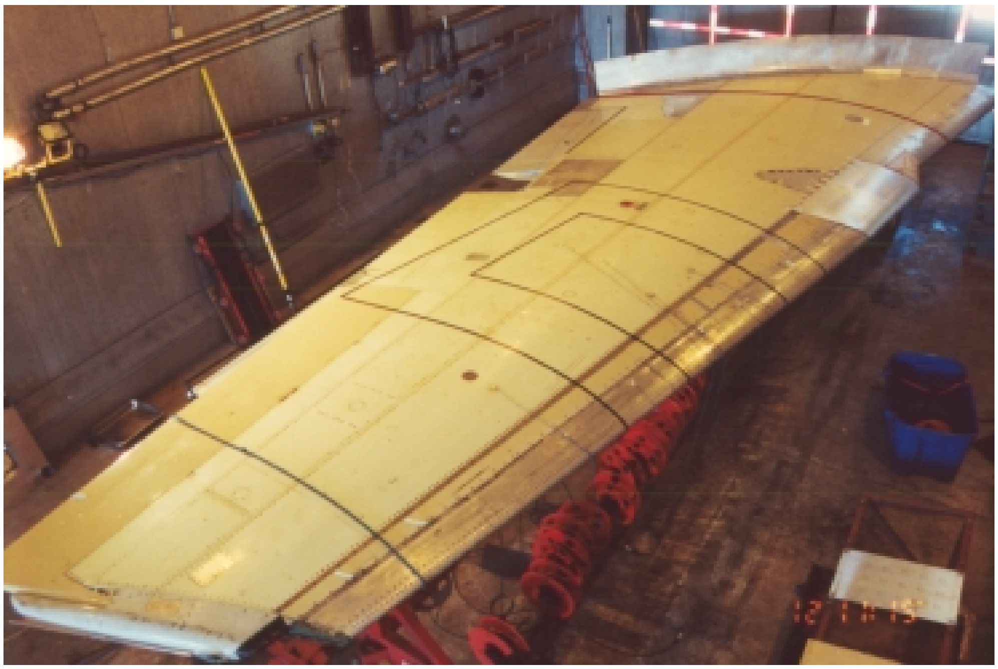
TP 13829E

Modification of Test Wing to Accommodate Fuel Load Effects for Deicing Research: 2001



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Transport Canada

APS AVIATION INC.

October 2001

Final Version 1.0

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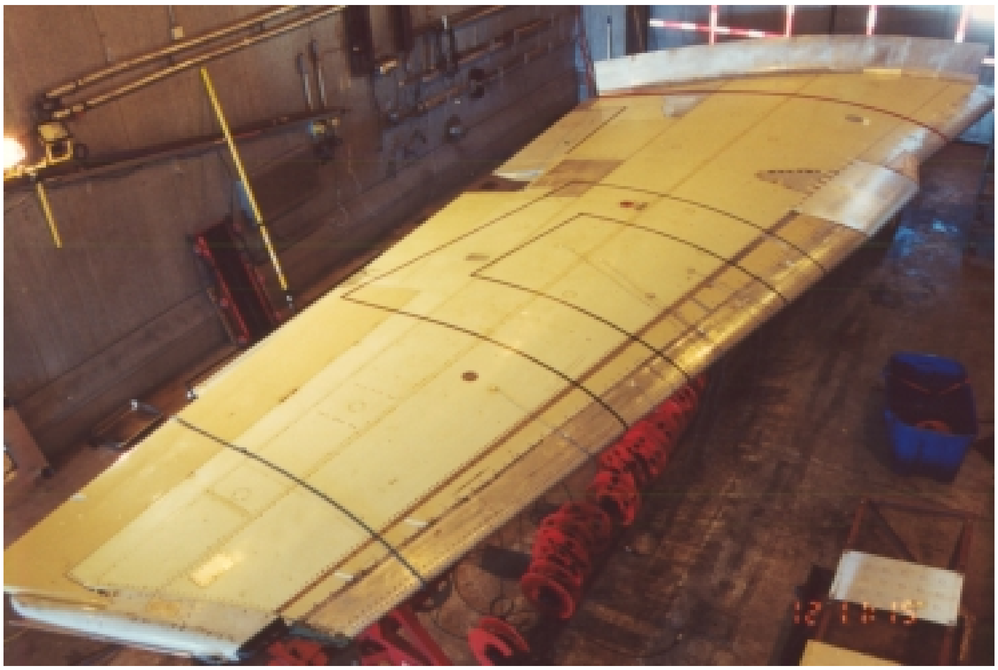

by

Alia Alwaid

APS AVIATION INC.

October 2001

Final Version 1.0

The contents of this report reflect the views of APS Aviation Inc. and not necessarily the official view or opinions of the Transportation Development Centre of Transport Canada.

The Transportation Development Centre does not endorse products or manufacturers. Trade or manufacturers' names appear in this report only because they are essential to its objectives.

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Un sommaire français se trouve avant la table des matières.

PREFACE

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

- To develop holdover time data for all newly qualified de/anti-icing fluids;
- To conduct endurance time frost tests for each temperature to substantiate the values in the current SAE holdover time guidelines for Type IV, Type II, and Type I fluids;
- To evaluate weather data from previous winters to establish a range of snow precipitation suitable for the evaluation of holdover time limits;
- To develop a protocol for Type I fluid testing;
- To examine the change in viscosity during the application of Type IV fluids;
- To compare holdover times in natural snow with those in NCAR's artificial snow;
- To prepare the JetStar and Canadair RJ wing for thermodynamic tests;
- To further evaluate the flow of contaminated fluid from the wing of a Falcon 20D aircraft during simulated take-off runs;
- To further evaluate hot water deicing;
- To provide support for tactile tests at Toronto Central Deicing Facility; and
- To investigate the use of ice sensors to the pre-take-off contamination check.

The research activities during the winter of 2000-2001 are documented in six reports. The last four objectives listed above have not yet been finalized and are not included in this series of reports. Results will be reported upon study completion. The titles of the documented reports are as follows:

- TP 13826E Aircraft Ground De/Anti-icing Fluid Holdover Time Development Program for the 2000-01 Winter;
- TP 13827E SAE Type I Fluid Endurance Time Test Protocol;
- TP 13828E Endurance Time Testing in Snow: Reconciliation of Indoor and Outdoor Data;
- TP 13829E Modification of Test Wing to Accommodate Fuel Load Effects for Deicing Research: 2001
- TP 13830E Winter Weather Data Evaluation (1995-2001); and
- TP 13831E Endurance Time Tests in Simulated Frost Conditions: 2001.

In addition, an interim report entitled *Viscosity Measurement of Type IV Fluids on Wing Surfaces* will be written.

This report, TP 13829E, documents the project with the following objectives:

- To modify the wing to obtain cold-soak capabilities; to examine the current wing support assembly and modify it, if required, to sustain the additional weight of a filled fuel tank; and to perform minor improvements on the wing body.

The fuel tank of the JetStar wing was modified and sealed to obtain cold-soak capabilities. A new wing mounting capable of sustaining the additional weight of a filled fuel tank was purchased and modified to hold the wing at an ideal working height and to facilitate the movement of the wing. Various improvements were made to the wing body. The galvanized metal originally used to replace missing panels was replaced with aluminum panels. Also, an end plate was attached to simulate the effects of a fuselage. Other sheet metal work was carried out on the wing.

ACKNOWLEDGEMENTS

This research was funded by the Civil Aviation Group, Transport Canada, with support from the U.S. Federal Aviation Administration. This program could not have been accomplished without the participation of many organizations. APS would therefore like to thank the Transportation Development Centre of Transport Canada, the Federal Aviation Administration, National Research Council Canada, the Meteorological Service of Canada, and several fluid manufacturers. Special thanks are extended to US Airways Inc., Air Canada, American Eagle Airlines Inc., National Centre for Atmospheric Research, AéroMag 2000, Aéroports de Montreal, Hudson General Aviation Services Inc., Union Carbide, Cryotech, and Fortier Transfert Ltée for provision of personnel and facilities and for their co-operation with the test program. APS would also like to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data. The author gratefully acknowledges the participation of Jeff Mayhew, Michael Chaput, Nicolas Blais, Nicoara Moc, Peter Dawson, Richard Campbell, Yagusha Bodnar, and Sami Chebil. Special thanks are extended to Frank Eyre and Barry Myers of the Transportation Development Centre for their participation, contribution, and guidance in the preparation of this document.

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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). Six reports (including this one) were produced as part of this winter's research program. Their subject matter is outlined in the preface.

16. Abstract

A full-scale test site implementation study carried out in 1999-2000 involved the purchase of a wing and mounting system, and the installation of the wing on a carriage. A Lockheed JetStar wing was purchased and modified. The control surfaces were reinstalled, a fairing was constructed for the leading edge, missing wing panels were replaced, the deicing boot was removed, and the leading edge was polished. The JetStar wing was installed on a mounting system consisting of an off-the-shelf boat trailer purchased for this purpose.

During the winter of 2000-2001 further modifications were made to the wing: sheet metal work was performed on the wing body, a wing fairing was installed at the wing root to simulate the effects of a fuselage, improvements were made to the wing flap mechanisms, and the wing tank was sealed to obtain cold-soak capabilities. A wagon was also purchased and modified to enable the addition of liquid to the wing to simulate fuel.

During the 1999-2000 and 2000-2001 test seasons, full-scale tests with the JetStar wing were conducted in natural and simulated precipitation conditions at National Research Council Canada in Ottawa, the Ottawa International Airport, and the Centralized Deicing Facility at Dorval Airport in Montreal. Testing consisted of fluid application trials to evaluate foaming, hot water deicing trials, ice detection sensor trials for end-of-runway application, evaluation of the Type I fluid holdover time test protocol, and forced air trials.

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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 a donné lieu à six rapports (dont celui-ci). On trouvera dans la préface l'objet de ces rapports.

16. Résumé

Une étude d'implantation d'un site d'essai en vraie grandeur réalisée en 1999-2000 comportait l'achat d'une aile et d'un système de montage, et l'installation de l'aile sur un chariot-support. Une aile de Lockheed JetStar a été achetée et modifiée. Les gouvernes ont été réinstallées, un carénage a été construit pour le bord d'attaque, les panneaux manquants de l'aile ont été remplacés, le boudin de dégivrage a été enlevé et le bord d'attaque a été poli. L'aile du JetStar a finalement été installée sur un chariot-support constitué d'une remorque porte-bateau du commerce, achetée exprès.

Au cours de l'hiver 2000-2001, d'autres modifications ont été apportées à l'aile : travail de tôlerie sur l'enveloppe de l'aile, installation d'un carénage à l'emplanture de l'aile pour simuler les effets d'un fuselage, amélioration des mécanismes actionnant les volets, et scellement du réservoir pour que l'aile puisse simuler une aile sur-refroidie. Une remorque agricole a enfin été achetée et modifiée, qui permet de verser dans l'aile du liquide tenant lieu de carburant.

Au cours des saisons 1999-2000 et 2000-2001, des essais en vraie grandeur utilisant l'aile de JetStar ont été réalisés sous des précipitations naturelles et artificielles au Conseil national de recherches du Canada à Ottawa, à l'Aéroport international d'Ottawa et au poste de dégivrage de l'Aéroport de Montréal-Dorval. Plusieurs types d'essais ont été menés : essais d'application de fluides pour évaluer le moussage des fluides, essais de dégivrage à l'eau chaude, essais de détecteurs de givrage pour utilisation en bout de piste, évaluation du protocole d'essai de la durée d'efficacité des fluides de type I, et essais dégivrage à air forcé.

17. Mots clés Aile d'avion, JetStar, aile d'essai, dégivrage, opérations hivernales, site d'essai, masse de carburant, remorque	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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EXECUTIVE SUMMARY

Under contract to the Transportation Development Centre, APS Aviation Inc. (APS) undertook a research program to further advance aircraft ground de/anti-icing technology.

Enhancements to the Wing During Winter 1999-2000

During the winter of 1999-2000 the full-scale test site implementation study was carried out in three phases: purchase of a wing, mounting of the wing on a suitable platform, and selection of an ideal test location.

A Lockheed JetStar wing was purchased in April 1999 for research purposes. Although not attached to the wing, all flight control surfaces were delivered with the main wing surface. During the winter of 1999-2000, an aircraft mechanic was contracted to reassemble the various control surfaces, construct a fairing for the leading edge, replace any missing panels, remove the rubber deicing boot, and polish the leading edge.

A mounting system for the JetStar wing, consisting of an off-the-shelf boat trailer, was proposed.

The third phase of the study involved the examination and selection of a suitable full-scale test site. The centralized deicing facility at Dorval Airport, operated by AéroMag 2000, was selected. National Research Council Canada's (NRC) Climatic Engineering Facility (CEF) was chosen as the ideal location to conduct indoor tests in simulated precipitation.

During the 1999-2000 test season, full-scale testing with the JetStar wing was conducted in natural and simulated precipitation conditions at NRC's CEF in Ottawa and at the central deicing facility at Dorval Airport in Montreal. The wing was used in various full-scale trials:

- Fluid application trials to evaluate fluid foaming;
- Hot water deicing trials;
- Testing of ice detection sensors for end-of-runway application; and
- Forced air trials.

Enhancements to the Wing During Winter 2000-2001

During the hot water deicing trials with the JetStar wing in 1999-2000, it was found that the measured times for the water to refreeze were inferior to those measured in previous years during full-scale trials on other aircraft. It was believed that the lack of wing thermal mass, due to the empty fuel tanks, might have contributed to the inferior times. It was recommended that the fuel system integrity of the JetStar wing be examined to determine the feasibility of filling the tanks with fluid to obtain cold-soak capabilities.

An Ottawa-based company, Canadian Aviation Maintenance Inc., was contracted to perform the necessary work. Cold-soak capabilities were attained in 2000-2001 testing.

Studies to examine cold-soak capabilities required the purchase of a new wing mounting that was capable of sustaining the additional weight of a filled tank. A farm wagon was purchased and modified to facilitate the addition of liquid to the wing to simulate fuel.

Several other observations were made during the course of the 1999-2000 test season, and all recommendations for improvement were addressed in 2000-2001. Modifications made to the wing included: sheet metal work performed on the wing body, installation of a wing fairing at the wing root to simulate the effects of a fuselage, improvements to the wing flap mechanisms, and sealing the wing tank to obtain cold-soak capabilities.

Tests to study the development of a Type I Holdover Time Test Protocol were also conducted in the winter of 2000-2001.

SOMMAIRE

En vertu d'un contrat avec le Centre de développement des transports, APS Aviation Inc. (APS) a entrepris un programme de recherche visant à approfondir la technologie de dégivrage/antigivrage des aéronefs au sol.

Améliorations apportées à l'aile au cours de l'hiver 1999-2000

Au cours de l'hiver 1999-2000, l'étude d'implantation d'un site d'essai en vraie grandeur a été réalisée en trois phases : achat d'une aile, montage de l'aile sur un support approprié, et choix d'un endroit optimal pour réaliser les essais.

En avril 1999, une aile de Lockheed JetStar était achetée. L'aile a été livrée avec toutes ses gouvernes, mais détachées. Pendant l'hiver 1999-2000, un mécanicien d'aéronef a été chargé par contrat de réinstaller les gouvernes, de construire un carénage pour le bord d'attaque, de remplacer les panneaux manquants, d'enlever le boudin de dégivrage et de polir le bord d'attaque.

Un système de montage pour l'aile de JetStar a été proposé, soit une remorque porte-bateau du commerce.

La troisième phase de l'étude comportait l'examen et la sélection d'un endroit optimal pour des essais en vraie grandeur. Le poste de dégivrage de l'Aéroport de Montréal-Dorval, exploité par AéroMag 2000, a été choisi. L'Installation de génie climatique (IGC) du Conseil national de recherches du Canada (CNRC) a par ailleurs été choisie comme l'endroit tout indiqué pour mener des essais intérieurs sous précipitations artificielles.

Au cours de la saison 1999-2000, divers essais en vraie grandeur utilisant l'aile de JetStar ont été menés sous des précipitations naturelles et artificielles à l'IGC du CNRC à Ottawa et au poste de dégivrage de l'Aéroport de Montréal-Dorval. Voici en quoi ont consisté ces essais :

- application de fluides pour évaluer le moussage des fluides;
- essais de dégivrage à l'eau chaude;
- évaluation de détecteurs de givrage pour utilisation en bout de piste;
- essais de dégivrage à air forcé.

Améliorations apportées à l'aile au cours de l'hiver 2000-2001

Les essais de dégivrage à l'eau chaude menés sur l'aile de JetStar en 1999-2000 ont révélé que l'eau commençait à geler plus vite sur l'aile d'essai que sur les ailes d'autres avions en vraie grandeur, selon les essais menés auparavant. Les chercheurs ont attribué cette différence au fait que le réservoir de l'aile étant vide, celle-ci ne constituait pas une masse thermique, contrairement à l'aile d'un avion réel. Ils ont donc recommandé d'examiner l'intégrité du circuit de carburant de l'aile de Jetstar afin de déterminer la possibilité de remplir les réservoirs de liquide et de pouvoir ainsi simuler une aile sur-refroidie.

Une entreprise d'Ottawa, Canadian Aviation Maintenance Inc., a été chargée par contrat d'exécuter les travaux. La capacité de l'aile de simuler une aile sur-refroidie a été validée lors d'essais menés en 2000-2001.

Ces études de validation ont nécessité l'achat d'un nouveau support capable de résister au poids supplémentaire d'un réservoir rempli. Une remorque agricole a été achetée et modifiée pour permettre de verser du liquide tenant lieu de carburant dans le réservoir.

Plusieurs autres observations ont été faites au cours de la saison d'essais 1999-2000, et toutes les améliorations recommandées ont été apportées en 2000-2001. Voici les modifications qui portaient sur l'aile : travail de tôlerie sur l'enveloppe de l'aile, installation d'un carénage à l'emplanture de l'aile pour simuler les effets d'un fuselage, amélioration des mécanismes actionnant les volets et scellement du réservoir pour que l'aile puisse simuler une aile sur-refroidie.

Les essais en vue de la mise au point d'un protocole d'essai de la durée d'efficacité des liquides de type I ont également été menés au cours de l'hiver 2000-2001.

CONTENTS

LIST OF APPENDICES

LIST OF FIGURES

Page

LIST OF PHOTOS

Page

GLOSSARY

APS	APS Aviation Inc.
CAM	Canadian Aviation Maintenance Inc.
CDF	Centralized Deicing Facility
CEF	Climatic Engineering Facility
HOT	Holdover Time
IREQ	Institut de Recherche d'Hydro-Québec
NCAR	National Centre for Atmospheric Research
NRC	National Research Council Canada
TDC	Transportation Development Centre

Aerodynamically quiet areas
There are two classes of aerodynamically quiet areas: aircraft cavities and aerodynamic surfaces with separated airflow.

Aerodynamically quiet cavities
All aircraft have cavities into which fluids may seep under gravity but where drainage may be inadequate for a viscous fluid to seep out. If the cavity is not sufficiently scoured by the airflow during take-off to effectively remove a fluid more viscous than water, it is called an aerodynamically quiet area.

Aerodynamically quiet surfaces
This term is used to describe those parts of the aircraft where a thin layer of fluid may move very slowly or not at all; this is the result of airflow separation from the aerodynamic surface, whereby there is a separation bubble formed (typically breakaway of laminar airflow followed by a turbulent airflow reattachment) and thus zones of very low velocity airflow occur at the surface.

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1. INTRODUCTION

Under contract to the Transportation Development Centre (TDC), APS Aviation Inc. (APS) undertook a research program to further advance aircraft ground de/anti-icing technology.

Aircraft ground de/anti-icing has been the subject of concentrated industry attention over the past decade because of a number of fatal aircraft accidents. Recent attention has been focused on the enhancement of anti-icing fluids to provide an extended duration of protection against further contamination following initial deicing. This has led to the development of fluid holdover time table (HOT table) guidelines, which are used by aircraft operators and accepted by regulatory authorities. New fluids continue to be developed to prolong fluid holdover times without compromising airfoil aerodynamics.

APS has conducted over 250 full-scale aircraft tests since 1993. Over the past few years, securing aircraft for full-scale testing has become increasingly difficult due to the complexities of these trials. The implementation of a full-scale test site was explored by APS during the 1998-99 test season, when APS was asked to examine the feasibility of implementing a full-scale test site centred on a wing test bed and supported by current fluid and rainmaking sprayers. A report entitled *Development of a Plan to Implement a Full-Scale Test Site*, TP 13487E (1), was prepared for Transport Canada and contains quotations from various suppliers, on which the JetStar wing selection was based.

This document reports the developments in the full-scale test site implementation study from 1999 to 2001. A previous report entitled *Preparation of JetStar Wing for Use in Deicing Research*, TP 13667E (2), presents a discussion of the activities carried out in 1999-2000, along with observations and conclusions. Suggested improvements to the full-scale implementation study reported in TP 13667E (2) were implemented in the 2000-2001 test season. The present document includes discussions from TP 13667E (2), and supercedes that report by detailing further developments of the full-scale implementation study.

1.1 1999-2000 Full-Scale Implementation Study

The full-scale test site implementation study conducted in 1999-2000 involved three phases: purchase of a wing, mounting of the wing on a suitable platform, and selection of an ideal test location. The three phases are discussed in detail in Subsections 2.1 and 2.2, and are described briefly below.

Following a long search, a Lockheed JetStar wing was purchased. Although not attached to the wing, all flight control surfaces were delivered with the main wing surface. The external fuel tank was removed and a fairing was constructed to maintain the original wing profile. Before using the wing for test purposes, the flight control surfaces were re-attached to the main wing section and the rubber deicing boot covering the leading edge was removed.

The second phase of the full-scale test site implementation study involved mounting the acquired JetStar wing onto a test platform. The design of the platform held the wing at an ideal working height and facilitated movement and use of the wing panel during testing. The design allowed the assembly to be towed at low speeds over short distances. It was possible to lift the wing dolly assembly onto a flatbed truck for long-distance transportation.

Dorval Airport's deicing facility, operated by AéroMag 2000, was selected as the outdoor site for tests with the JetStar wing because it addressed several concerns: ease of access, security, proximity to current APS test installations, availability of specialized personnel, and access to specialized equipment such as a glycol recovery system and deicing vehicles. National Research Council Canada's (NRC) Climatic Engineering Facility (CEF) in Ottawa was selected as a suitable location for wing tests conducted in simulated conditions.

In addition to the JetStar wing, the U.S. Federal Aviation Administration provided a Shorts 330 wing to APS in spring 2000. The wing was transported to the central deicing facility in Montreal and was loaned to AéroMag 2000 for training purposes. This wing could also be used in future testing.

Substantial testing was conducted with the Lockheed JetStar wing during the 1999-2000 test season in natural and simulated conditions at NRC's CEF in Ottawa and at the Central Deicing Facility at Dorval Airport in Montreal. Several observations related to the full-scale implementation study were made and are discussed in Subsections 2.3.1 to 2.3.3. A summary of the observations and work performed on the wing and the wing test bed in the 1999-2000 test season follows. These observations formed the basis for suggested improvements to the full-scale study:

- During hot water deicing trials, the measured times for the water to refreeze were inferior to those obtained in previous years during full-scale aircraft trials. Because the fuel tanks were empty, the wing thermal mass was minimal and this may have contributed to the inferior times;
- The mass of the JetStar wing with fluid added to the wing tanks was estimated to exceed the maximum weight capacity of the boat trailer

purchased for wing mounting purposes, which has implications for cold-soak capability testing;

- The small swiveling wheel located at the head of the trailer near the towing eye compromised the manoeuvrability and stability of the wing test bed during full-scale trials;
- Two small panels on the main wing section were missing and the external fuel tank was removed prior to delivery of the aircraft. A fairing was fabricated to fill the large hole in the leading edge where the tank had been located and to restore the original wing profile. The fairing and replacement panels were constructed from galvanized metal and then painted;
- The aileron, leading slats and trailing edge flaps were secured in position with chains and metal brackets; and
- The JetStar wing was leveled on the boat trailer using various shims to reproduce the 2° dihedral and 1° angle of incidence where the wing attached to the fuselage.

1.2 2000-2001 Full-Scale Implementation Study

Appendix A presents an excerpt from the project description of the work statement for the APS Aviation 2000-2001 winter research program. The work statement addresses the observations for improvement suggested in the winter of 1999-2000. The primary objectives of the full-scale implementation study conducted in 2000-2001 are listed below:

- To conduct fluid failure tests with the JetStar wing;
- To examine the fuel system integrity and determine the feasibility of filling the tanks with fluid to obtain cold-soak capability;
- To examine the structure of the trailer and the consequences of obtaining cold-soak capabilities on the overall weight capacity of the current wing trailer. If required, to conduct a search for an alternative wing mounting capable of sustaining the additional weight capacity of the wing filled with fluid;
- To examine the mobility and the stability of the current trailer;
- To introduce a more permanent and stable method of leveling the JetStar wing on the wing mounting assembly;

- To replace the galvanized metal panels and fairing with aluminum;
- To introduce a more permanent method of securing the various control surfaces; and
- To attach an endplate to the wing root to simulate some of the effects of a fuselage.

During the winter of 2000-2001, many of the proposed objectives were met. Further modifications were made to the wing purchased in the previous test season: sheet metal work was performed on the wing body, a wing fairing was installed at the wing root to simulate the effects of a fuselage, improvements were made to the wing flap mechanisms, and the wing tank was sealed to obtain cold-soak capabilities. A wagon with a substantial weight capacity was purchased for wing mounting purposes. The wagon was modified to facilitate the addition of liquid to the wing to simulate fuel.

In this report, the developments of the wing and the wing test bed are discussed in Section 2. Issues concerning transportation of the wing and the wing dolly assembly are addressed in Subsection 2.7. A discussion of test locations for the full-scale test site implementation study is presented in Subsection 2.8. An alternative to testing with the JetStar wing is to conduct the tests with a Canadair RJ wing provided by Bombardier Aerospace. This venue is reviewed in Subsection 2.9.

The characteristics of the Lockheed JetStar wing are described in Section 3. Examples of the use of the JetStar wing in other research related to de/anti-icing performed on behalf of Transport Canada are presented in Section 4.

2. METHODOLOGY: WING TEST BED PREPARATION

The full-scale test site implementation study involved three phases: purchase of a wing, mounting of the wing on a suitable platform, and selection of an ideal test location. This section explores the various aspects of these phases between 1999 and 2001, including delivery and transportation of the JetStar wing, wing and test bed assembly, observations and subsequent improvements to the test wing and mounting system, wing mounting considerations, and test locations. Bombardier Aerospace has recently offered APS a Canadair RJ wing that can be adapted as a deicing test bed, and several pertinent issues related to this alternative to the JetStar wing are considered in Subsection 2.9.

2.1 Wing Condition and Delivery

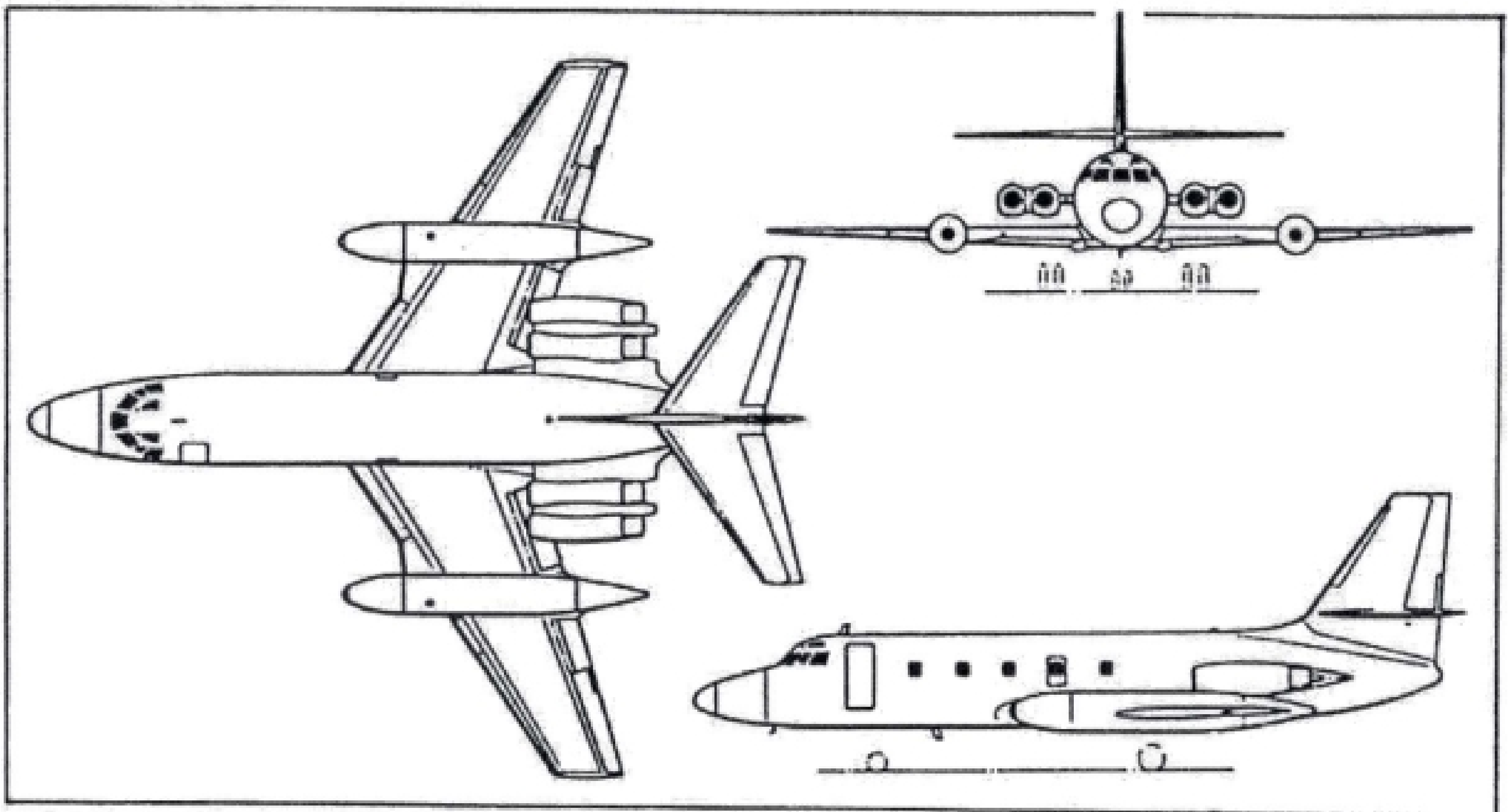
The implementation of a full-scale test site was explored by APS during the 1998-99 test season, prompted by problems obtaining operational aircraft for full-scale testing. The acquisition of a surplus wing, complete with all flight control surfaces, was central to the development of a test plan. After an arduous search, a Lockheed JetStar wing was obtained from an aircraft salvage company, Dodson International, in Rantoul, Kansas. A Lockheed JetStar is shown in Photo 2.1. A three-view schematic of the aircraft is given in Figure 2.1.

The Lockheed JetStar wing was delivered in April 1999 to NRC's Climatic Engineering Facility in Ottawa. The truck and trailer used to transport the wing from Kansas to Ottawa are shown in Photo 2.2. Although the control surfaces were not attached to the wing, they were delivered along with the main wing section, having merely been removed and placed in wooden crates for proper storage. The external fuel tank had been removed prior to delivery, and was not included in the negotiated price for the wing. The main wing section, without the various control surfaces, is shown in Photo 2.3 upon its arrival in Ottawa. The aircraft control surfaces and the wooden crates they were packaged in are shown in Photo 2.4.

The wing was removed from the transportation vehicle using a forklift operated by NRC personnel (see Photo 2.5) and placed on blocks outside the NRC facility. APS personnel deemed the overall condition of the wing and control surfaces to be highly satisfactory upon initial inspection.

FIGURE 2.1

Three-View Schematic of Lockheed JetStar



Source: Jane's Yearbook 1967/68

2.2 Wing Reassembly

During the winter of 1999-2000, APS obtained quotations for the reassembly of the various control surfaces, construction of a fairing for the leading edge, replacement of any missing panels, removal of the rubber de-icing boot, and polishing of the leading edge. The work was contracted to an aircraft mechanic in Ottawa.

Tests for a deicing system manufacturer requiring the JetStar wing were scheduled to begin in February 2000 at NRC's CEF and, as a result, the manufacturer funded the reassembly of the wing to accelerate the process and ensure that the work was completed prior to the start of testing. The JetStar wing reassembly was conducted at NRC's CEF with the support of NRC personnel.

Prior to reassembly, the wing and accessories were moved indoors and secured on a train trolley. The crates were then opened and the control surfaces were cleaned. It was discovered that the mounting rods and brackets for the trailing edge flaps were not included with the flap sections. Without these parts, the flaps could only be fixed permanently in a neutral position. However, all flight controls were required to be moveable to allow testing of the wing in various configurations and for inspection of the various quiet areas during testing. Consequently, inquiries about the availability of the mounting rods and brackets were directed to Dodson International. Following lengthy discussions with the salvage company, the requested parts were delivered to NRC at no extra cost. Photo 2.6 shows the inboard trailing flap in fully deployed position, illustrating a quiet area between the flap and the wing. The salvage company also provided APS with a copy of the Lockheed JetStar wing components manual. Copies of this manual have been provided to Transport Canada.

Actuators for the leading edge slats regulate the various flap positions. These parts were not included in the wing purchase agreement. Without the actuators, the unsecured hinged leading edge slats hung freely. It was decided to attach brackets to the moveable leading edge sections that could then be secured to the main wing section to maintain the leading edge in a neutral position (see Photo 2.7). The brackets could then be unfastened to allow inspection of the leading edge quiet areas (see Photo 2.8).

The aileron, an extension of the wing tip, was moveable when attached to the wing by the mechanic, and could be blocked in any given position using a wedge.

The rubber deicing boot on the leading edge of the JetStar wing was removed, and the entire leading edge was polished (see Photo 2.9).

Two small panels on the main wing section were missing when the aircraft was delivered to APS in April 1999 (see Photo 2.3). The salvage company had removed the external fuel tank (see aircraft three-view drawing in Figure 2.1) prior to delivery of the wing. A fairing was fabricated to fill the large hole in the leading edge where the tank had been and to restore the original wing profile. The fairing and replacement panels were constructed from galvanized metal and then painted.

2.3 Observations for Improvement

In 1999-2000, substantial testing was conducted with the Lockheed JetStar wing, and the following observations and recommendations were made:

2.3.1 Cold-Soak Capability

During hot water deicing trials with the Jetstar wing, the measured times for the water to refreeze were inferior to those measured in previous years during full-scale trials on other aircraft. Because the fuel tanks were empty, the wing thermal mass was minimal, and this may have contributed to the inferior times. A recommendation to examine the fuel system integrity of the JetStar wing was proposed to determine the feasibility of filling the tanks with fluid to obtain cold-soak capabilities.

2.3.2 Wing Body

Two small areas on the wing surface and the fuel tank fairing required replacement. The fairing and replacement panels were constructed of galvanized metal and painted. To prevent rust formation and to ensure consistency with the other wing sections, it was recommended that the galvanized metal panels and fairing be replaced with aluminum.

The aileron, leading edge slats and trailing edge flaps were secured in position using chains and metal brackets. It was recommended that an improved method of securing the various control surfaces be examined.

It was also recommended to attach an endplate to the wing root to simulate some of the effects that the fuselage would have, such as preventing fluid run off, and catching and reflecting spray.

2.3.3 Wing Mounting

The wing was mounted on a boat trailer purchased in 1999 for this purpose. Improvements to or replacement of the wing mounting system used in 1999-2000 were proposed.

The boat trailer had a weight capacity of 1 588 kg (3 500 lb.). The estimated weight of the empty JetStar wing was 1 134 kg (2 500 lb.). The combined weight of the wing and the fluid added to the wing tanks to obtain cold-soak capability exceeded the maximum capacity of the trailer. It was recommended that the structure of the trailer be examined to potentially increase the overall weight capacity or a mounting be acquired that is capable of sustaining the additional weight of the fuel filled tank.

During full-scale trials in 1999-2000 the small swiveling wheel located at the head of the trailer near the towing eye compromised the manoeuvrability and stability of the wing test bed. If the boat trailer were to be used as the wing mounting system in future full-scale testing, it was recommended that a larger inflatable wheel replace the small swiveling wheel and two retractable feet be installed. These feet could be extended for stability during testing.

The JetStar wing was leveled on the boat trailer using various shims to reproduce the 2° dihedral and 1° angle of incidence of the wing when attached to the fuselage. It was recommended that a more permanent and stable method of leveling the JetStar wing be examined.

2.4 Wing Improvements

In 2000-2001 an Ottawa-based company, Canadian Aviation Maintenance Inc. (CAM), was contracted to perform the necessary wing improvements. An estimate of 135 hours to complete the required work was proposed at a cost of CAN$55 per hour. The total cost including materials and delivery of the wing was CAN$10,067.

Following is a detailed account of the work performed on the wing during the winter of 2000-2001.

2.4.1 Sealing the Tank

2.4.1.1 Phase I – Preliminary Repair of the Fuel Tank and Initial Pressure Test

The focus of the work on the wing was to repair obvious holes and to replace missing parts on the main fuel tank along the wing root. Metal plates and bolts were replaced. An electrically conductive corrosion-inhibiting aircraft sealant, PRC-CS3204, was applied in the assembly of wing parts. The main fuel lines were either capped or sealed with expansion plugs. To test fuel tank integrity, a fuel line was modified to accept a compressed air inlet and a pressure gauge. The fuel vent was repaired and fully functional. The fuel vent access panel on the upper wing surface was replaced. The three fuel inlets and the access panel for the fuel vent are found on the upper wing surface and are shown in Figure 2.2 and Photo 2.10. Once capped, the fuel lines in the wing root act as a means to drain the fuel tanks.

Following repairs to the fuel tank, an initial pressure test was conducted to establish whether the fuel tank leaked. The test was conducted in December 2000 and results confirmed that more work was required to seal various leaks in the tank.

2.4.1.2 Phase II – Further Sealing of Tank and Pressure Test

The following procedures were conducted:

- PRC aircraft sealant was applied to the wing root cell panels where required;
- Extra bolts were used to fasten panels;
- The fuel vent actuator was temporarily sealed for the test;
- The fuel vent flange outlet was capped for temporary testing;
- An extraneous hole was filled with PRC aircraft sealant for the test sequence; and
- The tank was tested with 3 to 5 psi of compressed air for 12 hours.

A second pressure test was conducted under the same conditions to ensure that the tank was adequately sealed.

2.4.1.3 Phase III – Liquid Test

A partial liquid test was recommended after all other work on the tank was completed. It was postulated that the pressure exerted on the tank by the weight of the water would be a better gauge of the strength of the interior of the tank than the pressure exerted by the compressed air.

Since the weight of the wing filled with fluid would exceed the capacity of the boat trailer, the wing was lifted from the boat trailer prior to conducting the water test.

2.4.2 Wing Body

Several modifications were performed on the wing body, including sheet work on the upper surface of the wing, improvements to the position of the flight controls, addition of a fairing at the wing root to simulate the effects of a fuselage, and installation of a wing tip component.

2.4.2.1 Sheet Work

Sheet metal parts were constructed to replace several sections of the upper wing surface and the area where the external fuel tank was removed. These metal pieces were riveted into place and sealed with PRC aircraft sealant. “Ribs” were assembled under the sheet metal on the leading and trailing edge of the wing to maintain structural integrity. Other areas that required modification with sheet metal were one of the three fuel tank feeds, a cover for the fuel vent, and the actuator for the leading edge slat. The locations of the sheet work performed on the wing are shown in Figure 2.3 and Photo 2.11.

2.4.2.2 Flight Controls

The fitting of the flight controls required the installation of the main throw bushings for the flaps; modification of the mechanism was required to allow the flaps to move symmetrically. The flaps and slats could be moved into either a full "on" or "off" position.

FIGURE 2.2
Fuel Tank Integrity

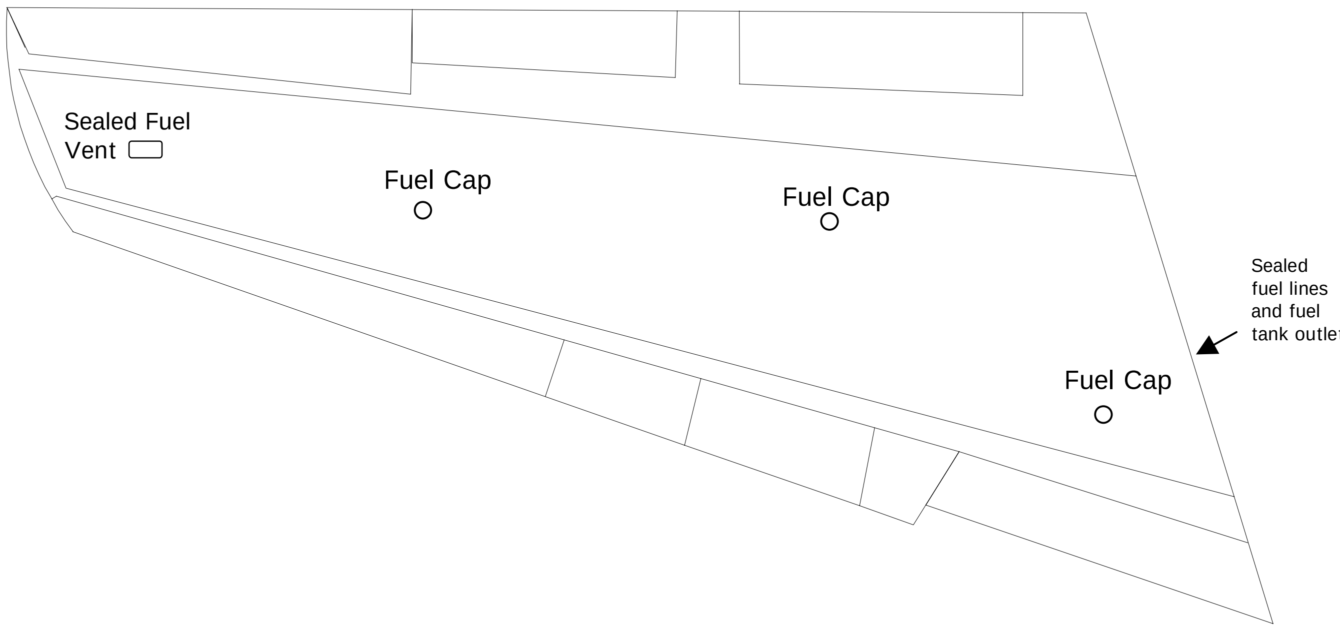
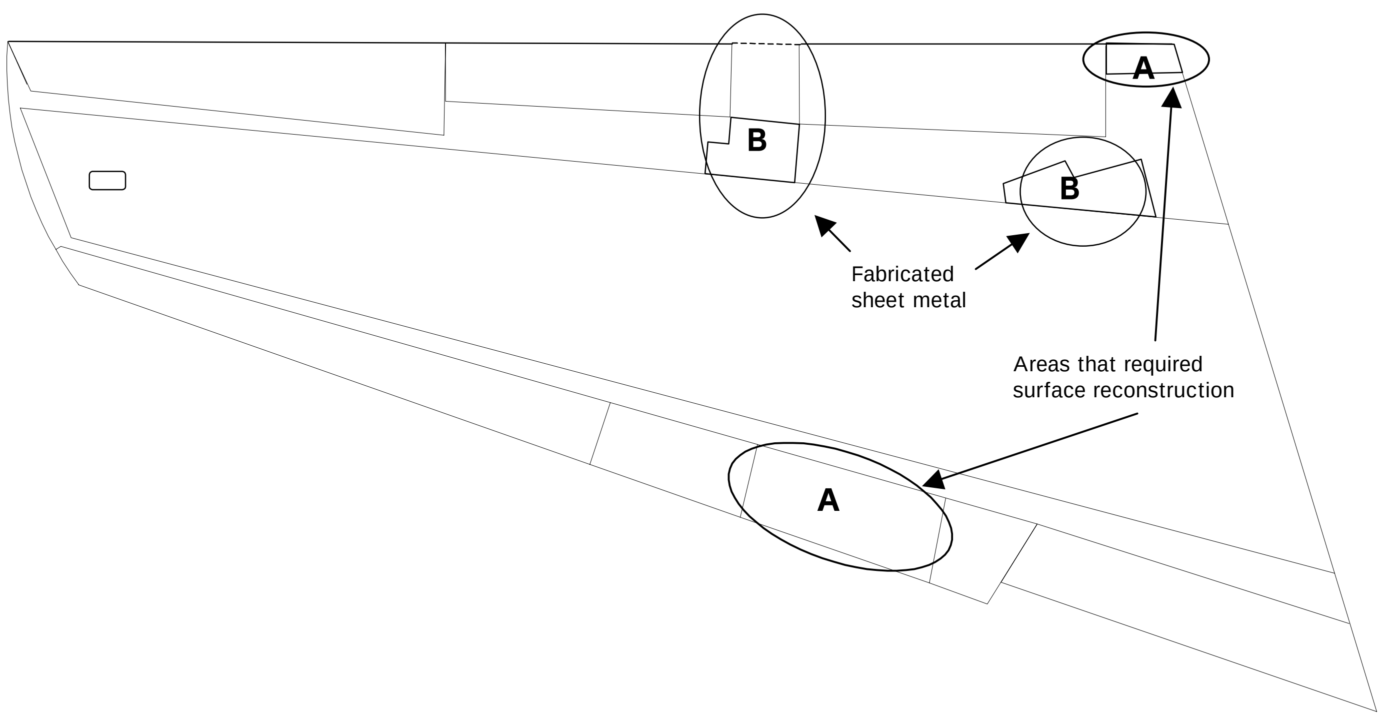


FIGURE 2.3
Sheet Metal Work



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The flaps of the trailing edge formed a flush surface when in the "up" position.

CAM initially suggested the use of a buckle mechanism to lift and drop the flaps. The approximate dimensions of the buckles were 2.54 cm x 6.35 cm x 1.27 cm thick. These buckles would be attached along the trailing edge and allow either a full "on" or "off" positioning of the flaps. This buckle was not employed because the upper wing surface would not be flush.

Instead, the leading and trailing edges were positioned in a semi-permanently locked-up position. Small metal plates (brackets), which were unobtrusive during fluid testing, were attached to the control surfaces (see Photos 2.12 and 2.13 and Figure 2.4). The section of the trailing edge where the external fuel tank was located was not modified with sheet metal (see Photo 2.14 and Figure 2.5).

2.4.2.3 Wing Root

A fairing was constructed along the wing root to simulate the fuselage. This fairing was installed on the original nut plates, and the same screw holes were used. Metal supports were positioned behind the fairing to provide structural support during testing. The fairing was completely removable for transport (see Photos 2.10 and 2.13 and Figure 2.5).

2.4.2.4 Wing Tip

The wing tip was installed; however, the leading edge of the tip was missing and was not replaced. Refer to Photo 2.11 and Figure 2.5.

2.5 Wing Fuel

Once cold-soak capabilities were obtained, it was necessary to select a fluid with which to fill the fuel tank. Kerosene has similar thermal properties to the jet fuel used in aircraft and would have been the ideal liquid to simulate fuel in a cold-soak wing. However, kerosene is highly flammable and its volatile properties made it a hazardous option. Glycol was found to be an adequate substitute to kerosene for several reasons:

FIGURE 2.4
Flight Controls

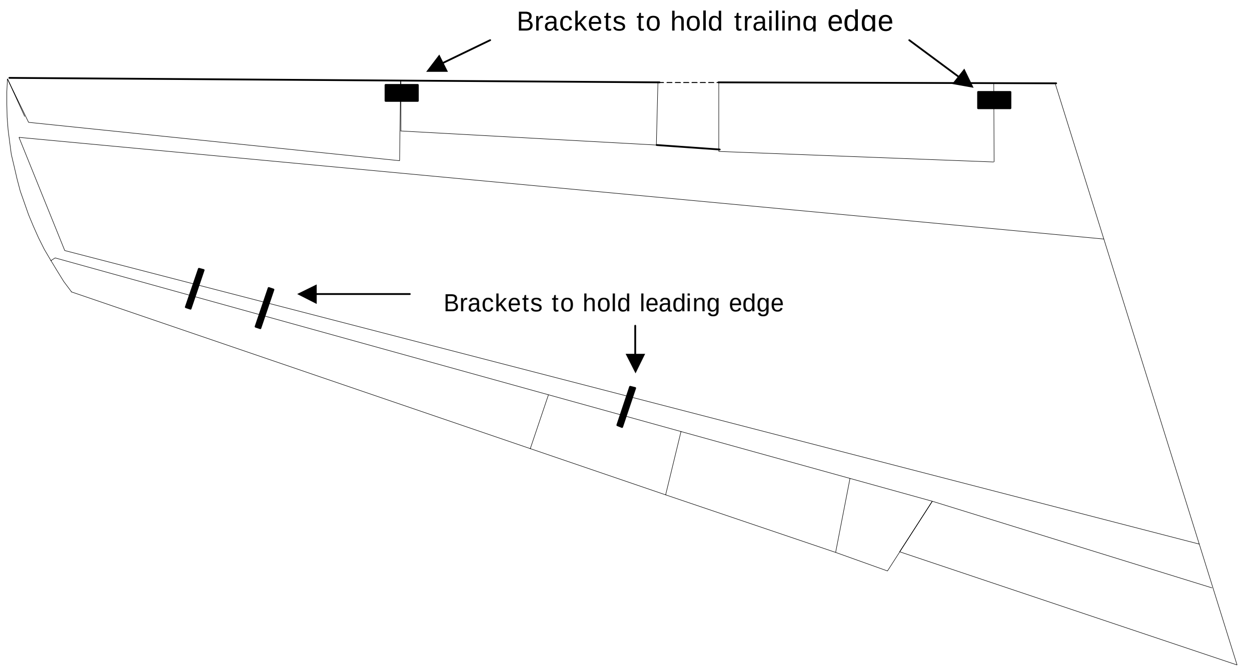
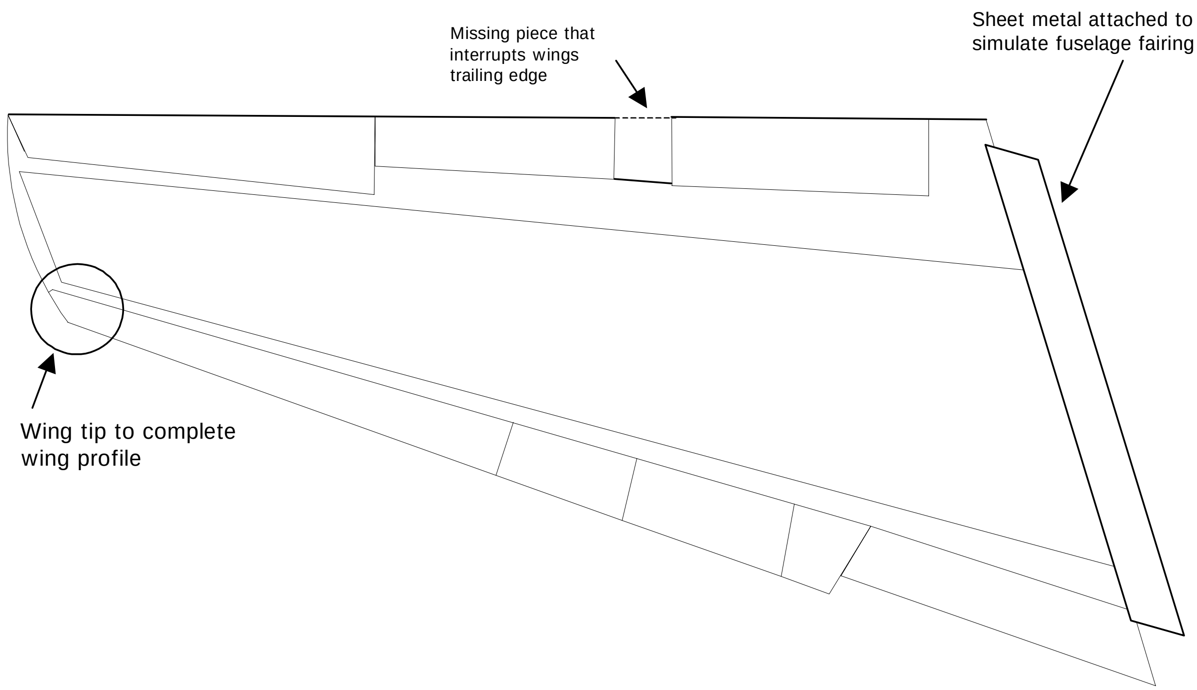


FIGURE 2.5
Wing Root and Wing Tip



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- Glycol is non-flammable and safer to work with than aviation fuel;
- Glycol is readily available in a sufficient quantity for testing; and
- The use of glycol facilitates waste disposal.

Because the thermal properties of glycol are slightly different from kerosene, tests were conducted to identify the differences between the volumes of glycol required to identically simulate one full tank of kerosene and one-half tank of kerosene. Refer to *SAE Type I Fluid Endurance Time Test Protocol* TP 13827E (3) for a detailed account of the tests conducted.

One of the tests reported indicated that the temperature profile for the cold-soak box with kerosene was slightly higher than that for the box with Type I 50/50 fluid, both 50% filled and completely filled. The difference was not substantial, and indicated that use of Type I fluid as a test substitute for real fuel was acceptable.

2.6 Wing Mounting Considerations

During the 1999-2000 test season, the second phase of the full-scale test site implementation study, TDC and APS considered mounting the acquired wing onto a platform. The ideal design of the platform was intended to hold the wing at an ideal working height, to facilitate movement (rotation) to permit actuation of the wing panel during testing, and to allow the wing to be towed at low speeds over short distances.

A mounting system for the JetStar wing was proposed. This mounting system consisted of an off-the-shelf 6.1 m (20 ft.) galvanized scissor-lift pontoon boat trailer, with a weight capacity of 1 588 kg (3 500 lb.).

The boat trailer was purchased in January 2000 and the wing was mounted on it shortly thereafter. The wing was leveled using various shims to reproduce the 2° dihedral and 1° angle of incidence of the JetStar wing when attached to the fuselage. Photo 2.15 shows the JetStar wing mounted on the boat trailer at NRC's CEF.

In December 2000 it was apparent that the wing had cold-soak capabilities and that the boat trailer was incapable of sustaining the weight of a cold-soaked wing.

In addition to the inadequate capacity of the trailer, other issues concerning the wing mounting system were determined. The small swivelling wheel located at the head of the trailer near the towing eye compromised the manoeuvrability and stability of the wing test bed. Once the tanks were filled, the centre of gravity changed and there was the possibility that the trailer could tip. Another problem involved leveling to a 2° dihedral. Due to the uneven weight distribution on the boat trailer, the trailer also exhibited a deflection to one side.

The modifications required for the trailer proved too complicated and costly. A decision was made to purchase a farm wagon and perform minor adjustments to its upper structure. This was an economical solution.

The wagon was purchased and transported to CAM, where the wing was transferred from the boat trailer to the wagon. The wing was mounted on upright supports in the proper position for testing. The 2º dihedral and 1º angle of incidence of the wing were achieved (see Photo 2.16).

2.6.1 Wagon Modifications

Various modifications were made to the wagon. Upright supports were added to the front and rear of the wagon; these could be used to raise and lower the wing. The tongue was extended to allow clearance for the wing while towing the wagon.

2.6.2 Capacity

The capacity of the wagon was 10 tons, which was sufficient to allow for the additional weight of the fluid-filled fuel tanks in cold-soak tests. At this capacity, the structure could continue to maintain the required stability of the wing.

2.6.3 Manoeuvrability

The wagon permitted easy handling of the wing into position, and allowed for low-speed towing. However, the ease of manoeuvrability of the present system is only possible in outdoor tests.

2.6.4 Leveling of the Wing

The leveling of the wing was accomplished by vertical supports added to the wagon. These supports allowed the wing to be placed at the correct testing height and reproduce the 2º dihedral and 1º angle of incidence required. At present, the wing is in the correct test position and further adjustments are not likely to be necessary (see Photo 2.16).

2.7 Wing Transportation

It was necessary to transport the wing dolly assembly from NRC's CEF in Ottawa to the AéroMag deicing facility at Dorval Airport in Montreal by means of a flatbed truck. Because the design of both the boat trailer and the current wing mounting system failed to conform to the Highway Code, several transportation companies were contacted to determine the costs related to the transportation of the wing dolly assembly. The company selected, Goldie Mohr Limited of Barhaven, Ontario (613-838-5042), operates flatbed trucks with sliding ramps (see Photo 2.17), which are ideal for loading and unloading equipment of this nature. The wing and trailer are shown on the flat bed truck in Photo 2.18, ready for transport from NRC's CEF in Ottawa.

2.8 Test Locations

The third and final phase of the full-scale test site implementation study involved the examination and selection of a suitable full-scale test site. In addressing these objectives, certain requirements, such as accessibility, security, proximity to current APS installations, and containment and recovery of sprayed fluids were examined.

The centralized deicing facility (CDF) at Dorval airport and NRC's CEF in Ottawa were selected as suitable test locations and have been used to conduct full-scale tests in the past.

The CDF at Dorval Airport is operated by AéroMag 2000. The CDF is easily accessible, secure, located within 1 km of the APS test site at Dorval Airport, and equipped with a glycol-recovery system. AéroMag deicing vehicles and personnel were available to spray fluids. In return for the use of the facility, APS made the wing section available to AéroMag personnel for training purposes.

NRC's CEF is an ideal location for conducting indoor tests in simulated precipitation.

The JetStar test wing is currently located at NRC's CEF in Ottawa, and has been used successfully as a test subject in the laboratory in several test programs.

Alternative locations for conducting outdoor testing include the exterior of NRC's CEF in Ottawa and the exterior of the ADGA hangar at Gatineau Airport. An alternative indoor site could be the Institut de Recherche d'Hydro-Québec (IREQ) climatic chamber in Varennes.

A second test wing would allow for outdoor tests at Dorval Airport, without the need for transporting the current wing between test locations.

2.9 Bombardier Canadair Regional Jet 200

During hot water deicing trials with the JetStar wing, it was found that the measured times for the water to refreeze were inferior to those measured in previous years during full-scale trials with other aircraft. It was believed that the lack of wing thermal mass, due to the empty fuel tanks, may have contributed to the inferior times. It was recommended that the fuel system integrity of the JetStar wing be examined to determine the feasibility of filling the tanks with fluid to obtain cold-soak capabilities.

In 2000-2001 cold-soak capabilities were obtained and hot water trials were conducted for a second time. Filling the wing at various fuel levels showed that the fuel does not have an effect on the measured time for the water to refreeze.

While the JetStar test wing has been an important step forward, introduction of a test bed based on a modern wing structure would be valuable.

Bombardier Aerospace has recently offered a Bombardier CRJ 200 wing, which had been used in its certification test program, that could be adapted as a deicing test bed. This test bed would greatly improve the simulation of full-scale testing, since it is widely used worldwide.

The CRJ 200 wing would need to be returned to its original configuration, which would involve the following modifications:

- Removing the strengthening plates and straps installed for Bombardier testing from its surface (it is assumed that Bombardier will provide this service free of charge);
- Replacing missing flight control surfaces; and
- Checking and repairing fuel system integrity.

The cost of securing and modifying the offered wing for future testing is expected to be minimal.

The wing could then be mounted on a carriage suitable for testing to enable local towing of the wing to and from the test site.

The Bombardier CRJ 200 would be used primarily as a testbed for outdoor tests; however, should the wing be needed for indoor testing, it could easily be moved into the NRC cold-chamber facility.

Refer to Appendix C for an excerpt of the design characteristics of the Bombardier CRJ 200.

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Photo 2.1
Lockheed JetStar

Photo 2.2
Truck and Trailer Used to Transport JetStar Wing

Photo 2.3
JetStar Wing upon Arrival in Ottawa

Photo 2.4
JetStar Wing Control Surfaces

Photo 2.5
Removal of the Wing from the Transportation Vehicle

Photo 2.6
Trailing Edge Quiet Area

Photo 2.7
Bracket Used to Secure Leading Edge Slat

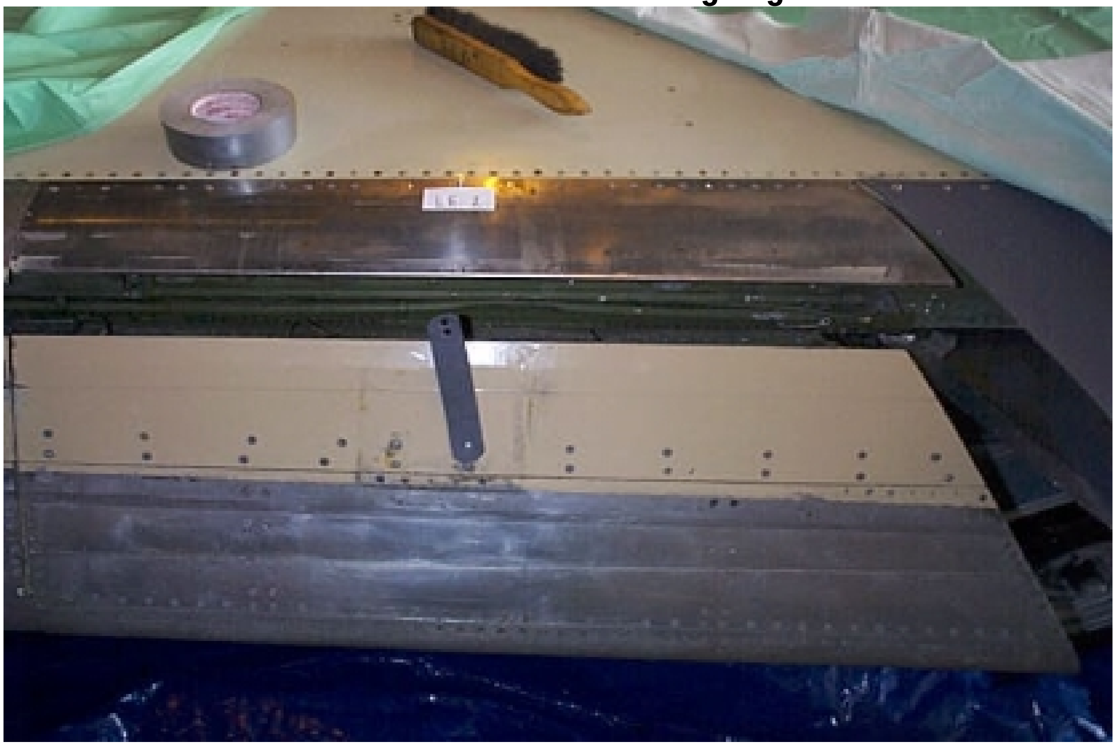


Photo 2.8
Leading Edge Quiet Area

Photo 2.9
Polished Leading Edge of JetStar Wing

Photo 2.10
Wing Root Showing Capped Fuel Lines and Sealed Fuel Tanks

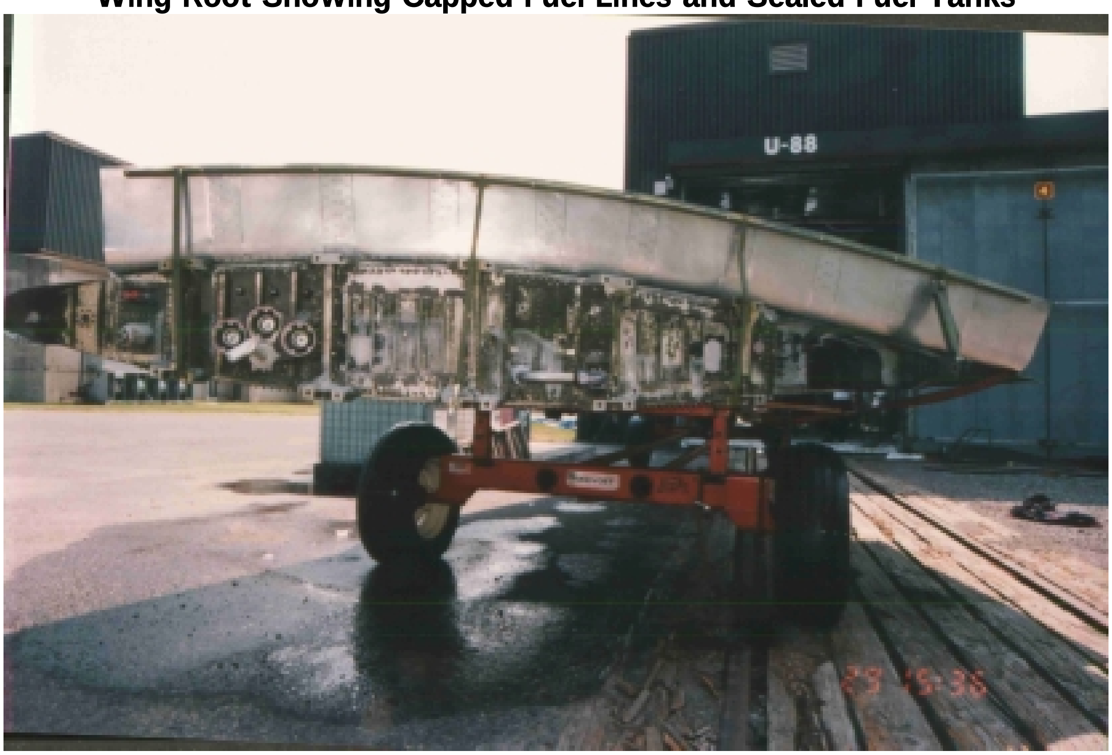


Photo 2.11
Wing Overview at NRC

Photo 2.12
Leading Edge Securing Strap

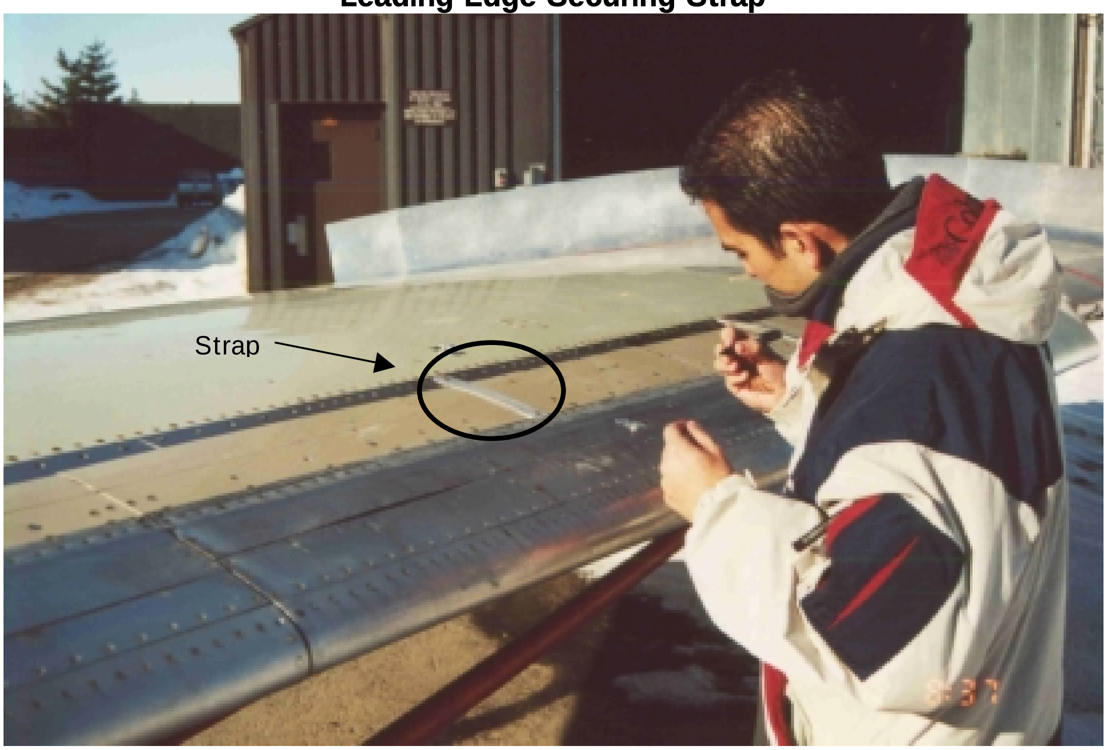


Photo 2.13
Simulated Fairing and Trailing Edge Plate

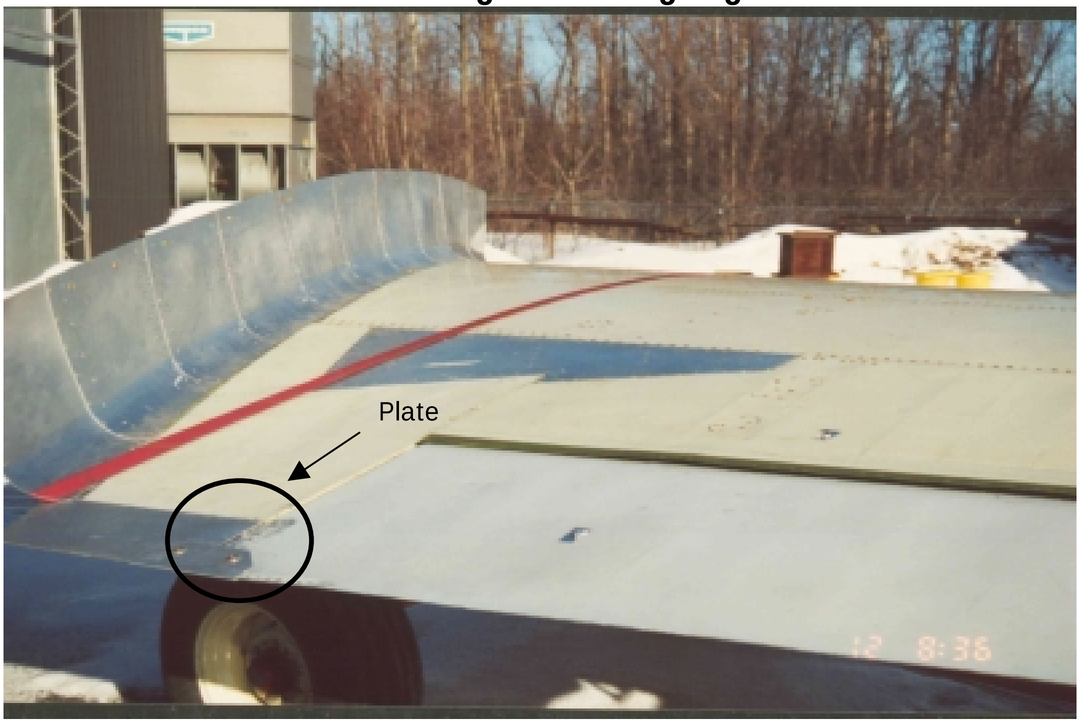


Photo 2.14
View of Trailing Edge and Gap Left from Removal of the External Fuel Tank

Photo 2.15
JetStar Wing on Boat Trailer

Photo 2.16
Wing on Trailer at NRC

Photo 2.17
Flatbed Truck Moveable Ramp Used to Transport JetStar Wing and Wing Mounting System

Photo 2.18
Wing and Trailer on Flatbed Truck at NRC

3. DESCRIPTION: LOCKHEED JETSTAR WING CHARACTERISTICS

3.1 Lockheed JetStar Wing Geometry

The following information pertains to the design characteristics of the Lockheed JetStar wing:

- Wing section NACA 63A112 at the wing root;
- Wing section NACA 63A309 (modified) at the wing tip;
- Wing chord of 4.16 m at the wing root (13 ft. 7¾ in.);
- Wing chord of 1.55 m at the wing tip (5 ft. 1 in.);
- Incidence of 1° at the wing root and -1° at the wing tip;
- 2° dihedral;
- Sweepback 30° at quarter-chord;
- Conventional fail-safe stressed-skin structure of high-strength aluminum; and
- Aluminum alloy aileron, double-slotted all-metal trailing edge flap, hinged leading edge slat, no spoilers.

Additional pertinent information on the design characteristics of the Lockheed JetStar was obtained from a Lockheed JetStar model specification manual and from Jane's 1967-68 Yearbook. This information has been reproduced in Appendix B.

During the 1999-2000 test season, APS personnel measured the precise dimensions of the JetStar wing. Figure 3.1 shows a diagram of the Lockheed JetStar wing, including the dimensions.

3.2 Lockheed JetStar Fuel System Design

The design of the fuel tank system of the Lockheed JetStar is displayed in Figure 3.2. When intact, the entire system consists of four integral wing tanks of approximately equal capacity (two tanks in each wing) and two external tanks installed on the wings. The total fuel capacity of the six tanks is approximately 10 070 L (5 790 L in the wing tanks and 4 280 L in the external tanks). When the tanks are completely filled with fuel, the upper wing surface is in direct contact with the fuel (no bladder).

The wing test bed consisted of a starboard JetStar wing. The external fuel tank (RH ext, see Figure 3.2) was removed by the salvage company and was not delivered with the main wing section. Therefore, the fuel capacity of the wing was restricted to the two integral wing tanks, main tanks no. 3

3.1 JetStar Wing Dimensions

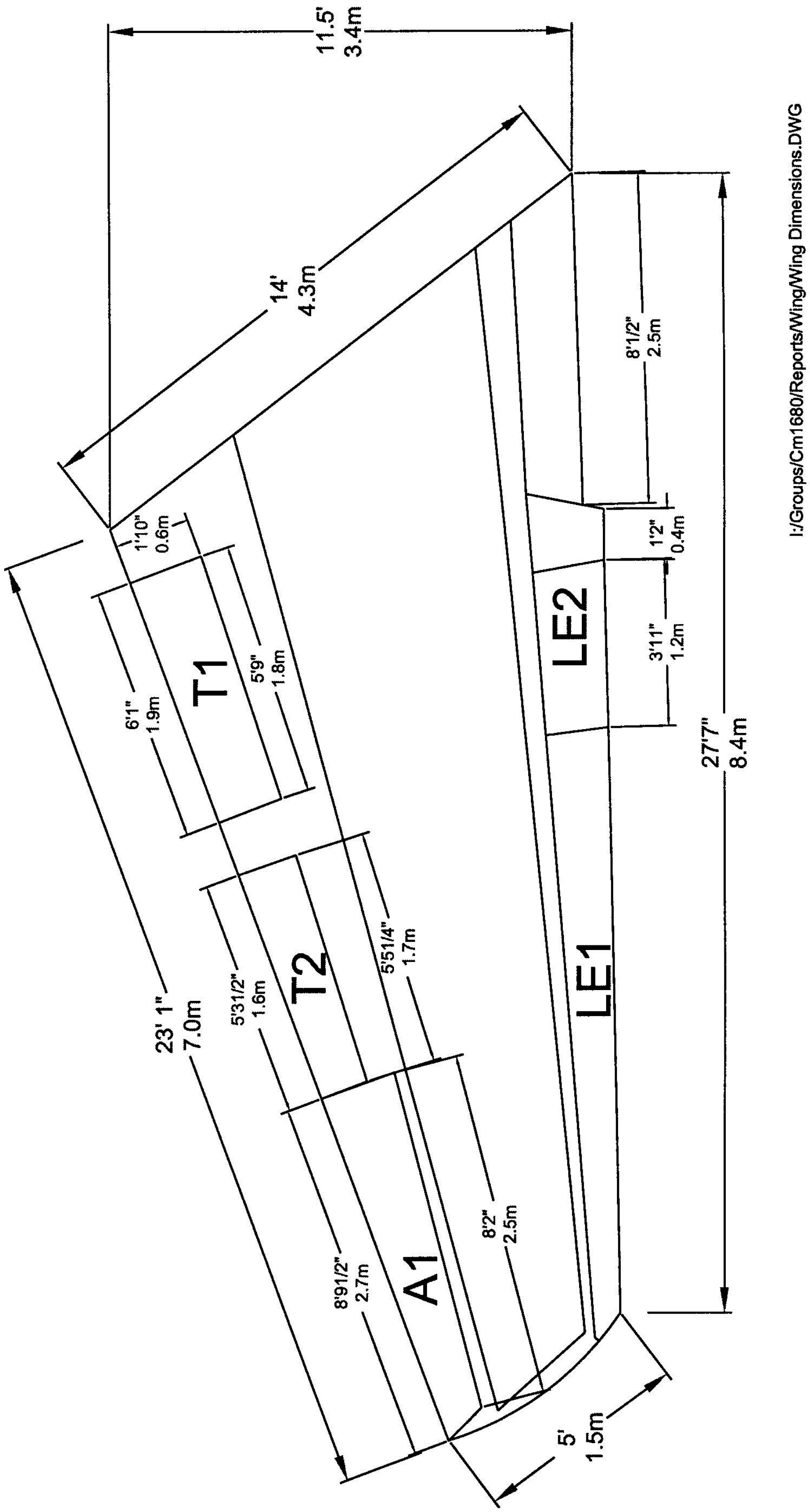
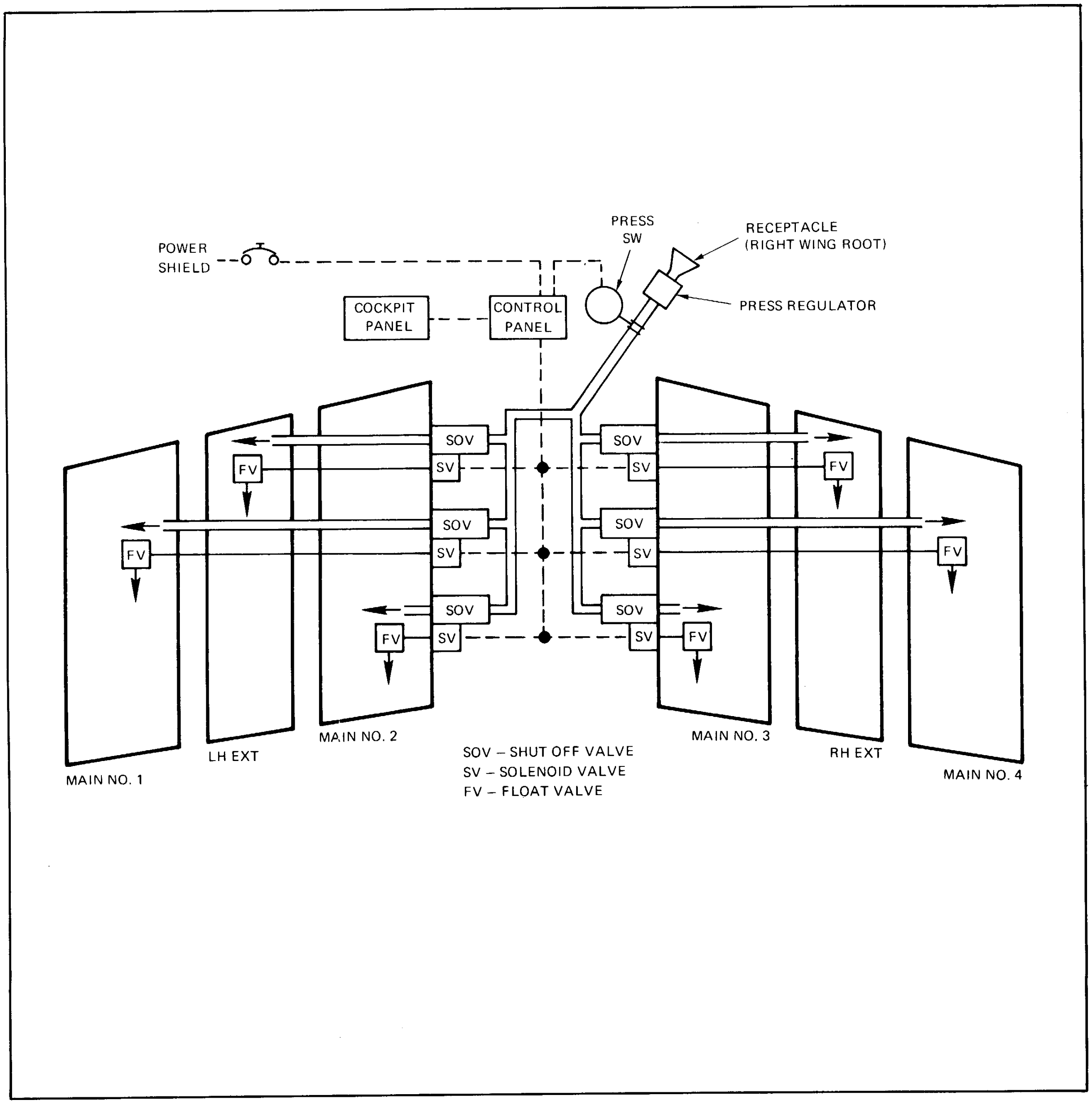


FIGURE 3.1
JetStar Wing Dimensions

FIGURE 3.2
Fuel System of the Lockheed JetStar



Source: Lockheed JetStar Model Specification Manual

M\Groups\CM1680(exBM3833)\Reports\Wing\Figure 3.2.doc and no. 4 (see Figure 3.2). During 2000-2001, CAM was asked to record the quantity of fluid held in each tank. The two tanks open into each other and they may be emptied through the ports on the wing root. The capacities of main tanks nos. 3 and 4 were 1 476 and 1 400 L, respectively.

3.2.1 Weight/Fluid Capacity

APS requested that the wing be weighed while it was both empty and filled with water. The tanks' capacities would also be measured during the water test. Here are some of the findings:

Capacity
Tank No. 3 (Inboard) holds 390 US gal. (1476 L)
Tank No. 4 (Outboard) holds 370 US gal. (1400 L)

Weight
The weight of the wagon is 440 kg
The weight of the empty wing is 800 kg
Total weight of the wing plus the wagon when filled with water is 3 570 kg

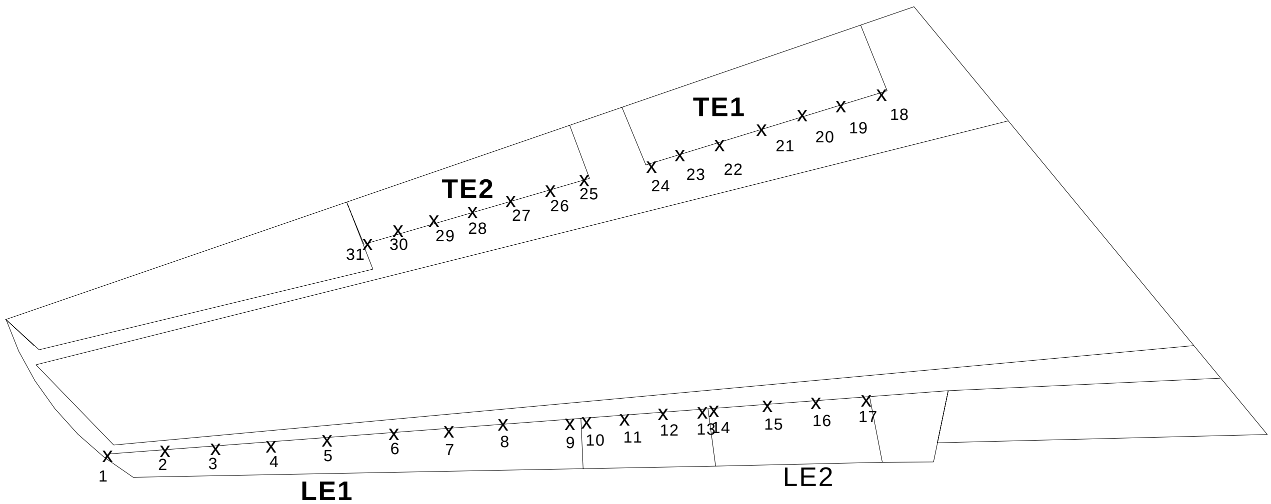
3.3 Wing Quiet Areas

Aerodynamically quiet cavities, for the purpose of this report, are defined as any control surface-related cavities that cannot be observed during clean wing configuration (with control surfaces retracted). The five quiet cavities on the JetStar wing are found behind the two leading edge slats (LE1 and LE2), in front of the two trailing edge flaps (T1 and T2), and in front of the aileron (A1). The locations of these controls are shown in Figure 3.1.

3.4 Main Wing and Flight Control Surface Wing Gaps

Gaps refer to the tolerance spaces between the main wing structure and the movable flight control surfaces. The gaps also correspond to the most likely path that water/fluid would take when entering a quiet cavity. Measurements for the JetStar wing were taken at 28 cm (11 in.) intervals at the upper wing surface. Figure 3.3 shows the measurements.

FIGURE 3.3
Hard Wing/Flight Surface Wing Gaps



Measurements taken at 28 cm intervals.

LE1	
Loc	Gap (mm)
1	1.75
2	2.24
3	1.75
4	1.75
5	2.29
6	1.19
7	1.75
8	0.61
9	1.19
10	1.75
11	1.75
12	1.75
13	0.61

LE2	
Loc	Gap (mm)
14	0.72
15	< 0.38
16	1.19
17	0.61

TE2	
Loc	Gap (mm)
18	0.97
19	0.89
20	1.19
21	2.29
22	1.75
23	1.19
24	< 0.38

TE1	
Loc	Gap (mm)
25	1.75
26	< 0.38
27	< 0.38
28	0.89
29	0.61
30	< 0.38
31	< 0.38

M:Groups\CM1680(exBM3833\Wing\Figure 3.3

3.5 JetStar Wing Tests in Simulated Conditions

National Research Council Canada's Climatic Engineering Facility (CEF) in Ottawa was selected as a suitable location for conducting indoor trials in simulated precipitation using the JetStar wing. The CEF is partitioned into two sections separated by an insulated dividing door. Each partition can be controlled separately, permitting different tests to be conducted simultaneously. Photo 3.1 provides a general indication of the size of the facility. Photos 3.2 and 3.3 show interior images of the small and large ends of the facility. The facility was designed and constructed for the testing of locomotives. The size of the chamber is 31 m by 6 m and its height is 8 m. The lowest temperature achievable is –46°C.

Figure 3.4 is a schematic of the JetStar wing in relation to NRC's CEF.

FIGURE 3.4
JetStar Wing Inside NRC Chamber

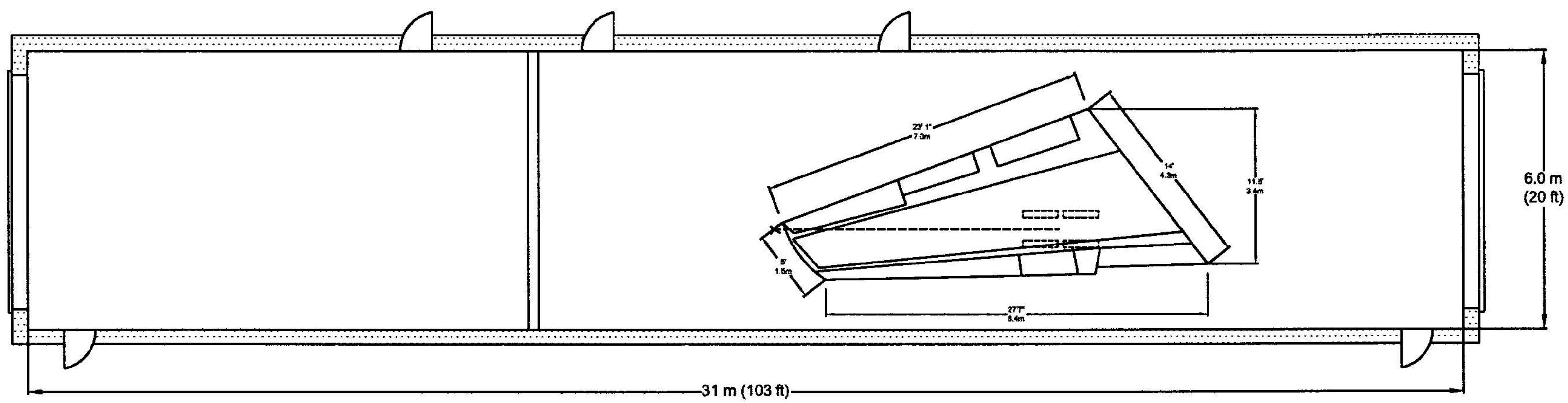


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Photo 3.1

Outdoor View of National Research Council Canada Climatic Engineering Facility

Photo 3.2

Inside View of Small End of Climatic Engineering Facility

Photo 3.3
Inside View of Large End of Climatic Engineering Facility

4. FULL-SCALE TESTING WITH JETSTAR WING

Since the 1999-2000 test season, full-scale testing with the JetStar wing was conducted in natural and simulated precipitation conditions at NRC's CEF in Ottawa and at Dorval Airport in Montreal. Testing included the following:

- Fluid application tests to evaluate fluid foaming (Subsection 4.1);
- Hot water deicing tests (Subsection 4.2);
- Use of ice detection sensors for end-of-runway application (Subsection 4.3);
- Forced air trials (Subsection 4.4); and
- Development of an SAE Type I Fluid Endurance Time Test Protocol (Subsection 4.5)

The purpose of this section is not to document the results of tests conducted during the past years, but rather to display the full-scale test capabilities of the JetStar wing. The results of hot water, ice detection sensor, forced air tests and Type I protocol with the JetStar wing are reported in detail in four associated reports:

- *Hot Water Deicing of Aircraft: Phase 2* TP 13663E (4),
- *Ice Detection Sensor Capabilities for End-of Runway Wing Checks: Phase 2 Evaluation* TP 13662E (5)
- *Safety Issues and Concerns of Forced Air Deicing Systems* TP 13664E (6); and
- *SAE Type I Fluid Endurance Time Test Protocol* TP 13827E (3).

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4.1 Fluid Application Tests

Objective: Fluid application tests were conducted on behalf of a fluid manufacturer to determine the behaviour – in particular, the foaming and wetting characteristics – of an aircraft deicing fluid on a wing when applied using standard industry methods.

Procedures: The JetStar test wing was set up outside NRC's CEF in Ottawa and positioned over a tarp for fluid collection purposes. The deicing fluid was heated to 80°C in a hot water tank and then applied to the JetStar wing using the APS mobile fluid sprayer.

Photo 4.1 JetStar Wing Test Set-Up for Fluid Application Tests

Photo 4.2 Type I Fluid Application Using Mobile Sprayer

4.2 Hot Water Deicing

Objective: Hot water deicing tests were conducted to assess the temperature limits for the use of hot water deicing as the first step of two-step deicing operations under conditions of snow.

Procedures: The JetStar wing was set up at the central deicing facility at Dorval Airport. The wing was exposed to artificial snow and then deiced using hot water under continuous snow precipitation. The time required for the wing to refreeze in continuous snow conditions was recorded for each test.

Discussions and Recommendations: Refer to *Hot Water Deicing of Aircraft: Phase 2* TP 13663E (4).

Photo 4.3 Test Set-Up for Hot Water Tests

Photo 4.4 Snow Failure on the JetStar Trailing Edge

4.3 Use of Ice Detection Cameras for End-of-Runway Inspections

Objective: Tests were conducted to examine the feasibility of and the procedures for performing wing inspections with remote ice detection camera systems at the entrance to the departure runway.

Procedures: The JetStar wing was set up at the central deicing facility at Dorval Airport. Snow was distributed on various sections of the JetStar wing to assess the Spar/Cox ice detection camera's ability to detect the contamination on the wing from varying distances and heights, and in conditions of varying light.

Discussions and Recommendations: Refer to *Ice Detection Sensor Capabilities for End-of Runway Wing Checks: Phase 2 Evaluation* TP 13662E (5).

Photo 4.5 Wing Set-Up at the Central Deicing Facility at Dorval Airport

Photo 4.6 Snow Accumulation on the JetStar Trailing Edge

4.4 Forced Air Deicing Tests

Objective: Laboratory tests were conducted to examine the safety issues and concerns of deicing aircraft with forced air deicing systems. The safety issues examined encompassed potential for injury to personnel, potential for damage to aircraft, and ability to provide a clean wing for the interval until an anti-icing treatment is applied.

Procedures: The JetStar wing was set up in the NRC cold chamber in Ottawa. A forced air deicing unit was provided by Vestergaard and was attached to a Vestergaard deicing vehicle. The JetStar wing was exposed to various simulated precipitation conditions and the ability of the forced air unit to clean the wing with air and fluid was examined, including inspections of the wing quiet areas. The time required for Type I fluid applied with a forced air unit to refreeze under continuous precipitation was also observed. Finally, the pressures and temperatures exerted on the JetStar wing surface during a forced air deicing operation were studied.

Discussions and Recommendations: Refer to *Safety Issues and Concerns of Forced Air Deicing Systems* TP 13664E (6).

Photo 4.7 Forced Air Deicing Set-Up at NRC

Photo 4.8 Freezing Rain on JetStar Wing Prior to Forced Air Deicing

4.5 SAE Type I Fluid Endurance Time Test Protocol

Objective: The objective of this project was to develop a protocol for measuring endurance times for SAE Type I fluids, reflecting real field operations. The protocol was intended to account for the effect on endurance times of heat transferred to the wing from the heated fluid, by using a test surface that is thermodynamically similar to real wings in natural weather conditions. The influence of wing tank fuel on wing skin temperatures was to be considered.

Procedures: Selection of an appropriate test surface included comparing fluid endurance times and temperature decay rates on the JetStar test wing to those candidate test surfaces. Prior to laboratory tests, the wing surface temperature decay rate was measured in outdoor conditions, with the wing tanks empty, and filled to 25 percent and 50 percent with a fuel substitute. Simultaneous trials in controlled laboratory artificial precipitation conditions were then conducted on the wing (with tanks half full) and on test surfaces. A limited test area on the wing was defined, thereby enabling application of fluid in a controlled repeatable manner, similar to the procedure used to apply fluid on the test surfaces. Thermistor probes were installed on the wing to track surface temperatures.

Discussions and Recommendations: Refer to *SAE Type I Fluid Endurance Time Test Protocol* TP 13827E (3).

Photo 4.9 Wing Test Area

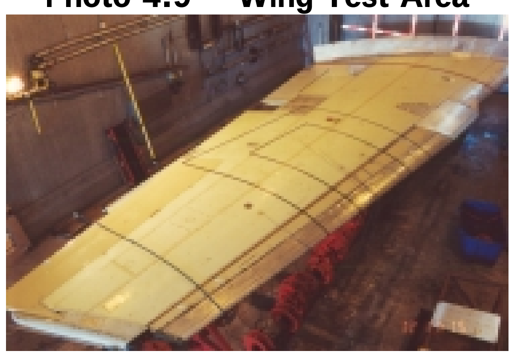

Photo 4.10 Wing Test Area Cleaned by Spraying

5. RECOMMENDATIONS

Fluid failure testing with the JetStar wing was scheduled to occur during the 2000-2001 test season to document similarities and differences between this wing and those of previously tested full-scale aircraft in natural precipitation. Due to the late start of the test season, this testing was not conducted. It is recommended that fluid failure tests with the JetStar wing be rescheduled for the 2001-2002 test season.

Bombardier Aerospace has recently offered a Bombardier CRJ 200 wing, which had been used for its certification test program, that could be adapted as a deicing test bed. The addition of the CRJ 200 wing would provide full-scale test opportunities in both Ottawa and Montreal with a modern wing that is widely used by today's airlines. It is recommended that Transport Canada acquire the Canadair RJ wing and prepare it to serve as a deicing test bed.

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REFERENCES

1. Chaput, M., Ruggi, E., Hanna, M., *Development of a Plan to Implement a Full-Scale Test Site*, APS Aviation Inc., Montreal, October 1999, Transport Canada report, TP 13487E, 24.

2. Chaput, M., Hanna, M., *Preparation of JetStar Wing for Use in Deicing Research*, APS Aviation Inc., Montreal, August 2000, Transport Canada report, TP 13667E, 46.

3. Dawson, P., *SAE Type I Fluid Endurance Time Test Protocol*, APS Aviation Inc., Montreal, August 2001, Transport Canada report, TP 13827E, 150.

4. Dawson, P., Hanna, M., *Hot Water Deicing of Aircraft: Phase 2*, APS Aviation Inc., Montreal, November 2000, Transport Canada report, TP 13663E, 56 (to be published).

5. Dawson, P., Hunt, M., *Ice Detection Sensor Capabilities for End-of Runway Wing Checks: Phase 2 Evaluation*, APS Aviation Inc., Montreal, August 2000, Transport Canada report, TP 13662E, 96 (to be published).

6. Dawson, P., *Safety Issues and Concerns of Forced Air Deicing Systems*, APS Aviation Inc., Montreal, November 2000, Transport Canada report, TP 13664E, 100.

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APPENDIX A

EXTRACT OF
TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT

APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE
EXTRACT
WORK STATEMENT
DC 187
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING
2000 -2001
(January 2001)

5.7 Wing Test Bed

In 1998-99, APS was asked to examine the feasibility of implementing a full-scale test site centered on a wing test bed. Following a long search, a Lockheed JetStar wing was purchased for this purpose. Although not attached to the wing, the various flight control surfaces were delivered along with the main wing section.

During the 1999-2000 test season, APS obtained quotations for reassembly of the various control surfaces, construction of a fairing for the leading edge, replacement of missing panels, removal of the deicing boot, and polishing of the leading edge. The work was contracted to a mechanic in Ottawa.

During the Spring 2000, a boat trailer was purchased for mounting of the wing for test purposes. The boat trailer had a maximum weight capacity of 3,500 pounds.

The mounted JetStar wing was used in several full-scale trials in 2000, including:

- Fluid application trials;
- Infrared deicing system trials;
- Hot water trials;
- Sensor capability trials; and
- Forced air trials.

Several recommendations for improvement to the test bed resulted from the full-scale testing with the JetStar wing. The most important was the examination of the fuel system integrity of the wing in order to obtain cold-soaking capabilities. This assessment, which has been included within an overall quote for work on the wing, shall be accomplished using a water or pressure test.

Fluid failure testing with the JetStar wing was scheduled to occur during the 1999-2000 test season to document similarities and differences between this wing and previously tested aircraft. This testing was not conducted due to extraneous factors.

Several other small modifications to the JetStar wing, including replacement of the small wheel at the head of the trailer, replacement of the galvanized metal panels, and securing of the various control surfaces, have been costed along with the examination of the fuel system.

If wing cold-soaking capabilities are obtained, the weight of the wing and the fluid contained within the tanks will exceed the weight capacity of the current mounting system. The structure of the trailer will be examined to increase the overall weight capacity. Furthermore, a search for a new trailer with increased capacity will be conducted. A provision for the cost of this last item has been included within the costing section.

5.7.1 Examine the fuel system integrity of the wing using a water or pressure test.

5.7.2 When wing cold-soaking capabilities are obtained, examine the structure of the trailer to increase the overall weight capacity or search for a new trailer with increased capacity.

5.7.3 Perform modifications to the JetStar wing setup, including replacement of the small wheel at the head of the trailer, replacement of the galvanized metal panels, and securing of the various control surfaces.

5.7.4 Conduct fluid failure testing with the JetStar wing to document similarities and differences between this wing and previously tested aircraft. Testing shall be conducted on one occasion. To reduce costs, JetStar testing shall be conducted simultaneously with other full-scale aircraft events.

5.7.5 Analyze the data collected and report the findings.

APPENDIX B

DESIGN CHARACTERISTICS OF THE LOCKHEED JETSTAR

5.0 STRUCTURE

5.1 GENERAL

5.1.1 Construction and Materials

In general, the airplane structure shall be fabricated of high strength aluminum alloys, including 2024 and 7075. Steel, titanium alloys and other FAA-approved aircraft materials shall also be used where advantageous to strength, endurance, weight or heat protection.

5.1.2 Structural Fasteners

Insofar as practicable, structural fasteners, such as bolts, nuts, washers, and others, shall be NAS, MS, and other standard parts common to the industry.

5.1.3 Corrosion Protection

Corrosion protection shall be incorporated for structure either by use of corrosion resistant materials or by use of protective finishes.

5.1.4 Drainage and Ventilation

Drainage ports shall be incorporated into the airplane structure at points where fluids or condensation may collect. These ports shall permit drainage of flushing fluids that may be introduced to clean out flammable fluids in areas where fluid lines are installed. Access plates shall be incorporated to permit entry into such areas for flushing. Ventilation shall be incorporated to avoid accumulation of hazardous vapors.

5.1.5 Surface Smoothness

The smoothness criteria of the structure shall be compatible with the speed characteristics of the airplane.

5.2 WING GROUP

5.2.1 General Description

The wing shall be of thin cantilever type, swept 30 degrees at the 25% chord. Major components of each wing, in addition to the basic root to tip structure, shall include aileron, leading edge flaps and trailing edge flaps. Each wing shall be designed for two separate integral fuel tanks of approximately equal capacity. Integral tank sealing shall be used to insure a fuel-tight tank. "O" ring seals and fuel-tight dome nuts shall be used in regions of removable access panels. The upper surface of the wing shall consist of large removable panels to permit access to the internal structure. The wing shall be attached to the fuselage with tension bolts along the upper and lower surfaces between the front beam and the rear beam.

5.2.2 Wing Box

The wing box structure shall be mainly high strength aluminum alloy and shall be conventional beam and rib stressed skin construction. Bending loads shall be carried by aluminum alloy integral skin-stringer extrusion, supported by aluminum alloy sheet ribs. Shear shall be carried by three beams consisting of extruded caps, sheet webs, and extruded stiffeners. The entire wing forward of the rear beam except the leading edge flaps shall be effective as a torsion box. Wing attachment to the fuselage shall be accomplished by pairs of horizontal tension bolts, inserted from inside the fuselage into barrel nuts held in a chordwise wing root fitting.

5.2.3 Ailerons

The ailerons shall be of all aluminum alloy construction, statically and dynamically balanced by balance weights which shall be contained inside the wing contour. The left aileron shall incorporate an electrically actuated trim tab. The right aileron shall incorporate a fixed trim tab with provisions for ground adjustment.

5.2.4 Leading Edge Flaps

Leading edge flaps shall be of aluminum alloy construction and shall be hinged from wing station 175.5 extending outboard to the wing tip. The leading edge flaps shall be sequenced to operate with the trailing edge flaps.

5.2.5 Trailing Edge Flaps

A double slotted flap divided into two sections shall be installed on each wing. The flaps shall be designed for a rotation from a faired position to 50 degrees down position. The flaps shall be interconnected by torque tubes so that both left and right hand flaps operate together. Asymmetry switches shall be installed on each flap to prevent operation of one flap only, in the event of failure of the interconnect. The flaps shall be mechanically actuated from a hydraulic motor-driven gearbox, through torque tubes and screw jacks.

5.3 TAIL GROUP

5.3.1 General Description

The tail section shall be of conventional design and construction with the horizontal stabilizer mounted on the vertical fin at approximately 30 percent of the fin span. Elevators and rudder shall be statically and dynamically balanced.

5.3.2 Vertical Tail

The vertical fin shall be mounted to the fuselage by a pivot fitting located at the 64% fin beam and with a dual pitch trim actuator. The two coupled screw jacks of the pitch trim actuator shall be incorporated at the 25% beam of the vertical fin to pivot the fin for airplane pitch trim. The rudder tab shall be a combined trim-balance type, actuated by dual electric screw jacks.

power for starting.

7.6 ENGINE CONTROL SYSTEM

The engine controls shall consist of a throttle quadrant with separate throttle and reverse thrust levers for each engine, four changeover boxes, cable systems between the quadrant and changeover boxes, and push-pull cables from the changeover boxes to the engine fuel controls.

7.7 FIRE EXTINGUISHING AND DETECTION

An electrically operated two-shot fire extinguisher installation shall be furnished to protect the nacelles in such a manner that one or both shots can be discharged to any nacelle. Suitable fire detection shall be incorporated in each nacelle. The fire extinguisher bottles shall be located in the aft fuselage equipment compartment.

7.8 FUEL SYSTEM

7.8.1 General

The fuel system shall supply fuel to each engine by means of a tank mounted boost pump feeding each engine directly from each tank. A crossfeed system shall be incorporated so that fuel can be supplied to any engine from any pump or any combination thereof. All fuel system components shall be located outside the cabin pressurized area. Check valves and remotely operated shut-off valves shall be installed to control fuel flow. Manually operated drain valves shall be furnished for the fuel jettison line and the low points in the fuel tanks.

7.8.2 Fuel Tanks

Four integral wing tanks (two tanks in each wing) shall be included within the wing structure to contain approximately 1,530 gallons of usable fuel. All four tanks shall be of approximately equal capacity. Baffles shall be installed in the wing tanks to control sloshing. The inboard section of each wing tank shall contain a fuel sump from which fuel shall be delivered to the engines. In addition, two external tanks, each having an approximate 565-gallon capacity, shall be installed on the wings.

7.8.3 Pumps

Four DC electric fuel boost pumps, each of which shall normally feed one engine, shall supply fuel from the wing tank sumps to the engines. Any two pumps shall be capable of supplying maximum fuel requirements to all four engines through the crossfeed manifold. In addition, two DC electric fuel boost pumps shall supply fuel from the external tanks to the engines through the crossfeed manifold. Inlet screens shall be integral components of all boost pumps. An auxiliary AC pump shall be installed in each external tank for use in the event of DC pump failure.

7.8.4 Vent System

The integral wing tanks shall be vented to atmosphere through non-icing outlets located in the wing lower surface near the wing tips. The external tanks shall be vented near the aft end of the tank.

7.8.5 Refueling

An electrically controlled single point refueling system shall be installed for refueling each of the six fuel tanks, with automatic shutoff at the full tank level. Individual overwing refueling filler caps shall be installed for each of the six fuel tanks.

7.8.6 Defueling

A manually operated valve in the crossfeed manifold shall be installed for defueling the airplane. All fuel tanks can be emptied by use of the tank mounted boost pumps.

LOCKHEED MODEL 1329 JETSTAR
USAF designation: C-140

First announced in March, 1957, the JetStar is a jet-powered utility transport with normal accommodation for a crew of two and eight or ten passengers. The first prototype, built as a private venture, flew on September 4, 1957, only 241 days after its design was started.

The two prototype JetStars were each powered originally by two Bristol Siddeley Orpheus turbojets, mounted on each side of the rear fuselage. One of them was re-engined in December, 1959, with four Pratt & Whitney JT12 turbojets mounted in lateral pairs in the same position. This power plant was standardised for the production version, which first flew in the Summer of 1960 and received FAA Type Approval in August 1961.

By June 1966, a total of 71 JetStars had been delivered for corporate and private use throughout the world, with production continuing at the rate of two aircraft per month. In addition, two versions have been delivered to the USAF, as follows:

C-140A. Five for use by the Air Force Communications Service, which is responsible for inspecting world-wide military navigation aids. First delivered in Summer of 1962.

VC-140B. Eleven transport versions for operation by the special air missions wing of MAC. One configuration accommodates a crew of three and eight passengers, the other a crew of three and 13 passengers. First delivered in late 1961.

Early JetStars had JT12A-6 engines, with max continuous rating of 2,400 lb (1,090 kg) st. In the Summer of 1963, these were superseded by JT12A-6A engines, with a max continuous rating of 2,570 lb (1,166 kg) st. The current version, known as the Dash 8 JetStar, flown for the first time in January 1967, has more powerful JT12A-8 turbojets, improved brakes and anti-skid units and a new pneumatic emergency extension system for the landing gear. Structural strength is increased to cater for a higher gross weight. Kits are available to convert earlier JetStars to Dash 8 standard, as described below.

Type: Four-jet light utility transport.

Wings: Cantilever low-wing monoplane. Wing section NACA 63A112 at root, NACA 63A309 (modified) at tip. Aspect ratio 5·27. Chord 13 ft 7¾ in (4·16 m) at root, 5 ft 1 in (1·55 m) at tip. Dihedral 2°. Incidence 1° at root, −1° at tip. Sweepback at quarter-chord 30°. Conventional fail-safe stressed-skin structure of high-strength aluminium. Bending loads carried by integral skin-stringer extrusion and sheet ribs, shear loads by three beams. Plain aluminium alloy ailerons are mechanically operated with hydraulic boost. Aileron trim-tabs actuated electro-mechanically. Double-slotted all-metal trailing-edge flaps. Hinged leading-edge flaps. No spoilers. Rubber boot de-icers on leading-edge.

Fuselage: Semi-monocoque fail-safe structure of aluminium alloy. Hydraulically-operated speed-brake on underside of fuselage aft of pressurised compartment.

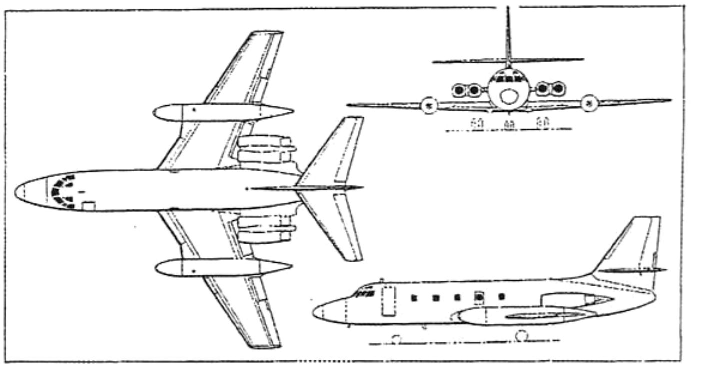
Tail Unit: Cantilever aluminium alloy structure with tailplane mounted part-way up fin. Fin is pivoted to vary tailplane incidence for trimming. Elevators mechanically operated with hydraulic boost. Rudder mechanically operated with servo assist. Rubber-boot de-icers on leading-edges.

Landing Gear: Hydraulically-retractable tricycle type with twin wheels on all units. Pneumatic emergency extension. Main units retract inward, nose-wheels forward. Oleo-pneumatic shock-absorbers. Main wheel tyres size 26 × 6·6 type VII, pressure 205 lb/sq in (14·41 kg/cm²). Nose-wheel tyres size 18 × 4·4 type VII, pressure 180 lb/sq in (12·65 kg/cm²). Hydraulic brakes with fully-modulated anti-skid units.

Power Plant: Four Pratt & Whitney JT12A-8 turbojet engines (each 3,300 lb = 1,497 kg st) mounted in lateral pairs on sides of rear fuselage. Thrust reversers fitted. Fuel in four integral wing tanks, total capacity 1,530 US gallons (5,792 litres), and two non-removable external tanks on wings. Total fuel capacity 2,660 US gallons (10,070 litres). Refuelling point on each tank. Oil capacity 6·3 US gallons (24 litres).

Accommodation: Normal accommodation for crew of two and ten passengers, with wardrobe, galley and toilet aft of cabin and baggage compartments fore and aft. Layout and furnishing can be varied to suit customer's requirements. Door on port side between flight deck and cabin.

Systems: Air-cycle air-conditioning and pressurisation system, using engine-bleed air. Pressure differential 8·9 lb/sq in (0·63 kg/cm²). Two independent hydraulic systems with engine-driven pumps; pressure 3,000 lb/sq in (210 kg/cm²). Four 28V 300A DC engine-driven starter-generators, three 3000VA single-phase 115V inverters and two 24V 36Ah batteries. No APU.



Lockheed JetStar four-engined light jet transport

Electronics and Equipment: Provision for full range of radio, radar and all-weather flying equipment, to customer's specification.

Dimensions, external:

Wing span	54 ft 5 in (16·60 m)
Length overall	60 ft 5 in (18·42 m)
Length of fuselage	58 ft 9½ in (17·92 m)
Height overall	20 ft 5 in (6·23 m)
Tailplane span	24 ft 9 in (7·55 m)
Wheel track	12 ft 3½ in (3·75 m)
Wheelbase	20 ft 7 in (6·28 m)
Cabin door:	
Height	4 ft 11 in (1·50 m)
Width	2 ft 2½ in (0·67 m)
Height to sill	approx 4 ft 6 in (1·37 m)

Dimensions, internal:

Cabin, excluding flight deck:	
Length	28 ft 2¼ in (8·59 m)
Max width	6 ft 2½ in (1·89 m)
Max height	6 ft 1 in (1·85 m)
Volume	850 cu ft (24·07 m³)

Areas:

Wings, gross	542·5 sq ft (50·40 m²)
Ailerons (total)	24·4 sq ft (2·27 m²)
Trailing-edge flaps (extended, total)	62·6 sq ft (5·82 m²)
Leading-edge flaps (total)	34·0 sq ft (3·16 m²)
Fin	94·0 sq ft (8·73 m²)
Rudder, including tab	16·2 sq ft (1·51 m²)
Tailplane	117·8 sq ft (10·94 m²)
Elevators	31·2 sq ft (2·90 m²)

Weights and Loadings (A = version with -6 engines; B = version with -8 engines):

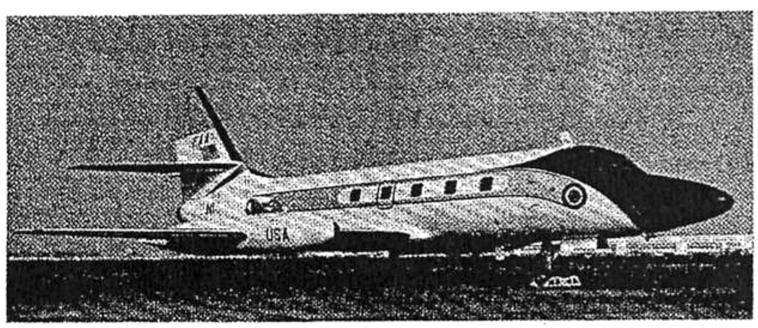
Basic operating weight:	
A	21,531 lb (9,766 kg)
B	21,713 lb (9,848 kg)
Max payload:	
A	3,469 lb (1,573 kg)
B	3,287 lb (1,491 kg)
Payload with full fuel:	
A	2,147 lb (974 kg)
B	2,965 lb (1,345 kg)
Max T-O weight:	
A	40,921 lb (18,550 kg)
B	41,900 lb (19,005 kg)
Max ramp weight:	
A	41,500 lb (18,825 kg)
B	42,500 lb (19,275 kg)
Max zero-fuel weight:	
A, B	25,000 lb (11,340 kg)
Max landing weight:	
A, B	35,000 lb (15,875 kg)
Max wing loading:	
A	75·4 lb/sq ft (368·1 kg/m²)
B	77·2 lb/sq ft (376·9 kg/m²)
Max power loading:	
A	3·4 lb/lb st (3·4 kg/kg st)
B	3·2 lb/lb st (3·2 kg/kg st)

Performance (at max T-O weight. A = version with -6 engines; B = version with -8 engines):

Max level speed below 22,350 ft (6,810 m) 403 mph (648 kmh) IAS; above 22,350 ft (6,810 m)	Mach 0·82
Max permissible diving speed below 17,500 ft (5,330 m) 490 mph (788 kmh) IAS; above 17,500 ft (5,330 m)	Mach 0·90
Max cruising speed at 21,000 ft (6,400 m):	
A	556 mph (895 kmh)
B	565 mph (909 kmh)
Econ cruising speed, reduced AUW, at 35,000 ft (10,670 m):	
A, B	501 mph (806 kmh)
Stalling speed, flaps down, at max landing weight	122 mph (196 kmh)
Rate of climb at S/L, at AUW of 38,000 lb (17,235 kg):	
A	3,730 ft (1,137 m) min
B	4,600 ft (1,400 m) min
Service ceiling, at AUW of 38,000 lb (17,235 kg):	
A	34,500 ft (10,515 m)
B	37,800 ft (11,520 m)
Service ceiling, one engine out, at AUW of 38,000 lb (17,235 kg):	
A	25,200 ft (7,680 m)
T-O run:	
A	3,900 ft (1,190 m)
B	3,525 ft (1,075 m)
T-O to 50 ft (15 m):	
A	5,275 ft (1,610 m)
B	4,700 ft (1,433 m)
Landing from 50 ft (15 m):	
A	3,880 ft (1,183 m)
B	3,600 ft (1,097 m)
Landing run:	
A	2,590 ft (790 m)
B	2,300 ft (701 m)
Range with max fuel, step climb, with 45 min reserve:	
A	2,220 miles (3,573 km)
B	2,170 miles (3,492 km)
Range with max payload, step climb, with 45 min reserve:	
A	1,930 miles (3,106 km)
B	2,050 miles (3,300 km)

LOCKHEED MODEL 200 STARLIFTER
USAF designation: C-141A

On March 13, 1961, it was announced that Lockheed-Georgia had won a design contest for a turbofan-powered freighter and troop carrier for operation by the US Military Airlift Command, in competition with Boeing, Douglas and General Dynamics/Convair. The specification to which the entries were designed was SOR-182 (Specific Operational Requirement 182). The initial contract covered five development, test and evaluation aircraft and the USAF has since ordered a total of 284 production aircraft,



Lockheed JetStar four-jet executive transport of the Federal Aviation Administration (*B. M. Service*)

APPENDIX C

DESIGN CHARACTERISTICS OF THE BOMBARDIER CANADAIR REGIONAL JET 200

Canadair Challenger 604, the latest long-range version of this business/regional transport aircraft

DIMENSIONS, INTERNAL:
Cabin: Length, incl galley, toilet and baggage area, excl flight deck 8.61 m (28 ft 3 in)
Max width 2.49 m (8 ft 2 in)
Width at floor level 2.18 m (7 ft 2 in)
Max height 1.85 m (6 ft 1 in)
Floor area 18.77 m² (202 sq ft)
Volume 32.6 m³ (1,150 cu ft)

AREAS:
Wings, gross (excl winglets) 48.31 m² (520.0 sq ft)
Ailerons (total) 1.39 m² (15.0 sq ft)
Trailing-edge flaps (total) 7.80 m² (84.0 sq ft)
Fin 9.18 m² (98.8 sq ft)
Rudder 2.03 m² (21.9 sq ft)
Tailplane 6.45 m² (69.4 sq ft)
Elevators (total) 2.15 m² (23.1 sq ft)

WEIGHTS AND LOADINGS (601-3R):
Manufacturer's weight empty 9,405 kg (20,735 lb)
Operating weight empty 11,684 kg (25,760 lb)
Max fuel 8,119 kg (17,900 lb)
Max payload 2,377 kg (5,240 lb)
Payload with max fuel 721 kg (1,590 lb)
Max T-O weight 20,457 kg (45,100 lb)
Max ramp weight 20,525 kg (45,250 lb)
Max landing weight 16,329 kg (36,000 lb)
Max zero-fuel weight 14,062 kg (31,000 lb)
Max wing loading 489.3 kg/m² (100.2 lb/sq ft)
Max power loading (without APR) 263.42 kg/kN (2.58 lb/lb st)

PERFORMANCE (601-3R at max T-O weight, except where indicated):
Max cruising speed 476 knots (882 km/h; 548 mph)
Normal cruising speed 459 knots (851 km/h; 529 mph)
Long-range cruising speed 424 knots (786 km/h; 488 mph)
Time to initial cruise altitude 24 min
Max operating altitude 12,500 m (41,000 ft)
Service ceiling, OEI 5,550 m (18,200 ft)
Balanced T-O field length (ISA at S/L) 1,844 m (6,050 ft)
Landing distance at S/L at max landing weight 1,006 m (3,300 ft)
Range with max fuel and five passengers, NBAA IFR reserves (200 nm; 370 km; 230 mile alternate) at long-range cruising speed 3,585 nm (6,639 km; 4,125 miles)
Design *g* limit +2.6

OPERATIONAL NOISE LEVELS (601-3R, FAR Pt 36):
T-O 79.7 EPNdB
Sideline 85.7 EPNdB
Approach 90.8 EPNdB

CANADAIR REGIONAL JET

TYPE: Twin-turbofan regional transport.

PROGRAMME: Design studies began Autumn 1987; basic configuration frozen June 1988; formal programme go-ahead given 31 March 1989; extended range 100ER announced September 1990. Three development aircraft built (c/n 7001-7003), plus static test airframe (c/n 7991) and forward fuselage test article (7992); first flight of 7001 (C-FCRJ) 10 May 1991; 7002 (C-FNRJ) first flew 2 August 1991 and 7003 on 17 November 1991; all three in 1,400 hour flight test programme in Wichita, USA. CF34-3A1 engine obtained its US type certificate 24 July 1991. Transport Canada type approval (100 and 100ER) 31 July 1992; first flight of first delivery aircraft (c/n 7004) 4 July 1992; first delivery (to Lufthansa CityLine of Germany) 29 October 1992; European JAA and US FAA certification 15 and 21 January 1993 respectively. Production rate being increased from two to three per month during 1994.

CURRENT VERSIONS: **Series 100:** Standard aircraft; designed to carry 50 passengers over 980 nm (1,816 km; 1,128 mile) range; max T-O weight 21,523 kg (47,450 lb).

Series 100ER: Extended range capability with optional increase in max T-O weight to 23,133 kg (51,000 lb) and optional additional fuel capacity, for range of 1,620 nm (3,000 km; 1,864 miles).

Series 100LR: Announced March 1994 as longer range version of ER (more than 1,900 nm; 3,519 km; 2,186 miles); max T-O weight increased by 907 kg (2,000 lb) to 24,040 kg (53,000 lb); launch customer Lauda Air of Austria (six firm orders plus six on option). Certification scheduled for second quarter 1994; available as retrofit to 100ER.

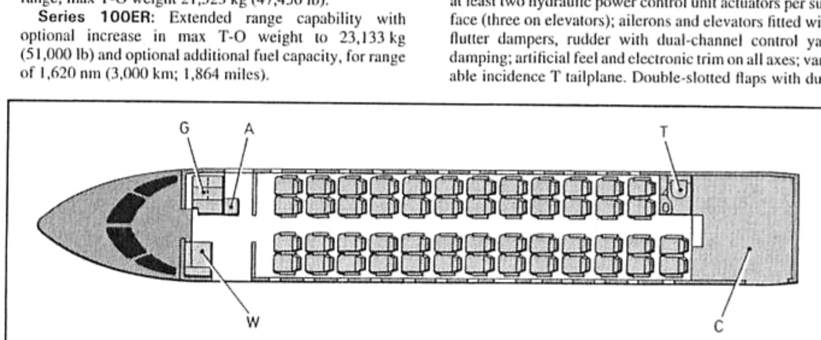
CUSTOMERS: 64 orders and 74 options and conditional orders early 1994. Launch customers are Lufthansa CityLine (13), MTM Aviation GmbH (two) and Comair Inc (The Delta Connection) (20); 27 delivered by early 1994.

COSTS: Programme development costs C$275 million.

DESIGN FEATURES: Evolved from Challenger (which see), designed expressly for regional airline operating environment. Advanced transonic wing design, with winglets for high-speed operations; fuel-efficient GE turbofans; options include higher design weights, additional fuel capacity, more comprehensive avionics, and max certificated altitude raised to 12,500 m (41,000 ft).

Wings, designed with computational fluid dynamics (CFD), have 13.2 per cent (root) and 10 per cent (tip) thickness/chord ratios, 2° 20′ dihedral, 3° 25′ root incidence and 24° 45′ quarter-chord sweepback.

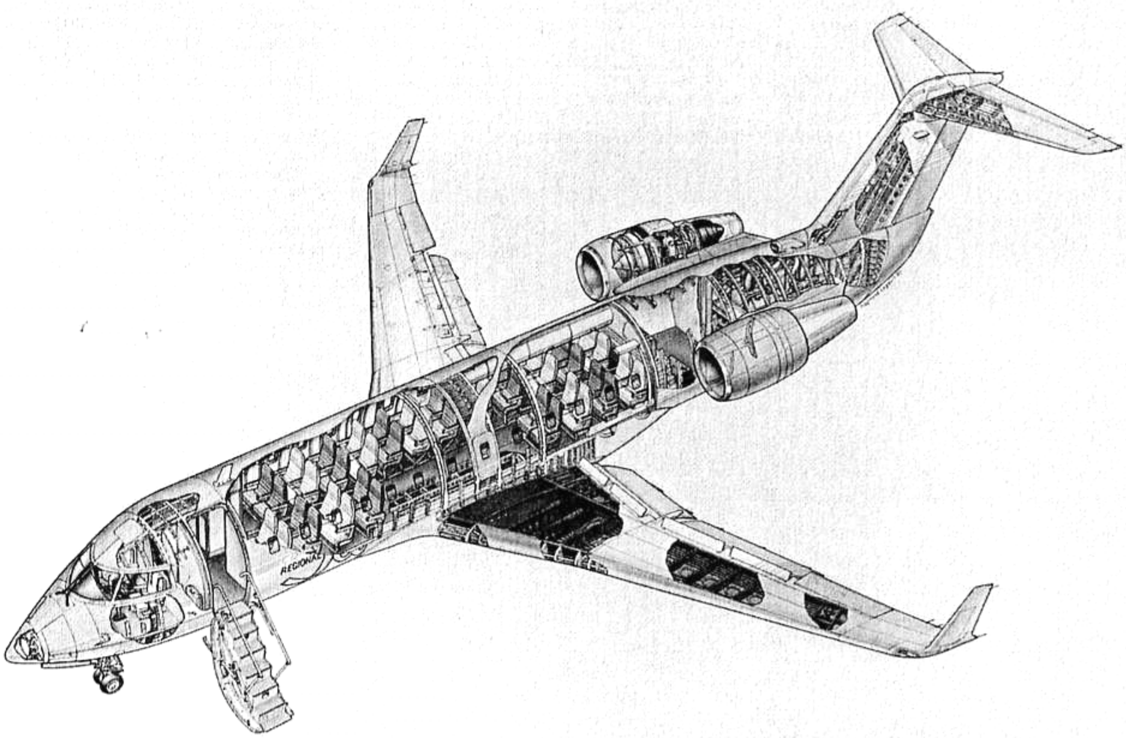
FLYING CONTROLS: Conventional three-axis primary controls with cables and push/pull rods for multiple redundancy; hydraulically actuated ailerons, elevators and rudder with at least two hydraulic power control unit actuators per surface (three on elevators); ailerons and elevators fitted with flutter dampers, rudder with dual-channel control yaw damping; artificial feel and electronic trim on all axes; variable incidence T tailplane. Double-slotted flaps with dual



Canadair Regional Jet standard 79 cm (31 in) pitch 50-seat layout *(Jane's/Mike Keep)*

C-1

Air Littoral operates one Canadair Regional Jet in Air France livery



Datron electric motors; GEC-Marconi Avionics fly-by-wire spoiler and spoileron system, four spoilers each side, with inner two functioning as ground spoilers, outer two comprising one flight spoiler and one spoileron, both also providing lift dumping on touchdown. Avionics suite includes engine indication and crew alerting system (EICAS).

STRUCTURE: Semi-monocoque fuselage is damage tolerant FAR/JAR Pt 25 certificated airframe with chemically milled skins; flat pressure bulkheads forward of flight deck and aft of baggage compartment; extensive use of advanced composites in secondary structures (passenger compartment floor, wing/fuselage fairings, nacelle doors, wing access door covers, winglets, tailcone, avionics access doors and landing gear doors); comprehensive anti-corrosion treatment and drainage. Wing is one-piece unit mounted to underside of fuselage; two-spar box joined by ribs, covered top and bottom with integrally stiffened skin panels (three upper and three lower each side) for smooth flow; machined or built-up spars and shearweb type ribs. Short Brothers (UK) manufactures fuselage central section, fore and aft fuselage plugs, wing flaps, ailerons, spoilerons and inboard spoilers.

LANDING GEAR: Hydraulically retractable tricycle type, manufactured by Dowty. Inward retracting main units each have 15 in Aircraft Braking System wheels with 29 × 9-15 Goodyear H tubeless tyres, pressure 11.17 bars (162 lb/sq in) unladen. Nose unit has Dowty Canada steer-by-wire steering and unladen tyre pressure of 8.62 bars (125 lb/sq in). Aircraft Braking System steel multi-disc brakes and fully modulated Hydro Aire Mk III anti-skid system. Min ground turning radius 22.86 m (75 ft 0 in).

POWER PLANT: Two General Electric CF34-3A1 turbofans, each rated at 41.0 kN (9,220 lb st) with APR and 38.8 kN (8,729 lb st) without. Nacelles produced by Vought Aircraft. Pneumatically actuated thrust reversers. Fuel in two integral wing tanks, combined capacity 5,300 litres (1,400 US gallons; 1,166 Imp gallons); increasable to 8,080 litres (2,135 US gallons; 1,778 Imp gallons) with optional centre wing tank. Pressure refuelling point in starboard leading-edge wingroot; two gravity points on starboard wing (one for centre tank) and one on port wing.

ACCOMMODATION: Two-pilot flight deck; one or two cabin attendants. Main cabin seats up to 50 passengers in standard configuration, four-abreast at 79 cm (31 in) pitch, with centre aisle; max capacity 52 seats. Various configurations, from 15 to 50 seats, available for corporate version. Downward opening front passenger door with integral airstairs on port side; plug type forward emergency exit/service door opposite on starboard side. Inward opening baggage door on port side at rear. Overwing Type III emergency exit each side. Entire accommodation pressurised, including rear baggage compartment.

SYSTEMS: Cabin pressurisation and air-conditioning system (max differential 0.57 bar; 8.3 lb/sq in). Primary flight control systems powered by hydraulic servo-actuators with distinct, alternate paths cable and pushrod systems. Electric trim and dual yaw dampers. Three fully independent 207 bar (3,000 lb/sq in) hydraulic systems. Three-phase 115V AC electrical primary power at 400Hz supplied by two 30kVA engine driven generators; alternative power provided by APU and air driven generator. Conversion to 28V DC by five transformer-rectifier units. Main (nickel-cadmium) battery 17Ah, APU battery 43Ah. Garrett GTCP 36-150 (RJ) APU and two-pack air-conditioning system in rear of fuselage. Wing leading-edges and engine intake cowls anti-iced by engine bleed air. Electric anti-icing of windscreen and cockpit side windows, pitot heads, air data vanes, static sources and sensors. Ice detection system standard.

AVIONICS: Collins Pro Line IV integrated all-digital avionics suite, including dual primary flight displays, dual multi-function displays, dual EICAS, dual AFCS, dual AHRS, dual nav/com radios, dual air data system and Cat. II capability. Digital weather radar system, GPWS, windshear detection system and TCAS. Loral Fairchild flight data recorder. Options include dual flight management system, dual inertial reference system in lieu of AHRS. Cat. IIIa landing capability using head-up guidance system, split-scan radar, weather radar with turbulence mode, HF radio, single Selcal, and MLS provisions.

DIMENSIONS, EXTERNAL: As for Challenger 601-3R except:
Wing span over winglets 21.21 m (69 ft 7 in)
Wing chord: at fuselage c/l 5.13 m (16 ft 10 in)
at tip 1.27 m (4 ft 2 in)
Wing aspect ratio (excl winglets) 8.85
Length: overall 26.77 m (87 ft 10 in)
fuselage 24.38 m (80 ft 0 in)
Height overall 6.22 m (20 ft 5 in)
Wheelbase 11.39 m (37 ft 4½ in)
Service door (stbd, fwd): Height 1.22 m (4 ft 0 in)
Width 0.61 m (2 ft 0 in)
Height to sill 1.61 m (5 ft 3½ in)
Baggage door (port, rear): Width 1.09 m (3 ft 7 in)

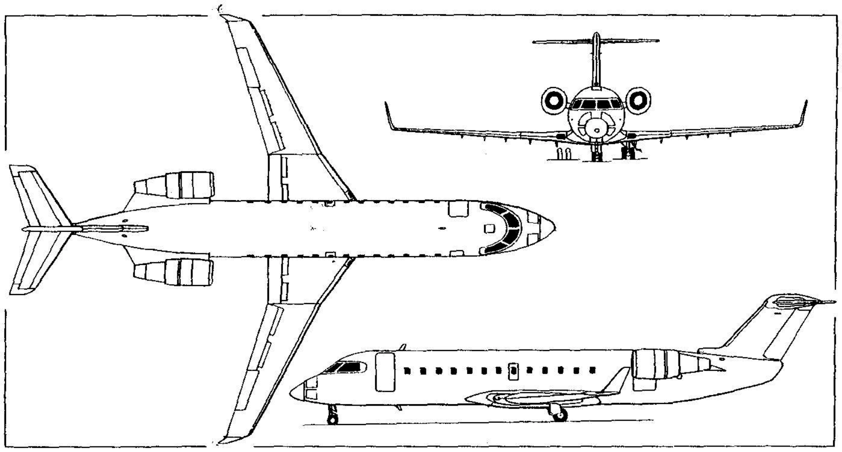
DIMENSIONS, INTERNAL: As for Challenger 601-3R except:
Cabin (incl baggage compartment, excl flight deck):
Length 14.76 m (48 ft 5 in)
Max height 1.87 m (6 ft 1½ in)
Floor area 32.14 m² (346.0 sq ft)
Volume 57.06 m³ (2,015 cu ft)
Stowage volume:
main (rear) baggage compartment 8.89 m³ (314.0 cu ft)
wardrobes/bins/underseat (total) 5.15 m³ (182.0 cu ft)

AREAS:
Wings: gross (excl winglets) 54.54 m² (587.1 sq ft)
net 48.35 m² (520.4 sq ft)
Ailerons (total) 1.93 m² (20.8 sq ft)
Trailing-edge flaps (total) 10.60 m² (114.1 sq ft)
Spoilers (total) 2.26 m² (24.3 sq ft)
Winglets (total) 1.38 m² (14.9 sq ft)
Fin 9.18 m² (98.8 sq ft)
Rudder 2.03 m² (21.9 sq ft)
Tailplane 9.44 m² (101.6 sq ft)
Elevators (total) 2.84 m² (30.52 sq ft)

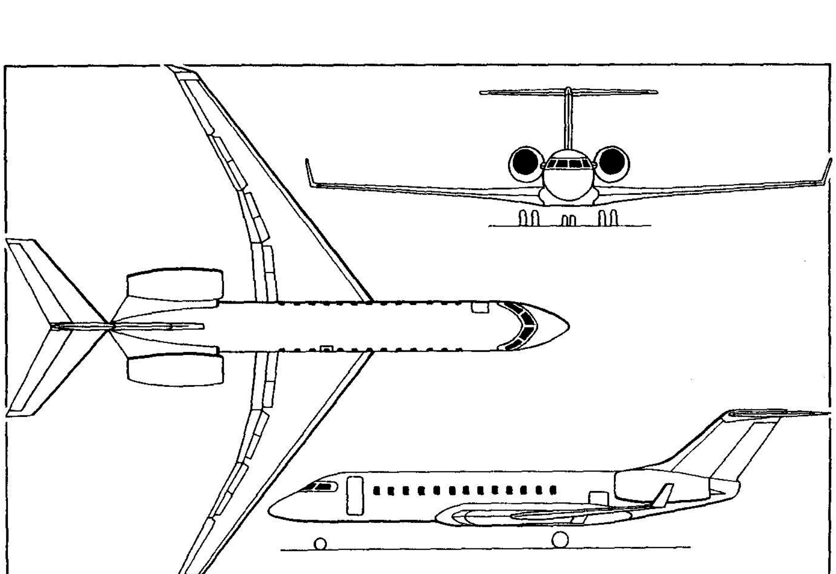
WEIGHTS AND LOADINGS:
Manufacturer's weight empty:
100, 100ER 13,236 kg (29,180 lb)
Operating weight empty: 100 13,653 kg (30,100 lb)
100ER 13,663 kg (30,122 lb)
Max payload (structural): 100 5,488 kg (12,100 lb)
100ER 6,295 kg (13,878 lb)
Max fuel: 100 4,254 kg (9,380 lb)
100ER 6,489 kg (14,305 lb)
Payload with max fuel: 100 3,728 kg (8,220 lb)
100ER 3,095 kg (6,823 lb)
Max T-O weight: 100 21,523 kg (47,450 lb)
100ER 23,133 kg (51,000 lb)
100LR 24,040 kg (53,000 lb)
Max ramp weight: 100 21,636 kg (47,700 lb)
100ER 23,246 kg (51,250 lb)
Max zero-fuel weight: 100 19,141 kg (42,200 lb)
100ER 19,958 kg (44,000 lb)
Max landing weight: 100 20,275 kg (44,700 lb)
100ER 21,319 kg (47,000 lb)
Max wing loading: 100 394.6 kg/m² (80.82 lb/sq ft)
100ER 424.14 kg/m² (86.87 lb/sq ft)
Max power loading (APR rating):
100 262.48 kg/kN (2.57 lb/lb st)
100ER 282.1 kg/kN (2.77 lb/lb st)

PERFORMANCE (at max T-O weight except where indicated):
Max operating speed:
above 9,570 m (31,400 ft) Mach 0.85
below 7,740 m (25,400 ft) 335 knots (621 km/h; 386 mph)
High-speed cruising speed at 11,275 m (37,000 ft) Mach 0.80 or 459 knots (851 km/h; 529 mph)
Normal cruising speed at 11,275 m (37,000 ft) Mach 0.74 or 424 knots (786 km/h; 488 mph)
Approach speed, 45° flap, AUW of 19,504 kg (43,000 lb) 137 knots (254 km/h; 158 mph)
Max rate of climb at 457 m (1,500 ft), 250 knots CAS/Mach 0.74 climb schedule: 100 1,128 m (3,700 ft)/min
100ER 1,036 m (3,400 ft)/min
Max operating altitude 12,500 m (41,000 ft)
FAR T-O field length at S/L, ISA 1,605 m (5,265 ft)
FAR landing field length at S/L, ISA, at max landing weight 1,440 m (4,725 ft)
Range with max payload at long-range cruising speed, FAR Pt 121 reserves:
100 980 nm (1,815 km; 1,128 miles)
100ER 1,620 nm (3,000 km; 1,864 miles)
100LR more than 1,900 nm (3,519 km; 2,186 miles)
Corporate (30 seats), NBAA IFR reserves 2,141 nm (3,967 km; 2,465 miles)

OPERATIONAL NOISE LEVELS:
T-O 78.6 EPNdB
Approach 92.1 EPNdB
Sideline 82.2 EPNdB



Canadair Regional Jet transport (two General Electric CF34-3A1 turbofans) ***(Jane's/Dennis Punnett)***



Preliminary three-view drawing of the Global Express ***(Jane's/Mike Keep)*** **(see next page)**