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C-105 P/AERO DATA/79

COMPARISON OF C-105 WITH REQUIREMENTS OF MIL-F-8785 (A.S.G.).



D. J. Foster

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A. V. ROE CANADA LIMITED

MALTON · ONTARIO

**TECHNICAL DEPARTMENT (Aircraft)**

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OF CF-105 WITH THOSE REQUIRED BY

UNITED STATES SPECIFICATION MIL-F-8785 (ASG).

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FORM 1316A

# A PRELIMINARY STUDY OF THE FLYING QUALITIES OF THE AVRO CF-105 WITH REGARD TO THE REQUIREMENTS OF THE UNITED STATES SPECIFICATION MIL-F-8785 (ASG), SECTION (U) "FLYING QUALITIES OF PILOTED AIRPLANES"

## INTRODUCTION

This report, which is to be considered essentially as a preliminary survey, indicates (on the basis of calculations similar to those required by 8785) which parts of the specification are likely to be met, which are not met, and those on which further work is required. Moreover, is is only in the last few weeks, with completion of low speed wind tunnel tests at the N.A.E. (Ottawa) and of high Mach Number tests at the Unitary tunnel N.A.C.A. (Langley Field), that finalized aerodynamic data has been obtained. Many calculations previously performed using estimates based on theory or extrapolation of the Cornell Wind Tunnel data will have to be repeated using the finalized data, and this will be a good opportunity to investigate those cases specifically demanded by the specification MIL-F-8785 (ASG) section (U).

Note that in the analysis of the feel system requirements in emergency mode, it was assumed that forces at the control valves are small and do not interfere with the feel characteristics. Development work is being carried out on these valves to ensure that their control forces are as low as possible.

Section 1.3

Classification

Class III (Fighter, Interceptor, General purpose attack).

1.3.1.

Designation L (Land Based).

3. Requirements

3.1 General

3.1.1. Airplane Loadings

Weight for specified C.G. corresponds to normal service loading
Normal service loadings govern C.G. for specified weight
Will be met for final configurations.

3.1.2. Altitudes

Requirement shall apply at all altitudes at which aircraft might be operated, specifically.

(1) Sea Level
(2) 80% Service ceiling
(3) 50% of (2) or 40,000' whichever is lower

Spec. met, as investigations have been made at 10,000 ft. intervals from S.L. to 60,000.

Only (1) considered for configurations L, $P_A$, WO and TO.

3.1.3. Operational Flight Envelopes

Operational flight envelopes shall be provided for all altitudes considered, showing cutoff points representing the highest Mach Number at which the aircraft is to be considered operational.
Spec. met (P/Control/78).

3.1.3.1.

Aircraft intended to fly supersonically only need not include transonic range in flight envelopes. But transonic regime has been considered for CF-105 anyway.

3.1.4. Maximum Permissable Speed Envelope

A $V_D$ (or $M_D$) vs altitude envelope shall be provided showing, at each altitude, the maximum speed from which a recovery can be made resulting in level flight at 2,000 ft. for dives entered at $V_H$. No Work Required (Aircraft can reach $V_D$ in level flight)

3.1.4.1.

Any dangerous flight condition associated with dive or pull out shall be gradual, so that pilot is warned - Work Required

3.1.5. External Stores

Agreement between procuring authority and manufacturer required on change of performance with expendable external stores. Considerations of malfunction of release mechanismn required. With full tank, A/C limited between +4.5g and -1.5g and M max = 0.95 at 47,000 lb. A.U.W.

3.1.6. Effects Of Armament Provisions

Operation of bay doors and movable protuberances shall not cause objectionable buffet or trim changes. To be evaluated from future W/T tests.

3.1.7. Release of Stores

Release of stores should not result in dangerous or objectionable flight conditions. Spec. met
Wind Tunnel tests at N.A.E.

3.1.8. Deceleration Devices

Class III aeroplanes shall be capable of deceleration, dive speed limitation etc. Spec. met
See Cornell dive brake W/T tests - P/Control/32

3.1.9. Configuration Code

3.2 Mechanical Characteristics Of Control System

3.2.1. All controls shall center at any normal trim setting. Spec. met, since system is fully automatic

Breakout forces shall not exceed the values given in table 1. With electric stick steering breakout forces will be artifically fixed at values to meet the specification.

3.2.1.1.

Measurement of breakout forces on the ground will ordinarily suffice in lieu of actual flight measurements. The forces quoted in 3.2.1.2. are design figures, final measurements have yet to be made.

3.2.1.2.

For emergency manual operation upon failure of power operated system, the allowable breakout forces may be doubled. Spec. met.

| Control | Recommended | C-105 |
|---|---|---|
| Elevator | 8 | 4.5 |
| Aileron | 4 | 3 |
| Rudder | 14 | 10.5 |

3.2.2. Adjustable Controls

10% tolerance allowed on force referred to mean adjustment Will be met.

3.2.3.

Rate Of Control Displacement

Performance shall not be limited by rates of control movement. Spec. met

3.2.4. Cockpit Control Free Play

Free play shall not be excessive Spec. met.

3.2.5. Artificial Stability Devices

Normal operation or failure of such a device shall not produce dangerous situation. Will be met, when emergency system is finalized.

3.3 Longitudinal Stability And Control

3.3.1. Elevator fixed static stability

The elevator fixed neutral points shall be aft of the C.G. position in the aft critical loading.
Met at 47,000 lb. C.G. = .31

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3.3.1.1.

At aft critical loading, elevator fixed static longitudinal stability at constant speed shall be positive (i.e. $C_{M_\alpha}$ shall be -ve).

This condition is met (P/Aero Data/59, p.1.7)

3.3.2. Elevator Free Static Stability

The elevator free neutral point shall be aft of the C.G. in aft critical loading. Considered satisfied if para. 3.3.2.1 is met.

3.3.2.1.

In the aft critical loading, at trim speeds, the variation of elevator control force with speed shall be a smooth curve, with a gradient which is stable through trim and remains stable throughout the specified speed range. Condition relaxed slightly for PA and P (climb) conditions.
Met Ref. P/Control/78, P/Control/86, except for transonic range, in emergency mode.

3.3.3. Exception In Transonic Flight

Relaxation of 3.3.1. and 3.3.2. in transonic flight. Not required for electric stick steering mode. For emergency mode, see para. 3.7.4.

3.3.4. Stability In Accelerated Flight

The slope of the curve of elevator deflection vs normal acceleration at constant speed shall be stable.
Spec. met P/Control/78 P.S. 5.1.-4.

3.3.5. Short Period Oscillations

The dynamic oscillations which occur at const. speed shall damp to 1/2 amp. in 1 cycle, and the magnitude of any residual oscillation shall not exceed ± .02g.

This requirement is met for the aircraft with no artifical damping below 47,000' altitude (P/Stab/109(level flight), but fully met with damping system operative.

The residual damping requirement will require verification by Flight Test and further analytical work.

3.3.5.1.

When the elevator is deflected and released, motion resulting shall be deadbeat. Spec. Met.

3.3.5.2.

No tendency for sustained and uncontrollable oscillations resulting from pilot's efforts to maintain steady flight. Spec. met.

3.3.5.3.

Required 3.3.5., 3.3.5.1., and 3.3.5.2., apply at all permissable airspeeds, in straight flight and turns.
Requires extensive analog studies and flight test to ensure completely.

3.3.6 Long Period Oscillations

No objectionable flight characteristics due to poor phugoid damping. In addition, if period is less than 15 seconds, the oscillation shall be at least neutrally stable.
Spec. met - P/Stab/103

3.3.7. Control Effectiveness In Unaccelerated Flight

The attainment of any speed above the stalling speed shall not be limited by the effectiveness of longitudinal controls.
Complied with P/Control/78 - pp. 3.1 to 3.7

3.3.8. Control Effectiveness In Accelerated Flight

Requires aircraft to perform to limit of flight envelope
Requires Flight Test

3.3.9. Control Forces In Steady Accelerated Flight

In steady turning flight and pull-outs, increases in pull-out force shall be required to produce increases in +ve normal acceleration. The variation of force with normal acceleration shall be approx. linear. The average force gradients shall be within the limits.

Max: $\frac{56}{n_L - 1} = \frac{56}{6.33} = 8.83$ lb/g

Min: $\frac{21}{n_L - 1} = \frac{21}{6.33} = 3.33$ lb/g

Spec. met

3.3.9.1.

The local value of the force gradient shall never be less than 3 lb/g — Spec. met.

3.3.9.2.

Relaxation of 3.3.9 for P, CO and D — Spec. met.

3.3.9.3.

Relaxation of 3.3.9 — Spec. met.

3.3.9.4.

Relaxation of 3.3.9 — Spec. met.

3.3.9.5.

Relaxation of 3.3.9 for -ve g — Spec. met.

3.3.10. Control Forces In Sudden Pull-Up

Ratio Max. elevator control force in sudden control movement. to the
Max. change in normal acceleration.
shall not be less than
Max. elevator control force for steady movement
Max. change in normal acceleration.

To be verified.

3.3.11. Control Effectiveness In Take-Off

Elevator Effectiveness shall not restrict the take-off performance of the aeroplane. It shall be possible, at a speed no greater than $V_{S_{TO}}$, to obtain take-off altitude at a variety of loadings with the C.G. in its most forward position.
($V_{S_{TO}}$ defined as speed for $\alpha$ = 15°, with ground effects, as this is limiting incidence due to fuselage fouling ground).

Requirement met (Ref. P/Control/36).

3.3.12. Control In Catapult Take-Off — Not Applicable

3.3.13. Control Forces In Take-Off

With trim optional but constant, elevator control forces required during take-off and during the ensuing acceleration to 1.3 $V_{S_{TO}}$ shall be within the limits 30 lb pull to 10 lb push.
Requirement met (P/Control/86)

3.3.14. Control Effectiveness In Landing

At forward critical loading, with aircraft trimmed for 1.2 $V_{S_L}$ in config. P.A., longitudinal control shall be sufficiently effective such that $V_{S_L}$ can be obtained in close proximity to the ground.
Spec. met - P/Control/86

3.3.15. Control Force On Landing

The forces involved in meeting 3.3.14 shall not exceed 35 lb. pull.
Spec. met - P/Control/86.

3.3.16. Control Forces In Dives

With aircraft trimmed for level flight at $V_H$, the elevator control force required in dives to any attainable speed within the operational flight envelope shall not exceed 50 lb push or pull. In similar dives, with trim optional, it shall be possible to maintain the forces within the limits of 10 lb. push or pull.
Spec. met

3.3.16.1.
With the A/C trimmed at $V_H$, but trim optional in dive, it shall be possible to maintain elevator control forces within the limits of 50 lb push and 35 lb. pull. Recovery forces $\geq$ 120 lb.
Spec. met.

3.3.17. Auxiliary Dive Recovery Device

Operation of an auxiliary device for dive recovery at any speed shall always produce a positive increment of normal acceleration. Spec. met.
The total normal load factor shall never be greater than 0.8 $N_L$, controls free, at aft critical loading.
Spec. met.

3.3.18. Effects Of Drag Devices

Operation of speed brakes shall not produce objectionable buffet or trim change on approach.
Spec. met - P/Control/82

3.3.19 Longitudinal Trim Change

A very comprehensive list of conditions to be investigated for trim change due to Gear, Flaps and Power.
Work Required

3.3.20. Longitudinal Trim Change Caused By Sideslip

The longitudinal force required to hold 50 lb. rudder pedal force shall not exceed the force to hold 1.0 g in accelerated manoeuvres, and in no event exceed 10 lb. pull or 3 lb. push.
Work Required

3.4.1. Damping Of The Lateral Directional Oscillation

$1/C_{\frac{1}{2}}$ shall have at least the value required by curve A of fig. 1. But see 3.4.1.1.

3.4.1.1.

For armed airplanes in the firing configuration $1/C_{\frac{1}{2}}$ shall have at least the value required by curve A of fig. 1 or 1.73 whichever is higher. Damping system will ensure this requirement is met.
Evaluation in progress on Analog Machine
Any residual oscillations shall be less than ± 5 mils. This will require flight test, unless decided that the requirement may be waived for C-105. With emergency system operative this requirement should be met.

3.4.1.2.

If an artificial stabalization device is employed the damping parameter $1/C_{\frac{1}{2}}$ with the device inoperative shall be at least 0.2. With emergency system operative this requirement should be met. Not yet evaluated. In config. P.A this parameter shall have at least the value given by curve B, fig. 1.
Spec. met.

3.4.3. Steady Sideslip Conditions

Definition of speeds etc. at which requirements should be met. Stipulates performance for max. rudder or 250 lb. pedal force. But all Avro calculations have been based on 150 lb. pedal force as max. pilot would care to exert, so this will be taken as max. force for all sideslip calculations. Only one power case considered so far.

3.4.4. Static Directional Stability (Rudder Position)

Left rudder pedal deflection is required in right side slips and right rudder pedal is required in left side slips.

Requirement is not met below 170 Kts.

Requirement is met above 209 Kts up to an altitude of 50,000'.At 60,000', sideslip is limited by aileron available.
Between 170 and 209 kts there is not enough aileron available to hold the side-slip asked in the requirement 3.4.3. But for the side-slips that can be held by the aileron available the requirement is met.

Ref. P/Control/79 sht. 12.6 P/Control/87 sht. 1.19.

Further analysis to be made based on latest wind tunnel information.

3.4.5. Static Directional Stability (Rudder Force)

Right rudder force is required in left sideslip and left rudder force in right sideslip.

Same conditions apply as in 3.4.4. as force is dependent on dynamic pressure and deflection for CF-105.

3.4.6. Dihedral Effect (Aileron Position)

Left aileron deflection shall be required for left sideslips right aileron shall be required for right sideslip. Met with automatic control system; in emergency mode a borderline case exists at M = 1.0 at sea level, where very small opposite aileron is required.

3.4.6.1.

Config. W.O. if necessary, may be excepted from 3.4.6. Exception Not necessary.

3.4.6.2.

The positive effective dihedral shall never be so great that more than 75% of full aileron cockpit deflection is required for the sideslips in 3.4.11.

Not met - full aileron required in power approach configuration and at 60,000'.

3.4.6.3.

Throughout rolls similar to those required in paragraph 3.4.16., but performed with rudder free, the rolling velocity shall always be in the correct direction.
Spec. met (irreversible rudder controls).

3.4.7. Dihedral Effect (Aileron Force)

Left aileron control force shall be required for left sideslip and right aileron control force shall be required for right sideslip. The variation of aileron control force with sideslip angle shall be essentially linear, and the aileron force required shall not exceed 15 lb.

This requirement is not met, because of the need to apply full aileron to hold the rudder rolling moment at 210 knts. Below this speed, sideslip requirement limited by full aileron, which requires 20 lb. force.

3.4.7.1.

Spec. met.

3.4.8. Side Force In Sideslips

The side force characteristics shall be such that increase in right bank angle accompanies an increase in right sideslip.
Spec. met. - P/Control/79, sheets 12.17 to 12.18
- P/Control/87, sheet 1.17.

3.4.9. Adverse Yaw

The angle of sideslip developed during a rudder-pedal fixed abrupt roll out of a trimmed, level, steady 45° banked turn at 1.4 $V_{SCR}$ in config. CR, and at 1.4 $V_{SPA}$ at config. PA, shall not exceed 15° etc. Should be met with automatic control system.

Work Required

3.4.10. Asymmetric Power (Rudder Free)

The motions following sudden failure of ono engine shall not be dangerous, with normal pilot corrective action. Requirement is expressed in terms of aileron angle to hold assymetric power, rudder free. No calculations have been made for this case, although extensive calculations have shown that the rudder is effective in holding the yawing moment produced by asymmetric power. (P/Control/79, 12.3) Work Required.

3.4.11. Directional Control (Symmetric Power)

Rudder control force must not exceed 180 lb. over specified speed range.
Spec. met

3.4.11.1.

Directional control shall be sufficient to permit 10° of steady sideslip in configuration L, with rudder forces less than 180 lb. Met above 146 knts.
P/Control/87, 1.17.

3.4.12. Directional Control, (Asymmetric Power)

It shall be possible to maintain straight flight at a roll angle of not more than 5° at all speeds above 1.2 $V_{STO}$. Rudder Pedal force shall not exceed 180 lb.

Spec. met (P/Control/79, 13.3 & 2.11)

3.4.13. Directional Control During Take-Off And Landing

The rudder control shall allow normal take-off in 90° cross-winds of at least 30% $V_{SL}$ or 40 knts. whichever is less, with not more than 180 lb. pedal force.
P/Control/79 13.6.
Spec. met above 105 kts. with front wheel off ground

3.4.13.1

Not applicable.

3.4.13.2

Work Required.

3.4.14. Directional Control To Counteract Adverse Yaw

In the rolling manoeuvres specified in 3.4.9. with the rudder employed for co-ordination rather than held fixed, zero sideslip shall be obtainable with rudder forces less than 180 lb. Work Required

3.4.15. Directional Control In Dives

Rudder forces shall be less than 50 lb. for zero sideslip in dives Spec. met

3.4.16. Lateral Control

Lateral control shall be adequate for compliance with the rolling performance in table VI, except that rate of roll need not exceed 220 deg/sec.
Spec. not met. (P/Control/39, 5.9 and 5.11)

3.4.16.1

On Class III airplanes the control requirement in configuration P and CO shall apply under all conditions of spanwise weight distribution. In configuration L tip tanks may be empty, or if full, a value of 0.03 may be substituted for .05 as the required average pb/W value.
Not Applicable

3.4.16.2

Not Applicable

3.4.16.3

The peak lateral control force shall not exceed 20 lb.
Spec. met.

3.4.16.4

Not Applicable

3.4.16.5

Aileron forces required in paragraphs 3.4.10, 3.4.11, 3.4.11.1, 3.4.12.
Spec. met, as full aileron required 20 lb. force.

3.4.16.6

Lateral control shall be effective in dives and pull-outs, with aileron forces not exceeding 10 lb. Spec. met.

3.4.16.7

Lateral control shall exist in correct direction at all permissable speeds Spec. met.

3.5 General Control And Trimability Requirements

3.5.1. Control For Spin Recovery

Normal controls shall be adequate to provide consistent prompt recoveries from fully developed erect and inverted spins.
Present indications are that the C-105 will not spin, but spinning tests are scheduled to be carried out.
Work Required.

3.5.2. Control For Taxiing

It shall be possible to perform all normal taxiing operations without undue pilot effort.
Spec. will be met

3.5.3. Control Surface Oscillations

All control surfaces shall be free from any tendancy towards undamped oscillations. Irreversible controls should prevent this, but complete investigations are being carried out to ensure the spec. will be met.

3.5.4. Primary Flight Control Trimability

The trimming device shall be capable of reducing the elevator, rudder and aileron control to zero, at all speeds between the minimum trim speed as specified in table VII and the upper limit of the speed ranges as specified in table II. Spec. met.
In addition, control force to be maintained within 10 lb. pull or push throughout the dives specified in paragraph 3.3.16. Work Required

3.5.5. Irreversibility Of Trim Controls

All trimming devices shall maintain a given setting indefinitely, unless changed by the pilot.
Spec. met.

3.5.6. Trim System Failure

Failure of a power actuated trim system shall not result in an unsafe flight condition.
Specification met, for there will be no trim change as long as aircraft controls are trimmed within certain limits of centralized control positions.

3.5.6. (Continued)

Failure outside these limits will cause a trim change which the pilot can correct manually. Analog studies of these cases will be performed.
A safe landing can be made with trim system inoperative.

3.6. Stall Requirements

3.6.1.

Stall requirements shall apply at all c.g. positions for configurations G, CR, L and PA in unaccelerated flight, and with normal acceleration up to the limits of the flight envelope.

3.6.2. Definition Of Stalling Speed $V_S$

$V_S$ is defined as the minimum speed attachable in flight, normally associated with breakdown in airflow over the wing.
This definition is not suitable for the C-105 as the $C_L$ vs $\alpha$ curve does not show any abrupt change of slope See 3.6.2.2.

3.6.2.1.

For aircraft with insufficient longitudinal control, the aircraft will reach some minimum speed, depending on the C.G. position, which may be taken as the stalling speed. Not applicable

3.6.2.2.

In the event that considerations other than max. lift coefficient or available longitudinal control determine the minimum usable flying speed, the stalling speed shall be defined as the minimum flying speed.
For the C-105, an angle of 16°, which is max. permissable ground angle, was taken as maximum incidence.
This figure has been used in structural design considerations.

3.6.3. Stall Warning Requirements

The approach to the complete stall shall be accompanied by an easily perceptible stall warning which occurs just above the stalling speed. The limiting incidence was decided from buffet considerations on similar aircraft. Flight Test is required to determine stall warning characteristics.

3.6.3.1.

Artificial stall warning. Not under consideration at present.

3.6.3.2.

No stall warning required for aircraft with limiting elevators. Not applicable

3.6.4. Requirements For Acceptable Stalling Characteristics

A mild nose up pitch at stall acceptable. Rolling or downward pitch after stall shall not exceed 30° from level. This required flight test to confirm, but wind tunnel tests show that pitch change at stall is small, while rolling moment due to sideslip is large and may produce wing dropping.

3.6.4.1.

It shall be possible to prevent complete stall by normal control use at the onset of stall warning. As buffet is expected to occur at an incidence considerably below true stall, this requirement should be met. In the event of a complete stall it shall be possible to recover by normal use of controls, without excessive loss of altitude or build up of speed. Work Required

3.7. Requirements For Power And Boost Control System

3.7.1. Normal Control System Operation

The control system shall satisfy applicable mechanical design requirements as well as the requirements of this specification. The system shall be capable of providing rapid and repeated control movement.
Spec. Met.

3.7.2. All airplanes employing power control systems shall be provided with suitable means for control following complete loss of power. Some power is available from wind milling engines.
Work required to determine controllability.

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3.7.3. Transfer To Alternate Control System - Trim Change

The trim change associated with transfer to the alternate control system shall never produce dangerous flight conditions. This shall apply not only in level flight, but in dives to $V_M$ with elevator control force out of trim by as much as ± 5 lb. If dual independent control systems are used, a transfer at cruising altitude shall cause no perceptable trim change.
Spec. met for duplicate power system, work in progress on emergency system.

3.7.3.1.

Upon transfer to the alternate control system in configuration PA at 1.15 VSL, with trim set for zero control forces prior to transfer, it shall be possible to maintain the airplane attitude with control forces not exceeding:- elevator, 20 lb, aileron 10 lb, rudder 50 lb.
Spec. met for duplicate power system, and emergency system.

3.7.3.2.

Requirement for airplanes intended for tactical employment at low altitude. Not Applicable

3.7.4. Longitudinal Control On Alternate System

At max level flight speed at sea level, it shall be possible, with the alternate control system inoperative, to obtain 3g with not more than 120 lb. elevator force.
Requirement met on duplicate power system and emergency system.

3.7.4.1.

Longitudinal control on the alternate system should be adequate to permit recovery from a dive to VD initiated from service ceiling and maximum level flight speed, with the primary control power system rendered inoperative at 20,000 ft. The elevator control force should not exceed 120 lb.
This requirement is not directly applicable as stated, as the max. permissable speed can be attained in level flight. Some similar requirement will have to be investigated with the emergency control system operative.

3.7.4.2.

On the emergency system, it shall be possible to execute a safe landing with not more than 35 lb. elevator force.
Spec. met

3.7.5. Lateral Control On Alternate System

It shall be possible to maintain a peak steady rolling velocity of 15°/sec or 50% of requirements of table VI, with aileron forces not exceeding 30 lb; and in configuration L at 1.1 $V_{SL}$ the mean value of pb/2V shall at least equal .02 with aileron force not exceeding 20 lb.
Spec. met.

3.7.6. Directional Control On Alternate System

On emergency system, it shall be possible to land in a cross wind of 20 knots, with rudder control force not exceeding 180 lb.
Spec. met.

3.7.7. Ability To Trim On Alternate System

On the emergency system it shall be possible to trim the control forces to zero at all level flight speeds above the minimum speeds specified in table VII.
Spec. met.

3.7.8. Feel System Failure

Failure of an artificial feel system shall not result in unsafe flight conditions, and shall not impair the ability to make a satisfactory landing. This requirement may only be waived if it is established that the possibility of feel system failure is exceedingly remote.
The feel system is a simple, rugged spring system and it is very unlikely to fail.