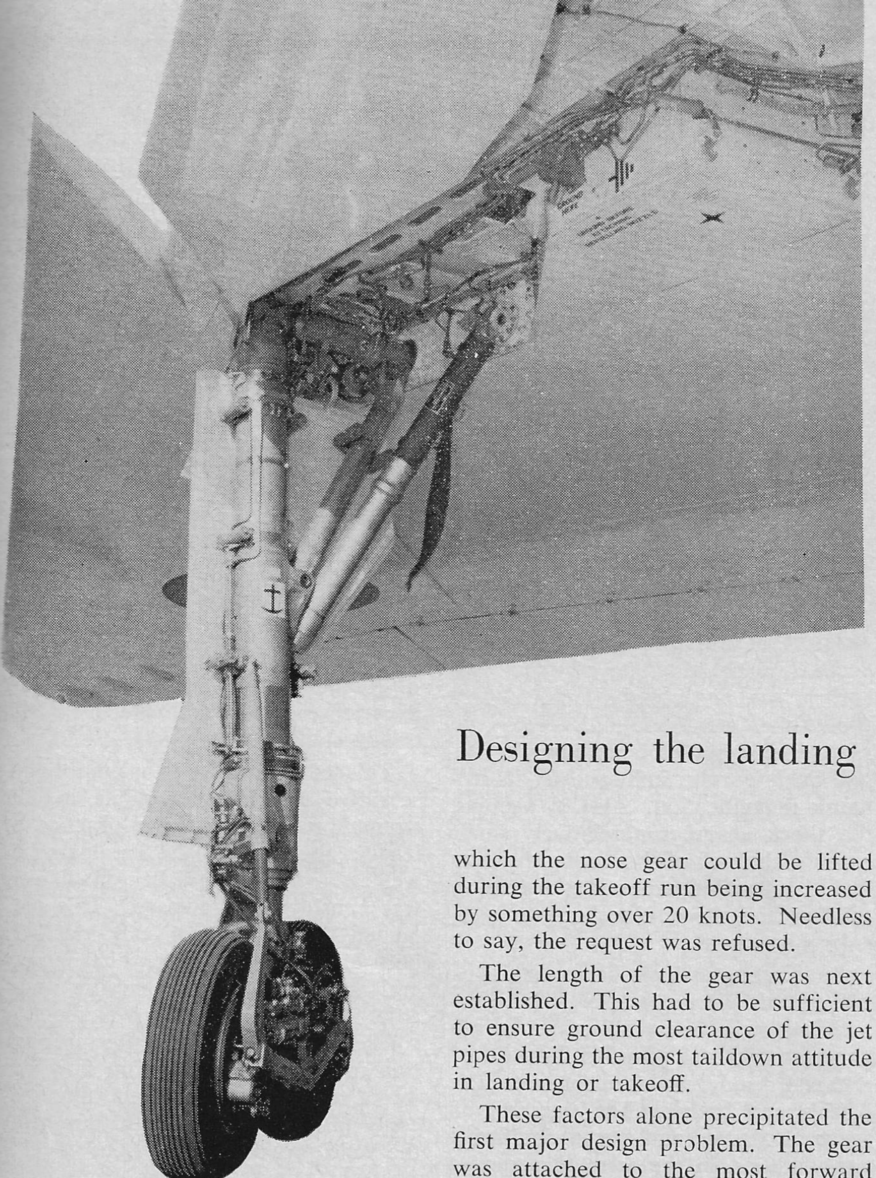


Feather-Weight Feet for 30-ton Giant

Designing the landing gear for the Avro Arrow

By H. Ralph Stratford

Design Section Head of Dowty Equipment of Canada Ltd.

> New and unique problems arose in the designing of the landing gear for the Avro CF-105 Arrow. How some of these difficulties were overcome is described in this article, prepared for CANADIAN AVIATION by the head of Dowty's design team.

A landing gear is regarded by an aircraft designer, as a necessary evil. Having accepted the necessity for such equipment, the designers of the Avro Arrow sought integration of the gear with the minimum disturbance of the more primary aspects of the aircraft design.

The longitudinal location of the main gear was the first point to be established. During the evolution of the retraction geometry, a request was made for a two inch aft displacement of the bogie assembly. But it was calculated by Avro that such a step would result in the minimum speed at which the nose gear could be lifted during the takeoff run being increased by something over 20 knots. Needless to say, the request was refused.

The length of the gear was next established. This had to be sufficient to ensure ground clearance of the jet pipes during the most taildown attitude in landing or takeoff.

These factors alone precipitated the first major design problem. The gear was attached to the most forward point in the wing that structural considerations permitted. It was not possible to retract the gear forward and inboard from this position without the wheels trespassing on the space reserved for the air intakes unless a considerable shortening of the gear could be effected during retraction.

Retraction directly inboard would have resulted in a thicker wing section in which to stow the bogie assembly. The shortening problem would have been even greater and the encroachment on the basic wing structure totally unacceptable.

Scale Model Built

Considerable discussion preceded the decision to make a working half-scale model of the gear. To provide the design assistance which was its prime purpose, the model had to be completed before the schedule date for freezing the design proper. It was inevitable, therefore, that considerable wastage occurred due to changes during the building of the model. On reflection, however, it is generally agreed that the decision and its timing were correct. The benefits derived justified the diversion of effort at that very busy period.

In addition to the stowage problems associated with the wing and gear relationship, new problems with respect to the considerable structural elasticity of this configuration arose. The magnitude of these was such as to render the standard stressing requirements for dynamic spin-up and spring back of a landing gear totally inadequate.

A detailed analysis had to be undertaken, primarily by Avro, to establish a rational design basis for this case. The order of the resulting dynamic loads is significant. It was found that the equivalent forward force, assumed to act at the bogie hinge at the cessation of wheel spin-up in the tail-down landing state, is significantly greater than the maximum drag force acting there during spin-up.

About this time, Avro made a basic decision that the inboard and forward retraction should be effected by retraction about an axis inclined to the fore-aft centre line and twisting of the bogie assembly rather than a fore-aft retraction axis and a horizontal hinge line located immediately below it. A telescopic rather than a folding stay was dictated by the space available and the location of the airframe strong-points. The next major design issue to be resolved was the location of such a stay.

Once it was established that retraction could be effected without fouling of the cross shaft, a strong case was

HALF-SCALE working model of the Arrow landing gear provided design assist.

New metals, modern techniques, explored in the

made for a stay going almost directly aft from the gear design standpoint. However, such an arrangement had to be waived in the face of substantial airframe design difficulties. The resulting selection of an inboard-located stay made the design of this unit a considerable problem in itself.

200,000 Pound Load

A compressive load in the order of 200,000 lb. had to be carried with the unit extended and a bearing overlap of less than 9 percent of the extended centre length. By evolving a lock for this unit which did not impair its column qualities, the need of a further lock in the main leg was also met.

Twisting and shortening of the leg during retraction did not provide a complete solution to the basic stowage problem. It was necessary to achieve a greater degree of shortening at the rear wheel, and this was accomplished by utilizing a tie member inherent in the suspension design to effect the necessary trimming.

In the early stages of the design of the Avro Vulcan gear at Cheltenham, a study had been made of the merits of utilizing the main shock absorber element of the gear to restrict bogie rotation during the time when only one set of wheels is in contact with the ground. In so doing, a useful contribution is made to the energy-absorption capacity during this interval.

As a result of this, two patents were lodged. One forms the basis of the suspension geometry of the Vulcan gear and the other that of the Arrow gear. In both cases, the single shock absorber is coupled to the midpoint on the bogie beam. To the extremity of the beam which mounts the wheels which are to touch the ground last, is an attached structure which freely collapses but will not further extend.

In this manner, the effect of a levered suspension, using one set of wheels only, is achieved in the initial stage of the landing. The normal telescopic suspension takes effect after the second set of wheels has made contact with the ground.

As they had previously, on both the Jetliner and the CF-100, Avro stipulated that the shock absorbing elements for both the main and nose landing gear should be of the **liquid spring** type. The straighter spring curve associated with this type of shock absorber was particularly important in the Arrow configuration. Here the rate of buildup of the landing reaction had an important influence on its dynamic magnification. Also by keeping the shock absorber a relatively small capsule, the task of shortening the gear during retraction, without endeavoring to close the shock absorber was considerably eased.

In selecting a single beam with cantilever axle in preference to a symmetrical twin beam structure, prime consideration was given to the ease of removal and replacement of the wheels and brakes. The question of space also arose and was a significant consideration in the selected arrangement.

A problem common to all types of pin-jointed suspensions is that of transmitting the braking torque back to the main structure without imparting pitching moments into the bogie assembly. The parallelogram configuration formed by the brake links, brake torque arms, bogie beam and lower end of the sliding member provides a complete solution in this gear.

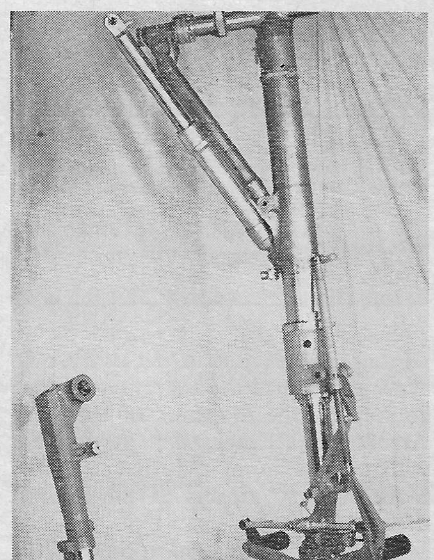
New Material Used

The strength/weight ratio of aluminum alloy and steel structure are fairly similar when other factors are not a major influence. But with the overall size of the members restricted by the available stowage space, the use of aluminum alloy was precluded in almost every major part. This same restriction tended to result in an undesirably heavy arrangement if the previously accepted maximum ultimate tensile strength for steel of 180-200,000 psi was adopted.

Avro recognized this problem. They decided to specify the relatively unexplored ultra high tensile steel and "modern fabrication techniques" in their basic requirement for the gear. A paper given by Dowty's chief engineer, G. F. W. McCaffrey during the 1957 annual meeting of the Canadian Aeronautical Institute outlined the design significance of this material. Interesting metallurgical, manufacturing and testing aspects were revealed. Comment here can be confined to the note that a weight saving in the order of 112 lb. per gear resulted from the adoption of this material.

The customer's requirement for modern fabrication techniques led to an intensive study of the various welding processes employed throughout the American industry. While flash butt welding had been extensively used with steels having an ultimate strength of 200,000 psi and below, very limited experience existed with the ultra high tensile steel.

This led to a desire to use more conservative design assumptions in this strength range. Also, the practice of leaving the bore of the members "as welded" with no further machining was considered ill-advised. This precluded the welding of two members both having blind bores which in several applications was otherwise desirable. While gas pressure welding was considered a more attractive proposition in respect to the grain flow adjecent to the weld, here again the necessity to clean up the inner bore after the weld proved a restriction.



GEARS COMPARED. Picture shows the main gears of left, the Avro CF-100, and right, that of the Avro CF-105.

The advocates of the various welding techniques readily admitted that no weld is structurally as good as the continuous parent metal. Therefore renewed study, with eventual success, was given to the prospect of obtaining larger, more complex forgings in which no welding would be necessary. Even with the best available controlled atmosphere or neutral salt heat treatment baths, some partial decarburization of the material on the surface is inevitable. This has an adverse effect on the fatigue resistance of these surfaces, and so it will be recognized that further metal removal after heat treatment, should be practised on as many surfaces as possible.

Since by far the most expensive machining is that after heat treatment and any welding must, of course, precede the heat treatment, the main economy arguments in favor of a welded up structure appeared to lose weight.

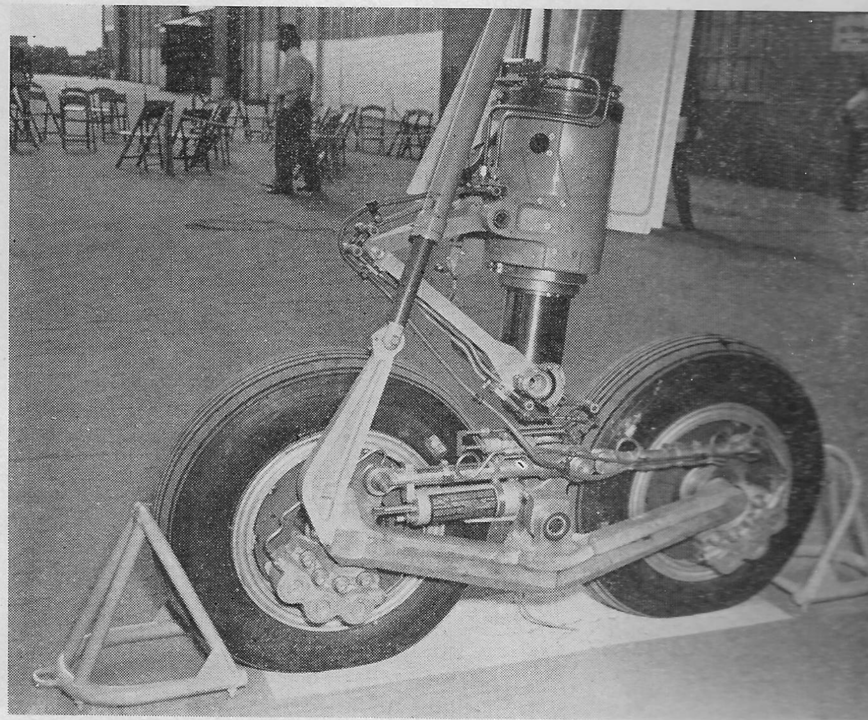
Production Tooling

To avoid delay at a later stage, Avro requested that the initial quantity of gears be manufactured using production tools and techniques, and to this end, it was decided to utilize closed die forgings for all the major members from the outset.

The nature of the retraction geometry and the importance of the dynamic behavior of the elastic structure led to particular emphasis being applied to the various structural joints to make them as rigid as possible. In general, this was achieved by extremely close fits used on all pinned joints. As far as possible, threaded joints were omitted to avoid notches of any type in this material. These could not be completely eliminated, however, and to give reasonable assurance of their acceptability, a special test program was undertaken.

The following brief selection of the design features will serve to illustrate the nature of the problems encountered. An early one was that of achieving 8.5 inches shortening of the leg during retraction. Another was the choice of an airframe attachment point, and the final envelope of the mechanism which were severely restricted by the shallow depth of the wing in this area.

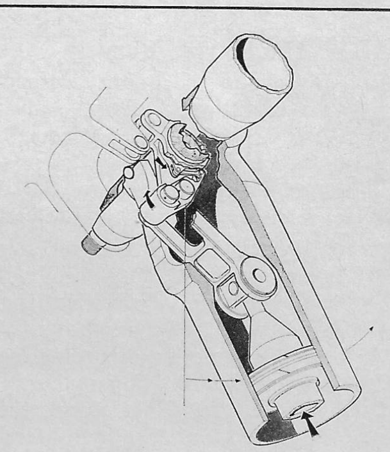
Being conscious of the considerable complexity of the initial solution to this problem, the opportunity to substitute a later conceived linkage arrangement on the Mark 2 Arrow was welcomed by all parties. A feature of this linkage which is not immediately apparent, is the shape of the curve obtained when the shortening achieved is plotted against the retraction angle. This curve is almost sinusoidal with the benefit of low acceleration forces and a minimum of overtravel resulting from the effect of wing deflection after the gear is stowed which approximates to 2.5 deg. of further retraction.



TANDEM gear of the Avro Arrow, showing the suspension geometry. Upper end of the telescopic tie attaches to fixed part of the leg. Compact rigid swiveling brake piping and temporary electrical lead are discernible in this view.

This wing deflection under "g" loads also considerably complicates the clearance studies of the stowed gear and in fact, in the extreme case, the gear is lifted clear of the uplock by the lower fairing door.

Deflection of the gear under ground loads also posed peculiar problems. Perhaps the best illustration of these is the fact that the shortening mechanism housed in the upper portion of the main outer fitting (which, at that point, is approximately 6.5 inches diameter and .3 inches thick) has to embody a universal joint at approximately its mid-length to ensure that no damage to the mechanism results from its bending in sympathy with the main fitting.



SHORTENING of the undercarriage leg during retraction is achieved by means of this linkage evolved for the Arrow II.

Many illustrations could be given of the impact of the space restrictions on detail design. The following is typical. Problem was that of finding a suitable strongpoint around the lower portion of the gear for the attachment of a towing bridle so that it could radiate throughout the required angle without fouling the gear. The final solution was the insertion of a towing eye inside the main bogie hinge pin, with spring-loading to ensure that whenever the towing shackle is disconnected it is retracted into the pin and so is clear of the upper wing surface when the gear is retracted.

The bogie assembly had to be twisted, through some 40 deg. during retraction. It was necessary, therefore, to embody within the torque carrying members, a device free of backlash which would automatically disengage and engage respectively on commencement of the retraction and completion of the extension. A search for an extremely precise, vertical-toothed dog clutch led eventually to the "Curvic Coupling" pioneered in North America by the Gleason Company of

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Arrow Gear

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Rochester. While the manufacturing techniques used in these couplings ensured a high order of concentricity and freedom from backlash, there was not, at that time, any knowledge of a comparable application and a searching test program became necessary.

Changes of ambient temperature detract from the energy absorbing performance of a *liquid spring* in a rather different manner than from an oleo-pneumatic shock absorber. While in the latter, the effect is one of variations in the load to cause initial closure and the slope of the curve spring, a *liquid spring* may find itself entirely dependent on dashpot for energy absorption during the initial axle travel.

While this is generally quite acceptable in most landing conditions, a by-product of this phenomenon is the lack of an internal force to effect final extension after takeoff. To ensure full extension of the gear within four seconds of the aircraft becoming airborne under all climatic conditions, an automatic compensator is mounted on, and utilizes the internal volume of, the front brake link. The compensator is coupled to the *liquid spring* through rigid swivelling pipes and a special valve.

Rigid swivelling pipes also form the basis of the hydraulic feed to the brakes. In addition to the temperature difficulties associated with flexible hose, flexure in an undesirable direction would require so much control as to make rigid pipes the natural choice. With the manufacture of the gear well advanced before the piping requirements were known, the routing of the pipe runs was particularly tricky but the back of the problem was broken when Avro found a solution for bridging the area between the fixed upper end and the shortening and twisting lower end of the gear. This solution comprises very small rigid dog leg swivels coupling directly to the lower unsupported end of telescopic assemblies.

In confining this account to the design aspects of the gear, it is not intended to suggest that the manufacturing and test and development aspects are any less significant but rather with the hope that, at some later date, those more closely related with these aspects might cover them more competently.

The foregoing inevitably sounds extremely mechanical and impersonal, but the enthusiastic participation in this design by so many associates within and beyond Ajax is gratefully acknowledged and will long be remembered by the author.