AGARD-AG-300 Vol.11

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AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT
7 RUE ANCELLE 92200 NEUILLY SUR SEINE FRANCE

AGARDograph 300

AGARD Flight Test Techniques Series Volume 11 on

The Testing of Fixed Wing Tanker and Receiver Aircraft to Establish their Air-to-Air Refuelling Capabilities

(Les Essais Pratiqués sur
les Avions Ravitailleurs et Ravitaillés
afin de Déterminer
leurs Capacités de Ravitaillement en Vol)

This AGARDograph has been sponsored by the Flight Mechanics Panel of AGARD.

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leurs Capacités de Ravitaillement en Vol)

by

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North Atlantic Treaty Organization
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— Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;

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Preface

Since its founding in 1952, the Advisory Group for Aerospace Research and Development has published, through the Flight Mechanics Panel, a number of standard texts in the field of flight testing. The original Flight Test Manual was published in the years 1954 to 1956. The Manual was divided into four volumes:

1 Performance
2 Stability and Control
3 Instrumentation Catalog, and
4 Instrumentation Systems.

As a result of development in the field test instrumentation, the Flight Test Instrumentation Group of the Flight Mechanics Panel was established in 1968 to update Volumes 3 and 4 of the Flight Test Manual by the publication of the Flight Test Instrumentation Series, AGARDograph 160. In its published volumes AGARDograph 160 has covered recent developments in flight test instrumentation.

In 1978, the Flight Mechanics Panel decided that further specialist monographs should be published covering aspects of Volumes 1 and 2 of the original Flight Test Manual, including the flight testing of aircraft systems. In March 1981, the Flight Test Techniques Group was established to carry out this task. The monographs of this series (with the exception of AG 237 which was separately numbered) are being published as individually numbered volumes of AGARDograph 300.

At the end of each volume of both AGARDograph 160 and AGARDograph 300 an Annex gives a list of volumes published in the Flight Test Instrumentation Series and in the Flight Test Techniques Series.

The present Volume (Vol.11 of AGARDograph 300) is entitled "The Testing of Fixed Wing Tanker and Receiver Aircraft to Establish their Air-to-Air Refuelling Capabilities".

Many military fixed wing aircraft types are now required to receive fuel from a tanker aircraft. Tanker assets are also being increased. Users require a wide flight envelope for air-to-air refuelling (AAR) to give operational flexibility, and demand high flow rates to minimise transfer times. However, problems have often been encountered both in the receiver role and in the tanker role, involving deficiencies in handling qualities, structural aspects or fuel systems.

This AGARDograph therefore describes the points that need to be considered when planning AAR trials to clear a new tanker or a new receiver aircraft for Service use. The paper assumes some familiarity with current AAR practices and equipments. It covers the two AAR systems in widespread use, namely the probe and drogue, and boom refuelling systems. Many of the points that need to be considered are common to both.

Préface

Depuis sa création et 1952, le Panel de la Mécanique du vol, sous l'égide du Groupe Consultatif pour la Recherche et les Réalisations Aérospatiales a publié, un certain nombre de textes qui font autorité dans le domaine des essais en vol. Le Manuel des Essais en Vol a été publié pour la première fois dans les années 1954—1956. Il comportait quatre volumes à savoir:

1 Performances
2 Stabilité et Contrôle
3 Catalogue des appareils de mesure, et
4 Systèmes de mesure.

Les novations dans le domaine des appareils de mesure pour les essais en vol, ont conduit à recréer, en 1968, le groupe de travail sur les appareils de mesure pour les essais en vol pour permettre la remise à jour des volumes 3 et 4. Les travaux du groupe ont débouché sur l'édition d'une série de publications sur les appareils de mesure pour les essais en vol, l'AGARDographie 160. Les différents volumes de l'AGARDographie 160 publiés jusqu'à ce jour couvrent les derniers développements dans le domaine.

En 1978, le Panel de la Mécanique du vol a signalé l'intérêt de monographies supplémentaires sur certains aspects des volumes 1 et 2 du Manuel initial et notamment les essais en vol des systèmes avioniques. Ainsi, au mois de mars 1981, le groupe de travail sur les techniques des essais en vol a été recréé pour mener à bien cette tâche. Les monographies dans cette série (à l'exception de la AG 237 qui fait partie d'une série distincte) sont publiées sous forme de volumes individuels de l'AGARDographie 300.

A la fin de chacun des volumes de l'AGARDographie 160 et de l'AGARDographie 300 figure une annexe donnant la liste des volumes publiés dans la série "Appareils de mesure pour les essais en vol" et dans le série "Techniques des essais en vol".

Ce volume 11 de l'AGARDographie 300 s'intitule "Les essais pratiqués sur les avions ravitailleurs et ravitaillés afin de déterminer leurs capacités de ravitaillement en vol".

Un grand nombre d'aéronefs militaires à voilure fixe nécessitent maintenant d'être ravitaillés en carburant par des avions-citernes. Le nombre d'avions capables d'effectuer des missions de ravitaillement augmente. Les exploitants demandent un large domaine de vol pour le ravitaillement en vol afin d'assurer la souplesse opérationnelle nécessaire, avec des débits élevés afin de minimiser les temps de transfert. Le ravitailleur et le ravitaillé ont souvent rencontré des problèmes au niveau de la qualité de la maniabilité; des aspects structuraux et des systèmes de carburants.

La présente AGARDographie évoque les points qui doivent être pris en compte lors de la planification des essais de ravitaillement en vol d'un nouvel avion-citerne ou d'un nouvel avion à ravitailler, en vue de son homologation. Le lecteur est supposé être familier avec la pratique courante de ravitaillement en vol et le matériel employés dans ce domaine. Elle couvre les deux principaux systèmes de ravitaillement en vol utilisés couramment, c'est à dire le système sonde-cône et la méthode à perche rigide. Beaucoup des éléments à prendre en considération sont commun aux deux systèmes.

Acknowledgement
to
Working Group 11 Members

In the preparation of the present volume the members of the Flight Test Techniques Group listed below took an active part. AGARD has been most fortunate in finding these competent people willing to contribute their knowledge and time in the preparation of this and other volumes.

La liste des membres du groupe de travail sur les techniques des essais en vol ont participé activement à la rédaction de ce volume figure ci-dessous. L'AGARD peut être fier que ces personnes compétentes aient bien voulu accepter de partager leurs connaissances et aient consacré le temps nécessaire à l'élaboration de ce et autres documents.

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Contents

THE TESTING OF FIXED WING TANKER AND RECEIVER AIRCRAFT TO ESTABLISH THEIR AIR-TO-AIR REFUELLING CAPABILITIES

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1. INTRODUCTION AND PURPOSE

Many military fixed wing aircraft types are now required to receive fuel from a tanker aircraft. Tanker assets are also being increased. Users require a wide flight envelope for air-to-air refuelling (AAR) to give operational flexibility, and demand high flow rates to minimise transfer times. Problems have been encountered when testing a number of aircraft in the receiver role, particularly some large aircraft whose handling qualities require a high degree of pilot compensation to achieve the task. Structural problems have also been encountered. Tanker aircraft have displayed a number of unsatisfactory features and systematic testing is necessary to ensure suitability for the dispensing role. Prior to modifying an aircraft to a specific tanker configuration, consideration should be given to flying some representative receiver types in the anticipated refuelling positions to gain assurance that no unacceptable handling characteristics are inherent in the proposed layout.

The object of this Agardograph is to describe the points that need to be considered when planning AAR trials to clear a new tanker or a new receiver aircraft for Service use. The paper assumes some familiarity with current AAR practices and equipments. It covers the two AAR systems in widespread use, namely the probe and drogue, and boom refuelling systems. Many of the points that need to be considered are common to both.

2. TANKER AIRCRAFT - ASSESSMENT FOR AAR

When an aircraft type is procured as, or converted to, a tanker, the testing agency must give consideration to the following topics related to its ability to dispense fuel. These may well be additional to any tests that are required to establish compliance with a specification.

2.1. Fuel System

A number of areas need to be considered here:

2.1.1. Testing must be carried out to ensure that the equipment meets the specification with regard to flow rates and pressures required. It is likely that the pumping capability of the basic aircraft fuel system will not be able to cope with dispensing fuel to one or more receivers whilst still maintaining a constant feed to the engines and hence additional pumps will need to be added. Testing must be carried out to ensure that the electrical/ hydraulic systems can cope with the load demanded by the extra pumps.

2.1.2. Consideration must be given to surge pressures that can be generated in the receivers. Ground refuel tests of the tanker with a 'worst case' receiver should have been carried out prior to flight trials.

2.1.3. The tanker AAR operator needs to have sufficient control over the fuel being dispensed. For example, he must be able to cut off the flow immediately if he is getting too low or if a problem arises.

2.1.4. In the case of a tanker which is a conversion, a detailed appraisal of the installation of the additional fuel system must be carried out to ensure that it is sound eg is it well sealed or can fuel leak or fumes be present?

2.2. Controls and Displays
The tanker will have a number of controls and displays to indicate precisely what is happening at any time. The following may be fitted and will need to be assessed:

a. Visual display of receiver, eg Closed Circuit Television (CCTV) monitor, which allows the tanker crew to see the receiver in contact and also, preferably, anywhere in the vicinity of the tanker. Testing will need to be carried out to ensure that this display functions adequately in all weather conditions and that it does not suffer from interference due to operation of any of the aircraft systems.
b. Gauges to indicate fuel flow rates and pressures while dispensing.
c. Parameters associated with fuel pumps which are additional to the basic aircraft fuel system, eg electrical or hydraulic.
d. Indications of hose/boom status parameters such as the hose/boom position, failures present etc.
e. For hose/drogue systems, a display showing the corresponding refuelling signal lights being displayed to the receiver pilot (see para 2.4).

2.3. Tanker Identification Lights
If a tanker identification lighting system is embodied, its effectiveness as a tanker acquisition aid, when viewed from receiver aircraft, should be assessed.

2.4. Signal Lights
Each hose and drogue dispensing station will incorporate signal lights for the benefit of the receiver pilot. They are:

Red - stand off/emergency breakaway
Amber - ready to refuel
Green - fuel transferring

Some Nations use a flashing red to signal the emergency breakaway and a flashing amber to indicate the inner limit of the refuelling range.

The lights need to be visible from a wide aspect astern the tanker and to be compelling in all ambient light conditions but without dazzling the receiver pilot at night.

2.5. Positioning Aids
For boom/receptacle type refuelling, the receiver pilot uses director lights located on the underside of the tanker forward fuselage. These lights give up/down and forward/aft directions. Boom telescope length is indicated by markings on the sides of the telescope section. In addition, the receiver may have markings in front of the receptacle installation to aid the boom operator in making contact.

For both hose/drogue and boom systems, the tanker may have various line up marking arrangements painted on the under fuselage.

All the above aids need to be assessed for adequacy and usefulness by day and night. It is important that the receiver pilot is able to detect quickly and unambiguously any tendency to close up on, or drift back from the tanker.

2.6. Tanker Floodlighting
The tanker has to be suitably illuminated to enable night AAR to be conducted safely while avoiding excessive and unnecessary light emission. There must be sufficient illumination to allow the receiver pilot an adequate roll attitude reference. There must be no light sources to dazzle a receiver pilot when in echelon position, approaching the refuelling position, or when refuelling. Any line up markings

and station keeping aids should be adequately lit. Dimming arrangements will almost certainly be needed, to cater for the range of ambient light conditions. The way these are grouped together for various light sources needs to be assessed. Redundancy of lighting should be provided and assessed.

2.7. Covert Procedures
Most Services use hand or light signals from the tanker to the receiver in conditions of radio silence. The feasibility of using these should be assessed for a new tanker/receiver combination.

2.8. Flight Envelope
The flight envelope within which the AAR equipment may be deployed, used and recovered must be checked. Testing must cover the tanker weight, airspeed and Mach ranges which it is intended to clear for Service use. Drogue stability in level flight and in turns must be assessed to determine whether the drogue provides a steady target for the receiver pilot. This assessment should be carried out in both smooth and turbulent conditions. If it is intended to refuel slow receivers, then the tanker may need to extend its high lift devices, in which case the tests will need to be repeated in this configuration.

2.9. Handling
Normally a tanker will dispense fuel while under autopilot control but should also be capable of doing so when being flown manually. Tests should be made under both types of control to ensure that it can provide a stable refuelling platform. It should be capable of making smooth entries to and recoveries from turns at bank angles of up to ±30°. Likewise smooth entry to and recovery from a descent should be possible. Accurate speed holding over the intended dispensing speed range is also a requirement.

2.10. Performance of Tanker
The performance of the tanker with dispensing equipment deployed must be measured so that aircrew can be provided with flight planning information.

2.11. Performance of AAR Equipment

2.11.1. Flight testing is required to demonstrate that the hose(s)/boom can be deployed and retracted reliably, without damage to the tanker or to the refuelling equipment. This shall be demonstrated throughout the equipment envelope. Any operational penalties arising from system limitations (eg time limits between cycles) must be carefully considered.

2.11.2. The tanker and the AAR equipment must be shown to be capable of dispensing fuel reliably within the declared dispensing envelope. No undue skills should be demanded of the tanker crew or receiver pilot.

2.11.3. If the tanker has more than one refuelling station, failure in the operation of one station must not prevent use of any other station, eg if there is a failure present in one hose unit, then that hose must be able to be stowed safely or jettisoned to enable use of the other hose or hoses. Hose jettison testing must be carried out to ensure that jettisoning of a hose does not cause damage to the aircraft or its systems so that refuelling can continue with the remaining AAR equipment.

2.11.4. The possibility of a failure where the hose cannot be stowed or jettisoned, or the boom cannot be retracted, must be considered. It is advised that a hose trailed landing is carried out during the trials programme. Prior to landing with the hose trailed a low speed handling check should be carried out progressively as speed is reduced and the configuration changed, in case hose instability necessitates an emergency jettison.

2.11.5. Tests should also be carrie out to ensure that fuel can be dispensed with certain failures present, eg inoperative fuel pumps.

2.11.6. It must be demonstrated that the equipment operates reliably over the required range of ambient temperature conditions as defined in the specification, and in a realistic operating environment (eg icing cloud penetration, dust).

2.12. Instrumentation

2.12.1. To assess the performance of the fuel system and AAR equipment the following parameters are required:

Fuel flow rate
Fuel pressures
Hydraulic system parameters for hydraulic fuel pumps
Electrical system parameters for electrical fuel pumps
Hose/boom status parameters
Temperatures
Fuel tank contents
IAS
IALT
OAT

Some of these parameters will already be available as part of the normal aircraft instrumentation. However, ideally, these parameters will also be recorded on the same medium as the trials instrumentation parameters for ease of analysis.

Consideration must be given to the sampling rates of these parameters, particularly for fuel pressures. Experience has shown that, in order to capture fuel pressure surges, sampling rates in excess of 100 samples per second are required.

2.12.2. In order to assess the aspects listed in paras 2.8, 2.9 and 2.10, a flying qualities and performance suite of instrumentation should be provided. A suggested 'minimum list' of parameters is as follows:

IAS
Pressure altitude
OAT
Heading
Normal G
Pitch attitude
Roll attitude
Pitch rate
Yaw rate
Roll rate
Engine speeds
Engine turbine temperatures or equivalent
Engine fuel flows
Engine pressure ratio (if applicable)
Fore and aft stick (yoke) position
Lateral stick (yoke) position
Rudder pedal position
Pitch control surface position
Roll control surface position
Rudder surface position

2.12.3. Some tankers have a CCTV fitted as part of the normal operational fit. However when this is not the case, it is advisable for a CCTV, preferably with video recording capability, to be fitted as part of the instrumentation suite for trials purposes.

3. ASSESSMENT OF A RECEIVER AIRCRAFT - GENERAL POINTS

Before an aircraft can be used in the receiver role, regardless of tanker type, the points listed in the following paragraphs must be considered by the testing agency.

3.1. Fuel System Compatibility

An appraisal of the fuel system is required to ensure that it is suitable for AAR and that fuel can be loaded safely and in a controllable manner that respects the C of G limits without undue crew workload. It must be ascertained, prior to flight trials, that the tanker cannot generate fuel pressure surges in the receiver which are in excess of the design limits. In addition, where there is a requirement to refuel from a tanker fitted with a pressure regulating coupling, it must be shown that the likelihood of the failure of the regulator is acceptably low, or that failure of the coupling will not damage the receiver. An assessment of the compatibility of hose and drogue should be made, taking into account pull off forces, weak links etc.

3.2. Physical Hazards

3.2.1. During AAR with a probe and drogue system it can be anticipated that, in Service, there will be numerous occasions when the probe fails to engage cleanly with the drogue. The drogue may then 'brush' the nose of the receiver. It should be assumed that the drogue can contact any part of the fuselage surface from the nose to a point at least half a fuselage diameter behind the probe tip and from the top of the fuselage downwards on either side through an arc of ±130°. The surface so defined should be examined to ensure that any externally mounted sensors or antennae are not likely to catch in the drogue, or that if they are, the consequences of them being damaged can be tolerated for the remainder of a flight. For the boom system, consideration must be given to the presence of such sensors or antennae in the vicinity of the receptacle. Mil-A-87166 requires that protrusions should not be installed in an area 8 ft long by 5 ft wide forward of the receptacle and within 2 ft to either side of and behind the receptacle.

3.2.2. If an unusual or exceptionally forceful contact is made with the drogue, the receiver should withdraw and examine the drogue carefully before proceeding. In the event of physical drogue damage being sustained (torn canopy, bent spokes) it will almost certainly be necessary to discontinue the trials flight because the behaviour of the drogue may be unrepresentative. For boom refuelling, if the boom operator or receiver pilot consider that an unusual or unsuccessful engagement attempt has resulted in receiver or boom damage then clearly testing may have to be restricted or even discontinued.

3.2.3. Careful attention must be paid to the risk of the drogue entering the propeller disc in the event of a missed approach on a propeller driven receiver. Measurement of the achievable deceleration may be necessary to establish the maximum closure speed from which an approach can be aborted without a dangerous 'overshoot' of the drogue occurring.

3.3. Airflow Disturbance

The disturbed airflow behind the drogue/boom may affect pitot and static pressure sensors and airflow direction devices. Before flight trials are undertaken, the consequences of any false information being generated by these sensors must be considered and the appropriate precautions taken.

It may be possible for the drogue to pass in front of an engine intake and cause severe inlet flow distortion and possibly surge. If this can occur, the engine manufacturers should be consulted to determine if any additional instrumentation is needed. It is conceivable that additional operating precautions or limitations for the initial trials may be recommended.

3.4. Airframe/Engine Integrity

Operation as a receiver aircraft can present a much more severe environment than that for which an aircraft was originally designed. In particular this applies to large transport type aircraft being converted to act as AAR receivers. The aircraft Design Authority should consider whether any specific stress recording instrumentation is needed in order to apply 'lifing' factors in the AAR role.

Areas that have given rise to structural concern in the past have been:

a. Probe and probe installation loads.
b. Boom loads.
c. Pitch oscillations causing significant 'g' excursions and fatigue consumption.
d. Empennage loads.

e. Excitation of HF aerial wires and consequent failure.
f. Abnormal propeller loads caused by the propellers operating in the tanker's wing vortex system.

Also, depending on the specific tanker type, the tanker exhaust plume(s) may impinge on the receiver. In addition to causing local structural concerns the receiver's engine(s) may suffer inlet flow disturbance or exhaust gas ingestion. If this is possible, the engine manufacturer should also be consulted to advise on any precautions that should be taken during the trials. For a transport aircraft being used for the first time in the receiver role, the pattern of engine power demand during AAR will be very different from that experienced in the primary role. The engine manufacturer's advice should be sought with respect to any lifing requirements in the short or long term, together with advice on the maximum power ratings that can be used during AAR, given the 'cyclic' nature of the power demand.

3.5. Cockpit Layout and Control Characteristics

3.5.1. Consideration needs to be given to the control arrangements on multicrew aircraft. Ideally the aircraft should be capable of being flown completely from either pilot's or co-pilot's position with the seat adjusted so that the probe tip (probe/drogue refuelling) is visible to the occupant while seated in a comfortable position. Longitudinal trim adjustment should be possible without removing the hand from the yoke. It should be possible to manipulate the throttles and obtain the maximum permitted power rating without abnormal reach and without the pilot having to pay undue care to avoid exceeding the engine limitations. Where it is not possible to achieve these requirements, consideration must be given to the 'split' of crew duties to enable refuelling to be achieved safely and without exceeding any limitations.

3.5.2. For an emergency breakaway, when refuelling with a probe/drogue system, it may be necessary to use airbrake as well as 'throttle chop' to achieve the required deceleration. A decision should be made, depending on the handling characteristics, as to whether any trim changes induced by use of airbrake would be acceptable when close to the tanker aircraft.

3.5.3. For aircraft fitted with stability augmentation systems or flight control systems it will be necessary to consider what modes will be used for refuelling. The possibility of sensors giving false input to such systems needs to be considered when deciding what facilities will and will not be engaged. Some systems will schedule gain changes as functions of speed or altitude which need to be considered when planning the test programme.

3.5.4. On some aircraft it may be necessary to use reheat to achieve a refuelling position. Consideration must be given as to how the thrust (or drag) can be modulated when in reheat in order to maintain the correct separation from a tanker.

3.6. Failure Cases

Many aircraft have considerable system redundancy and the user Service may wish for clearances to refuel with various failures present. For instance a multi-engined aircraft might be able to refuel with an inoperative engine or with some other failure present that might affect the handling of the aircraft. Consideration should also be given to receiving fuel in abnormal configurations that might arise from a specific operational scenario eg undercarriage down. These cases should be considered when defining the trials programme and decisions made as to which simulated failures will be flight tested.

3.7. Stores

Many receivers will be required to

refuel in various stores configurations. The cases to be flight tested need to be decided tentatively prior to the trials programme and confirmed or amended in the light of initial experience. Configurations to be considered should include the maximum drag stores and those giving maximum pitch, maximum roll inertia and lateral imbalance.

3.8. Flight Envelope

The flight envelope over which the aircraft is to be used for receiving needs to be declared by the Design Authority. Experience has shown that a minimum speed giving at least a 1.3 g (0.3 g increment) manoeuvre capability when receiving is advisable.

3.9. Receiver Instrumentation

3.9.1. Fuel System

The minimum parameters required in the receiver to assess suitability of the fuel system to be able to take on fuel from the tanker, are fuel pressures measured in a number of positions in the fuel system depending on the design of the system. These pressures need to be sampled at a high rate (see para 2.12.1). In addition fuel tank contents should be recorded.

3.9.2. Stress Recording

The appropriate Design Authorities should call up any stress recording instrumentation required for receiver trials flying. Consideration should be given to strain gauging the probe and displaying the critical axial and bending loads to the crew, as well as recording them. The loads display will assist in determining the limits to which the receiver can be flown relative to the tanker (ie the vertical and lateral displacement and closure rate) as well as assisting in the recognition of deficiencies in the tanker hose take up system.

3.9.3. Flying Qualities

The following is the minimum list suggested for assessing the receiver flying qualities:

IAS
Pressure altitude
OAT
Normal g
Lateral g
Heading
Pitch attitude
Roll attitude
Angle of attack
Sideslip angle
Pitch rate
Roll rate
Yaw rate
Engine speeds
Engine turbine temperatures or equivalent
Throttle positions
Fore and aft stick (yoke) position
Lateral stick (yoke) position
Rudder pedal position
Longitudinal trim position
Pitch control surface position
Roll control surface position
Rudder surface position
Fore and aft stick (yoke) force
Lateral stick (yoke) force
Rudder pedal force

4. ASSESSMENT OF A SPECIFIC TANKER/RECEIVER COMBINATION

When a test agency is tasked with clearing a specific aircraft combination, the extent of the ground and flight trials depends on whether the tanker or the receiver have been used in the AAR role previously. It is unlikely that a new type of tanker would be tested, in the first instance, with an aircraft that had never been operated previously in the receiving role. Therefore the following paragraphs are based on the assumption that either the tanker only or the receiver only is being assessed for the first time in the AAR role. If both aircraft have been used previously in the role then the programme suggested may be shortened depending on the degree of similarity with previous combinations tested. For the initial contacts of a new tanker/receiver combination it is strongly recommended that the behaviour should be recorded from a chase aircraft. The need for a chase aircraft to be employed for subsequent contacts can then be decided.

4.1. Ground Fuel Transfer

Prior to in-flight testing, ground refuel tests should be carried out between the tanker and receiver aircraft where possible. The main purpose of ground testing is to establish the flow rates and surge pressures that are likely to be seen as receiver tanks shut off and when the receiver becomes full. Flow rate is progressively built up by adding more pumps until a maximum flow rate is achieved. The results of the ground tests will give an indication as to the likelihood of the receiver fuel system pressures being exceeded and, in such cases, an opportunity to develop procedures which will minimise pressure surges. These can be done easily from a centreline hose unit, but ground tests from wing pods may be more difficult as a Ram Air Turbine (RAT) is normally needed to pump the fuel. In the latter case, evidence from ground testing of the receiver against the tanker wing pod will be required prior to flight testing. For boom refuelling, fighter type aircraft can be placed behind some tankers such as the KC-135. For other aircraft, a ground test adaptor from the boom to the receiver receptacle can be constructed.

4.2. Physical Clearance Consideration

Depending on the relative sizes of the two aircraft it may be necessary to conduct a careful dimensional assessment to determine if the physical clearances between the tanker and receiver aircraft remain broadly comparable with past experience. Clearly this will have been considered carefully at the tanker design stage but an independent appraisal by the flight test agency may be prudent, particularly when dealing with receiver types that were not necessarily considered when the tanker was designed (eg belonging to Foreign Services). Any combinations that encroach on established practice will require to be approached with considerable caution. Adequate tolerances for mispositioning to cater for turbulence/inexperience must be allowed for and the test team should take advice from experienced receiver pilots of similar types, preferably with an AAR instructional background. It should be noted that, for hose/drogue refuelling, Mil-Spec 19736B requires that the nose of the receiver shall be aft of the tail of the tanker when the receiver is 15 ft forward of the position that occurs when the hose is fully trailed. Also a design objective is to provide not less than 15 ft of vertical separation between the tanker and receiver aircraft.

4.3. Tanker Exhaust Plume

If there is any possibility of the tanker exhaust plume being ingested by the receiver engines, or if it is likely to affect other installations such as radomes, then consideration needs to be given to the possible consequences and perhaps the need for special instrumentation to be incorporated.

Exhaust plume temperatures have not been a problem for receiver structures to date (at high altitude the plume has often cooled to the point where the water vapour has condensed into visible droplets/ice crystals within 50 m of the exhaust nozzle). However the turbulence from the exhaust plume can cause buffeting and structural problems for a receiver. If the tanker/receiver configurations make this a possibility, then the consequences should be considered, as should ways of reducing the problem eg selective throttling of the tanker engines.

4.4. Flight Envelope Compatibility

The dispensing flight envelope of the tanker must be compared with the predicted AAR envelope for the receiver to determine where they overlap and hence define the widest potential envelope for AAR test of the combination. The test team must be aware of the pressure error differences between the two aircraft when defining limiting values of IAS or IMN at which trials will be conducted.

4.5. **Flight Tests - Background**
Trials on a large number of tanker/receiver combinations have shown that AAR has eventually been possible for all combinations tested up to the time of writing this Agardograph. However in a number of cases considerable development has proved necessary to obtain an AAR capability acceptable for use in Service. Definition of an acceptable contact/disconnect envelope is an early priority in a trials programme. Envelopes have, in the past, had to be restricted for a variety of reasons including the following:

a. Poor hose take-up characteristics.
b. Boom/receptacle binding.
c. Bow wave effects.
d. Receiver structural considerations.
e. Inadequate lighting for night AAR operation.
f. Poor receiver flying qualities, eg:
   Large and variable trim changes in pitch and roll.
   Tendency to enter a short period pitch oscillation.
   Directional wandering especially at high values of tanker C_L.
   Large roll forces when operating behind a heavy tanker.
g. Receiver engine surge at high altitude and ingestion of tanker exhaust plume.
h. Difficulty in respecting the receiver power limitations.
i. Receiver buffet levels in the tanker wake.
j. Receiver performance limitations.
k. Tanker aircraft upset by the presence of the receiver behind it.

4.6. **Flight Tests - AAR Envelope Definition**

4.6.1. Because of the possible difficulties listed in 4.5, a systematic process of investigating the AAR envelope is required to ensure that any problems are uncovered during the task of making and maintaining a refuelling contact and breaking away from the tanker subsequently. It is recommended that the test points should be approached progressively, starting with a medium to lightweight tanker and receiver, at low altitude and in the expected mid speed range, with the receiver at a mid C of G. It may be prudent to commence by exploring the airflow behind the tanker without the hose being extended.

4.6.2. A possible 'Matrix' for envelope expansion is shown in Table 1. This is designed to explore the envelope in a progressive manner and ensure that tests are made in all areas where experience has shown that handling or performance problems can occur. Clearly the suggested approach to envelope expansion will have to take account of the characteristics of the specific aircraft involved, the extent of the clearance actually required by the users, and the experience (if any) already gained with the receiver aircraft from other tanker types. The tests are designed to explore the flight envelope systematically in order to investigate the flying qualities, performance and fuel transfer aspects. In particular a large fuel transfer can often usefully be tested in going from Condition 3 to Condition 4 in Table 1.

4.6.3. At each test condition shown in Table 1 the following sequence should be considered for the hose/drogue system:

a. The receiver records datum conditions in free air in echelon formation with the tanker.
b. The receiver moves astern the tanker dispensing station approximately 20 ft aft of the drogue and manoeuvres up, down, left and right approximately 10 ft in each direction to

evaluate any adverse tanker airflow disturbances on receiver handling qualities.

c. The receiver moves 5 ft aft of the drogue and manoeuvres up, down, left and right approximately 5 ft in each direction to evaluate any adverse tanker airflow disturbances on receiver handling qualities.

d. The receiver performs engagement with the drogue using slow, medium and fast closure rates provided that means are available to ensure that the maximum design closure rate or probe loads are not exceeded.

e. The receiver holds the normal refuelling position long enough to establish power requirements and flying qualities and to transfer any fuel as required.

f. The receiver manoeuvres behind the tanker in straight and level flight to check that there are adequate tolerances for becoming mispositioned laterally, vertically and when at the closest possible position to the tanker.

g. The tanker rolls into a turn of up to 30° bank under either manual or autopilot control and then reverses the turn while the receiver follows, holding the refuelling position, and then levels off.

h. The tanker initiates a descent of up to 1000 ft/min. The receiver follows, in contact while holding the refuelling position.

i. The receiver performs a normal break or emergency 'rapid separation' from the drogue and returns to free air in echelon with the tanker. When performing a normal break the effect of being displaced from the optimum position should be assessed. This should encompass being about 5 ft high, low, left or right of the optimum, depending upon the position of the probe.

4.6.4. **Boom Refuelling**
The following test points should be considered for each of the test conditions in Table 1. The boom will be in the normal mid position.

a. The receiver records datum conditions in free air.

b. The receiver establishes a position approximately 50 ft behind the boom and manoeuvres around the estimated limits of the boom envelope.

c. The receiver repeats b at approximately 25 ft behind the boom.

d. Receiver handling qualities and boom control authority are then evaluated at the contact position; the boom operator flies the boom just clear of the receptacle while the receiver pilot manoeuvres around the estimated boom envelope.

e. Initial contact is made in the middle of the boom position envelope. Disconnect capability is evaluated by the receiver pilot, co-pilot (where relevant) and boom operator.

f. Contact and disconnect envelopes are then established by expanding outward from the centre of the boom envelope in 5° increments in elevation and azimuth, at mid boom extension. Receiver handling qualities in level flight and during turns of up to 30° bank are also concurrently evaluated.

g. Test f is repeated at the long and short boom extension ranges.

h. Pressure disconnect capability, tension disconnects and manual boom latching/receiver override operations should be assessed.

4.6.5. Experience has shown that, in some cases, considerable pilot compensation is required to achieve the refuelling task because of the deterioration in receiver flying qualities when operating in the tanker wake. Pilots reports are a vital adjunct to the quantitative data being recorded. It is important to get more than one sample of pilot opinion particularly when handling difficulties are encountered.

4.6.6. Once experience had been gained by day, night operations must be evaluated. These should include a floodlighting and signal lighting assessment including the effects of various light source failures and the effectiveness of specific refuelling equipment illumination (including any hose/drogue and boom lights). The effectiveness of the receiver probe or receptacle lights should also be assessed.

4.6.7. The ability to conduct AAR with possible system failures present in either tanker or receiver should be assessed once experience has been gained with all systems functioning.

4.6.8. The test sequences outlined above allow the performance of the receiver aircraft in the tanker's wake to be calculated. There is usually a significant increase in power required to make and maintain a refuelling contact compared to the equivalent 'free air' flight conditions, because of the performance penalty due to operating in the tanker's downwash. It has been possible to non-dimensionalise the results of the flight tests and show the performance penalty in contact. The steady state performance in contact can be expressed either as a plot of receiver C_L increment as a function of the product of tanker and receiver lift coefficients (Figure 1), or as a separate performance polar, Figure 2. This information, combined with a knowledge of the transient excesses of thrust over drag needed to make and maintain contact, will allow more accurate prediction of the AAR capabilities of a tanker and receiver for flight planning purposes; ie it will be possible to schedule the heights, speeds and start/finish weights at which AAR will be possible at various ambient temperatures.

4.7. Flight Tests - Fuel System

The ground trials will indicate the flow rates and fuel pressures likely to be seen and the format of the fuel transfers in flight can be based on the ground test experience. The following areas should be tested:

4.7.1. Fuel transfers should be made with different pump combinations running and building up to maximum flow rate.

4.7.2. The receiver should be filled to full so that fuel surge pressures can be measured as the tank valves shut.

4.7.3. Emergency disconnects.

4.7.4. Bracket refuelling should be carried out. This is where the receiver, having been filled to full, remains in contact. As fuel is consumed, the receiver's shut off valves open and close causing cyclic pressure fluctuations. (Note: This cannot be performed for boom refuelling if the receiver is fitted with a pressure disconnect facility).

4.7.5. Where more than one aircraft is required to be refuelled simultaneously, this should be tested to ensure that adequate fuel flows can be achieved.

4.8. Simulation

The use of simulators in the AAR development process has not generally proved necessary. However, in one instance, a simulator was used to change the yaw damper control laws to overcome a directional handling problem on one receiver type. When the assessing pilots flew the 'real' task they considered that correlation with the simulator was poor. It was suspected that the modelling of the tanker flow field was not sufficiently accurate. A research contract has been placed with a UK university to study the effect of a tanker wake on a receiver's flying qualities. A combination which has already been flight tested was chosen and it is hoped to obtain an improved match between prediction and observed behaviour. Thus, in future, with a well modelled flow field, the simulator might well prove to be a more useful development tool than it has been in the past.

A number of training simulators are now being required to have an AAR capability. It is likely that there will be increased pressure to use data obtained from flight trials on the real aircraft, to give realistic simulation in these machines. Thus an AAR trials programme might also include test points to derive information for the simulator manufacturer.

TABLE 1 - SUGGESTED APPROACH TO AAR ENVELOPE EXPANSION

CONDITION	TANKER MASS	RECEIVER MASS	RECEIVER C OF G	RECEIVER CONFIG	ALTITUDE	SPEED	COMMENT
1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9	MEDIUM TO LIGHT	MEDIUM TO LIGHT	MID	CLEAN	LOW MEDIUM HIGH	MID SLOW FAST MID SLOW FAST MID SLOW FAST	Tests designed to give initial experience at 'easiest' conditions and working up to the more demanding areas of the flight envelope.
2.1 to 2.9	MEDIUM TO LIGHT	MEDIUM TO LIGHT	AFT	CLEAN	Similar to points 1.1 to 1.9.		Similar to points 1.1 to 1.9 but with receiver on aft C of G to give most adverse handling case.
3.1 to 3.9	HEAVY	MEDIUM TO LIGHT	AFT	CLEAN	Similar to points 1.1 to 1.9 but reduced tanker performance may limit altitudes available.		The heavy tanker can cause more severe downwash effects than a light one, particularly at low speeds.
4.1 to 4.9	MEDIUM TO LIGHT	HEAVY	MID TO FWD	CLEAN	Similar to points 1.1 to 1.9 but reduced receiver performance will limit envelope available.		Gives high receiver inertia and often high roll inertia as well due to wing fuel. Can follow Serial 3 after fuel transfer.
5	HEAVY	HEAVY	NOT CRITICAL	CLEAN	Only very limited envelope likely to be available.		Simulates heavy receiver being "topped up" just after t/o. High receiver inertia in roll plus strong lateral restoring forces from tanker wing vortices can cause receiver lateral control problems when manoeuvring.
6	HEAVY	MEDIUM TO LIGHT	NOT CRITICAL	High drag plus high roll inertia case.	Repeat selected points to determine any effects of stores.		

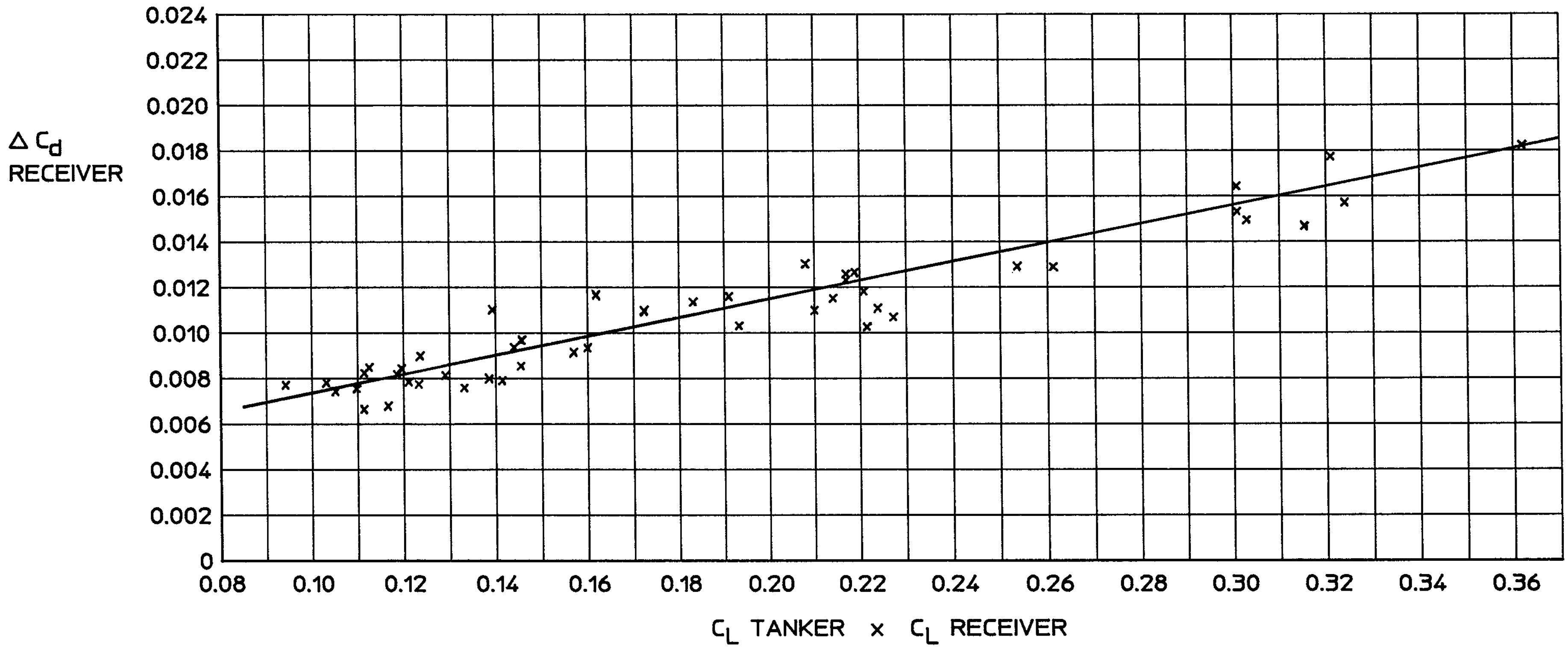

FIG.1 VC 10 C Mk1 RECEIVING FROM TRISTAR K Mk1 TANKER. INCREASE IN DRAG COEFFICIENT Vs THE PRODUCT OF THE TANKER AND RECEIVER LIFT COEFFICIENTS.

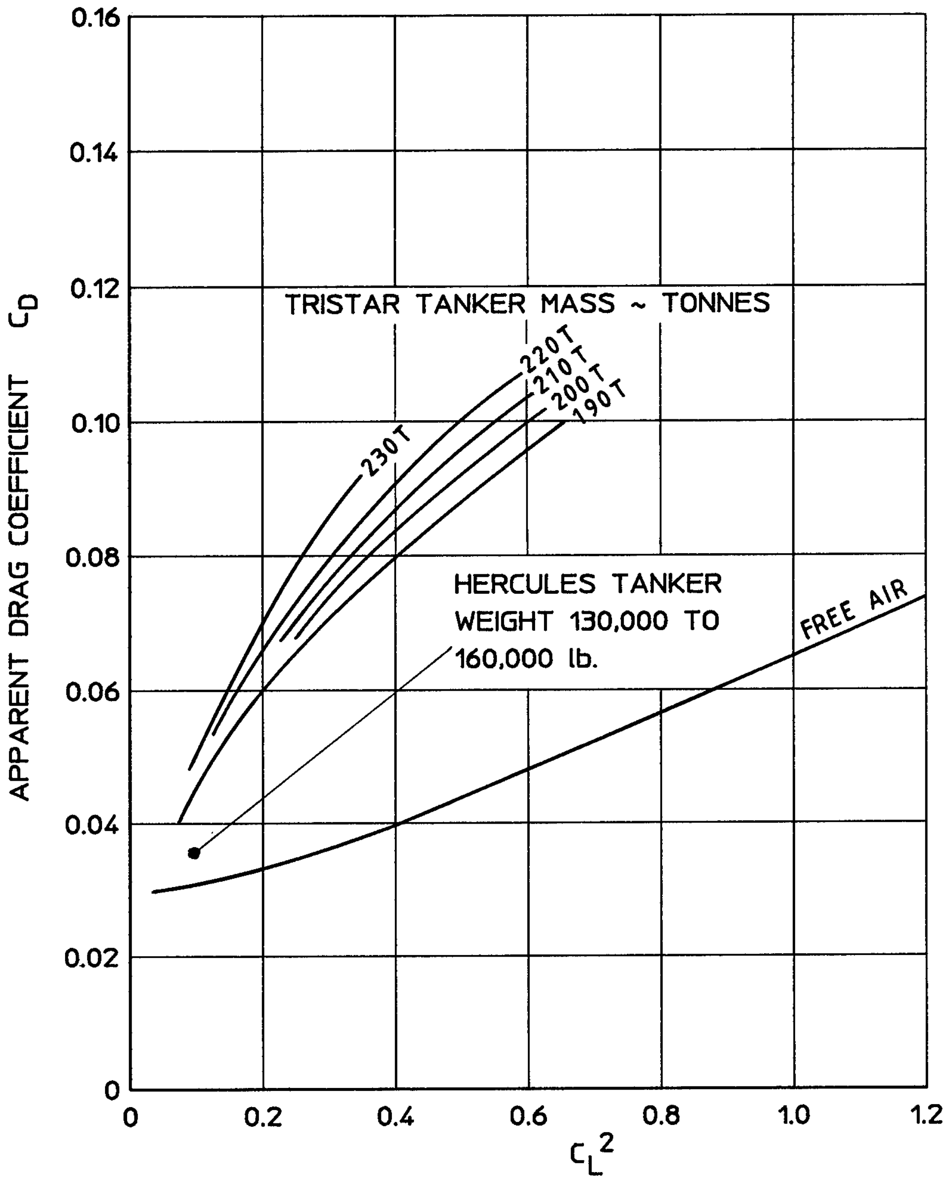

FIG. 2 HERCULES C Mk1 & C MK3. PERFORMANCE WHEN RECEIVING FROM A TRISTAR K Mk1, FROM A HERCULES C Mk1 K AND IN FREE AIR.

Annex

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This Volume in the AGARDograph 300 Flight Test Techniques Series therefore describes the points that need to be considered when planning AAR trials to clear a new tanker or a new receiver aircraft for Service use. The paper assumes some familiarity with current AAR practices and equipments. It covers the two AAR systems in widespread use, namely the probe and drogue, and boom refuelling systems. Many of the points that need to be considered are common to both.

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