TP 13667E

Preparation of JetStar Wing for Use in Deicing Research

Prepared for

Transportation Development Centre
On behalf of
Civil Aviation

Transport Canada

APS AVIATION INC.

August 2000

Final Version 1.0

TP 13667E

Preparation of JetStar Wing for Use in Deicing Research

by

Michael Chaput
and
Medhat Hanna

APS AVIATION INC.

August 2000

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 and other sponsors.

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.

DOCUMENT ORIGIN AND APPROVAL RECORD

Prepared by:	Michael Chaput Manager, Aircraft De-icing Fluid Testing	22/2/2002 Date
And by:	Medhat Hanna, Eng.	

Reviewed by:	John D'Avirro Program Manager	Feb 22 2002 Date
Approved by:	R.V. Potter, Ph.D. Vice-President Policy and Co-ordination	28 Feb 02 Date

Un sommaire français se trouve avant la table des matières.

PREFACE

At the request of the Transportation Development Centre of Transport Canada, APS Aviation Inc. (APS) 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 Type IV fluids using lowest-qualifying viscosity samples, and to develop holdover time data for all newly qualified de/anti-icing fluids;
- To conduct flat plate holdover time tests under conditions of frost;
- To further evaluate the flow of contaminated fluid from the wing of a Falcon 20 aircraft during simulated takeoff runs;
- To determine the patterns of frost formation and of fluid failure initiation and progression on the wings of commercial aircraft;
- To evaluate whether the proposed locations of AlliedSignal's wing-mounted ice sensors on an Air Canada CL65 are optimally positioned;
- To evaluate the second generation of the NCAR snowmaking system;
- To evaluate the capabilities of ice detection camera systems;
- To examine the feasibility of and procedures for performing wing inspections with a remote ice detection camera system at the entrance to the departure runway (end-of-runway);
- To reassemble and prepare the JetStar aircraft wing for mounting, to modify it to obtain cold-soak capabilities, and to conduct fluid failure tests in natural precipitation using the wing;
- To extend hot water deicing tests to aircraft in natural outdoor precipitation conditions, and to correlate outdoor data with 1998-99 laboratory results;
- To examine safety issues and concerns of forced air deicing systems; and
- To evaluate snow weather data from previous winters to establish a range of snow precipitation suitable for the evaluation of holdover time limits.

The research activities of the program conducted on behalf of Transport Canada during the 1999-2000 winter season are documented in nine reports. The titles of these reports are as follows:

- TP 13659E Aircraft Ground De/Anti-icing Fluid Holdover Time and Endurance Time Testing Program for the 1999-2000 Winter;

- TP 13660E Aircraft Full-Scale Test Program for the 1999-2000 Winter;
- TP 13661E A Second Generation Snowmaking System: Prototype Testing;
- TP 13662E Ice Detection Sensor Capabilities for End-of-Runway Wing Checks: Phase 2 Evaluation
- TP 13663E Hot Water Deicing of Aircraft: Phase 2;
- TP 13664E Safety Issues and Concerns of Forced Air Deicing Systems;
- TP 13665E Snow Weather Data Evaluation (1995 - 2000);
- TP 13666E Contaminated Aircraft Simulated Takeoff Tests for the 1999-2000 Winter: Preparation and Procedures; and
- TP 13667E Preparation of JetStar Wing for Use in Deicing Research.

This report, TP 13667E, has the following objectives:

- To reassemble and prepare the JetStar aircraft wing for mounting, to modify the wing to obtain cold-soak capabilities, and to conduct fluid failure tests in natural precipitation using the JetStar wing.

The JetStar wing was reassembled, the missing panels were replaced, the deicing boot was removed, and the leading edge was polished. The wing was then mounted on a boat trailer to hold the wing at an ideal working height and to facilitate movement and use of the wing.

Because of the late start of the test program during the 1999-2000 winter, the cold-soak capabilities of the JetStar wing were not examined, and no fluid failure tests using the JetStar wing were performed.

ACKNOWLEDGEMENTS

This research has been funded by the Civil Aviation Group, Transport Canada, with support from the US 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, the National Research Council Canada, Atmospheric Environment Services Canada, and several fluid manufacturers. Special thanks are extended to US Airways Inc., Air Canada, National Centre for Atmospheric Research, AéroMag 2000, Aéroports de Montreal, G. Vestergaard A/S, Hudson General Aviation Services Inc., Union Carbide, Cryotech, BFGoodrich, Cox and Company Inc., Fortier Transfert Ltée, and MTN Snow Equipment Inc. for provision of personnel and facilities and for their co-operation with the test program. The authors gratefully acknowledge the participation of Jeff Mayhew and Donald Robitaille. 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. APS would also like to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data.

Transport Canada / Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No. TP 13667E	2. Project No. 9789	3. Recipient's Catalogue No.
4. Title and Subtitle Preparation of JetStar Wing for Use in Deicing Research		5. Publication Date August 2000 6. Performing Organization Document No. CM1589-001
7. Author(s) Michael Chaput and Medhat Hanna		8. Transport Canada File No. ZCD2450-23-14 (DC-182)
9. Performing Organization Name and Address APS Aviation Inc. 1100 René Lévesque Blvd. West Suite 1340 Montreal, Quebec Canada H3B 4N4		10. PWGSC File No. XSD-9-01714 11. PWGSC or Transport Canada Contract No. T8200-9-9563/001/XSD
12. Sponsoring Agency Name and Address Transportation Development Centre (TDC) 800 René Lévesque Blvd. West Suite 600 Montreal, Quebec H3B 1X9		13. Type of Publication and Period Covered Final 14. Project Officer B. Myers

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

Research reports produced on behalf of Transport Canada for testing during previous winters are available from the Transportation Development Centre (TDC). Nine reports (including this one) were produced as part of this winter's research program. This subject matter is outlined in the preface.

16. Abstract

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.

A Lockheed JetStar wing was purchased for this purpose. During the 1999-2000 winter test season, 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.

In addition, a new mounting system for the JetStar wing, consisting of an off-the-shelf boat trailer, was proposed. The cost of the trailer represented a savings of more than CAN$10 000 over the cheapest quotation received in 1999 for the mounting of the wing.

Because the combined assembly did not conform to the Highway Code, transportation companies were contacted to determine the costs related to the long-distance transportation of the wing dolly assembly by means of a flatbed truck. Several transport companies were contacted for quotations and a company was selected.

Full-scale testing with the JetStar wing was conducted in natural and simulated precipitation conditions at NRC Canada in Ottawa and at the central deicing facility at Dorval Airport in Montreal. Testing consisted of fluid application trials, hot water deicing trials, ice detection sensor trials for end-of-runway application, and forced air trials.

17. Key Words JetStar wing, wing assembly, winter operations, deicing	18. Distribution Statement Limited number of copies available from the Transportation Development Centre

19. Security Classification (of this publication) Unclassified	20. Security Classification (of this page) Unclassified	21. Declassification (date) —	22. No. of Pages xiv, 46, app.	23. Price Shipping/ Handling

CDT/TDC 79-005
Rev. 96

Canada

Transports Canada | Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. N° de la publication de Transports Canada TP 13667E	2. N° de l'étude 9789	3. N° de catalogue du destinataire
4. Titre et sous-titre Preparation of JetStar Wing for Use in Deicing Research		5. Date de la publication Août 2000 6. N° de document de l'organisme exécutant CM1589-001
7. Auteur(s) Michael Chaput et Medhat Hanna		8. N° de dossier - Transports Canada ZCD2450-23-14 (DC-182)
9. Nom et adresse de l'organisme exécutant APS Aviation Inc. 1100, boul. René-Lévesque Ouest Bureau 1340 Montréal, Québec Canada H3B 4N4		10. N° de dossier - TPSGC XSD-9-01714 11. N° de contrat - TPSGC ou Transports Canada T8200-9-9563/001/XSD
12. Nom et adresse de l'organisme parrain Centre de développement des transports (CDT) 800, boul. René-Lévesque Ouest Bureau 600 Montréal (Québec) H3B 1X9		13. Genre de publication et période visée Final 14. Agent de projet B. Myers

15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)

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 neuf rapports (dont celui-ci). On trouvera dans la préface l'objet de ces rapports.

16. Résumé

L'étude d'implantation d'une installation d'essai en vraie grandeur comportait trois phases : achat d'une aile, montage de l'aile sur un support approprié et choix d'un endroit optimal pour réaliser les essais.

Une aile de Lockheed JetStar a d'abord été achetée. Au cours de la saison d'essai 1999-2000, les gouvernes ont été réinstallées sur l'aile, 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.

Un nouveau système de montage de l'aile a en outre été proposé, soit une remorque porte-bateau du commerce. Le recours à une telle remorque représentait une économie de plus de 10 000 $CAN par rapport à la meilleure proposition de prix reçue en 1999 pour un chariot-support.

Mais l'ensemble aile-remorque n'étant pas conforme au Code de la route, les chercheurs ont demandé des propositions de prix à des transporteurs routiers pour le chargement de l'aile et de son support à bord d'un fardier et son transport à longue distance. Après réception de multiples propositions, une entreprise a été sélectionnée.

Des essais en vraie grandeur utilisant l'aile de JetStar ont été réalisés sous des précipitations naturelles et artificielles au CNRC, à Ottawa et au poste de dégivrage de l'Aéroport de Montréal-Dorval. Divers types d'essais ont été menés : application de fluides antigivrage, dégivrage à l'eau chaude, évaluation de détecteurs de givrage en bout de piste et dégivrage à air forcé.

17. Mots clés aile de JetStar, montage d'aile, opérations hivernales, dégivrage	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

19. Classification de sécurité (de cette publication)	20. Classification de sécurité (de cette page)	21. Déclassification (date)	22. Nombre de pages	23. Prix
Non classifiée	Non classifiée	—	xiv, 46, ann.	Port et manutention

EXECUTIVE SUMMARY

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.

Following a long search, a Lockheed JetStar wing was purchased in April 1999. Although not attached to the wing, all flight control surfaces were delivered with the main wing surface. During the 1999-2000 winter test season, 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 deicing boot, and polishing of the leading edge. The work was contracted to an aircraft mechanic in Ottawa.

Quotations for the design and fabrication of the wing dolly assembly were received from several companies in 1999. During the 1999-2000 test season, a new mounting system for the JetStar wing, consisting of an off-the-shelf boat trailer, was proposed. Since the design of the wing mounting system did not conform to the Highway Code, transportation companies were contacted to determine the costs related to the long-distance transportation of the wing dolly assembly by means of a flatbed truck. Several transport companies were contacted for quotations and a company was chosen.

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. NRC Canada's Climatic Engineering Facility was selected as the ideal location for any indoor tests in simulated precipitation.

Additional objectives of the 1999-2000 wing test bed implementation project included examining the integrity of the JetStar fuel system to determine wing cold-soak capabilities and conducting fluid failure trials with the JetStar wing. These objectives were not attained because of the late start of the test season.

During the 1999-2000 test season, full-scale testing with the JetStar wing was conducted in natural and simulated precipitation conditions at NRC Canada in Ottawa and at the central deicing facility at Dorval Airport in Montreal. Testing consisted of:

- Fluid application trials;
- Testing of the Radiant Energy Corporation Deicing System;
- Hot water deicing trials;
- Use of ice detection sensors for end-of-runway application; and
- Forced air trials.

Several recommendations for the improvement of the wing test bed design are listed below and should be implemented prior to any future testing:

- Fluid failure tests with the JetStar wing should be rescheduled for the upcoming test season.
- The fuel system integrity of the JetStar wing should be examined to determine the feasibility of filling the tanks with fluid to obtain cold-soaking capabilities.
- The structure of the trailer should be examined to potentially increase the overall weight capacity. Furthermore, a search for a boat trailer with additional weight capacity should be conducted.
- The small swivelling wheel should be replaced by a larger inflatable wheel and consideration should also be given to modifying the design to include two retractable feet that could be extended for stability during testing.
- A more permanent and stable method of levelling the JetStar wing should be examined.
- The galvanized metal panels and fairing should be replaced with aluminum.
- A more permanent method of securing the various control surfaces should be examined.

SOMMAIRE

L'étude d'implantation d'une installation d'essai en vraie grandeur comportait trois phases : achat d'une aile, montage de l'aile sur un support approprié et choix d'un endroit optimal pour réaliser les essais.

Après de longues recherches, une aile de Lockheed JetStar a été achetée en avril 1999. L'aile a été livrée avec toutes ses gouvernes, mais détachées. Pendant la saison d'essai 1999-2000, APS a demandé des propositions de prix pour la réinstallation des gouvernes, la construction d'un carénage pour le bord d'attaque, le remplacement des panneaux manquants de l'aile, l'enlèvement du boudin de dégivrage en caoutchouc et le polissage du bord d'attaque. Les travaux ont été confiés à un mécanicien d'aéronefs d'Ottawa.

En 1999, plusieurs entreprises ont soumis des propositions de prix pour la conception et la fabrication d'un chariot-support pour le montage de l'aile. Mais pendant la saison d'essai 1999-2000, un nouveau système de montage a été proposé, soit une remorque porte-bateau du commerce. Ce nouveau montage n'étant pas conforme au Code de la route, des propositions de prix ont été demandées à des transporteurs routiers pour le chargement de l'aile et de son support à bord d'un fardier et son transport à longue distance. Une firme a été sélectionnée parmi les entreprises soumissionnaires.

La troisième phase de l'étude consistait à choisir une installation d'essai en vraie grandeur. Le poste de dégivrage de l'Aéroport de Montréal-Dorval, exploité par AéroMag 2000, a été retenu. L'Installation de génie climatique du Conseil national de recherches du Canada a pour sa part été choisie comme étant l'endroit idéal pour les essais intérieurs sous précipitations artificielles.

L'année 1999-2000 du projet d'implantation d'une aile d'essai en vraie grandeur comportait d'autres objectifs, soit l'examen de l'intégrité du circuit de carburant de l'aile afin de déterminer ses capacités de sur-refroidissement et la conduite d'essais de durée d'efficacité de liquides antigivrage sur l'aile de JetStar. Ces objectifs n'ont pu être atteints en raison du début tardif de la saison d'essai.

La saison d'essai 1999-2000 a donné lieu à divers essais en vraie grandeur mettant en jeu l'aile de JetStar menés sous des précipitations naturelles et artificielles au CNRC à Ottawa et au poste de dégivrage de l'Aéroport de Montréal-Dorval. Voici en quoi ont consisté ces essais :

- application de fluides antigivrage;
- essai du système de dégivrage de Radiant Energy Corporation;
- dégivrage à l'eau chaude;
- utilisation de détecteurs de givrage pour évaluer l'état de givrage des ailes d'un avion en bout de piste;

- dégivrage à air forcé.

Plusieurs recommandations ont été formulées pour améliorer l'installation d'essai d'une aile en vraie grandeur. Il conviendra de donner suite à ces recommandations avant d'entreprendre tout autre essai. Voici la teneur de ces recommandations :

- Que l'on réaménage le prochain calendrier des essais de durée d'efficacité de fluides antigivrage mettant en jeu l'aile de JetStar.

- Que l'on examine l'intégrité du circuit de carburant de l'aile de JetStar afin de déterminer la possibilité de remplir les réservoirs de liquide et de simuler ainsi une aile sur-refroidie.

- Que l'on examine la structure de la remorque dans la perspective d'en augmenter la capacité pondérale. Qu'une recherche soit également menée pour trouver une remorque porte-bateau ayant une plus grande capacité pondérale.

- Que la petite roue pivotante soit remplacée par un pneumatique à plus grand diamètre et que l'on étudie la possibilité d'ajouter à la remorque deux pieds télescopiques qui, déployés, aideraient à stabiliser l'ensemble pendant les essais.

- Que l'on cherche un moyen de mettre de niveau l'aile de JetStar de façon plus permanente et plus stable.

- Que les panneaux et le carénage en acier galvanisé soient remplacés par des panneaux et un carénage en aluminium.

- Que l'on étudie une méthode pour fixer de façon plus permanente les gouvernes.

CONTENTS

Page

APPENDICES

LIST OF FIGURES

Page

LIST OF PHOTOS

Page

GLOSSARY

APS	APS Aviation Inc.
CEF	Climatic Engineering Facility
HOT	Holdover Time
IREQ	Institut de recherche d'Hydro-Québec
NCAR	National Center for Atmospheric Research
NRC Canada	National Research Council Canada

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:
Those parts of the aircraft where a thin layer of fluid may move very slowly or not at all; this is as a 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 at the surface.

This page intentionally left blank.

1. INTRODUCTION

At the request of the Transportation Development Centre, APS has undertaken a research program to further advance aircraft ground deicing/anti-icing technology.

Aircraft ground deicing/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 placed upon 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 tables (HOT tables), which are used by aircraft operators and accepted by regulatory authorities. New fluids continue to be developed specifically 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. In 1998-99, 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.

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.

Following a long search, a Lockheed JetStar wing was purchased for this purpose. Although not attached to the wing, all flight control surfaces were delivered with the main wing surface. The external fuel tank was removed and it was necessary to construct a fairing to maintain the original wing profile.

Quotations for the design and fabrication of the wing dolly assembly were received from several companies, including NRC Canada. The assembly's design would hold the wing at normal aircraft height and facilitate movement and use of the wing during tests. The assembly would allow low-speed towing over short distances. The wing dolly assembly would be lifted onto a flatbed truck for any long-distance transportation. The estimated total cost of re-attaching the control surfaces and mounting the wing on the dolly assembly was less than CAN$18 000.

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 APS concerns, including ease of access, security, and proximity to current APS test installations. The facility is also equipped with a glycol recovery system. Furthermore, AéroMag deicing vehicles and personnel could be used to spray de/anti-icing fluids during wing tests. NRC Canada's Climatic Engineering

Facility in Ottawa was selected as a suitable location for wing tests conducted in simulated conditions.

In addition to the JetStar wing, a Shorts 330 wing was provided to APS by the Federal Aviation Administration 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.

This document reports the 1999-2000 developments in the full-scale test site implementation study.

1.1 Objectives

APS was asked to continue the implementation of a full-scale test site. The work statement states the following four objectives:

1.1.1 JetStar Wing Reassembly and Removal of the Deicing Boot

Because of problems obtaining aircraft for full-scale testing in recent years, a plan was developed to implement a full-scale test site, centred on a wing test bed. In April 1999, a Lockheed JetStar was purchased for this purpose. Although not attached to the wing, all of the flight control surfaces were delivered along with the main wing section. Before using the wing for test purposes, the flight control surfaces need to be re-attached to the main wing section and the rubber deicing boot, which currently covers the leading edge, needs to be removed. The contractor shall complete these tasks.

1.1.2 Mounting of the JetStar Wing on the Wing Dolly Assembly

The second phase of the full-scale test site implementation study involves the mounting of the acquired JetStar wing onto a test platform. The design of the platform will hold the wing at an ideal working height and facilitate movement and use of the wing panel during testing. The design will allow for low-speed towing for short distance transportation. A quotation was received from NRC Canada for the design and fabrication of the wing dolly assembly.

1.1.3 Full-Scale Aircraft Tests with JetStar Wing

Conduct fluid failure testing on the JetStar wing in natural precipitation, to document similarities and differences between this wing and those of previously tested full-scale aircraft. Tests will be conducted outside the NRC Canada cold chamber in Ottawa on two occasions.

1.1.4 Cold-Soak Capability of JetStar Wing

Future cold-soaked wing trials could be conducted at NRC Canada using the JetStar wing. The contractor shall explore the possibility of filling the JetStar fuel tanks with chilled fluid to obtain this capability.

This page intentionally left blank.

2. WING TEST BED PREPARATION

2.1 Wing Reassembly

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 has also been included in Figure 2.1.

Although the control surfaces were not attached to the wing, they were delivered along with the main wing section, having been removed and placed in wooden crates for proper storage. The external fuel tank had previously been removed, and was not included in the negotiated price for the wing purchase.

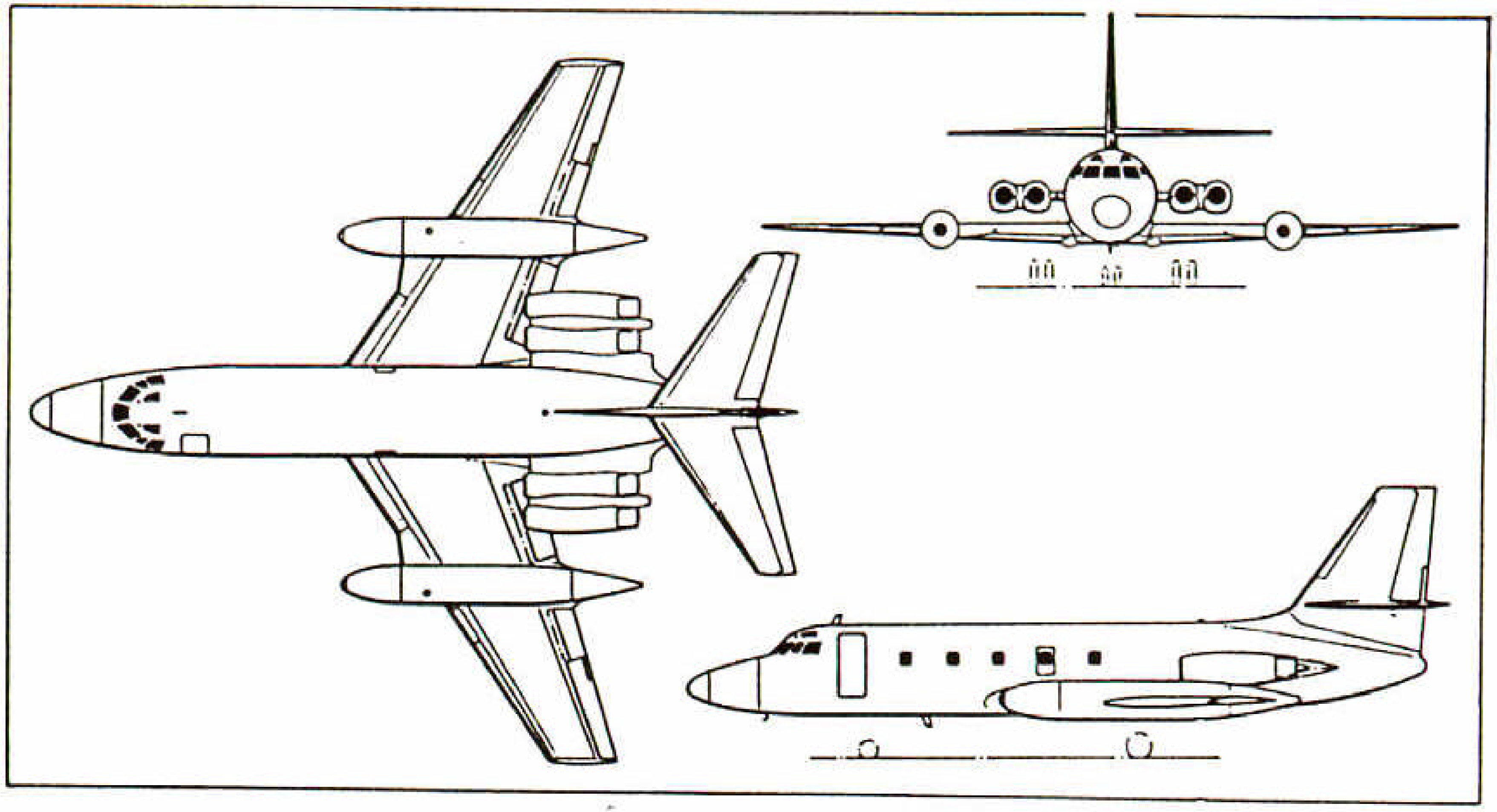
The Lockheed JetStar wing was delivered in April 1999 to NRC Canada's Climatic Engineering Facility in Ottawa. The truck and trailer used to transport the wing from Kansas to Ottawa are shown in Photo 2.2. The main wing section, without the various control surfaces, is shown in Photo 2.3 upon its arrival in Ottawa. As promised, all aircraft control surfaces were packaged in wooden crates and delivered with the main wing section (see Photo 2.4). The wing was removed from the transportation vehicle using a forklift operated by NRC Canada personnel (see Photo 2.5), and was placed on blocks outside the NRC Canada facility. The overall condition of the wing and control surfaces were deemed to be highly satisfactory upon initial inspection by APS personnel.

During the winter 1999-2000 test season, 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 deicing boot, and polishing of the leading edge. The work was contracted to an aircraft mechanic in Ottawa.

Testing of the InfraTek infrared deicing system with the JetStar wing was scheduled to begin in February 2000 at NRC Canada and, as a result, Radiant Aviation Services 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 the NRC Canada facility with the support of NRC Canada personnel.

Figure 2.1

Three-View Schematic of Lockheed JetStar



Source: Jane's Yearbook 1967/68

Prior to the 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 neutral position. Since it was a fundamental requirement that all flight controls be moveable to allow testing of the wing in various configurations and inspection of the various quiet areas during testing, inquiries were made to Dodson International regarding the availability of these parts. Following lengthy discussions with the salvage company, the required rods and brackets were delivered to NRC Canada at no extra cost. Photo 2.6 shows the inboard trailing edge flap in the fully deployed position. 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.

The actuators for the leading edge slats, which regulate the various flap positions, were not included in the wing purchase agreement. Without the actuators, the unsecured hinged leading edge slats would hang 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 bracket could then be unsecured for inspection of the leading edge quiet areas (see Photo 2.8).

The aileron, which is 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.

Two small panels on the main wing section were missing when the aircraft was delivered to APS in April 1999 (see Photo 2.3). In addition, the external fuel tank (see aircraft three-view drawing in Figure 2.1) was removed by the salvage company prior to delivery of the wing, requiring the fabrication of a fairing to fill the large hole in the leading edge where the tank was located and to restore the original wing profile. The fairing and missing panels were constructed of galvanized metal and painted.

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

2.2 Wing Mounting Considerations

The second phase of the full-scale test site implementation study considered mounting the acquired wing onto a platform. The ideal design of the platform would: hold the wing at an ideal working height; facilitate movement (rotation); permit actuation of the wing panel during testing; and allow for low-speed towing for short distance transportation. Several companies, such as Lazer Inox, Max-Atlas, Chagnon Ltée, and NRC Canada were approached in 1999 to tender quotations for the design and fabrication of a wing dolly system.

The companies proposed similar dolly designs. In general, the dolly would have consisted of two separate components; one to support the wing at the wing root, and the second to support the wing at the wing tip. The dolly assembly would fasten to existing attachment points at the wing root, while requiring minor modifications to the wing tip in order to facilitate the attachment of the dolly assembly at that end. The portion of the assembly at the wing root would consist of two non-swivelling wheels. The portion of the assembly at the wing tip would consist of one retractable swivelling wheel, two retractable feet that could be extended for stability during testing, and a towing eye. The dolly assembly would be designed so that the working height of the top surface of the wing would be approximately five feet above the ground.

The quotations received in 1999 for the design and fabrication of the wing dolly assembly varied in price from CAN$13 600 to $20 000.

During the 1999-2000 test season, a new mounting system for the JetStar wing was proposed. It 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 design of the trailer was examined in detail and was found to address every one of the following test bed mounting system requirements:

- The height of the trailer would allow the wing to be positioned at an ideal working height approximately 1.5 m (5 ft.) above the ground;
- The swivelling wheel at the end of the trailer would facilitate movement and allow the wing to be rotated during a test;
- The design of the trailer would not impede actuation of the various wing surfaces during testing; and
- And the trailer was sufficiently stable to allow for low-speed towing for short distance transportation.

More importantly, the purchase of the trailer represented a savings of more than CAN$10 000 over the cheapest quotation received in 1999 for the mounting of the wing. The boat trailer was purchased in January 2000 and the wing was mounted upon it shortly thereafter. The wing was levelled using various shims to reproduce the 2° dihedral and 1° angle of incidence of the JetStar wing when attached to the fuselage. Photo 2.10 shows the JetStar wing mounted on the boat trailer at the NRC Canada facility.

2.3 Test Site Selection

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 at Dorval Airport, operated by AéroMag 2000, was selected in 1999 because it addressed every concern: the deicing facility is easily accessible, secure, and located within one kilometre of the APS test site at Dorval Airport. It is also equipped with a glycol recovery system. Furthermore, AéroMag deicing vehicles and personnel could be used to spray de/anti-icing fluids during wing tests. Outdoor tests using artificial precipitation sprayers could also be performed at this facility. In return for the use of the facility, APS would make the wing section available to AéroMag personnel for training purposes.

Alternative locations for outdoor testing include the exterior premises of NRC Canada's Climatic Engineering Facility in Ottawa and the exterior premises of the ADGA hangar at Gatineau Airport.

NRC Canada's Climatic Engineering Facility would be an ideal location for any indoor tests in simulated precipitation. An alternative indoor site could be the Institut de recherche d'Hydro-Québec (IREQ) climatic chamber in Varennes.

2.4 Wing Transportation

Since the design of the wing mounting system does not conform to the highway code, transportation companies were contacted to determine the costs of transporting the wing dolly assembly from the NRC Canada facility in Ottawa to the AéroMag deicing facility at Dorval Airport in Montreal by means of a flatbed truck.

Several transport companies were contacted for quotations. The chosen company, Goldie Mohr Limited of Barhaven, Ontario, operates flatbed trucks with sliding ramps (see Photo 2.11), which are ideal for loading and unloading equipment of this nature. The average transportation cost for a one-way delivery between Montreal and Ottawa was CAN$700.

This page intentionally left blank.

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

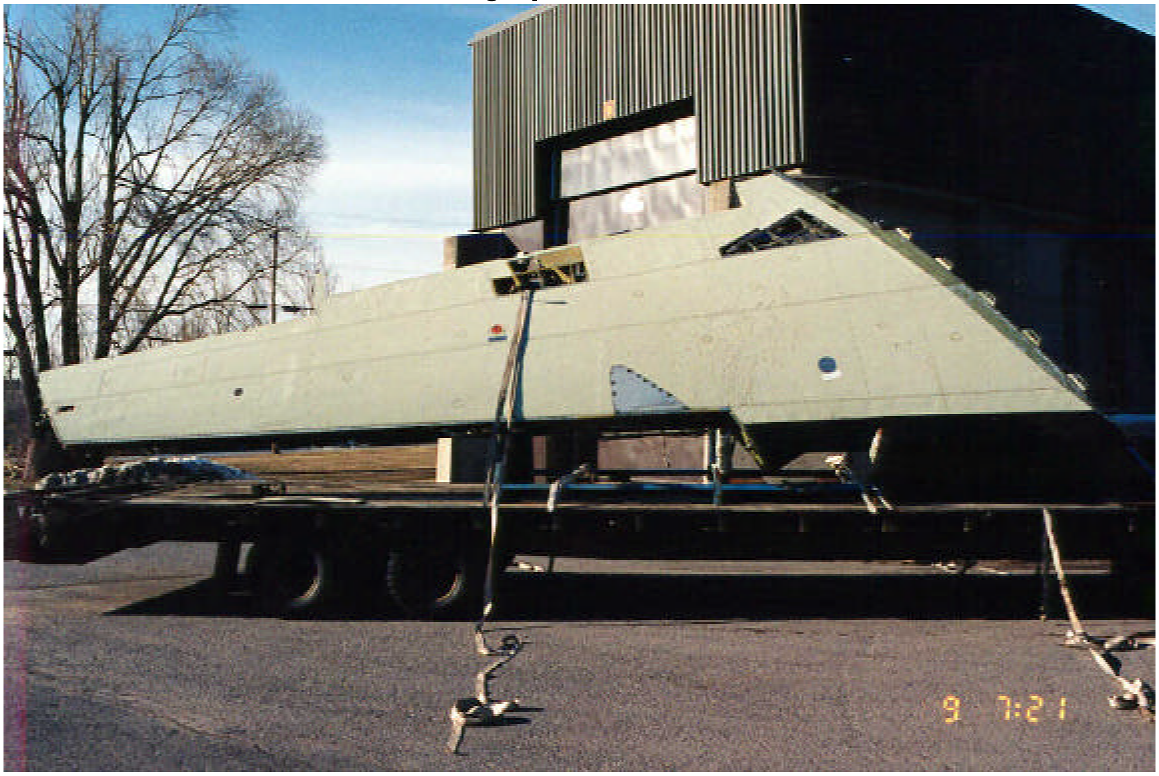


Photo 2.4
JetStar Wing Control Surfaces

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 Flap

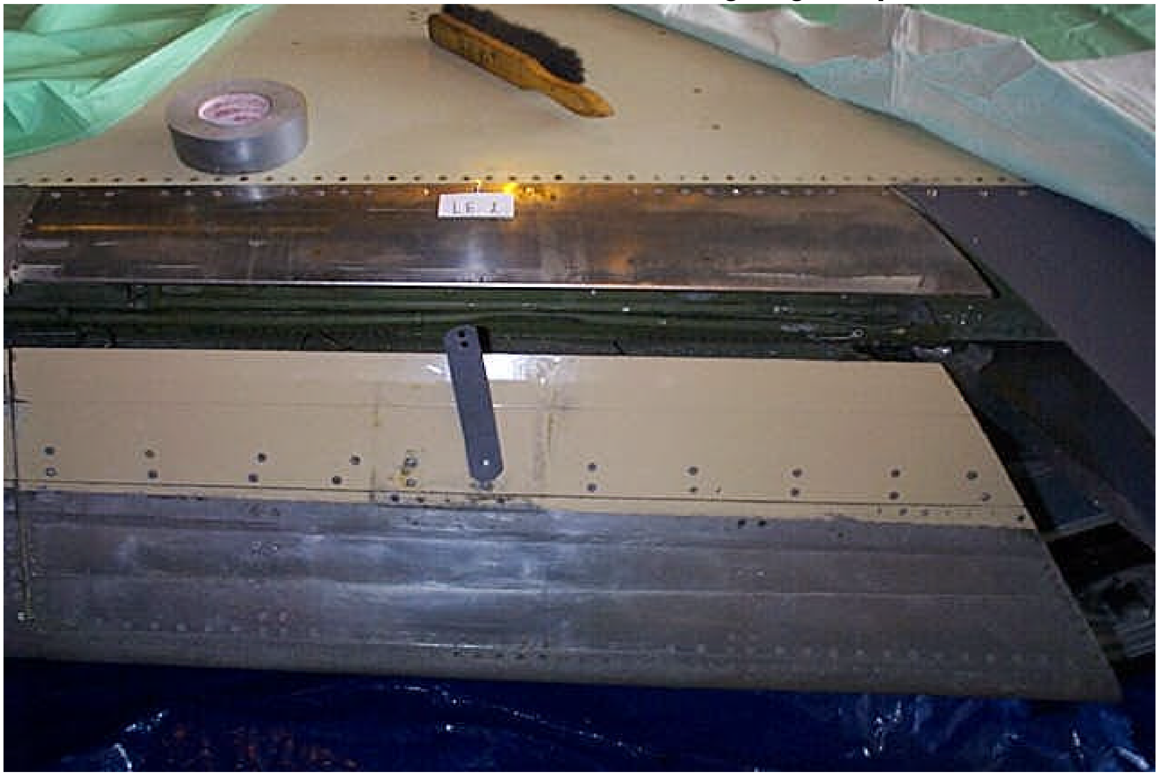


Photo 2.8
Leading Edge Quiet Area

Photo 2.9
Polished Leading Edge of JetStar Wing

Photo 2.10
JetStar Wing on Boat Trailer

Photo 2.11

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

Photo 2.12

Wing and Trailer on Flatbed Truck at NRC Canada

3. 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 1° at the wing root, -1° at the wing tip;
- Dihedral 2°;
- 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 flaps, hinged leading edge slats, no spoilers.

Additional pertinent information on the design characteristics of the Lockheed JetStar has been obtained from a Lockheed JetStar model specification manual and from Jane's 1967-68 Yearbook (see Appendix A).

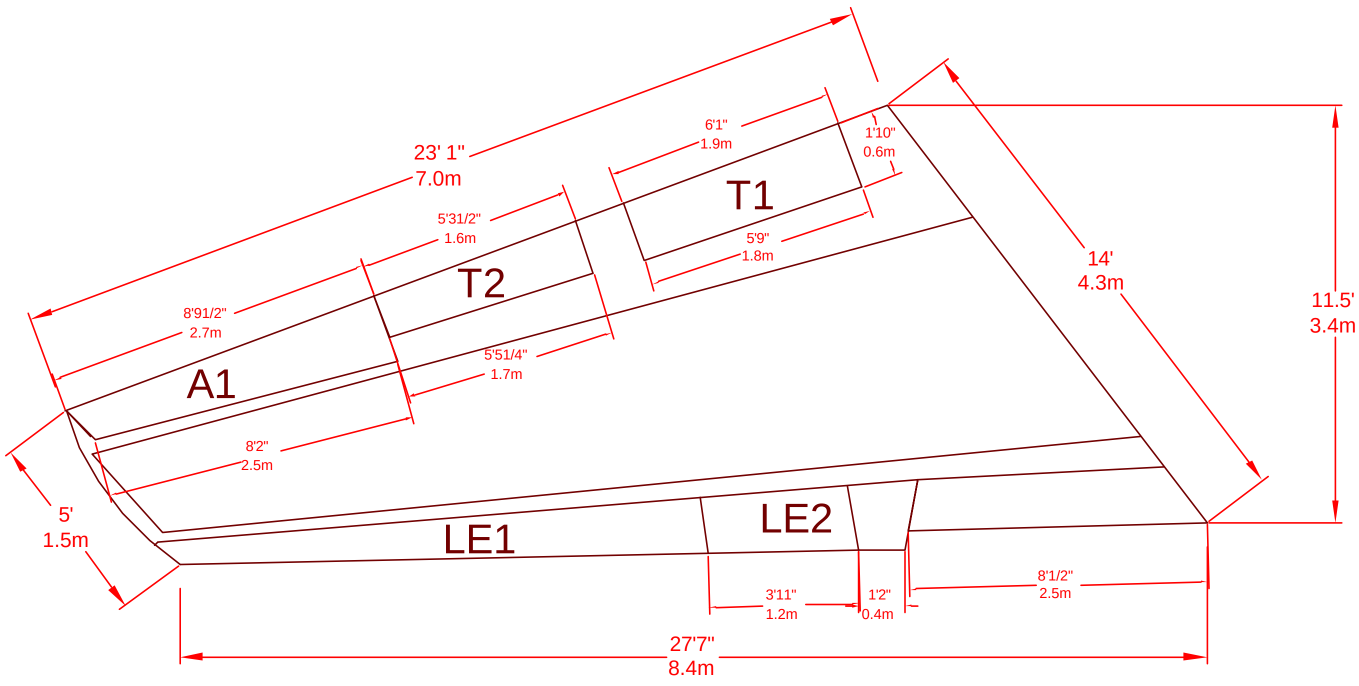
During the 1999-2000 test season, APS personnel measured the precise dimensions of the JetStar wing. Figure 3.1 shows a diagram of the Lockheed JetStar wing including dimensions.

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).

The wing test bed consists 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 is restricted to the two integral wing tanks, main tanks no.3 and no.4 (see Figure 3.2). The capacity of main tanks no.3 and no.4 are 1 476 and 1 420 L, respectively.

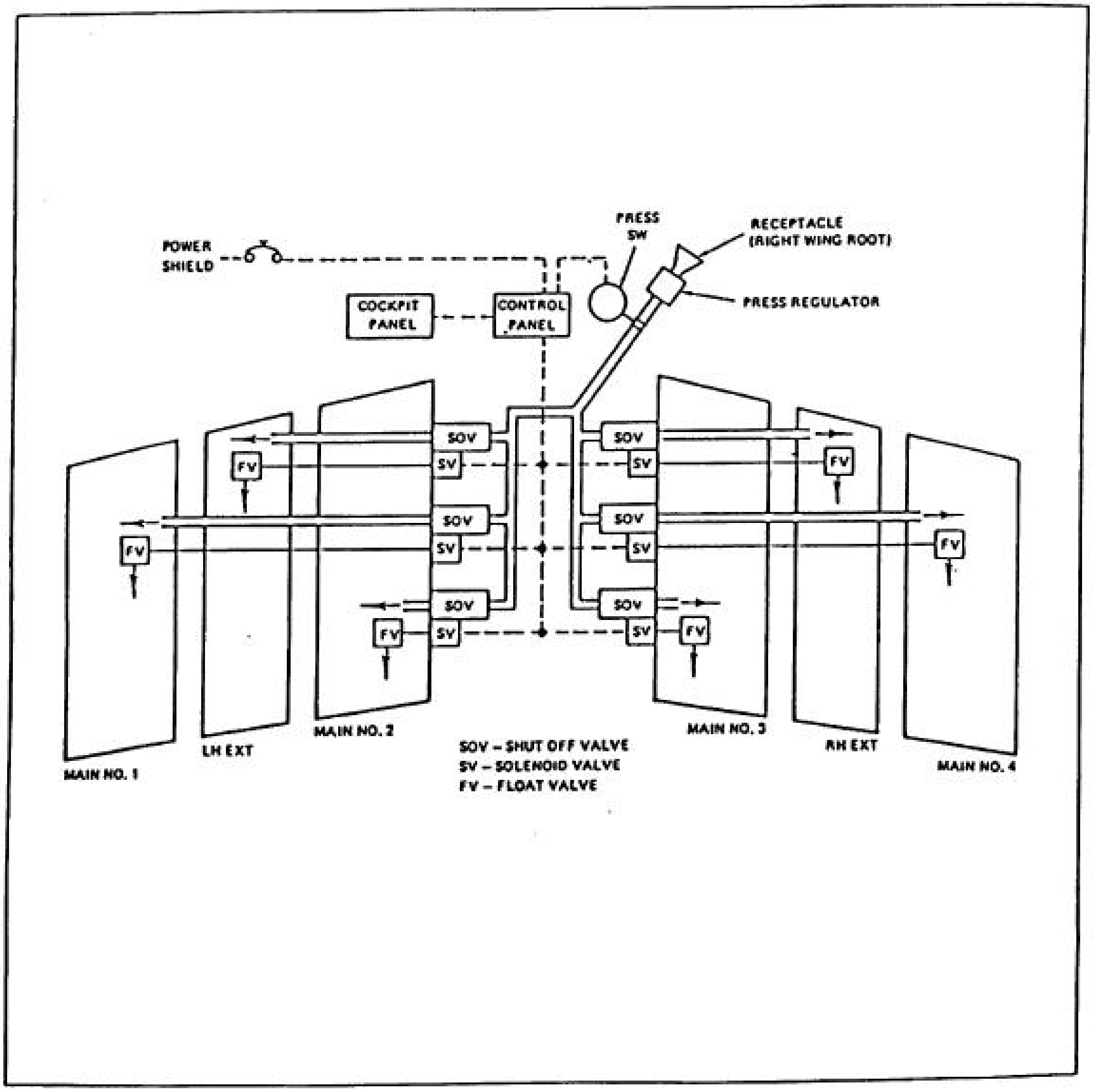
Figure 3.1
JetStar Wing Dimensions



cm1589/reports/wing/Wing Dimensions.DWG

Figure 3.2

Fuel System of the Lockheed JetStar



Source: Lockheed JetStar Model Specification Manual

To obtain cold-soaking capabilities for future tests, the fuel tanks of the JetStar wing would have to be filled with chilled liquid. If glycol is chosen, a total of 3 185 kg would be required to fill the tanks to full capacity (1 623 kg in main tank no.3 and 1 562 kg in main tank no.4).

3.3 Wing Quiet Areas

Wing quiet areas include aerodynamically quiet cavities. These control surface-related cavities often 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

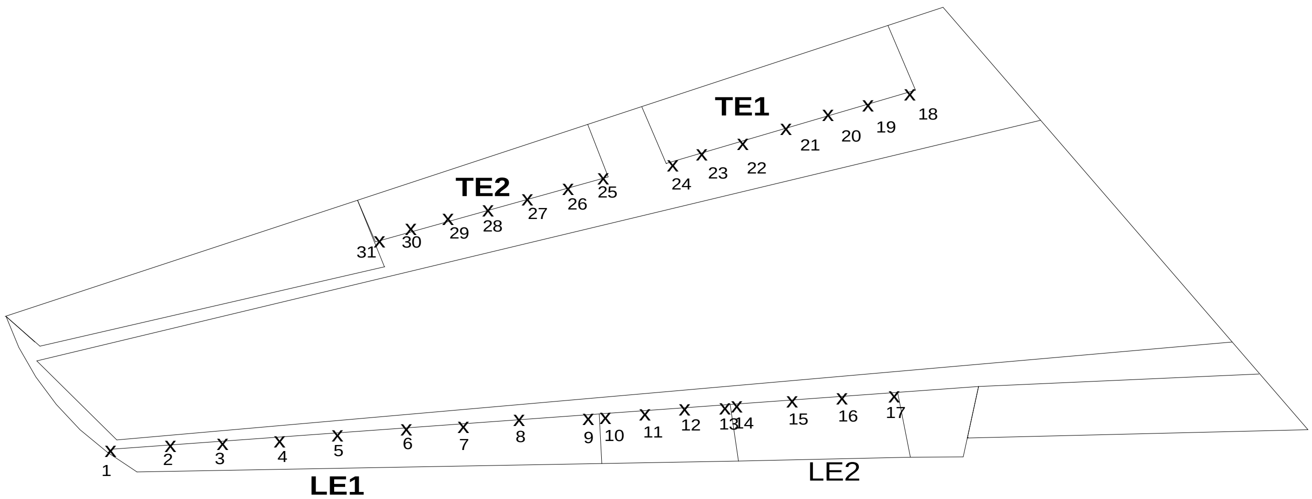
Gaps refer to the tolerance spaces between the main wing structure and the movable flight control surfaces. The gaps also correspond to the most likely path that water/fluid would take when entering a quiet cavity. Measurements for the JetStar wing were taken at 28 cm (11 in.) intervals at the upper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

3.5 JetStar Wing Tests in Simulated Conditions

The NRC Canada Climatic Engineering Facility (CEF) in Ottawa was selected as a suitable location for the conduct of 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 provide 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 the NRC Canada CEF cold chamber in Ottawa.

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

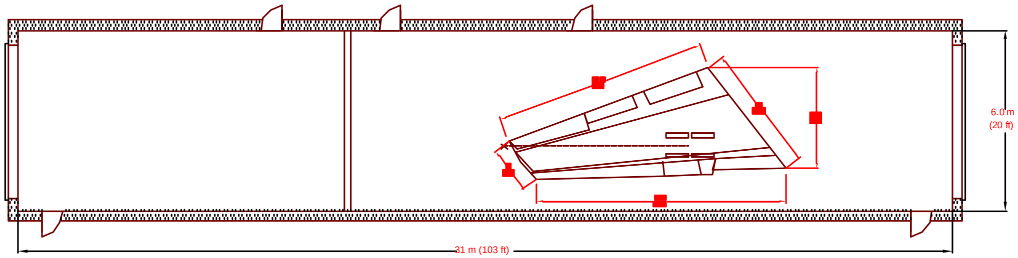
LE2	
Loc	Gap (mm)
14	0.72
15	< 0.38
16	1.19
17	0.61

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

Figure 3.4

JetStar Wing Inside NRC Canada Chamber



cm1589/reports/wing/Wing inside Chamber (Version 2).DWG

Photo 3.1
Outdoor View of NRC 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

During the 1999-2000 test season, full-scale testing with the JetStar wing was conducted in natural and simulated precipitation conditions at NRC Canada in Ottawa and at Dorval Airport in Montreal. Testing consisted of:

- Fluid application trials (Section 4.1);
- Testing of the Radiant Energy Corporation Deicing System (Section 4.2);
- Hot water deicing trials (Section 4.3);
- Use of ice detection sensors for end-of-runway application (Section 4.4); and
- Forced air trials (Section 4.5).

The purpose of this section is not to document the results of tests conducted during the past year, but rather to display the full-scale test capabilities of the JetStar wing. The results of Hot Water, Ice Detection Sensor, and Forced Air trials with the JetStar wing are reported in detail in three associated reports, TP 13663E, TP 13662E, and TP 13664E.

This page intentionally left blank.

4.1 Fluid Application Trials

Objective: Fluid application trials 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 of NRC Canada in Ottawa and positioned over a tarp for fluid collection purposes (Photo 4.1). The deicing fluid was heated in a hot water tank to 80°C and then applied to the JetStar wing using a mobile fluid sprayer developed by APS on behalf of Transport Canada (Photo 4.2).

Photo 4.1

JetStar Wing Test Set-up for Fluid Application Trials

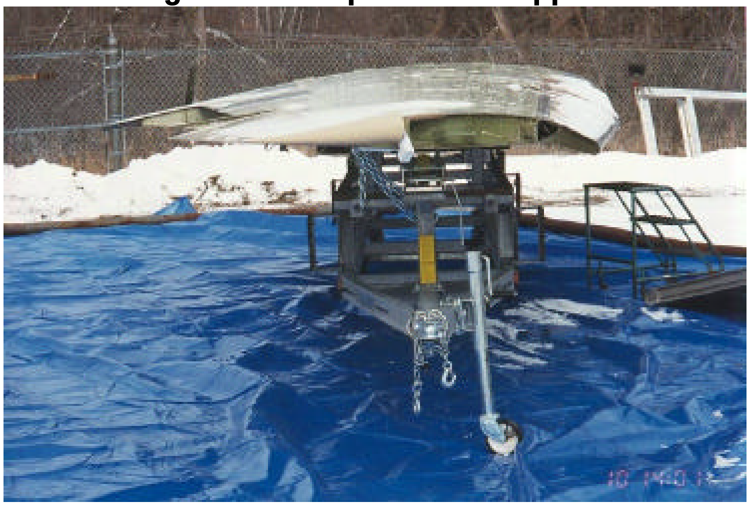


Photo 4.2

Type I Fluid Application using Mobile Sprayer

This page intentionally left blank.

4.2 Testing of the Radiant Energy Corporation Deicing System

The wing was also used in proprietary tests conducted and paid for by Radiant Energy Corporation of Orchard Park, New York. These tests were conducted during the winter 2000 test season at the NRC Canada chamber in Ottawa (Photo 4.3).

Photo 4.3
Deicing JetStar Wing Using Conventional Deicing System From Scissor Lift

This page intentionally left blank.

4.3 Hot Water Deicing

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

Procedures: The JetStar wing was set up at the central deicing facility at Dorval Airport (Photo 4.4). The wing was exposed to simulated 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 (Photo 4.5).

The results, conclusions and recommendations derived from these trials are described in Transport Canada Report TP 13663E.

Photo 4.4
Test Set-up for Hot Water Trials

Photo 4.5
Snow Failure on the JetStar Trailing Edge

This page intentionally left blank.

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

Objective: Trials 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 (Photo 4.6). Snow was distributed on various sections of the JetStar wing (Photo 4.7) 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.

The results, conclusions and recommendations that were derived from these tests are provided in Transport Canada Report TP 13662E.

Photo 4.6
Wing Set-up at the Central Deicing Facility at Dorval Airport

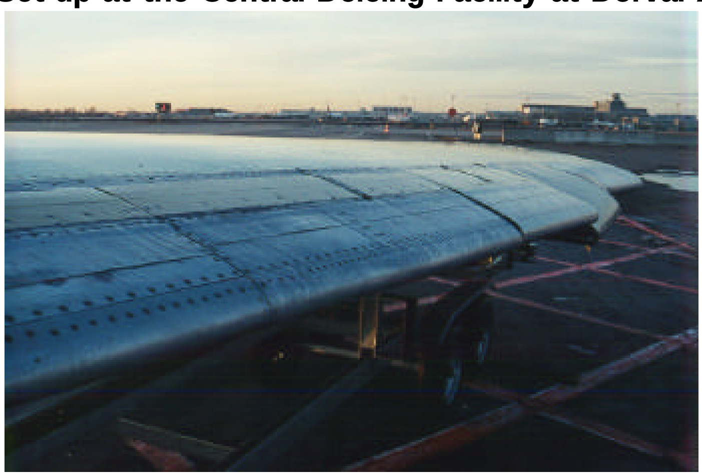
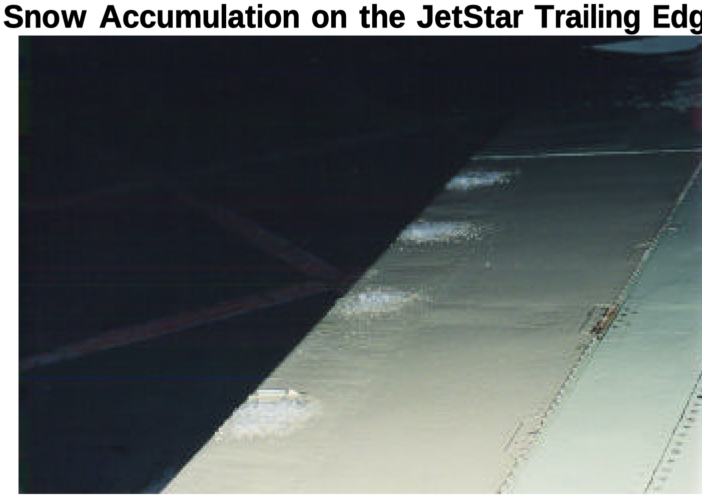


Photo 4.7
Snow Accumulation on the JetStar Trailing Edge



This page intentionally left blank.

4.5 Forced Air Deicing Trials

Objective: Laboratory trials 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 the 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 Canada cold chamber in Ottawa (Photo 4.8). 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 (Photo 4.9). The ability of the forced air unit to clean the wing with air and fluid was examined. The examination included 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 upon the JetStar wing surface during a forced air deicing operation were studied.

The results, conclusions and recommendations that were obtained from these tests are described in Transport Canada Report TP 13664E.

Photo 4.8
Forced Air Deicing Set-up at NRC Canada

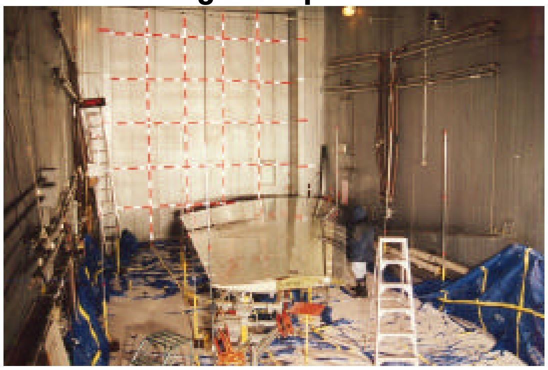
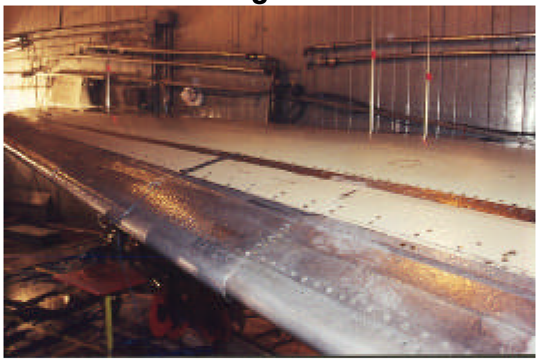


Photo 4.9
Freezing Rain on JetStar Wing Prior to Forced Air Deicing



This page intentionally left blank.

5. DISCUSSION AND RECOMMENDATIONS

This section provides recommendations relating to the conduct of fluid failure pattern testing with the JetStar Wing, and contains suggestions for improvements needed to restore the wing.

5.1 Fluid Failure Patterns on JetStar Wing

Testing with the JetStar wing to measure fluid failure patterns was scheduled to occur during the past test season to document similarities and differences between this wing and those of previously tested full-scale aircraft in natural precipitation. Because of 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 upcoming test season.

5.2 Repairs Needed to Obtain Cold-Soaking Capabilities

Substantial testing was conducted with the Lockheed JetStar wing during the 1999-2000 test season.

During hot water deicing trials, it was found that the measured times for the water to refreeze were shorter than those measured in previous years during full-scale aircraft trials. It is believed that the lack of wing thermal mass, due to the empty fuel tanks, may have contributed to the shorter times. It is 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-soaking capabilities.

5.3 Evaluation of Trailer

The weight capacity of the boat trailer purchased for wing mounting purposes is 1 588 kg (3 500 lb.). The JetStar wing has an estimated weight of 1 134 kg (2 500 lb.) when empty. If the cold-soaking capability is obtained in the future, the combined weight of the wing and the fluid added to the wing tanks will certainly exceed the maximum capacity of the trailer. It is recommended that:

- The structure of the trailer be examined to potentially increase the overall weight capacity. Furthermore, a search for a boat trailer with additional weight capacity should be conducted.

5.4 Mobility of Wing and Trailer

The moveability and stability of the wing test bed was determined to be inadequate during full-scale trials, because of the small swivelling wheel located at the head of the trailer near the towing eye. It is recommended that:

- The small swivelling wheel be replaced by a larger inflatable wheel; consideration should also be given to modifying the design to include two retractable feet that could be extended for stability during testing.

The JetStar wing was levelled 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 is recommended that:

- A more permanent and stable method of levelling the JetStar wing be examined.

5.5 Wing Surface Repairs

Two small panels on the main wing section were missing when the aircraft was delivered to APS. In addition, the external fuel tank was removed by the salvage company prior to delivery of the wing, so a fairing was required to fill the large hole in the leading edge where the tank had been and to restore the original wing profile. The fairing and missing panels were constructed of galvanized metal and painted. To prevent rust formation and to ensure consistency with the other wing sections, it is 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 is recommended that:

- A more permanent method of securing the various control surfaces be examined.

5.6 Repair Cost Estimates

A quotation for the repairs to the JetStar wing was obtained from GRL Campbell Consulting. The total cost for all of the work and repairs outlined in this section were estimated at CAN$7 500, including parts.

APPENDIX A

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 7¼ 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.

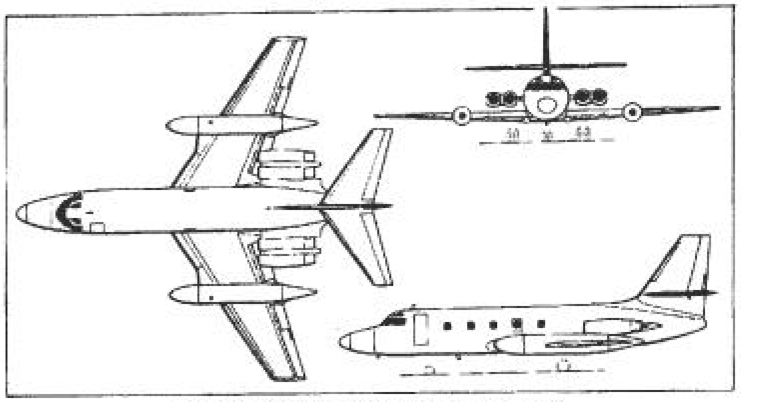
Tail Unit: Cantilever aluminium alloy structure with tailplane mounted part-way up fin. Fin is pivoted to vary tailplane incidence for trimming. Elevators mechanically operated with hydraulic boost. Rudder mechanically operated with servo assist. Rubber-boot de-icers on leading-edges.

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 9¼ 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 (18,560 kg)
B	41,900 lb (19,005 kg)
Max ramp weight:	
A	41,600 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):

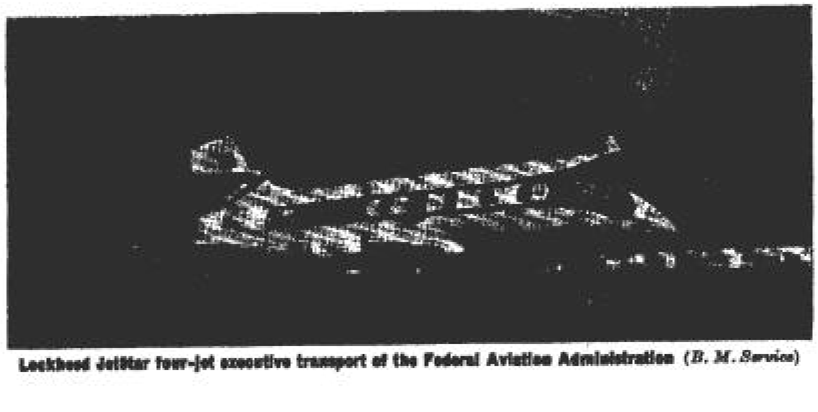
Max level speed below 22,350 ft (6,810 m) 403 mph (648 kmh) IAS; above 22,350 ft (6,810 m) Mach 0·82

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 300 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)*