TSAR: A LARGE-SCALE SIMULATION FOR ASSESSING FORCE GENERATION AND LOGISTICS SUPPORT IN A COMBAT ENVIRONMENT

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ABSTRACT

The objectives of this paper are to provide an overview of the TSAR/TSARINA simulation models, and to illustrate their use with a simple application. The TSAR/TSARINA simulation models have been developed to provide a method of evaluating how a wide range of airbase improvement options could increase the combat capability of airbases during wartime. Following a description of model highlights, the application of these models is illustrated with some results from a recent analysis.

1. BACKGROUND

In the event of conflict in Central Europe, NATO plans call for massive air operations to be conducted from a limited set of large, semi-autonomous airfields located in Western Germany and the Benelux countries, with additional aircraft to be based in the UK. Each base is equipped to provide almost the entire necessary organizational maintenance and some battle damage repair, as well as much of the intermediate maintenance (parts repair). Over the years, airbase growth has paralleled the growth in aircraft sophistication, and airbases are now complex conglomerates of maintenance specialists, fragile test and repair facilities, and extensive supply and fuel storage facilities.

In recent years there has also been a dramatic improvement in Warsaw Pact offensive air capabilities that threatens to seriously jeopardize NATO’s strategic dependence on air support at the outset of a conventional war in Europe. Air power must not only withstand this new challenge of air attacks during the opening phase of any large scale conventional war, but must simultaneously be capable of supporting NATO ground forces in countering the massive ground operations expected by the Warsaw Pact. These well-recognized problems have led to NATO plans for generating high sortie rates ("surges") during the opening days of the conflict and to programs intended to "toughen" the airbases and to improve their active defenses. But despite the accomplishments of the past, many difficulties still exist and a wide range of possible improvements are under consideration to help mitigate various weaknesses and vulnerabilities. The diversity of these possibilities is suggested in Fig. 1.

- SELECTIVE HARDENING AND/OR DISPERSAL OF FACILITIES
- IMPROVED AIR, MORE SURFACES, AND/OR REDUCED REQUIREMENTS
- INCREASED WAR RESERVE MATERIAL
- MANPOWER POLICIES
- REPLACEMENT POLICIES AND FAT LOSSES
- REVISED MAINTENANCE
- IMPROVED BATTLE DAMAGE REPAIR CAPABILITIES
- IMPROVED INTRA-THEATER TRANSPORTATION
- IMPROVED THEATER RESOURCES Visibility and Management

Fig. 1—Options for Enhancing wartime sortie generation

The development and application of the TSAR/TSARINA simulation models has been supported by Headquarters USAF as a part of the Project AIR FORCE contract with The Rand Corporation.
In light of the fiscal implications of the disparate set of improvement options, it was apparent that a method was needed that could be used to compare their individual and joint contributions to a force's combat capabilities. Unfortunately no analytic tools, or simulations, existed that would permit detailed examinations of the impact of likely air attacks. To do that it would be essential not only to analyze all the airdrome activities that affect sortie generation at a sufficient level of detail to capture the dependencies among the numerous specialized types of resources, but also to be able to include the benefits that might be expected from improved theater management of available resources. It is for these reasons that the TSAR/TSARINA simulation models have been developed.

2. MODEL DESCRIPTION

2.1 General

The only constraints on the continuous recycling of aircraft in wartime are the requirements for adequate launching surfaces, the availability of aircrews, munitions, and fuel, and the necessary maintenance to permit the aircraft to fly. Without maintenance constraints, estimation of an airbase's sortie potential would be relatively straightforward, and would require little or no computer analysis. But if these maintenance constraints are to be analyzed under the impact of (1) a "surge" flight program, (2) extensive aircraft battle damage, and (3) the highly irregular patterns of damage to essential base facilities that would be experienced during airbase attacks, it is important that the analysis procedure include sufficient detail so that the critical effects of these factors can be captured. Unless these possibilities for bottlenecks, as well as the emergency procedures that could be adopted, are acknowledged, the likely behavior of an airbase during wartime operations could hardly hope to be represented.

TSAR and TSARINA are Monte Carlo models designed for these kinds of examinations. TSARINA simulates user-specified air attacks, and estimates the losses and damage to various classes of resources and key facilities. TSAR simulates the activities at each of a set of interdependent airbases, that are supported by shipments from the United States and by intra-theater transportation, communication and resource management systems. The nature of the TSAR/TSARINA simulations and their interactions are suggested in Fig. 2. An important objective in the original design formulation was to achieve a sufficiently high speed of operation so that the extensive sequence of runs would be frequently necessary in research and analysis would be economically practical. Adaptation of existing airbase maintenance models (e.g., LCON, NASM) was rejected for several reasons, including the extent of the modifications that would have been required and the prohibitive costs that would have been associated with their use for problems of the size that were contemplated. The resultant, custom-designed program achieves a substantially higher speed by virtue of more efficient processing, and by taking advantage of the recent dramatic increase in the speed of the core storage of modern computers.

Fig. 2--TSAR-TSARINA -- For Analyzing Sortie Improvement Initiatives
The classes of resources that are treated include aircraft, aircraft personnel, ground personnel, support equipment, aircraft parts, aircraft shelters, munitions, TRAP, fuel, building materials, and a variety of airbase facilities. Many different types of each resource class are distinguished. On-equipment maintenance tasks, parts, and equipment repair jobs, munitions assembly, and facility repair tasks are simulated for each of several airbases. Asset accounting for each of the eleven classes of resources, and for each type within each class, permits assessment of a broad range of policy options that could improve the efficiency of resource utilization on a theater-wide basis.

TSAR is readily adaptable to problems across a broad range of complexity. When specific features are not needed for the examination of a particular issue, they simply need not be used. Thus, TSAR permits one to represent either a single base, a set of independent airbases, or a set of interdependent airbases, without any adjustment or modification of the program. Similarly, the user may not wish to examine the effects of airbase attacks, or may wish to ignore the possible constraints imposed by shortages of aircraft, personnel, ground personnel, support equipment, aircraft parts, munitions, TRAP, fuel, and/or bases. TSAR aircraft, automatically to all such problem representations. And although the present discussion focuses exclusively on aircraft, TSAR also is in use on a real study of Army readiness, in which tasks and other any vehicle successfully fulfill "aircraft" roles without modification of the TSAR code.

2.2 Airbase Activities

In TSAR, specified numbers of aircraft of various types can be assigned to each airbase. The aircraft of a given type at any airbase may be supported by a common pool of personnel and equipment, or the aircraft may be organized into two or three subgroups (squadrons) each supported by its own set of resources. The aircraft therefore are launched on sorties in response to a set of user-supplied sortie demands, differentiated by base, aircraft type, mission type, and priority. The user is given substantial flexibility in defining the rules by which aircraft maintenance tasks are to be processed. He may permit the activities of certain groups of shops to proceed simultaneously, and may require that the activities of several such groups of shops proceed in a specified order. He also may control the operations, for simultaneous and sequential operations, separately for each aircraft type at each base. Fig. 3 illustrates how ground maintenance operations might be organized to make an aircraft flight. In this example, the three tasks in parallel—load guns, shelter aircraft, and check—can all be completed after hang, munitions, and repair have been dealt with and battle damage has been repaired. And when these tasks are complete, the same tasks shown in parallel can all begin, given that the required resources are available. These features permit alternative maintenance operating doctrine to be simulated and to be examined for their influence on sortie generation capabilities. Work speed-up and other procedures to shorten on-equipment, pre-flight and off-equipment activities also may be specified.

Each on-equipment maintenance task may require a team composed of one or two types of maintenance specialists, specialized equipment, a spare part, and a specified amount of time; each unscheduled maintenance task is either a single set of such requirements, or it may be a network of tasks, each with its own demands. When resources are limited, those aircraft most likely to be readied first (given sufficient resources) may be given priority.

![Fig. 3--Simulated Sortie Generation Procedures](image-url)
If a required part is not available, (1) the broken one that is removed may be repaired on base, (2) the appropriate part may be cannibalized, (3) a part may be obtained from another base, or (4) the part may be ordered from a central source within the theater. When a part cannot be repaired on base it may be sent to a neighboring base or to a centralized facility in the theater. When parts cannot be repaired within the theater, a replacement may be requested from a depot in the United States. Often the parts subjected to delays, cancellations and losses.

The theater-wide management of the various resources is supported by a user-specified scheduled transportation system that may be subjected to delays, cancellations and losses. TSAR also permits the user to represent a theater-wide reporting system that can be used to provide the central authority with periodic status reports from the several operating bases; these reports may be delayed, incomplete or lost.

When these transportation and communication systems are coupled with a set of rules for distributing and redistributing the operating bases, various concepts of theater resource management may be represented and examined in the context of realistic transportation and communication imperfections. In its current formulation TSAR already includes certain alternatives for the theater management rules and has been designed in a fashion that will permit additions or modifications to be readily accommodated.

Daily estimates may be prepared of each base's capabilities for generating different kinds of sortie with different types of aircraft. These estimates can be used to provide the basis for various aircraft management decisions. One application is in selecting which base is to be "fragged" with sorties for which no base has been specified. These data can also be used to support assignment decisions when aircraft must be diverted in flight, and to redistribute aircraft among airbases to improve the balance between flight requirements and support capabilities.

The options currently available for theater-wide management of aircraft and spare parts are suggested in Figs. 4 and 5, respectively.

In addition to simulating a set of airbases, the user also may specify the existence of a centralized theater distribution center and/or a centralized theater repair facility at which some or all intermediate maintenance is conducted. The centralized distribution facility can receive spare parts from the United States and either retain them until demanded by a base, or transfer (some or all) to the base with the earliest projected requirement. The theater management features may also be used to direct the lateral shipment of parts and other resources from one base to another. The repair facility, sometimes referred to as a CIRF, is assigned maintenance personnel, equipment, and spare parts (LRUs and SRUs). Parts are shipped to and from the CIRF from the operating bases and are processed in the manner prescribed by the user's choice of which theater management rules are to govern these operations. Parts repair priorities can be based on existing and projected demands and on the relative essentiality of parts for the various missions. Shipment priorities are related to the current and projected demands, on-base reparables, and reserve replaceables. When central stocks are...
insufficient to meet a base's demand, another base can be directed to ship the required part, if both the requesting base and the donor base meet certain conditions relative to the importance of the demand and the availability of stock.

2.4 Output Statistics

Normal outputs include the number of sortie files, the maintenance tasks accomplished, shop performance statistics, and resource constraint statistics. One optional feature enables the user to observe the daily activity of 24 aircraft in detail. Data may be displayed on a daily, trial, or multiple trial basis. While the output options that are provided permit the user to examine a substantial portion of the more relevant results, all possible outputs certainly are not available. Custom additions can and should be readily included by users as the need arises.

2.6 Technical

TSAR was written in FORTRAN IV and was recently converted to FORTRAN V (i.e., FORTRAN 77) with a minimum of difficulty. The only feature not supported by ANSI FORTRAN V is the widespread TSAR usage of packed half-word integers for data storage (a feature available on IBM machines); for those systems that do not permit half-words to be addressed, data storage requirements (in words) will be nearly doubled.

Currently TSAR consists of some 135 subroutines and functions with a total of 240 entry locations; the source code consists of somewhat more than 33,000 card images, exclusive of the Common statements. Core storage for the executable statements is approximately 46,500 bytes (8 bits) on an IBM 370/168 when an efficient overlay structure is used. The additional core required for data storage is indicated in Fig. 6 for a current configuration; 2.4 min limits imposed by the program architecture are also indicated.

A table, but serviceable, rate of throughput, PDSM's computational efficiency can be expressed in terms of sorties simulated per 15 minute. Although such a measure naturally varies with the complexity of the representation, the level of theater activity, and the extent of sortie shortages, a majority of our analyses have run at 2000 to 4000 sorties per CPU minute on an IBM 370/168. Cases that involve heavy damage and extensive shortages have dropped to a low of 1000 to 1500 sorties/CPU minute, and the examinations of Army readiness regularly attained 4000 sorties/CPU minute.

### Resource Types

<table>
<thead>
<tr>
<th>Base/AC Types</th>
<th>Personnel</th>
<th>Equipment</th>
<th>Munitions</th>
<th>Fuel</th>
<th>LMRs, SRs</th>
<th>Shelters</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 (9)</td>
<td>100 (320)</td>
<td>100 (100)</td>
<td>75 (100)</td>
<td>75 (100)</td>
<td>600 (1700)</td>
<td>1 per base</td>
</tr>
</tbody>
</table>

### Procedures

<table>
<thead>
<tr>
<th>On Equipment Tasks</th>
<th>Damage Data</th>
<th>COMS Cargo</th>
<th>Intratower Cargo</th>
<th>Equipment Repairs</th>
</tr>
</thead>
<tbody>
<tr>
<td>750 (5000)</td>
<td>7000</td>
<td>2500</td>
<td>2000</td>
<td>100 (5000)</td>
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</tbody>
</table>

### Tasks & Queues

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<thead>
<tr>
<th>Ongoing</th>
<th>Parts</th>
<th>Waiting</th>
<th>Interdicted</th>
<th>Deferred</th>
<th>Parts Delay</th>
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<tbody>
<tr>
<td>1000</td>
<td>250</td>
<td>1500</td>
<td>400</td>
<td>4000</td>
<td>1500</td>
</tr>
</tbody>
</table>

### COMPUTER DATA

<table>
<thead>
<tr>
<th>SPACE:</th>
<th>Instructions X (300 - 500) Bytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage</td>
<td>550 X (100-1000+) Bytes</td>
</tr>
<tr>
<td>Total</td>
<td>1000 X (400-1500+) Bytes</td>
</tr>
</tbody>
</table>

### Fig. 6—TSAR Dimensions and Storage Requirements

Current Max.
In a recent analysis, we examined the simulated wartime activities of three Air Force units in West Germany—72 F-4Gs at a main operating base (MOB) and two F-106s at another base. Each base was resupplied with the personnel, equipment, and spares necessary for such bases; the lateral resupply and repair of spare parts was supported by a transportation system that provided daily deliveries. Although the results are, of course, specific to this set of bases and resources, these bases were representative of the general Air Force situation.

For the first week of the war, these units were directed to "surge" at rates of approximately 100 combat sorties per day. Aircraft were to be flown in groups of three to five, during the first week. The resupply levels were held constant throughout the analysis presented here.

It was assumed, as is frequently done, that losses will be instantly replaced, and that damaged aircraft will not affect sortie production. These assumptions are largely fulfilled, as shown in Fig. 7.

The upper line indicates the total number of sorties that the three bases might expect to achieve under these conditions. Although not representative of actual wartime operations, this performance is used as a reference case for the other results.

![Graph showing sortie generation with and without attrition and battle damage](image)

**Fig. 7:** Effects of Attrition and Battle Damage on Sortie Generation

We next examined the same scenario, as it might actually develop during the first week in wartime. It was assumed that the attrition rate for flight operations would drop off as a function of time, and would average just under three percent per sortie during the first week. It was also assumed that the damage-to-flight rate would be the same as that experienced in the Southeast Asia (SEA) theater, and that the same replacement times for damaged aircraft would be used for that region. The reduction in the sorties under these circumstances is shown in Fig. 8.

In Fig. 8 we have assumed, first, that 2/3 aircraft will be available as replacements within about two-and-one-half days after loss. Performance is improved, but still falls far short of the reference case. As shown by the next-to-lowest curve, Fig. 8 also indicates the incremental improvement that might be achieved by having additional ARUN aircraft battle damage control specialists available on short notice in addition to the replacement aircraft. As was presumed here, attrition and battle damage are highest at the beginning of the conflict, there will still be a substantial sortie shortfall during the critical first week. Even then, the absence of an attack, it seems questionable that the planned objectives of a "surge" can be attained because of the difficulty of maintaining a full complement of combat capable aircraft at the forward operating bases.

![Graph showing aircraft replacement and ARUN personnel effectiveness](image)

**Fig. 8:** Reducing Effects of Attrition and Battle Damage: Aircraft Replacement and Extra ARUN Personnel

And what of air attack? Despite long-term Air Force efforts to obtain the funds needed to shelter all aircraft planned for deployment to the Central Region in Europe, Congress has strongly resisted the necessary expenditures. Based on the programs that are currently funded, only about 60 percent of the US Air Force aircraft expected to be in SAD's central region after a week of mobilization can be sheltered. No shelters will be available for US Air Force aircraft on some of the OBOs where early deployment is planned, and very few of the support facilities have any special protection.

In our analyses of air attacks we assumed that one of the two OBOs does not have shelters, but that the aircraft would be well dispersed on base. Furthermore, we assumed the same types of construction and the same locations for the support facilities as for those that actually exist at three bases in West Germany. The attack levels examined are those that three bases might expect if the Kursk Pact were to initiate hostilities with an air campaign that stressed...
attacks on Nato's air assets, as it is frequently presumed that they would. The attacks consisted of third-generation fighter-bombers and medium bombers delivering conventional munitions; the attacks are repeated, at reduced strength, every couple of days during the first week. Chemical attacks and attacks with surface-to-surface missiles have not been considered.

The air attacks we examined presumed that the enemy would concentrate on the aircraft shelter areas and on the concentrations of maintenance and support facilities. Our earlier analyses examined runways, as well as the shelter areas, as possible enemy targets, and both types of attack would seriously affect aircraft operations; our present focus derives in part from the fact that many actions are already underway in the Air Force to counter the threat of runway attacks.

If lost aircraft are not replaced, and additional ARDR personnel are not in place at D-day, the sorties that might be generated in the face of these hypothetical Warsaw Pact airbase attacks are shown by the lowest line in Fig. 9. Only about one-third as many sorties are achieved, as in our reference case. The irregular generation profile is in part due to the assumption that unscheduled maintenance is disrupted for six hours after heavy air attack; only ready aircraft are launched and ongoing weapons loading and aircraft fueling tasks completed during this period. The attacks destroy or damage over 50 aircraft, as well as substantial numbers of maintenance specialists, critical support equipment, and spare parts. In addition, many parts repair facilities are damaged.

If we now presume that replacement aircraft are available within two-and-one-half days, and that extra battle damage specialists are in place when the conflict begins, the force still is unable to achieve more than about 50 percent of the sorties flown in the reference case, as the next to the lowest line in Fig. 9 indicates. Some sorties are prevented by the unpredictable losses among maintenance equipment and personnel; when these are also replaced within two-and-one-half days of their loss, performance is improved somewhat, as also shown in Fig. 9, but not very much. With critical problem in airframes. There are discouragingly small numbers of aircraft available to respond to the demand for sorties, despite the introduction of substantial numbers of replacement aircraft.

Furthermore there has been serious damage to many of the backshop facilities that will have to be rebuilt or replaced before reparable spare parts can be processed in order to sustain even these limited numbers of sorties. And these problems will be further compounded by the heavy losses that were sustained in some trials to the stocks of serviceable spare parts, and to munitions and fuel.

What else can be done to improve matters? More rapid aircraft replacement, more effectively protected facilities, larger numbers of personnel, equipment, spares, etc.--all of these obviously would help. But without a means of assessing the impact that airbase attacks will have on sortie generation, there is limited motivation to consider such changes to existing plans, and without those same means there are few credible approaches to assessing how possible changes would improve combat capability. But with the assessments that can be generated with TSAR/TSARINA simulations we believe that decisionmakers will be increasingly motivated to make changes that will improve matters, and that they will have a better basis for deciding which of widely disparate options that are available should be chosen.

4. CONCLUSIONS

TSAR and TSARINA have been designed to provide a variety of potential users with an analytic structure within which a rich variety of potential improvements for theater airbases may be tested in a common context. New passive defenses, new maintenance doctrine, modified manning levels, increased stock levels for parts and equipment, etc., as well as a variety of concepts for improved theater-wide resource management--all of these can be examined with TSAR/TSARINA within a common context in terms of their ultimate impact on the system's capabilities for generating sorties.

ACKNOWLEDGMENTS

The development of TSAR demanded uninterrupted concentration over an extended period. My debts to the Air Force and Rand management are obvious; not so obvious are the debts owed a most understanding family. Among my colleagues at Rand, I would particularly like to acknowledge Lou Wegner and Mike Poindexter for their many suggestions regarding various programming problems, and Nils Kamins and Major John Halliday for their ideas that have been incorporated into the model logic, and for their careful work in generating essential data bases. My thanks go also to Feliz Kozarcka for similar contributions to TSARINA.
REFERENCES


