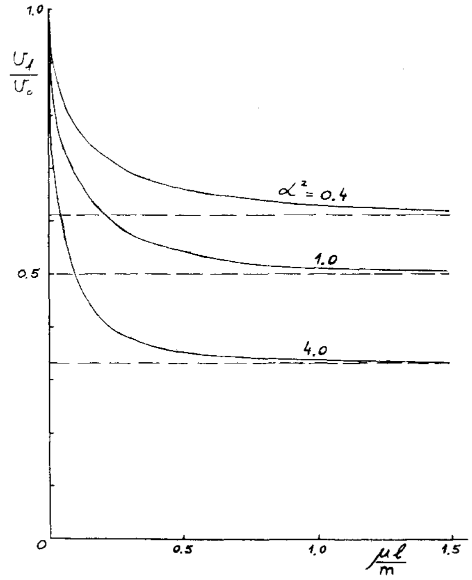

Fig. 2 Cable velocity at end of deployment.

Expressions (6a and b) are presented graphically in Fig. 2, and it may be seen that the final velocity tends quite sharply to its asymptotic value (7).

References

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KC-135 Boom Operator's Head-Up Display

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Refueling Operations

DURING air-to-air refueling, the receiver aircraft flies in a close trail formation slightly below the tanker. The Boom Operator (BO) lies prone, facing aft, and views the receiver through a window. The BO controls the ruddevators on the boom with a control stick in his right hand. This allows him to fly the boom from +12.5 deg (stowed position) to −45 deg (full down) and approximately 15 deg to either side. He can also extend the telescoping nozzle 0-20 ft using a control stick in his left hand. Figure 1 shows the approximate volume of coverage. If the limits in Fig. 1 are exceeded, the nozzle will automatically disconnect.

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To make contact with the receiver, the BO flies the boom to the refueling receptacle on the receiver aircraft and extends the nozzle into the receptable. During contact, he will fly the boom to follow the receiver motion. This is done to minimize the stress on the nozzle.

The BO also coaches the receiver pilot into the proper position. If the refueling limits are approached, the BO calls corrections for the receiver pilot, disconnects the nozzle, or calls for a breakaway, depending on the severity of the situation. (A breakaway is an emergency rapid separation of the two aircraft with the receiver slowing and descending and the tanker accelerating and then climbing.) Further details and descriptions are found in the air refueling technical order.[1]

Visual Problem

The primary visual problem for the BO is estimating the receiver position along the axis of the boom. He also has a great deal of difficulty in determining the actual extension position of the nozzle without looking at his gauges. His primary visual cue to determine receiver distance is the apparent size of the receiver. Since the actual size of the receiver aircraft varies from the very large C-5 or E-4 (Boeing 747) to the small fighters, this is not a reliable cue for an inexperienced BO.

The BO can estimate extension of the nozzle by viewing it directly. However, as can be seen in Fig. 2, the perspective is quite forshortened. In fact, the nozzle is not always visible, depending on boom elevation. The limits of view for the nozzle are sketched in Fig. 3. These limits were obtained by inflight observation of the extension necessary for the nozzle to be visible.

Judging the receiver position in elevation and azimuth seems to be less of a problem. There does seem to be some difficulty in determining quantitative position data and in determining proximity to the refueling limits. The rate of approach to these refueling limits seems to affect the BO's ability to judge position as well.

Night refueling is much worse, since many of the cues used by the BO are absent or greatly reduced. Clearly, the apparent size of the receiving aircraft will be quite different at night than during the day. Night operations use a light on the boom that shines down the length and illuminates the nozzle. Care must be taken to keep this light from shining in the receiver pilot's eyes. This may require a nonstandard (compared to daylight) approach to the receptacle for some airplanes.

Other Problems

Because of the receptacle design on some receiver airplanes, a reduced refueling envelope is needed. This reduces the chance of nozzle binding and an inability to disconnect. Since the limits are reduced from the normal values, the automatic disconnection feature cannot be used to prevent exceeding the refueling envelope (see Table 1). Several BO's have also commented on the need for having the receiver call sign in view.

Refueling Accidents

Using data from the Safety Center at Norton AFB, all refueling accidents for the past three years were reviewed. From these accidents, 30% were identified as significant. These accidents could have been prevented by a Boom Operator head-up display (HUD). The two criteria for including an accident in this group were failure or inability of the BO to determine proximity to the refueling envelope limits, or accident caused by the BO going "head down" to consult his instruments.

Data Requirements

The present BO instrument panel presents the following data for use during air-to-air refueling: 1) boom elevation position, 2) boom azimuth position, 3) boom nozzle ex-

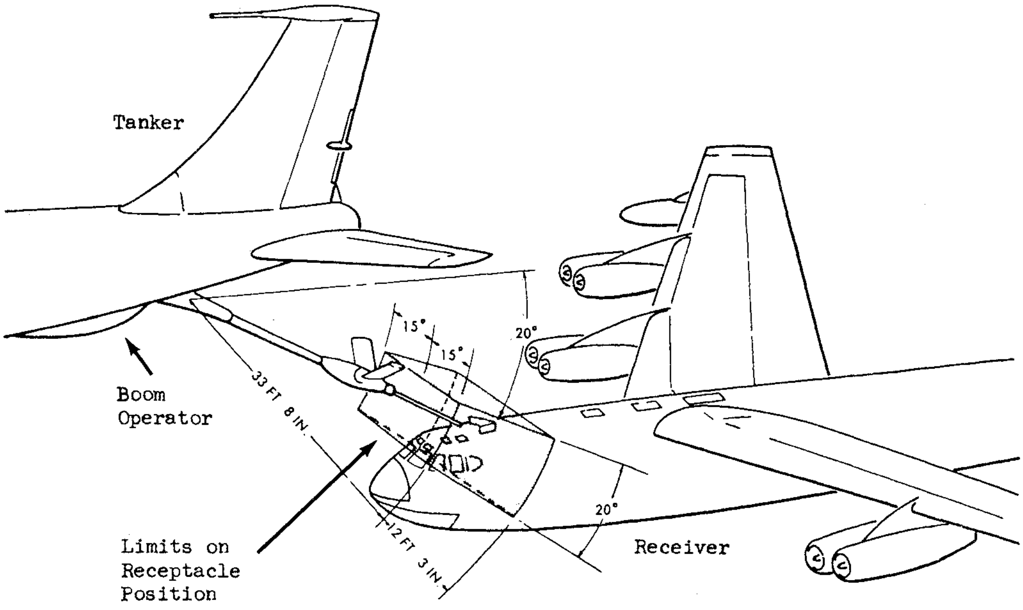

Fig. 1 Refueling geometry (adapted from Ref. 1).

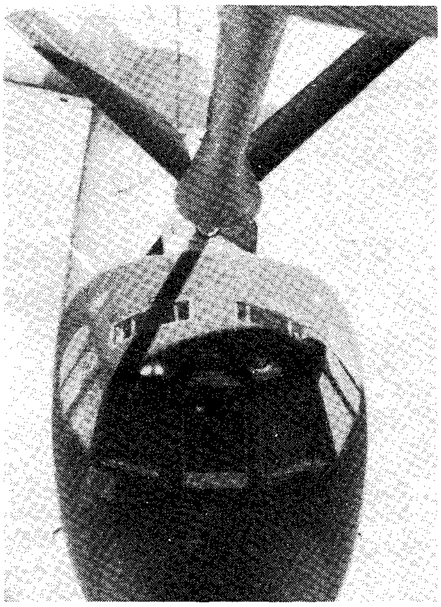

Fig. 2 Boom operator's view.

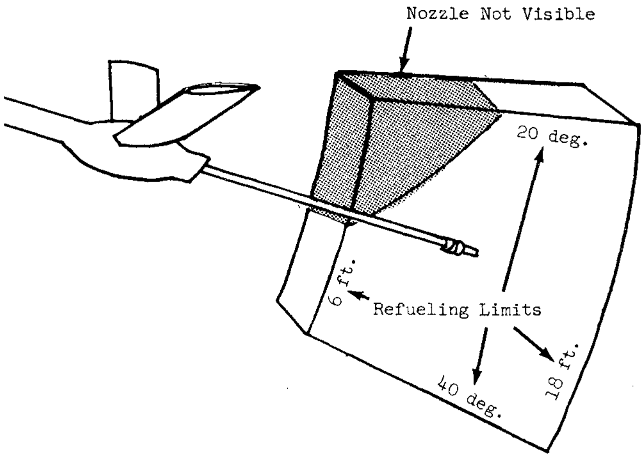

Fig. 3 Refueling envelope showing region where nozzle is not visible.

tension, 4) ready for contact light, 5) contact made light, and 6) disconnect light. In addition, the following data should be included: 7) actual refueling envelope (for the particular receiver) and 8) steering command (based on telescoping flex to minimize stress). As a minimum, any BO head-up display should include these eight parameters in its format. The following data may be desirable for a BO HUD: 9) boom position rates, 10) approaching limits warning, 11) receiver/tanker call signs, 12) actual receiver receptacle position (for refueling in instrument weather), 13) receiver position (repeater from tanker radar for assistance in rendezvous), and 14) receiver distance from ideal refueling position (in feet left/right, up/down, forward/aft, to assist BO in coaching receiver pilot into proper position).

The actual symbology is not as constrained in a BO HUD as it is in a pilot HUD since the BO's have a minimum of preconceived ideas about symbols. Several BO's have been insistent, however, on integrating the display so that the telescope extension cue is very close to the nozzle as viewed by the BO. Figure 4 shows a suggested display format for a BO HUD. This format uses the actual refueling envelope limit cue to supply the scales for both boom elevation and azimuth positions. The location of the nozzle (computed from the elevation, azimuth, and telescoping) is shown by the cross-hair/pipper symbol which will move with the nozzle. In a no-flex condition, the aiming symbol will overlie the nozzle; therefore, any flex will show up as an obvious difference. By flying the aiming cue to the actual nozzle position, telescoping stress can be minimized. The extension cue is integrated with the aiming symbol and should move with it. While a thermometer cue is shown, a range circle could be used instead. The three condition lights (R, C, and D) are descrete lights and only one would be visible at a time.

Table 1 Refueling limits for boom operator's HUD

Limit group	Elevation limits, deg	Azimuth limits, deg	Aircraft types
1	20-40	15L-15R	B-52, C-135
2	25-40	10L-10R	F-4, F-15, F-105, F-106
3	20-40	10L-10R	A-10, C-130, E-3, E-4
4[a]	20-35	15L-15R	C-5
5[b]	25-40	10L-12R	A-7, F-111
6[b]	25-40	12L-12R	F-101

[a] Could be combined with Group 1 by using the 5-deg scribe to show the lower elevation limit.
[b] Could be combined with Group 2 by using the 2-deg circle for one or more azimuth limits.

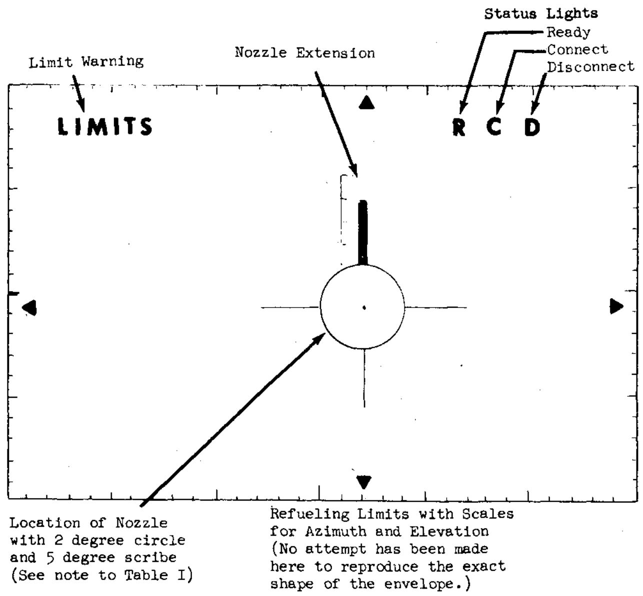

Fig. 4 Boom operator's HUD format.

Summary

Based on conversations with air-to-air refueling boom operators, observations of refueling operations, and general familiarity with head-up displays, it is felt that a BO HUD would improve mission effectiveness and flight safety. These goals are achieved by providing the BO's with the minimum data they need in their field of view. A HUD would minimize the need to look at their instruments. As a result, hook-ups would be faster with fewer disconnects, and flight safety would improve. The BO HUD would be of most benefit when refueling unusual sized airplanes, such as the very large C-5 or E-4 or the very small fighters, or at night.

Since the student BO would have quantitative data in his field of view, training requirements may be reduced when using a HUD. A HUD would also minimize the time needed for an experienced BO to become proficient in refueling a new receiver aircraft. This results from the reinforcement of accurate augmented cues and the lessening of the use of vague size-related cues.

References

[1] *Basic Flight Crew Air Refueling Procedures*, USAF T.O. 1-1C-1, July 1972, revised through April 1974.

Technical Comments

Comments on "Feasibility Study of a Hybrid Airship Operating in Ground Effect"

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IN Ref. 1, an assessment is made of the economic feasibility of a hybrid airship concept in the long-haul cargo market. The concept consists of a helium-filled rectangular cross-sectioned body with a fixed wing, operating in ground effect. (Since only 5½% of the total lift is due to static lift, one wonders why static lift was employed at all.) The conclusion of the paper is that for a range of payload sizes the concept offers economic advantages over both conventional airships and airplanes. This conclusion, however, is rendered invalid by the many errors and overly optimistic assumptions which apparently were made in the paper. It is the purpose of this Technical Comment to discuss the most serious of these.

First, the structural weight of the hybrid concept has been underestimated by a significant amount due to the following four factors: 1) the problems and weight penalties associated with attaching the heavily loaded wing structure to the relatively very lightly loaded body structure were ignored; 2) bodies with noncircular cross sections were assumed to weigh the same as bodies with circular cross sections on an equal volume basis; 3) the influence of speed (i.e., dynamic pressure) on hull weight was neglected; and 4) the effects of the severe near-sea environment were neglected. These assumptions imply that the body of a noncircular cross-sectioned hybrid airship with a heavy wing operating at 150 knots near the surface of the water would have the same weight as a conventional, circular cross-sectioned, wingless airship operating at 75 knots out of ground effect for the same enclosed volume. The unrealistically low empty weight which results is evidenced by the data in Table 5 of Ref. 1. A more realistic empty weight would be 50% higher than that shown, resulting in a halving of the payload for the same mission. In fact, a preliminary study of winged hybrid airships (Ref. 2) which took account of the above factors concluded that such vehicles were uncompetitive with other airship concepts due mainly to their high structural weights.

Second, and more seriously, major errors apparently were made in the estimation of crew costs. These are as follows: 1) there are many items in the crew cost element of D.O.C. other than crew salary such as the cost of fringe benefits and proficiency training; 2) flight crew salaries for the large-size vehicles being considered likely would be closer to $60,000/year than the $30,000/year which was assumed; 3) flight crew typically work 1000 hours/years – since the vehicles are assumed to have a utilization of about 6000 hours/year, six crews will be needed per vehicle, not the one which apparently was assumed; 4) because of the long flight durations (in excess of 20 hours) relief personnel must be onboard, giving a flight crew of six and not the three which was assumed. The combined effect is to underestimate the annual crew costs by as much as a factor of 25; this alone is enough to invalidate the conclusion of the study. It should be noted that many other recent airship economic studies have made these same mistakes, as discussed in Ref. 3.

Third, there are some accounting problems with the operating cost calculation as follows: 1) To compute indirect costs as a percentage of direct costs defeats the purpose of breaking down costs into D.O.C and I.O.C. since it has the effect of making the latter an element of the former. This can lead to serious errors in comparing significantly different systems. By definition, D.O.C. is the cost directly associated with actual operation of the vehicle while I.O.C. is the rest of the cost of operating the transportation system. 2) Ground crew is normally an I.O.C. and not a D.O.C. element. 3)It is not clear why ten onboard technicians are needed for the conventional airship but not for the hybrid.

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