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AIR TRANSPORTATION PROBLEMS REGARDING THE MS-40 BRIDGE

Abstract: The article presents the possibilities of large-size cargo transportation by air, as well as the requirements towards the transported loads and the methods of transport. The article also provides a detailed overview of the technical conditions for the transport of subsequent assemblies of the MS-40 bridge by the C-130 Hercules transport aircraft.

Keywords: transport aircraft, cargo, payload , laying vehicle, bridge span.

1. INTRODUCTION

In various sectors of transportation, loads with non-standard parameters are defined as oversize cargo. This is due to the limitations resulting from the design of transport means and existing infrastructure. For example, it is not possible to load onto an aircraft a cargo that is larger than the aircraft cargo hold. Another limiting condition is the shape of the cargo, and especially its geometry, which may disrupt the static and dynamic stability of the aircraft. To retain that stability, appropriate calculations must be made, cargo must be properly secured and, when necessary, reinforcements must be used.

The rule adopted in the air transportation business is that when a load does not fit into a scheduled flight plane (aircraft container or pallet), and it therefore requires a special charter plane, it is an oversized cargo [9].

The nature of military actions and operations carried out in recent years clearly indicates the growing importance of air transport. The basic limitations of air transport include weight and dimensions of the equipment related to the dimensions of the cargo holds and to aircraft payload. However, they are not as explicit as in land transport, and fulfilling them is not necessarily the sufficient condition. The limitations must be understood and properly interpreted for proper planning and preparation of equipment air transportation.

2. GEOMETRIC AND WEIGHT LIMITATIONS OF THE CARGO

General restrictions on air transport are defined by international agreements (IATA) [1] and by cargo standards and norms in force in the country of the aircraft manufacturer (an aircraft may require additional certification in the recipient country). Specific requirements for military air transport, are standardized in NATO countries [2], [3], generally in accordance with US military standards [4], [5], [6], and with US air transport instructions, because the American armed forces have the largest fleet of transport aircraft, have the greatest experience in the use thereof and form the core of joint operations [8].

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Air transport is only possible if the cargo can be loaded into the aircraft hold. There are here, however, a number of restrictions directly related to geometrical parameters and aircraft payload, viz.:

- maximum equipment dimensions should allow the safe transport and loading thereof. Free space required on each side of the load (15 cm) allows its tilting during flight without endangering the supporting structure (Fig. 1). Reducing the permissible clearance dimensions in relation to the size of the hold is also necessary for the safe loading of equipment into the hold (Fig. 2);
- front and rear overhang and a ramp crest angle should allow the loading of cargo to the hold using the loading ramp (Fig. 3);
- maximum allowable load height can be limited by the overhang when entering a ramp (Fig. 4) or by the height of the hatch opening in case of significant length or long wheelbase - Fig. 2;
- offset position of the centre of gravity of the load or offset entry to the hold must not exceed the limit values in order to avoid disrupting the transverse stability (Fig.5);

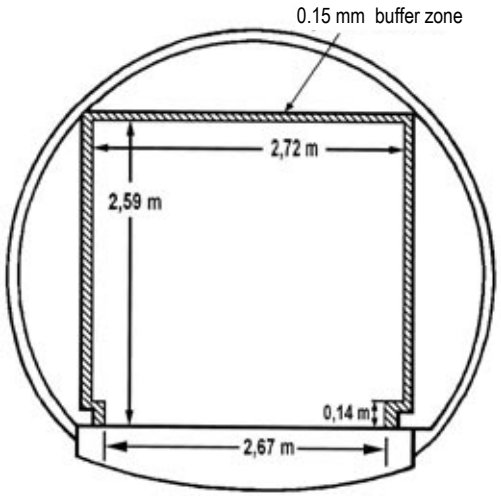

Fig. 1. Illustration of the free loading space limitations in a C-130 transport aircraft [7]

Fig. 2. Container being loaded into the cargo hold of a transport aircraft [7]

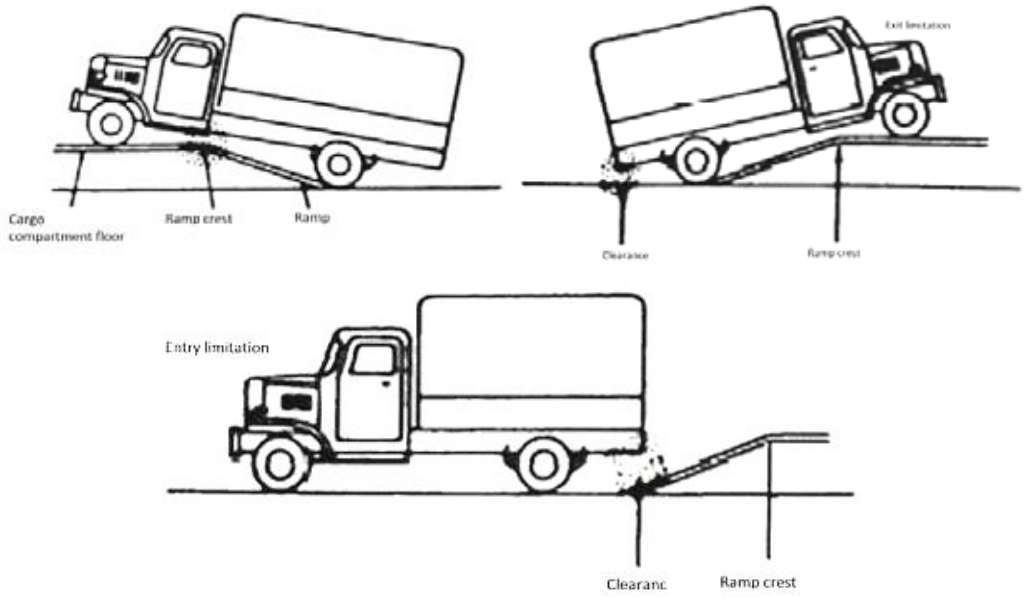

Fig. 3. Front and rear overhang and ramp crest angle that constitute limitations of entry into the cargo hold [7]

– loading of the axles of a wheeled vehicle must not exceed 80% of the permissible road load or 100% of the permissible off-road load.

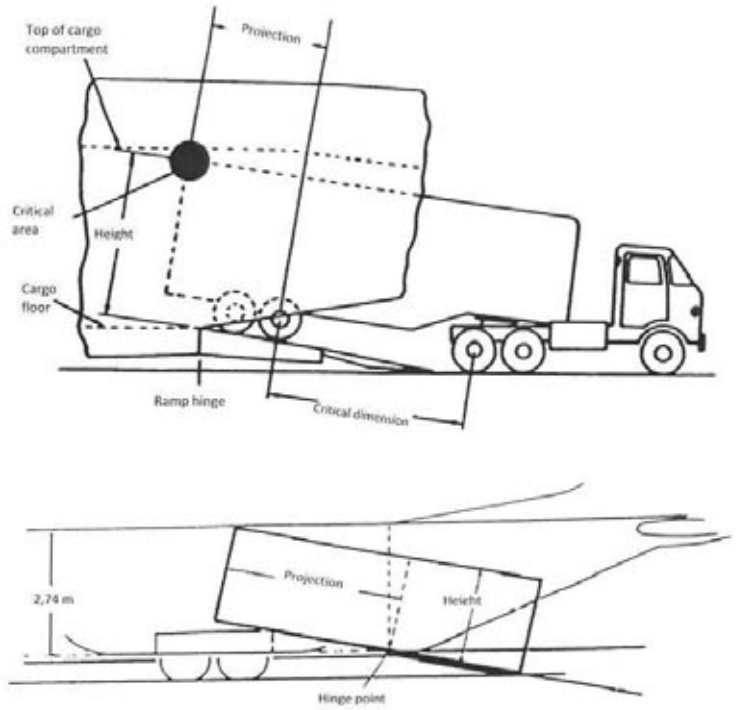

Fig. 4. Load height limitations resulting from overhang distance during loading [7]

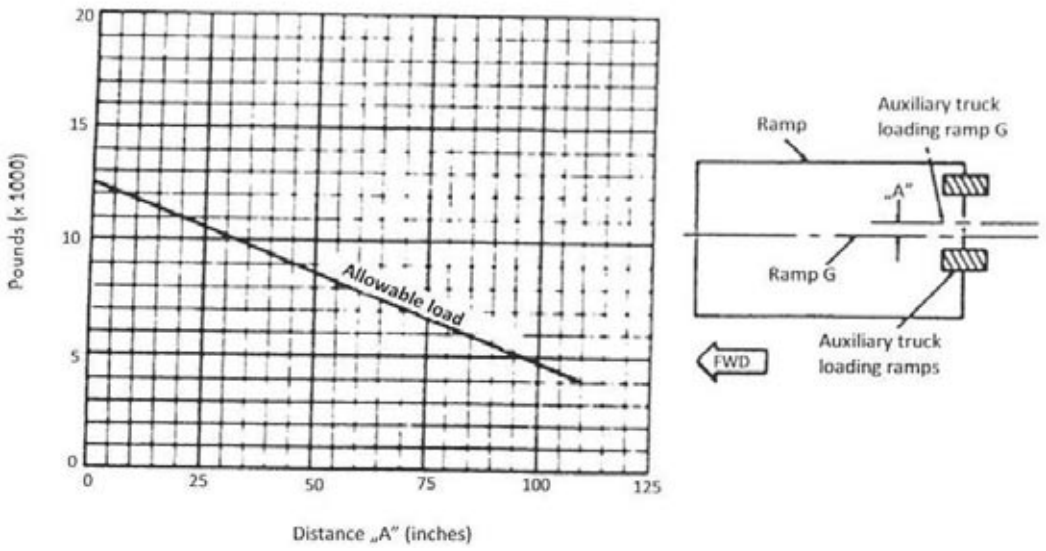

Fig. 5. Permissible maximum offset position of load centre of gravity affecting the transverse stability of the aircraft (graph for C-130) [5]

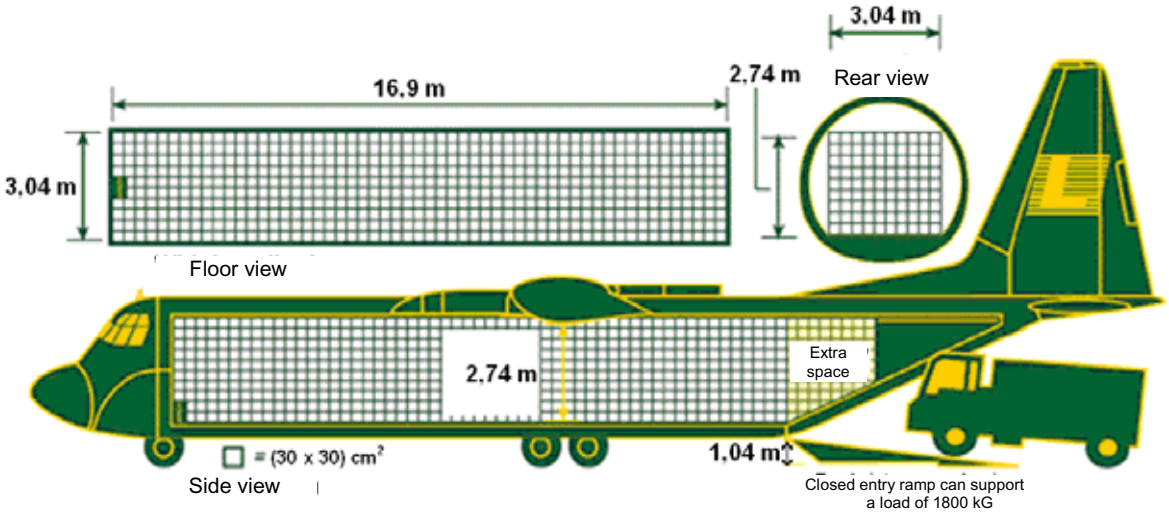

Fig. 6. Dimensions of the loading space of the C-130J-30 Hercules transport aircraft [9]

Fig. 6 shows as an example the maximum overall dimensions of the loading space of the C-130J-30 Hercules aircraft. These dimensions are as follows: (LxWxH): 16.9 m x 3.04 m x 2.74 m, where: L – length; W – width; H – height.

2.1. Useful load of transport aircraft

Unlike in land transport means, the useful load of an aircraft depends on many factors. The design of each plane is characterized by the so-called maximum take off weight which consists of the empty weight of the aircraft, load weight and fuel weight. Payload depends on

the required flying range of the aircraft. Longer flying range requires more fuel and lower cargo weight, that is useful load. In the case of C-130E take off in conditions close to ideal, these parameters are as follows [7]:

- range 111 km (60 nautical miles) payload 19,050 kg (42,000 lbs);
- range 926 km (500 nautical miles) payload 18,140 kg (40,000 lbs);
- range 1111 km (600 nautical miles) payload 17,690 kg (39,000 lbs);
- range 1593 km (860 nautical miles) payload 17,240 kg (38,000 lbs);
- range 1852 km (1000 nautical miles) payload 16,330 kg (36,000 lbs).

The term "conditions close to ideal" means air temperature of 15°C, and airport located at sea level. Higher altitude of the airport or higher air temperature means lower air density, lower lift and reduced payload. Season of the year, excessive temperature or altitude, can preclude the return transport of cargo previously delivered by air.

2.2 Requirements for securing the load in the cargo space of the aircraft

Requirements for the security of cargo during the flight are as follows [8]:

- during air transport the equipment carried must not lose stability and efficiency at accelerations with respect to that of gravity (g):
  - in the direction of the aircraft cabin - 3g (does not apply to the windshield);
  - vertical – 2g;
  - transverse – 1.5g;
  - towards the rear of the aircraft – 1.5g.
- tiedowns should ensure the transfer of loads resulting from limit accelerations;
- the tiedowns should be arranged symmetrically on the vehicle frame (50% of the tiedowns can be located in the chassis) and should be capable of transferring the required loads, taking into account the increased force due to deviation of the stays (fastening straps) from the principal axis (Fig. 7);
- tiedowns should be easily accessible and adapted to the standard tiedown provisions, according to MIL-STD-209;
- fastening stays must not cause damage to on-board systems: brake, electrical, hydraulic, etc.;
- installed equipment (spare wheels, tools, attachments) should be fitted with fasteners able to withstand accelerations acting on the equipment and vertical loads: downward – up to 4.5g, and upward 2g (integrality of the vehicle must be maintained);

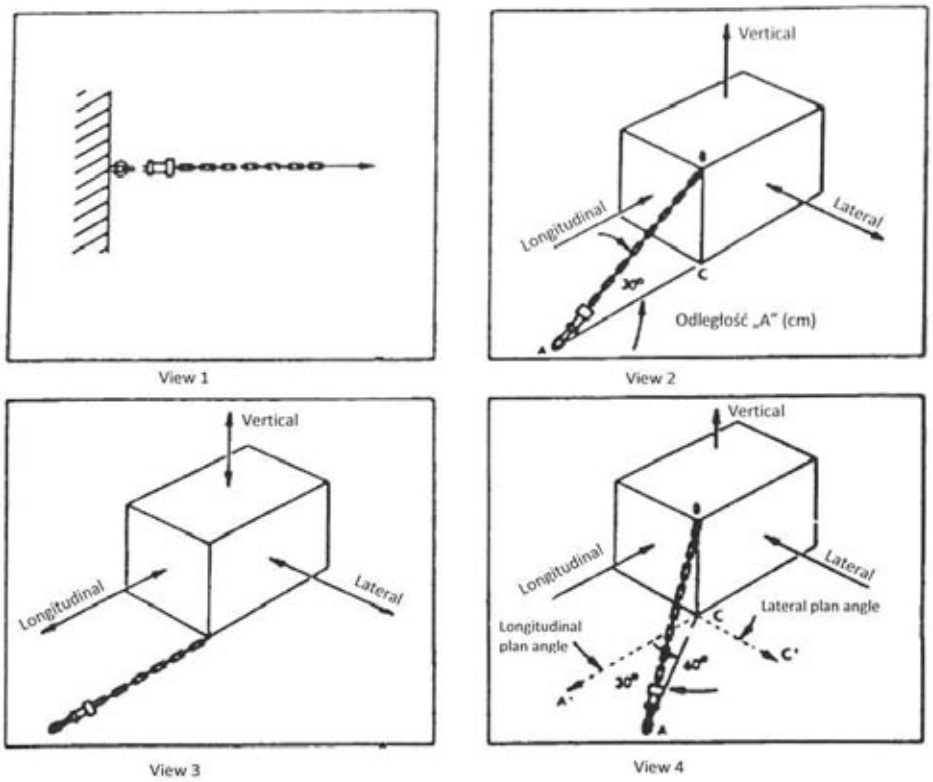

Illustration of the effect of oblique arrangement of stays on the forces in the main directions of reaction (at reduced strength of rope and anchoring system), and of the transfer of loads resulting from flight instability [8]

- equipment must be provided with fuel level indicators: electronic, optical or bayonet (during flight fuel level cannot exceed 50% of the tank capacity);
- fuel tanks and the fuel system should be tightly closed and protected against leaks during acceleration or inclination. The capacity of individual tanks should not exceed 500 dm^3;
- all tanks must be fitted with vents for equalizing pressure when gaining height or approaching to land;
- tanks with liquids that foam during pressure changes should be protected with siphon systems and expansion tanks (permissible descent or discharge of operating fluids);
- all tanks should withstand implosion, i.e. an increase in external pressure of 55 kPa during 0.5 s, occurring during emergency landing approach;
- batteries should be secured and protected against spills, accidental short circuit and sparking (dismantling is acceptable).

3. AIR TRANSPORT OF MS-40 BRIDGE

MS-40 bridge prototype developed and manufactured at OBRUM [10] is based on repetitive segment elements of spans. This enables construction of a bridge of any span up to 40 metres.

Requirements for mobility and erection of such a bridge in freely selected remote crossing points, impose the need to examine the possibility of the air transport of bridge components.

Currently, the most popular means of tactical military transport in Poland is the C-130E Hercules (Fig. 8).

Fig. 8. C-130E Hercules transport aircraft. General view and cargo hold interior

Overall dimensions of the hold (excl. ramp): (LxWxH):12.5 m x 3.04 m x 2.74 m, maximum cargo weight 19,050 kg, payload depends on the required flight range. For instance, if the required flight range is ca. 1111 km, payload is lower at ca. 17,690 kg.

Theoretically, it is possible to transport the MS-40 bridge assembly using the C-130E aircraft with cargo space dimensions (LxWxH) of 12.5 m x 3.04 m x 2.74 m. This, however, requires the use of several transport aircraft.

In order for the laying vehicle (Fig. 9) fit in the cargo space of the aircraft, the JELCZ C662D.OP carrier truck needs to have the following parts dismantled: armoured cab, spare wheel support, suction system stack. The trailer needs to have the crane and layer dismantled. Additionally, the truck and layer have to be disconnected and treated as separate loads.

Then the approximate dimensions of the units are as follows: truck: (LxWxH: 7.5 m x 2.55 m x 2.63 m), layer: (LxWxH: 10.8 m x 2.55 m x 2.25 m). The permissible weight

(17,690 kg) and axle load (5,900 kg) are not exceeded by any of the units. Parts dismantled from the truck and trailer can readily be carried as a separate load.

The carrier vehicle (Fig. 10) can only be transported without the bridge spans and subframe on the trailer and with the cab and other parts dismantled as in the case of the truck. The truck and trailer also have to be disconnected. The approximate dimensions of the trailer are as follows: (LxWxH: 11.15 m x 2.35 m x 1.95 m).

Fig. 9. View of MS-40 bridge layer vehicle

Fig. 10. View of carrier vehicle with main MS-40 bridge spans

Fig. 11. Auxiliary spans of MS-40 bridge on carrier vehicle

The units above meet the safety requirements for cargo transport, i.e.:

- fuel tanks of the JELCZ trucks are provided with vents in inlet plug, with electronic fuel indicators and are protected against leaks in case of acceleration or inclination. The capacity of the largest fuel tank in the JELCZ truck is only 250 dm^3;
- space above oil in hydraulic oil tanks is empty, which protects against leaks in case of foaming;
- battery mounting system in the truck protects against accidental short circuiting.

The spans (folded) must be transported as a separate load. Overall dimensions of one segment of the main span are as follows: LxWxH: 5.72 m x 2.98 m x 1.27 m. The small margin along the width of the main span does not meet the requirement of 15 cm free space on the sides of the load.

Dismantling the girders of the span segment reduces the width of the load (span platform) to 2.58 m. Then the overall dimensions of each of the dismantled girders are as follows: LxWxH: 5.72 m x 1.48 m x 1.05 m. This enables transportation of all (8) segments of the main spans upon dismantling.

Transport of the auxiliary spans (Fig. 11) and of other smaller bridge components does not pose then any problem. It must only be remembered that the maximum cargo weight, i.e. 17,690 kg, cannot be exceeded.

Smaller components of the bridge can be transported by air on pallets or in shipping containers.

The largest of available pallets, the 2-PMC type, has the following parameters:

- maximum gross weight - 6,804 kg;
- maximum outer dimensions- LxWxH: 317 cm x 244 cm x 244 cm.

The largest available container of the LD-9 type has the following parameters:

- maximum gross weight - 6,033 kg;
- maximum outer dimensions- LxWxH: 317 cm x 223 cm x 162 cm.

Another issue is the transport of three subframes of carrier vehicles onto which spans are loaded for transport.

Parameters of these frames are shown in Table 1.

Table 1. Dimensions and weights of subframes of transport trailer

Item	Subframe no.	Dimensions: L x W x H mm	Weight kg
1	I	5130 x 2990 x 628	705
2	II	5700 x 2980 x 290	840
3	III	5361 x 2900 x 1200	1600

The width of each of the subframes exceeds the permissible width (2740 mm) allowing to retain the required distance of 15 cm from the hold wall.

In order to meet the above condition, special supports could be provided to enable inclined positioning of the subframe in relation to plane floor. In the most favourable case (frame width: 2990 mm) the height of such support must be 1200 mm.

Because the width of the cargo space of the aircraft is 3040 mm, and the height and weight of the subframes is not high, in a particular case transport of these subframes would be allowed provided they be secured individually against moving sideways by fastening them to

the floor with straps, without maintaining the required free space of 15 cm on the sides of the load.

Securing the MS-40 bridge units in the cargo space is possible by means of straps or stays fastened to tiedowns in the floor of the aircraft (Fig. 8).

According to available data, the maximum load on fastening stays (belts or chains) may not be higher than 44 kN (up to 110 kN at selected points).

4. MODERN STANDARD OF TRANSPORT AIRCRAFT

The requirements arising from the limitations of the current version of the Hercules aircraft cause that the above standard does not fully satisfy present needs. It is expected that these aircraft will be used in the Polish Air Force for ca. 20 years [11].

Analyzing the disadvantages and shortcomings of the current Hercules aircraft (and taking into account the need to recall exploited aircraft in the future), a new standard for tactical transport aircraft was developed in Europe.

Table 2 shows the performance characteristics of selected modern military transport aircraft.

An example of the approach is the Ukrainian Antonov An 70 the design of which eliminates the limitations of the Hercules aircraft.

The use of Antonov An-70 to carry the MS-40 bridge components would make it possible to overcome the limitations of the Hercules aircraft.

Table 2. Performance characteristics of selected military transport aircraft [7].

Transport aircraft	Cruising speed km/h	Dimensions of the hold (excl. ramp) Length/Width/Height, m	Maximum payload[1)]	Nominal payload and range	Operating payload[2)]
An-12	**600-640**	**13.50 / 3.50 / 2.60**	**20,000 kg**	**16,000 kg / 3,600 km**	
C-130E/H Hercules	**500-600**	**12.50 / 3.12 / 2.74**	**19,050 kg** (*42,000 lbs*)	**16,550 kg** *(36,500 lbs)*/ **1,945 km** [2)]	**11,340 kg** *(25,000 lbs)*
C-130J-30 Hercules	**550-650**	**16.74 / 3.04 / 2.74**[)]	**19,960 kg** (*44,000 lbs*)	**16,330 kg** *(36,000 lbs)*/ **3150 km** [2)]	**11,340 kg** *(25,000 lbs)*
Antonov An-70	**750-800**	**19.10 / 4.00 / 4.10**	**47,000 kg**	**37,000 kg**	
Airbus A-400M	**740-780**	**17.71 / 4.00 / 3.85**[)]	**37,000 kg**	**31,500 kg**	

[1)] – under conditions close to ideal
[2)] – according to USAF standard

Dimensions of the loading space of An-70 are as follows: LxWxH: 19.1 m x 4.0 m x 4.1 m, at nominal payload of 37,000 kg. Due to the much higher permissible width and height of the load, this would allow to minimize the necessary dismantling operations (including MS-40 vehicles and main spans), and would dramatically reduce the cost of transportation.

5. SUMMARY

MS-40 bridge units can be transported by air using the C130-E Hercules transport aircraft currently operated by the Polish Armed Forces. However, (as indicated by the studies carried out at OBRUM), this would be uneconomic due to the need to dismantle some units prior to transport and the need to use several aircraft.

When analyzing the performance and cost of acquiring transport aircraft, consideration should be given to cooperation with Ukraine in order to acquire the An-70 aircraft, or to the joining of the Airbus A400M program.

When seeking interoperability within NATO, at least the most moderate requirements for adaptation to air transport should be placed for every new or improved equipment. The minimum scope of such requirements should arise from the new standard determined by Antonov An-70 and Airbus A400M aircraft, and from general requirements of air transport safety.

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