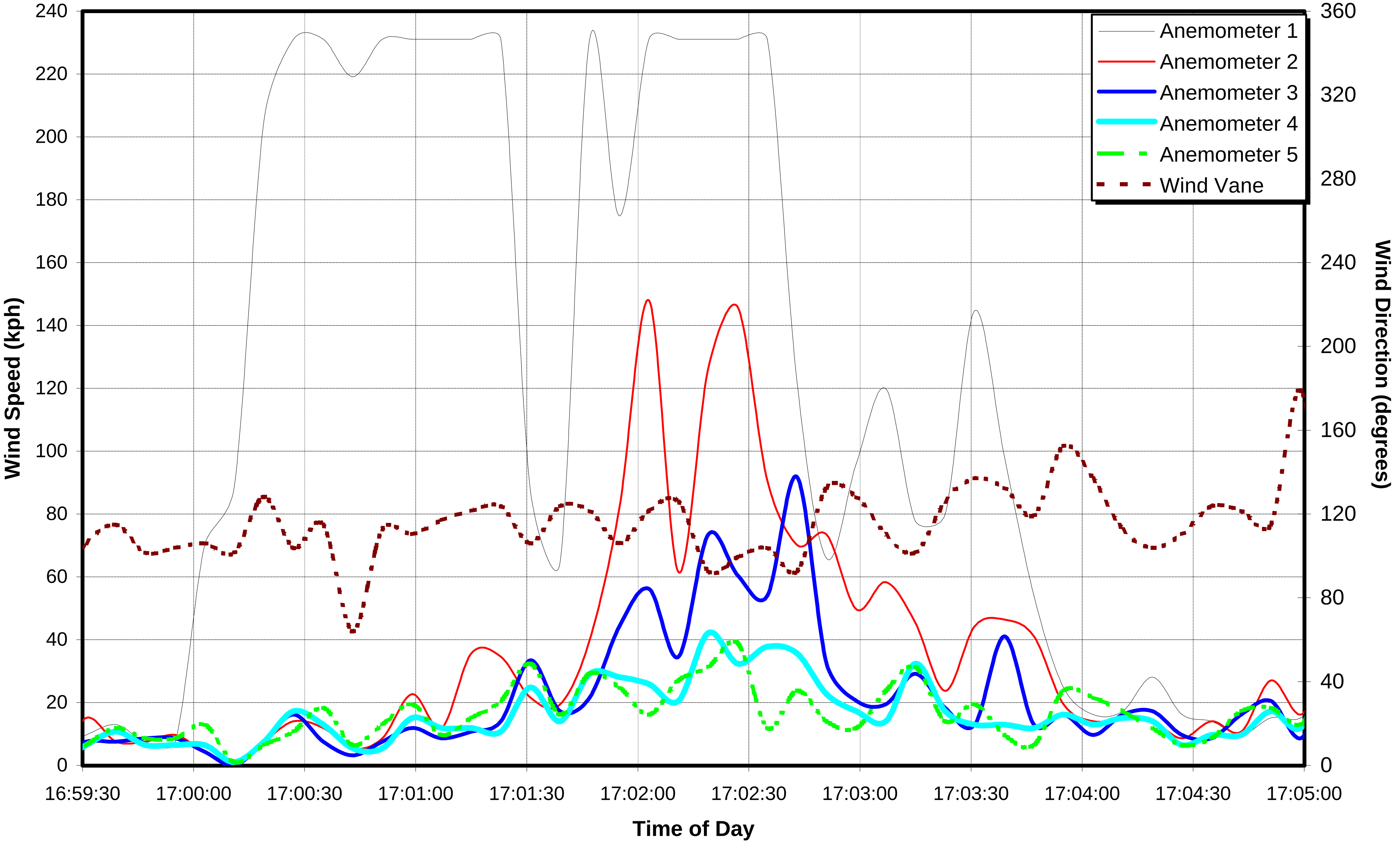


cm1514/analysis/wind_vel/march_06/Wnd_mr06.xls
At: Run2

WIND VELOCITY MEASURMENTS

March 06, 1999

Run # 3, A319 - ID # 5

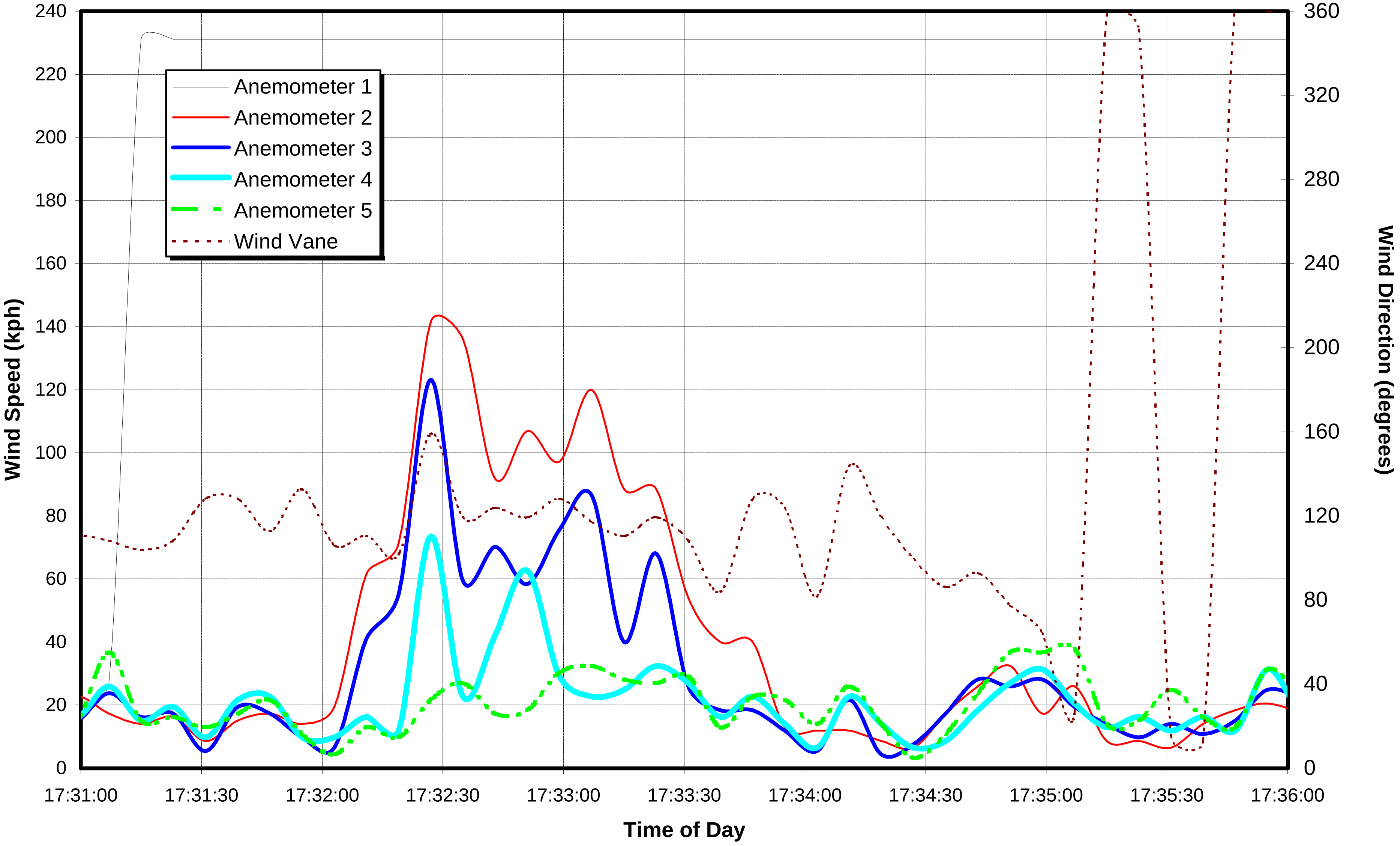


cm1514/analysis/wind_vel/march_06/Wnd_mr06.xls
At: Run3

WIND VELOCITY MEASURMENTS

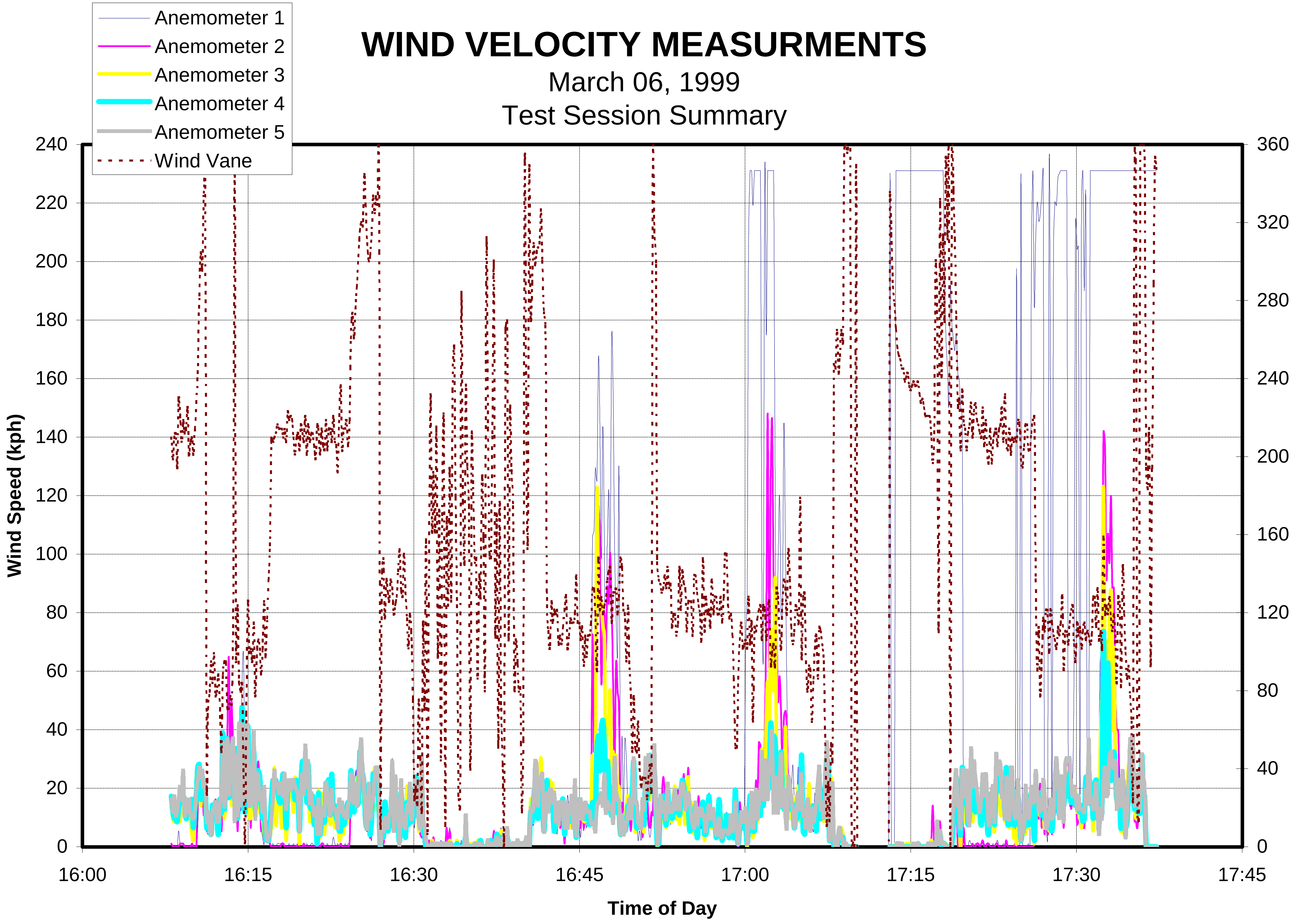
March 06, 1999

Run # 4, A319 - ID # 6



cm1514/analysis/wind_vel/march_06/Wnd_mr06.xls

At: Run4

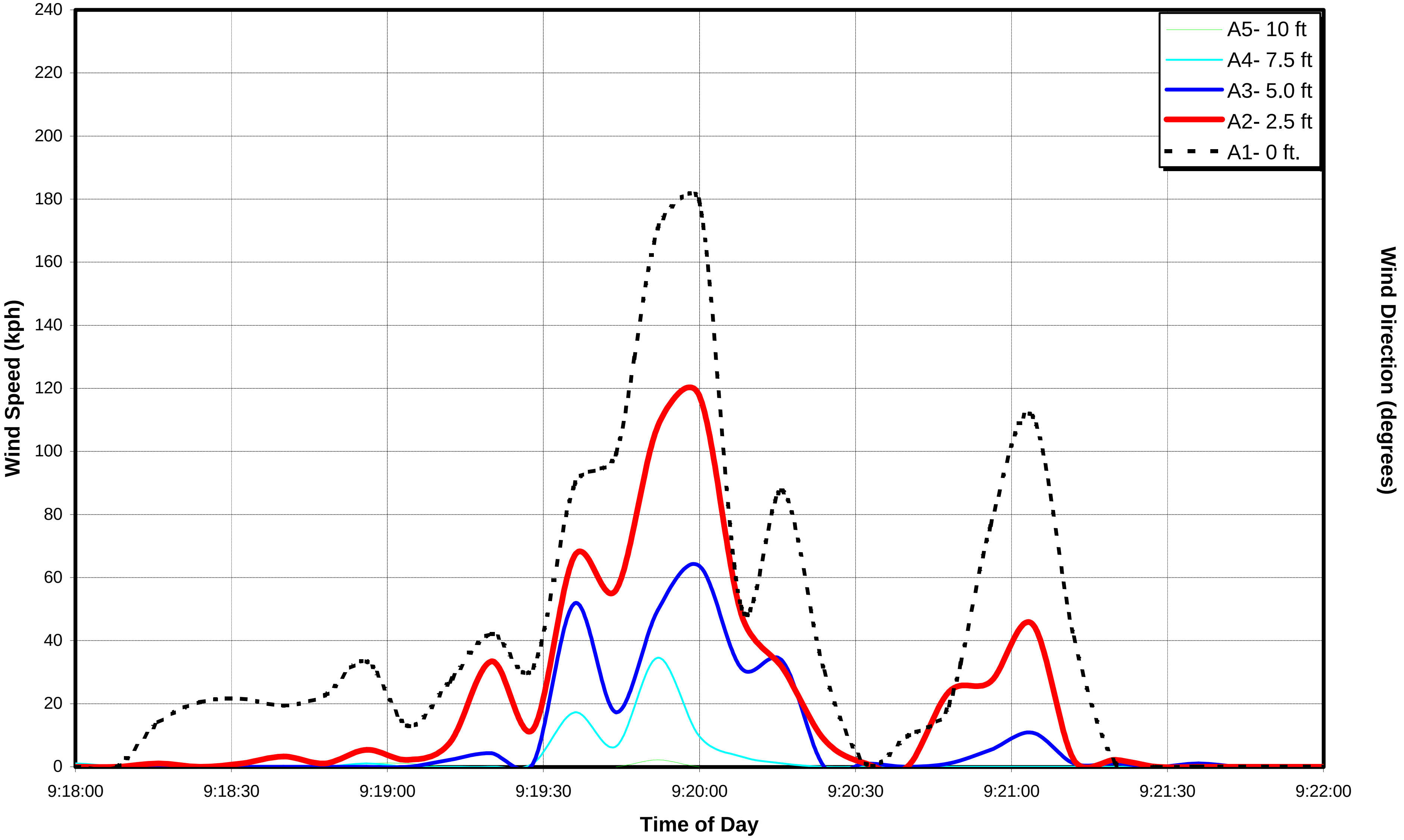


cm1514/analysis/wind_vel/march_06/Wnd_mr06.xls
At: March 06

WIND VELOCITY MEASURMENTS

March 13, 1999

Run # 1, A320 - ID # 7

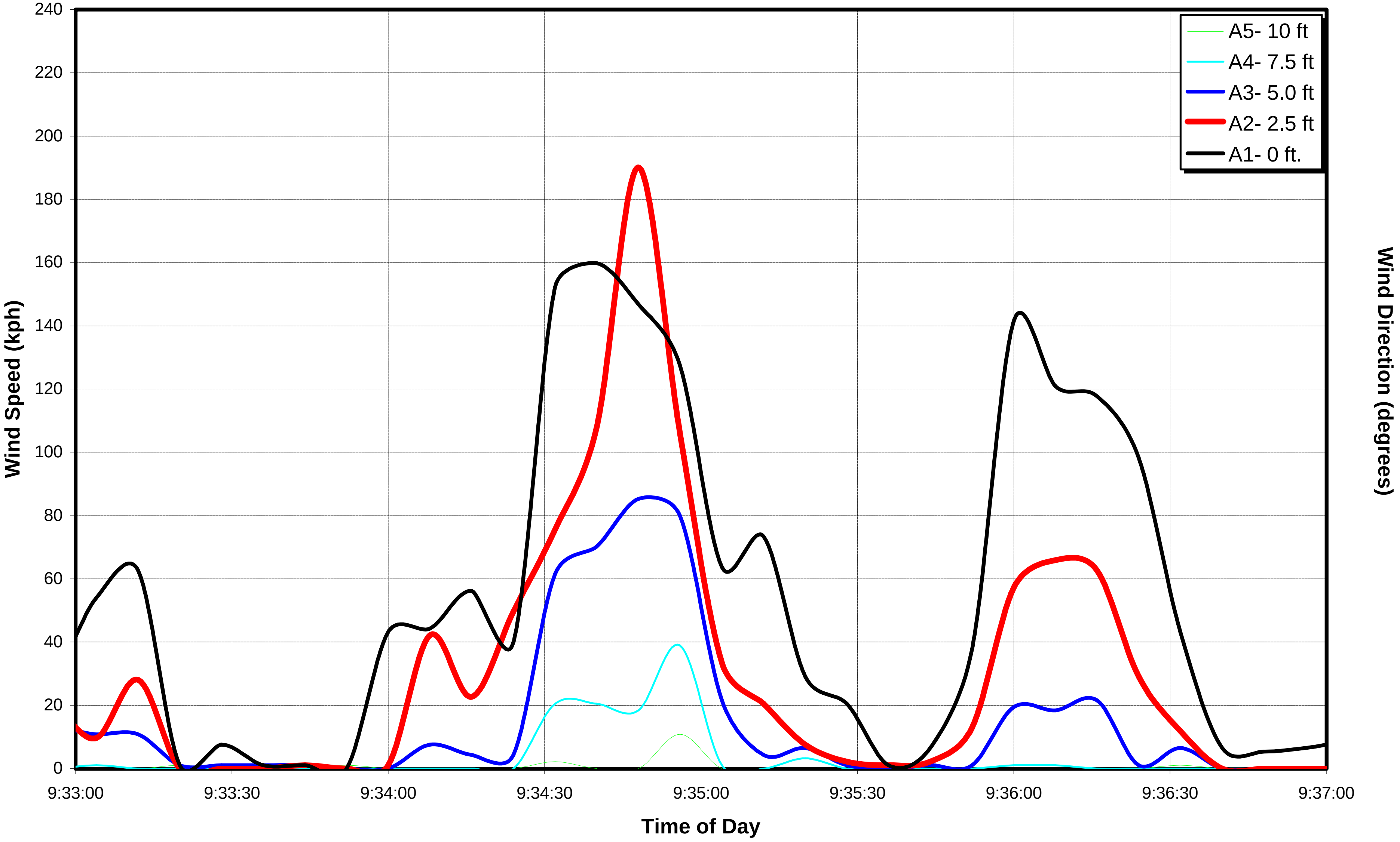


cm1514/analysis/wind_vel/march_13/Wnd_mr13.xls
At: Run1
04/07/01, 4:43 PM

WIND VELOCITY MEASURMENTS

March 13, 1999

Run # 2, A320 - ID # 8

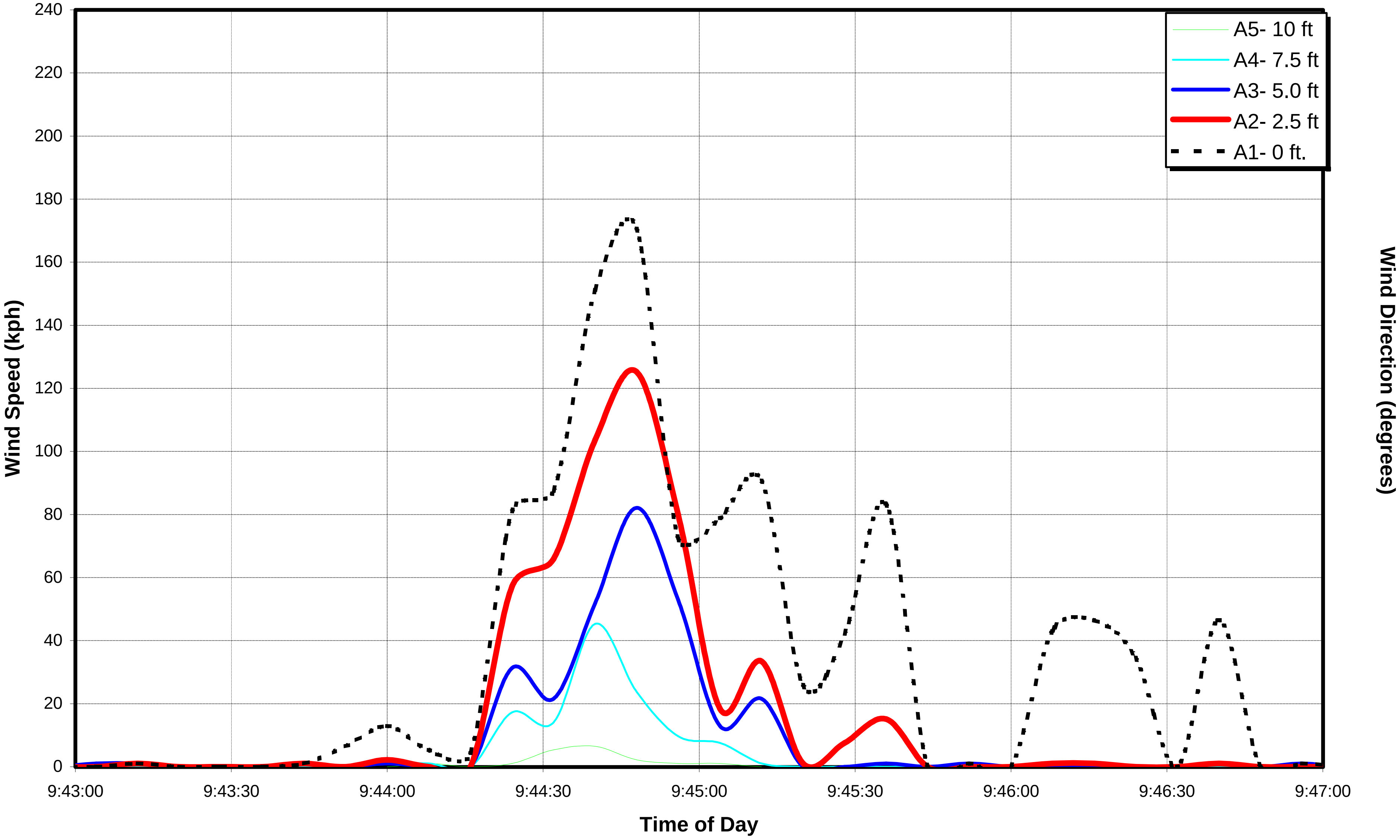


cm1514/analysis/wind_vel/march_13/Wnd_mr13.xls
At: Run2
04/07/01, 4:44 PM

WIND VELOCITY MEASURMENTS

March 13, 1999

Run # 3, A320 - ID # 9



cm1514/analysis/wind_vel/march_13/Wnd_mr13.xls
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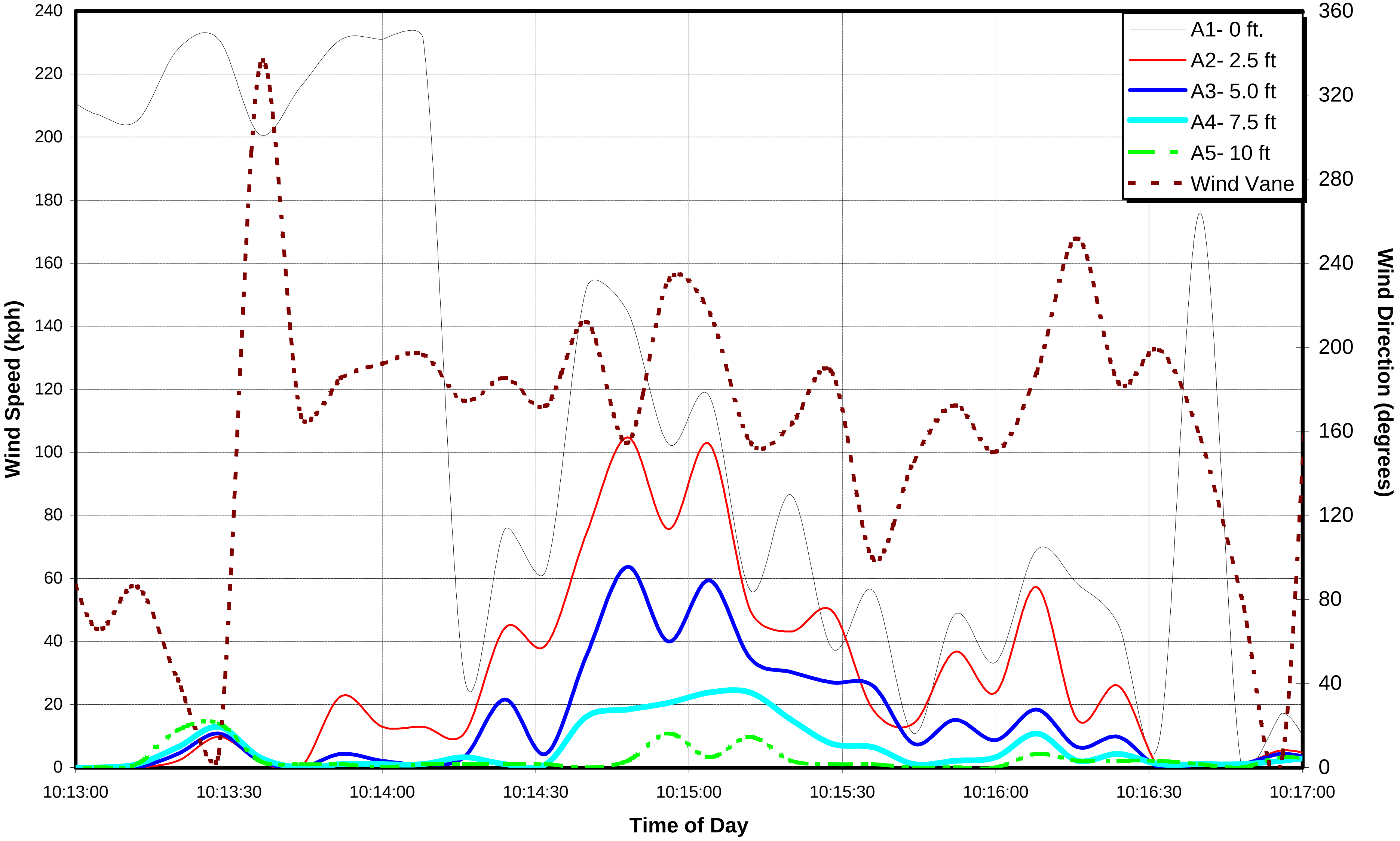
04/07/01, 4:44 PM

WIND VELOCITY MEASURMENTS

March 13, 1999

Run # 4, A320 - ID # 10

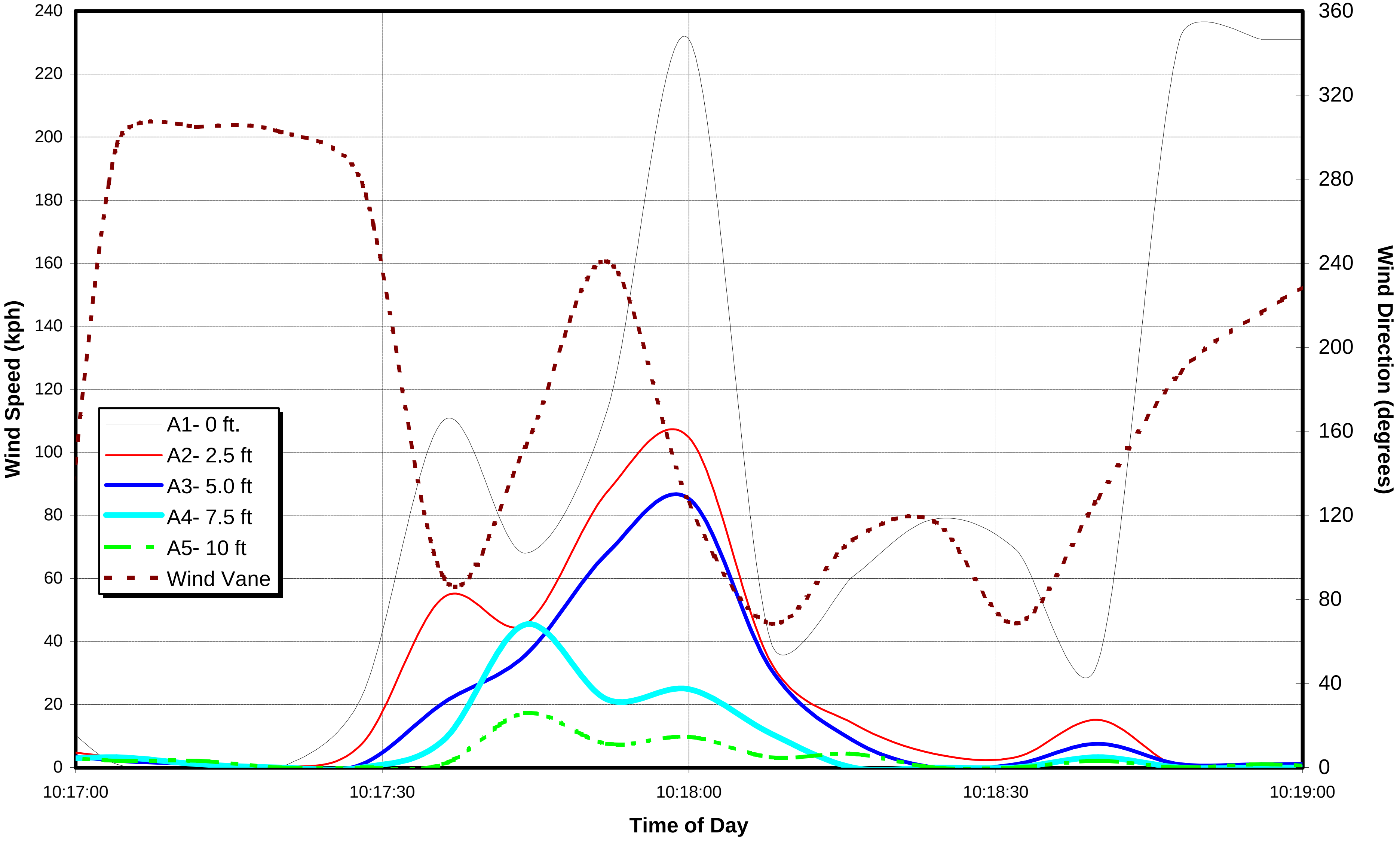


cm1514/analysis/wind_vel/march_13/Wnd_mr13.xls
At: Run4
04/07/01, 4:44 PM

WIND VELOCITY MEASURMENTS

March 13, 1999

Run # 5, A320 - ID # 11

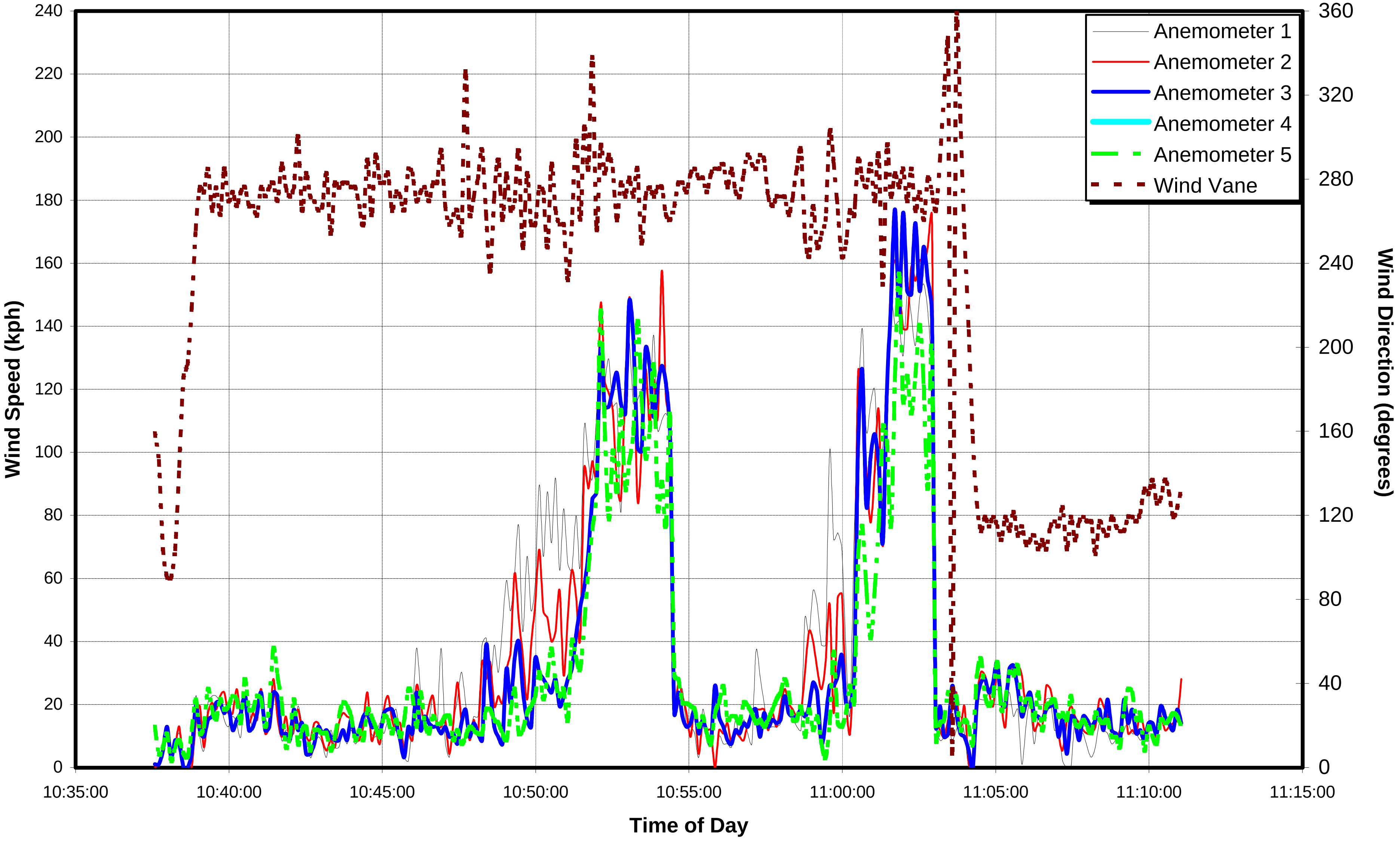


cm1514/analysis/wind_vel/march_13/Wnd_mr13.xls
At: Run5
04/07/01, 4:45 PM

WIND VELOCITY MEASURMENTS

March 23, 1999

A310 - ID # 12

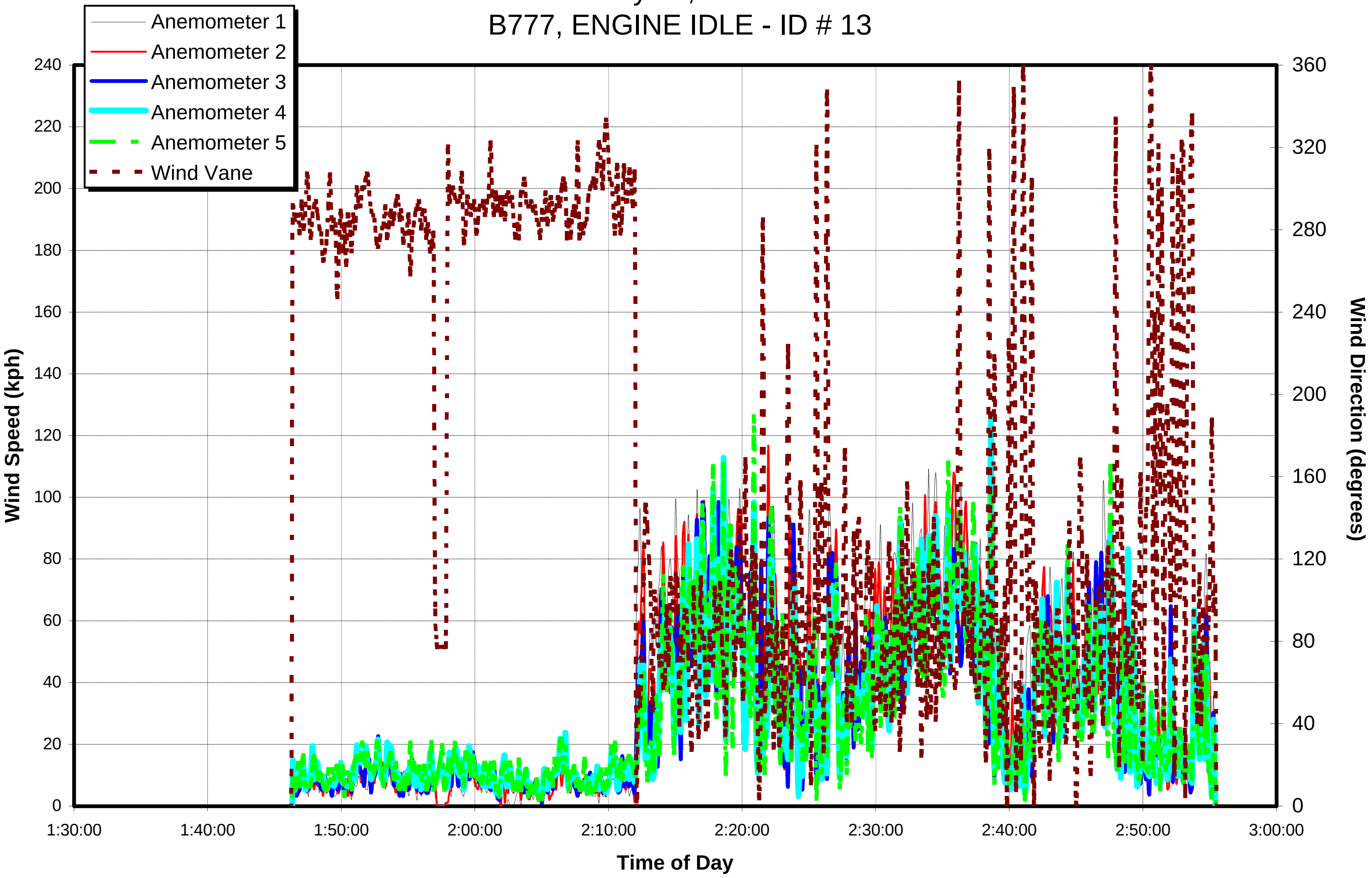


cm1514/analysis/wind_vel/march_23/Wnd_mr23.xls
At: Run1
04/07/01, 4:46 PM

WIND VELOCITY MEASURMENTS

May 09, 1999

B777, ENGINE IDLE - ID # 13

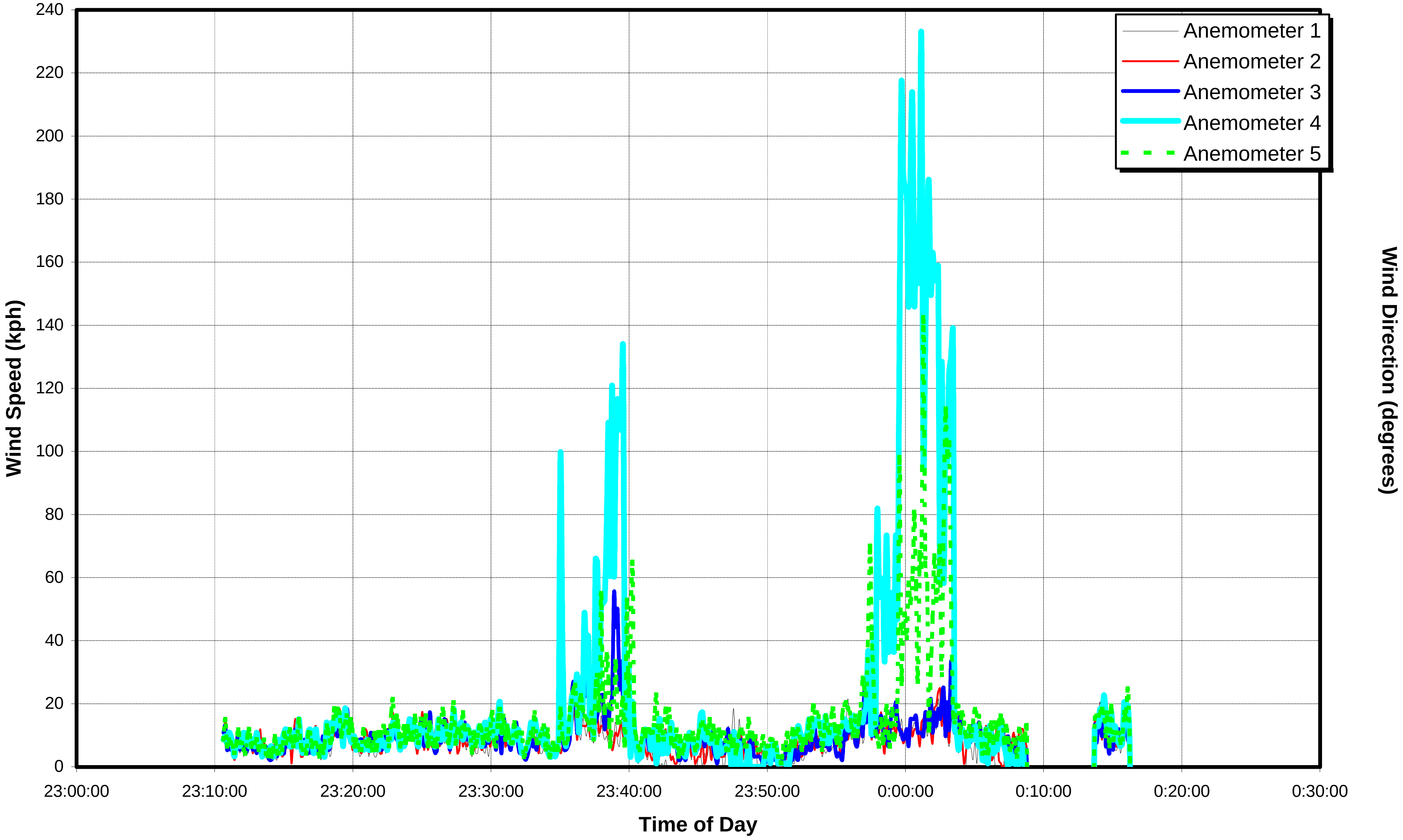


cm1514/analysis/wind_vel/may_06/May_06.xls
At: Idle
05/07/01, 10:07 AM

WIND VELOCITY MEASURMENTS

May 09, 1999

B777, APU EXHAUST - ID # 14

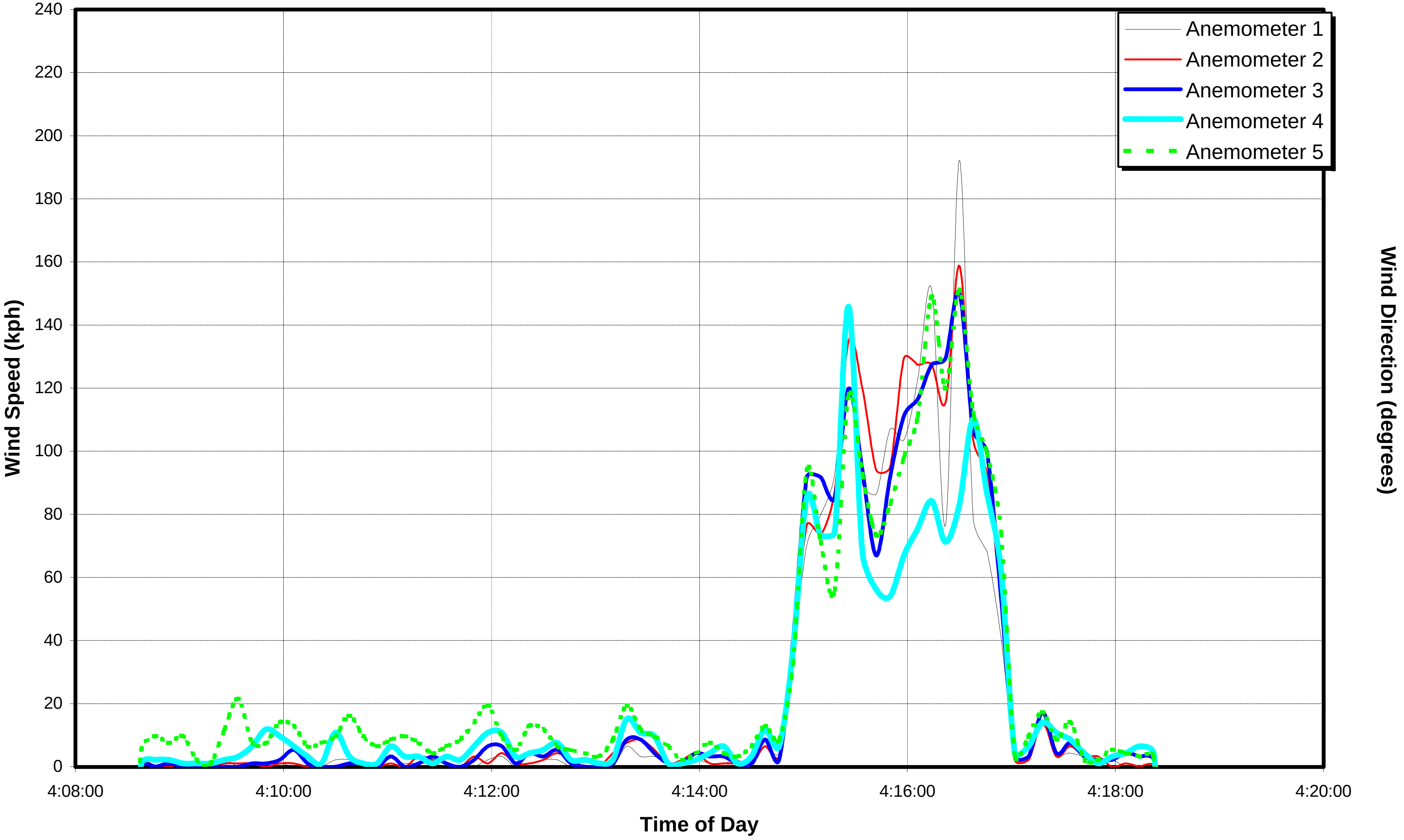


cm1514/analysis/wind_vel/may_06/May_06.xls
At: APU
05/07/01, 10:11 AM

WIND VELOCITY MEASURMENTS

May 09, 1999

B777, ENGINE 3/4 THROTTLE - ID # 15



cm1514/analysis/wind_vel/may_06/May_06.xls
At: 300 ft
05/07/01, 10:12 AM

APPENDIX D

PRELIMINARY TESTS

ENGINE AIR VELOCITY DISTRIBUTIONS

ENGINE AIR VELOCITY DISTRIBUTIONS NEAR DEICING VEHICLES
PHASE I
Winter 1998/99

At the request of Delta Airlines and the Transportation Development Center (TDC) of Transport Canada, APS Aviation Inc. conducted preliminary tests to measure air velocity distributions in the vicinity of a de-icing truck when de-icing a large aircraft whose engines are running.

A total of six wind velocity measurement tests were conducted on January 11, 1999 at Aéromag Deicing Center at Dorval International Airport. The tests were conducted during live deicing operations, following an overnight snowfall, on four different aircraft: A319, A320, B737 and B767.

Measurements were taken at a distance of approximately eight feet from leading edge of tail section of the aircraft, at different heights from the core of the engine.

Test results are attached and summarized below.

Run	**Aircraft**	**Air Velocity Measurements (kph)**					
#	**Type**	Ground	-3 ft	0 ft (Centre)	+ 3 ft	+ 6 ft	+ 9 ft
1	A320			86	36	22	
2	A319			6			
3	B767			67, 80	40	27	20
4	B737	120	106	75, 92	70	54	
5	A320	33, 46, 57		50	56, 83	24, 27	
6	A320	38, 49		32	32, 50	16, 60	

Tests were conducted to determine whether the air velocity caused by the exhaust of wing mounted turbine engines, of idle aircraft, exceeds 45 mph (72 kph). The results indicate the wind velocity exceeded the 45 mph limit, mainly at the centre of the engine.

A hand-held anemometer mounted on an extendable pole was used to obtain data. The anemometer was centered on the horizontal symmetrical axis of the engine and was moved, in intervals, along the vertical symmetrical axis of the engine. The anemometer was held perpendicular to the airflow at all times.

Positions on the vertical axis were designated numerically. The center of the engine or the intersection of the horizontal and vertical symmetries was considered the datum and assigned the number zero. Any distance above the datum was made to be positive, any distance below was made to be negative. A measurement was also made at true ground level and labeled “ground”. All distance measurements are visual estimates made from the truck cabin.

As the anemometer was moved along the vertical axis, readings from the unit were recorded. Typically a value was recorded when it was deemed stable or representative of any series of readings. Peak values were also recorded. A value was considered peak if it did not correspond to the stable readings, but did occur more than once.

It is interesting to note a phenomenon that was observed during the test trials. In conditions of crosswinds, the wind was sufficient to significantly deflect the direction of the exhaust. The deflection resulted in extremely low readings in the typical measurement areas. Effectively the exhaust had been redirected, in some cases directly to the ground, in others up against the fuselage.

Effects of the exhaust were also experienced in the cabin of the de/anti-icing truck. These translated mainly into turbulent effects being experienced within the cabin.

Recommendations:

- Tests should be repeated with equipment that allows the development of vertical wind profiles;
- Effects of the truck orientation versus airflow should be explored to possibly establish standard patterns of approach;
- Examine possibility of exploring the effects of wind loads on trucks using weigh scale method. (Put a weigh scale under each tire and expose truck to wind loads);
- Mount anemometers on truck and examine wind distribution over truck
- Explore possibilities of using “*Pitot*” tubes to measure pressure distributions on trucks; and
- Purchase laser distance measurement instrument.

ENGINE VELOCITY MEASUREMENTS

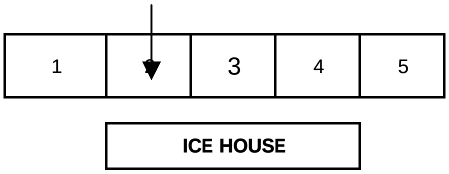
DATE: January 11, 1999

DE-ICING BAY #: 2

RUN #: 1

WING: PORT (A) [✓ STARBOARD (B)]

DRAW DIRECTION OF A/C WRT DE-ICING BAY:



AIRCRAFT TYPE: A320

ENGINE MANUFACTURER: CFMI

AIRLINE: Canadian

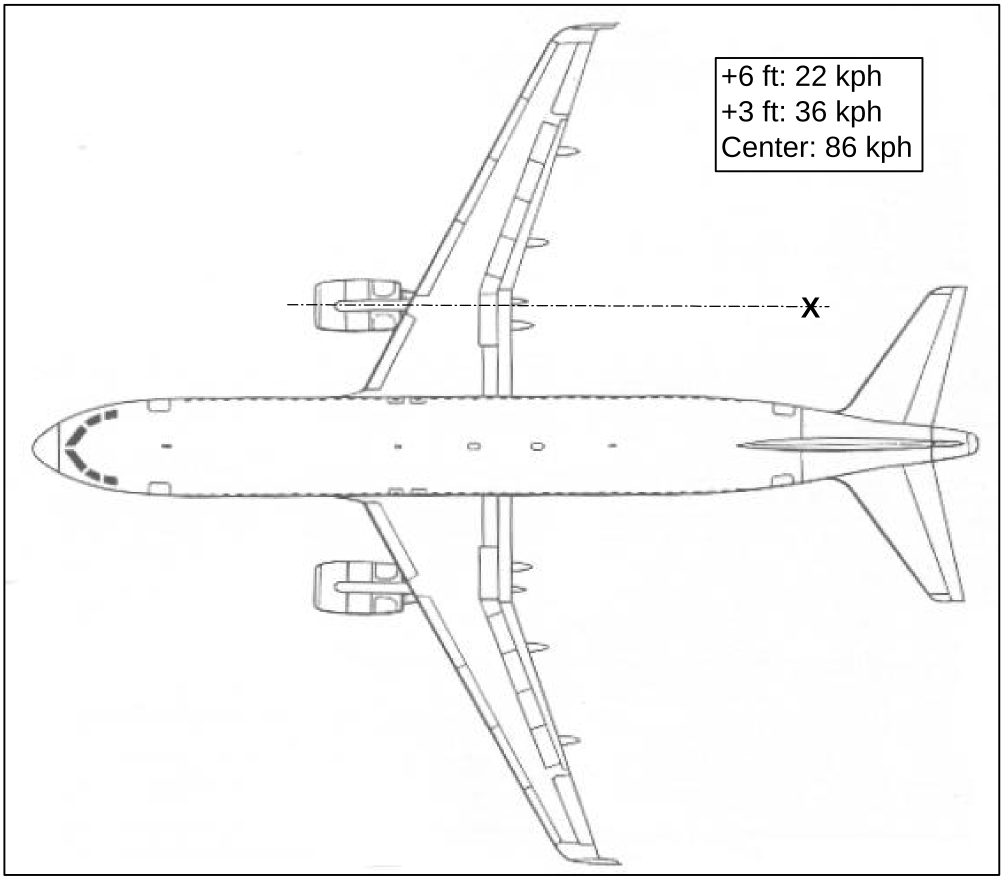
ENGINE TYPE: CFM56-5

FIN #: 411

SERIAL #: C-FSLU

Start of Test Time: 7:00 (hr:min)

End of Test Time: 7:05 (hr:min)



+6 ft: 22 kph
+3 ft: 36 kph
Center: 86 kph

Measurements were taken at an approx. Distance of 8 to 10 ft from LE of the tail.
Centre represents centre core of engine.
+ xx ft represents height above (or below) center core.

ENGINE VELOCITY MEASUREMENTS

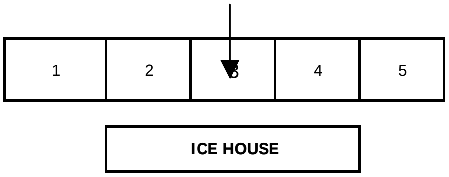
DATE: January 11, 1999

DE-ICING BAY #: 3

RUN #: 2

WING: [✓ PORT (A)] STARBOARD (B)

DRAW DIRECTION OF A/C WRT DE-ICING BAY:



AIRCRAFT TYPE: A319

ENGINE MANUFACTURER: CFMI

AIRLINE: Air Canada

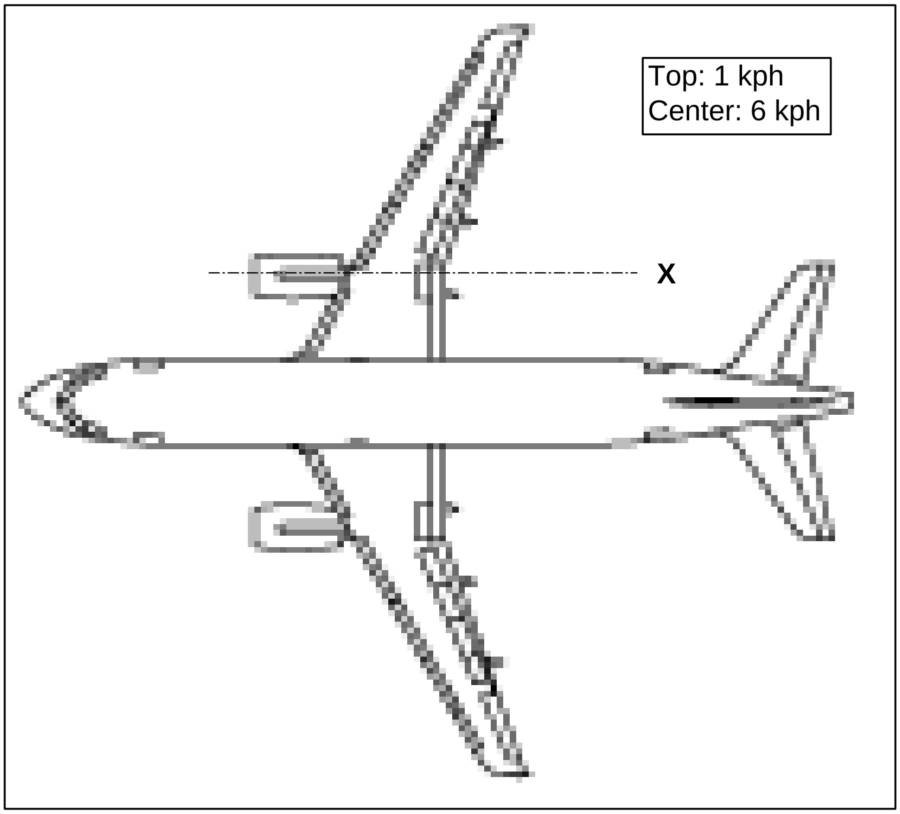
ENGINE TYPE: CFM56

FIN #: 280

SERIAL #: C-GBIA

Start of Test Time: 7:10 (hr:min)

End of Test Time: 7:18 (hr:min)



Measurements were taken at an approx. Distance of 8 to 10 ft from LE of the tail.
Centre represents centre core of engine.
+ xx ft represents height above (or below) center core.

ENGINE VELOCITY MEASUREMENTS

DATE: January 11, 1999

DE-ICING BAY #: 3

RUN #: 3

WING: [✓ PORT (A)] STARBOARD (B)

DRAW DIRECTION OF A/C WRT DE-ICING BAY:

1	2	3	4	5

ICE HOUSE

AIRCRAFT TYPE: B767

ENGINE MANUFACTURER: Pratt and Whitney

AIRLINE: Air Canada

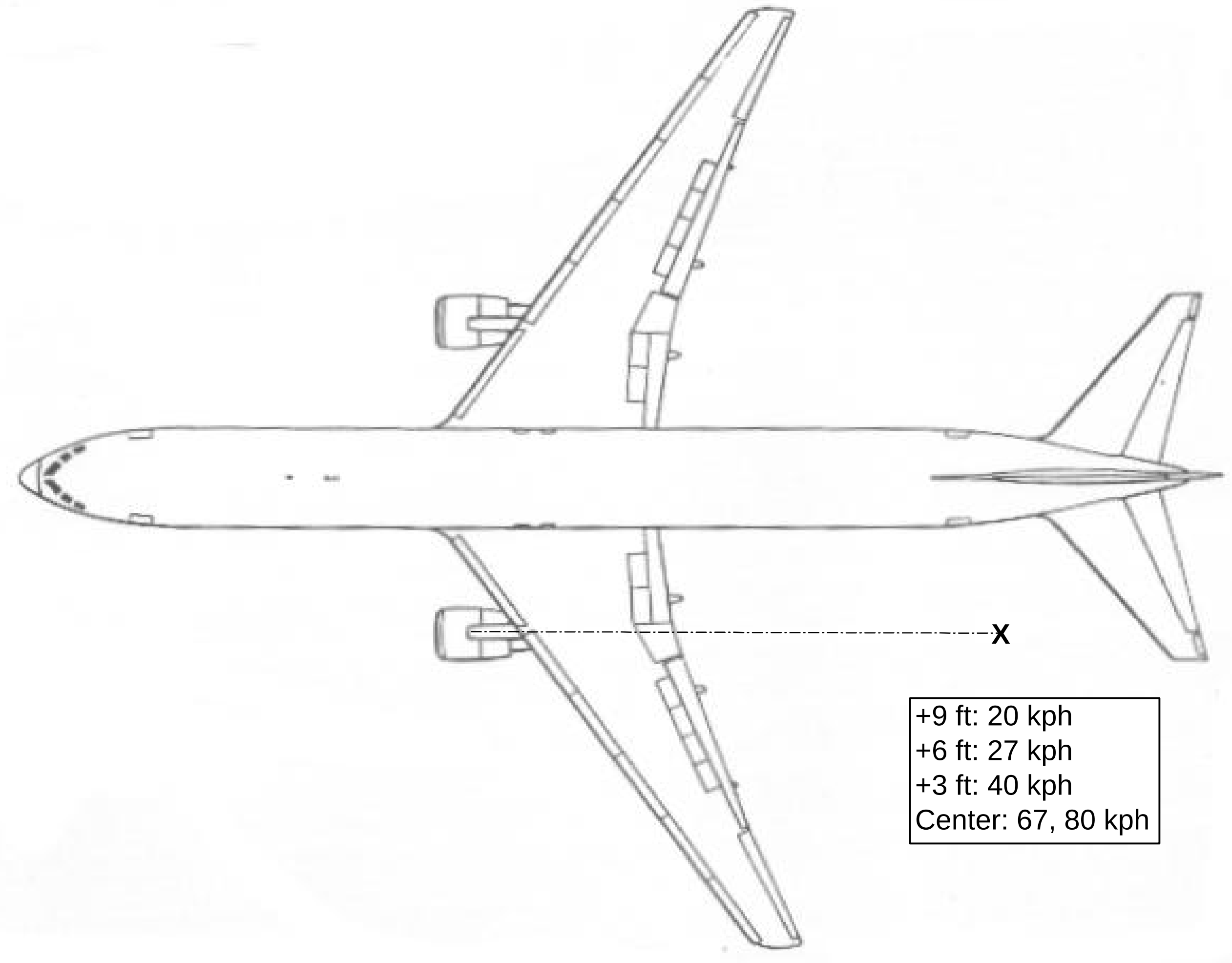
ENGINE TYPE: JT9D-7R4D

FIN #: 609

SERIAL #: C-GAUY

Start of Test Time: 7:30 (hr:min)

End of Test Time: 7:40 (hr:min)



+9 ft: 20 kph
+6 ft: 27 kph
+3 ft: 40 kph
Center: 67, 80 kph

Measurements were taken at an approx. Distance of 8 to 10 ft from LE of the tail.
Centre represents centre core of engine.
+ xx ft represents height above (or below) center core.

File:g:\cm1514\analysis\wind_vel\:B767_r3.xls
Printed: 05/07/01, 10:55 AM

ENGINE VELOCITY MEASUREMENTS

DATE: January 11, 1999

DE-ICING BAY #: 4

RUN #: 4

WING: PORT (A) [✓ STARBOARD (B)]

DRAW DIRECTION OF A/C WRT DE-ICING BAY:

1	2	3	4	5

ICE HOUSE

AIRCRAFT TYPE: B737

ENGINE MANUFACTURER: CFMI

AIRLINE: USAirways

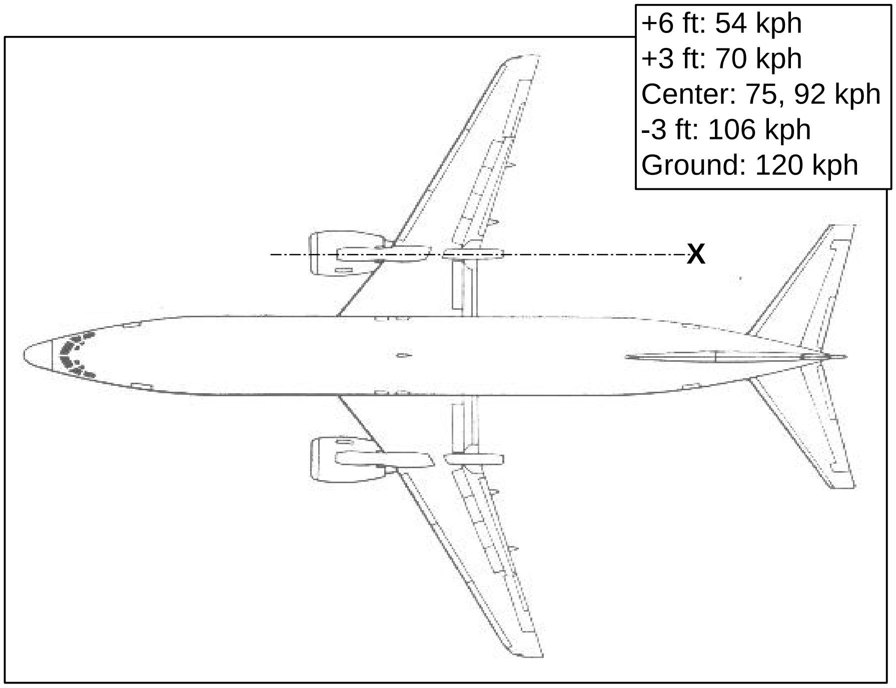
ENGINE TYPE: CFM56

FIN #: 588

SERIAL #: N588US

Start of Test Time: 7:54 (hr:min)

End of Test Time: 7:58 (hr:min)



+6 ft: 54 kph
+3 ft: 70 kph
Center: 75, 92 kph
-3 ft: 106 kph
Ground: 120 kph

Measurements were taken at an approx. Distance of 8 to 10 ft from LE of the tail.
Centre represents centre core of engine.
+ xx ft represents height above (or below) center core.

ENGINE VELOCITY MEASUREMENTS

DATE: January 11, 1999

DE-ICING BAY #: 5

RUN #: 5

WING: PORT (A) [✓ STARBOARD (B)]

DRAW DIRECTION OF A/C WRT DE-ICING BAY:

1	2	3	4	▼

ICE HOUSE

AIRCRAFT TYPE: A320

ENGINE MANUFACTURER: CFMI

AIRLINE: Air Canada

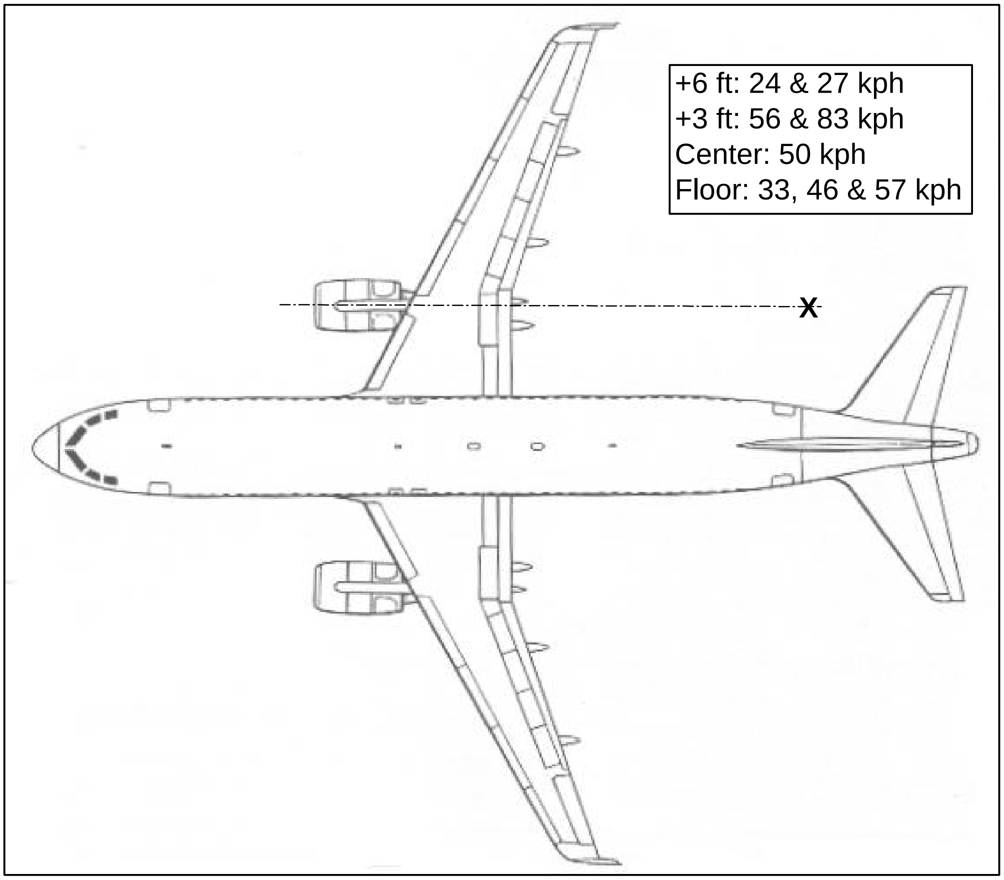
ENGINE TYPE: CFM56-5A1

FIN #: 229

SERIAL #: C-FMJK

Start of Test Time: 9:10 (hr:min)

End of Test Time: 9:17 (hr:min)



+6 ft: 24 & 27 kph
+3 ft: 56 & 83 kph
Center: 50 kph
Floor: 33, 46 & 57 kph

Measurements were taken at an approx. Distance of 8 to 10 ft from LE of the tail.
Centre represents centre core of engine.
+ xx ft represents height above (or below) center core.

File:g:\cm1514\analysis\wind_vel\:A320_r5.xls
Printed: 05/07/01, 11:00 AM

ENGINE VELOCITY MEASUREMENTS

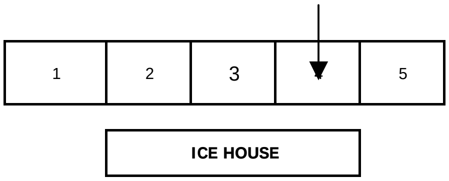
DATE: January 11, 1999

DE-ICING BAY #: 4

RUN #: 6

WING: [✓ PORT (A)] [✓ STARBOARD (B)]

DRAW DIRECTION OF A/C WRT DE-ICING BAY:



AIRCRAFT TYPE: A320

ENGINE MANUFACTURER: CFMI

AIRLINE: Air Canada

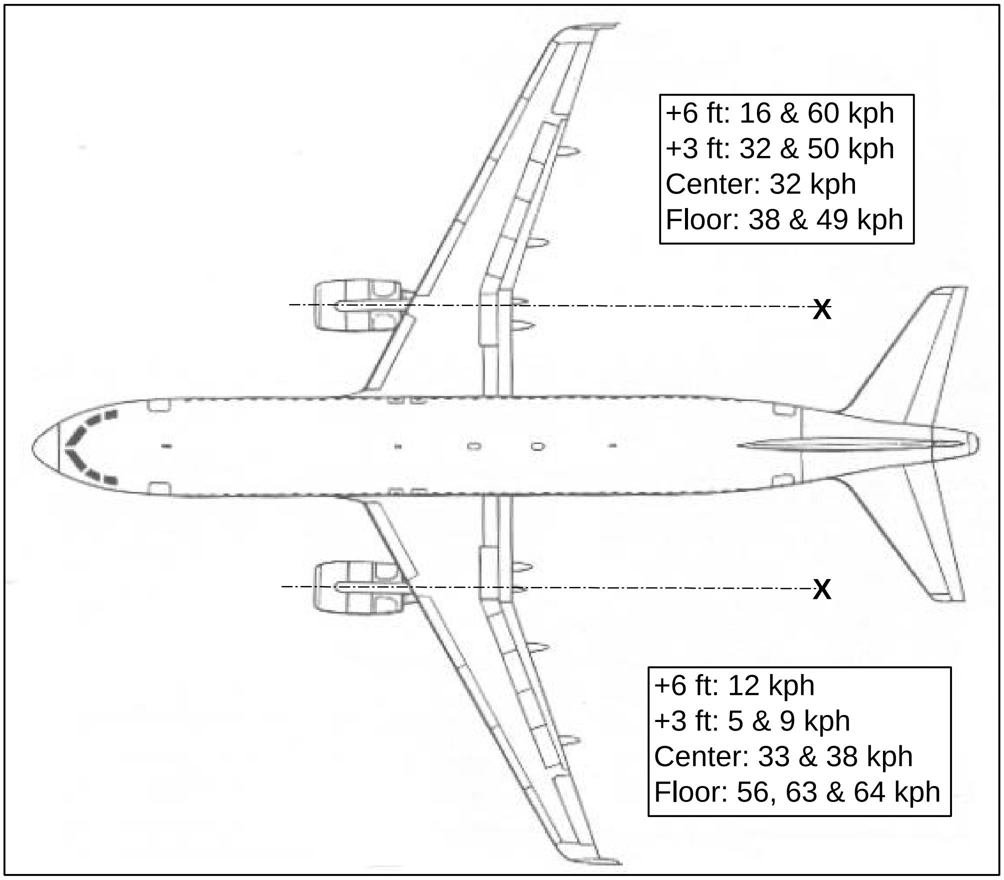
ENGINE TYPE: CFM56-5A1

FIN #: 212

SERIAL #: C-FFWN

Start of Test Time: 9:45 (hr:min)

End of Test Time: 9:50 (hr:min)


+6 ft: 16 & 60 kph
+3 ft: 32 & 50 kph
Center: 32 kph
Floor: 38 & 49 kph

+6 ft: 12 kph
+3 ft: 5 & 9 kph
Center: 33 & 38 kph
Floor: 56, 63 & 64 kph

Measurements were taken at an approx. Distance of 8 to 10 ft from LE of the tail.
Centre represents centre core of engine.
+ xx ft represents height above (or below) center core.